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THE PRE-CAMBRIAN MAZATZAL REVOLUTION

IN

CENTRAL ARIZONA

A Thesis Submitted to the Department of Geology and Geography of Harvard University in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

by

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INTRODUCTION

STATEMENT OF THE PROBLEM

Rocks which have been classified as pre-Cambrian are very prominent in Arizona, as indicated by the State Geologic Map.[1] The most complete sequences of so-called Archean and Algonkian types known in the Southwest crop out in the Grand Canyon. Formations of known or supposed pre-Cambrian age constitute about half of the visible rocks in the State's numerous widely distributed mountain ranges which are largely isolated from one another by basins underlain with Tertiary and Quaternary beds.

Arizona's greatest exposures of pre-Cambrian sedimentary and volcanic rocks are in the central mountain ranges, within distances of 90 to 200 miles from the Grand Canyon. This central region has yielded approximately $500,000,000 worth of copper, gold, silver, lead, and zinc, mainly from the Jerome pre-Cambrian deposit and partly from numerous Mesozoic or Tertiary veins in pre-Cambrian host rocks whose salient controlling structures appear largely to be heritages from pre-Cambrian events.

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[1] Prepared by the Arizona Bureau of Mines in cooperation with the U. S. Geological Survey, 1924.

Although portions of this central region have previously been studied, the locally complex relations, augmented by the rough, brushy surface of much of the country, have made regional separation, correlation, and structural analysis rather difficult. As long as the broader relations of the several pre-Cambrian formations remained unknown, the local stratigraphy and structure have been interpreted diversely by various geologists. Also the structural features that were accurately determined and had been mapped could not be correlated or dated, and analytical speculation as to the causes of these locally important features seemed impracticable.

The problem of the present research has been to determine the chief features of pre-Cambrian regional structure within part of central Arizona. "There is need for a broad study of the pre-Cambrian mineralization of the West,"[2] and such a study necessarily depends upon structural interpretations. Central Arizona, which contains the West's most productive pre-Cambrian mineral deposits, merits much structural investigation of which the present research represents only a fraction.

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[2] Butler, B. S., Relation of ore deposits to structural features and associated igneous activity: Am.Inst. Min. and Met. Eng., Lindgren Volume, p. 232, 1933.

Lindgren[3] has emphasized the difficulty of separating the greenstone and sedimentary schists, which are the two oldest formations exposed in the region. In other words, a large element of the structural study is the particular consideration that must be given to the definition and description of the formations, which are the material units of the problem, in order to establish the criteria for their recognition as definitely and precisely as possible. Broad conclusions regarding formations of such antiquity, particularly in the structurally complex and discontinuous exposures afforded by Basin Ranges, are inevitably based to a disquieting extent upon assumptions.

FIELD WORK AND ACKNOWLEDGMENTS

This investigation was begun in 1930, after studies of the pre-Cambrian rocks in the Jerome and Black Hills districts had revealed complexities which might be solved by obtaining an understanding of the regional structure. The field work occupied approximately six months' time,

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[3] Lindgren, Waldemar, Ore deposits of the Jerome and Bradshaw Mountains quadrangles, Arizona: U. S. Geol. Survey Bull. 782, pp. 20 and 56, 1926; also pre-Cambrian greenstone complex of the Jerome quadrangle (discussion): Jour. Geol., vol. 38, p. 462, 1930.

distributed over widely scattered intervals until late 1935. It was begun as a research problem for the Arizona Bureau of Mines, whose generous support was supplemented in 1933 by a grant of $315.00 from the Penrose Fund of the Geological Society of America.

The members of the Department of Geology of Harvard University, especially Professors Kirk Bryan, Marland Billings, Russell Gibson, and D. H. McLaughlin, gave many constructive suggestions regarding the scope of the work and the organization of the data. Professor Gibson spent several days examining the field relations in the region during the summers of 1932 and 1934. The writer is further indebted to Professors Bryan, Billings, and Gibson for careful reading and criticism of the manuscript. Acknowledgments are also due Dr. G. M. Butler, Director of the Arizona Bureau of Mines, for encouraging this research; and Professors B. S. Butler, R. J. Leonard, M. N. Short, and A. A. Stoyanow, of the University of Arizona, for valuable suggestions.

SUMMARY OF FACTS AND INTERPRETATIONS

Regional Setting

The central Arizona areas studied particularly for this research lie within a portion of the Basin and Range Province 120 miles long by 15 to 50 miles wide bordering the southwestern margin of the Colorado Plateau.

In order to sketch the regional setting, the main topographic, stratigraphic, and structural features of Arizona are outlined in Part I and further summarized as follows:

Arizona lies within two major physiographic provinces (see Fig. 1); the Colorado Plateau comprises the northeastern half, and the Basin and Range Province the southwestern half, of the State.

The Colorado Plateau in Arizona is a structurally controlled surface, 4,300 to more than 9,000 feet in altitude, surmounted by high volcanic mountains and deeply incised by canyons of the Colorado River system. This plateau here consists of a basement of pre-Cambrian rocks unconformably overlain by maxima of 3,700 feet of Paleozoic and 5,400 feet of Mesozoic to Tertiary beds. Its main structural features are broad to narrow, dominantly northward-trending Laramide folds and probable Miocene and later normal faults. Its major uplift and differentiation from the province to the south occurred in post-Eocene time.

The Basin ranges in Arizona generally do not exceed 55 miles in length by 20 miles in breadth and 10,000 feet in altitude. They consist of rocks broadly similar to those of the Plateau but with a somewhat thicker Paleozoic section and many intrusive masses of Mesozoic and Tertiary ages. The intermont valley troughs are commonly filled to considerable depths with Pliocene and probably also Miocene conglomerate, sandstone, gravel, sand, and

silt, veneered with Quaternary debris. These ranges and valleys are believed to represent fault blocks whose principal development began with the close of Miocene time. The southeastern and northwestern portions of this province in Arizona have been affected by Laramide to Pliocene folding and thrust faulting, and the whole region has been complexly broken by normal faults, particularly of Tertiary to Recent ages.

According to the published descriptions, abstracted in Part I, the pre-Cambrian rocks of Arizona comprise the following units: (1) Laminated to schistose sedimentary and igneous rocks, exemplified by the thick Vishnu series of the Grand Canyon and by the Yavapai, Pinal, and other schists of the Basin and Range Province, whose chief structural features prevailingly strike northeast to northward, as a result of regional compression; (2) dioritic to mafic stocks and dikes; (3) Batholithic masses of granite with associated dikes; (4) the Mazatzal quartzite of central Arizona; (5) the Unkar and Chuar strata, of the Grand Canyon, which unconformably overlie (1), (2), and (3); and (6) the Apache group, which is probably equivalent in age to the Unkar and rests unconformably upon (1), (2), (3), and (4).

Central Arizona Region

General Statement

The field work for this research was limited mainly

to the Mazatzal Mountains, Pine Creek, eastern Tonto Basin or northern Sierra Ancha, Del Rio, and southern Black Hills areas (Plate IV) which, as shown by previous work, contain extensive exposures of pre-Cambrian rocks whose relations have not been largely obscured by metamorphism. Collectively, these several areas reveal the pre-Cambrian regional geology much more completely than does any one locality.

The present investigation yielded many new data regarding the pre-Cambrian stratigraphy and structure of central Arizona and leads to the conclusion that the principal features of regional structure originated from a great pre-Cambrian crustal disturbance, termed the Mazatzal Revolution.

Topography

The principal features of relief, as shown on Plate IV, are the Sierra Ancha, Tonto Valley, Mazatzal Mountains, Verde Valley, Black Hills Range, and Lonesome Valley, all of which trend northwestward. Each of the ranges exceeds 7,500 feet, but none more than 8,000 feet, in altitude. They are from 30 to 50 miles long by 12 to 20 miles wide and approximately 25 miles apart. Their slopes are characteristically steep, rugged, and brushy. The ranges and valleys are regarded as slightly tilted horsts and grabens which were formed largely in late Tertiary time.

Stratigraphy

General Statement: The pre-Cambrian of central Arizona has a recognizable stratigraphy, divisible, in chronological order, as follows: The Yavapai group; the Deadman quartzite, Maverick shale, and Mazatzal quartzite; the City Creek series; diorite porphyry, porphyritic pyroxenite, granite, and granite porphyry; and the conglomerate, quartzite, shale, and limestone of the Apache group. Paleozoic and Cenozoic sedimentary and volcanic beds overlie the pre-Cambrian rocks.

Yavapai group: The oldest formation here consists of volcanic and sedimentary rocks which have previously been grouped together under the general category of Yavapai schist. Since that formation is only locally schistose, it is designated in this report as the Yavapai group. Its volcanic members are termed the Yaeger greenstone and Red Rock rhyolite, and its sedimentary portion the Alder series. The relative ages of these members have been obscured by faulting. The sedimentary series has previously been regarded as the oldest by some geologists, but the meager evidence available appears to indicate that it is the youngest of the group and that the greenstone is the most ancient.

The Yaeger greenstone crops out in the Black Hills, Mazatzal Mountains, and eastern Tonto Basin areas. Like the oldest rocks in the Lake Superior region, it is made

up of intermediate to mafic volcanics, together with a minor amount of intercalated sedimentary material, all extensively affected by low-grade metamorphism.

The Red Rock rhyolite occurs prominently in the Mazatzal Mountains, Pine Creek, eastern Tonto Basin, and Black Hills areas. It consists mainly of massive rhyolitic flows and agglomerate and minor intrusive material which characteristically show little alteration other than devitrification. Locally included greenstone fragments suggest that it is younger than the Yaeger member.

The Alder series appears extensively in the Mazatzal Mountains, eastern Tonto Basin, and Black Hills and forms a small outcrop in the Del Rio area. This series consists largely of shale, slate, and grit, with some quartzite and conglomerate which, near large intrusive bodies, particularly, grade into schist. The conglomerate contains pebbles of rhyolite similar to the Red Rock, which suggests that the Alder series is the youngest member of the Yavapai group.

Deadman quartzite: Unconformably overlying the Red Rock rhyolite in the northern half of the Mazatzal Mountains is the Deadman quartzite whose thickness ranges from 90 to 110 feet in the northern portion and attains a maximum of approximately 800 feet in a thrust block near the central portion of the mountains. This formation has not been recognized in the other areas.

Maverick shale: Resting with apparent conformity upon the Deadman quartzite in the Mazatzal Mountains is the Maverick shale, which ranges in thickness from 500 feet at the northwest to 800 feet at the southeast. Due, probably, to further northwestward thinning, it is not present in the Pine Creek area. It does not appear in the eastern Tonto Basin and Del Rio areas.

Mazatzal quartzite: Lying conformably upon the Maverick shale in the Mazatzal Mountains and unconformably upon the Red Rock rhyolite in the Pine Creek area is the Mazatzal quartzite of which a maximum thickness of 3,800 feet has escaped removal by erosion. In the eastern Tonto Basin and Del Rio areas, its base is not exposed.

City Creek series: In fault contact with the Yaeger greenstone at the northern end of the Mazatzal Mountains is the City Creek series, which consists of more than 1,500 feet of comparatively unmetamorphosed shale with some quartzite. Resembling nothing known elsewhere in the pre-Cambrian of the Southwest, this series may represent a formation, younger than the Mazatzal quartzite, that elsewhere has been removed by erosion.

Porphyry and granite: Diorite porphyry, porphyritic pyroxenite, granite, and granite porphyry intrude the Yavapai group. The granite, tentatively correlated with the Bradshaw granite, of the Bradshaw Mountains, has been intruded into the porphyritic pyroxenite, Maverick shale, and Mazatzal quartzite.

Apache beds: The granite in the Mazatzal Mountains and the granite and deformed Mazatzal quartzite in eastern Tonto Basin are unconformably overlain by the conglomerate, shale, quartzite, and limestone of the Apache group. These members of the Apache group are considered to be of the same general age as the pre-Cambrian Unkar strata, of the Grand Canyon. They are intruded by sills and dikes of diabase.

Paleozoic strata: Middle Cambrian sandstone, Devonian, Mississippian, and Pennsylvanian limestone, and Permian shale, sandstone, and limestone unconformably overlie the pre-Cambrian rocks.

Cenozoic rocks: Tertiary conglomerate, sandstone, limestone, gravel, sand, and silt, intercalated with and overlain by lava, rest upon an eroded surface of the older rocks and are locally veneered with Quaternary debris.

Structure

General statement: The chief structural features of the pre-Cambrian of central Arizona are closed, open, and drag folds and reverse and normal faults. The folds and reverse faults are of sub-parallel, northeast to northward trend. Some of the normal faults strike parallel to these features and others approximately at right angles to them.

Folds: Closely appressed folds prevail throughout the incompetent Alder series, whose beds dip steeply or even vertically and strike northeast to northward. A few

folds of this type and of the same general trend are revealed in the Deadman quartzite and Maverick shale.

Broad, open folds of low northeast to northward plunge are characteristic of the more competent formations, particularly the Mazatzal quartzite, and are also present in the City Creek, Deadman, and Maverick strata.

Drag folds, prevailingly of low northeast to northward plunge, affect particularly the Maverick shale and thin-bedded members of the Deadman and Mazatzal quartzites.

Faults: Thrust faulting is an important structural feature of the pre-Apache formations in central Arizona, as exemplified by the Mazatzal thrust, a great low-angle initial shear fault that involves the northern half of the Mazatzal Mountains. With low southeastward dip, it cuts diagonally across the underlying gently southeastward-dipping Mazatzal strata in the northern portion. Although concealed by the Tertiary formations that flank the central segment of the range, this fault doubtless affects also the Red Rock rhyolite and Alder series of the central segment. Above the fault are imbricated, slightly deformed to closely folded sheets, separated by steeply dipping reverse faults which branch upward from the sole. Its minimum displacement appears to be seven miles.

Reverse faults which dip at angles of 45° to 80° are of common occurrence in the pre-Apache rocks. Part of these faults appear to be contemporaneous with the low-

angle thrusting, and part of them probably followed the batholithic intrusion.

A few vertical faults strike at right angles to the folds and thrust faults and show more horizontal than vertical displacement. They may be regarded as tear faults. They are believed to be of pre-Apache age.

Normal faults are fairly abundant in central Arizona. Part of them are pre-Cambrian, probably pre-Apache, and part are Tertiary. Many of them are of indeterminate age, but, wherever they lack topographic expression, they are regarded as of pre-Cambrian age. The normal faults of known and supposed pre-Cambrian age strike northeast to northward, dip steeply, and show maximum displacements of several thousand feet. The later normal faults of Tertiary age comprise two main systems of which one strikes northwest to westward and the other northeast to northward. They are strongly reflected in the present topography, although no true fault scarps are present. The mountain ranges stand above the intervening valley troughs because the upthrown mountain blocks have been resistant to the erosion of Quaternary time relative to the soft Tertiary beds of the downthrown blocks.

Origin of the pre-Cambrian structural features: The Mazatzal Revolution: It is concluded that the chief features of pre-Cambrian structure resulted from a profound crustal disturbance, termed the Mazatzal Revolution. The subparallel folds, thrust faults, and imbricate, steeply

dipping reverse faults clearly resulted from intense northwest-southeastward regional compression. The transverse faults are believed to have been formed, also during the compression, by shearing normal to the trend of the folds. Widespread igneous activity, marked by the intrusion of intermediate to ferromagnesian stocks and dikes and the largest batholithic invasion of granite in central Arizona, culminated this most intense crustal disturbance. Consequent readjustments gave rise to normal and steeply dipping reverse faults.

The mountains upheaved by the Mazatzal Revolution were deeply eroded to a plain, locally surmounted by ridges of considerable relief, prior to deposition of the Apache group. Some of these ridges, buried by Permian to Tertiary beds and exhumed by Tertiary to Recent erosion, still survive. As the Apache beds are probably equivalent in age to the Unkar, the great pre-Apache erosion interval may be reasonably correlated with the unconformity that separates the Vishnu series from the Unkar group in the Grand Canyon.

A crustal disturbance of such magnitude as the Mazatzal Revolution doubtless involved a region much larger than central Arizona. This revolution is believed to have produced the northeast to northward-trending structures that characterize the pre-Apache and pre-Unkar formations throughout Arizona. Its close folding doubtless gave a rigid and positive character to those areas where the

sedimentary succession was very thick. The Colorado Plateau, whose folded Vishnu schist has an estimated thickness of 25,000 feet, remained relatively positive after the great pre-Cambrian folding, and the adjacent central Arizona region underwent no great folding or faulting between the Mazatzal Revolution and the Tertiary Basin and Range orogeny. Structural weaknesses inherited from the Mazatzal Revolution may have influenced the localization of many of Arizona's prevailingly northeastward-trending veins and the pattern of the Tertiary Basin and Range faulting.

Figure 1. Map showing location of the central Arizona region in reference to geomorphological provinces.

PART I. REGIONAL SETTING

INTRODUCTION

The pre-Cambrian formations studied particularly for this research appear prominently in central Arizona, within Gila, Yavapai, and Maricopa counties (see Figure 1, page 16), and extend beneath later rocks for an unknown distance northeastward. While the present investigation is particularly concerned with a northwestward-trending region, 100 miles long by generally less than 50 miles wide, these formations are probably represented to some degree in other pre-Cambrian outcrops of the Southwest. Obviously, the structural history involves a large region of which Arizona represents only a portion. In order to confine the descriptions within reasonable bounds, however, consideration of the regional setting is for the most part restricted to a brief sketch of the main geologic features of this State, particularly inasmuch as Arizona lies within the two main geomorphologic provinces of the Southwest, with the Plateau-Basin Range boundary [4] roughly bisecting the State from southeast to northwest (see Figure 1, page 16). As shown by many geologists, these two provinces differ

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[4] Gilbert, G.K., Report on the geology of portions of New Mexico and Arizona, examined in 1873: U.S.Geog. and Geol. Surveys W. of the Hundredth Meridian, vol. III, Geol., p. 507, 1875.

markedly not only in topography but also in geologic history, stratigraphy, structure, and mineralization.

CHAPTER I - PLATEAU PROVINCE

Definition

The Plateau of northern and northeastern Arizona, locally termed the Arizona Plateau, is part of the Colorado Plateau which comprises also a large area in Colorado, Utah, and New Mexico. In Arizona, its general surface constitutes large plains which range in altitude from about 4,300 to more than 9,000 feet, mainly as a reflection of bedrock structure. These plains are surmounted by several high volcanic mountains and are deeply incised by canyons of the Colorado River system. On the southwest and south, the Plateau terminates with the Mogollon Escarpment, a raggedly indented line of cliffs that, except where locally interrupted by lava flows, range from a few hundred to more than 1,500 feet in height.

Stratigraphy of the Plateau[5]

The Plateau consists of pre-Cambrian to Quaternary formations which show considerable local variation in character and thickness.

The Grand Canyon reveals basement rocks of schist, gneiss, and granite. Overlying this mass unconformably there are tilted strata which in places total nearly 12,000 feet in thickness (see pages 73-76). Both these groups of pre-Cambrian rocks are unconformably overlain by some 3,700 feet of Paleozoic beds. The Paleozoic formations have been designated as follows:

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5 Powell, J. W., Exploration of the Colorado River of the West: Washington, 1875.

Walcott, C. D., Pre-Carboniferous strata in the Grand Canyon of the Colorado: Am. Jour. Sci., vol. 26, pp. 437-442, 1883.

Noble, L. F., The Shinumo quadrangle, Grand Canyon district, Arizona: U. S. Geol. Survey Bull. 549, 1914.

Noble, L. F., A section of the Paleozoic formations of the Grand Canyon at the Bass Trail: U. S. Geol. Survey Prof. Paper 131, pp. 23-33, 1923.

Darton, N. H., A résumé of Arizona Geology: Univ. of Ariz., Ariz. Bureau of Mines Bull. 119, pp. 182-189,1925.

Stoyanow, A. A., Correlation of Arizona Paleozoic formations: Geol. Soc. Am., Bull., vol. 47, pp. 459-540, 1936.

Formation		Thickness in feet
Permian -		
Kaibab limestone....	Dense gray crystalline limestone with buff limestone and calcareous sandstone....	400-600
Coconino sandstone..	Fine-grained cross-bedded light-buff cliff-forming sandstone.....	250-350
Hermit shale.....	Brick-red sandy shale and fine-grained sandstone.....	265-750+
Unconformity		
Permian (?) and Pennsylvanian.		
Supai formation.....	Predominantly reddish soft sandstone and sandy shale.....	950+
Unconformity (?)		
Mississippian-		
Redwall limestone...	Predominantly massive gray cliff-forming limestone.....	600-700+
Unconformity (?)		
Devonian-		
Temple Butte limestone.....		0-100+
Unconformity		
Cambrian (Middle)-		
Muav limestone.....	Impure thin-bedded mottled bluish-gray limestone.....	450-475
Bright Angel shale..	Soft greenish micaceous shale.....	25-390
Tapeats sandstone...	Slabby cross-bedded brown sandstone, conglomeratic at base....	0-330+
Great Unconformity	Total	2,940-3,695+
Pre-Cambrian		

Northeastward, the Paleozoic section thins greatly; in the Defiance uplift (Plate II) Supai (Permian) strata unconformably surround a small outcrop of pre-Cambrian quartzite and, as shown by drill records, rest directly on granite. A maximum of 5,400 feet of Mesozoic and Tertiary beds, mainly of continental origin, are represented in the northeastern portion of Arizona.[6]

Volcanic rocks, localized chiefly in east-central Arizona and in the San Francisco Mountains,[7] Hopi Buttes,[8] and Shiwits-Trumbull[9] areas, cover many thousand square miles of the Arizona Plateau. They represent central and

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6 Gregory, H. E., Geology of the Navajo Country: U.S. Geol. Survey Prof. Paper 93, 1917; also Longwell, C. R., Miser, H. D., Moore, R. C., Bryan, Kirk, and Paige, Sidney, Rock formations in the Colorado Plateau of southeastern Utah and northern Arizona: U. S. Geol. Survey Prof. Paper 132, pp. 1-23, 1925.

7 Robinson, H. H., The San Francisco volcanic field, Arizona: U. S. Geol. Survey Prof. Paper 76, 1913.

8 Gregory, H. E., work cited, pp. 83-90.

9 Dutton, C. E., Tertiary history of the Grand Canyon district: U. S. Geol. Survey Mon. 2, 1882.

fissure types of Tertiary to Recent age. The greatest eruptions took place in the east-central and San Francisco Mountains fields, near the southwestern margin of the Plateau, and extend southward, over the Plateau escarpment, into the Basin and Range Province. As they rest upon Permian and Mesozoic strata in the Plateau and are considerably later than the initiation of the Basin-Range Province, their age is regarded as Pliocene and younger. As indicated by Darton's structural map (Plate II, page 23), the great lava fields are associated with broad anticlines, whereas the plugs are mostly grouped within the margins of the Black Mesa basin, and the western and southeastern borders of the San Juan Basin.

Structure of the Plateau[10]

Where well revealed, in the restricted area of the Grand Canyon, the pre-Cambrian structure of the Plateau is complex, as summarized on pages 44-46, 75-76.

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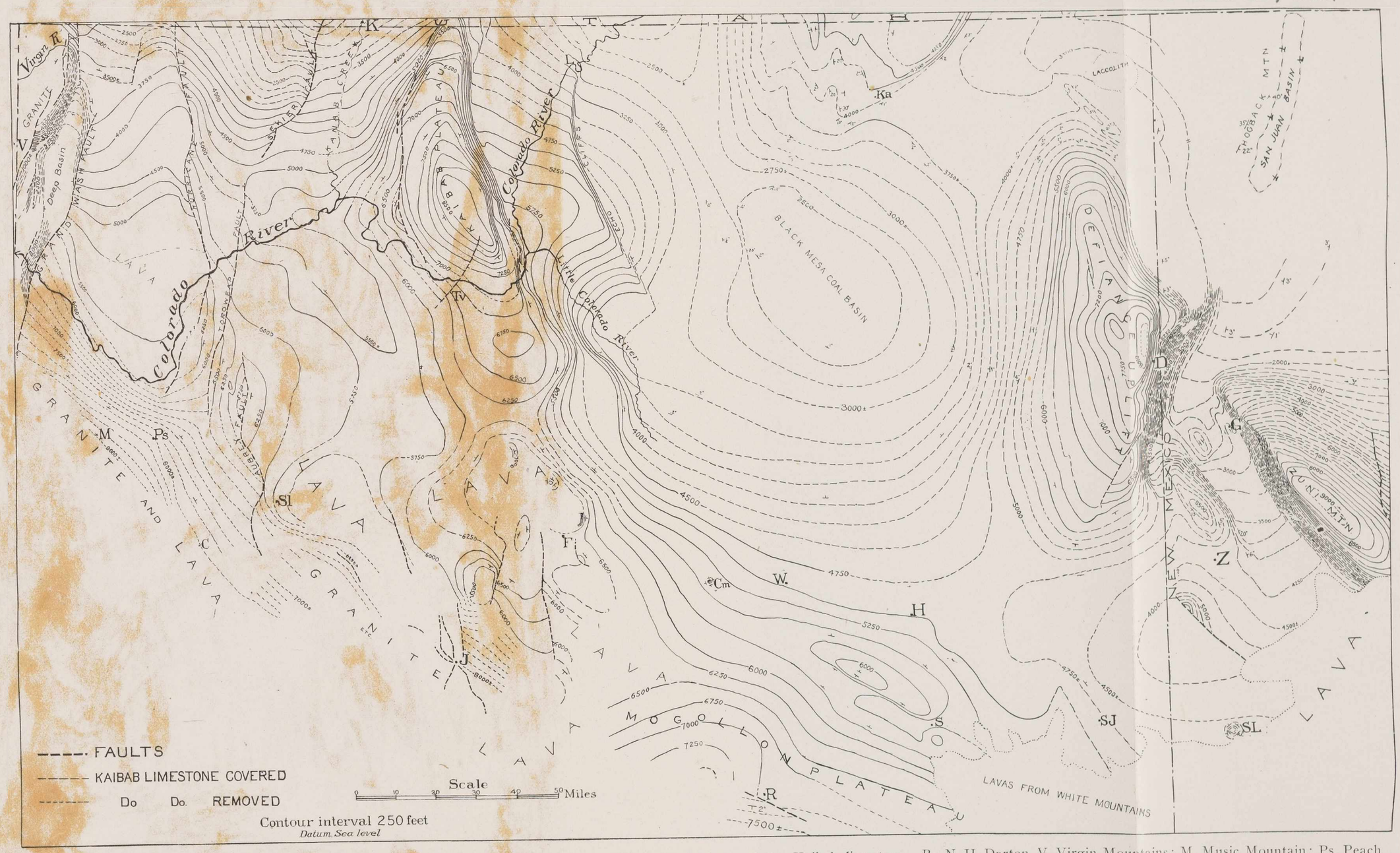
[10] Gilbert, G. K., work cited, pp. 556-567; also Final Repts., U. S. Geog. and Geol. Surveys W. 100th Mer., pt. 1, p. 54, 1873.

(From Ariz. Bureau of Mines Bull. 119, 1925)



Map showing deformation of strata in Plateau Region of Arizona, by contour lines at the base of the Kaibab limestone. By N. H. Darton, V, Virgin Mountains; M, Music Mountain; Ps, Peach Springs; Sl, Seligman; C, Cross Mountain; K, Kanab, Utah; F, Flagstaff; L, Lees Ferry; Tv, El Tovar; Cm, Crater Mound; R, Ramer (Wallace) Ranch; J, Jerome; W, Winslow; H, Holbrook; Ka, Kayenta; S, Snowflake; D, Fort Defiance; Sj, St. John; SL, Salt Lake, N. M.; G, Gallup, N. M.; Z, Zuni, N. M.

PLATE II-Structural map of Plateau in Arizona, by N. H. Darton.

The later structural features, as denoted by ample exposures, consist of Laramide folds and post-Eocene normal faults. These features for the most part trend northward and find clear expression in the topography. The folds range from broad to narrow and in general are sharply assymetrical or monoclinal, as indicated by Plate II. The larger faults, which occur mainly west of Longitude 112°, drop the Plateau with successive broad steps, fronted with steep fault-line scarps, westward. The greatest

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Dutton, C. E., Tertiary History of the Grand Canyon district: U. S. Geol. Survey Mon. 2, 1889.

Huntington, Ellsworth, and Goldthwait, J. W., the Hurricane fault in the Toquerville district, Utah: Harvard Univ. Mus. Comp. Zool. Bull. 42, 1904.

Gregory, H. E., work cited.

Darton, N. H., A résumé of Arizona geology: Univ. of Ariz., Ariz. Bureau of Mines Bull. 119, p. 147, 1925.

Moore, R. C., Structural features of the Colorado Plateau and their origin (Abstract): Geol. Soc. Am. Bull., vol. 34, No. 1, pp. 88-89, 1923.

Butler, B. S., Relation of the ore deposits of the southern Rocky Mountain region to the Colorado Plateau: Colo. Sci. Soc., Proc., vol. 12, pp. 23-36, 1929.

King, P. B., An outline of the structural geology of the United States: XVI Int. Geol. Cong. Guidebook 28, pp. 31-32, 1932.

vertical displacement, mounting to approximately 16,000 feet,[11] occurs on the Grand Wash fault at the mouth of the Grand Canyon and there separates the western portion of the Plateau from the Basin and Range Province.

The cliffs of the Mogollon Escarpment, which limit the Plateau on the southwest and south, appear to have originated partly through erosion guided by faults and fractures transverse to the present cliff fronts, and partly as fault-line scarps.

Notwithstanding Robinson's interpretations of the age of the greatest uplift as Quaternary,[12] the principal elevation of the Plateau appears to have occurred during Tertiary time, contemporaneous with the Basin-Range orogeny. This date of the uplift is suggested by the Tertiary, probably Pliocene, lava flows that mantle, and unconformably abut against, the Mogollon Escarpment at several places.

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11 Longwell, C.R., Geology of the Boulder Reservoir floor, Arizona-Nevada: Geol. Soc. America, Bull., vol. 47, p. 1458, 1936.

12 Robinson, H. H., work cited.

CHAPTER II - BASIN AND RANGE PROVINCE

Definition

Limiting the Plateau on the southwest, the Basin and Range Province includes the southwestern half of Arizona and extends into Mexico, California, and Nevada. In Arizona, it contains some 150 prevailingly linear, north-northwestward-trending mountain ranges abruptly rising from plains or valleys which locally form closed basins but for the most part drain to the Colorado River.

Subdivisions

As may be seen from the topographic and geologic maps of Arizona, the Basin and Range Province is composed of several local geomorphologic units. These various units, however, are not readily amenable to definition, and their proper analysis will be possible only after much further structural study. A dual subdivision has been made by Ransome[13] who terms the northeastern, pre-

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13 Ransome, F. L., Geology of the Globe copper district, Arizona: U. S. Geol. Survey Prof. Paper 12, pp. 10-16, 1903; Copper deposits of Ray and Miami, Arizona: Idem, Prof. Paper 115, p. 15, 1919; and Description of the Ray quadrangle: Idem, Folio 217, p. 1, 1923.

vailingly mountainous belt the Mountain Region and the southwestern portion, which lacks any definite northeastern boundary, the Plains or Desert Region (see Figure 1, page 16). The Mountain Region is regarded as a continuation of the Mexican Highlands and the Plains or Desert Region as part of the Sonoran Desert.

The Mountain Region contains relatively large north-northwestward-trending ranges of which the longest measures about 55 miles, the widest 20 miles, and the highest peak more than 10,000 feet above sea level or 7,000 feet above adjacent valleys or plains. Broad plain-forming valleys are exceptional in the central portion of Arizona's Mountain Region, but several with maximum widths of 20 to more than 30 miles appear in its southeastern portion.

In the Desert or Plains Region, according to Ransome, the chief topographic characteristic is the predominance of broad and comparatively low desert plains. This definition, however, is subject to the objection that the intermont plains here, although constituting half to three-fourths of the region, are scarcely broader than some of those in the Mountain Region. More characteristic of the Desert Region are its generally smaller but steeper mountains, with sharply angular profiles resulting from the relatively greater aridity. There are a few exceptionally large ranges of which the longest measures nearly 100 miles, the widest 18 miles, the highest peaks

some 7,000 feet above sea level, and the maximum local relief about 5,400 feet. The prevailingly north-northwestward trend of the ranges is interrupted in northern Yuma County, in west-central Arizona, where relatively large ranges occur elongated in westerly to southwesterly directions.

Stratigraphy of Basin and Range Province

The mountains of the Basin and Range Province in Arizona consist of pre-Cambrian to Quaternary formations, whereas the valleys or plains, although commonly fringed with pediments cut on hard rock, are floored with loosely consolidated sediments of mid-Tertiary to Recent Age. The principal mountain-making formations include pre-Cambrian schist and gneiss; relatively unmetamorphosed pre-Cambrian sedimentary rocks; pre-Cambrian batholiths and stocks of granite, stocks and dikes of diorite, and dikes of felsic to mafic composition; pre-Cambrian (Apache) beds, 1,400 feet in maximum thickness and intruded by great sills of diabase; 5,000 feet of Paleozoic strata; 4,700 or more feet of Jurassic and Cretaceous beds; Mesozoic to Tertiary intrusive masses, predominantly of felsic to intermediate composition; and thick Tertiary to Quaternary volcanic formations.

The Geologic Map of Arizona indicates that pre-Cambrian schist and gneiss, intruded by great batholiths of pre-Cambrian and later granitic rocks, are of wide-

spread and prominent occurrence within the mountains of the Basin and Range Province. The published information regarding these formations is briefly outlined on pages 46-70.

The Apache group, of late pre-Cambrian age, consists of quartzite, cherty limestone, shale, and conglomerate, intruded by thick sills of diabase. It crops out prominently in the northwestern portion of southeastern Arizona and extends northward through the Sierra Ancha, disappearing beneath the Paleozoic strata of the Plateau. This group of rocks is described on pages 76-79.

Lower Cambrian rocks appear to be lacking in the Basin and Range Province of Arizona, but Middle and Upper Cambrian[14] strata are well represented in the Mountain Region and in the southeastern portion of the Desert or Plains Region. They attain their maximum thickness of 1,200 feet at Bisbee[15] and Tombstone, in the southeastern part of the State.

Ordovician beds several hundred feet thick occur

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14 Stoyanow, A.A., Correlation of Arizona Paleozoic formations: Geol. Soc. Am., Bull., vol. 47, pp. 462-481,1936.

15 Ransome, F. L., U.S. Geol. Survey Prof. Paper 98, p. 145, 1916.

at Morenci [16] and at Dos Cabezas,[17], in southeastern Arizona, but are not represented elsewhere in the region.

Silurian formations have not been found in Arizona.

Devonian and Carboniferous strata occur in many of the ranges of the Mountain Region and attain a maximum thickness of more than 4,000 feet at Bisbee [18] where, through southeastward thickening, the Mississippian and Pennsylvanian total more than 3,700 feet. These formations also appear in several of the southern Desert ranges as far west as the Vekol Mountains (Longitude 112°10'), but farther west they constitute only sparsely scattered, relatively small, metamorphosed outcrops.

The Mesozoic era is represented in the Basin and Range Province of Arizona by sedimentary and volcanic rocks and by intrusive masses. These formations are

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16 Lindgren, Waldemar, Copper deposits of the Clifton-Morenci district, Arizona: U. S. Geol. Survey Prof. Paper 43, pp. 62-65, 1905.

17 Darton, N. H., work cited, p. 296, 1925.

18 Ransome, F. L., Prof. Paper 98, 145-148, 1916.

present in the southern half of the Mountain Region where their strata thicken southeastward to more than 4,700 feet and overlap a deeply eroded surface of older rocks. Some, at least, of the metamorphosed shale, sandstone, conglomerate, and limestone of southwestern Arizona, which are shown on the State Geologic Map as pre-Cambrian, are probably of Mesozoic age.[19]

The southwestern region contains considerable sodic granite of post-Paleozoic aspect. Stocks of granitic to monzonitic composition occur in numerous ranges of southern Arizona and are important features of many of the mining districts. Some of these intrusions penetrate Lower Cretaceous rocks, whereas others cut only Paleozoic or earlier formations, and many show no definite age relations. They are believed to be of post-Jurassic to early Tertiary age.

Volcanic rocks, including rhyolitic to basaltic flows, tuff, breccia, and minor intrusions, constitute important mountain-making formations in the Basin and Range Province of Arizona. They locally form series of great magnitude, as in the Black Mountains [20] of north-

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19 Wilson, Eldred D., Geology and mineral deposits of southern Yuma County, Arizona: Univ. of Ariz., Ariz. Bureau of Mines Bull. 134, pp. 27-30, 1933.

20 Ransome, F. L., Geology of the Oatman gold district, Arizona; U. S. Geol. Survey Bull. 743, 1923.

western Arizona, where the succession amounts to possibly more than 16,000 feet in thickness. They represent fissure and central eruptions, with the fissure type apparently predominating. Their age, which ranges from Cretaceous to Recent, has been definitely determined for only a few areas. In the northern and central portions of the Mountain Region, the volcanic rocks appear to be related to the Plateau eruptions which Robinson[21] regarded as late Tertiary. In the Deer Creek[22] region, southeast of Globe, however, the andesitic extrusive succession is of Upper Cretaceous age. Of probable Tertiary age are the extensive dacite flows that, in the Globe, Ray, and Superior regions, underlie Pliocene Gila conglomerate and overlie truncated dikes that cut the Cretaceous rocks.[23] Throughout the remainder of the Basin and Range Province of Arizona, the volcanic rocks of felsic to intermediate composition locally overlie Lower Cretaceous beds and have been assumed to be Tertiary, although the possibility that some of them are late Mesozoic

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21 Robinson, H. H., The San Franciscan volcanic field, Arizona: U. S. Geol. Survey Prof. Paper 76, pp. 91-92, 1913.

22 Campbell, M. R., The Deer Creek coal field, Arizona: U.S.Geol. Survey Bull. 225, 1904.

23 Ransome, F. L., U. S. Geol. Survey Prof. Paper 115, pp. 57-71, 1919.

can not be denied. In the Trigo Mountains, along the Lower Colorado River, they are overlain by Miocene or Pliocene beds.[24] Younger basalts, in part of Recent aspect and locally resting upon Tertiary and Quaternary sediments, occupy considerable areas in the southwestern portion of the State.

Most of the intermont troughs are filled to depths of several hundred to a few thousand feet with sedimentary deposits of Tertiary to Quaternary age.[25] The oldest exposed members consist of medium to coarse-grained arkosic conglomerate and stratified arkosic shale and sandstone which appear prominently as tilted fault blocks at Mt. McDowell, in the lower Verde Valley, at Tempe Butte,[26] on lower Salt River, at Baker Peaks, in the Lower Gila Valley, at Osborne's Well,[27] east of Parker, at the mouth of the Grand Canyon,[28] and at several localities in the

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24 Wilson, Eldred D., Marine Tertiary in Arizona: Science, vol. 74, pp. 567-568, 1931.

25 Bryan, Kirk, The Papago Country, Arizona: U.S.Geol.Survey Water-Supply Paper 499, 1925.

26 Lee, W. T., Underground waters of the Salt River Valley, Arizona: U.S.Geol. Survey Water-Supply Paper 136,p.97, 1905.

27 Wilson, Eldred D., Ariz. Bureau of Mines Bull. 134, 1933, and Science, vol. 74, pp. 567-568, 1931.

28 Lee, W. T., Geological reconnaissance of a part of western Arizona: U.S.Geol. Survey Bull. 352, 1908.

Papago[25] and Lower Gila[29] regions. These members, which are intimately associated with volcanic rocks in their upper portion and unconformably underlie beds of Pliocene aspect, are regarded as of Miocene age. The younger Tertiary members comprise a thick series of faulted conglomerate, sand, silt, and local lake beds, broadly analogous to the Gila conglomerate which Gilbert[30] and Ransome[31] regarded as Pleistocene but which Bryan, on the basis of paleontological[32] and geomorphological evidence, regards as Pliocene. Relatively thin deposits of loosely consolidated gravel, sand, and silt of Pleistocene to Recent age mantle the older deposits in many places.

Structure of Arizona Basin and Range Province

Origin of the ranges

In the Basin and Range Province of Arizona, the mountain ranges and their intervening valleys or plains are believed to be largely of structural origin. Few of them appear to have been formed by erosion alone, and most

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29 Ross, C.P., Geology of the lower Gila region, Ariz.: U.S.Geol.Survey Prof. Paper 129, 1922.

30 Gilbert, G.K., Report of explorations west of the 100th Meridian, vol. 3, pp. 540-541, 1875.

31 Ransome, F. L., U. S. Geol. Survey Prof. Papers 12 and 115.

32 Gidley, J. W., Preliminary report on fossil vertebrates of the San Pedro Valley, Arizona: U. S. Geol. Survey Prof. Paper 131, pp. 120-121, 1922.

of them possess abundant geologic or geomorphologic characteristics of mid-Tertiary and later tectonic masses which have been more or less modified by semi-arid erosion.

It seems hardly conceivable that streams, at first sufficiently vigorous to form valleys locally exceeding 7,000 feet in depth and subsequently of the sluggish or meandering quality necessary to produce plains of 20 or more miles' width, ever separated these numerous mountain ranges. Spurr,[33] nevertheless, concluded that the topographic forms of the Great Basin are the "net results of compound erosion active since Jurassic times, operating on rocks upheaved by compound earth movements which have been probably also continuous during the same period," and that only the more recent folds or faults find expression in the topography. Keyes, in papers too numerous to mention here, likewise supports the erosional idea, but with the radical contention that the principal agency was deflation acting on broad belts of weak rocks which faulting had brought into juxtaposition with narrow belts of harder rocks.

Contrary to these hypotheses of Spurr and Keyes, abundant geologic and physiographic evidence for the predominantly structural origin of the Basin ranges has been

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[33] Spurr, J. E., Origin and structure of the Basin Ranges; Geol. Soc. America Bull., vol. 12, pp. 264-266, 1901.

brought forth by Gilbert,[34] Clarence King,[35] Dutton,[36] Russell,[37] Emmons,[38] Davis,[39], Johnson,[40], Ransome,[41],

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34
Gilbert, G. K., work cited, p. 41, 1875; also Studies of Basin Range structure: U. S. Geol. Survey Prof. Paper 153, 1928.

35
King, Clarence, U. S. Geol. Expl. Fortieth Parallel Rept., vol. 1, p. 735, 1878.

36
Dutton, C. E., Geology of the High Plateaus of Utah: U.S. Geog. and Geol. Survey Rocky Mtn. Region, pp. 47-48, 1880.

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Louderback,[42] Baker,[43] Ferguson and Cathcart,[44] Bryan,[45] Longwell,[46] Lindgren,[47] P. B. King,[48] and others.

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42 Louderback, G. D., Basin Range structure of the Humboldt region: Geol. Soc. America, Bull., vol. 15, pp. 289-346, 1904; and Basin-Range structure in the Great Basin: Calif. Univ. Dept. Geol. Bull., vol. 14, pp. 329-376, 1923.

43 Baker, C. L., The nature of the later deformations in certain ranges of the Great Basin: Jour. Geol., vol. 21, pp. 273-278, 1913.

44 Ferguson, H. G., and Cathcart, S. H., Major structural features of some western Nevada ranges (abstract): Wash. Acad. Sci., Jour., vol. 14, pp. 376-379, 1924.

45 Bryan, Kirk, The Papago Country, Arizona: U. S. Geol. Survey Water-Supply paper 499, pp. 70-118, 1925.

46 Longwell, C. R., Structural studies in southern Nevada and western Arizona: Geol. Soc. America, Bull., vol. 37, pp. 551-584, 1926; also Geology of the Muddy Mountains, Nevada, with a section through the Virgin Range to the Grand Wash Cliffs, Arizona: U. S. Geol. Survey Bull. 798, 1928.

47 Lindgren, Waldemar, Ore deposits of the Jerome and Bradshaw Mountains quadrangles, Arizona: U. S. Geol. Survey Bull. 782, p. 8, 1926.

48 King, P. B., An outline of the structural geology of the United States: XVI Int. Geol. Cong., Guidebook 28, pp. 36-43, 1932.

Ransome[49] has shown that the mountains and valleys of central and southern Arizona are of tectonic origin, with complex fault blocks rather than folds predominating. In the south-southwestern part of the State, Bryan[50] found that many of the mountain ranges and plains are demonstrably fault blocks of post-lava age, and, although some mountains of uncertain origin existed prior to the Tertiary volcanic activity, no recognized post-Paleozoic folding is present there. In southeastern Arizona, the uplift of the existing mountains by normal faulting has been superimposed upon rocks affected by pre-existing folds and thrust faults without apparent or recognized relation in trend or pattern.

Structure within the ranges

The internal structure of Arizona's mountain ranges has been complicated by extensive normal faulting and igneous intrusion, considerable thrust faulting, and folding.

Intense folding and normal and reverse faulting are characteristic of the pre-Cambrian rocks. One of the great periods of pre-Cambrian revolution is discussed on subsequent pages.

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49 Works cited.

50 U. S. Geol. Survey Water-Supply Paper 499, p. 71.

Folding during the Appalachian Revolution has not been recognized here, although regional uplift must have occurred at that time to provide the land masses from which the Triassic and Jurassic sediments of northern Arizona were derived. Notable intra-range folds of Paleozoic and later strata are known in southeastern Arizona, in west-central Arizona, and in northwestern Arizona.

South of the Gila River and east of Longitude 111°15', the folds are mainly of Laramide age. King regards them as representing northwestern extensions of the Mexican Highland structures.[51] They generally trend northwestward and in many localities are genetically associated with southwestward-dipping, low-angle thrust faults of the same age.

The basins in which the Pliocene Gila conglomerate was deposited are believed to be tectonic, but whether due to faulting or folding is not clear.

Between Tucson and Benson, thrust faults have affected the Pantano formation, which is regarded as of late Tertiary age. These thrusts are exceptional, and may not represent a general phenomenon, as the Pliocene Gila conglomerate is, so far as known, affected only by normal faults.

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51 King, P. B., An outline of the structural geology of the United States: XVI Int. Geol. Cong. Guidebook 28, p. 42, 1932.

In the west-central region, in northern Yuma and southern Mohave counties, folds affect Paleozoic and Mesozoic strata.[52]

In northwestern Arizona, folds of north-northeastward strike occur in the Virgin Mountains region, representing the eastward limit of the Great Basin folds and thrusts whose age lies between Jurassic and middle Pliocene.[53]

Steeply dipping reverse and normal faults are fairly abundant in the folded regions. Some of these faults are of great magnitude, as at Tombstone, where displacements amounting to more than 4,000 feet are evident. Butler[54] regards this type of steep faults as having followed the igneous wave that was consequent upon the close folding and low-angle thrust faulting. They antedate perhaps most of the ore deposits.

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52 Darton, N. H., A résumé of Arizona geology: Univ. of Ariz., Ariz. Bureau of Mines Bull. 119, pp. 215-22,1925.

53 Longwell, C. R., Geology of the Muddy Mountains, Nevada, with a section through the Virgin Range to the Grand Wash Cliffs, Arizona: U. S. Geol. Survey Bull. 798, 1928.

54 Butler, B. S., Ore deposits as related to stratigraphic, structural, and igneous geology in the western United States: Am. Inst. Min. & Met. Eng., Lindgren volume, pp. 223-226, 1933.

Various systems of normal faults affect the ranges and in several localities form patterns of great complexity. These faults are mostly interpreted as results of tensional strains incidental to the regional and local adjustments that followed the Laramide Revolution and the Tertiary eruptive activity. They continued intermittently into Quaternary time. No very recent or late Pleistocene faulting of importance is demonstrable here.

CHAPTER III. SUMMARY OF PUBLISHED KNOWLEDGE OF ARIZONA PRE-CAMBRIAN

General Statement

Pre-Cambrian rocks crop out in the Grand Canyon, in the Defiance Uplift of northeastern Arizona, and in most of the mountain ranges of the southwestern half of the State, as shown on the Geologic Map of Arizona. Four principal lithologic divisions have been recognized: (1) A basement of schist, gneiss, and small intrusive bodies; (2) batholithic masses of granite; (3) the Mazatzal quartzite, whose relation to the older rocks has not previously been determined; and (4) younger pre-Cambrian strata which have undergone relatively little folding and metamorphism. The younger pre-Cambrian beds (4) in the Grand Canyon and central Arizona have received considerable attention, but the older basement rocks, outside of the Grand Canyon and a few mining regions or districts, have not been studied in detail.

According to published information, the pre-Cambrian stratigraphic succession in Arizona is as follows:

Correlation of Arizona pre-Cambrian formations according to published knowledge

Region	Plateau Province		Basin and Range Province	
	Grand Canyon	Defiance Uplift	Central Arizona	Southern and western Arizona
Later pre-Cambrian: "Algonkian"; "Proterozoic" (probably Beltian)	Chuar group: Shale, sandstone, and limestone.	Missing	Missing	Missing
	—Unconformity—	- - - - - -	- - - - - -	- - - - - -
	Unkar group: Sandstone, quartzite, shale, and limestone; intruded by diabase.	Missing	Apache group: Quartzite, shale, limestone, and conglomerate; extensively intruded by diabase; in most areas rests unconformably on granite and schist.	Apache group in north-central portion, only.
	- - - - - -	- - - - - -	Unconformity—	- - - - - -
Later pre-Cambrian(?) "Proterozoic"	Missing	Mazatzal(?) quartzite. Base not exposed.	Mazatzal quartzite.	Missing
	—Unconformity—	- - - - - -	Unconformity(?)—	Unconformity—
Earlier pre-Cambrian: "Archean" "Archaeozoic"	Vishnu schist: Sedimentary schist with more or less gneiss; extensively intruded by granite and mafic rocks.	Not exposed	Yavapai schist: Sedimentary and greenstone schist, extensively intruded by granite and intermediate to mafic rocks.	Pinal and Yavapai schists: Sedimentary and greenstone schist, locally with gneiss; extensively intruded by granite and intermediate to mafic rocks.

According to published descriptions, the planes of foliation or lamination in the old schist and gneiss prevailingly strike northeast to northward and dip steeply or even vertically, as a result of intense lateral compression which preceded the emplacement of most of the pre-Cambrian intrusive bodies. The Mazatzal quartzite has been described as somewhat deformed and faulted, but its structural features have not hitherto been studied. The younger pre-Cambrian Unkar and Apache strata underwent faulting, tilting, and slight local folding, followed by extensive peneplanation, before Cambrian time.

Earlier Pre-Cambrian Rocks

General statement

The earlier pre-Cambrian of Arizona is represented by schist and gneiss, with small intrusive bodies of felsic to mafic composition, and batholithic masses of granite. The antiquity of these rocks in the Grand Canyon and part of central and southeastern Arizona has been established by stratigraphic sequence, but, in most of the Basin and Range Province, it has been assumed from lithology or intensity of metamorphism.

Schist and gneiss

The Geologic Map of Arizona shows that, within the Plateau Province, schist appears only in the Grand Canyon, whereas, within the Basin and Range Province, it constitutes portions of numerous mountain ranges. It is prominent in the central and southeastern segments of the Mountain Region and in western and northwestern portions of the Desert Region, but occurs as small, scattered areas in the southwestern part of the State. The schist category, as thus used, includes the Vishnu schist of the Grand Canyon, the Yavapai and Pinal schists of central Arizona, and some areas of granitic gneiss in southern and western Arizona, together with undifferentiated areas of shale, grit, quartzite, conglomerate, and igneous rocks which, although more or less folded, faulted, and sheared, have not been materially recrystallized or foliated except near large intrusive bodies.

Vishnu schist: Major Powell's exploration demonstrated[55] that the pre-Cambrian formations in the Grand Canyon comprise two main systems, differing greatly in degree of metamorphism and separated by a profound uncon-

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55 Powell, J. W., Exploration of the Colorado River of the West: Washington, 1875; Geology of the eastern portion of the Uinta Mountains, p. 70, 1876.

formity. The older, which constitutes the basal complex, has been termed the Vishnu schist and assigned to the Archean.

Noble found that the Vishnu schist is composed of approximately 50 percent granitic gneiss, hornblende gneiss, and amphibolite; 30 percent mica schist, apparently sedimentary in origin; 10 percent mafic intrusive rocks; and 10 percent pink siliceous intrusive rocks. The gneiss is thought to be the oldest. The foliation of the Vishnu is predominantly of northeastward strike and nearly vertical dip except in the western portion where a northwestward strike is common.[56]

Ian Campbell and J. H. Maxson,[57] who have conducted field and laboratory studies of the Archean rocks of the Bright Angel quadrangle between Lone Tree Canyon on the east and Boucher Creek on the west, determined that the schist there is dominantly metamorphosed sediments

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[56] Noble, L. F., The Shinumo quadrangle, Grand Canyon district, Arizona: U. S. Geol. Survey Bull. 549, 1914; (and J. F. Hunter), A reconnaissance of the Archean complex of the Granite Gorge, Grand Canyon, Arizona: U. S. Geol. Survey Prof. Paper 98, pp. 95-113, 1916.

[57] Campbell, Ian, and Maxson, J. H., Geological studies of the Archean rocks at Grand Canyon: Carnegie Inst. Wash., Yearbook 32, pp. 305-306, 1933; idem., 33, pp. 284-285, 1934.

which appear to have been deposited as sand and sandy clay in the neritic zone of a shallow, subsiding geosyncline. This series differs from the Proterozoic largely in greater degree of metamorphism and intensity of granitic intrusion in the earlier era. The evidence obtained seems to indicate that the tilting of the Archean sediments had been largely accomplished before any of the major granitic intrusions took place, since in their emplacement these clearly have been influenced by the earlier structure. Probably the contact metamorphism has been superimposed upon the earlier regional metamorphism. The Archean section here seems to be not less than 25,000 feet thick. Its beds lie in the limbs of a northeastward-trending isoclinal syncline.

Yavapai schist: Laminated to schistose rocks occur extensively in central Arizona. They were first described by Blake[58] as follows: "This is a great slate formation which is extensively developed in Arizona. Lithologically it is like the Taconic slates, and I have called them the Arizona slates."

Jaggar and Palache[59] studied this formation in the Bradshaw Mountains, renaming it the Yavapai schist. They

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58 Blake, Wm. P., Rep't. of the Governor of Arizona, 1899, p. 139.

59 Jaggar, T. A., and Palache, Charles, Description of Bradshaw Mountains quadrangle: U. S. Geol. Survey Folio 126, 1905.

correlated it with the Vishnu schist of the Grand Canyon, which, at that time, was regarded as Algonkian. Their description may be summarized as follows: The Yavapai schist consists mainly of argillaceous phyllite varying to slate, mica-schist and chlorite-schist, with locally included gneiss, granulite, hornfels, epidote-schist, hornblende-schist, conglomerate, quartzite, and sandstone. The typical phyllite is a finely foliated blue or silvery aggregate of quartz and sericite with sparse grains of plagioclase; although some rare facies contain abundant microcline and albite, indicating a derivation from acid igneous rocks, most of the phyllite appears to be of sedimentary origin. The conglomerate lenses contain well-rounded to angular, locally deformed pebbles of granite, schist, quartz, and quartzite, indicating that land masses of these rocks existed in the region. The quartzite occurs as lenses associated with both the phyllite and the conglomerate. It is a dense fine-grained rock of gray, bluish or greenish-white color, somewhat laminated and cut in every direction with veinlets of white quartz. Fractured surfaces characteristically are lined with films of specularite or limonite. Microscopically, the rock generally shows a uniformly fine clastic grain, locally separated by films of sericite and chlorite. The "hornblende schist" is a complex including typical hornblende schist, amphibolite, mica schist, epidote, zoisite, garnet,

and tourmaline schists, hornfels, and uralitic diabase. Of these, the hornblendic schist and amphibolite are of igneous origin; the mica-epidote-, zoisite-, garnet-, and tourmaline schists and hornfels are believed to represent local metamorphic phases of the phyllite.

The foliation of the schist is generally parallel to the original bedding. Although the sequence of the series is probably interrupted by thrust and normal faults, its thickness is estimated at 5,000 to 7,000 feet.

The authors cited interpret the Yavapai schist as having been compressed into close folds of north-northeastward trend, after which it was intruded by stocks of Bradshaw granite and diorite, dikes of granite porphyry, diorite porphyry, and other rocks, and later stocks of quartz diorite. Near the granite is a metamorphic zone, characterized by the presence of staurolite, andalusite, hornblende, tourmaline, and biotite.

Lindgren,[60] who examined the schist of the Bradshaw quadrangle during part of the summer of 1922, presents the following views: The pure sericite schist does not predominate, but a more common variety is chloritic mica schist, in part doubtless of sedimentary origin. Banded magnetite with some red jasperoid occurs in many places.

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60 Lindgren, Waldemar, Ore deposits of the Jerome and Bradshaw Mountains quadrangles, Arizona: U. S. Geol. Survey Bull. 782, pp. 18-19, 1926.

PLATE III. Schistose rhyolite near Stoddard, Bradshaw Mountains Quadrangle.

Amphibolite and allied greenstone, probably for the most part schistose and altered mafic igneous effusive rocks and agglomerate, are more abundant than Jaggar and Palache indicated. Schistose rhyolite or rhyolite porphyry (see Plate III) occurs in association with sedimentary schist in most of the districts. The Yavapai schist as a whole, therefore, appears to represent a series, unestimated in thickness, of sedimentary beds with a large amount of interbedded, supracrustal effusive and minor intrusive rocks. Lindgren correlates the formation with the Vishnu schist of the Grand Canyon (page 44) and the Pinal schist of southern Arizona.

Schist in Black Hills (Jerome quadrangle): The schist complex of parts of the Black Hills Range has received considerable attention from geologists in connection with the Jerome mining district, but, as indicated by the following summaries of the published descriptions, their restricted observations have resulted in conflicting views of the local relations.

Provot[61] interpreted the schist formation as having resulted from intense folding and alteration of lava and sedimentary beds. He states that in Algonkian time these beds were compressed into northeastward-trending folds and intruded by great diorite dikes follow-

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61 Provot, F. A., Geological reconnaissance of the Jerome district, Jerome, Arizona (Abstract): Eng. and Min. Jour., vol. 102, pp. 1028-1031, 1916.

ing the lamination.

Finlay,[62] in a somewhat speculative article, stated that the oldest rocks seem to be gray or dark-colored greenstone, derived largely from lava and tuff which had been considerably folded along north-south axes and intruded by quartz porphyry and diorite.

Reber[63] regarded the schist as divisible into a great greenstone complex and an apparently younger series of bedded sedimentaries containing much fragmental volcanic material. Later a period of deformation, probably related to the approaching invasion of a granitic batholith, squeezed the bedded sedimentary rocks into close folds of north-northeastward trend and the greenstone in the southern end of the district into eastward-trending folds. The area was then invaded by masses of "quartz porphyry" which were rendered schistose by further deformation and followed by the intrusion of diorite. These disturbances no doubt produced a rugged and mountainous land area, high above sea level.

Reber described the greenstone complex as a unit in regard to thorough dynamic metamorphism and prevalent

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62 Finlay, J. R., The Jerome district of Arizona: Eng. and Min. Jour., vol. 106, pp. 557-562, 605-610, 1918.

63 Reber, L. E. Jr., Geology and ore deposits of Jerome district: A.I.M.E., Trans., vol. 66, pp. 3-26, 1920.

green color, although including much siliceous material among its several different rock types. Part of the metamorphism may be the result of deformation earlier than that connected with the intrusion of the Bradshaw granite. The greenstone, of which some members are identical with those of the Lake Superior pre-Cambrian, appears to be largely surface volcanics with small intrusives. Large areas of fragmental material, in part of sedimentary but mainly of volcanic origin, are present.

According to Reber, the bedded sedimentaries are "characteristically more massive than schistose, though closely folded; however, they probably correspond closely enough in composition and general appearance with parts of the Yavapai schist, to the south, to be included in that formation, though preferably as a distinct member." In the Jerome area they represent a variety of rock types, from very fine-grained quartzite and slate to thick-bedded conglomerate. Their beds dip steeply due to close folding, and some of the siliceous bands show remarkable crenulations and drag folds.

Lindgren,[64] who studied the geology of the Black Hills during part of the summer of 1922, states that the pre-Cambrian schist in the Jerome quadrangle corresponds to the Yavapai schist of the Bradshaw Mountains, though it

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64 Lindgren, Waldemar, Ore deposits of the Jerome and Bradshaw Mountains quadrangles, Arizona: U. S. Geol. Survey Bull. 782, 1926.

shows a slightly different facies and contains less sedimentary material. In places the schistosity is less well marked and varies in direction. He describes a long north-south belt about one mile wide of fissile, almost vertical schist continuing northward from the Bradshaw Mountains quadrangle along the western margin of the Black Hills, finally passing beneath the Cambrian Tapeats sandstone. Where crossed by the Cherry Creek road this belt from west to east consists of brown and red volcanic agglomerate, followed by purple schist and finally by chlorite-sericite schist, all members striking N. 20° E. and standing about vertical. The schist is adjoined on the east by greenstone and granite. The greenstone is largely, but not entirely, of mafic composition. In Yaeger Canyon it consists of fine-grained tuff with intercalated masses of fragmental material, the series dipping 45° E. In the Jerome district greenstone, with interbedded or earlier masses and streaks of clay slate, quartzite, banded chert, and other sedimentary rocks, prevails. The greenstone is rudely schistose, generally not fissile, and locally shows lenses of volcanic agglomerate. Near Jerome there is much light-colored massive to schistose rhyolite which in part is intrusive into the greenstone and in part represents flows. He concludes that there seems to be no reason for separating these predominantly volcanic rocks from the Yavapai schist, and any distinction between them seems futile.

Hansen[65] states that the oldest rocks of the district consist of a complex, as a whole corresponding to the Yavapai schist of the Bradshaw Mountains. He believes that it may be divided into four major units: tuff, fragmental greenstone (Deception porphyry), flows, and bedded sediments. The tuff is siliceous to andesitic in composition, and the fragmental greenstone is a rhyolitic extrusive. The flow series, which exceeds 400 feet in thickness, is rhyolitic with small round pebbles of jasper marking the base of each flow. Overlying these rocks is a series of well-exposed sedimentary beds which occur widely throughout the district. They include quartzite, arkosic shale, calcareous slate, and coarse-grained conglomerate. Following the deposition of these members, the series was compressed into close north-northeastward-trending folds with steeply northwestward-dipping limbs. It was then intruded by "quartz porphyry" and diorite. The main or Verde fault, which strikes N. 43° W. and dips 58° N. E., began in pre-Cambrian time with a vertical displacement estimated at 2,500 feet; in late Tertiary time, renewed movement upon it amounted to 1,360 feet vertically and 600 feet horizontally.

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65 Hansen, Mayer G., Geology and ore deposits of the United Verde mine: Mining Cong. Jour., vol. 16, pp. 306-311,1930.

Lausen[66] separated the metamorphic rocks of the Jerome quadrangle into Yavapai schist and greenstone complex, restricting the former to predominantly sedimentary material and the latter to volcanic rocks with some included beds of sedimentary origin. His conclusions may be summarized as follows:

The Yavapai schist extends northward from the Bradshaw Mountains quadrangle as a narrow continuous belt (page 53) along the western base of the Black Hills. This belt consists mainly of quartz sericite schist and brown slate, together with some chloritic schist which may have been derived from andesitic material. The brown slate includes numerous thin layers of impure buff-colored dolomitic limestone. West of the Shylock mine is exposed a bed of conglomerate at least 60 feet wide consisting of well-rounded pebbles of quartz, quartzite, jasper, gneiss, and felsite in a schistose micaceous, siliceous cement. The schistosity strikes northward and dips vertically or steeply westward, more or less parallel to the original bedding.

The greenstone complex, according to Lausen, consists of a prevailingly green to black schist derived from volcanic flows, tuff, and agglomerate together with

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66 Lausen, Carl, Pre-Cambrian greenstone complex of the Jerome quadrangle: Jour. Geol., vol. 38, pp. 174-183, 462-465,1930.

more or less sedimentary material, intruded by stocks and dikes of augite diorite and rhyolite porphyry and limited on the south by a granitic batholith that converted the greenstone into gneiss for a distance of 1,000 feet from the contact. The flows, in order of supposed sequence, are mainly andesite, latite, and rhyolite. Generally, the tuff, which grades into fragmental rock, is highly indurated and yet shows distinct bedding. Beds of quartzite and argillite occur in a few places between flows. The andesite flows are at least 5,000 feet thick and the felsic flows at least 2,000 feet.

Lausen states that the greenstone complex rests on the eroded upturned edges of the Yavapai schist; near the Shylock mine at the western foot of the Black Hills, the lower formation is thoroughly recrystallized and schistose, while the basal flows of the greenstone are massive and show no evidence of dynamic stresses other than deformation into a series of folds. Apparently the felsic flows are separated from the andesite by an unconformity. All of the rocks have been metamorphosed to some extent and are locally schistose. He believes that the greenstone complex is older than the Mazatzal quartzite and the Grand Canyon series.

Lindgren,[67] however, expressed doubt of the existence of the folds and unconformity described by Lausen, and

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[67] Jour. Geol., vol. 38, pp. 460-462, 1930.

considered the break between the greenstone and sedimentary schist to be due to ancient faulting. The greenstone, he stated, mainly represents extrusive rocks which were rendered more or less plainly schistose by the same set of stresses applied in the same general period as those that affected the sedimentary schist.

Schist in Mazatzal Mountains and Sierra Ancha: Some features of the schist in the Mazatzal Mountains and Sierra Ancha areas have been noted by Ransome,[68] whose descriptions may be summarized as follows:

Between Mt. Ord and Mazatzal Peak is a belt of schistose and slaty rocks which crosses the central segment of the Mazatzal Range with a northeast trend and a width of about 5 miles. To the northeast, it crosses Tonto Basin and extends, with a width of at least 15 miles, through the northern end of the Sierra Ancha. This belt of schist appears to coincide with a ridge or barrier (pages 71-72) that separates Paleozoic sections of different character. Associated with the schist and slate are great masses of quartzite, accompanied by some conglomerate and shale, all clearly older than the Apache (page 76) and Tonto (Cambrian) groups. Whether the pre-

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68 Ransome, F.L., Quicksilver deposits of the Mazatzal Range, Arizona: U. S. Geol. Survey Bull. 620, pp. 111-128,1915; Some Paleozoic sections in Arizona and their correlation: U.S. Geol. Survey Prof. Paper 98, pp. 155-159, 1916.

Cambrian quartzites of this region are all or only in part younger than the schist was not determined. The southwestern part of the schist belt, in the quicksilver district, on the West Fork of Sycamore Creek, is divisible longitudinally into at least eight zones consisting, from southeast to northwest, of gray slaty to sericitic schist, rhyolite porphyry, brown slate, sericitic schist, jaspery dolomitic limestone, sericitic schist with schistose grit, brown slate, and rhyolite porphyry (cf. Plate XXII). According to Ransome, this distribution of the rocks suggests that the jasper zone occupies the axis of a compressed syncline or anticline.

Pinal schist: The schist of the Globe, Miami, Ray, and Bisbee districts was named the Pinal schist by Ransome.[69] His descriptions may be summarized as follows:

This oldest exposed series, like most crystalline formations, is not uniform in appearance but shows divergencies which are due both to differences in original composition and to local variations in the intensity of the metamorphism. In general the Pinal schist is light-gray to bluish-gray, with a more or less satiny luster on cleavage surfaces. Texturally the varieties range from

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69 Ransome, F. L., Geology and ore deposits of the Globe copper district, Arizona: U.S.Geol. Survey Prof. Paper 12, 1903; and Copper deposits of Ray and Miami, Arizona: U. S. Geol. Survey Prof. Paper 115, 1919.

very fine-grained slaty sericitic schist to imperfectly cleavable, coarsely crystalline quartz-muscovite schist carrying andalusite and sillimanite in the vicinity of the Madera diorite, in the Pinal Mountains. Associated with the lustrous sericitic schist are a few layers of green amphibolitic schist. West of Ray is an exceptional facies that probably was originally a glassy rhyolitic lava. Some diabasic members occur near Ray.

The schist of the Bisbee district,[70] which, on the basis of lithologic similarity, is correlated with the Pinal schist, consists of a uniform fine-grained imperfectly cleavable aggregate, mainly of quartz and sericite, ranging in color from light to dark gray or greenish with a satiny sheen. Its general character indicates derivation from arkosic sands or silts. The dominant trend of the schistosity appears to be northeastward, but wide departures from this direction are common.

The mineral and chemical composition of the prevailing kinds of schist, their regular banding, and finely fissile character are indicative of sedimentary origin. Furthermore, conglomeratic, sandstone, and shale members are locally recognizable. The general metamorphism

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[70] Ransome, F. L., Geology and ore deposits of the Bisbee quadrangle, Arizona: U. S. Geol. Survey Prof. Paper 21, 1904; and Description of the Bisbee quadrangle: U. S. Geol. Survey Folio 112, 1914.

of the Pinal and equivalent schists at Clifton and Bisbee, and the probable equivalent schists of the Bradshaw Mountains and Grand Canyon, was probably connected directly with the extensive batholithic invasions of granitoid rocks in pre-Cambrian time and was locally intensified by later intrusions.

As might be expected in rocks so old and so intricately intruded by batholithic granite masses during more than one geologic period, the Pinal schist shows variations in the strike and dip of its planes of schistosity, and locally these planes are intensely crumpled and contorted. The prevailing strike is northeast or at right angles to the principal mountain ranges of the region. The dip ranges from 45° to vertical. As a rule the schistosity is approximately parallel with the original bedding of the rocks.

In the Clifton quadrangle, some 80 miles east of the Pinal Mountains and 130 miles north of Bisbee, is a small area of pre-Cambrian schist which, because of its geologic relations and lithologic character, Lindgren correlated with the Pinal schist.[71] He described it as a reddish or reddish-brown quartzose rock, for the most part imperfectly cleavable but locally fissile with satiny sur-

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[71] Lindgren, Waldemar, Copper deposits of the Clifton-Morenci district, Arizona: U. S. Geol. Survey Prof. Paper 43, 1905.

faces. Microscopically it is a fine-grained aggregate of quartz with some sericite. In places, small amphibolitic members are present. The attitude of the schistosity varies capriciously and has been obscured by jointing, but the strike prevailingly ranges from east to northeast, and the dip is steep. The formation has been intruded by some aplitic and pegmatitic dikes and possibly also by granite.

Darton noted schist of Pinal type at Bronco Ledge and Haystack Butte, near Salt River, 24 miles north of Globe. It occurs associated with great quartzite beds that strike northeastward and dip steeply.[72]

Pre-Cambrian schist of Pinal type crops out at Courtland [73] and in South Pass[74] of the Dragoon Mountains. Its prevailing northeastward strike and steep dip have been locally disturbed by faulting.

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72 Darton, N. H., A résumé of Arizona geology: Univ. of Arizona, Ariz. Bureau of Mines Bull. 119, pp. 229-230, Figs. 49 and 50, 1925.

73 Wilson, Eldred D., Geology and ore deposits of Courtland and Gleeson, Arizona: Univ. of Ariz., Ariz. Bureau of Mines Bull. 123, pp. 17-18, 1927.

74 Dumble, E. T., Notes on the geology of southeastern Arizona: Am. Inst. Min. Eng., Trans., vol. 31, p. 713,1902.

Metamorphic rocks of southwestern Arizona: As shown by the Geologic map of Arizona, schist occurs in many of the ranges of southwestern Arizona. According to Bryan,[75] the pre-Cambrian rocks of the region form a highly metamorphosed complex consisting largely of sericitic, chloritic, and hornblende schist, phyllite, and gneiss. They are intruded by granites which he considers as of pre-Cambrian and of possible Mesozoic ages. Some of the metamorphic rocks in the southwesternmost portion of this region are probably younger than pre-Cambrian.[76]

The schist of the Phoenix Mountains, which is separated from the metamorphic rocks of the Mazatzal Range by an interval of only some 35 miles, consists of well-metamorphosed sericitic, chloritic, and rhyolitic schist, quartzite, slate, and marble. These rocks are

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75 Bryan, Kirk, The Papago Country: U. S. Geol. Survey Water-Supply Paper 499, pp. 54-55, 58-59, 1925.

76 Wilson, Eldred D., Geology and mineral deposits of southern Yuma County, Arizona: Univ. of Ariz., Ariz. Bureau of Mines, Bull. 134, 1933.

laminated closely parallel to original bedding, with a prevailing northeastward strike and steep southeastward dip. They are intruded by dikes of olivine diabase and possibly also by granite.[77]

Metamorphic rocks of western and northwestern Arizona: Lee mentioned the occurrence of metamorphosed, faulted quartzite, argillite, and limestone, presumably of pre-Cambrian age, in Virgin and Williams canyons.[78]

Bancroft described gneiss, schist, quartzite, limestone, dolomite, and argillite, all of supposed pre-Cambrian age, occurring extensively in northern Yuma County. The quartzite, argillite, and dolomite show only local metamorphism and resemble nothing known in the pre-Cambrian of the Southwest.[79]

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77 Lausen, Carl, and Gardner, E. D., Quicksilver resources of Arizona: Univ. of Ariz., Ariz. Bureau of Mines Bull. 122, pp. 45-47, 1927.

78 Lee, W. T., Geologic reconnaissance of a part of western Arizona: U. S. Geol. Survey Bull. 352, p. 15, 1908.

79 Bancroft, H., Ore deposits in northern Yuma County, Arizona: U. S. Geol. Survey Bull. 451, pp. 22-27, 1911.

Ross[80] mentions the widespread occurrence in western Arizona, north of the Gila River, of granitoid gneiss, metamorphosed schistose rocks, and metamorphosed but not schistose limestone and quartzite. He regards those rocks, with the possible exception of the limestone and quartzite, as pre-Cambrian. Darton[81] discovered Carboniferous fossils in some outcrops of limestone, and Wilson[82] found limestone conglomerate pebbles, containing upper Carboniferous fossils, in the argillite of this region.

In northwestern Arizona, according to Schrader,[83] chloritic and sericitic schist and schistose gneiss are of common occurrence. The schistosity generally trends N. 30° E. and dips steeply.

Earlier pre-Cambrian intrusive rocks

Invading the schist and gneiss are dikes and small

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80 Ross, C. P., Geology of the lower Gila region, Arizona: U. S. Geol. Survey Prof. Paper 129, pp. 183-186, 1922.

81 Ariz. Bureau of Mines Bull. 119, pp. 215-222.

82 Arizona Bureau of Mines Bull. 134, p. 80, 1933.

83 Schrader, F. C., Mineral deposits of the Cerbat Range, Black Mountains, and Grand Wash Cliffs, Arizona: U. S. Geol. Survey Bull. 397, pp. 28-29, 1909.

bodies of felsic to mafic composition and batholithic masses of granite. These intrusives are prominent in the Grand Canyon, and the granite, as shown on the Geologic Map of Arizona, forms large areas in the Basin and Range Province, particularly in the Mountain Region. As these igneous rocks have been given little detailed study outside of a few areas and mining districts, extensive correlation of them is not yet practicable.

In the Grand Canyon, Noble found that the Vishnu schist was intruded by mafic and pink siliceous rocks. The feldspars of the latter are generally orthoclase, microcline, and soda plagioclase. Some of the pink granitic intrusives are clearly later than the regional metamorphism that caused the foliation of the gneiss and schist.[84]

For some 50 miles downstream from the Hurricane fault to a point within 20 miles of the Grand Wash Cliffs, the inner gorge of the Grand Canyon consists mainly of granite, granite pegmatite, and granitic gneiss with local small areas of schist whose lamination strikes north-northeastward. The granite, which ranges in color between light bluish gray, pinkish, and reddish, is pre-

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[84] Noble, L. F., and Hunter, J. F., A reconnaissance of the Archean complex of the Granite Gorge, Grand Canyon, Arizona: U. S. Geol. Survey Prof. Paper 98, pp. 95-113, 1916.

dominantly of medium to rather coarse texture. Moore regarded it all as Archean.[85]

As described by Jaggar and Palache,[86] the granite of the Bradshaw Mountains, which they named the Bradshaw granite, is normally a coarse granitic aggregate of quartz, orthoclase, and microcline in about equal amounts, with a little oligoclase, biotite, magnetite, and rare green hornblende.

Grading into the Bradshaw granite at some localities are masses of quartz diorite which are of granitic aspect though darker colored. It consists of abundant green hornblende; albite or albite-oligoclase largely altered to sericite, zoisite, and calcite; and a little interstitial quartz. This diorite was interpreted by Jaggar and Palache as representing either (1) endomorphic differentiation in the granite, (2) a local change in composition of the granite due to solution of materials from the schist, or (3) a later intrusion of diorite along the contact of granite and schist while the granite was still in a semi-fluid condition.

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85 Moore, R. C., Geologic report on the inner gorge of the Grand Canyon of the Colorado River: U. S. Geol. Survey Water-Supply Paper 556, Appendix B, 1925.

86 Jaggar, T. A., and Palache, Charles, Description of Bradshaw Mountains quadrangle: U. S. Geol. Survey Folio 126, 1905.

Intruded into the Yavapai schist in the Bradshaw quadrangle are small stocks and dikes of massive granular to porphyritic dark-colored diorite consisting of green to brown locally fibrous hornblende; feldspar ranging from sodic oligoclase to sodic labradorite; and abundant accessory apatite and magnetite. Gabbroid facies of this type are characterized by more calcic plagioclase and the presence of augite more or less completely changed to uralite-hornblende.

In the Black Hills, the principal pre-Cambrian intrusive rocks are of granitic and dioritic composition. The granite, which appears in the southern portion of this area as a northward extension from the Bradshaw Mountains, is regarded by Lindgren[87] as normal Bradshaw granite. Lausen[88] states that, near the schist contact, it is a granodiorite. Diorite occurs as numerous dikes and several small stocks which Reber regarded as facies of the Bradshaw granite and which Lindgren states is surely one of the youngest of the pre-Cambrian rocks. He describes it as a normally medium-grained dark rock composed of about equal parts of augite and altered andesine or oligoclase, with more or less alteration to chlorite, sericite, and epidote.

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87 U. S. Geol. Survey Bull. 782, p. 97.

88 Jour. Geol., vol. 38, p. 180, 1930.

In the Mazatzal Range, between Four Peaks and Mt. Ord, is abundant rather coarse porphyritic granite similar to granite known to be of pre-Cambrian age in other localities in Arizona.[89]

The Pinal schist of the Globe, Miami, and Ray districts[90] is intruded by large masses of granite and diorite which are unconformably overlain by Apache (younger pre-Cambrian) strata. The Ruin granite consists of phenocrysts of flesh-colored, slightly microperthitic potash feldspar in a groundmass of coarsely crystalline anhedral plagioclase,probably oligoclase, and quartz, with a moderate proportion of biotite. The diorite is a granitic rock consisting essentially of andesine, locally with orthoclase and microcline, quartz, and biotite.

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89 Ransome, F. L., Quicksilver deposits of the Mazatzal Range, Arizona: U. S. Geol. Survey Bull. 620, pp. 111-128, 1915; Some Paleozoic sections in Arizona and their correlation: U. S. Geol. Survey Prof. Paper 98, pp. 155-159, 1916.

90 Ransome, F. L., U. S. Geol. Survey Prof. Paper 12, 1903; and Prof. Paper 115, 1919.

At Bisbee a stock of probable pre-Cambrian granite intrudes the Pinal schist. This granite consists of brown microperthitic orthoclase, quartz, some sodic oligoclase, and a little biotite, together with accessory tourmaline, muscovite, apatite, zircon, and magnetite.[91]

The pre-Cambrian granite at Clifton consists of large reddish grains of orthoclase, commonly with microperthite, a few grains of probable albite, quartz, and accessory magnetite and zircon. An extreme, local modification consists chiefly of hornblende, soda-lime feldspar, and grains of magnetite or ilmenite.[92]

The Geologic Map of Arizona shows that granitic rocks occur extensively in southwestern Arizona. Much of this granite has been found to be of a sodic composition corresponding to that of granites of known Mesozoic, rather than pre-Cambrian, age.[93]

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91 Ransome, F. L., U. S. Geol. Survey Prof. Paper 21, 1904; and U. S. Geol. Survey Folio 112, 1914.

92 Lindgren, Waldemar, U. S. Geol. Survey Prof. Paper 43, 1905.

93 Bryan, Kirk, The Papago country: U. S. Geol. Survey Water-Supply Paper 499, pp. 54-55, 58-59, 1925.

Wilson, Eldred D., Geology and mineral deposits of southern Yuma County, Arizona: Univ. of Ariz., Ariz. Bureau of Mines Bull. 134, 1933.

Western and northwestern Arizona contains extensive areas of coarse-grained, locally gneissic red to gray granite which, in part at least, is of pre-Cambrian age. According to Lee,[94] the rock is composed of orthoclase, microperthite, microcline, oligoclase, quartz, and biotite.

Mazatzal quartzite

Ransome[95] described the occurrence of faulted, deformed quartzite, with some conglomerate and shale, in the Mazatzal Mountains, Pine Creek, and eastern Tonto Basin areas. He found it resting unconformably upon "granite" (cf. page 241) and rhyolite but did not determine its relation to the schistose rocks. He proved that the quartzite is unconformably overlapped by Paleozoic strata along Pine Creek and by Apache (younger pre-Cambrian) beds in the southern part of the eastern Tonto Basin area.

In 1922 Wilson[96] described some of the strati-

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94 Lee, W. T., U. S. Geol. Survey Bull. 352, p. 15, 1908.

95 Ransome, F. L., Quicksilver deposits of the Mazatzal Range, Arizona: U. S. Geol. Survey Bull. 620, pp. 111-128, 1915; Some Paleozoic sections in Arizona and their correlation: U. S. Geol. Survey Prof. Paper 98, pp. 155-159, 1916.

96 Wilson, Eldred D., Proterozoic Mazatzal quartzite of central Arizona: Pan Am. Geol., vol. 38, pp. 299-312, 1922.

graphic features of this pre-Cambrian quartzite, naming it the Mazatzal quartzite and correlating with it the quartzite of the Del Rio area and that of the northern portion of eastern Tonto Basin. The formation showed a thickness of 950 feet at the northern end of the Mazatzal Range, 2,406 feet on Pine Creek, and 1,780 feet in the Del Rio area. It was found to be unconformably overlapped by lower Paleozoic beds at Del Rio and by Apache and Paleozoic rocks in the northern portion of eastern Tonto Basin.

Darton [97] recorded further details regarding the unconformable relation of the Mazatzal quartzite to the Apache and Paleozoic strata.

Ransome[98] concluded that, in Cambrian time, the quartzite and other hard rocks of the Mazatzal Mountains and eastern Tonto Basin comprised a land barrier "between the depositional basin of central and southern Arizona and that now corresponding to the Arizona Plateau, or at least to that part of the plateau between Payson

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97 Darton, N. H., A résumé of Arizona geology: Univ. of Ariz., Ariz. Bureau of Mines Bull. 119, pp. 229, 234-236, 1925.

98 U. S. Geol. Survey Prof. Paper 98, pp. 165-166.

and the Grand Canyon" and that "the natural barrier supposed to exist in Cambrian time may have persisted in some form, possibly as a submarine ridge, throughout the Paleozoic era." Stoyanow[99] reported facts corroborating the presence of an ancient land in central Arizona, apparently an extension of the Ensenada land of Schuchert,[100] and proposed for it the name, Mazatzal land.

Gregory[101] described an old quartzite that, unconformably overlain by Permian red beds, crops out in an area of about 1/2 square mile in Quartzite Canyon, in the Defiance uplift, some 150 miles northeast of Tonto Basin. This quartzite, though prevailingly massive, contains some strata 1 to 8 inches thick, the planes of which are coated with fine sand, muscovite

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99 Stoyanow, A. A., Correlation of Arizona Paleozoic formations: Geol. Soc. Am., Bull., vol. 47, p. 462, 1936.

100 Schuchert, Charles, Paleogeography of North America: Geol. Soc. Am., Bull., vol. 20, p. 470, 1910.

101 Gregory, H. E., Geology of the Navajo Country: U. S. Geol. Survey Prof. Paper 93, pp. 17-18, 1917.

fragments, and flattened pebbles of slate. Thin lenses of conglomerate occur irregularly. Considerable disseminated hematite, probably derived from magnetite, is present. The strata show angular cross bedding, ripple marks, and mud cracks. Microscopically, the quartzite consists of extremely irregular angular quartz grains and a few well-rounded zircon grains, cemented with silica.

The outcrop is intersected by four sets of joints, trending N. 15° W., N. 55° W., N. 15° E., and N. 70° E. Gregory does not mention the attitude of the beds, but their prevailing strike appears to be N. 30° W. and their dip 18° SW. He points out that the quartzite resembles some of the members of the Unkar group and inclines to the belief that it is of lower Algonkian age. Darton[102] regards it as part of an old ridge that extended northwest from the Zuni Mountains in New Mexico and apparently persisted through a large part of Paleozoic time. It is probably equivalent to the Mazatzal quartzite.

Later Pre-Cambrian Rocks

Grand Canyon series

Restricted to the Grand Canyon, the Grand Canyon series rests unconformably upon the Vishnu schist and granite and is unconformably overlain by Middle Cambrian

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102 Darton, N. H., A résumé of Arizona geology: Univ. of Ariz., Ariz. Bureau of Mines Bull. 119, p. 15, 1925.

Tapeats (Tonto) sandstone. This series of strata was discovered by Major Powell and separated by Walcott[103] into two groups of which the lower or Unkar has an exposed thickness of more than 6,800 feet and the upper or Chuar more than 5,100 feet.

The Unkar group in the Shinumo quadrangle, west of El Tovar, was separated by Noble[104] into the following formations:

Unkar formations in Shinumo quadrangle

	Feet
Dox sandstone: Micaceous shaly sandstone; greenish gray in lower portion, red-brown and vermilion above. Characterized by ripple marks and cross-bedding. Cut by thin sills of intrusive diabase....	2,297
Shinumo quartzite: Hard, compact cross-bedded sandstone and quartzite, usually of fine and even grain.....	1,564
Hakatai shale: Argillaceous red shale, grading upward into arenaceous red shale and sandstone; prevailingly ripple marked. Cut by thick sill of diabase.....	580

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103 Walcott, C. D., Pre-Carboniferous strata in the Grand Canyon of the Colorado: Am. Jour. Sci., vol. 26, p. 437-442, 1883; Algonkian rocks of the Grand Canyon of the Colorado: Jour. Geol., vol. 3, pp. 312-330, 1895.

104 Noble, L. F., The Shinumo quadrangle, Grand Canyon district, Arizona: U. S. Geol. Survey Bull. 549, 1914.

Bass limestone: White crystalline limestone alternating with beds of argillaceous and calcareous sun-cracked red shale. Cut by thick sill of diabase near which chrysotile asbestos is locally developed..... 335

Hotauta conglomerate: Arkose conglomerate characterized by lack of sorting and transportation. Rests on an extremely even erosion surface of Vishnu schist..... 6

According to C. E. Van Gundy,[105] these formations, excepting the basal conglomerate, are recognizable in the Unkar area of Walcott, upstream from the Shinumo quadrangle.

The Chuar group, which is known only between the northern side of Nankoweap Valley and the upper end of the big bend of the Colorado River, was found by Walcott to consist largely of variegated sandstone and shale, together with a few thin limestone members.

Structurally, the Grand Canyon series comprises tilted wedges and blocks which, downfaulted relative to the pre-Tonto surface, escaped removal by the extensive post-Chuar peneplanation of that surface. The Unkar Wedge in the Shinumo quadrangle is limited on the northeast by the West Kaibab fault which, according to Noble,[106]

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105 Carnegie Inst. Wash. Year Book No. 33, pp. 307-308, 1934.

106 Work cited, p. 308.

has a northwestward trend, a dip of 60° SW., a pre-Cambrian vertical displacement exceeding 5,800 feet, and a post-Paleozoic throw of more than 500 feet. He determined that the wedge itself is cut by numerous northwestward-trending faults of less than 400 feet, and commonly about 50 feet, throw. In Bass Canyon, a sharp monoclinal flexure of about 500 feet throw trends northeastward and passes into a small thrust fault; Noble, without presenting conclusive evidence, implies that it is of pre-Cambrian age.

In the eastern section of the Canyon, Walcott found that the Butte fault, which extends south-southeastward from Nankoweap Creek to the beginning of the big bend, has a pre-Cambrian displacement of 400 to 4,000 feet and a post-Paleozoic displacement of 2,700 feet, dying out at either end.

Apache group

Unconformably overlying the schist, granite, and Mazatzal quartzite in central Arizona is a succession of quartzite, conglomerate, shale, and limestone that Ransome[107] termed the Apache group. He gave its standard section as follows:

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107 Ransome, F. L., U. S. Geol. Survey Prof. Paper 12, pp. 28-39, 1903; Prof. Paper 98, pp. 136-141, 149-156, 164-166, 1916; Prof. Paper 115, pp. 39-45, 1919.

	Feet
Troy quartzite: Generally pebbly cross-bedded quartzite or sandstone with lenses of conglomerate. Shaly beds with worm casts at top	400
Vesicular epidotized basalt flow.....	25-75
Mescal limestone: Thin varicolored, more or less dolomitic beds with conspicuous cherty layers. Intruded by diabase.....	225
Dripping Spring quartzite: Fine-grained varicolored arkosic quartzite, much of it with dark-red and gray banding. Partings between beds not distinct; ripple marked. Intruded by diabase.....	450
Barnes conglomerate: Smooth, generally rounded pebbles in hard arkosic cement. Intruded by diabase.....	5-50
Pioneer shale: Maroon shale, arkosic and quartzitic near base. Intruded by diabase	50
Scanlan conglomerate: Generally rounded pebbles in hard arkosic cement; grades upward into arkosic sandstone. Intruded by diabase.....	0-15

The Apache group crops out beneath the Paleozoic strata of the Plateau at the northeastern margin of Tonto Basin where it unconformably overlaps pre-Cambrian schist and Mazatzal quartzite. Resting unconformably upon granite and schist, it forms the Sierra Ancha and the northeastern portion of the Natanes Plateau along upper Salt River and is present in the mountain ranges of an irregular area, 85 miles in maximum width, that, extending southwestward for 150 miles, includes the southeastern Mazatzal, Apache,

Pinal, Mescal, Tortilla, Galiuro, Santa Teresa, Santa Catalina, and Vekol ranges.

Ransome originally classified the Apache group as Cambrian, largely because of its generally conformable attitude beneath Devonian strata and the lithologic resemblance of its Mescal limestone to the Upper Cambrian Abrigo limestone of southeastern Arizona. Later, however, Darton [108] found that the Troy formation in the Mescal Mountains unconformably overlaps the other members of the Apache group and in most places includes in its upper portion or is unconformably overlain by a sandstone containing Upper Cambrian lingulae. He concluded that the members of the Apache group below the Troy are pre-Cambrian, and that the Mescal limestone is equivalent to the pre-Cambrian Bass limestone of the Unkar group, in Grand Canyon.

Ransome,[109] in 1932, stated that "It has become increasingly probable during recent years that this restricted Apache group (below the Troy quartzite) is generally equivalent to the Unkar group."

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108 Darton, N. H., A résumé of Arizona geology: Univ. of Ariz., Ariz. Bureau of Mines Bull. 119, pp. 27-37, 1925.

109 Ransome, F. L., Ore deposits of the Southwest: XVI Int. Geol. Cong., Guidebook 14, p. 6, 1932.

Stoyanow[110] found, in the Santa Catalina Mountains, that the Crepicephalus texanus fauna, which is characteristic of the Upper Cambrian Abrigo formation, occurs 400 feet above the top of the Troy quartzite; therefore the Mescal limestone, an older formation than the Troy, can not be correlated with the Abrigo. He differentiated the Troy quartzite from the Apache group, "not only because it overlaps the Mescal limestone, but because it carries Cambrian fossils and conformably underlies younger Middle Cambrian strata." As now restricted, the group includes only pre-Cambrian rocks.

The relative age of the Apache group is a most important factor from the standpoint of the present research. The establishment of its age as pre-Cambrian means that the granite, upon whose deeply eroded surface it unconformably rests, was intruded during a period of great crustal disturbance that obtained long before the end of pre-Cambrian time.

Diabase

The diabase, which occurs as dikes and great sills intruding the Apache group, is of uncertain age. Ransome[111]

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110 Stoyanow, A. A., Correlation of Arizona Paleozoic formations: Geol. Soc. America, Bull., vol. 47, pp. 472-476, 1936.

111 Ransome, F. L., Description of the Ray quadrangle, Arizona: U. S. Geol. Survey Folio 217, pp. 10-11, 1923.

found diabase cutting Paleozoic rocks in the Ray quadrangle, and assigned it to the early Mesozoic or late Paleozoic. Short and Ettlinger[112] and Galbraith[113] reached similar conclusions from studies in the Superior district. Darton, however, believes that the post-Troy diabase of Ray and Superior represents an intrusive younger than the great diabase bodies that elsewhere do not penetrate the Troy.

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112 Short, M. N., and Ettlinger, I. A., Ore deposition and enrichment at the Magma mine, Superior, Arizona: A.I.M.E., Trans., vol. 74, p. 176, 1926.

113 Galbraith, F. W., The geology of the Silver King area, Arizona: Unpublished Doctorate Thesis, Univ. of Ariz., 1935.

PART II. GENERAL FEATURES OF THE CENTRAL ARIZONA REGION

CHAPTER I. GEOGRAPHY

Limits

The present investigation was limited mainly to the Mazatzal Mountains, Pine Creek, eastern Tonto Basin or northern Sierra Ancha, Del Rio, and southern Black Hills areas (Plates I and IV) which, as shown by previous work, contain extensive exposures of pre-Cambrian rocks whose relations have not been largely obscured by metamorphism. Collectively, these several areas reveal the pre-Cambrian regional geology much more completely than does any one locality. They occur within a region 100 miles long by 15 to 50 miles wide, bounded by the southwestern base of the Plateau escarpment on the north, Salt River on the south, Pleasant Valley (Longitude 110° 50') on the east and Lonesome Valley (Longitude 112° 28') and the lower Verde Valley on the west (Plates I and IV and Fig. 1).

Relief

Mountains and valleys

Plate IV, based upon the 1933 edition of the

Topographic Map of Arizona,[114] shows the general relief of this region and the relative positions of its quadrangles that have been topographically mapped by the U. S. Geological Survey. Of these quadrangles the Roosevelt, Turret Peak, and Jerome sheets, on a scale of 1:125,000 and with contour intervals of 100 feet, were of great service in studying the region, whereas the Verde and Holbrook reconnaissance sheets, on a scale of 1:250,000 and with contour intervals of 250 feet, were unsuitable as base maps.

Bordering the region on the north and northeast is the broadly linear though deeply indented Plateau escarpment whose rim presents a fairly even skyline ranging from 7,500 feet in altitude at the southeast to 6,500 feet at the northwest. This feature is in strong contrast with the mountainous region under consideration, whose principal features of relief, from southeast to west and northwest, are the Sierra Ancha, Tonto Basin and Tonto Valley, Mazatzal Mountains, Verde Valley, Black Hills Range, and Agua Fria or Lonesome Valley. As indicated by structural and geomorphologic evidence (pages 34-38), these ranges represent fault blocks which were elevated with very little tilting in reference to the relatively depressed troughs occupied by the intermont valleys. Their orogeny is believed to

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114 Published by the Arizona Bureau of Mines in cooperation with the U. S. Geological Survey.

have occurred largely in late Tertiary time. Although there has been subsequent intermittent uplift, as evidenced by the dissection and successive terracing of the valleys, the integrated character of the Gila River drainage, pointed out by Waibel[115], indicates that the region has remained fairly stable during recent geologic time. Each of the ranges exceeds 7,500 feet, but none rises higher than 8,000 feet, in altitude or 6,300 feet above the lowest point in the region. These summits are essentially accordant with the surface of the adjacent Plateau. The ranges are from 30 to 50 miles long by 12 to 20 miles wide, with rather linear boundaries that trend approximately N. 30° W. They are characterized by steep, ruggedly dissected slopes which culminate in roughly parallel axial crest lines approximately 25 miles apart.

Drainage

General features

Central Arizona is drained by the perennial streams, Verde River and Tonto Creek, and the inter-

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115 Waibel, Leo, Die Inselberglandschaft von Arizona und Sonora: Z. der Gesell. fur Erdk. zu Berlin, Sonderabdruck aus dem Jubilaums-Sonderband, pp. 68-91, 1928.

mittent Agua Fria River, all of which are tributaries to Salt River. Their relative sizes are indicated by the following table of run-off in acre feet during two 12-month periods:[116]

Stream	1920	1919
Tonto Creek near Roosevelt	269,000	112,000
Verde River near McDowell	1,270,000	542,000
Agua Fria River near Glendale	---	74,500
Salt River near Roosevelt	1,620,000	881,000

Within the mountains nearly all of the canyons carry water for a few weeks following the melting of the snow and for several days after summer storms, but only a few scattered springs survive the driest seasons.

Structural control of drainage

As shown on Plates I and IV, Tonto Creek flows southeastward through a broad valley, as does the Verde River upstream from the mouth of Fossil Creek. In the lower part of its course the Verde River follows a locally narrow canyon with southeastward, southwestward, and southward-trending segments. The East Verde River has a northwest course. The tributaries of these streams have northeast-southwest courses. As Bryan has pointed

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116 Surface water supply of Colorado River Basin, 1919-1920: U. S. Geol. Survey Water-Supply Paper 509, 1925.

PLATE V-A. Looking southward down Verde Valley from mouth of Fossil Creek.

PLATE V-B. Looking northeastward up canyon of Fossil Creek whose rather straight course suggests a fault zone.

out, there is a general regional strike northwest-southeast in which there are developed considerable valleys, and most of the streams have narrow canyons in the northeast-southwest direction. He suggested the probable relation of these trends to post-Gila formation faulting and to the position of the lava beds.[117]

The topographic pattern of the region prior to deposition of the late Tertiary (Gila) beds is not revealed. There existed great valley troughs in which the Gila sedimentation occurred, and highlands from which these sediments were derived. All of the available field evidence points to a general correspondence of these topographic features with the present ranges and valley troughs. The Plateau escarpment was sculptured essentially to its present form prior to eruption of the Pliocene lavas, as revealed by ample exposures in the canyon of Fossil Creek. The post-Gila formation faulting resulted in relative uplift of the mountains, accompanied by little or no tilting north of Latitude 33° 45'. The present large, southeastward-trending valleys in central Arizona are essentially grabens, and the northeastward-trending stream courses seem to be governed largely by faults and fractures which are later than the post-Gila lavas.

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117 Bryan, Kirk, written communication.

Climate and Vegetation

The temperature, precipitation, and vegetation of central Arizona are governed rather closely by the altitude and hence show a wide range between the limits, 1,600 and 7,900 feet above sea level, represented.

The following seasonal variations in temperature have been recorded:

Station	Elevation	Years record	Maximum	Minimum
Roosevelt	2,175	23	114°	18°
Payson	5,000	15	104°	-18°
Natural Bridge	4,990	14	103°	6°
Clemenceau	3,460	9	110°	13°
Jerome	4,743	27	104°	7°
Prescott	5,320	27	105°	-12°

The daily range in temperature is great, and at some places may exceed 65°.

The precipitation is rather seasonal. Nearly one-half of it occurs from December to March, inclusive, nearly one-fourth in July and August, and nearly one-fourth during April, September, October, and November, with May and June each receiving only fractions of an inch. In winter the storms tend to be gentle but long continued, with snow common above altitudes of 5,000 feet

and often attaining depths of 48 to 60 inches above altitudes of 7,000 feet. The summer storms are prevailingly of a local, short, torrential type that in the mountains often produce violent flash-floods of great erosive power. No records for the higher country are available, but the precipitation above altitudes of 6,000 feet probably exceeds 30 inches annually. Normal yearly precipitation recorded in the region is as follows:

Station	Elevation	Years record	Inches
Roosevelt	2,175	22	18.06
Payson	5,000	21	21.34
Natural Bridge	4,990	38	24.17
Childs (Verde River near Fossil Creek)	2,650	33	17.67
Jerome	4,743	29	18.65
Prescott	5,320	59	18.52
Crown King (Bradshaw Mts.)	6,000	--	32.42

The vegetation of central Arizona is divisible into overlapping zones whose limits are governed primarily by altitude. Factors such as soil, groundwater, topography, and shelter exert great local influence. As a whole the region exhibits four typical major zones of plant life: forest, woodland-brush, grass, and desert shrub. Forests, mainly of Western Yellow Pine with some oak and juniper, are common above altitudes of 5,500 feet. Dense thickets of oak, manzanita and various thorny bushes abound from altitudes of 4,000 to 5,500, and locally up to 7,000, feet. There are con-

PLATE VI. Juniper zone adjacent to pine and brush zones, north of Pine Mountain, Mazatzal Range. Alder series in foreground, Mazatzal quartzite ridge in background.

siderable areas of mountain slopes which, exceeding the angle of soil repose, appear as quite bare rock.

CHAPTER II - STRATIGRAPHY

General Statement

Central Arizona is underlain with pre-Cambrian sedimentary, metamorphic, and igneous rocks whose exposures are limited by Paleozoic strata, Tertiary sedimentary and volcanic formations, and Quaternary alluvium. The stratigraphic section is as follows:

Age classification	Formation	Member	Character	Thickness in feet
Quaternary: Pleistocene and Recent	Alluvium		Unconsolidated silt, sand, gravel, and boulders, mainly of local origin.	
	Unconformity			
Tertiary: Pliocene(?)	Volcanic rocks		Largely basaltic and andesitic lava and intercalated tuff.	5-2,000+
	Gravel, conglomerate, sand, silt, and limestone		Loosely to firmly consolidated gravel, sand, and silt, locally with thin limestone beds and intercalated basalt flows; in upper Verde Valley, predominantly limestone (Verde formation); probably synchronous with Gila conglomerate.	2,000+
	Unconformity			
Miocene or Pliocene	Volcanic rocks		Andesitic and dacitic lava and intercalated tuff.	2,500+
Miocene (?)	Conglomerate		Conglomerate and sandstone.	1,200+
	Unconformity			
Permian	Coconino sandstone		Light-colored cross-bedded sandstone in Mogollon Escarpment.	900-1,000
	Supai formation		Reddish sandstone and shale in and near Mogollon Escarpment.	645-1,000
Carboniferous: Pennsylvanian	Limestone		Light-gray compact limestone.	1,000+
Carboniferous: Mississippian	Limestone		Light-gray, partly crystalline limestone: Redwall limestone in northwestern portion of region, Tornado limestone in southeastern portion.	50-250
Carboniferous: Devonian	Limestone		Dark-gray thin to medium-bedded limestone: Jerome formation in northwestern portion of region, Martin limestone in southeastern portion.	300-500.
	Disconformity			
Cambrian (Middle)	Sandstone		Red-brown cross-bedded pebbly Troy sandstone in northern Sierra Ancha and southern Mazatzal Mountains areas; dark red-brown cross-bedded friable Tapeats sandstone, 75-100 feet thick, in northwestern portion of region.	75-400
	Unconformity			
Pre-Cambrian: Later pre-Cambrian	Apache group (in eastern Tonto Basin and southeastern portion of Mazatzal Mountains)	Basalt	Vesicular, epidotized basalt, present at most places.	0-75
		Mescal limestone	Thin-bedded cherty dolomitic limestone, intruded by diabase.	225-300
		Dripping Spring quartzite	Reddish-brown generally massive, fine-grained arkosic quartzite. Intruded by diabase.	450-700
		Barnes conglomerate	Smooth, rounded pebbles in sandy, arkosic cement. Intruded by diabase.	5-50
		Pioneer shale	Brownish-red hard shale. Intruded by diabase.	150-250
		Scanlan conglomerate	Imperfectly rounded pebbles in sandy, arkosic cement. Intruded by diabase.	0-30
	Unconformity			
Pre-Cambrian: Earlier pre-Cambrian	Mazatzal quartzite		Light-brown to gray, vitreous, hard quartzite. Intruded by granite.	3,800
	Maverick shale		Gray to maroon shale; appears only in Mazatzal Mountains. Intruded by granite.	500-800
	Deadman quartzite		Light-brown to gray, vitreous hard quartzite, pebbly at base; appears only in Mazatzal Mountains. Rests unconformably on Red Rock rhyolite. Intruded by granite.	90-800
	Unconformity			
	Yavapai group (previously termed Yavapai schist)	Alder series	Shale and grit with some quartzite and conglomerate; locally metamorphosed. Intruded by diorite porphyry, porphyritic pyroxenite, granite, and rhyolite porphyry.	5,000+
		Fault contact		
		Red Rock rhyolite	Massive rhyolitic flows and agglomerate with minor intrusives. Intruded by granite.	1,000±
		Fault contact		
		Yaeger greenstone	Volcanic rocks of intermediate to mafic composition together with some intercalated sedimentary material; generally affected by low-grade metamorphism. Intruded by diorite porphyry, granite, and rhyolite porphyry. Base not exposed.	2,000±

Pre-Cambrian Rocks

Formations recognized

The pre-Cambrian rocks of central Arizona may be divided into the following formations:

(1) Yavapai group, including the Yaeger greenstone, Red Rock rhyolite, and Alder series; (2) Deadman quartzite; (3) Maverick shale; (4) Mazatzal quartzite; (5) diorite porphyry; (6) porphyritic pyroxenite; (7) granite; (8) rhyolite porphyry; and (9) Apache group. In addition there is the City Creek series, a unit of doubtful correlation tentatively regarded as younger than the Mazatzal quartzite.

Yavapai group

General statement: The oldest rocks exposed in central Arizona consist of greenstone, rhyolite, shale, and grit, with some quartzite and conglomerate. In the Bradshaw Mountains and Jerome quadrangles, these rocks are more or less schistose, depending upon local conditions of metamorphism, and were originally grouped together as one formation, the Yavapai schist.[118] This usage was

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118 Jaggar, T. A., and Palache, Charles, Description of the Bradshaw Mountains quadrangle: U. S. Geol. Survey Folio 126, 1905.

Lindgren, Waldemar, Ore deposits of the Jerome and Bradshaw Mountains quadrangles, Arizona: U. S. Geol. Survey Bull. 782, pp. 18-19, 1926.

followed throughout the region in preparing the Geologic Map of Arizona. As the Yavapai formation is only locally schistose, however, it is referred to in this report as the Yavapai group rather than as the Yavapai schist. Its members are designated as the Yaeger greenstone, Red Rock rhyolite, and Alder series.

Yaeger greenstone: Probably the oldest member of the Yavapai group is the greenstone that crops out in the Black Hills, Mazatzal Mountains, and eastern Tonto Basin areas. This member is termed the Yaeger greenstone, from its typical occurrence east of the Yaeger mine, in the southwestern portion of the Black Hills.

The Yaeger greenstone characteristically forms ruggedly dissected slopes of 15° to 35°, more or less mantled by dark olive-drab soil and dense brush. Like the oldest formation in the Lake Superior region, it is composed largely of intermediate to mafic flows and small intrusives, tuff, and agglomerate, together with some sedimentary material. These rocks show extensive alteration to greenish-black and grayish-green aggregates of fine-grained chlorite, sericite, and quartz, with local rude schistosity but little definite texture. They have undergone considerable deformation and were extensively invaded by pre-Cambrian batholithic masses of granite and small bodies of felsic to mafic composition. The thickness of the member has not been determined but appears to exceed 2,000 feet.

PLATE VII. Southward view of greenstone slopes east of Yaeger mine, Black Hills.

The Yaeger greenstone is equivalent to the "greenstone complex" of the Black Hills, as described by Reber,[119] Lindgren,[120] Hansen,[121] and Lausen[122] (abstracted on pages 51-57, exclusive of the rhyolitic rocks, which, in part, at least, are equivalent to the Red Rock rhyolite.

Red Rock rhyolite: In fault contact with the Yaeger greenstone is a thick series of dominantly rhyolitic rocks, consisting of flows together with minor

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119 Reber, L. E., Jr., Geology and ore deposits of Jerome district: A.I.M.E., Trans., vol. 66, pp. 3-26, 1920.

120 Lindgren, Waldemar, Ore deposits of the Jerome and Bradshaw Mountains quadrangles, Arizona: U. S. Geol. Survey Bull. 782, 1926.

121 Hansen, Mayer G., Geology and ore deposits of the United Verde mine: Mining Cong. Jour., vol. 16, pp. 306-311, 1930.

122 Lausen, Carl, Pre-Cambrian greenstone complex of the Jerome quadrangle: Jour. Geol., vol. 38, pp. 174-183, 462-465, 1930.

PLATE VIII-A. Red Rock, the type locality of the Red Rock rhyolite.

PLATE VIII-B. Red Rock rhyolite on northwestern side of Deer Creek, Mazatzal Mountains.

amounts of agglomerate, breccia, and intrusives. This member which crops out prominently in the Mazatzal Mountains, Pine Creek, eastern Tonto Basin, and southern Black Hills areas, is termed the Red Rock rhyolite, from its typical occurrence in Red Rock Butte, in the central segment of the Mazatzal Range.

The Red Rock rhyolite tends to form blocky, joint-controlled slopes of 35° to 70° or more, comparatively bare of soil and vegetation (Plate VIII-B). It is characteristically massive throughout, with flow banding or bedding apparent only in places, and its intrusive masses are not readily distinguishable from the flows. It has undergone considerable folding and faulting, followed with invasion by granite. Due to its massiveness and deformation, the thickness of the rhyolite is unknown, but apparently exceeds 1,000 feet.

The typical rhyolite is a grayish-brown to reddish-brown dense rock that breaks with a splintery fracture whose surfaces reveal sparse small phenocrysts of quartz and orthoclase in a stony groundmass. Microscopically, the rock consists of a faintly banded, finely granular to microcrystalline groundmass of quartz and feldspar with locally corroded phenocrysts of quartz and orthoclase generally less than 0.25 mm. in diameter (Plate IX).

In places the Red Rock rhyolite is of porphyritic texture. In eastern Tonto Basin its phenocrysts commonly range up to 1.75 mm. in maximum dimension, and the rock

A

B

PLATE IX. Microphotographs of Red Rock rhyolite from near Club Ranch, Mazatzal Mountains.

A- Showing flow bands marked by microcrystalline quartz; ordinary light, 23 diameters.

B- Showing texture; crossed nicols, 68 diameters.

locally contains numerous fragmental, fine-textured spherulites. Since, according to Grout,[123] spherulites form only in glass, this spherulitic rhyolite represents a devitrified glassy flow.

An exceptionally porphyritic variety occurs at the northern end of the Mazatzal Range and also below Natural Bridge, on Pine Creek. This variety is characterized by phenocrysts, up to 5 mm. in diameter, of pink feldspar and sparse quartz in an abundant dense groundmass. Examined microscopically, the feldspar phenocrysts are seen to consist of corroded orthoclase and minor albite which have undergone more or less sericitization and, in places, complete kaolinization. The groundmass is made up of microcrystalline, locally sericitized feldspar and quartz, extensively interspersed with finely divided hematite and irregular patches of chlorite.

The Red Rock rhyolite in places contains fragments of greenstone, which suggests that it is younger than the Yaeger member.

Alder series: In fault contact with the Yaeger greenstone and Red Rock rhyolite is a thick series of locally metamorphosed shale, grit, quartzite, and conglomerate. This member of the Yavapai group crops out extensively in the Mazatzal Mountains, eastern Tonto

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123 Grout, F. F., Petrography and Petrology, pp. 32 and 232, 1932.

Basin, and Black Hills, and to a small extent in the Del Rio area. It is termed the Alder series, from its typical occurrence in the vicinity of Alder Creek, in the central segment of the Mazatzal Range.

The Alder series tends to form steep-sided canyons and sharp ridges, thinly mantled in places with soil and talus. Except for its quartzite and conglomerate beds, which tend to be massive, this series is characterized by thin lamination, generally parallel to original stratification. It is schistose in the vicinity of large intrusive bodies.

Shaly members, locally metamorphosed to slate, phyllite, and schist, comprise more than half of the Alder series. These members range in thickness from a few feet to apparently 4,000 or more feet, but there is probably some duplication by faulting or folding. Aside from local differences in texture, these shaly rocks are prevailingly fine grained, readily cleavable, and irregular to splintery on fractured surfaces. The most common variety consists largely of dark-gray to black locally arenaceous compact shale which cleaves into small slabs and flakes with smooth to splintery fracture. Another common variety is maroon to hematite-red, locally spotted shale which breaks into smooth thin slabs several inches to more than a foot across. Microscopically, both varieties of shale consist of fine angular to ovoid grains of quartz, generally less than 0.1 mm. in diameter, in an abundant argillaceous cement of sub-

PLATE X-A. Looking south from Pine Mountain at Mt. Ord in Mazatzal Mountains. The steep, deeply dissected slopes are of Alder series.

PLATE X-B. Upper Gold Creek Canyon north from Pine Mountain, Mazatzal Range, showing Alder series and grayish Pine Mountain porphyry.

microscopic fineness. The maroon shale is rather hematitic, and the splintery variety carries numerous small shreds of kaolin. All of the mineral particles have their long dimensions parallel to the lamination. Schistose phases are characterized by alteration to finely divided muscovite, chlorite, and secondary calcite, and, in places, various contact silicates.

Approximately one-third of the Alder series is composed of dark-gray to brownish-gray argillaceous arkosic grit. This rock generally consists of poorly rounded to angular grains of quartz and feldspar, mostly less than 2 mm. in diameter, in a finely divided muscovitic cement. Due to stratification of the mineral particles, it is characteristically flaggy to thinly laminated, and some of its more micaceous beds resemble schist.

Conglomerate and quartzite, in many places grading into the grit, comprise about 15 per cent of the Alder series. The conglomerate members range in thickness from a few feet to 1,000 feet, and are generally lenticular. Depending upon the hardness of their cementing material, some form prominent reefs, whereas others have little or no topographic expression. This rock consists typically of subangular to rounded pebbles, mostly less than 4 inches in diameter, of rhyolite, quartz, jasper, and quartzite in a gritty, argillaceous, locally micaceous cement. Microscopically, the rhyolite of the pebbles closely resembles the Red Rock rhyolite. The cementing material of

the conglomerate is generally laminated, but the pebbles show little or no evidence of squeezing.

The quartzite members range from less than a foot to more than 150 feet in thickness and tend to be lenticular. They are the most resistant of the Alder series and stand out as reefs of which some are more than 50 feet high. Although prevailingly massive, they are in places thin bedded with shale partings. The rock is white to gray and grayish brown in color and generally cross bedded. It ranges from fine grained to pebbly, in places grading into conglomerate and arkosic grit. It is commonly intersected by veinlets of white quartz.

The Alder series is equivalent to the sedimentary portion of the Yavapai schist. Due to intense folding and faulting, the exposed thickness of the series is unknown; it appears, however, to exceed 5,000 feet. As all the observed contacts of the Alder series with the Yaeger greenstone and Red Rock rhyolite are faults, its relative age is not definitely known. The character of the rhyolite pebbles in its conglomerate members, however, strongly suggests that it is younger than the Red Rock rhyolite.

Deadman quartzite

Resting upon an eroded, deeply oxidized surface of Red Rock rhyolite in the northern half of the Mazatzal Range, north of Latitude 34°, is the Deadman quartzite. This formation, which is named from its typical occurr-

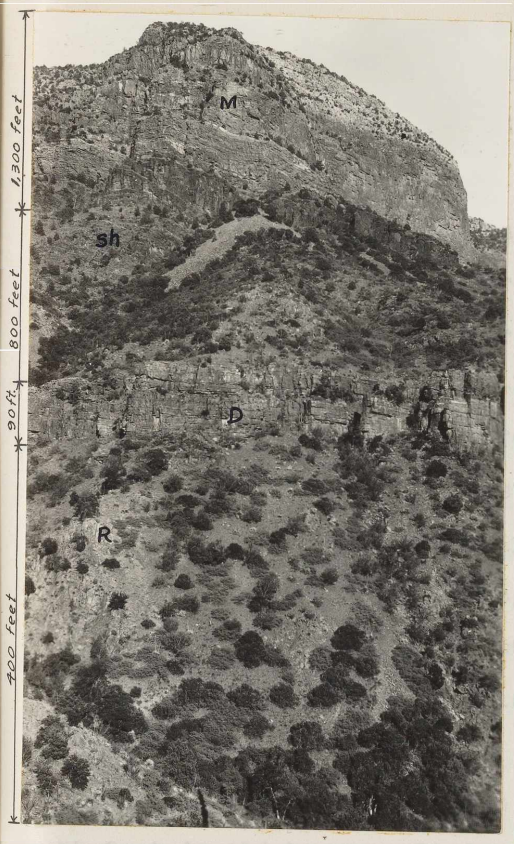

PLATE XI-A.
Deadman quartzite (D) resting on Red Rock rhyolite (R), and overlain by Maverick shale (sh) and Mazatzal quartzite (M), eastern slope of Maverick basin, Mazatzal Range.

PLATE XI-B. Thick Deadman quartzite resting on Red Rock rhyolite, (R), east of Cactus Point, Mazatzal Range.

ence on the North Fork of Deadman Creek, consists of hard, fine- to medium-grained, thinly stratified, cross-bedded, cliff-forming quartzite, together with some thin conglomerate and hematitic shale members and an irregular basal conglomerate. In general, the upper one-third of the Deadman quartzite weathers grayish brown to white, in contrast with the reddish-brown tint of the lower portion. The thickness of the formation ranges from 90 to 110 feet except in a thrust block at the southeast where it attains approximately 800 feet (Plate XI-B and sec. N-S of Plate XXI). This thick segment may have been thrust to its present location from a place several miles farther southeast towards which the quartzite progressively thickened during deposition.

The basal conglomerate ranges from a few inches to 25 feet in thickness. It is made up largely of pebbles of rhyolite, quartz, and red jasper, a fraction of an inch to a foot in diameter, in a rusty-red argillaceous, sandy cement. Beneath the basal conglomerate the Red Rock rhyolite is extensively oxidized, in places to depths of more than 100 feet, indicating an unconformity of considerable magnitude.

Found only within the northern half of the Mazatzal Range, the Deadman quartzite probably thins out northward, and to the south it has been removed by erosion. It does not crop out in contact with the Alder series, but, for reasons given on page 111, it is believed to be

younger.

Maverick shale

Overlying the Deadman quartzite with apparent conformity is the Maverick shale, named from its typical occurrence in Maverick Basin, in the northwestern portion of the Mazatzal Mountains.

In its type section the Maverick formation consists of thin-bedded, locally ripple-marked, fine-grained, dense, gray shale generally sprinkled with fine flakes of mica on the bedding planes and containing alternating thin sandy to quartzitic beds in the upper portion. It has been recognized only within the Mazatzal Mountains. In the northern portion of the range, north of Latitude 34°, it lies with apparent conformity above the Deadman quartzite. Near the southern end of the range, on the western slopes of Four Peaks, it has been intruded by granite at or near the base. The Maverick shale is 800 feet thick at Maverick Basin but thins to about 500 feet at North Peak; apparently it is thinning greatly northward. Along the eastern flank of the range, it is generally deformed by drag folds which increase its apparent thickness (see Plate LII). On the western slope of Four Peaks, the formation measures approximately 1,000 feet, but there, also, drag folding has thickened it to some extent.

In the vicinity of North Peak, the Maverick shale

PLATE XII-A. Typical Maverick shale in Maverick Basin, faulted against Red Rock rhyolite (R) which is intruded by granite (gr).

PLATE XII-B. Maverick shale on western side of Four Peaks, Mazatzal Range.

ranges in color from gray and dark gray to maroon with light-gray diffusion spots; the maroon color seems to be more common in the lower portion, which locally contains a few thin beds of gray quartzite. The base is characteristically ripple marked and micaceous. South of North Peak, the shale is prevailingly gray to pale-greenish gray on fresh fracture, weathering to dull gray or pale yellowish. In Barnhardt Canyon and on the western slopes of Mazatzal Peak, the interbedded quartzitic members of the upper portion appear in greater abundance than elsewhere. Because of their massiveness and pale brownish color, they are in strong contrast with the shale and tend to make its structure visible from a distance (see Plate LII). Microscopically, this interbedded quartzite consists of closely packed subangular to poorly rounded grains of quartz, up to 1.25 mm. in diameter, in a limonitic, finely granular quartz cement. Pronounced wavy extinction is characteristic of the quartz grains. Of the exposure in Shake Tree Canyon, between Cactus Ridge and Mazatzal Peak, Ransome says:[124] "These shales resemble nothing I had previously seen in Arizona. They are gray-green, weathering yellow, fairly hard, and only moderately fissile, and they effervesce in acid when powdered. Evidently they are somewhat dolomitic.

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124 Ransome, F.L., Some Paleozoic sections in Arizona and their correlation: U. S. Geol. Survey Prof. Paper 98, p. 158, 1916.

For about 50 feet from their top they alternate with thin beds of quartzite and conglomerate. The conglomerate layers are less than a foot thick and carry pebbles of quartz and red jasper." Specimens of the shale from many different localities failed to show any effervescence in acid; probably Ransome chanced upon a rare dolomitic horizon.

Microscopic examination of Maverick shale from several localities shows it to consist of fine quartz grains and micaceous shreds, well stratified in an ultra-fine, isotropic cement. The quartz grains are generally less than 0.10 mm. in diameter, and the micaceous shreds 0.15 mm., although exceptionally ranging up to 0.25 mm., in length. Some of this micaceous mineral is muscovite, but much of it is chlorite which imparts its greenish hue to the rock. Locally, the cement is marked by limonitic splotches.

According to the microscopic data, the Maverick shale is characteristically finer-grained and more argillaceous than the shale of the Alder series.

Mazatzal quartzite[125]

The Mazatzal quartzite, named for the Mazatzal Range, crops out in four different areas in central Arizona. Resting with apparent conformity upon the Maverick shale and intruded in places by granite, it makes up the high, main ridge of the northern half, and the crest of Four

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125 Wilson, Eldred D., Proterozoic Mazatzal quartzite of Arizona: Pan Am. Geol., vol. 38, p. 304, 1922.

Peaks at the southern end, of the Mazatzal Range. Along Pine Creek it lies unconformably upon the Red Rock rhyolite and is unconformably overlapped by Paleozoic and Tertiary beds. In northeastern Tonto Basin, in Christopher Mountain and vicinity, it occurs faulted against the Red Rock rhyolite and unconformably overlapped by Apache, Paleozoic, and Tertiary formations. Near Del Rio it is in fault contact with metamorphosed shale of the Alder series and unconformably overlapped by Cambrian, Devonian and Tertiary beds.

Typically, the Mazatzal is a very hard, vitreous, fine to medium-grained, prevailingly cross bedded, locally ripple-marked quartzite. Its weathered surfaces are pale brown, reddish brown, light gray, or nearly white, but with a characteristic faint purplish tint that is particularly noticeable from a distance. Its strata, which prevailingly form rugged cliffy to boulder-controlled slopes (see Plates XIII-A and XXXVI), range from a few inches to several feet in thickness with 2- to 6-foot beds probably the most common. In places relatively thin members of conglomerate and maroon shale are present. On Pine Creek the formation has a basal conglomerate 300 feet thick.

Measured sections of the Mazatzal quartzite show it to be 1,300 feet thick in the Mazatzal Mountains (p. 191), 3,800 feet on Pine Creek (p. 242), and 1,780 feet near Del Rio (p. 282).

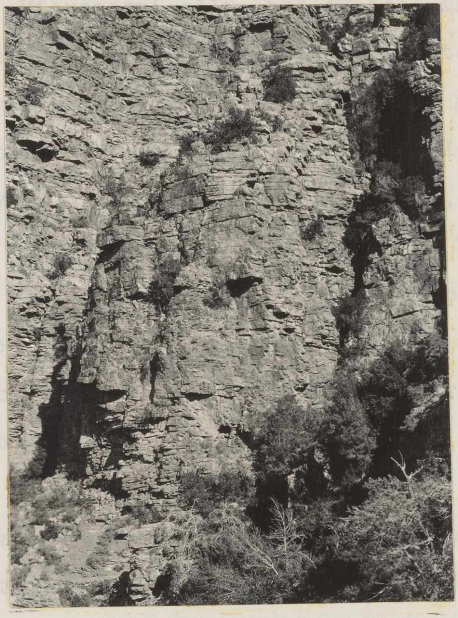

PLATE XIII-A. Near view of typical Mazatzal quartzite.

PLATE XIII-B. Microphotograph of typical Mazatzal quartzite.
Crossed nicols, 23 diameters.

Microscopically, the typical Mazatzal quartzite consists of a closely-packed aggregate of angular to subangular quartz grains in a finely granular, siliceous, somewhat limonitic cement (Plate XIII-B). The grains, which mostly do not exceed 1 mm. in length, are characteristically 25 to 50 per cent longer than wide. The interbedded maroon shale of the formation consists of sparse, extremely fine particles of quartz and kaolin in an abundant argillaceous, iron oxide cement. In places they are mottled, probably due to unequal diffusion of the iron oxide.

Relation to the Yavapai group: The Mazatzal quartzite, Maverick shale, and Deadman quartzite rest unconformably only on the Red Rock rhyolite. They have not been found overlying the Yaeger greenstone and Alder series, probably because the foundation provided by these folded, faulted, relatively soft members of the Yavapai group could poorly resist the erosion that the Red Rock rhyolite has withstood.

On Pine Creek the Mazatzal quartzite is separated from the Red Rock rhyolite by an erosional unconformity, proclaimed by a basal conglomerate 300 feet thick. That the old rhyolite surface sloped southward is indicated by the coming in and southward thickening of the Maverick shale and Deadman quartzite beneath the Mazatzal quartzite in the Mazatzal Mountains.

While it is possible that the Mazatzal quartzite, Maverick shale, and Deadman quartzite were deposited as

near-shore phases of the Alder series, these formations do not appear to finger out or grade into the Alder type of rocks southward, away from the rhyolite oldland; on the contrary, the Maverick and Deadman thicken in that direction. Furthermore, it can scarcely be argued that the Alder series is younger than the Deadman, Maverick, and Mazatzal strata, for the Alder conglomerate beds contain abundant pebbles of typical Red Rock rhyolite but only sparse pebbles of quartzite, and that quartzite is unlike Deadman and Mazatzal material.

It seems most likely that, prior to deposition of the Deadman, Maverick, and Mazatzal strata, the region underwent uplift, probably accompanied by some faulting, and the areas of Red Rock rhyolite now overlain by these strata were stripped of any Alder rocks that may have covered them.

City Creek series

A thick succession of shale with some interbedded quartzite is exposed at the northern base of the Mazatzal Mountains, on the western side of City Creek (Long.111° 30'), beyond the northern limit of Plate XXI. These beds are termed the City Creek series.

Here, a northward-sloping pediment, capped by Cambrian Tapeats sandstone, Devonian limestone, and Tertiary-Quaternary gravel, has been dissected to depths of 200 or 300 feet by northward-flowing tributaries of

PLATE XIV. City Creek series with small scale thrust showing in quartzitic member.

the East Verde River and limited on the north by the narrow bottom-lands of that stream. The City Creek series crops out for an east-west length of about one mile in the bluffs of the pediment overlooking the river, and for approximately 1½ miles southward in the lower reaches of the tributary gulches.

The City Creek series constitutes a faulted, somewhat folded block that appears to be a northward-plunging, spoon-shaped syncline with steepening limbs on the east and south. Its contacts with the Yaeger greenstone on the east, west, and south are greatly obscured by talus and brush, but seem almost certainly to be steeply dipping faults. The series is intruded by a few narrow dikes of diorite porphyry and overlain, with well-exposed, pronounced angular unconformity, by Cambrian Tapeats sandstone.

Apparently the lowest exposed members of the series are at the southeastern margin of the pediment (see sketch section, Figure 2). There, the canyon of City Creek cuts through well-stratified grayish-black to purplish siliceous shale which is at least 800 feet thick and contains at the top a 15-foot member of alternating shale and novaculitic quartzite (see Plate XIV). In places this black shale weathers splintery, not unlike member (4) of the Alder series south of Sheep Mountain (page 171). The City Creek black shale is sufficiently hard to scratch ordinary glass, yet can be marked by a knife, and shows no reaction with acid. Microscopically,

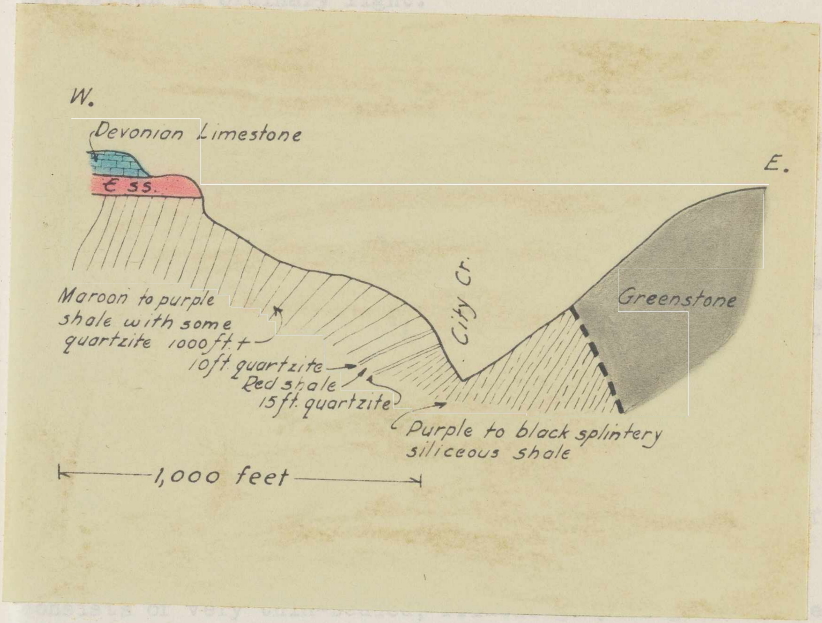

Figure 2. Sketch section across upper City Creek.

the black shale consists of angular particles of quartz and shreds of kaolin (?), 1/25 to 1/50 mm. in diameter, stratified within an abundant, isotropic cement that is pale green in ordinary light.

The next higher member of the series consists of thin-bedded, friable maroon shale, about 50 feet thick, with a 10-foot member of alternating novaculitic quartzite and shale at the top (see Fig. 2).

Resting upon this member is thin-bedded maroon to purple shale with some interbedded quartzite. These beds, which dip rather steeply and extend northwestward beneath Paleozoic and Tertiary-Quaternary formations, have an apparent thickness of at least 1,000 feet, but there is possibly some duplication of faulting or folding.

Farther northwest, where it reappears in the bluffs fronting the East Verde River, the City Creek series consists of very thin-bedded, friable grayish-green shale. As this member is very poorly exposed, its thickness and structure were not determined.

Resembling nothing known in the pre-Cambrian of the Southwest and appearing only in fault contact with the Yaeger greenstone, the relation of the City Creek series to the other pre-Cambrian rocks is unknown. As it is affected by broad folds and small thrusts (Plate XIV), this series probably antedates the great period of folding and faulting that involved the Mazatzal quartzite as described on pages 137-145 . Possibly it represents

the protected remnant of a succession, younger than the Mazatzal quartzite, that elsewhere has been removed by erosion.

Diorite porphyry

Dikes of grayish-black diorite porphyry occur rather commonly intruding the Yaeger greenstone, City Creek, and Alder series. In general these dikes strike northeastward, parallel to the regional lamination, indicating that they were intruded after the principal epoch of folding. As this folding affected the Mazatzal quartzite, they are probably younger than that formation.

Microscopically, the diorite porphyry consists essentially of extensively kaolinized feldspar, chloritized hornblende, and secondary quartz, together with minor accessories. Its feldspar, where determinable, is chiefly oligoclase and some sodic labradorite. The rock bears a strong field resemblance to the diorite porphyry of the Bradshaw Mountains and Jerome quadrangles[126] and may be essentially of the same age.

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126 Jaggar, T. A., and Palache, Charles, Description of the Bradshaw Mountains quadrangle: U.S. Geol. Survey Folio 126, p. 5, 1905.

Lindgren, Waldemar, Ore deposits of the Jerome and Bradshaw Mountains quadrangles, Arizona: U. S. Geol. Survey Bull. 782, pp. 57-58, 1926.

Mt. Ord pyroxenite

A stock of dense blackish-colored porphyritic rock, intruding the Alder series and in turn invaded by granite on its southeast, crops out as a belt 3/4 to 2 1/8 miles wide that extends northeastward across the Mazatzal Range at Mt. Ord (Plate XXII). Many dikes of this rock, generally less than 75 feet wide and of northeastward trend, intrude the Alder series for a distance of some 3,000 feet from the stock, becoming less numerous northward.

Exposures of this stock are characterized by blocky forms of somewhat subdued angularity (Plate XV-A) whose erosion has been guided by a principal jointing that strikes S. 60° W. and dips 75° S E. On the northeastern slope of the mountain, particularly, the rock has been carved into steep-sided spurs and canyons, but its slopes above altitudes of 6,000 feet tend to be gentle and largely covered with soil which supports exceedingly dense thickets of oak, manzanita, and other brush up to altitudes of 6,800 feet, with juniper and pine predominating at higher elevations. Dikes of the porphyry in the less-resistant Alder series commonly find expression as canyon narrows and ridge prominences.

Typical material from the stock appears pale greenish gray on weathered surfaces and black on fresh fracture, with phenocrysts of pyroxene up to 5 mm. in diameter in a dense groundmass. Microscopically, the typical variety is seen to consist of well-formed phenocrysts of a mono-

PLATE XV-A. Northwestern slope of Mt. Ord, Mazatzal Mountains. Rock is porphyritic pyroxenite, largely mantled by soil and vegetation.

PLATE XV-B. Microphotograph of Mr. Ord pyroxenite. Phenocrysts of pyroxene, probably diopside, in a groundmass of finely felted pyroxene. Crossed nicols, 80 diameters.

clinic pyroxene (Plate XV-B) in a holocrystalline groundmass of finely felted pyroxene which in places has undergone considerable alteration to serpentine and chlorite. The pyroxene of this rock has the indices and sharp extinction of diopside. Near the granite the pyroxenite shows silicification of its groundmass.

An exceptional variety of the pyroxenite is characterized by small rounded segregations of the phenocrysts which, on weathered surfaces, stand out as nodules.

The relation of the Mt. Ord pyroxenite to the diorite porphyry has not been determined. Obviously guided by the northeastward-trending regional structure, the intrusion of the pyroxenite took place after the principal folding and faulting which, as described on pages 137-145, involved the Mazatzal quartzite. Hence the pyroxenite is younger than that formation.

Granite

Granite, intruding the Mazatzal quartzite and older rocks, makes up more than half of the Mazatzal Mountains and eastern Tonto Basin areas, the southern part of the Black Hills, and a small part of the Pine Creek area.

As a rule the granite forms steep, fairly rugged slopes, eroded under guidance of northeast and northwestward-trending joints. In places, particularly the Mazatzal Esplanade (page 152 and Plate XXV), it retains a fairly smooth, flat surface which is the remnant of a pre-Cambrian peneplain.

PLATE XVI-A. Granite intruded into greenstone, southeast of North Peak, Mazatzal Mountains.

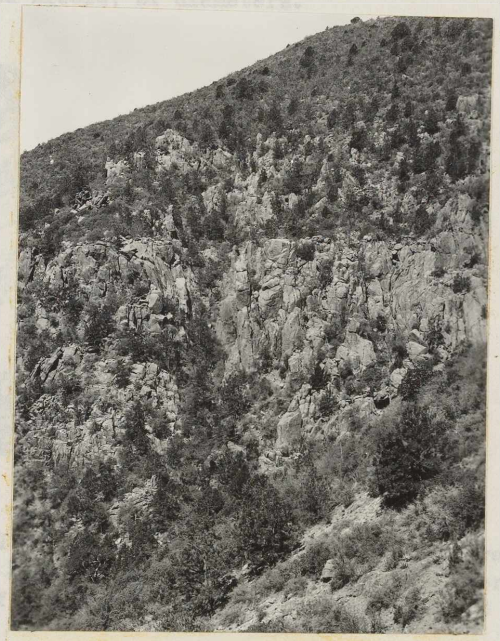

PLATE XVI-B. Jointed granite in Maverick Basin, Mazatzal Mountains.

PLATE XVII-A. Microphotograph of granite from Mazatzal Esplanade, west of Maverick Basin. Or, orthoclase; M, microperthite; q, quartz. Crossed nicols, 21 diameters.

PLATE XVII-B. Microphotograph of pre-Apache granite east of Four Peaks, Mazatzal Range. A, albite; M, microperthite; q, quartz, in part of later generation. Crossed nicols, 14 diameters.

This formation includes several varieties or phases whose detailed study and separation is a problem beyond the scope of the present research. They are believed to have been intruded from a common source during one general period.

The prevailing type of granite is of medium to coarse texture and pinkish-brown color, deeply weathered to pale yellowish brown. Microscopically it consists of partially kaolinized feldspar, quartz, some chloritized biotite, and limonite derived from alteration of ferromagnesian minerals. Its feldspars are principally orthoclase and microcline, with some albite and microperthite (Plate XVII).

In eastern Tonto Basin and the southern part of the Mazatzal Range, the granite is unconformably overlain by younger pre-Cambrian (Apache) beds. In the northern part of the Mazatzal Range, along the East Verde River, and in the Black Hills, it is unconformably overlain by Middle Cambrian sandstone. It is probably equivalent to the Bradshaw granite, of the Bradshaw Mountains (page 66), and the Ruin Granite, of the Globe district (page 68), with which it is virtually identical.

Rhyolite porphyry

Dikes of rhyolite porphyry occur sparsely in the Yaeger greenstone and Alder series at various places. These dikes generally do not exceed 50 feet in width, though the

PLATE XVIII. Northeastward-trending dike of rhyolite porphyry intruding Alder series and forming crest of ridge. Upper Alder Creek, Mazatzal Mountains.

one that extends across the Mazatzal Range, through Pine Mountain and Sunflower Camp (Plate XXII) has a maximum width of one mile. Following the prevailing structure of the region, they strike generally northeast to eastward. Within the Alder series, particularly, these dikes form prominent ridge crests and narrow canyons. Pine Mountain ridge in places has a relief of 1,500 feet. The locus of intrusion of its dike was a fault contact between slate and conglomeratic grit (members 12 and 13, pp. 173-175).

The rhyolite porphyry is typically a fine-grained porphyritic gray rock that weathers pale yellowish gray. Microscopically, it shows phenocrysts of quartz, orthoclase, and sodic plagioclase in a microcrystalline groundmass of sericitized, kaolinized feldspar and quartz.

The smaller dikes of rhyolite porphyry show little or no dynamic metamorphism, but the Pine Mountain dike is laminated for some tens of feet inward from its edges. Ransome[127] states that "it appears to have been affected by the same forces that gave the schists their present character." This lamination, however, could be explained as the result of cooling of the dike and relief or readjustment of regional stresses, acting on original flow planes which were particularly well developed near the edges of

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127 Ransome, F. L., Quicksilver deposits of the Mazatzal Range, Arizona: U.S. Geol. Survey Bull. 620, p. 117,1915.

the mass.

The concordance of the rhyolite porphyry dikes with the local and regional structure is strong evidence that they were intruded after the principal epoch of folding and faulting and hence are younger than the Mazatzal quartzite. They may be genetically related to the granite.

Apache group

The Apache group, of younger pre-Cambrian age, unconformably overlaps the Yavapai group, Mazatzal quartzite, and granite in the eastern Tonto Basin area, and the granite at the southeastern end of the Mazatzal Range. It does not appear farther northwest in the central Arizona areas.

The general lithology and age relations of the Apache group have been described on pages 76-79.

Paleozoic Rocks

The Paleozoic rocks of the Plateau crop out in the Mogollon escarpment, beneath which the pre-Cambrian terrane of central Arizona disappears northeastward. That Paleozoic strata at one time covered the central region and have been largely stripped away, back to this ragged line of cliffs, is evidenced by their several scattered, deeply eroded remnants in the areas studied.

The Mogollon escarpment affords the following

Paleozoic section:[128]

Erosion surface

	Feet
PERMIAN	
Kaibab formation: gray to buff limestone and calcareous sandstone; more or less removed by erosion	500 max.
Coconino sandstone: Light-yellow to white fine-grained massive cross-bedded sandstone.....	600-1,000
Supai formation: Red shale and sandstone with some sandy limestone.....	1,000
Disconformity	
PENNSYLVANIAN	
Limestone with interbedded conglomerate, sandstone, and shale; thins out northwest of Pine.....	0-1,000
Disconformity	
MISSISSIPPIAN	
Redwall limestone: Gray to buff limestone	50-300
Disconformity	
DEVONIAN	
Jerome formation: Gray compact limestone, in part arenaceous	350-500

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128 Compiled from the following sources: Ransome, F. L., Some Paleozoic sections in Arizona and their correlation: U. S. Geol. Survey Prof. Paper 98, 1916; Darton, N. H., A résumé of Arizona geology: Univ. of Ariz., Ariz. Bureau of Mines Bull. 119, 1925; Stoyanow, A. A., Correlation of Arizona Paleozoic formations: Geol. Soc. Am., Bull., vol. 47, pp. 459-540, 1936; and Wilson, Eldred D., unpublished notes.

Disconformity

CAMBRIAN (MIDDLE)

Tapeats sandstone: Dull red-brown cross-bedded friable pebbly sandstone..... 80-100

Great unconformity

PRE-CAMBRIAN

At the southeastern margin of the Mazatzal Mountains and of Mazatzal land, the Paleozoic strata rest upon the basalt of the Apache group and present the following section:[129]

MISSISSIPPIAN

	Feet
Erosion surface	
Tornado limestone: Light-gray pure, comparatively massive limestone.....	0 - 75+
DEVONIAN	
Martin limestone: yellowish to brown arenaceous and argillaceous limestone and sandstone.....	350+
CAMBRIAN (MIDDLE)	
Troy sandstone: Light-brown cross-bedded pebbly sandstone.....	160

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129 After Ransome, F. L., Work cited, and Stoyanow, A.A., work cited.

The Paleozoic strata of the Plateau were deposited upon a pre-Cambrian surface that has undergone deep erosion and extensive peneplanation. In central Arizona, however, there remained a northeastward-trending mountain ridge that, as Ransome pointed out (page 71), comprised a land barrier between the Paleozoic depositional basins of northwestern and southeastern Arizona. The size of this barrier, which Stoyanow termed Mazatzal land (page 72) has not been determined, but it must have been at least 50 miles wide, including the Mazatzal Mountains, Pine Creek, and eastern Tonto Basin areas, and it extended for an unknown distance northeastward, appearing in the Defiance uplift (pp. 72-73), 150 miles northeast of Tonto Basin. Stoyanow[130] has brought forth convincing lithologic and faunal evidence showing that the Mazatzal land acted as a barrier through later pre-Cambrian and all through early Paleozoic, up to Pennsylvanian time "when the sea encroached upon the existing part of the barrier and, indeed, rolled over it." The materials that make up the Permian Coconino sandstone were, according to McKee,[131] derived from Mazatzal land.

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130 Stoyanow, A. A., Correlation of Arizona Paleozoic formations: Geol. Soc. Am., Bull., vol. 47, pp. 459-540, 1936.

131 McKee, E. D., The Coconino sandstone - its history and origin: Carnegie Inst. Wash., Publ. No. 440, pp. 77-115, 1933.

Mesozoic Interval

No Mesozoic rocks are present in central Arizona, but they may once have covered the region and since been stripped by the erosion of Tertiary and Quaternary time. All that can be said in our present state of knowledge is that there is a break in the stratigraphic record from the Permian to the Tertiary.

Tertiary Rocks

General statement

The Tertiary is represented by loosely to firmly consolidated sedimentary beds and by volcanic rocks. Although these formations have not yielded fossils, their probable age can be fairly well inferred from existing knowledge of the structural, physiographic, and sedimentation history of the Tertiary in adjacent parts of Arizona. As the Tertiary rocks are involved in the later structural events of the region, they merit more attention than could be given them during the present research. No attempt has been made to work out their details of stratigraphy and structure or to show more than their general distribution on Plates XXI, XXII, XXIII, LVII, and LXVI.

These Tertiary formations represent two epochs of which the older is regarded as Mid-Tertiary, possibly Miocene, and the younger as Pliocene.

Mid-Tertiary rocks

The mid-Tertiary rocks include sedimentary beds, andesite, and dacite.

The sedimentary beds consist of stratified, indurated hematite-red arkosic conglomerate and sandstone. This succession, which crops out with a thickness of more than 1,000 feet at Mt. McDowell, northwest of the junction of the Verde and Salt rivers (Plate IV), underlies the later deposits of the deeper valleys to an unknown extent. The red beds are lithologically identical to those at Papago Saguaro and Tempe Butte, 15 miles farther southwest, which Bryan [132] has described and considers as pre-Pliocene in age. In all localities they have been faulted and tilted, and at Tempe Butte they are overlain by a thick, tilted bed of andesite. The abundance of ferric iron in the red beds indicates that their materials were derived from a region that had previously undergone deep oxidation. They may be equivalent in age to the Whitetail conglomerate of the Globe and Ray districts, which underlies the dacite

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132 Bryan, Kirk, The Papago Country, Arizona: U. S. Geol. Survey Water-Supply Paper 499, pp. 59-60, 1925; and written communication.

and is probably early or middle Tertiary.[133]

The dacite of the Globe and Ray districts, which Ransome regarded also as early or middle Tertiary, extends northwestward through the Superstition Mountains and abuts against the southern end of the Mazatzal Range. Between this range and the Salt River, the dacite consists of essentially flat-lying flows and tuff, totalling more than 1,500 feet in thickness. In places it is underlain by andesite.

Late Tertiary rocks

Unconformably overlying the mid-Tertiary red beds and dacite is a thick series of poorly stratified conglomerate, sandstone, silt, and impure limestone. This series floors the intermont troughs and in many localities extends high into the mountain ranges. In places it is intercalated with and overlain by volcanic rocks of andesitic and basaltic composition.

The conglomerate crops out at many places, chiefly as bluffs and steep slopes cut by the deeper stream channels of the Verde and Tonto valleys. It consists of ill-assorted angular to rounded boulders, pebbles, and sand, eroded from the older rocks of the region. These materials are more or less firmly consolidated and dis-

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133 Ransome, F. L., Copper deposits of Ray and Miami, Arizona: U. S. Geol. Survey Prof. Paper 115, pp. 67-68, 88, 1919.

PLATE XIX-A. Deformed late Tertiary conglomerate in lower Verde Valley, west of Club Ranch.

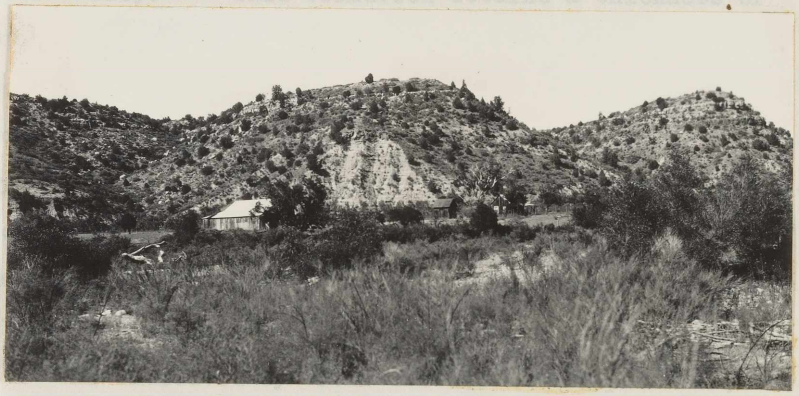

PLATE XIX-B. Late Tertiary silt and limestone near East Verde River at Longitude 111° 30′.

tinctly bedded (Plate XIX-A).

Soft, friable, pale yellowish-brown sandstone, interbedded with conglomerate, silt, limestone, and basalt, make up a large part of the younger Tertiary sedimentary series between the northeastern base of the Mazatzal Range and the East Verde River. It also mantles much of the older rock surface at an altitude of approximately 6,000 feet between Maverick Basin and Knob Mountain, in the northern portion of the Mazatzal Range.

In some localities impure hard to chalky limestone occurs associated with the late Tertiary beds. Interbedded with conglomerate, clay, and basalt and containing large saline deposits, it constitutes the Verde formation which covers an area of 300 square miles in the upper Verde Valley.[134] This formation attains a thickness of more than 2,000 feet and rests upon basalt. Limestone, associated with conglomerate and basalt flows, forms prominent bluffs along the lower Verde River in the vicinity of Latitude 34°. Interbedded with conglomerate, sandstone, and silt, it crops out at the northeastern end of the Mazatzal Range and also in the western part of Tonto Valley, near Latitude 34°.

As indicated by their texture and composition, the conglomerate, sandstone, and silt were laid down by local

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134 Jenkins, Olaf P., Verde River lake beds near Clarkdale, Arizona: Am. Jour. Sci., 5th ser., vol. 5, pp. 65-81,1923.

streams under semi-arid climatic conditions. The limestone was deposited in lakes which resulted from temporary obstruction of the main drainage channels by lava flows, aided to some extent by faulting.

Although these deposits have not yielded fossils in central Arizona, their age is regarded as late Tertiary, probably Pliocene. They are broadly similar to the Gila conglomerate, of southern Arizona, which Bryan has shown to be Pliocene. Like that formation, they represent the period of sedimentation that occurred after the present ranges and valleys had been outlined and preceded the Basin and Range faulting. Furthermore, they overlie and are interbedded with lava flows of probable Pliocene age.

Volcanic rocks mantle large areas in the region, as shown by the Geologic Map of Arizona. Extending across the Plateau escarpment from the San Francisco Mountains volcanic field, these extrusive rocks cap the Black Hills, floor much of the Verde Valley downstream from Camp Verde, and cover portions of the Mazatzal Range. They consist of flows, breccia, and tuff, in part andesitic but largely basaltic in composition. The series, which ranges in thickness from less than 100 to more than 2,000 feet, rests upon an irregular surface of erosion.

The eruption of these rocks evidently occupied a rather long interval of late Tertiary time. They occur intercalated with and overlying the late Tertiary sedimentary beds, and in the Black Hills and Mazatzal Moun-

PLATE XX-A. Southeastern side of Table Mountain, Mazatzal Range, showing 2,000-foot succession of Tertiary volcanic rocks.

PLATE XX-B. Tertiary basalt (b) resting on late Tertiary gravel (gl) which lies on granite. North bank of Salt River at southwestern foot of Mazatzal Range.

tains, they clearly antedate the block faulting that gave rise to the mountain ranges. A large portion of the series is later than the development of the Plateau escarpment, which probably followed the initial uplift of the ranges.

Quaternary Deposits

The intermont troughs of central Arizona are veneered in most places with ill-assorted, commonly unstratified gravel, sand and silt, from less than a foot to a few tens of feet thick. This alluvium is of local derivation. It is doubtless of Quaternary age and in places is undergoing deposition at the present time.

CHAPTER III. STRUCTURE

General Statement

The earlier pre-Cambrian rocks of central Arizona have undergone intense folding, accompanied by reverse and normal faulting and widespread batholithic invasion, whereas the later pre-Cambrian, Paleozoic, and Tertiary formations have been dislocated mainly by normal faulting. The folds and reverse faults are of subparallel, northeast to northward trend. Some of the normal faults strike parallel to these features and others approximately at right angles to them.

The earlier folding, faulting, and associated igneous activity, which occurred long before deposition of the Apache group, mark a crustal disturbance termed the Mazatzal Revolution. After this revolution the region passed through many cycles of uplift, erosion, and subsidence, but appears to have undergone comparatively little further deformation until normal faulting in late Tertiary time gave rise to the present mountain ranges.

Folds

The folds in central Arizona are of closed, open, and drag types. As a rule they plunge at low or moderate angles northeast to northward, and their axial planes tend to dip southeastward. The formations involved in the folding are, in order of observed intensity, the Alder series, Maverick shale, Deadman quartzite, Yaeger greenstone, City Creek series, Mazatzal quartzite, and Red Rock rhyolite, all of pre-Apache age.

The closed folds are sharp, steep-limbed flexures which tend to be slightly overturned northwestward. They range in width from a few inches to several thousand feet; the syncline exposed west of Mazatzal Peak (Plate XXI, sec. N-S) has a minimum amplitude of 4,000 feet, and the one indicated by Plate XXII, section S-O, in the central segment of the Mazatzal Range, appears to be more than six miles across. Throughout central Arizona most of the

Alder series, a large part of the Yaeger greenstone, and in places the Red Rock rhyolite, Deadman quartzite, Maverick shale, and the lower portion of the Mazatzal quartzite, are affected by folds of this type. The folded strata, particularly if argillaceous, are more or less laminated parallel to original bedding, but, except on bends, show no change in thickness due to flowage, and no microscopic evidence of recrystallization due to regional pressure. Their metamorphism to phyllite and schist is restricted to the vicinity of intrusive bodies, particularly of granite.

Open rather than closed folds predominate in the relatively competent Red Rock rhyolite, Deadman quartzite, and Mazatzal quartzite, and also in the City Creek series. These open folds are generally broad, gentle flexures whose limbs dip less than 50° (Plates XXI and LXVI), but some are sharp bends of which one limb, due to northwestward overturning, dips steeply or even vertically (Plate XXI). They have the same northeast to northward trend and plunge as the closed folds.

Drag folds, affecting all the deformed rocks, though best developed in the Maverick shale, Deadman quartzite, and the lower portion of the Mazatzal quartzite (Plates LII and LV) occur within the bends of many of the major folds and in the lower portions of the thrust slices. They are rather uniform, sharp flexures, generally less

than ten feet in amplitude, with pronounced northwestward overturn. Marking zones of differential movement, they die out or give way to bedding faults in the more competent rocks.

Faults

Age and expression

The principal faults recognized in central Arizona are of two ages, pre-Apache and late Tertiary. The pre-Apache faults are of low-angle thrust and steeply dipping reverse and normal types that, as a rule, have not greatly influenced the present topography, whereas the Tertiary faults are of normal type and tend to be strongly expressed in the topography.

Reverse faults

Striking parallel to the folds are numerous reverse faults which have greatly dislocated the Mazatzal quartzite and older formations but do not affect the Apache and younger rocks. These faults exert more or less control over drainage lines and saddles. In places the actual fault plane is visible. Where hard, brittle rocks, particularly quartzite and rhyolite, are involved, the trace of the fault is marked by breccia and gouge, and the footwall tends to be shattered.

The reverse faults dip from a few degrees to 80°

southeastward. The low-angle thrusts are apparent only in the more competent beds but possibly involve also the closely folded Alder series. Although some of the steeply dipping reverse faults probably followed the batholithic invasion, most of them appear to be related to low-angle thrusts. Due to insufficient key beds, their maximum displacement is generally indeterminate; in many cases it plainly exceeds 1,000 feet.

The low angle and steeply dipping reverse faults are particularly well exemplified by the Mazatzal thrust, a great low-angle initial shear fault that involves the northern half of the Mazatzal Mountains. From its apex in a saddle one mile south of North Peak, it is treaceable southward for 7 miles, disappearing where intruded by pre-Cambrian granite on the southwest (Plate XXI) and concealed by Tertiary formations on the east, beyond the limits of Plate XXI. It probably continues 10 miles farther southeastward, beneath the central segment of the range, to the intrusive bodies at Mt. Ord. Its minimum displacement is 7, and may exceed 17, miles. The exposed portion of the thrust cuts, with low southeastward dip, diagonally across the underlying gently southeastward dipping Mazatzal strata. Above the fault are imbricated, slightly deformed to closely folded sheets of Red Rock rhyolite, Deadman quartzite, Maverick shale, and Mazatzal quartzite. These sheets are separated by steeply southeastward dipping reverse faults which branch up-

ward from the sole. Above the presumed southeastward extension of the thrust in the central segment of the range are blocks of Red Rock rhyolite and folded, steeply tilted Alder beds. These blocks are separated by steeply dipping faults (Plate XXII) that strike northeastward.

Tear faults

The pre-Apache rocks are cut in places by vertical faults which strike northwestward, perpendicular to the folds, and affect the topography only as zones of weakness to erosion. They are further characterized by horizontal displacements of a few hundred feet, but their vertical displacements are generally indeterminate. A fault of this type exposed along the South Fork of Deadman Creek, in the Mazatzal Mountains (Plate XXI), shows a displacement of approximately 150 feet vertically and more than 200 feet horizontally. Another, between Red Rock and Sheep Mountain, in the same range (Plate XXII), has a displacement of approximately 300 feet horizontally and an unknown amount vertically.

These faults are interpreted as pre-Apache tears which resulted from the compressive stresses that gave rise to the folds.

Normal faults

Normal faults are fairly abundant in central Arizona. Part of them, truncated by a pre-Cambrian erosion surface

and overlain by undisturbed Cambrian strata, are of pre-Cambrian, probably pre-Apache, age. Some are of indeterminate age, but, wherever they lack topographic expression they may reasonably be regarded as pre-Cambrian. Others are strongly reflected in the present topography and in places cut Tertiary beds.

The normal faults of known and supposed pre-Cambrian age strike northeast to northward, dip steeply, and show displacements of a few tens to several thousand feet. They are well exemplified in the northern and central portions of the Mazatzal Range (Plates XXI and XXII), as described on pages 208-228, and in the Black Hills (Fig. 13 and page 297).

The Tertiary normal faults comprise two main systems of which one strikes northwest to westward and the other northeast to northward. Their displacement ranges from a few feet to more than 1,000 feet. They dip steeply or even vertically and are characterized by strong reflection in the present topography. Minor faults of this type occur locally within the mountains, as shown in the Pine Creek area (pages 254-255). Those of great displacement are found in places separating the Tertiary (Pliocene) beds of the valley troughs from the hard rocks of the mountain ranges. There appears to have been little or no tilting associated with these faults north of Latitude 33° 45'. No true fault scarps are present, but the moun-

tain fronts may be regarded as profoundly eroded fault-line scarps. The mountain ranges stand above the intervening valley troughs because the upthrown mountain blocks are resistant to erosion relative to the soft Tertiary beds of the downthrown blocks.

Correlation of the Structural Features

The volcanic activity that formed the earliest known rocks, the Yaeger greenstone and Red Rock rhyolite, was doubtless occasioned by crustal unrest, but its associated structural features are obscure. It was followed by a long period of erosion and sedimentation during which the several thousand feet of Alder beds were deposited. This sedimentation was interrupted by regional uplift, accompanied probably by some faulting, and consequent denudation of large areas of Red Rock rhyolite upon which the Deadman quartzite, Maverick shale, and Mazatzal quartzite unconformably rest. Hence some of the normal faults that separate Yaeger greenstone and Red Rock rhyolite from Alder beds may have originated in pre-Mazatzal time.

The field relations indicate that the major features of pre-Cambrian structure in central Arizona resulted from one profound crustal disturbance, the Mazatzal Revolution, which occurred after deposition of the Mazatzal quartzite and long before Apache sedimentation. The sub-

parallel folds, thrust faults, and imbricate, steeply dipping reverse faults, so strongly developed in the Mazatzal quartzite and older formations, clearly resulted from intense northwest-southeastward regional compression; the overturn of the folds indicates that the direction of thrusting was northwestward. The tear faults, which strike normal to the trend of the folds, are believed to have been formed by shearing stresses set up by the compression. Widespread igneous activity, consisting of the intrusion of dioritic to pyroxenitic stocks and dikes and the largest batholithic invasion of granite in central Arizona, culminated this most intense crustal disturbance. The regional compression induced lamination and slaty cleavage, but no marked recrystallization, in the incompetent rocks. Schistosity is apparent only in the vicinity of the larger intrusive bodies. Readjustments consequent upon the compression and igneous activity gave rise to normal and steeply dipping reverse faults of northeastward strike.

The Tertiary block faults, which are parallel to pre-Apache structural features, probably followed breaks or zones of weakness inherited from the Mazatzal Revolution.

PART III - DETAILS OF CENTRAL ARIZONA AREAS

CHAPTER I - MAZATZAL MOUNTAINS

Geography

General topography

The Mazatzal Mountains are in central Arizona, near the southwestern margin of the Plateau. The range trends about N. 30° W., from the Salt River on the south to the East Verde River on the north, between the valley of Tonto Creek on the east and the Verde River on the west. It is 50 miles long by 12 to 18 miles wide and has a somewhat sinuous crest that presents a skyline of prevailingly rounded, though locally rugged, peaks and saddles. The saddles exceed 4,500 feet in altitude, whereas the higher peaks rise about 3,000 feet higher. From north to south, these summits are: North Peak (altitude 7,449); Mazatzal Peak (7,914); Cactus Point (7,600); Sheep Mountain (7,360); Pine Mountain (6,250); Mt. Ord (7,155); and Four Peaks (altitude 7,645 feet above sea level or 5,500 feet above Roosevelt dam). Most of the range is asymmetrical in cross section, with the slopes considerably shorter and steeper on the east than on the west. The slopes on both sides have been intricately dissected by deep and narrow

canyons.

Climate, vegetation, fauna, and industries

At Roosevelt the temperature extremes so far recorded are 114° and 18° F., and the mean annual precipitation is approximately 18 inches. No climatic records for the range are available, but its highest portions probably have minimum temperatures of -20° or lower, and a mean annual precipitation of more than 30 inches. This high country contains many small intermittent and perennial streams, whereas most of the streams in the canyons of the lower flanks are ephemeral and carry only seasonal run-off, largely as flash floods.

The slopes that exceed the angle of repose in steepness appear as rather bare rock, but the ridge crests and gentler slopes commonly maintain sufficient soil to support a fairly dense vegetative cover. Western Yellow Pine, with some spruce and scattered oak, abound in favorable places above altitudes of 5,500 feet. Between altitudes of 4,000 to 5,500, particularly, and up to 7,000 feet on some southwestern slopes, are dense thickets, 4 to 10 feet high, of oak, manzanita, and other varieties of brush. A widely overlapping zone of juniper lies between the timber and brush zones.

The principal native animals are bear, deer, mountain lion, wildcat, wolf, coyote, numerous kinds of

smaller animals, and many varieties of birds.

Seasonal grazing, prospecting, mining, and trapping are the only industries. Most of the inhabited ranches are in the low country near the southwestern margin. Aside from the foot-hill areas, the remainder of the range, including more than 500 square miles, had in 1935 about 6 year-long residents.

Accessibility

A highway connecting Roosevelt with Payson follows the valley of Tonto Creek and connects with the Bush Highway, which skirts the southwestern portion of the range and crosses its middle segment. A few secondary roads branching from these highways lead to mines and prospects. The northern foot of the range is reached by a road that leads from Payson to Taylor's ranch, on the East Verde River. Trails built by the Forest Service, stockmen, and prospectors greatly facilitate animal transportation into the more remote sections, but much of the country is so rugged and brushy as to be accessible only on foot, and many sections of the brushy areas can not be penetrated without cutting.

Geomorphology

Northern portion

The northern portion of the Mazatzal Range, as here

PLATE XXIV. Looking west from Tonto Basin at northern portion of Mazatzal Range. North Peak at right, Mazatzal Peak at extreme left.

considered, extends from the East Verde River (approximately Latitude 34° 15') on the north to Sheep Mountain (Latitude 34°), 5 miles south of Mazatzal Peak, on the south, and from the Verde River on the west to the floor of Tonto Basin on the east. It comprises an area 10 to 23 miles long from west to east by 15 miles wide and includes more than 250 square miles.

In this area, the summits are more than 7,000 feet above sea level, with Mazatzal Peak rising to 7,914 feet, the highest point in the range. For about 3 miles north of Sheep Mountain, the crest of the range is an irregular peak-studded ridge whose ruggedly dissected, sparsely wooded slopes are characteristic of the massive and jointed Red Rock rhyolite. Northward, the crest is broader, with a succession of six rounded to blocky peaks rising above a locally timbered ridge of narrow rolling mesas notched by five rather abrupt passes a few hundred feet deep. The general configuration of the mesas reflects the gently folded structure of the constituent Mazatzal quartzite, and the notch-like passes mark traces of reverse faults.

Northward from North Peak, which is 7,449 feet above sea level, the range descends gradually in 4½ miles to a terminus at the East Verde River where it has an altitude of 3,300 feet. This descent begins with a steep to cliffy, somewhat bushy surface that cuts across 950 feet of flat-lying Mazatzal quartzite and continues with a

PLATE XXV. Looking northward from near Club ranch at a remnant of a pre-Paleozoic surface (Mazatzal Esplanade) carved on Red Rock rhyolite and granite. Ridge of Mazatzal quartzite at right.

30°-35° slope over some 500 feet of horizontal Maverick shale to a narrow, timbered flat on the Deadman quartzite, thence over fairly steep northward-ridged brushy surfaces of Red Rock rhyolite and Yaeger greenstone to a wide dissected terrace of loosely consolidated Tertiary sediments flooring the valley of the East Verde River. Two well-defined breaks in the greenstone slopes mark traces of prominent southeastward-trending faults.

In cross-section, the northern portion of the Mazatzal Range is asymmetrical, with a long western back slope and a steep eastern front (see sections, Plate XXI) that suggests a dissected fault-line scarp.

Westward from the crest of the range there is a rather abrupt descent on Mazatzal quartzite and Red Rock rhyolite to a deeply dissected area, 7 to 10 miles wide from east to west, that appears to be the remnant of a gently westward-sloping surface, here termed the Mazatzal Esplanade, whose altitude ranges from about 6,300 feet on the east to 4,300 feet on the west (see Plates XXI and XXV). On the north, west of City Creek, it terminates with a slope on greenstone that descends about 2,000 feet in a mile, forming the southern wall of East Verde Canyon. On the west it overlooks, with an indented front of extreme irregularity, the narrow valley of the Verde River. The Esplanade itself is floored by pre-Cambrian quartzite and rhyolite along its eastern margin,

pre-Cambrian greenstone along its northern edge, and elsewhere by pre-Cambrian granite. As the granite and greenstone are overlain by isolated and thin remnants of Cambrian and Devonian strata and by many bodies of Tertiary gravel and lava, the Esplanade is believed to represent a peneplain of pre-Cambrian age that was largely stripped and resurrected by erosion in Tertiary time. Since the eruption of the Tertiary lavas that once covered this resurrected plain, it has been again dissected. The pre-Cambrian surface appears to have extended nearly to the western base of the present upper ridge, which probably stood as an island during Cambrian and later Paleozoic sedimentation. The relatively late dissection of this resurrected peneplain has been accomplished by southwestward flowing tributaries of the Verde River, particularly Deadman, Sycamore, and Wet Bottom creeks, which have carved steep-sided canyons, 1,500 to 2,500 feet deep. Their long parallel southwest courses indicate structural control as do the courses of their branch streams. Both sets of stream courses appear to follow faults of two systems having southwest and southeast trends. Both types of faults are shown in Plate XXI.

North of Barnhardt Canyon, which trends eastward from the pass 2 miles north of Mazatzal Peak, the eastern descent of the range begins with a steep to cliffy, somewhat ruggedly indented surface that cuts across 500

to 1,000 feet of Mazatzal quartzite and continues with a locally dissected 20° - 40° slope over Maverick shale to a folded, faulted reef of quartzite. For about a mile north of Barnhardt Canyon or to the deep south fork of Rock Creek Canyon, the eastern flank below the quartzite reef is a fairly gentle brushy slope of faulted, tilted shale and quartzite which have been deeply dissected into eastward-trending alternating canyons and spurs. The crests of these spurs show a general accordance of elevation. North of the south fork of Rock Creek, this segment is a 15° - 35° slope of Yaeger greenstone which is generally characterized by its exceedingly dense cover of brush. Where the older rocks terminate against the Tertiary sediments of Tonto Basin, the spurs are commonly marked by a well-developed notch, 20 to 100 feet deep, that suggests the trace of a fault. Eastward, the spurs end rather abruptly at the irregular western margin of the upper valley terrace, which here is dissected to depths of 100 to 150 feet. At the north-eastern foot of North Peak, present dissection of the Tertiary beds is somewhat retarded by a dense growth of cypress that gives way southward to grass lands with scattered brush.

Southward, between the deep notch of Barnhardt Canyon and that of Shake Tree Canyon, the eastern flank of Mazatzal Peak descends as a long quartzite slope of about 25° that steepens to 35° - 45° a short distance

west of its contact with the Tertiary sediments. South of Shake Tree Canyon is a northeastward-trending ridge, called Cactus Ridge, of steeply-dipping quartzite (Plates XXI and LIII) which culminates in Cactus Point. To the west and south are long, steep, ruggedly dissected Red Rock rhyolite slopes which culminate in Sheep Mountain and constitute the northwestern side of the Canyon of Deer Creek.

Middle segment

The middle segment of the Mazatzal Range, as here considered, extends from Sheep Mountain (Latitude 34°) on the northwest to the summit of Mt. Ord on the southeast and from the Verde River on the west to the floor of Tonto Basin on the east. It is an area of 150 square miles that is 16 to 20 miles long from east to west by 9 miles wide.

The topography of this segment differs from that of the northern portion of the range in accordance with its geology. Composed essentially of northeastward-trending belts of steeply dipping slate, grit, rhyolite, and intrusive bodies, locally overlain by Tertiary gravel and volcanic rocks, its topography reflects the combined influences of structure, stratigraphy, and antecedent configuration.

Southeast of the rhyolite mass of Sheep Mountain and west of the main divide the area has been deeply

PLATE XXVI. View southwestward from Pine Mountain showing southwestward and southward courses of canyons. Foreground is largely Alder series.

dissected with narrow canyons tributary to the southward-flowing drainage of Sycamore Creek (Plates XXII and XXIII). In the pre-Cambrian rocks, these tributaries flow in zig-zag courses, guided by joints, minor faults, and the lamination of the Alder series. Their intervening ridges tend to be flat-topped with accordant summits between altitudes of 5,400 to 5,600 feet. These summits, which are locally mantled with loosely consolidated Tertiary debris containing large angular blocks of basal Paleozoic sandstone, seem in part to represent an erosion surface of moderate but still mountainous relief. Whether this surface is pre-Cambrian, like the pre-Paleozoic Mazatzal Esplanade described on pages 152-153, or is Tertiary, has not been determined. Sheep Mountain, Mt. Ord, and Pine Mountain probably survived as mountains rising above this surface.

East of the main divide and north of Slate Creek is a succession of deep, narrow canyons tributary to Slate and Gold creeks and principally of southeastward trend, which appear to have eroded headward under guidance of joints and minor faults perpendicular to the regional strike.

Slate Creek pursues a northeastward course generally parallel to the regional strike, although somewhat influenced by local structures. Its tributaries from the south have cut deep, narrow canyons, mostly perpendicular, but in part parallel, to the regional strike.

The dissection of the pyroxenite stock of Mt. Ord has been accomplished by canyons eroding headward along joint systems.

Southern portion

The southern portion of the Mazatzal Range, as here considered, extends from the summit of Mt. Ord on the north to the Salt River on the south and from the Verde Valley on the west to the floor of Tonto Valley on the east. It is an area of 350 square miles that is 24 miles long from northwest to southeast and 12 to 18 miles wide. This area is geomorphologically distinct from the northern and middle segments of the range because it consists largely of granite with only small local masses of sedimentary and volcanic rocks. This granite gives rise to relatively less angular topographic forms, and the slopes as a rule are somewhat gentler, with canyons that tend to be broader. In the small areas of sedimentary, metamorphic, and volcanic rocks, however, the relief is decidedly angular and rugged.

Southward from the summit of Mt. Ord (elevation 7,155) to Four Peaks the crest of the range consists of rounded peaks of less than 6,300 feet altitude, separated by broad flats or saddles generally less than 1,000 feet lower. The most notable of these flats, at Reno Pass, Edwards Park, and Four Peaks Pass, as shown on the topographic map (Plate XXIII), are 1½ to 2 miles long by 3/4

to $1\frac{1}{2}$ miles wide. Although ranging in altitude from about 4,800 feet at Reno Pass to 5,700 feet at Four Peaks Pass, their surface is thinly mantled with soil and loosely consolidated gravel. They may represent remnants of the same ancient surface as appears between Mt. Ord and Sheep Mountain. Four Peaks (altitude 7,645), which represents an eroded roof pendant of steeply eastward-dipping Mazatzal quartzite and metamorphosed Maverick shale, intruded by granite, has a jagged crest, a steep eastern dip slope, and a precipitous western front more than 1,000 feet high (see Plate XXIII). Southeast of Four Peaks the divide is marked by another flat area, about $2\frac{1}{2}$ miles long by 3/4 miles in maximum width and 6,100 feet in altitude. Mantled with gravel and soil, it may be a remnant of the old surface that appears in Four Peaks Pass. South from Four Peaks, the range descends, in a horizontal distance of 6 miles, from an altitude of 7,645 feet to 1,600 feet at the Salt River. The regularity of this slope is interrupted near the river by the dissected flat lava mesas forming the Painted Cliffs.

Sycamore Creek, in the southwestern portion of the range, occupies a fairly straight southward-trending canyon that, in part at least, follows a fault zone. The lateral canyons in the southern portion of the range prevailingly trend northeast-southwest, in accord with the principal jointing in the granite (page 196).

Many of their tributaries follow northwest-southeast courses, which is the direction of a minor system of jointing. The intercanyon spurs show a general accordance of summits at altitudes of 3,300 to 3,500 feet, like those at the northeastern base of the range (page 154). They may be the dissected remnants of an uplifted Tertiary pediment.

Geology

Status of investigation

In 1912 Ransome[135] made two short trips into the eastern portion of the Mazatzal Mountains incidental to a general study of the conditions of Paleozoic sedimentation in Arizona. He described a pre-Cambrian rhyolite, unconformably overlain by a series of quartzite and shale whose structural relations were not understood. He inferred that these rocks had comprised a barrier ridge in the Paleozoic seas (page 71).

In 1914, Ransome made a ten-day examination of the

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135 Ransome, F. L., Some Paleozoic sections in Arizona and their correlation: U. S. Geol. Survey Prof. Paper 98, pp. 157-159, 165-166, 1916.

quicksilver deposits[136] that had recently been discovered in the canyons of Sycamore Creek, southwest of Pine Mountain, in the central part of the range. Incidental to his description of these deposits, he gave an interpretation of the local structural features (pages 57-58) and some speculations on the composition of parts of the range.

During parts of 1920 and 1921, the geologists of the Arizona Bureau of Mines mapped the range. Due, however, to the rough, brushy character of the country and a shortage of time and funds, this work was limited to a broad classification of the formations,[137] and no attempt was made to work out the structural details.

In 1924-1926, Carl Lausen and E. D. Gardner made a brief study of the quicksilver resources,[138] which had

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136 Ransome, F. L., Quicksilver deposits of the Mazatzal Range, Arizona: U. S. Geol. Survey Bull. 620, pp. 111-128, 1915.

137 Wilson, Eldred D., Proterozoic Mazatzal quartzite of central Arizona: Pan Am. Geol., vol. 38, pp. 299-312, Nov., 1922.

138 Lausen, Carl, and Gardner, E. D., Quicksilver resources of Arizona: Univ. of Ariz., Ariz. Bureau of Mines Bull. 122, pp. 60-105, 1925; Lausen, Carl, Tourmaline-bearing cinnabar veins of the Mazatzal Mountains, Arizona: Econ. Geology, vol. 21, pp. 782-791, 1926.

undergone considerable development during the decade subsequent to Ransome's work.

A short summary of the geology of the range was prepared by Lausen for the Lindgren volume.[139]

Approximately four months' time, distributed over widely separated intervals from the middle of 1930 until late 1935, was spent in the Mazatzal Mountains area for the present research. Due to the rough, brushy character of most of the country this field work was largely done on foot, using animal transportation mainly to establish a few temporary camps in the more remote localities. The U. S. Geological Survey Turret Peak advance topographic sheet, on a scale of 1:96,000, was used as a base map for the northwestern portion of the range, and enlargements of the Roosevelt sheet, published in 1912 on a scale of 1:125,000, for the middle and southern segments. No adequate topographic map was available for the area that adjoins the Turret Peak sheet on the east and includes the eastern slope of the range north of Latitude 34°.

Professor Russell Gibson, of Harvard University, spent approximately five days in the area and provided many helpful suggestions.

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139 Am. Inst. Min. and Met. Eng., Lindgren volume, pp. 318-319, 1933.

Formations represented

Age classification	Northern portion		Middle segment		Southern portion	
	Formation	Thickness in feet	Formation	Thickness in feet	Formation	Thickness in feet
Quaternary	Alluvium		Alluvium		Alluvium	
	Unconformity		Unconformity		Unconformity	
Tertiary (Pliocene)	Basalt and andesite	2,000+	Basalt and andesite	1,000±	Basalt and andesite	1,000+
	Sedimentary beds	1,500+	Sedimentary beds	1,500+	Sedimentary beds	1,500+
	Unconformity		Unconformity		Unconformity	
(Miocene ?)	Missing		Missing		Dacite and andesite	2,000+
	Unconformity		Unconformity		Unconformity	
Carboniferous (Mississippian)	Missing		Missing		Tornado limestone	75+
Devonian	Jerome limestone	50+	Missing		Martin limestone	350±
	Disconformity				Disconformity	
Cambrian (Middle)	Tapeats sandstone	100	Missing		Troy sandstone	160
	Unconformity				Unconformity	
Later pre-Cambrian	Missing		Missing		Apache group	
					Basalt	50
					Mescal limestone	300
					Dripping Spring quartzite	500±
	Diorite porphyry and granite		Diorite porphyry, porphyritic pyroxenite, rhyolite porphyry, and granite		Barnes conglomerate	15-20
					Pioneer shale	255
					Scanlan conglomerate	30
					Unconformity	
Earlier pre-Cambrian	City Creek series	1,500+	Missing		Granite	
	??				Missing	
	Mazatzal quartzite	1,300+	Missing		Mazatzal quartzite	1,250+
	Maverick shale	500-800	Missing		Maverick shale	800+
	Deadman quartzite	90-800	Missing		Missing	
	Unconformity					
	Yavapai group		Yavapai group		Missing	
	Missing		Alder series	5,000+		
			Fault contact			
	Red Rock rhyolite	1,000±	Red Rock rhyolite	1,000±		
	Fault contact					
	Yaeger greenstone	2,000±	Missing			

Pre-Cambrian rocks

Yavapai group: The Yaeger greenstone, Red Rock rhyolite, and Alder series, which comprise the Yavapai group and were previously termed the Yavapai schist, appear extensively in the Mazatzal Mountains, north of Latitude 34°.

Yaeger greenstone: Greenstone occurs throughout several square miles in the northernmost portion of the range. From the granitic area of the Mazatzal Esplanade (Plate XXI) this formation extends northward for some 3 miles, disappearing beneath Tertiary volcanic rocks on the northern side of East Verde Canyon, beyond the limits of Plate XXI. For a mile west of City Creek it is limited on the north by fault contact with the City Creek series (Fig. 2). North of North Peak and southeastward to the vicinity of Rock Creek, beyond the limits of Plate XXI, it crops out as narrow fault blocks bounded mainly by Red Rock rhyolite along the base of the mountains and by Tertiary sedimentary beds northeastward. Small areas of so-called "greenstone" occur within the Alder series (page 173), but they are chloritized or dark ferruginous beds of that series rather than of the unit under consideration.

The greenstone of the Mazatzal Mountains is intruded by the post-Mazatzal granite at the northern margin of the Mazatzal Esplanade (Plate XXI) and by a small stock of similar granite at the eastern base of

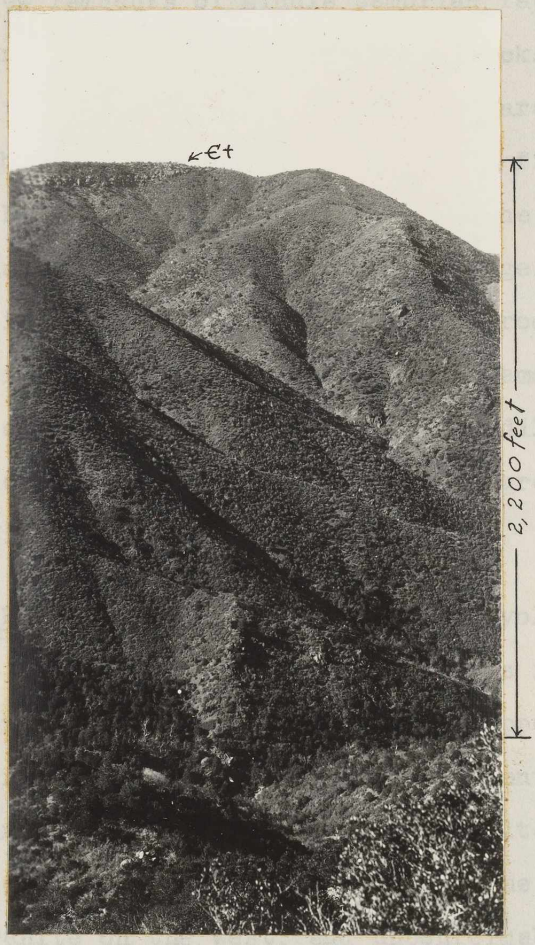

PLATE XXVII. Looking west at greenstone slopes on northern end of Mazatzal Range west of City Creek. Cap rock (Ꞓt) on upper left is Cambrian Tapeats sandstone.

North Peak, beyond the limits of Plate XXI. It is overlain by a few remnants of Middle Cambrian Tapeats sandstone, Devonian limestone, and Tertiary rocks, but its contacts with the other formations of the area are faults. Its pre-Cambrian age is established by its field relations with the Paleozoic beds and with the post-Mazatzal granite, which is of pre-Apache age. Composed largely of intermediate to mafic volcanic rocks that have been extensively affected by low-grade metamorphism, the greenstone of this range constitutes a readily distinguishable unit identical to the Yaeger greenstone of the Black Hills (pp. 92-94).

Red Rock rhyolite: The Red Rock rhyolite which, for reasons stated on pages 98, 111-112, is regarded as next younger than the Yaeger greenstone, appears extensively in the northern and central segments of the Mazatzal Range (Plates XXI and XXII). Faulted against the greenstone on the north, intruded by the post-Mazatzal granite on the west, and unconformably overlain by Deadman quartzite, it is the fundamental rock from North Peak to Cactus Point. From Cactus Point to a fault contact with the Alder series at the southern base of Sheep Mountain (Latitude 34°), it forms the high main ridge. In its type locality of Red Rock, a butte in the central segment of the range, the rhyolite crops out over an area 3/4 to 2½ miles wide by more than 7 miles

PLATE XXVIII-A. Red Rock rhyolite in Davenport Canyon, west of Club ranch.

PLATE XXVIII-B. Massive Red Rock rhyolite showing south-southeastward jointing, southeast of Club Ranch.

PLATE XXIX. Jointing in Red Rock rhyolite, Sycamore Creek.

long (Plate XXII), limited on the northwest and southeast by fault contact with Alder beds.

Alder series: The Alder series, which is regarded as next younger than the Red Rock rhyolite (pages 102, 112), occurs typically in the basin of Alder and Slate creeks, in the central segment of the range. Between Sheep Mountain and Mt. Ord the series crops out as two northeastward-trending belts, each about 3½ miles in maximum breadth, separated medially by the fault block of Red Rock rhyolite that includes Red Rock. The northern belt is limited on the northwest by fault contact with the Red Rock rhyolite of Sheep Mountain, and the southern belt terminates on the south at the Mt. Ord pyroxenite intrusion. Fair to excellent exposures obtain on some of the slopes and in many of the canyons, revealing the members shown on Plate XXII. These members, however, mostly represent groupings of smaller units, the detailed mapping and study of which are beyond the scope of the present problem.

The following section obtains between Sheep Mountain and Mt. Ord:

Section of Alder series between Sheep Mountain and Mt. Ord (numerals refer to the cross-section, Plate XXII).

Feet

1) The first sedimentary member, southeast

of the Red Rock rhyolite mass of Sheep Mountain, consists of thinly laminated, soft, dark reddish-brown to hematite-red,[140] spotted slate, separated from the rhyolite by a fault that dips 70° SE. Due to its relative softness, this slate forms saddles across the southeastward-trending ridges of the locality. This member is characterized mainly by its paper-thin, slightly wrinkled laminae which are commonly marked with diffused reddish-gray lenticular spots up to 1 inch by 1/4 inch in size. Microscopically the typical material consists of very fine ovoid to angular grains of quartz, generally less than 0.1 mm. in diameter, in a hematitic clay cement of sub-microscopic fineness. These grains are well stratified, with their long dimensions parallel to the lamination. This lamination dips 70° - 80° southeastward. In places, it is cut by fracture cleavage which indicates that the top side of the beds is on the southeast. A few dikes of rhyolite porphyry here intrude the series parallel to its stratification; although generally narrow, these dikes locally measure 200 or more feet in width and form ridge crests between southwestward-flowing tributary canyons (Plate XVIII). Thickness of member (1) ..... 500±

2) Southeastward, the first slate grades into a belt of dark purplish-red mudstone with predominating lenses of conglomerate whose pebbles consist mainly of rhyolite, quartzite, slate, and jasper. These pebbles, which are rounded to ovoid and subangular, as a rule range up to 4 inches in diameter, with some exceptional ones of rhyolite, up to a foot in diameter, near the southeastern margin. Microscopically the typical rhyolite of these pebbles consists of phenocrysts of quartz and orthoclase, up to 1.5 mm. in maximum dimension, within a microcrystalline groundmass of quartz and orthoclase. Of the phenocrysts, the quartz shows rounded to embayed outlines, and the orthoclase commonly forms crystals of rectalinear cross section. Sparse shreds of biotite, largely altered to chlorite, are present. Epidote is fairly abundant in the groundmass, but the ortho-

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140 Ridgeway's 7^2m to 5^2m.

clase phenocrysts are unaltered. This rhyolite bears a striking resemblance to the Red Rock rhyolite. Thickness of (2) ..... 1,000+

3-11). Faulted against this conglomeratic member on the southeast is a belt of locally schistose grit, shale, and slate. It is intruded by a few narrow dikes of rhyolite porphyry and diorite porphyry which strike and dip with the lamination. Beginning with about 200 feet of reddish-purple slate (3) it grades into fairly massive to moderately fissile, splintery, dark-gray slate (4) which dips steeply southeastward and crops out over a width of about 1/4 mile. Microscopically, this splintery variety consists of subangular to well-worn ovoid grains of quartz, generally less than 0.05 mm. in length, together with numerous smaller shreds of kaolin and somewhat larger grains of an unknown dark opaque mineral, in a cement of submicroscopic fineness. These grains are arranged with their longer dimensions parallel, apparently by original stratification rather than as a result of metamorphism. In places, this splintery variety contains beds of maroon shale and laminated grit which dip 80° SE. Some of the grit grades into conglomerate, with rounded pebbles mainly of quartz and quartzite. The splintery shale grades into gray quartzitic beds, approximately 500 feet thick (5), succeeded by some 1,100 feet of moderately laminated greenish shale (6) with about 75 feet of grayish spotted beds, containing a few narrow veins of carbonate and jasper adjacent to which notable chloritization has taken place. This shale is followed by about 600 feet of schistose grit (7) which grades into conglomerate (8) approximately 300 feet thick. This conglomerate contains long slivers of shale and subrounded pebbles, up to several inches across, of quartzite and rhyolite. It grades into well-bedded argillaceous dark grit (9) approximately 800 feet thick, laminated parallel to the bedding.

PLATE XXX-A. Slate of member 12, Alder series.

PLATE XXX-B. Sharp anticline in member 12 of Alder series.

The next member consists of about 1/3 mile of chloritic schist (10) containing irregular, lenticular, late Tertiary veins of dolomite with jasper, as shown on Plate XXII and described on pages 205-207. It is succeeded by 1/4 mile of schistose sedimentary material including quartz-sericite schist, black slate, and conglomeratic beds (11). On Alder Creek, at Sunflower Camp, this member contains cinnabar lodes, adjacent to which more or less chloritization is apparent.

Total thickness of members (3-11) ..... 7,900±

12) Faulted against (11) on the southeast is a belt of chocolate-brown slate very similar to (1) but without the prevalent grayish mottling. It is well laminated, for the most part parallel to the bedding. Except for a sharp anticline that appears at the northeastern margin, in the canyon of Sycamore Creek (Plates XXII, sec. S-O, and XXX-B), this bedding ranges in dip from 75° to 85°. This member contains the Pine Mountain group of cinnabar deposits. Intruded along the southeastern margin of the slate is a branching, irregular dike of Pine Mountain rhyolite that attains a maximum width of nearly a mile but locally pinches out (Plate XXII and pages 124-126). 2,640

13) Along the southeastern margin of (12), except where obliterated by the Pine Mountain rhyolite dike, is a bed of conglomerate locally grading into quartzite along the strike and forming a prominent reef 50-200 feet wide. It is made up of pebbles of red jasper, quartz, quartzite, rhyolite, and sericitic slate in a sericitic, gritty, grayish to brownish cement. These pebbles, which are subangular to poorly rounded, mostly do not exceed 3 inches in diameter, though some are considerably larger. They show little or no squeezing, but their cement is rather fissile

PLATE XXXI. Flaggy, laminated grit of member 14, Alder series.

parallel to the bedding. The rhyolite of these pebbles resembles typical Red Rock rhyolite. Microscopically, it consists of an aggregate of very finely crystalline quartz and feldspar, together with sparse, small phenocrysts of quartz and scattered grains of magnetite, veined with dark iron oxide and thin stringers of quartz that shows wavy extinction. Near the Pine Mountain rhyolite dike, particularly, the cement is veined with thin, branching quartz stringers which tend to follow the lamination. On upper Sycamore Creek where the Pine Mountain rhyolite dike pinches out, the conglomerate member is apparently in fault contact with the shale of (12), indicating this contact to be the locus of the rhyolite dike intrusion 50-200

14) Conglomeratic member (13) grades southeastward into a series of dark gray schistose feldspathic grit, gray quartz-sericite schist, schistose quartzite, shale, and several relatively thin conglomerate beds. The grit tends to be rather friable and flaggy (Plate XXXI). In the vicinity of the Mercuria and Gold Creek cinnabar deposits, this series shows extensive sericitization and bleaching; on Alder Creek it includes about 100 feet of chloritic schist. The conglomerate contains considerable shaly material and rather abundant subangular to rounded pebbles of rhyolite which closely resembles the Red Rock rhyolite. Microscopically, the typical rhyolite of these pebbles consists of a finely crystalline groundmass of quartz and feldspar with sparse phenocrysts, up to 2 mm. in diameter, of quartz and orthoclase; the quartz phenocrysts are corroded and embayed, and the orthoclase forms subhedral crystals. Traversing the rock are veinlets of fine-grained quartz which shows wavy extinction, as does the quartz of the phenocrysts. The beds of member (14) prevailingly

PLATE XXXII. Looking northwestward at northeastward-trending quartz reef in fault zone between Red Rock rhyolite and member 15 of Alder series.

strike N. 30°-65° E. and dip 70°-85° SE. Secondary cleavage, observed at a few places, indicates that the top of the section is towards the southeast. A fault that strikes northeastward and dips 30°-45° NW. terminates this member against Red Rock rhyolite on the southeast..... 5,300±

Southeastward from this medial mass of Red Rock rhyolite, the Alder series continues. Within the area mapped on Plate XXII, the contact between rhyolite and sedimentary rocks is obscured by talus and soil, but north of Gold Creek, it appears as a fault whose fissure is occupied by a vein of jaspery quartz veined with white quartz. This jaspery vein, which locally forms a reef 150 feet high (Plate XXXII), indicates that the fault strikes N. 35° - 45° E. and dips 70° SE.

(The following observations regarding members (15) to (44), inclusive, apply to the section exposed in the southeastward-trending canyon that heads a short distance north of Red Rock and joins Slate Creek at a point 1/4 mile below the Rattlesnake quicksilver property).

15) The first member exposed southeast of the rhyolite, within the area mapped on Plate XXII, is a belt of rather massive dark gray to black rock whose lamination strikes N. 60° E. and dips 70° - 85° SE. Its contact with the rhyolite is obscured by talus.

Much of the dark-gray portion of this member is densely mottled with lenticular black spots, up to 4 mm. in length, which prove to be flakes of altered shale. Microscopically, the rock is seen to be extensively altered to chlorite and calcite; abundant sericite, finely divided grains of quartz and magnetite, a few lath-shaped crystals of a cloudy mineral re-

sembling feldspar, and sparse augen of pinkish secondary calcite, up to 6 mm. in diameter, are present. The sericite particles, particularly, show parallel arrangement.

A minor portion of this member is massive, dense, fine-grained black rock with scattered round to eye-shaped quartz grains which range up to 1 cm. in diameter. Microscopic examination of this rock reveals a mineral composition similar to that of the main portion, except for much less sericite and calcite and more abundant magnetite, quartz, and chlorite.

Apparent thickness of (15) 225

16) Soil covered; forms low saddle on adjacent ridges 50

17) Slabby, thinly laminated gray to brownish-gray grit. This grit is composed mainly of rounded to subangular grains of quartz, up to 2 mm. in diameter but generally smaller, together with slivers of dark gray slate, in fine-grained muscovitic cement. The longer dimensions of the grains are parallel to the lamination and bedding 425

18) Like (17) but much finer grained..... 40

19) Alternating shaly gray laminated grit and quartzite. Cross bedding indicates that the top side is northwest..... 100

20) Grayish-brown quartzite..... 15

21) Slabby schistose grit 10
A dioritic dike, approximately 450 feet wide, occurs between members (21) and (22).

22) Platy, fissile, brown schist consisting of quartz, sericite, and sericitized slivers of slate..... 10

23) Thin-bedded, slabby, cross-bedded gray quartzite with shale partings which are less prominent southeastward..... 250

24) Like (23), but with less shale..... 75

25) Thin-bedded, cross-bedded gray quartzite with a few shaly partings and a white 10-foot reef-forming member 10 feet from contact with (24) 50

26) Cross-bedded, fine grained gray quartzite grading into thin-bedded quartzite that alternates with gray shale. Cross-bedding shows the upper side to be on the northwest..... 100

27) Thinly laminated micaceous slate forming gradational contact with (26)..... 10

28) Thinly laminated, fine-grained, irregularly pitted micaceous schist, characteristically mottled with long, thin irregular lenses of limonite..... 2

29) Moderately fissile, mediumly fine-grained micaceous gray grit with some particles of shale; inter-bedded with numerous thin layers of brown quartzite and intruded, parallel to the lamination, by a diorite-porphyry dike 40 feet wide..... 65

30) Poorly laminated muscovitic grit, locally quartzitic; grains mainly of well-rounded quartz, less than 1 mm. in diameter; weathered surfaces splintery and of brown-ish-gray to dark-gray color; dips 55° NW..... 75

31) Medium-bedded, medium-grained quartzite, weathers brownish colored. Contact with (30) is a fault that strikes N.35° E. and dips almost vertically..... 60

32) Shaly sandstone with good fracture cleavage which indicates that the northwestern side went relatively up 15

PLATE XXXIII. Quartzite reef of member 35, Alder series.

33) Quartzite like (31) 10

34) Platy sandstone forming saddles on adjacent ridges..... 20

35) Medium-grained white quartzite, in beds 2-3 feet thick, sparsely veined with quartz stringers; weathers to a prominent brownish colored reef (Plate XXXIII).. 50

36) Moderately laminated, pebbly, micaceous gray grit; pebbles, which consist mainly of coarse angular to splintery shale and quartzite, range up to 4 inches in length 75

37) Coarse-grained, pebbly, prominent reef-forming, gray quartzite; forms gradational contact with (36). Cleavage indicates that the northwestern side went relatively up 10

38) Massive grayish-green chloritic schist..... 15

39) Medium to thin-bedded, medium-grained, cross-bedded, reef-forming, gray quartzite; contains small sparsely disseminated pyrite metacrysts and a few small spots of copper stain; strikes N. 60° E. and dips 56° NW. (Plate XXXIV-A)..... 30

40) Well-laminated sandy to gritty pale-brown shale; contains flakes of shale together with grains of quartz and jasper up to 2 mm. in diameter; cross bedding shows top side to be towards the northwest; forms gradational contact with (41)..... 25

41) Thinly laminated dark gray to purplish gray phyllite. Shows considerable crenulation and a few specularite-bearing sandstone members about 175 feet

PLATE XXXIV-A. Quartzite reef of member 39, Alder series.

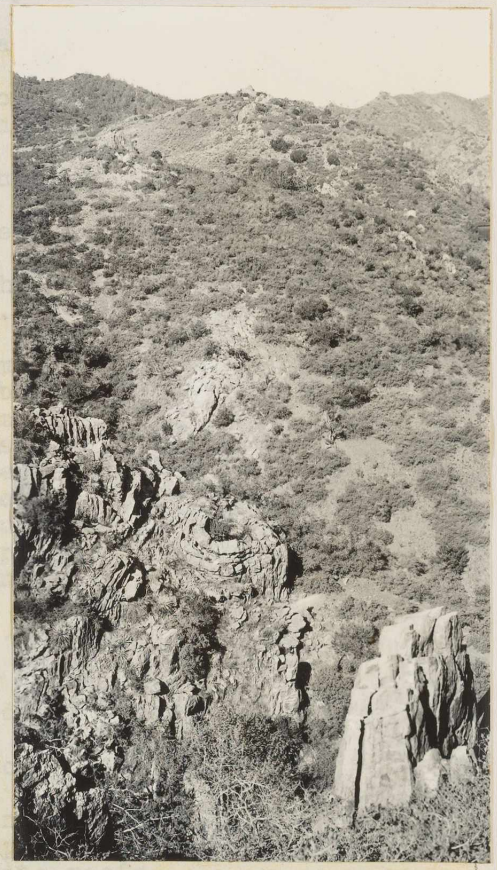

PLATE XXXIV-B. Looking southwestward at squeezed quartzite reef, member 44, Alder series.

from (40). Weathers slabby to splintery. Intruded, a few feet from (40) and parallel to lamination, by a 25-foot dike of diorite porphyry..... 750

42) Rather massive fine-grained gray quartzite, extensively veined with quartz stringers and somewhat crenulated; weathers shiny brownish gray to faint purplish gray and forms prominent reef which strikes N. 60° E. and dips 70° - 85° NW. Contact with (41) not exposed..... 60

43) Covered by talus but shows abundant shaly float..... 50

44) Thin-bedded, fine to medium-grained, purplish- to brownish-gray quartzite with some thin shale partings. Extensively veined with stringers of white quartz which locally contains abundant specularite. This member shows crenulations of broad amplitude and appears to be folded into a sharp syncline. Forms reef locally more than 50 feet high..... 25

Some two miles farther east, in the vicinity of the Ord group of quicksilver claims, quartzite reefs (42) and (44) show considerable faulting and folding and apparently represent the upper portion of a closely appressed anticline. The quartzite reefs lens out along the strike (Plate XXII), due probably to faulting. Important quicksilver deposits are localized along this zone of disturbance.

45) Faulted against (44) is a belt principally of slate with some phyllite. Thin lenses of quartzite locally occur along its southern margin. Some 800 feet south of the Rattlesnake property, this slate belt contains an infaulted wedge, approximately a mile long by 500 feet

PLATE XXXV-A. Looking southwestward up Slate Creek at quartzite reefs in Alder series in the vicinity of Ord group of quicksilver claims.

PLATE XXXV-B. View from north slope of Mt. Ord across Slate Creek Canyon showing quartzite reefs in Alder series.

wide of brownish-gray gritty beds. The slate, which strongly resembles members (1) and (12), is thinly laminated, mostly parallel to the original bedding, and weathers into large slabs. The color, which is dark purplish and hematite red in the vicinity of the quicksilver deposits on the northern side of Slate Creek, ranges through pale buff to various shades of gray southeastward. Microscopically this slate consists of rounded to angular grains of quartz, generally less than 0.1 mm. in diameter, stratified within a hematitic, clayey cement. Thickness of (45) ..... 3,500±

46) Faulted against the slate of (45) on the southeast is a belt of dark-gray to purplish-gray shale which is similar to (45) but more massive and locally gritty..... 2,600-4,000

47) Low reef of medium-grained to pebbly dark-gray to purplish-gray quartzite which crops out, as indicated on Plate XXII, for a length of about 1½ miles, cut out by strike faulting eastward; dips 80° N.; cross-bedding indicates that top is to north..... 150

48) Slate similar to (45) 200

49) Prominent reef-forming coarse-grained grayish-white quartzite; dips 80° N 125

50) Slate like (46), grading into phyllite southward..... 1,000+

51) Southward from (50) the phyllite grades into grayish-white to reddish quartz-sericite schist and schistose grit. This belt is intruded by many dikes of porphyritic pyroxenite, most of which strike east-northeastward, parallel to the schistosity. Approaching the Mt.Ord pyroxenitic stock, the member shows more intense metamorphism, characterized by foils of fine-

grained quartz and sericite curved around quartz augen which range up to 0.2 inch in diameter. Exposures here (altitude 5,000-6,300) are considerably mantled with soil which supports a dense growth of brush and timber..... 4,000

On the south and southeast, (51) is limited by the Mt. Ord pyroxenite intrusion as shown on Plate XXII.

Deadman quartzite, Maverick shale, and Mazatzal quartzite: In the northern portion of the Mazatzal Mountains the Red Rock rhyolite is unconformably overlain by the Deadman quartzite, succeeded by the Maverick shale and Mazatzal quartzite, which make up the high main ridge from North Peak to Cactus Point (Plates XXI and XXIV). The general features of these strata have been described on pages 102-112.

As indicated at the head of Maverick Basin (pages 194, 214 and Figs. 3 and 4), the Deadman, Maverick, and Mazatzal formations were probably intruded by the pre-Cambrian granite in the northwestern part of the area. They do not appear in the central segment of the range. In the southern portion, at Four Peaks, the Maverick shale and Mazatzal quartzite (Plates XII-B, XXXVII, and XXXIX) occur as a roof pendant of the pre-Cambrian granite batholith (Plate XXIII), but the Deadman quartzite is not exposed.

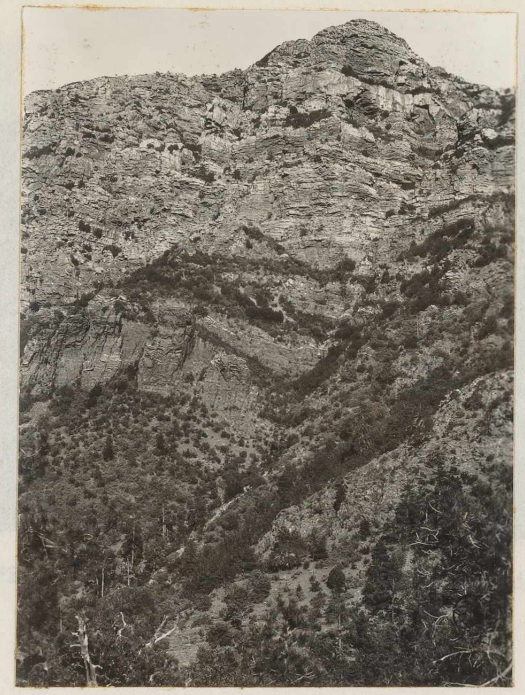

PLATE XXXVI-A.
Mazatzal quartzite in cliff 1,150 feet high resting on Maverick shale which forms slopes, west side of Mazatzal Peak.

PLATE XXXVI-B. Looking north at Mazatzal quartzite on northwestern side of Barnhardt Canyon.

PLATE XXXVII-A. Mazatzal quartzite forming bluffs 1,000 feet high on western side of Four Peaks.

PLATE XXXVII-B. Microphotograph of Mazatzal quartzite from Four Peaks. Crossed nicols, 28 diameters.

Above the Mazatzal thrust (pp. 141-142), the Deadman, Maverick and Mazatzal formations have been extensively dislocated by folding and faulting, but beneath it their sequence remains undisturbed. Their most complete succession appears on the eastern side of Maverick Basin (North Fork of Deadman Creek, near C-C', Plate XXI). Here the canyon wall slopes from an altitude of 6,500 to 3,900 feet in a distance of 1/2 mile and affords the following section:

Section on eastern wall of Maverick Basin

Formation	Features	Thickness in feet
Mazatzal quartzite	Top of spur; altitude 6,500 feet.	
	1) Quartzite, hard, vitreous, fine-grained, cross-bedded; beds 1 foot or less thick and ripple-marked.....	250
	2) Quartzite, hard, vitreous, fine-grained, cross-bedded;beds 2 feet or more thick	225
	3) Quartzite like (2) but coarser and less vitreous.....	75
	4) Quartzite, hard, medium- to coarse-grained, prevailingly cross-bedded; grayish-brown, weathering brownish; beds mostly 2-6 feet thick and cliff-forming.....	300

	5) Quartzite similar to (4) but fine-to medium-grained, more vitreous, and locally cross-bedded; some beds weather hackly	210
	6) Quartzite, hard, fine-grained, brownish-gray, weathering dark brown; beds 2 feet thick near top, grading to less than a foot thick in lower portion..	240
	(Total Mazatzal quartzite).....	1,300
Maverick shale	7) Shale, thin bedded, fine grained, dense, gray; locally ripple marked and micaceous on bedding planes; contains alternating sandy to quartzitic beds in upper few feet	800
Deadman quartzite	8) Quartzite, hard, fine-grained, cross-bedded, weathers reddish-brown; beds 1/2 to 1 foot thick; forms bluff.....	75
	9) Quartzite, hard, fine-grained to pebbly, thin-bedded. Bedding planes marked by thin layers of maroon shale containing small flakes of muscovite; weathers light gray and forms bluff.....	15
	10) Conglomerate of small rounded pebbles of rhyolite and quartz in a siliceous cement.....	1/2-2
	(Total Deadman quartzite).....	92

Red Rock rhyolite, upper portion somewhat oxidized.

The following section is present at North Peak:

Formation	Features	Thickness in feet
Mazatzal quartzite	1) Top of North Peak, altitude 7,449. Faint bluish-gray to white quartzite, for the most part fine-grained but containing cross-bedded layers of relatively coarse grain.....	100
	2) Irregular bed of conglomerate: Oval pebbles, to one inch in diameter, of white quartz, red jasper, rhyolite, and slate, in an arkosic cement.....	1
	3) Similar to (1) but generally coarser grained.....	139
	4) Conglomerate bed like (2).....	3
	5) Massive, cliff-forming coarse-grained gray quartzite with some altered feldspathic grains.....	102
	6) Similar to (5) but more brownish in color.....	25
	7) Pebbly red-brown quartzite with numerous cross-bedded layers.....	80
	8) Similar to (7) but more vitreous, finer grained, and thinner bedded. Contains relatively darker lenses and bands up to 2 inches wide. A few argillaceous strata, up to 3 inches thick, in	

	lower 150 feet. General color brownish-gray to red-brown	250
	9) Massive, medium to fine-grained cross-bedded vitreous red-brown to grayish-brown quartzite; weathered surfaces sandy....	150
	10) Massive, cliff-forming red-brown quartzite with some fine to coarse-grained dark-red layers. Contains small pebbles of white quartz, red jasper, feldspar, and slate. Includes a few strata of ripple-marked, spotted maroon shale up to about 10 inches thick	100
	(Total Mazatzal quartzite).....	950
Maverick shale	12) Gray and dark-gray to maroon shale.....	400
	13) Shale like (12) but largely maroon with light-gray diffusion spots. Lower portion contains a few thin beds of gray quartzite. Base characteristically ripple marked and micaceous	100
	(Total Maverick shale).....	500
Deadman quartzite	14) Hard, fine to medium-grained, thinly stratified, cross-bedded grayish-brown to white quartzite; forms cliff. Contains a few feet of shaly, ferruginous, locally micaceous ripple-marked beds at the top	30

15) Hard, fine to medium-grained, thinly-stratified, cross-bedded reddish brown quartzite; forms cliff 55

16) Massive red shale with rounded pebbles of rhyolite..... 5
Total Deadman quartzite..... 90

Red Rock rhyolite, deeply oxidized.

City Creek series: (See pages 112-117).

Diorite porphyry: Dikes of diorite porphyry, described on pages 114, 117, intruded the Yaeger greenstone, Alder series, and City Creek series at many places. Most of them, however, are too narrow for expression on maps of the scale of Plates XXI and XXII.

Mt. Ord pyroxenite: The Mt. Ord pyroxenite, which crops out only in the central portion of the Mazatzal Range, has been described on pages 118-120.

Granite: Granite constitutes more than half of the Mazatzal Mountains area. In the northern portion of the range it crops out over a large area on the Mazatzal Esplanade, west of the main ridge (see Plate XXI), and as a small area southeast of North Peak (Plate XVI-A), beyond the eastern limit of Plate XXI. In the southern part of the area it forms the bulk of the range from Mt. Ord to the Salt River.

This formation includes several varieties or phases whose detailed study and separation are beyond the scope of the present problem. They appear, however, to have been

intruded from a common source during one general period at the culmination of the Mazatzal Revolution (page 145).

Northern portion of range: On the western side of the range, north of Latitude 34°, the granite is unconformably overlain by remnants of Cambrian sandstone, Devonian limestone, Tertiary gravel, and Tertiary volcanic flows. It intrudes Yaeger greenstone on the north and Red Rock rhyolite on the southeast. Its contact with the Red Rock rhyolite is particularly well exposed in Maverick Basin where the granite has a fine-grained border phase "frozen" to the rhyolite and contains inclusions of rhyolite up to 10 by 6 feet in size. Near the head of this basin a tongue of the granite 300 feet wide intrudes the rhyolite as sketched in Figure 3, page 210. About 3/4 mile farther north a similar tongue of granite intruding the rhyolite is separated from the Mazatzal quartzite by a width of only a few hundred feet of talus. The quartzite here is extensively silicified and veined with quartz stringers which in the Maverick fault zone (page 214) form a prominent quartz lode that is traceable for some 7 miles farther southwestward. This southeastern contact of the granite, along the North Fork of Deadman Creek (Plate XXI), forms a rather straight line and appears to have been localized by the Maverick fault.

The granite of the small stock that intrudes the

PLATE XXXVIII-A. Granite slopes southeast of Four Peaks.

PLATE XXXVIII-B. Aplitic dikes intruding Maverick shale at Four Peaks.

Yaeger greenstone southeast of North Peak, beyond the eastern limit of Plate XXI, is similar to the granite of the northwestern part of the range.

Finer-grained phases, weathering pinkish or pale reddish brown, are locally common, as in the vicinity of the Mazatzal trail east of Knob Mountain (Plate XXI).

Southern portion of range: Granite intrudes the Mt. Ord pyroxenite on the southeastern slopes of Mt. Ord and, forming most of the range from there to the Salt River, constitutes an area 24 miles long by a maximum of 17 miles wide. It is strongly jointed in two directions of which one strikes N. 25° W. with a dip of 75° NE., and the other strikes N. 40° E. with a dip of 75° SE.

In general, this granite is of similar appearance and identical mineralogic composition to the granite of the northwestern part of the area. Southward it is predominantly of coarser texture, with orthoclase phenocrysts ranging up to 2 inches in diameter. Aplitic phases occur prominently in the area northeast of Four Peak Pass.

The granite of the southern part of the area has a roof pendant of Maverick shale and Mazatzal quartzite at Four Peaks (Plate XXIII) and includes numerous, mostly small, masses of schistose, altered rock,

PLATE XXXIX. Part of Four Peaks roof pendant. Rock is contorted Mazatzal quartzite, dipping steeply eastward.

particularly in the area extending for 3½ miles east of Four Peaks. Here are notable areas of medium-grained hornblende diorite which appear to be border phases of the granite, although there is a possibility that they represent a separate intrusion. Microscopically, this rock is composed essentially of kaolinized oligoclase and sodic labradorite together with chloritized hornblende and a little interstitial orthoclase. Five miles east of Four Peaks the granite unconformably underlies Apache strata. Microscopic examination shows this pre-Apache granite to be mineralogically identical to the granite of the northwestern part of the range.

Pine Mountain porphyry: The Pine Mountain porphyry occurs sparsely as dikes at various places in the Yaeger greenstone and Alder series and is prominent only in the vicinity of Pine Mountain, in the central part of the range (Plate XXII). This formation has been described on pages 123-126.

Apache group: In the southeastern portion of Mazatzal Mountains, in the vicinity of Roosevelt dam, Apache strata unconformably overlie the pre-Cambrian granite throughout an area of several square miles (Plates I and XXIII). In places they are overlain by Middle Cambrian Troy Sandstone.

Ransome [141] measured the following section of the Apache beds in the canyon of Salt River at Roosevelt dam:

1.	Vesicular basalt flow.....	50
2.	Mescal limestone: Hard, rather thin-bedded cherty dolomitic limestone.....	300
3.	Dripping Spring quartzite: Fine-grained varicolored arkosic quartzite, much of it with dark-red and gray banding; partings between beds not distinct; ripple marked.....	500
4.	Barnes conglomerate: Pebbles mainly of white quartz and hard vitreous quartzite generally less than 4 inches in diameter, in abundant sandy matrix.....	20
5.	Pioneer shale: maroon shale grading into hard arkosic sandstone below. Intruded by diabase sill probably 800 feet thick.....	255
6.	Scanlan conglomerate: Well-rounded pebbles, up to 9 inches in diameter, of white quartz, brown fine-grained vitreous quartzite, and a little red jasper, closely packed in a matrix of dull red-brown coarse sandstone.....	30
7.	Coarse-grained reddish granite; red tint generally fades to gray	

141 Ransome, F.L., Some Paleozoic sections in Arizona and their correlation: U. S. Geol. Survey Prof. Paper 98, pp. 149-152, 1916.

PLATE XL-A. Tapeats sandstone resting on City Creek series and overlain by Devonian limestone (gray) in upper left. Northern margin of Mazatzal Esplanade in left background.

PLATE XL-B. Ridge of gently northeastward-dipping Troy sandstone in background, Tertiary gravel in foreground. Southeastern portion of Mazatzal Mountains.

a short distance below the contact.

The quartzite pebbles of the Scanlan and Barnes conglomerates are lithologically identical to material from the Mazatzal quartzite. Probably they were derived from some nearby portion of the ancient Mazatzal Mountain range; their large size indicates that they did not travel far.

As stated on page 78, the Apache section below the Troy quartzite or sandstone is regarded as of Unkar type. It is separated in age from the Mazatzal quartzite by an interval that included the Mazatzal Revolution and extensive peneplanation.

Paleozoic formations

Distribution: In the northern part of the Mazatzal Mountains are several small erosional remnants of Cambrian Tapeats sandstone and Devonian Jerome limestone. Some of these remnants are on the northern margin of the Mazatzal Esplanade, as indicated by Plate I and in part by Plate XXI, and others (Plate I) are at the northern foot of the range, at elevations 1,600 to 2,300 feet lower than those on the Esplanade.

At the southeastern foot of the range, near Roosevelt dam (Plates I and XXIII), Cambrian Troy sandstone, Devonian Martin limestone, and Mississippian

Tornado limestone (page 128) occupy an area of several square miles.

Tapeats sandstone: The basal Paleozoic formation in the northern part of the area consists of dull red-brown cross-bedded friable pebbly sandstone, generally conglomeratic at the base and 80 to 100 feet thick.

Where the main trail reaches the Mazatzal Esplanade, 2¼ miles northwest of North Peak, a small remnant of this formation, resting upon the pre-Cambrian granite and Yaeger greenstone (Plate XXI), consists of a basal conglomerate, about 50 feet thick, grading upward into thick-bedded pebbly pale-red brown sandstone. The conglomerate is composed mainly of smooth ellipsoidal pebbles, up to eight inches in diameter, of Red Rock rhyolite, coarse and fine-grained granite, and a little quartzite, in a sandy cement. This conglomerate, which is lacking in the outcrops farther north, suggests the proximity of a land mass during lower Paleozoic time.

The occurrence of large angular blocks of this sandstone on the flat-topped ridges southwest of Pine Mountain (page 157) indicates that the basal Paleozoic beds once covered that part of the range and were removed by erosion during Tertiary time.

The basal Paleozoic sandstone of the northern part of the Mazatzal Mountains is lithologically identical to sandstone occurring six miles farther north, in the Pine

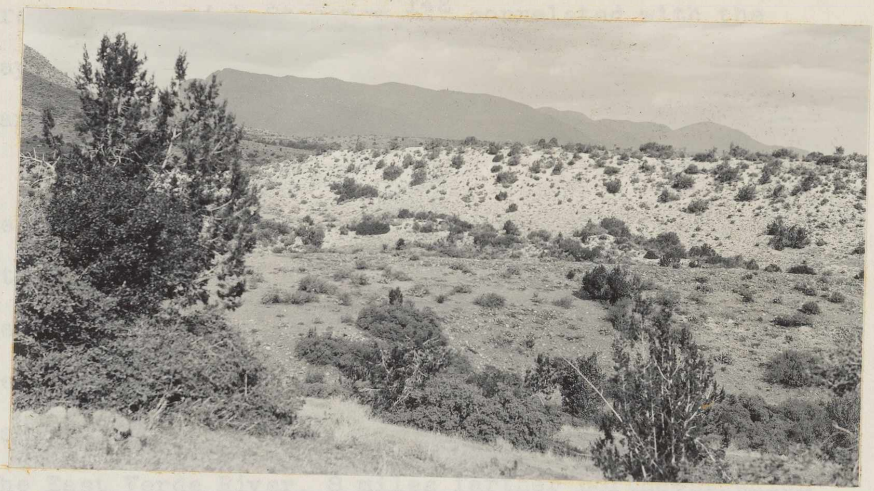

PLATE XLI-A. Tertiary limestone in Tonto Valley, north of lower Gold Creek. Northern portion of Mazatzal Range in background.

PLATE XLI-B. Distant view of Saddle Mountain whose volcanic succession rises high above the accordant-topped ridges of the Alder series.

Creek area, which Stoyanow [142] correlated with the Tapeats (Middle Cambrian) sandstone of the Grand Canyon section.

Jerome limestone: Remnants of thin to medium-bedded hard light-gray limestone overlie Tapeats sandstone in the northern portion of the Mazatzal Mountains area. Although yielding no fossils other than a few poorly preserved Spirifer fragments, this limestone is lithologically identical to the beds occurring near the East Verde River, 8 miles farther northeast, which Stoyanow [143] correlated with the Devonian Jerome formation.

Tertiary rocks

Sedimentary beds: The Tertiary sedimentary beds that floor the Verde and Tonto valleys and in places extend high onto the Mazatzal Mountains are described on pages 130-135 and indicated in part on Plates XXI, XXII, and XXIII.

Volcanic rocks: (See pages 130-137 and Plates I, XXI, and XXII).

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142 Stoyanow, A. A., Correlation of Arizona Paleozoic formations: Geol. Soc. America, Bull., vol. 47, p. 462, 1936.

143 Stoyanow, A. A., work cited, pp. 497-500.

Carbonate-jasper formation: Extending northeastward across lower Alder Creek, southwest of Pine Mountain, is a zone, about 1/8 mile in maximum width, of yellowish dolomitic limestone with red jasper (Plate XXII). It occurs as branching lenticular vertical veins within the Alder series and as overlying masses which appear to have been deposited on the surface.

In the veins, which pinch out 2 miles east of Longitude 111° 30', the dolomitic limestone includes broken fragments of jasper ranging from less than an inch up to more than a foot in diameter, together with some irregular bands of jasper; locally the whole is traversed with a network of white quartz veinlets. In places, the jasper contains finely disseminated pyrite. Within distances of a few hundred feet on each side of the main zone are several veins of the dolomitic limestone without jasper and a few thinner veins of jasper with little or no limestone. In the vicinity of these veins as well as of those of the main zone, the Alder rocks show strong chloritization and local staining by iron oxide. Within a distance of a few hundred feet downstream from the main zone are several bands, up to 10 or 20 feet thick, of hematitic, slightly pyritic iron formation in the Alder series.

The overlying masses, which are best exemplified by the bold outcrops in the walls of the canyon of Alder Creek, consist of alternating bands, from less than an

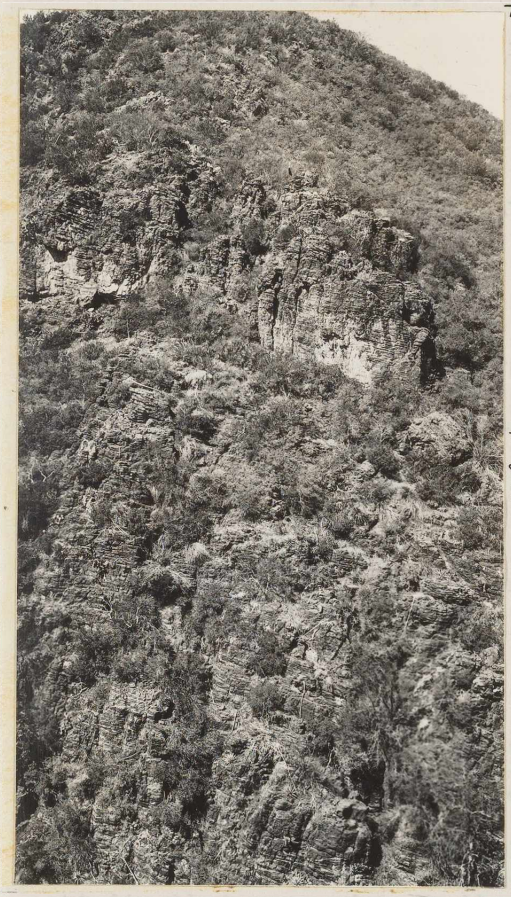

PLATE XLII-A. Carbonate-jasper formation resting unconformably upon Alder series.

PLATE XLII-B. Near view of (A), showing the resistant jasper layers.

inch to more than a foot wide, of the dolomitic limestone and jasper (Plate XLII). These banded masses lie, with low northwestward dip, upon a rugged erosion surface of the Alder series. Near their northern margins, particularly, they are transected by vertical brecciated zones which resemble the veins.

The jasper and carbonate material seems clearly to be of hydrothermal origin. Apparently the jasper was formed first, then brecciated, and later recemented by calcium-magnesium carbonate; further fracturing and silicification formed the veinlets of white quartz.

Ransome [144], followed by Lausen [145], regarded the jasper and dolomitic limestone as of pre-Cambrian age and occupying the axis of a compressed syncline or anticline. On the contrary, evidence of late Tertiary age for the deposit seems to be offered by its flat-dipping, undeformed masses which rest upon an erosion surface little different from the present topography. The material may represent a phase of the hydrothermal activity that gave rise to the quicksilver deposits of this immediate region.

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144 Work cited and U. S. Geol. Survey Prof. Paper 98, p. 157.

145 Lausen, Carl, and Gardner, E. D., Quicksilver resources of Arizona: Univ. of Ariz., Ariz. Bureau of Mines Bull. 122, pp. 63, 65, 1927.

Quaternary deposits

The mountain pediments, valley terraces, and flood plains are veneered in most places with ill-assorted, commonly unstratified gravel, sand, and silt from less than a foot to a few tens of feet thick. This alluvium is of local derivation and of Pleistocene and Recent age.

Structure

Structure in northern portion: In the northern portion of the range, the principal feature of structure is the Mazatzal thrust (pages 141-142). Above its sole the pre-intrusive rocks have been extensively dislocated and folded, but below it they are deformed only by broad folds and by faults of normal and tear types. The direction of overturning of the folds and the dip of the reverse faults indicates that the thrusting was northeastward.

On the map and cross sections of Plate XXI, the dominant structural units or blocks are designated by numerals. Blocks 1, 1-a, and 1-b lie below the Mazatzal thrust, and blocks 3, 4, 4-a, 5, and 6 are above its sole. Blocks 2, 2-a, 2-b, 2-c, and 2-d are interpreted as portions of the thrust mass which have been dislocated by normal faulting in reference to block 1.

PLATE XLIII-A. Looking southwestward into upper Maverick Basin along Maverick fault zone, near northwestern margin of block 2. M, Mazatzal quartzite; sh, Maverick shale; R, Red Rock rhyolite.

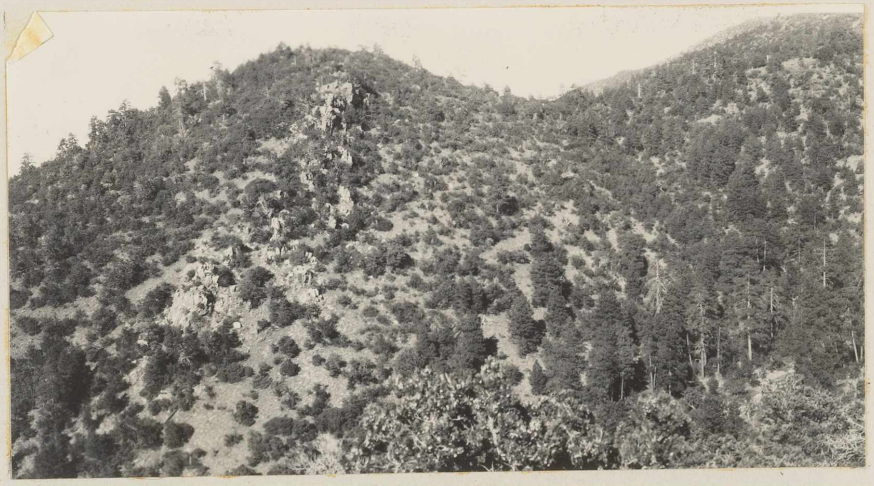

PLATE XLIII-B. View northeastward along Maverick fault zone in block 2 showing quartz reef mentioned on page 194.

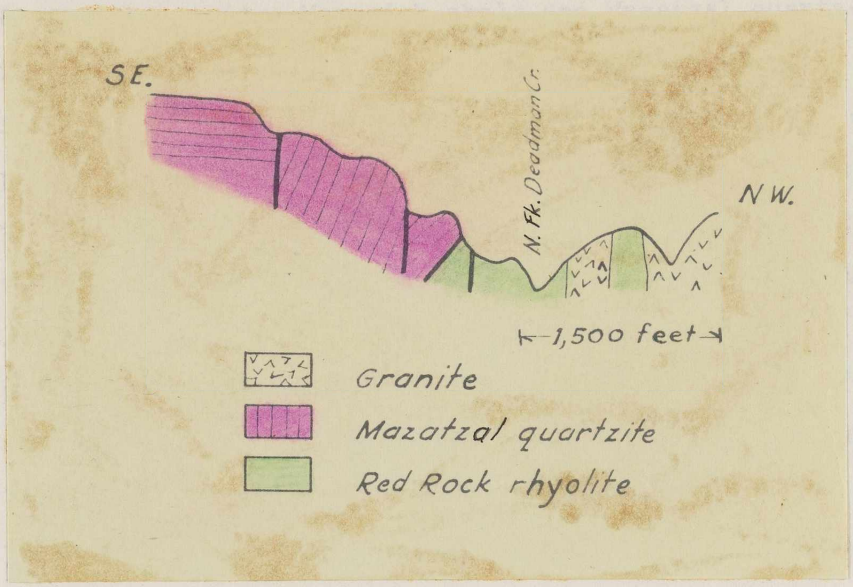

Figure 3. Sketch section showing relations near northern end of Maverick Basin.

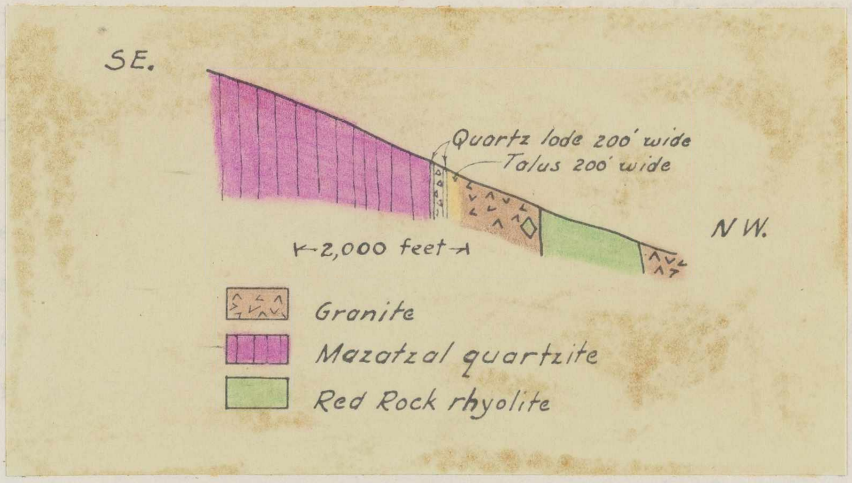

Figure 4. Sketch section showing relations at northern end of Maverick Basin.

Blocks 1 and 1-b consist of Red Rock rhyolite, Deadman quartzite, Maverick shale and Mazatzal quartzite. Southwest of North Peak their beds are gently flexed into a broad open syncline of low southwestward pitch. This southwestward pitch is in marked contrast to the prevailing northeastward pitch of the folds in the thrust masses. Southwest of the Club Ranch, block 1-b displays a broad, open anticline of northeastward pitch. Blocks 1 and 1-b are separated at the South Fork of Deadman Creek by a northwestward-trending tear fault that shows a displacement of approximately 150 feet vertically and more than 200 feet horizontally. Block 1 is a horst between blocks 2 and 2-d.

Block 1-a, which consists of Red Rock rhyolite and flat-lying Deadman quartzite, has been dropped by normal faulting for approximately 100 feet in reference to 1. It is a horst between blocks 2 and 2-a on the northwest and 2-b on the southeast.

Blocks 2 and 2-a are complex thrust slices of Red Rock rhyolite, Deadman quartzite, Maverick shale, and Mazatzal quartzite which occur as a graben between Yaeger greenstone on the northwest and blocks 1 and 1-a on the southeast.

In block 2-a is exposed a faulted syncline (Plate XLIV and Fig. 5) that trends somewhat west of north. This radical departure from the trend of the regional

PLATE XLIV. Looking westward at syncline in block 2-a, north of North Peak. D, Deadman quartzite; sh, Maverick shale; gst, Yaeger greenstone. In right background are Paleozoic strata (P) resting on City Creek beds (C) and in fault contact with the greenstone.

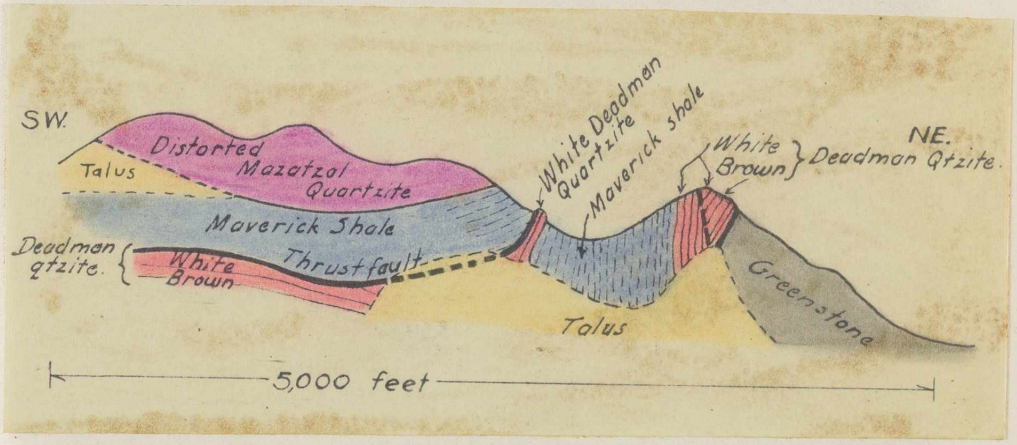

Figure 5. Sketch section through northeastern portions of blocks 2-a and 2, north of North Peak.

PLATE XLV. Folded Mazatzal quartzite in block 2, northwest of North Peak.

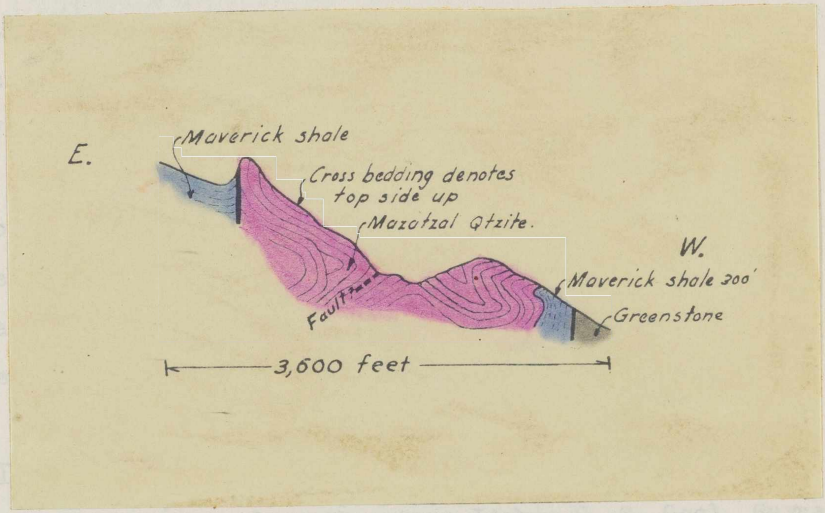

Figure 6. Sketch section of folds in Mazatzal quartzite of block 2, northwest of North Peak.

folding may have been caused by pre-existing, opposing structure that deflected the compressive forces. A like explanation was suggested by Mansfield [146] to explain the almost right-angled change in direction of the Rocky Mountain thrusts along the northern base of the Uinta Mountains.

The northeastern fourth of block 2 has undergone intense folding and faulting, as shown by Plate XLV and Fig. 6. This block has been depressed about 500 feet in reference to block 1-a, and its southwestern portion is intruded by the pre-Cambrian granite on the northwest. Its contact with the granite appears to have been localized by a southwestward continuation of the fault that separates it from the Yaeger greenstone on the northwest. In Maverick Basin, this fault formed a zone, two branches of which are shown on Plate XXI and Fig. 3. It is termed the Maverick fault zone.

Block 2-b presents a roughly triangular outcrop of Red Rock rhyolite, Deadman quartzite, and Maverick shale, separated by normal faults from blocks 1-a, 1, and 2-d on the west and from Yaeger greenstone on the east. Northeast of North Peak, it is overlain by a small

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146 Mansfield, G. R., Geography, geology, and mineral resources of part of southeastern Idaho: U. S. Geol. Survey Prof. Paper 152, p. 383, 1927.

PLATE XLVI. Thrust block 2-c of disordered Mazatzal quartzite (M) northeast of North Peak. Sh, Maverick shale; D, Deadman quartzite; R, Red Rock rhyolite.

XLVII-A

XLVII-B

XLVII-C

PLATE XLVII. Folds in Deadman quartzite (D) along eastern flank of range. A and B, upper Rock Creek; C, southeast of North Peak. Maverick shale (sh) is in fault contact on left; A and B do not appear on map.

PLATE XLVIII-A. Looking southwestward in canyon of South Fork of Deadman Creek at Deadman quartzite in northwestern limb of syncline (block 5) faulted against Mazatzal quartzite (M) of block 4-a.

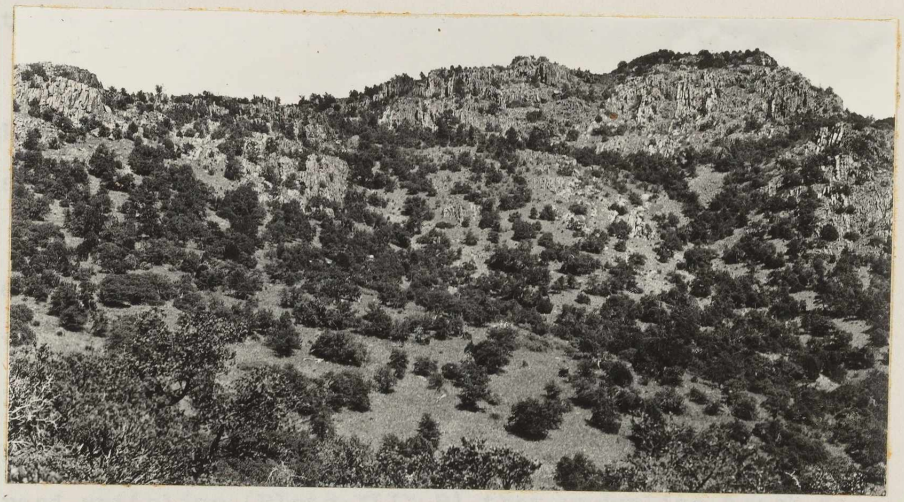

PLATE XLVIII-B. Northeastward view of same limb as shown in PLATE XLVIII-A.

thrust slice (2-c) of contorted Mazatzal quartzite.

Block (2-d), which consists for the most part of steeply eastward to almost vertically dipping Maverick shale, lies between block 1 on the west and block 2-b and Yaeger greenstone on the east. Along the western margin of block 2-d, the Deadman quartzite of block 1 has been steeply upturned, faulted, and folded (Plate XLVII).

Block 3 is a slightly crenulated thrust slice of Maverick shale and Mazatzal quartzite resting on block 1.

Block 4 is a thrust slice of Mazatzal quartzite resting on block 1 and separated from block 3 by a steeply southward-dipping reverse fault.

Block 4-a consists of Mazatzal quartzite thrust upon block 1-b and separated from block 4 by the tear fault in the South Fork of Deadman Creek.

Block 5 is made up of Deadman quartzite and Maverick shale, separated from blocks 4 and 4-a by a steeply southeastward-dipping reverse fault. These beds are folded into a gently northeastward-pitching closed syncline whose southeastern limb passes sharply into the broad anticline (Plate XLIX-B) that underlies block 6; these folds are overturned northwestward. The Deadman quartzite, which is seven or eight times thicker than the normal, may have been thrust to its present location from a place several miles farther southeast towards which it

PLATE XLIX-A. Looking eastward across ridge southeast of Club Ranch and west of South Fork of Deadman Creek. Shows syncline (block 5) of Deadman quartzite (D) and Maverick shale (sh) overridden by Red Rock rhyolite (R) of block 6.

PLATE XLIX-B. Sharp monoclinal fold in thick Deadman quartzite, South Fork of Deadman Creek.

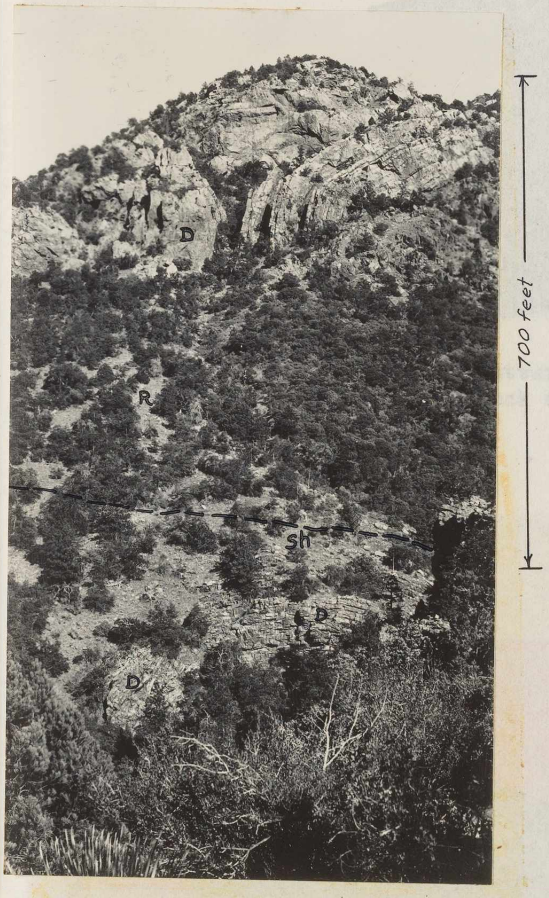

PLATE L. Looking eastward at Deadman quartzite and Red Rock rhyolite of block 6, thrust upon the Maverick shale and Deadman quartzite of block 5, $1\frac{1}{4}$ miles west of Mazatzal Peak. R, Red Rock rhyolite; D, Deadman quartzite; sh, Maverick shale.

PLATE LI. Looking north-northeastward at the slopes west of Mazatzal Peak (part of block 6).

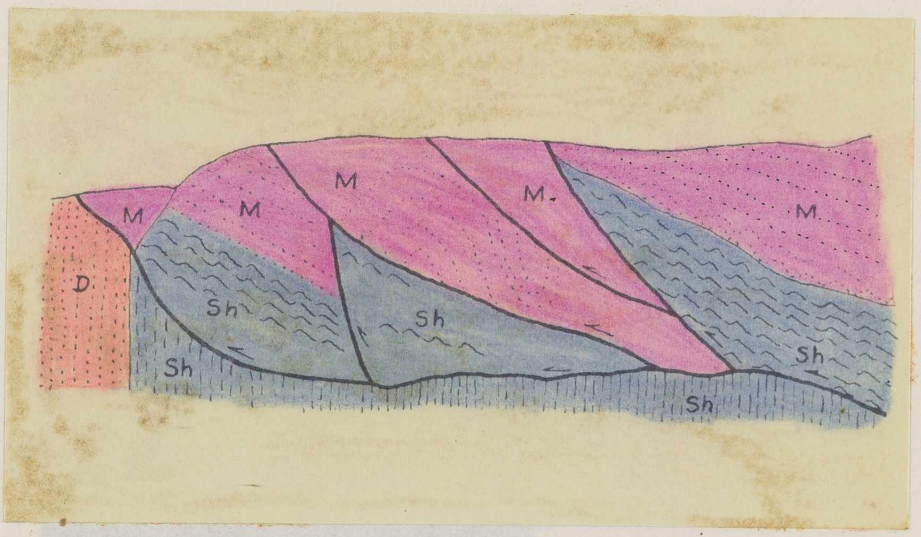

Figure 7. Diagrammatic sketch section of structural relations displayed in PLATE LI. Shows faulted and disordered Mazatzal quartzite (M) and Maverick shale (Sh) of block 6 thrust over Maverick shale and Deadman quartzite (D) in syncline of Block 5.

PLATE LII-A. Maverick shale showing drag folds from thrusting, west side of Mazatzal Peak.

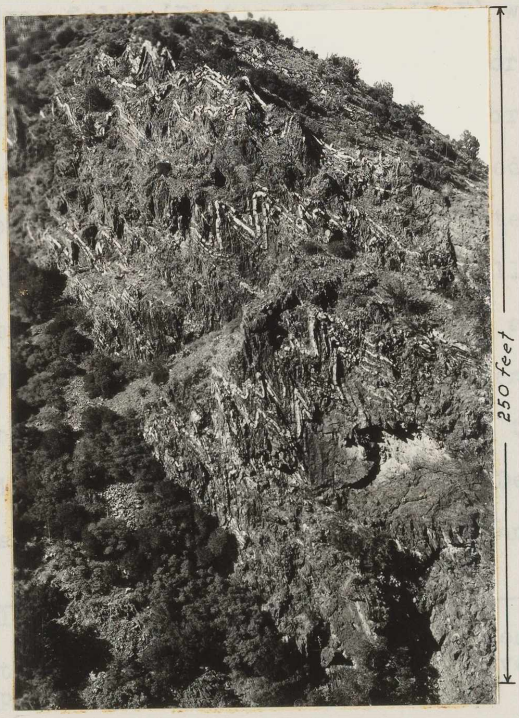

PLATE LII-B. Maverick shale showing drag folds from thrusting, Barnhardt Canyon.

progressively thickened during deposition.

Block 6, which includes Mazatzal Peak, Cactus Ridge, and Sheep Mountain, is a very large thrust slice of Red Rock rhyolite, Deadman quartzite, Maverick shale, and Mazatzal quartzite, overlying blocks 5 and 1-b. Its Deadman quartzite, like that of block 5, is 700-800 feet thick. Southeast and southwest of the Club Ranch, the Red Rock rhyolite of this block is intruded by the pre-Cambrian granite. Southeast of this ranch, the rhyolite is separated from the granite by a steeply southeastward-dipping reverse fault (Plate XXI) that is interpreted as having followed closely upon the intrusion. The strata of block 6 have been strongly affected by drag folds (Plates LII and LV-B) whose overturning indicates that the thrusting was northwestward. South and southeast of Mazatzal Peak is a broad, open, northeastward-pitching syncline, overturned northwestward. Its eroded, steeply dipping southeastern limb forms Cactus Ridge and Cactus Point (Plates LIII and LIV). A cross-section sketch of this syncline, as exposed on the North Fork of Deer Creek (Shake Tree Canyon), near the eastern base of the mountains and beyond the limits of Plate XXI, is shown in Figure 8. Here the Deadman beds show a slight discordance in dip that Ransome [147] attributed to

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147 Ransome, F.L., Some Paleozoic sections in Arizona and their correlation: U.S.Geol. Survey Prof. Paper 98, p. 158 and Fig. 13, 1916.

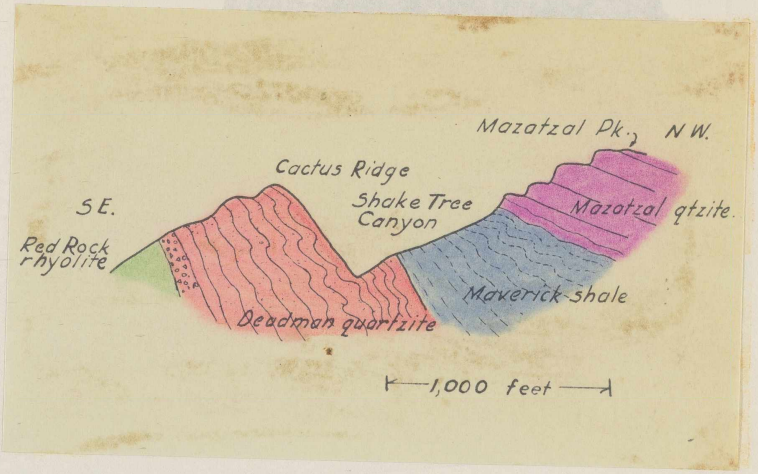

Figure 8. Sketch section through Cactus Ridge.

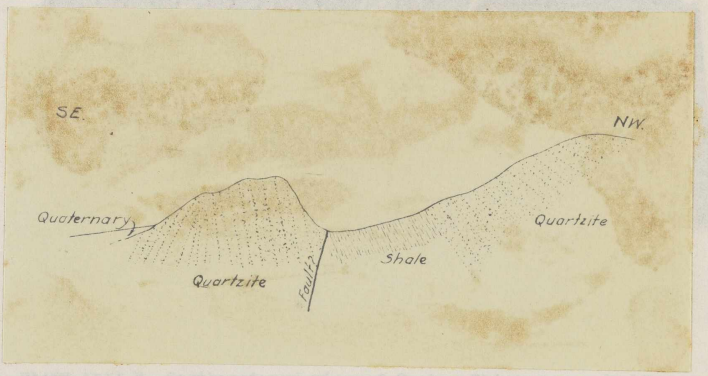

Figure 9. Ransome's sketch section through Cactus Ridge.
(From U. S. Geol. Survey Prof. Paper 98, Fig. 13.)

250 feet

PLATE LIII-A. Northeastward view of Deadman quartzite in Cactus Ridge, the upturned limb of the syncline shown in PLATE LIV.

500 feet

PLATE LIII-B. Southwestward view of Cactus Ridge; cross-bedding shows top side to be on right. Compare with Figure 9.

PLATE LIV-A. Syncline in thick Deadman quartzite east of Cactus Point, looking northeastward. Right-hand limb is Cactus Ridge.

PLATE LIV-B. Looking northeastward along same syncline as in (A), south of Mazatzal Peak. D, Deadman quartzite of Cactus Ridge; sh, Maverick shale showing drag folds; M, Mazatzal quartzite.

PLATE LV-A. Drag folds in lower part of Mazatzal quartzite, Four Peaks.

PLATE LV-B. Drag folds in lower part of Mazatzal quartzite, dying out upward; Barnhardt Canyon.

a sharp anticline, as illustrated in Figure 9. Detailed examination, however, reveals good tangential cross bedding that proves the top side of the beds throughout this section to be towards the northwest.

Structure in central portion: The Mazatzal thrust probably dips deeply beneath the middle segment of the range. Block 6, of the northern portion, terminates at the southeastern base of Sheep Mountain (Plate XXII) where a fault that strikes northeastward and dips 70° SE. separates it from red shale (member 1, page 170) of the Alder series. In the vicinity of Windsor's cabin, about 1½ miles beyond the northern limit of Plate XXII, this fault contact is followed by the deep canyon of Deer Creek.

Between Sheep Mountain and Mt. Ord the range consists of two blocks of the Alder series, separated by a fault block of Red Rock rhyolite. The northwestern block is intruded by an irregular body of Pine Mountain porphyry that trends northeastward, and the southeastern block is limited on the southeast by the Mt. Ord pyroxenite intrusion, which also trends northeastward. On the southeastern slopes of Mt. Ord, this pyroxenite is intruded by the pre-Apache granite.

The beds of the Alder series, which strike northeastward and dip steeply, have been dislocated by numerous bedding faults and deformed in places by minor folds.

Nevertheless, their somewhat symmetrical distribution and respective structural positions, as determined by cross bedding, conglomeratic layers and false cleavage, are such as to indicate that they occupy a broad closed syncline (Plate XXII, Section S-O) with gentle northeastward pitch. Northwest of Red Rock is a tear fault that probably was formed at the time of the folding. The parallelism of the intrusive bodies with the strike of the bedding indicates that they were emplaced after the folding. Their advent probably marked the culmination of the Mazatzal Revolution.

Structure in southern portion: The pre-Apache granite that intrudes the Mt. Ord pyroxenite on the southeastern slopes of Mt. Ord forms most of the southern portion of the range. It is strongly jointed in two directions of which one strikes N. 25° W. with a dip of 75° NE., and the other strikes N. 40° E. with a dip of 75° SE.

In the vicinity of Four Peaks, this granite includes numerous, mostly small, bodies of metamorphosed rock, largely of sedimentary origin. The high mass of Four Peaks is a roof pendant of Maverick shale and Mazatzal quartzite (Plate XXIII) whose beds strike northeastward, dip steeply southeastward, and have been strongly affected by drag folds (Plate LV-A) whose direction of overturn indicates northwestward thrusting.

Correlation of structural features: The northeastward-trending, subparallel folds, thrust faults, and steeply dipping reverse faults and the northwestward-trending tear faults are attributed to the compressive stresses that marked the Mazatzal Revolution and culminated with the intrusion of the diorite porphyry, Mt. Ord pyroxenite, and pre-Apache granite of central Arizona. These structural features do not involve the Apache, Paleozoic, and later rocks of this region. They affect rocks which, at the head of Maverick Basin and in Four Peaks, are intruded by the pre-Apache granite. The parallelism of the intrusive bodies with the regional structure, as exemplified in the central portion of the range (pages 117-126), indicates that their emplacement followed the folding. Furthermore, the above-mentioned folds and faults are identical to structures of known pre-Apache age which are present in the eastern Tonto Basin area (pages 271-276).

The northeastward-trending normal faults within the range find little expression in the topography, except where followed by stream courses. They are probably related to the Mazatzal Revolution.

Origin of the range: The Mazatzal Revolution doubtless gave rise to a gigantic northeastward-trending mountain range. This range comprised the land barrier (Mazatzal land) which, as Ransome and Stoyanow have shown (pages 71-72), existed

through late pre-Cambrian and a large part of Paleozoic time. The Tertiary Basin and Range faulting, which may have been localized in part by structural weaknesses inherited from the Mazatzal Revolution, cut this ancient mountain range at right angles into graben and horst blocks. The present Mazatzal Mountain range represents one of these horsts, between the Tonto-East Verde graben on the northeast and the less-definite narrow graben or fault zone of the lower Verde Valley on the southwest. This graben-and-horst relation is indicated by strong evidence.

Along the northeastern front of the range, north of North Peak, is a well defined fault (Plate I), referred to as the East Verde fault, that separates Tapeats sandstone and Devonian limestone on the north from Yaeger greenstone on the south. The base of the Tapeats here is at an altitude of 4,000 feet, which is 2,000 feet below the base of the Tapeats sandstone remnant on the Mazatzal Esplanade (Plate XXI). Hence there is a vertical displacement here of 2,000 feet, but some of it may be on unrecognized faults that find no expression in the steep, brushy greenstone surface. The East Verde fault is marked by a well-defined topographic break in the greenstone slopes, whereby it was traced with reasonable certainty for a distance of 8 miles. It is probably of late Tertiary age.

The contact of the Tertiary sedimentary beds with the older rocks along the northeastern foot of the range is a fault marked by a notch, 20 to 100 feet deep, on the ridges. In the gulches, it is generally obscured by talus, but in a few places is seen to dip 75° NE. It may represent a southeastward continuation of the East Verde fault.

Six miles northeast of Rye Creek, in the vicinity of Payson (Plate I), are numerous exposures of flat-lying Tapeats sandstone at altitudes of 5,000 feet or more, proving that the northeastern side of the Tonto-East Verde trough here was displaced 1,000 feet vertically. At the southeastern end of the Mazatzal Range, a series of step faults on the northeastern side of the trough have effected a vertical displacement exceeding 5,000 feet, as shown by the elevations of the Apache strata on the Sierra Ancha and at Roosevelt reservoir (Plates I and IV).

The Apache, Paleozoic and Tertiary beds in the southeastern portion of the range, in the vicinity of Roosevelt reservoir, are tilted at low to moderate angles northeastward. The main part of the range, however, does not appear to be tilted. At numerous places on its crest and high ridges are remnants of Tertiary sedimentary and volcanic beds which show only initial dips. Furthermore, the remnants of Paleozoic strata upon the Mazatzal Esplanade also lie flat.

Little evidence was obtained for the graben nature of the lower Verde Valley, downstream from the mouth of the East Verde River, because the formations exposed there consist almost entirely of granite overlain by Tertiary sedimentary and volcanic rocks in which no key beds have been recognized. The late Tertiary beds in the lower part of the valley have been faulted and tilted (Plate XIX-A). The steep spur-ends that mark the western limit of the Mazatzal Esplanade are suggestive of a dissected fault-line scarp, but they might also be due to lateral planation by the Verde River. The lower Verde Valley, which pursues an irregular S. 30° W. to S. 40° E. course, may, as Bryan [148] suggests, have been localized by post-Gila formation faulting and by the position of the lava beds. Its tributaries have long, rather straight southwest and southeast courses, apparently governed largely by fault lines.

The southern end of the range is marked by the Salt River whose course is governed in part by jointing and in part by post-dacite faulting.

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148 Written communication.

CHAPTER II. PINE CREEK AREA

Geography

Situation and extent

The Pine Creek area, which extends southward along Pine Creek from the base of the Mogollon Escarpment to a point 6 miles north of the Mazatzal Mountains, is 10 miles long and 9 miles wide. The area is accessible by the Payson-Pine road, which crosses its northeastern corner, and by a branch road that leads to Natural Bridge.

Climate, vegetation, and population

At Natural Bridge (altitude 4,990) the maximum recorded temperature is 103°, the minimum is 6°, and the average annual precipitation exceeds 24 inches. The southward-sloping mesas flanking Pine Creek Canyon range up to more than 6,000 feet in altitude and receive somewhat heavier precipitation. They are fairly well mantled with soil which supports scattered groves, chiefly of juniper and scrub pine, interspersed with areas of grass and shrubs. Oak and thorny brush predominate on the lower slopes. The irrigated, thinly soil-mantled travertine terrace at Natural Bridge is intensively farmed. Here is

PLATE LVI. Natural Bridge over Pine Creek. Rock is travertine.

situated a summer resort that contains the only local population.

Geomorphology

The central feature of the Pine Creek area is a southwestward-trending ridge of steeply northwestward-dipping Mazatzal quartzite that crops out through essentially flat-lying Paleozoic and Tertiary beds. Erosion has stripped away part of the Tertiary beds and dissected the pre-lava Tertiary peneplain or pediment that here slopes southward from the base of the Mogollon Escarpment. This dissection has been accomplished largely by the drainage system of Pine Creek, a perennial tributary of the East Verde River with a rather straight course to the south-southwest. This creek has carved a narrow canyon, locally 1,200 feet deep, through the northern end and along the southeastern contact of the quartzite ridge. Springs issuing from the Carboniferous limestone at a point 5 miles downstream from Pine have deposited a large terrace of travertine that extends across the inner gorge of the canyon, forming the picturesque arch known as the Goodfellow Natural Bridge.

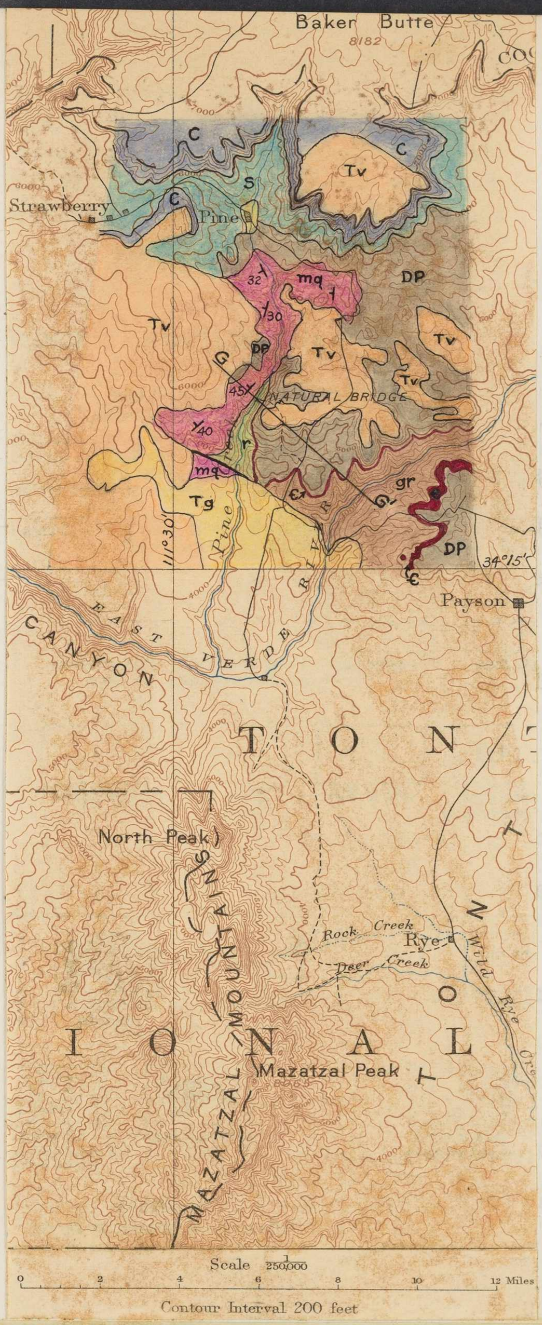


PLATE LVII.
Geologic map of
Pine Creek area

E X P L A N A T I O N

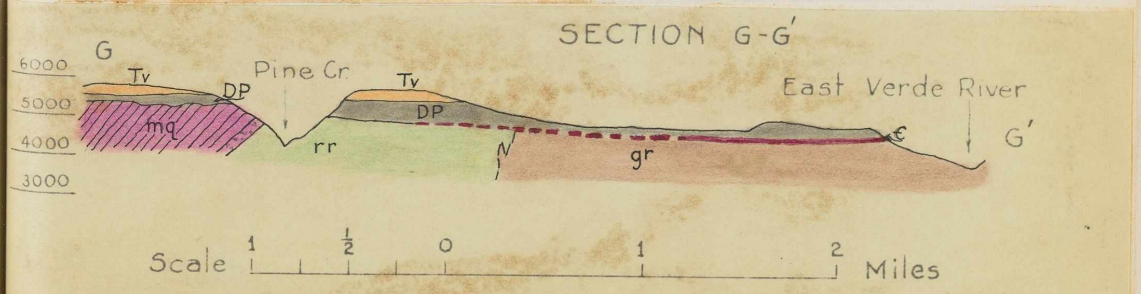
Tertiary
- Tv — Volcanic rocks
- Tg — Gravel, sand, and silt

Permian
- C — Coconino sandstone
- S — Supai formation

Devonian-Pennsylvanian
- DP — Limestone

Cambrian
- Ꞓ — Tapeats sandstone

Pre-Cambrian
- gr — Granite
- mq — Mazatzal quartzite
- r — Red Rock rhyolite
- Fault



Geology

Status of investigation

In 1912, Ransome [149] made a brief reconnaissance of the Natural Bridge area, incidental to a general study of the conditions of Paleozoic sedimentation in Arizona. He recognized that the pre-Cambrian quartzite rose as a monadnock in the Paleozic strata.

During parts of 1920 and 1921, the writer mapped this area for the Geologic Map of Arizona and measured stratigraphic sections [150] of the quartzite.

Four days were spent in the Pine Creek area for the present investigation, in order to review the stratigraphy and structure of the quartzite and to correlate the underlying formation.

Formations represented

The Pine Creek area is made up of pre-Cambrian rocks overlain by Paleozoic strata and Tertiary sedimentary

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149 Ransome, F. L., Some Paleozoic sections in Arizona and their correlation: U. S. Geol. Survey Prof. Paper 98, pp. 158-159, and Fig. 14, 1912.

150 Pan Am. Geol., vol. 38, pp. 299-312, 1922.

and volcanic beds.

The pre-Cambrian rocks include Red Rock rhyolite, Mazatzal quartzite, and pre-Cambrian granite.

The Paleozoic strata, which overlie the rhyolite and unconformably overlap the quartzite, consist of Cambrian sandstone, Devonian, Mississippian, and Pennsylvanian limestones, and Permian shale and sandstone.

Tertiary sedimentary beds in places mantle the Paleozoic formations and are overlain by Tertiary volcanic flows.

Plate LVII indicates the general distribution of formations in the Pine Creek area. This map, however, is based on the Verde reconnaissance topographic sheet (1885) whose scale is inadequate for more than a very generalized expression of the geologic features.

Pre-Cambrian rocks

Red Rock rhyolite: The oldest exposed formation consists of chocolate to red-brown locally porphyritic rhyolite which forms the steep-walled inner gorge of Pine Creek Canyon downstream from Natural Bridge. This formation weathers to blocky joint-controlled slopes which, although generally free from soil, give little or no hint as to the original structure.

The porphyritic variety (page 98) predominates at Natural Bridge but gives way downstream to

PLATE LVIII. Microphotograph of porphyritic Red Rock rhyolite, Pine Creek. White is quartz, gray is albite. Crossed nicols, 18 diameters.

PLATE LIX. Southward view of Mazatzal quartzite west of Pine Creek, overlapped by Tertiary gravel on upper right.

the typical Red Rock material, characterized by an aphanitic groundmass and small quartz phenocrysts, with only local phases of the porphyritic variety. In places, it contains inclusions of altered greenstone.

Although this formation has previously been termed granite [151] and granite porphyry,[152] its general field and microscopic characteristics are essentially identical with those of the Red Rock rhyolite of the Mazatzal Mountains (pages 94-98, 166).

Mazatzal quartzite: In the Pine Creek area no Deadman quartzite and Maverick shale are apparent, but a thick succession of typical Mazatzal quartzite, with prominent basal conglomerate unconformably overlying the Red Rock rhyolite, crops out as an irregular northeastward-trending area, 6½ miles long by 3½ miles wide, which is surrounded and unconformably overlapped by the Paleozoic and Tertiary beds. True to its general type, the Mazatzal quartzite along Pine Creek Canyon forms blocky, rugged, barren slopes whose prevailing pale-

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151 Ransome, F. L., work cited.

152 Hinds, Norman E. A., Ep-Archean and Ep-Algonkian intervals in western North America: Carnegie Inst. Wash. Publ. No. 463, p. 10, August, 1935.

brown to reddish-brown color embodies a distinctive faint purplish tint that is particularly noticeable from a distance. Its thickest exposed section is near the southwestern end of the area, where headward erosion of tributaries to Pine Creek have stripped back the later formations.

Section of Mazatzal quartzite near southwestern end of Pine Creek area

	Feet
1) Medium to coarse-grained, banded, cross-bedded, vitreous red-brown and grayish-brown quartzite in beds 1 to 3 feet thick	60
2) Like (1) but with conspicuous partings of ripple-marked red shale	35
3) Like (1) but weathers redder.....	15
4) Red sandy shale.....	5
5) Like (1) but redder and more strongly cross bedded.....	75
6) Like (2)	25
7) Like (1) but with thin hematitic sandy partings.....	60
8) Medium to coarse-grained, cross-bedded, sparkling, vitreous brownish red quartzite, in beds ½ to 2 feet thick	25
9) Like (8) but with some sandy to shaly partings.....	65

	Feet
10) Like (8)	35
11) Like (9)	40
12) Medium-to coarse-grained, cross-bedded, vitreous, sparkling, brownish-red quartzite, in beds ½ to 2 feet thick, with fewer sandy to shaly partings than in (9)	60
13) Alternating fine-grained red quartzite and slabby sandy red shale	30
14) Fine-grained cross-bedded red quartzite with some sandy shale partings.....	15
15) Like (13), with one-third to one-half ripple-marked sandy red shale.....	95
16) Fine-grained, cross-bedded, sparkling, vitreous quartzite, in beds 1/4 to 1 foot thick.....	30
17) Like (15) but with less shale...	75
18) Like (16) but fine to medium-grained and with some sandy red shale partings.....	70
19) Fine to medium-grained, cross-bedded, sparkling, vitreous red-brown quartzite, in beds 1/2 to 2 feet thick with Hematitic sandy partings.....	180
20) Like (19) but in beds 2 to 3 feet thick with some thin layers of small, well-rounded quartz pebbles.....	140
21) Like (20) but browner; beds ½ to 1 foot thick, weathering more massive in lower portion....	655
22) Thin-bedded sandy member.....	10

	Feet
23) Similar to (21) but contains more conglomeratic beds with generally rounded pebbles of rhyolite, jasper, and quartz up to 1½ inches in diameter; forms reef and weathers grayish brown.....	50
24) Like (21) but approximately 1/3 sandy red shale.....	15
25) Brownish-red to purplish spotted sandy shale and shaly sandstone.....	160
26) Fine to medium-grained vitreous red-brown quartzite, in beds ½ to 2 feet thick with approximately 1/3 spotted purplish-red sandy shale.....	25
27) Like (26) but with very little shale.....	10
28) Like (26) but more than one-half shale.....	35
29) Like (26)	40
30) Massive pale-brown reef-forming quartzite with local pebbly layers like (23)....	70
31) Like (30) but in beds ½ to 3 feet thick; forms ridge.....	345
32) Similar to (31) but more conglomeratic, with pebbles of rhyolite, jasper, and white quartz; cross bedded on grand scale; bedding massive and indistinct.....	70
33) Like (32) but in distinct beds 1 to 3 feet thick.....	285
34) Like (33) but redder.....	205
35) Like (33) but redder and more cross bedded.....	120

	Feet
36) Iron-stained, kaolinized rhyolite.....	75 (est.)
37) Fine to medium-grained, locally pebbly, hard, vitreous grayish-brown quartzite.....	200 (est.)
38) Grayish-brown arkosic conglomerate with rounded to subangular pebbles, less than an inch to more than a foot in diameter, of Red Rock rhyolite, quartzite, and jasper; rests on eroded surface of Red Rock rhyolite.....	300 (est.)

Northeastward along the strike, the upper portion of this section is mantled by Paleozoic and Tertiary beds, but the lower portion crops out uninterruptedly in the bluffs along the west side of Pine Creek. A short distance northwest of the travertine arch where these lower members are readily accessible for detailed examination, the following section was measured by tape.

Section of Mazatzal quartzite at Natural Bridge

	Feet
1) Measuring down from immediately below contact with Carboniferous limestone. Hard, vitreous gray to red-brown quartzite, alternatingly coarse and fine grained. Beds 6 inches to 2 feet thick.....	24

	Feet
2) Similar to (1) but finer grained.....	8
3) Hard, vitreous, gray to brown quartzite with subangular grains up to 1/8 inch in diameter. Beds massive and slightly cross bedded.....	32
4) Parting layer of fine-grained, shaly mauve-colored sandstone, grading into 3.....	1/6
5) Like (3)	1 3/4
6) Like (4); grades into (5).....	1½
7) Hard, vitreous gray to red-brown quartzite, alternatingly coarse and fine grained, with quartz grains up to ¼ inch in diameter in lower portion. Contains a notable amount of red jasper particles. Beds massive and slightly cross bedded...	56
8) Parting layer of fairly hard, fine-grained red shale.....	1
9) Hard, vitreous, coarse-grained, like (7)	12 2/3
10) Fairly hard, fine-grained, flaggy sandstone containing some grains of red jasper.....	1½
11) Like (9)	18 3/4
12) Like (8) but ripple-marked and slightly sandy.....	2/3
13) Hard, vitreous, light brown quartzite. Mostly fine grained, but with grains up to ¼ inch in diameter intermingled or sorted into bands. Notable amounts of red shale and jasper fragments. Locally kaolinized. Beds massive and fairly even.....	29½

	Feet
14) Hard spotted, maroon shale, forming ripple-marked contact with the quartzite.....	1/2
15) Light-gray quartzite whose grains are mostly white quartz averaging about 1/16 inch in diameter, together with some smaller ones of red jasper.....	15
16) Ripple-marked red, spotted shale..	1 1/6
17) Like (15) but some of the coarse particles range up to ¼ inch in diameter.....	7 2/3
18) Like (16)	1½
19) Vitreous, somewhat cross-bedded, gray to light-brown quartzite, largely an aggregate of fine and coarse grains with some bands of coarser material, a few lenses of shale like (16), and a few lenses of arkose. In general, the particles are rounder than those in the higher members of the series, and fewer are of jasper. Bedding ranges from 1/2 to 3 feet in thickness.....	111
20) Shaly bed grading into mauve-colored sandstone and quartzite. Shows grand-scale ripple marks of which some are 7 feet from crest to crest by 9 inches high....	1
21) Highly vitreous reddish quartzite, generally fine grained but with some coarse subangular particles. Contains several lenses of red shale. Bedding ½ to 4 feet thick, lower 20 feet cross bedded....	96
22) Red, spotted, ripple-marked shale....	1

	Feet
23) Cross-bedded red-brown quartzite, generally a semi-sorted aggregate of fine and coarse subangular particles up to 1/8 inch in diameter; some grains of red jasper present. Beds 5 feet in maximum thickness.....	50
24) Like (23) but more reddish.....	30
25) Like (23) but somewhat more vitreous.....	51
26) Fairly persistent red, gray-spotted argillaceous sandstone grading into quartzite.....	2
27) Similar to (25).....	25
28) Iron-stained rhyolite, locally spherulitic and containing masses of compact kaolin more than 0.2 inch in diameter.....	74½
29) Hard, vitreous, fairly even-grained grayish-brown quartzite, in beds ½ to 3 feet thick. Contains some beds about one foot thick of hard, vitreous fairly uneven-grained, cross-bedded, grayish-brown quartzite with noticeable subangular particles of red jasper. Tends as a whole to be fractured and jointed and forms jagged topography.....	190
30) Brick-red conglomerate with arkosic cement. Pebbles, well-rounded or oval to subangular in shape, of typical red Rock rhyolite, quartzite, red shale, and jasper, generally less than an inch in diameter near top, but increasing to a foot or more near base. Shows rude massive bedding, best developed in the upper 75 feet, and considerable jointing.....	200
31) Like (30), but mainly conglomeratic coarse arkose with irregularly distributed pebbles;	

	Feet
sheared parallel to bedding; rests on eroded surface of Red Rock rhyolite.....	100
Total thickness of section...	1,145

Petrographic features of quartzite section:

Thin sections of samples taken from 12 different beds of the Mazatzal quartzite in the Pine Creek area show closely packed angular to sub-angular, locally enlarged grains of quartz cemented with finely divided siliceous limonitic material. The typical interbedded maroon shale is mainly argillaceous and ferruginous material of ultra-microscopic fineness with sparse fine particles of quartz and kaolin.

Microscopically the interbedded rhyolite member (36, page 245, and 28, page 248) shows corroded, altered phenocrysts of orthoclase, up to 0.2 inch in diameter, in an altered, siliceous, microcrystalline groundmass. The feldspars of the rock have been extensively replaced by kaolin. Much secondary quartz and finely divided iron oxide have been developed in the groundmass.

Stratigraphic considerations: The thick basal conglomerate with its coarse angular boulders, predominantly of Red Rock rhyolite, indicates the proximity

of a pre-Mazatzal highland. As no conglomerate of such thickness and with boulders of such size and angularity occurs in the Mazatzal Mountains section, this highland probably rose northwestward. Thus if the pre-quartzite surface of rhyolite sloped southeastward with a gradient of a little more than 100 feet per mile, it could have stood considerably higher in the Pine Creek area than the top of the Maverick shale of the Mazatzal Mountains area. That the non-deposition of the Maverick in the Pine Creek area may have been due to such a sloping of the old continental shelf is suggested by the northward thinning of the Maverick in the Mazatzal Mountains, as stated on page 105.

The intraformational rhyolitic member probably represents a flow that was erupted during a brief pause in sedimentation, rather than a sill. There is no evidence of erosion of its upper surface, such as might be expected in an intraformational flow. On the other hand, it shows no cross-cutting relations and did not effect any appreciable metamorphism of the quartzite. In places it shows chilled borders and swirling flow lines. Furthermore, its spherulites are indicative of a surface flow [153] with glassy ground-

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153 Grout, Frank F., Petrography and Petrology, pp. 32-232, 1932.

mass.

Granite: Medium to coarse-grained, pinkish-brown granite, unconformably overlain by Paleozoic and Tertiary beds, forms the gorge of the East Verde River in this area, as shown on Plate LVII. It is microscopically identical to the prevailing type of pre-Cambrian granite of central Arizona (pp. 120-123).

Paleozoic formations

Tapeats sandstone: The basal Paleozoic formation of the Pine Creek area consists of dull red-brown, cross-bedded, friable, pebbly Tapeats sandstone which is exposed in Pine Creek Canyon, downstream from a point about 3/4 mile south of Natural Bridge, and in the East Verde gorge (Plate LVII). Its thickness averages about 100 feet but, due to irregularities in the pre-Cambrian surface, ranges considerably from that amount. In Pine Creek Canyon it rests on Red Rock rhyolite and unconformably abuts against the Mazatzal quartzite near which it tends to be conglomeratic. Along the East Verde River it unconformably overlies the pre-Cambrian granite.

Devonian and Carboniferous rocks: More than 1,300 feet of limestone beds overlie the basal sandstone and unconformably lap against the Mazatzal quartzite near which they are sandy to conglomeratic and

cherty. Stoyanow [154] has studied these limestones from East Verde crossing, 5½ miles east of Pine Creek, northward to the Mogollon Escarpment and obtained fossil evidence for subdividing them as follows:

	Thickness in feet
Pennsylvanian - moderately bedded limestone much interbedded with conglomerate, sandstone, and shale; includes a conglomerate, in places more than 50 feet thick, containing boulders of Mazatzal quartzite. Separated from Mississippian by a 50-foot basal conglomerate.....	1,000 +
Mississippian (Redwall limestone) - Light-gray, crinoidal, partly crystalline limestone.....	50-80
Devonian (Jerome formation)- Thin to medium-bedded limestone. Lower 25-30 feet flaggy and somewhat sandy; grades upward into compact limestone overlain by about 20 feet of red shale.....	300 +

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154 Stoyanow, A. A., Notes on recent stratigraphic work in Arizona: Am. Jour. Sci., vol. 12, pp. 311-315, 1926; and Correlation of Arizona Paleozoic formations: Geol. Soc. America, Bull., vol. 47, pp. 497-500, 512, 1936.

In the Mogollon Escarpment, within a distance of less than 2 miles north of the Mazatzal quartzite outcrop (Plate LVII), the Pennsylvanian strata are overlain by approximately 650 feet of Supai (Permian) red beds, succeeded by more than 1,000 feet of Coconino (Permian) sandstone. These formations doubtless once extended southward over the Pine Creek area and were removed by pre-Pliocene erosion.

Cenozoic formations

The pre-Pliocene Tertiary pediment that encroaches upon the southwestern margin of the Plateau, along the base of the Mogollon Escarpment, is locally mantled with moderately consolidated sandy conglomerate, overlain by basaltic flows which cap the mesas overlooking Pine Creek. In this conglomerate, well-rounded pebbles of granite indicate that a granitic mass somewhere in this region stood higher than the pediment when the gravels were deposited. Conglomerate, sandstone, and impure limestone representative of the lacustrine beds described on page 134, limit the area on the south. For reasons stated on pages 34, 135, these formations are believed to be of Pliocene age.

Quaternary gravel and silt occur as a thin veneer upon parts of the mesas and along the stream courses.

Structure

The Mazatzal quartzite of the Pine Creek area constitutes a northeastward-trending ridge flanked by unconformably overlapping Paleozoic and Tertiary formations. This ridge disappears beneath the Carboniferous strata of the Plateau on the northeast and is limited by pre-Pliocene Tertiary graben step faults on the southwest. Near the southern limit of the quartzite outcrop, three of these northwestward-trending faults are well exposed cutting the Paleozoic section east of Pine Creek. From northeast to southwest, they show vertical displacements of approximately 50,200, and 300 feet, respectively. The southwestern-most exposures of Cambrian sandstone here are approximately 800 feet higher in elevation than those at the mouth of Pine Creek, indicating that one or more additional faults of this succession probably occur, hidden from view by the Tertiary formations of the East Verde Valley. These faults are believed to be of pre-Pliocene Tertiary age, and they may represent renewed movement upon zones of weakness which were developed during the Mazatzal Revolution.

The quartzite beds constituting the ridge in general strike northeastward and dip 33° to 55° NW., but in the northwestern portion of the area they deviate somewhat from this attitude, as shown on Plate LVII.

They are broken, at right angles to the strike, by numerous joints and small faults along which notable sericitization and deposition of specularite have taken place. In the northwestern portion of the area the Mazatzal quartzite has been cut by a fault that strikes northeastward and dips 70°NW.

The old quartzite ridge is either a fault block or the eroded limb of a fold. If a fault block, it may represent the northeastern continuation of block 2, of the Mazatzal Mountains (see page 211 and Plate XXI). In either case it was upheaved prior to the Paleozoic sedimentation, probably during the Mazatzal Revolution as part of the great northeastward-trending mountain range of which the pre-Cambrian rocks of the present Mazatzal Mountains, eastern Tonto Basin, and Del Rio areas are remnants. The northwestward-striking faults and joints may have been initiated as shear breaks resulting from the northwestward-trending compressive forces that gave rise to the folds during the Mazatzal Revolution. The steeply northwestward-dipping fault in the northwestern portion of the area may have been formed upon release of the compressional stresses.

CHAPTER III - EASTERN TONTO BASIN AREA

Geography

Situation and extent

The eastern Tonto Basin area, which extends along the base of the Mogollon escarpment between Tonto Creek on the west and Pleasant Valley on the east, is 11 miles long by 7 miles wide.

Relief and drainage

In this area the principal topographic feature is Christopher Mountain which trends eastward from the head of Tonto Creek to Gordon Canyon, between the Pleasant Valley trail on the south and Christopher Creek, at the foot of the Mogollon Escarpment, on the north. This mountain, which is 6 miles long and 1½ miles wide, rises steeply from an altitude of 5,000 feet at Tonto Creek to a long, narrow mesa crest with an altitude of 6,700-7,000 feet. Except near the few principal canyons, the mountain has not undergone particularly rugged dissection. Its top appears to represent a remnant of an early Tertiary or pre-Tertiary peneplain. Composed essentially of hard, resistant quartzite, it has withstood well the erosion to which it has been subjected since denudation

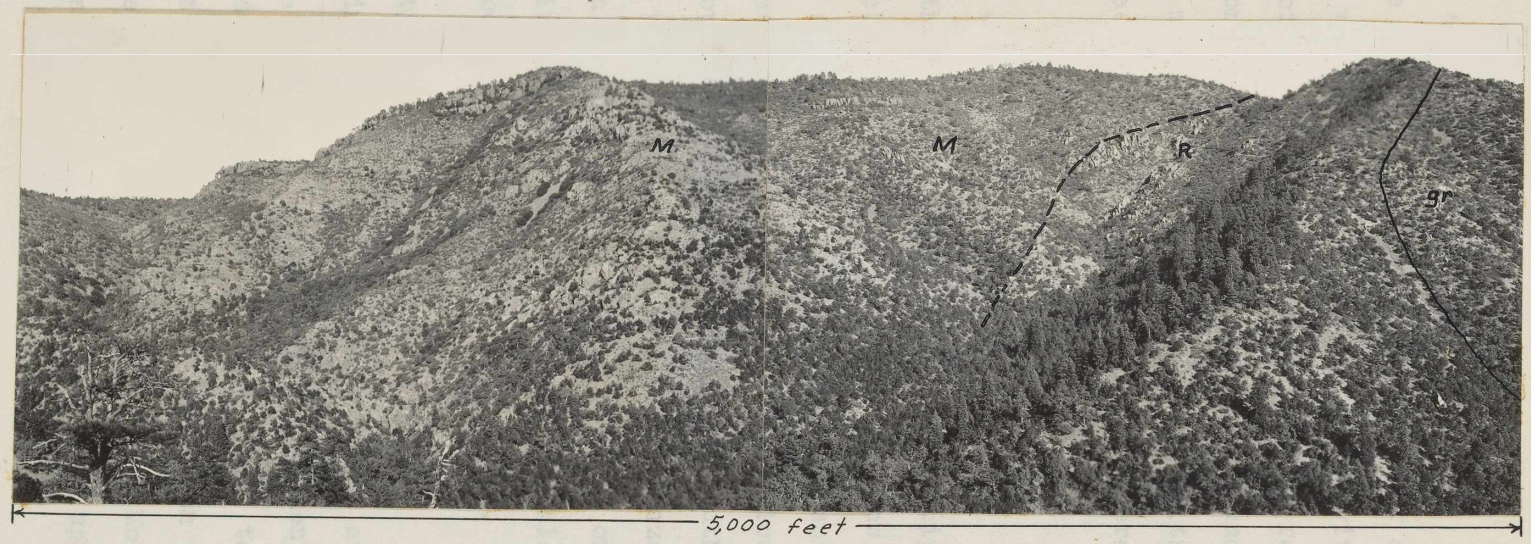

PLATE LX. Christopher Mountain from west side of Tonto Creek. Rock is Mazatzal quartzite (M) faulted against Red Rock rhyolite (R) which is intruded by granite (gr).

in Tertiary and Quaternary time.

The area is drained by Tonto Creek and its tributaries which have carved out a basin with a succession of closely spaced, generally narrow, deep canyons. Tonto Creek flows southwestward under control of the major regional structure, and its tributaries show guidance by joints, bedding, and differential hardness.

Climate and vegetation

As this area receives a yearly precipitation of 25 to 30 inches, including considerable snow, the canyon bottoms and surfaces that permit soil accumulation support a fairly heavy growth of pine timber, particularly on northern slopes. Portions of its lower southerly slopes are mantled with a thick growth of oak, manzanita, and desert brush. Tonto Canyon and the valley of Christopher Creek contain several small patches of arable land upon which hay, corn, and truck crops are grown.

Accessibility

An improved road from Payson leads across upper Tonto Creek, along the foot of the escarpment, via the head of Gordon Creek and Colcord Mountain, to Young. The Pleasant Valley trail leads down Gordon Canyon and, skirting the southern base of Christopher Mountain, joins the Payson road at Kohl's ranch, on upper Tonto Creek.

Geology

Status of investigation

During 1920-21, while carrying on reconnaissance mapping of the region for the Geologic Map of Arizona, the writer found quartzite of Mazatzal type unconformably overlapped by the Apache and Paleozoic rocks in the northeastern portion of the area. Additional visits were made in 1922 and 1927, primarily to review the conditions of the Paleozoic unconformity.

In 1925, Darton,[155] after careful examination of the Gordon Canyon and Haigler Creek localities, published a brief description of the relations of the pre-Cambrian and Paleozoic formations there.

Five days were spent in the eastern Tonto Basin area for the present investigation, in order to review the critical relations in Gordon Canyon, Haigler Canyon, Upper Tonto Creek, and Christopher Creek. This study was made to check the previous observations that the Mazatzal quartzite had been deformed in pre-Apache time, and to determine the relations of the pre-Cambrian igneous rocks to the Mazatzal Revolution in this area. As the only topographic maps available for the region

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155 Darton, N. H., A résumé of Arizona geology: Univ. of Ariz., Ariz. Bureau of Mines Bull. 119, pp. 234-236, 1925.

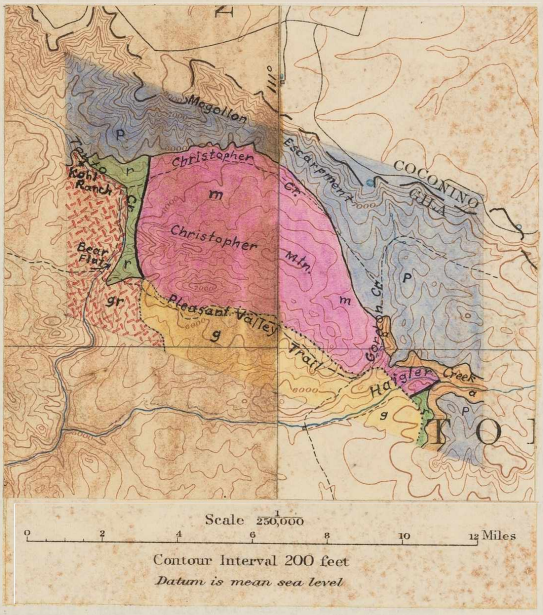

Figure 10. Geologic sketch map of eastern Tonto Basin area

EXPLANATION

Tertiary and Quaternary
- Gravel, sand, and silt

Paleozoic
- Sedimentary beds

Pre-Cambrian
- Apache beds
- Granite
- Mazatzal quartzite
- Red Rock rhyolite
- Fault

were the old Verde and Holbrook sheets, on a scale of 1:250,000, no geologic mapping was attempted.

Formations represented

The eastern Tonto Basin area is made up largely of pre-Cambrian rocks (Fig. 10) of the same general lithology and structure as those of the Mazatzal Range from which they represent a northeastward continuation. They include folded and faulted Red Rock rhyolite and Mazatzal quartzite, granite, and unconformably overlying Apache beds. The Paleozoic strata of the Plateau unconformably overlap the pre-Cambrian formations on the north. Loosely consolidated gravel, sand, and silt of Tertiary and Quaternary ages mantle much of the southeastern portion of the area.

Pre-Cambrian rocks

Red Rock rhyolite: The rhyolite appears in two irregular areas. The larger of these outcrops, which is faulted against Mazatzal quartzite on the east, intruded by granite on the southwest and west, and overlapped by Tertiary and Quaternary beds on the southeast, extends, with a width of generally less than a mile, from the ridge east of Bear Flat northward along the western base of Christopher Mountain to the foot of the Plateau escarpment where it disappears beneath

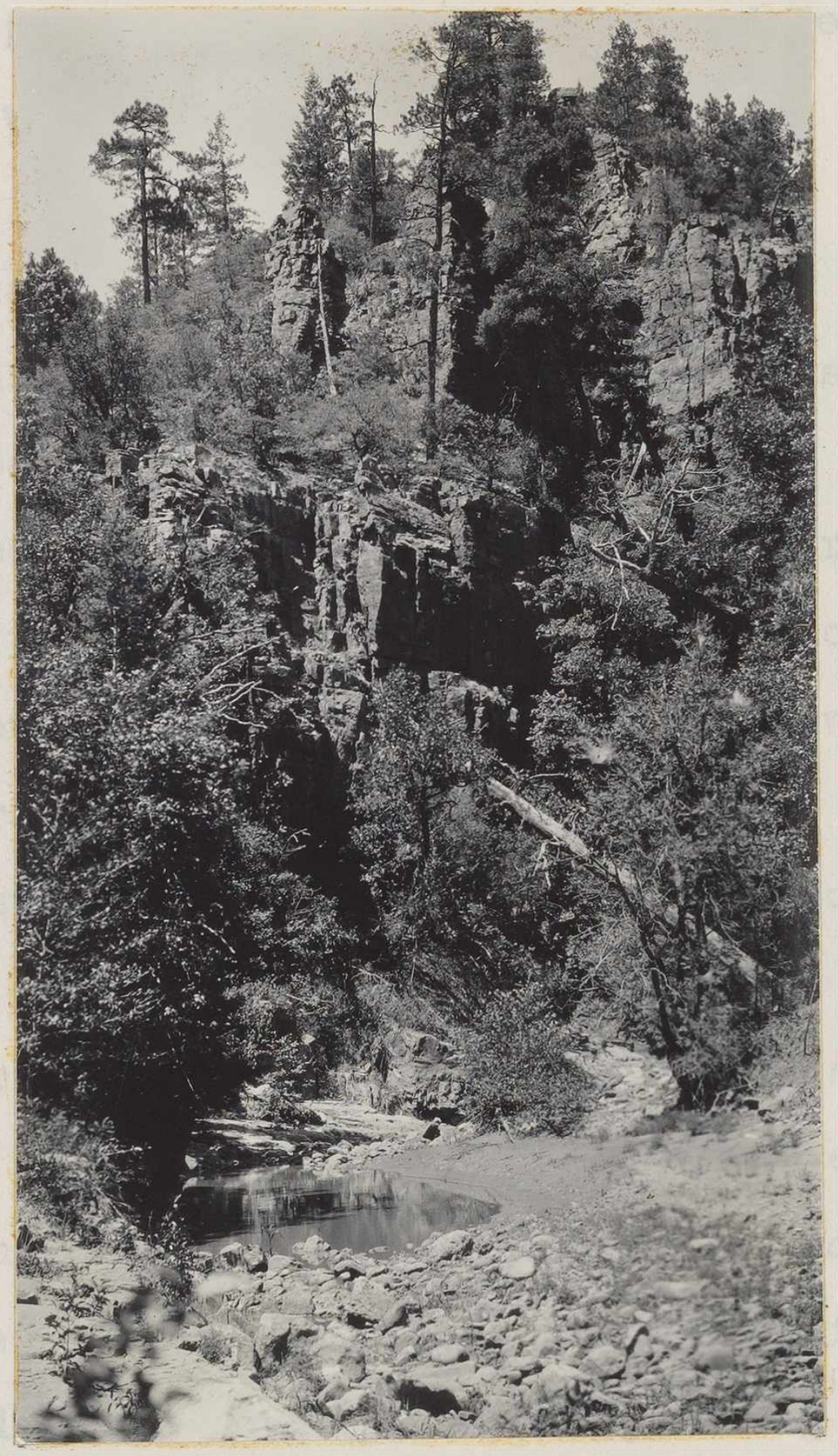

PLATE LXI. Red Rock rhyolite, Tonto Creek.

Paleozoic limestone. The other rhyolite area trends northeastward along upper Haigler Creek, faulted against Mazatzal quartzite on the northwest and overlapped by Apache, Paleozoic, and Tertiary formations. It was termed granite by Darton.

The rhyolite is largely of extrusive aspect. It locally reveals well-defined flows and agglomeratic phases but generally is homogeneous, dense, and without apparent bedding planes. The rock prevailingly forms steep to cliffy, rugged, locally brush-covered slopes of pale-brown to reddish-brown color. These slopes show several systems of joints of which the strongest strikes southwestward and a weaker one strikes northwestward. Constituting the zones of minimum resistance to erosion, these joints determine the courses of narrow, steep-walled canyons. This structural control of streams is strikingly exemplified in the canyon of Tonto Creek, 2 miles downstream from Kohl's ranch, where a deeply incised meander a mile long by 1/4 mile wide clearly follows jointing in the rhyolite.

Microscopically, the rock consists of a finely granular to microcrystalline groundmass of quartz and feldspar with fairly abundant locally corroded phenocrysts of quartz and orthoclase. The phenocrysts of quartz commonly range up to 1 mm. in diameter, and those of orthoclase attain lengths of 1.75 mm. Some

PLATE LXII. Microphotograph of Red Rock rhyolite from southeast of Bear Flat. White is quartz, gray is orthoclase, and black (s) are largely fragmental spherulites. Crossed nicols, 23 diameters.

specimens contain numerous fragmental, fine-textured spherulites up to 1.5 mm. in diameter. In the vicinity of the granite contact, abundant fine-grained secondary quartz and some epidote have been developed.

Spherulites, according to Grout,[156] form only in glasses, and their presence is one of the criteria for distinguishing surface flows from intrusive sheets.

This rhyolite closely resembles the Red Rock rhyolite of the Mazatzal Mountains, with which it is correlated.

Mazatzal quartzite: In the eastern Tonto Basin area no Deadman quartzite and Maverick shale are exposed, but more than 1,000 feet of typical Mazatzal quartzite is faulted against, and presumably overlies, the Red Rock rhyolite. This quartzite appears at the southern base of the Mogollon Escarpment, within the angle between Tonto and Gordon creeks where, forming Christopher Mountain, it crops out over an irregular area 6 miles long from east to west by 1½ to 4 miles wide, as indicated on Fig. 10. A few small isolated masses of the formation are exposed between Gordon Creek and Young. The Christopher Mountain outcrop is faulted against Red Rock

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156 Grout, Frank F., Petrography and Petrology, pp. 32 and 232, 1932.

PLATE LXIII-A. Ripple-marked Mazatzal quartzite, Gordon Canyon.

PLATE LXIII-B. Casts of dessication cracks in Mazatzal quartzite, Gordon Canyon.

rhyolite on the west and southwest and unconformably overlapped by Paleozoic limestone on the north, Apache strata on the east, and loosely consolidated Tertiary and Quaternary beds on the south. In the northwestern slope of the canyon of upper Haigler Creek, the quartzite is faulted against Red Rock rhyolite on the southeast and unconformably overlapped by Apache strata on the east, Paleozoic formations on the north, and Tertiary and Quaternary beds on the west. On Tonto Creek, 1-3/4 miles downstream from Kohl's ranch, a small, narrow block of the quartzite is intruded by granite on the west and apparently faulted against Red Rock rhyolite on the east.

The pre-Apache quartzite of eastern Tonto Basin forms angular, barren slopes of prevailing pale-brown to reddish-brown color. The formation is thick to thin bedded, fine to coarse grained, prevailingly cross bedded, very hard and vitreous, locally ripple marked (Plate LXIII-A), and in places contains thin partings of arenaceous spotted maroon shale of which some are marked by dessication cracks (Plate LXIII-B). It bears such close lithologic similarity to the typical Mazatzal quartzite, of the Mazatzal Mountains, that there can be little doubt of its identity with that formation.

Granite: In eastern Tonto Basin a batholithic mass of granite unconformably underlies the Paleozoic and Apache strata on the north and east. On Upper Tonto Creek, 1¼ miles downstream from Kohl's ranch, the granite intrudes a small fault block of typical Mazatzal quartzite. East of upper Tonto Creek and southeast of Bear Flat it intrudes the Red Rock rhyolite. For more than 100 feet away from this contact it shows a fine-grained border phase and locally includes blocks of the rhyolite. Near the contact, the rhyolite has been notably silicified and epidotized and in places contains disseminated iron oxide pseudomorphous after pyrite.

This granite forms gentle wooded to steep, rugged barren slopes whose configuration shows in a marked way the effects of rather intense northeastward-trending jointing. It is a pinkish-brown coarse-grained holocrystalline rock consisting largely of pink feldspar and grayish-white quartz. Microscopically, the feldspar is entirely orthoclase and microperthite. No ferromagnesian minerals are present. Sericite, kaolin, and iron oxide are rather abundant as alteration products, and cloudy masses of limonite and an undetermined amorphous grayish-white mineral occur interstitially. The rock very closely resembles the normal pre-Cambrian granite of the Mazatzal Mountains.

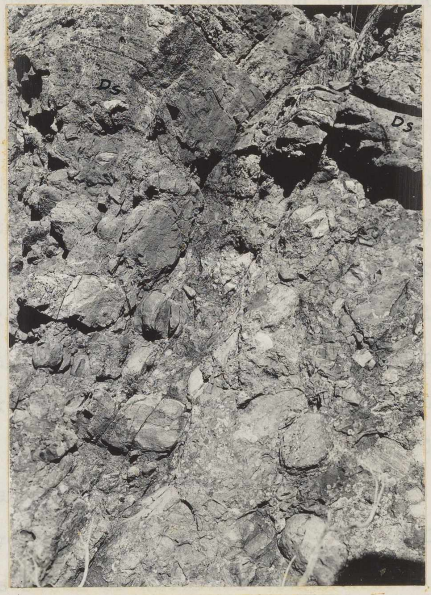

PLATE LXIV. Basal Apache conglomerate, overlain by Dripping Spring quartzite (Ds), Haigler Creek.

Apache group: Strata of the Apache group are exposed unconformably overlapping the Red Rock rhyolite on upper Haigler Creek and the Mazatzal quartzite in Haigler and Gordon canyons (Figs. 11 and 12, pages 272 and 273).

The lowest exposed Apache member is Dripping Spring quartzite which, near the contact with the Mazatzal quartzite and Red Rock rhyolite, is conglomeratic. On Haigler Creek the contact is marked by a basal or marginal conglomerate, approximately 100 feet thick, of oval to angular and domino-shaped pebbles in a sparse arkosic cement. The pebbles, which range from an inch up to 4 feet in diameter, are mostly of Mazatzal quartzite with a few small ones of oxidized Red Rock rhyolite (Plate LXIV). On Gordon Creek the pebbles of the basal or marginal conglomerate are angular near the contact and rounded some 50 feet farther away. The Dripping Spring quartzite lacks the hardness and vitreous luster of the Mazatzal quartzite and is thin bedded, well banded, and of grayish to maroon color. On Haigler Creek, according to Darton,[157] it is intruded by an irregular sill of diabase, 175 feet below the top.

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157 Work cited, p. 235.

The Dripping Spring quartzite is overlain by 80-100 feet of altered, siliceous, locally shaly Mescal limestone, followed by Paleozoic strata.

Paleozoic formations: Overlying the Apache beds at the east and unconformably overlapping the pre-Cambrian Red Rock rhyolite and Mazatzal quartzite on the north is Carboniferous limestone which extends northward beneath the strata of the Plateau. In the vicinity of its contact with the older rocks, this limestone is very conglomeratic. On the northwest, the Carboniferous limestone is underlain by Devonian limestone and Cambrian Tapeats sandstone which in turn rests upon the granite. Ransome and Stoyanow (pages 71-72, 128) have pointed out that the pre-Carboniferous rocks on the northwest of this area differ markedly from those on the southeast.

Structure

The pre-Apache formations of the eastern Tonto Basin area comprise part of the northeastward-trending mountain range, referred to on page 230, that was upheaved during the Mazatzal Revolution, long before Apache time.

In the canyon of Gordon Creek the Mazatzal quartzite strikes N. 15° E. and has a general dip of 45° SE., whereas the Dripping Spring quartzite that unconformably overlaps it strikes N. 27° W. and dips

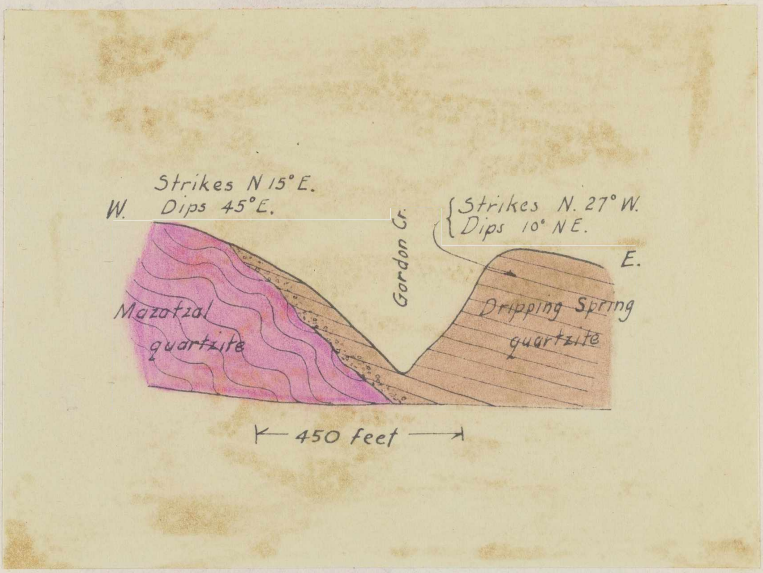
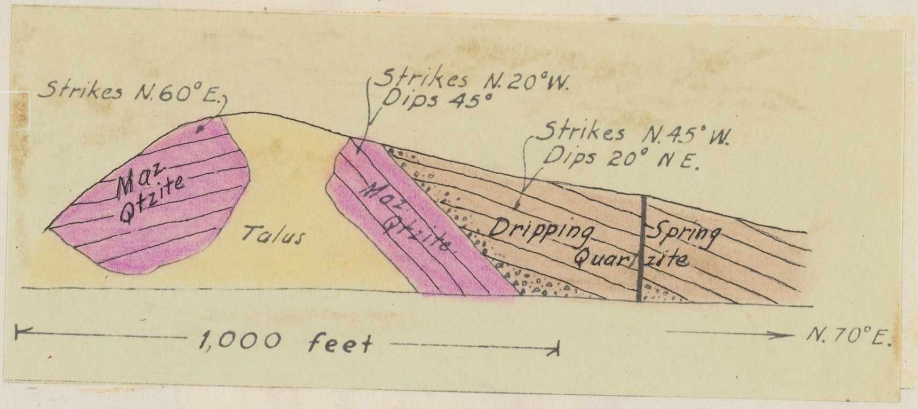


Figure 11. Sketch section showing relations in Gordon Canyon.



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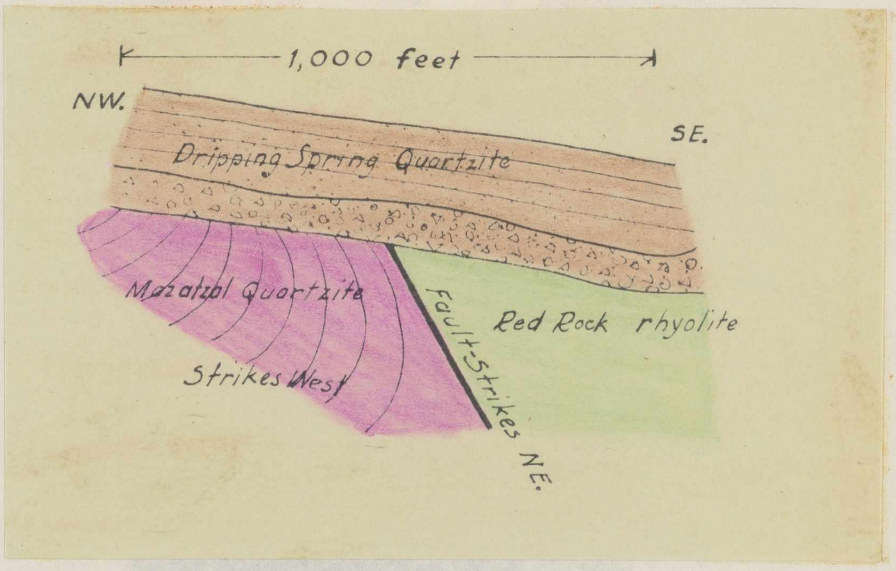

B

Figure 12. Sketch sections of relations in Haigler Canyon. A, looking northwestward; B, looking northeastward.

PLATE LXV-A. Folds in Mazatzal quartzite, Gordon Canyon.

PLATE LXV-B. Southwestward view along Haigler Creek Canyon. Red Rock rhyolite (R) on left in reverse fault contact with Mazatzal quartzite (M).

10° NE., flattening considerably northeastward. The Mazatzal strata show large-scale drag folds (Plate LXV-A and Fig. 11), in contrast to the uncrenulated thin-bedded Dripping Spring quartzite and the overlying incompetent Mescal limestone.

On the northern side of Haigler Creek Canyon the Mazatzal quartzite lies in an anticline that pitches approximately N. 20° E. and whose limbs dip 45°. Because of its pitch the strike of its northwestern limb is N. 60° E., and of its northeastern is N. 20° W. The steepness of this pitch is largely due to upturn or drag in the vicinity of a reverse fault that strikes N. 60° E., dips 60° SE., and brings Red Rock rhyolite on the hanging-wall side against Mazatzal quartzite (Plate LXV-B and Figure 12). The rhyolite near this fault is silicified, and the quartzite for more than 150 feet away from it is much shattered. The conglomerate and Dripping Spring beds that unconformably overlap the northeastern limb strike N. 45° W. and dip 20° NE., flattening considerably northeastward. They also overlap the rhyolite, but are nowhere displaced by the fault; hence its movement is of pre-Apache age.

Northeast of Bear Flat and east of Tonto Creek the Mazatzal quartzite of Christopher Mountain is faulted against Red Rock rhyolite on the southwest and west.

This fault contact, which trends about S. 10° E. and swings southeastward across the ridge east of Bear Flat, is characterized by rather extensive shearing in both formations. No good exposures of its dip were found, but its southeastern segment appears to be a steeply dipping reverse fault that, northwestward, passes into the zone of a shear fault. The quartzite of the mountain lies in gentle north-northeastward-trending folds, locally complicated by steeply dipping reverse and normal faults which, in all probability, closely followed the folding and granitic intrusion as a phase of the Mazatzal Revolution. The tilting of the Apache beds in the northeastern part of the area may be interpreted as having resulted from later local uplift; Darton [158] implies that it was of pre-Troy age.

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158 Work cited, p. 234.

CHAPTER IV. DEL RIO AREA

Geography

Situation and extent

The Del Rio pre-Cambrian area, as mapped on Plate LXVI, extends for a length of 6 miles by a maximum width of 2 miles along Granite Creek, upstream from the junction of that stream with the Verde River. It begins at a point one mile east of Del Rio, a station on the Phoenix branch of the Santa Fe railway, some 20 miles north of Prescott and 6 miles south of the Plateau.

The Phoenix-Ash Fork highway passes a short distance west of Del Rio, and secondary branch roads lead from this highway into the southern, western, and northern portions.

Geomorphology

This section of country represents the northwestern extremity of the Black Hills Range which, as Lindgren [159] states, appears to be a horst. The Del Rio

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159 Lindgren, Waldemar, Ore deposits of the Jerome and Bradshaw Mountains quadrangles, Arizona: U. S. Geol. Survey Bull. 782, p. 8, 1926.

pre-Cambrian outcrops are bounded by the loosely consolidated gravel and sand of Chino Valley on the south, a lava-capped plain, 4,500 feet above sea level, on the west, dissected Paleozoic strata on the north, and a group of ridges, carved in volcanic rocks, on the east. These ridges, which attain a maximum altitude of 5,500 feet, with general local relief of a few hundred feet, have been intricately dissected by tributaries of the Verde River and of Granite Creek. Granite Creek has bisected the pre-Cambrian area with a meandering, northwestward-trending shallow canyon whose course has been determined largely by structure. Near the northern end of the area the Verde River has carved a shallow canyon whose meandering, east-northeastward course seemed to be determined, at least in part, by local structures within the Paleozoic strata.

Climate, vegetation, and population.

The annual precipitation of this area probably ranges from 14 to 20 inches. The temperature commonly exceeds 100° in summer and drops to a few degrees below zero in winter.

Excepting the quartzite, whose slopes are essentially bare, all of the rocks are mantled with thin but somewhat discontinuous soil which supports a relatively

sparse growth of juniper, brush, and grass. Some farming is done at Del Rio, and a few ranches are distributed along the Verde River and Granite Creek, parts of which carry water throughout the year.

Geology

Status of investigation

During 1920 and 1921 the writer mapped the Del Rio area for the Geologic Map of Arizona and correlated[160] the pre-Cambrian quartzite there with the Mazatzal quartzite of the Mazatzal Mountains. The Paleozoic and later formations were mapped in 1927 and 1929, incidental to a detailed survey of the Jerome quadrangle.

Three days were spent in the Del Rio area for the present investigation, in order to review the stratigraphy and structure of the pre-Cambrian quartzite and its relations to the Paleozoic strata. Professor Russell Gibson, of Harvard University, spent part of a day in the area and contributed helpful observations.

Formations represented

The formations exposed here consist of pre-Cambrian

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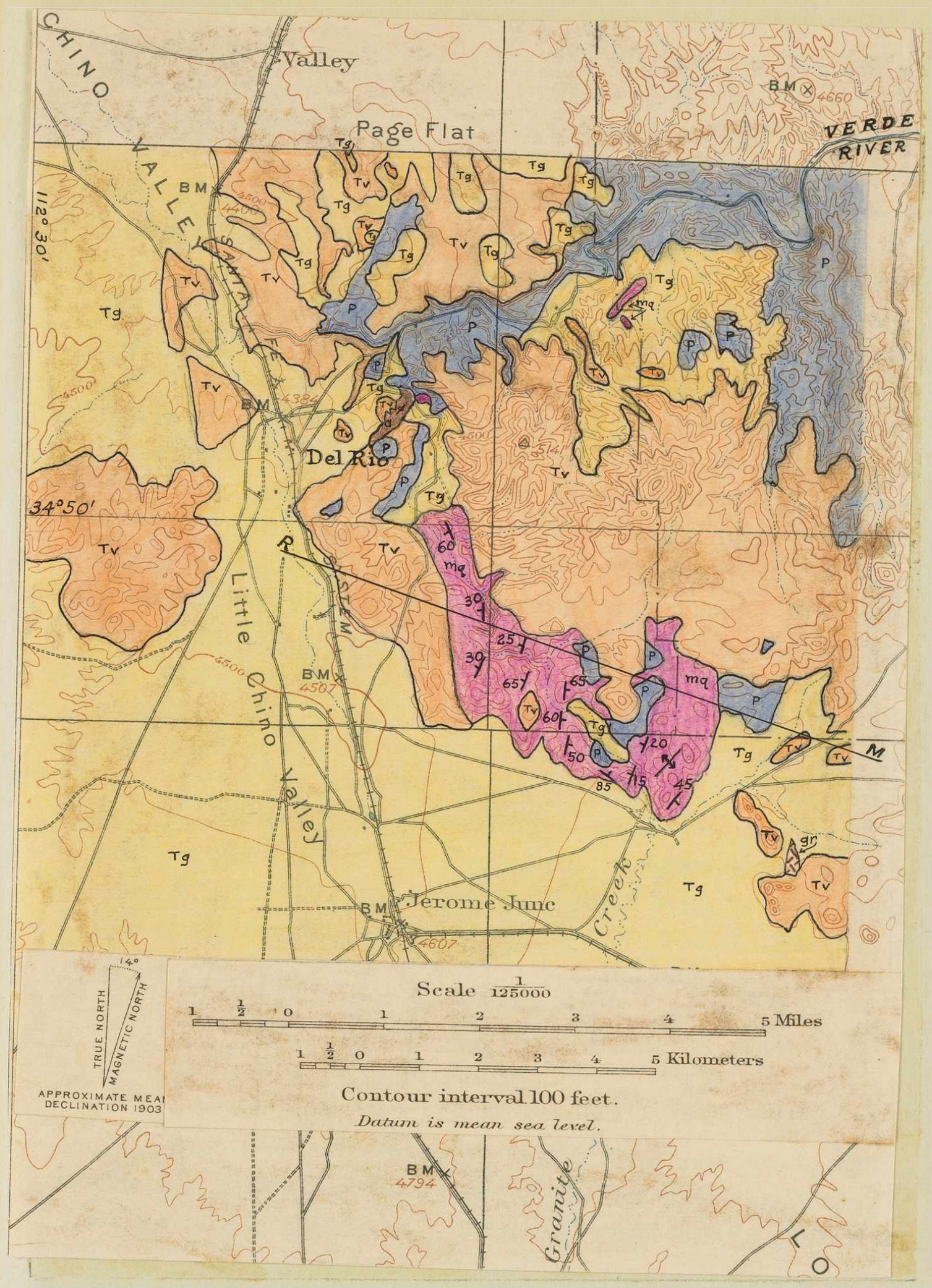
160 Pan Am. Geol., vol. 38, pp. 299-312, 1922.



EXPLANATION

Tertiary and Quaternary

Tv — Volcanic rocks

Tg — Gravel, sand, and silt

Paleozoic

P — Sedimentary beds

Pre-Cambrian

gr — Granite

mq — Mazatzal quartzite

a — Alder series

SECTION R-M

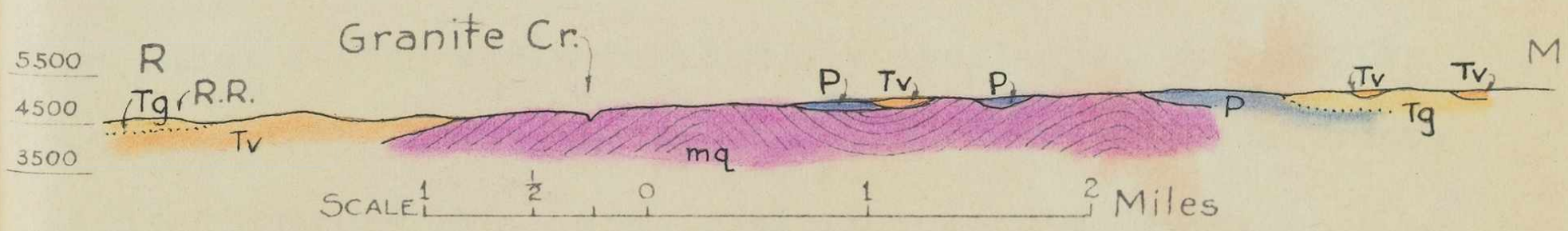


PLATE LXVI. Geologic map of Del Rio area

Alder series, Mazatzal quartzite, and granite, Cambrian sandstone, Devonian and Mississippian limestones, Permian red beds, Tertiary and Quaternary sedimentary beds, and Tertiary volcanic rocks.

Pre-Cambrian rocks

Alder series: Near the mouth of Granite Creek (Plate LXVI) is a northeastward-trending area, 3/4 mile long by 1/8 mile wide, of generally fine-grained, well-laminated, dark-gray to brown phyllite and argillaceous sandstone of Alder type. Its lamination and apparent bedding strike N. 45° E. and dip 50° NW. It is unconformably overlain by the Paleozoic and Tertiary beds and faulted against Mazatzal quartzite on the northeast.

Mazatzal quartzite: The next oldest exposed formation consists of quartzite which, on the basis of lithology, structure, and stratigraphic position, is correlated with the Mazatzal quartzite. It crops out as an irregular area, 2 miles in maximum width, that extends northwestward for 4-3/4 miles along Granite Creek, and as two small areas near the Verde River (Plate LXVI). The quartzite is faulted against the Alder series and unconformably overlapped by Cambrian sandstone, Devonian limestone, Tertiary and Quaternary sedimentary beds, and Tertiary volcanic rocks.

The following section of the quartzite was

measured by tape, beginning with the stratigraphically highest exposed member in the western part of the area:

Section of Mazatzal quartzite east of Del Rio

		Feet
1)	Medium to fine-grained, generally sorted, cross-bedded, hard, vitreous light-gray quartzite, in beds 1 to 5 feet thick.....	250
2)	Alternating cross-bedded, hard, vitreous red-brown massive quartzite and conglomeratic beds with oval to subangular pebbles, ranging from 1/4 inch to 3 inches in diameter, of quartzite, white quartz, red jasper, and red slate.....	150
3)	Similar to (2) except for parting bands of hard, arkosic ripple-marked red slate ranging from about 1/8 inch to more than 28 inches in thickness.....	35
4)	Conglomeratic light gray quartzite with pebbles up to 6 inches in diameter.....	50
5)	Similar to (4) but with sparser pebbles in a rusty-red cement.....	250
6)	Like (5) but somewhat more vitreous and lighter colored. Pebbles generally less than an inch in diameter.....	200

7) Coarse-grained hard, vitreous quartzite with some conglomerate like (6) 75

8) Coarse-grained, cross-bedded, slabby red quartzite, locally sandy and banded..... 40

9) Fine-grained, cross-bedded, hard, vitreous light-brown to gray quartzite..... 160

10) Similar to (9) but coarser grained to conglomeratic with rounded pebbles, up to an inch in diameter, mainly of white quartz..... 70

11) Coarse-grained, cross-bedded, locally conglomeratic dark-brown sandstone with some reddish bands..... 200

12) Coarse-grained flaggy sandstone with alternating bands of micaceous, arenaceous spotted red slate 65

13) Conglomerate of unassorted subangular to rounded pebbles, 1/8 inch to 6 inches in diameter, of white quartz, red jasper, and slate in a coarse arkosic cement.. 85

14) Coarse-grained, cross-bedded, hard vitreous gray to light-brown quartzite, locally streaked with magnetite..... 100

15) Similar to (14) but very hematitic, particularly along fractures. Sequence is interrupted here by a fault that strikes N. 20° E. and dips 10° NW..... 50

Total thickness of section.. 1,780

East of the fault that interrupts the section in member (15), there appears to be several hundred feet of quartzite beds, stratigraphically higher than (1), which weather blackish.

Of the two small outcrops mentioned as occurring near the Verde River, one appears 1/2 mile southeast of the mouth of Granite Creek, at the northeastern end of the exposure of Alder beds, and the other is 2¼ miles farther northeast. The one near Granite Creek is about 1/8 mile in diameter and consists of coarse-grained, pebbly, vitreous quartzite which strikes N. 30° E., dips 30° NW., and is faulted against the schist on the southwest; it is unconformably overlapped by Cambrian sandstone, Devonian limestone, Tertiary lava, and alluvium. The northeasternmost outcrop is approximately 1/2 mile long by 150 feet wide and consists of coarse-grained, pebbly, vitreous quartzite which for the most part strikes N. 55° W. and dips 10° SE. but has been somewhat disturbed by faulting. It is entirely surrounded by Tertiary and Quaternary sedimentary beds.

An outstanding feature of the Mazatzal quartzite of the Del Rio area is the prevalence of fine, well-rounded to sub-angular pebbles of white quartz. At the time of its deposition, therefore, a fairly high, rugged land mass with many exposed quartz veins existed in the vicinity.

Granite: A small mass of aplitic granite, bounded by Tertiary sedimentary and volcanic beds, crops out in the southeastern part of the area (Plate LXVI). It is lithologically similar to aplitic phases of the pre-Cambrian granite of central Arizona, and is believed to be of pre-Cambrian age.

Paleozoic formations

The basal Paleozoic formation that unconformably overlies the Alder series and overlaps the Mazatzal quartzite consists of coarse-grained to conglomeratic, flaggy, red to white sandstone whose exposed thickness ranges from a few feet to several tens of feet. Where thick, it is lithologically identical to the Middle Cambrian Tapeats sandstone of the Grand Canyon region, but where thin and overlapping the quartzite, it is less like the typical Tapeats and may be of Devonian age.

Overlying the Tapeats sandstone and in places directly overlapping the Mazatzal quartzite are a few hundred feet of dark gray to buff impure Jerome limestone (Devonian). In places near the Mazatzal contact it contains pebbles and angular blocks of the quartzite.

The Devonian limestone is locally overlain by fairly pure light-gray Redwall limestone (Mississippian), which on the northeast is succeeded by Supai (Permian) red beds.

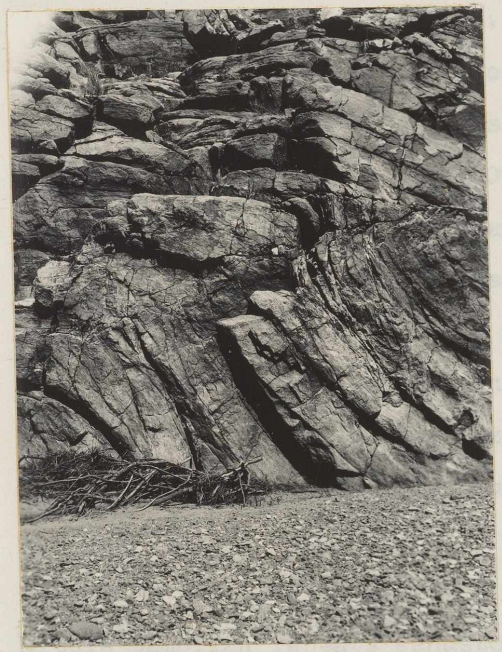
Tertiary and Quaternary formations

Overlying the pre-Cambrian and Paleozoic formations and comprising the high ridges east of Granite Creek is a series of several hundred feet of andesitic to dacitic platy volcanic flows and allied breccia and tuff of probable Tertiary age. The peak 2½ miles east of Del Rio is a cone of these rocks, indicating them to be of central eruption type.

Resting upon these volcanic rocks and the older formations is a series of loosely consolidated, poorly stratified gravel and sand of probable Pliocene age. They are overlain by basalt flows west of Granite Creek and north of Del Rio. With a thin mantle of Quaternary debris and silt, these Tertiary beds form the wide floor of Chino Valley.

Structure

The beds of pre-Cambrian Alder series exposed in the Del Rio area strike N. 45° E. and dip 50° NW. The Mazatzal quartzite against which they are faulted has similar strike and dip. The quartzite of the main area, as shown by Plate LXVI and Section R-M, lies in broad folds of prevailing northeastward trend, with limbs of moderate to steep dip and N. 40° E. to N. 20° W. strike. These folds are locally associated with north-



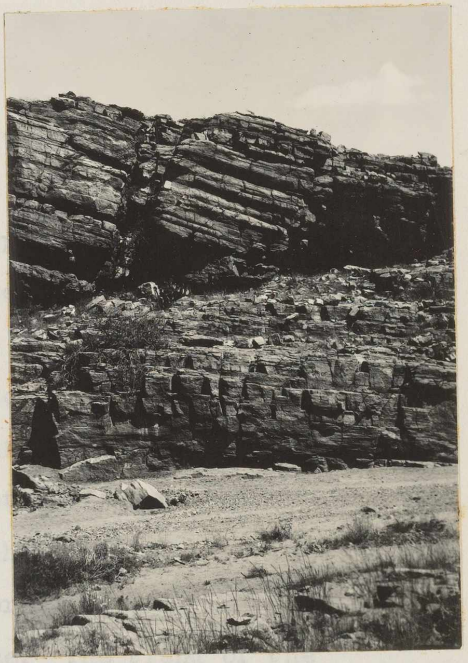


PLATE LXVII. Thrust faults exposed in Mazatzal quartzite along Granite Creek.

eastward-striking thrust faults, as illustrated by Plate LXVII. At its southwestern margin the quartzite has been steeply to vertically upturned (see Plate LXVI), presumably by a northwestward-trending fault whose trace is concealed by alluvium.

The Paleozoic strata for the most part lie essentially flat but in the southeastern portion of the area strike northwestward and dip 20° NE. This disturbance of the Paleozoic rocks, which appears also east of the volcanic cone and several miles eastward, antedates the andesitic lavas.

The Paleozoic strata unconformably overlap the roughly eroded folds of the Mazatzal quartzite with a very marked discordance in structure, proving that the principal folding and faulting that affected the pre-Cambrian formations took place prior to deposition of the Middle Cambrian Tapeats sandstone. The trend of the folds, the attitude of the pre-Cambrian strata, and the strike of the thrust faults are all characteristic of the Mazatzal Revolution.

CHAPTER V. SOUTHERN BLACK HILLS

General Statement

The Black Hills comprise a horst range, 25 miles long by a maximum of 10 miles wide, that trends northwestward from Cherry Creek to the Verde River, between the Verde Valley on the northeast and the Agua Fria or Lonesome Valley on the southwest.

This range, which contains the great pre-Cambrian copper deposits of Jerome in its northeastern portion, the Yaeger copper deposit at its southwestern base, the Cherry Creek pre-Cambrian auriferous veins on the south, and numerous small prospects, has received considerable attention from geologists, although its details have never been completely or satisfactorily worked out. An abstract of the published results of these investigations is given on pages 50-57 and 67. The topography was mapped in 1902-1903 by the U. S. Geological Survey as part of the Jerome quadrangle, on a scale of 1:125,000. In 1919-1920 a geologic reconnaissance map [161] of this quadrangle was made by Olaf P. Jenkins and the writer, for the Arizona

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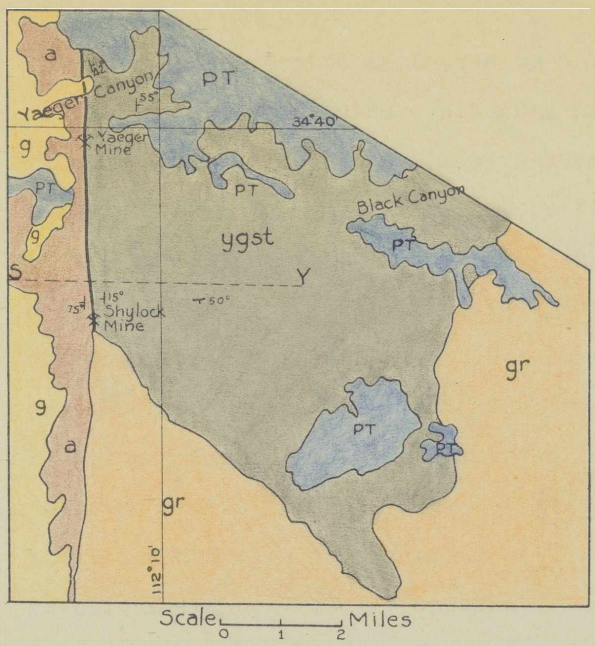
[161] U. S. Geol. Survey Bull. 782, Plate I.

Bureau of Mines. During parts of 1925-1930 detailed mapping of the geology was carried on by the Arizona Bureau of Mines, with Carl Lausen beginning a study of the pre-Cambrian rocks and the writer separating the Paleozoic and later formations.

The Black Hills Range is made up of a basement of pre-Cambrian rocks unconformably overlain by some 2,300 feet of Cambrian to Permian strata which are locally capped by Tertiary basalt and Tertiary and Quaternary sedimentary beds. It attains a maximum elevation of 7,720 feet above sea level or 4,400 feet above the Verde River and 2,800 feet above Lonesome Valley. Its northeastern front represents a precipitously eroded fault zone along which, as estimated by the United Verde geologists, at least 2,500 feet of vertical displacement occurred in pre-Cambrian time and more than 1,350 feet since the eruption of the Tertiary basalt. These later movements have involved the lacustrine and gravelly sedimentary beds of probable Pliocene age that occur in the Verde Valley. The southwestern slope of the range also represents an eroded fault zone of pre-Cambrian to late Tertiary age.

The pre-Cambrian rocks consist largely of greenstone, rhyolitic, and sedimentary schists, intruded by diorite, granite porphyry, and rhyolite porphyry, and limited on the south by intrusive contact with a batho-



EXPLANATION

Tertiary and Quaternary
g Gravel, sand, and silt

Paleozoic and Tertiary
PT Sedimentary and volcanic rocks

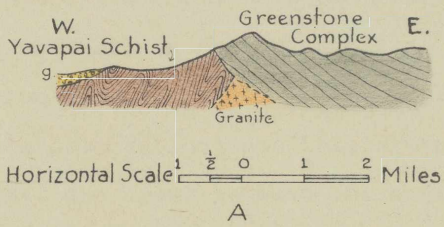
Pre-Cambrian
gr Granite

a / ygst Yavapai group: a, Alder series; ygst, Yaeger greenstone

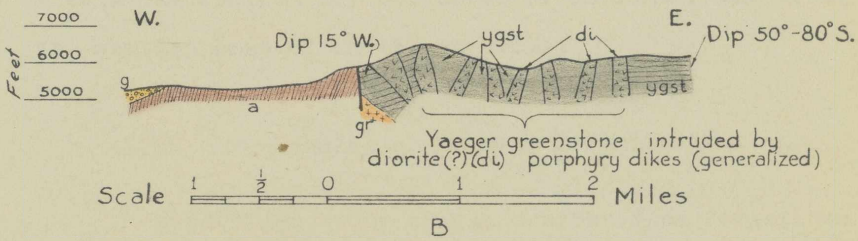
Fault

Figure 13. Geologic map of southern portion of Black Hills. (Modified from map by Carl Lausen and Eldred D. Wilson)

Structure sections along line S-Y



A



B

lithic mass of granite analogous to the Bradshaw granite of the Bradshaw Mountains. Although much detailed work remains to be done before the structural relations of these pre-Cambrian formations can be fully understood, it has been shown that in pre-Cambrian time, probably before the advent of the principal intrusions, the schists were compressed into close folds of prevailing north-northeastward trend and affected by locally complex faulting. Considerable pre-Cambrian faulting also followed the intrusions. Due to these structural complexities and also to obscurity of the contacts, the local relations are not readily apparent. As stated on pages 51-54, Reber and Hansen, of the United Verde Copper Company regarded the greenstone as older than the sedimentary schist, while Lausen cited (page 56) what he regarded as unconformities to prove that the greenstone is younger and is in turn overlain by the rhyolite. On the other hand, Lindgren (pages 56-57) strongly disagreed with Lausen's observations and interpretations and suggested that the break between the sedimentary and greenstone schists may be due to an ancient fault along the western base of the Black Hills.

Results of Present Investigation

A detailed study of the pre-Cambrian formations

PLATE LXVIII. Yaeger greenstone south of Mt. Mingus.

of the Black Hills is beyond the scope of this research. From what is already known of the area, it seems likely that the "greenstone complex" here is in large part equivalent to the greenstone of the Mazatzal Mountains, the rhyolite is analogous to the Red Rock rhyolite, and the sedimentary schist is equivalent to the Alder series of that range. In view of this probability, the discordance of Lausen's conclusions (pages 55-56) with evidence found in the Mazatzal Mountains necessitated an examination of the critical points of his field evidence as to age relations. Accordingly, seven trips, of which one was with Professor Russell Gibson, of Harvard University, were made into the southwestern portion of the range in search of the unconformity and the contrasts in grades of metamorphism that Lausen featured there. Five days were spent examining the greenstone in the central portion, south of Mt. Mingus, and the rhyolite in the southeastern portion of the range.

The intermediate to mafic rocks of the "greenstone complex" are termed the Yaeger greenstone (pages 92-94) and correlated with the greenstone of the Mazatzal Mountains.

The rhyolitic portion of the "greenstone complex" is commonly a pale-brown to gray rock which shows small phenocrysts of clear quartz and white feldspar in an abundant dense, fine-grained groundmass. It is identical

PLATE LXIX. Red Rock rhyolite, Black Canyon, southern Black Hills.

PLATE LXX. Steeply westward-dipping Alder beds near Yaeger greenstone contact.

in field appearance and microscopic features to typical Red Rock rhyolite, with which it may reasonably be correlated.

The sedimentary schist, which has been intruded locally by narrow dikes of diorite porphyry, consists of thinly laminated, brown to brownish-red slate and phyllite with some arkosic sandstone and a prominent bed of squeezed conglomerate composed of well-worn pebbles, mainly of quartz, jasper, and rhyolite in a fine-grained siliceous, sericitic cement. As these metamorphosed sedimentary rocks bear a striking field resemblance to portions of the Alder series of the Mazatzal Range, they are correlated with that formation.

The field work failed to demonstrate that the greenstone unconformably overlies the sedimentary schist, as postulated by Lausen, or to support his statement that the sedimentary schist is "thoroughly recrystallized and schistose while the basal flows of the greenstone are massive and show no evidence of dynamic stresses other than deformation into a series of folds." On the contrary, a steeply or vertically dipping fault of northward strike separates the two formations throughout a distance of more than 4 miles, with intermittent exposures extending from the overlying Paleozoic beds north of Yaeger Canyon to the granite tongue 1/8 mile south of the Shylock Mine. This granite tongue (Fig. 13), which

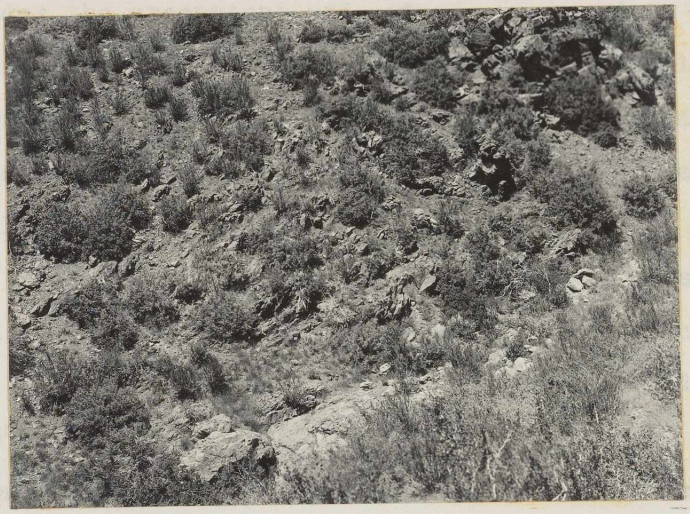


PLATE LXXI-A. Westward-dipping Yaeger greenstone immediately east of contact with Alder series.

PLATE LXXI-B. Dioritic (?) porphyry dike in Yaeger greenstone immediately east of contact with Alder series.

intrudes the greenstone and extends westward to the southern projection of the fault zone, is doubtless responsible for at least part of the hydrothermal metamorphism that has affected both the Alder series and the Yaeger greenstone in this area.

Immediately east of the fault the greenstone consists of coarse-grained, intensely sheared, clastic beds (Plate LXXI-A) which strike northward and dip 15° to 75° W. They have been intensely chloritized and carbonatized and weather pale yellowish-brown to dull green in color. Intruding them are large irregular dikes of dense, dark-colored rock which dominate the landscape (Plate LXXI-B) and probably are the "massive andesitic flows" of Lausen.[162] Examined microscopically, this rock shows skeletal phenocrysts of entirely sericitized feldspars in a fine-grained chloritic, sericitic groundmass.

In the central portion of the area, south of Mt. Mingus and 2 to 4 miles east of the Shylock mine, the greenstone contains relatively more recognizable volcanic members and has been extensively intruded by large dikes of diorite porphyry. There its bedding strikes

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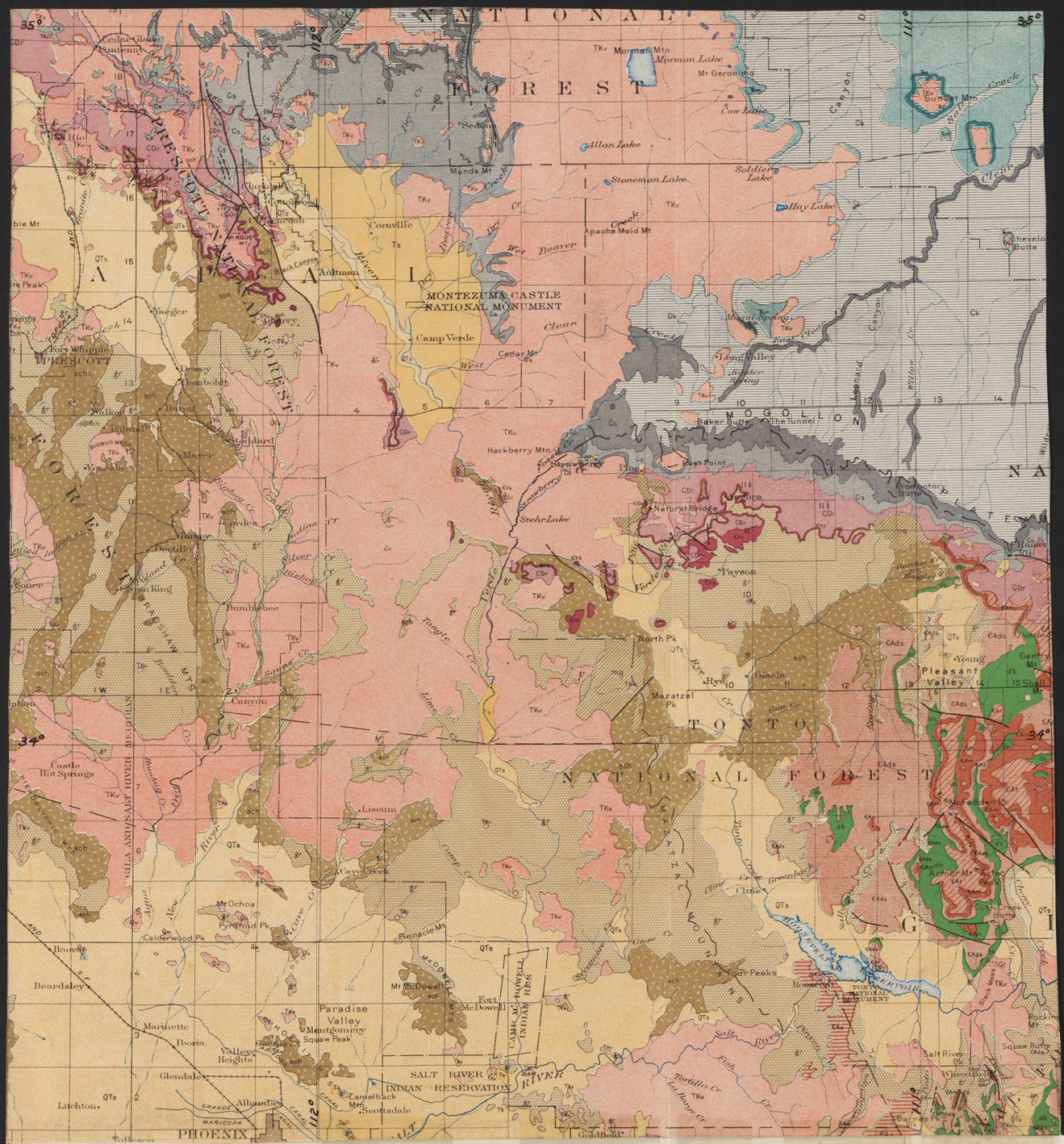
[162] Jour. Geol., vol. 38, p. 179, 1930.

N. 60° E. and dips steeply southeastward.

No definite evidence for the relations of the rhyolite to the greenstone was obtained. Wherever seen together, these two formations are in fault contact.

The lamination of the Alder series, which closely parallels original bedding, strikes N. 20° E. and dips steeply to almost vertically.

It is concluded that the principal structures in the southern portion of the Black Hills Range resulted from the Mazatzal Revolution. Large, closed folds, such as are characteristic of the Mazatzal Revolution, appear to have involved the Yaeger greenstone and Alder series, whose beds prevailingly strike northeast to northward and dip steeply. In all probability, the Red Rock rhyolite of the area was also involved in this folding. The faults that separate the Yaeger greenstone from the Red Rock rhyolite and Alder series strike northeast to northward. They are earlier than the Paleozoic beds and also, so far as known, earlier than the pre-Cambrian granite; hence their correlation with the Mazatzal Revolution seems highly probable.


NATIONAL FOREST
PRESCOTT NATIONAL FOREST
MONTEZUMA CASTLE NATIONAL MONUMENT
Camp Verde
Cornville
Clarkdale
Jerome
Mormon Mtn
Mormon Lake
Mt Geronimo
Sedona
Munds Mt
Allan Lake
Stoneman Lake
Soldier Lake
Hay Lake
Apache Maid Mt
Cow Lake
Sunset Mtn
Chevelon Butte
Long Valley
Baker Butte
The Tunnel
Hackberry Mtn
East Point
Natural Bridge
Strawberry
Stehr Lake
Payson
North Pk
Rye
Gisela
Mazatzal Pk
Pleasant Valley
Young
Gentry Mt
Shell Mt
TONTO NATIONAL FOREST
Liscum
Cave Creek
Mt Ochoa
Pyramid Pk
Calderwood Pk
Pinnacle Mt
Mt McDowell
Fort McDowell
Fort McDowell Indian Res
Four Peaks
Roosevelt
TONTO NATIONAL MONUMENT
Paradise Valley
Mentgomery Squaw Peak
SALT RIVER INDIAN RESERVATION
Camelback Mt
Scottsdale
PHOENIX
Glendale
Litchfield
Beardsley
Hoover
Castle Hot Springs
Salt River
Squaw Butte
Rocking Mt
Barnes Pk
Goldfield
Tortilla Cr
Fish Cr
Cline
Bumblebee
Cordes
Yarnell
Kirkland
Prescott
Dewey
Humboldt
Mayer
Stoddard
Wolfe
Yaeger
Cedar Glade
Puntenney
Rio!
Tore Whipple
Cedar Mt
Apache Spring
Mount Spring
Black Canyon
Black Mesa
Sycamore Cr
Verde
Tonto Creek
Salt River
Gila River
Hassayampa River
Lime Cr
Tangle Cr
Silver Cr
Indian Cr
Spring Cr
Gun Cr
Rye Cr
Pine Cr
Strawberry Cr
Clear Cr
Beaver Cr
Dry Cr
Wet Beaver Cr
Verde River
Sycamore Cr
Granite Cr
Big Bug Mts
Bradshaw Mts
Weaver Mts
Sierra Ancha Mts
Mogollon Mesa
Mogollon Rim
Garden Hayden
Cedar Creek
Sycamore Cr
Spring Cr
Gun Cr
Rye Cr
Pine Cr
Tonto Creek
Greenback Cr
Cline Cr
Salt River
Fish Cr
Tortilla Cr
Hassayampa River
Verde River
Gila

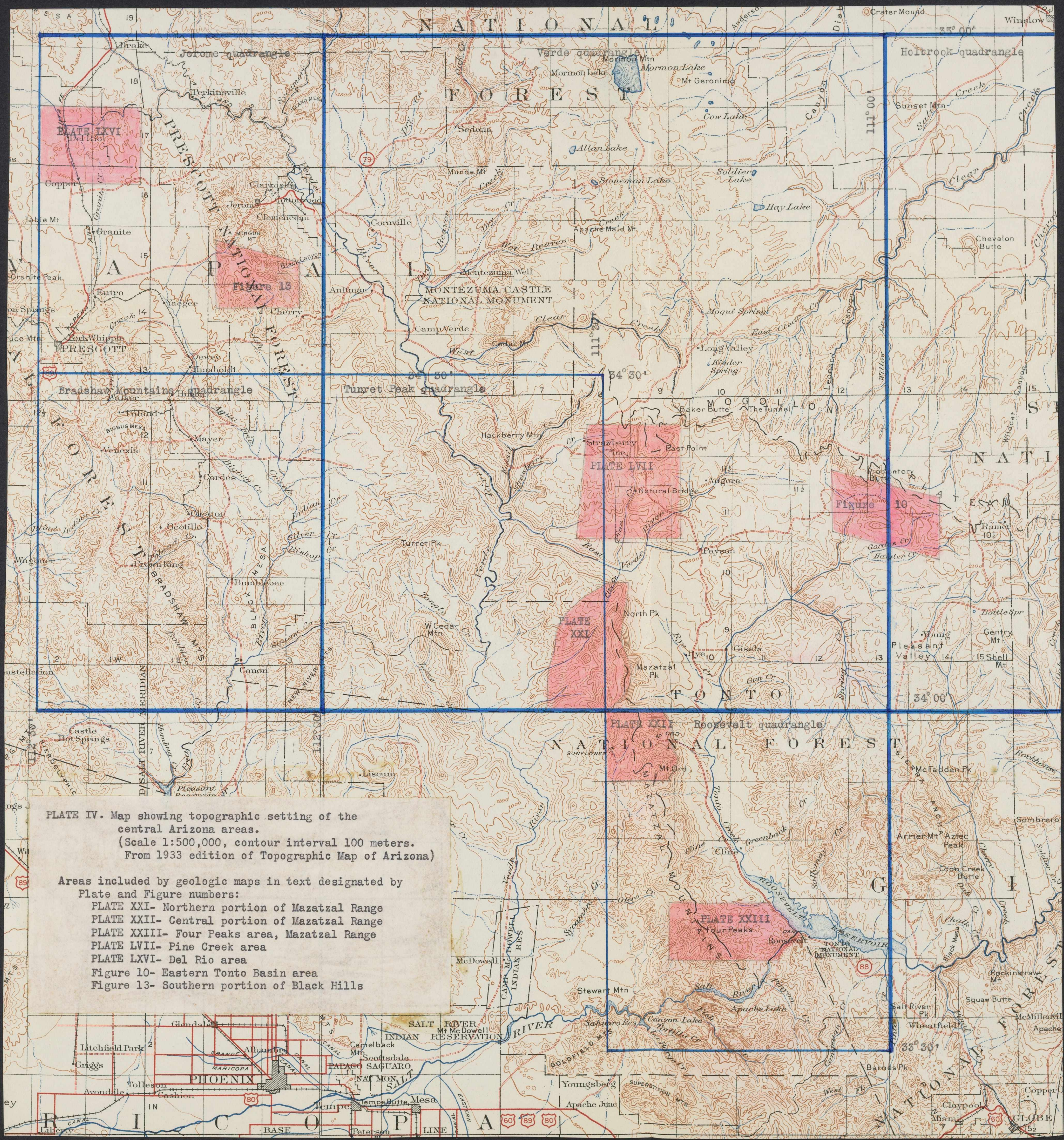
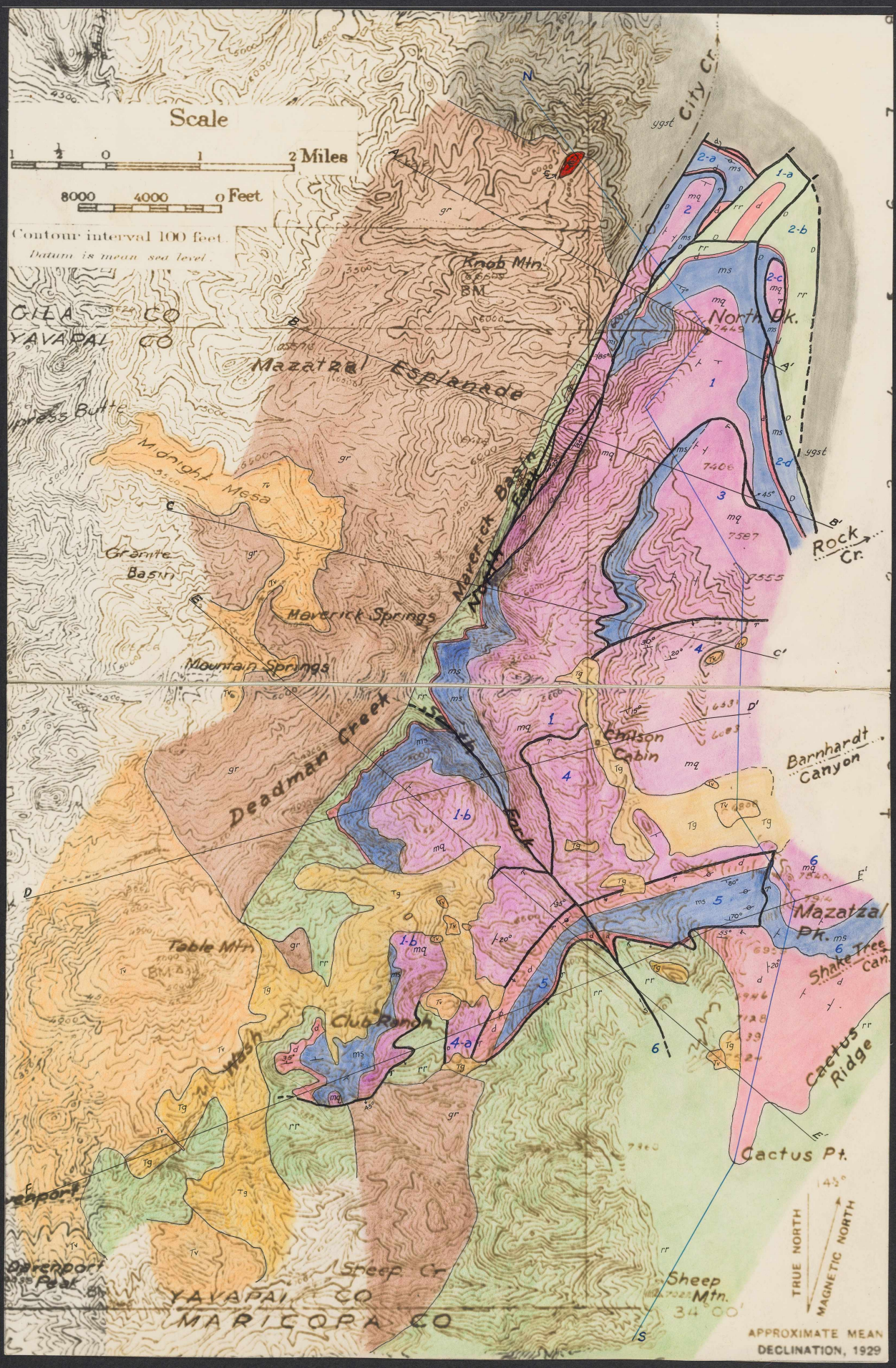


PLATE IV. Map showing topographic setting of the central Arizona areas.
(Scale 1:500,000, contour interval 100 meters. From 1933 edition of Topographic Map of Arizona)

Areas included by geologic maps in text designated by Plate and Figure numbers:

- PLATE XXI- Northern portion of Mazatzal Range
- PLATE XXII- Central portion of Mazatzal Range
- PLATE XXIII- Four Peaks area, Mazatzal Range
- PLATE LVII- Pine Creek area
- PLATE LXVI- Del Rio area
- Figure 10- Eastern Tonto Basin area
- Figure 13- Southern portion of Black Hills


Scale
1 ½ 0 1 2 Miles
8000 4000 0 Feet
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GILA CO
YAVAPAI CO
Knob Mtn
BM
Mazatzal Esplanade
Cypress Butte
Midnight Mesa
Granite Basin
Maverick Springs
Mountain Springs
Maverick Basin
North Fork
North Pk.
City Cr.
Rock Cr.
Deadman Creek
South Fork
Ellison Cabin
Barnhardt Canyon
Mazatzal Pk.
Snake Tree Can.
Table Mtn
Club Ranch
Cactus Ridge
Cactus Pt.
Davenport Peak
Sheep Cr.
Sheep Mtn.
YAVAPAI CO
MARICOPA CO
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1929

PLATE XXI. Geologic map of northern portion of Mazatzal Range.

EXPLANATION

Late Tertiary

- Tv — Basaltic and andesitic volcanic rocks
- Tg — Semi-consolidated, locally stratified gravel, sand, and silt

Middle Cambrian

- Ꞓ — Tapeats sandstone (Red-brown cross-bedded friable sandstone)

Early pre-Cambrian

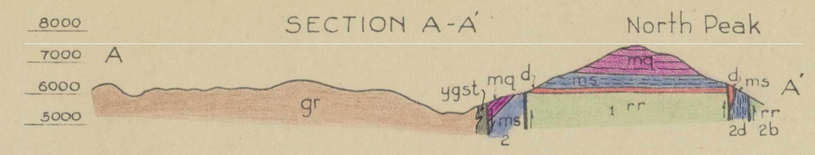
- gr — Granite (Intrusive masses)
- mq — Mazatzal quartzite (Light-brown to gray vitreous hard quartzite)
- ms — Maverick shale (Gray to maroon shale)
- d — Deadman quartzite (Light-brown to gray vitreous hard quartzite, pebbly at base)
- rr / ygst — Yavapai group
  - Red Rock rhyolite (rr) (Massive flows and agglomerate with small intrusives)
  - Yaeger greenstone (ygst) (Weakly metamorphosed intermediate to mafic volcanic rocks with some sedimentary beds)

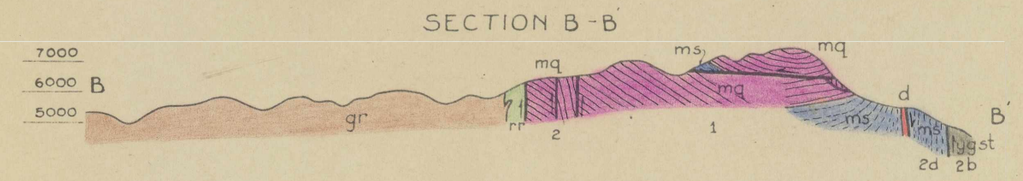
D — Normal fault (D, downthrown side)

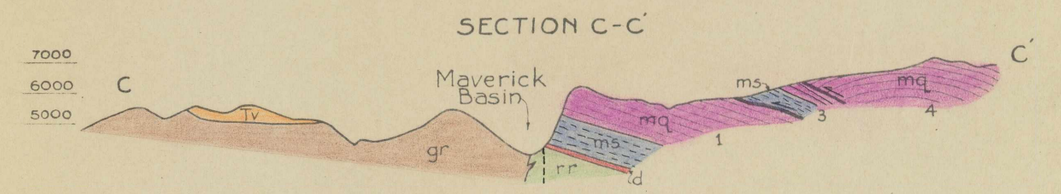
S — Tear fault

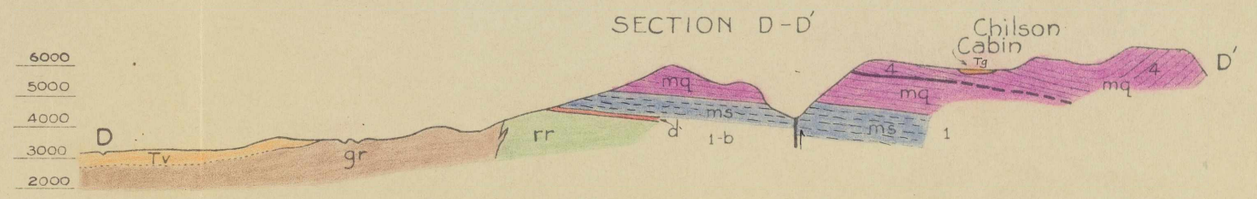
T — Thrust fault (T, overthrust side)

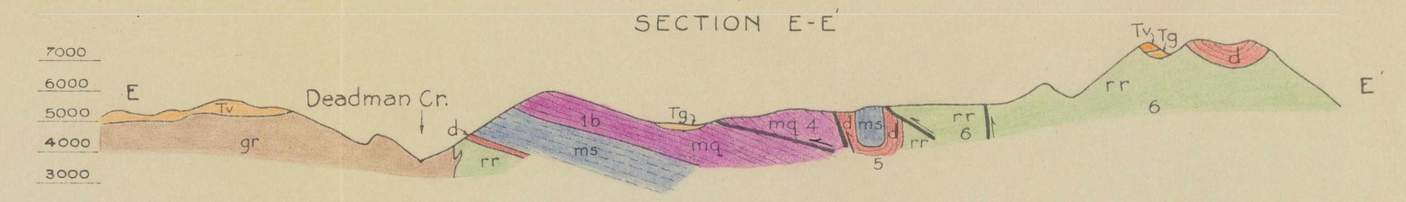
Numerals refer to fault blocks described in text

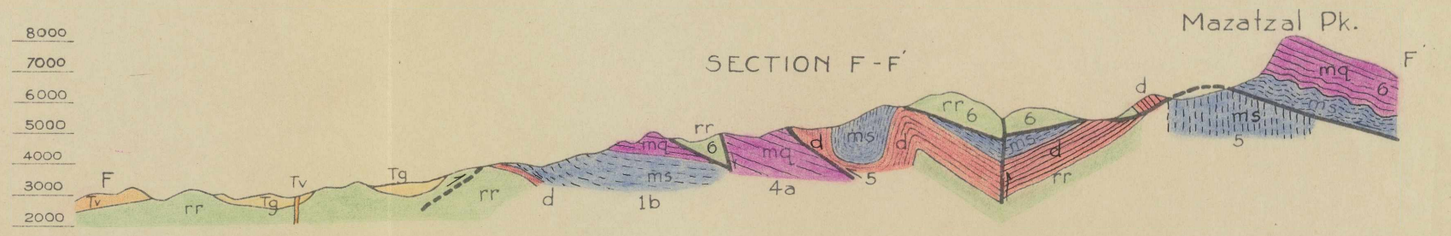


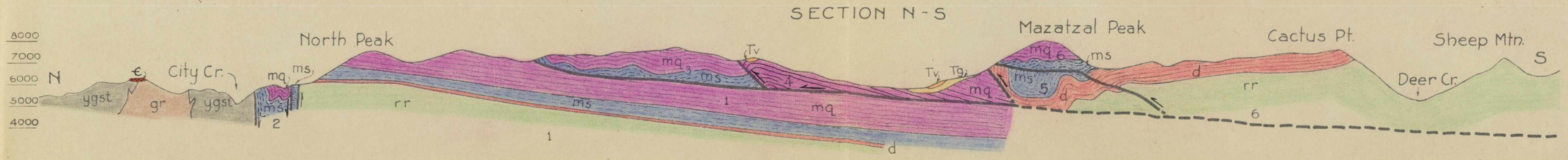












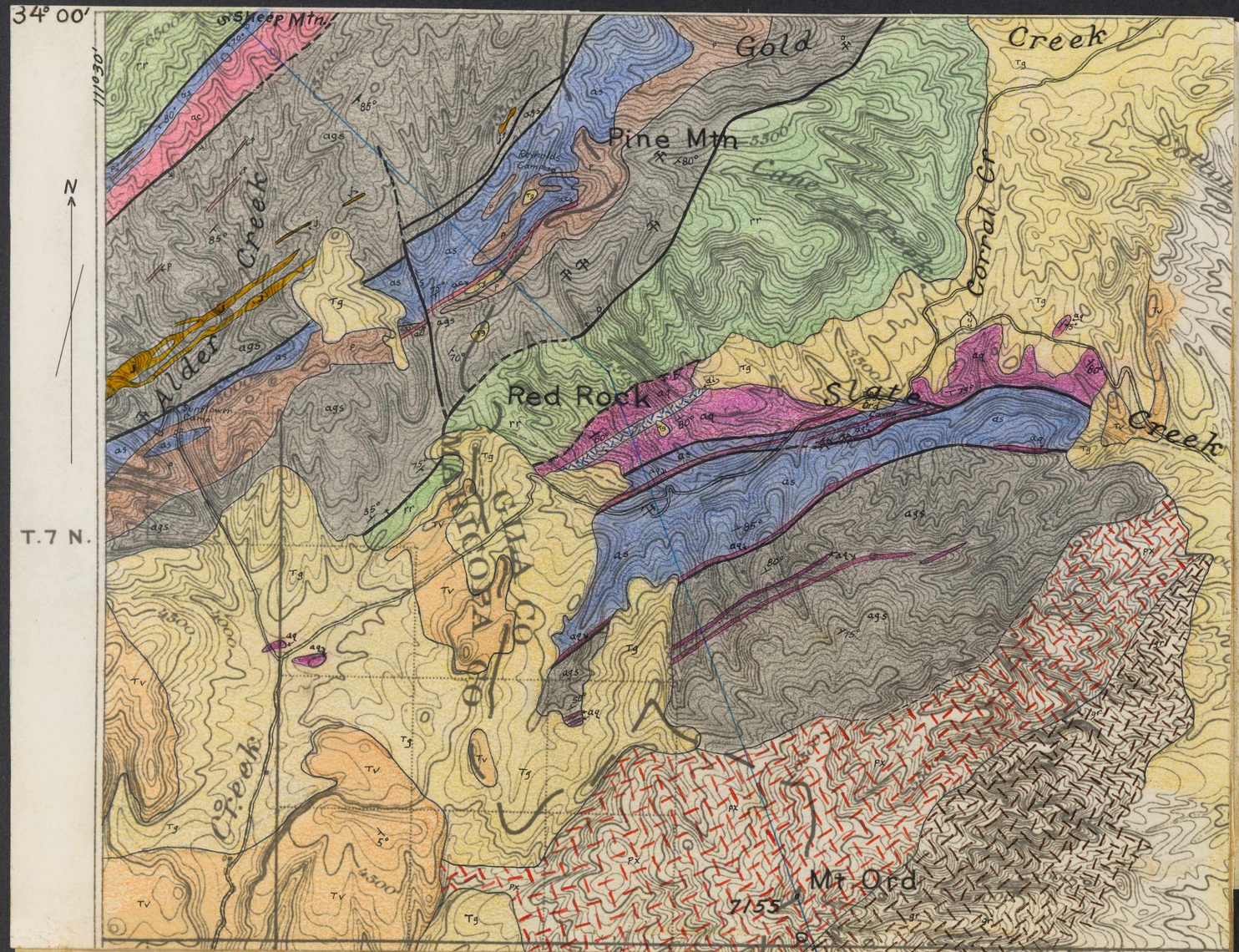


PLATE XXII. Geologic map of central portion of Mazatzal Range.

EXPLANATION

Late Tertiary

Carbonate-jasper formation (Hydrothermal vein and surface deposits)

Basaltic and andesitic volcanic rocks

Semi-consolidated, locally stratified gravel, sand and silt

Early pre-Cambrian

Pine Mountain porphyry (Irregular dikes of rhyolite porphyry)

Granite (Intrusive mass)

Mt. Ord pyroxenite (Stock and dikes of porphyritic pyroxenite)

Diorite porphyry (Dikes)

Yavapai group

Alder series

Grit, shale, and slate (ags)

Quartzite and grit (aq)

Conglomerate (ac)

Slate (as)

Red Rock rhyolite (rr) (Massive flows and agglomerate with small intrusives)

Normal fault (D, downthrown side)

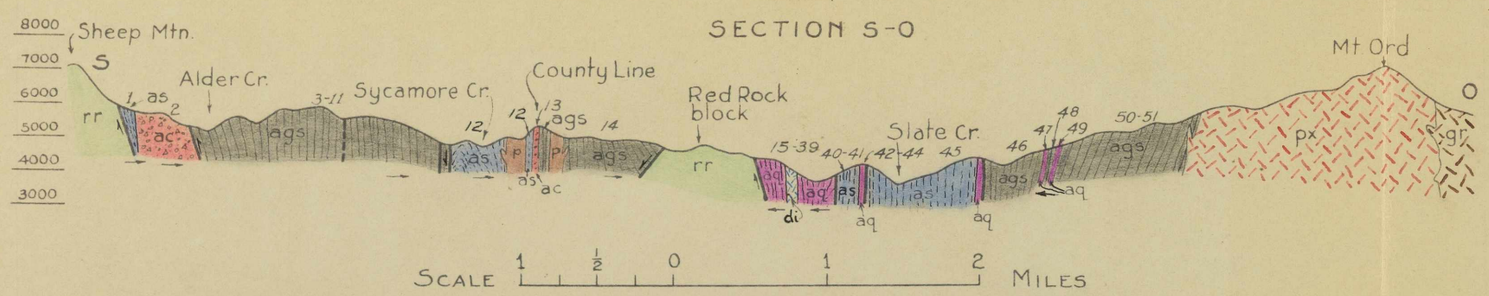
Thrust fault (⊣, overthrust side)

Tear fault

Direction of movement on faults in section

Top side of beds in section

Numerals of section refer to members described in text



DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

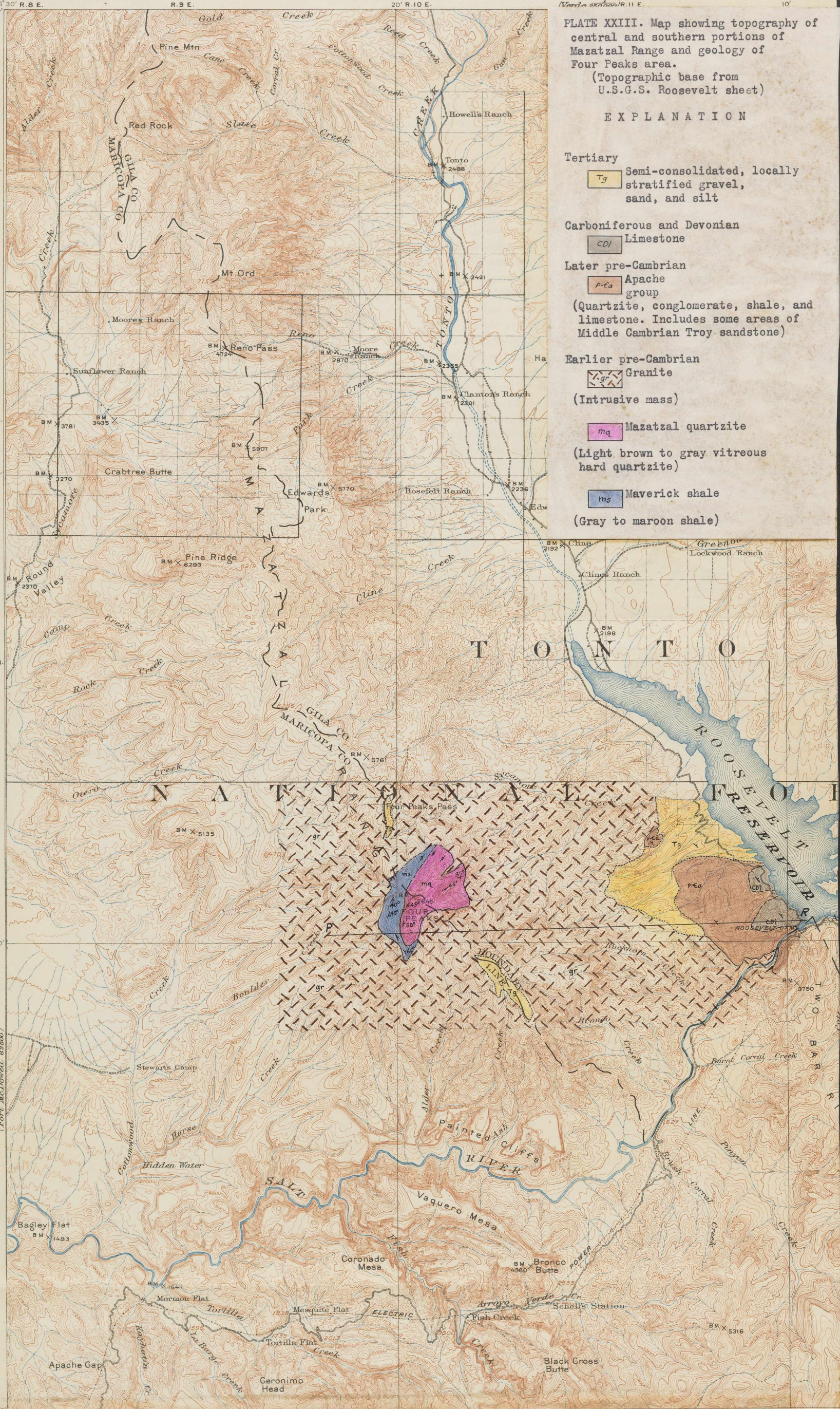


PLATE XXIII. Map showing topography of central and southern portions of Mazatzal Range and geology of Four Peaks area.
(Topographic base from U.S.G.S. Roosevelt sheet)

EXPLANATION

Tertiary

Tg — Semi-consolidated, locally stratified gravel, sand, and silt

Carboniferous and Devonian

CDl — Limestone

Later pre-Cambrian

p-Ꞓa — Apache group
(Quartzite, conglomerate, shale, and limestone. Includes some areas of Middle Cambrian Troy sandstone)

Earlier pre-Cambrian

gr — Granite
(Intrusive mass)

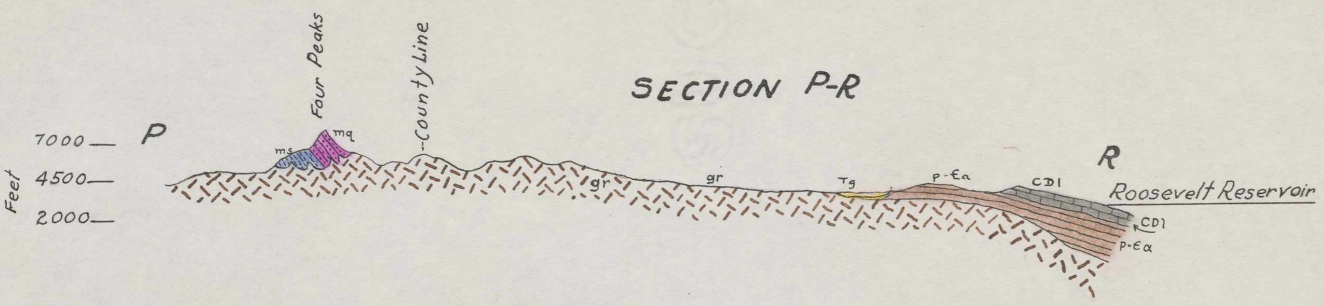
mq — Mazatzal quartzite
(Light brown to gray vitreous hard quartzite)

ms — Maverick shale
(Gray to maroon shale)

E.M. Douglas, Geographer.
T.M. Bannon, in charge of section.
Topography by T.M. Bannon, A.P. Meade, Jr., Gilbert Young, S.N. Stoner, J.I. Gayetty, and R.M. LaFollette.
Control by T.M. Bannon.
Surveyed in 1905 - 1907.

APPROXIMATE MEAN DECLINATION 1907.

Scale $\frac{1}{125000}$
1 ½ 0 1 2 3 4 5 Miles
1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 100 feet.
Datum is mean sea level.

SECTION P-R