Precambrian Geology of the Northern Bradshaw Mountains, Yavapai County, Arizona

GEOLOGICAL SURVEY BULLETIN 1336

Precambrian Geology of the Northern Bradshaw Mountains, Yavapai County, Arizona

By C. A. ANDERSON *and* P. M. BLACET

GEOLOGICAL SURVEY BULLETIN 1336

A study of the stratigraphy and the structure of the Precambrian stratified and associated intrusive rocks

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1972

UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, *Secretary*

GEOLOGICAL SURVEY

V. E. McKelvey, *Director*

Library of Congress catalog-card No. 72–600084

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 (paper cover)
Stock Number 2401–2101

CONTENTS

ILLUSTRATIONS

TABLES

PRECAMBRIAN GEOLOGY OF THE NORTHERN BRADSHAW MOUNTAINS, YAVAPAI COUNTY, ARIZONA

By C. A. Anderson and P. M. Blacet

ABSTRACT

The Precambrian and younger rocks of the Bradshaw Mountains have been mapped in the northeast quarter of the Mount Union quadrangle and the northwest quarter of the Mayer quadrangle to provide a guide for mineral exploration. The Precambrian stratified rocks are largely assigned to the Big Bug Group of the Yavapai Series and total approximately 20,000 feet in thickness. These rocks consist of volcanic, volcaniclastic, and some sedimentary rocks that have been metamorphosed to the greenschist facies. Higher grade metamorphic rocks are present adjacent to the younger plutonic rocks.

The Big Bug Group is divided into three formations. The oldest, the Green Gulch Volcanics, consists of a basal dark-gray slate overlain by pillow and amygdaloidal mafic flows that contain intertonguing rhyolitic rocks and mixed rhyolitic and mafic tuffaceous beds. The Spud Mountain Volcanics, the middle formation, is divided into a lower unit and an upper unit. The lower unit is dominated by bedded andesitic-rhyolitic breccia with coarse-graded bedding suggesting subaqueous pyroclastic flows. Southward in the Mount Union quadrangle, these breccia beds grade into thickly bedded coarse-grained crystal tuffs. The upper unit is dominated by bedded andesitic and rhyolitic tuffaceous sediments that intertongue with the lower part of the overlying Iron King Volcanics, the youngest formation. The Iron King Volcanics is a thick sequence of pillow and amygdaloidal mafic flows containing interbeds of sedimentary rock, including ferruginous cherts and small amounts of rhyolitic flows and tuffs.

Intrusive masses of quartz porphyry occur in all three formations of the Big Bug Group, but the large masses are limited to the Spud Mountain Volcanics. A large mass of granophyre intrudes these volcanic rocks. The presence of clasts of quartz porphyry in some of the volcanic breccia beds suggests that the quartz porphyry and granophyre represent rhyolitic magma that crystallized at shallow depths in the volcanic pile or locally reached the surface as protrusive domes.

Large masses of Precambrian quartz-bearing plutonic rocks younger than the Big Bug Group are found only in the northwest and northeast corners of the mapped area, but earlier gabbroic rocks are more widespread, occurring in part as masses semiconcordant with the volcanic rocks. These gabbroic rocks may represent sills of mafic magma injected during the accumulation of the

thick sequences of mafic volcanics. Some of the larger masses of gabbro may have been intruded after the deformation of the Big Bug Group. The quartz-bearing plutonic rocks include quartz diorite, which is part of a large pluton exposed chiefly to the north in the Mingus Mountain quadrangle; the Government Canyon Grandodiorite, which resembles a pluton exposed to the northwest in the Prescott quadrangle; and the Crooks Canyon Granodiorite, which is the dominant Precambrian plutonic rock in the Mount Union quadrangle. Small masses of alaskitic rocks are exposed in the northern part of the Mount Union quadrangle; they intrude the Government Canyon Granodiorite. Prescott Granodiorite and fine-grained granite are southward extensions of larger masses exposed to the north.

The Texas Gulch Formation, composed of slate, bedded rhyolitic tuff, arkosic sandstone, and conglomerate, was deposited on the Brady Butte Granodiorite in the southeast quarter of the Mount Union quadrangle, but in the area of this report, all outcrops of Texas Gulch Formation are bounded by faults. As radiometric dating has proved that the Brady Butte Granodiorite is younger than the Big Bug Group, the Texas Gulch Formation is not included in that group.

Stocks of granodiorite and dikes of rhyolite porphyry emplaced during Late Cretaceous or early Tertiary time are exposed largely in the Mount Union quadrangle. Many of the smaller ore deposits in this region are related to these rocks.

The Hickey Formation of late Miocene and early Pliocene age covers large areas of the Precambrian rocks; it consists of basaltic flows and intertonguing gravel, sand, silt, and marl. Older gravels of late Pliocene or Pleistocene age, younger Quaternary gravels, terrace deposits, and riverwash occur locally.

Three structural blocks of Precambrian rocks are defined by the Chaparral fault and Shylock fault zone. Northwest of the Chaparral fault, the dominant Green Gulch Volcanics forms a northwestward-trending anticline and northeastward-trending syncline. The large block between the Chaparral fault and Shylock fault zone contains two major folds, an overturned anticline and complementary syncline, both trending northeastward. These two folds are separated by a long narrow fault block of Texas Gulch Formation that widens southward into a north-plunging anticline. East of the Shylock fault zone, minor folds in Spud Mountain Volcanics trend northwestward adjacent to this major fault zone, but farther east, trends in similar rocks are more westerly.

The Shylock fault zone is a major Precambrian structural feature consisting of a zone about 1 mile wide containing fault slices of diverse Precambrian rocks. A minimum of 5 miles of right-lateral slip is indicated. The Chaparral fault also has a component of right-lateral slip, but it does not contain the spectacular fault slices found in the Shylock fault zone.

Mining activity started about 1875, when rich silver-gold deposits were discovered; mining of base metals followed in the early part of the 20th century. During and after World War II, base metals were mined at six deposits, but during the period of this geological survey, no mines were operating.

INTRODUCTION

The Bradshaw Mountains are in central Arizona, south of Prescott. The economic importance of the Iron King lead-zinc mine in the Prescott quadrangle and of copper mines in the Mingus Mountain quadrangle stimulated earlier studies of the Precambrian rocks

(Krieger, 1965; Anderson and Creasey, 1958) to obtain the regional geologic setting as a guide for future mineral exploration. This report on the northern Bradshaw Mountains discusses the southward extension of some of the Precambrian geology of the Prescott and Mingus Mountain quadrangles and clarifies some of the stratigraphic and structural uncertainties. It covers an area equivalent to two 7½-minute quadrangles, the northeast quarter of the Mount Union quadrangle and the northwest quarter of the Mayer quadrangle (fig. 1). (The bases for the geologic maps, plates 1 and 2, are the 7½-minute parts of the Mount Union and Mayer quadrangles enlarged to a scale of 1:24,000 from the 15-minute topographic maps.)

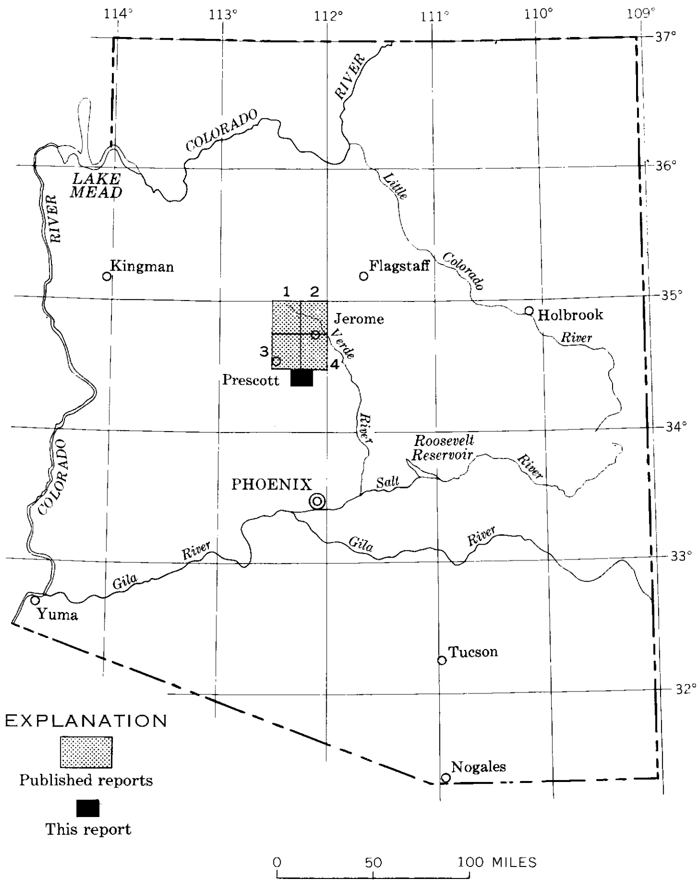


FIGURE 1.—Index map of Arizona showing location of the area covered by this report. Geologic maps of the adjacent Prescott and Jerome areas have been published (Anderson and Creasey, 1958; Lehner, 1958; Krieger, 1965). 1, Paulden quadrangle; 2, Clarkdale quadrangle; 3, Prescott quadrangle; 4, Mingus Mountain quadrangle.

The pioneer work of Jaggar and Palache (1905) is the first adequate description of the Precambrian rocks in the Bradshaw Mountains, and it is a pleasure to report the overall excellence of their reconnaissance survey. An important work on the ore deposits by Lindgren (1926) contains a wealth of information on the mines and prospects. Preliminary geologic maps of the two 7½-minute quadrangles have been released (Anderson, 1959; Anderson and Blacet, 1962), and geologic maps of the Mount Union and Mayer 15-minute quadrangles are in press (Anderson and Blacet, 1972a, b).

ACKNOWLEDGMENTS

Fred Gibbs of Prescott, Ariz., has long familiarity with the mining activities in the area covered by this report, and he has been generous with information that was not available elsewhere. We are grateful for his careful review of the chapter on ore deposits. L. L. Farnham of Tucson, Ariz., kindly provided data on the last operations at the Boggs mine.

We wish to thank L. T. Silver, of the California Institute of Technology, and our colleague T. W. Stern for their tremendous help in the isotopic dating of the Precambrian volcanic and plutonic rocks in the Prescott-Jerome area which has helped resolve some of the stratigraphic and structural problems in the area. Their review of the geology in critical areas to guide sampling for isotopic studies helped us to reorient our thinking and modify early conceptions.

PRECAMBRIAN ROCKS

YAVAPAI SERIES

The Precambrian stratified rocks in the Prescott and Jerome areas were assigned to the Yavapai Series by Anderson and Creasey (1958). In the Mingus Mountain quadrangle, two groups were distinguished: the Ash Creek and the Alder, separated by the Shylock fault. No evidence was found to indicate their age relations. Subsequent isotopic dating has revealed that the Ash Creek Group is older and that the term Alder Group should be replaced by the new name Big Bug Group (Anderson and others, 1971). In the area covered by this report, the Big Bug Group is the only part of the Yavapai Series that is exposed.

Isotopic dating makes it possible to use the name Yavapai Series as a provincial time-stratigraphic term, defined as the time interval from 1,770±10 m.y. to 1,820 plus m.y. (million years) (Anderson and others, 1971).

The stratified rocks composing the Yavapai Series are largely of volcanic origin, and although these rocks are metamorphosed, sufficient relict textures and structures are exposed to determine the character of the rocks before metamorphism. Therefore, the prefix "meta" is not used in our stratigraphic nomenclature. Most of the rocks in the Yavapai Series are in the greenschist facies, but higher grade metamorphic rocks are present adjacent to younger intrusive rocks.

BIG BUG GROUP

The Big Bug Group is exposed along the west margin of the Mingus Mountain quadrangle (Anderson and Creasey, 1958) and in the southern part of the Prescott quadrangle (Krieger, 1965) and extends southward into the area covered by this report. In general, the deformation of the Big Bug Group was intense to the west of the Shylock fault zone, resulting in isoclinal folds and pervasive foliation complicated by later faulting. To the east of the Shylock fault zone, deformation was less intense, and foliation is not pervasive.

The Big Bug Group is divided into three formations. The youngest, the Iron King Volcanics, and the oldest, the Green Gulch Volcanics, contain pillow and amygdaloidal mafic flows, whereas the middle formation, the Spud Mountain Volcanics, consists of an intertonguing complex of andesitic and rhyolitic pyroclastic rocks and amygdaloidal mafic flows. The thickness of the Big Bug Group cannot be measured with confidence because of the probability that unrecognized small folds on the flanks of the major folds duplicate the section and because of probable thinning and thickening of units during deformation. An additional complication is the known lenticularity of some of the volcanic units in the group. A reasonable estimate of the thickness is 20,000 feet.

GREEN GULCH VOLCANICS

The Green Gulch Volcanics is a sequence of basaltic and rhyolitic flows and tuffaceous beds of variable composition well exposed in Green Gulch northwest of the Chaparral fault in the southeast corner of the Prescott quadrangle (Krieger, 1965, p. 17). All exposures of the formation in the area of this report are north of the Chaparral fault (pl. 1). Basaltic and rhyolitic rocks in the northwestern part of the Mingus Mountain quadrangle were named Indian Hills Volcanics by Anderson and Creasey (1958, p. 20–21), but subsequent studies have proved that these rocks are the Green Gulch Volcanics (Anderson and others, 1971).

In the Prescott quadrangle in the type section, the basaltic flows face both east and west, but the prevalence of west-facing flows suggests that the rhyolitic tuffaceous beds to the west overlie the basaltic flow unit. Krieger (1965, p. 17) estimated that the Green Gulch Volcanics in the type section is more than 5,000 feet thick. Recent mapping by Anderson in the western part of the Mount Union quadrangle suggests a greater thickness; 7,000 feet is likelier to be the minimum.

In the southern part of the Prescott quadrangle (Krieger, 1965, pl. 1) and northern part of the Mount Union quadrangle (pl. 1), the Green Gulch Volcanics is separated by intrusive igneous rocks of diverse types; thus correlations of widely spaced stratified rocks are difficult. Krieger (1965) cautiously avoided assignment of some of the volcanic rocks in the southern part of the Prescott quadrangle to specific formations; these rocks can now be assigned to the Green Gulch Volcanics (Anderson and others, 1971).

In the area of this report, the basaltic flows of the Green Gulch Volcanics are best exposed along Lynx Creek and its tributaries, shown in the northwest corner of plate 1. The polished outcrops in the streambeds reveal excellent relict structures such as vesicles, amygdules, flow-breccia tops, and pillows. The concentration of vesicles and amygdules at flow tops and the shapes of some of the pillow structures are useful for determining the directions that the flows face; knowing these directions permits structural interpretations of the sequence. The flows are commonly separated by interbedded sedimentary rocks, locally 50 feet thick. Bedded chert, slate, and tuffaceous beds containing rhyolitic clasts are common. Some of the thick chert beds show intense plastic deformation, presumably the result of slumping before later flows buried the sediment.

In the northwest corner of the area shown on plate 1, light- to dark-gray slate forms the core of an anticline (section *A–A′*). This band of slate (ggs on pl. 1) extends northward into the Prescott quadrangle, forming wider exposures consisting in part of ferruginous chert and pebble-conglomerate beds. The structural relations prove that these slaty beds are older than the overlying basalts and that they represent the basal part of the Green Gulch Volcanics. Northward the slate belt contains some thin amygdaloidal basaltic flows. Krieger (1965, pl. 1), on the advice of Anderson, designated these slaty rocks in the Prescott quadrangle as the Texas Gulch Formation. However, isotopic dating has proved that correlation of the slate beds with the Texas Gulch Formation is erroneous (Anderson and others, 1971).

The slaty rocks in the northwest corner of the area shown on plate 1 have a fine clastic texture with the grain size averaging about 0.03 millimeter in diameter. Numerous quartz grains are separated by abundant chloritic flakes, epidote granules, and disseminated magnetite crystals.

In general, the basalt is poorly foliated, and relict intergranular textures revealed in thin section show little or no obvious mineral orientation. Albitic feldspar averaging about 0.1 mm in length is generally separated by yellow-green to greenish-blue amphibole, but in a few specimens fine crystalline chlorite is the matrix. Epidote, commonly associated with chlorite, is present in granules and clots. Small grains of quartz are uniformly distributed throughout the rock. Some specimens contain abundant black opaque grains; in others, granular sphene is the abundant minor accessory mineral. Veinlets of chlorite and calcite are common. Locally, the interior of some flows contains plagioclase phenocrysts 10 mm long. The silica content shown by two chemical analyses of Green Gulch basalt given in table 1 suggests that these volcanic rocks are on the border between the basalt and the andesite fields.

TABLE 1.—*Chemical analyses of rocks in Green Gulch Volcanics*

[Rapid rock analyses by Paul Elmore, Sam Botts, Lowell Artis, Gillison Chloe, John Glenn, and Hezekiah Smith]

	1	2	3	4	5
SiO_2	51. 0	51. 2	59. 4	70. 3	77. 3
Al_2O_3	14. 9	15. 9	16. 1	15. 2	12. 3
Fe_2O_3	4. 5	3. 1	3. 8	1. 4	. 46
FeO	9. 5	10. 3	3. 9	1. 4	. 58
MgO	4. 2	4. 7	2. 1	. 40	. 1
CaO	6. 3	7. 5	5. 9	1. 8	. 95
Na_2O	1. 7	3. 7	3. 5	4. 0	4. 0
K_2O	. 04	. 69	. 70	4. 0	3. 0
K_2O^-	. 06	. 02	. 04	. 03	. 10
H_2O^+	3. 9	1. 4	2. 1	. 87	. 33
TiO_2	2. 4	. 67	1. 0	. 41	. 14
P_2O_5	. 26	. 11	. 24	. 08	. 02
MnO	. 23	. 23	. 13	. 04	. 02
CO_2	. 35	. 05	. 40	. 09	. 18
SO_3	. 00	. 05	---	---	---
Powder density	---	---	2. 85	2. 70	2. 66
Bulk density	2. 94	3. 00	2. 85	2. 70	2. 66

1. Amygdaloidal basalt, Mount Union quad., 1,268,400 N., 362,100 E.
2. Pillow basalt, Mount Union quad., 1,272,300 N., 364,650 E.
3. Tuffaceous siltstone, Mount Union quad., 1,267,000 N., 372,100 E.
4. Rhyolitic flow, Mount Union quad., 1,268,100 N., 376,500 E.
5. Flow-banded rhyolite, Mingus Mountain quad., 1,330,600 N., 404,900 E.

Tuffaceous rocks consisting largely of mixed rhyolitic and mafic volcanic detritus crop out on the northwest side of the Chaparral fault. The distinction in the field between these tuffaceous rocks and some of the flows is difficult because of the poor exposures. The unweathered mixed tuffaceous beds are dark gray, but in general the outcrops are buff. The chemical composition of a tuffaceous siltstone (table 1, No. 3) suggests a rock of mixed parentage.

The rhyolite occurs as flows, as small intrusive masses, and as tuffaceous beds. The tuffs are generally foliated and consist chiefly of quartz and sericite. The flows and intrusives are generally nonfoliated and have sharp albitic phenocrysts 0.5–1.5 mm long in a microcrystalline patchy groundmass of quartz and alkalic feldspar accompanied by some sericite. Albitic microlites commonly show flow structure around the larger feldspar phenocrysts. Granular sphene, black opaque granules, epidote and clinozoisite, and apatite are present. Chemical analyses of two rhyolitic flows in table 1 (Nos. 4, 5) show that the rhyolite from the Mount Union quadrangle is almost a dacite in composition, whereas the rhyolite from the Mingus Mountain quadrangle is a true rhyolite.

SPUD MOUNTAIN VOLCANICS

The Spud Mountain Volcanics has been divided into two units: the lower one, characterized by beds of volcanic breccia, contains many angular clasts of rhyolite and porphyritic andesite, and the upper unit consists largely of bedded andesitic tuffaceous rocks. The transition from the andesitic breccia to the overlying tuffaceous rocks is gradational in many places, and locally the position of the contact is arbitrary. In the NW¼ Mayer quadrangle (pl. 2) the Shylock fault zone, which contains a faulted wedge of Texas Gulch Formation, intrusive plugs of diorite porphyry, and wide dikes of quartz porphyry, separates the lower breccia facies to the east from the younger tuffaceous facies to the west.

Generalized columnar sections of the Spud Mountain Volcanics sequence exposed in the Mount Union and Mayer quadrangles are shown in figure 2. The base of the formation is poorly exposed in the NE¼ Mount Union quadrangle (northwest corner of pl. 1), but it is not exposed elsewhere in the area covered by this report. The top of the upper unit is not exposed in the NE¼ Mount Union quadrangle (pl. 1), for it is cut out by major faults or destroyed by younger intrusive rocks; however, it is well exposed in the NW¼ Mayer quadrangle (pl. 2), where it intertongues with the younger Iron King Volcanics.

The determination of the thickness of the Spud Mountain Volcanics is difficult because beds are duplicated by minor folding. The maximum thickness shown in figure 2, 12,000 feet, is an approximation.

Andesitic Breccia

The andesitic breccia, limited to the lower unit of the Spud Mountain Volcanics, consists of massive to poorly bedded breccia containing interbeds of crystal tuff, tuffaceous sandstone, siltstone, and, locally, thin beds of ferruginous chert. These interbeds are well exposed along the larger stream channels; in areas of poor exposures, only the more massive breccia beds are revealed.

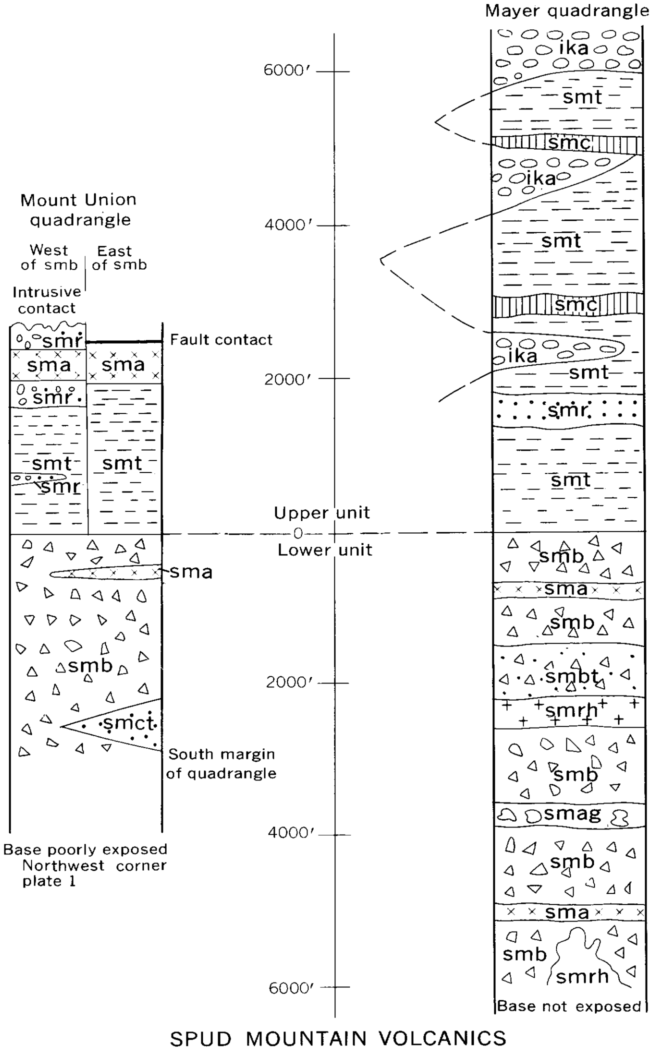


FIGURE 2.—Generalized columnar sections of Spud Mountain Volcanics and basal section of Iron King Volcanics illustrating the lenticularity and variation in the lithologic types. Thicknesses are only approximate. Iron King Volcanics: ika, andesitic and basaltic flows. Spud Mountain Volcanics, upper unit: smt, bedded andesitic tuffaceous sedimentary rocks; smr, rhyolitic tuffs and flows; sma, andesitic and basaltic flows; smc, interbedded ferruginous chert and slate. Spud Mountain Volcanics, lower unit: smb, andesitic breccia; sma, andesitic and basaltic flows; smag, interbeds of andesitic agglomerate; smbt, thick interbeds of fine-grained tuffaceous sedimentary rocks; smct, massive-bedded crystal tuff; smrh, rhyolitic breccia and tuff and intrusive rhyolite.

The breccia is well exposed in the core of a northeast-trending overturned anticline in the northeastern part of the Mount Union quadrangle (pl. 1). In Big Bug Mesa in the southern part of the area covered by plate 1, the breccia is largely covered by the Hickey basalts. South and southeast of this mesa, only lenses of breccia mixed with andesitic tuff of the upper unit of the Spud Mountain Volcanics crop out. This outcrop pattern may be formed by small folds plunging either southwest or northeast or by intertonguing of the breccia and tuff. No evidence is available to resolve this problem, but the existence of folds is reasonable and the preferred interpretation.

Along the south margin of the area shown on plate 1, the breccia lenses are associated with thickly bedded quartz-bearing crystal tuff that extends southward into the SE¼ Mount Union quadrangle, where Blacet (1968) found it to be the dominant rock type of the lower unit of the Spud Mountain Volcanics. The thinning of the breccia south of the Big Bug Mesa can be explained by assuming that the major anticline plunges southwestward; if this interpretation is valid, a reversal of plunge of the major anticline is required to explain the wide outcrops of breccia and contemporaneous crystal tuff in the SE¼ Mount Union quadrangle.

North of the Chaparral fault (pl. 1), poor exposures of volcanic breccia reveal porphyritic andesitic clasts that permit correlation of these rocks with the Spud Mountain breccia. Andesitic breccia also crops out within and east of the Shylock fault zone, but outcrops are small in size and few in number to the east of the splay of the Shylock fault (pl. 2).

The massive breccia contains clasts ranging in size from 1 to 18 inches across, and in some beds the size of the clasts may be uniform. In general, the thinner breccia beds contain the smaller clasts. Coarse-graded bedding is well exposed locally (pl. 1, 1,267,000 N., 387,300 E. to 1,267,650 N., 388,400 E.). These graded beds are 10–30 feet thick, and clasts 2–6 inches across are concentrated at their base; upward, in beds of crystal tuff, angular and somewhat equant-shaped plagioclase grains, 2–5 mm in diameter, are embedded in a fine-grained matrix. These crystal tuff beds grade upward to thinly bedded siltstone, 1 foot or more thick, that is overlain by a younger breccia bed that grades upward into another top unit of siltstone. These coarse-graded breccia beds are undoubtedly in part the product of turbidity current deposition and resemble subaqueous pyroclastic flows (Fiske, 1963; Fiske and Matsuda, 1964).

The dominant rock type forming clasts in the breccia is porphyritic andesite containing saussuritized plagioclase phenocrysts, generally 4–8 mm long, arranged in clusters or as separate crystals (fig. 3).

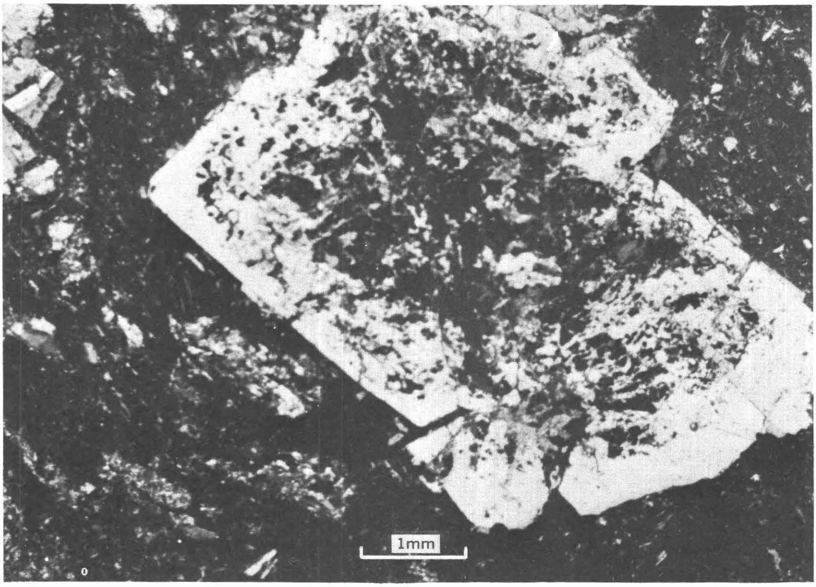


FIGURE 3.—Conspicuous plagioclase phenocryst in microcrystalline groundmass of albitic laths and interstitial chlorite and sericite in clast from Spud Mountain breccia. Center of phenocryst clouded by clinozoisite and calcite. Crossed nicols. (Pl. 2, 1,250,000 N., 416,800 E.).

In the northwest quarter of the Mayer quadrangle, the feldspar, albite, is clouded with sericite and contains variable amounts of clinozoisite or calcite. The microcrystalline groundmass is composed of albite laths separated by chlorite, epidote, clinozoisite, leucoxene, and, locally, calcite. Microphenocrysts of quartz, 0.5–1 mm in diameter, were observed in a few thin sections, but no quartz was visible in the groundmass; microgranular aggregates of quartz were noted in the groundmass in other thin sections. Some samples show chlorite arranged parallel to foliation planes. In the northeast quarter of the Mount Union quadrangle, the plagioclase phenocrysts contain much more clinozoisite than does the andesite breccia in the northwest quarter of the Mayer quadrangle; also, the groundmass of the breccia in the Mount Union contains more epidote and white to green amphibole, but less chlorite. In some breccia beds, vesicular and amygdaloidal andesitic clasts are present: they are either aphyric or porphyritic with small (1 mm) phenocrysts of saussuritized plagioclase.

Rhyolitic clasts are abundant throughout the breccia but may be absent in many beds. The clasts are light colored and felsitic and locally contain small (0.5–1 mm) phenocrysts resembling those in rhyolitic flows and intrusives described in this section under "Rhyo-

458-804 O - 72 - 2

litic Rocks." In general the rhyolitic clasts are smaller in size than the associated andesitic clasts. Two unusual types of rhyolitic clasts were noted. One type contains quartz and albite phenocrysts, 0.5–2 mm across, embedded in a microgranular aggregate of quartz and alkalic feldspar cut by streaks of clinozoisite granules. The other type has round micrographic quartz and albite, 1 mm in diameter, as well as separate quartz phenocrysts, 0.5 mm in diameter, both embedded in a patchy microcrystalline groundmass of quartz, albite, and clinozoisite. The clasts with micrographic intergrowth may have been picked up from an underlying granophyre.

The matrix of the breccia consists largely of andesite clasts that range in size from granules to fine sand, but also contains subordinate angular- to equant-shaped grains of saussuritized plagioclase. In many places the lithic andesite clasts are nonporphyritic, and some are highly vesicular with quartz and chlorite filling the vesicles (fig. 4). In some breccia beds the matrix appears ashy: lenticular to platy clasts containing albitic laths are embedded in what may have been pumice, now collapsed and bent around the laths. In breccia beds containing rhyolitic clasts, the matrix contains quartz grains and

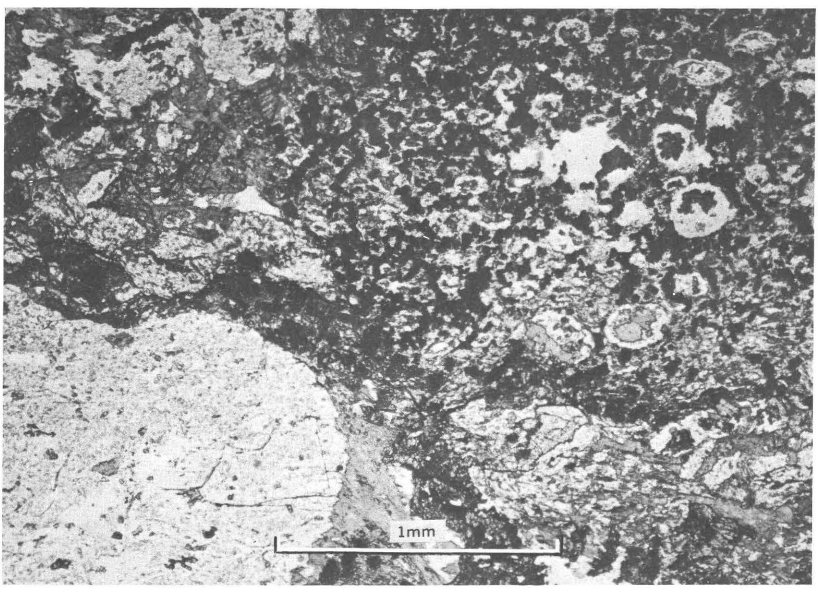


FIGURE 4.—Lithic and crystal clasts in matrix of Spud Mountain breccia. Albitic plagioclase (lower left corner) and vesicular andesite (upper right corner). Chloritic nests and granular clinozoisite in fine-grained matrix. Ordinary light. (Pl. 2, 1,248,300 N., 417,000 E.)

chips of rhyolite. In the northeast quarter of the Mount Union quadrangle pale-green amphibole, clinozoisite, and epidote are common in the matrix, and chlorite is sparse. In the northwest quarter of the Mayer quadrangle, the matrix contains clinozoisite, epidote, sericite, and chlorite in abundance.

The thickly bedded and generally massive crystal tuff that intertongues with the breccia south of Big Bug Mesa is characterized by abundant stubby crystals and crystal fragments of albite, up to 5 mm long, and by nearly ubiquitous sparsely scattered quartz "eyes" set in a fine-grained matrix. The distinctive quartz "eyes" range in size from 1 to 5 mm and consist of blueish-gray bipyramidal crystals that are often deeply embayed. The matrix varies from granular to foliated and consists predominantly of quartz, albite, epidote-clinozoisite, and chlorite. Sporadic lithic fragments, ranging from rhyolite to andesite, and collapsed pumice lapilli occur in some beds. Locally the crystal tuff grades into tuff-matrix andesitic breccia. Individual beds range in thickness from several feet to tens of feet and generally span more than a single outcrop; thus the large-scale bedding is difficult to observe except along well-scoured streambeds. Interbeds of fine-grained bedded tuff, pumiceous tuff, and breccia occur locally in the crystal tuff, which probably was deposited as a series of subaqueous pyroclastic flows.

Fine-textured sedimentary rocks intertongue with the andesitic volcanic breccia east of the Shylock fault zone and are well exposed north of Agua Fria River (smbt on pl. 2). In this general locality, the rocks are chiefly thinly bedded sandstone and siltstone, but numerous thin interbeds of fine to coarse volcanic breccia make up about one-third of the section exposed.

South of Copper Mountain, similar fine-textured sedimentary rocks are recognized only with difficulty because of the pervasive alteration of the lower unit of the Spud Mountain Volcanics (pl. 2). Fewer interbeds of breccia are exposed, and the fine-textured beds range in thickness from less than 1 inch to 2 feet. Locally chert beds an inch or more thick are exposed; some are jasper and contain magnetite or hematite. These fine-textured sedimentary rocks are greenish gray. Examination in thin section reveals many angular quartz grains; those from some beds average 0.1 mm in diameter, and those from other beds only 0.02 mm. Albite is rare or absent, and sericite, associated with microcrystalline aggregates of chlorite, is conspicuous. Leucoxene and calcite are minor constituents. Presumably these beds are a mixture of rhyolitic and andesitic debris, deposited in an environment favorable for sorting into silt and fine sand fractions.

Andesitic Tuffaceous Rocks

Andesitic tuffaceous rocks dominate the upper unit of the Spud Mountain Volcanics. In the NE¼ Mount Union quadrangle (pl. 1), these rocks crop out in two bands: west and east of the older volcanic breccia. They contain intertonguing rhyolitic tuffs and flows and basaltic and andesitic flows. The west band is in contact with the Chaparral fault or younger intrusive rocks; the east band is in fault contact with the Texas Gulch Formation. South of Big Bug Mesa (pl. 1), some of the andesitic tuffaceous rocks are so poorly exposed that intertonguing basalt and rhyolite could not be distinguished in mapping. Bedded tuffaceous rocks were observed in a sufficient number of places to indicate that these rocks are the upper unit of the Spud Mountain Volcanics.

In the NW¼ Mayer quadrangle, the andesitic tuffaceous rocks crop out in and west of the Shylock fault zone (pl. 2). West of the Whitney fault, the andesitic tuffaceous rocks intertongue with the younger Iron King Volcanics.

The andesitic tuffaceous rocks are generally foliated, and the finer the grain size, the more pronounced the foliation. Where the foliation is weak, relict bedding is commonly preserved, particularly in the well-exposed, waterworn surfaces of the major gulches. Folds of small amplitude are common particularly where the rock is fine grained. Locally, folded cleavage demonstrates a later period of deformation.

The rocks of this unit are largely dark grayish green because they contain abundant chlorite. In some outcrops chlorite is less abundant, and sericite is an important constituent; these rocks are generally light grayish green.

Crystal-lithic tuffs form an appreciable thickness of the andesitic tuffaceous rocks. In some exposures these tuffs are thickly bedded, and in others they are thinly bedded; locally they show graded bedding. The crystal-lithic tuffs contain conspicuous albitic plagioclase clasts, which in thin section show a light clouding with sericite or a large epidote content. The clasts commonly are 3 mm across, but the average length is 0.5–1 mm. Fragments of andesite, generally rather platy, are also abundant in the tuff. Some of the andesitic clasts contain albitic plagioclase phenocrysts embedded in a microcrystalline groundmass of albite laths, interstitial chlorite, and black opaque grains. The matrix of the tuff is rich in epidote, clinozoisite, and chlorite; and leucoxene grains are common.

Sericitic-rich wispy plates that in outline suggest collapsed pumice (fig. 5) are common constituents of many of the crystal-lithic tuffs. Albite crystals in some of the larger sericitic aggregates suggest that andesitic crystal-rich pumice fragments form part of the crystal-lithic tuff beds.

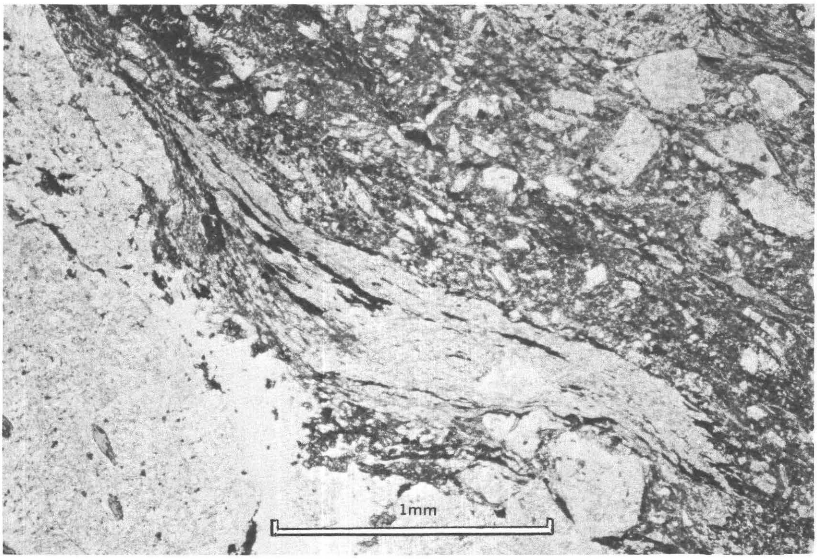


FIGURE 5.—Crystal-lithic tuff in upper unit of Spud Mountain Volcanics. Albitic clasts (lower left corner). Wispy sericitic aggregate (center) suggests collapsed pumice. Platy clasts of microporphyritic andesite above sericitic aggregate. Ordinary light. (Pl. 1, 1,268,400 N., 381,800 E.)

The presence of clasts that contain quartz and albitic microphenocrysts in a felsitic groundmass indicates that rhyolitic debris is a common constituent of some of the volcanic detritus. Where rhyolitic chips are present, angular quartz grains 0.2–0.3 mm in diameter are present in the crystal-lithic tuff beds.

The fine-grained andesitic tuffaceous rocks are schists or phyllites, with chlorite, the dominant mafic mineral, separated by albite and quartz grains 0.02–0.03 mm in diameter. In some specimens quartz exceeds albite. Small granules of leucoxene or microcrystalline sphene are common. Epidote and clinozoisite are sparse, but calcite is common. Perhaps the volcanic detritus was deposited in a calcareous environment, as a few limestone interbeds ¼–4 inches in width occur at several localities.

A lenticular bed of pebble-cobble conglomerate occurs in these tuffaceous rocks at one locality (pl. 2, 1,268,200 N., 408,900 E.). The largest cobbles are 6 inches in diameter. The clasts are predominantly quartz and chert, but a few consist of bedded sandy tuff and granophyre. One cobble of quartz-tourmaline was found. The lens is 30 feet thick in its widest part; it thins rapidly to the north, grading into thin chert beds. This thinning is indicative of the lenticular character of the unit.

Chemical analyses of two samples of the andesitic tuffaceous rocks are given in table 2 (Nos. 1, 6). Recalculation of analysis 1 by eliminating the H_2O and CO_2 content indicates an original SiO_2 content of 53.5 percent, placing the rock in the andesite range. Analysis 6 indicates that the rock is probably a mixture of rhyolitic and andesitic debris, and the high Al_2O_3 content suggests some original clay fraction.

TABLE 2.—*Chemical analyses of mafic volcanic rocks in Spud Mountain Volcanics*

[Sample 1: from Anderson and Creasey (1958, p. 159); samples 2-7: rapid rock analyses by Paul Elmore, Lowell Artis, Sam Botts, Gillison Chloe, John Glenn, Hezekiah Smith, and Dennis Taylor]

	1	2	3	4	5	6	7
SiO_2	48. 38	46. 9	49. 6	47. 8	52. 0	56. 8	62. 4
Al_2O_3	12. 18	18. 0	13. 0	16. 5	17. 4	19. 0	14. 3
Fe_2O_3	2. 90	3. 7	1. 4	1. 7	2. 7	1. 8	1. 9
FeO	10. 44	6. 8	4. 7	9. 0	8. 2	6. 2	6. 8
MgO	3. 67	6. 5	3. 5	5. 7	4. 5	4. 1	2. 9
CaO	7. 81	9. 6	14. 1	5. 9	7. 6	2. 3	3. 8
Na_2O	2. 80	1. 6	3. 3	4. 1	2. 6	5. 0	2. 1
K_2O	. 11	. 00	. 04	. 15	. 45	. 46	2. 8
H_2O^-	. 14	0. 7	. 16	. 12	. 13	. 08	. 03
H_2O^+	3. 69	3. 7	2. 6	4. 1	2. 9	3. 3	1. 4
TiO_2	1. 76	. 30	. 34	. 72	. 94	. 77	. 72
P_2O_5	. 30	. 10	. 09	. 38	. 17	. 21	. 22
MnO	. 21	. 13	. 15	. 37	. 24	. 02	. 02
CO_2	5. 61	1. 8	6. 9	3. 2	$<.05$	$<.05$	. 21
S	. 36						
BaO	. 01						
	100. 37						
Less O_2 for S	. 09						
	100. 28						
Bulk density		2. 87	2. 95	2. 74	2. 94	2. 72	2. 82

1. Mafic tuffaceous rock, 900 level, Iron King mine, upper unit, Spud Mountain Volcanics.
2. Amygdaloidal basalt, lower unit of Spud Mountain Volcanics, northwest quarter of Mayer quad. 1,245,-900 N., 416,400 E.
3. Basaltic andesite agglomerate, lower unit of Spud Mountain Volcanics, northwest quarter of Mayer quad. 1,258,100 N., 423,900 E.
4. Amygdaloidal basalt, lower unit of Spud Mountain Volcanics, southwest quarter of Mayer quad. 1,215,-250 N., 412,000 E.
5. Amygdaloidal andesite, lower unit of Spud Mountain Volcanics, northeast quarter of Mount Union quad. 1,266,900 N., 390,100 E.
6. Andesitic crystal tuff, upper unit of Spud Mountain Volcanics, northwest quarter of Mayer quad., 1,255,-300 N., 415,000 E.
7. Andesitic (?) flow, upper unit of Spud Mountain Volcanics, northeast quarter of Mount Union quad., 1,253,900 N., 371,000 E.

MAFIC FLOWS AND AGGLOMERATE

Mafic lava flows that range in composition from basalt to andesite intertongue with the lower andesitic breccias and upper andesitic tuffaceous rocks. In the NW¼ Mayer quadrangle (pl. 2), they are limited largely to the lower unit of the Spud Mountain Volcanics and are a dominant rock type between the Shylock fault and Yarber Wash

(1,256,000 N., 430,000 E.). In the NE¼ Mount Union quadrangle (pl. 1), these flows are limited to the north exposures of the lower andesitic breccias and to the upper andesitic tuffaceous rocks north and east of Big Bug Mesa.

Most of these mafic flows are well exposed and are easily recognized by their greenish-gray color and conspicuous amygdaloidal structure. Quartz and calcite are the chief infillings of the vesicles, and where the calcite has been leached from the outcrops, the flows have a pronounced vesicular appearance.

The relict textures of the amygdaloidal flows range from aphyric to porphyritic. The phenocrysts are generally from 1 to 5 mm in length, in contrast to the larger phenocrysts (4–8 mm) in the porphyritic clasts in the andesitic breccia. Foliation is more widespread in the flows cropping out in the west exposures (pl. 1) than in the east exposures (pl. 2). In the west exposures, the plagioclase phenocrysts are now an aggregate of clinozoisite, epidote, and sparse calcite in an albitic base. Relict textures of the groundmass or aphyric flows are rarely preserved; examination in thin section reveals an aggregate of greenish-white to pale-green actinolitic amphibole separated by interstitial chlorite, sericite, clinozoisite, epidote, leucoxene, and sparse quartz and calcite. Foliation is displayed by the orientation of many needles of amphibole (fig. 6).

The mafic flows associated with the quartz porphyry in the Shylock fault zone are similar to those in the west exposure, but to the east of this fault zone excellent relict textures are preserved (fig. 7). The phenocrysts in general contain granules of clinozoisite and epidote and flakes of sericite set in a clear albitic base. The groundmass is generally pilotaxitic, containing albite laths separated by interstitial chlorite, granular epidote, clinozoisite, leucoxene, and sparse quartz grains.

Small pillow structures associated with bedded ash and cinders were observed in thin basaltic flows along Rattlesnake Canyon northwestward of a point in the NW¼ Mayer quadrangle (pl. 2, 1,254,300 N., 423,100 E.). Because these beds and lava are too narrow to map on plate 2, they are shown as a part of the breccia facies. The pillows are 6–12 inches in length, amygdaloidal in structure, and grayish green in outcrop, similar in color to the more widespread amygdaloidal basalt. Ash and cinder beds are closely associated with the pillow lava, and in one exposure the relations suggest that some of the pillows sank into the water-logged pyroclastics which squeezed upward between pillows.

The amygdules in the pillows are of two sizes: the smaller ones, of chlorite, are 2–4 mm long and the larger ones, of quartz, are 5–8 mm long. Albitic phenocrysts 1–2 mm long contain a little chlorite in

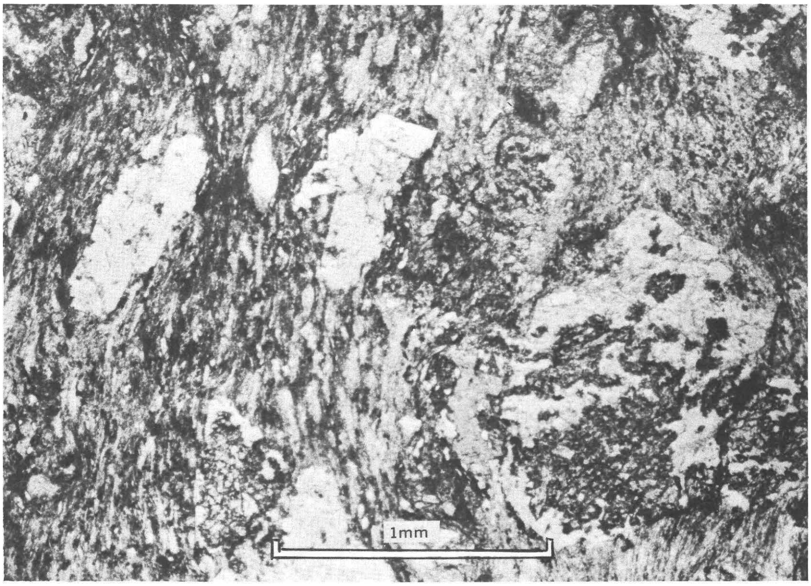


FIGURE 6.—Foliated andesitic flow intertonguing with Spud Mountain breccia. Phenocrysts of plagioclase, partly replaced by clinozoisite, separated by a felt of fine pale-green amphibole needles and chlorite flakes. Ordinary light. (Pl. 1, 1,272,400 N., 394,100 E.)

veinlets and, locally, associated granules of epidote. The groundmass contains abundant albite laths 0.1–0.3 mm long and chlorite, calcite, epidote, radiating needles of zoisite, and leucoxene. The fragments of ash and cinders in the bedded deposits are similar in texture and mineralogy to the adjacent pillow lava except that calcite is abundant as amygdules, veins, and cement.

Beds of agglomeratic material are limited to the lower unit of the Spud Mountain Volcanics exposed in the NW¼ Mayer quadrangle (pl. 2). One outcrop 1½ miles long is cut off by quartz porphyry at the north end (pl. 2, 1,260,000 N., 423,000 E.), and the south end pinches out against quartz porphyry and andesitic volcanic breccia (pl. 2, 1,254,000 N., 425,000 E.). Other masses of agglomerate are exposed to the east, intercalated between amygdaloidal mafic flows (pl. 2, 1,256,000 N., 434,000 E.).

The outlines of the lapilli and bombs composing the agglomerate are well preserved; bedding structures are absent. Presumably these deposits are submarine pyroclastic flows that consisted predominantly of juvenile ejecta. The bombs and lapilli average about 3 inches in diameter, and some bombs are 8 inches long. Locally bombs 6 inches long are abundant and closely packed with a minimum of ashy matrix.

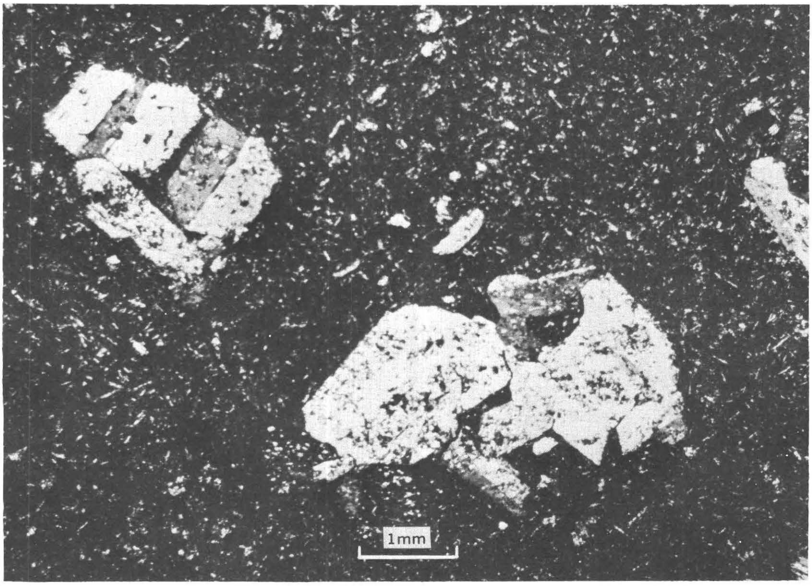


FIGURE 7.—Porphyritic andesite flow intertonguing with Spud Mountain breccia. Albitic phenocrysts containing epidote and sericite inclusions. Pilotaxitic groundmass of albitic laths, sparse quartz, interstitial chlorite, and granular epidote. Crossed nicols. (Pl. 2, 1,260,300 N., 419,850 E.)

The vesicles in the lapilli and bombs are small, averaging about 0.15 mm in diameter, and are filled largely with chlorite, sericite, quartz, and calcite. The largest plagioclase crystals are 0.5 mm in length; most of the plagioclase forms narrow laths about 0.05 mm long (fig. 8). The larger plagioclase crystals are albitic, but the groundmass laths appear more calcic (oligoclase?). Chlorite, epidote, and patchy microcrystalline feldspar are interstitial to the oligoclase laths. Calcite is the common matrix between fragments.

Chemical analyses of four mafic flows and one of the agglomerate are given in table 2. Recalculation of the analysis of the agglomerate by eliminating the H_2O and CO_2 content indicates an SiO_2 content of 55 percent, placing the rock in the andesite range. Except for analysis 7 (table 2), the mafic flows have a range in composition from basalt to mafic andesite. The sample for analysis 7 was collected in Big Bug Creek (pl. 1, 1,253,900 N., 371,300 E.), and the texture is that of a hornfels; large and numerous ellipsoidal clots of epidote are surrounded by microgranular quartz containing flakes of biotite and chlorite and granules of sphene. The composition differs from the other mafic flows in the Spud Mountain Volcanics in that the SiO_2 and K_2O

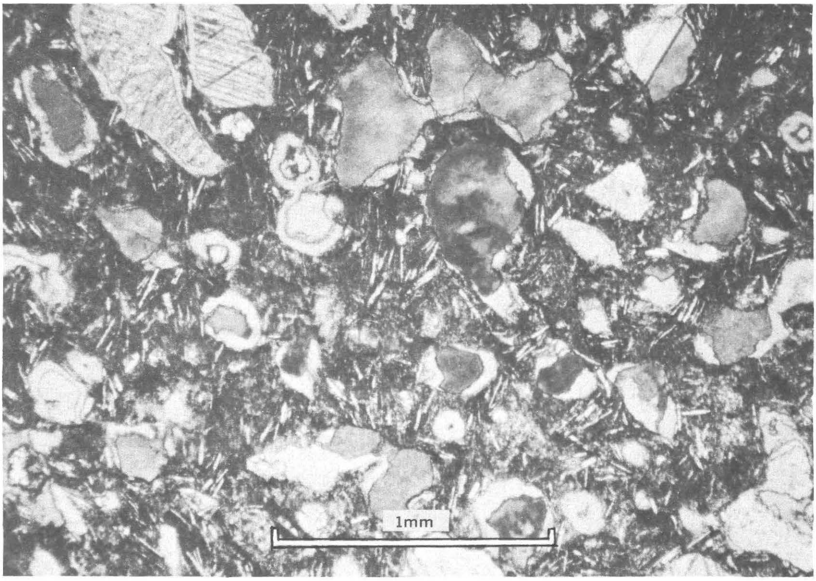


FIGURE 8.—Lapillus in agglomerate in lower unit of Spud Mountain Volcanics. Sodic plagioclase laths in matrix of chlorite and epidote. Vesicles filled with chlorite, quartz, and calcite. Ordinary light. (Pl. 2, 1,258,100 N., 423,900 E.)

are appreciably higher. The original rock may have been andesitic and subsequently modified by contact metamorphism, or it may have been a trachyandesite.

RHYOLITIC ROCKS

Rhyolitic rocks in the lower unit of the Spud Mountain Volcanics are limited to exposures east of the Shylock fault zone (smrh on pl. 2). These rocks are largely massive and locally flow banded. They are gray to purplish gray on fresh surfaces, but weather to light-tan or cream-colored outcrops. Breccia facies contain angular fragments 3–10 inches in length that are commonly tightly packed; the breccias are locally intruded by massive rhyolite. Foliation is rare except in outcrops near the Shylock fault zone.

The rhyolite east of the splay of the Shylock fault clearly intruded the mafic flows and agglomerate of the Spud Mountain Volcanics. To the west, some masses may be intrusive, but some may be extrusive. One mass (pl. 2, 1,266,700 N., 418,600 E.) clearly reached the floor of the basin of deposition, for on the west side of the rhyolite, beds of andesitic breccia contain abundant clasts of rhyolite. This rhyolite may be a flow or a protrusive dome that rose above the basin floor.

The rhyolitic rocks in the lower unit are slightly porphyrytic, containing albitic phenocrysts, 0.5–3 mm long, locally in clusters. Quartz phenocrysts, partly resorbed and 0.5–1.5 mm in diameter, are present in many exposures. Thin sections reveal a microcrystalline groundmass of patchy intergrowths of quartz and alkalic feldspar; the individual grains average about 0.01 mm in diameter (fig. 9). Where quartz is absent as phenocrysts, it appears as scattered crystals, 0.03–0.2 mm in diameter, in the patchy groundmass. Sericite is not prominent, and in general it is confined to the albite. In a few samples, sericite occurrence in two intersecting planar structures indicates crystallization along incipient shear planes. Clinozoisite, epidote, calcite, and chlorite are present in minor amounts in various thin sections. Apatite and finely crystalline sphene were noted in a few samples. Some of the rhyolite is purplish gray owing to hematite dust in the groundmass.

Bedded rhyolitic tuffs and sericitic slate in the upper unit of the Spud Mountain Volcanics are almost continuously exposed for 6 miles in the NW¼ Mayer quadrangle (smr on pl. 2, 1,232,500 N., 410,300 E. to 1,264,000 N., 412,400 E.). These rocks weather to gray and white, whereas the adjacent andesitic tuffaceous rocks whether to brownish shades. The rhyolitic rocks range from thickly bedded coarse sandy tuffs, locally showing graded bedding, to thinly bedded fine sandy to

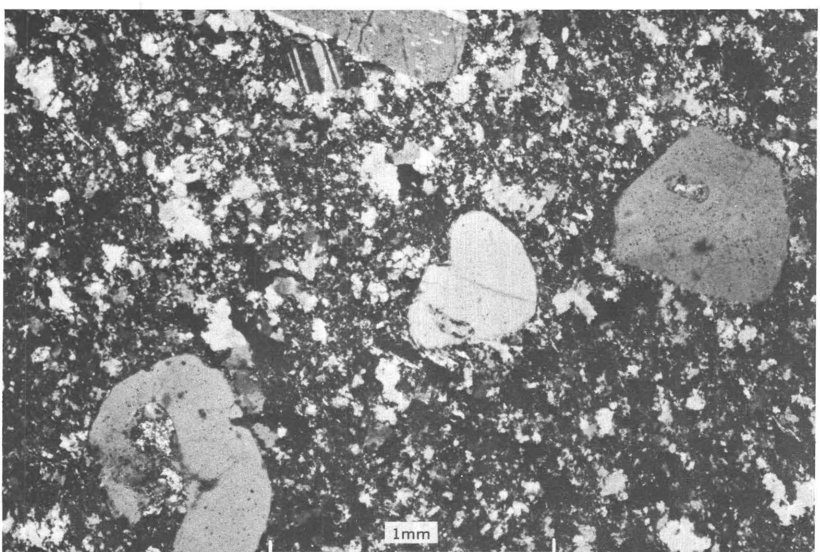


FIGURE 9.—Rhyolitic flow in lower unit of Spud Mountain Volcanics. Albitic and resorbed quartz phenocrysts in a patchy microcrystalline groundmass of quartz and alkalic feldspar. Crossed nicols. (Pl. 2, 1,260,500 N., 421,000 E.)

silty tuffs. The slate beds are gray to greenish white. In general, these bedded rocks are well foliated, particularly where the texture is fine grained. Small folds are common, resulting in numerous exposures of cleavage-bedding intersections, largely plunging south (pl. 2). The southern part of this band of rhyolitic rocks is dominantly slaty, and the sandy facies are more conspicuous in the middle part of this band.

Angular quartz clasts ranging in diameter from 0.5 to 1 mm are conspicuous in the medium- to fine-grained sandy beds (fig. 10), and thin sections reveal numerous albite clasts of similar or smaller size. Locally, the sandy beds are enriched in lithic fragments 6–10 mm long that microscopic studies show to be chert and volcanic chips. The volcanic fragments resemble in part the groundmass of rhyolite, and some may be dacitic, as shown by albitic phenocrysts embedded in a microcrystalline aggregate of quartz and alkalic feldspar separated by conspicuous chlorite. Lenticular wispy aggregates of sericite may be collapsed pumice, and one aggregate contains a relict quartz phenocryst. A few coarse grains are micrographic intergrowths of quartz and alkalic feldspar which indicates a granophyric parentage. Some coarse grains are composed of epidote, clinozoisite, and quartz. Sericite is

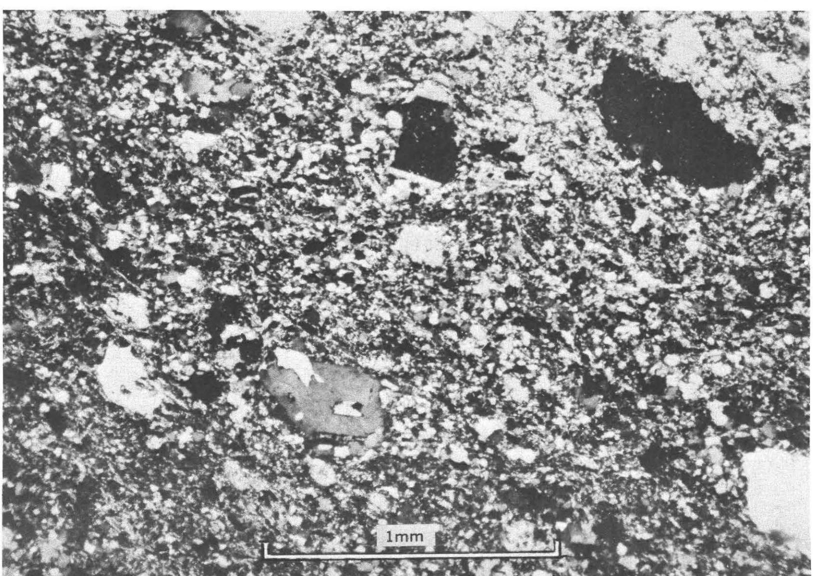


FIGURE 10.—Bedded rhyolitic tuff in upper unit of Spud Mountain Volcanics. Angular clasts of quartz and albite separated by abundant sericite and sparse chlorite. Magnetite grains conspicuous. Crossed nicols. (Pl. 2, 1,243,300 N., 411,100 E.)

common along foliation planes, associated with chlorite in varying amounts.

The thinly bedded sandy tuffs contain abundant angular quartz grains, 0.1 mm in diameter, associated with albite clasts of similar size embedded in a finer grained matrix of the same minerals, 0.02 mm in diameter. Abundant sericite and sparse chlorite are present along the foliation planes. Apatite is a common accessory, and calcite, locally, is disseminated or is in veins. Octahedra of magnetite ranging in size from 0.1 to 1 mm are conspicuous on many of the foliation planes of the finer textured beds. Thin sections reveal that in some specimens feathery quartz has crystallized perpendicular to the crystal faces of the magnetite in pressure shadows. This feature suggests that the magnetite may be porphyroblasts. Chlorite is a common associate with the feathery quartz.

In the NE¼ Mount Union quadrangle (pl. 1), rhyolitic rocks of the upper unit of the Spud Mountain Volcanics intertongue with the andesitic tuffaceous rocks southeast of the Chaparral fault. Differentiation between flows and tuff is difficult because of the strong foliation near the Chaparral fault. These foliated rocks contain quartz grains 0.1 mm in diameter in a matrix of quartz and alkalic feldspar with individual grains ranging from 0.01 to 0.04 mm in diameter. Abundant sericite along the closely spaced foliation planes wraps around the quartz "eyes." Cleavage-bedding intersections indicate that a large part of the rhyolitic rock is tuffaceous. Some of the less foliated rocks appear to have relict quartz and albitic phenocrysts in a microgranular groundmass of quartz and alkalic feldspar, with abundant sericite and sparse chlorite along the more widely spaced foliation planes; in these rocks, magnetite is a common accessory.

Southwestward to Big Bug Mesa, more-massive rhyolitic rocks are intercalated with mafic flows (pl. 1), but exposures are poor because of the forest cover, except along Big Bug Creek. These massive rhyolitic rocks are almost aphyric, but have a few albitic phenocrysts 0.5–1.5 mm long associated with scattered quartz phenocrysts 0.2–0.4 mm in diameter. The groundmass contains quartz and untwinned albite; a little potassium feldspar is revealed by staining. Sericite is in parallel orientation along weak foliation planes; a small amount of chlorite is in streaks cutting the foliation.

Northeast of Big Bug Mesa in the east band of andesitic tuffaceous rocks (pl. 1, 1,250,000 N., 383,000 E.), intertonguing rhyolitic tuffs and sericitic slate are exposed. The tuff has recrystallized in the north exposures, south of Big Bug Creek, because of proximity to the Upper Cretaceous or lower Tertiary granodiorite, and layers of granular quartz and feldspar are separated by rosettes of bluish-green amphibole and magnetite. Southward, relict quartz clasts mixed with microgranular quartz and alkalic feldspar are recognizable. Lenticular aggregates of sericite suggest collapsed pumice, but the chief micaceous mineral is light-brown mica (biotite?).

Chemical analyses of five samples of Spud Mountain rhyolitic rocks are given in table 3. Sample 1 apparently represents an impure rhyolitic tuffaceous rock containing an admixture of mafic volcanic detritus, whereas sample 3 is predominantly rhyolitic debris. The rhyolitic flows and intrusive masses show appreciable range in the content of Na_2O and K_2O, a characteristic also of other Precambrian rhyolitic rocks in this area (Anderson, 1968a).

TABLE 3.—*Chemical analyses of silicic volcanic rocks in Spud Mountain Volcanics*

[Rapid rock analyses by Paul Elmore, Lowell Artis, Sam Botts, Gillison Chloe, John Glenn, Hezekiah Smith, and Dennis Taylor]

	1	2	3	4	5
SiO_2	68. 5	73. 6	75. 4	80. 7	71. 1
Al_2O_3	13. 2	14. 5	14. 5	10. 9	14. 0
Fe_2O_3	4. 3	. 90	1. 6	. 17	. 50
FeO	1. 6	1. 0	. 34	. 48	3. 5
MgO	1. 6	. 42	. 10	. 3	1. 5
CaO	1. 8	. 78	. 10	. 42	1. 5
Na_2O	2. 7	4. 1	4. 9	5. 7	4. 6
K_2O	2. 0	3. 0	1. 6	. 11	. 22
H_2O^-	. 26	. 22	. 06	. 07	. 12
H_2O^+	1. 7	1. 0	1. 0	. 51	2. 50
TiO_2	. 74	. 20	. 17	. 18	. 31
P_2O_5	. 15	. 02	. 02	. 03	. 10
MnO	. 04	. 04	. 02	. 00	. 12
CO_2	1. 1	$<$. 05	$<$. 05	$<$. 05	$<$. 05
Powder density	2. 75	2. 65	2. 68	----------	----------
Bulk density	2. 68	2. 65	2. 63	2. 65	2. 69

1. Sandy tuff, upper unit of Spud Mountain Volcanics, Mayer quad., 1,243,300 N., 411,100 E.
2. Foliated rhyolitic flow, upper unit of Spud Mountain Volcanics, Mount Union quad., 1,253,600 N., 370,500 E.
3. Foliated rhyolitic tuff, upper unit of Spud Mountain Volcanics, Mount Union quad., 1,267,700 N., 380,-900 E.
4. Rhyolite flow, lower unit of Spud Mountain Volcanics, Mayer quad., 1,235,100 N., 421,500 E.
5. Intrusive rhyolite into lower unit of Spud Mountain Volcanics, Mayer quad., 1,262,100 N., 433,100 E.

FERRUGINOUS CHERT

Ferruginous chert beds of appreciable width and length crop out in the northwestern part of the Mayer quadrangle (pl. 2) in the upper unit of the Spud Mountain Volcanics close to or intertonguing with the Iron King Volcanics. Similar chert beds appear in the lower part of the Iron King Volcanics in this quadrangle. This zone of ferruginous chert defines an accumulation that began during the deposition of the youngest Spud Mountain Volcanics and that continued into the early stages of outpouring of the basaltic lavas of the Iron King Volcanics.

The chert beds in the upper unit of the Spud Mountain Volcanics, as distinguished in the field mapping, are a complex mixture of ferruginous chert and interleaves of fine clastic material; they are found in bedded rhyolitic tuffs, bedded andesitic tuffs, mixed andesitic-rhyolitic sediments, and thin highly amygdaloidal basaltic flows. Except for the chert beds, the rocks are well foliated and marked by abundant sericite and (or) chlorite along the foliation planes. The total assemblage forms black to greenish and light-gray outcrops in which the cherty beds rarely constitute more than a quarter of the section.

The ferruginous chert beds in the Spud Mountain Volcanics and the Iron King Volcanics generally contain magnetite in layers that are 2–20 mm thick and that average about 5 mm. Locally, hematite is present in place of magnetite. The chert layers are now microcrystalline quartz: the grain size ranges from 0.02 to 0.09 mm, and the average is about 0.04 mm. The magnetite crystals range from 0.01 to 3 mm in diameter and average about 0.04 mm. In general, the magnetite is richly disseminated in cherty layers that consist of quartz and sericite, but a few layers, 1–2 mm thick, of solid magnetite were observed. In some beds chains of magnetite grains cut across the chert layers. Colorless garnet, ranging from 0.04 to 0.6 mm in diameter, is locally present, commonly containing inclusions of magnetite. Sericite is widespread in the beds and in places forms sericitic-rich layers. Golden brown mica, generally in books transverse to the foliation or parallel to faces of magnetite crystals, is probably stilpnomelane, for it has all the characteristics that Turner (in Williams and others, 1954, p. 221) ascribed to stilpnomelane occurring in metamorphosed ferruginous chert in the greenschist facies. Tiny blue tourmaline crystals are present in some thin sections.

Partial chemical analyses of six samples of ferruginous chert and spectrographic analyses of three samples are given in table 4. X-ray diffraction studies by M. L. Sorensen have revealed that the high content of manganese in sample 2 is due to spessartite garnet, the chief manganese-bearing mineral in this sample. The only manganese-bearing mineral in an adjacent sample is secondary pyrolusite that coats it.

The rhyolitic tuffs interbedded with the ferruginous chert resemble the sandy and slaty facies of similar rhyolitic rocks described in the previous sections. Lithic clasts of chert and rhyolitic groundmass are common in the coarse sandy beds; sericitic-rich lenses suggest collapsed pumice. In some beds, coarse grains resemble granophyric clasts. Chlorite is rare in the light-gray tuffaceous beds, and the individual crystals are five times as thick as the associated sericite flakes and are arranged transverse to the foliation. The greenish-gray inter-

TABLE 4.—*Partial chemical analyses and semiquantitative spectrographic analyses of ferruginous chert*

[Samples 1-3: chemical analyses by H. N. Elsheimer and semiquantitative spectrographic analyses by Chris Heropoulos; samples 4-6: from Harrer (1964, p. 101, 103, 103, respectively)]

	1	2	3	4	5	6
Chemical analyses (in percent)						
Fe	17.8	21.1	30.2	27.2	27.3	35.6
Mn	4.7	10.8	1.8	1.4	1.9	1.8
SiO_2	52.6	49.4	49.1	51.0	39.0	46.9
TiO_2				.2	.02	.30
P				.10	.17	
S				.09	.10	
Semiquantitative spectographic analyses (in percent)						
Ba	0.3	0.2	0.007			
Co	.005	.005	.001			
Cr	.003	.002	.015			
Cu	.015	.015	.005			
Ni	.003	.005	.0015			
Pb	.007	.007	.005			
V	.007	.007	.005			

1. Chip sample 1 ft in length across bedding. In upper unit of Spud Mountain Volcanics, Mayer quad., 1,272,300 N., 407,900 E.
2. Sample of bed 2 in. wide. In upper unit of Spud Mountain Volcanics, Mayer quad., 1,272,300 N., 407,900 E.
3. Sample of bed 3 in. wide. In lower part of Iron King Volcanics, Mayer quad.
4. Character sample collected by U.S. Bureau of Mines, in upper unit of Spud Mountain Volcanics, Mayer quad. South of 1,241,800 N., 410,000 E.

5, 6. Two character samples, 1 mile apart, collected by U.S. Bureau of Mines, in upper unit of Spud Mountain Volcanics, Mayer quad. In beds cut by coordinates 1,230,000 N., 410,500 E.

beds contain much chlorite with quartz and carbonate, which may be ankerite, for it shows limonite staining. Leucoxene is a common accessory where chlorite is abundant. The thin basaltic flows contain numerous amygdules of dusty carbonate with central infillings of clear carbonate and quartz surrounded by a foliated chloritic matrix containing microcrystalline quartz and alkalic feldspar.

IRON KING VOLCANICS

The Iron King Volcanics consists largely of a lower sequence of pillow and amygdaloidal andesitic and basaltic flows with interbeds of sedimentary rocks and rhyolitic flows and tuffs, and an upper assemblage (ikat on pls. 1, 2) of mixed mafic and rhyolitic tuffaceous rocks that thin and disappear to the southwest (pl. 1, 1,235,000 N., 390,500 E.).

The Iron King Volcanics is folded into a major overturned syncline; the upper, tuffaceous, unit appears in the keel of this fold (pl. 1, section *C–C′*). The disappearance of this unit southward may be due to lensing out or to a northward plunge of the syncline. The west boundary of the formation is in the Mount Union quadrangle (pl. 1), where it is in fault contact with the Texas Gulch Formation. Southward, much of the overturned west limb of the syncline is cut out by the faulted block of Texas Gulch Formation (pl. 1, section *D–D′*). The thickness of the formation on this west limb is about 5,500 feet in its widest exposure.

The east boundary (pl. 2) of the Iron King Volcanics is entirely within the Mayer quadrangle, where the formation intertongues with the underlying Spud Mountain Volcanics. In the northwest corner of plate 2, the map pattern of these two formations could be interpreted as a series of small south-plunging folds, and indeed, one fold identified in the field within the Spud Mountain Volcanics (pl. 2. 1,267,000 N., 411,000 E.) supports this interpretation; however, intertonguing of the two formations is demonstrated by the Spud Mountain chert beds within the Spud Mountain Volcanics near the north margin of the Mayer quadrangle (pl. 2, 409,500 E.). This mappable unit of chert beds extends southward for almost 3 miles, and for about half that distance, it intertongues with the Iron King Volcanics.

Additional evidence that strongly indicates intertonguing of these two volcanic formations is the presence of pillow and amygdaloidal mafic flows in the andesitic tuffaceous beds of the Spud Mountain Volcanics and the reverse situation, the presence of tuffaceous beds in the Iron King pillow and amygdaloidal lavas. These features are represented in the northwestern part of plate 2 by pillow lava symbols in the andesitic tuffaceous unit of the upper unit of the Spud Mountain Volcanics and by bedding symbols in areas shown as Iron King Volcanics. Numerous top determinations indicate that the sections shown in the northwestern part of plate 2 are essentially homoclinal, with most of the beds and lava flows facing west.

The Iron King Volcanics is in fault contact with the Spud Mountain Volcanics near the north margin of plate 2 (412,300 E.), but this fault dies out about 2½ miles to the south, ending within Spud Mountain Volcanics. At the north end, the fault displaces the Tertiary Hickey Formation and thus was active late in the geologic history of the region.

North of Mayer, the Iron King Volcanics has an outcrop width of more than 3 miles on the east limb of the major syncline. Dips of interbedded sedimentary rocks range from 70° W. to 90° W. No large-scale duplication by folding can be demonstrated, but at the east margin of the formation, interbedded chert occurs in small amplitude folds. This outcrop width suggests nearly 15,000 feet of mafic lavas and interbedded sedimentary rocks as compared with about 10,000 feet north of the Agua Fria River. The actual thickness may be much less owing to possible duplication of section by unrecognized folds.

458-804 O - 72 - 3

Although it can be stated with certainty that the Iron King Volcanics represents an unusually thick sequence of pillow and amygdaloidal mafic flows, the thickness of 10,000 feet for the Iron King Volcanics used for structural diagrams is only an approximation.

Andesitic and Basaltic Flows

Amygdaloidal and pillow structures are common in the Iron King andesitic and basaltic flows, and in places they determine the tops of the flows. Individual flows range in thickness from several feet to more than 100 feet. The thin flows are generally amygdaloidal and highly foliated, whereas the thick flows tend to be massive and commonly contain pillows. In places, the thick flows are highly sheared, and relict textures and structures are difficult to recognize. The flows range from grayish green to greenish black, the color depending on the dominant mafic mineral and on the degree of foliation—the stronger the foliation, the more greenish the color, owing to the high content of chlorite. Actinolitic amphibole is the dominant mafic mineral in the darker flows.

Two mineral assemblages are present: (1) actinolite, albite-oligoclase, epidote, and clinozoisite, with accessory leucoxene and (2) chlorite, albite, epidote, and clinozoisite, commonly with calcite and quartz. Relict porphyritic textures are rare; presumably the original textures were intergranular or intersertal, typical of most basaltic flows.

Thin sections of the first mineral assemblage reveal that the actinolite is pale green to pale bluish green and, in general, has a crude parallel arrangement in which many crystals are at large angles to the planar structure. In other thin sections, the arrangement of actinolite is random. Epidote and clinozoisite grains are abundant and are intergrown with microgranular plagioclase whose composition ranges from albite to sodic oligoclase. Quartz and calcite may be present, generally in small quantities; some of these aggregates may be relict amygdules. Chlorite is rare; where present it is either associated with calcite or occurs in minute shear planes that cut across the actinolite. Relict plagioclase phenocrysts are represented by many crystal aggregates of epidote and clinozoisite in an albitic base.

In the second mineral assemblage, green chlorite with low birefringence is abundant and concentrated in parallel arrangement along foliation planes, commonly associated with microgranular quartz and calcite. Microgranular albite is present in many thin sections. Epidote and clinozoisite grains are common, but they may be absent where the calcite content is high. Amygdules of quartz and calcite are generally attenuated parallel to the foliation.

In both assemblages, minor amounts of brown biotite replace actinolite or are associated with chlorite and calcite. The biotite is commonly at an angle to the foliation, an arrangement suggesting late crystallization. Blue tourmaline is a minor constituent in some of the flows exposed in the southeast corner of the area of plate 1. Platy ilmenite and (or) magnetite octahedra may be present in both facies; leucoxene is the more common accessory.

Chemical analyses of seven mafic flows, given in table 5, show a range in composition from basalt to basaltic andesite. Sample 1 has a high content of CO_2, and recalculation on the basis of no H_2O and CO_2 content yields an SiO_2 content of 51 percent.

The interbeds between the mafic lava flows comprise basaltic-andesitic tuffaceous rocks, rhyolitic tuffaceous rocks, and chert beds. Limestone beds, 1 inch to 5 feet thick, are present locally, particularly in the southerly exposures in both quadrangles. The tuffaceous beds are well foliated and green to gray, depending on the ratio of chlorite to sericite. Minor folds are common where chert or limestone is present. Their lithologic contrast to the surrounding tuffaceous rocks facilitates the recognition of the folds. Much of the bedded material is rich in quartz

TABLE 5.—*Chemical analyses of mafic volcanic rocks in Iron King Volcanics*

[Samples 1, 3–7: rapid rock analyses by Paul Elmore, Lowell Artis, Sam Botts, Gillison Chloe, John Glenn, Hezekiah Smith, and Dennis Taylor; sample 2: from Anderson and Creasey (1958, p. 28)]

	1	2	3	4	5	6	7
SiO_2	45. 9	47. 6	49. 4	50. 2	51. 7	53. 1	53. 8
Al_2O_3	13. 9	15. 4	14. 9	14. 5	18. 0	18. 0	15. 0
Fe_2O_3	2. 0	3. 5	3. 4	3. 1	1. 2	2. 5	1. 0
FeO	8. 6	8. 6	8. 0	9. 1	8. 2	7. 2	8. 7
MgO	5. 6	6. 6	4. 9	6. 9	6. 3	5. 7	5. 6
CaO	9. 6	11. 9	8. 9	9. 3	4. 5	5. 1	4. 6
Na_2O	2. 6	2. 0	2. 9	2. 8	5. 6	5. 0	2. 4
K_2O	. 00	. 14	. 00	. 08	. 17	. 04	. 10
H_2O^-	. 04		. 06	. 00	. 13	. 06	. 09
		[1] 2. 20					
H_2O^+	4. 3		2. 8	1. 9	2. 7	1. 7	4. 7
TiO_2	1. 0	1. 2	1. 9	1. 1	1. 0	. 98	. 68
P_2O_5	. 08	. 19	. 17	. 07	. 15	. 13	. 11
MnO	. 14	--------	. 08	. 11	. 23	. 09	. 12
CO_2	6. 3	--------	2. 4	. 41	<. 05	<. 05	3. 00
Powder density	--------	--------	--------	--------	2. 91	--------	--------
Bulk	2. 76	--------	2. 90	3. 00	2. 80	2. 84	2. 73

[1] Ignition loss.

1. Pillow basalt, Mayer quad., 1,265,150 N., 403,500 E.
2. Pillow basalt, Mayer quad., 1,266,600 N., 403,400 E.
3. Pillow basalt, Mayer quad., 1,239,650 N., 404,900 E.
4. Pillow basalt, Mayer quad., 1,257,250 N., 477,000 E.
5. Pillow basalt, Mayer quad., 1,246,100 N., 401,500 E.
6. Massive basaltic andesite, Mayer quad., 1,247,600 N., 418,500 E.
7. Massive basaltic andesite, Mount Union quad., 1,250,100 N., 387,900 E.

associated with chlorite, albitic feldspar, clinozoisite, and, rarely, biotite. Less common are beds with actinolite and alkalic feldspar; quartz is less abundant than in the chloritic rocks.

Rhyolitic Rocks

Rhyolitic rocks are limited to the east limb of the syncline (southeast corner, pl. 1; northwest corner, pl. 2) and to the keel of the syncline. These rhyolitic rocks are in part quartz-sericite schists, and in many exposures relict textures and structures are partly destroyed by the dominant foliation.

The well-exposed relict bedding in the band between 1,259,000 N., 409,500 E., and 1,263,000 N., 409,000 E. (pl. 2), reveals that this unit consists of thick- to thin-bedded sandy tuff containing a few chert beds and several interbeds of massive buff limestone, 10 or more feet thick. The sandy tuff is similar to the rhyolitic tuffaceous rocks in the Spud Mountain Volcanics to the east and consists of angular quartz and albite clasts, 0.2–0.5 mm in diameter, embedded in a sericitic matrix with a microcrystalline aggregate of quartz and alkalic feldspar. Finer textured beds consist of leaves of abundant sericite separated by microgranular quartz and alkalic feldspar. The limestone is impure, containing quartz and albite clasts as large as 0.1 mm in diameter embedded in calcite crystals 0.1–0.15 mm in diameter. Sericitic streaks with a little chlorite cut the calcite. Blue tourmaline crystals 0.02–0.05 mm in diameter appear in the sericitic streaks in the sandy tuff and limestone.

Three narrow bands of rhyolitic tuff are exposed north of Mayer, and a chemical analysis from a sample of the largest band is given in table 6 (No. 3). These bands of tuff are characterized by many elongate clasts ranging from 5 to 60 mm in length. Thin sections reveal that some of these clasts resemble rhyolitic groundmass containing much sericite parallel to the foliation. Other clasts are sericite rich and may be collapsed pumice Much of the rock is microgranular quartz associated with abundant parallel flakes of sericite. A few tiny blue tourmaline crystals are present.

The other masses of rhyolite intercalated with the basaltic flows are probably flows or shallow intrusives. Relict porphyritic textures are revealed in thin section; the phenocrysts are largely albitic and resorbed quartz in a microgranular groundmass of quartz and alkalic feldspar cut by many parallel streaks of sericite. A chemical analysis of one of the porphyritic rhyolites is given in table 6 (No. 2).

Rhyolitic tuffaceous rocks in the upper part of the Iron King Volcanics are well exposed only at the north end of this unit (pl. 2). Weathered surfaces reveal that in many beds, platy rhyolitic fragments, ranging in length, from a fraction of an inch to more than 2

TABLE 6.—*Chemical analyses of silicic volcanic rocks in Iron King Volcanics*

[Rapid rock analyses by Paul Elmore, Lowell Artis, Sam Botts, Gillison Chloe, John Glenn, Hezekiah Smith, and Dennis Taylor]

	1	2	3
SiO_2	65.0	72.1	75.2
Al_2O_3	14.3	14.3	13.7
Fe_2O_3	3.4	1.1	.68
FeO	3.6	.61	1.2
MgO	2.2	.29	1.9
CaO	5.8	1.3	.16
Na_2O	1.5	3.4	2.1
K_2O	2.4	4.3	2.3
H_2O^-	.23	.03	.22
H_2O^+	.77	.70	2.1
TiO_2	.52	.35	.15
P_2O_5	.09	.05	.02
MnO	.11	.02	.00
CO_2	$<.05$	.89	$<.05$
Powder density	2.84	2.75	2.70
Bulk density	2.78	2.66	2.64

1. Rhyolitic tuff with some admixed mafic detritus, Mayer quad., 1,265,650 N., 400,500 E.
2. Rhyolitic flow, Mount Union quad., 1,230,400 N., 394,000 E.
3. Rhyolitutic ff, Mayer quad., 1,242,350 N., 402,600 E.

inches, grade into finer textured beds. Some fragments containing quartz phenocrysts in a microcrystalline groundmass of quartz and alkalic feldspar, separated by clasts of quartz and albite and wispy aggregates of sericite that suggest collapsed pumice. Magnetite dust outlines many of the sericitic aggregates. The fine clastic material is now microcrystalline quartz, alkalic feldspar, sericite, and chlorite.

Some mafic detritus in some of the tuff beds is indicated by associated clinozoisite, epidote, and chlorite, minerals which are reflected in the chemical composition (table 6, No. 1). In general, the tuffaceous beds in the upper part of the Iron King Volcanics become darker in the more southerly exposures as the mafic content increases, but locally (pl. 1, 1,244,800 N., 393,900 E.), rather pure beds of rhyolitic tuff intertongue with the more mafic facies.

QUARTZ PORPHYRY AND GRANOPHYRE

The larger masses of quartz porphyry in the NW¼ Mayer quadrangle (pl. 2) are limited to the Spud Mountain Volcanics within and east of the Shylock fault zone. The single mass of granophyre intrudes the Spud Mountain Volcanics east of the splay of the Shylock fault (pl. 2). The quartz porphyry in the Iron King Volcanics (pls. 1, 2) is largely concentrated within or near the upper tuffaceous rocks in the keel of the major syncline, except for a cluster of small masses near the south half of the west fault contact with the Texas Gulch Formation (pl. 1). Here the evidence is convincing that the fault cuts off two dikelike masses of the quartz porphyry, and the small lens within the Texas Gulch Formation has highly sheared margins, indicating that it is a fault sliver (pl. 1). A dikelike mass is exposed in Spud Mountain Volcanics south of Big Bug Mesa, and another intrudes the Green Gulch Volcanics in the northwest corner of the area of plate 1.

The presence of clasts of quartz porphyry in some of the breccia facies of the Spud Mountain Volcanics indicates either contemporaneity or an older period of quartz porphyry emplacement. The possibility of contemporaneous flows of quartz porphyry cannot be ignored as flows of this composition and texture have been widely recognized in other Precambrian and younger terranes. No flows of quartz porphyry have been recognized in the Precambrian rocks of central Arizona, but additional mapping may reveal their presence. Concordant contacts with host rocks are indicated by some masses of quartz porphyry, but these in part have discordant contacts, as for example the mass exposed in the northeastern part of the area of plate 2 (1,260,-000 N., 422,800 E.). The very fine grained groundmass texture of the quartz porphyry indicates fairly shallow depths of emplacement and rapid cooling.

The large elongate masses of quartz porphyry within the Shylock fault zone (pl. 2) are highly foliated along their west margins. The outcrop pattern along their east margins clearly shows an intrusive relation of the quartz porphyry to the mafic flows and breccia of the Spud Mountain Volcanics. The limitation of these large masses to the Shylock fault zone might imply some contemporaneity of the intrusions with the formation of the fault zone. The regional picture indicates, however, that the Shylock fault zone is younger than the plutonic rocks emplaced after folding of the Yavapai Series (Anderson, 1967), and no evidence is available to indicate that any quartz porphyry was intruded after the period of plutonism.

The quartz porphyry contains conspicuous quartz phenocrysts, 2–5 mm in diameter, that occur as partly to deeply corroded bipyramids. Albitic plagioclase is a common associate; phenocrysts range in length from 1 to 5 mm. Locally, feldspar phenocrysts are almost as abundant as quartz, and in some facies, feldspar phenocrysts equal or exceed quartz phenocrysts in abundance. Thin sections reveal that the groundmass is composed of an aggregate of quartz and alkalic feldspar averaging about 0.02 mm across. Potassium feldspar is rare in crystals large enough for optical determination. Sericite is variable in size and distribution; along the west margins of the long masses in the Shylock fault zone, sericite is abundant in closely spaced foliation planes. Secondary calcite appears in some specimens, generally filling minute fractures. Sphene(?) and leucoxene(?) in minute grains are common accessory minerals. In a few places inclusions of mafic rocks presumably contributed chlorite, clinozoisite, and epidote.

The quartz porphyry and granophyre are probably related to rhyolitic volcanic activity during the accumulation of formations of the Big Bug Group. The numerous rhyolitic intrusive masses, flows, and breccias, as well as clasts of rhyolite and quartz porphyry in the Spud Mountain breccia, indicate that rhyolitic volcanism was contemporaneous with the outpouring of andesitic and basaltic flows and deposition of the bedded pyroclastic rocks. The quartz porphyry and granophyre may represent rhyolitic magma that crystallized at shallow depths in the volcanic pile, locally reaching the surface as protrusive domes accompanied by explosive eruptions that supplied rhyolitic pyroclastic material to all three formations in the Big Bug Group.

The granophyre contains numerous scattered large quartz crystals (3–4 mm in diameter) embedded in a fine-grained matrix mottled by streaky aggregates of chlorite. Thin sections reveal that the dominant feldspar is albitic, 1–2.5 mm in length, sharply twinned, and clouded by sericite. Potassium feldspar is subordinate. Large micrographic to spherulitic intergrowths of quartz and albitic feldspar are the striking textural features, locally reaching a diameter of 2.5–3 mm (fig. 11).

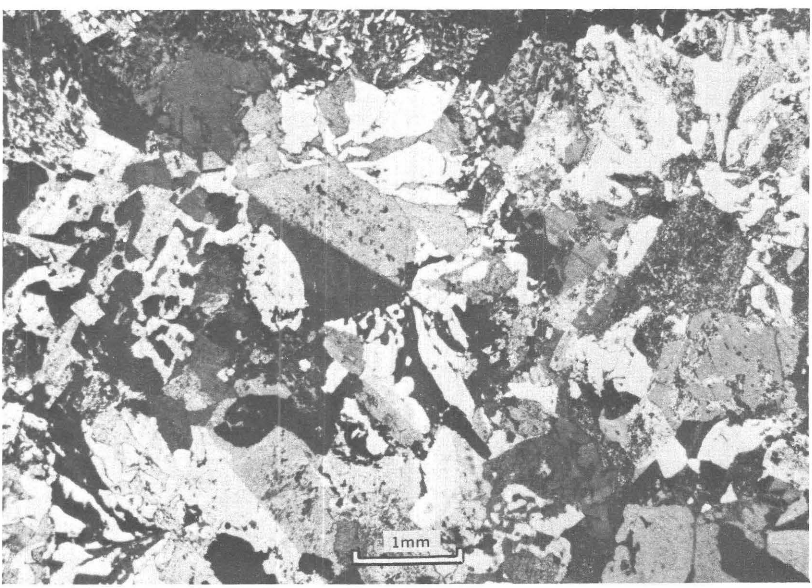


FIGURE 11.—Granophyre with micrographic intergrowths of quartz and alkalic feldspar. Twinned albitic plagioclase conspicuous. Crossed nicols. (Pl. 2, 1,261,400 N., 429,300 E.)

Fine-granular quartz and alkalic feldspar are interstitial to the larger crystals and micrographic intergrowths, and clots of chlorite and green biotite are in this matrix.

Chemical analyses of seven samples of quartz porphyry are given in table 7; four are from the Mingus Mountain quadrangle. Two samples of granophyre are given in table 7. Except for sample 1 (table 7), the composition indicates the rhyolitic character of these rocks, the only difference being the pronounced porphyritic or granophyric texture. The alkali content of these rocks is variable owing to some loss and migration of alkalis (Anderson, 1968a).

A few narrow dikes of quartz porphyry cut the granophyre, but only two are wide enough to plot on plate 2 (1,263,800 N., 428,900 E.; 1,263,500 N., 431,200 E.). These dikes contain quartz phenocrysts as large as 10 mm in diameter and albitic plagioclase phenocrysts, 2–4 mm in length, that are loaded with epidote. The microgranular groundmass of quartz and alkalic feldspar contains numerous granules of clinozoisite. A sample from a dike 3 feet wide (table 7, No. 1) reveals that these dikes are less silicic and more calcic than the other analyzed quartz porphyries and granophyre. These dikes may be much younger than the granophyre.

TABLE 7.—*Chemical analyses of quartz porphyry and granophyre*

[Rapid rock analyses: sample 1 analyzed by Paul Elmore, Lowell Artis, Sam Botts, Gillison Chloe, John Glenn, James Kelsey, and Hezekiah Smith; samples 2, 4–6 analyzed by Paul Elmore, Lowell Artis, Sam Botts, and Hezekiah Smith; samples 7–9 analyzed by Paul Elmore, Lowell Artis, Sam Botts, Gillison Chloe, John Glenn, and Hezekiah Smith. Sample 3: from Anderson and Creasey (1958, p. 35)]

	1	2	3	4	5	6	7	8	9
SiO_2	69.2	73.9	74.6	75.0	75.6	77.7	78.5	74.4	77.0
Al_2O_3	13.2	12.3	12.5	12.1	12.2	12.9	11.5	12.2	12.4
Fe_2O_3	2.3	.71	1.6	.51	.80	1.1	1.6	1.1	.55
FeO	2.8	1.9	2.0	1.9	1.4	.42	.18	2.4	1.5
MgO	1.5	2.0	.66	.1	3.7	.7	.35	.36	.21
CaO	4.3	.79	1.2	1.5	.27	.27	1.4	1.6	.56
Na_2O	2.3	.73	3.6	3.0	.21	1.9	.10	3.7	4.4
K_2O	1.6	4.9	2.6	2.9	2.3	3.3	3.5	1.3	2.5
H_2O^-	.06	.05	[1] 1.2	.09	.16	.09	.00	.08	.09
H_2O^+	1.7	.16		.11	2.9	1.4	1.0	1.2	.79
TiO_2	.25	.17	.26	.07	.13	.11	.17	.27	.00
P_2O_5	.02	.00	.06	.02	.04	.02	.03	.02	.00
MnO	.66	.04	.10	.08	.08	.00	.00	.00	.00
CO_2	<.05	.26	--------	.65	<.05	<.05	.88	.74	<.05
Powder density	2.82	2.73	--------	2.71	2.72	2.72	-------	-------	-------
Bulk density	2.81	2.66	--------	2.65	2.64	2.56	2.72	2.67	2.62

[1] Ignition loss.

1. Quartz porphyry, Mayer quad., 1,260,300 N., 431,300 E.
2. Quartz porphyry, Mingus Mountain quad., 1,360,500 N., 438,000 E.
3. Quartz porphyry, Mingus Mountain quad., 1,325,000 N., 438,000 E.
4. Quartz porphyry, Mingus Mountain quad., 1,331,000 N., 435,400 E.
5. Quartz porphyry, Mingus Mountain quad., 1,355,600 N., 436,300 E.
6. Quartz porphyry, Mayer quad., 1,246,300 N., 415,700 E.
7. Quartz porphyry, Mount Union quad., 1,261,100 N., 398,000 E.
8. Granophyre, Mayer quad., 1,261,400 N., 429,300 E.
9. Granophyre, Mayer quad., 1,260,300 N., 431,300 E.

PLUTONIC ROCKS

The larger masses of Precambrian plutonic rocks are limited to the northwest corner and west margin of the NE¼ Mount Union quadrangle (pl. 1) and to the northeast corner of the NW¼ Mayer quadrangle (pl. 2). Dikelike masses of gabbro are shown in the northwest quarter of plate 2 and northeast quarter of plate 1.

The age relations between all the various plutonic rocks are not known. In general, the gabbroic rocks are the oldest except for some fine-grained facies (diabasic in part) that intrude some of the quartz-bearing plutonic rocks. The Government Canyon Granodiorite in the Prescott quadrangle is younger than the large gabbroic masses (Krieger, 1965, p. 34), but these rocks are not in contact in the area of this report. The Crooks Canyon Granodiorite and alaskitic rocks intrude gabbroic rocks, but only the alaskitic rocks intrude the Government Canyon Granodiorite (north margin, pl. 1). In the Prescott quadrangle (Krieger, 1965, p. 47), the fine-grained granite intrudes the Prescott Granodiorite, which is younger than the Government Canyon Granodiorite.

A large mass of gabbro in the northeast corner of the Mayer quadrangle is clearly intruded by the south prong of quartz diorite that is exposed in much of the south half of the Mingus Mountain quadrangle, where it intrudes the Ash Creek Group (Anderson and Creasey, 1958). Two small dikes of gabbro, however, intrude the quartz diorite in the area covered by plate 2. To the north in the Mingus Mountain quadrangle, the quartz diorite is not exposed west of the Shylock fault except for fault slivers in the Shylock fault zone.

In the NE¼ Mount Union quadrangle (pl. 1), the Government Canyon Granodiorite, Crooks Canyon Granodiorite, and alaskitic rocks intrude the Green Gulch Volcanics and Spud Mountain Volcanics, and the Prescott Granodiorite and the fine-grained granite intrude only the Green Gulch Volcanics.

GABBRO AND RELATED ROCKS

The striking concentration of many of the narrow dikelike masses of gabbro in the Iron King Volcanics shown in the northeastern part of plate 1 and northwestern part of plate 2 suggests that these masses of gabbro represents sills of mafic magma injected during the accumulation of the extremely thick sequence of pillow lavas in the Iron King Volcanics. The general similarity in mineralogy and chemical composition (tables 5, 8) supports this possibility, but there is no compelling evidence to prove or disprove this interpretation.

In the Mingus Mountain quadrangle, the evidence is convincing that the rocks of the Ash Creek Group were folded prior to the emplacement of the gabbro that in general is concordant to the folds but in detail locally crosscuts the stratified rocks (Anderson and Creasey, 1958, p. 36). In the Prescott and Mount Union quadrangles, much of the gabbro is essentially concordant with the Green Gulch Volcanics north of the Chaparral fault. On the northwest side of the Chaparral fault and the southeast side of the Spud fault, dikelike masses of gabbro are parallel to these faults (pl. 1) and have a strong northeast foliation. The gabbro northwest of the Chaparral fault may be dragged into this orientation, but southeast of the Spud fault, the gabbro is essentially concordant with the Spud Mountain Volcanics. The evidence suggests that most of the larger masses of gabbro were emplaced after the folding of the Big Bug Group. The Chaparral fault occurred later than this folding, and it is possible that some gabbro was emplaced during or after the first movement on the fault.

The gabbro in the larger masses is dark and granular; the grain size is variable, but in general it is medium. Some of the smaller masses have a relict fine-grained diabasic texture, such as the outcrops south of Big Bug Creek that intrude the Spud Mountain breccia and andesitic tuffaceous rocks (pl. 1).

Relict textures are vague or destroyed in many of the larger gabbro masses that intrude the Spud Mountain and Iron King Volcanics between the Chapparal fault and Shylock fault zone (pls. 1, 2). Original plagioclase is represented by irregular-shaped albite heavily charged with clinozoisite and zoisite, separated by chlorite and (or) amphibole. The amphibole ranges from brown to bluish green to pale green to white and is in part fibrous. Scattered grains and clusters of epidote are common, and leucoxene is conspicuous. Interstitial quartz is rarely present. The gabbro sample (table 8, No. 6) taken from near an outcrop of Upper Cretaceous or lower Tertiary granodiorite (pl. 1, 1,261,300 N., 398,800 E.) contains albite in which sharp outlines are preserved. The albite is heavily charged with clinozoisite granules, and the matrix of the albite crystals is microgranular quartz, epidote, calcite, and biotite. The development of the biotite may be related to the nearby Upper Cretaceous or lower Tertiary granodiorite. Granodiorite of the same age has apparently modified the diabase exposed south of Big Bug Creek (pl. 1, 1,253,500 N., 383,500 E.), for oligoclase partly clouded by sericite is surrounded by greenish amphibole associated with large sphene crystals and magnetite.

Gabbro northwest of the Chaparral fault (pl. 1, 1,271,500 N., 382,500 E.) contains albite that is clear in part but generally is clouded by clinozoisite with appreciable aggregates of clinozoisite between the albite, associated with some interstitial quartz and sericite. The major

TABLE 8.—*Chemical analyses of gabbro and related rocks*

[Samples 2-8: rapid rock analyses by Paul Elmore, Lowell Artis, Sam Botts, Gillison Chloe, John Glenn, and Hezekiah Smith; sample 1: from Jaggar and Palache (1905, p. 4)]

	1	2	3	4	5	6	7	8
SiO_2	45.73	48.0	48.4	51.5	52.1	53.8	60.5	60.8
Al_2O_3	19.45	15.0	14.7	15.2	15.2	15.5	14.8	15.0
Fe_2O_3	5.28	3.6	3.5	2.4	2.1	3.7	2.0	2.2
FeO	3.18	8.3	6.3	6.9	8.7	4.8	6.6	4.7
MgO	6.24	6.9	8.7	6.4	5.4	4.7	2.2	2.7
CaO	13.86	11.0	12.5	10.5	8.4	7.1	6.1	6.4
Na_2O	.64	2.3	1.7	2.4	2.9	3.1	2.7	3.0
K_2O	.32	.05	.05	.99	.94	.49	1.2	1.3
H_2O^-	1.57	.00	.15	.03	.03	.00	.00	.06
H_2O^+	3.56	1.9	2.6	1.9	2.9	3.6	2.3	2.2
TiO_2	.23	1.8	.73	.67	.85	.65	.70	.42
P_2O_5		.13	.06	.22	.14	.21	.57	.14
MnO		.19	.17	.22	.17	.19	.19	.15
CO_2	.28	$<$.05	.08	.54	.08	1.2	$<$.05	.70
Bulk density		3.02	3.04	2.96	2.91	2.85	2.85	2.81

1. Gabbro, Mayer quad., west of Yarber Wash.
2. Gabbro, Mayer quad., 1,257,900 N., 405,800 E.
3. Gabbro, Mayer quad., 1,265,300 N., 401,900 E.
4. Gabbro, Mount Union quad., 1,249,100 N., 363,100 E.
5. Gabbro, Mount Union quad., 1,271,200 N., 369,400 E.
6. Gabbro, Mount Union quad., 1,261,300 N., 398,800 E.
7. Quartz-bearing gabbro, Mayer quad., 1,259,800 N., 431,100 E.
8. Quartz-bearing gabbro, Mayer quad., 1,261,100 N., 430.700 E.

mineral is amphibole, ranging from brown to bluish green to white, that is fibrous in part. Leucoxene is common. The other large masses of gabbro shown in the western part of plate 1 are spatially near younger Precambrian intrusive rock, and the plagioclase ranges from oligoclase to andesine, containing granules of clinozoisite and epidote. Green to brown amphibole is common, associated with interstitial quartz, and locally chlorite is present. Gabbro near alaskite and the fine-grained granite commonly contains a small amount of pale-brown biotite and potassium feldspar.

Augite was observed only in the gabbro dikes that intrude the Government Canyon Granodiorite (pl. 1, 1,270,000 N., 375,000 E.) and is associated with plagioclase that ranges from albite to andesine and contains clinozoisite. The augite is rimmed by fibrous bluish-green to yellow amphibole.

The dikelike masses of northwest-trend that cut granophyre in the northeastern part of the northwest quarter of the Mayer quadrangle contain an appreciable content of quartz. In the outcrop the quartz is recognizable but not conspicuous, and the dark granular appearance of the rock resembles gabbro exposed elsewhere. In sample 8 (table 8) albite containing abundant clinozoisite and sericite is present with sharp straight boundaries separated in large part by micrographic quartz and sericitized alkalic feldspar. The rest of the rock consists of bluish-green to yellow amphibole, epidote, chlorite, calcite, and leucoxene. Sample 7 (table 8), from the same general locality, has a fine-grained texture; it contains albite crystals that rarely exceed 0.5 mm in length and that are in large part surrounded poikilitically by quartz crystals as large as 2.5 mm in diameter. The albite contains abundant clinozoisite granules, but sericite is rare. Fibrous yellow to green to bluish-green amphibole is the chief mafic mineral. Both samples contain numerous slender to stubby prisms of apatite.

The limitation of the quartz-bearing gabbro to the dikes cutting the granophyre suggests that the quartz and micrographic quartz and alkalic feldspar may have been picked up from the granophyre and that the quartz-bearing gabbro is a contaminated rock.

The chemical analyses of most of the gabbroic rocks exposed in the area of this report (table 8, Nos. 1–6) indicate that the rocks range from gabbro to diorite. Six samples of gabbroic rock from the United Verde mine in the Mingus Mountain quadrangle show this same range (Anderson and Creasey, 1958, p. 38).

QUARTZ DIORITE

The quartz diorite exposed in the northeast corner of the NW¼ Mayer quadrangle is a massive rock containing few inclusions of foreign material. In the Mingus Mountain quadrangle, the pluton sharply truncates the folds in the Ash Creek Group (Anderson and Creasey, 1958, pl. 1).

Plagioclase, orthoclase, quartz, hornblende, and biotite are the major minerals. In the eastern part of the pluton in the Mingus Mountain quadrangle, the average grain size ranges from 1 to 2 mm, whereas in the western part the average size ranges from 3 to 4 mm. The orthoclase content is 9 percent in the western part and only 4 percent in the eastern part. The change in orthoclase content and grain size is transitional. Although the western part approaches a granodiorite in composition (fig. 12), the greater part of the pluton approaches quartz diorite, and this term was used by Anderson and Creasey (1958, p. 38).

The western part of the pluton, which extends into the NW¼ Mayer quadrangle (pl. 2), contains zoned plagioclase ranging from andesine to sodic labradorite. In many specimens the calcic core is altered to saussurite, an aggregate of clinozoisite, epidote, calcite, and sericite, separated by an albitic base. The orthoclase is poikilitic in part and interstitial in part. The hornblende is pleochroic in shades of green to yellowish brown, and the biotite is partly altered to chlorite. The quartz commonly is an aggregate of granules. Accessory minerals are magnetite, apatite, and sporadic sphene.

Granodiorite porphyry dike swarms cut the quartz diorite and Ash Creek Group in the Mingus Mountain quadrangle (Anderson and

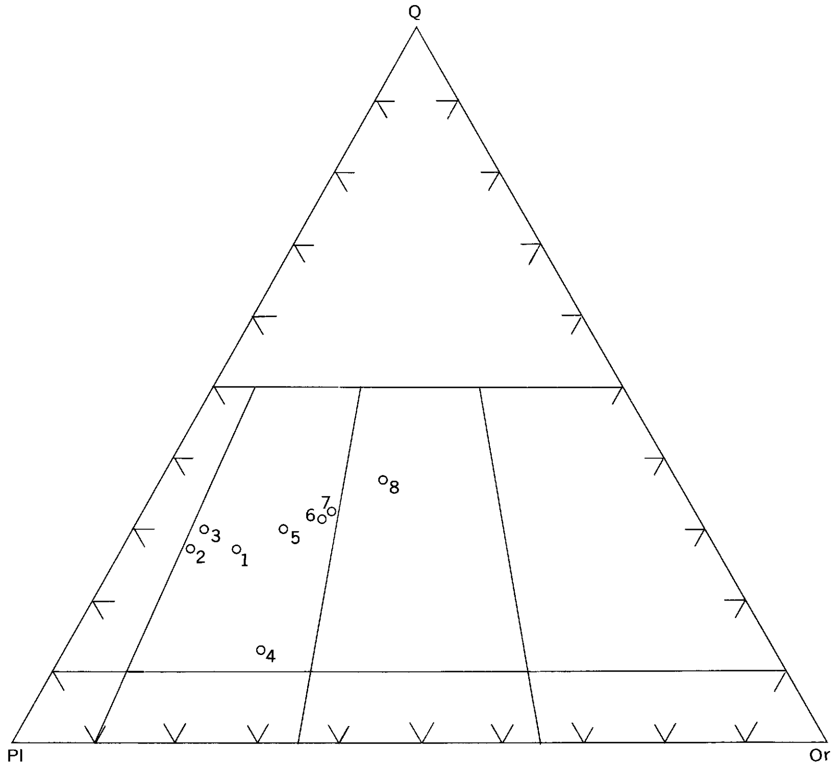


FIGURE 12.—Normative quartz-orthoclase-plagioclase of Precambrian quartz-bearing intrusive rocks. Numbers refer to table 9.

Creasey, 1958, pl. 1); the south tip of one of these dikes shows on plate 2 (1,273,300 N., 321,000 E.). Similar dikes in a cluster trending northwest intrude the granophyre (pl. 2, 1.260,000 N., 428,500 E.). These granodiorite porphyry dikes contain quartz and dulled plagioclase phenocrysts embedded in a pale-gray microcrystalline groundmass. Hornblende phenocrysts are sporadic in distribution, and some hornblende may appear in the groundmass. Presumably these dikes are satellitic to the quartz diorite and represent later intrusions in the closing phase of the magmatic activity.

CROOKS CANYON GRANODIORITE

The Crooks Canyon Granodiorite, a newly named unit, is the dominant Precambrian intrusive rock cropping out in the NE¼ Mount Union quadrangle (pl. 1), where it is exposed on the high ridge south of the Chaparral fault that culminates eastward in Mount Elliot. Small bodies of the granodiorite occur northwest of the Chaparral fault, and one small body crops out near the southeast corner of the quadrangle. In general, this granodiorite is resistant to erosion and forms tan to gray bold outcrops. The rock is mylonitized along the Chaparral fault and in the two small lenses exposed along the fault. A septum of gabbro separates the Crooks Canyon Granodiorite to the northwest of Big Bug Mesa; at the northeast end of the gabbro (pl. 1, 1,257,000 N., 370,300 E.), dikes of this granodiorite penetrate the gabbro, and inclusions of gabbro in the granodiorite prove that the Crooks Canyon Granodiorite is younger than the gabbro. The age relation of the Crooks Canyon Granodiorite to the Government Canyon Granodiorite is unknown.

Mapping in 1968 by C. A. Anderson and R. G. Hickman of the west half of the Mount Union quadrangle demonstrated that this mass of granodiorite extends to the southwest corner of the 15 minute quadrangle and is covered in part by Tertiary sedimentary and volcanic rocks. Crooks Canyon, about 2 miles south-southwest of Mount Union, is selected as the type locality for the Crooks Canyon Granodiorite. Some of this mass was distinguished as the Crooks Complex by Jaggar and Palache (1905) and was defined as closely associated with their Bradshaw Granite, although marked by alternations of diorite, aplite, gabbro, schist, and granite. The Crooks Canyon Granodiorite is not as complex in character as suggested by this description, and Lindgren (1926, pl. 2) included the Crooks Complex with the Bradshaw Granite. The current mapping program of the U.S. Geological Survey in this general region has demonstrated that the Bradshaw Granite can be divided into many plutons of variable petrographic types; thus the term Bradshaw Granite is considered abandoned (Krieger, 1965, p. 1), and the term Crooks Complex should be abandoned.

The eastern part of the Crooks Canyon Granodiorite south of the Chaparral fault is similar to the two masses that intrude gabbro north of the fault (pl. 1, 1,272,000 N., 381,400 E. and 383,500 E.). The rock is medium grained and massive to foliated. The potassium feldspar is microcline and microperthite, the plagioclase is partly sericitized albite, and quartz is interstitial to the feldspar. The ratio between potassium feldspar and plagioclase is variable, and locally, potassium feldspar exceeds albitic plagioclase. Small crystals of biotite in aggregates, concentrated largely in granulated feldspar and quartz, are suggestive of cataclasis. In places the biotite is replaced by chlorite. Accessory minerals include conspicuous zircon and allanite.

Mylonitized Crooks Canyon Granodiorite is exposed on the main ridge south of the Chaparral fault (pl. 1, 1,259,300 N., 366,200 E.). Augen of potassium feldspar and albite, 1–2.5 mm long, are separated by parallel streaks of quartz and feldspar grains, averaging 0.2–0.3 mm in diameter. Colorless garnet is present in small amounts associated with feldspar.

The content of mafic minerals gradually increases toward the southwestern part of the granodiorite mass, producing dark shades of gray in the fresh rock. The plagioclase is largely albitic, but contains abundant granules of clinozoisite; epidote associated with biotite is conspicuous. Granular sphene increases in content as compared with the less mafic facies. Granulation of quartz is common, indicating either protoclasis or cataclasis.

Much of the Crooks Canyon Granodiorite exposed in the west half of the Mount Union 15-minute quadrangle is typically granular in texture and contains biotite in booklike habit. Quartz, microcline-perthite, and saussuritized plagioclase are the major minerals. A chemical analysis (table 9, No. 5) indicates that this granular facies has the composition of a granodiorite, whereas two samples in which the biotite is in aggregates (table 9, Nos. 6, 7) approach quartz monzonite in composition (fig. 12). The available chemical data indicate that the Crooks Canyon Granodiorite is much more silicic than the Government Canyon Granodiorite (table 9).

The lens-shaped mass of Crooks Canyon Granodiorite exposed in the southeastern part of the NE¼ Mount Union quadrangle (pl. 1) is in fault relation with the Iron King Volcanics on the northward extension of the fault separating Texas Gulch Formation from the Iron King Volcanics. The margins of this lens are highly sheared.

TABLE 9.—*Chemical analyses of quartz-bearing intrusive rocks*

[Samples 1, 4, 8: from Krieger (1965, p. 30); samples 2, 3, 5–7: rapid rock analyses by Paul Elmore, Lowell Artis, Sam Botts, Gillison Chloe, John Glenn, James Kelsey, and Hezekiah Smith]

	1	2	3	4	5	6	7	8
SiO_2	65.6	65.8	68.9	61.4	70.2	70.6	73.8	77.9
Al_2O_3	16.2	15.9	15.5	16.7	15.2	14.6	13.4	13.2
Fe_2O_3	2.5	2.1	1.4	2.6	.66	1.2	.33	.61
FeO	2.3	2.3	1.8	2.7	1.4	1.8	1.7	.06
MgO	1.7	1.5	.99	2.8	.80	.74	.24	.05
CaO	4.6	5.2	4.2	4.7	2.8	2.6	1.1	.22
Na_2O	3.6	4.2	4.4	4.2	4.1	3.5	4.3	4.1
K_2O	2.1	1.2	1.3	3.4	2.9	3.5	3.7	4.5
H_2O^-		.04	.02		.03	.05	.23	
	.84			.62				.3
H_2O^+		.68	.84		.82	.84	.77	
TiO_2	.38	.27	.16	.69	.25	.16	.14	.11
P_2O_5	.14	.22	.11	.35	.11	.07	.04	.00
MnO	.08	.08	.08	.08	.07	.08	.02	.00
CO_2	.07	<.05	<.05	.06	.05	<.05	.05	.08
Bulk density		2.71	2.68			2.67		

1. Quartz diorite, Mingus Mountain quad., 1,291,700 N., 427,200 E.
2. Quartz diorite, Mingus Mountain quad., 1,289,400 N., 437,800 E.
3. Quartz diorite, Mingus Mountain quad., 1,300,500 N., 454,000 E.
4. Government Canyon Granodiorite, Prescott quad., 1,280,000 N., 341,000 E.
5. Crooks Canyon Granodiorite, Mount Union quad., 1,228,200 N., 341,700 E.
6. Crooks Canyon Granodiorite, Mount Union quad., 1,250,300 N., 364,900 E.
7. Crooks Canyon Granodiorite, Mount Union quad., 1,251,800 N., 359,500 E.
8. Alaskite, Prescott quadrangle, 1,283,700 N., 367,000 E.

The interior consists of partly weathered granodiorite that in general resembles the northeast exposures of the mass adjacent to the Chaparral fault except that the albitic feldspar contains abundant clinozoisite and exceeds the potassium feldspar in amount.

GOVERNMENT CANYON GRANODIORITE

The Government Canyon Granodiorite was defined by Krieger (1965, p. 34) from exposures in the southwest corner of the Prescott quadrangle. In the Mount Union quadrangle to the north of the Chaparral fault, a large mass and smaller offshoots of Government Canyon Granodiorite form rounded bold outcrops. The rock is massive except adjacent to the Chaparral fault, where locally it is intensely sheared and mylonitized. To the south, between Eugene and Big Bug Creeks, a smaller mass with a pronounced gneissic structure is less well exposed.

The texture and mineralogy of the north mass is similar to the Government Canyon Granodiorite exposed in the Prescott quadrangle. Essentially, the texture is medium grained and seriate; the conspicuous, zoned plagioclase crystals range from 2 to 6 mm in length and average between 2 and 3 mm. The cores of the plagioclase are loaded with clinozoisite and epidote granules, and the outer rims are albitic. Orthoclase is interstitial to the other minerals and contains some larger poikilitic grains; it is subordinate to plagioclase. Quartz ranges from 0.5 to 4 mm in diameter; the larger grains may be poikilitic. Hornblende and biotite average about 2 mm in length; locally both are appreciably altered to chlorite. The accessory minerals are magnetite (?), sphene, apatite, and zircon.

The smaller mass of Government Canyon Granodiorite has a gneissic structure developed by the alinement of the dark minerals. The texture of this facies has some similarities to the massive rock north of the Chaparral fault, but the quartz is in granular aggregates. The biotite is altered to chlorite, and the hornblende is replaced by epidote and chlorite.

The chemical composition of the Government Canyon Granodiorite in the Prescott quadrangle is given in table 9 (No. 4).

ALASKITIC ROCKS

In the Prescott quadrangle, Krieger (1965, p. 40–42) recognized alaskite and related rocks as conspicuous intrusive masses that form bold light-brown to white outcrops. The texture of the alaskitic rocks is variable, and Krieger (1965, pl. 1) distinguished alaskite, alaskite porphyry, and aplite. Southerly extensions of these rocks are exposed along the north border of the Mount Union quadrangle. The alaskitic rocks consist largely of albitic plagioclase, potassium feldspar, and quartz. Textures are medium grained equigranular to cataclastic. The porphyritic facies can be distinguished by abundant quartz and feldspar phenocrysts in a finely crystalline groundmass. Aplite and aplitic alaskite are fine grained and have a sugary texture (Krieger, 1965, p. 42). The alaskitic rocks intrude the Government Canyon Granodiorite in the northwest corner of the NE¼ Mount Union quadrangle, but no evidence is available as to the age relation of the alaskitic rocks to the Crooks Canyon Granodiorite.

Short dikelike masses of alaskitic rock intrude the Iron King Volcanics to the northeast of the faulted lens of Crooks Canyon Granodiorite (pl. 1, 1,240,000 N., 395,500 E.). The dikes have a seriate texture with grains of quartz and feldspar ranging from 1 to 2 mm in size that are separated by granular quartz and feldspar 0.3–0.5 mm in diameter. Micrographic quartz and alkalic feldspar are sparse. A similar seriate-textured dike intrudes the upper unit of the Spud Mountain Volcanics (pl. 2, 1,252,000 N., 411,800 E.).

Two dikelike masses of aplitic rock exposed in the upper unit of the Spud Mountain Volcanics separate ferruginous chert from the adjacent tuffaceous beds (pl. 2, 1,266,000 N., 407,000 E.; 1,275,000 N., 407,600 E.). The texture in these granular rocks is fine grained. Albitic plagioclase greatly exceeds potassium feldspar in amount. Intersecting thin veins of ankerite give a crackled appearance to the rock. The carbonate is partly oxidized to limonite, and pyrite is a minor accessory. A third aplitic dike is exposed in Spud Mountain rhyolite south of the Agua Fria River (pl. 2).

PRESCOTT GRANODIORITE AND FINE-GRAINED GRANITE

The Prescott Granodiorite is exposed principally in the city of Prescott (Krieger, 1965, pl. 1), but one band crops out to the east and extends a short distance into the Mount Union quadrangle (northwest corner of pl. 1). The Prescott Granodiorite is a fine- to medium-grained massive rock consisting of andesine plagioclase, potassium feldspar, quartz, and biotite. A characteristic feature is numerous square to rectangular poikilitic potassium feldspar crystals averaging about 6 mm in size (Krieger, 1965, p. 37).

The fine-grained granite is exposed as a narrow band in the south-central part of the Prescott quadrangle and extends for a very short distance into the Mount Union quadrangle (northwest corner of pl. 1). Krieger (1965, p. 47) emphasized that the fine-grained granite is contaminated with older rocks, a feature that can be recognized in the Mount Union quadrangle. In general, the grain size averages about 1 mm; locally some albitic plagioclase is 2 mm long and contains in

458-804 O - 72 - 4

places abundant sericite and elsewhere granules of clinozoisite. Potassium feldspar is erratic in distribution and commonly is poikilitic with a variety of included minerals. Quartz is largely interstitial to the feldspar and locally is granulated. In places, deeply pleochroic green to brown hornblende is the dominant mafic mineral, with or without biotite. In other places, chlorite, biotite, and epidote are the mafic minerals. The chemical composition (Krieger, 1965, table 8, No. 13) indicates that the fine-grained granite is not a normal plutonic rock in comparison with the other quartz-bearing plutonic rocks in the area.

TEXAS GULCH FORMATION

The Texas Gulch Formation, as defined by Anderson and Creasey (1958, p. 28–30), is composed of an alternating sequence of bedded rhyolitic tuff and purple slate, cropping out in a band about 2,500 feet wide in the Shylock fault zone in the western part of the Mingus Mountain quadrangle (Anderson, 1967). In this fault zone, the formation is so intensely deformed that commonly the abrupt termination of a particular slate or tuff unit could be related either to a steep-plunging fold or to a lens or to a gross boudin. Both the east and west boundaries of the outcrop area of the formation are faults, and internally most of the contacts between tuff and slate are probably faults. Therefore it was impossible to determine the thickness of the Texas Gulch Formation in the type locality or the stratigraphic relations with other formations.

The Texas Gulch Formation in the area covered by this report is limited to outcrops bounded by faults, as in the Shylock fault zone in the Mayer quadrangle, where it ends against a lenticular mass of diorite porphyry (pl. 2, 1,266,000 N., 415,000 E.). In the NE¼ Mount Union quadrangle, the widest outcrop of the formation is in fault contact with the Iron King Volcanics to the east and with the Spud Mountain Volcanics to the west, near the south edge of the map area (pl. 1). This faulted sliver of Texas Gulch Formation extends to the north margin of the Mount Union quadrangle, where it has an outcrop width of only 300 feet. It is continuously exposed except where it is cut out by the Upper Cretaceous or lower Tertiary granodiorite and partly covered by the Hickey Formation at Little Mesa. In the southeast corner of the NE¼ Mount Union quadrangle, a wedge of Texas Gulch Formation is in fault contact with Iron King Volcanics.

The stratigraphic position of the Texas Gulch Formation is revealed only in the southeast quarter of the Mount Union 15-minute quadrangle, where Blacet (1966) found that the Texas Gulch Formation is in depositional contact with the underlying Brady Butte Granodiorite. Radiometric dating (Anderson and others, 1971) proves that the Brady Butte Granodiorite is younger than the Big Bug Group. The Texas Gulch Formation is therefore not a part of the Big Bug Group, but a distinctly younger formation that accumulated after episodes of deformation and plutonism involving the Big Bug Group.

The Texas Gulch Formation is made up essentially of two distinct units: (1) slate and (2) bedded rhyolitic tuff grading into sandy tuff and rhyolitic tuffaceous sandstone. Locally some sandstone beds contain a high proportion of nonvolcanic detritus. Thin interbeds of limestone, ranging from a few inches to 5 feet in thickness, crop out locally, particularly in the western part of the Mingus Mountain quadrangle (Anderson and Creasey, 1958, pl. 1). Pebble and cobble conglomerate beds occur with the slate, but more commonly with the sandy beds.

The conglomerate beds provide information about the nature of some of the source material that forms the Texas Gulch Formation. Jasper and gray chert are common as pebbles and cobbles, but the main rock type is granophyre similar to that of cobbles and boulders that Blacet (1966) found in the basal conglomerate at Brady Butte. Textural variations of the granophyre are alaskite porphyry and seriate alaskite. Sparse rhyolite pebbles have been found. The granophyre is seriate to porphyritic in texture, containing albitic phenocrysts as much as 3 mm in length associated with quartz phenocrysts of similar size. In some pebbles, albitic phenocrysts appreciably exceed quartz phenocrysts; in others, the two minerals are about equal in amount. Orthoclase (perthite, microcline) is generally smaller (0.2–0.3 mm) and less conspicuous. The matrix is largely graphic intergrowths of quartz and alkalic feldspar. Locally the intergrowths have a diameter of 1–1.5 mm; in some pebbles, the micrographic intergrowths are smaller and are a part of a fine-grained groundmass. Biotite is a rare accessory and of small size (0.2 mm). Secondary calcite appears as veinlets in a few pebbles.

Conglomerate beds were found at five localities in the Texas Gulch Formation in the northeast quarter of the Mount Union quadrangle (not plotted on pl. 1). The most southerly outcrop is near the east fault contact with the Iron King Volcanics (pl. 1, 1,238,800 N., 387,500 E.); the conglomerate is interbedded with fine-grained tuffaceous sandstone. A second outcrop near this fault contact (pl. 1, 1,240,500 N., 386,900 E.) contains boulders of granophyre 10–18 inches in diameter; the conglomerate bed can be traced for 250 feet. The matrix of this conglomerate is very coarse grained sandstone, and the adjacent rocks are coarse-grained sandstone. At a third locality (pl. 1, 1,236,600 N., 385,000 E.) four beds of pebble conglomerate, 6 inches to 1 foot wide, are interbedded with silty beds (phyllite to slate). North of Big Bug

Creek, a fourth outcrop was found near the Upper Cretaceous or lower Tertiary granodiorite (pl. 1, 1,260,600 N., 391,400 E.); however, the rocks are appreciably hornfelsed, and only recrystallized chert pebbles can be recognized. The most northerly exposure (pl. 1, 1,272,500 N., 397,400 E.) reveals scattered pebbles in sandy tuff and interbedded limestone beds.

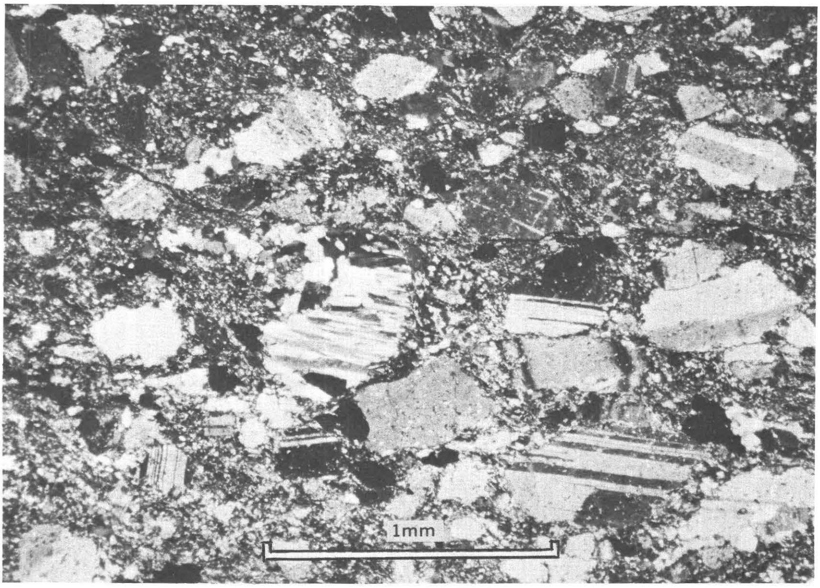
The sandy facies of the Texas Gulch Formation is thin to thick bedded; it ranges from coarse to very fine grained, but most is medium grained. The grains are angular, and except in fine sand, the sorting is poor (fig. 13, upper). Volcanic detritus includes sharply embayed quartz crystals representing resorbed phenocrysts; chips of typical rhyolitic groundmass; and a few groundmass clasts containing small quartz phenocrysts. Other detrital chips resemble devitrified glass containing albitic microlites. In some beds, white wispy plates, several times as long as the diameter of associated grains, strikingly resemble collapsed pumice fragments found in unmetamorphosed rhyolitic pyroclastic rocks. Thin sections reveal that they are now composed of aggregates of sericite (fig. 13, lower).

Some of the volcanic detritus may be dacitic, for in two localities east of Little Mesa, medium-grained sandy tuff contains abundant clinozoisite grains associated with albite, quartz, sericite, and pale-green chlorite.

Nonvolcanic detritus is revealed by grains of micrographic intergrowths of quartz and alkalic feldspar and by chips of chert. Microcline (or perthite) may also be nonvolcanic, as it is rare in the rhyolitic rocks in the Big Bug Group; it may have its source in disintegrated granophyre, which could supply some of the angular albite and quartz clasts. Epidote grains and blue tourmaline needles are present as minor constituents in some of the sandy facies containing much volcanic detritus and in some beds with little volcanic material.

In general, the bedded sandy rocks that contain an abundance of apparent rhyolitic detritus, are characterized by abundant albite and subordinate quartz grains and an absence of chert and microcline. These rocks are undoubtedly bedded rhyolitic tuff. In the sandy rocks that contain abundant and large quartz grains, micrographic intergrowths are sparse to common, and microcline may be present. These rocks may be properly termed tuffaceous sandstone. No samples were found that contained only nonvolcanic detritus. Careful sampling of the formation to determine more precisely the ratio of rhyolitic tuffs to tuffaceous sandstone was beyond the scope of this study.

The slate facies in the Texas Gulch Formation as exposed in the Mingus Mountain quadrangle is largely purple except for some of the most westerly exposures (Anderson and Creasey, 1958, p. 29), where it is greenish gray. The slate shown in the Mayer quadrangle



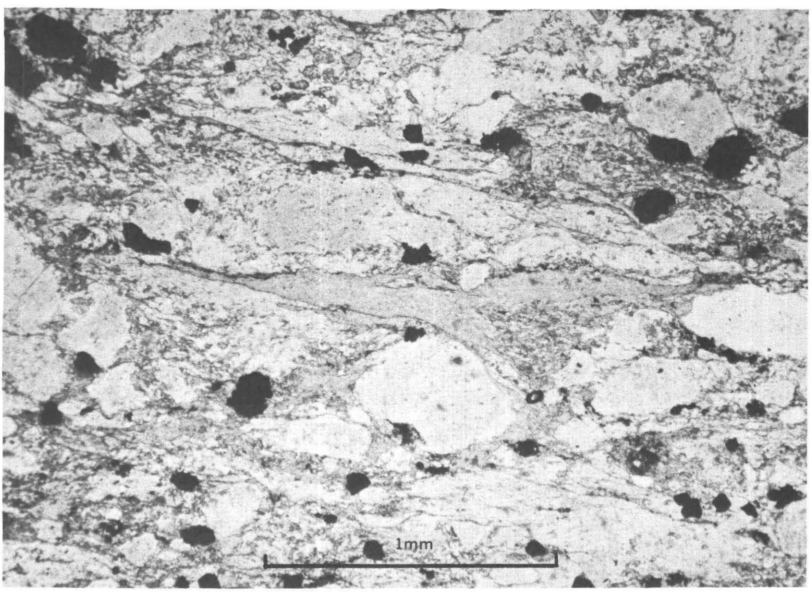


FIGURE 13.—Bedded rhyolitic tuff in Texas Gulch Formation. *Upper:* Poorly sorted albite and quartz clasts in a fine matrix of quartz, alkalic feldspar, sericite, and calcite. Prominent magnetite grains. Crossed nicols. (Pl. 1, 1,233,700 N., 379,800 E.) *Lower:* Collapsed pumice in right center embedded in poorly sorted albite and quartz clasts. Magnetite conspicuous. Ordinary light. (Pl. 1, 1,233,700 N., 379,800 E.)

is predominantly purple and is mapped separately from the bedded rhyolitic tuff on the geologic map. The slate facies is not distinguished from the tuffaceous rocks in the Mount Union quadrangle (pl. 1), but the slate is limited to the north exposures. In general, this slate is gray except near the north margin of the area of plate 1 where it is tan to gray and contains thin interbeds of gray limestone.

The purple slate is revealed in thin sections to consist of abundant oriented sericite, detrital quartz, and hematitic dust. Apatite is a common accessory mineral. The quartz grains are about 0.05 mm in maximum dimension, and the individual sericite flakes are about 0.03 mm long. The gray slate is similar except that black opaque plates (magnetite?) are interstitial to the quartz and sericite. Blue tourmaline needles are associated with the sericite, and stubby tourmaline crystals occur with the quartz.

Presumably the slates were originally silty shale, and the chemical analyses of purple and gray slate indicate that they probably are normal terrigenous sedimentary rocks rather than fine-grained rhyolitic tuffs (table 10).

The Texas Gulch Formation apparently represents an accumulation of nonvolcanic detritus mixed with contemporaneous pyroclastic detritus, largely of rhyolitic composition. The sandy beds are poorly sorted and undoubtedly represent sediment poured into the basin of deposition at a rate so rapid that there was little or no selection for size or reworking by currents.

DIORITE PORPHYRY AND FELDSPAR PORPHYRY

Plugs and dikes of diorite porphyry are limited to the Mayer quadrangle. Two pluglike masses are in the Shylock fault zone: one forms the south margin of the Texas Gulch Formation, and the other is surrounded by Spud Mountain Volcanics. Smaller plugs and a northeast-trending dike swarm intrude Spud Mountain Volcanics in the southeast corner of the area of plate 2.

The diorite porphyry within the Shylock fault zone contains plagioclase phenocrysts 2 mm long embedded in a microcrystalline groundmass of feldspar laths and some interstitial quartz. The original feldspar must have been calcic, as it now is albite that is crowded with epidote granules and locally some associated sericite. The outline of chlorite and epidote aggregates suggests original hornblende phenocrysts. Foliation is marked by the parallel arrangement of some sericite and chlorite. The chemical analysis (table 11, No. 1) indicates that the rock is between granodiorite porphyry and diorite porphyry in composition.

The diorite porphyry in the southeast corner of the northwest quarter of the Mayer quadrangle is nonfoliated, although the Spud

TABLE 10.—*Chemical and semiquantitative spectrographic analyses of rocks in Texas Gulch Formation*

[Sample 1: from Anderson and Creasey (1958, p. 30); samples 2-5: rapid rock analyses by Paul Elmore, Lowell Artis, Sam Botts, Gillison Chloe, John Glenn, James Kelsey, and Hezekiah Smith and semiquantitative spectrographic analyses by Chris Heropoulos]

	1	2	3	4	5
Chemical analyses (in percent)					
SiO_2	62. 2	60. 6	62. 7	73. 3	78. 7
Al_2O_3	19. 4	18. 3	17. 8	11. 5	11. 7
Fe_2O_3	7. 5	6. 1	2. 7	4. 6	2. 1
FeO	. 30	1. 2	3. 0	. 80	. 15
MgO	1. 6	2. 4	2. 1	. 80	. 42
CaO	. 08	1. 1	3. 7	1. 2	. 15
Na_2O	1. 3	2. 0	3. 7	1. 9	3. 1
K_2O	3. 6	3. 8	1. 1	3. 4	2. 1
H_2O^-	[1]3. 3	. 36	. 02	. 06	. 06
H_2O^+		2. 6	1. 9	1. 1	1. 1
TiO_2	. 75	. 72	. 69	. 65	. 23
P_2O_5	. 20	. 15	. 24	. 06	. 05
MnO	. 02	. 40	. 21	. 00	. 00
CO_2		<. 05	. 18	. 26	<. 05
Powder density			2. 75	----------	2. 75
Bulk density			2. 75	----------	2. 53
Semiquantitative spectrographic analyses (in percent)					
B		0. 01	0. 0015	0. 0015	0. 0007
Ba		. 07	. 03	. 07	. 07
Be		0	. 0002	0	. 00015
Co		. 003	. 002	. 0007	. 0005
Cr		. 005	. 005	. 007	. 0015
Cu		. 0003	. 007	. 001	. 0007
Ga		. 0015	. 0015	. 0015	. 001
La		. 005	. 003	0	. 003
Nb		0	. 001	. 001	. 0015
Ni		. 005	. 005	. 0015	. 001
Pb		. 002	. 005	0	. 0015
Sc		. 002	. 0015	. 001	. 0005
Sr		. 03	. 1	. 01	. 015
V		. 007	. 007	. 007	. 002
Y		. 002	. 002	. 003	. 003
Yb		. 0002	. 0002	. 0003	. 0003
Zr		. 01	. 015	. 03	. 02

[1] Ignition loss.

1. Purple slate, Mingus Mountain quad., 1,312,900 N., 418,500 E.
2. Gray slate, northeast quarter of Mount Union quad., 1,251,000 N., 387,700 E.
3. Silty sandstone, southeast quarter of Mount Union quad., 1,225,800 N., 384,500 E.
4. Arkosic sandstone, southeast quarter of Mount Union quad., 1,227,200 N., 377,800 E.
5. Pumice-crystal tuff, northeast quarter of Mount Union quad., 1,243,800 N., 385,800 E.

Mountain breccia host is locally foliated. The albitic plagioclase phenocrysts average about 2 mm long and contain appreciable sericite; the groundmass consists of microcrystalline quartz and alkalic feldspar surrounding spherulitic aggregates of albite 0.5 mm in diameter.

Chlorite forms aggregates and veinlets. Some outcrops contain rare quartz phenocrysts, suggesting that locally the diorite porphyry in this area may be more silicic than the porphyry exposed in the Shylock fault zone.

The diorite porphyry plugs and dikes clearly intrude the Spud Mountain Volcanics in the southeast corner of the northwest quarter of the Mayer quadrangle, and locally some of the gabbro seems to intrude the diorite porphyry. In the Shylock fault zone, the outcrop pattern suggests that the diorite porphyry intrudes the Texas Gulch Formation, and the foliation in the porphyry indicates emplacement before the last period of deformation. It is possible that the plugs in the Shylock fault zone are fault slivers. No evidence is available as to the age relation of the diorite porphyry in the Shylock fault zone to the porphyry intrusive to the southeast in the Spud Mountain Volcanics.

The feldspar porphyry is limited to one dike that intrudes the Texas Gulch Formation south of Big Bug Creek (pl. 1). Conspicuous albitic phenocrysts that range from 1 to 2 mm in length are embedded in a medium-gray microcrystalline groundmass containing microphenocrysts of quartz ranging from 0.25 to 0.5 mm in diameter. Epidote and clinozoisite granules and patches of chlorite separate parallel streaks of calcite and sericite that give a foliation to the rock. Chemically (table 11, No. 2) the rock is a granodiorite porphyry, but to distinguish it from younger granodiorite porphyry dikes, the descriptive term of feldspar porphyry is used.

TABLE 11.—*Chemical analyses of diorite porphyry and feldspar porphyry*

[Rapid rock analyses by Paul Elmore, Lowell Artis, Sam Botts, Gillison Chloe, John Glenn, James Kelsey, Hezekiah Smith, and Dennis Taylor]

	1	2
SiO_2	59.0	66.5
Al_2O_3	17.3	15.9
Fe_2O_3	2.6	1.3
FeO	3.5	1.6
MgO	3.1	1.2
CaO	5.4	3.3
Na_2O	4.1	4.9
K_2O	2.1	1.5
H_2O^-	.12	.16
H_2O^+	1.5	1.4
TiO_2	.72	.37
P_2O_5	.28	.11
MnO	.11	.02
CO_2	.06	1.6
Powder density	2.84	2.72
Bulk density	2.78	2.64

1. Diorite porphyry, Mayer quad., 1,263,200 N., 415,300 E.
2. Feldspar porphyry, Mount Union quad., 1,251,000 N., 387,400 E.

UPPER CRETACEOUS OR LOWER TERTIARY ROCKS

Rocks of Late Cretaceous or early Tertiary age in the report area are entirely igneous in origin and are largely limited to the Mount Union quadrangle (pl. 1). This igneous episode began by the intrusion of granodiorite stocks, essentially in an east-west belt across the northern part of the quadrangle. Several short dikes of granodiorite porphyry intrude the Spud Mountain Volcanics and Government Canyon Grandodiorite south of Eugene Gulch (pl. 1, 1,255,000 N., 376,000 E.). Rhyolite porphyry dikes clearly intrude one of the Upper Cretaceous or lower Tertiary granodiorite stocks (pl. 1, 1,261,500 N., 362,100–362,500 E.). In the northwest corner of the NE¼ Mount Union quadrangle, rhyolite porphyry dikes intrude the Green Gulch Volcanics and gabbro; a second group intrudes the Spud Mountain Volcanics south of Eugene Gulch; a third group intrudes the Spud Mountain Volcanics and Texas Gulch Formation in a zone extending from the northeast corner of the quadrangle to east of Big Bug Mesa.

GRANODIORITE

The youngest plutonic rocks in the northern Bradshaw Mountains are granodiorite stocks exposed largely in the Mount Union quadrangle. The longest stock is partly exposed at the west margin of the NE¼ Mount Union quadrangle, where it has destroyed the trace of the Chaparral fault; this stock extends nearly 4 miles southwestward into the adjacent area. The town of Walker is located in the eastern part of the stock (west of pl. 1). The stock along Big Bug Creek has an east-west exposed length of 3 miles and a similar exposed length to the northeast. Two smaller exposures of granodiorite are in Eugene Gulch between the two larger stocks.

Jaggar and Palache (1905, p. 5) noted at the time of their study that the principal mines occurred along or near the contacts of these stocks, locations suggesting a genetic relation. Lindgren (1926, p. 21–22) reported that the stock at Walker is granodiorite and pointed out the similarity to other intrusive stocks of Cretaceous or early Tertiary age in the Western States. Furthermore, radiometric dating indicates similar ages: the stock at Walker is 64 m.y. old, and the one along Big Bug Creek is 70 m.y. old (Anderson, 1968, p. 1168b); thus the time of intrusion is Late Cretaceous or early Tertiary.

Much of the granodiorite weathers into spheroidal forms separated by friable sandy soil. A notable exception is the steep rugged ridge north of Big Bug Creek, where bold outcrops are continuous. Hydrothermal alteration is common in many places in the stock along Big Bug Creek, resulting in bleached or limonite-stained outcrops.

The granodiorite in general is medium grained. It contains conspicuous zoned plagioclase crystals between 2 and 3 mm in length and composed of sodic to calcic oligoclase. Potassium feldspar is generally smaller in size except for occasional poikilitic grains 2 mm or more in diameter. Interstitial quartz grains averages about 1 mm in diameter, with some as small as 0.3 mm. Hornblende is conspicuous, particularly in the hand specimen, and in the eastern part of the stock along Big Bug Creek, hornblende crystals are locally 5–7 mm long; in general, they average about 2 mm in length, and a few crystals are as long as 3 mm. The large hornblende crystals contain biotite and magnetite inclusions. Biotite is rarely larger than 2 mm in size, generally averaging between 1 and 2 mm. Accessories are magnetite, irregular sphene, stubby apatite, and tiny zircon crystals. The chemical analyses of the medium-grained facies indicate that the rock is granodiorite (table 12, Nos. 2, 3, 4).

The stock that is exposed along Big Bug Creek has a prong that extends northward, bounded on the west by the Spud fault and on the east by the Spud Mountain breccia (pl. 1). The granodiorite in this prong is more altered than along Big Bug Creek, and the potassium feldspar content is appreciably lower. The quartz crystals, 2–3 mm in diameter, are strained and recrystallized and locally enclose sericitized plagioclase poikilitically. The biotite is partly altered to chlorite, and most of the hornblende is altered to chlorite and epidote. Secondary greenish-blue fibrous amphibole (actinolite?) is present along fractures. Anderson and Creasey (1958, p. 41) called this north prong quartz diorite because of the low orthoclase content and assigned it to the Precambrian because of the granulation of the quartz and alteration of the plagioclase. The geologic mapping southward has demonstrated that it is a quartz diorite facies of the granodiorite stock exposed along Big Bug Creek.

Small pluglike and dikelike exposures of fine-grained granodiorite are along the east margin of the Mount Union quadrangle (pl. 1) and western margin of the Mayer quadrangle (pl. 2). This fine-grained granodiorite contains hornblende needles that range in length from 0.5 mm to 3 mm but average about 1 mm. Biotite, in places altered to chlorite, rarely exceeds 1 mm in diameter and is generally smaller. The plagioclase is strongly zoned and rarely more than 1 mm in length. Orthoclase and quartz are largely interstitial to the plagioclase and hornblende and are 0.1 mm or more in diameter. The texture is more seriate than hypidiomorphic granular. The accessories are the same as in the medium-grained granodiorite. The chemical composition of this facies is less silicic than the medium-grained granodiorite and approaches a diorite in composition (table 12, No. 1).

TABLE 12.—*Chemical analyses of Upper Cretaceous or lower Tertiary igneous rocks*

[Samples 1–3, 6: rapid rock analyses by Paul Elmore, Lowell Artis, Sam Botts, Gillison Chloe, John Glenn, and Hezekiah Smith; samples 4, 5, 7: from Lindgren (1926, pp. 21, 23, 23, respectively)]

	1	2	3	4	5	6	7
SiO_2	61.5	63.6	65.7	65.74	65.83	69.1	71.20
Al_2O_3	16.0	15.8	16.9	16.76	15.76	16.5	17.57
Fe_2O_3	2.8	2.8	2.1	3.99	2.51	1.6	1.50
FeO	2.1	2.4	1.8			0.46	
MgO	2.4	1.0	1.8	1.70	.79	.15	.21
CaO	4.9	4.9	4.1	3.78	3.16	.59	.37
Na_2O	5.0	4.2	3.9	3.37	2.84	5.8	.05
K_2O	2.5	2.5	2.7	3.55	4.15	3.6	5.92
H_2O^-	.31	.29	.22			.44	
			.99		5.41		2.86
H_2O^+	1.3	.66	.48			1.0	
TiO_2	.54	.58	.00			.25	
P_2O_5	.20	.45	.16			.37	
MnO	.09	.05	.06			.03	
CO_2	<.05	.05	.08			.12	
Powder density			2.75				
Bulk density	2.71		2.65				

1. Fine-grained granodiorite, Mount Union quad., 1,259,600 N., 396,300 E.
2. Granodiorite, Mount Union quad., 1,258,600 N., 385,800 E.
3. Granodiorite, Mount Union quad., 1,259,400 N., 362,400 E.
4. Granodiorite, Mount Union quad., Sheldon mine, southwest of Walker.
5. Rhyolite porphyry, Mount Union quad., south portal of Poland tunnel.
6. Rhyolite porphyry, southeast quarter Mount Union quad., 1,217,000 N., 394,000 E.
7. Rhyolite porphyry, Tip Top mine, southern Bradshaw Mountains.

The granodiorite porphyry dikes are presumably satellitic to the granodiorite and are limited to the area south of Eugene Gulch (pl. 1). These dike rocks contain slender black needles 2–6 mm long associated with sparse plagioclase phenocrysts 1–1.5 mm long containing abundant sericite. The fine-grained groundmass consists of plagioclase clouded with sericite, orthoclase, and quartz, the grain size averaging about 0.2 mm in diameter. Micrographic intergrowths of wormy quartz in orthoclase are common. The black needles are resolved under the microscope to random aggregates of biotite and pale epidote, possibly replacing original hornblende phenocrysts. Scattered minute biotite crystals are interstitial to the quartz and feldspar.

RHYOLITE PORPHYRY

The rhyolite porphyry forms dikes that are generally parallel to, or slightly discordant to, the foliation and bedding in the Big Bug Group. North of the Chaparral fault in the northwest corner of the NE¼ Mount Union quadrangle (pl. 1), the dikes have a northerly trend, whereas to the southeast of the fault the trend is north-northeast. The faults along the margins of the Texas Gulch Formation as well as the slates and fine-bedded tuffaceous beds in the formation were favorable zones of weakness penetrated by rhyolite porphyry dikes.

The width of the dikes in general ranges from 10 to 50 feet; however, in the drainage of Lynx Creek in the northwest corner of the northeast quarter of the Mount Union quadrangle, some of the dikes locally are wider, and one measures 200 feet in width (pl. 1, 1,265,500 N., 363,400 E.).

The dikes are generally dull white to cream colored and appreciably altered. In places, the major texture is aphanitic, as thin sections reveal irregular-shaped microscopic grains of quartz embedded in a cryptocrystalline base. Spherulitic structures were observed in some of the flow-banded margins of the aphanitic facies.

In places, the central part of the dikes is coarsely porphyritic, in contrast to the aphanitic margins. At one locality (pl. 1, 1,264,000 N., 392,900 E.) the dike is 19 feet wide; aphanitic margins 3½ feet wide are in sharp contact with a central core 12 feet wide. In the core, quartz phenocrysts, partly embayed, range from 0.5 to 5 mm in diameter and are subordinate to albitic phenocrysts 2–3 mm in length. Orthoclase phenocrysts are smaller, 1–1.5 mm in length. Both feldspars are heavily loaded with sericite. Muscovite phenocrysts, 0.5–1 mm in diameter, contain granular sphene, suggesting alteration from biotite. The fine-granular groundmass consists of quartz, sericitized alkalic feldspar, and radiating biotite crystals, all averaging about 0.1 mm in size. Zircon is a common accessory, appearing in the groundmass and in the larger muscovite crystals.

Tourmaline, associated with stubby crystals of apatite, was noted as minute grains and in radiating needles in several places in the rhyolite porphyry dikes. Chlorite, presumably after biotite, is present in other dikes, in places associated with calcite.

The chemical composition of three dikes (table 12, Nos. 5, 6, 7) shows variation in the content of sodium and potassium, and the high water content is a reflection of the alteration that accompanied or followed the emplacement of the rhyolite porphyry. Both Jaggar and Palache (1905, p. 5) and Lindgren (1926, p. 24) emphasized the close spatial association of these dikes with some of the late ore deposits in the Bradshaw Mountains, a feature that is not obvious in the area covered by this report.

CENOZOIC ROCKS

The Cenozoic rocks comprise the Hickey Formation of late Miocene and early Pliocene age; older gravels of late Pliocene or Pleistocene age; younger Quaternary gravels; and Quaternary terrace and riverwash deposits. The Hickey Formation consists of olivine basalt flows with intertonguing gravel and sand, locally cemented and compacted to conglomerate and sandstone. The younger formations are essentially unconsolidated gravel ranging in size from boulder to pebble gravel and containing interbeds of coarse sand to silt.

HICKEY FORMATION

The Hickey Formation was defined by Anderson and Creasey (1958, p. 56–69) as a sequence of basaltic flows and intertonguing basaltic sediments exposed on the summit area of Mingus Mountain. At the base of the volcanic rocks in the type area, coarse gravel and sand are exposed, composed largely of nonvolcanic debris. Southward from Mingus Mountain, the basaltic flows diminish in thickness and intertonguing gravel, sand, and, locally, silt and fine marl increase in thickness. Krieger, Creasey, and Marvin (1971) and McKee and Anderson (1971) obtained potassium-argon dates from the volcanic rocks indicating that the age is late Miocene and early Pliocene.

The exposures of Hickey Formation in the northeast corner of the NE¼ Mount Union quadrangle (pl. 1) and in the northwest corner and east margin of the NW¼ Mayer quadrangle (pl. 2) are southward extensions of both the basaltic and sedimentary facies exposed in the Mingus Mountain quadrangle.

The basaltic flows on Big Bug Mesa extending eastward beyond Little Mesa (pl. 1) resemble similar rocks on the summit area of Mingus Mountain. At various places along the southwest and south margins of these two mesas, gravels composed of nonvolcanic debris are poorly exposed at the base of the basaltic flows. Apparently these deposits represent channels filled with debris and covered by the overlying basalt. Along the south margin of the NW¼ Mayer quadrangle (pl. 2), intertonguing gravel and sand form the dominant rock types of the Hickey Formation, for the basaltic flows exposed are relatively thin compared with the sediments exposed. The source area for this lava and sediment was in part the Big Bug Mesa area, but to the east along the south margin of the NW¼ Mayer quadrangle (pl. 2), clasts of Redwall and Martin Limestone and quartz diorite indicate a source from the Mingus Mountain quadrangle to the north.

The surface relief on which the Hickey Formation accumulated is revealed on the margins of the Big Bug and Little Mesas (pl. 1). Along the central part of the east margin of Little Mesa (pl. 1, 237,000 N., 383,500 E.), the bedrock surface is about 250 feet higher than at the southeast tip of the mesa. A series of basaltic flows impinge northward on the rising surface, proving that the changes in elevation of the base of the formation are not due to structural deformation. At the headwaters of Wolf Creek (pl. 1, 1,237,500 N., 369,000 E.), a northward-trending channel filled with coarse boulder gravel to a thickness of 250 feet is covered by younger basaltic flows. Crooks Canyon Granodiorite and gabbro are the dominant clasts in the west exposures of Hickey gravels, but along the southwest margin of Little Mesa, the channel-filled debris is largely derived from the Spud Mountain Volcanics.

The Big Bug and Little Mesas contain a number of flows, ranging from 20 to 50 feet in thickness. The lava is vesicular at the flow tops, and some columnar jointing is present in the interior of many flows. At the north end of Little Mesa (pl. 1, 1,242,000 N., 382,000 E.), a basaltic cinder cone is partly exhumed, containing interfingering tongues of basalt. Possibly other cones are buried beneath the lava flows, which have a maximum thickness of about 800 feet on Big Bug Mesa. No doubt many of the flows were erupted from fissures.

All the basaltic flows contain olivine that is generally altered in part to reddish iddingsite. Samples of lava from the Mayer quadrangle contain abundant olivine and augite phenocrysts, averaging about 1 mm in size, embedded in an intergranular groundmass of small zoned bytownite crystals, augite granules, and black opaque crystals. Calculations of the normative minerals reveal that analyzed lavas from the Mayer quadrangle (table 13, Nos. 1, 2) are undersaturated and contain normative olivine.

The samples from Big Bug Mesa and Little Mesa in the Mount Union quadrangle contain olivine, augite, and labradorite-bytownite phenocrysts embedded in fine crystalline intergranular aggregate of plagioclase, augite, and black opaque grains. Iddingsite is generally conspicuous. The normative minerals determined from two chemical analyses (table 13, Nos. 3, 4) contain about 1 percent of normative quartz, indicating that these two lavas are saturated. They might appropriately be termed basaltic andesites. All the analyzed samples have an unusually high content of K_2O and thus suggest alkalic affinities.

TABLE 13.—*Chemical analyses of basaltic flows in Hickey Formation*

[Rapid rock analyses by Paul Elmore, Lowell Artis, Sam Botts, Gillison Chloe, John Glenn, Dennis Taylor, and Hezekiah Smith]

	1	2	3	4
SiO_2	44.8	48.2	52.5	53.0
Al_2O_3	14.2	15.9	16.1	16.9
Fe_2O_3	4.0	5.3	3.5	3.9
FeO	4.9	4.1	4.9	4.5
MgO	11.6	6.0	5.2	4.6
CaO	11.1	9.6	9.0	8.3
Na_2O	2.4	3.7	3.9	4.1
K_2O	1.5	1.8	1.4	1.7
H_2O^-	.50	.71	.30	.31
H_2O^+	2.2	1.4	.61	.63
TiO_2	1.6	2.1	1.2	1.4
P_2O_5	1.0	.86	.46	.66
MnO	.17	.13	.10	.21
CO_2	$<.05$	.08	$<.05$	$<.05$
Powder density				2.92
Bulk density	3.29	2.88	2.74	2.95

1. Olivine basalt, Mayer quad., 1,248,000 N., 420,400 E.
2. Olivine basalt, Mayer quad., 1,270,100 N., 402,700 E.
3. Basaltic andesite, Mount Union quad., 1,244,500 N., 362,300 E.
4. Basaltic andesite, Mount Union quad., 1,241,300 N., 382,050 E.

OLDER GRAVELS

Along Big Bug Creek from a point west of Poland Junction (pl. 1, 1,258,000 N., 390,000 E.) to southeast of Mayer (pl. 2, 1,230,000 N., 409,000 E.), boulder, cobble, and pebble gravel with sand interbeds from almost continuous exposures. These deposits accumulated after the establishment of the Big Bug drainage system and are therefore younger than the Hickey Formation. They are older than the reddish gravels of Pleistocene age that veneer pediment surfaces in the area. They may be correlative with the Verde Formation exposed to the east of Mingus Mountain (Anderson and Creasey, 1958, p. 59) and dated as late Pliocene by McKee and Anderson, 1971.

The clasts are mostly derived from the rocks exposed in the Big Bug Creek drainage system and consist largely of Crooks Canyon Granodiorite, gabbro, Spud Mountain and Iron King Volcanics, and the Upper Cretaceous or lower Tertiary granodiorite.

These gravels and sands are of special interest because they contain the well-known onyx marble deposits that have been quarried for many years to the north of Mayer. According to Merrill (1895, p. 562) stone was hauled by wagon to Prescott for shipment by train in the latter part of the 19th century, but Jaggar and Palache (1905, p. 11) reported that quarrying operations had stopped by 1901. Activity has been intermittent since that time.

The onyx marble, or travertine as it is sometimes called, occurs in the gravel as low-dipping veins ranging in width from 1 inch to a maximum of about 3 feet. The veins intersect at low angles, but are sufficiently parallel to produce a cumulative thickness of many feet of relatively uncontaminated onyx marble.

The onyx marble is banded in various shades of red, brown, green, and white. In the deeper quarries where little surface oxidation has occurred, the onyx marble is generally white or pale green. The chief constituent is $CaCO_3$ and the colored varieties contain more than 5 percent $FeCO_3$. The brown varieties contain Fe_2O_3 (table 14).

TABLE 14.—*Chemical analyses of onyx marble from Mayer*

[Analyses from Merrill (1895; table facing p. 558); n.d., not determined]

	1	2	3	4	5
$CaCO_3$	93.93	93.50		93.82	
$MgCO_3$	.56			.53	
$FeCO_3$	5.50	5.51	4.27	4.06	1.22
Fe_2O_3				1.73	3.53
SiO_2	.05			.05	
H_2O	n.d.	.40		n.d.	
	100.04	99.41		100.19	

1–3. Green onyx marble.
4, 5. Brown onyx marble.

The enclosing gravels, composed largely of subangular clasts of Iron King Volcanics, are strongly cemented by $CaCO_3$ adjacent to the onyx marble. The veins are of the displacement type in that fractured segments of cobbles or older veins can be matched on opposite sides. It is doubtful that large low-dipping open fractures existed in the gravel, even though no satisfactory explanation can be given to account for thick veins in this environment. Perhaps narrow cracks were filled with $CaCO_3$ along the walls, and the crystallizing carbonate expanded the width of the vein openings and subsequently was partly recrystallized.

Jagger and Palache (1905, p. 2) suggested that hot springs supplied the $CaCO_3$, but no evidence for such springs was found in the underlying Iron King Volcanics. Instead, the widespread cementation of the gravel surrounding the onyx marble deposit indicates that migrating ground water is a logical transporting medium, and ample $CaCO_3$ is exposed northward in the limestone interbeds in the Iron King Volcanics to be the source.

YOUNGER GRAVELS

Younger gravels assigned to the Quaternary constitute the surface mantle in much of Lonesome Valley in the Mingus Mountain and Prescott quadrangles; they are essentially gravel veneers on pediment surfaces (Anderson and Creasey, 1958, p. 61). Similar gravels, predominantly reddish in color, are exposed along Big Bug Creek and in the lower part of tributaries to this Creek (pls. 1, 2) and also along tributaries to the Agua Fria Creek in the southeast corner of the NW¼ Mayer quadrangle (pl. 2). Elsewhere, these gravels occur in small patches. Grayish coarse gravels that accumulated on steep slopes in the Eugene Gulch drainage system have been included in this unit.

These younger gravels are largely a heterogeneous accumulation of boulders, cobbles, pebbles, and fine-grained sediment, all of local derivation, forming deposits less than 1 foot to more than 30 feet thick; the surface exposures are largely stained by reddish iron oxide. In general, they rest on bedrock, but locally they represent reworked gravels of the Hickey Formation and of the older gravels along Big Bug Creek.

RECENT RIVERWASH AND TERRACE DEPOSITS

Most of the riverwash occurs in Agua Fria Creek and Yarber Wash (pl. 2). Narrow strips of riverwash are present along parts of Big Bug Creek, but they are not shown on plate 1.

Terrace deposits are best developed along Yarber Wash and Agua Fria River (pl. 2) and the lower part of Big Bug Creek (pls. 1 and 2). One small terrace is present along Lynx Creek (northwest corner of pl. 1). The terrace deposits range in thickness from 10 to 15 feet and consist of alternating layers of fine, medium, and coarse sand, several inches to a foot thick, scarce gravel lenses, and a few silty beds.

STRUCTURE OF THE PRECAMBRIAN ROCKS

Three blocks of Precambian rocks are defined by the Chaparral fault and the Shylock fault zone. To the northwest of the Chaparral fault, the Green Gulch Volcanics is dominant and is cut by several intrusive masses. The largest block lies between the Chaparral fault and Shylock fault zone; in the area of this report, the major rock units in this block are the Spud Mountain Volcanics and Iron King Volcanics, deformed respectively into a major anticline and a complementary syncline. Except along the Chaparral fault, Precambrian intrusive masses are areally insignificant. To the east of the Shylock fault zone, Spud Mountain Volcanics is dominant except in the northeast quadrant of the NW¼ Mayer quadrangle, where younger plutonic rocks are exposed.

STRUCTURE OF ROCKS NORTHWEST OF THE CHAPARRAL FAULT

A south-plunging anticline is the major structural feature in the Green Gulch Volcanics and extends northward into the Prescott quadrangle from the northwest corner of the area shown on plate 1. A complementary syncline appears to be present to the east, indicated by the basal unit of the Spud Mountain Volcanics (pl. 2, section *A–A′*). Foliation is excellent in the basal slate unit of the Green Gulch Volcanics; elsewhere locally foliation is weak and in general parallels the northerly trends of the two major folds. Adjacent to the Chaparral fault, strong foliation, parallel to this major fault, is present in all the Precambrian rocks. In addition, these rocks have a pronounced southwest trend in a zone north of the Chaparral fault.

STRUCTURE OF ROCKS BETWEEN THE CHAPARRAL FAULT AND SHYLOCK FAULT ZONE

The western part of the block between the Chaparral fault and Shylock fault zone is dominated by an overturned anticline in westward-dipping Spud Mountain Volcanics pierced by a granodiorite stock of Late Cretaceous or early Tertiary age (pl. 1). Foliation is conspicuous in the Spud Mountain Volcanics and is essentially parallel to the trace

458-804 O - 72 - 5

of the axial plane of the overturned anticline. Folds of smaller amplitude, which have resulted from the deformation of the upper unit of the Spud Mountain Volcanics, are common in the west margin of this block (pl. 2, section *B–B′*). As discussed in the section describing the Spud Mountain Volcanics, the outcrop pattern southwest of Little Mesa may be formed by plunging small folds or intertonguing volcanic breccia and andesitic tuffaceous beds.

The eastern part of this block is dominated by an overturned syncline in westerly dipping Iron King Volcanics and the upper unit of the Spud Mountain Volcanics (pl. 2, section *A–A′*). Foliation is conspicuous throughout this block; the strike of the foliation is generally parallel to the trace of the axial plane. In the overturned west limb of the syncline, many foliation planes dip eastward, whereas in the east limb the foliation largely dips westward, parallel to the dip of the axial plane (pls. 1, 2). Folds of small amplitude are common in the upper unit of the Spud Mountain Volcanics in the east margin of this block (pl. 2).

The two major folds are separated by a faulted segment of Texas Gulch Formation (pl. 1) that widens southward in the southeast quarter of the Mount Union 15-minute quadrangle, where it rests unconformably above the Brady Butte Granodiorite (Blacet, 1966). In the area of this report, vertical separation is indicated by the Texas Gulch Formation in fault relation with the Spud Mountain Volcanics and Iron King Volcanics, but the amount of vertical slip on each fault cannot be proved. The trace of the boundary faults indicates steep to vertical dips; appreciable strike slip may be involved, but no evidence is available to prove or disprove this possibility. East of Little Mesa (pl. 1), the east boundary fault of the Texas Gulch Formation departs from a straight course for 2 miles. To the north (fig. 14 *X–X′*), the fault dips at a low angle eastward, whereas to the south (fig. 14, *Y–Y′*), the fault dips more steeply westward. Presumably these departures from a straight, nearly vertical fault plane have been produced by later deformation, suggesting perhaps that the original vertical fault may have been in part displaced (fig. 14, *X–X′*).

The northward thinning of the faulted segment of Texas Gulch Formation is striking (pl. 1). Anderson and Creasey (1958, p. 25) originally placed this unit in the Spud Mountain Volcanics, but noted the similarity to the Texas Gulch Formation. Later Anderson and Blacet (1962) recognized the faulted margins of the Texas Gulch Formation southward in the area covered by plate 1 and designated the rocks in the north strip as Texas Gulch Formation. Gilmour and Still (1968, p. 1246) questioned this assignment because they did not recognize any major faults at the margins of this formation in the washes

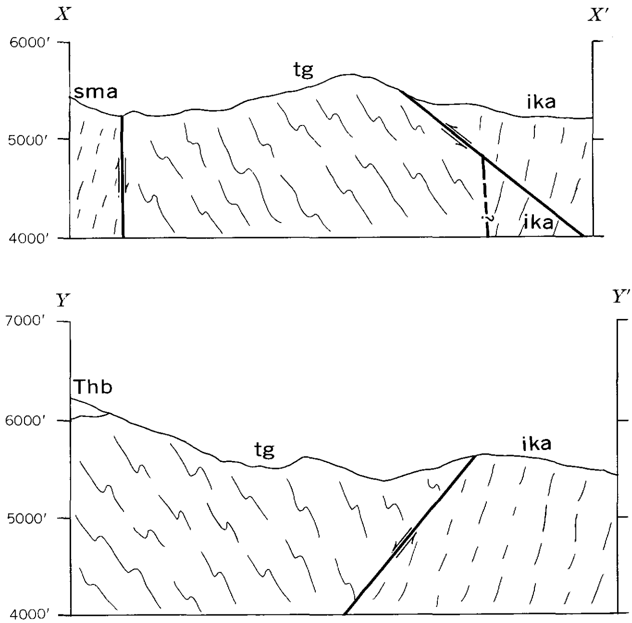


FIGURE 14.—Sections across fault segment of Texas Gulch Formation. See plate 1 for locations and explanation of symbols.

cutting across the narrow strip at the north end. They failed to recognize that the intense foliation at the margins of the Texas Gulch Formation is the result of shearing at depth where gouge and fault breccia do not form. The evidence of faulting is clear, for the Iron-King Volcanics is truncated by the east fault at the southern part of the area of plate 1; here no gouge or fault breccia is present, but both the Iron King Volcanics and Texas Gulch Formation are highly foliated by shearing at their contact.

The southern part of the Texas Gulch Formation is folded to a north-plunging anticline that contains a core of Brady Butte Granodiorite in the southeast quarter of the Mount Union quadrangle (Blacet, 1966, fig. 1). Northward, the trace of the axial plane is truncated by the west fault margin (pl. 1, 1,248,000 N., 384,500 E.), and only the east limb of the anticline extends northward. Many minor folds indicate a general northward plunge, but east of Little Mesa, a local southward plunge is indicated. It should be emphasized that the strike of the widespread foliation in the Texas Gulch Formation is essentially parallel to the strike of the foliation in the adjacent Spud Mountain Volcanics and Iron King Volcanics; the dips of the foliation range from vertical to steep and are inclined to the west or east.

The faulted wedge of Texas Gulch Formation within the Iron King Volcanics (pl. 1, 1,230,000 N., 392,000 E.) extends southward into the southeast quarter of the Mount Union quadrangle, where the west margin is in fault contact with the Brady Butte Granodiorite, and Blacet (1966, p. B3) showed that a left-lateral separation of about 1½ miles is indicated.

STRUCTURE EAST OF THE SHYLOCK FAULT ZONE

East of the Shylock fault zone the lower unit of the Spud Mountain Volcanics is the only formation of the Big Bug Group that is exposed, and the volcanic breccia is the dominant rock except to the east of the splay of the Shylock fault, where intrusive rhyolite and andesitic agglomerate predominate (pl. 2). At the north end, between the Shylock fault zone and granophyre mass, the dips are largely homoclinal to the west except where folds of small amplitude are present (pl. 2). Small folds are common in the tuffaceous sedimentary interbeds exposed east of the Shylock fault zone in the southern part of the NW¼ Mayer quadrangle (pl. 2, 1,235,200 N., 427,000 E.). The structural interpretation of the rocks exposed south of the Agua Fria River is made difficult by the large volume of silicified and sericitized rock in which relict textures and structures are not recognizable.

Adjacent to the Shylock fault zone, foliation is conspicuous, but to the east of the zone, foliation is uncommon. The structural trends to the west of the splay of the Shylock fault are largely north-northwest; however, to the east of the splay, the agglomerate beds suggest westerly trends (pl. 2). Perhaps the northerly trends near the Shylock fault are the result of drag along the fault zone.

SHYLOCK FAULT ZONE

The Shylock fault zone is a major structural feature that has been mapped for a distance of more than 30 miles. It extends about 12 miles northward into the Mingus Mountain quadrangle, where it disappears beneath unbroken exposures of Cambrian Tapeats Sandstone. Southward the fault zone continues beyond the margin of the Mayer 15-minute quadrangle. The fault zone is approximately 1 mile wide and contains slices of quartz diorite, Spud Mountain Volcanics, Texas Gulch Formation, and quartz porphyry. A minimum of 5 miles of right-lateral slip is indicated by offset slices of quartz diorite (Anderson, 1967).

In the Mingus Mountain quadrangle, the northern part of the east margin of this fault zone is a straight high-angle fault separating the Ash Creek Group and quartz diorite on the east from the Texas Gulch Formation and the upper unit of the Spud Mountain Volcanics to the west. Southward this fault separates the lower unit of the Spud

Mountain Volcanics from the east exposure of quartz diorite, which includes outcrops of hornfels of Spud Mountain breccia. This fault continues as a splay from the fault zone into Mayer quadrangle (pl. 2), separating Spud Mountain breccia and quartz porphyry from granophyre. The splay dies out southeastward in Spud Mountain Volcanics. In the northern part of the Mayer quadrangle, the precise location of the fault at the east margin of the fault zone is difficult to determine, but the definite fault at the west margin of the fault zone is also named the Shylock fault (pl. 2).

In the area covered by this report, a fault sliver of Texas Gulch Formation appears at the north end of the Shylock fault zone and is bounded on the east by Spud Mountain andesitic breccia and on the west by Spud Mountain andesitic tuffaceous rocks. Southward the fault zone contains tuffaceous rocks, andesitic flows, and andesitic breccia of the Spud Mountain Volcanics as well as masses of quartz porphyry with sheared margins.

Earlier, Anderson (1967) suggested that the Texas Gulch Formation was the basal formation in the Precambrian sequence of volcanic and sedimentary rocks. Juxtaposition of the Texas Gulch Formation with the supposedly younger Spud Mountain Volcanics in the Shylock fault zone required an appreciable component of upward displacement, indicating that the fault slice of Texas Gulch Formation represented a piercement structure. We now know that the Texas Gulch Formation is younger than Spud Mountain Volcanics and some of the plutons (Anderson and others, 1971); the interpretation is no longer valid that the fault slices of Texas Gulch Formation are piercement structures. Instead, they may have been emplaced in the Shylock fault zone by lateral displacement, possibly accompanied by a component of downward vertical displacement.

The Shylock fault zone is clearly older than the Cambrian Tapeats Sandstone and therefore Precambrian in age. To the north and south of the area covered by plate 2, three plutons are clearly older than the Shylock fault zone (Anderson, 1967), but the time interval is unknown between the intrusion of the plutons and the later deformation that created the Shylock fault zone.

CHAPARRAL FAULT

The Chaparral fault appears to have a large component of right-lateral slip, as shown by the change of structural trend from northward in the Green Gulch Volcanics to southwestward adjacent to the Chaparral fault (pl. 1). That older Green Gulch Volcanics are superimposed against younger Spud Mountain Volcanics and Crooks Canyon Granodiorite indicates vertical separation, but a vertical slip cannot be proved. The Chaparral fault does not contain the spectacular fault slices typical of the Shylock fault zone, and much of the fault is a narrow mylonite zone in which cataclasis is dominant. The relation of the Chaparral fault to the Shylock fault zone is unknown because of the cover of Cenozoic rocks in the critical area to the northeast in the Prescott and Mingus Mountain quadrangles.

The Upper Cretaceous or lower Tertiary granodiorite stock at the west margin of plate 1 is clearly younger than the Chaparral fault, for the mylonite zone along the fault has been recrystallized to hornfels adjacent to the stock. This evidence clearly proves that the Chaparral fault formed before the time of intrusion of the granodiorite. The general similarities of the Chaparral fault to the Precambrian Shylock fault zone are the basis of assigning the Chaparral fault to Precambrian deformation.

FAULTS YOUNGER THAN PRECAMBRIAN

The Spud fault separates one of the Late Cretaceous or early Tertiary granodiorite stocks from Spud Mountain Volcanics (pl. 1, 1,265,200 N., 380,000 E.). This fault is exposed for about 3 miles in the area of this report and extends northeastward for a similar distance into the Prescott quadrangle, where it is covered by Cenozoic rocks. To the southwest it dies out in the Spud Mountain Volcanics (pl. 1). The Spud fault is essentially parallel to the Chaparral fault, but the displacement along the fault is clearly later than displacement along the Chaparral fault. The Spud fault may have formed during or after Late Cretaceous or early Tertiary time.

Along the north margin of the Mayer quadrangle (pl. 2, 412,300 E.), the north-trending Whitney fault has displaced basalt of the Hickey Formation and for a short distance separates Spud Mountain Volcanics from Iron King Volcanics. The vertical displacement must be small, because the Whitney fault dies out in a short distance southward (pl. 2). This fault extends northward into the Mingus Mountain quadrangle, where it separates gravels of the Hickey Formation to the west from Spud Mountain Volcanics to the east (Anderson and Creasey, 1958, pl. 1). It is possible that the Whitney fault is a local reactivated west strand of the Shylock fault zone.

METAMORPHISM

Data available are sufficient to indicate that the metamorphic history in the area of this study is complex and requires a regional analysis. Much of the metamorphism would be considered "regional" except for contact metamorphism adjacent to the granodiorite stocks of Late Cretaceous or early Tertiary age.

There appears to be general agreement that regional metamorphism is a thermal phenomenon, and for the upper zones Turner and Verhoogen (1960, p. 669) defined it as "essentially a chemical adjustment of rocks to temperatures and pressures imposed by depth of burial in areas of abnormally high heat flow where, in addition, simultaneous or nearly simultaneous mechanical deformation is responsible for folding and development of schistosity." But in the area of this study, foliation (schistosity) is uniformly developed only in the block between the Chaparral fault and Shylock fault zone where the folds are overturned and isoclinal. Foliation is intense locally within and at the margins of the Shylock fault zone, but this foliation may have developed late in the metamorphic history.

Albite, sericite, actinolite, chlorite, and epidote minerals characterize the greenschist facies, and these are the common minerals in the rocks of the Big Bug Group in the area of this study. In some of the massive outcrops of the mafic flows in the Iron King Volcanics in which actinolite is the dominant green mineral, some of the plagioclase is more calcic, approaching oligoclase in composition. In adjacent flows in which chlorite is dominant, however, the plagioclase is albite. Possibly this reflects local retrogression.

Except in and adjacent to the major faults, the foliation is generally parallel to the axial planes of the folds, and at the crests and troughs of small folds, the cleavage-bedding intersections are helpful in determining the plunge of the fold axes. In some places, however, the foliation appears slightly discordant to the rocks having bedding structures, such as west of the Shylock fault zone in the southern part of the NW¼ Mayer quadrangle (pl. 2).

It should be emphasized that the foliation in the Texas Gulch Formation is essentially parallel to the foliation in the adjacent rocks of the Big Bug Group, suggesting that the well-developed foliation in the block between the Chaparral fault and Shylock fault zone was formed late during a period of deformation following the major plutonic episode and the deposition of the Texas Gulch Formation. Perhaps the overturned folds in this block are also the result of this period of deformation, for the foliation is in part concordant with the fold structures. Some anomalies are present, however, in the southern part of the synclinal structure of the Iron King Volcanics. Some foliation dips eastward (pl. 1), whereas the bedding structures dip westward (pl. 1, sections *D–D′*, *E–E′*).

Around the margin of the Upper Cretaceous or lower Tertiary granodiorite stock that is cut by Big Bug Creek (pl. 1), the rocks are partly recrystallized, darkened in color, and generally contain sufficient magnetite to affect a Brunton compass. Relict textures and structures are rarely masked. Microscopic studies reveal that in the more mafic volcanic rocks plagioclase is reconstituted to oligoclase and andesine, separated by prismatic greenish-blue amphibole. Colorless diopside(?) is rare. In the more silicic tuffaceous rocks, small flakes of biotite are common. These rocks are not sufficiently recrystallized to use the term "hornfels," but some of the more massive facies approach a hornfels in appearance.

QUARTZ LENSES, PODS, AND VEINS

The siliceous lenses, pods, and veins are variable in character and include white granular quartz, reddish jasper, and dark-gray to black quartz containing disseminated hematite and (or) magnetite. In general, the jaspery pods are closely associated with quartz porphyry (pl. 2, 1,253,000 N., 428,000 E.), and dark quartz pods and veins are common in or at the margin of some of the quartz porphyry in the Shylock fault zone (pl. 2).

Gray to black quartz pods and veins are strikingly conspicuous in the Iron King Volcanics in the east limb of the overturned syncline (pls. 1 and 2). Many of these may be recrystallized ferruginous chert, for the outcrop patterns of some resemble the patterns shown by interbeds of ferruginous chert; however, all bedding structures have been destroyed. These dark pods and veins consist of a microgranular aggregate of quartz containing magnetite and (or) hematite cut by intersecting veinlets of coarser grained quartz without the iron minerals.

These lenses, pods, and veins must have diverse origins, as many are clearly not recrystallized ferruginous chert. In places some are parallel to foliation trends that are discordant to the trend of the formations, as shown on plate 2 (1,242,500 N., 412,300 E.). Others appear to be related to the margins of the Shylock fault zone (pl. 2, 1,235,500 N., 414,700 E.), whereas some of the thick lenses of white granular quartz must represent local areas of silicification (pl. 2, 1,265,000 N., 407,700 E.).

SILICIFIED AND SERICITIZED ROCKS

Three belts of silicified and sericitized rocks occur in andesitic or basaltic rocks in the area covered by plate 1. These altered rocks are characterized by numerous intersecting quartz veins containing pyrite, associated with abundant sericite; the resulting light-colored rock contrasts sharply with the enclosing chloritic mafic rocks. The largest of these altered zones is about 1 mile in length and extends south-southwestward from the Iron King mine, which is in the Prescott quadrangle a short distance from the north margin of the Mount

Union quadrangle (pl. 1, 397,400 E.). This belt of silicified and sericitized rock also contains appreciable ankerite. The other two belts are near the keel of the major syncline (pl. 1, 1,240,000 N., 1,246,000 N.) to the north and south of the Hackberry mine.

The greatest volume of silicified and sericitized rocks is largely present south of the Agua Fria River and involves the lower unit of the Spud Mountain Volcanics, particularly the breccia facies. The geologic map (pl. 2) illustrates how the various units of the Spud Mountain Volcanics, north of the Agua Fria River, have south to southeast trends that are largely obliterated south of the river; only patches of Spud Mountain Volcanics within the area of alteration maintain these structural trends. The south to southeast structural trends continue south of the area of silicified and sericitized rocks.

The bold craggy outcrops of these silicified and sericitized rocks are reminiscent of the outcrops of hydrothermally altered Deception Rhyolite south of the United Verde mine in the Mingus Mountain quadrangle (Anderson and Creasey, 1958, p. 17). However, no relict textures or structures have been found to indicate that the altered rocks in the northwest quarter of the Mayer quadrangle were originally rhyolitic; such features can be found in the altered Deception Rhyolite (Anderson, 1968a, pl. 2). The alternative interpretation is that the sericitized rocks shown on plate 2 are extremely altered Spud Mountain breccia, tuffaceous rocks, andesitic flows, and, to some extent, rhyolitic flows.

The silicified and sericitized rocks are light to medium gray on fresh surfaces and generally have a tan weathered surface. Foliated rocks are of limited distribution, and only in local areas are the rocks highly foliated, marked by abundant sericite. Most outcrops show tight intersecting fractures. Microscopic studies reveal that the rocks are composed largely of quartz, appearing as granular blebs, as rounded aggregates, and as irregular grains, averaging about 0.5 mm in diameter. The matrix is largely microcrystalline quartz and sericite, spotted by nests of chlorite (fig. 15). Minor amounts of sphene, leucoxene, and rutile appear in the matrix, but rarely do all three titanium minerals appear in the same sample. Chemical analyses of samples of the foliated and massive facies collected from the same quarry (table 15) indicate the range in composition over a short distance.

Locally, chlorite-rich facies containing spherical to ellipsoidal aggregates of granular quartz, 2–3 mm in diameter are exposed. These aggregates resemble amygdules in appearance, but the matrix is predominantly finely crystalline chlorite containing minute grains of quartz and bears no resemblance to groundmass of mafic lava. The

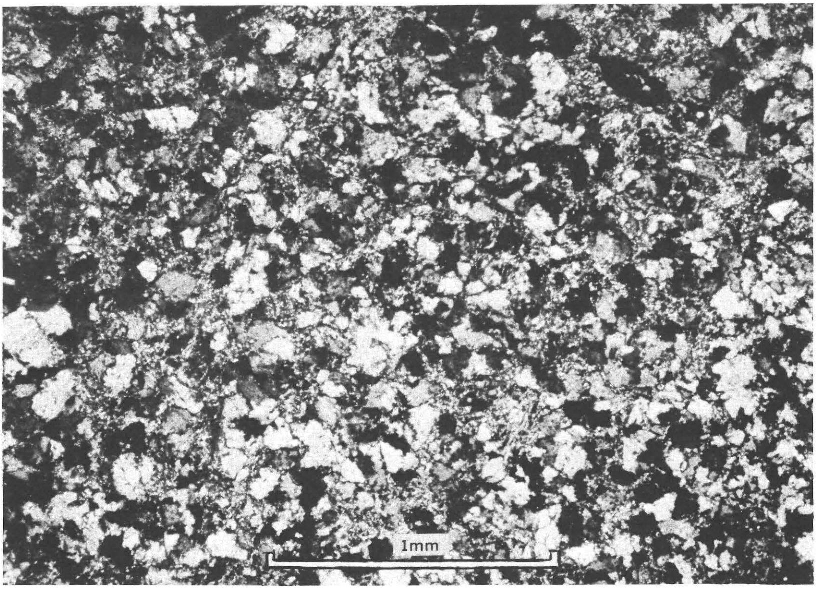


FIGURE 15.—Massive silicified and sericitized rock. Irregular quartz grains separated by finer grained quartz and sericite. Opaque crystals are leucoxene(?). Crossed nicols. (Pl. 2, 1,230,600 N., 419,600 E.)

TABLE 15.—*Chemical analyses of silicified and sericitized rocks*

[Rapid rock analyses by Paul Elmore, Lowell Artis, Sam Botts, and Hezekiah Smith]

	1	2
SiO_2	71.9	77.8
Al_2O_3	14.2	11.7
Fe_2O_3	.63	.56
FeO	3.3	2.4
MgO	3.3	1.7
CaO	.15	.26
Na_2O	.24	.18
K_2O	2.6	2.6
H_2O^-	.13	.09
H_2O^+	3.2	2.2
TiO_2	.13	.11
P_2O_5	.03	.03
MnO	.05	.03
CO_2	$<.05$	$<.05$
Powder density	2.77	2.76
Bulk density	2.62	2.67

1. Foliated silicified and sericitized rock, Mayer quad., 1,243,350 N., 418,400 E.
2. Massive silicified and sericitized rock, Mayer quad., 1,243,350 N., 418,400 E.

small and irregular distribution of these chlorite-rich masses in the silicified and sericitized rock indicates that they are a product of iron-magnesium metasomatism, and the aggregates of granular quartz are more properly termed "pseudoamygdules." Figure 16 illustrates two of the small "pseudoamygdules" set in a foliated chlorite-rich matrix; this chlorite has a beta index of refraction of 1.595, low birefringence, and negative elongation. The Fe/(Fe+Mg) ratio in this chlorite is about 20 percent, as determined from the diagram of Albee (1962, p. 865). Elsewhere in the large mass of silicified and sericitized rock, chlorite of higher indices of refraction and with positive elongation indicates a much higher Fe/(Fe+Mg) ratio (60 percent plus). Presumably there is no uniformity in the ratios of Fe and Mg in the widely distributed chlorite occurring as nests in the matrix of the more typical silicified and sericitized rock.

Widespread alteration producing silicified and sericitic rocks is unique in this general area, and thus skepticism for its occurrence is justified. Some support for the concept of profound alteration is given by the copper content in the altered rocks (fig. 17), for it is much higher than in any of the rhyolitic rocks of the general area. One analysis exceeds the highest copper content of the basaltic and andesitic rocks of low silica content. Two points of 70 parts per million of

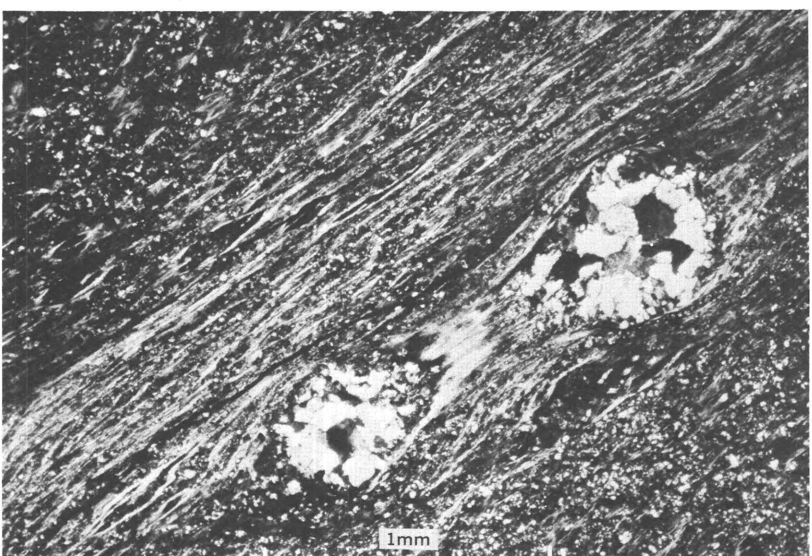


FIGURE 16.—Quartz "pseudoamygdules" in a foliated chlorite-rich matrix containing dispersed minute quartz grains. Crossed nicols. (Pl. 2, 1,245,000 N., 419,100 E.)

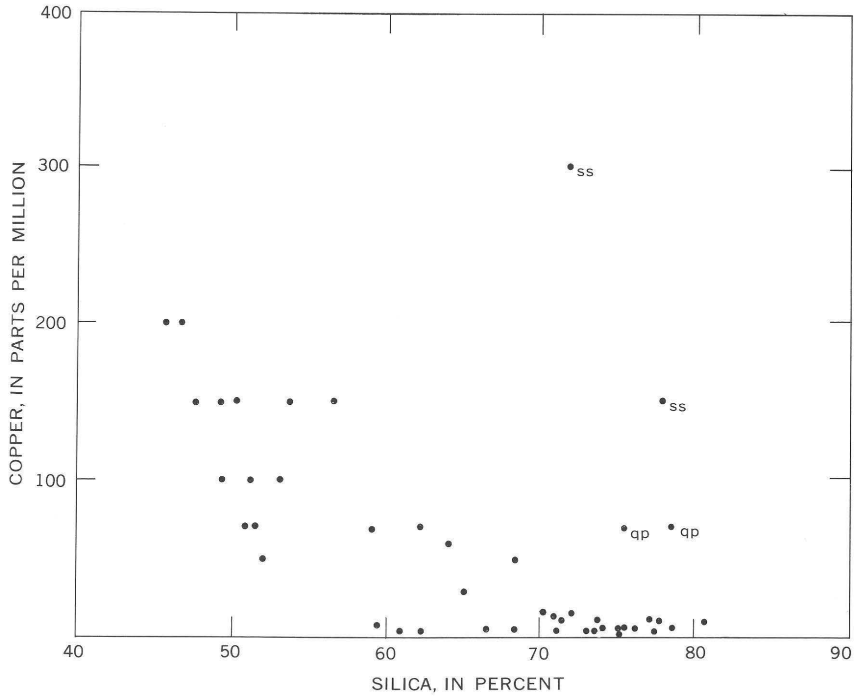


FIGURE 17.—Copper content in Precambrian volcanic rocks, including quartz porphyry, plotted against silica content. Two samples labeled "ss" are of silicified and seriticized rocks. Two samples labeled "qp" are of quartz porphyry. Copper content determined by semiquantitative spectrographic analyses by Chris Heropoules.

copper in rocks of high silica content are from quartz porphyry: one is from a zone of alteration near the United Verde mine at Jerome; the second, from a highly foliated facies in the Mount Union quadrangle.

The presumption is that the silicified and sericitized rocks in the northeast quarter of the Mount Union quadrangle (pl. 1) are related to the adjacent ore deposits that are of Precambrian age, but this is debatable. No evidence is available to date the extensive alteration south of the Agua Fria River (pl. 2). The Copper Queen mine, within the Shylock fault zone, is north of the Agua Fria River and adjacent to silicified and sericitized rock. The Stoddard mine, south of the river, is within the large mass of altered rock. These ore deposits are considered to be of Precambrian age, but there is a possibility that the alteration followed the formation of the Shylock fault zone, because altered rocks show no marked displacement along the east margin of this zone. Again, it is possible that this alteration is related to regional ore deposition in Late Cretaceous or early Tertiary time.

ORE DEPOSITS

HISTORY

Mining activity began in 1863 in the northern Bradshaw Mountains by the discovery of gold placers in Lynx Creek (pl. 1) and in the Hassayampa River in the western part of the Mount Union 15-minute quadrangle; however, the gravels were not rich compared with those in California, and the early placer mining left no permanent imprint. The first lode mining began about 1875 with the location of some of the rich silver-gold deposits such as the Silver Belt–McCabe vein in the northeast corner of the Mount Union quadrangle (pl. 1). By 1885, many of the rich oxidized ore bodies had been worked out, but because there was lower grade ore at depth, mining activity continued; this activity gradually declined after 1905. By 1922, when Lindgren (1926) studied the ore deposits in the Bradshaw Mountains, only a few mines were in operation.

From 1922 to the beginning of World War II, only two mines were active in the report area—the Arizona National and McCabe mines, both on the Silver Belt–McCabe vein. The Iron King mine is north of the report area (see pl. 1), but the older workings extend into the Mount Union quadrangle. Early mining operations at the Iron King were limited to oxidized gold-silver ore. In 1938, a bulk flotation mill was built to concentrate lead-zinc sulfide ore, and by 1939, the mill had been converted to differential flotation to produce separate lead and zinc concentrates. This conversion increased the mill capacity to 225 tons per day. Subsequently, mill capacity was increased gradually, and in recent years, the Iron King mine has been the largest producer of lead and zinc in central Arizona. This success has stimulated exploration activities in the Bradshaw Mountains.

During and after World War II, the following mines produced copper: Boggs (pl. 1, 1,254,750 N., 398,000 E.), Lone Pine (pl. 2, 1,260,500 N., 399,700 E.), Binghampton (pl. 2, 1,257,200 N., 417,000 E.), Copper Queen (pl. 2, 1,256,500 N., 417,900 E.), and Stoddard (pl. 2, 1,244,100 N., 420,300 E.). Copper, lead, and zinc ore were produced from the Hackberry mine (pl. 1, 1,242,500 N., 392,500 E.). During the period of our geological survey, no mines were operating in the area covered by plates 1 and 2, but the Iron King mine was active.

DEPOSITS OF PRECAMBRIAN AGE

The deposits of Precambrian age are found in the Iron King, Boggs, Iron Queen, and Hackberry mines (pl. 1), and the Lone Pine, Binghampton, Copper Queen, and Stoddard mines (pl. 2). The assignment of these deposits to the Precambrian is based on their general similarity to the massive sulfide deposits at Jerome (United Verde and

United Verde Extension mines), where the Cambrian Tapeats Sandstone covers leached capping and gossan ore over the United Verde Extension ore body. Mauger, Damon, and Giletti (1965) determined lead isotopic ratios in galena from the United Verde and Iron King deposits that indicate a model age of 1,750 m.y. for the former and 1,640 m.y. for the latter, clearly within the Precambrian.

The Iron King deposit is in andesitic tuffaceous rocks of the upper unit of the Spud Mountain Volcanics. The Lone Pine, Boggs, Iron Queen, and Hackberry deposits are in the mixed basaltic and rhyolitic rocks that constitute the upper part of the Iron King Volcanics and are exposed in the keel of the major syncline. The Binghampton and Copper Queen deposits occur in schistose Spud Mountain breccia within the Shylock fault zone, and the Stoddard mine is in the large mass of silicified and sericitized rock south of the Agua Fria River.

IRON KING MINE

Oxide ore, yielding gold, silver, and copper, was mined from the Iron King in 1907, but the period which followed was marked by inactivity until World War I, when a small tonnage of ore was mined. In 1934, Fred Gibbs purchased the mine, and in 1937, he and associates organized the Iron King Mining Co. to mine the lead-zine ore bodies. Shattuck Denn Corp. purchased the property in 1942 and operated the mine until January 1, 1968. Subsequently, McFarland and Hollinger took over the property and resumed mining and milling operations until December 1968, when the mine closed. Production from 1907 to 1964 totals 616,493 ounces of gold, 18,494,491 ounces of silver, 125,375 tons of lead, 367,569 tons of zinc, and 9,551 tons of copper. The average grade of ore mined is 0.123 ounces of gold and 3.69 ounces of silver per ton, 2.50 percent lead, 7.34 percent zinc, and 0.19 percent copper (Gilmour and Still, 1968, p. 1240–41).

The ore deposit consists of 12 veins arranged en echelon, striking N. 22° E. and dipping 71° NW. In plan view, each vein extends farther to the north than the adjacent vein on the east; the north end of the veins plunges northward. The width of the veins ranges from 1 to 14 feet, and the lengths are hundreds of feet. The veins consist of fine-grained massive sulfide containing pyrite, arsenopyrite, sphalerite, galena, chalcopyrite, and tennantite, held together by a gangue of ankerite, quartz, sericite, and residual chlorite. The north ends of the veins are almost exclusively quartz (Creasey, 1952).

The veins have been mined to a depth of 2,600 feet, and on the lower levels the ore zone consists of alternating thin bands of sulfides and chlorite schist. Locally, white brecciated quartz-carbonate contains coarse-grained sphalerite and galena (Gilmour and Still, 1968).

LONE PINE MINE

The Lone Pine mine is owned by Fred Gibbs of Prescott, Ariz., who supplied the following description (written commun., Nov. 19, 1967). The older workings consist of an adit with connecting winzes, extending southward from a dump at the north end of the mineralized zone. Two shafts were sunk on the mineralized zone south of the dump. The north shaft is 200 feet deep and connects with a drift and footwall crosscut, and two small tightly lagged stopes are at the top of the drift. The south shaft is 183 feet deep and connects with a drift and crosscut; the bottom of this shaft is 100 feet higher in elevation than the bottom of the north shaft.

Recent mining was limited to the south shaft, where Fred Gibbs mined oxidized copper ore from 1947 to 1953. Near the end of this mining operation, Gibbs unwatered the shaft, and the crosscut, driven east of the drift, revealed about 20 feet of mineralized schist: there were stringers as much as 6 inches wide of compact pyritic ore containing chalcopyrite, galena, and sphalerite, and sulfide minerals were disseminated between the stringers.

In 1957, lessees dewatered the north shaft, and Gibbs reported that 10 feet of mineralized schist was exposed in the crosscut west of the drift but that the compact solid sulfides were only an inch or more wide. Several years ago, a flash flood cut away part of the old dump, and chunks of compact pyritic ore were exposed, containing the same minerals as in the bottom of the south shaft. An "old timer" reported to Gibbs that one of the winzes below the adit level contained about 18 inches of compact pyritic lead-zinc ore.

Gibbs (written commun. Nov. 19, 1967) emphasized that sparsely disseminated pyrite and chalcopyrite form a zone as much as 100 feet wide on the footwall (west) side of the main ore body; this zone is in contrast to the sharp boundaries of the ore zones at the Iron King and Hackberry deposits.

Incomplete records from 1907 to 1957 show that 2,763 tons of ore were shipped. The average grade was 0.20 ounces of gold and 3.16 ounces of silver per ton and 5.35 percent copper (Gibbs, written commun. April 10, 1969).

BOGGS, IRON QUEEN, AND HACKBERRY MINES

The Boggs, Iron Queen, and Hackberry mines were first operated by the Commercial Mining Co., a subsidiary of Phelps Dodge Co., and the ores were treated in a local smelter near Mayer. During the period 1905–09, the Boggs and Hackberry mines were operated by the George A. Treadwell Co., but the Iron Queen has been inactive since its early period of operation (Lindgren, 1926, p. 139–141).

The last mining activity at the Boggs was from 1943 to 1945, when the Liberty Hills Mines Co. leased the mine from L. E. Hesla and Fred Gibbs. L. L. Farnham (written commun. May 1965), who was in charge of the operations, reported that a shipment in September 1943 of 98 tons from the 200 level assayed 0.45 ounces of gold and 5.2 ounces of silver to the ton, 1.07 percent copper, and 4.3 percent zinc. According to Farnham, the deepest workings are at the 500 level, where only scant mineralized rocks are exposed, and the stopes are largely above the 300 level. The ore body is a thin tabular deposit, ranging from 10 inches to several feet in width, that strikes N. 20° E. and dips steeply northwest (Farnham, written commun. May 1965). The ore minerals are pyrite, chalcopyrite, and sphalerite (Lindgren, 1926, p. 140).

The Iron Queen deposit is 2,000 feet south of the Boggs mine. Lindgren (1926, p. 140) reported that the ore minerals are the same as in the Boggs deposit, but the grade is lower—0.025 ounces of gold and 1 ounce of silver to the ton and 2–2.75 percent copper. The Iron Queen ore was used largely as a flux for richer ores from other mines.

After the George A. Treadwell Co. stopped mining in 1909, the Hackberry mine was idle for many years. Fred Gibbs purchased the property in 1930 and operated it spasmodically until 1943, when it was leased to Liberty Hills Mines Co., who operated it until 1945. According to Fred Gibbs (written commun. Nov. 19, 1967), 13,000 tons of ore mined by Liberty Hills Mines Co. had an average grade of 0.113 ounces of gold and 5.18 ounces of silver per ton, 2 percent copper, 3.5 percent lead, and 9 percent zinc. Most of this ore came from the margins of the old stopes mined by the George A. Treadwell Co., for little new exploration was done by the Liberty Hills Mines Co. No record is available of the production by the Treadwell Co., but stope volumes indicate that at least 20,000 tons of ore was mined, probably of higher grade than the later production by Liberty Hills Mines Co. (Gibbs, written commun. Apr. 10, 1969).

The Hackberry deposit, a small edition of the Iron King deposit, consists of five lenses that dip steeply northwest and strike and plunge steeply to the northeast; the lenses overlap, with the west side stepping north. Only 350 feet of strike length has been explored, and each lens is short, ranging from 60 to 140 feet in length. The average width of the ore lenses is 6 feet; the widest, 24 feet, contained much chalcopyrite.

BINGHAMPTON AND COPPER QUEEN MINES

Lindgren (1926, p. 146–147) reported that in 1922 the Binghampton mine was owned by the Arizona-Binghampton Mining Co., and mining was active between August 1916 and March 1919 and in short periods in 1920 and 1923. Mine production through 1923 was 150,000 tons of ore containing 3 percent copper. The concentrates were smelted at Humboldt and yielded 200 ounces of gold, 33,197 ounces of silver, and 4,000 tons of copper. Mining was limited to three ore shoots, in places 10 feet wide. The ore contained considerable amounts of fine-grained quartz, chalcopyrite, and some pyrite. In addition, chalcopyrite is disseminated in the schist or occurs in veinlets with dolomite and quartz. This siliceous and disseminated ore is different from the compact massive sulfide ore characteristic of the Iron King, Boggs, and Hackberry deposits. The Binghampton mine was operated by various lessees between 1940 and 1947, and production totaled about 25,000 tons of high-silica copper ore (Dunning, 1959, p. 349).

The Copper Queen mine was owned by the Copper Queen Gold Mining Co. in 1922. Lindgren (1926, p. 148) reported that there were extensive underground mine workings and that two ore bodies, 7–12 feet wide, are present on the 900 level. Chalcopyrite and tetrahedrite are the chief copper minerals, and the ore contains some gold and silver. Lindgren (1926, p. 148) does not report any production from the Copper Queen mine prior to 1922. In 1949, a small tonnage of high-silica copper ore was mined (Needham and Luff, 1951, p. 1392).

STODDARD MINE

Much oxidized copper ore was mined from the Stoddard in the early days according to Lindgren (1926, p. 148); in part it was reduced in a smelter near the Agua Fria River. The mine was developed by extensive upper workings and a lower adit level, and the ore body, consisting almost entirely of oxide-copper ore, tapered in depth to the lower adit level. The mine was reopened in 1945 by Eugene Meyer, who produced high-silica oxide-copper ore until 1950. The total production from this period of activity was 14,000 tons containing 3.82 percent copper (Dunning, 1959, p. 381). The Stoddard mine differs from the other deposits assigned to the Precambrian in that it occurs in the silicified and sericitized rocks south of the Agua Fria River. The age assignment is tentative and is based on its location in a part of the area of this report in which younger deposits of base metals are unknown.

DEPOSITS OF LATE CRETACEOUS OR EARLY TERTIARY AGE

The deposits of Late Cretaceous or early Tertiary age are largely gold-silver veins that are clustered about the granodiorite stocks of the same age exposed in the northern part of the Mount Union quadrangle. These are typical fissure veins, straight and narrow with well-defined walls. Quartz is the dominant gangue mineral, and it shows drusy and comb structures. Ankerite occurs in many veins, and barite is common where silver is the important precious metal. Sulfide minerals are not present in large volume; they include arsenopyrite, pyrite, sphalerite, galena, chalcopyrite, tetrahedrite, and, less commonly, ruby silver (Lindgren, 1926, p. 41–53). Most of these deposits were mined in the early days, and Lindgren's (1926) bulletin is the best available source of information.

Creasey (Anderson and Creasey, 1958, p. 169–174) updated the information on the mines along the Silver Belt–McCabe vein and included longitudinal sections of the Silver Belt and Arizona National mines. Silver and lead characterized the Silver Belt deposit at the north end of the vein (pl. 1). In the Arizona National mine to the south, the content of lead and silver was lower than that in the Silver Belt, and the ore contained zinc and iron, chiefly as sphalerite and pyrite. In the Lookout mine (pl. 1), the ore was complex and contained lead, zinc, iron, copper, silver, and gold. The McCabe-Gladstone mine at the south end of the vein also contained complex sulfide ore; the content of iron, copper, and gold was higher than in the Lookout deposit, but the content of lead and probably of silver was lower (Creasey in Anderson and Creasey, 1958, p. 170).

Production from the Silver Belt mine is reported to have a value of $330,000 and from the Arizona National, $300,000 (Dunning, 1959, p. 380; p. 347). Very little ore was mined from the Lookout deposit, but the McCabe-Gladstone mine produced gold, silver, copper, lead, and zinc having a total value of about $3 million (Creasey in Anderson and Creasey, 1958, p. 171, 174). The last activity at the McCabe-Gladstone was in 1934, when Howard Fields and associates reopened the mine and treated old fills and dump material and mined fresh ore; a total of 60,000 tons was milled. The average grade of their selected ore and concentrates was 1.5 ounces of gold and 10 ounces of silver per ton, 2 percent copper, 2.1 percent lead, and 4.7 percent zinc (Dunning, 1959, p. 369).

The Kit Carson vein west of the Silver Belt–McCabe vein (pl. 1) is parallel to the east vein, but has an opposite dip to the east. The vein has been prospected by eight shafts and prospect pits, but no production has been recorded.

Creasey (Anderson and Creasy, 1958, p. 170) emphasized that the time of the formation of the Silver Belt–McCabe vein could not be definitely established and a Precambrian age could not be disproved. Radiometric dating has been cited to prove the Late Cretaceous or early Tertiary age of the granodiorite stocks shown on plate 1. The Rebel mine is in the granodiorite stock southwest of the Silver Belt–McCabe vein, and the fact that a shear zone contains a silicified zone striking N. 50° E. and dipping 70° SE. suggests that the ore deposit is a southwestward extension of the Silver Belt–McCabe vein structure. Supporting evidence is the presence on the dump of the Rebel mine of fragments of sheared quartz containing partly oxidized pyrite and some galena. The similarity of the Silver Belt–McCabe vein to other veins that are spatially related to the granodiorite stocks also supports a Late Cretaceous or early Tertiary age.

The stock exposed east of the Spud fault contains many mineralized areas as shown by the numerous prospect symbols within the stock (pl. 1). In this connection, it is important to note that the granodiorite stock in Eugene Gulch (pl. 1) contains veinlets of pyrite and chalcopyrite where the rate of erosion is greater than the rate of weathering.

The Henrietta mine, to the north of Big Bug Creek (pl. 1), was known as the Big Bug mine in the early days of mining; in 1883 and 1884 it was an important producer of gold and silver (Lindgren, 1926, p. 137). About 1900, a prospector relocated the claim and named it in honor of Henrietta Crossman, the popular pinup girl of the times (Dunning, 1959, p. 364). The last mining activity was between 1914 and 1919 (Lindgren, 1926, p. 137), and the mine production totaled $1,200,000 in gold and $50,000 in silver (Dunning, 1959, p. 364). The ore came from a north-trending vein that dips about 70° W., and a deep oxidized zone provided the ore (Lindgren, 1926, p. 137).

The Butternut mine is about 1¼ miles south-southeast of the Henrietta mine (pl. 1), and the early production came from the oxidized zone, reportedly high in gold. In the lower part of the mine, pyrite, chalcopyrite, and sphalerite are associated with quartz (Lindgren, 1926, p. 142). Production in the early part of the century is reported at a value of $225,000 (Dunning, 1959, p. 351).

In 1916, the Henrietta and Butternut mines were acquired by the Big Ledge Mining Co., which was highly capitalized with 2,800,000 shares that reached a high of $6 per share. The company built a smelter at Mayer, planning to supply the smelter with gold ore from the Henrietta mine and copper ore from the Butternut. The smelter operated for a week, and then the company failed financially. The stack is still there as a prominent landmark (Dunning, 1959, p. 351, 364).

PLACER DEPOSITS

Lynx Creek was one of the richest streams in the region for placer gold because of the number of gold-bearing veins near the granodiorite stocks (Lindgren, 1926, p. 53–54). This creek was mined for many miles downstream from Walker. A short segment of Lynx Creek is shown on the northwest corner of plate 1. Big Bug Creek has been worked downstream as far as Mayer (pl. 2), and dredge tailings are prominent along Big Bug Creek south of the Henrietta mine and northeast of the Hackberry mine (pl. 1). Placer gold from Big Bug Creek was reported in the U.S. Bureau of Mines Minerals Yearbooks for 1945 to 1950. More than 500 ounces of gold was recovered; this included some dragline dredging near Mayer. Smaller quantities have been recovered by sluicing along Big Bug Creek.

REFERENCES CITED

Albee, A. L., 1962, Relationships between the mineral association, chemical composition, and physical properties of the chlorite series: Am. Mineralogist, v. 47, nos. 7–8, p. 851–870.

Anderson, C.A., 1959, Preliminary geologic map of the NW¼ Mayer quadrangle, Yavapai County, Arizona: U.S. Geol. Survey Mineral Inv. Field Studies Map MF–228, scale 1 : 24,000.

——— 1967, Precambrian wrench fault in central Arizona, *in* Geological Survey Research 1967: U.S. Geol. Survey Prof. Paper 575–C, p. C60–C65.

——— 1968a, Metamorphosed Precambrian silicic volcanic rocks in central Arizona, *in* Coats, R. R., Hay, R. L., and Anderson, C. A., eds., Studies in volcanology: Geol. Soc. America Mem. 116, p. 9–44.

——— 1968b, Arizona and adjacent New Mexico, *in* Ridge, J. D., ed., Ore deposits of the United States 1933–67 (Graton-Sales Volume 2) : New York, Am. Inst. Mining, Metall., and Petroleum Engineers, Inc., p. 1163–1190.

Anderson, C. A., and Blacet, P. M., 1962, Preliminary geologic map of the NE¼ Mount Union quadrangle, Yavapai County, Arizona: U.S. Geol. Survey open-file report.

——— 1972a, Geologic map of the Mayer quadrangle, Yavapai County, Arizona: U.S. Geol. Survey Geol. Quad. Map GQ–996, scale 1 : 62,500 (in press).

——— 1972b, Geologic map of the Mount Union quadrangle, Yavapai County, Arizona, U.S. Geol. Survey Geol. Quad. Map GQ–997, scale 1 : 62,500 (in press).

Anderson, C. A., Blacet, P. M., Silver, L. T., and Stern, T. W., 1971, Revision of the Precambrian stratigraphy in the Prescott-Jerome area, Yavapai County, Arizona : U.S. Geol. Survey Bull. 1324–C, 16 p.

Anderson, C. A., and Creasey, S. C., 1958, Geology and ore deposits of the Jerome area, Yavapai County, Arizona: U.S. Geol. Survey Prof. Paper 308, 185 p.

Blacet, P. M., 1966 Unconformity between gneissic granodiorite and overlying Yavapai Series (older Precambrian), central Arizona, *in* Geological Survey Research 1966: U.S. Geol. Survey Prof. Paper 550–B, p. B1–B5.

——— 1968, Geologic map of the SE¼ Mount Union quadrangle, Yavapai County, Arizona : U.S. Geol. Survey open-file report.

Creasey, S. C., 1952, Geology of the Iron King mine, Yavapai County, Arizona: Econ. Geology, v. 47, no. 1, p. 24–56.

Dunning, C. H. (with E. H. Peplow, Jr.), 1959, Rock to riches: Phoenix, Ariz., Southwest Publishing Co., 406 p.

Fiske, R. S., 1963, Subaqueous pyroclastic flows in the Ohanapecosh Formation, Washington : Geol. Soc. America Bull., v. 74, no. 4, p. 391–406.

Fiske, R. S., and Matsuda, Tokihiko, 1964, Submarine equivalents of ash flows in the Tokiwa Formation, Japan: Am. Jour. Sci., v. 262, no. 1, p. 76–106.

Gilmour, Paul, and Still, A. R., 1968, The geology of the Iron King mine, *in* Ridge, J. D., ed., Ore deposits of the United States 1933–67 (Graton-Sales Volume 2): New York, Am. Inst. Mining, Metall., and Petroleum Engineers, Inc. p. 1238–1257.

Harrer, C. M., 1964, Reconnaissance of iron resources in Arizona: U.S. Bur. Mines Inf. Circ. 8236, 204 p.

Jaggar, T. A., and Palache, Charles, 1905, Description of Bradshaw Mountains quadrangle [Ariz.]: U.S. Geol. Survey Atlas, Folio 126, 11 p.

Krieger, M. H., 1965, Geology of the Prescott and Paulden quadrangles, Arizona: U.S. Geol. Survey Prof. Paper 467, 127 p.

Krieger, M. H., Creasey, S. C., and Marvin, Richard, 1971, Ages of some Tertiary andesitic and latitic volcanic rocks in the Prescott-Jerome area, north-central Arizona, *in* Geological Survey research 1971: U.S. Geol. Survey Prof. Paper 750–B, p. B157–B160.

Lehner, R. E., 1958, Geology of the Clarkdale quadrangle, Arizona: U.S. Geol. Survey Bull. 1021–N, p. 511–592.

Lindgren, Waldemar, 1926, Ore deposits of the Jerome and Bradshaw Mountains quadrangles, Arizona: U.S. Geol. Survey Bull. 782, 192 p.

McKee, E. H., and Anderson, C. A., 1971, Age and chemistry of Tertiary volcanic rocks in north-central Arizona and relation of the rocks to the Colorado Plateaus: Geol. Soc. America Bull., v. 82, p. 2767–2782.

Mauger, R. L., Damon, P. E., and Giletti, B. J., 1965, Isotopic dating of Arizona ore deposits: Soc. Mining Engineers Trans., v. 232, p. 81–87.

Merrill, G. P., 1895, The onyx marbles; their origin, composition, and uses, both ancient and modern: U.S. Natl. Mus. Ann. Rept. 1893, p. 539–585.

Needham, C. E., and Luff, Paul, 1951, Arizona gold, silver, copper, lead, and zinc: U.S. Bur. Mines Minerals Yearbook 1949, p. 1369–1394.

Turner, F. J., and Verhoogen, John, 1960, Igneous and metamorphic petrology [2d ed.]: New York, McGraw-Hill Book Co., 694 p.

Williams, Howel, Turner, F. J., and Gilbert, C. M., 1954, Petrography—an introduction to the study of rocks in thin sections: San Francisco, Calif., W. H. Freeman and Company, 406 p.

INDEX

[Italic page numbers indicate major references]

U. S. GOVERNMENT PRINTING OFFICE : 1972 O - 458- 804