Mesozoic Stratigraphy of the Santa Rita Mountains, Southeast of Tucson, Arizona

GEOLOGICAL SURVEY PROFESSIONAL PAPER 658-C

Mesozoic Stratigraphy of the Santa Rita Mountains, Southeast of Tucson, Arizona

By HARALD DREWES

MESOZOIC STRATIGRAPHY IN SOUTHEASTERN ARIZONA

GEOLOGICAL SURVEY PROFESSIONAL PAPER 658-C

A description of seven thick sequences of volcanic and sedimentary rocks and an interpretation of the sporadically active continental environments in which they were deposited

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1971

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

William T. Pecora, *Director*

Library of Congress catalog-card No. 70-609555

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price $1.50 (paper cover)

CONTENTS

ILLUSTRATIONS

TABLES

MESOZOIC STRATIGRAPHY OF THE SANTA RITA MOUNTAINS, SOUTHEAST OF TUCSON, ARIZONA

By Harald Drewes

ABSTRACT

The Santa Rita Mountains, Ariz., consist of complexly deformed sedimentary, volcanic, and intrusive rocks of Precambrian through Cenozoic ages. The Mesozoic rocks comprise 12 formations, have a cumulative thickness of more than 30,000 feet, and represent parts of at least the Triassic and Cretaceous Periods. These rocks were almost all deposited subaerially, many of them in basins associated with block faulting or volcanism or both, but others were deposited in a more gently downwarped basin. The rocks of the Late Cretaceous show signs of increasing orogenic activity, and the deposition sequence described here ends at the close of that period with the intrusion of large plutons. Fossils from two of the formations and isotopic dates from six of them augment the geologic field relations to provide a framework for the interpretation of the geologic development of the area through the Mesozoic.

The Triassic rocks consist of the Mount Wrightson and Gardner Canyon Formations, and the Triassic and Jurassic rocks are represented by the Canelo Hills(?) Volcanics. These formations are dominantly composed of rhyolitic to andesitic volcanics and of red beds, arkose, and sandstone. Of minor abundance, but of major importance in deciphering the geologic history, are the intercalated cobble conglomerates, eolian sandstones, and pillow lavas of the Mount Wrightson and the coaly limestone of the Gardner Canyon.

During the Early Cretaceous, the Temporal and Bathtub Formations, the Glance Conglomerate, and the Willow Canyon, Apache Canyon, Shellenberger Canyon, and Turney Ranch Formations were deposited. The first two of these formations are mixed volcano-clastic rocks, whose coarse conglomerate wedges and whose basal unconformity indicate a locally rugged relief. The other formations of Early Cretaceous age, all part of the Bisbee Group, are strongly arkosic and typically are increasingly finer grained upsection, thus indicating a waning local relief. A little marine limestone is intercalated near the middle of the group.

During the Late Cretaceous, the Fort Crittenden and Salero Formations were deposited: black shaly rocks were deposited first, followed by intertonguing drab-colored arkoses and red volcanic conglomerate and siltstone, and then by a complex sequence of volcanic rocks. Of special significance in these rocks is the evidence of the close association of volcanic and tectonic events with succeeding plutonic events, all of which record the first part of the Laramide orogeny.

INTRODUCTION

Volcanic and sedimentary rocks of Mesozoic age underlie much of the Santa Rita Mountains and comprise a composite stratigraphic sequence more than 30,000 feet thick. The Santa Rita Mountains are the first range of mountains southeast of Tucson; they extend more than 25 miles southward from Pantano Wash, site of the main railroad and the highway east of Tucson, to Sonoita Creek, about 12 miles from the Mexican border (figs. 1, 2). The mountains commonly reach elevations of 6,000 to 7,000 feet; the high point is Mount Wrightson, whose elevation is 9,453 feet. The broad valley to the east is at an elevation of about 4,500 feet, whereas that to the west is at an elevation of only 3,000 feet. The mountains thus are sufficiently high to support extensive largely scrubby forests, which contrast markedly with the grasslands to the east and the Sonoran Desert vegetation to the west. The mountains are also sufficiently rugged to provide good exposures which have helped in unraveling the stratigraphy of the Mesozoic rocks.

Mesozoic strata are divided into 14 formational-rank units, of which five are combined to form one group. The names, relations, thicknesses, and lithologies of these units are listed in table 1. The table does not emphasize, however, that the thicknesses of the individual formations, which range from 600 to 8,500 feet, are highly variable and that commonly only 2,000–10,000 feet of beds is present at any one place. Most geologic relations shown in the table are demonstrable in the Santa Rita Mountains, but a few of them are demonstrable in adjacent ranges, especially the Empire Mountains and the Canelo Hills, both to the east. Nevertheless, the Santa Rita Mountains apparently provide the most complete Mesozoic geologic record in southeastern Arizona.

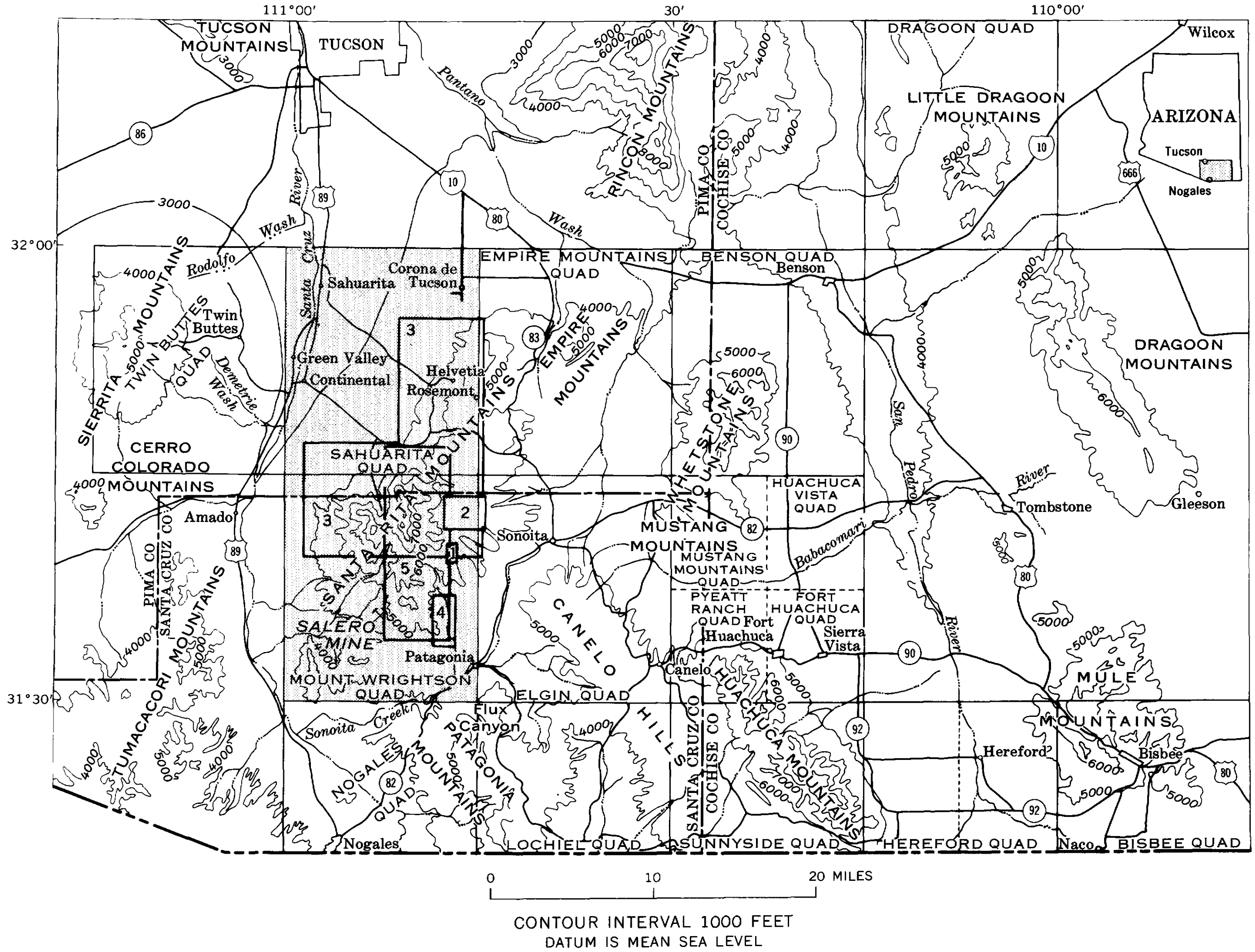


FIGURE 1.—Location of the Sahuarita and Mount Wrightson quadrangles and the Santa Rita Mountains, southeastern Arizona. The geology of the other outlined quadrangles is described in collateral reports. Areas covered by geologic maps in this report: 1, figure 34; 2, figure 11; 3, figure 28; and 4, figure 18. Area 5 is Salero area. Contour interval 1,000 feet. Datum is mean sea level.

The relative completeness of the Mesozoic record in these mountains adds considerably to the geologic history of the region. Some of the more important contributions concern the environments of deposition and the record of tectonic activity during the Mesozoic Era. These contributions may be useful in stimulating the exploration for deposits of copper, lead, zinc, and silver, which were emplaced chiefly during the Laramide orogeny (the orogenic period at the close of the Mesozoic). An improved knowledge of the Mesozoic stratigraphy should aid in delimiting potential host rocks of the mineralization. Similarly, knowledge of the deformation that occurred earlier during the Mesozoic should help in deciphering the structural complexities of the Laramide and the related problems of structural control.

This report describes the stratigraphy and petrography of the Mesozoic strata and interprets the depositional environments of the strata. Rocks older and younger than Mesozoic and the Mesozoic intrusive rocks are planned to be described in separate reports and are mentioned here only to provide a framework for the description of the Mesozoic layered units. Likewise, the structure of the Santa Rita Mountains will be described and interpreted in a separate report. Geologic maps of the Mount Wrightson and Sahuarita quadrangles (Drewes, 1971a, b), covering the area of this report, will prove helpful in understanding much of the material herein. Other brief reports on economic and tectonic topics are also available (Drewes, 1967, 1968, 1970; Simons and others, 1966).

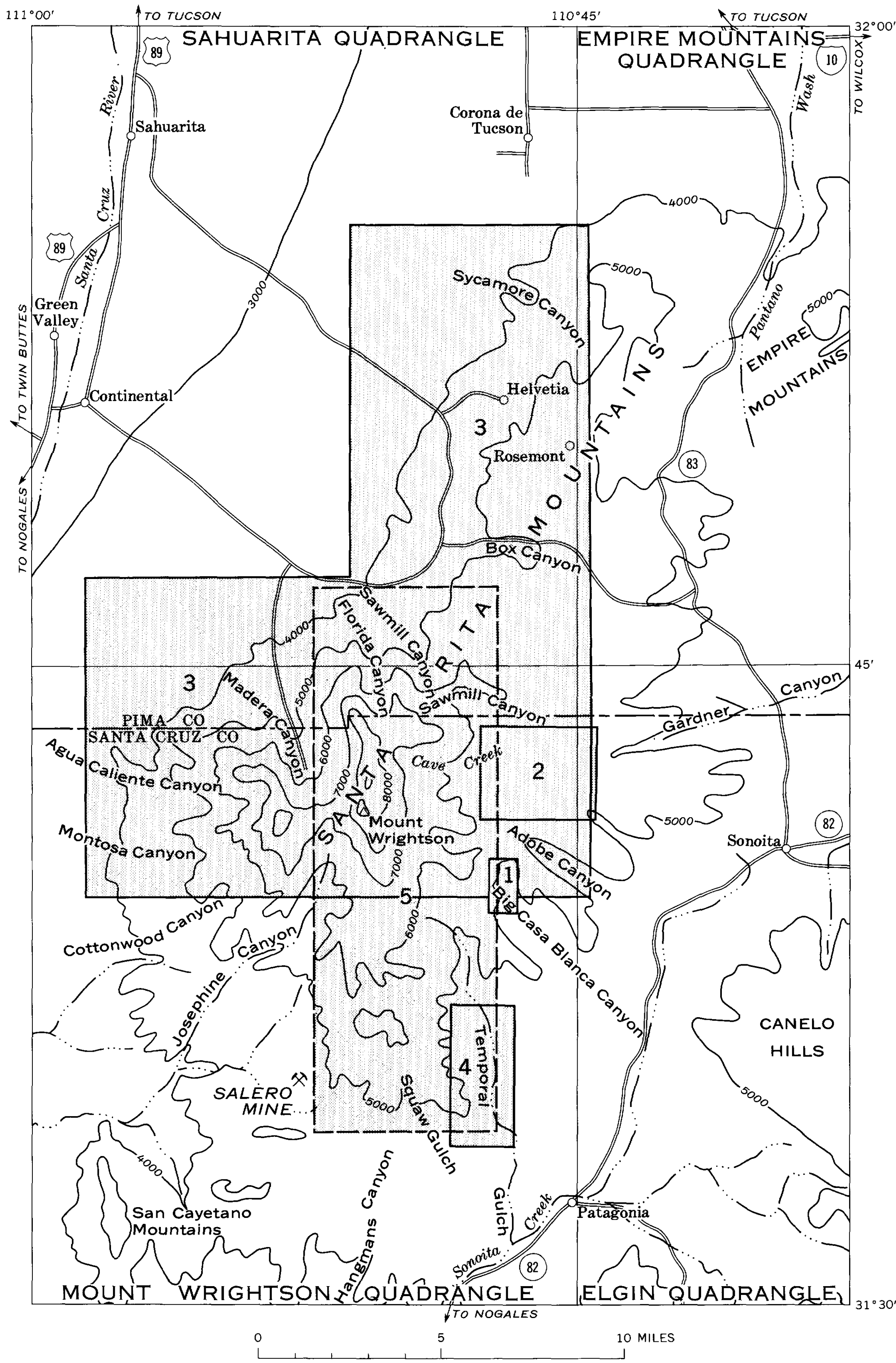


FIGURE 2.—The Santa Rita Mountains showing places discussed in text. Areas covered by geologic maps in this report: 1, figure 34; 2, figure 11; 3, figure 28; and 4, figure 18. Area 5 is Salero area.

404-482 O - 71 - 2

TABLE 1.—*Summary of the Mesozoic stratigraphy of the Santa Rita Mountains*

[m.y., million years]

Age	Group	Formation	Thickness (feet)	Subdivisions	Description
Paleocene(?)		Gringo Gulch Volcanics			Rhyolitic volcanics and clastic rocks.
		—Unconformity (major intrusions)—			
Late Cretaceous		Salero Formation	5, 000±	Upper member	Sedimentary and volcanic rocks; 2,500± ft.
				Arkose member	Arkose and conglomerate largely facies of welded-tuff member; 500± ft.
				Welded-tuff member	Rhyodacite welded tuff; 1,200+ ft. 72.5± 2.2 m.y.
				Exotic-block member	Dacitic volcanics containing large exotic blocks; 1,000± ft.
				Lower member	Dacitic volcanics; 400+ ft.
		—Unconformity—			
		Fort Crittenden Formation	4, 200–5, 800+	Rhyolitic tuff member	Tuff intercalated in upper red conglomerate; 0–650 ft.
				Upper red conglomerate member.	Volcanic conglomerate to siltstone; 1,400+ ft.
				Brown conglomerate member.	Arkosic conglomerate to siltstone; 2,000+ ft.
				Lower red conglomerate member.	Volcanic conglomerate to siltstone; 800–1,200 ft.
				Shale member	Fossiliferous shale, and sandstone; 4–550+ ft.
		—Unconformity—			
Early Cretaceous	Bisbee Group (7,500+ ft)	Turney Ranch Formation	1, 500+		Sandstone and red siltstone.
		Shellenberger Canyon Formation	1, 600+		Siltstone and arkose.
		Apache Canyon Formation	1, 500–2, 000		Arkose, siltstone, and limestone lenses.
		Willow Canyon Formation	2, 200+		Arkose and conglomerate.
		Glance Conglomerate	0–1, 500+		Limestone-and-granite cobble conglomerate.
		—Unconformity—			
		Bathtub Formation	1, 500–2, 300	Upper member	Dacite volcanics and tuffaceous sandstone; 0–1,500 ft.
				Middle member	Rhyolite to andesite volcanics; 800–1, 500 ft.
				Lower member	Conglomerate and volcanic sandstone; 700± ft.
		—Minor unconformity—			
		Temporal Formation	1, 000–2, 000	Upper member	Conglomerate and rhyolite volcanics; 600–1,000 ft.
				Middle member	Rhyolite to latite volcanics and conglomerate; 100–400 ft.
				Lower member	Rhyolitic to dacitic volcanics and fanglomerate; 200–1,300 ft.
		—Unconformity (major granite intrusion)—			
Early Jurassic and Late Triassic		Canelo Hills(?) Volcanics	600+		Arkose, tuffaceous sandstone, tuff, and conglomerate. 173±7 m.y.
		—Disconformity—			
Triassic		Gardner Canyon Formation	1, 000+	Mudstone member	Red mudstone, dacite volcanics and conglomerate. 192±20 m.y.
				Siltstone member	Red siltstone and chert pebble conglomerate.
		—Unconformity—			
		Mount Wrightson Formation	8, 500±	Upper member	Eolian sandstone, andesitic to rhyodacitic volcanics; 2,000+ ft.
				Middle member	Rhyolitic to latitic volcanics, trace of clastic rocks; 5,000± ft. 220±30 m.y.
				Lower member	Dacitic to andesitic volcanics, and sandstone; 1,500+ ft.
		—Inferred unconformity—			
Permian		Rainvalley Formation			Marine limestone, dolomite, and sandstone.

The geologic investigation of the Santa Rita Mountains is part of a larger program of the U.S. Geological Survey to establish the regional setting of mineralization in the ranges between Tucson and Bisbee. Many geologists are involved in the program, and most of the fieldwork has been completed. Cooper (1970) has mapped the Sierrita Mountains, Finnell (1970) the Empire Mountains, Creasey (1967) the Whetstone Mountains, R. B. Raup the Canelo Hills, F. S. Simons the Patagonia Mountains, P. T. Hayes the Huachuca Mountains, Raup the Mustang Mountains (see Hayes and Raup, 1968, for the geologic map of the Huachuca and Mustang Mountains), and Hayes and Landis (1961, 1964) the Mule Mountains. This collateral work has provided abundant data which support interpretations of the geology of the Santa Rita Mountains given here and also some data which restrict those interpretations. Thus, for example, the divisions of the Mesozoic rocks presented in this report have been found practical over a broader region than that covered in this report alone. Nevertheless, some interpretations on correlation and environments of deposition included here are only permissive interpretations and therefore are my sole responsibility. Where my colleagues prefer an alternative explanation or wish to avoid one favored here, they will do so in other chapters of this professional paper. Inasmuch as not all the other areas contain significant amounts of Mesozoic strata, not all the above-mentioned geologists have contributed directly to this professional-paper series; however, all of them have been intimately involved with the growth and development of the ideas of the authors of this series and with the editing of the maps and reports.

GEOLOGIC SETTING

The geologic events of the Paleozoic Era that led up to the deposition of the oldest Mesozoic rocks in southeastern Arizona are relatively well established; however, the record of still earlier events remains fairly fragmentary. In brief, the pre-Mesozoic geologic history involves five major episodes: (1) a period of early Precambrian sedimentation, (2) orogeny with attendant metamorphism and batholithic intrusion of at least one age, (3) further sedimentation, largely of clastic rocks, during late Precambrian time, (4) an episode of diabase intrusion and minor uplift, and (5) deposition during Paleozoic time, largely of marine carbonate rocks.

The oldest known rock unit in southeastern Arizona is the Pinal Schist, which includes some slate, metavolcanics, gneiss, and migmatite. The Pinal in this part of Arizona is exposed in the Little Dragoon Mountains, where Cooper and Silver (1964, p. 11–23) described it in considerable detail as a sequence at least 20,000 feet thick of metamorphosed conglomerate, sandstone, siltstone, and shale, and lava flows of rhyolite and basalt. They further described the major aspect of this sequence as a "cyclic graywacke-slate lithology * * *" which contains "graded bedding, the intercalated lava flows, and abundant volcanic debris." L. T. Silver (oral commun., 1968) dated a rhyolite flow as $1{,}715 \pm 10$ m.y. (million years), using the uranium-lead isotopic method on a suite of zircon samples. Cooper and Silver (1964) interpreted the thickness and lithology of the Pinal Schist as indicative of geosynclinal deposits. Some aspects of the geosyncline were reviewed by Anderson (1951, p. 1345).

In the Santa Rita Mountains, schist and gneiss that are correlated with the Pinal Schist form inclusions, roof pendants, and possible remnants of wallrock within large granitic plutons. Only very rarely were they the source rocks of detritus incorporated in the coarser clastic formations of Mesozoic age. The Precambrian rock that was exposed to erosion during the Mesozoic was largely of the granitic varieties.

Many of the ranges of southeastern Arizona in which the Pinal is exposed also contain extensive masses—some probably of batholithic proportions—of coarse-grained or porphyritic alkali granite, quartz monzonite, and granodiorite. These masses usually contain assorted small bodies of aplitic rock, fine-grained quartz monzonite, pegmatite, and lamprophyre. The batholiths and stocks intrude the Pinal and commonly metamorphose the schist along their contacts. Several of these granitic masses have been isotopically dated using the uranium-lead, lead-alpha, and rubidium-strontium methods, separately or together. Three of the dates fall in the range 1,410 to 1,655 m.y., three other dates are later in the Precambrian, and one is post-Cambrian. The youngest date demonstrably reflects a younger recrystallization event; the other relatively young dates are believed to be minimum dates, caused by loss of radiogenic daughter products. It seems likely that southeastern Arizona contains intrusives that are representative of both the older (1,650–1,700 m.y.) and the younger (1,430–1,460 m.y.) magmatic episodes that were described by Silver (1969). Locally, the plutonic rocks were modified by later thermal events, such as the Laramide orogeny.

In the Santa Rita Mountains, much of the basement rock is a coarse-grained porphyritic granodiorite and quartz monzonite of the 1,450-m.y.-old type. One sample of this rock yielded a Precambrian date by rubidium-strontium and lead-alpha methods, but another sample dated by the potassium-argon method records only a Laramide thermal event (Drewes, 1968, p. C5).

In the mountain ranges east of Tucson, rocks of the Apache Group of late Precambrian age unconformably overlie the Pinal Schist and various granitic masses. The stratigraphic sequence of this group is probably most complete in the Little Dragoon Mountains, where the units were described in detail by Cooper and Silver (1964, p. 36–41). But, even there, the upper two of the six formations that make up the Apache Group to the north are absent, and it is doubtful whether as many as four formations of this group are present anywhere between Tucson and the Little Dragoon Mountains. However, all these areas contain some diabasic intrusive bodies which are associated with remnants of the Apache Group. The absence of the Apache Group from the central and southern parts of southeastern Arizona and the absence of the upper third of that group from the northern part indicate that these areas either remained sufficiently high so as not to receive sediments during all of Apache time or more likely were uplifted so that the top of the Apache deposits was eroded. None of these rocks are present in the Santa Rita Mountains.

In Paleozoic time, shallow marine deposits were spread uniformly across all of southeastern Arizona, where they locally lie with minor angular discordance on rocks of late Precambrian age. Initially they formed a composite sheet about 6,000 feet thick; the oldest rocks are the Middle Cambrian Bolsa Quartzite, and the youngest are the Permian Rainvalley Formation. Sedimentation during the Paleozoic was interrupted probably several times; the longest of the hiatuses represents at least part of Ordovician time and all of Silurian time. Rocks of late Paleozoic age comprise, in rising order, the Earp Formation Colina Limestone, Epitaph Dolomite, Scherrer Formation, Concha Limestone, and Rainvalley Formation. The Rainvalley Formation and commonly also other Permian rocks, which are typical widespread marine units, are absent from southeastern Arizona east of the San Pedro River. Apparently, the Mesozoic rocks near the Santa Rita Mountains preserved the Permian rocks from subsequent erosion. Thus, the absence of Permian rocks to the east could be due to the lack of deposition of Mesozoic rocks there. During Rainvalley time, sometime near the middle of the Permian, southeastern Arizona was uplifted, the sea receded, and a continental environment was established. The epeirogenic movements associated with this major marine regression continued, perhaps with increased intensity, into the Triassic and set the stage for the volcanic and stratigraphic events in the Santa Rita Mountains, of prime interest in this report.

SUB-TRIASSIC UNCONFORMITY

Regionally, the Triassic strata are inferred to be separated from the underlying Paleozoic beds by an unconformity. Both the configuration and the precise age of this unconformity remain conjectural because the unconformity is so poorly exposed and because the Triassic rocks are relatively poorly dated. The contact between the Rainvalley Formation and the oldest Triassic unit, the Mount Wrightson Formation, is nowhere actually exposed owing to the abundance of faults and intrusive rocks. Nevertheless, the change from a major marine sequence to a continental one implies a crustal movement most consistent with existence of a widespread unconformity.

In the Santa Rita Mountains, for example, the base of the oldest Triassic rocks is concealed by a string of plutons. Despite this, an unconformity is inferred at the base of the Mount Wrightson because these volcanics contain some lenses of conglomerate whose clasts were derived from pre-Mesozoic rocks. In the Gardner Canyon area (fig. 11), the Triassic Gardner Canyon Formation overlies the Permian Rainvalley Formation, either with disconformity or with minor angular unconformity; and nearby it lies unconformably upon the Epitaph Formation. However, even these contacts are poorly exposed, because the siltstone at the base of the Gardner Canyon Formation is so weak that it is usually covered by colluvium.

The precise age range of the sub-Triassic hiatus remains problematic because of the lack of precise dating of the adjacent formations. The fauna of the Rainvalley is like that of the underlying Concha Limestone and is devoid of the most diagnostic Permian fossils, the fusulinids. Thus, Bryant and McClymonds (1961, p. 1333) initially dated the Rainvalley as Guadalupe(?), and Bryant (1968, p. 42) later stated that it may be late Leonard but more probably is early Guadalupe in age. The overlying Mount Wrightson Formation is unfossiliferous, but a lava flow from the middle member was isotopically dated by T. W. Stern by the lead-alpha method as 220±30 m.y. (in Drewes, 1968, p. C7). Even if that date is fairly accurate, there is several thousand feet of rock beneath the dated horizon whose age can only be estimated. The oldest exposed part of the formation could be as old as Late Permian or as young as Triassic. Because the latter age is believed to be the more reasonable one, the duration of time represented by the sub-Triassic unconformity is probably 30 m.y.

The character of the sub-Triassic contact must at present be inferred from the geologic history of the region around the Santa Rita Mountains, only a local part of which will be discussed in this report. The remainder will be discussed in the collateral reports previously mentioned. In brief, I believe that after the general uplift that led to the marine regression, uplift increased and block faults developed concurrently with the oldest Triassic volcanism. The base of the oldest Triassic rocks of the region is inferred to lie over a gentle angular unconformity or possibly even a disconformity. This unconformity is also believed to merge with the larger unconformity, which in Gardner Canyon separates the younger Triassic rocks from the Rainvalley and Epitaph Formations. Farther east, the same unconformity separates still younger Mesozoic rocks from the Rainvalley (Hayes and Raup, 1968), and elsewhere it commonly separates Cretaceous rocks from Pennsylvanian or Permian rocks.

TRIASSIC AND EARLY JURASSIC STRATIGRAPHY

Most rocks of Triassic and Early Jurassic age are volcanic, and lesser amounts are sedimentary red beds. These rocks constitute, in ascending order, the Mount Wrightson Formation and Gardner Canyon Formation of Triassic age and the Canelo Hills(?) Volcanics of Triassic and Jurassic age. These formations have in common a predominance of volcanic elements over sedimentary ones. They also form relatively thick deposits of limited extent, which suggests that they accumulated in deep local basins rather than in broad depressions. The combination of abundant volcanism and local deep basins of deposition suggests a block-faulted structural environment. A similar inference of lower Mesozoic block-faulted terrane is obtained from the structure of the Santa Rita Mountains, which is described in a companion paper (Drewes, unpub. data). The deposition of Triassic and Jurassic rock in this area ended with the emplacement of a large granitic stock into rocks as young as Triassic and was followed by uplift and erosion. The resulting hiatus is the most significant one in the Mesozoic record.

MOUNT WRIGHTSON FORMATION

A sequence dominantly of volcanic rocks and subordinately of sedimentary rocks, at least 8,500 feet thick, underlies the crest of the high, central part of the Santa Rita Mountains. These rocks were considered Tertiary by Schrader (1915, pl. 2) and Cretaceous by W. R. Jones, C. G. Bowles, and D. C. Hedlund, as reported by Wilson, Moore, and O'Haire (1960), but they were assigned a Triassic age by Drewes (1966) and were named the Mount Wrightson Formation by Drewes (1968, p. C6). The formation is divided informally into upper, middle, and lower members, which are distinguished by general lithologic differences, the chief one being a restriction of most of the andesitic rocks to the upper and lower members.

DISTRIBUTION

The Mount Wrightson Formation is exposed mainly in the Mount Wrightson quadrangle (Drewes, 1971a) but extends slightly northward into the Sahuarita quadrangle (Drewes, 1971b). The largest of three general outcrop areas of the formation is shown in figure 3. The rocks in this area form a simple homoclinal structural block, which has provided most of the information about the stratigraphic succession and facies variation. The formation is also exposed in two outlying structural blocks, the one about 6 miles west of the central part of the range, and the other 2 miles northwest of Patagonia.

The lower member underlies a discontinuous band along the west side of the main outcrop area and is accessible along Mansfield Canyon, the uppermost reaches of Temporal Gulch, and near Bog Spring. Probably most or all of the inclusions of altered volcanic rocks in the intrusive complex west of the main outcrop area are of the lower member.

The middle member of the formation underlies most of the main outcrop area and makes an unbroken belt extending from near Mansfield Canyon, across Mount Wrightson, to the mouth of Florida Canyon. It also underlies an accessible low hill just north of the mouth of that canyon and just north of the north edge of the area of figure 3, as well as the two outlying structural blocks. Rocks of the middle member, in small fault slices, also appear west of Elephant Head (Drewes, 1971a) and as exotic blocks in the Salero Formation (Drewes, 1968; Simons and others, 1966).

The upper member is restricted to the area near Gardner and Sawmill Canyons (fig. 3), an area only 3 miles long. A sliver of this member lies along the fault, which bounds the east margin of the main mass of the upper member but which lies east of the area of figure 3. Several other slices, either of this member or possibly of the middle member, also appear along the northeast side of the Sawmill Canyon fault zone, which adjoins the wedge of the Paleozoic sedimentary rock that is shown in figure 3.

LITHOLOGY AND PETROGRAPHY

LOWER MEMBER

Rocks of the lower member of the Mount Wrightson Formation are at least 1,500 feet thick, and their base is intruded by plutonic rocks. Most of the rocks of the lower member are dacitic or andesitic volcanics, but they also include a small amount of latite or rhyolite volcanic rocks and sedimentary rocks. The dacitic to andesitic rocks usually are medium-gray aphanitic or very finely porphyritic lava flows, in which individual flows are only rarely recognizable. In the upper reaches of Temporal Gulch, a more coarsely porphyritic andesite, resembling some rocks locally referred to as "turkey track porphyry," overlies finer grained rocks. One of these porphyries, in which the phenocrysts are fairly small, is shown in figure 4. Vesicles and amygdules appear in scattered outcrops west of Mount Wrightson and in Mansfield Canyon. Near Dripping Spring to the south, the member contains two lenses of tuffaceous fanglomerate or block breccia, which contain clasts of dacitic or other felsitic material that are probably of local origin. Lenses of quartz sandstone or quartzite, generally about 20 feet thick and a few hundred yards long, are scattered throughout the member, and near Bog Spring several tongues of sandstone thicken northward and join to make a single body several hundred feet thick.

In outcrop, the volcanics of the lower member are invariably slightly altered to moderately intensely altered and contain abundant epidote, chlorite, and clay minerals. The intensity of alteration increases westward toward the plutonic rocks that intrude the volcanics. A faintly gneissic foliation is superposed on the sandstone and the volcanics near Bog Spring, and west and south of Dripping Spring a hackly fractured hornfels forms the lowest rocks. Elsewhere along the contact with the plutonic rocks, the volcanics have been changed to a closely fractured sugary-textured massive rock.

Under the microscope, most of the rocks in the lower member are seen to retain vestiges of their original texture and mineralogy, although quantitative measurements are difficult to make and are thus of limited value. Phenocrysts range in abundance from 20 to 50 percent and appear in a felty- or trachytic-textured groundmass of feldspar laths (fig. 5) and interstitial material which is commonly obscured by alteration. In a few thin sections, the interstitial material consists of abundant ferromagnesian minerals. Plagioclase is abundant but is almost always albitized; the few unalbitized remnants are of sodic labradorite. Phenocrysts of clinopyroxene and pseudomorphs of uralite, chlorite, and epidote after pyroxene are present in

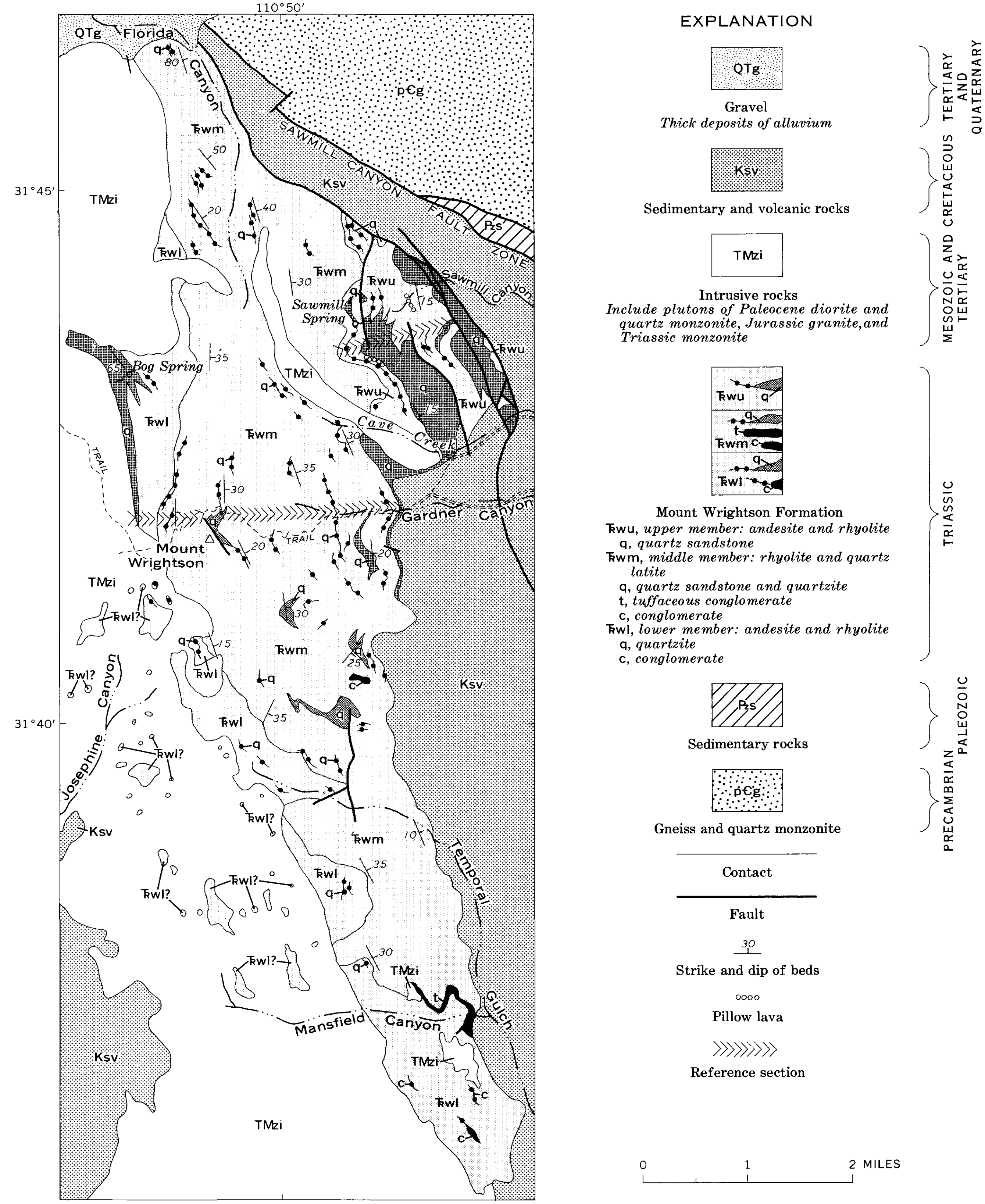


FIGURE 3.—Distribution of the main body of the Mount Wrightson Formation. NOTE.—More recent data indicate that the diorite and quartz monzonite plutons are Cretaceous in age, not Paleocene.

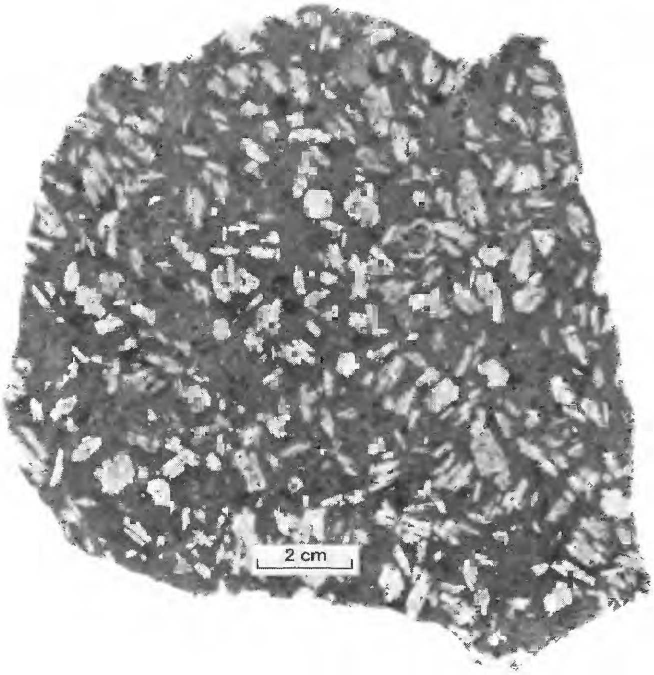


FIGURE 4.—Specimen of an augite andesite of the lower member of the Mount Wrightson Formation, obtained from the upper reaches of Temporal Gulch.

many of the rocks, in some pseudomorphs after amphibole, and in a few possible pseudomorphs after olivine. Titaniferous magnetite and apatite are the usual accessory minerals. Secondary minerals include, in addition to those already mentioned, sericite, kaolinite, quartz, and schorlite tourmaline.

The chemistry of the rocks of the lower member (table 2) is discussed in the section "Chemistry" (p. C13).

MIDDLE MEMBER

The middle member of the Mount Wrightson Formation consists of a sequence about 5,000 feet thick of chiefly rhyolitic and latitic rock but includes about 5 percent of dacitic rock and less than 1 percent of sandstone, quartzite, and conglomerate. No sharp contact with the rocks of the lower member has been seen because commonly the change from the more andesitic

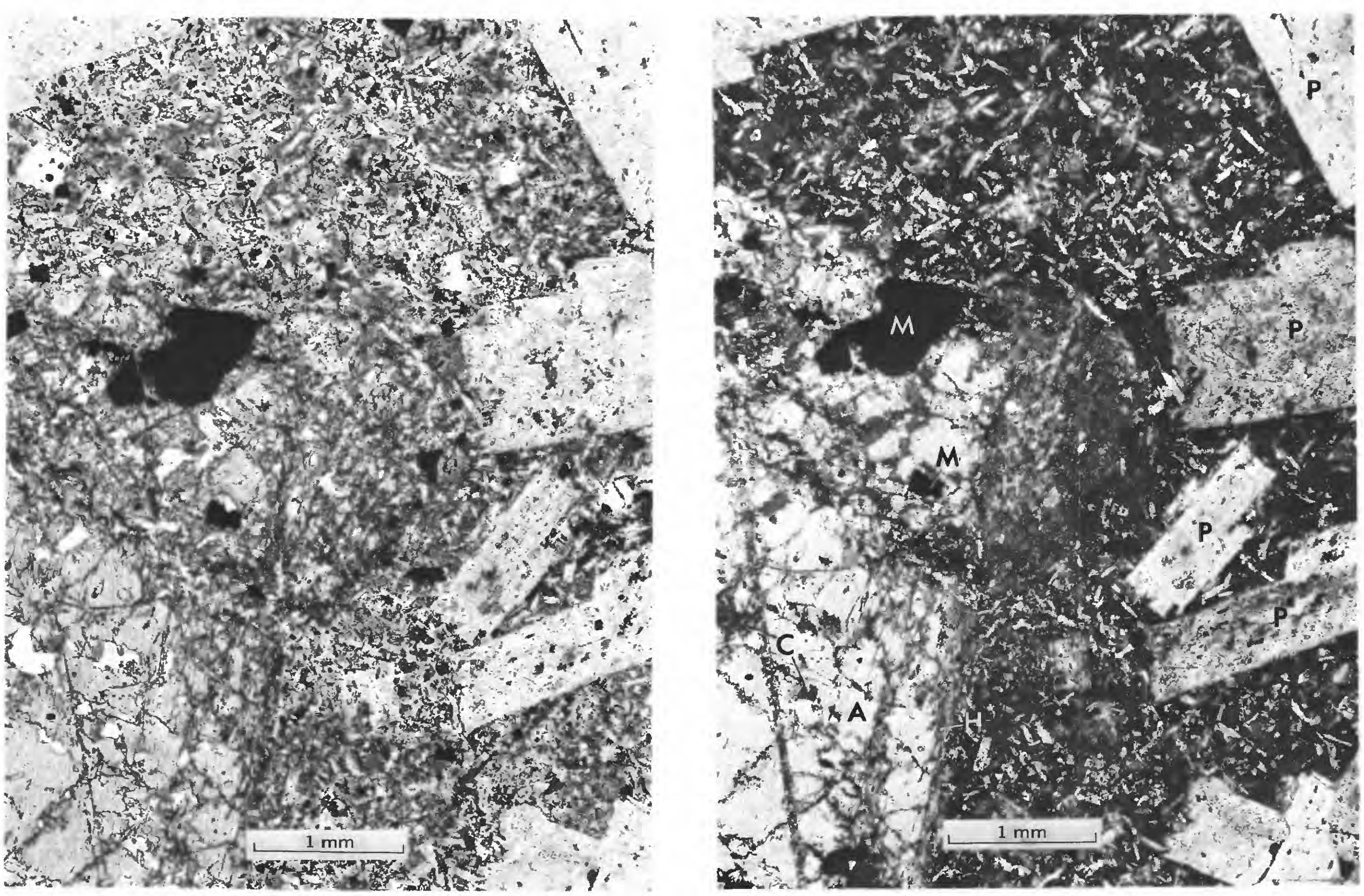


FIGURE 5.—Photomicrographs of augite andesite (fig. 4) from the lower member of the Mount Wrightson Formation. Left, plane-polarized light; right, crossed nicols. Phenocrysts: twinned augite (A), containing patches of chlorite alteration (C), and a uralitized hornblende(?) (H) reaction rim; altered plagioclase (P); and magnetite (M).

rocks below to the more rhyolitic ones above lies beneath an apron of talus or colluvium. The volcanics of the middle member are typically pale red and grayish red, but some tend toward pale reddish purple, pale reddish brown, or light brownish gray. Rocks of this member are usually highly resistant to weathering and thus underlie extensive cliffs and prominent ridges, such as the high crest of the Santa Rita Mountains.

Lava flows are the dominant type of rock in the central part of the main outcrop area; their textural variety is large, but their phenocryst variety is small. Many flows are conspicuously layered (fig. 6), and laminae less than one-quarter of an inch thick are especially characteristic of this member and are preserved even in some strongly altered rocks. However, nonlaminated flows are also present, particularly low in the member west and north of Mount Wrightson. In places, individual flows appear to be about 100–300 feet thick. Locally, parts of the flows are vuggy or contain spherical lithophysaelike structures ¼–1 inch across.

The volcanic facies changes away from the central part of the main outcrop area. Welded tuff is more dominant to the north than lava flows, and some welded tuff also appears in a smaller outcrop area on the western flank of the range (fig. 7). This welded tuff is strongly lamellar, but the laminae seem to consist largely of lenticular crushed pumice fragments rather than of unbroken layers like those in the lava flows. (Compare figs. 7 and 6.) The middle member contains much flow breccia and some tuff breccia which is the most plentiful to the south, between the upper reaches of Temporal Gulch and Mansfield Canyon. These rocks are commonly very light gray. Sheets of flow breccias alternate with nonbrecciated flows, and in some places the nonbrecciated flows appear to grade laterally into brecciated ones. However, small amounts of tuff breccia and flow breccia are scattered throughout the middle member, and several small pipelike bodies of volcanic breccia are exposed in the member along the crest of the mountains near Mount Wrightson.

Under the microscope, rock texture and composition are seen to be those of normal rhyolitic or latitic volcanics. The fine laminae of the flows show up as alternating zones of finely crystalline and more coarsely crystalline material, as alined crystal laths, and as thin iron oxide layers and trains of iron oxide specks (fig. 8). Phenocrysts of albitized plagioclase constitute as much as 25 percent of the rock, and phenocrysts and xenocrysts of quartz constitute 2–5 percent. Potassium feldspar, in several thin sections demonstrably sanidine, is commonly present in subordinate amounts. The feldspar phenocrysts of most rocks are less than 5 mm

FIGURE 6.—Specimen of layered rhyolitic lava flow from the middle member of the Mount Wrightson Formation, obtained from 2 miles northeast of Mount Wrightson. Each unit in scale on right is 0.05 cm.

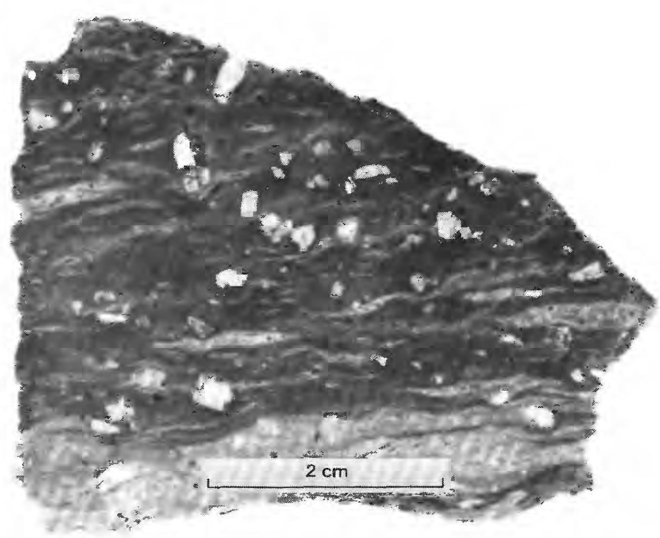


FIGURE 7.—Specimen of rhyolitic welded tuff from the middle member of the Mount Wrightson Formation, obtained from the west flank of the Santa Rita Mountains about 5 miles east of Amado.

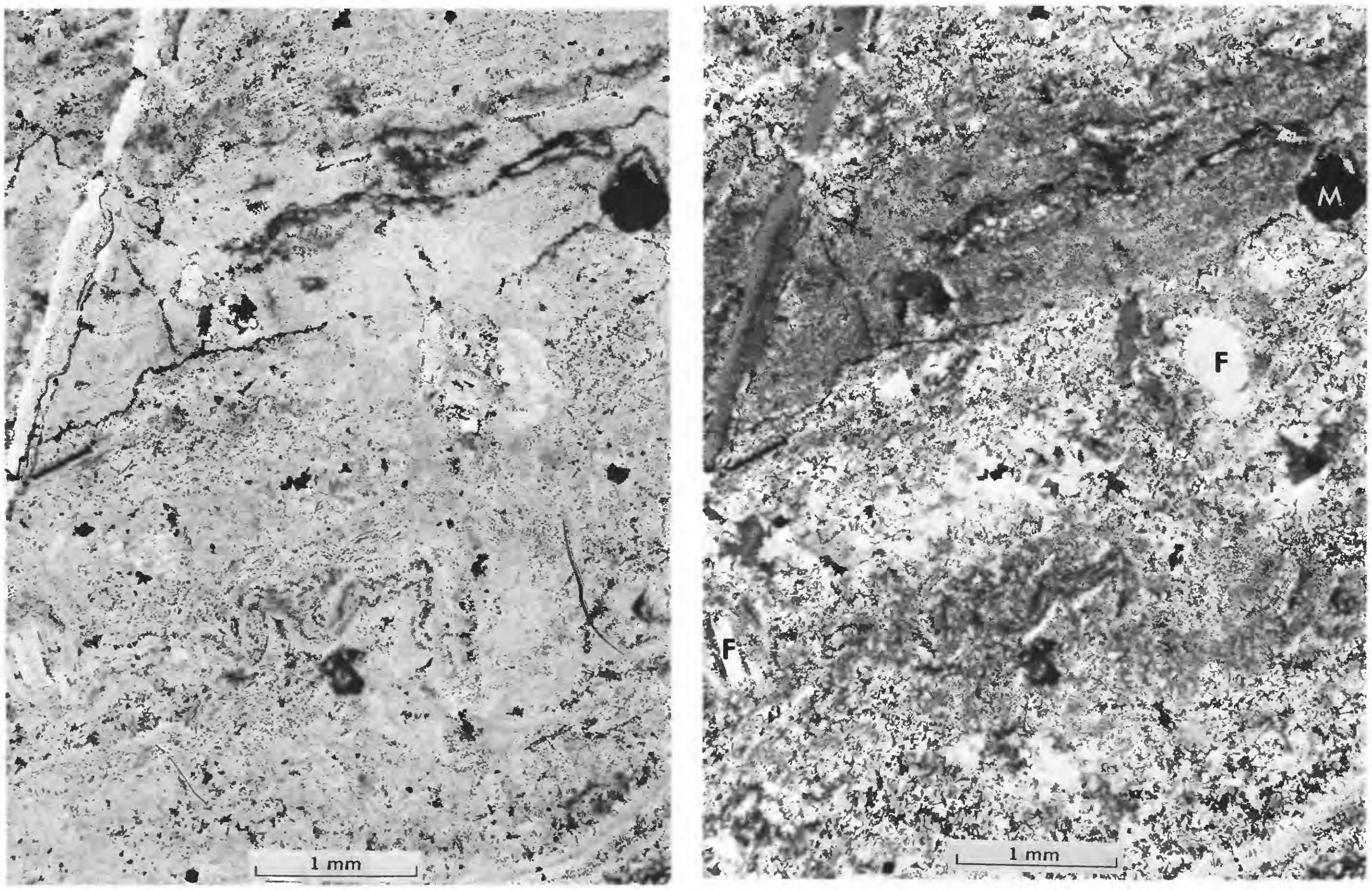


FIGURE 8.—Photomicrographs of a latitic flow (fig. 6) from the middle member of the Mount Wrightson Formation, showing flow laminations gently inclined toward the left and a quartz veinlet steeply inclined toward the left. Left, under plane-polarized light; alined black specks and bands of iron oxide mark the flow laminations, some of which are crinkled. Right, under crossed nicols, variations in the grain size emphasize the laminations. Phenocrysts of feldspar (F) and magnetite (M).

(millimeters) long, but in a few rocks they are 2–3 cm (centimeters) long and thus resemble those of the much younger "turkey track" porphyries of the region. About half the thin sections contain a few percent, at most, of chlorite pseudomorphic after biotite, and a very few contain traces of uralite or chlorite pseudomorphic after amphibole and possibly after pyroxene. Accessory titaniferous magnetite, apatite, and zircon are usually present. Altered devitrified glass is present in many thin sections; probably most of the rocks were once glassy. Petrographic and X-ray defraction analyses indicate that kaolinite, epidote, chlorite, minerals of the group illite-sericite, and some uralite are the common alteration minerals and that montmorillonite is sparse.

Chemical descriptions (table 2) are presented in the section on "Chemistry", which covers discussion on all members of the formation.

Lenses of sandstone and quartzite, similar to those in the lower member, are widely scattered throughout the middle member of the Mount Wrightson Formation. Altogether, about 30 lenticular bodies are sufficiently large to be shown for the Mount Wrightson on the geologic maps of the Mount Wrightson and Sahuarita quadrangles. They are intercalated in the volcanics of the middle member, where they weather to form small ledges of pale-yellowish-brown slabby-weathering rock. A large sweeping type of crossbedding is always present in the lenses, and the grains are well sorted, commonly subrounded, and 0.2–0.5 mm in diameter. Quartz makes up 70–80 percent of most sandstone lenses, and clay minerals or sericite derived from the clay makes up most of the remainder. Some lenses, however, contain considerable amounts of pumiceous shards, as shown in figure 9. Traces of tourmaline, zircon, leucoxene, plagioclase, orthoclase, microcline, and possibly monazite and epidote are found. Tourmaline, apatite, and rutile are included in some of the quartz grains. Although the rocks contain the same assemblage of alteration minerals as do the adjacent volcanics, the

404-482 O - 71 - 3

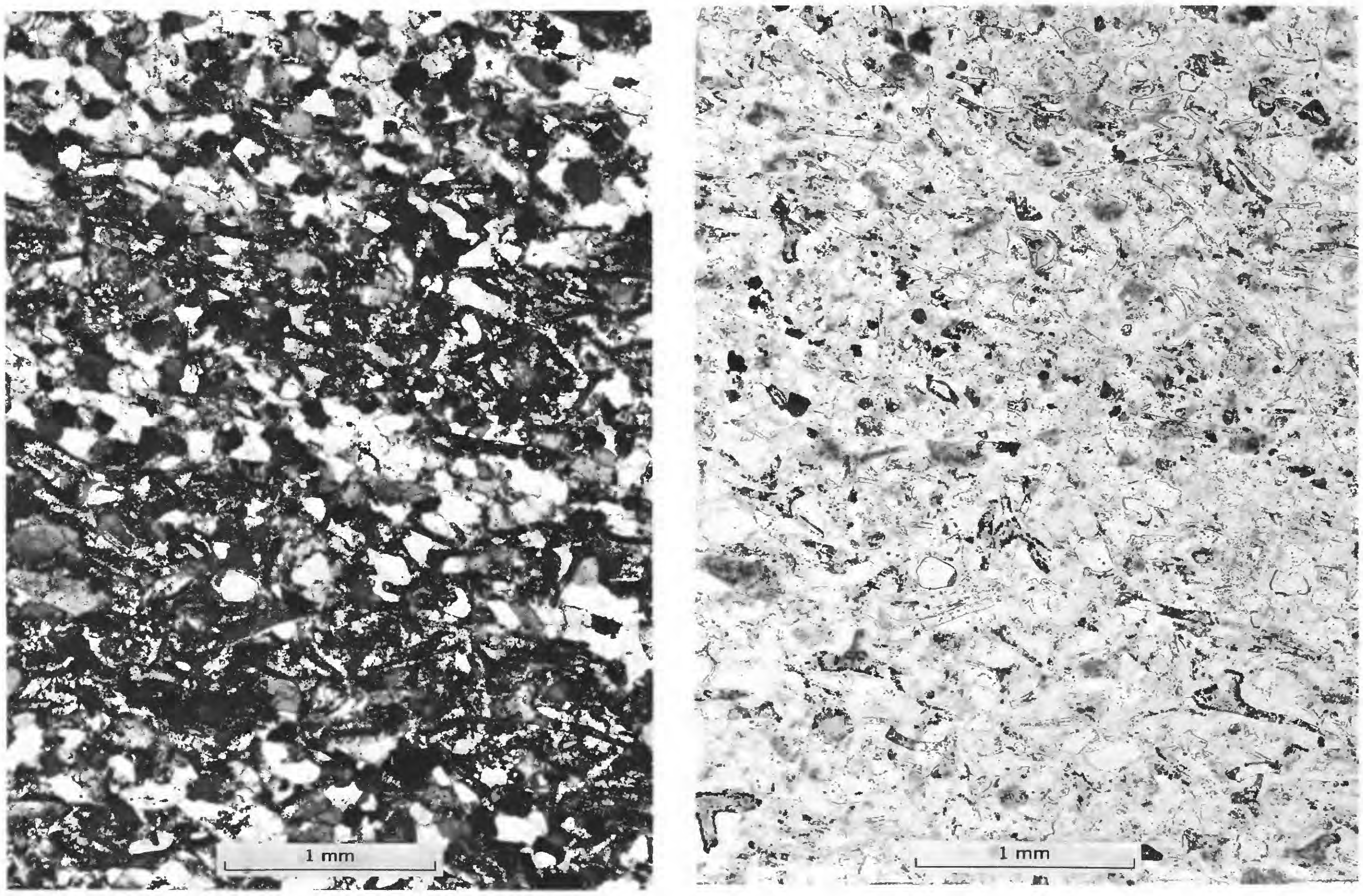


FIGURE 9.—Photomicrographs of a tuffaceous sandstone intercalated in the middle member of the Mount Wrightson Formation. obtained from about 1 mile north of Mansfield Canyon and 1½ miles west of Temporal Gulch. Left, under crossed nicols, shows sorting and degree of roundness of quartz grains. Right, under plane-polarized light, shows pumiceous shards.

occurrence of some clastic tourmaline, of possible clastic epidote, and also of tourmaline in quartz suggests that some of the source rocks of the sandstone had already been metamorphosed before the deposition of the Mount Wrightson Formation. Most likely, these tourmaline-bearing quartz grains were derived from a Precambrian source, because by Triassic time the Precambrian rocks were typically metamorphosed, whereas the Paleozoic rocks were not.

Several conglomerate lenses are also intercalated in the middle member of the Mount Wrightson Formation. One lens, exposed just north of the upper reaches of Temporal Gulch, contains abundant cobbles of a very coarsely porphyroblastic coarse-grained quartz monzonite or granodiorite, aplite, and fine-grained aplitic quartz monzonite, an assemblage resembling only the Precambrian rocks of this region and especially typical of the Continental Granodiorite in the northern part of the mountains. Another lens 1 mile north of Mount Wrightson contains another type of granitic rock, also probably derived from a Precambrian source rock, along with abundant volcanic fragments that could have been derived from the nearby flows of the older portions of the Mount Wrightson Formation. Detrital microcline in the sandstone and quartzite must likewise have come from Precambrian rock, because the other plutonic rocks of the nearby area are virtually free of microcline. A conglomerate lens on the north side of Mansfield Canyon contains about 30 percent shards of very delicate finely vesicular devitrified volcanic glass, in addition to the more usual volcanic detritus; it also contains some well-rounded and well-sorted grains of quartz, microcline, zircon, and possibly orthoclase. The source of the coarse volcanic fragments was probably very local. The source of the delicate pumiceous shards, even though different from the source of the coarse volcanic fragments, was probably also local, because the shards would have been destroyed by extensive transportation or by transportation with coarse detritus. The quartz grains, however, have had a history of extensive abrasion and may have come a great distance.

UPPER MEMBER

The upper member of the Mount Wrightson Formation is at least 2,000 feet thick and is about 50 percent sandstone, 40 percent dacitic and andesitic volcanics, and 10 percent rhyodacitic volcanics. Flows of dacitic to andesitic rock of the upper member intertongue with the more rhyolitic rocks at the top of the middle member; so the contact between these members was arbitrarily placed at the base of a sandstone-rich part of the sequence. This contact lies slightly above the zone at which rhyolitic rocks begin to be subordinate to andesitic rocks.

Sandstone in the upper member of the Mount Wrightson Formation forms fewer but much thicker lenses—as much as 800 feet thick—than sandstone in the lower and middle members. It forms small cliffs and gentle slopes on which bare rock is exposed over large areas, giving these slopes a moderate-orange-pink to grayish-orange-pink color. Large sweeping crossbedding, whose foreset beds commonly slope southeastward (R. F. Wilson, oral commun., 1968) is conspicuous, and the quartz grains are frosted, well rounded, and well sorted. Photomicrographs of typical sandstone of this member are shown in figure 10. The rock closely resembles some of the eolian sandstones of the Colorado Plateau and may even be contemporaneous with some of them.

In hand specimen, the volcanic rocks of the upper member of the Mount Wrightson Formation are seen to be very much like those of the other members. They are largely lava flows but include some agglomerate. The rhyodacite flows intertongue with the dacitic and andesitic flows and seem to be more abundant northward. Pillow lava appears in the canyon bottom half a mile east of Sawmill Spring and high in the unnamed canyon south of that spring (fig. 3). Individual pillows are as much as 3 feet across and are set in a sandstone or limy siltstone matrix. Pillows typically are sheathed in red oxidized andesite and contain annular zones of vesicles or amygdules of zeolite and epidote. Other dacitic and andesitic rocks of this member are also amygdaloidal or vesicular, and some of the rhyodacite is welded tuff. However, in this member too, individual flow units are difficult to detect because the pervasive mild alteration has left much of the rock too fractured and friable to produce many large outcrops.

Little more can be seen in thin sections of these rocks than in thin sections of the other volcanics of the formation. Phenocrysts commonly form 30–45 percent of the rock. Plagioclase is invariably albitized, and a little quartz and kaolinized potassium feldspar is present in many rocks. Most rocks contain chloritized biotite, and a few also contain replaced amphibole and pyroxene. Accessory minerals are magnetite, apatite, and zircon; secondary epidote, sericite, chlorite, and clay minerals are moderately abundant. On the basis of their modes alone, the volcanics of the upper member range in composition from rhyodacitic to andesitic rocks; too much of the groundmass is obscured to make more specific determinations.

CHEMISTRY

Modal, chemical, and spectrographic analyses and calculated norms of volcanic rocks of the upper member, as well as those of the other members, are presented in table 2. Study of these analyses suggests that at least some of the rocks are more intensely altered than is indicated by thin sections; most likely, selective addition or removal of material has occurred, as well as reconstitution of minerals. For instance, the chemical analyses show that specimens 3 and 5 contain nearly 80 percent silica, which seems high even for rocks in which some deuteric silica was deposited in vugs. Specimens 3, 5, and 8 are unusually low in CaO, whereas the K_2O content of at least specimens 7 and 8 is high in comparison to the common values of rhyodacites and even of the alkali rhyolites reported by Nockolds (table 3). Thus there is evidence of metasomatic changes from both chemistry and petrography. As a consequence, the calculated norms have limited significance. The appearance of normative magnesite in specimens 8 and 10, for example, and the appearance of "normative phosphate" in specimens 3, 4, 5, and 9 (footnote 3, table 2) are abnormalities in the rock chemistry indicative of cation transfer, not merely mineral reconstitution. Apparently some of the rocks have been silicified, potash metasomatized, and leached of lime.

Although the limitations implied by local metasomatism must be kept in mind, it is useful, nevertheless, to compare the chemical analyses of the Mount Wrightson volcanics (table 3, this report) with those tabulated by Nockolds (1954). The average composition of the lower member resembles that of Nockolds' average andesite, whereas that of the average upper member has affinities with both Nockolds' average rhyodacite and his average peralkaline trachyte. The average chemical composition of the middle member resembles most nearly Nockolds' alkali rhyolite, atlhough the fit is poorer than it was with the other members. In each analysis, contents of SiO_2, Al_2O_3, total FeO, MgO, and TiO_2 of the Mount Wrightson volcanics compare most closely with Nockolds' values, whereas contents of CaO, Na_2O, K_2O, and P_2O_5 compare least favorably; and

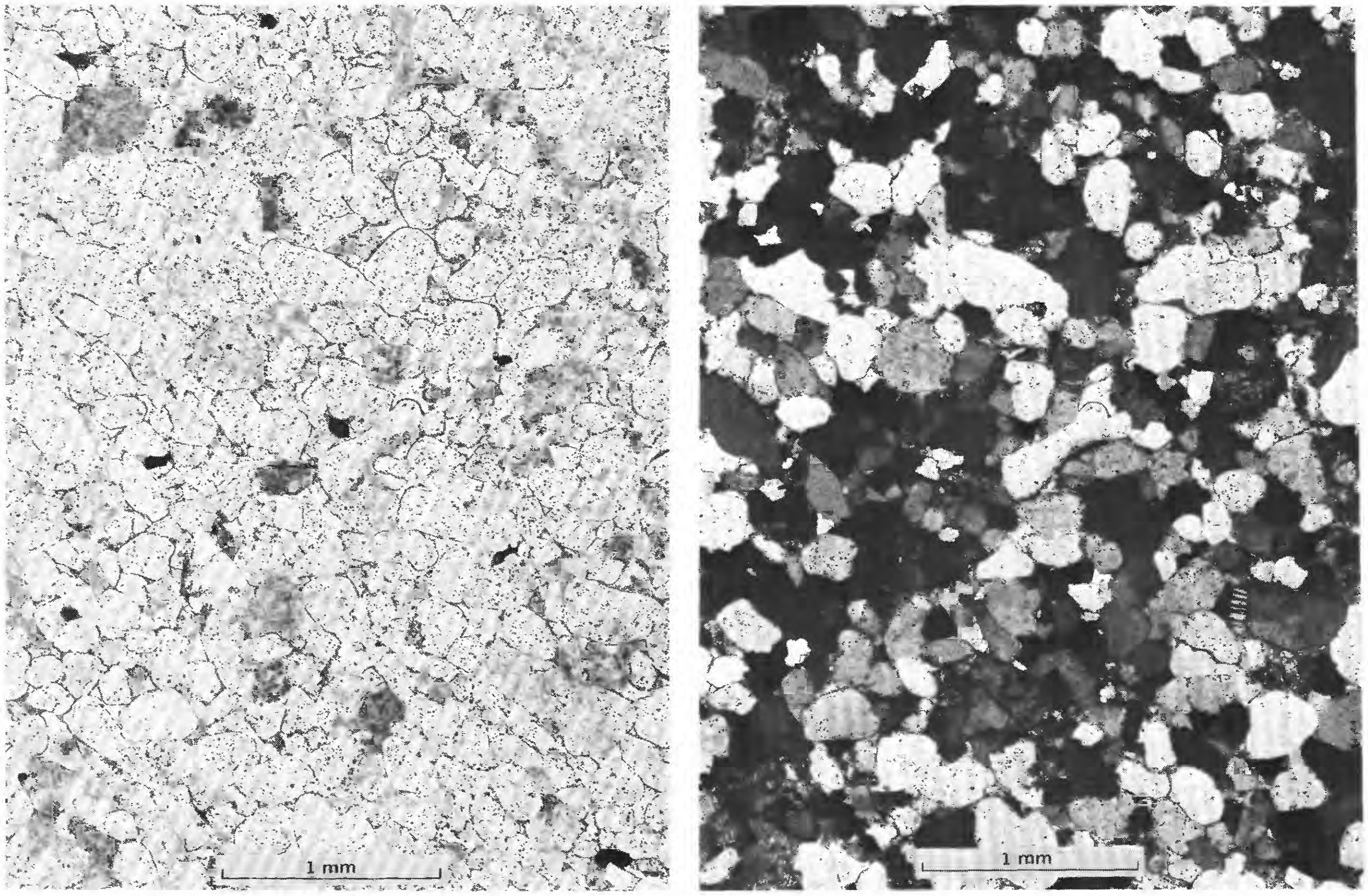


FIGURE 10.—Photomicrographs of a typical eolian sandstone intercalated in the upper member of the Mount Wrightson Formation, obtained from 1 mile southeast of Sawmill Spring on Cave Creek. Left, plane-polarized light, shows quartz as nearly white grains and potassium feldspar as light-gray grains. Right, under crossed nicols, shows a single striped plagioclase grain.

that disparity is greatest, percentagewise , in the rhyolitic rocks. The amount of alteration, however, is not so great as to affect the broadly inclusive rock names that have been assigned to the volcanics.

AGE AND CORRELATION

From geologic evidence, the Mount Wrightson Formation is dated as pre-Late Triassic and post-Early Permian, but because the volcanics were deposited in a continental environment much more typical of the Mesozoic than the Paleozoic Era, a Triassic age is favored. In the Patagonia Mountains, the Mount Wrightson Formation is demonstrably younger than Early Permian, because it lies unconformably on the marine Concha Limestone of Early Permian age (Leonard provincial series of West Texas). The marine Rainvalley Formation, which conformably overlies the Concha, is also present in the Santa Rita and Patagonia Mountains but is not in contact with the Mount Wrightson Formation; presumably, the Mount Wrightson overlies the Rainvalley Formation, as well as the Concha. The Mount Wrightson Formation is also older than Late Triassic, because it is intruded by plutons as old as 184±20 m.y., and detritus of the formation is incorporated in the Gardner Canyon Formation, dated by T. W. Stern as 192±20 m.y. (Drewes, 1968, p. C7–C8).

The age of the Mount Wrightson is determined directly by isotopic methods. A zircon concentrate from a welded tuff (specimen 7, table 2), which was collected from near the middle of the middle member within the type area, was dat ed as 220±30 m.y. by T. W. Stern (in Drewes, 1968, p. C7) by means of the lead-alpha method. This age is probably reliable because it fits the geologic relations and the other isotopic ages well. At least some of the Mount Wrightson Formation is of Triassic age and possibly even of Early Triassic age.

A zircon concentrate from specimen 8 (table 2) was dated by T. W. Stern (written commun., 1966) as 60±10 m.y. This specimen almost certainly came from the middle member of the Mount Wrightson Formation, but inasmuch as it came from a highly weathered outcrop on a pediment rather than from a blasted outcrop on a steep mountain slope, R. F. Marvin suggested (oral commun., 1968) that it may have lost lead owing to weathering. To the skeptical, neither age may be acceptable, but inasmuch as most of the 25 available ages are internally consistent and fit the geologic picture developed independently of the isotopic dating, the 220-m.y. age seems credible to me.

Rocks whose composition, appearance, and age are similar to those of the Mount Wrightson Formation appear in two mountain ranges bordering the Santa

TABLE 2.—*Modal, chemical, and spectrographic analyses and norms of volcanic rocks from the Mount Wrightson Formation*

Stratigraphic position	Lower member		Middle member						Upper member	
Specimen No.	1	2	3	4	5	6	7	8	9	10
Field No.	63D141	63D179	62D114	62D126	63D153	63D226	65D794	65D751	62D67	62D57
Modal analyses (percent)										
Quartz	0	1.6	0	0.8	20.2	2.0	1.8	5.8	7.9	8.6
Plagioclase	60.9	81.9	.9	3.0	2.0	3.5	5.4	2.3	14.0	18.1
Potassium feldspar	0	0	.2	.4	3.5	10.5	11.6	8.6	7.0	5.6
Biotite	0	.7	.3	.4	1.0	.3	.4	1.0	.2	2.2
Amphibole	28.1	5.6	0	.2	.1	0	0	0	.3	.7
Pyroxene	1.0	2.8	0	0	0	0	.1	0	0	0
Olivine(?)	0	3.3	0	0	0	0	0	0	0	0
Magnetite	10.0	3.6	0	.1	.3	.5	.1	1.3	.5	1.3
Apatite	0	0.6	0	0	0	.1	.1	.1	.1	.3
Sphene	0	0	0	0	0	0	0	0	0	.1
Zircon	0	0	0	.1	0	.1	.1	.1	.1	.1
Groundmass	0	0	98.6	95.1	72.8	83.0	80.3	80.8	69.9	63.1
Total	100.0	100.1	100.0	100.1	99.9	100.0	99.9	100.0	100.0	100.1
Chemical analyses (percent)[1]										
SiO_2	49.9	55.2	79.7	72.5	79.7	---------	71.6	71.5	67.7	63.9
Al_2O_3	16.7	15.1	11.4	14.0	11.3	---------	15.0	14.7	15.3	15.9
Fe_2O_3	8.0	5.1	.36	1.2	.59	---------	1.2	1.6	3.3	3.6
FeO	4.8	4.0	.14	.04	.24	---------	.26	.08	.10	.28
MgO	4.4	3.7	.1	.1	.1	---------	.1	.2	.1	.1
CaO	6.6	4.7	.30	.55	.20	---------	.42	.08	.48	1.5
Na_2O	2.7	3.3	3.8	2.1	.23	---------	2.6	2.0	4.2	4.8
K_2O	2.2	3.1	2.7	6.5	4.8	---------	7.6	8.3	6.2	5.9
H_2O-	.15	.14	.14	.31	.25	---------	.15	.22	.38	.08
H_2O+	1.9	2.3	.58	1.1	1.7	---------	.45	.73	.82	.92
TiO_2	1.5	1.4	.08	.24	.12	---------	.17	.42	.71	.77
P_2O_5	.60	.75	.28	.45	.26	---------	.02	.04	.50	.50
MnO	.28	.18	.02	.24	.00	---------	.21	.02	.00	.13
CO_2	.11	.46	.05	.14	.05	---------	.08	.11	.09	.68
Total (rounded)	100.00	99.00	100.00	99.00	100.00	---------	100.00	100.00	100.00	99.00
Semiquantitative spe trographic analyses [2]										
B	0	0	<.003	0.01	0.01	---------	0.003	0	0	0
Ba	.1	.1	.07	.07	.1	---------	.05	.1	.15	.15
Be	.0001	.0001	.0002	.00015	.0002	---------	.0001	0	.0001	.00015
Ce	.01	.03	0	.01	0	---------	0	.02	.02	.02
Co	.007	.005	0	0	0	---------	.0003	.0003	0	0
Cr	.0005	.002	0	0	0	---------	0	0	0	.0003
Cu	.005	.05	.002	.00015	.0007	---------	.0003	.001	.00015	.0007
Ga	.002	.002	.0015	.00015	.0015	---------	.001	.001	.001	.0015
La	.01	.01	0	.01	0	---------	.005	.005	.01	.01
Mo	.0003	0	0	.0003	0	---------	0	.0003	0	0
Nb	0	0	0	.0005	0	---------	0	.001	.0003	.0003
Ni	0	.01	.003	0	0	---------	0	0	0	0
Pb	.002	.0015	0	.003	.002	---------	.007	.002	.002	.003
Sc	.03	.03	0	.005	.03	---------	.0003	.0007	.0015	.001
Sr	.07	.07	.005	.005	.07	---------	.01	.005	.01	.03
V	.03	.02	0	0	.03	---------	.0007	.003	.005	.005
Y	.003	.005	0	.005	.003	---------	.002	.003	.003	.003
Yb	.0003	.0005	0	.0005	.0003	---------	.0002	.0003	.0003	.0003
Zr	.015	.02	.007	.03	.015	---------	.02	.07	.03	.02

See footnotes at end of table.

TABLE 2.—*Modal, chemical, and spectrographic analyses and norms of volcanic rocks from the Mount Wrightson Formation*—Continued

Stratigraphic position	Lower member		Middle member						Upper member	
Specimen No.	1	2	3	4	5	6	7	8	9	10
Field No.	63D141	63D179	62D114	62D126	63D153	63D226	65D794	65D751	62D67	62D57
Norms (percent) [3]										
Q	7.221	11.467	47.094	35.180	60.096	---	26.656	27.926	19.125	13.406
C	0	.635	1.999	3.220	5.636	---	1.969	2.426	1.382	1.633
or	13.021	18.423	16.043	38.732	28.555	---	44.973	49.046	36.810	3.195
ab	22.883	28.084	32.332	17.918	1.959	---	22.031	16.923	35.707	41.001
an	26.994	15.598	.654	.872	.352	---	1.449	0	.836	0
di {en	.418	0	0	0	0	---	0	0	0	0
di {fs	.009	0	0	0	0	---	0	0	0	0
di {wo	.492	0	0	0	0	---	0	0	0	0
hy {en	10.557	9.268	.250	.251	.251	---	.249	.296	.250	.206
hy {fs	.240	1.161	0	0	0	---	0	0	0	0
mt	11.618	7.437	.286	.218	.429	---	1.032	0	0	0
hm	0	0	.165	1.059	.298	---	.490	1.600	3.315	3.634
il	2.853	2.674	.153	.460	.229	---	.323	.211	.212	.878
ru	0	0	0	0	0	---	0	.309	.602	.315
ap	1.423	1.786	.190	.358	.119	---	.047	.095	.357	1.195
cc	.250	1.052	.114	.321	.114	---	.182	.049	.206	1.516
mg[4]	0	0	0	0	0	---	0	.169	0	.038
Total	97.98	97.59	99.28	98.59	98.04	---	99.40	99.05	98.80	99.02

[1] Rapid rock analyses determined by means of methods described by Ward, Lakin, Canney, and others (1963), supplemented by atomic absorption methods. Analysts: P. L. D. Elmore, Samuel Botts, Lowell Artis, Gillison Chloe, H. Smith, and John Glenn.

[2] Results are reported in percent to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, and so on, which represent approximate midpoints of group data on a geometric scale. The assigned group for semiquantitative results includes the quantitative value about 30 percent of the time. Elements looked for but not found: Ag, As, Au, Bi, Cd, Eu, Ge, Hf, Hg, In, Li, Nd, Pd, Pr, Pt, Re, Sb, Sm, Sn, Ta, Te, Th, Tl, U, W, and Zn. Analysts: W. B. Crandell and J. L. Harris.

[3] The chemical analyses of specimens 3, 4, 5, and 9 show a P_2O_5 content that is so high relative to that of CaO that not all of it can be accommodated by normative apatite. Inasmuch as the reported values of these oxides are all low, amounts of P_2O_5 of 0.35 percent (specimen 3), 0.2 percent (specimen 4), 0.3 percent (specimen 5), and 0.25 percent (specimen 9) are arbitrarily subtracted from the reported values; the subtracted values may be considered normative P_2O_5. The norms thus obtained are only slightly modified because the amounts of P_2O_5 subtracted are small. In the rocks, small amounts of an undetected secondary mineral, such as wavellite or variscite, may be present.

[4] Normative magnesite.

SPECIMEN DESCRIPTIONS

1. Altered andesite from upper flow of lower member, trachytic groundmass; NW¼NW¼ sec. 33, T. 20 S., R. 15 E., unsurveyed.
2. Altered andesite from flow near top of lower member, ophitic groundmass; NE¼NW¼ sec. 4, T. 21 S., R. 15 E.
3. Altered rhyolite fragment of an autoclastic flow breccia from upper third of middle member, cryptocrystalline groundmass; SW¼SW¼ sec. 21, T. 20 S., R. 15 E., unsurveyed.
4. Altered rhyolitic specimen from flow in lower third of middle member, groundmass layered, possibly vesicular; SE¼SE¼ sec. 29, T. 20 S., R. 15 E., unsurveyed.
5. Altered rhyolite from friable laminated flow containing quartz pods and veinlets and lithic fragments; SW¼SW¼ sec. 3, T. 21 S., R. 15 E.
6. Altered rhyodacitic vitrophyre from laminated and vesicular flow in unknown position in middle member; SW¼SE¼ sec. 35, T. 22 S., R. 15 E.
7. Altered rhyodacitic vitrophyre from welded tuff from low in middle third of middle member; SE¼SW¼ sec. 7, T. 20 S., R. 15 E., unsurveyed.
8. Altered rhyolitic specimen from a strongly laminated probably vitric flow probably from middle member; NW¼NW¼ sec. 13, T. 20 S., R. 13 E.
9. Altered dacitic specimen from flow, cryptocrystalline groundmass, from high in upper member; NW¼NW¼ sec. 3, T. 20 S., R. 15 E., unsurveyed.
10. Altered dacitic specimen from a flow with an hyalopilitic groundmass from high in upper member; NE¼NW¼ sec. 10, T. 20 S., R. 15 E., unsurveyed.

TABLE 3.—*Comparison of average analyses of the volcanics of the Mount Wrightson Formation with average analyses of Nockolds (1954, tables 1, 2, 3, 6)*

	Average lower member	Nockolds' andesite	Average middle member	Nockold's alkali rhyolite	Nockolds' rhyodacite	Average upper member	Nockolds' peralkaline trachyte
SiO_2	52.6	54.20	75.9	74.57	66.27	65.8	61.65
Al_2O_3	15.9	17.17	12.9	12.58	15.39	15.2	17.22
Fe_2O_3	6.5	3.48	.9	1.3	2.14	3.5	3.16
FeO	4.4	5.49	.13	1.02	2.23	.19	1.81
MgO	4.1	4.36	.1	.11	1.57	.1	.45
CaO	5.7	7.92	.28	.61	3.68	1.0	1.58
Na_2O	3.0	3.67	2.0	4.13	4.13	4.5	6.92
K_2O	2.6	1.11	5.6	4.73	3.01	6.0	5.80
H_2O-	.15	---	.23	---	---	.23	---
H_2O+	2.1	.86	1.0	.66	.68	.87	.58
TiO_2	1.4	1.31	.22	.17	.66	.74	.52
P_2O_5	.68	.28	.26	.07	.17	.50	.12
MnO	.23	.15	.07	.05	.07	.07	.19
CO_2	.28	---	.09	---	---	.38	---
Total (rounded)	100.00	---	100.00	---	---	99.00	---

Rita Mountains; these three mountain ranges are alined northwest–southeast. In the southeastern part of the Sierrita Mountains, the Oxframe Formation of Lootens (1965) lies 12 miles to the northwest of the nearest exposures of the Mount Wrightson Formation. Similar rocks underlie part of the Flux Canyon area in the north end of the Patagonia Mountains. (See southeast corner of Mount Wrightson topographic quadrangle map, U.S. Geological Survey, 1958; and Drewes, 1971a). In the Sierrita Mountains area, some volcanics have been recognized by J. R. Cooper (oral commun., 1963) and in the Patagonia Mountains by F. S. Simons (oral commun., 1968) as possibly early Mesozoic. My impression is that the lithologies of rhyodacitic to latitic flows and tuff breccias that contain intercalated quartzite lenses are sufficiently distinctive and unique to be correlated with the Mount Wrightson Formation. However, all the Mesozoic volcanics are considerably altered, and some of them change facies rapidly within each area; therefore, applying one formation name to these rocks in both areas may be undesirable, despite the correlation suggested here. More detailed work on this problem is not apt to lead to the resolution of the problem because neither fossils nor unaltered minerals suitable for direct isotopic dating, other than zircon, are likely to be obtained from these formations.

ENVIRONMENT OF DEPOSITION

The Mount Wrightson Formation is a continental sequence that was deposited almost entirely subaerially; it is the oldest continental sequence deposited after the final regression of the Paleozoic seas. Not only had the region around the Santa Rita Mountains emerged from the sea, but locally the relief was considerable, because some of the detrital components in the formation were derived from a Precambrian source rock which had been deeply buried beneath Paleozoic sediments. The northwestward alinement of faults and plutonic bodies of Mesozoic age indicates that a strong structural grain had already been established in the region. Block faulting is believed to have uplifted parts of the region sufficiently to enable erosion to remove the Paleozoic cover. The linear distribution of the bodies of Triassic volcanics is inferred to reflect an initial restriction of the thicker parts of the volcanic field to structural troughs between the postulated block-faulted ranges.

The lenses of sandstone and quartzite intercalated in the volcanics are probably eolian deposits. The strong resemblance of these deposits to some of the Triassic eolian deposits of the Colorado Plateau region may not be accidental; the well-sorted and rounded crossbedded sandstones of the two regions are partly contemporary, and their direction of deposition, to the southeast, also is alike. Furthermore, Hayes, Simons, and Raup (1965, p. M8) suggested that the source of the volcanic material in the fluviatile Upper Triassic Chinle Formation of northeastern Arizona may have been in southeastern Arizona. Although the intercalated eolian sandstone indicates at least a moderately arid climate, the pillow lavas were formed in some local ponds, and, conceivably, some streams could have flowed northward out of the region toward northeastern Arizona.

In the central part of the Mount Wrightson Formation of the Santa Rita Mountains, lava flows are strongly dominant over pyroclastic rocks, whereas pyroclastic rocks are more abundant to the northwest and southeast. This suggests that the volcanics of the Mount Wrightson area may have been deposited close to their volcanic vents.

GARDNER CANYON FORMATION

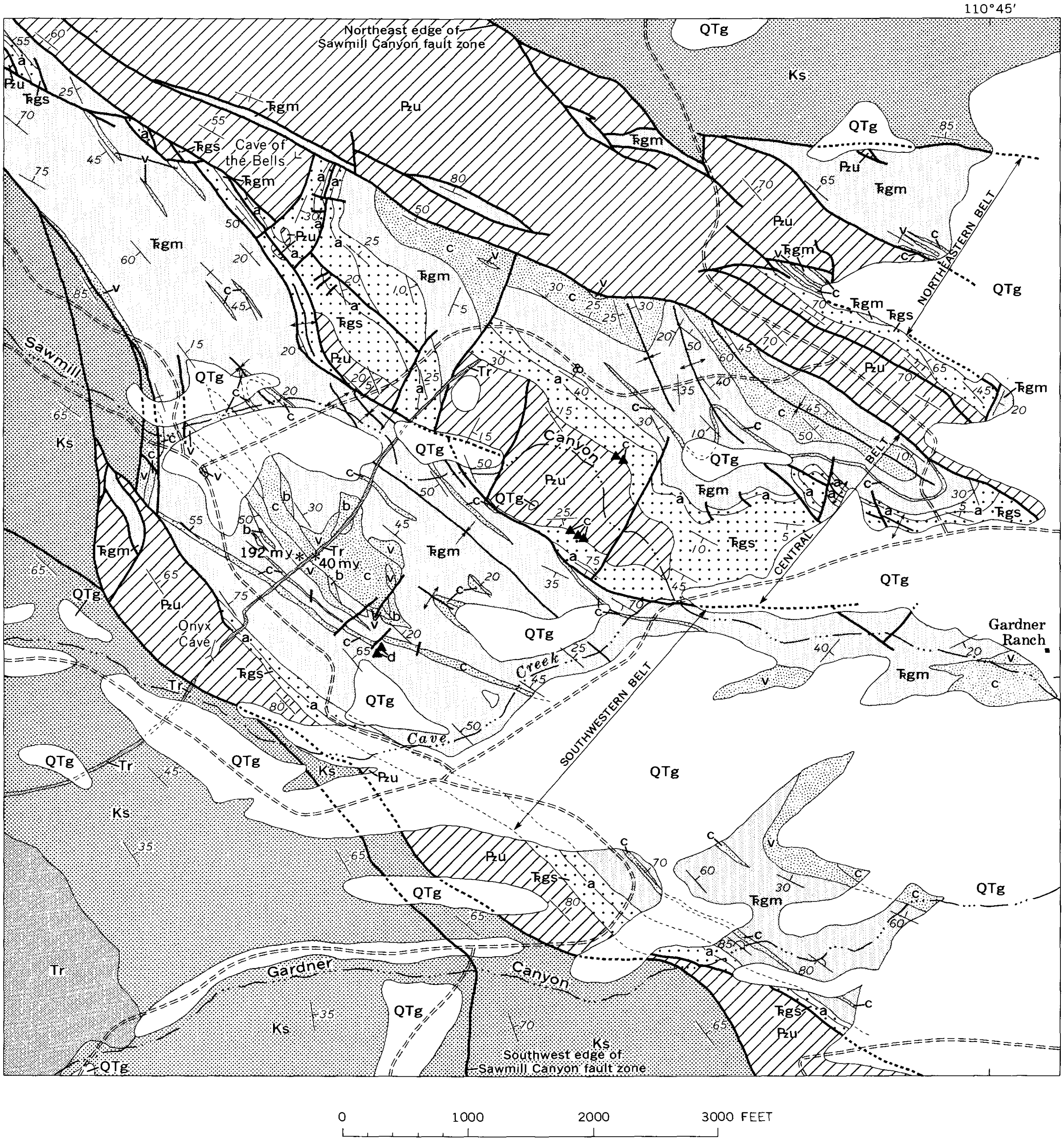
The Gardner Canyon Formation consists of a red-bed sequence at least 1,000 feet thick that underlies several small areas in the northern part of the Santa Rita Mountains. These rocks have been considered to be part of a Cretaceous sequence since the orginal mapping by Schrader (1915, pl. 2) but, as a result of more detailed study, they are now believed to be Triassic (Drewes, 1968, p. C7). In its type area near Gardner Canyon and Cave Creek, the formation consists of an underlying siltstone member and an overlying mudstone member, but this division is not recognized farther north where faulting and metamorphism are more intense.

DISTRIBUTION

The Gardner Canyon Formation underlies several small areas near the Cave Creek–Sawmill Canyon area (fig. 11) and several near Sycamore Canyon (Drewes, 1971b). The combined extent of these areas is less than 2 square miles. In the type area, the red beds form essentially three belts of outcrops, all lying within the Sawmill Canyon fault zone. The rocks of the three belts are progressively more broken up by the faults toward the northeast; details of their stratigraphy and facies thus come largely from the southwestern and central belts of red beds.

The southwestern belt of red beds extends from the gravel cover just south of Gardner Canyon northwestward about 2½ miles. A fault bounds the northeastern edge of the belt and the northern half of its southwestern edge. Along the southern half of the southwestern edge east of Onyx Cave, however, the red beds rest unconformably on the Rainvalley Formation. Excellent exposures of the formation occur along the bottoms of Gardner Canyon, Cave Creek, and Sawmill Canyon, where these valleys cut across the red-bed belt, and also in the low hills midway between Cave Creek and Sawmill Canyon (fig. 11). Basically, this belt of red beds forms a northeastward-dipping structural wedge which contains fairly open folds to the south and tighter folds, as well as faults, to the northwest. Several small slivers of red beds closely associated the main southwestern belt of red beds have been faulted into the Permian limestone along the southwestern edge of the Sawmill Canyon fault zone—for example, northwest of Onyx Cave.

The central belt of red beds lies between Cave of the Bells on the northwest and the eastern part of Cave Creek on the southeast. The contacts of the red beds of this outcrop belt are also largely faulted, but near the southwestern edge of the belt the red beds also lie unconformably on Permian rocks, here the Epitaph Dolomite. Basically, the rocks of this belt form another northeastward-dipping homoclinal structural block that is only moderately tightly folded toward the east. However, toward the northwestern end of this belt, where faulting was more intense, the red beds are



broken into several small slivers which are wedged between structural blocks of Paleozoic rock.

The red beds of the most fragmented northeastern outcrop belt follow the structural pattern of the other two belts. Several small fault slices of red beds lie between blocks of Paleozoic and Cretaceous rocks northwest and north of Gardner Ranch. Most contacts are faults, but the red beds of the largest structural slice, which are largely covered by gravel, dip homoclinally northeastward and appear to lie unconformably on the Epitaph Dolomite.

Several deposits of red beds and associated phyllite, arkose, conglomerate, and tuffaceous sandstone believed to be part of the Gardner Canyon Formation occur in several areas along Sycamore Canyon near the north end of the mountains. The largest of these deposits lies

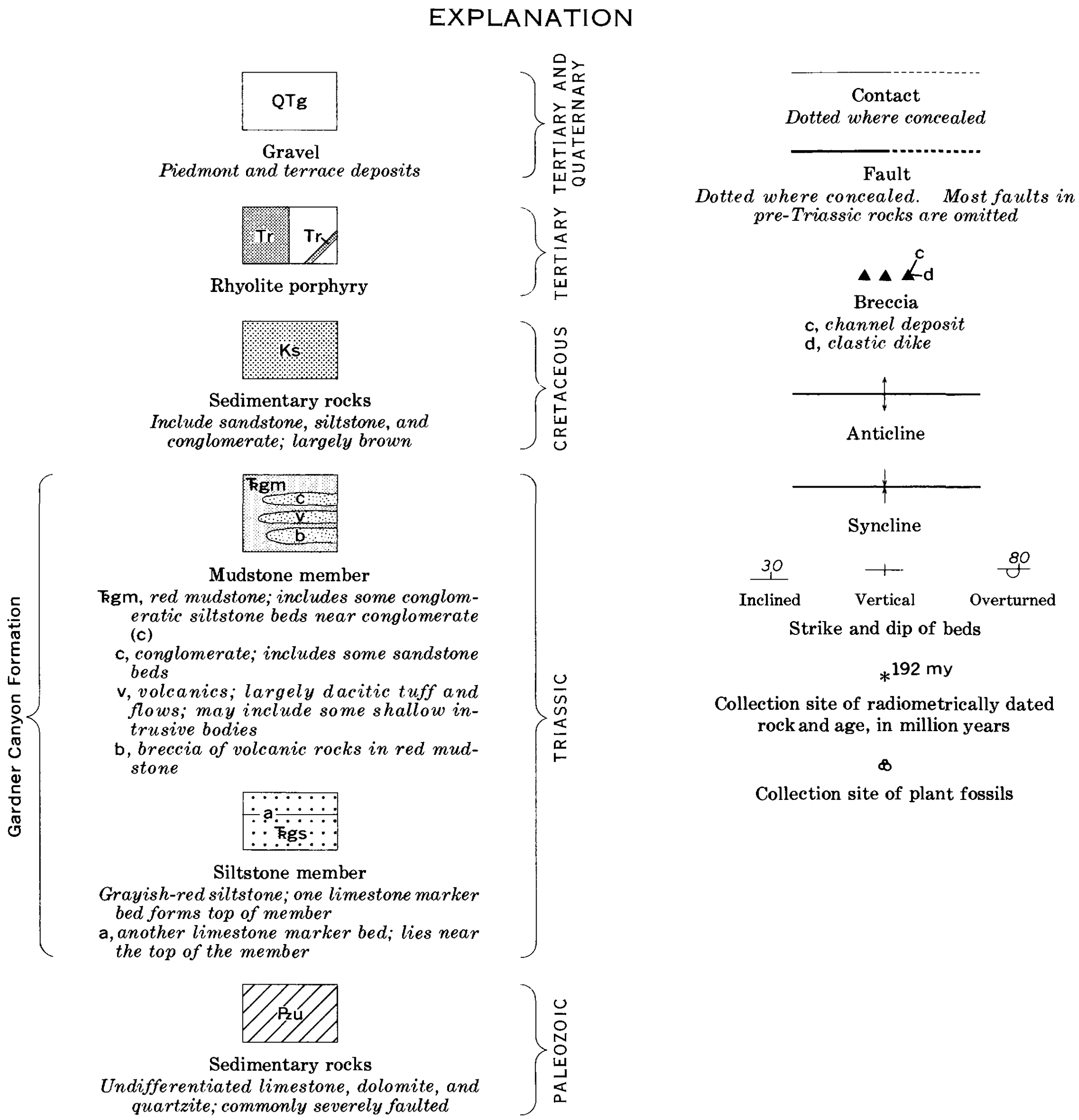


FIGURE 11.—Gardner Canyon–Cave Creek area, showing the distribution and subdivisions of the Gardner Canyon Formation.

to the south of Johnson Ranch, near the mouth of the canyon, where it forms the basal part of a synclinally folded thrust plate. The southeast end of the klippe is faulted, and the rocks there are poorly exposed. Metasedimentary rocks that possibly are correlative with the Gardner Canyon Formation also crop out half a mile west to southwest of the ranch. A third body of phyllitic red beds that is believed to be Gardner Canyon Formation crops out a mile northeast of the ranch. It forms a separate thrust plate of steeply northeastward-dipping rock that overlies a plate of Permian rocks and underlies a plate of Glance Conglomerate.

Finally, along the road near the head of Wasp Canyon (Drewes, 1971b), about midway between the two main groups of outcrops of the Gardner Canyon Formation, a thin sheet of red beds is in thrust contact with a plate of Permian rocks below and a plate of Glance Conglomerate above. Although the rocks of this sheet are not metamorphosed, the exposed sequence is sufficiently small and undiagnostic that it cannot be distinguished with certainty from some beds of the Bisbee Group; only by association with the structure northeast of Johnson Ranch does the correlation of these red beds with the Gardner Canyon become reasonable.

LITHOLOGY AND PETROGRAPHY

SILTSTONE MEMBER

The siltstone member is about 200 feet thick and is typically a grayish-red massive or faintly bedded siltstone. Its basal contact, an unconformity, is exposed only locally near the mouth of the Sawmill Canyon in the Mount Wrightson quadrangle, about 2,000 feet west of Gardner Ranch where the basal siltstone is draped around blocks of dolomite of the Permian Epitaph Dolomite. The siltstone member contrasts subtly with the upper member in that the siltstone member is coarser grained and more resistant to weathering; it also contains two limestone marker beds. The top of the upper marker bed is taken as the top of the member; this position coincides roughly with the top of the zone of gradual upward transition from siltstone to mudstone.

The siltstone is fairly uniform in composition, but locally it does vary in color and grain size. The chief variant is a rock along the lower mile of Sawmill Canyon that is a light-gray to pale-yellowish-brown fine-grained sandstone. At the base of the member (fig. 11) there are two lenses of quartzite breccia, each about 10 feet thick and 50 feet long. These lenses fill channels—perhaps two sections of the same channel—cut into the underlying Permian rocks. The quartzite blocks were probably derived from the Scherrer Formation, which locally had been eroded before Gardner Canyon time. In a few places, the lower part of the siltstone member also contains small cobbles of light-gray finely crystalline limestone, which probably are stray clasts derived from the Paleozoic terrane on which and against which the siltstone was deposited. Elsewhere the member also contains nodules and pods of limy siltstone at least 1 inch long, like those that occur in other red-bed units of Mesozoic age.

In thin section a fine-grained sandstone of this member is seen to consist largely of poorly sorted angular grains about 1 mm in diameter. Modal analysis of the sandstone is as follows:

Mineral	*Percentage*
Quartz	20
Plagioclase	20
Rock fragments	20
Orthoclase(?)	10
Clay minerals	20
Iron oxides	10
Calcite cement	1
Muscovite	1
Chert grains	Trace
Magnetite	Trace
Zircon	Trace
Apatite inclusion	Trace
Tourmaline	Trace

The lower limestone marker bed is generally about 5 feet thick, and it commonly is composed of a lower, slightly reddish light-gray silty limestone and an upper, light-gray crystalline limestone. Both limestones resemble some of the underlying Paleozoic rocks. Bedding is indistinct or absent, and the dominant sedimentary feature is usually a bouldery or hummocky surface on the reddish light-gray limestone. Some zones of limestone sedimentary breccia, conglomerate, or pods occur in a red silty and limy matrix. Small chert chips are scattered through this limestone. South of Cave Creek, the lower limestone marker bed is entirely reddish gray but is distinctly of a shade lighter than that of the upper member.

The upper limestone marker bed lies 10–50 feet above the lower one and is typically about 10 feet thick, although locally it is twice that thick. This limestone is distinguishable from the lower limestone marker and from the Paleozoic limestones by the combination of its dark-gray color, its laminations, and its medium-coarse-grained bioclastic texture. Fresh surfaces have a faint fetid odor. In a few places, this dark-gray limestone conformably overlies the hummocky top of a lighter gray bed of algal(?) limestone. South of Cave Creek, the laminations are inconspicuous but the dark color persists. Several samples of these limestones have been checked, in vain, for fossil pollen.

MUDSTONE MEMBER

The mudstone member of the Gardner Canyon Formation is at least 1,000 feet thick and conformably overlies the siltstone member. The lower 300–400 feet consists of moderate-red to pale-reddish-brown massive or very poorly bedded mudstone. The basal few tens of feet of this unit contains some fine-grained siltstone in transition from the underlying member; a few siltstone beds which are intercalated throughout the mudstone, provide indistinct bedding, as shown in figure 12. A few thin zones in the mudstone contain limy pockets or blebs rarely as much as 1 inch across (fig. 13) and crudely developed limy nodules a few inches across (fig. 14). These limy zones are believed to be lithified old caliche zones. High in the mudstone unit, there are also a few inconspicuous thin beds of arkosic sandstone.

About midway between Cave of the Bells and Gardner Ranch, and 20 feet above the base of the member, there is a small lens of fossiliferous shale. The lens is only 1 foot thick and about 10 feet long; it crops out just downslope from an old road grade (fig. 11), which locally on the topographic map of the Mount Wrightson quadrangle has been placed too far east. The rock is a fetid coaly shale to carbonaceous limestone which contains chips of coal and fragments of plants that resemble reeds. The material collected at and near the surface, however, contained no identifiable material, including pollen.

The mudstone member also includes some conglomerate and conglomeratic sandstone, the lowest occurrences

FIGURE 12.—Typical outcrop of the mudstone member of the Gardner Canyon Formation, along Cave Creek near Gardner Ranch. Yucca stalk in center of outcrop is about 10 feet long.

of which are generally 300–400 feet above the base of the member. These materials make up about 5 percent of the rock of the southwestern structural slice, as much as 15 percent of the central slice, but less than 1 percent of the northeastern slice (fig. 11). In the southwestern structural slice, north of Cave Creek, the lowest conglomerate unit is fairly extensive; but higher ones form lenses, commonly 10–20 feet thick and in one place more than 100 feet thick, and probably are channel deposits. In the northern part of the central structural slice, conglomeratic sandstone first appears about 350 feet above the base of the member, but in the southern half of that slice it appears about 100 feet lower. In the southern half of the central structural slice, pebbles, instead of occurring in lenticular channel conglomerates, are more widely scattered, and there are only a few distinct conglomerate beds, such as the marker bed near Gardner Ranch (fig. 11). The clasts of many conglomerates are well-rounded pebbles of limestone, chert, and quartzite, all derived from the Paleozoic rocks. A few beds also contain pebbles and small cobbles of subrounded intensely indurated laminated volcanics derived from the Mount Wrightson Formation.

Volcano-clastic material makes up some of the coarse-grained beds in the mudstone member. Cobbles and blocks of the dacitic volcanics, like those interbedded with the red beds, constitute small lenses in the mudstone member. These sedimentary volcanic breccias usually lie near their sources and wedge out rapidly away from the flows. Fairly high in the mudsone member, near the stratigraphic position at which some tuff appears, tuffaceous sandstone and conglomerate and arkosic sandstone beds are more abundant than the red mudstone, and the formation is faintly varicolored rather than uniformly red, and the outcrops are larger. The few thin conglomerate beds in the northeastern structural slice are chert- and quartzite-pebble beds, and, as they are associated with a little tuff, they probably belong high in the mudstone member.

A small granite-pebble dike intrudes the lower part of the red mudstone about 700 feet east of Onyx Cave.

FIGURE 13.—Small limestone pockets and blebs in the mudstone member of the Gardner Canyon Formation, cropping out along Cave Creek near Gardner Ranch. Bedding dips gently to the left.

Two blocks of Paleozoic limestone, the largest about 15 feet thick and more than 50 feet long, are intercalated in the red beds of the northeastern structural slice. One of them lies near the faulted contact with the Paleozoic rocks, and the other is several hundred feet higher stratigraphically. These blocks may have slumped or slid onto the red mud from an adjacent high area before the consolidation of the mud; thus, in a modest way, they resemble some of the exotic blocks described by Raup (in Simons and others, 1966, p. D14–D16) in the red beds in the Canelo Hills 6–10 miles to the southeast.

Small lenses of faintly purplish gray dacitic porphyry volcanics appear in about a dozen places in the middle and upper parts of the mudstone member of the Gardner Canyon Formation. The largest body of volcanics lies 1,000 feet northeast of Onyx Cave, and others are exposed in the canyon below Gardner Ranch and on a hill between Cave Creek and Gardner Canyon, about 2,000 feet southwest of the Gardner Ranch. Most of the volcanic bodies are roughly lenticular and lie parallel to at least the underlying bedding, and surrounding mudstone beds apparently lap against the volcanics rather than are truncated by the volcanics. Volcanic breccias near some of the volcanic bodies are noteworthy in that the volcanic fragments are scattered in a red mudstone matrix in such a way that they rarely are in contact with each other. Apparently these breccias are colluvial rather than fluvial deposits. The volcanic breccia in the canyon below Gardner Ranch contains abundant fragments of vesicular rock. Very light gray tuff overlies a relatively dark gray flow on the hill southwest of the ranch, and other small bodies of tuff appear north of Cave Creek.

A typical dacitic rock that is associated with the mudstone member is shown in figure 15. The abundance of small phenocrysts, and especially of bronzy biotite, is a common feature. Likewise, the scarcity or absence of quartz distinguishes this rock from the more rhyolitic tuff of the overlying Canelo Hills(?) Volcanics.

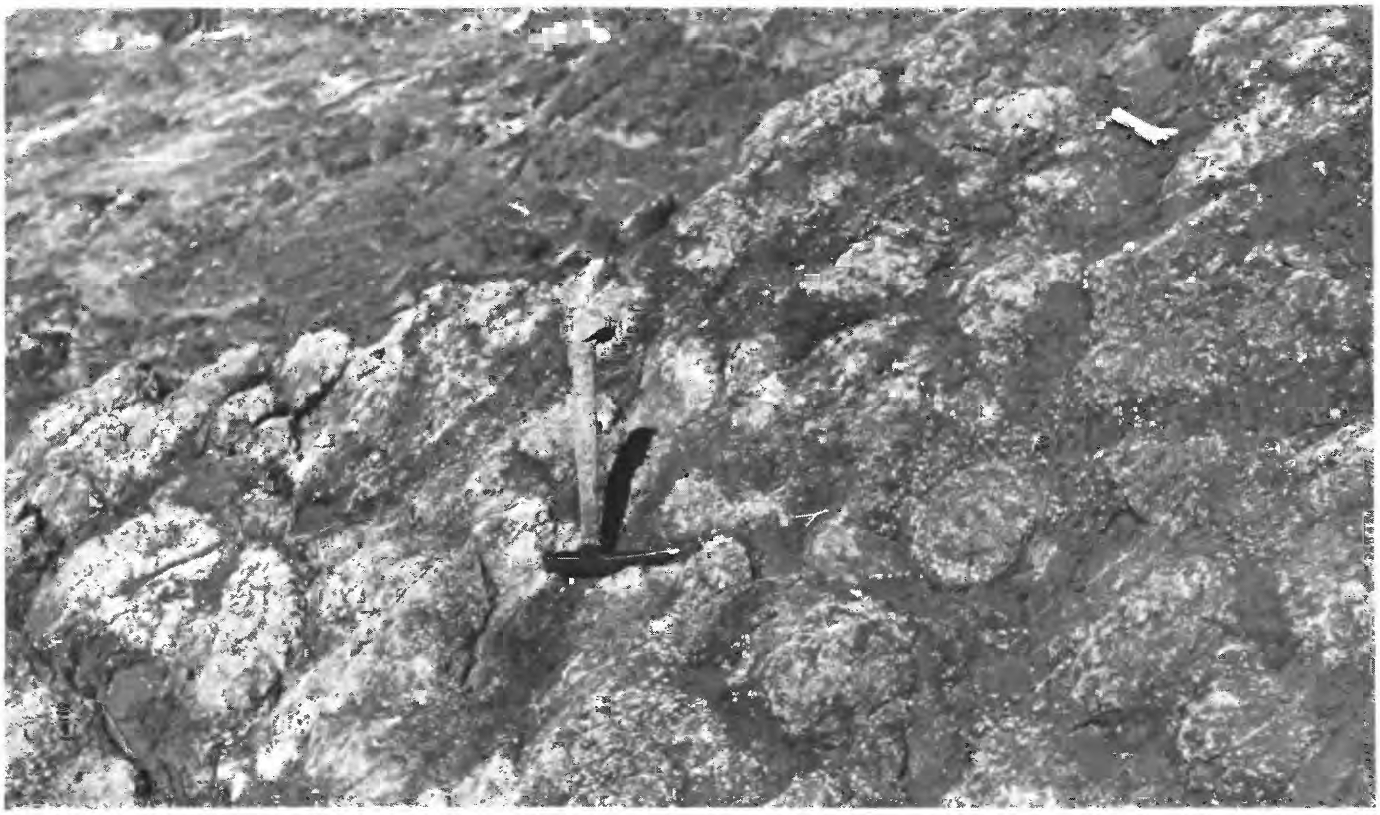


FIGURE 14.—Crudely developed limestone nodules in red mudstone of the mudstone member of the Gardner Canyon Formation, cropping out along Cave Creek near Gardner Ranch.

Thin sections available from six volcanic bodies indicate that tuffaceous rocks are the most abundant, because several specimens of rocks not showing a macroscopic fragmental texture do have a very fine grained fragmental texture and contain relict shards. Most of the tuffs and flows or shallow intrusives are petrographically alike; they are dacitic rocks that contain 5–20 percent phenocrysts which are commonly 2–4 mm long and are set in a cryptocrystalline matrix. The largest crystals always include xenocrystic quartz, phenocrystic albitized plagioclase, and altered biotite, each constituting 2–3 percent of the rocks. In some rocks, the largest crystals also include potassium feldspar and altered amphibole. The relatively dark flow rock from the hill southwest of the Gardner Ranch contains a few percent of relict augite(?) in addition to the other ferromagnesian minerals. Accessory minerals include traces of apatite, magnetite, and zircon, which is relatively abundant in two specimens. Alteration minerals are abundant; ferromagnesian minerals are replaced by sericite and iron oxides, feldspars are changed to clay minerals, and a few rocks also contain a little chlorite. The intensity of alteration has discouraged extensive petrographic and chemical study of these rocks; but as a whole, the rocks resemble other volcanics of the Santa Rita Mountains, many of which are less altered and are classified as rhyodacites, quartz latites, or dacites—a large family of rocks here included in the term "dacitic" volcanics (fig. 16).

The volcanics are believed to be nearly contemporaneous with the red beds; they are largely extrusive rocks but may include some rocks that intruded the once unconsolidated deposits near the surface. This contemporaneity is indicated by the abundance of tuffs and especially by the presence in the conglomerates of dacitic prophyries identical with those in the adjacent volcanics. Although the volcanic breccias also appear to have formed at the surface, some of them alternatively may have been formed by an injection of fluid mud into the edges of flows or sills. The breccia of vesicular dacite near the Gardner Ranch likewise appears to be of sedimentary rather than of intrusive origin.

The slightly metamorphosed plate of rocks southeast of Johnson Ranch that is assigned to the Gardner Canyon Formation consists of a clastic sequence. Its base is faulted, and its top is arbitrarily placed at the top of a thin calc-silicate bed. This upper contact with the Canelo Hills(?) Volcanics is selected because lime-

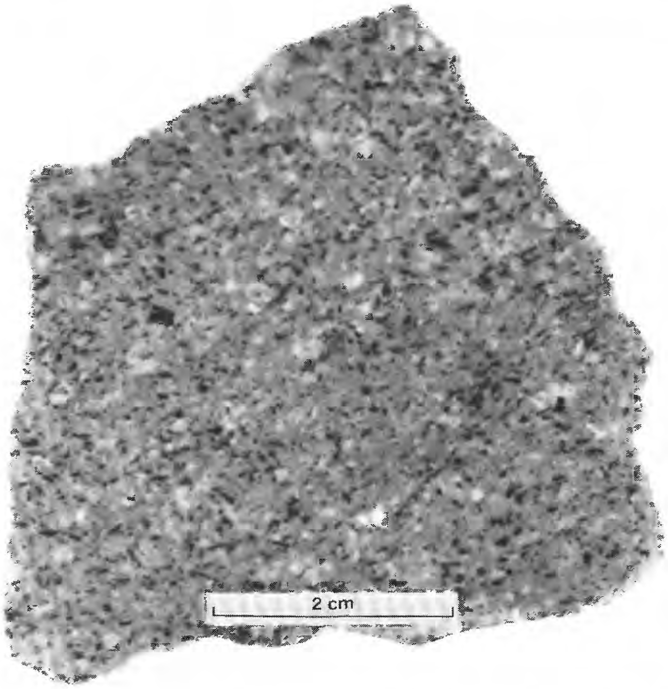


FIGURE 15.—Specimen of a dacitic flow(?) associated with the mudstone member of the Gardner Canyon Formation, obtained from about 1,000 feet northeast of Onyx Cave in the Cave Creek area. A zircon concentrate from this rock gives a calculated age of 192 m.y.

stones are known in the Gardner Canyon but not in Canelo Hills(?) Volcanics and because the tuff of the overlying rocks resembles the rhyolitic tuff in the Canelo Hills(?) more than it does the dacitic tuff in the Gardner Canyon Formation. The stratigraphic sequence on the north limb of the syncline southeast of Johnson Ranch is:

Unit	*Minimum thickness (feet)*
Calc-silicate rock	5
Brown hornfelsed siltstone	60
Blue-gray phyllitic siltstone	40
Brown arkose and conglomerate hornfels	70
Blue-gray phyllitic siltstone	100
Arkosic sandstone	100
Light-gray phyllite	80
Arkosic sandstone	80
Arkosic conglomerate	5
Arkosic sandstone	90
Total	630

Of these units, at least the two phyllitic ones were probably red beds, because, despite their dominant color, some patches retain a reddish cast. The sequence on the south limb is much attenuated, and all but the highest units are sheared out. The sequence northeast of Johnson Ranch, about 500 feet thick, is largely of phyllite, which presumably was also a red-bed unit.

FIGURE 16.—Photomicrograph of a dacitic flow(?) (fig. 15) intercalated in the mudstone member of the Gardner Canyon Formation. White tabular crystals are altered plagioclase; dark-rimmed lozenge-shaped crystal is a pseudomorph of chlorite and iron oxide after amphibole; and dark tabular crystals are similar pseudomorphs after biotite.

AGE AND CORRELATION

The Gardner Canyon Formation is younger than the Mount Wrightson Formation of Triassic age, whose pebbles it contains. The Gardner Canyon is believed to be equivalent either to the rocks at the base of the type Canelo Hills Volcanics of Jurassic and Triassic age or to the rocks immediately beneath it. The available fossils are undiagnostic, but the volcanics interbedded in the mudstone member northeast of Onyx Cave are dated isotopically. A zircon concentrate yielded a lead-alpha age calculated at 192 m.y. and presented as 190±20 m.y. by T. W. Stern (Drewes, 1968, p. C7). Provisionally, then, this formation is assigned to the Triassic.

Rocks of similar lithology have been identified in several adjacent ranges. The red beds and conglomerate low in the Canelo Hills Volcanics (Feth, 1948; Hayes and others, 1965, p. M3), as mapped in the Canelo Hills and Mustang Mountains (Hayes and Raup, 1968), are probably equivalent to the upper part of the Gardner Canyon Formation. The slightly metamorphosed red beds, conglomerate, arkose, and some rhyodacite volcanics that were mapped by Finnell (1970) in the Empire Mountains and similar red beds and volcanics of Rodolfo Wash that were mapped by Cooper (1970) in the Sierrita Mountains are probably also correlative with the Gardner Canyon Formation. The Recreation Redbeds of the Tucson Mountains, described by Brown (1939) and Kinnison (1958), may be correlative with the Gardner Canyon Formation. These relations are discussed in greater detail by Hayes and Drewes (1968, p. 51–54).

ENVIRONMENT OF DEPOSITION

During Gardner Canyon time, perhaps late in the Triassic, the Gardner Canyon area appears to have consisted of at least one basin into which detritus from the adjacent volcanic, granitic, and limestone hills was deposited. The presence of rather fine grained conglomerates and subrounded chert and volcanic pebbles suggests that the local relief was low, and possibly recycling of detritus produced the roundness of hard rock types that apparently are of local origin. These deposits, then, filled their old channels and ultimately buried the Paleozoic terrane. Early during Gardner Canyon time, the basin was closed at least twice; these closures resulted in shallow lakes, whose chief forms of life may have been algal. Reeds flourished at least locally along the shore. Fluvial silt and mud filled the lakes as the center of deposition shifted elsewhere. The streams again carried detritus of older rocks from the surrounding hills as well as volcanic detritus from a new and more local source. At first, the volcanics appear to have been ejected on, and possibly injected into, the sediments along the already established Sawmill Canyon fault zone; but toward the close of this time, the volcanics were spread more widely, and tuffaceous components were reworked and incorporated into rocks of the upper part of Gardner Canyon Formation.

CANELO HILLS(?) VOLCANICS

Arkose, tuffaceous sandstone, tuff, and conglomerate, together more than 600 feet thick, occur in a small area near the north end of the Santa Rita Mountains. These rocks are mildly metamorphosed and poorly exposed. They form the upper part of a thrust plate and lie with apparent conformity upon rocks which are correlated with the Gardner Canyon Formation and which make up the lower part of that thrust plate (Drewes, 1971b). The tuffs associated with this sequence are rhyolitic rather than dacitic, and thus they are tentatively assigned to the Canelo Hills Volcanics, which is the next younger formation, rather than to the Gardner Canyon itself.

The rocks here considered as possible correlatives of the Canelo Hills Volcanics crop out on the low hills along the road about ¾–1½ miles southeast of Johnson Ranch near the mouth of Sycamore Canyon. The low north-trending spur which reaches the jeep road just east of the northernmost group of prospects (Drewes, 1971b) provides the best local section in this formation. These rocks overlie the Gardner Canyon Formation to the north and west and are presumed to overlie them also to the south. Large remnants of terrace gravel cover the central part of the outcrop area. The northwestern part of these rocks clearly forms an asymmetric southeastward-plunging syncline.

The sequence exposed along the north-trending spur, in rising order, is composed of about 180 feet of brown arkosic conglomerate and sandstone, 15 feet of rhyolitic tuff, about 200 feet of volcanic and arkosic conglomerate, 0–15 feet of quartzite, and at least 250 feet of arkosic and tuffaceous sandstone. The tuff is a crystal-lithic tuff that contains fragments of quartz and potassium feldspar and some pseudomorphs after fragments of biotite(?) and plagioclase. Quartzose siltstone and impure sandstone chips are scattered, together with the crystal fragments, in a much-altered cryptocrystalline weakly laminated groundmass. The quartzite forms beds 4–12 inches thick in which there are some finer laminations. The rock is light gray but weathers brownish gray, and it is medium coarse grained.

The age of these rocks is presumed to be Triassic and Jurassic by correlation of these rocks with the Canelo Hills Volcanics. This age range is sufficiently broad to allow for the uncertainties of correlation as well as for the uncertainty of age assignment of the type Canelo Hills Volcanics. A tuff within them has been dated isotopically as 173±7 m.y. old by S. C. Creasey (in Hayes and others, 1965, p. 1965, p. M7), but the age range of the formation is thought to be large. Apparently, the dacitic volcanism that began during Gardner Canyon time continued with greater frequency and had a more rhyolitic composition from about Late Triassic time into the Early Jurassic. This volcanic activity may have been an early near-surface magmatic phenomenon that culminated with the intrusion of a large granite stock during the Jurassic.

SUB-CRETACEOUS UNCONFORMITY

Cretaceous sedimentary and volcanic rocks are separated from Jurassic or older rocks by a major unconformity, along which the relations vary from place to place. In a few places, such as along the lower reaches of Temporal Gulch (bottom of fig. 18), this unconformity is marked by a pronounced angular discordance. Along the middle reaches of Josephine Canyon (Drewes, 1971a) and north of Johnson Spring (fig. 18), Cretaceous strata lie across truncated coarse-grained Jurassic, Triassic, and Precambrian plutonic rocks. Near the mouth of Mansfield Canyon, Cretaceous beds lie with apparent conformity on Triassic beds. Thus, both the age of the underlying rock and the degree of angularity vary along the unconformity.

The age of the rocks directly above the sub-Cretaceous unconformity also varies from place to place in the Santa Rita Mountains. Along the southeast flank of the mountains, the oldest Cretaceous rocks overlie the unconformity. In the Box Canyon area, the upper Lower Cretaceous rocks occupy this position, whereas along the southwestern flank of the mountains the upper Upper Cretaceous rocks are the oldest ones above the unconformity. Indeed, from place to place various members of this upper Upper Cretaceous formation occupy the basal position.

The complex variety of relations along the sub-Cretaceous unconformity suggests that the unconformity is composite, in the sense that it is the result of several episodes of erosion whose effects are separable in some places but are combined in others. The stratigraphic record of the Cretaceous rocks also bears out the idea that this major unconformity was composite. The pertinent features are the intercalated wedges of coarse conglomerate and the minor intraformational unconformities. Because the component parts of the composite unconformity are most intimately associated with the rocks that overlie them, they will be described with the overlying rocks. The combined records of the composite unconformity will demonstrate that the area had a rugged relief at recurrent intervals before and during the Cretaceous Period.

CRETACEOUS STRATIGRAPHY

The Cretaceous formations, in rising order, are the Temporal and Bathtub Formations, the sequence of Glance Conglomerate, Willow Canyon, Apache Canyon, Shellenberger Canyon, and Turney Ranch Formations of the Bisbee Group, and the Fort Crittenden and Salero Formations.

In contrast to the older Mesozoic deposits of the Santa Rita Mountains, these formations, as a whole, are dominantly sedimentary. Volcanic elements are most abundant in the oldest and the youngest formations but are virtually absent, except as clasts, from the thick units of the middle of the Cretaceous sequence. Although the Cretaceous rocks reflect a continental environment, they were largely deposited in broader, shallower basins than were the earlier Mesozoic rocks. This contrast in modes of deposition is most pronounced with the brief incursion of an arm of the continental sea during at least part of Apache Canyon time.

PRE-BISBEE ROCKS

TEMPORAL FORMATION

A formation of mixed rhyolitic to andesitic volcanic rock and sedimentary rock, 1,000–2,000 feet thick, occurs in a long area low on the east flank of the Santa Rita Mountains. These rocks lie with pronounced unconformity upon rock as young as the Squaw Gulch Granite, of Jurassic age, and they are unconformably overlain by another volcano-sedimentary formation, which in turn is overlain by the Bisbee Group, of late Early Cretaceous age. These volcanic and sedimentary rocks were mapped as Tertiary andesite by Schrader (1915, pl. 2) and as Cretaceous andesite by W. R. Jones, C. G. Bowles, and D. C. Hedlund, as reported by Wilson, Moore, and O'Haire (1960). As the result of more recent and more detailed work, their geologic relations indicate that they are Early Cretaceous, and they were named the Temporal Formation (Drewes, 1968, p. C8).

DISTRIBUTION

The Temporal Formation forms an outcrop belt about 10 miles long that extends from 1 mile west of Patagonia northward to Cave Creek. The formation is easily accessible along the Temporal Gulch road, near the head of the road up Gardner Canyon, and near the mouth of Temporal Gulch. It is commonly well exposed because of the sparsity of vegetation on the lower part of the mountain flank and beause of the moderate dips and alternating weak and resistant lithology of the rock. As a result, the stratigraphic relations and facies variations within the formation are clear and are mapped in considerable detail (Drewes, 1971a).

The rocks in this outcrop belt form a homoclinal sequence, which dips 20°–30° eastward. They are usually unfaulted or only very slightly faulted; however, toward both ends of the belt the rocks are more abundantly, but not complexly, faulted.

The Temporal Formation underlies a relatively gentle terrain which contains small ridges, knolls, and gullies. The more resistant rocks, such as lava flows and welded or indurated tuff, form alined ledges and steep slopes, whereas many of the less resistant rocks, such as the tuffs, are stripped bare of their colluvial cover. Figure 17 shows a typical area underlain by the Temporal Formation.

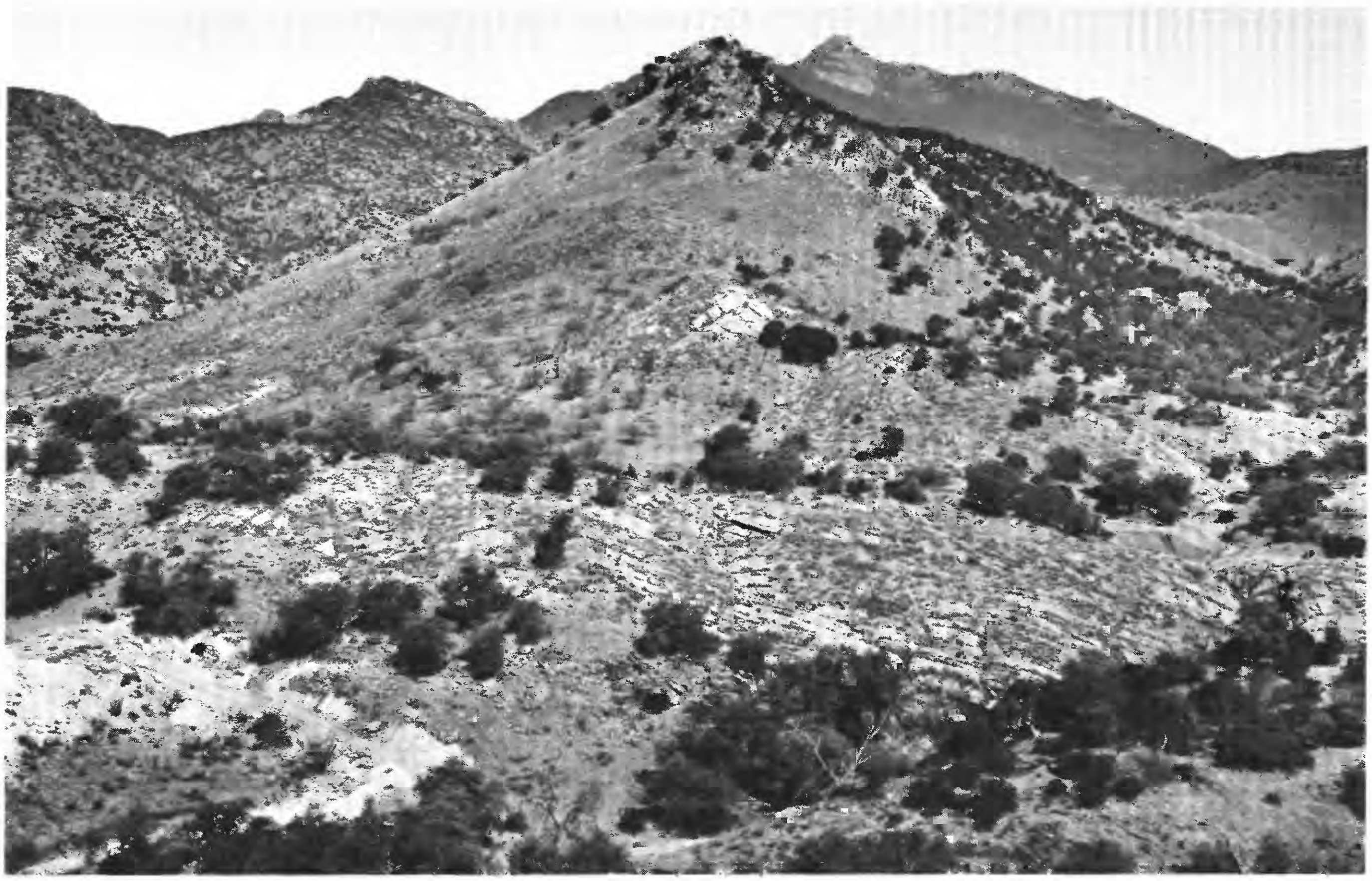


FIGURE 17.—Typical terrain underlain by the Temporal Formation. View north-northwest from about 1,000 feet east of the junction of Mansfield Canyon and Temporal Gulch toward Mount Wrightson, the distant skyline peak. The knoll in the middle distance, center, is capped by rhyolite tuff of the middle member of the Bathtub Formation, dipping east. The west slope of that knoll and the tuffaceous sandstone in the foreground are of the middle member of the Temporal Formation. The two nearly horizontal lines of trees in the foreground lie along normal faults which bound a small horst. Slightly mineralized quartz veins, here marked by prospects, follow the faults.

BASAL UNCONFORMITY

The unconformity at the base of the Temporal Formation is well exposed and shows a highly varied pre-Temporal paleotopography. North of Gardner Canyon, the Temporal Formation cuts gradually across the underlying rocks of the upper member of the Mount Wrightson (Drewes, 1971a), which, together with the slight divergence of attitudes across the contact, indicates that it is an angular unconformity. From Gardner Canyon south to Mansfield Canyon, the two formations appear to be conformable, and the sub-Temporal surface is very regular. For the first few miles south of Mansfield Canyon (upper half of fig. 18), the surface is a disconformity. Several small hills and a small valley were cut on the older rocks and were filled with the deposits of the Temporal Formation. In figure 18, the marker horizon is seen to lap against these hills. The rocks adjacent to the old surface are virtually parallel, although bedding in the nearby part of the Mount Wrightson Formation is obscure. Locally then, the surface is a disconformity. Still farther south, at Johnson Spring (lower half of fig. 18) the trace of the pre-Temporal surface swings widely to the west into a granite terrane and abruptly returns to a position of alinement with the trace to the north. The basal rocks of the Temporal Formation lap against the underlying granite and consist of volcanic rocks and arkosic fanglomerate, which interfinger along the lower marker horizon shown in the figure. Just south of Johnson Spring, there are remnants of upended Mount Wrightson Formation lying alongside the granite, upon both of which the Temporal rocks were deposited with a strong angular unconformity.

The sub-Temporal surface is interpreted to be a highly irregular old land surface. Part of it was a plain and part was hills and valleys. The deepest valley, exposed in oblique section near Johnson Spring as a result of an eastward tilting of about 30° in post-Temporal time,

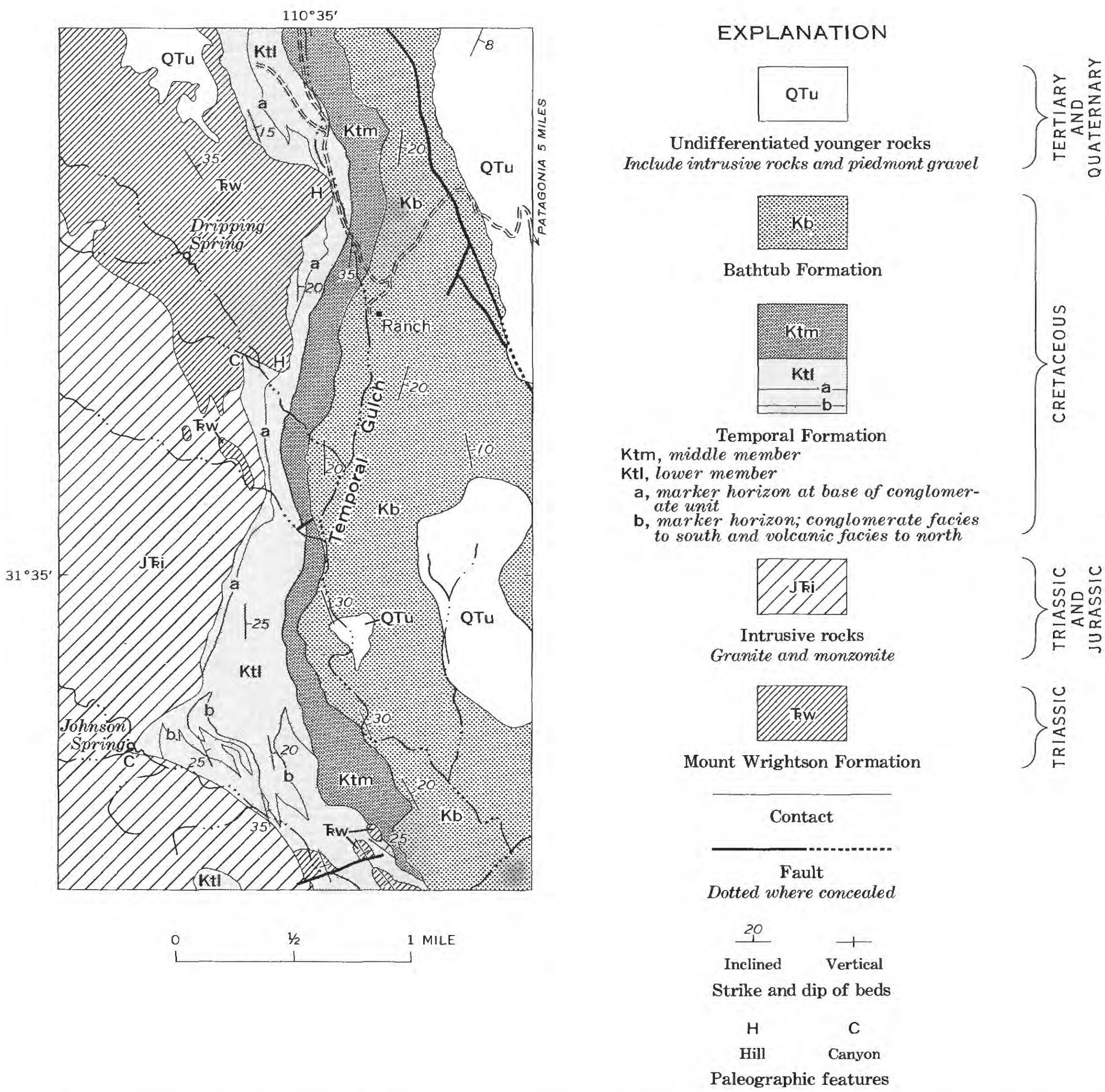


Figure 18.—Temporal Gulch area, showing that part of the sub-Temporal unconformity indicative of a rugged topography.

was about 800 feet deep. The paleotopography in pre-Temporal time appears to have been comparable to the present topography. Mansfield Canyon is a deep V-shaped valley comparable to the deep paleocanyon, and along the flanks of the Santa Rita Mountains there are some little-dissected surfaces like the surface recorded along the unconformity north of Mansfield Canyon. The angular discordance across the unconformity seems restricted to the extreme north and south and thus suggests that structural tilting in pre-Temporal time was localized.

LITHOLOGY AND PETROGRAPHY

Three stratigraphic subdivisions of the Temporal are mapped as upper, middle, and lower members. These members are separated chiefly by conglomerate marker beds. Because of the rapid lateral variation of thickness and facies, no more than two of these members are present in any stratigraphic section across the formation. At any one given place, the formation as a whole typically is 1,000–2,000 feet thick; a composite maximum thickness of the individual members, however, is about 3,800 feet. In general, the middle member is restricted to the southern half of the outcrop belt and the upper member to the northern half. Near the center of the belt, both the middle member and the lower member are lateral equivalents of a pile of volcanics which remains undivided. Thus, in addition to the three members, a unit of lower and middle member undivided is also described.

Lower Member

The lower member of the Temporal Formation is recognized over a distance of about 5½ miles, approximately between the junctions of Mansfield Canyon and Gringo Gulch with Temporal Gulch (Drewes, 1971a). It is 200–1,300 feet thick, a range of thickness reflecting various amounts of fill on the rugged relief of the underlying unconformity. The member has been further subdivided into more than a dozen lithologic units which intercalate or intertongue with each other (fig. 19). In general, the member consists, in ascending order, of volcanics, epiclastic rocks, and more volcanics.

The basal volcanic unit consists of rhyolitic to dacitic pyroclastic rocks. Dacitic volcanic breccia fills the bottom of the paleocanyon near Johnson Spring, rises to about 900 feet on the north side of the paleocanyon and laps over some of the rocks deposited on the north shoulder, and, on the south side of the canyon, beginning 350 feet above the base of unit, intertongues with fanglomerate adjacent to the south wall. The dacitic breccia is a bluish-gray unbedded rock with fragments rarely more than a few inches across that are strongly argillized.

A sheet of rhyolitic tuff breccia lies along the base of the lower member north of the large paleocanyon (fig. 19). Commonly, it is 80–100 feet thick, but locally it fills a shallower paleocanyon to a depth of 200 feet. A little tuffaceous sandstone, which is too thin to be mapped, appears at the base of the formation west of the ranch and is the northernmost remnant of this unit. Likewise, a thin tongue of rhyolitic tuff, which is interbedded in the fanglomerate along the south wall of the large paleocanyon at the stratigraphic level of the rhyolite to the north of that canyon, is the southernmost occurrence of this unit. The rhyolitic tuff breccia is a very pale orange to grayish-orange poorly indurated or "punky" rock in most places, but over a distance of about half a mile on the north side of the paleocanyon it is welded to a light-gray crystal-lithic tuff which contains alined porous inclusions commonly about ½–1 inch long. Comparison with similar features in less altered rocks indicates that the inclusions are flattened pumice chips in a welded tuff.

In thin section, lithic framments are seen to be about as abundant as crystal fragments, which consist of quartz, sericite pseudomorphs after biotite, magnetite, apatite, and zircon in sufficient abundance to be readily concentrated for isotopic dating. An intense clay-min-

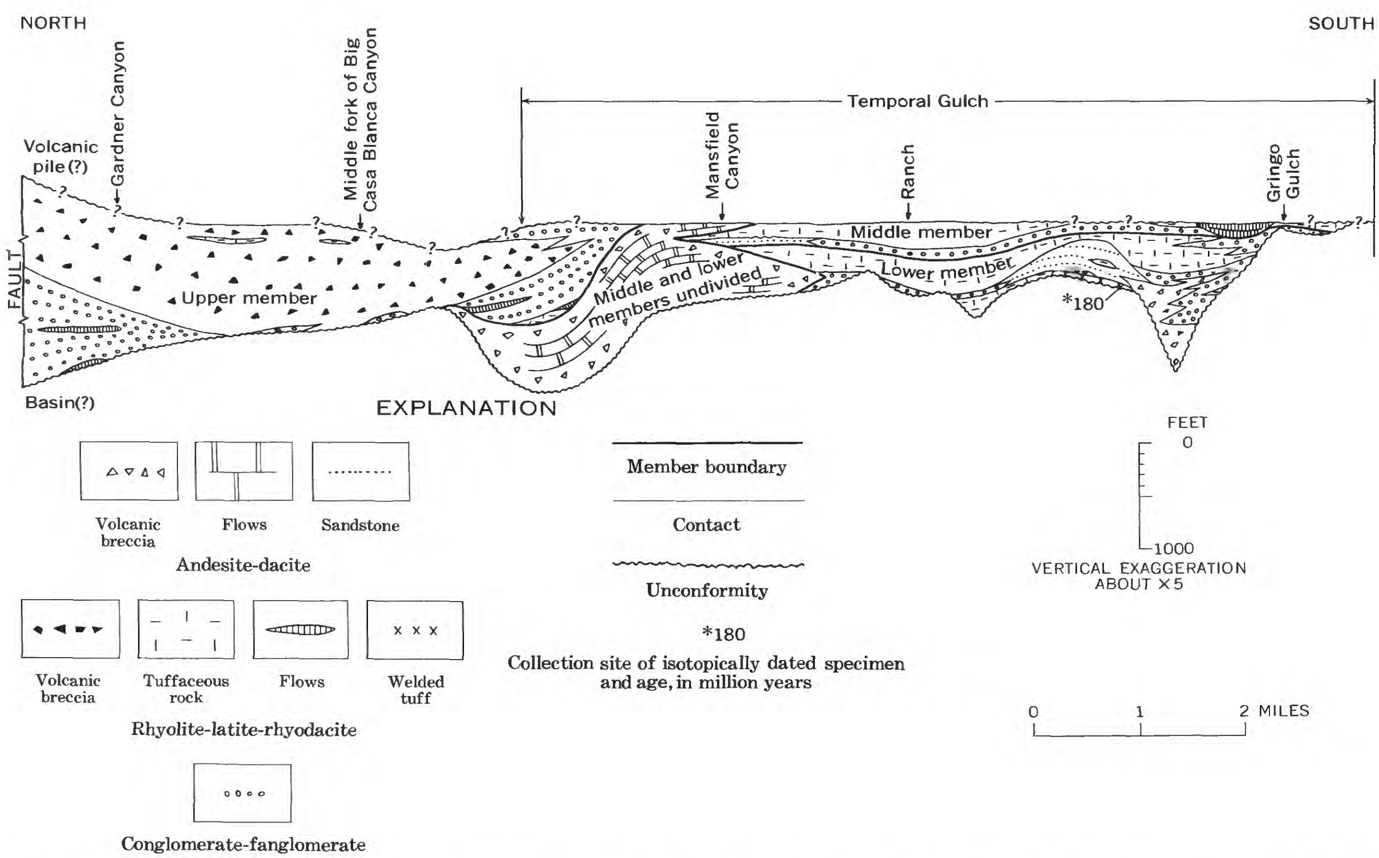


Figure 19.—Stratigraphic and facies diagram of the Temporal Formation. Datum is top of Temporal Formation, modified to show greatest post-Temporal erosion and volcanic pile of possible late Temporal age.

eral alteration has almost obliterated the textural details of a cryptocrystalline groundmass, which seems to consist of plagioclase, a potassium feldspar, and quartz.

The clastic rocks of the middle units of the lower member of the Temporal Formation consist of conglomerate and sandstone, which extend for 4 miles and are interrupted only by two small hills on the sub-Temporal unconformity. To the north where the clastic rock is at the base of the formation, it is a dark-reddish-brown polymictic conglomerate which contains boulders of porphyritic dacite, andesite, and rhyolite, as well as of diorite(?), granite, and aplite; all of these boulders could have been derived from within a distance of a few miles to the west. The source of the diorite(?) is least certain; it may have been derived from the Triassic(?) diorites that appear to the northwest (Drewes, 1971a) or from a dioritic rock included in, or intruded into, the Squaw Gulch Granite near Johnson Spring. The matrix of the conglomerate is sandy to the north but more tuffaceous southward; about 1 mile south of the ranch, the conglomerate grades laterally into a dacitic conglomerate and sandstone facies, which thickens to about 300 feet above the welded tuff. On the north flank of the large paleocanyon, these volcanic sediments grade into the top of the dacite breccia that fills much of the canyon, and they also are correlative with some of the fanglomerate tongues that are interbedded with the dacite volcanic breccia (fig. 19).

Near the junction of Gringo Gulch and Temporal Gulch, fanglomerate is the dominant rock throughout the lower member of the Temporal Formation. It intertongues with each of the three subdivisions of the lower member, and its largest tongues may actually be parts of the conglomerate sheets that are mapped as separate units in the middle of the lower member and at the base of the middle member. Fanglomerate near the granite on the south flank of the large paleocanyon is a sedimentary breccia of very local origin, because most clasts are granite detritus and some are the diorite(?), similar to rock appearing in the adjacent Jurassic granite. Farther from the south wall of the paleocanyon, arkosic sandstone and gritty conglomerate alternate with fanglomerate. Fragments of volcanic rocks are admixed in the arkosic fanglomerate of a few lenses, especially near the volcanic tongues. South of the Gringo Gulch junction, a basal unit of tuffaceous sandstone is probably correlative with the clastic rocks in the paleocanyon, because the southern end of this sandstone lens is conglomeratic.

A rhyolitic tuff 100–600 feet thick forms the upper unit of the lower member of the Temporal Formation. It extends from the mouth of Mansfield Canyon southward almost to the mouth of Gringo Gulch, and in two places near the ranch where the underlying unconformity forms ancient hills, the tuff is the only unit of the lower member. To the north, the rock is typically a poorly indurated, "punky," very pale orange to pinkish-gray or yellowish-gray thickly bedded tuff and fine-grained tuff breccia. A more indurated coarsely blocky tuff breccia or agglomerate sheet, as much as 400 feet thick, overlies the tuff to the southeast and is the only facies present to the southwest. In the absence of petrographic or chemical analyses of these pyroclastic rocks, they are considered to be rhyolitic, in the sense that their actual composition probably falls in the range of rhyolite-latite-rhyodacite.

Middle Member

The middle member of the Temporal Formation is commonly 100–400 feet thick and is almost coextensive with the lower member, reaching from half a mile north of the mouth of Mansfield Canyon to more than half a mile south of the mouth of Gringo Gulch. The member is subdivided on the map (Drewes, 1971a) and in figure 19 into lower clastic units, an upper rhyolitic tuff, and, to the south, porphyritic latite flows which occur as a lens occupying about the same stratigraphic interval as the other units combined.

Most of the conglomerate of the lower clastic units is a reddish-brown polymictic cobble conglomerate, about 100 feet thick, that closely resembles the conglomerate in the lower member. The clasts of this conglomerate are granite, aplite, porphyritic rhyolite, and porphyritic andesite or dacite. However, 1 mile north of the ranch, the conglomerate grades laterally into a gray monomictic conglomerate and sandstone of andesitic detritus that appears to be derived from the

FIGURE 20.—Andesitic sandstone of the middle member of the Temporal Formation, exposed along a tributary east of Temporal Gulch 1 mile north of the ranch house on that gulch.

volcanics of the undivided lower and middle members to the north. Grain size, bedding, and sorting of this sandstone, illustrated in figure 20, indicate deposition by gently flowing streams. In an area 1½–2 miles south of the ranch, andesitic or dacitic clasts become sufficiently abundant so that locally the unit is indistinguishable from the basal unit of the overlying Bathtub Formation.

A second unit of rhyolitic tuff and tuff breccia, as much as 250 feet thick, overlies the conglomerate unit of the middle member. The tuff and tuff breccia is a very pale orange "punky" or poorly indurated, rock which contains lithic fragments usually smaller than half an inch in diameter. The tuff is thickest near the ranch, it thins to about 150 feet toward Mansfield Canyon, where it grades into slightly bluish gray tuffaceous sandstone which contains andesitic debris, and it wedges out between andesite flows and volcanic breccia. Half a mile south of Mansfield Canyon, the rhyolitic tuff fills a channel cut a few tens of feet into the underlying andesitic conglomerate, thus indicating that minor disconformities are probably common within this formation. A mile and a half south of the ranch, the tuff breccia also contains andesitic chips and wedges out, reappearing only in two small lenses near the mouth of Gringo Gulch.

A porphyritic latite lava flow, or flows, make up a unit about 1 mile long and 200 feet thick, just north of the mouth of Gringo Gulch. The porphyritic latite is a medium-dark-gray to brownish-gray blocky-weathering rock that contains small plagioclase phenocrysts. In thin section, it is seen to be holocrystalline, with strongly alined phenocrysts as much as 3 mm long making up about 15 percent of the rock and with groundmass laths 0.05–0.1 mm long. The mode of a typical specimen of porphyritic latite is given in table 4, specimen 1. In this rock, plagioclase phenocrysts are albitized and are strongly altered to sericite, calcite, and clay minerals. Amphibole and possibly biotite appear as anhedral pseudomorphs of chlorite, iron oxides, and calcite. The groundmass contains a little interstitial quartz and abundant feldspar laths, which have a strong kaolinite alteration that suggests the presence of potassium feldspar.

TABLE 4.—*Modes of three volcanic rocks of the Temporal Formation*

Rock	Latite	Andesite		Rhyodacite
Specimen No.	1	2	3	4
Field No.	63D205	63D183	66D993	62D19
Quartz	0	0	0	3.1
Plagioclase	11.8	35.8	14.5	12.4
Potassium feldspar	0	0	0	7.3
Amphibole	2.3	1.7	5.7	1.7
Biotite(?)	.3	1.2	0	.8
Augite(?)	1.2	3.2	2.1	0
Magnetite	.3	2.8	2.0	1.7
Apatite	.1	.3	0	.3
Sphene	0	0	.2	.1
Zircon	0	0	0	Trace
Groundmass	84.0	55.0	75.6	72.6
Total	100.0	100.0	100.1	100.0

SPECIMEN DESCRIPTIONS

1. Altered latite porphyry from lower quarter of flow (or flows?) of the middle member, hyalopilitic groundmass of laths 0.05–0.1 mm long, containing phenocrysts as much as 2 mm long; from half a mile northwest of the mouth of Gringo Gulch (NW¼NW¼ sec. 35, T. 21 S., R. 15 E.).
2. Andesite porphyry from possible feeder dike of the volcanics of the lower and middle members undivided, hyalopilitic to cryptocrystalline groundmass; from lower Mansfield Canyon (SE¼SE¼ sec. 10, T. 21 S., R. 15 E.).
3. Altered andesitic porphyry intrusive into altered latitic(?) tuffs of the middle member, hyalopilitic groundmass; from Smith Gulch (NW¼NW¼ sec. 2, T. 22 S., R. 15 E.).
4. Altered rhyodacite vitrophyre from high in upper member, groundmass an altered devitrified glass, phenocrysts as much as 2 mm long; from half a mile southwest of Tunnel Spring (SW¼NE¼ sec. 15, T. 20 S., R. 15 E., unsurveyed).

LOWER AND MIDDLE MEMBERS UNDIVIDED

Near the mouth of Mansfield Canyon, the lower and middle members of the Temporal Formation abut medium-gray to dark-gray andesite volcanic breccia and flows. The lateral change occurs 1½ miles farther south in the basal unit of the lower member than it does in the tuff unit of the middle member. Because the andesite occupies the same stratigraphic interval as the lower and middle members, it is considered to be the undivided stratigraphic equivalent of those members. Most likely, the contact between the andesite breccia and the rocks of the divided lower and middle members is largely a local unconformity, but the andesitic conglomerate facies of the conglomerate unit of the middle member may actually grade into the andesitic volcanic breccia by way of a zone of tuff breccia that is exposed north of the mouth of Mansfield Canyon.

The andesite unit forms a lens 600–700 feet thick and 3½ miles long in the upper reaches of Temporal Gulch. Its greatest extent appears at a low stratigraphic position, and at Anaconda Spring, three-fourths of a mile north of Mansfield Canyon, it makes up the entire thickness of the formation. Massive andesite and andesite breccias are about equally abundant. Most of the rocks are intensely altered to clay minerals, and as a result the structural features of the original rock are obliterated; thus, it is not possible to be certain that all the massive andesite is lava. Some remnants of less altered rock, however, do show that flows were present, and the widely scattered occurrences of these remnants suggest that flows may have been abundant. Several bodies of relatively unaltered rock cut across other andesite and thus indicate that they may be local intrusive bodies, some of which may have been pipes for the effusive material. I suspect that some of the apparently crosscutting bodies, however, are only steep contacts between more intensely and less intensely altered andesite. Most of the andesite is weakly resistant to erosion and is pale bluish gray due to alteration. In some rocks, an original darker gray color is preserved, along with amygdaloidal zones.

A small irregularly shaped body of augite andesite that intrudes(?) altered tuffaceous sandstone of the lower member along Smith Gulch (Drewes, 1971a), south of Johnson Spring, is probably related to these volcanics. Its mode is listed as specimen 3 in table 4.

Under the microscope, the andesite is seen to be about half altered granular cryptocrystalline groundmass and half blocky phenocrysts, which are commonly less than 2 mm long (fig. 21). The mode of the rock that is shown in figure 21 is given in table 4 (specimen 2); chemical and spectrographic analyses and calculated norms are given in table 5. This rock is nearly unaltered and was collected from a body in the SE. cor. SE¼SE¼ sec. 10, T. 21 S., R. 15 E., that is probably a local intrusive pod associated with the volcanics.

Plagioclase forms blocky euhedral crystals, which are largely altered to sericite and clay minerals but which contain some unaltered calcic andesine to sodic labradorite remnants. Most ferromagnesian minerals are altered to iron oxide, clay minerals, sericite, calcite, and a little quartz, but some augite crystals still contain very pale brown unaltered patches. Amphibole is recognizable by the euhedral outlines of its pseudomorphs, and the combination of chlorite and leucoxene in other pseudomorphs may have been derived from biotite. Quartz veinlets and pods appear with the other alteration minerals.

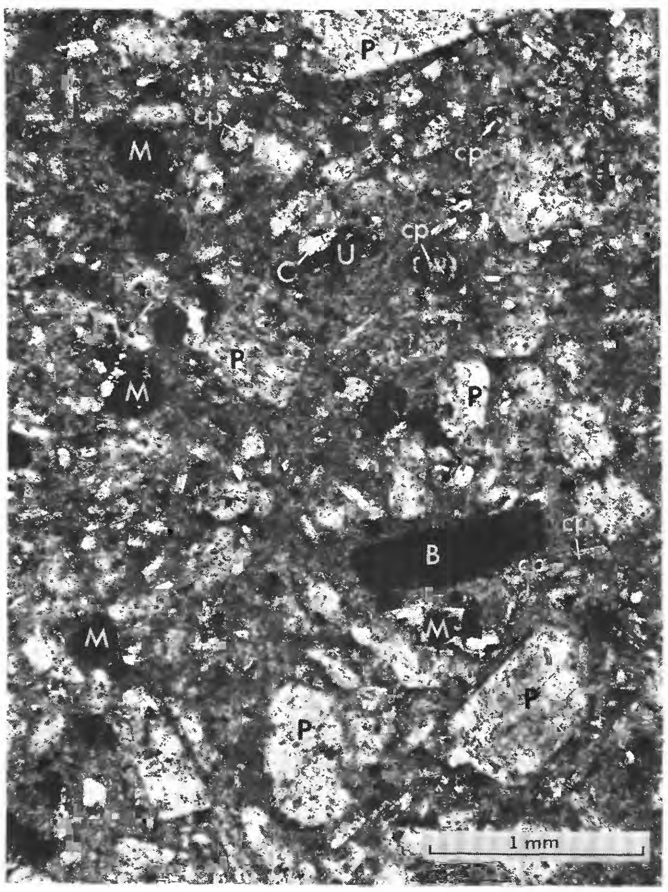


FIGURE 21.—Photomicrograph of augite andesite of the lower and middle members undivided, Temporal Formation. Phenocrysts, roughly in decreasing order of abundance: plagioclase, chiefly labradorite (P); clinopyroxene, probably augite (cp); chlorite (C) and uralite (U) pseudomorphs after amphibole(?); magnetite (M); iron oxide and clay mineral pseudomorph after biotite (B).

TABLE 5.—*Chemical and spectrographic analyses and calculated norms of a specimen, field No. 63D183, of andesite from the Temporal Formation*

[See specimen 2, table 4, for modes]

Chemical analysis (percent) [1]

SiO_2	58.3	H_2O-	.35
Al_2O_3	17.7	H_2O+	1.1
Fe_2O_3	4.0	TiO_2	.80
FeO	1.9	P_2O_5	.35
MgO	2.6	MnO	.12
CaO	5.6	CO_2	.18
Na_2O	4.4		
K_2O	2.5	Total	100.0

Semiquantitative spectrographic analysis [2]

Ba	0.15	Nb	.0015
Be	.0001	Sc	.001
Co	.0015	Sr	.07
Cr	.0007	V	.007
Cu	.0015	Y	.0015
Ga	.0015	Yb	.00015
La	.007	Zr	.015

Norms (percent)

Q	9.443	mt	4.201
or	14.788	hm	1.107
ab	37.269	il	1.521
an	21.183	ap	.830
di en	1.154	cc	.410
di fs	0		
di wo	1.336	Total (rounded)	98.57
hy en	5.327		
hy fs	0		

[1] Rapid rock analysis made by means of methods described by Ward, Lakin, Canney, and others (1963), supplemented by atomic absorption methods. P. L. D. Elmore, Samuel Botts, Lowell Artis, Gillison Chloe, H. Smith, and John Glenn, analysts.

[2] Results are reported in percent to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, and so on, which represent approximate midpoints of interval data on a geometric scale. The assigned interval for semiquantitative results will include the quantitative value about 30 percent of the time. Elements looked for but not found: Ag, As, Au, B, Bi, Cd, Ce, Ge, Hf, In, Li, Mo, Ni, Pb, Pd, Pt, Re, Sb, Sn, Ta, Te, Th, Tl, U, W, and Zn. J. L. Harris and W. B. Crandell, analysts.

UPPER MEMBER

The upper member of the Temporal Formation appears only in, and north of, the upper reaches of Temporal Gulch, where it overlies the andesite of the undivided lower and middle members. The upper member commonly is 600–1,000 feet thick; it wedges out to the south but is almost 2,000 feet thick north of Gardner Canyon near where it is faulted out. It is divided into a lower conglomerate unit, small lenses of rhyolite flows and tuff, and a large overlying tongue of rhyodacite breccia.

The conglomerate unit forms a tongue that is about 1,000 feet thick north of Gardner Canyon but wedges out along the base of the upper member about 1 mile south of that canyon (fig. 19). Small lenses of conglomerate lie at or near the base of the upper member along the middle fork of Big Casa Blanca Canyon, and as much as 400 feet of basal conglomerate reappears in the upper reaches of Temporal Gulch, with more conglomerate lapping over the thin end of the rhyodacite breccia. In general, the conglomerate is not very resistant to weathering and, so, forms gentle slopes, which are locally capped by the more strongly indurated rhyodacite breccia. Boulders as much as 3 feet in diameter are scattered in the conglomerate, but most clasts are cobbles and pebbles; all the detritus is set in a gray gritty to silty matrix. Sand lentils and pebble beds, although few, are generally available for determination of attitudes. The clasts are subrounded and consist of abundant volcanic and plutonic detritus and a little reworked sedimentary rock. Of special interest are fragments of porphyritic quartz monzonite that resembles the Precambrian rock which is exposed a few miles north of the conglomerate, a granite that resembles the Jurassic Squaw Gulch Granite, and a diabasic rock a little like some rocks assigned to the Triassic that are exposed to the northwest within a few hundred feet of the conglomerate. Volcanic clasts consist of porphyritic rhyolitic to dacitic rock, as well as a "turkey track" type of andesitic rock; these clasts are typical of the Mount Wrightson Formation on which the conglomerate is deposited. Other clasts, of reddish-brown quartzitic sandstone, were also derived from the Mount Wrightson Formation. Sparse clasts of very light gray recrystallized limestone, fine-grained gray limestone, and light-brownish-gray to purplish-gray quartzite probably were derived from Paleozoic rocks.

Rhyolite flows form two thin lenses in the conglomerate unit in the Gardner Canyon area and two more in the upper reaches of Temporal Gulch. Each of these lenses is 50–100 feet thick, but none is more than 1 mile long. Rhyolitic tuff is associated with the southernmost lens. The rhyolite is a light-gray to pale-reddish-gray massive to slightly flow laminated and locally flow brecciated rock that contains sparse phenocrysts, chiefly of plagioclase. In some places, it also contains vugs.

A sheet of rhyodacite breccia as much as 1,000 feet thick overlies the conglomerate unit in Gardner Canyon and intertongues with that conglomerate in the upper reaches of Temporal Gulch. The rhyodacite breccia forms low cliffs and high spurs above the conglomerate unit, but its resistance to weathering is variable, depending largely on the proportions of resistant blocky components to less resistant tuffaceous matrix. The included blocks are medium gray, slightly porphyritic, and commonly 1–3 inches across but may be as large as 6 inches. Their matrix is finely comminuted rhyodacite that has been deuterically(?) altered to a "punky" rock rich in clay minerals. Thin beds of volcanic sandstone and volcanic conglomerate are scattered throughout the breccia, and two lenses of tuff breccia occur high in the unit between the middle fork of Big Casa Blanca Canyon and Gardner Canyon. Locally, fragments other than rhyodacite appear in the breccia sheet. For instance, along the abandoned ditch on the north wall of the north fork of Big Casa Blanca Canyon half a mile south of hill 6445 (Drewes, 1971a), abundant rhyolite or latite fragments are mixed with the rhyodacite. Likewise, half a mile southwest of Tunnel Spring in Gardner Canyon, about 10 percent of the fragments are volcanics, other than rhyodacite; and widely scattered fragments of Precambrian porphyritic quartz monzonite, which must have been derived from the northeast or from depth, also occur there.

In thin section, the rhyodacite fragments in the breccia sheet are seen to consist of a strongly altered vitrophyre containing 25 percent phenocrysts as much as 3 mm long (fig. 22). The groundmass is mottled light-brown to darker brown devitrified and kaolinized glass. The matrix in the southern tongue of this sheet contains abundant alined microlites. A mode of rhyodacite vitrophyre is given in table 4, specimen 4.

Quartz forms euhedral to anhedral crystals which typically are embayed or rounded owing to partial resorption. Plagioclase forms subhedral crystals, which in some specimens have the composition of sodic andesine with normally zoned rims of sodic oligoclase but which in other rocks are albitized. Amphibole and biotite(?) are completely altered to chlorite, sericite, iron oxide, and clay minerals and are recognizable only by their distinctive euhedral crystal forms. Magnetite is titaniferous. Zircon is present but is not abundant enough to be concentrated for isotopic dating. The phenocryst assemblage resembles most closely that of the more thoroughly analyzed rhyodacite of the Grosvenor Hills Volcanics of Oligocene age; therefore, despite the relatively dark gray color of the rock, it is here called a rhyodacite rather a dacite or andesite.

AGE AND CORRELATION

The Temporal Formation is dated as Early Cretaceous because of its geologic relations to adjacent rocks. It demonstrably overlies the Jurassic Squaw Gulch

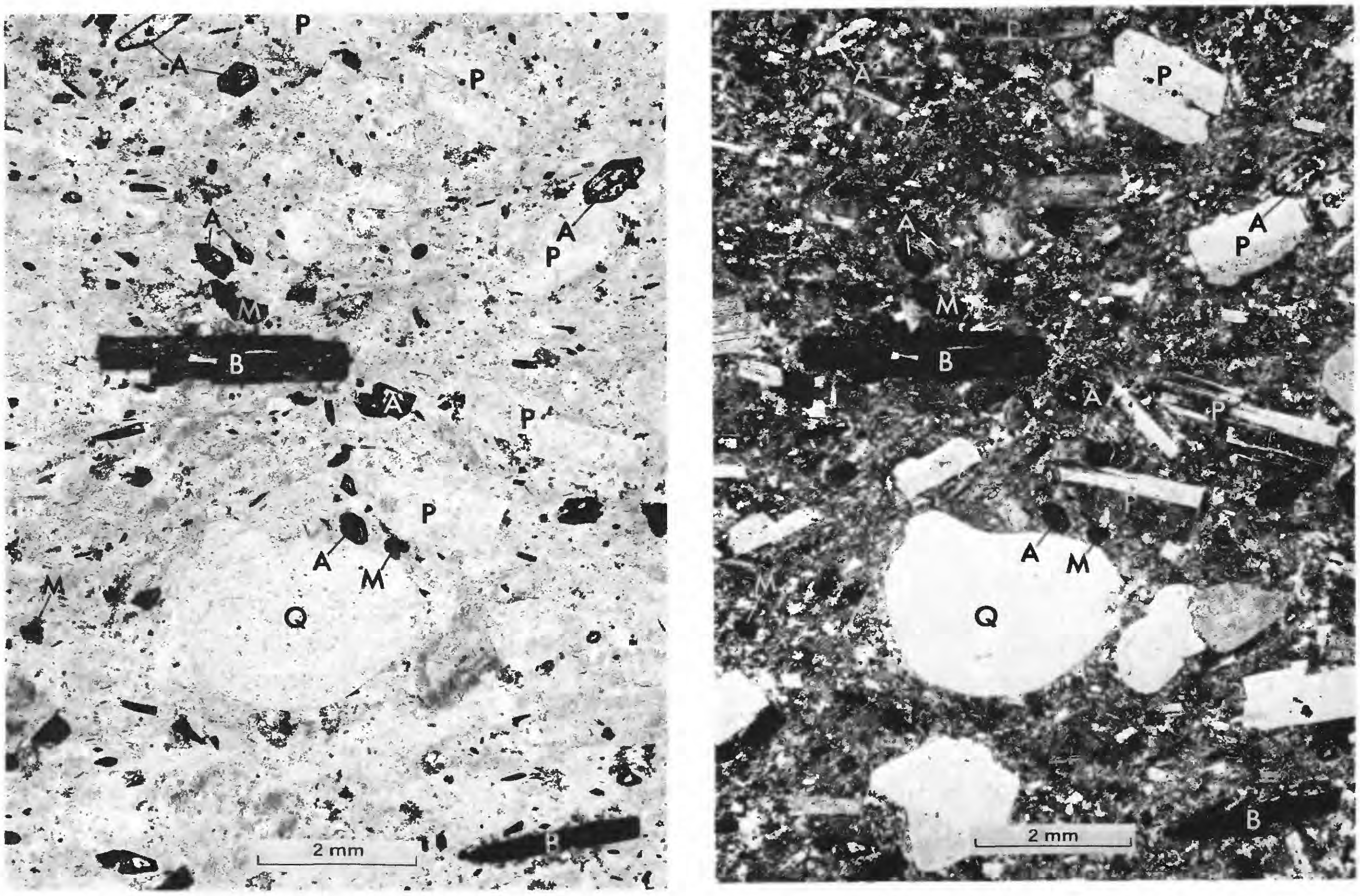


FIGURE 22.—Photomicrographs of rhyodacite of the upper member of the Temporal Formation. Left, plane-polarized light; right, crossed nicols. Phenocrysts: albitized plagioclase (P); quartz (Q); iron oxide and mica pseudomorph after biotite (B); titaniferous magnetite (M); and iron oxide and chlorite(?) pseudomorph after amphibole (A).

Granite and underlies the Bathtub Formation, which in turn underlies the Glance Conglomerate and other formations of the Bisbee Group of known Early Cretaceous age. The Temporal and Bathtub Formations could be assigned an age from Late Jurassic to Early Cretaceous; however, an Early Cretaceous age is preferred because a greater span of time would have been needed to expose and deeply erode the granite before Temporal time than would have been needed for deposition and minor erosion between Temporal and Glance times.

The welded-tuff lens at the base of the lower member of the Temporal Formation has been isotopically dated, but the age is somewhat older than anticipated. A zircon concentrate from the welded tuff was dated by the lead-alpha method as 180±20 m.y. (T. W. Stern, written commun., 1966). This age falls at the older limit of the available time range of the Temporal as determined from geologic evidence and is similar to the age of the Squaw Gulch Granite. Because of the refractory property of zircon and the presence of the welded tuff directly upon the granite, the age obtained may not date the tuff itself; rather, it seems likely that the zircons are xenocrysts picked up by the tuff as it flowed over grus-covered granite terrane and thus were formed independent of the cooling process of the tuff. The sparsity of zircon in all the other volcanic units of the Temporal Formation and the intensity of the alteration of biotite, amphibole, and other minerals may prevent direct dating of the formation.

Rocks of earliest Cretaceous age have not been reported in southeastern Arizona, and rocks having an appropriate geologic age range and an appropriate lithology to be correlated with the Temporal Formation are scarce. In the Huachuca Mountains, Hayes (Hayes and Raup, 1968) mapped a lower part of the Glance Conglomerate as containing many lenses of andesite breccia. This unit also overlies Jurassic granite. Thus, his lower part of the Glance probably is correlative with an unknown part of the combined Temporal and Bathtub Formations. Gilluly (1956, p. 68–70) briefly described pre-Bisbee Cretaceous rocks in the

Dragoon Mountains, still farther east. These, too, are chiefly andesitic to rhyolitic volcanic rocks and are subordinately tuffaceous sandstone and grit. Pyroclastic rocks are more common than flows. These rocks also overlie Jurassic granitic rocks and underlie the Glance Conglomerate and, so, are also probably correlative to some part of the combined Temporal and Bathtub Formations.

ENVIRONMENT OF DEPOSITION

The abundant data available on the facies variations and stratigraphic sequence of the Temporal Formation provide considerable insight into the environment of deposition of the formation. Subaerial conditions are, of course, indicated by the sorting and rounding characteristics of the sedimentary units and by their strong lenticularity. Furthermore, during Temporal time, the area must have had a rugged relief to shed so much more conglomerate and fanglomerate than finer grained sediments. Finally, the association of rugged relief and volcanism suggests a time of tectonic activity.

By establishing the source areas of the various clastic components in the conglomerates, the general location of some high areas may be deduced. For instance, the more unusual clasts (limestone and quartzite) in the conglomerate unit of the upper member could only have been derived from within or beyond the Sawmill Canyon fault zone (Drewes, unpub. data) a few miles to the north or east; likewise, the abundant cobbles of porphyritic quartz monzonite of Precambrian age could only have come from the northeast, just beyond that fault zone, where they are presently exposed and lie unconformably beneath sediments of Early Cretaceous age. The southward wedging-out of the conglomerate unit in the upper member of the Temporal Formation further substantiates the proposed northern source of the cobbles. A southerly direction of flow is similarly deduced for the rhyodacite breccia, because the breccia also wedges out southward and contains scattered fragments of porphyritic quartz monzonite of Precambrian age. Very likely, that flow moved down the slope of a large fan which had been deposited at the foot of an uplifted fault block northeast of the Sawmill Canyon fault zone.

Conglomerate units of the lower and middle members of the Temporal Formation also provide some clues about their source area and direction of transport. However, the inferred source area of these conglomerates cannot be pinpointed too closely because the most common clasts in them are granite and older volcanics. The present distribution of these rocks is widespread, and their past distribution could have been even more widespread. The rugged canyon topography that underlies the conglomerate-bearing rocks and the coarseness of the conglomerate indicate that the source lay nearby; indeed, the arkosic fanglomerate unit rests on its granite source rock. The easterly or westerly trends of the paleocanyons gives us the most likely alternative directions of transport of the cobbles. A western source area is certainly plausible because Jurassic granite is abundantly exposed to the west, and the Triassic volcanic host rocks of the granite almost certainly extended over that area, too. However, an alternate eastern source area, along the present Sonoita Creek valley, cannot be precluded simply because only younger rocks are exposed in the area.

BATHTUB FORMATION

A second sequence of volcanic and sedimentary rocks of early Early Cretaceous age, 1,500–2,300 feet thick, lies along the east flank of the Santa Rita Mountains. This sequence overlies the Temporal Formation with minor local disconformity and is overlain with probable unconformity by rocks correlated with the Glance Conglomerate of late Early Cretaceous age. It is intruded by dikes and by a plug which, as a result of isotopic dating, are assigned to the Paleocene. The rocks of this sequence were previously considered as Tertiary by Schrader (1915, pl. 2) and as Cretaceous by W. R. Jones, C. G. Bowles, and D. C. Hedlund, as mapped by Wilson, Moore, and O'Haire (1960). As a result of recent mapping, the sequence has been assigned to the Early Cretaceous and named the Bathtub Formation (Drewes, 1968, p. C9).

The disconformity at the base of the Bathtub Formation is not everywhere apparent. However, in the Big Casa Blanca Canyon drainage, the lowest unit of the Bathtub Formation thickens several hundred feet precisely where the underlying rocks thin a few hundred feet. These relations suggest that a broad channel that had been cut into the Temporal was filled with the basal unit of the Bathtub. A local unconformity is also inferred to lie beneath the northern part of the Bathtub because the basal beds there are massive conglomerate; their deposition presumably was accompanied by some scouring of underlying rocks. An unconformity may also underlie the southernmost part of the formation, because neither the middle nor the upper members of the Temporal Formation is present there.

The Bathtub Formation is divided into lower, middle, and upper members, each of which is further subdivided into fairly local lenticular units. The lower member consists chiefly of conglomerate and sandstone, the middle member of rhyolite pyroclastics to the north and andesite flows to the south, and the upper member of dacitic volcanic breccia.

404-482 O - 71 - 6

DISTRIBUTION

The Bathtub Formation extends from the low hills about 1 mile west of Patagonia northward about 10 miles to Gardner Canyon. The outcrop belt lies along the foothills of the mountains, where the local relief is ideal to provide abundant outcrops and where vegetation is sparse. The rocks of the belt dip gently to moderately steeply eastward, are only slightly faulted, and are covered on the east by younger volcanics or by gravel. The Bathtub Formation is faulted out at both ends of the belt.

The three members are generally not present together. The lower member extends from about 1 mile north of the southern limit of the formation to near the mouth of Mansfield Canyon (Drewes, 1971a). After being cut out for almost 3 miles, it reappears north of the upper reaches of Adobe Canyon and extends to the northern bounding fault. The middle member is the most extensive one and is absent only at the extreme north. The upper member is the most restricted one, occurring only in the basin of Big Casa Blanca Canyon, and is scarcely 2 miles long.

No single stratigraphic section is both accessible and complete because of the discontinuity of the members and their subdivisions. The most complete section known extends almost 2 miles northwestward from Bath Tub Water in Big Casa Blanca Canyon; however, this section lies far from a road and is largely on a dip slope. Therefore, a section just south of the ranch in Temporal Gulch (fig. 18) that is less complete but more accessible has been selected as the type area. The base of the formation and the lower beds in the type area are exposed along tributaries to Temporal Gulch about 1,000 feet east of the gulch, and the upper units occur on the south walls of Temporal Gulch. In the type area, the lower member is a gray andesitic sandstone and conglomerate, and the middle member consists of a sequence of pyroclastic and epiclastic rocks, whereas elsewhere the lithologies are different and must be individually determined. The conglomerate unit of the lower member is most accessible a quarter of a mile southwest of Tunnel Spring. The andesite flows that form the southern facies of the middle member can best be reached 2 miles northwest of Patagonia along lower Gringo Gulch and west of the end of the jeep trail. (This trail actually extends 1 mile farther westward than is shown on the Mount Wrightson quadrangle topographic map.) The upper member is most accessible along the middle reaches of Big Casa Blanca Canyon, northwest of the ranch house at the end of the road in that canyon.

LITHOLOGY AND PETROGRAPHY

Lower Member

Strongly lenticular conglomerate and sandstone, which together have a maximum thickness of about 700 feet, make up the lower member of the Bathtub Formation (fig. 23). To the north, the rocks of the lower member consist of polymyctic boulder conglomerate, and to the south they form a monomyctic volcanic conglomerate and sandstone facies. Both facies appear about 1 mile north of the ranch house in Temporal Gulch, but the relation between them is obscured by local faulting.

The polymyctic boulder conglomerate is a brownish-gray massive nearly unsorted rock which is as much as 600 feet thick near Gardner Canyon but which wedges out only 2½ miles to the south. Its clasts are typically subrounded boulders and cobbles, the largest of which are as much as 4 feet in diameter; its matrix is sand and grit. Many clasts are of volcanics, which range in composition from rhyolite to andesite and which include flow-layered and porphyritic types typical of the Mount Wrightson Formation. However, granitic clasts that resemble the Squaw Gulch Granite and coarsely porphyritic granodiorite clasts that resemble the Precambrian rocks are also common; clasts of limestone and marble that are derived from either the normal Paleozoic rocks or the recrystallized Paleozoic rocks are also present but sparse. Most of these rock types could have been derived from a source area to the northwest or to the northeast of the conglomerate wedge. However, the Precambrian granodiorite boulders must have been derived from the northeast because this is the only known nearby place where Precambrian granodiorite was exhumed from its cover of pre-Bathtub rocks.

The small lenses of polymictic conglomerate 1 mile north of the ranch house are reddish brown and contain abundant subangular pebbles and some cobbles of latite or dacite and also some of aplite. This conglomerate is associated with thin units of rhyolitic tuff breccia and andesitic breccia too small to be mapped at a scale of 1:48,000.

To the south, roughly between the mouths of Mansfield Canyon and Gringo Gulch, a distance of 3½ miles, volcanic conglomerate and sandstone make up another lens of the lower member of the Bathtub Formation. The central 2 miles of the lens is 500–700 feet thick. Locally, to the south, a thin tongue of the top of this unit interfingers with the basal part of the overlying flows. A small-scale interfingering of rocks of the top of the lower member with rocks at the base of the middle member may also occur north of the ranch,

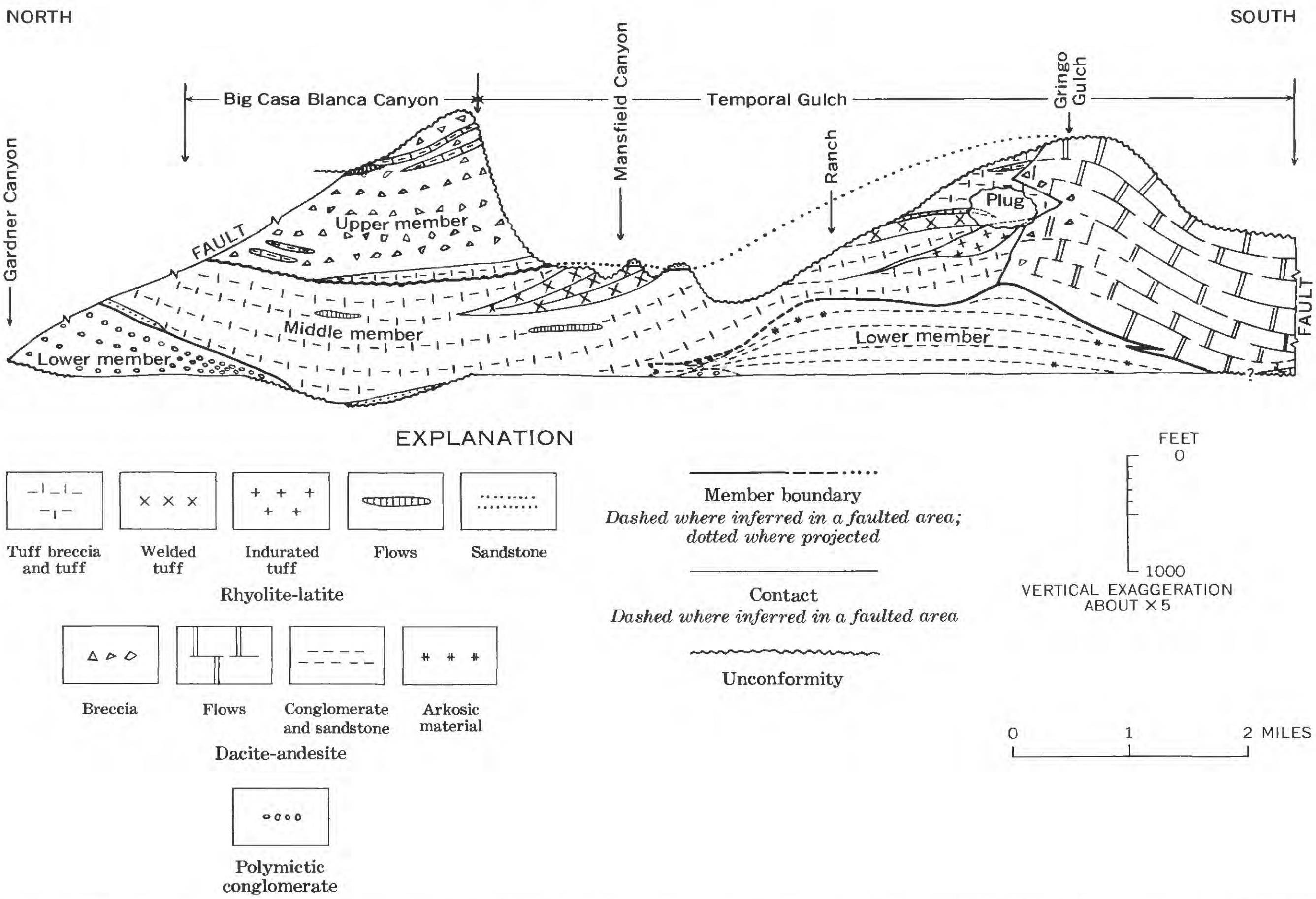


Figure 23.—Stratigraphic and facies diagram of the Bathtub Formation. Datum is base of Bathtub Formation, modified to show pre-Bathtub erosion and pre-Bathtub volcanic pile.

where minor faulting has obscured the stratigraphic sequence.

The conglomerate and sandstone of the lower member consist almost wholly of dacitic or andesitic detritus in beds 1–6 inches thick. A few thin beds, however, contain some clasts of a dioritic rock, and other beds high in the unit contain granitic pebbles. In the type area of the Bathtub, the fragments are 2–4 inches across; but this size diminishes northward, and the proportion of sandy to conglomeratic beds also increases northward. Southward from the type area, increasing amounts of arkosic detritus are admixed with the volcanic detritus, and the rock resembles a gritty to conglomeratic subgraywacke.

Two source areas probably contributed to the southern lens of the lower member. The granitic detritus was derived from the Squaw Gulch Granite to the west, and likewise the dioritic clasts may have come from rocks such as those that are included in the Jurassic Squaw Gulch Granite near Johnson Spring. The volcanic detritus is inferred to have come from other nearby areas, possibly from the Temporal Formation.

Middle Member

Rhyolite tuff breccia and subordinate tuff, together 800–1,000 feet thick, make up most of the middle member of the Bathtub Formation. These rhyolitic pyroclastic rocks contain several lenses of tuffaceous sandstone, two larger lenses of welded tuff, and two small lenticular rhyolitic flows. A lens of indurated tuff forms an additional subdivision south of the ranch, but the origin of the induration could either be a metamorphic effect of the nearby Paleocene plug or a diagenetic effect related to the deposition of the volcanics. Half a mile north of the lower reaches of Gringo Gulch, these rhyolitic pyroclastic rocks abut against, and interfinger slightly with, a unit of dacitic to andesitic flows 1,200–1,500 feet thick, which are the southernmost subdivision of the middle member.

The rhyolitic tuff breccia unit is itself a heterogeneous body in which color, sorting, and size of fragments vary laterally and, to some extent, vertically. Weathered and fresh rock surfaces typically are very pale green to light greenish gray and, less commonly, as north of Temporal Gulch, pinkish gray. East of the upper reaches of Temporal Gulch, the pyroclastics are subtly varicolored; they occur as alternating units of white to light bluish gray and pale yellow to pale brown, and one unit is grayish orange. Near the ranch in Temporal Gulch, pale-bluish-gray tuff overlies a nearly white tuff low in the middle member, and a pale-yellowish-brown tuff overlies the welded tuff high in the member. Bedding consists of thin lentils to massive sheets about 100 feet thick. Typical beds are ½–10 feet thick and consist of alternating layers of coarse and fine fragments. Tuffaceous sandstone lentils are scattered throughout the middle member but usually are too small to be used as marker beds. The more massive beds contain a faint parting that is parallel to the bedding of adjacent less massive units.

The fragments in the tuff breccia are commonly 1–9 inches across, but in some beds they are as much as 12 inches across; a few blocks are even larger. The coarser blocks are most abundant north of Temporal Gulch; they also occur in the units that overlie the welded tuff south of the ranch house in Temporal Gulch. Most fragments in the tuff breccia are volcanic debris of pumiceous rhyolite and light-gray or reddish-gray laminated to unlaminated porphyritic rhyolite or rhyodacite. However, half a mile northwest of Bath Tub Water in Big Casa Blanca Canyon, the tuff breccia high in the middle member is about 10 percent granitic chips and orthoclase grit, presumably derived from a granite grus.

The pale-bluish-gray tuff is typical of the rhyolitic tuff-breccia unit. It contains about 35 percent rhyolitic chips ½–1½ inches across. The matrix is fine-grained volcanic ash that is indurated and altered to a soft punky material. This punky ash weathers readily to release the lithic fragments, which accumulate on the slopes to an extent that is out of proportion to their abundance in the parent rock.

Under the microscope, the tuff is seen to consist of equally abundant crystal and lithic fragments, which together make up half the rock and are scattered in a cryptocrystalline groundmass rich in argillic alteration products. Relict shard textures are only rarely preserved. A mode of tuff breccia specimen 62D28 from near the northern end of the outcrop area, contains:

Mineral	*Percentage*
Quartz	3.5
Plagioclase	6.8
Potassium feldspar	3.6
Biotite	.2
Magnetite	Trace
Apatite	Trace
Zircon	Trace
Groundmass	63.2
Lithic fragments	22.7
Total	100.0

The plagioclase is always albite and probably is albitized. Some of the potassium feldspar crystals are coarse patch perthite, and in one specimen they are microcline, which probably was derived from Precambrian source rock. Most of the visible quartz is fragmental, but a little quartz fills small cavities in the groundmass. Other secondary minerals are sericite (after biotite and feldspars), clay minerals, calcite, iron oxides, and possibly chlorite. Many lithic fragments are probably altered devitrified glass.

The welded tuff forms two lenses intercalated in the rhyolite tuff breccia at about the same stratigraphic position high in the member. The northernmost lens, which extends 1½ miles southward from the upper reaches of Little Casa Blanca Canyon, is 300–400 feet thick. Zones of unwelded tuff alternate with the welded tuff, thus marking several cooling units in this part of the middle member; but most textural details are obliterated by pervasive deuteric(?) alteration. The welded tuff is a pinkish-gray to pale-red flow-laminated rock, along some zones of which lenticules of gray

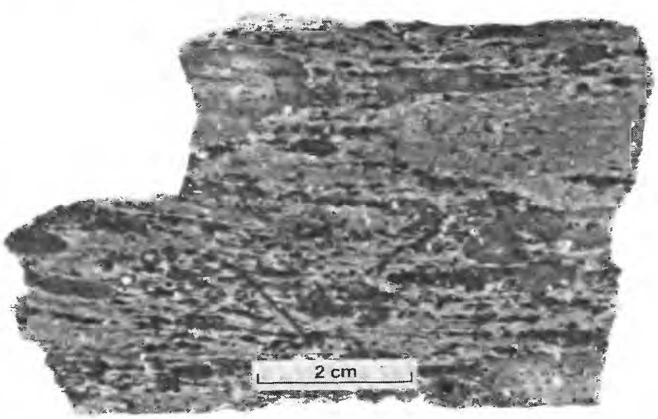


FIGURE 24.—Specimen of strongly flow-laminated intensely indurated welded tuff from the northern unit of the middle member of the Bathtub Formation.

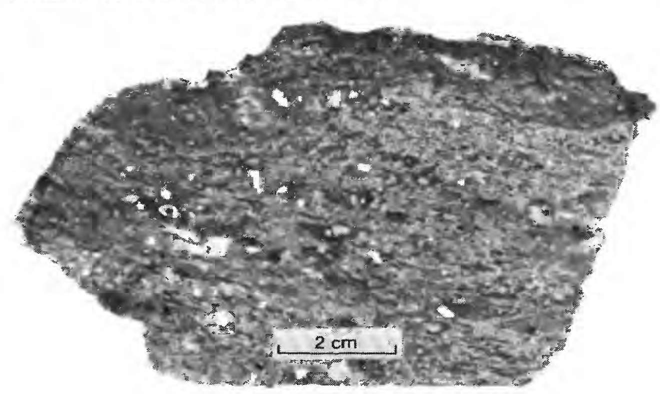


FIGURE 25.—Specimen of less strongly welded tuff from the northern lens of the middle member of the Bathtub Formation.

altered and flattened pumiceous fragments are abundant. These fragments reach a size of about ½ inch by 2 inches by 8 inches and are elongate in various directions in the bedding plane. The southern lens of welded tuff, half a mile southeast of the ranch house in Temporal Gulch, probably represents a single cooling unit only and is less than 200 feet thick; it is less conspicuous than an overlying sandstone unit. The lens grades upward from a gray indurated tuff at the base to a purplish-gray conchoidally fractured welded tuff which contains lenticules that are presumed to be pumiceous chips. The overlying sandstone unit is 5-20 feet thick and forms a row of low brownish-black cliffs with coarse blocky debris at their base. The grains of the sandstone include clastic quartz as well as volcanic detritus.

Under the microscope, the welded tuff is seen to be flow laminated (fig. 24), as emphasized by strongly attenuated lenses of devitrified and oxidized material. These attenuated lenses are much larger and better preserved than any others seen in the Mount Wrightson Formation, but the laminated rock in a few areas does resemble some of the older rock. Figure 25 illustrates a specimen of the welded tuff in which the lenticularity of the deformed pumice fragments is not extreme. The vitric groundmass still shows shard remnants (fig. 26). Lithic fragments or unattenuated pumiceous chips are present in one specimen. Apparently these tuffs were only locally hot enough during deposition to be welded.

Phenocrysts are largely fragmental and form 10–20 percent of the rock. Several specimens have the following modes:

Mineral	Percentage		
	Northern lens		Southern lens
Quartz (phenocrysts)	0.7	2.7	0
Quartz (secondary)	2.1	1.0	.5
Plagioclase	5.3	3.8	18.0
Potassium feldspar	.3	.4	0
Biotite (or oxybiotite)	.4	.8	1.2
Amphibole	Trace	Trace	0
Magnetite	.2	.1	.5
Apatite	0	0	.1
Zircon	Trace	0	0
Lithic fragments	0	0	4.8
Groundmass	91.0	91.2	74.9
Total	100.0	100.0	100.0

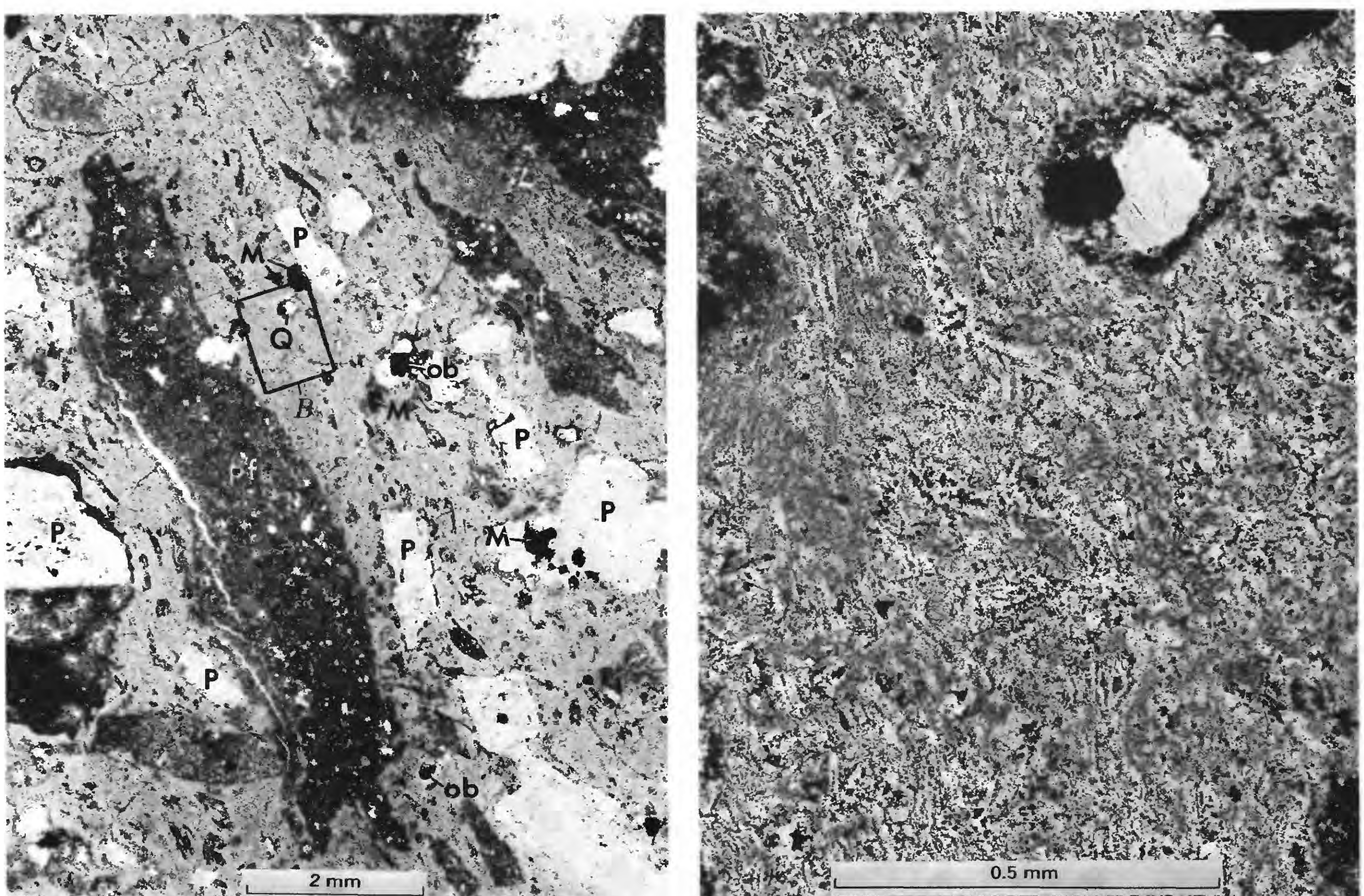


FIGURE 26.—Photomicrograph of same welded tuff shown in figure 25. Left, at × 11.5, showing eutaxitic structure. Phenocrysts: albitized plagioclase (P), oxybiotite (ob), titaniferous magnetite (M), secondary quartz (Q), and pumice fragment (pf); *B*, area of photomicrograph at right outlined. Right, at × 100, showing relict shards in vitreous groundmass.

Most plagioclase is albitized, but one specimen contains a remnant of andesine, which may indicate the initial composition. Potassium feldspar is usually too intensely kaolinized for specific identification, but the feldspar of one specimen may be perthitic orthoclase. Biotite or oxybiotite and amphibole appear as pseudomorphs, now of iron oxide, sericite, clay minerals. Accessory magnetite is fairly free of titanium, and zircon crystals are small and sparse. Alteration minerals comprise iron oxides, sericite, abundant clay minerals, and a little quartz or chalcedony found in small cavities and as veinlets.

Two small lenses of rhyolite lava flows, each about 50–100 feet thick and less than half a mile long, are intercalated near the middle of the middle member of the Bathtub Formation. The lava commonly crops out along low spurs and ledges in the more readily weathered tuff breccia and appears as a reddish-gray to light-medium-gray sparsely flow brecciated rock.

In thin sections of the flows, phenocrysts, less than 3 mm long, are seen to be sparsely scattered in a finely crystalline to devitrified glassy groundmass, which probably consists largely of a mixture of feldspars and quartz. A mode of the northern flow is tabulated as follows:

Mineral	*Percentage*
Quartz phenocrysts	0. 2
Quartz, secondary	2. 4
Plagioclase	4. 2
Sanidine(?)	3. 1
Oxybiotite	. 6
Amphibole(?)	Trace
Magnetite	. 4
Zircon	. 1
Groundmass	89. 0
Total	100. 0

Most of the quartz forms anhedral crystals in small cavities, possibly as amygdules, but some forms veinlets or anhedral phenocrysts. Plagioclase is so severely altered to clay minerals that its composition cannot be determined, but presumably it has been albitized. Some of the potassium feldspar has the small (−)2V of sanidine, but most of it is intensely kaolinized and indeterminable. Biotite and amphibole are intensely oxidized and sericitized.

The southern part of the middle member of the Bathtub Formation consists of andesitic lava flows which crop out in low rolling hills that are cut by small steep-walled gullies. Individual flows commonly weather out to form brownish-gray subdued cliffs and alined rubbly outcrops. The margins of flows or materials deposited between the flows form intervening small benches. South of lower Gringo Gulch, seven individual flows are recognized; these average 175–200 feet in thickness. North of Gringo Gulch, individual flows, especially in the lower part of the member, are difficult to recognize, perhaps because they coalesce. Most tops of the flows are a platy-fractured rock, or they contain zones of flow breccia or vesicular and amygdular rock. Amygdules of chalcedony, quartz, calcite, and epidote(?) are common in the upper few tens of feet of most flows; and the top of the uppermost flow contains especially abundant vesicles and geodes lined with quartz, calcite, opaline material, and hematite. Weathered andesite is brownish gray, but the few relatively unweathered rock surfaces are medium dark gray to greenish gray, and even the abundant feldspar phenocrysts have a greenish tinge and the amphibole the dull luster of altered crystals.

In thin section, the andesitic flows (fig. 27) are seen to have a strongly felty to intergranular texture in which alined phenocrysts 1–4 mm long make up 15–20 percent of the rock. The finely crystalline groundmass is made up of altered equidimensional and lath-shaped grains. Modes of two rocks of these flows, specimens 1 and 3, are given in table 6. Specimen 1 is from one of the lower flows and was collected in a narrow part of an unnamed tributary that lies about half a mile northwest of the junction of Temporal and Gringo Gulches. Specimen 3 is from the upper flow and was collected about half a mile southeast of the junction of Temporal and Gringo Gulches.

The finely granular groundmass of specimen 3 probably contains 1–2 percent clinopyroxene, and some of the pseudomorphic grains of hematite which are reported as magnetite may have been biotite or amphibole. Plagioclase of some specimens is calcic andesine or sodic labradorite (An=47–52), but in others it is albitized. Clinopyroxene is very pale brown and has a $Z \wedge c$ of 42°–45°, suitable for augite. Amphibole and biotite are altered to chlorite, iron oxide, and clay minerals. Other secondary minerals are epidote, calcite, and sericite.

Chemical and spectrographic analyses and calculated norms of specimens 1 and 3 are given in table 6. Specimen 1 is an epidotized andesite porphyry with a nearly obscured felty groundmass, which was collected from the north end of one of the lower flows of the middle member of the Bathtub Formation in the NW¼NE¼ sec. 35, T. 21 S., R. 15 E. Chemically, it most closely resembles the average doreite of Nockolds (1954, p. 1018), having distinct calc-alkali affinities. Specimen 3 is a vesicular andesite porphyry with a felty to granular groundmass. It was collected near the south end of the uppermost flow of the middle member near Gringo Gulch, in the NW. cor. SW¼SE¼ sec. 36, T. 21 S., R. 15 E.

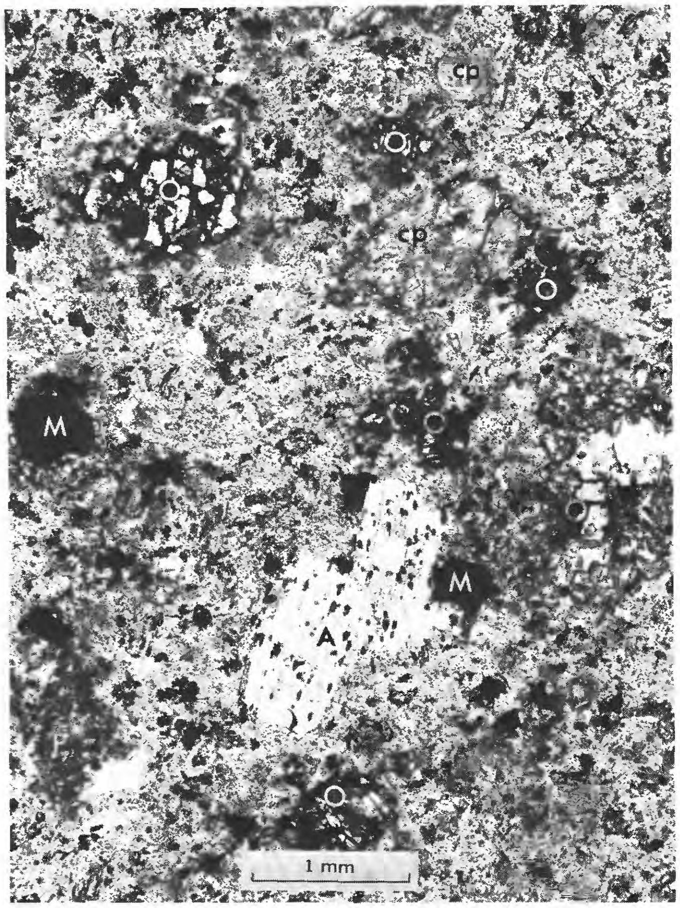


FIGURE 27.—Photomicrograph of porphyritic andesite from the southern part of a flow (specimen 1, table 6) of the middle member of the Bathtub Formation. Phenocrysts: plagioclase (P), also dominant in groundmass; chlorite and iron oxide pseudomorphs after possible olivine (O); clinopyroxene, possibly augite (cp); magnetite (M); and chlorite pseudomorphs after possible amphibole (A).

TABLE 6.—*Modal, chemical, and spectrographic analyses and norms of dacitic to andesitic rocks of the middle and upper members of the Bathtub Formation*

Specimen No.	1	2	3
Field No.	63D217	62D32	63D223
Member	Middle	Upper	Middle
Modal analyses (percent)			
Plagioclase	84. 5	32. 1	82. 9
Clinopyroxene	7. 4	0	[1] 5. 1
Amphibole	3. 3(?)	5. 6	0(?)
Olivine(?)	. 4	0	[1] 1. 7(?)
Biotite	0	4. 3	0
Magnetite	3. 4	2. 5	7. 7
Apatite	. 2	. 7	. 9
Zircon	0	. 1	0
Glass	0	54. 7	0
Chlorite [2]	. 8	0	0
Quartz [3]	0	0	1. 7
Total	100. 0	100. 0	100. 0

See footnotes at end of table.

TABLE 6.—*Modal, chemical, and spectrographic analyses and norms of dacitic to andesitic rocks of the middle and upper members of the Bathtub Formation*—Continued

Specimen No.	1	2	3
Field No.	63D217	62D32	63D223
Member	Middle	Upper	Middle
Chemical analyses (percent) [4]			
SiO_2	54. 2	66. 9	----------
Al_2O_3	15. 3	16. 3	----------
Fe_2O_2	5. 0	3. 9	----------
FeO	2. 4	. 20	----------
MgO	5. 4	. 26	----------
CaO	5. 9	2. 0	----------
Na_2O	4. 2	4. 3	----------
K_2O	2. 6	4. 1	----------
H_2O-	. 48	. 18	----------
H_2O+	2. 3	. 59	----------
TiO_2	1. 2	. 47	----------
P_2O_5	. 27	. 23	----------
MnO	. 14	. 05	----------
CO_2	. 56	<. 05	----------
Total (rounded)	100	99	----------
Semiquantitative spectrographic analyses [5]			
Ba	0. 07	0. 1	----------
Be	0	. 0001	----------
Ce	0	. 01	----------
Co	. 003	. 0005	----------
Cr	. 02	. 0003	----------
Cu	. 005	. 001	----------
Ga	. 003	. 0007	----------
La	. 005	. 005	----------
Nb	. 0015	. 002	----------
Ni	. 01	0	----------
Pb	. 0015	. 0005	----------
Sc	. 0015	. 0003	----------
Sr	. 15	. 07	----------
V	. 02	. 002	----------
Y	. 002	. 0015	----------
Yb	0	. 0001	----------
Zr	. 015	. 007	----------
Norms (percent)			
Q	3. 334	22. 416	----------
C	0	1. 827	----------
or	15. 361	24. 342	----------
ab	35. 520	36. 557	----------
an	15. 224	8. 142	----------
di {en	3. 153	0	----------
di {fs	0	0	----------
di {wo	3. 647	0	----------
hy {en	10. 291	. 651	----------
hy {fs	0	0	----------
mt	4. 714	0	----------
hm	1. 749	3. 918	----------
il	2. 279	. 532	----------
ru	0	. 192	----------
ap	. 639	. 547	----------
cc	1. 274	. 114	----------
Total	97. 186	99. 238	----------

[1] Reported value may be too low; groundmass contains much obscure granular altered material.
[2] Of uncertain origin, in groundmass.
[3] Filling cavities.
[4] Rapid rock analyses determined by methods described by Ward, Lakin, Canney, and others (1963), supplemented by atomic absorption methods. Analysts: P. L. D. Elmore, Samuel Botts, Lowell Artis, Gillison Chloe, H. Smith, John Glenn, and D. Taylor.
[5] Results reported in percent, to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, and so forth, which represent approximate midpoints of group data on a geometric scale. The assigned group for semiquantitative results includes the quantitative value about 30 percent of the time. Elements looked for but not detected: Ag, As, Au, B, Bi, Cd, Ge, Hf, Hg, In, Li, Mo, Pd, Pt, Re, Sb, Sn, Ta, Te, Th, Tl, U, W, and Zn. Analysts: J. C. Hamilton and J. L. Harris.

Upper Member

In the Big Casa Blanca Canyon area, a sequence as much as 1,500 feet thick, chiefly of dacitic volcanics, overlies the rhyolite tuff breccia of the middle member of the Bathtub Formation with minor unconformity. Small lenses of tuffaceous sandstone and of rhyodacitic tuff and a lava flow are intercalated in the dacite (fig. 23). These rocks are provisionally considered to be the upper member of the Bathtub Formation (rather than a younger formation, such as the Gringo Gulch Volcanics of Paleocene(?) age that lie unconformably over the middle member near Patagonia) because to the east they are cut by a fault of Laramide age and because the small rhyodacitic tuff bodies intercalated in the dacitic volcanics resemble the coarser grained yellower tuff breccia of the Bathtub Formation more than they resemble the finer grained white to pale-purplish-gray tuff of the younger volcanics.

The unconformity between the middle and upper members is usually very subtle and is marked only by minor discrepancies in attitudes across the contact. Along the southern part of the contact however, units of the middle member are truncated by the basal unit of the upper member. Elsewhere, such as along the canyon northwest of Bath Tub Water, a well-exposed contact separates apparently disconformable beds of the two members.

Tuffaceous sandstone forms a sheet 200 feet thick and more than 1 mile long at the base of the upper member in the southwest corner of the basin of Big Casa Blanca Canyon, precisely where underlying rhyolitic tuff breccia is gently truncated by the basal unconformity. The tuffaceous sandstone consists largely of fine-grained light-colored rhyolitic detritus but locally includes an admixture of darker dacitic fragments. Toward the north, the tuffaceous sandstone body grades laterally into dacitic breccia with an increase in the darker fragments and a corresponding decrease in the light-gray matrix. The tuffaceous sandstone is poorly sorted and is generally less indurated than the adjacent rocks.

Most volcanics of the upper member are dacitic flow breccias, which crop out in a basin that contains many broad expanses of bare rock. These outcrops form low rounded bosses of medium-dark-gray to slightly brownish gray massive to very thick bedded rock which are strewn with blocks weathered from the flow breccia. The breccia blocks are angular to subangular and are generally about 4 inches across; near the base of the member, however, the blocks are less than 2 inches in diameter, and at several levels in the central and upper parts of the member they are as much as 24 inches across. The blocks are set in a matrix of comminuted and altered dacitic material that weathers readily and possibly is tuffaceous. Bodies of fairly unaltered dacitic rock, low in the member, may be remnants of flows or may mark vents of this volcanic field.

In thin section, blocks from the dacitic breccia are seen to be porphyritic and intensely argillized. Phenocrysts are commonly less than 1 mm long and make up about 30 percent of the rock; the groundmass is finely granular to cryptocrystalline. Plagioclase, which is probably albitized, and iron oxide pseudomorphs, which have the shape of amphibole and contain sparse cores of unaltered green hornblende, each make up about a third of the phenocrysts. Pyroxene and biotite phenocrysts may also be present but cannot be reliably distinguished from other altered ferromagnesian minerals. Accessory magnetite and apatite appear; secondary clay minerals are abundant, and epidote and chlorite are also present.

The less altered intrusive(?) rock that is associated with the dacitic breccia is texturally much like the dacitic breccia blocks; but the plagioclase phenocrysts are stubbier, and their size ranges from 2.5 mm to 0.25 mm, the size of the granular groundmass. A phenocryst mode of a specimen of intrusive rock is tabulated as follows:

Mineral	*Percentage*
Plagioclase	74. 5
Pyroxene	17. 3
Oxybiotite	1. 0
Oxyhornblende	2. 2
Magnetite	4. 6
Apatite	. 1
Zircon	. 1
Quartz(?)	. 2
Total	100. 0

The determination of the abundance of combined oxybiotite and oxyhornblende, 3.2 percent, is more reliable than the separate counts of the minerals because they are so intensely altered to iron oxides as to be nearly indistinguishable. Likewise, the reported abundance of pyroxene is uncertain because the pyroxene appears chiefly as altered granular crystals. Plagioclase forms euhedral to subhedral crystals, whose cores are calcic labradorite (An=57–65) and whose rims are calcic andesine to sodic labradorite (An=35–50). Most pyroxene is anhedral, and all of it is in the groundmass and is intensely altered. Oxyhornblende and oxybiotite relicts appear in euhedral to subhedral pseudomorphs of iron oxide, calcite, and chlorite. Quartz of possible primary origin makes a few small interstitial patches in the groundmass.

A pale-reddish-gray porphyritic rhyolite flow is intercalated in the upper part of the upper member of the Bathtub Formation. This flow is poorly exposed along a row of alined noses and small spurs on the east wall of the north fork of Big Casa Blanca Canyon. Macroscopically, the rhyolite with its small feldspar and quartz phenocrysts resembles the lithic fragments in the few lenses of rhyolite tuff intercalated in the member, one lens of which overlies the flow itself.

Six lenses of rhyodacitic tuff and tuff breccia are also intercalated in the dacitic volcanics of the upper member. Two appear near Bath Tub Water, three lie half a mile west of the ranch in Big Casa Blanca Canyon, and another lies adjacent to the fault that bounds the east edge of the formation. The blocks in the rhyodacitic tuff breccia west of the ranch are as much as 12 inches across and are so thoroughly altered as to be punky—almost like pumice but without the abundant vesicles of pumice. Some blocks, however, consist of slightly less argillized rhyodacitic vitrophyre, which contains small phenocrysts of biotite, hornblende, and plagioclase; and so, except for its lighter color, the rock resembles the dacitic flow breccia. Conceivably, the rhyodacitic tuff lenses are alteration lenses rather than intercalated depositional units.

A vitrophyric fragment from the uppermost of the two intercalated lenses near Bath Tub Water (SW¼-SE¼ sec. 26, T. 20 S., R. 15 E., projected) is moded and chemically and spectrographically analyzed in table 6 (specimen 2). Chemically, this specimen closely resembles Nockolds' (1954) rhyodacite. The modal plagioclase forms albitized and kaolinized euhedral to anhedral grains. Hornblende is pleochroic in bright green to pale olive green; and biotite is almost completely altered to granular iron oxide, leucoxene, and chloritic or sericitic material, but one biotite crystal is still pleochroic in brown. The groundmass glass is very pale brown, contains few percent microlites, and is only slightly devitrified, which is surprising for a rock assigned a Cretaceous age in this region of widespread Laramide alteration.

AGE AND CORRELATION

The Bathtub Formation is unfossiliferous and has not been directly dated by isotopic means, but geologically the available age range is limited. The Bathtub overlies the Temporal Formation, which in turn overlies the isotopically dated Jurassic Squaw Gulch Granite. The formation is also intruded by dikes and small plug which are dated (five determinations on three specimens, zircon, hornblende, and biotite) as Paleocene. The youngest age of the formation is geologically further restricted because a small part of the formation is overlain by conglomerate correlated with the Glance Conglomerate of late Early Cretaceous age. Therefore, the Bathtub Formation is assigned to the early Early Cretaceous.

The Bathtub Formation, either by itself or with the underlying Temporal Formation, is probably correlative with the lower part of the Glance Conglomerate, as mapped by Hayes in the Huachuca Mountains (Hayes and Raup, 1968). This part of the Glance contains large intercalated masses of andesitic volcanics as well as exotic blocks, rock types that are absent from the type Glance near Bisbee. The Bathtub Formation may also be correlative with some or all of the andesite volcanics of the Dragoon Mountains, which Gilluly (1956, p. 68–70) mapped as post-Jurassic granitic rocks and as pre-Bisbee. The widespread occurrence of volcanic clasts in the Glance Conglomerate at the base of the Bisbee Group as compared with the reported occurrence of pre-Glance volcanics, suggests that such volcanics may have occurred in other local deposits that either are covered or have been eroded.

ENVIRONMENT OF DEPOSITION

During Bathtub time, conditions of deposition were virtually like those of the immediately preceding time. The time between the deposition of the Temporal and Bathtub Formations was probably one of renewed uplift on the fault block to the northeast. During early Bathtub time, fanglomerate that was shed from this block was deposited in the northern part of the outcrop area of the formation. Volcanism was renewed during middle Bathtub time, involving an andesitic source near the south end of the area and a rhyolitic source farther north. After a brief period of erosion and local tilting, the northern part of the area was again overwhelmed by a thick cover of dacitic breccia, whose source probably lay nearby and, in part perhaps, within the area.

BISBEE GROUP

The Bisbee Group, a thick sequence of conglomerate, arkose, and red siltstone, crops out in scattered areas along the flanks of the central and northern parts of the Santa Rita Mountains. Although most commonly faulted or intruded, the sequence lies unconformably on rocks as young as the Bathtub Formation. The sequence is unconformably overlain by rocks as old as the Fort Crittenden Formation of Late Cretaceous age. In a few places, the sequence contains thin limestone beds that have a sparse marine molluscan fauna; thus, in many respects the sequence resembles the Bisbee Group of the Mule Mountains. The Bisbee Group, with which the sequence is correlated, was first described by Dumble (1902) and later described in more detail by Ransome (1904, p. 56).

The Bisbee Group of the Santa Rita Mountains, however, shows some differences in lithology with respect to the type Bisbee, so that most of its subdivisions are not recognized with confidence. Only the basal

Glance Conglomerate persists this far northwest of its type area, and it, too, is changed in that it is highly lenticular and occupies various stratigraphic horizons, but always as a basal sheet or lens. Recent work in the Empire Mountains by Tyrrell, (1957) and by Schafroth (1965) and current work there by T. L. Finnell (oral commun., 1968) have led to establishment of other subdivisions of the Bisbee Group which are more practical to use in the Santa Rita Mountains. In rising succession, the Bisbee Group described here consists of the Glance Conglomerate and the Willow Canyon, Apache Canyon, Shellenberger Canyon, and Turney Ranch Formations. The chief distinction between the type Bisbee Group and the Bisbee of the Empire, Santa Rita, and surrounding mountains is the absence of the Mural Limestone from the northwestern part of the area; to the southeast, this limestone forms a conspicuous unit in the middle of a thick and uniform arkose and siltstone sequence. Because of the absence of the Mural from what will here be referred to as the northwestern facies of the Bisbee Group, more subtle changes in lithology involving the kind and abundance of clastic components are the bases of the subdivisions used by Tyrrell, Schafroth, and Finnell.

The local thickness of the Bisbee Group is about 7,500 feet, but this amount is a total of the common thicknesses of its component formations rather than a measure across a single stratigraphic section. In the Santa Rita Mountains, few of the areas that are underlain by the Bisbee contain more than parts of two formations; thus, the values for the estimated composite thickness are obtained over a distance of more than 10 miles, with no assurance that the individual formations are less lenticular than the units within the Bathtub and Temporal Formations. Contact metamorphism has also changed the lithology and thickness of parts of the Bisbee in several areas and adds to the difficulties in estimating a representative composite thickness and in establishing a useful local section.

GLANCE CONGLOMERATE

The basal formation of the Bisbee Group is a lenticular conglomerate that was named the Glance Conglomerate by Ransome (1904, p. 56, 57). In the Santa Rita Mountains the conglomerate is more lenticular than it is in its type area, and it is as much as 1,500 feet thick, although in most areas it is only a few tens to a few hundred feet thick. Where not faulted or intruded, the Glance rests unconformably upon either the Bathtub Formation or the Precambrian Continental Granodiorite. Because of its intertonguing relations with the overlying rock, some small wedges of Glance may locally overlie rocks with Willow Canyon lithology.

The conglomerate of the Glance is typically a reddish-brown cobble conglomerate whose clasts are detritus of Paleozoic rocks or of Precambrian rocks but in places also include detritus of Mesozoic volcanic and granitic rocks. The composition of these fragments may vary rapidly along strike, so that from one outcrop area to the next the lithologies appear unlike. Nevertheless, these changes are believed to reflect lateral facies variations rather than vertical stratigraphic changes.

DISTRIBUTION

The Glance Conglomerate has been recognized in a few widely separated areas in the Santa Rita Mountains, as shown in figure 28. The southernmost of these outcrop areas, *A* in figure 28, lies near Bathtub along the north fork of Big Casa Blanca Canyon (Drewes, 1971a). There a homoclinally eastward dipping body of conglomerate overlies the Bathtub Formation on the west and is faulted out against the Fort Crittenden Formation on the east. A few miles farther north, two small slices of nearly upended Glance are faulted into the Sawmill Canyon zone between fault slices of the Gardner Canyon and Mount Wrightson Formations on the west and a fault slice of Precambrian rock on the east. Another small wedge of Glance lies just north of the 31° 45′ parallel. Its western contact is locally unfaulted, but a large unexposed fault lies virtually parallel to, and closely adjacent to, the contact; its eastern contact with Willow Canyon is normal.

In the Box Canyon area (loc. *B*, fig. 28; see also Drewes and Finnell, 1968), several bodies of Glance have different clast types and different basal contacts. The three westernmost bodies of Glance lie unconformably upon Continental Granodiorite, Bolsa Quartzite, and Abrigo Limestone. These bodies of conglomerate dip moderately steeply southward or southeastward, although the underlying rocks, where bedded, are upended. Glance also underlies a larger area, extending from just south of Box Canyon to about 1 mile north of the canyon, where it dips southeastward to eastward and rests unconformably upon the granodiorite on the north but is faulted on the south. This mass of Glance is overlain by the Willow Canyon Formation in a normal sequence. Just northeast of locality *B*, the Glance overlies a thrust fault and dips moderately steeply to the west. Six small much-faulted bodies of Glance, generalized as two patches in figure 28, occur in the Rosemont district, locality *E*.

In the Sycamore Canyon area, locality *C*, there are also two small bodies of Glance. The southern body underlies the Willow Canyon Formation, and both dip

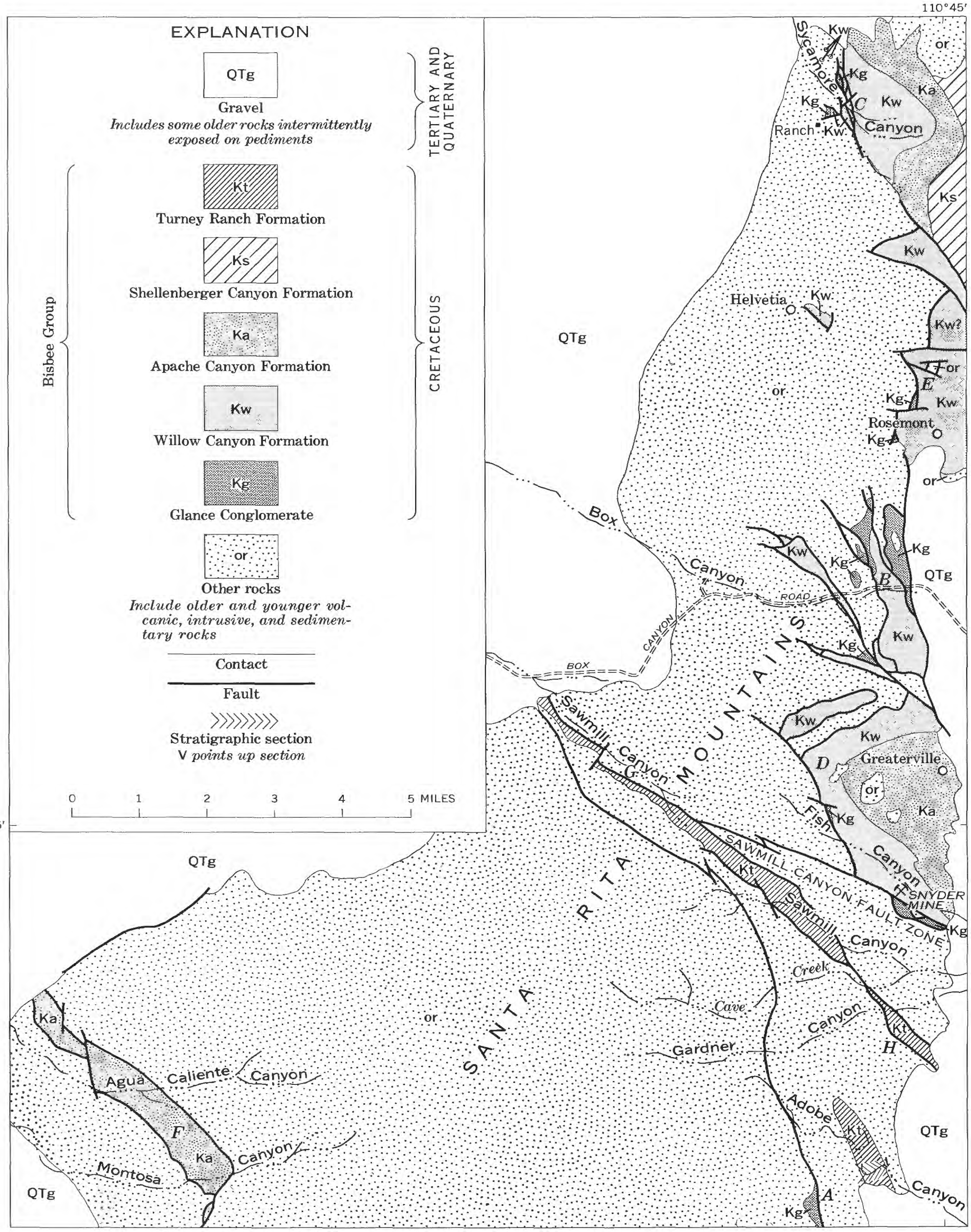


Figure 28.—Distribution of rocks of the Bisbee Group in the Santa Rita Mountains. Localities *A–H* are referred to in the text.

steeply eastward. The Glance there is thrust upon the Pennsylvanian Horquilla Limestone and is intruded by a lower Tertiary quartz monzonite. The northern body of Glance forms a gently eastward dipping sheet between an underlying thrust plate of nearly upended Gardner Canyon Formation and an overlying plate of westward-dipping Willow Canyon Formation.

LITHOLOGY

The conglomerate near Bathtub, locality *A* in figure 28, is a poorly exposed brownish-gray to greenish-gray cobble-and-boulder conglomerate that is poorly bedded and poorly indurated. Most of the clasts are subrounded to subangular and are 4–6 inches across, but some are angular and some are as much as 2 feet across. The clasts consist of a heterogeneous assortment of granite, limestone, cherty and fossiliferous limestone, flow-laminated volcanics, porphyritic granodiorite, and dioritic rocks, but in one zone they consist of angular detritus almost wholly made up of laminated volcanics. The fossiliferous limestone clasts contain fragments of a large gastropod that resembles *Omphalotrochus* sp.

The source rocks of the clasts are generally identifiable. The granite closely resembles the Jurassic Squaw Gulch Granite, and the granodiorite porphyry is typical of the Precambrian Continental Granodiorite. The laminated volcanics were derived from the Mount Wrightson Formation. The fossiliferous limestone probably is from the Permian Colina Limestone, but the other limestones could have come from any of the several Permian formations. The dioritic rock was eroded either from the Triassic intrusives related to the Piper Gulch Monzonite or from the lamprophyres in the Precambrian or Jurassic granitic rocks.

The matrix of the conglomerate is a friable tuffaceous sandstone. Some of the friability may, however, be a secondary feature, imparted to the rock through deformation during the Laramide orogeny.

The Glance Conglomerate in the Sawmill Canyon fault zone consists of a brown pebble-and-cobble conglomerate which is well indurated. It is exposed along the jeep track south of the Snyder mine (Drewes, 1971a) but is poorly exposed southeast of the track. Most of the subrounded pebbles and cobbles are Paleozoic limestone, dolomite, and quartzite, and some are moderate-orange-pink to pale-red siltstone that was derived either from the siltstone member of the Triassic Gardner Canyon Formation or from the Pennsylvanian and Permain Earp Formation. The matrix of the conglomerate in this area is also sandy, and locally the rock is strongly sheared.

The small wedge of conglomerate south of locality *D* (fig. 28) is a unit of pebble conglomerate and sedimentary breccia set in a red mudstone matrix. The clasts are granite gneiss that resembles the Precambrian granite gneiss that lies immediately west of the conglomerate; the clasts differ from those in the several thin conglomerate beds a few hundred feet stratigraphically above, which contain pebbles and cobbles of quartzose sandstone. Barring the added complication of undiscovered additional local faults, this wedge of gneiss conglomerate may lie some distance above the bottom of the Bisbee of this area as a tongue intercalated into the Willow Canyon, which is believed to form a thrust plate upon the Precambrian rocks (Drewes, 1970, 1971b).

In the Box Canyon area (loc. *B*, fig. 28), two types of Glance occur in separate thrust plates. The rocks of the two plates may have been telescoped for an unknown distance, and the Glance of the upper, or eastern, plate may actually have overridden that of the western plate, inasmuch as regional evidence suggests that the relative movement of the upper plate during the Piman phase of the Laramide orogeny (Drewes, 1969; unpub. data) was northeastward. The Glance of the lower plate of the three western outcrop areas at locality *B* is a sedimentary breccia and arkosic conglomerate almost wholly made up of detritus derived from the underlying Continental Granodorite. Bedding is virtually absent from the lower half of the formation where it is exposed along the Box Canyon road (Drewes and Finnell, 1968, p. 319, 321); bedding is faintly developed, as intercalated sandy lentils and red mudstone stringers, in the upper half. Where the Glance laps across the upended Bolsa Quartzite and Abrigo Limestone, the dominantly arkosic detritus also includes some angular clasts of quartzite. This part of the Glance seems to be a fanglomerate that was deposited in the immediate vicinity of its source rocks.

The Glance of the upper plate in the Box Canyon area is typically a red limestone cobble-and-pebble conglomerate, moderately strongly foliated parallel to the bedding. This facies of Glance contains abundant limestone clasts, about 2–12 inches across, set in a matrix of well-indurated red limy sandstone that makes the rock strongly resistant to weathering. The conglomerate of the southern third of this sheet also contains a subordinate number of clasts of dolomite, quartzite, and granodiorite. The abundance of quartzite and granodiorite clasts increases upsection, apparently reflecting the progressive stripping of the younger carbonate source rocks. A slightly different interpretation of the significance of the upward change in clast types was suggested by Heatwole (1966), who recognized the essentials of this lithologic change but emphasized the possibility of a significantly different age for the limestone-clast lower beds and the polymictic upper beds.

The Glance in the Syramore Canyon area, (loc. *C*, fig. 28) is also a limestone pebble conglomerate, unlike the scattered conglomerate beds in the overlying formations of the Bisbee. The rocks in the Bisbee are mildly metamorphosed. They form fairly resistant outcrops that extend from the canyon bottom just above the ranch to a spur on the north wall of the canyon, and they also form a low discontinuous ledge farther northeast of the ranch.

ENVIRONMENT OF DEPOSITION

The Glance by definition is a coarse clastic rock and thus must have been derived from a source area of considerable relief. The variation in clast type from one lens to another of the conglomerate, and locally even within a single conglomerate body, shows that the source terranes were eroded to different stratigraphic levels over short distances. Although this condition could be provided solely by a rugged relief in the source area, it would be facilitated by differential vertical movement, perhaps even by faulting, of structural blocks to juxtapose some Triassic volcanic, Paleozoic limestone, and Precambrian granodiorite terranes.

The size of the detritus deposited at the foot of a mountainous area does not only depend on the relief of the mountains or on the distance between the site of deposition and the mountains, but it also depends on the lithology of the rock in the mountains, as is illustrated by the recent deposits along the western flank of the northern Santa Rita Mountains. Little coarse detritus is being shed from the hills that are underlain by the Continental Granodiorite, a rock which disaggregates readily upon weathering; however, coarse gravels are being deposited at the foot of volcanic and limestone hills north and south of the granodiorite hills. Thus, after lithification, these gravels will have a basal conglomerate facies developed to the south and north of the granodiorite hills that will be separated by an arkose facies adjacent to the granodiorite hills. This arkose facies will be indistinguishable from the arkoses that will be deposited upon the basal conglomerate as the present cycle of erosion and deposition progresses and the volcanics and limestone are stripped off the underlying granodiorite. With this situation in mind, it seems plausible that some of the arkose identified as Willow Canyon is a lateral, or facies, equivalent of the typical Glance. Thus, the lenticularity of the Glance could be the result of provenance variations, as well as of topographic conditions.

WILLOW CANYON FORMATION

The Glance Conglomerate of the Box Canyon area (loc. *B*, fig. 28) grades upward over an interval of a few hundred feet into finer grained and progressively better bedded and sorted rocks. Above the horizon at which thick conglomerate beds cease, the rock is assigned to the Willow Canyon Formation. Along most of this contact, however, the position of the Willow Canyon cannot be located with precision because outcrops are sparse. The Willow Canyon Formation consists dominantly of arkose about 2,200 feet thick; it contains a considerable number of thin conglomerate beds and toward its top some siltstone beds and a few limestone lentils. Locally, the formation shows rapid lateral changes in facies; it may even grade laterally into the Glance lithology.

DISTRIBUTION

Willow Canyon rocks have been identified only north of the Sawmill Canyon fault zone. The largest belt that is underlain by the formation abuts the fault zone (loc. *D*, fig. 28). The rocks of this outcrop belt, which are considerably altered, are faulted along most of three sides and are overlain to the east by the Apache Canyon Formation; locally they appear to lie conformably on a small wedge of Glance. The Willow Canyon crops out in a klippe north of locality *D* and also is present in grabens between localities *D* and *B*. Willow Canyon rocks reappear in a belt that extends from about 2 miles south of Box Canyon, locality *B*, to 1 mile north of the canyon. This belt of rocks is also typically bounded by faults; but at and north of Box Canyon, it rests conformably upon the Glance. Both mildly metamorphosed and severely altered rocks of the Willow Canyon are exposed in six large structural blocks, largely along the east flank of the range, in and north of the Rosemont district. The identification of the rocks in one of the northern blocks is in doubt, and to a lesser degree this uncertainty extends to rocks of the adjacent blocks. Along the western margin of these blocks, the Willow Canyon and Willow Canyon(?) of this area are faulted against Paleozoic rocks or locally against the Glance; to the east, beyond the edge of the area shown in figure 28, they are unconformably overlain by younger Cretaceous or Tertiary rocks. In the Helvetia district, on the west flank of the range, a small area within the Helvetia klippe is also underlain by altered rocks assigned to the Willow Canyon.

Willow Canyon rocks are extensively exposed in the basin of Sycamore Canyon (loc. *C*, fig. 28), where they are locally conformable above Glance and extensively conformable beneath the Apache Canyon Formation. The rocks of the main mass of the Willow Canyon are folded into a syncline and a slightly overturned anticline; they are slightly metamorphosed to the north and are faulted and intruded along the western margin of the mass. The formation is also exposed in small fault slices along the tear and thrust fault system which bounds the main mass of Willow Canyon; in some of the slices, the rocks are more intensely metamorphosed, and in all of them the rocks are considerably sheared. Near the ranch and southwest of locality *C*, the Willow Canyon of the lowest thrust plate overlies the Glance with apparent conformity. Northwest of locality *C*, numerous inclusions of metasedimentary rocks presumed to be Willow Canyon, only a few of which are shown schematically in figure 28, are included in a granodiorite and quartz monzonite intrusive complex of the lowest thrust plate. Near the ranch, there are also several small masses of poorly exposed arkosic rock assigned to the Willow Canyon and of intensely metamorphosed arkosic(?) rock of Willow Canyon(?) designation.

LITHOLOGY

Most observations on the stratigraphy of the Willow Canyon Formation were obtained from the three largest outcrop areas, at localities *D*, *B*, and *C* (fig. 28). In the southernmost of these areas, the rocks vary laterally from a sandstone-rich facies near locality *D* to a siltstone facies toward both the northeast and the southeast. The transitions between these facies are much better exposed to the northeast than to the southeast. To the southeast, the rocks of the lower part of the formation consist of abundant brown sandstone beds and sparse gray siltstone and shale. The bedding of many of the sandstones is subtly graded; more rarely, channel-scour markings and crossbedding are also present. The abundance of the shale and siltstone beds increases gradually upsection, and a few beds are limy. Scraps of molluscan fossils appear in a few beds.

Near locality *D* (fig. 28) the Willow Canyon rocks are largely grayish-red to yellowish-brown coarse-grained arkose with scattered thin beds of conglomerate, conglomeratic sandstone, and greenish-gray siltstone. Beds in the arkose are commonly 2–4 feet thick, and some include a few finer laminations. The conglomeratic beds are made up chiefly of grit and of pebbles less than 2 inches across; but they also contain some scattered cobbles which consist mainly of sandstone, less comonly of silicic volcanic rock, and least commonly of fine-grained siliceous rock, possibly chert. One mile northeast of locality *D*, the conglomerate and grayish-red to yellowish-brown sandstone beds are fewer and finer grained, and the intercalated greenish-gray siltstone beds are more abundant and thicker. The coarser beds interfinger with the finer ones, and the coarser beds that are high in the formation transgress northeastward beyond the limit of those low in the formation.

The lowest few hundred feet of the formation in the klippe north of locality *D* and also those at least a mile northeast of locality *D* contain some scattered beds, each a few feet thick, of chip-bearing red mudstone. The chips in these beds are unsorted, and some are fragments of orthoclase. These beds closely resemble the consolidated equivalents of the weakly developed soils formed on the low terrace deposits of streams that drain areas underlain by the Continental Granodiorite. By analogy, they are believed to be regolith beds, which have either formed in place or been brought in from nearby areas by sheet wash or colluvial action rather than by streams.

The Willow Canyon Formation of the Box Canyon area, locality *B* (fig. 28), is sufficiently different from that near locality *D*, to the south, that detailed correlation of units within the formation has not been possible. A short distance south of Box Canyon, the formation consists of alternating beds of grayish-orange-pink conglomeratic arkose and arkosic grit and beds of pale-reddish-brown arkosic sandstone, in units tens of feet to a few hundred feet thick. The light-colored coarse-grained beds form low ribs of outcrops and are usually thinner than the other units; northward toward Box Canyon they are gradually thinner, and some of the upper beds wedge out. The pebbles in the southern part of these beds are quartzite and make up scarcely 1 percent of the units; most pebbles are no larger than an inch across, although a few are 3 inches across. In contrast to the lighter colored gritty beds, the red beds are better sorted and bedded and in many places are crossbedded. Toward the north, their grain size also decreases, so that near Box Canyon many of these units are siltstone. On the south flank of Box Canyon, one of the red-bed units contains limy nodules 1–2 inches across; nodules such as these appear sporadically in many of the red-bed formations. In thin section (fig. 29) one such red-bed unit is seen to consist of 30 percent quartz grains, a slightly larger percentage of feldspars that include chiefly albitized plagioclase but also some microcline and orthoclase, and a few percent of volcanic rock fragments, all in an abundant fine-grained matrix.

The largest graben block north of Box Canyon and northwest of locality *B* (fig. 28) also consists of alternating light-colored grit beds and red sandstone and siltstone of this facies of the Willow Canyon Formation. The rocks of the other graben blocks are arkose or arkosic conglomerate mixed in places with red beds; they thus resemble most closely the rocks of the Willow Canyon in locality *D*.

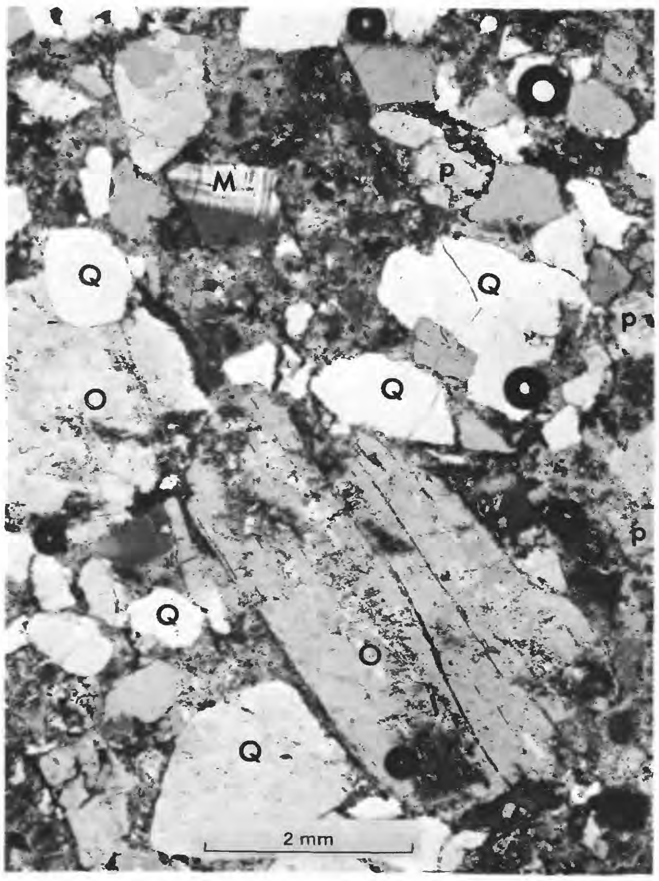


FIGURE 29.—Photomicrograph of an arkose from the red beds of the Willow Canyon Formation in the Box Canyon area. Crossed nicols. Grains: perthitic orthoclase (O), microcline (M), quartz (Q), and plagioclase (P).

The identification of the red sedimentary rocks of the structural blocks in and north of Rosemont is a problem because of their poor exposure and their intense iron-oxide alteration. The southernmost structural block contains two short lenses of thin platy limestone, like those most commonly associated with the Apache Canyon Formation but which also appear in the Willow Canyon and Shellenberger Canyon. In the second structural block, at locality *E*, a thick massive unit of coarse volcanic conglomerate is overlain by a thick unit of arkose and arkosic conglomerate. Inasmuch as the upper unit resembles the Willow Canyon and the lower unit differs markedly from nearby exposures of the Glance, both are mapped as Willow Canyon. Volcanic conglomerate also appears in the Willow Canyon farther north; therefore, that rock type is not unique in the formation. In the next block to the north, the drab-colored sandstone and thin beds of conglomerate, in places also intensely flooded with iron oxide, probably are Willow Canyon, and possibly the rocks in the next block to the north are too. However, along the east edge of the area of figure 28, a rhyolitic tuff appears to be interbedded in the red clastic rocks of this block; thus, conceivably this sequence, as well as that in some of the adjacent blocks, is a pre-Bisbee Mesozoic unit. Finally, the poorly exposed beds in the northernmost structural block are also a red-bed sequence of sandstone, siltstone, and conglomerate. The base of the block contains some lentils of limestone conglomerate, which are suggestive of the Glance, and the upper third of the block contains red mudstone and some tuffaceous(?) sandstone. A Willow Canyon correlation is favored for this sequence, although again the alternate possibility of a correlation with older rocks remains.

In the Sycamore Canyon area, locality *C* (fig. 28), the Willow Canyon Formation consists of arkose and arkosic conglomerate that typically crop out in only small areas and weather pale brownish gray. Low in the formation, a thick volcanic conglomerate unit is interbedded with the arkose, and in the upper third some units are gray siltstone. The volcanic conglomerate lies on the ridge north of Sycamore Canyon, where it appears as a poorly exposed massively bedded drab-colored rock containing abundant subangular clasts of rhyolitic and dacitic composition of unknown, but presumed local, provenance. The dominant rock of the formation in this area is a yellowish-brown arkose, which is usually coarse grained; in places, a grit or conglomeratic arkose occurs whose pebbles are subrounded sandstone or quartzite. A little calc-silicate hornfels in the middle of the formation indicates that some calcareous siltstone is also present.

In thin section, a sample of arkose from north of Sycamore Canyon is seen to contain about equal amounts of quartz and feldspar grains and fine-grained interstitial material, which includes cementing and alteration products. In contrast to the reddish-brown arkose of the Box Canyon area, however, the feldspars consist largely of microline grains. Fragments of perthitic orthoclase, resembling only the large crystals in the Continental Granodiorite, are also present. This arkose apparently was derived from an area that was underlain entirely by Precambrian rocks.

FAUNA AND AGE

Limy black shale beds from southeast of locality *D* (fig. 28) contain some fragments of molluscan fossils. One such bed, a third of a mile east of the Snyder mine (Drewes, 1971a), contains the following fauna, identified by E. G. Kauffman of the U.S. Geological Survey (USGS Mesozoic locality 28715):

Mactra sp. indet.
Ostrea sp. immature
Corbicula? sp.

Thracia sp. cf. *T. gracilis* Meek and Hayden
Nuculava sp. cf. *N.* sp. *B.* of Stephenson
Tellina sp.

Kauffman indicates that this is a marine fauna, except for the *Corbicula?* sp., which is a brackish- to fresh-water element. The fossils are not sufficiently well preserved or diagnostic to allow a placement more precise than Cretaceous.

ENVIRONMENT OF DEPOSITION

Like the Glance Conglomerate beneath it, the Willow Canyon Formation shows by its lateral variations and its abundant content of coarse clasts that it was deposited mainly in a piedmont environment by streams. During Willow Canyon time, the mountains were more subdued or were farther from the site of deposition than they were during Glance time, but they still contained locally a variety of rock types that provided dominantly granitic, but some volcanic, detritus. Even during Willow Canyon time, the progressive subduing of the source areas is marked by the gradual upward decrease in grain size of the sediments. The lenticularity and the poor sorting of the deposits are compatible with deposition by running water, conceivably in a semiarid environment like the present environment in southwestern Arizona.

The abundance of detritus in the northern Santa Rita Mountains that has been derived from a Precambrian granitic source suggests that the source area lay to the west, because in other directions the available nearby exposures indicate the Paleozoic cover to be extensive and also because the available Precambrian contains relatively little granitic rock.

APACHE CANYON FORMATION

The Apache Canyon Formation, a sequence of siltstone and arkose 1,500–2,000 feet thick, conformably overlies the Willow Canyon Formation. This formation shows less lateral variation in lithology than do the underlying ones, but it also becomes increasingly finer grained upsection. Its basal contact is broadly gradational, generally being placed at the approximate position at which siltstone is dominant over arkose. Locally, more specific positions were selected for this contact based on convenient marker beds, and so it is unlikely that it is a fully synchronous horizon as mapped.

DISTRIBUTION

The Apache Canyon Formation is recognized on the west flank of the central part of the mountains and in two places on the east flank of the northern end. On the west flank at locality *F* (fig. 28), the Apache Canyon underlies a northwest-trending belt of low hills between Montosa Canyon to the south and the lower reaches of Agua Caliente Canyon to the north. To the southwest, these rocks are separated by faults from either Permian limestone which underlies rugged hills or Triassic volcanics which underlie a pediment. They are separated by a fault or by an intrusive contact from younger granitic rock to the northeast. The ends of the belt of Apache Canyon rocks are also faulted. The rocks within the belt dip steeply southwestward and are moderately to strongly hornfelsed and epidotized.

East of locality *D* (fig. 28), Apache Canyon rocks appear in the trough of the Boston Gulch syncline (Drewes, 1970). The rocks of the southern part of this area generally dip steeply northeastward but locally are folded so that dips vary; in the northern part of the area, they dip more gently southeastward. The rocks lie conformably upon the Willow Canyon to the west and are unconformably overlain by gravel to the east. Near locality *D*, epidotized and slightly hornfelsed rocks form an elliptical contact aureole 1 mile by 2 miles in extent centered around a swarm of quartz latite porphyry intrusives.

A sinuous belt of Apache Canyon Formation also lies east of locality *C* (fig. 28) on the east side of the basin of Sycamore Canyon. The rocks there lie conformably between the overlying and underlying formations of the Bisbee Group and dip moderately steeply southeastward to northeastward, depending on their location along the several folds that produce the sinuosity of this outcrop belt. To the south, the Apache Canyon is faulted out, and to the north it is intruded or covered by gravel.

LITHOLOGY

In each area, the Apache Canyon Formation consists dominantly of siltstone and mudstone but includes considerable fine-grained sandstone and arkose, a small amount of pebble-and-chip conglomerate, and a few thin beds of limestone. East of locality *D* (fig. 28), for example, siltstone and shale make up about 70 percent of the rock and sandstone 25 percent, with the sandstone in beds 1–3 feet thick. Usually the siltstone beds are medium dark gray to greenish gray and weather to a brownish gray, but at locality *F* some of them are pale red to grayish red. Locally, graded bedding, channel-scour features, and crossbedding are present, and some of the red mudstone along the upper part of Agua Caliente Canyon at locality *F* is limy. Strongly crossbedded arkose is shown in figure 30, and slightly hornfelsed siltstone with limy nodules in the bed behind the pick is shown in figure 31. In thin section, the arkose is also seen to contain several percent fragments of volcanics. The dominant feldspar among the clasts is orthoclase, and the plagioclase grains are of albite.

FIGURE 30.—Outcrop of crossbedded arkose of the Apache Canyon Formation along Agua Caliente Canyon.

FIGURE 31.—Outcrop of slightly hornfelsed mudstone and siltstone of the Apache Canyon Formation along Agua Caliente Canyon.

The pebbles in the intercalated conglomerate beds are usually less than 1 inch across. At locality *F* (fig. 28), they are porphyritic to vitrophyric volcanics of rhyolitic to dacitic composition, which are possibly derived from the Mount Wrightson Formation. Elsewhere, such as at locality *D*, they are of fine-grained siliceous material, possibly chert, and in places they are also of sandstone.

Intercalated limestone beds are either thin platy to laminated rocks or are blocky-fracturing calcarenite. They range in thickness from a few inches to a few feet and in color from light gray to grayish brown. Most of them are unfossiliferous; however, sparse unidentifiable fragments of clams and gastropods have been collected from three limestone lenses, which are half a mile south-southwest of Greaterville, north of the lower reaches of Fish Canyon, and high on the spur a quarter mile north of Montosa Canyon. These beds resemble some of the fossiliferous beds of the adjacent formations, whose faunas thrived in a brackish-water or saline environment.

FAUNA

A small molluscan fauna was collected from some thin limestone beds assigned to the Apache Canyon Formation, located about half a mile southwest of Greaterville and about 1,000 feet east of the Greaterville-Fish Canyon road. N. F. Sohl (written commun., 1970) identified the gastropods *Neridomus* and *Nerita* in this assemblage, and Erle Kauffman (written commun., 1970) lists many bivalves of a single species, cf. *Meretrix* or *Transenella* sp. indet., which is new for the Cretaceous of the interior States. Both groups of fossils are common in an estuarine environment and suggest a brackish-water situation.

ENVIRONMENT OF DEPOSITION

The Apache Canyon sediments were deposited in a lowland, chiefly by streams, and partly in local short-lived ponds or lagoons, whose waters were probably brackish or saline. The source rocks were still dominantly granitic but in part volcanic. The preponderance of gray and green shale and siltstone over red beds, even away from contact aureoles, suggests that reducing conditions existed at the deposition sites. Limy deposits accumulated in shallow bodies of water; a few of these seem to have supported a fauna of clams and gastropods. The association of the bodies of water with reducing environments in nearby mudflats suggests that a high water table at least helped to inhibit oxidation.

SHELLENBERGER CANYON FORMATION

A sequence of black shale and siltstone that contains intercalated sandstone and limestone beds conformably overlies the Apache Canyon Formation of the Sycamore Canyon area, east of locality *C* (fig. 28). This sequence is assigned to the Shellenberger Canyon Formation of the Bisbee Group, a formation that is normally about 1,500 feet thick. Scarcely half of the formation is present within the Sahuarita quadrangle (Drewes, 1971b); an unmetamorphosed part of it is present on the southern limb of a large anticline and a moderately metamorphosed part on the northern limb of that fold. The lower contact is broadly gradational, and so for convenience it is placed above a fairly extensive limestone marker bed.

To the south, the dominant rocks are dark-gray fissile shale, laminated shale, some black shale with siliceous nodules, and siltstone with well-developed crossbedding, graded bedding, and ripple marks. Relatively thin beds of limestone and olive-brown sandstone, like those in the underlying formation, are also present, as are lentils of intraformational conglomerate and chip conglomerate whose fragments are of siliceous material. Beds of limestone are rarely as much as 3 feet thick and are similar to those in the Apache Canyon Formation in most respects. Limestone with paper-thin laminae, in places finely crenulated, and fossil hash beds are more common in this formation than in the underlying rocks, however. Locally, two marker beds about 30 feet apart contain a hash of molluscan shells; these beds are similar to beds recognized by T. L. Finnell (oral commun., 1968) in the Empire Mountains.

The rocks of the Shellenberger Canyon Formation are believed to have been deposited largely in a lagoonal or estuarine environment. The relative abundance of limestone beds in this formation and in the top of the Apache Canyon Formation and the occurrence of marine fossils in the Empire Mountains (T. L. Finnell, oral commun., 1968) suggest that these rocks may be generally correlative with the Mural Limestone of the Bisbee Group in its type area. The marine incursion represented by the Mural is inferred to have advanced northwestward from the region of north-central Mexico to Bisbee and on to the vicinity of the northern part of the Santa Rita Mountains. This incursion roughly coincided with the maximum degradation of the uplands that supplied the abundant coarse detritus during most of early Bisbee time.

TURNEY RANCH FORMATION

In the northern part of the Santa Rita Mountains, just beyond the edge of the Sahuarita quadrangle and locality *C* (fig. 28), the shales of the Shellenberger Canyon are conformably overlain by a sequence of alternating siltstones and fairly quartzose sandstones that are assigned to the Turney Ranch Formation, the highest unit of the Bisbee Group. This sequence reappears in several places farther south in the Santa Rita Mountains, where it is at least 1,500 feet thick. From outcrop area to outcrop area, the lithology of the formation is seen to vary slightly along strike in such a way that locally it resembles the lithology of other Cretaceous rocks. In these southern areas, however, the base of the formation is unexposed, and inasmuch as the top is an unconformity, different stratigraphic intervals may be represented in the several areas.

DISTRIBUTION

Rocks of the Turney Ranch Formation appear in the core of a tightly folded anticline in the Adobe Canyon area 1 mile northeast of locality *A* (fig. 28). The Turney Ranch Formation is unconformably overlain by the Fort Crittenden Formation, and to the southeast both formations are covered by gravel deposits. Part of the southwestern contact is faulted. The Turney Ranch is exceptionally well exposed along the many deeply incised small canyons and is accessible by a small road up Adobe Canyon.

Rocks of this formation also crop out in a narrow northwest-trending zone that extends along the flanks of the two canyons named Sawmill Canyon, whose common divide lies approximately along the boundary between the Sahuarita and Mount Wrightson quadrangles. In this zone, the rocks are either faulted against or are unconformably(?) overlain by the Fort Crittenden Formation on the southwest, and they are faulted against Triassic or older rocks of the Sawmill Canyon fault zone on the northeast. The rocks in this outcrop zone are broken by faults in two places. The rocks of the southeastern segment of the zone, locality *H* (fig. 28), are in a fault block along the edge of the Sawmill Canyon zone and dip moderately steeply northeastward. Those in the other two segments commonly dip moderately steeply to steeply southwestward but locally are warped into tight folds subparallel to the Sawmill Canyon fault zone, so that dip directions change abruptly. Axial-plane faults break the stratigraphic continuity around some of these folds.

LITHOLOGY

In both of these areas, red mudstone or siltstone is three to four times as abundant as the intercalated beds of sandstone. The outcrop expression of the formation changes markedly in response to the variation in thickness and induration of the sandstone beds.

In the Adobe Canyon area, northeast of locality *A* (fig. 28), the sandstone beds are thickest, and many are quartzitic. Inasmuch as they are upended on the east flank of the anticline there, the quartzite beds weather out to form prominent ribs of rock and walls which jut out into the canyon. Bath Tub Tank is a natural pool, augmented by a small concrete dam, which is formed in a group of quartzite beds. A stratigraphic section of almost 1,500 feet of the Turney Ranch is measured in Adobe Canyon (fig. 32). Its base lies about 1,000 feet southwest of Bath Tub Tank near a large alligator juniper along the western fork of a gully tributary to Adobe Canyon from the west (SW¼SW¼ sec. 24, T. 20 S., R. 15 E., unsurveyed). The rocks are almost completely exposed along the tributary gully and along a part of Adobe Canyon. The top of the section is at the base of an olive-gray conglomerate, just west of the roadhead.

A typical sandstone or quartzite unit is a very light gray medium-coarse-grained thick-bedded rock about 40 feet thick. Pebbles are scattered in the lowest beds, and finer sand is common in the upper ones. Large sweeping crossbedding is present in many beds. The sandstone units low in the formation are more arkosic and less well indurated than those high in the formation, and they tend to grade into the adjacent siltstone units. Some of the beds are reddish brown and are separated from neighboring gray sandstone beds by thin siltstone units (fig. 33).

Two thin sections of a typical quartzite, unit 19 of the measured section, collected from 1 mile northwest of the section and from a third of a mile south of it, show the rock to be an impure quartzite with well-sorted grains 0.2–0.3 mm in size. The grains are either subrounded or have been partly resorbed to form an interlocking mosaic in which some of them have silica overgrowths. Quartz grains make up 80–90 percent of the rock, granular argillaceous material (perhaps altered feldspar or reworked clay chips) and intergranular argillaceous material make up 5–10 percent, and schorlitic tourmaline, zircon, magnetite, and pyrite appear in trace amounts. A few flakes of sericite lie between quartz grains, and apatite is included within the quartz grains.

A typical siltstone unit is about 150 feet thick and contains 10–30 percent each of intercalated thin sandstone beds and of shale. It is grayish red and massive or thick bedded where not sandy. It may contain zones 2–10 feet thick of irregularly shaped limestone nodules and pods, most of which are less than 1 inch across but some of which are as much as 6 inches across; the pods make up as much as 30 percent of a zone. Small chips of organic debris appear in some of the upper siltstone units, one of which, unit 18 of the measured section, contains small fragments of clams, gastropods, and silicified wood. One fine-grained sandstone block from a siltstone unit contains an intricately chambered feature that may have been algae or seaweed.

The Turney Ranch Formation at locality *H* (fig. 28) differs from that along Adobe Canyon in that the sandstone units are commonly only 5–20 feet thick, are more arkosic, and are so weakly indurated as to make only low rows of outcrops or rubble-covered ribs. Like their counterparts in Adobe Canyon, however, they are sufficiently extensive to be mapped separately (Drewes, unpub. data). Most of the 16 or more groups of sandstone beds are fine grained to medium coarse grained and pale brownish gray; the basal parts of a few of them are gritty or conglomeratic sandstone. The typical siltstone unit is 30–100 feet thick, is pale red, and is poorly exposed. Some of the lower units contain small limestone nodules.

About a third of the way from localities *H* to *G* (fig. 28), in the SW¼ sec. 35, T. 19 S., R. 15 E., only one sandstone bed, on the hill west of the cattle tank (Drewes, 1971a), is sufficiently well indurated to make a persistent outcropping ledge. However, other light-colored sandstone beds are exposed along some of the more deeply incised gullies that trend across the strike of the beds; on the slopes, these beds typically are hidden by the colluvium which is derived from the more abundant redder rocks. Similar lithologies are exposed along the northwestern Sawmill Canyon, about two-thirds of the way from localities *H* to *G*. In that area, a quartzite bed forms a rugged rib of rock for about 1 mile but gradually blends into the adjacent rock types over a distance of another mile in both directions as the unit becomes thinner and less quartzitic. Farther to the northwest, the rocks are slightly metamorphosed, in part at least dynamically, and the red mudstone and siltstones are harder. Some of these beds contain zones in which small cavities are prevalent, each roughly 1 inch long and alined parallel to the bedding. These appear to have been formed by the solution of the limy nodules like those that are present in some of the red beds to the south.

Near locality *G* (fig. 28), there are as many as four massive units of quartzite beds, some of which are truncated by the overlying unconformity. A sample of one of these beds, seen under the microscope, shows a typical mosaic texture of metaquartzite. Clay minerals and quartz cement of the matrix make up only 15 percent of the rock, quartz grains make up more than 80 percent, and traces of clastic zircon, tourmaline, iron oxide, leucoxene, albite, orthoclase, and apatite make up the remainder.

ENVIRONMENT OF DEPOSITION

The Turney Ranch rocks are believed to have been deposited in a near-shore environment. The quartzitic sandstone beds of the Adobe Canyon area resemble beach deposits in their degree of sorting and their crossbedding. The fragments of molluscan fossils also suggest an aqueous environment, if not actually a marine situation. However, the abundant fragments of fossil wood in one of the siltstone units in the Adobe Canyon area indicate a site of deposition on or near the shore. Likewise, I believe the limestone nodules in red siltstone and mudstone were probably formed, as caliche nodules, in a subaerial environment. This time of lagoonal or estuarine deposition came to a close with the first uplift and deformation that culminated in the Laramide orogeny.

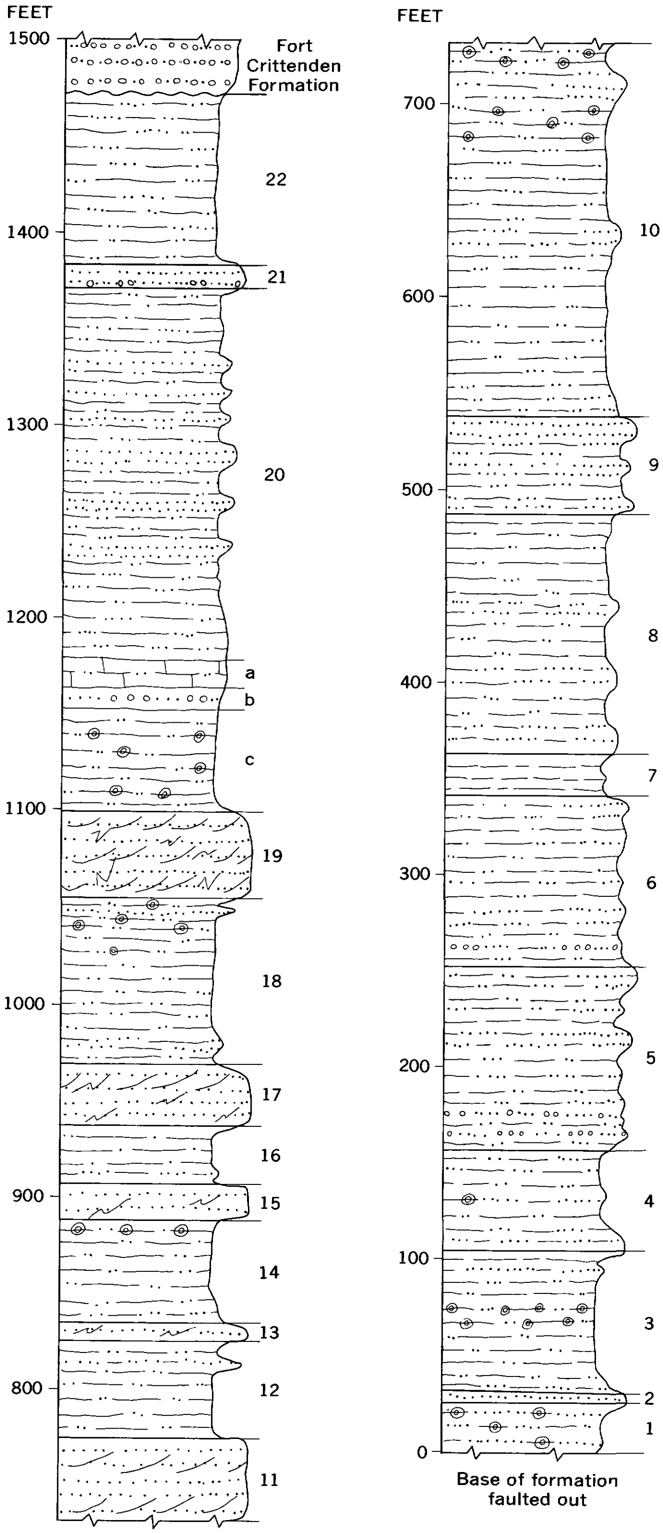


FIGURE 32.—Measured stratigraphic section of the Turney Ranch Formation, Adobe Canyon, Santa Rita Mountains.

Description of units shown in figure 32

Conglomerate of the Fort Crittenden Formation.

Turney Ranch Formation:

22. Siltstone (90 percent) and sandstone (10 percent). Siltstone, reddish-gray and massive. Sandstone, light-greenish-gray to yellowish-gray; base of beds gritty to coarse grained, remainder medium coarse grained.
21. Sandstone. Light greenish gray; mainly medium coarse grained except bottom 4 ft, which is coarse grained and contains basal grit conglomerate. This unit thickens to north.
20. Sandstone (50 percent) and siltstone (50 percent). Sandstone, yellowish-gray to grayish-red, medium-fine-grained; in subunits as much as 6 ft thick. Siltstone, reddish-gray, massive. Lower part of unit includes:
    a. Limy sandstone,
    b. Conglomeratic sandstone containing chips, and
    c. Siltstone, containing 5 percent very fine grained sandstone and 1 percent limestone nodules, mainly ½–2 in. in diameter.
19. Quartzite. Very light gray, well sorted, fine grained to medium coarse grained; sweeping crossbedding; upper part of unit grades into sandstone. Site of Bath Tub Tank.
18. Siltstone. Reddish gray, massive; scattered limestone nodules as much as ¼ in. in diameter, mainly near top of unit; some fine-grained reddish-gray sandstone near top and bottom of unit.
17. Quartzitic sandstone. Light gray to pinkish gray, mostly medium coarse grained; contains coarse sandstone and chip conglomerate near base of unit.
16. Siltstone. Reddish gray, massive; contains 5 percent reddish-gray fine-grained sandstone at base of unit.
15. Sandstone and quartzitic sandstone. Light gray, mostly medium coarse grained, very well sorted, slightly arkosic; base of unit is a very coarse grained slightly limy sandstone with sweeping crossbedding and scattered chips.
14. Siltstone. Reddish gray, massive; contains 3 percent limestone nodules especially concentrated in upper 1 ft.
13. Quartzitic sandstone. As in unit 17. Basal chip conglomerate and sandstone has limestone chips as much as ½ in. across.
12. Siltstone (80 percent) and sandstone (20 percent). Siltstone, reddish-gray, massive; includes 2 ft of clay shale containing markings of possible organic origin beneath sandstone subunit. Sandstone, as in unit 17. Forms lens high in unit that thins rapidly to south.
11. Quartzitic sandstone. Light gray, medium coarse grained; in 4- to 72-in.-thick beds; contains some sweeping crossbeds; thins rapidly to north.
10. Siltstone (75 percent) and sandstone (25 percent). Siltstone, grayish-red, massive; includes a little light-greenish-gray shale; contains two zones near top of unit which include 5 percent limy nodules as much as 1 in. in diameter. Sandstone, light-brownish-gray to pinkish-gray, fine-grained, slightly limy; includes a small amount of chip conglomerate.
9. Sandstone. Very fine grained to silty sandstone (40 percent), and medium-coarse-grained slightly limy sandstone (60 percent); in beds 1–9 ft thick that are faintly color laminated and crossbedded.

Turney Ranch Formation—Continued

8. Sandstone (50 percent) and siltstone (50 percent). Sandstone, light-gray to pinkish-gray and less commonly pale-greenish-gray to pale-red; in beds 2–18 in. thick; faintly laminated and crossbedded; some beds contain mud flakes. Siltstone, grayish-red, massive.
7. Mudstone (90 percent) and sandstone (10 percent). Mudstone, grayish-red, massive. Sandstone, grayish-red; consists of three intercalated beds, each 6–18 in. thick.
6. Siltstone (60 percent) and sandstone (40 percent). Siltstone, grayish-red, massive. Sandstone, light-gray to pinkish-gray, fine- to medium-fine-grained; faintly laminated by dark minerals; contains a subunit of chip conglomerate 8 ft thick near base of unit, whose chips include limestone and volcanics and are commonly ½ in. and rarely as much as 2 in. in diameter.
5. Sandstone (80 percent) and siltstone (20 percent). Sandstone, light- to pinkish-gray, medium-coarse-grained; in beds 3–36 in. thick; faintly laminated by dark minerals and crossbedded. The bases of some sandstone beds contain a small amount of chip conglomerate. Siltstone, grayish-red; in beds 1–3 ft thick.
4. Sandstone (70 percent) and mudstone (30 percent). Sandstone, grayish-pink to pale-red, fine- to medium-coarse-grained; in beds 6–36 in. thick. Mudstone, grayish-red, silty; especially abundant near top and bottom of unit.
3. Mudstone. Grayish red, mostly massive; contains a 1-ft-thick sandstone bed near top of unit; also contains a limestone module zone near middle of unit, in which nodules constitute as much as 20 percent.
2. Sandstone. Grayish red, coarse grained, with parting of fine-grained sandstone; contains 1 percent limestone chips.
1. Mudstone. Grayish red, massive; contains nodules of light-gray aphanitic limestone 1–6 in. across that make up as much as 20 percent of some beds.

Base of formation faulted out.

FIGURE 33.—Typical sandstone beds of the lower part of the Turney Ranch Formation cropping out along Adobe Canyon about half a mile northwest of Bath Tub Tank.

POST-BISBEE ROCKS

FORT CRITTENDEN FORMATION

Along the east flank of the Santa Rita Mountains, the Fort Crittenden Formation, a sequence of red and brown conglomerate and sandstone and of fossiliferous black shale, as much as 5,500 feet thick, unconformably overlies the Turney Ranch Formation of the Bisbee Group. A small body of these rocks is also present on the west flank of the range, where it is overlain with apparent conformity by volcanics of the Salero Formation, some of which have been dated as uppermost Cretaceous by geologic and isotopic methods.

The rocks of the Fort Crittenden were included by Schrader (1915, p. 51–54, pl. 2) in an unnamed unit of sedimentary rocks chiefly of Cretaceous age. They were later included by Stoyanow (1949, p. 59–60) in his Fort Crittenden Formation, and this formation along with the underlying Fort Buchanan Formation made up his Sonoita Group. As a result of the present study in the area, the Fort Crittenden Formation of Stoyanow has been modified (Drewes, 1968, p. C10) to include at least 4,000 feet more of conglomerate, sandstone, and fanglomerate above the original top of the formation. Furthermore, the Sonoita Group is formally abandoned as a stratigraphic unit, because it included such diverse formations as the Turney Ranch, a part of the already established Bisbee Group of Early Cretaceous age, the Gardner Canyon of Triassic age, and the modified Fort Crittenden of Late Cretaceous age.

The Fort Crittenden Formation consists of five informal members; four are sedimentary rocks, and one is lenticular volcanic rock. The sedimentary members are, in rising succession, the shale member, the lower red conglomerate member, the brown conglomerate member, and the upper red conglomerate member. The four sedimentary members show at least a small amount of interfingering with adjacent members, in addition to their dominant sequential order. This interfingering is most pronounced between the lower red conglomerate and the brown conglomerate, as shown in figure 34. Some of the brown clastic rocks are scattered within the red conglomerates, and a few tongues of red rocks also appear within the dominantly brown beds. The fifth member, a rhyolitic tuff, is intercalated chiefly in the upper red conglomerate but also in the adjacent part of the brown conglomerate. To emphasize its geologic significance, I consider it a separate member because it is the first record of volcanism associated with the magmatic activity of the Laramide orogeny, and it occurs over a distance of at least 10 miles and may occur as far distant as northern Sonora.

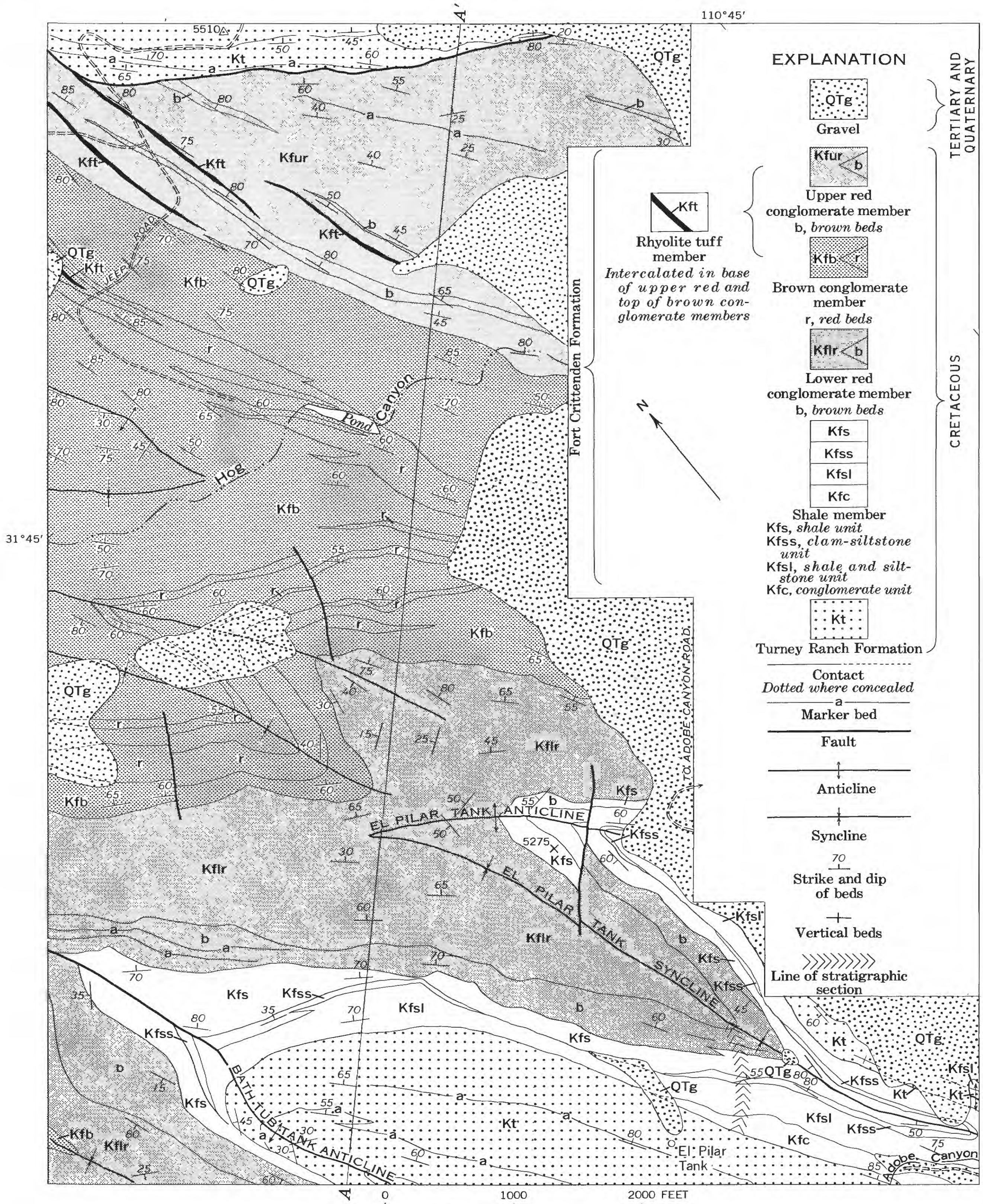


FIGURE 34.—Part of the Adobe and Hog Canyons area, showing the relations between the members of the Fort Crittenden Formation. *A–A′*, line of section shown in figure 38.

DISTRIBUTION

The Fort Crittenden Formation crops out in at least three areas in the Santa Rita Mountains, only two of which are in the Mount Wrightson (Drewes, 1971a) and Sahuarita (Drewes, 1971b) quadrangles. The other areas occur in the extreme northeastern tip of the mountains; they will be described separately by T. L. Finnell (unpub. data) in his report on the Empire Mountains.

The main body of the formation underlies a belt that extends from the lower reaches of Big Casa Blanca Canyon northward to the Sawmill Canyon fault zone (fig. 28) and then diagonally across the range to the spur between the mouths of Florida and northwestern Sawmill Canyon. In general, these rocks form a graben bounded by faults on the northeast and the southwest. To the northwest and southeast, they are overlain by piedmont gravel. In the core of the tight anticline in Adobe Canyon, however, the Turney Ranch Formation lies unconformably beneath the Fort Crittenden, as shown by the truncation of one of the marker beds (a in figure 34). The rocks within the graben block are folded subparallel to the bounding faults; dips are very steep in Adobe Canyon and near Florida Canyon but are moderate to gentle elsewhere.

The formation also underlies a small zone between Montosa and Agua Caliente Canyons on the west flank of the mountains. This zone lies parallel to, and about 1 mile west of, the belt of Apache Canyon Formation at locality *F* in figure 28, and the rocks of the zone dip moderately westward. Although the rocks of this zone are much faulted, those along the southwestern edge probably have depositional contacts. The contact relations are best illustrated on the north wall of Montosa Canyon (Drewes, unpub. data).

LITHOLOGY

Shale Member

The shale member underlies the flanks of the tightly folded Bath Tub Tank anticline in Adobe Canyon, where it is more than 550 feet thick on the east flank of the fold but thins rapidly around the crest and is only 4–10 feet thick on the west flank. A composite stratigraphic section of this member was measured along the thick sequence on the east side of the fold (fig. 35). The lowest rocks were measured along Adobe Canyon, as a continuation of the section of the Turney Ranch Formation (fig. 32). The remainder of the rocks were measured east of El Pilar Tank, a quarter of a mile to the north, where the shale member is completely exposed.

The most characteristic rock of the shale member is a dark-gray shale and mudstone, but the member also contains siltstone, limy sandstone, conglomeratic sandstone, and conglomerate. These rocks may be grouped into four units; in rising sequence, they include a lenticular basal conglomerate, a shale and siltstone unit, a clam-siltstone, and a shale unit. The base of the shale member is everywhere covered, but along the flanks of the fold, the beds adjacent to the contact are parallel. Only the appearance of a lenticular basal conglomerate and the truncation of the uppermost several hundred feet of the conglomerate around the crest of the fold suggest that a slight angular unconformity underlies the shale member.

The basal conglomerate and conglomeratic sandstone form a tongue that is 100 feet thick near the roadhead in Adobe Canyon but pinches out north of El Pilar Tank (fig. 34). The rock is massive to faintly bedded and is so friable that good exposures are sparse. Most of the rock is drab colored, but locally, as along Adobe Canyon, the lower half of the conglomerate unit weathers to reddish gray. The clasts are mostly of pebble and cobble size, but a few are boulders. They consist of (1) volcanics, some of which were derived from the Mount Wrightson Formation, (2) sandstone, some of which may be Turney Ranch, and, more rarely, (3) Paleozoic limestone. The clasts lie in beds or are scattered in a friable fairly well bedded sandstone and silty sandstone.

The shale and siltstone unit of the shale member of the Fort Crittenden Formation is slightly more than 125 feet thick. Conglomeratic siltstone at its base marks a lithologic transition from the underlying conglomerate unit. The beds above the transition zone consist of about 75 percent reddish-gray to medium-dark-gray thin-bedded silty shale, 5 percent grayish-orange fine-grained sandstone in beds 2–5 feet thick, and 20 percent siltstone intercalated in the shale and most abundant near the sandstone beds. Small nodules of limestone and chips of clams appear in the upper half of the unit.

The clam-siltstone, 125 feet thick, has the most heterogeneous lithology of the four units (fig. 36). It is probably unit 3 of Stoyanow (1949, p. 60) in which the conglomerate content has been overemphasized owing to the extreme brevity of his description. In the measured section (fig. 35), there are a few feet of pebble conglomerate in the center of the unit and a little conglomeratic sandstone at its base, which together make up less than 5 percent of the unit. Although the abundance of conglomerate does vary along strike of the beds, it is nowhere significantly more abundant than in the measured section. However, inasmuch as the pebbles are relatively resistant rock, they are concentrated on weathered surfaces and give the impression of great

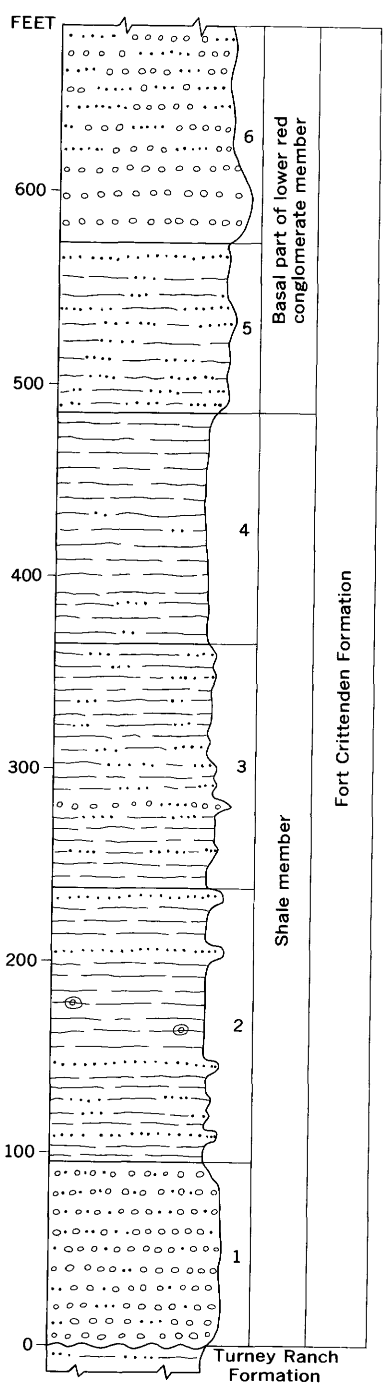


FIGURE 35.—Measured stratigraphic section of part of the Fort Crittenden Formation.

Description of units shown in figure 35

Basal part of lower red conglomerate member of Fort Crittenden Formation:

6. Conglomerate. Brown; pebbles and cobbles in a sandy matrix; includes 10 percent yellowish-gray to pale-grayish-orange siltstone in beds 2–18 in. thick; some sandstone is very coarse grained (units 6 and 5 are brown units in the predominantly red lower red conglomerate member).
5. Sandstone (50 percent) and siltstone (50 percent). Siltstone, yellowish-gray to pale-grayish-orange. Sandstone, brown, medium coarse to very coarse grained; in beds 2–18 in. thick.

Shale member of Fort Crittenden Formation:

4. Shale. Dark-gray fissile shale and some massive mudstone; contains molluscan fragments; also contains 2 percent of sandstone in beds 6–18 in. thick.
3. Clam-siltstone. Pale-reddish-purple siltstone; contains clam detritus (80 percent); includes fossiliferous black shale and mudstone intercalated with siltstone (10 percent); also includes brownish-gray sandstone in beds 1–3 ft thick (8 percent), and conglomerate (2 percent).

Shale member of Fort Crittenden Formation—Continued

2. Shale (60 percent) and siltstone (40 percent). Shale, reddish-gray to grayish-orange, very thin bedded. Siltstone, reddish-gray to medium-gray; includes about 5 percent sandstone and a trace of conglomerate and of limestone; also contains some molluscan chips and limy nodules.

Break in continuity of section.

1. Conglomerate. Pebbles, cobbles, and boulders in a sandy matrix; clasts of volcanics and sandstone; chiefly reddish gray, but top is greenish gray.

Turney Ranch Formation:

Siltstone and sandstone.

---

abundance. Pale-reddish-purple to brownish-gray siltstone and sandstone make up about 85 percent of the unit, black shale and mudstone make up about 10 percent, and thin lenses of limestone and limy sandstone, along with the conglomerate, make up the remainder. Black calcite shells of clams and gastropods are very abundant in some siltstone beds and in the intercalated mudstone; many whole valves and even paired mudstone-filled valves weather out. Some shells are slightly compressed, probably as a result of folding of the rock; but most shells are undeformed, and their internal morphology is well preserved.

The shale unit is about 120 feet thick and consists almost entirely of dark-gray mudstone, shale, and silty shale, in equal amounts; it also contains about 2 percent sandstone. The mudstone is poorly bedded or is unbedded, and it also contains abundant clams and gastropods. The shale is flaky to highly fissile and commonly is silty but in places is a clay shale; most is dark gray, but it grades into olive gray, especially to the north, where the silt content increases. The intercalated sandstone beds are 6–18 inches thick, medium coarse grained, well sorted and locally crossbedded, feldspathic and quartzose, and light brownish gray. E. B. Leopold checked several specimens of this unit for pollen without success.

FIGURE 36.—Typical outcrop of the clam-siltstone unit of the shale member of the Fort Crittenden Formation, located just east of the head of the road in Adobe Canyon. The clam-siltstone unit underlies the steeper slope with the ledgy outcrop, center; the shale and siltstone unit underlies the gentler slope, lower right corner; and the shale unit underlies the gentler slope, upper left corner.

LOWER RED CONGLOMERATE MEMBER

The lower red conglomerate member lies conformably above the shale member. It is about 1,000 feet thick along the line of the structure section shown in figure 38 but probably varies considerably in thickness owing to the rapid interfingering with brown conglomerate at the top and possibly also owing to attenuation on the flanks of the folds. Although red color and conglomerate lithology are most characteristic of the unit, it contains brown beds and intercalated sandstone and siltstone beds resembling those of the next overlying member. A lenticular yellowish-gray to grayish-orange sandstone and conglomerate at the bottom are units 5 and 6 in the measured section (fig. 35).

The lower red conglomerate member crops out on the northeast and northwest flanks of the basin along Adobe Canyon, and it underlies the basin that centers on an unnamed syncline to the west of the Bath Tub Tank anticline. The red conglomerate extends southward to Big Casa Blanca Canyon, where it is faulted on the west and overlapped by gravel on the east.

A typical sequence of beds in this member consists of 35 percent pebble-and-cobble conglomerate, 50 percent sandstone, and 15 percent siltstone and mudstone, an assortment shown in figure 37. The beds are commonly 2–10 feet thick, but some are finer laminations, and a very few are crossbeds; scour marks appear on bedding surfaces. Fresh and weathered surfaces alike are grayish red. The conglomerate is polymictic; the clasts consist dominantly of laminated and nonlaminated intensely indurated rhyolitic volcanics (probably derived from the Mount Wrightson Formation) and subordinately of granitic rock (largely of Jurassic origin) and of sandstone, quartzite, and siltstone (of Paleozoic or Mesozoic origin). Some red conglomerate west of Adobe Canyon is a monomyctic volcanic pebble conglomerate whose clasts are subrounded or subangular and are set in a sandy and argillaceous matrix.

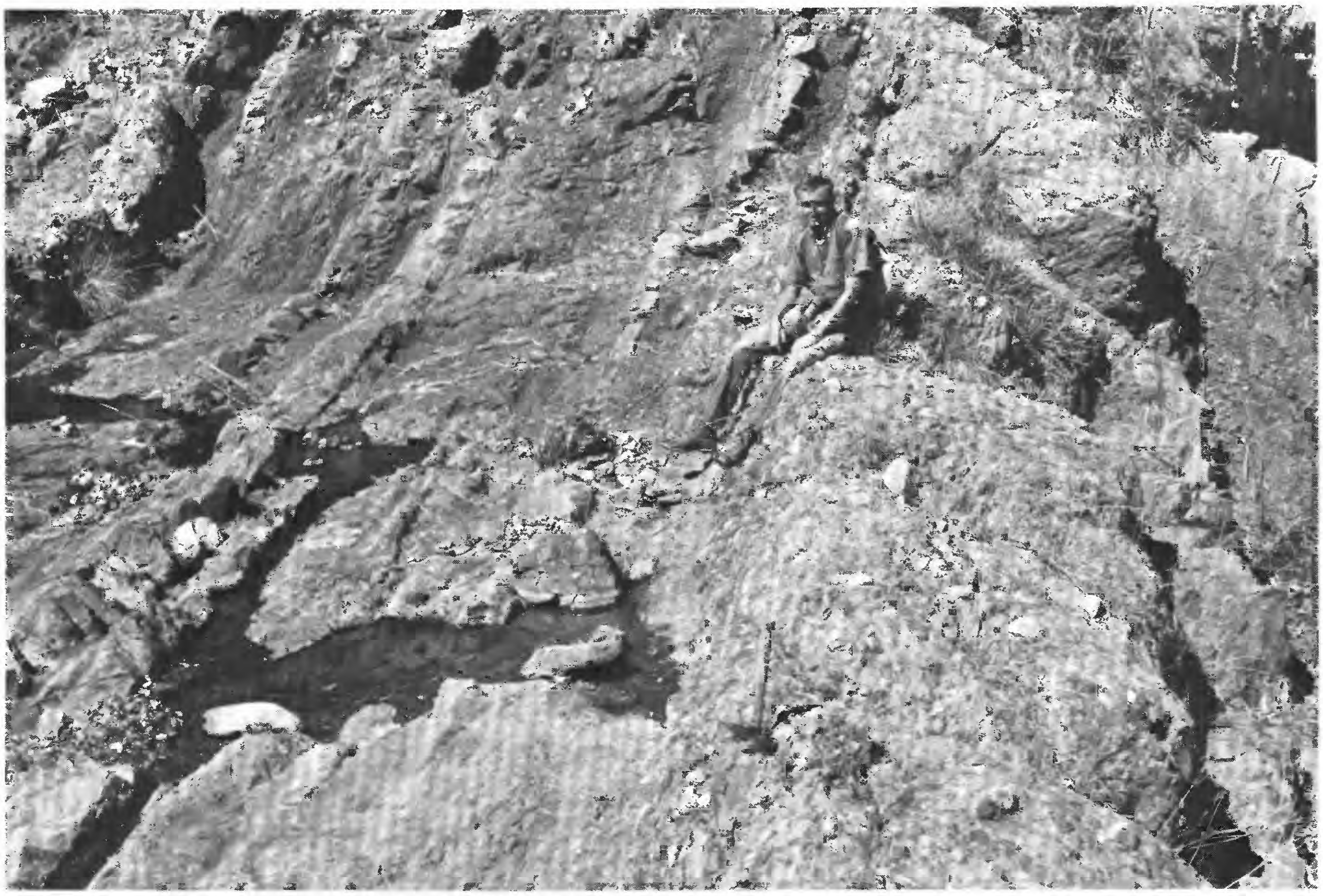


FIGURE 37.—Typical beds of the lower red conglomerate member of the Fort Crittenden Formation along Adobe Canyon about half a mile northwest of El Pilar Tank. The hammer lies on a thick bed of conglomerate; to the left of this bed, red siltstone is dominant over sandstone beds to form several small ribs.

Sandstones, and presumably the finer grained clastic rocks, are subarkose to subgraywacke. Northward, as well as stratigraphically upward, the lower red conglomerate intertongues into the brown conglomerate member.

Brown Conglomerate Member

About 2,030 feet of dominantly brown conglomerate overlies the lower red conglomerate member in the northeastern part of Adobe Canyon and adjacent canyons. The base of the brown conglomerate member is placed beneath an 80-foot-thick brown unit at about the 5,200-foot contour on the northeast flank of the Adobe Canyon basin (Drewes, 1971a; unpub. data). This contact continues around two minor folds on the ridge between Adobe and Hog Canyons, from which an incompletely exposed stratigraphic section extends roughly along the line of the structure section shown in figure 38. Around the northern end of the Adobe Canyon basin, however, more abundant brown beds appear lower in the section, and the mapped base of the member drops in stratigraphic level (Drewes, unpub. data). So defined, the brown conglomerate member underlies an extensive area from Hog Canyon and the upper reaches of Adobe Canyon northwestward to the west side of the Santa Rita Mountains.

This member also consists of heterogeneous rock types, although brown conglomerate is its most typical rock. Unweathered rocks are light greenish gray, but the weathered ones are pale yellowish brown. Between Adobe Canyon and Cave Creek, the member contains intercalated red beds large enough to be mapped at a scale of 1:12,000. Most of the beds of the member are a few feet thick, but they range in thickness from 1 to 50 feet. The rocks consist of pebble-and-cobble conglomerate (10–40 percent), sandstone and arkose (20–50 percent), and siltstone and mudstone (20–30 percent). A few grain-size and color changes are systematic. The red beds intercalated in the brown conglomerate member, for example, decrease in thickness and in grain size northward, which suggests that their provenance lay in the southern quadrants. Clasts in the brown conglomerate are dominantly granitic and prob-

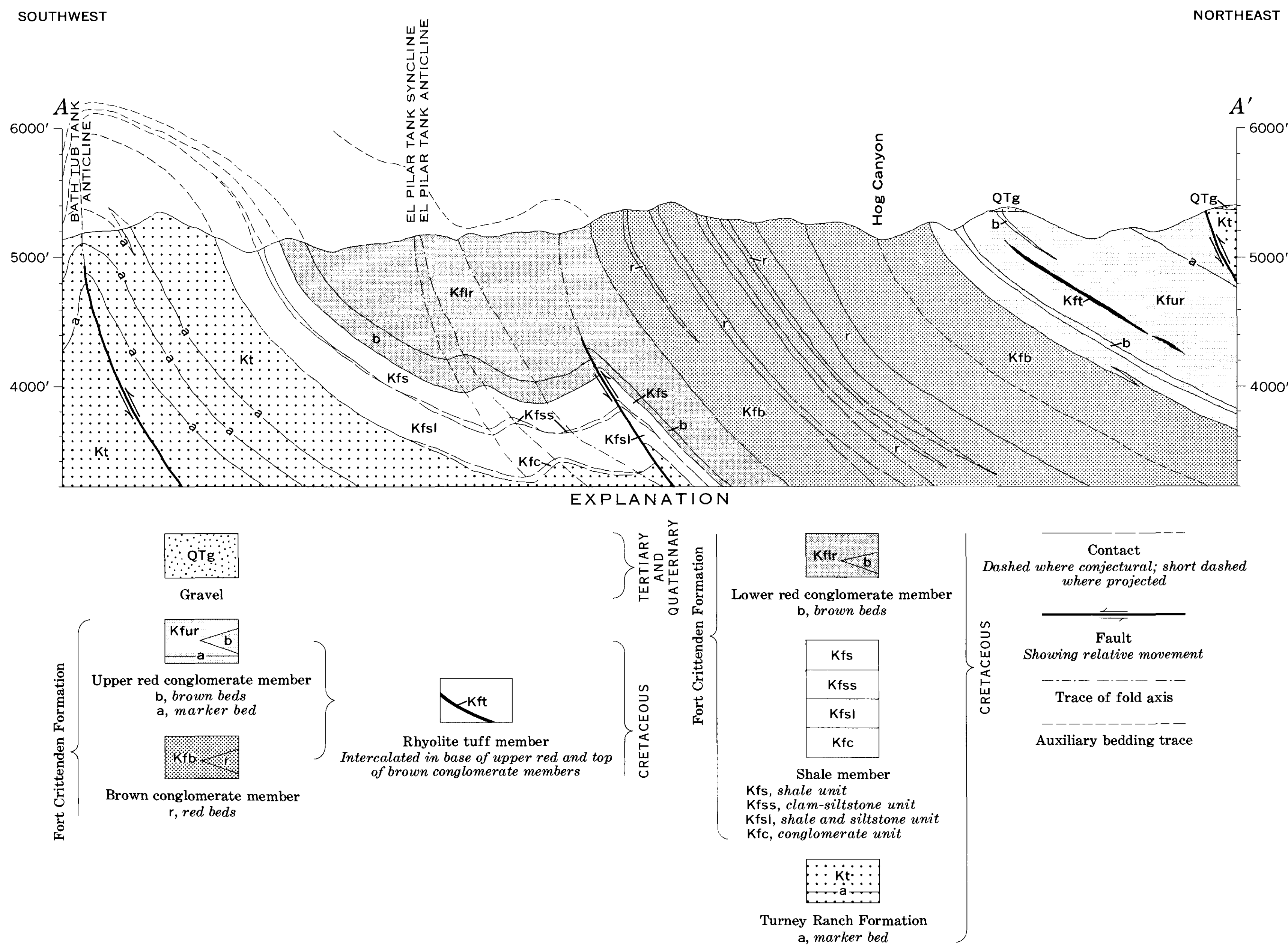


FIGURE 38.—Section showing structure along line *A–A′* (fig. 34).

ably were derived from a Precambrian source to the north. The finer grained brown beds are arkose, also believed to have come from the north. Some arkose beds exposed a few hundred feet west of the jeep road in Hog Canyon and others in probably the same general horizon that crop out between Cave Creek and Aliso Spring contain fragments of silicified wood, and in one place along Cave Creek scraps of dinosaur(?) bone were found.

One mile north of Cave Creek, the brown conglomerate member is sheared along crests of tight chevron folds, and stratigraphic control within the member is lost. The Fort Crittenden rocks of the Florida and Sawmill Canyons area are like those of the brown conglomerate member, but it is unclear whether these rocks occupy the stratigraphic position of the brown conglomerate in Hog Canyon or whether they are a northern facies of one of the red conglomerate members. Under these conditions, separation of the Fort Crittenden from the similar-appearing Bisbee Group is difficult.

Upper Red Conglomerate Member

In Hog Canyon, at least 1,400 feet of red conglomerate conformably overlies the brown conglomerate member. The base of this red unit is relatively sharp. Interfingering with the underlying brown beds is minor; very few beds, and only those beds of brown conglomerate and sandstone which are thin, are intercalated in the upper red conglomerate. The rocks of the Fort Crittenden Formation on the west flank of the mountains at Montosa Canyon probably also belong to this member.

The rocks of the upper red conglomerate member are like those of the lower red conglomerate member in most respects. However, the rocks of the upper member in Hog Canyon include abundant coarse nearly monomyctic reddish-brown sedimentary breccia. Fragments in the breccia beds range in size from 2 to 24 inches and are almost wholly of a quartzitic sandstone that resembles most closely the sandstone beds in the fault block of the Turney Ranch Formation juxtaposed on the northeast. A few clasts of Paleozoic carbonate rocks are also in the sedimentary breccia beds. The rounding and sorting of these beds seems to increase stratigraphically upward and possibly also northward. In addition, the upper red conglomerate member, unlike the lower one, contains tuff beds, which are mapped as the rhyolitic tuff member.

Rhyolitic Tuff Member

On the west flank of the Santa Rita Mountains, about 65 feet of rhyolitic tuff is intercalated near the top of the Fort Crittenden Formation. On the east flank, however, the tuff makes several beds too thin to be mapped at a scale of 1:48,000, but they are shown schematically in figures 34 and 38. The thicker tuff bed and most of the thinner ones are in the upper red conglomerate member, but a few thin ones appear at the top of the brown conglomerate member in the Hog Canyon area. In the Montosa Canyon area, the thick tuff bed is poorly exposed in five separate fault blocks; the largest and best exposed outcrops lie about 1,000 feet west of the place where the Montosa Canyon road descends into that canyon from the north side (SW¼ sec. 19, T. 20 S., R. 13 E.). The rock here is a much fractured and moderately intensely altered tuff and underlies gentle knolls and shoulders that rise above the adjacent conglomerate terrane.

The tuff is a pale-greenish-gray to light-brownish-gray finely crystalline rock. Phenocrysts of quartz, plagioclase, and altered biotite are visible in specimens of the thicker body, but only sparse quartz and feldspar crystals appear in the thin beds. Shard textures and finely fragmental textures are barely recognizable in hand specimen.

In thin section, the thick tuff unit is seen to be a recrystallized crystal-lithic tuff. Crystals make up about a third of the rock and consist largely of potassium feldspar, albite, partly resorbed quartz, and a biotite that is completely altered to hydromica and disseminated grains of iron oxide; a little titaniferous magnetite, apatite, zircon, and amphibole(?) are also present. The abundance and size of zircon crystals are adequate for isotopic dating. The phenocrysts are commonly 0.5 mm in diameter, but a few are as much as 3 mm across. Lithic fragments in one specimen are of an intensely oxidized volcanic rock which has alined crystal laths. A small amount of devitrified volcanic glass is preserved in cavities in quartz and, before alteration, was probably abundant throughout the now thoroughly altered groundmass. Clay minerals, sericite, hydromica, iron oxide, and epidote are moderately abundant.

The tuff differs from the next overlying volcanics in its rhyolitic rather than andesitic composition, a compositional difference indicated by a lighter color, by relatively abundant quartz crystals, and by the sparsity of ferromagnesian minerals of the tuff. Furthermore, the rhyolitic rock is probably an airfall tuff, whereas the andesitic rock is a flow breccia.

The tuff of the thin beds of the Hog Canyon area is finer grained than that to the west; phenocrysts are commonly 0.3 mm in diameter and rarely as much as 1 mm across. The phenocrysts are the same kind as those to the west, thus permitting a correlation of the beds across the mountains. This correlation is reinforced by the correlation of the associated red conglomerate. If this correlation is valid, the source of the tuff probably was to the west, the direction in which both the beds are thicker and the crystal fragments are coarser.

FAUNA AND AGE

The Fort Crittenden Formation has yielded a fairly abundant fauna that provides a reliable Late Cretaceous age and indicates a probable late Late Cretaceous age (Santonian, Campanian, and Maestrichtian Stages) of Europe. Most fossils have been collected in the Adobe Canyon area but were reported without adequate description of locality or of the stratigraphy of the collection site. In some reviews of the faunas collected in this formation, a spuriously precise age is introduced as a result of oversimplifying or ignoring the uncertainties of the original fossil determinations. For example, a close comparison in the size of fossil teeth with those of a dinosaur, X, has been reported to mean that the author making this comparison claimed the teeth were actually those of dinosaur X.

Schrader (1915, p. 55) reported the occurrence of the following fossils, identified by T. W. Stanton, from an unspecified locality in Adobe Canyon. The bracketed comments are mine.

Unio sp., related to *U. rectoides* White [clams]
Viviparus sp. [gastropod]
Viviparus sp., related to *S. wyomingensis* Meek [gastropod]
Physa sp. [gastropod]

Most likely these were collected from the shale member near the roadhead in Adobe Canyon.

Stoyanow (1949, p. 59, 60) reported, in addition to these genera, *Sphaerium* sp. and the remains of fish and turtle and dinosaur teeth, the size of which Barnum Brown compared to the size of the teeth of *Gorgosaurus libratus*.

Miller (1964, p. 378–383) described in considerable detail additional fossils from Adobe Canyon.

Hadrosaurian, gen. indet. [dinosaur jaw]
Plastomenus sp. [turtle scute]
Aspcridctes sp. [turtle scute]
Elopid, gen. indet. [fish jaw]
Lepidosteus sp. [fish scale]
Amioid, gen. indet. [fish vertebra]
Protelliptio? sp. [elongate clam]
Unio sp. [round clam]
Viviparus? sp. [conically spired gastropod]
Physa, cf. *P. reesidei* [elliptoidal-shaped gastropod]

The hadrosaurian remains apparently were collected from either the base of the shale member or high in the underlying Bisbee Group at the east end of El Pilar Tank. Miller (1964) stated that the tarponlike elopid fish remains were considered by J. T. Gregory to be closely related to *Pachyrhizodus*. Most likely they were collected from the shale member. The fish vertebra and most of the fish scales were probably also obtained from the shale member, but some scales may have come from the underlying rocks. The clams and gastropods likewise were presumably collected from the shale member, where they are most abundant.

D. W. Taylor (written commun., 1963) has identified the following fossils, collected in the present study, from the clam-siltstone unit of the shale member at a site 1,250 feet east of El Pilar Tank (SW¼NE¼ sec. 24, T. 20 S., R. 15 E., unsurveyed).

U.S. Geological Survey Mesozoic locality No. 28710 (field No. 62D26f):

Plesielliptio sp. [elongate clam]
Bellamya sp. [gastropod]
Small high-spired gastropod, indet.

Another collection of fossils from the same horizon in the draw about 600 feet east-northeast of the roadhead in Adobe Canyon (NW¼SE¼ sec. 24, T. 20 S., R. 15 E., unsurveyed) were also identified by him.

U.S. Geological Survey Mesozoic locality No. 28711 (field No. 62D66f):

Plesielliptio sp. [elongate clam]
Bellamya sp. [gastropod]
Eupera sp. [round(?) clam]

Plesielliptio sp., and *Bellamya* sp. were also collected from the shale member on the west flank of the El Pilar Tank anticline where the shale crosses the 5,200-foot contour line (SE¼SE¼ sec. 14, T. 20 S., R. 15 E., unsurveyed).

The *Protellioptio* and *Unio* fauna of Miller is very likely the same as the *Plesielliptio* and *Eupera* fauna of Taylor, according to W. A. Cobban (oral commun., 1968).

H. W. Miller and K. W. Schwab (written commun., 1966) further identified and described a large variety of microfossils, including fish teeth, an ostracode *Cypridopsis*, a mosquito, hystrichomorphs, chitmozoans, charophytes, and fungus remains. They indicate that these fossils are of mixed origin, including reworked Paleozoic and earlier Mesozoic forms as well as Late Cretaceous ones. Of these, the Late Cretaceous fossils also indicate a fresh-water, quiet-water, and muddy bottom environment.

Unidentified silicified wood and scraps of dinosaur bones collected from several localities in the brown conglomerate member provide no further data useful in dating or in ecological interpretation.

The age of the combined fauna listed above is late Late Cretaceous—Santonian to Maestrichtian—and more likely late than early in this interval. However, no single collection seems sufficiently adequate for an unequivocal age determination. Additional support to this age is available from an isotopic determination, assuming that the correlation of the upper red conglomerate of the Fort Crittenden Formation across the mountains is correct. A rhyodacite welded tuff from the sequence of rocks overlying the red conglomerate on the west side of the mountains contains biotite that gives a potassium-argon age of 72 m.y., as described in the following section. The Fort Crittenden Formation also overlies the uppermost rocks of the Bisbee Group, whose middle units contain fossils of late Early Cretaceous age. In summary, the Fort Crittenden Formation is probably of Late Cretaceous but not latest Cretaceous age.

CORRELATION

Sedimentary rocks of unquestioned Late Cretaceous age are scarce in the region around the Santa Rita Mountains, but undoubtedly more will be recognized when areas thus far only mapped in reconnaissance are studied in detail and when other red-bed sequences are dated. The deposits which have a lithology and age most similar to the lithology and age of the Fort Crittenden Formation are the Cabullona Group in Sonora, Mexico, 70 miles southeast of Adobe Canyon and 18 miles east-southeast of Bisbee. These rocks, according to Taliaferro (1933), unconformably overlie the Lower Cretaceous Bisbee Group and make a sequence about 8,000 feet thick which contains, in rising succession, (1) the Snake Ridge Formation, of red conglomerate and sandstone, 2,000 feet thick; (2) the Camas Sandstone, of crossbedded sandstone and red and green shale, 1,200 feet thick; (3) the Packard Shale, a dark gray shale containing thin beds of bentonite and capped by white sandstone, 1,800–2,500 feet thick; (4) the upper red beds, of sandstone and shale, 2,000 feet thick; and (5) the light-gray rhyolite tuff, 800 feet thick. Both marine and nonmarine fossils are present, and adrosaurian remains from the upper part of the Snake Ridge Formation are probably of Santonian age, an age apparently preferred for the entire Cabullona Group.

The Fort Crittenden Formation has also been recognized by Hayes in the northwestern corner of the Huachuca Mountains (Hayes and Raup, 1968), about a quarter of the distance from the Santa Rita Mountains to the Cabullona area. The rocks of this area consist of at least 1,500 feet of interbedded shale, sandstone, and conglomerate, which are also dominantly reddish brown but include some greenish-gray to dark-gray beds. They rest unconformably upon folded and faulted rocks high in the Bisbee Group and are themselves folded; thus, the structural relations also resemble those in Adobe Canyon.

East and northeast of Adobe Canyon, there are also some rocks which I believe may be correlated with the Fort Crittenden Formation. In the Winchester Mountains, 10 miles northeast of the Little Dragoon Mountains, Cooper and Silver (1964, p. 76–77) described red and green conglomerate, sandstone, and shale about 4,000 feet thick, which contains intercalated rhyolitic tuff and which is overlain by andesitic sedimentary and volcanic rocks. Likewise, in the Chiricahua Mountains, about 30 miles northeast of Bisbee, the Javelina formation of Epis (1956) consists of conglomerate and sandstone, apparently lying unconformably between the Bisbee and andesitic volcanics, a stratigraphic position suggestive of the Fort Crittenden.

To the north and west, similar rocks are reported, although they are assigned various stratigraphic positions. Fort Crittenden rocks were recognized by T. L. Finnell (oral commun., 1968) in the northeast corner of the Santa Rita Mountains, where they also contain some rhyolitic tuff lenses. J. R. Cooper (oral commun., 1968) described rocks in Demetrie Wash in the Sierrita Mountains as consisting of a lower tongue of conglomerate, siltstone, and sandstone overlain by rhyolite tuff and andesite breccia. At least the lower tongue in Demetrie Wash may be correlated with the Fort Crittenden Formation, and the breccia may be correlated with the lowest two members of the Salero Formation.

Each of these areas of southeastern Arizona has a similar succession of Cretaceaus rocks. From older to younger, they are: (1) Bisbee; (2) unconformably overlying conglomerate, sandstone, and shale, which are dominantly red and commonly contain lenses of rhyolite tuff at or near their tops; (3) andesitic volcanic breccia, locally including andesitic sandstone; and (4) rhyodacitic tuff, commonly welded. This regional similarity strongly suggests that the units are generally correlative, and although specific units such as the rhyolitic tuff may not be completely synchronous, the volcanic rocks may be of roughly the same age, having come from several vent areas during the waxing phase of magmatism that culminated early during Laramide orogeny.

ENVIRONMENT OF DEPOSITION

The Fort Crittenden Formation was deposited subaerially in a tectonic environment. The abundance of coarse locally derived clastic rocks and of rocks of arkose and subgraywacke lithologies in the formation indicates that the detritus of which they were formed came from areas of considerable relief, was transported only a short distance, and was rapidly deposited. The presence of fossil land plants and animals also indicates a subaerial environment—one which was characterized by a mingling of local lacustrine and more widespread fluvial and piedmont conditions.

Reviewed in more detail, the local record indicates that following a little uplift and erosion during post-

Bisbee–pre-Fort Crittenden time, gravels were deposited at the base of uplifted areas. A lake or freshwater lagoon covered a small area near the site of the present Adobe Canyon and briefly lapped over the gentle rise on its southwestern shore. Organic-rich mud and silt was deposited in the lake, which supported an abundant molluscan fauna and an assortment of fish, turtle, and dinosaur life. Gradually the lake, or at least the part of it that is represented by the present Adobe Canyon area, was filled by gravels brought in by streams. These gravels were contributed by at least two drainage systems, whose domination in the area fluctuated; one system brought in arkosic detritus from the northeast, and the other contributed volcanic detritus from the southwest and perhaps also from the southeast. The increased abundance of fanglomerate that was deposited toward the end of this time resulted from a gradual increase in local relief that is believed to have been associated with an early phase of the Laramide orogeny. Rhyolitic tuff that was deposited in the gravels late during Fort Crittenden time was probably a preliminary sign of the major volcanic episode that followed, and its deposition brought to a close the time of deposition of abundant clastic rocks in the Late Cretaceous.

SALERO FORMATION

Dacitic volcanic rocks, about 5,000 feet thick, that grade upward and laterally into arkosic sedimentary rocks overlie the red beds of the Fort Crittenden Formation with apparent conformity and are intruded by latest Cretaceous plutons. In past studies, parts of this sequence have been variously identified because they underlie structurally separate areas, consist of diverse rock types, and are subtly crosscut and little altered by the plutons. Schrader (1915, pl. 2), for instance, considered most of these rocks to be Tertiary andesite and rhyolite that postdate the major plutonic bodies; this is a reasonable first approximation that seems supported by the equally gentle attitudes of some volcanics of this sequence and of some overlying glassy volcanics of undoubted Tertiary age. Even in the current study, the geologic relation between the nonglassy older volcanics, which have been separated from the glassy Oligocene volcanics, and the latest Cretaceous plutons is not everywhere unequivocal; however, in places the plutons demonstrably intrude the dacitic volcanics. This field relation is supported by the isotopic ages of about 72 m.y. for the volcanics and 62–68 m.y. for the plutons. The sequence of older volcanics is assigned to the Salero Formation (Drewes, 1968, p. C11) of Late Cretaceous age.

DISTRIBUTION

The Salero Formation is exposed over more than 15 square miles, chiefly in areas that extend from the drainage divide south of Aqua Caliente Canyon to the south edge of the Mount Wrightson quadrangle. The main outcrop area lies between Montosa Canyon and Mata Site Spring, 2½ miles south of the Salero mine (Drewes, 1971a); an outlier of the formation caps the quartz monzonite on the ridge north of Montosa Canyon, and some of these volcanics overlie red beds in the pediment north of that canyon. Small bodies of the Salero Formation form the wallrocks and numerous roof pendants and inclusions within the Josephine Canyon Diorite between Hangmans Canyon and Squaw Gulch. The formation also is the host rock to a second cupola of similar intrusive rock in the San Cayetano Mountains, a small range in the southwest corner of the Mount Wrightson quadrangle. The Grosvenor Hills Volcanics between the two cupolas of Josephine Canyon Diorite are probably underlain by a sheet of the Salero Formation, which is exposed in two inliers in the northern part of the volcanics. A small body of Salero also crops out along a thrust fault half a mile north of the Johnson ranch house in Sycamore Canyon (fig. 28; Drewes, 1971b). Much more of this rock lies east of this outcrop, just outside the area of the Sahuarita quadrangle.

BASAL UNCONFORMITY

In most places, the Salero Formation lies unconformably on the Jurassic Squaw Gulch Granite, but in the pediment north of Montosa Canyon it overlies the Upper Cretaceous Fort Crittenden Formation with probable conformity. The basal contact is poorly exposed in the pediment north of Montosa Canyon, on whose north bank, roughly a quarter of a mile west of the place where the Montosa Canyon road leaves the terrace along the canyon, the underlying red beds, the contact, and the overlying volcanics all dip about 45° westward. A little rhyolitic tuff is interbedded in the top of the Fort Crittenden Formation, and a few small bodies of red beds appear to be intercalated in the basal part of the Salero Formation; such an interstratification suggests a slight overlapping of depositional environments that is particularly compatible with a conformable contact.

Over large areas, the Salero Formation overlies the pale-orange-gray coarse-grained Squaw Gulch Granite with a highly irregular angular unconformity. Typically, the granite forms a paleotopography of hills and canyons, which are now partly exhumed from beneath the Salero. In the area of low rolling hills west of the Salero Ranch, the partly exhumed old granite knolls are low; likewise, small residual patches of the Salero Formation occupy old topographic depressions that were cut on the large body of granite in sec. 32, just south of Cottonwood Canyon. The height of the old granite knobs which underlie the formation increases in the hills near the Bull Spring mine, where some granite crops out only in present canyon bottoms, some underlies only flanks of present hills, and some caps present hills. Along Josephine Canyon half a mile southwest of Bull Spring mine, the pre-Salero surface forms a canyon as deep as, or slightly deeper than, the present canyon, which has been superposed on the ancient canyon for a short distance; the present canyon is floored by the Salero Formation, most of the present canyon walls are granite, and the gentle hills away from the present canyon are capped by the Salero Formation.

The old erosion surface forms a steep canyon flanked by some very prominent knobs between Salero Mountain and the San Ramon mine, largely in secs. 12 and 13, T. 21 S., R. 14 E. The ancient knobs of granite in that area have been exhumed to form knobs on the present land surface. Tuffaceous and arkosic sediments, including fanglomerate and some sedimentary breccia, filled the ancient canyon and now form unfaulted nearly flat-lying beds that surround the knobs. Younger diorite and a fine-grained quartz monzonite border phase of the diorite locally cut the arkose and granite. The absence of especially coarse sedimentary breccia deposits from the arkose member of the Salero Formation at the foot of the ancient knobs suggests that the knobs were eroded primarily by disaggregation of grains, as is common around many granite knobs today. The local relief on the ancient canyon was more than 800 feet, similar to the present local relief of the area.

LITHOLOGY AND PETROGRAPHY

The Salero Formation is divisible into five members, of which four make a stratigraphic sequence and one is a lateral facies, largely of one of the sequential members. From older to younger, the sequential members are a lower member, of dacitic flows and tuff breccia; an exotic-block member, which has a dacitic volcanic matrix; a welded-tuff member, of rhyodacite; and an upper member of volcanic and sedimentary rocks composed of conglomerate, agglomerate, tuff, quartzite, and red beds. The fifth member is the arkose member, a fanglomerate deposit that is largely a lateral facies of the welded-tuff member but locally underlies it and elsewhere intertongues with the upper member. The sequential members are distributed in the main outcrop area from north to south; the arkose member occurs mostly along the eastern edge of the main outcrop area of the Salero Formation, between Josephine Canyon and the Salero mine.

Lower Member

Dacitic to andesitic lava flows and tuff breccia at least 400 feet thick form the lower member of the Salero Formation. These rocks are best exposed along the upper part of Cottonwood Canyon, along the road 1 mile northeast of the Montosa mine in the NW¼ sec. 21, T. 20 S., R. 14 E., and south of Agua Caliente Spring in and around sec. 24, T. 20 S., R. 13 E. (Drewes, 1971a). The composition of the lower member volcanics is like that of the volcanics of the overlying more widespread exotic-block member, but it differs from them in that it does not include the exotic blocks. It may thus only be a locally developed facies in the lower part of the Salero Formation. Lower-member rocks underlie the northern part of the outcrop area of the Salero and dip gently southward.

The rocks of the lower member consist of a mixture of volcanic types, and very locally they include a few sedimentary beds. Northwest of the Montosa mine, the rocks are unlayered, intensely fractured, and altered and are either lava flows or sills. Likewise, in the upper part of Cottonwood Canyon, unlaminatd and unbrecciated rocks may be flows or small intrusives. A mile northeast of the Montosa mine, the rock is largely a tuff(?) breccia, which locally may be welded. A thin lens of tuffaceous sandstone and gritty arkosic conglomerate appears 1 mile east of the Montosa mine, and two small patches of red beds appear to be intercalated in the dacite sheets northwest of the mine.

In hand specimen, the dacitic rock appears as a greenish-gray to medium-gray finely porphyritic rock whose phenocrysts of feldspar are dominant over amphibole laths. The dacitic rocks are commonly moderately intensely argillized and epidotized, but locally, especially east of the Montosa mine, they are pyritized and more intensely argillized. Most likely, this intense alteration is related to the proximity of the contact with the uppermost Cretaceous quartz monzonite, but the geologic relations along this contact are somewhat unclear.

In thin section, the combined phenocrysts are seen to make up about half the rock. They are rarely more than 2.5 mm long, and they are set in a granular groundmass whose crystals are 0.05–0.1 mm across (fig. 39). Feldspar phenocrysts (20–30 percent of the rock) are largely albitized plagioclase, and several specimens also contain potassium(?) feldspar. Amphibole (10–15 percent of the rock) commonly appears as pseudomorphs of chlorite and iron oxides. Some rocks also

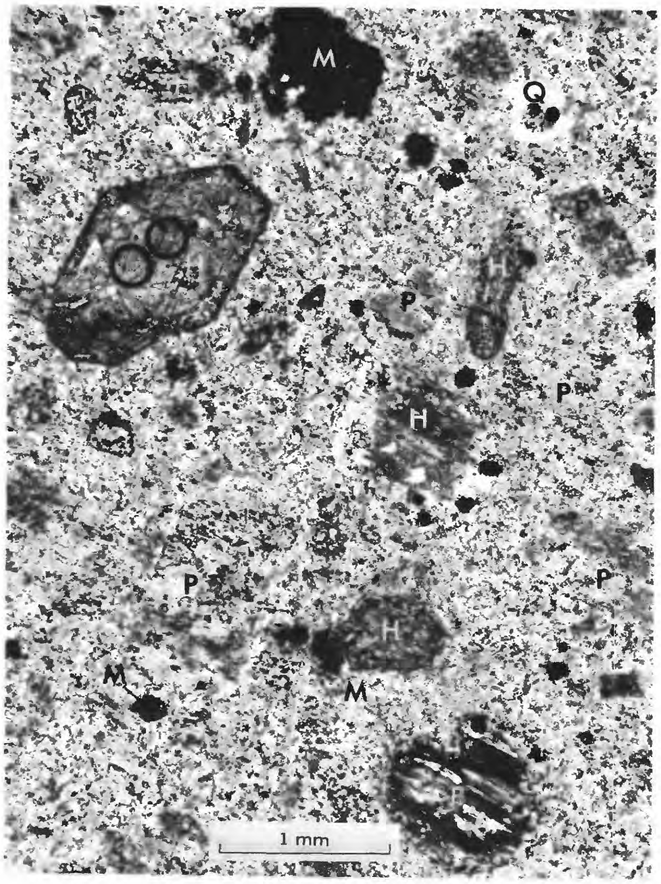


FIGURE 39.—Photomicrograph of a fairly unaltered specimen (field No. 65D680) of a dacite flow of the lower member of the Salero Formation. Phenocrysts: hornblende (H), biotite (B), magnetite (M), plagioclase (P), and quartz (Q). Groundmass is largely quartz (white) and feldspathic minerals (gray).

contain a few percent biotite, now completely altered to sericite, epidote, clay minerals, leucoxene, iron oxide, and a few percent pyroxene. Ilmenitic magnetite and apatite are common accessory minerals, and sphene may also be present. Abundant alteration minerals, as mentioned above, obscure the composition of the groundmass.

Chemical and spectrographic analyses are given in table 7 (specimen 1) of a relatively unaltered dacitic porphyry of the lower member collected from a flow(?) in the SE. cor. NE¼NE¼ sec. 24, T. 20 S., R. 13 E.

EXOTIC-BLOCK MEMBER

Conformably overlying the lower member is about 1,000 feet of dacite breccia, which contains many allochthonous blocks derived from pre-Salero formations. These allochthonous blocks, here called exotic blocks, come from formations that are exposed in place somewhere in the Santa Rita Mountains but not all at a single locality.

The exotic-block member has a broadly gradational basal contact with the lower member and laps beyond the southern edge of that member onto the Squaw Gulch Granite. Its gentle southwest dip across similarly sloping terrane gives it a broad outcrop area that extends from Montosa Canyon to Josephine Canyon. In many places, the exotic-block member can be distinguished, even at a distance, from the underlying dacitic rocks by its randomly scattered bold outcrops of relatively vivid and variegated—reddish-gray, grayish-orange-pink, very light gray—rock on otherwise somber-toned slopes, although elsewhere it blends in with the adjacent members. The jeep road constructed between Cottonwood Canyon and the Bull Spring mine in 1965 (since the publication of the topographic map) passes through much of this terrane, and exposures along this road show some varieties of exotic blocks, as well as their matrix.

In the field, the exotic-block member appears as a nearly massive sheet that consists of three components: exotic blocks, coarse volcanic fragments, and friable pulverized material. The coarse volcanic fragments and the friable pulverized material comprise the matrix of the exotic blocks. This matrix is a poorly exposed bluish-gray to greenish-gray dacitic porphyry that is strongly argillized and considerably epidotized and chloritized. The coarse fragments are typically 3–6 inches across, and the pulverized material is unsorted and mostly silt-sized to grit-sized debris. In one part of the member about ½–1 mile north of Bull Spring mine, however, few fragments are more than 1 inch across, and the fine debris possibly contains an admixture of tuff. This finer grained tuffaceous(?) variety of the exotic-block member lies at the top of the member; it is 400 feet thick to the north but wedges out southward near Josephine Canyon.

In thin section, the fragments of the matrix are seen to be subtly brecciated (fig. 40) in such a manner that the chips are distinctly outlined in some places but blend in with the groundmass in others. These chips are a fraction of a millimeter to at least several millimeters across and consist of small phenocrysts set in hyalopilitic to hyaloophitic material. Phenocrysts of albitized plagioclase, biotite, and amphibole are commonly 0.2–2 mm long and, together with traces of quartz, titaniferous magnetite, apatite, and leucoxene pseudomorphs after sphene, in various combinations, make up 40–60 percent of the rock. Microlite laths are 0.01–0.03 mm long and make up 10–55 percent of the rock, and glass or altered glass makes up 5–30 percent of the rock. The material between the chips is cataclastic and consists of abundant debris of the phenocryst assortment present in the chips, set in a granular

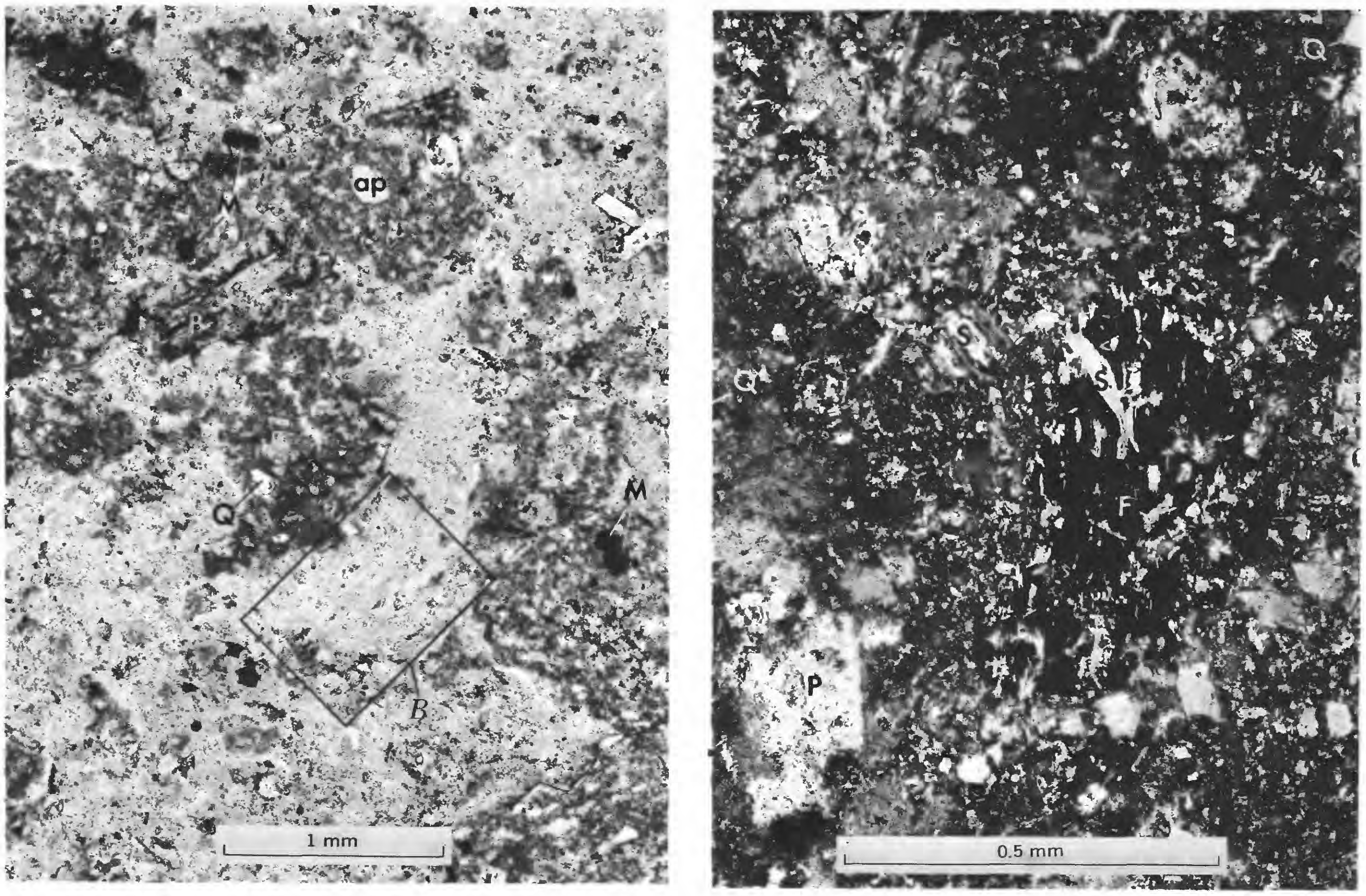


FIGURE 40.—Photomicrographs of a dacitic fragment in the matrix to the exotic blocks, exotic-block member of the Salero Formation. Left, chip-breccia texture; *B*, outline of area of photomicrograph on right, plane-polarized light. Right, groundmass of the chips, crossed nicols. In both photomicrographs, the crystals are plagioclase (P), relict biotite (B), magnetite (M), quartz (Q), apatite (ap), feldspar (F), and sericite (S).

to cryptocrystalline base that may be recrystallized (fig. 40). Both chips and interstitial material are pervasively sericitized; the feldspars are thoroughly altered to clay minerals; and the ferromagnesian minerals are almost completely altered to epidote, chlorite, and iron oxides.

Chemical and spectrographic analyses of a sample of matrix of the exotic blocks, collected from a blasted cut on the new unmapped jeep trail in the NW. cor. SE¼SW¼ sec. 33, T. 20 S., R. 14 E., are given in table 7 as specimen 2. This specimen and that of the lower member, specimen 1, are most like those of Nockolds' (1954) average dacite and trachytes (p. 1015, 1016), but neither of the analyses fits Nockolds' analysis closely. This difference may be due to chemical changes resulting from a genesis and alteration more complex than that of the samples considered by Nockolds.

The pulverized matrix of the coarse dacite fragments closely resembles the groundmass of the finer chips of which the dacite fragments are made, and it seems likely that both this matrix and the groundmass constitute the same component of the volcanic rock complex. The pulverized matrix also contains abundant phenocryst debris (50–80 percent of the component) in a finely granular to cryptocrystalline base (fig. 41). X-ray powder patterns indicate that at least this component of the rock contains a small amount of potassium feldspar. Sericite, kaolinite, nontronite(?), calcite, epidote, iron oxide, and secondary quartz are abundant alteration products.

Exotic blocks, seemingly scattered at random throughout the member, have been briefly described by me (in Simons and others, 1966, p. D9–D21, fig. 5). They are rocks of Cretaceous or older age, all older than the Salero Formation, and they range in length from less than 1 inch to as much as 1,000 feet. The composition and distribution of nearly 200 of the larger more common types of blocks and of somewhat smaller blocks of the less abundant types of blocks are also indicated on the geologic map of the Mount

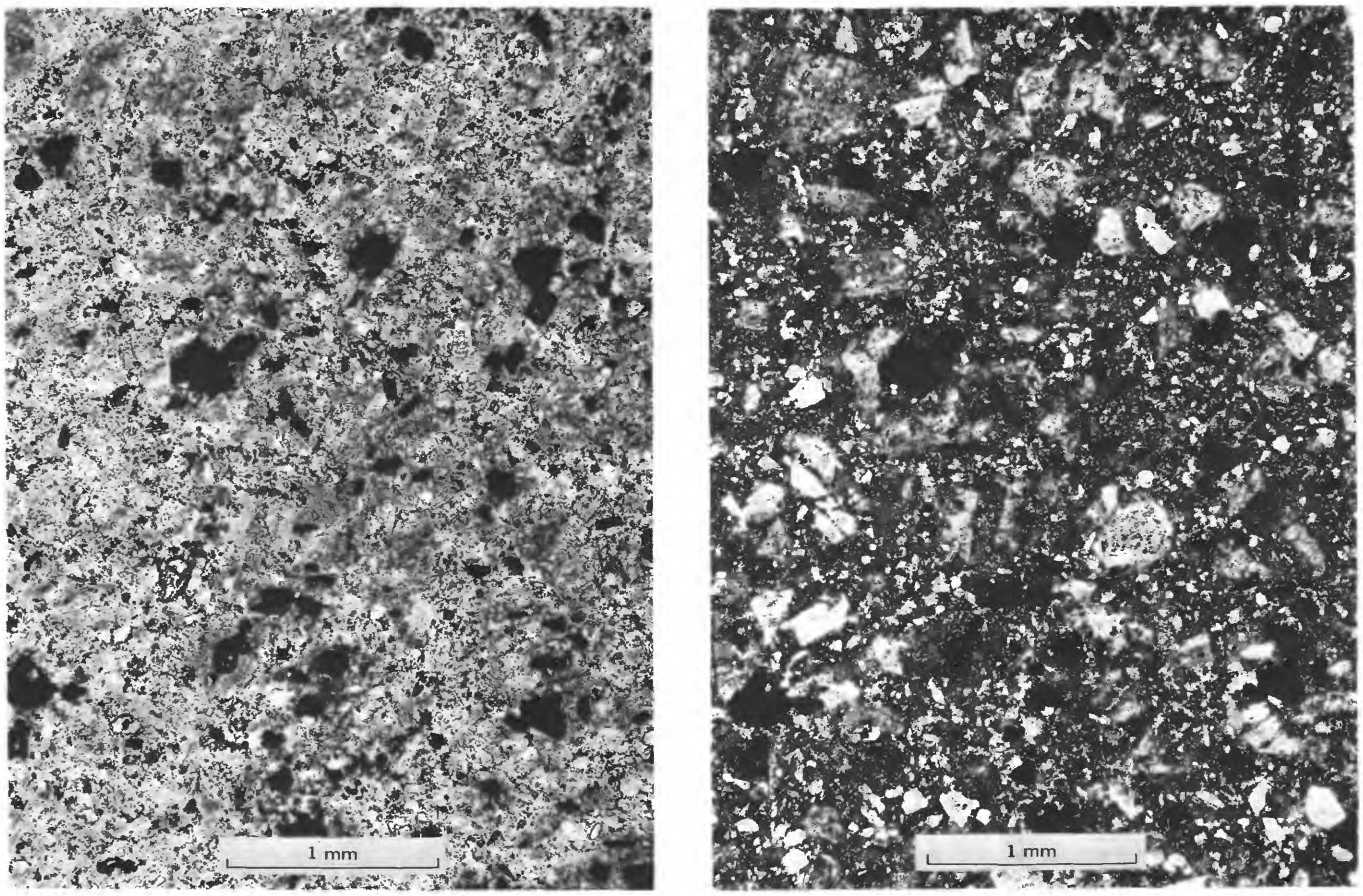


FIGURE 41.—Photomicrographs of the pulverized component to the exotic blocks, exotic-block member of the Salero Formation. Left, plane-polarized light. Right, crossed nicols.

Wrightson quadrangle (Drewes, 1971a). The blocks are slightly less plentiful along the northeastern edge of the outcrop area of the member than they are elsewhere but otherwise seem to be uniformly distributed and without apparent stratigraphic order with respect to each other. The most abundant and generally the largest exotic blocks are assorted flow-layered latite, rhyodacite, and andesite volcanics that were derived from the Triassic Mount Wrightson Formation. Blocks of Jurassic Squaw Gulch Granite are next in size and abundance, and where the exotic-block member rests directly upon that granite, much granite grus has been incorporated into the pulverized part of the dacite matrix. Blocks of Triassic Piper Gulch Monzonite and brown quartzitic sandstone, of the Mount Wrightson Formation, are also present, as are a few small blocks of granite and gneiss of Precambrian origin. Blocks of Paleozoic rocks add much to the color variations of the slopes that are underlain by the exotic-block member; most of these blocks were derived from the Permian limestones, of which fossiliferous Concha Limestone is the most commonly identifiable, but some blocks were derived from Cambrian Bolsa Quartzite and from brown dolomite of the Devonian Martin Limestone. Blocks or pods of friable red siltstone and sandstone, such as those that appear along the unmapped jeep trail in the SW¼SW¼ sec. 33, T. 20 S., R. 14 E., and also in the gully east of the road below the unnamed small mine shown in the SE¼NW¼ sec. 29, T. 20 S., R. 14 E., resemble the red beds of the Bisbee Group or Fort Crittenden Formation. The exotic blocks generally form discrete unshattered subequant unoriented angular bodies, but the red siltstone seems plastically deformed. Some limestone blocks are embayed by fine-grained pulverized dacite, in which are included chips of granite and other rocks (Simons and others, 1966, fig. 6).

Potential source areas for all the exotic blocks that are included in the member are within several miles of their present location. The Mount Wrightson Formation, for instance crops out extensively along the crest of the range 3 miles to the northeast and in small areas in the pediment 2 miles to the northwest. Squaw Gulch Granite is widespread, in part directly beneath the exotic-block member, and a little Precambrian gneissic granite appears both northeast and west of the main mass of the exotic-block member. Piper Gulch Monzonite xenoliths are found in Cretaceous plutons to the northeast, and hence this formation may have been more widespread before those plutons were emplaced. Cretaceous and Paleozoic rocks appear immediately to the north of the member. However, at present, no area as large as even a few square miles contains the entire assortment of source rocks found among the exotic blocks.

Welded-Tuff Member

The welded-tuff member consists of rhyodacite welded tuff and small amounts of unwelded tuff breccia, at least 1,200 feet thick, which overlie the exotic-block member. The welded-tuff member forms an almost unbroken sheet of more than 6 square miles that reaches from Cottonwood Canyon southeastward to near the Salero mine and southward to the San Cayetano Mountains and that appears in several inliers and upfaulted blocks between the San Cayetano Mountains and Salero. This tuff is also present in and east of Sycamore Canyon at the northern end of the Santa Rita Mountains. The widespread distribution of inliers and outliers of this welded tuff indicate that the tuff initially extended well over 30 square miles in the southern part of the mountains alone. Throughout this area, its average thickness probably was about 500–600 feet, thus indicating that at least 3 cubic miles of material accumulated to form this unit. The abundance of detritus of this welded tuff in post-Salero rocks indicates that the initial volume deposited may have been several cubic miles larger.

The welded tuff rests with probable disconformity and possible local conformity upon the exotic-block member. North of Cottonwood Canyon and just east of the Glove Mine (Drewes, unpub. data), the field relations in a structurally complex area indirectly indicate that the base of the welded tuff is a disconformity. A tear fault in that area separates the lower exotic-block member of the Salero Formation from Paleozoic rocks, but the faulting does not extend upward into the welded-tuff member; in this member, the layering is warped upward and subparallel to the position of the tear fault. The rocks are believed to have been faulted during the exotic-block-member and welded-tuff-member interval or simultaneously with the emplacement of, but before the final welding of, the tuff. Locally, northeast of Bull Spring mine, the upward gradation in the exotic-block member from a coarse volcanic breccia to a finer one that has a tuffaceous(?) matrix suggests an upward gradation and conformable relations between the members. Thus, if the contact beneath the welded-tuff member near the Glove mine is disconformable, that disconformity is a minor one. The minor irregularities along the contact between the exotic-block member and the welded-tuff member are believed to reflect initial variations in the position of the top of the exotic-block member, rather than erosion of that top, because there are no epiclastic lenses associated with the contact irregularities.

To the south, the welded tuff laps across the edge of the exotic block member and onto the Squaw Gulch Granite, where it buries an ancient hill-and-canyon topography already described. The basal contact of the welded-tuff member in this area commonly dips gently southwestward parallel to its sheeting.

The welded-tuff member is a nearly homogeneous unit in which sheeting and fracturing are usually well developed. Toward the southeast, there is a gradual transition from welded tuff to an unwelded tuff which contains arkosic admixtures near the underlying granite. However, where the arkosic tuff forms bodies sufficiently large to be mapped, it is grouped with the arkose member rather than with the welded-tuff member. Like the underlying members, the welded tuff has a uniform somber-colored brownish-gray or greenish-gray appearance on the weathered surface and is medium gray where unweathered. Outcrops are small on hills but extensive along the shallow canyons northwest of the Salero Ranch. The rock is subtly layered and is cut by several sets of joints which are inclined at about right angles to the layering. Small dark-greenish-gray pods of altered flattened pumiceous material lie parallel to the sheeting and are the most conspicuous on weathered joint surfaces. Inasmuch as these are absent or are very inconspicuous to the southeast, that part of the tuff is believed to be unwelded. A few percent of lithic fragments, commonly ½–2 inches across but as much as 6 inches across, are scattered in the welded tuff; the fragments consist largely of material like the tuff itself but include a few pieces of strongly laminate flows of the Mount Wrightson Formation and of Squaw Gulch Granite. Only a few chips of Piper Gulch Monzonite, quartzite, and Precambrian gneiss and chlorite schist are present.

Phenocrysts make up about half (40–60 percent) of the rock and are of uniform size (2–4 mm long) and of uniform relative proportion throughout the area; this characteristic is one of the most distinctive features of this member (fig. 42). In hand specimen, feldspars which have dull cleavage surfaces and which contain bronze to greenish-gray altered biotite are always seen to be abundant; and quartz, although seen to be some-

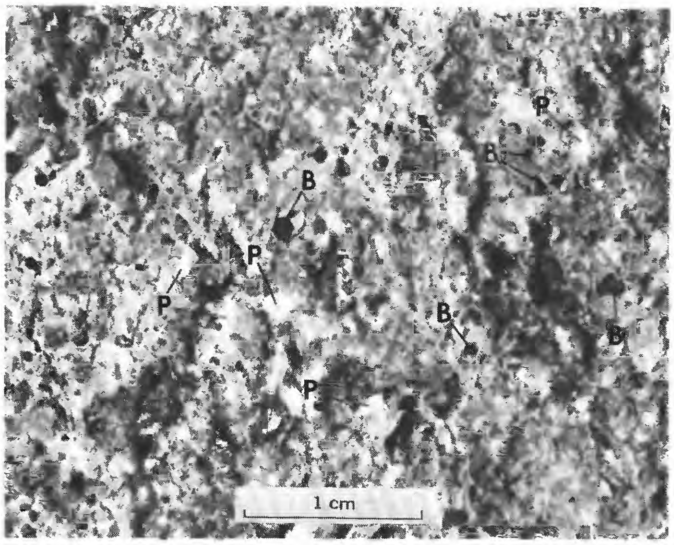


FIGURE 42.—Hand specimen of fairly unaltered rhyodacite of the welded-tuff member of the Salero Formation. The size and abundance of phenocrysts, especially of the biotite, are distinctive features of this rock. Biotite, B; plagioclase, P.

what less abundant than the other phenocrysts, is much more abundant than in the lower members.

In thin section, the laminar texture of alined crystals, crystal fragments, and devitrified pods is even more conspicuous than in the hand specimen. (Figure 42 was taken normal to the sheeting to show biotite books rather than the sheeting.) Although pumiceous fragments are flattened, the intensity of the compaction is only moderate. Thus, the shards, which are sparse and are best seen under magnification greater than that used in figure 42, are generally only slightly deformed. Plagioclase in two-thirds of the specimens is a sodic andesine (An=32–40), and in the remainder it is albitized. Biotite forms small euhedral crystals and deformed flakes, most of whose cores are altered to nontronite(?), penninite, or other chlorite, and whose rims are iron oxide. However, in a few specimens, the cores of biotite are unaltered and show a pleochroism in yellowish brown to dark brown, and in one specimen the biotite is sufficiently unaltered to be dated isotopically. Traces of magnetite and apatite are ubiquitous, traces of zircon common, and traces of sphene and a potassium feldspar sparse. One specimen contains a xenocryst of schorlitic tourmaline. Epidote, chlorite, sericite, clay minerals, iron oxide, leucoxene, and calcite are typical alteration minerals. The specimen shown in figure 43 is typical of rhyodacite of this unit, except that it contains xenocrysts of orthoclase of Jurassic granite. Other parts of the thin section of figure 43 also contain granite xenoliths. Modal analyses of typical specimens of welded tuff are presented in table

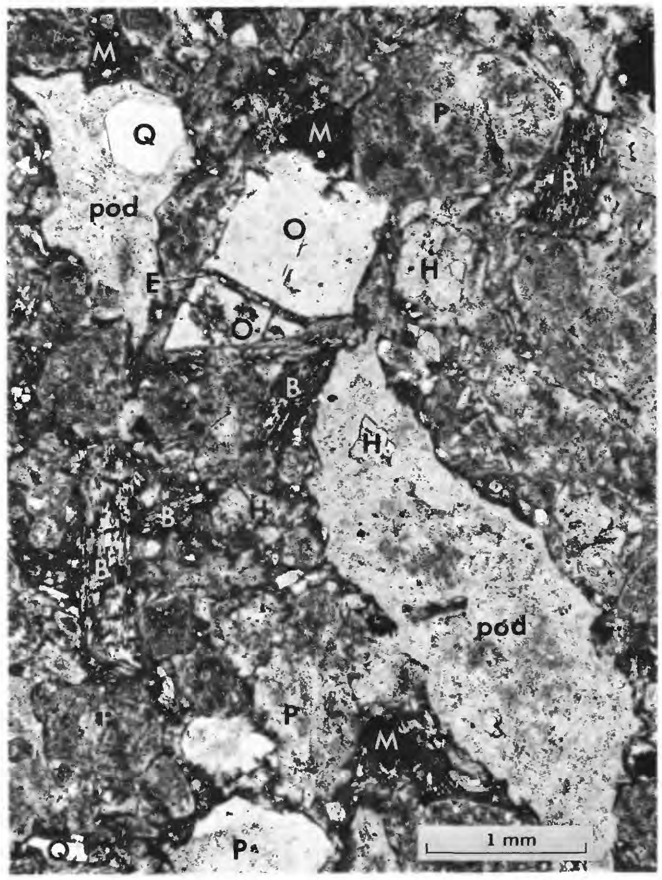


FIGURE 43.—Photomicrograph of rhyodacite from the welded-tuff member of the Salero Formation, showing compacted pumice(?) pods, a broken xenocryst of perthitic orthoclase (O) derived from the Squaw Gulch Granite, argillized plagioclase (P), quartz (Q), chloritized biotite (B), hornblende (H), magnetite (M), and epidote (E), all in a vitric groundmass. Plane-polarized light.

8. Chemical and spectrographic analyses of a specimen collected from the SE¼SE¼ sec. 17, T. 21 S., R. 14 E., and also isotopically dated are presented in table 7 (specimen 3). The chemical analysis resembles fairly closely that of Nockolds' (1954, p. 1014) average rhyodacite.

ARKOSE MEMBER

The arkose member consists of gently westward dipping arkosic rocks at least 500 feet thick that lie between the welded-tuff member and the granite terrane east of the tuff and that extend from Josephine Canyon southward to the Salero mine. A thin sheet of similar arkose commonly underlies adjacent parts of the welded tuff and is also intercalated in the basal part of the upper member, so that the stratigraphic interval occupied by the arkose is slightly greater than that occupied by the welded-tuff member. The arkose member unconformably overlies or laps against the Jurassic

TABLE 7.—*Chemical and spectrographic analyses and norms of members of the Salero Formation*

Specimen No.	1	[1]2		3
Field No.	65D680	66D1095		64D499
Member	Lower	Exotic block		Welded tuff
Chemical analyses (percent) [2]				
SiO_2	59.1	58.7	59.1	63.2
Al_2O_3	16.7	18.6	17.7	16.8
Fe_2O_3	3.6	6.1	5.9	2.7
FeO	2.9	.28	.22	1.2
MgO	2.8	2.4	2.6	.80
CaO	3.9	3.2	2.8	3.9
Na_2O	3.8	5.0	5.6	3.7
K_2O	3.5	2.7	2.8	3.4
H_2O-	.28	.22	.15	.80
H_2O+	1.8	1.1	1.3	1.5
TiO_2	.85	.80	.75	.47
P_2O_5	.30	.35	.36	.17
MnO	.25	.09	.07	.09
CO_2	.09	.30	.11	1.2
Total	100	100	99	100
Semiquantitative spectrographic analyses [3]				
B	0	0.005	0.01	0
Ba	.1	.1	.2	.15
Be	0	.0001	.00015	.0003
Ce	0	.01	.01	0
Co	.002	.0015	.002	.001
Cr	.001	.0005	.0005	.0015
Cu	.001	.0002	.0007	.0015
Ga	.001	.001	.002	.002
La	.003	.005	.007	.005
Mo	.0003	0	0	0
Nb	0	.002	.0003	0
Ni	<.003	<.003	.0003	.001
Pb	.005	.0001	.003	.0015
Sc	.001	.001	.0015	.001
Sr	.1	.07	.15	.1
V	.015	.003	.01	.01
Y	.0015	.0015	.0015	.002
Yb	.00015	.0001	.00015	.0002
Zr	.007	.015	.02	.01
Norms (percent)				
Q	11.537	10.674	7.291	22.894
C	.497	3.172	1.490	3.133
or	20.709	15.980	16.636	20.087
ab	32.196	42.376	47.643	31.292
an	16.841	11.712	10.903	10.649
hy {en	6.982	5.987	6.510	1.992
hy {fs	1.414	0	0	0
mt	5.226	0	0	2.799
hm	0	6.110	5.932	.770
il	1.616	.785	.617	.893
ru	0	.388	.429	0
ap	.711	.830	.857	.403
cc	.205	.683	.251	2.729
Total (rounded)	97.94	98.70	98.56	97.64

[1] Two columns of data represent analyses of two portions of the same specimen.
[2] Rapid rock analyses determined by methods described by Ward, Lakin, Canney, and others (1963) supplemented by atomic absorption methods. Analysts: Lowell Artis, Samuel Botts, P. L. D. Elmore, Gillison Chloe, H. Smith, and John Glenn.
[3] Results are reported in percent to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, and so forth, which represent approximate midpoints of group data on a geometric scale. The assigned group for semiquantitative results will include the quantitative value about 30 percent of the time. Elements looked for but not found: Ag, As, Au, Bi, Cd, Ge, Hf, Hg, In, Li, Nd, Pd, Pr, Pt, Re, Sb, Sm, Sn, Ta, Te, Th, Tl, U, W, and Zn. Analysts: W. B. Crandell, J. L. Harris, and A. L. Sutton.

TABLE 8.—*Modal analyses (in percent) of rhyodacite from the welded-tuff member of the Salero Formation*

Specimen No.	3	4	5	[1]5a
Field No.	63D499	64D608	64D641	64D641 (inclusions)
Quartz	1.5	1.1	2.3	5.0
Plagioclase	31.5	42.0	29.8	33.0
Orthoclase and perthite	0	0	0	5.0
Biotite	6.1	6.4	4.7	3.0
Amphibole	4.3	3.0	6.9	8.0
Magnetite	1.6	1.7	.8	1.0
Apatite	.1	.1	Trace	0
Zircon	.1	.1	Trace	0
Sphene	0	0	.1	Trace
Xenoliths and xenocrysts	[2].6	0	[1]15.6	---------
Groundmass	54.2	45.6	39.8	45.0
Total	100.0	100.0	100.0	100.0

[1] The xenoliths and xenocrysts of specimen 5 are tabulated in column 5a. The specimen probably contains more xenocrystic plagioclase than was recognized. The chief contaminant in the specimen is Jurassic granite, but volcanic contaminants are also present.
[2] Orthoclase.

Squaw Gulch Granite on a rugged surface that has been described above.

The basal part of the member and that part lapping against the granite consist of an arkosic sedimentary breccia whose fragments are wholly or predominantly made up of the granite. In the upper reaches of the two forks of Alto Canyon, the arkose also contains a few fragments of Piper Gulch Monzonite, and farther north in Bond Canyon it also contains a few clasts of volcanics and quartzite of the Mount Wrightson Formation. The fragments in the arkose are unsorted to poorly sorted, are angular, and commonly are 2–10 inches in diameter, but near Alto Canyon some sheets of sedimentary breccia contain blocks as much as 5 feet across.

In many places, the basal rocks are unsorted and seem to be a granite grus with little or no admixed tuff. A short disance above the basal rocks, beds of coarse gritty arkose alternate with conglomerate or fanglomerate. The arkose beds are relatively thin and few near the granite to the east, but within 1 mile west of the granite they thicken and are numerous. The conglomerate beds, in a complementary manner, thin equally rapidly westward, and their fragment size decreases. The westernmost tongues of conglomerate form the more conspicuous low cliffs along the front of the mountains just east of the Alto townsite; the intervening beds there are more friable units of arkosic sandstone.

Several groups of siltstone beds, each as much as 10 feet thick, are intercalated in the arkosic rocks north of the crest of the ridge at the Alto mines. These beds are distinctly anomalous to the general distribution pattern of coarser rocks to the east and finer ones to the west, and they appear to represent deposits of a very local environment. They are important, however, because in the NE¼SE¼SE¼ sec. 12, T. 21 S., R. 14 E., they contain fragments of plant fossils, which consist of grasslike or sedgelike material and of a narrow leaf. R. A. Scott (1966, written commun.,) reported the presence also of poorly preserved pollen of pine from a sample of this siltstone.

The matrix of most of the arkose contains greenish-gray tuff, and the proportion of tuff to granite detritus increases westward. Near the underlying granite to the east, some sedimentary breccia can be distinguished from the granite only where tuff separates the clasts. Farther west, near the Salero Ranch–Josephine Canyon road, tuff beds are intercalated with the sandstone. The mapped contact between the dominantly arkosic beds and the dominantly tuffaceous ones is broadly gradational, with some tuff beds appearing 1,000 feet farther east and a few tuffaceous sandstone and conglomerate beds appearing in the tuff 1,500 feet to the west.

Thin sections of the arkose member substantiate most of the megascopic features already described. The groundmass material is too strongly argillized to indicate the original composition of the volcanic components. However, the crystal fragments in the matrix are albitized plagioclase, potassium feldspar, chloritized biotite, magnetite, apatite, zircon, and leucoxene; and lithic fragments are at least as abundant as the crystal fragments. Secondary minerals include the usual sericite, chlorite, epidote, calcite, and a little quartz. Most likely the volcanic components were derived from the rhyodacite tuff.

Upper Member

Mixed sedimentary rocks and dacitic to rhyolitic volcanic rocks conformably overlying the welded-tuff member of the Salero Formation make up the upper member. These rocks crop out in three elongate areas: in the San Cayetano Mountains, southwest of the Salero mine, and on the ridge east of the Weatherhead Ranch (Drewes, 1971a). In each of these places, the rocks are too poorly exposed or their component units are too lenticular to establish a useful sequence or to provide a basis for calculation of their thickness. However, if the sequences are assumed to be virtually unfaulted, they are each estimated to be about 2,000–2,500 feet thick and possibly are even thicker. The rocks of the three areas are sufficiently similar that they may represent the same stratigraphic sequence, interrupted over short distances by a cover of younger volcanics or by a younger pluton. Additional small masses of wallrock, roof pendants, and inclusions in and around the pluton of Josephine Canyon Diorite between the Salero mine and Sonoita Creek are also correlated with the upper member.

The basal contact of the upper member appears to be conformable with the underlying welded-tuff member, but relations are nowhere fully clear. At the north end of the San Cayetano Mountains, this contact is a faulted bedding plane that lies at the base of a cliff-making sandstone and conglomerate unit. The movement on the fault is believed to be minor and the thickness of beds sheared out along the fault negligible, because the fault is probably a local structural feature that is associated either with the emplacement of a nearby small pluton or with stress adjustments that occurred during the gentle tilting of the San Cayetano fault block. One mile west of the Salero mine, poorly exposed flat-lying welded and unwelded tuff grades upward into tuffaceous conglomerate and sandstone that contain some intercalated tuff beds; the contact in that area is placed beneath the lowest fairly thick epiclastic beds. Northeast of the Weatherhead Ranch, the basal contact of the upper member is inferred to lap onto, or is faulted against, the Squaw Gulch Granite.

In the San Cayetano Mountains, the rocks of the upper member consists of interbedded tuff breccia, welded(?) tuff, volcanic breccia, sandstone, conglomerate, and sedimentary breccia, which make a southward-rising sequence that is interrupted and mildly hornfelsed by a thick sill of porphyritic latite and by a stock or cupola of Josephine Canyon Diorite. The individual volcanic units range in thickness from about 30 to 150 feet and together form less than 25 percent of the rock. They are most abundant near the middle of the sequence. Tuffs low in the sequence are dacitic; those higher in the sequence are rhyolitic. Fragments from a dacitic volcanic breccia low in the sequence contain amphibole, biotite, and accessory minerals much like those in the volcanics of the lower members of the Salero Formation. A pale-greenish-gray rhyolitic tuff breccia from near the middle of the sequence contains volcanic xenoliths and relict shards, as well as abundant phenocrysts of quartz, albite, and potassium feldspar, a few phenocrysts of chloritized biotite, and traces of magnetite, apatite, and zircon. This tuff resembles some of the tuff breccia high in the welded-tuff member, except that it contains more quartz.

Sedimentary rocks of the San Cayetano sequence are largely yellowish-brown sandstone and grit conglomerate; however, some beds are reddish gray, and the rocks range in coarseness from siltstone to cobble-bearing pebble conglomerate. Most of these beds contain tuffaceous material; some of them are subgraywacke and others are arkose. The clastic fragments are largely of local volcanic origin, but they also include much detritus derived from the Squaw Gulch Granite and a little derived from the volcanics of the Mount Wrightson Formation. A silty shale unit 10 feet thick on the southwest spur of Mount Shibell (NW¼-NE¼ sec. 24, T. 22 S., R. 13 E., unsurveyed) contains scraps of plant fossils that resemble pine needles. The rocks of this sequence are mildly metamorphosed; epidotization and chloritization increase southward, and hornfelsing is strongest in beds low along the east flank of the range and near Mount Shibell. The hornfelsed beds contain patches of red rocks, which suggests that they were originally a red-bed sequence whose red color was largely lost through the metamorphism.

The upper member southwest of the Salero mine also is composed of tuffaceous and arkosic sandstone, volcanic conglomerate and breccia, and tuff breccia. Coarse volcanic breccia is more abundant in that area than in the San Cayetano sequence, and red siltstone is absent. Drab-colored tuffaceous sandstone, as much as 700 feet thick, forms the lowest unit of this sequence. It appears to grade upward and laterally from the arkose member through a gradually diminishing admixture of granite detritus. These beds thin to the west, where they overlie the flat-lying tuff that caps the welded-tuff member.

A sheet of dacite tuff breccia and agglomerate as much as 1,400 feet thick overlies the tuffaceous sandstone with minor, and perhaps only a local, unconformity. North-northeast of Cinigita Tank (S½ sec. 25, T. 21 S., R. 14 E.), the breccia sheet is slightly discordant over the sandstone, but to the northeast it appears to be conformable. To the northwest, this contact is so poorly exposed that its position can be only estimated. Tuff breccia intertongues with the agglomerate, and the contacts between some of the larger tongues provide useful local marker horizons. One tuff breccia unit may be welded. Epiclastic beds likewise are intercalated in the upper part of the pyroclastic beds and seem to be more abundant to the east than to the west.

Petrographically, the volcanic sequence of the upper member near the Salero mine resembles that of the lower member, much as do the dacitic volcanics low in the San Cayetano sequence. They are commonly an altered plumose-patterned vitrophyre in which the phenocryst content is 30–40 percent. Most phenocrysts are no more than 3 mm long, but some are twice that length. The phenocryst content comprises abundant albitized plagioclase; several percent each of quartz, amphibole, and biotite; and traces of magnetite, apatite sphene, zircon, and, rarely, clinopyroxene. All the rocks are strongly argillized and contain sericite, epidote, chlorite, leucoxene, iron oxide, calcite, and possibly secondary quartz. The alteration is not noticeably more intense adjacent to the Josephine Canyon Diorite, which truncates and intrudes the eastern edge of this sequence, than it is away from that intrusive.

The sequence of the upper member exposed northeast of the Weatherhead Ranch consists largely of rhyodacite volcanics and intercalated feldspathic quartzite, which is faulted to the south and is altered by the Josephine Canyon Diorite to the north. In much of the area, beds dip gently south to west, but in the faulted part they commonly dip more than 45° to the south and locally are upended. To the north, the lowest unit of the sequence is a subtly layered rholitic flow, which is overlain by 30 feet of white metaquartzite and then 30–50 feet of brownish-gray quartzite. Under the microscope, the white quartzite is seen to consist of partly interlocking quartz grains, iron oxide, zircon and an argillic material that makes up about 30 percent of the rock. Zones of sheared and recrystallized quartz also indicate that the quartzite is considerably deformed. Strongly altered volcanics, probably a tuff breccia, overlie the quartzite, and these are overlain by hornfelsed arkosic sandstone and a little conglomerate which contains pebbles of Squaw Gulch Granite. More strongly altered volcanics, which wedge out southeastward, and another lens of quartzite overlies the conglomerate. The middle of the sequence northeast of Weatherhead Ranch is largely light-brownish-gray to pale-purplish-gray rhyolitic to dacitic lava that contains several small lenses of quartzite, sandstone, and conglomerate. Under the microscope, the lava is seen to consist of strongly altered feldspar remnants, zircon, sericite, schorlitic tourmaline, chlorite, iron oxide, and abundant clay minerals. The upper part of the Weatherhead Ranch sequence is epiclastic, consisting of tuffaceous sandstone overlain by conglomerate. The clasts from low in the conglomerate are largely of volcanics of the Salero Formation, granite debris increases toward the top, and scattered clasts resemble the strongly laminated volcanics of the Mount Wrightson Formation.

Most of the wallrock remnants, roof pendants, and inclusions in the Josephine Canyon Diorite south and west of the Weatherhead Ranch are arkosic sandstone, conglomerate, and quartzite that bear a close resemblance to the rocks of the Weatherhead Ranch sequence of the upper member.

AGE AND CORRELATION

The Salero Formation is isotopically dated as late Late Cretaceous, an age which fits the geologic relations and isotopic ages of other rocks. Biotite that is sufficiently unaltered so that it is datable was concentrated from the analyzed specimen from the welded-tuff member (table 7, specimen 3). According to H. H. Mehnert, R. F. Marvin, and Wayne Montjoy (Drewes, 1968, p. C12), this biotite has a potassium-argon age of 72.5±2.2 m.y. The Salero Formation is geologically dated as post-Fort Crittenden Formation and pre-Josephine Canyon Diorite. Inasmuch as the Fort Crittenden is dated by fossils as late(?) Late Cretaceous and the Josephine Canyon Diorite is isotopically dated as latest Late Cretaceous (Drewes, 1968, p. C12), the age of the Salero is substantiated as late Late Cretaceous.

Rocks that have a composition and age generally similar to those of the Salero Formation are relatively widespread in southeastern Arizona. The key units are an underlying dacitic to andesitic breccia and an overlying rhyodacitic to rhyolitic tuff; they may include unwelded rocks and possibly even hypabyssally intruded tuff. The Salero-like rocks near the Santa Rita Mountains may be closely correlative volcanics, some of which may even have been extruded from the same vent or vents as the type Salero rocks; those in more distant mountains almost certainly were extruded from separate vents and merely reflect a comparable stage of development of the widespread magmatic phase of the Laramide orogeny.

Fairly close to the Santa Rita Mountains and to the southeast in the Flux Canyon area of the Patagonia Mountains and about 1 mile south of the southeast corner of the Mount Wrightson quadrangle, dacitic breccias contain exotic blocks. The largest of these blocks is the body of Paleozoic limestone at the Flux mine, but many of the small blocks resemble the volcanics of the Mount Wrightson Formation. These dacitic breccias are probably correlative with the exotic-block member of the Salero Formation, and although they undoubtedly were extruded from separate vents, the vents probably were on the same major structural feature (Drewes, unpub. data).

The rocks on the first hills east of Sonoita Creek and roughly 4–5 miles northeast of Patagonia resemble the welded-tuff member of the Salero Formation. Similar rocks, which overlie andesitic volcanics, were also mapped along the southwest flank of the Canelo Hills by R. B. Raup (oral commun., 1967). Likewise, the biotite-rich tuff of the volcanic and sedimentary rocks of Jones Mesa, which is isotopically dated 72 m.y. (R. B. Raup, unpub. data), and their underlying andesitic volcanics are thought to be correlative with the welded-tuff and exotic-block members, respectively.

At the northeast end of the Santa Rita Mountains, there are also some rhyodacite welded tuffs of late Late Cretaceous age that are indistinguishable from the welded-tuff member. Some of the andesitic rocks in the lowlands between this end of the mountains and the Empire Mountains may be correlative with the lower members of the Salero.

In the Sierrita Mountains, 15 miles to the west, J. R. Cooper (oral commun., 1967) mapped andesitic volcanics along Demetrie Wash and an overlying rhyolite tuff at Red Boy Peak. These rocks are believed to be correlative with the lower three members of the Salero.

In the Tucson Mountains, about 40 miles to the northwest, Brown (1939) and Kinnison (1958) mapped a thick sequence of rocks of late Late Cretaceous age: the Silver Bell Formation (Wood, 1959), which is an andesitic breccia that contains exotic blocks, and the overlying Cat Mountain Rhyolite (Brown, 1939), which is a welded tuff whose plagioclase was isotopically dated as about 65–70 m.y. by Bikerman and Damon (1966, p. 1232). In the Roskruge Range, 15 miles west of the Tucson Mountains, Bikerman (1967, p. 1032) dated the upper part of his Roskruge Volcanics, which resemble the Cat Mountain Rhyolite, as 66–72 m.y. by several isotopic methods that made use of several minerals. Of these, the potassium-argon age on biotite gives the oldest age and plagioclase the youngest age, an age that is virtually the same as that of the plagioclase of the Cat Mountain Rhyolite.

In the vicinity of Tombstone, about 30 miles east of the Santa Rita Mountains, at least some of the Uncle Sam Porphyry (Gilluly, 1956, p. 94–101) appears to be a welded tuff whose phenocryst type and abundance and whose widespread chloritization resemble those characteristics of the welded-tuff member of the Salero. A specimen of the Uncle Sam Porphyry collected from the west edge of the outcrop area, about 2 miles south of Arizona Highway 82 and 3 miles west of the San Pedro River, however, contains fresh biotite which was dated by the potassium-argon method as 71.9±2.4 m.y. by R. F. Marvin, H. H. Mehnert, and V. M. Merritt (written commun., 1968).

The Sugarloaf Quartz Latite (Gilluly, 1956, p. 90–92) also resembles the welded-tuff member of the Salero. Biotite obtained from the north spur of the type area at Sugarloaf Hill near Gleeson (fig. 1) was given an isotopic potassium-argon age of 72.8±2.5 m.y. by R. F. Marvin, H. H. Mehnert, and V. M. Merritt (written commun., 1969).

ENVIRONMENT OF DEPOSITION AND ORIGIN

Several aspects of the rocks of the Salero Formation indicate that they are orogenic deposits. The relief on the basal unconformity, the size of the clasts in the arkose member, and possibly also the presence of exotic blocks indicate deposition by high-energy agents. Even more indicative is the close temporal association of the deposition of the Salero with both the development of large structural features and the emplacement of plutons. Although the structural and plutonic topics are scheduled for discussion in collateral articles, a few of the conclusions bearing on the origin and emplacement of the Salero Formation are introduced here to indicate the extent of support that is available for the interpretation that the Salero is an orogenic deposit.

During early Salero time, the report area was locally rugged. The coarseness of the clasts in the sedimentary breccia of the arkose member that lies upon the granitic terrane indicates that deposition occurred at the foot of a high area. The coarsest arkose does not form only a widespread basal sheet but commonly intertongues with finer deposits throughout a thick stratigraphic sequence, which further suggests that the relief was at least maintained throughout the time of deposition of the arkose member. Similarly, the unconformity beneath the arkose member is an irregular surface interpreted as a paleotopography of deep canyons and rugged knobs or spurs. In the Cottonwood–Montosa Canyons area, where volcanics form the lowest member of the Salero and where there is no direct indication of the amount of the local relief, some rocks may have accumulated in a local basin and may include some rocks that were not deposited subaerially. Around Josephine Canyon, where the exotic-block member forms the basal deposits of the Salero, the surface underlying the member is believed to have sloped southwestward, because the most probable source of the exotic blocks lies to the northeast and the mode of transport probably was gravity controlled.

At the first stage of development of the volcanic complex of the Salero, the magma present near or at the surface had about the composition of dacite. A little of this magma may have breached the surface to form normal lava flows, such as those along the lower reaches of Montosa Canyon. Most of the magma, however, is suspected to have had a different history, one that was more violent but apparently not unique to the Santa Rita Mountains, as judged from the occurrence of exotic block deposits of the Salero type in the rocks of the Tucson and Patagonia Mountains and perhaps also farther to the east.

Three features of the dacitic rock itself are especially pertinent to the mode of origin of the rock. First, fragmentation and pulverization of the matrix to the exotic blocks is pervasive. Clearly the mode of origin involved the release of a vast amount of energy. Together with the absence of any signs of sorting or layering, aside from the local capping wedge of tuffaceous(?) exotic-bearing rock, the pulverization further indicates a highly turbulent movement. Second, the type of intricate penetration of the pulverized but fluid mass of rock (or semisolid magma?) into the dacitic fragments of the matrix, as well as into some of the exotic blocks, suggests that the mass was either corrosive or was under considerable pressure, or both. A permissive penetration of shattered fragments would produce a much sharper and more reticulate pattern of penetration than has been seen. Apparently then, the dacite complex was not deposited in a normal surface environment as a volcanic breccia flow. Third, the groundmass of the pulverized matrix and of the matrix of the chips within the dacitic fragments is finely crystallized, and the rock is pervasively epidotized and sericitized. Apparently, after extrusion, the pulverized dacitic rock was still sufficiently hot and contained sufficient fluids to result in this fine crystallization and intensive alteration.

Four features of the rocks and structural features which are adjacent to the dacitic complex are also pertinent to the mode of origin of the dacite:

1. The lack of sorting of the exotic blocks with respect to each other suggests turbulent transport. The lithologic diversity of the blocks makes it difficult to picture them as having been plucked from the wall of a conduit, although some blocks may have been derived in this manner, because stratigraphic sections sufficiently complete to provide this diversity are not found. The indication of a fairly high pressure environment also makes it difficult to believe that the blocks were plucked from the base of a postulated surface flow or resulted from an infalling of landslide debris into such a flow. But the wide assortment of exotic blocks coupled with the suggestion of high pressure is fairly compatible with a postulated origin of foundering of the roof of a shallow intrusive body.
2. Another local field relation of the dacitic complex, however, does suggest that a surface environment caused a little contamination. In the area where the exotic-block member lies unconformably upon the Squaw Gulch Granite, granite grus has been incorporated into the base of the dacite breccia. Furthermore, the breccia rests upon the old surface itself, so that in places it appears to have been an extrusive mass.
3. The differences in the structural relations of the dacitic complex and of the overlying rhyodacite welded tuff to the rocks lying to the northwest are also instructive but are only summarized here. The dacitic rock is separated from adjacent Mesozoic and Paleozoic sedimentary rocks by a tear fault, whereas the welded tuff flowed against these rocks. The Paleozoic rocks moved over the

lower Mesozoic rocks on a thrust fault that abuts into, and does not appear beyond, the tear fault. At least some of the movement on the thrust is thus coeval with movement on the tear fault. These observations indicate that the faulting must be older than, or of the same age as, the cooling of the welded tuff. The thrust plate contains the entire suite of Paleozoic formations. A few miles northwest of the tear fault, the plate also contains volcanics of the Mount Wrightson Formation and red beds, probably both of Triassic age, and volcanics of the Fort Crittenden Formation; this is an assortment of formations such as those that occur as exotic blocks in the dacitic complex. The important point, though, is that some thrust faulting is virtually contemporaneous with the formation of the dacitic complex.

4. The geologic relations of the volcanic complex to the adjacent plutonic rocks must be considered. Immediately northeast of the Salero Formation lie several large plutons of Triassic, Jurassic, and Late Cretaceous ages, the youngest of which intrudes the Salero Formation. These plutons were emplaced along a major structural zone that trends northwestward across the mountains and had been active at least since Triassic time. Of the several Late Cretaceous plutons, the slightly older Josephine Canyon Diorite and Madera Canyon Granodiorite and the slightly younger quartz monzonite of Quantrell and Elephant Head stocks, all dated as about 68 m.y. old, are of special interest here. The change from a magma that first produced dioritic rock to a magma that produced quartz monzonitic rock parallels the change from a magma that first produced dacitic volcanics to one that produced the rhyodacitic volcanics, a change that occurred about 72 m.y. ago. Apparently then, at the present level of exposure, two magmas were active during an interval of time lasting at least 4 m.y. The earliest magma to penetrate the rocks reached the surface and became part of the wallrocks and roof rocks for the magma masses that moved upward slightly later. The details of the plutonic development and the ramifications of the situation outlined here are to be the objective of a planned companion paper to this series of reports; but of importance to explaining the origin of the dacitic complex are the indications that two magmas apparently were available near the surface for a considerable time.

The separate pieces of the volcano-tectonic picture described above may now be assembled to show how I believe the exotic-block member may have been formed. During pre-Salero time, the region was uplifted and deeply eroded so that much of the southern part of the area was largely stripped to the level of the large Jurassic granite pluton. The remaining cover of bedded rocks of Mesozoic and Paleozoic age to the north was thrust faulted (perhaps as a surface thrust), and the upper plate was broken into two segments by a northeast-trending tear fault. Dacitic-dioritic magma was injected as a sill beneath the southern segment of the upper plate, and locally the magma reached the surface. The roof of the sill, however, became unstable, perhaps as a result of a continued rising of the area that shortly thereafter became the site of intrusion of the Late Cretaceous plutons, and the roof shifted downslope toward the southwest. The sudden release of pressure on the magma in the sill produced a flash degassing; as a result, the semisolid body was fluidized and was thus enabled to flow southwestward with great rapidity and turbulence. Movement of the northern segment of the thrust plate continued up to this time to produce the tear fault between the rapidly cooling dacitic complex and the plate of Paleozoic rocks. The distal end of the dacitic sill became a surface flow, and some granite grus was incorporated in it as it moved over the ancient hilly topography.

The sudden relaxation of pressure in the upper part of the dacitic-dioritic magma conduit system may have triggered the rapid upward movement of the rhyodacite–quartz monzonite magma to bring about the outpouring of rhyodacite tuff. The wide distribution of the rhyodacite tuff in a mountainous terrain suggests that the tuff was ejected with considerable explosive force; the large volume of the tuff and the absence of intercalated bedded units suggest that it probably was a composite air-fall tuff which formed a single cooling unit. The southern part of the air-fall tuff may have been deposited farthest from the vent or may have been thinnest, because it remained unwelded and graded laterally into epiclastic deposits. After this rapid and violent volcanism, abundant epiclastic material and some additional pyroclastics were deposited at least in the southern part of the area.

REFERENCES CITED

Anderson, C. A., 1951, Older Precambrian structure in Arizona: Geol. Soc. America Bull., v. 62, no. 11, p. 1331–1346.

Bikerman, Michael, 1967, Isotopic studies in the Roskruge Mountains, Pima County, Arizona: Geol. Soc. America Bull., v. 78, no. 8, p. 1029–1036.

Bikerman, Michael, and Damon, P. E., 1966, K/Ar chronology of the Tucson Mountains, Pima County, Arizona: Geol. Soc. America Bull., v. 77, no. 11, p. 1225–1234.

Brown, W. H., 1939, Tucson Mountains, an Arizona basin range type: Geol. Soc. America Bull., v. 50, no. 5, p. 697–760.

Bryant, D. L., 1968, Diagnostic characteristics of the Paleozoic formations of southeastern Arizona, *in* Titley, S. R., ed., Arizona Geol. Soc. Guidebook 3, Southern Arizona, 1968: p. 33–47.

Bryant, D. L., and McClymonds, N .E., 1961, Permian Concha Limestone and Rainvalley Formation, southeastern Arizona: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 8, p. 1324–1333.

Cooper, J. R., 1970, Preliminary geologic map of the Twin Buttes quadrangle, Pima County, Arizona: U.S. Geol. Survey open-file report.

Cooper, J. R., and Silver, L. T., 1964, Geology and ore deposits of the Dragoon quadrangle, Cochise County, Arizona: U.S. Geol. Survey Prof. Paper 416, 196 p.

Creasey, S .C., 1967, Geologic map of the Benson quadrangle, Cochise and Pima Counties, Arizona: U.S. Geol. Survey Misc. Geol. Inv. Map I–470.

Drewes, Harald, 1966, Road log for southern Santa Rita Mountains, Santa Cruz and Pima Counties, Arizona: U.S. Geol. Survey open-file report, 6 p.

——— 1967, A geochemical anomaly of base metals and silver in the southern Santa Rita Mountains, Santa Cruz County, Arizona, *in* Geological Survey research 1967: U.S. Geol. Survey Prof. Paper 575–D, p. D176–D182.

——— 1968, New and revised stratigraphic names in the Santa Rita Mountains of southeastern Arizona: U.S. Geol. Survey Bull. 1274–C, 15 p.

——— 1969, The Laramide orogeny of Arizona southeast of Tucson, *in* Abstracts for 1968: Geol. Soc. America Spec. Paper 121, p. 501.

——— 1970, Structural control of geochemical anomalies at Greaterville, southeast of Tucson, Arizona: U.S. Geol. Survey Bull. 1312–A, 49 p.

——— 1971a, Geologic map of the Mount Wrightson quadrangle, southeast of Tucson, Santa Cruz and Pima Counties, Arizona: U.S. Geol. Survey Misc. Geol. Inv. Map I–614 (in press).

——— 1971b, Geologic map of the Sahuarita quadrangle, southeast of Tucson, Pima County, Arizona: U.S. Geol. Survey Misc. Geol. Inv. Map I–613 (in press).

Drewes, Harald, and Finnell, T. L. (leaders), 1968, Mesozoic stratigraphy and Laramide tectonics of part of the Santa Rita and Empire Mountains southeast of Tucson, Arizona, Field Trip 2, *in* Titley, S. R., ed., Arizona Geol. Soc. Guidebook 3, Southern Arizona, 1968: p. 315–324.

Dumble, E. T., 1902, Notes on the geology of southeastern Arizona: Am. Inst. Mining and Metall. Engineers Trans., v. 31, p. 696–715.

Epis, R. C., 1956, Geology of the Pedregosa Mountains, Cochise County, Arizona: California Unv. unpub. Ph. D. thesis.

Feth, J. H., 1948, Permian stratigraphy and structure, northern Canelo Hills, Arizona: Am. Assoc. Petroleum Geologists Bull., v. 32, no. 1, p. 82–108.

Finnell, T. L., 1970, Preliminary geologic map of the Empire Mountains quadrangle, Pima County, Arizona: U.S. Geol. Survey open-file report.

Gilluly, James, 1956, General goelogy of central Cochise County, Arizona, *with sections on age and correlation* by A. R. Palmer, J. S. Williams, and J. B. Reeside, Jr.: U.S. Geol. Survey Prof. Paper 281, 169 p.

Hayes, P. T., and Drewes, Harald, 1968, Mesozoic sedimentary and volcanic rocks of southeastern Arizona, *in* Titley, S. R., ed., Arizona Geol. Soc. Guidebook 3, Southern Arizona, 1968: p. 49–58.

Hayes, P. T., and Landis, E. R., 1961, Lower member of Mural limestone of Early Cretaceous age, Bisbee quadrangle, Arizona, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–B, p. B125–B127.

——— 1964, Geologic map of the southern part of the Mule Mountains, Cochise County, Arizona: U.S. Geol. Survey Misc. Geol. Inv. Map I–418.

Hayes, P. T., and Raup, R. B., 1968, Geologic map of the Huachuca and Mustang Mountains, southeastern Arizona: U.S. Geol. Survey Misc. Geol. Inv. Map I–509.

Hayes, P. T., Simons, F. S., and Raup, R. B., 1965, Lower Mesozoic extrusive rocks in southeastern Arizona—The Canelo Hills Volcanics: U.S. Geol. Survey Bull. 1194–M, 9 p.

Heatwole, D. A., 1966, Geology of the Box Canyon area, Santa Rita Mountains, Pima County, Arizona: Arizona Univ. unpub. M. S. thesis, 70 p.

Kinnison, J. E., 1958, Geology and ore deposits of the southern section of the Amole Mining district, Tucson Mountains, Pima County, Arizona: Arizona Univ. unpub. M.S. thesis.

Lootens, D. J., 1965, Structure and petrography of the east side of the Sierrita Mountains, Pima County, Arizona: Dissert, Abs., v. 26, no. 4, p. 2135.

Miller, H. W., Jr., 1964, Cretaceous dinosaurian remains from southern Arizona: Jour. Paleontology, v. 38, no. 2, p. 378–384.

Nockolds, S. R., 1954, Average chemical compositions of some igneous rocks: Geol. Soc. America Bull., v. 65, no. 10, p. 1007–1032.

Ransome, F. L., 1904, The geology and ore deposits of the Bisbee quadrangle, Arizona: U.S. Geol. Survey Prof. Paper 21, 168 p.

Schafroth, D. W., 1965, Structure and stratigraphy of the Cretaceous rocks south of the Empire Mountains, Pima and Santa Cruz Counties, Arizona: Arizona Univ. unpub. Ph. D. thesis.

Schrader, F. C., 1915, Mineral deposits of the Santa Rita and Patagonia Mountains, Arizona, with contributions by J. M. Hill: U.S. Geol. Survey Bull. 582, 373 p.

Silver, L. T., 1969, Precambrian batholiths of Arizona, *in* Abstracts for 1968: Geol. Soc. America Spec. Paper 121, p. 558–559.

Simons, F. S., Raup, R. B., Hayes, P. T., and Drewes, Harald, 1966, Exotic blocks and coarse breccias in Mesozoic volcanic rocks of southeastern Arizona, *in* Geological Survey research 1966: U.S. Geol. Survey Prof. Paper 550–D, p. D12–D22.

Stoyanow, Alexander, 1949, Lower Cretaceous stratigraphy in southeastern Arizona: Geol. Soc. American Mem. 38, 169 p.

Taliaferro, N. L., 1933, An occurrence of Upper Cretaceous sediments in northern Sonora, Mexico: Jour. Geology, v. 41, no. 1, p. 12–37.

Tyrrel, W. W., Jr., 1957, Geology of the Whetstone Mountain area, Cochise and Pima Counties, Arizona: Yale Univ. unpub. Ph. D. thesis.

Ward, F. N., Lakin, H. W., Canney, F. C., and others, 1963, Analytical methods used in geochemical exploration by the U.S. Geological Survey: U.S. Survey Bull. 1152, 100 p.

Wilson, E. D., Moore, R. T., and O'Haire, R. T., 1960, Geologic map of Pima and Santa Cruz Counties, Arizona: Arizona Bur. Mines.

Wood, P. A., 1959, Tertiary deposits in southern Arizona: Arizona Geol. Soc. Guidebook, p. 58–59.

INDEX

[Italic page numbers indicate major references]

U. S. GOVERNMENT PRINTING OFFICE : 1971 O - 404-482