Mesozoic Stratigraphy of the Sierrita Mountains, Pima County, Arizona

GEOLOGICAL SURVEY PROFESSIONAL PAPER 658-D

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By JOHN R. COOPER

MESOZOIC STRATIGRAPHY IN SOUTHEASTERN ARIZONA

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Descriptive stratigraphy of more than 20,000 feet of Triassic, Jurassic, and Cretaceous terrestrial volcanic and sedimentary rocks

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MESOZOIC STRATIGRAPHY OF THE SIERRITA MOUNTAINS, PIMA COUNTY, ARIZONA

By JOHN R. COOPER

ABSTRACT

Mesozoic rocks in the Sierrita Mountains, Pima County, Ariz., comprise more than 20,000 feet of terrestrial sedimentary and volcanic rocks and are divided into eight formations. Three formations are newly named in this report. These eight formations are not all found at any one place, however, and none has yielded closely datable fossils. Local geologic relations, radiometric age determinations, and regional correlations suggest that three of the formations are Triassic, one is Upper Triassic or Lower Jurassic, one is Lower Cretaceous(?), one is Lower Cretaceous, and two are Upper Cretaceous.

The lower Mesozoic formations are the Ox Frame Volcanics, Tascuela Redbeds, Rodolfo Formation, and Stevens Mountain Rhyolite. The oldest formation, the Ox Frame Volcanics, is at least 5,000 feet thick and is divisible into three members: a lower silicic member, which consists predominantly of massive rhyolitic flows in the core of the mountains and rhyolitic and rhyodacitic tuffs and tuff-breccias in the western foothills; a middle andesitic member, which consists predominantly of flows of dark porphyritic andesite; and an upper silicic member, which is characterized by rhyolitic welded tuffs and flows containing intercalated lenses of quartzite and, particularly in the western foothills, volcanic sandstone and conglomerate. Sedimentary interbeds are present locally but are scarce in the middle and lower members except in a unit of rhyolitic tuff, conglomerate, and slate that probably is the basal unit of the formation. This unit is found only within a fault block in the western foothills, where it lies unconformably on Paleozoic carbonate rocks. The upper contact of the formation in the western foothills is a disconformity at the base of the Tascuela Redbeds. Elsewhere the Ox Frame is bounded by faults, by intrusive igneous rocks that range in radiometric age from 190 to 56 million years, and by unconformably overlying Upper Cretaceous and Cenozoic rocks.

The Tascuela Redbeds and Stevens Mountain Rhyolite are exposed in the western foothills of the mountains and are each as much as 2,000 feet thick. The Tascuela lies disconformably on the Ox Frame Volcanics and generally has a basal conglomerate, 0–200 feet thick, composed of pebbles and cobbles of the Ox Frame Volcanics and Paleozoic limestone, quartzite, and chert in a matrix of red silty to sandy mudstone. The conglomerate grades upward into a sequence, 1,600–1,800 feet thick, composed of red shale, argillite, and sparse interbeds of quartzite, sandstone, and sandy limestone. The Stevens Mountain Rhyolite lies with apparent conformity on the Tascuela Redbeds and consists of a lower volcanic conglomerate unit tens to hundreds of feet thick overlain by rhyolitic crystal tuffs, welded tuffs, and flows which contain a few lenticular interbeds of sandstone and quartzite. The Stevens Mountain Rhyolite is overlain with major unconformity by the Demetrie Volcanics.

The Rodolfo Formation (new), a sequence of red beds and volcanic rocks, overlies Paleozoic rocks and underlies the Whitcomb Quartzite in the pediment east of the Sierrita Mountains. The formation is at least 2,400 feet thick and is divisible into three members. The basal member, at most about 70 feet thick, lies unconformably on the Rainvalley Formation of Permian age and consists of coarse-grained grayish-orange sandstone and conglomerate composed largely of fragments of Paleozoic chert, quartzite, and limestone. The middle member, at least 1,300 feet thick, is made up of siltstone, a small amount of sandstone, and conglomerate—all grayish red except in metamorphosed or hydrothermally altered areas where they are mostly medium gray. The conglomerate and sandstone in the lower part of this member are generally clean silica-cemented rocks containing fragments of the Ox Frame Volcanics, whereas rocks near the top are generally andesitic graywacke and conglomerate of intraformational source. The upper member, 200 to nearly 1,100 feet thick, has an interfingering lower contact with the upper part of the middle member and consists of a thick lower unit of andesitic breccia, which locally contains two thin beds of much-altered rhyolitic tuff, and an upper unit of red beds and andesitic flows. The lower and middle members of the Rodolfo Formation are correlated with the Tascuela Redbeds; the upper member may be correlative with the Stevens Mountain Rhyolite.

The Whitcomb Quartzite (new) lies disconformably on the Rodolfo Formation west of Helmet Peak and consists of 300–600 feet of yellowish-gray fine- to medium-grained orthoquartzite which contains lenses of light-gray, well-indurated rhyolitic tuff in the upper part. The Whitcomb is overlain

disconformably by the Angelica Arkose near the type localities of the two formations, but the contact is gradational and conformable in an isolated exposure about 5 miles to the east. Because of the locally gradational contact and also the presence in the Angelica Arkose of quartzite beds similar in lithology to the Whitcomb, the Whitcomb Quartzite is assigned to the Lower Cretaceous(?) with recognition of the possibility that the formations in the isolated outcrop have been misidentified and that the Whitcomb could be a pre-Cretaceous equivalent of the Stevens Mountain Rhyolite.

The Angelica Arkose (new) overlies the Whitcomb Quartzite and is a thick Lower Cretaceous sequence of interbedded feldspathic sandstone, siltstone, conglomerate, and a little quartzite and limestone. A basal conglomerate unit, locally more than 500 feet thick, contains pebbles and cobbles of various Mesozoic and Paleozoic formations. The succeeding unit, as much as 2,000 feet thick, consists of interbedded siltstone and well-sorted arkosic sandstone in sharply defined beds mostly less than 2 feet thick. Overlying this unit with sharp but interfingering contact is a thick-bedded unit as much as 3,000 feet thick that is characterized by coarse-grained ill-sorted arkosic grit and pebble conglomerate containing recognizable fragments of Jurassic granite. Locally the grit unit contains a thick quartzite bed and sparse lenticular beds of limestone. It is overlain with angular unconformity by the Demetrie Volcanics.

Upper Cretaceous rocks comprise the Demetrie Volcanics and the Red Boy Rhyolite. The Demetrie Volcanics, a sequence of andesitic and dacitic breccias and flows having a local basal conglomerate and two intercalated rhyolitic tuff units, lies with angular unconformity on formations as old as the Ox Frame Volcanics and as young as the Angelica Arkose. The Demetrie is apparently about 8,000 feet thick south of the Sierrita Mountains, but it wedges out beneath the Red Boy Rhyolite in the core of the mountains. The Red Boy Rhyolite is 700 to perhaps 1,000 feet thick and consists of nonwelded and welded rhyolitic tuffs and tuff-breccias and minor rhyolitic flows. The formation lies unconformably on the Demetrie Volcanics, on Jurassic and Triassic(?) intrusive rocks, and on the Ox Frame Volcanics. South of the mountains the Red Boy is overlain unconformably by gravels and volcanic rocks of middle Tertiary age.

INTRODUCTION

The Sierrita Mountains are about 25 miles southwest of Tucson, Ariz., within the Twin Buttes and Palo Alto Ranch quadrangles. (See fig. 1.) An index map of the Sierrita Mountains region is shown in figure 2. This report deals principally with the Twin Buttes quadrangle, where I started fieldwork in 1957, but it also contains information obtained during my reconnaissance mapping of the Palo Alto

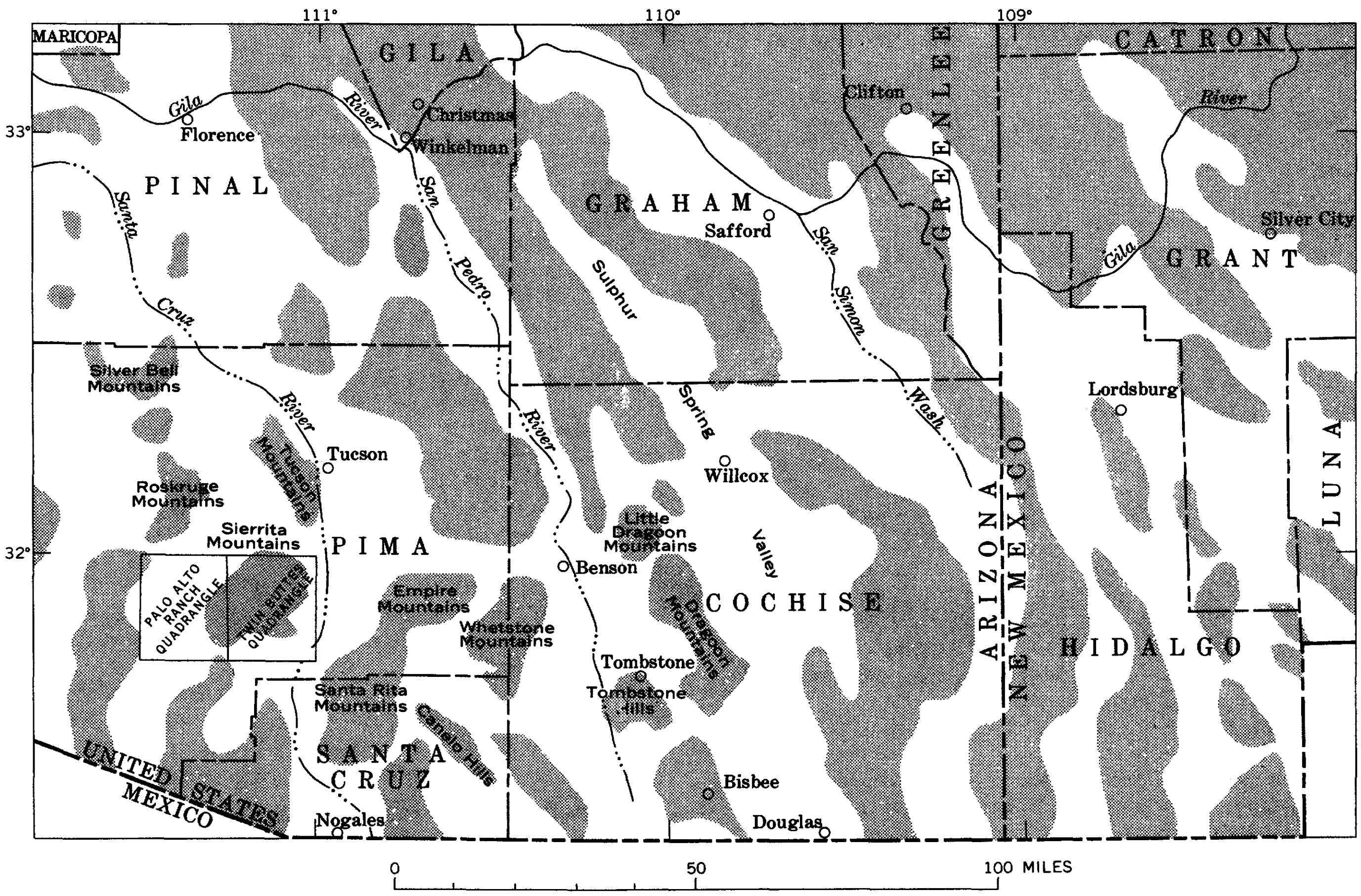


FIGURE 1.—Map of southeastern Arizona and southwestern New Mexico showing location of study region.

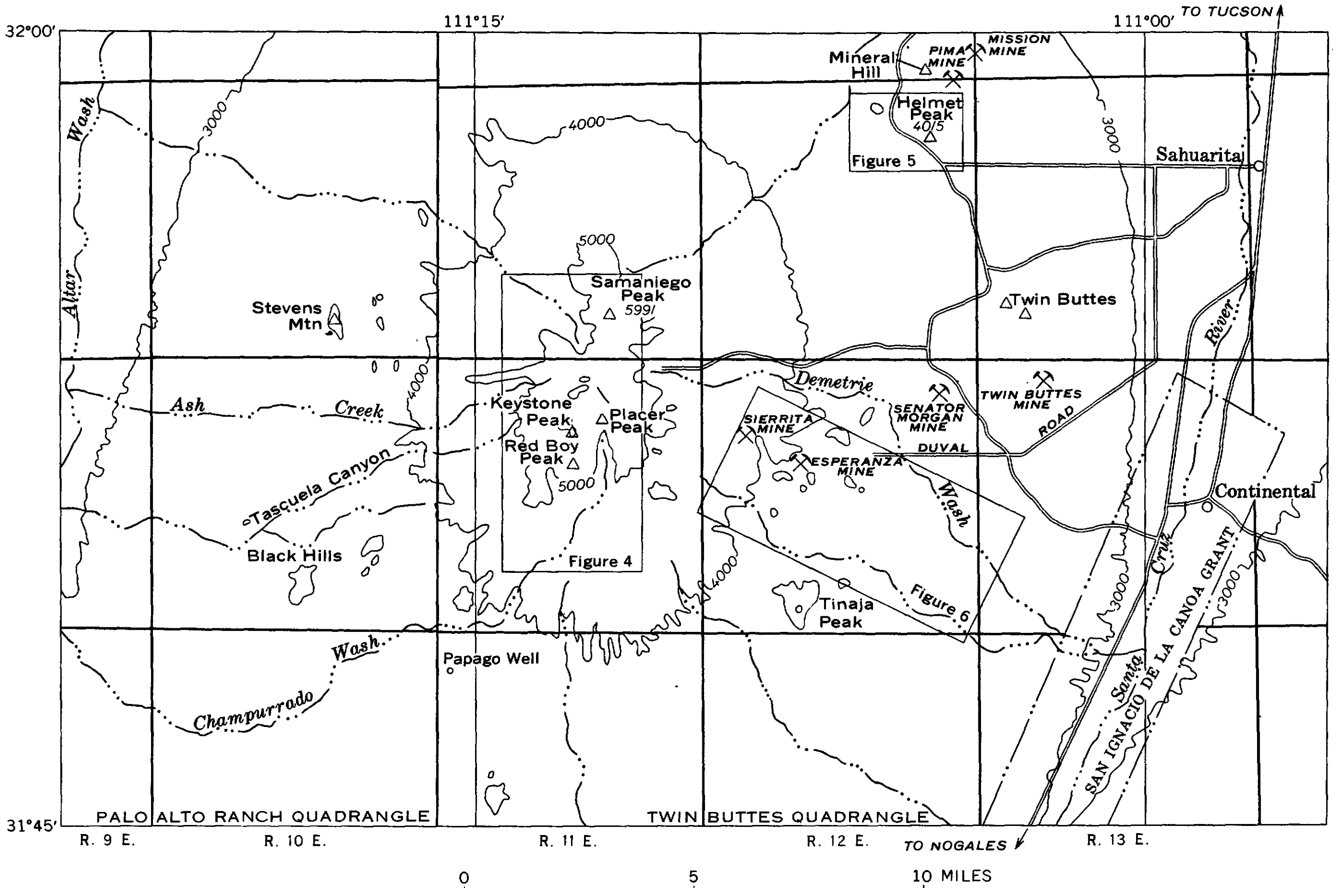


FIGURE 2.—Index map of the Sierrita Mountains region showing areas of figures 4–6. Contour interval 1,000 feet.

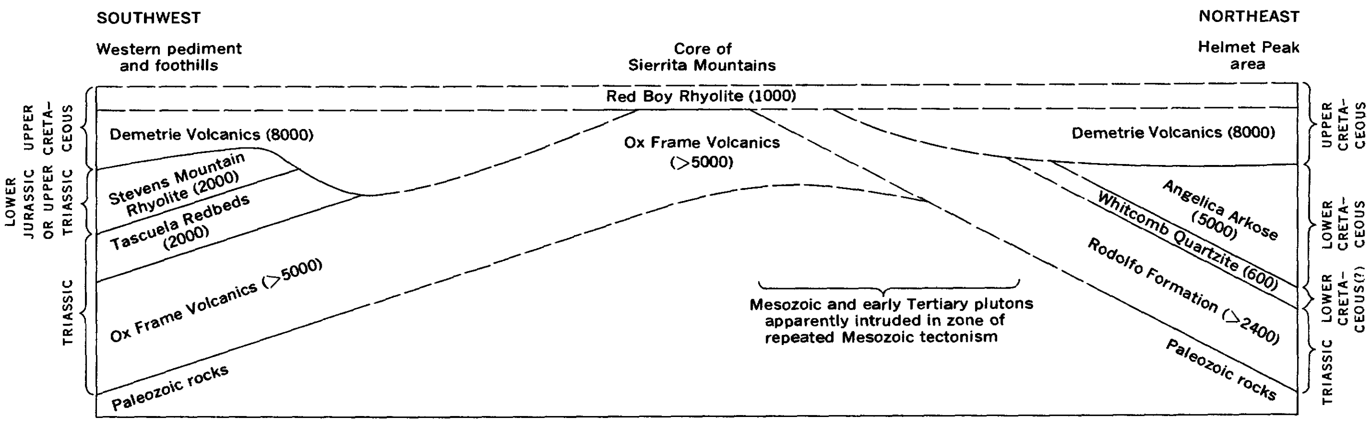


FIGURE 3.—Diagrammatic cross section through the Sierrita Mountains showing Mesozoic sedimentary and volcanic formations and their approximate maximum thickness, in feet. Exposed stratigraphic relations shown in solid lines, inferred relations in dashed lines. Not to scale.

Ranch quadrangle during 1960 as well as information from the work of Thoms (1966). J. C. Wright, J. H. Stewart, A. R. Conroy, and J. L. Gualtieri assisted in the Twin Buttes work at various times.

Mesozoic rocks in the Sierrita Mountains comprise more than 20,000 feet of terrestrial sedimentary and volcanic rocks which are herein divided into eight formations. These formations, their stratigraphic relations, and their probable ages are shown diagrammatically in figure 3. Note that the oldest Mesozoic formation, the Ox Frame Volcanics, is absent northeast of the mountains; that the youngest Mesozoic formation, the Red Boy Rhyolite, lies directly on the Ox Frame Volcanics in the core of the mountains; and that the intervening formations are largely different on the two sides. Evidently there was repeated Mesozoic tectonism that localized basins of deposition and areas of erosion during Mesozoic time. A major tectonic line active throughout the Mesozoic and now occupied by a large Paleocene pluton trends northwest between the core of the range and the Helmet Peak area. The Laramide orogeny started after deposition of the Lower Cretaceous rocks and ended after deposition of the Upper Cretaceous rocks (and apparently before emplacement of the Paleocene pluton).

PREVIOUS WORK

Although copper, zinc, and lead-silver deposits in the Sierrita Mountains have been known for considerably more than 100 years, the geology was first described by Ransome (1922), who briefly examined the eastern and western pediment and foothills in 1920. He concluded that the range consisted principally of an intrusive granitic core flanked by sedimentary and volcanic rocks which have been metamorphosed to various degrees. He noted that the intruded rocks on the east side, near Helmet Peak and Twin Buttes, included volcanic and clastic sedimentary rocks of probable Mesozoic age as well as Paleozoic limestone and probable Precambrian granite. On the west side, he noted a sequence of uncertain age consisting of highly sheared and schistose volcanic and clastic sedimentary rocks containing limestone lenses which he interpreted as lenticular beds.

Darton (1925, p. 284) found a probable *Camerotoechia* of Devonian age in the limestone on the west slope of the range and depicted the limestone as Paleozoic on the old geologic map of Arizona (Darton and others, 1924); the enclosing volcanic and clastic sedimentary rocks, together with Ransome's Mesozoic(?) beds on the east side of the range, were shown as Early Cretaceous, the only well-dated Mesozoic rocks then known in southeastern Arizona. Later investigations support Darton's general interpretation, although the Mesozoic stratigraphy is more complex then he supposed.

Between 1922 and 1949, mineralized parts of the eastern pediment and foothills were described in seven unpublished theses by students at the University of Arizona (Gordon, 1922; Brown, R. L., 1926; Park, 1929; Eckel, 1930; Mayuga, 1942; Whitcomb, 1948; Houser, 1949). Work on the stratigraphy was hampered by the complex structure, metamorphism, and rather small discontinuous outcrops. Nevertheless, it was shown that the Cambrian through Permian formations then recognized in the Bisbee-Tucson region were present and were for the most part entirely normal in lithology. Mayuga (1942) recognized that the Mesozoic strata of Ransome (1922) in the Helmet Peak area were similar in a general way to the Cretaceous rocks of W. H. Brown (1939) in the Tucson Mountains and suggested that their ages and sequences might be the same—undifferentiated volcanic and sedimentary beds at the bottom overlain in turn by the Recreation Redbeds of W. H. Brown (1939) and arkose containing shale and a little limestone. The state of knowledge of stratigraphy gleaned during this period was concisely summarized by Wilson (1950, p. 40–41).

In 1950 the Pima copper deposit was discovered beneath 200 feet of gravel east of Mineral Hill (Thurmond and Storms, 1958), and much exploratory work by many mining companies followed. Other large low-grade copper deposits, listed in the following table, have been found and developed, and a tremendous amount of geological, geophysical, geochemical, and drill-core data has been added to company files.

Major new open-pit mines in production or development in the Sierrita Mountains at the end of 1968

Mine	Company	Year production started	Rated capacity (tons of ore per day)
Pima	Pima Mining Co	1956	30,000
Mission	American Smelting and Refining Co.	1961	27,000
(1)	..........do	1967	(2)
Esperanza	Duval Corp	1959 }	15,000
West Esperanza	..........do	1964 }	
Sierrita	Duval Sierrita Corp	(3)	72,000
Twin Buttes	The Anaconda Co	(3)	30,000

[1] An unnamed open pit on San Xavier Indian Reservation about 2 miles northwest of Mission mine.

[2] A little copper ore was mined during 1967; production was expected to increase in succeeding years.

[3] Production was expected to start during late 1969.

Geologists with the American Smelting and Refining Co. were the first to complete a geologic survey of the entire Sierrita Mountains. Courtright (1958) and Richard and Courtright (1960) pointed out that the distinctive part of rocks assigned in this paper to the Demetrie Volcanics is much like a unit they called the Silver Bell Formation in the Silver Bell Mountains and other units in southeastern Arizona and southwestern New Mexico that commonly have unconformities at their bases and locally overlie fossiliferous Upper Cretaceous (Colorado) beds. A. G. Blucher (unpub. data) distinguished the principal stratigraphic and plutonic units in the central, southern, and western parts of the range. In 1959 he collected silicified brachiopods from one of the limestone lenses in the highly schistose volcanic and sedimentary rocks on the west slope (SW1/4 sec. 23, T. 17 S., R. 10 E.). E. D. McKee and R. J. Ross, Jr., examined these fossils and stated (written commun., May 22, 1961): "The brachiopods in these samples are poorly preserved but are certainly Paleozoic types. That they are of late Paleozoic age (perhaps Pennsylvanian) is suggested. However, far more extensive collections would be required to determine unquestionably the system to which the enclosing rock should be assigned." Although to my knowledge no other fossils have been found in the lenses, their lithology suggests that parts of several Paleozoic formations are represented, including the distinctive quartzite of the Scherrer Formation of Permian age.

Lacy (1959) assigned post-Paleozoic rocks east of the range to the Cretaceous and Tertiary. He agreed with earlier workers that these rocks contain units that resemble the Recreation Redbeds and Amole Arkose of W. H. Brown (1939) in the Tucson Mountains, but he believed that too little work had been done to permit correlation. A large low-angle fault, long known in the Helmet Peak–Mineral Hill area, was named the San Xavier thrust and interpreted as a premineralization fault that underwent major postmineralization movement.

My preliminary report (Cooper, 1960) on the pediment and foothills northeast of the range dealt primarily with the postmineralization (middle Tertiary) stratigraphy and structure. It was shown that the San Xavier thrust is a postmineralization fault and that the upper plate contains the Pima and Mission ore deposits. The proposed hypothesis that the upper plate moved about 6.5 miles north-northwest required that the roots of these deposits be concealed beneath the alluvium near Twin Buttes, where the Twin Buttes (Anaconda) ore deposit was later found. The great complexity of the Mesozoic stratigraphy was recognized, but no attempt was made to decipher the sequence, which was mapped as the Cretaceous(?) complex and crudely subdivided on a lithologic basis. Fossils collected from a limestone unit in arkose consisted of unidentifiable gastropods and pelecypods and fresh-water ostracodes of a type common in Upper Jurassic through Holocene sediments (Cooper, 1960, p. 69).

During reconnaissance mapping of the central and western parts of the Sierrita Mountains in early 1960, I found two groups of post-Paleozoic plutonic rocks that differ from one another in petrography and geologic relations: (1) An older group of monzonite, quartz monzonite, and alkali granite which cuts the Ox Frame Volcanics and which is overlain unconformably by the Demetrie Volcanics and the Red Boy Rhyolite and (2) a younger group of diorite, granodiorite, and quartz monzonite that cuts the Demetrie Volcanics. The two episodes of plutonism are of great importance in the proper interpretation of the stratigraphy, but the date of neither episode was firmly established in 1960. On the geologic map of Pima and Santa Cruz Counties (Wilson and others, 1960), the younger intrusives are assigned to the Laramide interval (Late Cretaceous and early Tertiary), the Red Boy Rhyolite of this report to the Tertiary, and the Demetrie of this report and older Mesozoic rocks to the Cretaceous. The recently published geologic map of Arizona (Wilson and others, 1969) is only partly updated to the age assignments herein made, but it does indicate that the Demetrie, Red Boy, and younger plutonic rocks are all Laramide and that the Ox Frame Volcanics are Mesozoic.

K–Ar (potassium-argon) age determinations (Creasey and Kistler, 1962, p. D1; Damon and Mauger, 1966, p. 103; Mauger, 1966, p. 11–12) indicate that the Laramide plutonic rocks, the so-called biotite rhyolite southeast of Helmet Peak, and the mineralization are all of Paleocene age, obviously a minimum age for all the older strata. The pre-Laramide rocks are too metamorphosed and altered to date meaningfully by the K–Ar method. R. L. Mauger (in Damon, 1965, p. 28–31; 1966, p. 22–23) dated several of these rocks by the Rb–Sr (rubidium-strontium) method, but his date of 93 m.y. (million years) for the rocks now called Ox Frame Volcanics from the rim of the Esperanza open-pit mine is incompatible with his dates of 130 and 140 m.y. (Jurassic-Cretaceous boundary) for post-Ox Frame plutonic rocks. Pb-alpha (lead-alpha) analyses of zircons (Drewes, 1968, p. C7; this report, p. D13) suggests that the dates for plutonic rocks are probably their approximate dates of crystallization and that the age given for the Ox Frame is too young, perhaps because of potassium and rubidium metasomatism at the time of mineralization.

Lutton (1961, p. 44) recognized the angular unconformity that separates the volcanics (Ox Frame, this report) and Silver Bell Formation (Demetrie, this report) near the Esperanza mine. He also recognized that the Ox Frame (this report) consists of rhyolitic pyroclastic rocks and subordinate cross-bedded quartzite and that most of the rhyolitic rock is welded tuff whose flattened and coarsely devitrified pumice fragments have the mineral composition of true rhyolite.

Lootens (1965, 1966), in a study of the core of the Sierrita Mountains, recognized this ascending stratigraphic sequence: Ox Frame Formation, Silver Bell Formation (Demetrie Volcanics, this report), and younger rhyolite (Red Boy Rhyolite, this report). However, he did not recognize that an interval of plutonism and deep erosion followed deposition of the Ox Frame and preceded deposition of the Demetrie. He believed that the plutonic rocks were differentiation products of a single source magma and that they were emplaced during an interval of about 5 m.y. in early Tertiary and perhaps latest Cretaceous time. He assigned all the stratified rocks to the Cretaceous.

Thoms (1966) gave a detailed description of about 25 square miles on the west flank of the Sierrita Mountains in the vicinity of Tascuela Wash. He proposed the following stratigraphic sequence for this area:

Stratigraphic sequence in the Tascuela area excerpted from Thoms (1966, fig. 4)

Age	Formation	Thickness (feet)
Quaternary	Alluvial deposits	Not given.
	Unconformity	
Late Tertiary	Olivine basalt flows	Not given.
	Unconformity	
Early Tertiary	Fresnal Quartz Monzonite; dike rocks [Plutonism 3]	
	Red Boy Rhyolite	Not given.
	Unconformity	
Early Tertiary–Late Cretaceous	Demetrie Formation	2,000+
	Unconformity	
Late Cretaceous	Albite granite; quartz monzonite, monzonite, and quartz syenite; leucogranite [Plutonism 2]	
Early Cretaceous (?)	Stevens Mountain Rhyolite	2,000
	Tascuela Redbeds	2,000
	Ox Frame Volcanics	5,100+
	Fault contact	
	Sunshine Formation	700
	Unconformity	
Nevadan (?)	Porphyritic granodiorite; diorite [Plutonism 1]	
Paleozoic	Metasedimentary rocks including marble, quartzite, and calc-silicate hornfels	2,000+

Thoms' sequence of sedimentary and volcanic formations is well established by superposition, but his age assignments are based entirely on the inferred age of intrusive rocks. His Fresnal Quartz Monzonite, correlated for good reasons with radiometrically dated lower Tertiary intrusive rocks on the east side of the mountains, establishes only a minimum age for older formations. Intrusives that Thoms assigned to the Late Cretaceous include those dated as Jurassic and earliest Cretaceous by the Rb–Sr method (Damon, 1966). Because these intrusives are confined by field evidence to the interval between Ox Frame and Demetrie times, the Ox Frame Volcanics and probably the Tascuela Redbeds and Stevens Mountain Rhyolite are pre-Cretaceous. Evidence that Thoms' Nevadan (?) intrusives represent a separate plutonic episode is largely negative and not entirely convincing. These rocks intrude the Paleozoic rocks but were not found intruding younger formations; the only cited positive evidence that intrusion predated all the Mesozoic beds is in the following statement by Thoms (1966, p. 45): "A few pebbles and cobbles lithologically similar to the granodiorite occur in conglomerate of the Cretaceous (?) sequence . . . ."

TRIASSIC ROCKS

OX FRAME VOLCANICS

NAME AND TYPE LOCALITY

The name Ox Frame Volcanics was applied by Lootens (1966) to a thick rhyolitic to andesitic volcanic sequence exposed in Ox Frame Canyon in the Sierrita Mountains (fig. 4). This name is adopted in this report, and Ox Frame Canyon is here designated as the type locality. The bottom of the section there is the large Cowboy fault in the NE1/4 sec. 22, T. 18 S., R. 11 E., and the top is the parallel Ash Creek fault in the N1/2 sec. 3 of the same township and range. Between these boundaries, the formation is concealed at one place by an unconformable capping of the Red Boy Rhyolite. The type outcrops are cut by plugs and dikes of siliceous porphyry and are more metamorphosed than those in the western foothills of the mountains (Thoms, 1966). The sequence in the western foothills along Tascuela Canyon in sec. 18, T. 18 S., R. 11 E., where the bottom is defined by intrusive monzonite and the top by unconformably overlying conglomerate of the Tascuela Redbeds, is here designated as a reference section.

GENERAL DESCRIPTION, DISTRIBUTION, AND THICKNESS

Volcanic rocks of the Ox Frame consist of generally light-colored silicic types that range in composition from rhyolite to rhyodacite and darker colored andesite and dacite. These rocks occur as flows, flow breccias, welded and nonwelded tuffs, and tuff-breccias. Lenticular beds of sandstone and

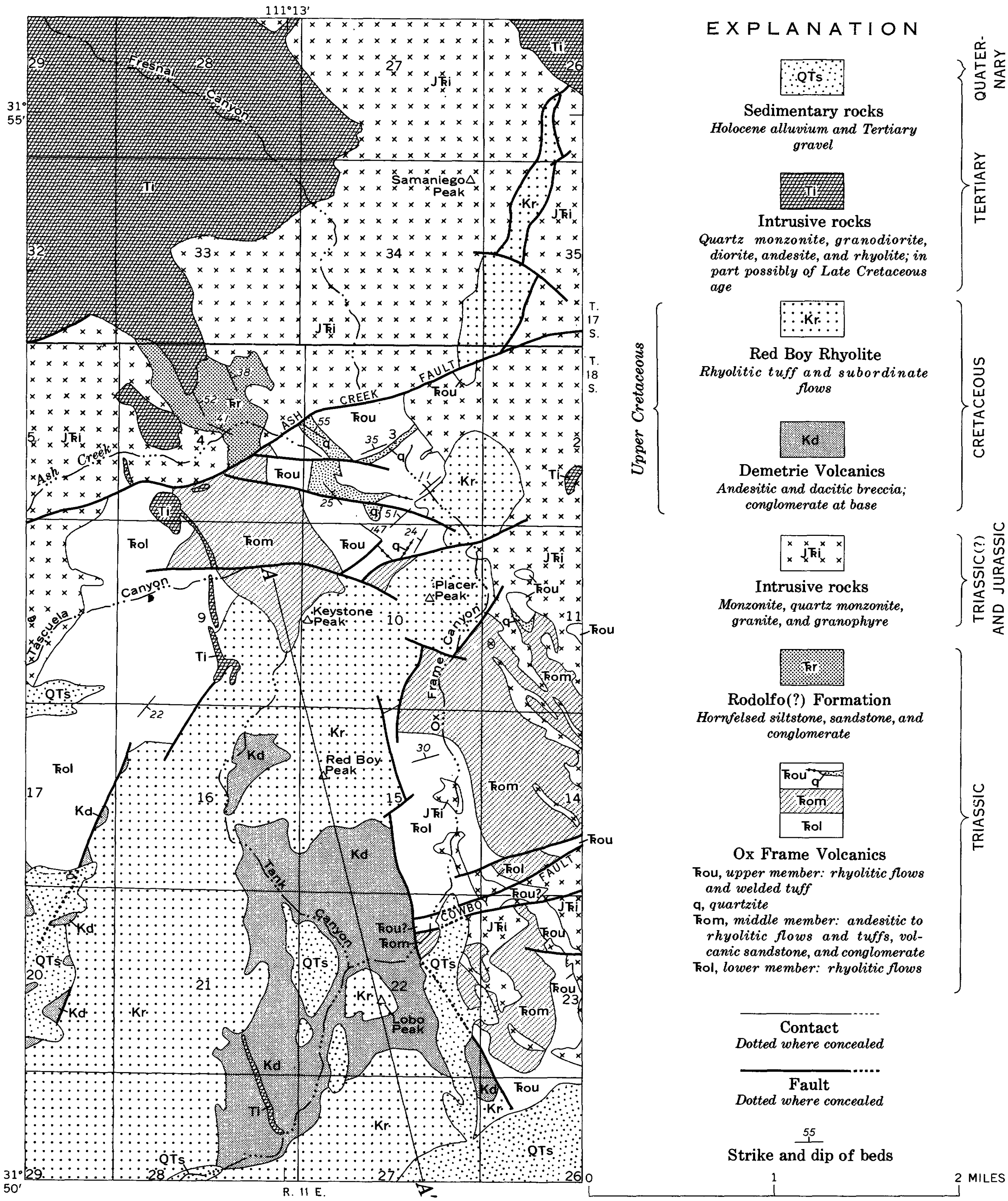


FIGURE 4.—Geologic sketch map of the Ox Frame Canyon area. Section A–A' shown in figure 7. Geology mapped, 1957–68; base from U.S. Geological Survey Twin Buttes 15-minute quadrangle, 1957.

conglomerate are intercalated with the volcanic rocks and make up a minor part of the formation.

The type locality is in Ox Frame Canyon, where the formation is about 4,000 feet thick. However, neither the top nor the bottom is exposed, as both contacts are faults. The lower third is characterized by light-gray to pale-red rhyolitic flows, the middle third by medium-dark-gray to dark-greenish-gray andesite and dacite flows and a few flow breccias, and the upper third by light-gray to medium-dark-gray rhyolitic welded tuffs and flows that contain interbeds of quartzitic sandstone. These members have interfingering contacts, and each contains some units lithologically characteristic of the adjacent member. The sequence is cut by penecontemporaneous rhyolitic dikes that are similar in lithology to the extrusive rock and by Triassic(?) and Jurassic quartz monzonite and granophyre. Both the Ox Frame and the quartz monzonite are overlain with angular unconformity by the Red Boy Rhyolite.

Rocks that resemble the middle and upper members are faulted against the lower member immediately south of the type locality (fig. 4), and to the east they crop out in a patch several square miles in extent in and around the Esperanza mine (fig. 6). The middle andesitic member is only partly exposed near the Esperanza mine, but the upper rhyolitic member, here predominantly rhyolitic welded tuff, appears to be at least 2,000 feet thick. These rocks are cut by Triassic(?) and Jurassic quartz monzonite, and near the Esperanza mine they are overlain with angular unconformity by the Demetrie Volcanics.

The Ox Frame also crops out in a separate belt about 7 miles long and less than a mile wide along the west side of the Sierrita Mountains within the Palo Alto Ranch quadrangle. Thoms (1966, p. 55) stated that here the formation is more than 5,100 feet thick and consists of four members which he summarized "from oldest to youngest" as follows:

(1) tuff breccia member, 1,200 to 1,500 feet thick, rhyodacitic breccias (1,000 feet) of probable flow origin overlain by fine-grained rhyolitic tuffs, welded tuffs, and interbedded thin arenites; (2) andesite porphyry member, 1,200 feet thick, flows and minor flow breccias; (3) coarse tuff member, 1,500 feet thick, rhyodacitic to quartz latitic to rhyolitic coarse tuffs, minor welded tuffs, and a few lenticular arenites; (4) rhyolite member, more than 1,200 feet thick, mainly welded tuffs, interbedded thin flows, lenticular conglomerates and arenites.

North of Ash Creek the top unit of the rhyolite member is a distinctive amygdaloidal andesite flow.

The reference locality, the most complete and least disturbed continuous section, is about 4,000 feet thick and differs from the outcrop described by Thoms in the summary just quoted in that the rhyolite member lies directly on the andesite porphyry member and the coarse tuff member is represented, according to Thoms (1966, p. 63), by a conformable lens of rhyodacitic tuff near the middle of the andesite porphyry member. This relation and others shown on Thoms' map suggest that, despite its varied lithology, the entire coarse tuff member is a lateral time equivalent of the andesite porphyry rather than a younger unit.

A narrow faulted belt of interbedded pyroclastic and clastic rocks that crops out in the western foothills and extends northwestward from the SE1/4 sec. 12, T. 18 S., R. 10 E., was described by Thoms (1966, p. 48–54; 1967). According to him, the sequence is at least 700 feet thick and consists of schistose latitic to rhyolitic tuff, stretched conglomerate, sandstone, and slate. The sequence overlies Paleozoic marble with slightly angular unconformity and contains stretched pebbles and cobbles of Paleozoic quartzite and marble. Other boundaries are fault or intrusive contacts. Thoms called the sequence the Sunshine Formation and assigned it a Cretaceous(?) age but recognized that it might be part of the Ox Frame Volcanics. Except for being somewhat sheared, the rocks are lithologically similar to the lower member of the Ox Frame Volcanics of this report and are here considered to be part of that formation.

In general, the Ox Frame sections in the western foothills and in the core of the range resemble each other in total thickness, lithology, and stratigraphic succession—silicic rocks, andesitic rocks, silicic rocks. The rocks in the two areas are regarded as general correlatives but are described separately inasmuch as they differ in details of lithology and are everywhere separated by younger formations.

LITHOLOGY

MEMBERS IN THE TWIN BUTTES QUADRANGLE

The Ox Frame Volcanics in the Twin Buttes quadrangle comprises metamorphosed and altered rhyolitic to andesitic volcanic rocks and a little quartzite, volcanic sandstone, and conglomerate. The dip and strike of these rocks, which indicate stratigraphic succession, are not well displayed, inasmuch as flow and pyroclastic units commonly lack discernible bedding or other primary planar structure and thus look alike in outcrop. My mapping and observations of the attitude of sedimentary interbeds, flow banding in lavas, and eutaxitic structure in welded tuffs indicate that strata at the type locality—along Ox Frame Canyon north of the Cowboy fault—have a generally northward dip and that therefore the oldest Ox Frame units are exposed at the south and the youngest at the north (fig. 4). This succession is opposite to that of Lootens (1965, 1966), whose inference of a southward dip seems to have been based on the attitude of the Red Boy Rhyolite, part of which he included in the Ox Frame Volcanics.

The lower member in Ox Frame Canyon consists predominantly of light-gray to pale-red rhyolitic flows that are massive and only rarely flow banded. Some of the rock is entirely aphanitic, but most of it contains 2–20 percent phenocrysts of feldspar 1–3 mm (millimeters) long. Some hand specimens also show tiny grains of quartz, very sparse aggregates of chlorite and epidote, specks of iron ore, and small aggregates of black tourmaline. The chlorite-epidote aggregates seem to have replaced primary biotite and perhaps pyroxene. The tourmaline probably was introduced at the time of emplacement of Triassic(?) and Jurassic granophyre dikes and plugs, which are common in this area and are generally tourmaline bearing. Other dikes are very similar to the flows in appearance and age and are difficult to distinguish from the extrusive rock.

In thin section, the feldspar phenocrysts in the flows are seen to be potassium feldspar having moderate to large optic angle and sericitic albite commonly rimmed by potassium feldspar. The groundmass is cryptocrystalline to microcrystalline felsic material in which very fine grained micrographic and sieve textures are locally perceptible. On the basis of cobaltinitrite-stained thin sections and rock slabs (Bailey and Stevens, 1960), the groundmass feldspar is judged to be mostly a potassic variety, and the presence of abundant quartz is demonstrated by poikiloblasts in optical continuity with adjacent quartz phenocrysts. Subparallel fluidal orientation of phenocrysts and microlites is discernible in some thin sections.

The lower member along the bottom of Ox Frame Canyon contains a few thin flows or sills of andesite but no clastic rocks, so far as is known. East and west of the canyon, the member contains lenses of rhyolitic tuff, tuff-breccia, and tuffaceous sandstone. The pyroclastic rock tends to be medium gray on fresh fractures and yellowish gray on weathered surfaces. Some of it contains conspicuous phenocrysts of quartz and feldspar.

The middle member of the Ox Frame Volcanics, as exposed in Ox Frame Canyon, has an interfingering lower contact and consists of andesite flows that contain some lenticular rhyolite flows like those in the lower member. Hand specimens of typical andesite show 15–35 percent phenocrysts of plagioclase 1–5 mm long in a dark-gray to greenish-gray aphanitic groundmass. The upper part of some flows contains sparse small amygdules of quartz and epidote and irregular pods, lenses, and streaks of dense red andesite.

All the andesite examined in thin section is much altered. The plagioclase phenocrysts are albite that contains epidote, sericite, and locally clay minerals. Scarcer and somewhat smaller pseudomorphs of actinolite and epidote have the stubby form of pyroxene, and a few contain unreplaced cores of augite. The groundmass shows microlites of albite, actinolite, and magnetite, and interstitial cryptofelsite—strewn with epidote, sericite, and commonly chlorite, calcite, and a little tourmaline. Flow orientation of the plagioclase microlites is commonly conspicuous. The cryptocrystalline interstitial matter is rich in potassium feldspar, as shown by cobaltinitrite staining of thin sections and rock slabs; therefore the rock as a whole is probably a potassic andesite.

The upper part of the middle member is exposed northwest of the younger mass of Red Boy Rhyolite and is partly exposed in faulted areas east and south of Ox Frame Canyon. Both east and south of the canyon, the andesite flows in the upper part of the member are intercalated with flows of dark dacite that contain small phenocrysts of quartz. Locally the member also has lenses of andesitic tuff, tuff-breccia, volcanic conglomerate, and crossbedded andesitic sandstone. The tuff-breccia and conglomerate generally contain fragments of rhyolite and andesite in a clastic andesitic matrix. Light-weathering rhyolite occurs as lenticular flows and welded tuff units and, in the ridge on the east side of Ox Frame Canyon, as numerous dikes oblique to the bedding. Inasmuch as the rhyolite is very resistant to erosion, one can easily get an exaggerated impression of its abundance.

Andesitic rock having the texture of microdiorite occurs where the middle member is exposed 1¼ miles west of the Esperanza mine. Hand specimens are medium dark gray and generally similar in appearance to flows already described, but commonly they are less distinctly porphyritic and contain discernible patches of dark mafic silicates as well as plagioclase crystals. In thin section, subhedral crystals of saussuritized plagioclase and actinolite, mostly a millimeter or less in size, are seen to be fairly closely packed, and the interstices are filled with subhedral orthoclase, magnetite, apatite, and poikiloblastic quartz. Epidote and secondary leafy biotite are abundant throughout the rock. In places, biotite flooding has destroyed the actinolite and masked the primary texture. A few amygdules of quartz and epidote have been found in the rock, but no flow boundaries or intercalated clastic beds have been recognized. Thus, the rock could be intrusive or extrusive in origin. It is assigned to the Ox Frame Volcanics inasmuch as it is cut by Triassic(?) and Jurassic quartz monzonite and related aplite dikes and is overlain with apparent conformity by quartzite and rhyolite of the upper member.

The upper member of the Ox Frame Volcanics in the Twin Buttes quadrangle consists of rhyolitic extrusive rocks that contain sparse intercalated lenses of quartzite. The extrusives include lava flows, common in the lower part of the member in Ox Frame Canyon, and welded and nonwelded tuff. The rock is light gray to medium dark gray and is locally flow banded. Hand specimens show 5–10 percent feldspar crystals 0.5–2 mm long in a hard flinty groundmass. The feldspar is subhedral and in thin section is seen to be dusty perthitic orthoclase that in most specimens is accompanied by sericitic albite and a little phenocrystic quartz. Small books of biotite much altered to muscovite, chlorite, and opaque material were found in one specimen studied. These minerals, together with accessory magnetite, leucoxene, and rarely zircon, are embedded in microcrystalline to cryptocrystalline felsic material that locally contains sparse flow-alined alkali feldspar microlites. The groundmass is commonly a sieve-textured mosaic of anhedral quartz grains 0.25–1 mm in diameter loaded with tiny unoriented grains of alkali feldspar and opaque specks. The flows are similar in composition to those in the lower member but, so far as is known, lack micrographic groundmasses.

Welded rhyolitic tuff is associated with the flows of the upper member of the Ox Frame and is the predominant rock type near the Esperanza mine. In the Ox Frame Canyon area the tuff is generally medium gray, and near the Esperanza mine it varies in color from dark gray to yellowish gray, brownish gray, and pale red. Some of the tuff is distinguishable in the field by planar eutaxitic structure resulting from flattened pumice fragments and by the texture of compressed glass shards that are discernible with a hand lens on freshly broken and moistened surfaces. The welded tuff origin of these rocks and of some rocks indistinguishable from flows in the field is shown in thin section by the microeutaxitic structure, the texture of compressed shards, the relict axiolitic devitrification structure, and the broken condition of many of the phenocrysts. At many places the primary features of the once-glassy material have been erased by recrystallization, and the broken phenocrysts are the only clue to the origin.

Lithic tuff and tuff-breccia occur as sparse units 10 to about 100 feet thick in the upper member of the Ox Frame Volcanics in the Twin Buttes quadrangle. These units are distinctive lithologically but seem to be highly lenticular and hence of little use as stratigraphic markers. They are well indurated and consist of poorly sorted angular and subangular fragments, as much as several inches in diameter, of light and dark volcanic rock and scarce quartzite in a matrix of light-gray to grayish-pink flinty volcanic ash. Hand specimens show flow-banded fragments and other fragments that lack this structure but differ from one another in color, groundmass texture, and the presence or absence of phenocrysts. In cobaltinitrite-stained thin sections, most fragments are seen to apparently range in composition from rhyolite to trachyte and include spherulitic flow-banded types and sieve-textured and granophyric-textured types resembling flows in other parts of the formation. Fragments of latite, andesite, and quartzite are scarce. The matrix is cryptocrystalline to microcrystalline felsic material that contains scattered chips of alkali feldspar and quartz and locally shows obscure markings whose form suggests pumice and shards. Neither axiolitic structure nor indications of compaction have been found. Apparently the rock was formed by explosive eruptions of the same magma that gave rise to the associated flows and welded tuffs—the juvenile constituents being contaminated by accessory and accidental fragments torn from the walls of the vent.

A small amount of volcanic conglomerate and sandstone is associated with the tuffs just described, but the most abundant and characteristic sedimentary rock in the upper member is fine- to medium-grained quartzite, which occurs as sporadic lenses a few feet to several hundred feet thick and a few tens of feet to several thousand feet long. The largest lenses are shown in figure 4. The quartzite locally shows relict sandstone texture and alluvial bedding and crossbedding. The thin sections examined are about 90 percent quartz, in part having mosaic texture and in part occurring as detrital grains that are well rounded, well sorted, closely packed, and cemented by fine-grained sericitic material. The quartzite must represent unusually pure quartz sand, presumably derived from pre-Ox Frame rocks outside the basin of deposition and deposited by streams during intervals of volcanic quiescence.

Some rock that superficially resembles the quartzite has been formed by silicification of welded tuff. Exposures near the Esperanza mine indicate that silicification started at scattered centers several inches to about a foot apart and gradually spread outward; it first formed fuzzy leopard-type spots of granular quartz in which all primary features of the rock are erased, and finally it replaced the entire rock. The end product is a fine- to medium-grained quartz rock distinguishable from the sedimentary quartzite only by the lack of bedding and relict sedimentary texture. Only sedimentary quartzite is shown in figure 4, although some silicified tuff may have been included inadvertently.

MEMBERS IN THE PALO ALTO RANCH QUADRANGLE

Rocks in the Palo Alto Ranch quadrangle considered herein to be the lower member of the Ox Frame Volcanics were described by Thoms (1966). The lower part is bluish-gray schistose tuff consisting of tiny grains of magnetite and partly albitized sodic andesine in an abundant foliated matrix of microcrystalline quartz, sericite, feldspar, biotite, chlorite, epidote, and calcite. A thin basal zone contains small lenses of marble that probably represent flattened pebbles and cobbles of the subjacent Paleozoic rock. Overlying the bluish-gray tuff is sheared greenish-gray rhyolitic tuff that contains thin beds of stretched volcanic conglomerate. The rhyolitic tuff interfingers laterally with an overlying unit of maroon to purple slate that contains subordinate interbedded tuff, sandstone, and conglomerate. A few cobbles of marble occur in one conglomerate bed.

In fault contact with the basal member is a diversified assemblage of andesitic to rhyolitic extrusive rocks and subordinate interbeds of sandstone and conglomerate. The sequence, best displayed near Tascuela Canyon, was described in detail by Thoms (1966). A brief summary of his units and lithologic description follows, beginning at the base.

The tuff-breccia member, whose lower contact is with intrusive monzonite, comprises about 1,000 feet of rhyodacitic tuff-breccia overlain by 200–500 feet of lighter colored rhyolitic rock that contains thin interbeds of sandstone and conglomerate. The rhyodacitic tuff-breccia is pale red purple to grayish red purple. Angular fragments of fine-grained andesitic to rhyolitic rock, typically less than 3 cm (centimeters) in diameter, make up 25–50 percent of the rock. The matrix is fine-grained tuff that contains sparse crystals of quartz, sanidine, and sodic andesine (An_{32}); a few collapsed devitrified pumice fragments were noted in thin section. A dark-grayish-blue quartzite bed 4–8 feet thick and about a mile long divides the tuff-breccia into two parts that are slightly different in color and texture. The top several hundred feet of the tuff-breccia member includes, in ascending order: (1) grayish-orange-pink rhyolitic tuff that contains sparse rock fragments and faint eutaxitic structure, (2) dusky-red welded vitric tuff only 4 feet thick, (3) pale-red rhyolitic crystal tuff, (4) pale-reddish-brown lithic graywacke that has volcanic pebble conglomerate at the base, (5) light-brownish-gray aphanite that contains sparse indistinct white phenocrysts, and (6) grayish-red arenite. The last two units are absent locally.

The andesite porphyry member is about 1,200 feet thick and consists of andesitic flows, minor flow breccias, and, near the top, a few lenticular units of crossbedded sandstone. These rocks lie on the tuff breccia member and locally contain inclusions of it in the bottom few feet. On the ridgecrest south of Tascuela Canyon, they are in nearly continuous outcrop to the contact with the overlying rhyolite member. Elsewhere lenses of rhyodacitic tuff that Thoms regarded as part of the coarse tuff member are intercalated in the andesite porphyry member and separate it into a lower and an upper part.

The andesitic flows and flow breccias are grayish red purple on fresh fracture and grayish red to brownish gray on weathered surfaces. Most are porphyritic and show well-developed flow structure by the parallel alinement of plagioclase laths 2–10 mm long. Other constituents discernible in hand specimen are sparse tiny grains of magnetite and dusky-green pyroxene. According to Thoms (1966, p. 59–60), the rock consists of 26.0 percent sodic andesine as partly saussuritized, serpentinized, and sericitized subhedral laths 2–10 mm long; 8.6 percent partly altered pyroxene; 2.8 percent magnetite; 0.6 percent rock fragments; and 62.0 percent cryptocrystalline to microcrystalline groundmass that contains disseminated red iron oxide dust and minute grains of magnetite and leucoxene. The flows and flow breccias have gradational contacts. Vesicular structure was observed at only one place, and other distinctive top-and-bottom structural and textural features are so obscure that individual flow boundaries are virtually unknown except at the few places where there is sandstone between the flows.

The coarse tuff member is represented near Tascuela Canyon by two lenticular units of rhyodacitic tuff, locally as much as 500 feet thick, near the middle of the andesite porphyry member. The tuff contains crystals and crystal fragments, as much as 3 mm in diameter, of quartz, sodic andesine, orthoclase, and altered biotite. The crystals are set in a cryptocrystalline to microcrystalline matrix with axiolitic structures resulting from the collapse and devitrification of pumice fragments.

Also included in the coarse tuff member is a rhyolitic sequence, apparently at least 1,500 feet thick, exposed 0.5–1.2 miles southeast of Tascuela Canyon on strike with the rhyodacite tuff and andesite but separated from them by a transverse fault. The lower contact of the sequence is concealed by alluvium and down-faulted conglomerate of the Demetrie Volcanics. The upper contact is conformable with the rhyolite member or with a thin intervening andesite unit correlated with the upper part of the andesite porphyry member (Thoms, 1966, p. 63). This part of the coarse tuff member includes crystal and crystal-lithic tuff, small amounts of welded vitric tuff, and several intercalated lenses of quartzite. The volcanic units contain variable proportions of crystals, crystal fragments, and rock fragments in a microcrystalline matrix that invariably makes up a dominant fraction of the rock. Quartz, sanidine, and orthoclase, in grains 0.5–3.0 mm in diameter, are the most abundant constituents discernible in hand specimen; plagioclase and biotite are less common and are much less abundant than in the rhyodacitic tuff. In thin section, the matrix was seen to be dusty-looking microlitic or felted material that contains tiny crystal fragments and locally shows microtextures indicating derivation from compacted pumice and glass shards. The quartzite lenses are grayish orange, medium grained, and well bedded. They consist of 70–80 percent quartz as well-rounded grains and secondary overgrowths, 5–10 percent rock fragments, and 10–15 percent fine-grained interstitial sericitic material.

The upper member of the Ox Frame Volcanics in the Palo Alto Ranch quadrangle, the rhyolite member (Thoms, 1966), has a maximum thickness in excess of 1,300 feet and consists of rhyolitic welded tuffs, subordinate flows, volcanic sandstones, and conglomerates. The lithologic sequence varies markedly along the strike owing to the lenticularity of units. Part of the reference locality in Tascuela Canyon, which is modified slightly from Thoms (1966, p. 73), shows most of the rock types found in the upper member.

Section of the rhyolite member of the Ox Frame Volcanics in Tascuela Canyon (sec. 18, T. 18 S., R. 11 E.) as interpreted by Thomas (1966)

	Feet
Tascuela Redbeds.	
Ox Frame Volcanics:	
Rhyolite member:	
12. Conglomerate, grayish-yellow; felsite and milky quartz pebbles and cobbles; lenticular	100
11. Rhyolite flow, grayish-yellow to grayish-purple; sparse phenocrysts of quartz and sanidine in distinctly flow banded aphanitic groundmass	60
10. Welded tuff, grayish-red to purple, very fine grained; has eutaxitic structure	50
9. Welded crystal tuff and tuff-breccia, pinkish-gray to yellowish-gray, rhyolitic to trachytic; vitroclastic matrix (not apparent in hand specimen); bottom 25 ft is finer textured and has eutaxitic structure	175
8. Volcanic arenite, red to maroon, coarse-grained; in part conglomeratic; well bedded	50
7. Welded crystal tuff; light gray in upper part, pink to pale reddish brown in lower part; rhyolitic to quartz latitic; subordinate fine-grained matrix has eutaxitic structure	550
6. Quartz latite porphyry (flow?), yellowish-gray to pale-red-purple; small phenocrysts in aphanitic groundmass	75
5. Felsite, grayish-yellow, dense	35
4. Quartzite, white, medium-grained; quartz grains well rounded; fragments from underlying unit near base	30
3. Volcanic arenite, dark-bluish-gray, medium- to coarse-grained	10
2. Felsite, white (very finely crystalline rhyolite)	50
1. Volcanic arenite, bluish-gray, medium-grained; fragments of andesite porphyry near base	15
Total	1,200
Andesite porphyry member.	

The sedimentary rocks in the lower part of this section (units 1, 3, and 4) have little lateral extent, whereas the thick welded crystal tuff (unit 7), which makes up almost half the member in Tascuela Canyon, extends at least a mile along the strike. This tuff generally consists of close-packed crystals and crystal fragments, as much as 3 mm in diameter, of plagioclase, potassium feldspar, and quartz in a subordinate microcrystalline matrix that shows inconspicuous small-scale eutaxitic structure in hand specimen and deformed axiolites in thin section. Northwest of Tascuela Canyon in the vicinity of Ash Creek and Stevens Mountain, the rhyolitic flows and tuffs above the thick welded tuff unit contain considerable interbedded volcanic conglomerate; a little volcanic sandstone and maroon slate; and two basaltic andesite flows, each about 50 feet thick. The upper andesite flow has remarkable lateral extension for such a thin unit. It is mostly aphanitic and grayish purple and contains conspicuous white amygdules. In thin section, its texture is trachytic. Nearly parallel subhedral laths of andesine (An_{33-37}) make up more than 60 percent of the rock. The length of these crystals is as much as 2 mm but averages less than 1 mm. The interstices in the feldspar framework are filled with very fine grained leucoxene, red iron oxide, and magnetite. The amygdules are composed of quartz, calcite, and locally epidote. This distinctive amygdaloidal flow is the top unit of the Ox Frame Volcanics for about 1.5 miles.

CONTACTS

The lower contact of the Ox Frame Volcanics is a fault contact or an intrusive contact at most places. On the west side of the Sierrita Mountains, however, the interbedded pyroclastic and sedimentary rock unit which I regard as the lower member of the Ox Frame lies with slight angular unconformity on Paleozoic sedimentary rocks.

The upper contact of the Ox Frame Volcanics is a disconformity at the base of the Tascuela Redbeds. At most places the Tascuela has a basal conglomerate that contains pebbles, cobbles, and boulders from two sources: many kinds of volcanic rocks found in the Ox Frame; and quartzite, limestone, and chert that may well have come from the Paleozoic rocks east of the range, where the Ox Frame is missing. The coarse texture of this conglomerate and the lithologic diversity of its constituents indicate that the disconformity was a surface of much greater topographic and structural relief than is apparent in outcrop.

AGE AND CORRELATION

Dating of these rocks must be based on local geologic relations, radiometric age determinations, and correlation of units with dated formations in other areas. Superposition of formations indicates that the Ox Frame postdates Paleozoic rocks and predates the Tascuela Redbeds and the Triassic(?) and Jurassic quartz monzonite.

Geologic mapping by Thoms (1966) and by the U.S. Geological Survey shows that the Ox Frame was faulted, intruded by monzonite, quartz monzonite, and alkali granite, and then deeply eroded before deposition of the Demetrie Volcanics and Red Boy Rhyolite. Following another period of deformation, diorite, granodiorite, and quartz monzonite were emplaced. The older intrusive suite was not recognized by Lootens (1966), who thought that all intrusive rocks of the area were of early Tertiary age and were "emplaced over a very short span of time (approximately 5 million years)." The radiometric age of the younger intrusive rocks and associated mineralization (Creasey and Kistler, 1962; Damon and Mauger, 1966) is about 60 m.y. and supports Lootens' generalization; but the radiometric age of the older intrusives is much greater as would be expected from the complex intervening geologic record indicated by field evidence. Obviously the age of the older intrusives is a critical minimum age for the Ox Frame Volcanics. (See following table.)

Radiometric ages of Mesozoic igneous rocks that cut the Ox Frame Volcanics

Sample	Field No.	Rock type	Locality	Apparent age, in millions of years, as determined by indicated method		
				K–Ar on biotite	Rb–Sr	Pb–alpha on zircon
1	T169	Alkali granite	SW¼ sec. 35, T. 17 S., R. 11 E.	[1] 55	....	[2] 150±20
2	RM–2–65	do	Very near sample 1 locality	....	[3] 140±14	....
3	RM–10–63	Monzonite border phase of quartz monzonite porphyry intrusion.	SE¼ sec. 8, T. 18 S., R. 11 E.	....	[4] 130±6	....
4	T400	Quartz monzonite of Harris Ranch	NE¼ sec. 13, T. 18 S., R. 11 E.	....	....	[2] 190±20

[1] S. C. Creasey (written commun., 1964).
[2] T. W. Stern (written commun., 1965, 1966).
[3] Whole-rock analysis, from Damon (1966, p. 23).
[4] Isochron age based on analyses of whole rock, potassium feldspar, and plagioclase; from Damon (1966, p. 23).

The disparity in apparent age of the alkali granite of sample 1 is undoubtedly due to Laramide metamorphism. The biotite in this rock is in recrystallized leafy form, and hence its K–Ar age should and probably does indicate the time of metamorphism.

As the Pb-alpha and Rb–Sr clocks are less readily reset by metamorphic events, the older intrusives are here assigned to the Jurassic (samples 1–3) and Triassic(?) (sample 4). The Ox Frame, which predates all these rocks, is assigned to the Triassic.

One attempt has been made to date the Ox Frame Volcanics directly, but the result is misleading. R. L. Mauger (in Damon, 1965, p. 31) obtained a whole-rock Rb–Sr age of 93±29 m.y. on rhyolitic welded tuff of the Ox Frame from the rim of Esperanza open-pit mine. This age is incompatible with Rb–Sr and Pb-alpha ages of post-Ox Frame intrusive rocks just discussed in that, about a mile west of the mine, the tuff is cut by quartz monzonite whose Pb-alpha age is 190 m.y. The tuff sample analyzed came from a mineralized area in which potassium metasomatism has taken place (Lynch, 1966). As rubidium accompanies potassium geochemically, one would expect the Rb–Sr age to be somewhere between the true age of the rock and the age of mineralization (dated radiometrically at about 60 m.y.).

The Ox Frame is correlated with the Mount Wrightson Formation in the Santa Rita Mountains. Both formations are thick sequences of rhyolitic to andesitic flows and pyroclastic rocks that contain intercalated beds of conglomerate, sandstone, and quartzite. Both are cut by intrusive rocks dated radiometrically as Jurassic (by several methods) and Late Triassic (by the Pb-alpha method). The Pb-alpha age of 220 m.y. reported by Drewes (1968, p. C7) for the middle member of the Mount Wrightson Formation is compatible with all other geologic and radiometric evidence. However, the Pb-alpha method is not very precise, and I regard this date as only a first approximation of the true age of the Ox Frame Volcanics.

TASCUELA REDBEDS

NAME, TYPE SECTION, AND GENERAL DESCRIPTION

The name Tascuela Redbeds, of Thoms (1966, 1967), is here adopted for the thick sequence of sedimentary rocks that overlies the Ox Frame Volcanics and underlies the Stevens Mountain Rhyolite in the western foothills of the Sierrita Mountains. The type section is along Tascuela Canyon, mostly in the E½ sec. 13, T. 18 S., R. 10 E., but extending a short distance into sec. 18, T. 18 S., R. 11 E.

In the type section the formation reaches a maximum thickness of about 2,000 feet and comprises two main units. A coarse basal conglomerate, as much as 200 feet thick but absent locally, is overlain by 1,600–1,800 feet of maroon shale and argillite that contains sparse beds of sandstone, quartzite, and sandy limestone.

The basal conglomerate consists of granules, pebbles, cobbles, and boulders in a maroon silty to sandy mudstone matrix. The larger fragments include a wide variety of volcanic rocks, evidently derived from the underlying Ox Frame Volcanics, and also pieces of quartzite, chert, and limestone of Paleozoic aspect. Upward in the basal unit, the conglomerate interbeds with maroon shale, and the particles decrease in grain size, until the unit becomes a monotonous sequence of maroon shale and argillite that contains a few blue-gray to green beds. The lower part of the sequence contains a few ledge-forming beds of yellowish-gray fine- to medium-grained quartzite, and the upper part contains a few thin beds of grayish-purple to grayish-red medium-grained volcanic graywacke. The graywacke consists of angular to rounded grains of quartz, feldspar, and rock fragments in a clay matrix. About 15 percent of the rock is matrix and at least 25 percent is feldspar and microcrystalline volcanic rock fragments.

The type section of the Tascuela Redbeds is near the south end of the known outcrops of the formation. The area of outcrop trends northwest and is about 6½ miles long and as much as half a mile wide. The formation passes beneath overlapping Demetrie Volcanics to the southeast and overlapping pediment gravel to the northwest. There is no evidence of pinching out in either direction. Owing to increasing metamorphism toward the north, the characteristic red color is gradually lost and the northern outcrops are gray slate, phyllite, and fine-grained mica schist. Thoms (1966, p. 100–101) reported conglomerate beds that contain elongate granitic cobbles and boulders near the top of the formation in the metamorphosed area. Except for the quartzite beds already mentioned, all parts of the formation are nonresistant to erosion and are inconspicuous topographically.

The Tascuela overlies the Ox Frame Volcanics with disconformable contact, as described in the section on the Ox Frame (p. D13), and it is overlain with apparent conformity by the Stevens Mountain Rhyolite. According to Thoms (1966, p. 101–102),

> The lowest, distinct unit in the Stevens Mountain Rhyolite is a grayish-pink to light-red conglomerate comprised of well-rounded pebbles and cobbles of light-colored volcanic rocks in

a tuffaceous matrix. The shales, argillites and slates of the Tascuela red beds grade upward into this conglomerate through an interval which ranges from a few feet to a few tens of feet in thickness. The interval usually contains at least one recognizable coarse tuff or sandy tuff bed. To complete the transition, lenticular shales, one or two feet thick, are interbedded in the lowest part of the conglomerate.

At some places, the Stevens Mountain Rhyolite is missing and the Tascuela is overlain with angular unconformity by the Demetrie Volcanics. Pre-Demetrie erosion removed all but remnants of the Stevens Mountain Rhyolite and cut deeply into and even through the Tascuela Redbeds. Red shale fragments are common in the basal conglomerate of the Demetrie where it lies directly on the Tascuela Redbeds.

AGE AND CORRELATION

Field evidence fixes the Tascuela Redbeds as post-Ox Frame Volcanics and pre-Stevens Mountain Rhyolite. Its age with respect to the Triassic(?) and Jurassic intrusive rocks in the Sierrita Mountains is not directly determinable, as the Tascuela is nowhere in contact with these rocks. Thus, direct geologic evidence provides only broad limits within which age assignment can be made.

The general lithology of the Tascuela resembles that of the lower part of the Bisbee Group in the latter's type area. The limestone-bearing conglomerate suggests the Glance Conglomerate, and the overlying red predominantly fine-grained detrital beds suggests the Morita Formation. Correlation with these formations is permitted by local field evidence but raises a number of problems when regional stratigraphic relations are considered. For instance, much evidence shows that the type Bisbee changes facies toward the northwest and grades into different-appearing arkosic rocks such as the Amole Arkose of W. H. Brown (1939) in the Tucson Mountains and the Angelica Arkose in the Helmet Peak area. Close to and west of the arkosic facies, the Tascuela resembles typical Bisbee; for them to be equivalent, however, would seem to require major fault displacement of the Bisbee, which would be entirely hypothetical in the present state of knowledge. Furthermore, the beds of volcanic graywacke and conglomerate that contain granite boulders in the upper part of the Tascuela are unlike typical Bisbee. Of more significance is the apparent upward gradation of the Tascuela into the Stevens Mountain Rhyolite. Elsewhere in southeastern Arizona, Cretaceous volcanic rocks of post-Bisbee age are separated from the Bisbee by a conspicuous unconformity. This unconformity is unquestionably represented in the Sierrita Mountains by the unconformity at the base of the Demetrie Volcanics—a surface of considerable relief cut in a wide variety of formations, including the Stevens Mountain Rhyolite, Tascuela Redbeds, and Angelica Arkose (which is a Bisbee equivalent). Either the Stevens Mountain Rhyolite represents Early Cretaceous volcanic activity not evident elsewhere in Arizona, or the Tascuela is not a Bisbee equivalent.

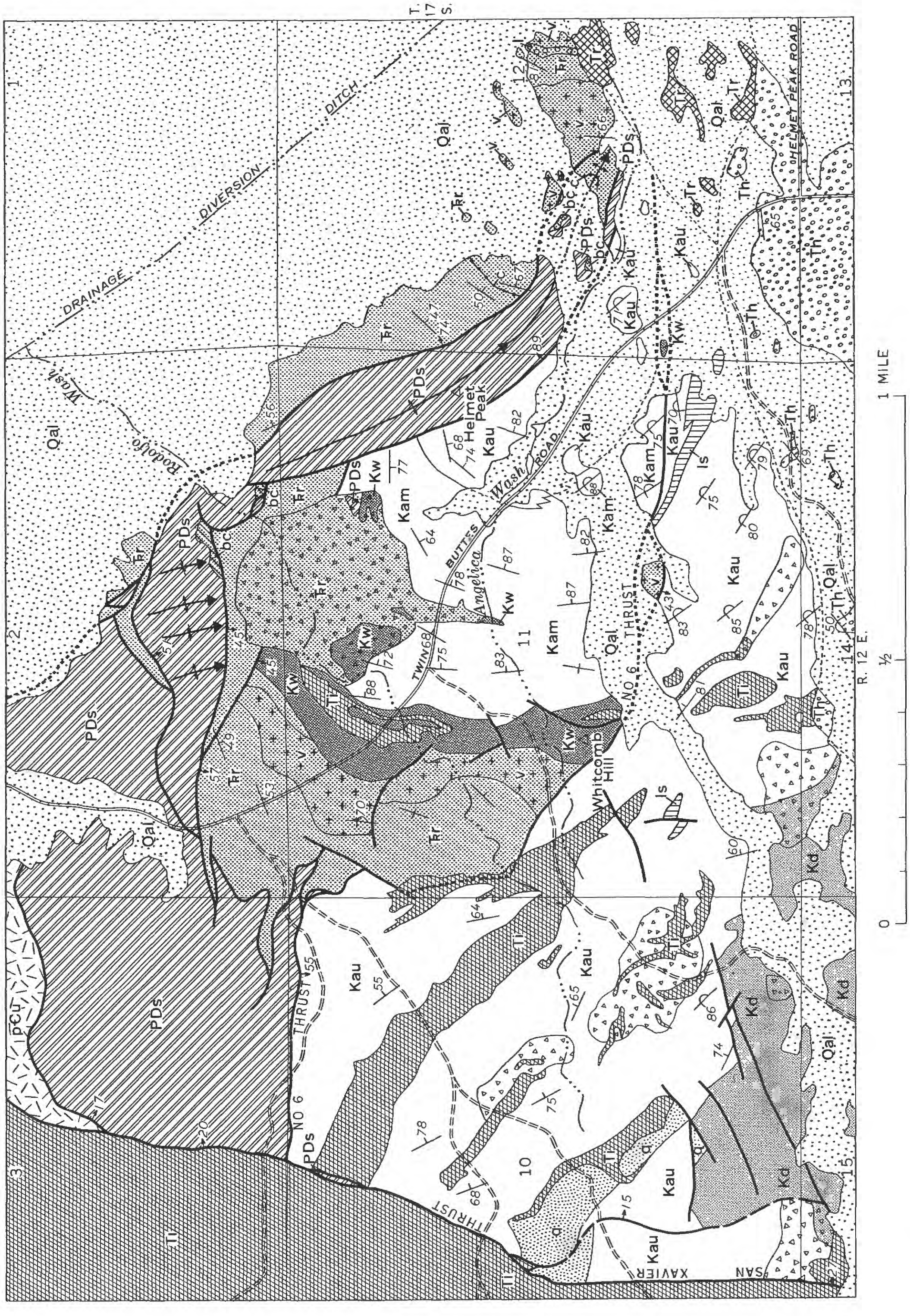
The Tascuela could be equivalent to the lower part of the Canelo Hills Volcanics whose basal unit, according to Hayes, Simons, and Raup (1965), is as much as 2,000 feet thick and consists of interbedded red siltstone, shale, sandstone, conglomerate, and rhyolitic to latitic volcanic rocks. The unit shows much lateral variation, but sedimentary rock is generally predominant in it, particularly in the lower part. Although no volcanic rocks have been found in the Tascuela, the presence of graywacke beds containing volcanic detritus in the upper part of the formation suggests contemporaneous volcanic activity in the vicinity. If the Tascuela is correlated with the basal unit of the Canelo Hills Volcanics, there is no problem with the distribution of Cretaceous facies and the Stevens Mountain Rhyolite simply represents the upper rhyolitic part of the Canelo Hills Volcanics.

Other red-bed units which resemble the Tascuela in lithology but which generally contain volcanic rocks are the Recreation Redbeds of W. H. Brown (1939) in the Tucson Mountains, the Gardner Canyon Formation in the Santa Rita Mountains, and the Rodolfo Formation in the eastern pediment of the Sierrita Mountains. The Recreation, long considered Cretaceous, is evidently Jurassic or older inasmuch as it is cut by porphyry whose K–Ar age is 150±5 m.y. (Damon, 1967, p. 69–70). Zircon from a lava flow in the Gardner Canyon Formation has a Triassic Pb-alpha age (Drewes, 1968, p. C7), and the Rodolfo Formation is Triassic as pointed out on page D22. Available geologic and radiometric age data suggest that all these formations are correlative. Therefore, the Tascuela Redbeds are here assigned to the Triassic.

RODOLFO FORMATION

NAME AND TYPE LOCALITY

The name Rodolfo Formation is here applied to the sequence of red beds and intercalated volcanic rocks that overlies Paleozoic rocks on the northeast side of the Sierrita Mountains. The composite type locality of the formation is east, southeast, and west of Helmet Peak (fig. 5). The most complete section is just south of Rodolfo Wash along the east side of


DRAINAGE
DIVERSION
DITCH
Rodolfo Wash
HELMET PEAK ROAD
Helmet Peak
TWIN BUTTES ROAD
Angelica Wash
Whitcomb Hill
NO 6 THRUST
SAN XAVIER THRUST
T. 17 S.
R. 12 E.
0
½
1 MILE

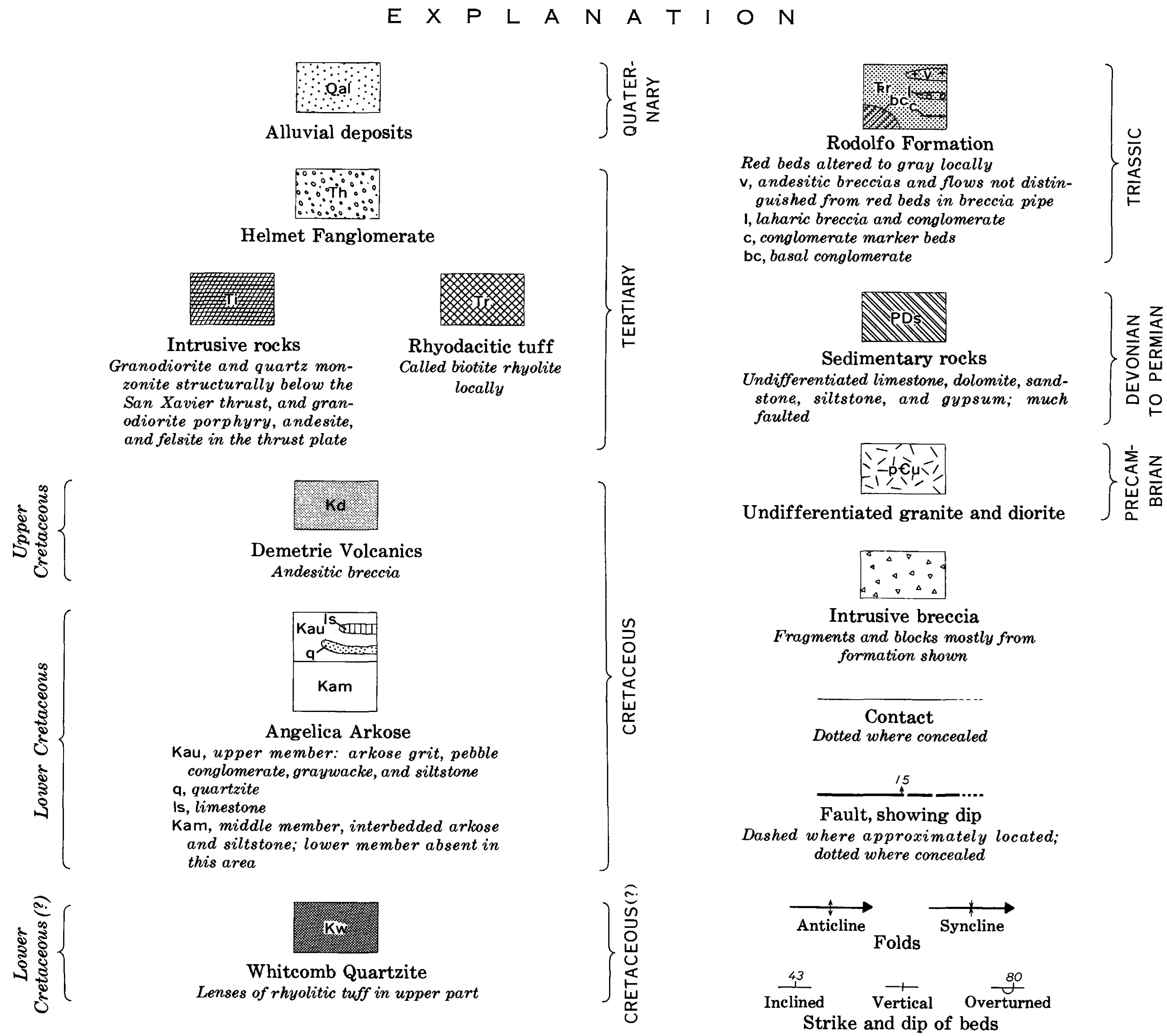


FIGURE 5.—Geologic sketch map of the Helmet Peak area. Geology mapped, 1957–68; base from U.S. Geological Survey Twin Buttes 15-minute quadrangle, 1957.

Helmet Peak where 2,400 feet of beds crops out but where neither the base nor the top is exposed. To the west, the lowest beds are in fault contact with Permian limestone and quartzite, and to the south the formation is overlain by lower Tertiary siliceous tuff known locally as the biotite rhyolite; this upper contact is discordant and is either an angular unconformity (Cooper, 1960, p. 76) or an intrusive contact (Kinnison, 1966, p. 281).

Rocks which I interpret to be the basal unit of the Rodolfo Formation are exposed at the south end of the Helmet Peak west of the fault between Paleozoic rocks and Rodolfo Formation. Here the Permian Rainvalley Formation is overlain unconformably by conglomerate and sandstone made up mostly of chert, limestone, and quartzite fragments from the underlying rocks. All rocks are in a very tight diapiric anticline, and no angular discordances in bedding are apparent (fig. 5). The conglomeratic unit is separated, by a short covered interval, from outcrops of red beds typical of the Rodolfo and is evidently the basal unit of that formation.

In support of this interpretation, the same relationship of Rainvalley Formation, conglomeratic unit, covered interval, and Rodolfo red beds is found at several places in a small faulted area half a mile north-northwest of Helmet Peak. Of course, faulting in the covered intervals has possibly cut out all but the basal conglomerate of some unknown unit and juxtaposed the conglomerate and the Rodolfo Formation at places nearly a mile apart. Faults with the location and magnitude required are unsupported by direct field evidence, and therefore the simplest interpretation is accepted—that the conglomerate is indeed the basal conglomerate of the Rodolfo Formation.

The top of the Rodolfo Formation is exposed about 4,000 feet west of Helmet Peak. Here a slightly metamorphosed gray facies of the Rodolfo is overlain by the Whitcomb Quartzite for about three-fourths mile. There is little angular discordance between the formations but, on the other hand, no indication of a gradation between them. The Whitcomb Quartzite lies with sharp gently undulating contact on an andesite unit and at one place on a sedimentary unit of the Rodolfo.

GENERAL DESCRIPTION, DISTRIBUTION, AND THICKNESS

The Rodolfo Formation in the composite type locality is at least 2,400 feet thick and comprises three members as follows: (1) a basal conglomeratic member, as much as 70 feet thick, which lies unconformably on Paleozoic rocks and consists mostly of fragments derived from these rocks; (2) a middle member of siltstone, less abundant sandstone, and conglomerate, at least 1,300 feet thick, and (3) an upper volcanic member, ranging from 200 to nearly 1,100 feet in thickness, which is in interfingering contact with the middle member and consists mostly of andesitic breccia but contains some flows and a thick red-bed unit. The upper member is overlain with sharp disconformable contact by the Whitecomb Quartzite.

The formation is nonresistant to erosion and crops out discontinuously on pediment surfaces and on the lower slopes of hills supported by more resistant rocks. In the exposures east of Helmet Peak, the siltstone member and much of the volcanic member are grayish red and distinctive, even from a distance. Elsewhere the andesitic units are medium gray to dark greenish gray, and the sedimentary units are mostly medium gray and commonly have a green or brown hue. The change in color of the sedimentary units from red to gray is strictly gradational at places and evidently is due to thermal metamorphism. Elsewhere hydrothermal processes were involved, as shown by the fact that the change in color begins along fractures and finally pervades the whole rock.

Most exposures of the Rodolfo are in the vicinity of Helmet Peak. Within about a mile to the west and northwest of the peak, parts of the formation crop out in fault blocks and as the predominant material in a large breccia pipe that cuts the Whitcomb Quartzite and Angelica Arkose (fig. 5).

To the northeast, the formation underlies Quaternary alluvium for a long distance, as shown by drilling. Siltstone and volcanic pebble conglomerate at the Mission mine were named the Papago Formation and the Kino Formation, respectively, by Kinnison (1966, p. 283) and were assigned an early Tertiary age on the basis of district and regional geologic considerations. These rocks are lithologically similar to the middle siltstone member of the Rodolfo Formation, and they immediately overlie altered Paleozoic rocks; I believe, therefore, that they represent part of the Rodolfo. Recently what seems to be part of the same member has been exposed beneath alluvium in the Twin Buttes open-pit mine 5.5 miles southeast of Helmet Peak (fig. 2).

West of the Twin Buttes mine, within the contact metamorphic aureole of a large granodiorite intrusive of Paleocene age, metamorphosed Rodolfo Formation overlies Permian tactite, marble, and quartzite in a small much-faulted area near the old Senator Morgan mine (fig. 2). The Rodolfo here consists of foliated and hornfelsed siltstone and minor sandstone and conglomerate. The conglomerate contains pebbles of calc-silicate hornfels, recrystallized chert, and quartzite, which evidently represent pieces of Paleozoic rock recrystallized and silicated in Paleocene time.

Also assigned to the Rodolfo(?) is about 2,000 feet of beds exposed over an area of one-fourth square mile at the head of Ash Creek in the Sierrita Mountains (fig. 4). These rocks are mostly fine-grained epidotic hornfels derived from argillaceous siltstone and fine-grained sandstone. There are also beds of medium-grained sandstone and, in the upper part, some conglomerate and breccia composed of volcanic material. Correlation with Rodolfo is based entirely on lithology inasmuch as the unit is everywhere bounded by fault and intrusive contacts. The intrusive rocks that cut the unit are those with radiometric ages between 140 and 190 m.y. (p. D13, table, Nos. 1, 2, 4).

LITHOLOGY

BASAL CONGLOMERATIC MEMBER

The basal member of the Rodolfo Formation near Helmet Peak comprises as much as 70 feet of conglomerate and sandstone lying unconformably on the Rainvalley Formation of Permian age. The principal outcrops are shown in generalized form in figure 5. Field relations already discussed indicate that these rocks are overlain by the siltstone member of the Rodolfo although the actual contact is concealed by Quaternary alluvial deposits.

The lower few feet to several tens of feet of the member is conglomerate consisting of ill-sorted pebbles and cobbles of chert, quartzite, and limestone in a light-gray to grayish-orange sandy matrix. All the pebbles and cobbles probably came from the underlying Paleozoic formations; most of them are well rounded, but some are subangular. Fragments as much as 8 inches in diameter are present, but those of pebble size are most abundant. The matrix commonly makes up about half the rock and consists of granules and coarse sand cemented by calcite. The matrix grains consist of quartz, quartzite, chert, and sparse nearly white argillized grains that are altered beyond recognition.

Coarse-grained sandstone, lithologically similar to the matrix material, occurs as lenses in the conglomerate and as overlying beds. In the thickest exposed section of the member, about 3,000 feet northwest of Helmet Peak, the conglomerate is 25 feet thick and is overlain by about 45 feet of grayish-orange coarse-grained clean sandstone and medium-grained sandstone having an abundant silty matrix. The sequence indicates an upward gradation from conglomerate toward rock resembling the overlying siltstone member in texture.

MIDDLE SILTSTONE MEMBER

The middle member of the Rodolfo Formation consists of siltstone having widely dispersed but generally subordinate interbeds of mudstone, sandstone, and conglomerate and at least one thin bed of impure limestone. In the type locality east of Helmet Peak, these rocks are red and show well-preserved sedimentary textures. Elsewhere, they are generally gray, and their sedimentary textures are masked, but rarely obliterated, by metamorphism and hydrothermal alteration. The total thickness of the member is not known inasmuch as there are no complete sections and no persistent stratigraphic markers by which the total section could be pieced together from separated areas. The incomplete section on the east side of Helmet Peak is about 1,300 feet thick and contains much volcanic detritus. A thick underlying sequence that contains less volcanic detritus has been found by drilling in the alluvium-covered area to the northeast. Therefore, the total thickness of the member is probably several thousand feet. It is the only part of the formation found at most places.

Indistinctly bedded, nonfissile siltstone predominates in the middle member of the Rodolfo Formation. The siltstone and associated mudstone near Helmet Peak are grayish-red soft rocks in which sparse sand-size grains and tiny glistening flakes of mica are commonly discernible with a hand lens. Detrital constituents identified in thin section include quartz, muscovite, potassium feldspar, plagioclase, and minute rock fragments. The recognizable grains lie in an abundant argillaceous matrix which is stained with red iron oxide and which locally contains a little calcite. There is an upward gradation from normal siltstone rich in recognizable quartz to volcanic siltstone in which grains of plagioclase and andesite are almost the only recognizable constituents and make up as much as half the rock. The highly volcanic facies is found in the upper part of the member, which interfingers with extrusive andesite breccia.

With metamorphism and hydrothermal alteration the siltstone was changed from red to gray and commonly became harder. The chief difference apparent in thin section is the presence of varying amounts of very fine grained chlorite, biotite, sericite, and feldspar instead of the hematite-rich matrix material. Near the Mission and Pima mines, the siltstone is represented by medium-dark-gray to light-greenish-gray or brownish-gray hornfels. Thin sections of these rocks, including many sections kindly lent me by J. H. Courtright of the American Smelting and Refining Co., show that the darker colors are due to relatively abundant biotite and that the rocks are generally richer in quartz than those near Helmet Peak. The biotite is an alteration product, whereas most of the quartz seems to be primary detrital grains. Because detrital quartz increases in abundance downward in the siltstones east of Helmet Peak, I believe that a stratigraphically lower part of the same sequence occurs in the Mission mine area.

Lenses of pebble conglomerate a few inches to a few feet thick are widely distributed in the siltstone member. Those in the lower part of the member near Helmet Peak are pale red to grayish red and consist of subrounded to well-rounded granules and pebbles of chert and rhyolite in a matrix of coarse sand cemented with silica. Paleozoic rocks are an obvious source of the chert pebbles. The Ox Frame Volcanics is the probable source of the rhyolite pebbles, which comprise welded tuff, nonwelded mixed tuff, and lava having the sieve-textured groundmass found in that formation. An unusually thick and persistent conglomerate of this type near the bottom of the member wraps around the anticlinal axis several thousand feet southeast of Helmet Peak (fig. 5). Unmapped conglomerates of the same type crop out north and northwest of the peak.

Pebbles of chert and rhyolite become increasingly scarce in the conglomerates stratigraphically higher in the member, and pebbles and cobbles of andesite become increasingly abundant. The andesitic conglomerate lenses—one of which, 1,200 feet east-southeast of Helmet Peak, is shown in figure 5—tend to be coarser, thicker, and more abundant than the lenses lower in the section. The andesitic conglomerates are evidently of intraformational derivation and are as much as 30 feet thick where the siltstone member interfingers with the upper volcanic member of the formation.

Pebble conglomerate also occurs near the Mission and Pima mines in the altered gray part of the siltstone member referred to by Kinnison (1966) as the Papago and Kino Formations. The conglomeratic texture here is commonly obscure in outcrop but is readily apparent in moistened drill cores, polished surfaces, and thin sections. Pebbles consist of recrystallized chert, volcanic rock, and apparently intraformational siltstone and sandstone. Pebbles of rhyolitic rock with relict vitroclastic texture occur in both the Papago and Kino Formations of Kinnison (1966).

Sandstone is more abundant than conglomerate in the siltstone member but is analogous to it in lithology, mode of occurrence, and distribution. In the lower part of the section east of Helmet Peak, the sandstone is grayish red, fine to coarse grained, and looks like arkose in hand specimen. Many grains that resemble argillized feldspar macroscopically are seen in thin section to be devitrified rhyolitic rocks like those in the associated conglomerate. Other grains include quartz, sodic plagioclase, potassium feldspar, chert, siltstone, and sandstone. Most of the sandstone beds in the lower part of the member are quite clean—the grains being coated with fine-grained hematite, and the interstices being filled with chemically deposited quartz. Sandstone beds in the upper part of the sequence are generally of the graywacke type and locally grade upward into siltstone. Grains of andesite and plagioclase predominate, and very fine grained slightly calcareous hematite-rich matrix makes up a large part of the rock. Modal analyses illustrating the two kinds of sandstone follow.

Percentage composition of two kinds of sandstone

	Rhyolitic arenite (specimen T307)	Andesitic graywacke (specimen T310)
Quartz	21.7	0.3
Plagioclase	5.0	16.5
Potassium feldspar	4.5	....
Muscovite	.3	....
Heavy minerals	Trace	.9
Lithic grains	49.3	40.0
Argillaceous matrix	....	42.3
Chemical cement	19.2	....
Total	100.0	100.0

Thin sandstone interbeds in the siltstone member near the Mission and Pima mines, though gray and altered, were probably similar in original lithology to the sandstones just described. Most were of the graywacke type but were not andesitic. Indeed these rocks generally contain more detrital quartz than do the sandstones in the Helmet Peak area.

The only limestone found in the middle siltstone member of the Rodolfo Formation is a lens about a foot thick near the bottom of the member 2,400 feet southeast of Helmet Peak. The lens can be traced 150 feet along the strike and is faulted off at its thickest point. The limestone is brown and contains much dispersed argillaceous and silty material. Alteration of this readily metamorphosed impure limestone could cause localized patches of calc-silicate rock.

UPPER VOLCANIC MEMBER

The upper volcanic member southeast of Helmet Peak is about 1,100 feet thick and consists of a thick lower unit of andesite breccia followed in turn by about 250 feet of red beds, 75 feet of laharic breccia and conglomerate, and 100 feet of andesite flows and intercalated red beds (fig. 5). These units are overlain with angular unconformity by lower Tertiary rhyodacitic tuff known locally as the biotite rhyolite; they are overlapped by the tuff a short distance to the northeast beneath the alluvial cover, as shown by drill-hole data. West of Helmet Peak, the volcanic member of the Rodolfo is less than 600 feet thick and is composed entirely of andesite breccia. It is overlain unconformably by the Whitcomb Quartzite and is faulted off at both ends. This locality and the one southeast of Helmet Peak are the only places where the volcanic member is now known.

The lower andesite breccia unit has an interfingering contact with the underlying siltstone member but is not perceptibly bedded or layered. It consists of unsorted subangular fragments of andesite as much as several inches in diameter in a fine-grained clastic matrix compositionally like the fragments. The least altered parts are dark gray to dark grayish red on fresh fracture; more altered parts are lighter, and the most altered parts are yellowish gray and felsic looking. The rock west of Helmet Peak is gray and strongly magnetic, whereas that southeast of the peak is red and virtually nonmagnetic because magnetite has been converted to hematite by oxidation.

In hand specimen, the andesite fragments in the breccia are characterized by phenocrysts about 1 mm long of plagioclase and mafic minerals in an abundant aphanitic groundmass; the matrix looks like the fragments except that many phenocrysts in it are broken. Thin sections examined are much propylitized but indicate the following initial composition: 25–35 percent plagioclase phenocrysts, about 10 percent mafic phenocrysts, 2–3 percent accessory magnetite and apatite, and 50–60 percent cryptocrystalline groundmass that shows tiny microlites of plagioclase locally. The plagioclase is mostly albitized but contains scarce remnants of unreplaced andesine. The primary mafic silicates are hornblende and less abundant augite occurring as kernels in the hornblende and as discrete grains. The igneous texture and minerals are largely destroyed in the much-altered yellowish-gray facies, which consists of euhedral to subhedral crystals of dusty albite in a microcrystalline groundmass of anhedral epidote, quartz, sericite, and opaque grains. Though quartz makes up nearly 20 percent of these rocks, a rough computation based on modal analysis indicates an overall silica content near 56 percent, about the same as Nockolds' (1954) average andesite or latite.

A small amount of probably extrusive dacitic and rhyolitic rock has been noted in the andesite breccia member. In the uppermost part of the siltstone member east of Helmet Peak, there is a small unmapped tongue of rock which superficially suggests loosely packed andesite conglomerate but which has a matrix of pale-red porphyry containing phenocrysts of quartz, feldspar, and altered biotite. In thin section, the porphyry shows saussuritized plagioclase, resorbed quartz, and scarce pseudomorphs of epidote, hematite, muscovite, and quartz after bent biotite books, in a cryptocrystalline felsic groundmass. As this interstitial porphyry is petrographically different from the fragments, the rock is interpreted as a dacitic flow loaded with andesite inclusions. A few hundred feet higher in the section, in the lower part of the andesite breccia unit, there are two poorly exposed thin layers of pale-red tuffaceous-looking rock in which scattered rock chips and round quartz grains are discernible macroscopically. As seen in thin section, the quartz grains have the form of resorbed crystals and angular crystal fragments—indicating that the rock is indeed a silicic tuff. The rock fragments include sandstone, siltstone, and cryptofelsite. The remainder of the rock is a confused aggregate of secondary clays, calcite, epidote, and quartz. Large blocks of very similar rocks containing only part argillized and calcitized sanidine occur in andesite breccia in the breccia pipe just west of Helmet Peak.

About 250 feet of grayish-red sandstone containing at least one thin bed of gray limestone overlies the andesite breccia unit southeast of Helmet Peak. The sandstone is fine to medium grained, well sorted, and locally laminated and cross laminated. The limestone is nowhere actually exposed, but it is found as abundant float and as tabular pieces mixed with red sandstone fragments in the dump of an old prospect pit now virtually filled by sheet wash. The limestone bed, apparently 4 inches or less in thickness, undoubtedly represents a local pond deposit intercalated with the sandstone. It is light olive gray and silty looking in hand specimen. In thin section, the main impurities are seen to be glass shards and pumice fragments containing tiny crystals and crystal fragments of andesine and clinopyroxene. Evidently volcanic ash fell into the accumulating lime mud and was protected from the alteration that affected other parts of the formation. The index of refraction of the glass (1.521–1.539) suggests a silica content near 60 percent, midway between the average andesite and average rhyodacite of Nockolds (1954).

Overlying the red sandstone unit just described is about 75 feet of andesitic conglomerate and laharic breccia. The breccia typically consists of unsorted and unbedded material ranging in size from particles of mud to subangular cobbles, whereas the conglomerate is fairly well sorted and distinctly bedded pebble and cobble conglomerate having a sandy matrix. The constituents are mostly of intraformational source but include some pebbles and cobbles of grayish-red andesitic porphyry and white plagioclase phenocrysts as much as 15 mm in diameter—a distinctive rock not found elsewhere in the Rodolfo Formation.

The top 100 feet of the Rodolfo Formation southeast of Helmet Peak consists of at least two andesite flows separated by a few feet of red beds. The flows are grayish-red propylitized rocks similar in lithology to fragments in the andesite breccia unit at the base of the volcanic member. The flows are not brecciated, however, and at least locally have chilled amygdaloidal tops. The amygdules, which are circular to elliptical in outline and as much as 10 mm in maximum diameter, are composed of white quartz, sericite, and calcite. Like other red rocks in the Rodolfo Formation, the color of the flows is due to disseminated fine-grained hematite.

CONTACTS

The basal contact of the Rodolfo Formation is an unconformity that, in small exposures near Helmet Peak, truncates tens of feet of beds in the underlying Rainvalley Formation of Permian age. The contact is easy to recognize in outcrop inasmuch as the Rodolfo Formation has a basal conglomerate composed of fragments of Paleozoic rock overlain by red beds whose lithology is different from that of any underlying formation. Except in the small outcrops near Helmet Peak (fig. 5), exposed contacts of the Rodolfo Formation with Paleozoic rocks are faults, many of which have been healed and obscured by alteration.

The Rodolfo Formation is overlain by the Whitcomb Quartzite. The contact, where exposed, is an undulating surface that apparently was eroded down to andesite breccia near the bottom of the upper volcanic member of the Rodolfo. Along the strike the contact bevels an overlying tongue of siltstone and graywacke of the Rodolfo, as shown by geologic mapping and exploratory drilling records. Because the exposed contact is slightly sheared and no basal conglomerate or recognizable fragments of Rodolfo have been found in the Whitcomb, the contact could be interpreted as a fault contact. However, the shearing is no greater than that commonly evident between units of contrasting lithology in this area, and so the contact is best interpreted as a disconformity along which trivial slippage has taken place.

AGE AND CORRELATION

The Rodolfo Formation obviously postdates the Permian Rainvalley Formation, which it overlies unconformably, and also the Ox Frame Volcanics of the Sierrita Mountains and the Mount Wrightson Formation of the Santa Rita Mountains, which yielded the rhyolite fragments in conglomerates and sandstones in the lower part of the Rodolfo. The Rodolfo predates the Whitcomb Quartzite and Angelica Arkose, which overlie it. If the hornfels at the head of Ash Creek (fig. 4) is truly Rodolfo, the formation must also predate the Jurassic and Triassic(?) intrusive rocks. Thus, field evidence indicates that the Rodolfo Formation is of Triassic age but is younger than the Ox Frame Volcanics.

Red beds and volcanic rocks correlated with the Rodolfo Formation on the basis of lithology and stratigraphic position consist of the Tascuela Redbeds, the Recreation Redbeds and overlying volcanic rocks of W. H. Brown (1939) in the Tucson Mountains, the Gardner Canyon Formation in the Santa Rita Mountains, the lower part of the Canelo Hills Volcanics, and the Walnut Gap Volcanics near the Little Dragoon Mountains. The upper volcanic member of the Rodolfo may be correlative with the Stevens Mountain Rhyolite.

Radiometric data bearing on the age of the Rodolfo Formation and its correlatives are consistent with each other and with the geologic field relations. The K–Ar age of 150 m.y. obtained by Damon (1967, p. 69) for an intrusive porphyry cutting the Recreation Redbeds indicates that the Recreation is Jurassic or older. The K–Ar age of 173 m.y. reported by Hayes, Simons, and Raup (1965, p. M7) for a rhyolite tuff unit high in the Canelo Hills Volcanics indicates that the lower part of the formation correlated with the Rodolfo cannot be younger than Early Jurassic. The Pb-alpha age of 192 m.y. reported by Drewes (1968, p. C7) for a dacite flow in the Gardner Canyon Formation is a Triassic age. The oldest intrusive cutting the Rodolfo(?) Formation in Ash Creek, the quartz monzonite of Harris Ranch, has a Pb-alpha age calculated as 187 m.y. and presented by T. W. Stern (written commun., 1966) as 190±20 m.y. Although the Pb-alpha method is not very precise, the Rodolfo Formation is here assigned to the Triassic.

UPPER TRIASSIC OR LOWER JURASSIC ROCKS

STEVENS MOUNTAIN RHYOLITE

NAME, TYPE LOCALITY, AND GENERAL DESCRIPTION

The name Stevens Mountain Rhyolite as defined by Thoms (1966, 1967) is here adopted for the rhyolitic volcanic sequence that overlies the Tascuela Redbeds and underlies the Demetrie Volcanics on the west side of the Sierrita Mountains. The type locality is on Stevens Mountain in sec. 34, T. 17 S., R. 10 E. Known exposures are in a belt as much as half a mile wide and about 5 miles long that extends northwest and southeast of this locality.

The Stevens Mountain Rhyolite consists of a basal volcanic conglomerate and overlying rhyolitic crystal tuffs, welded tuffs, and flows. Weathered surfaces of these rocks are generally pinkish or yellowish gray and contrast with the darker colors of the Tascuela Redbeds and Demetrie Volcanics. Lenticular interbeds of shale, siltstone, sandstone, and orthoquartzite are scarce. The formation as a whole is resistant to erosion and forms the crest of Stevens Mountain and some lower hills and ridges. Its contacts commonly are expressed by breaks in topography and by the contrasting colors of the formations in outcrops. The thickness of the Stevens Mountain, owing to pre-Demetrie erosion, ranges from 0 to about 2,000 feet.

The basal conglomerate in the type locality is light gray to pale red and is composed of well-rounded pebbles and cobbles of felsic volcanic rock in a tuffaceous matrix. Many of the larger clasts, though well rounded, lithologically resemble overlying extrusive rocks. The matrix consists mostly of grains of quartz and feldspar commonly 1–3 mm in diameter, but it contains scattered angular fragments of rhyolitic rock as much as 1 cm in maximum dimension. Thoms (1966, p. 105–106) reported that the small rock fragments have nondefinitive microcrystalline texture in thin section and that the principal matrix constituents are embayed grains and angular chips of quartz; euhedral crystals and crystal fragments of anorthoclase, orthoclase, and moderately sericitized plagioclase; and subordinate interstitial very fine grained sericitic material. The conglomerate grades upward into overlying crystal tuff that is practically identical with the conglomerate matrix in lithology.

The basal conglomerate unit of the Stevens Mountain Rhyolite is at most about 100 feet thick at the type locality but, according to Thoms (1966, p. 109), is about 1,000 feet thick in outcrops a mile or so to the southeast. Here the lower 200 feet of conglomerate is dark blue or maroon and contains a few thin beds of maroon shale and dark-purple siltstone. The upper part is light gray or pink and is like the upper part of the basal conglomerate in the type locality except for some interbeds of shale, tuff, and eutaxitic felsite and a capping maroon sandstone bed 6–10 feet thick. Detailed stratigraphic relations between the two localities are indeterminate because of intervening Demetrie Volcanics that fill an ancient valley.

The rhyolitic tuffs and flows that overlie the conglomerate and make up most of the formation are well-indurated light-colored rocks. Weathered surfaces are generally grayish pink, grayish orange, or yellowish gray; fresh surfaces range from pale red through pale red purple to grayish blue. Phenocrysts, generally 1–3 mm in diameter of orange anorthoclase, vitreous gray quartz, chalky plagioclase, and locally clear orthoclase and altered biotite are discernible in an aphanitic felsic groundmass. Phenocrysts are generally sparse in units which lack discernible pyroclastic texture and which are regarded as flows, but they make up about 25 percent of some eutaxitic welded tuffs and an even higher percentage of some crystal tuffs. Individual volcanic units are commonly 100–500 feet thick.

Lenticular interbeds of quartzite a few tens of feet thick have been noted in the volcanic rocks in the type locality and elsewhere. A typical specimen was described by Thoms (1966, p. 113) as a fine- to medium-grained nearly equigranular rock that consists almost entirely of subangular to subrounded grains of quartz. A few grains of microcline, anorthoclase, and plagioclase are also present. Sericite and microcrystalline quartz form the scant matrix. Although the rock is well indurated, individual grain outlines are maintained, and sutured or intergrown contacts are lacking. The quartzite is unquestionably of sedimentary origin.

In addition to the quartzites, Thoms (1966, p. 112) reported two lenticular maroon sandstones near the bottom of the volcanic sequence southeast of the type locality. These units, 50 and 200 feet thick, are in the area where the basal conglomerate is very thick and contains volcanic units in the upper part.

The contact of the Stevens Mountain Rhyolite with the underlying Tascuela Redbeds is gradational and is described in the section on the Tascuela. Though such a contact could possibly result from reworking of subjacent material along an unconformity, no positive evidence of unconformity has been found and the contact is believed to be conformable.

The top of the Stevens Mountain is a sharp angular unconformity at the base of the Demetrie Volcanics, which fills channels cut into and through the Stevens Mountain. Fragments from the Stevens Mountain are abundant in the basal conglomerate of the Demetrie.

AGE AND CORRELATION

Local geologic relations prove that the Stevens Mountain Rhyolite postdates the Tascuela Redbeds and predates the Demetrie Volcanics. Geologic relations also show that the Stevens Mountain is in gradational conformable contact with the underlying Tascuela. For reasons already pointed out (p. D15), both these formations are correlated with the Canelo Hills Volcanics. According to this interpretation the Stevens Mountain Rhyolite is equivalent to only part of the rhyolitic rocks of the Canelo Hills Volçanics. The uppermost very thick and highly potassic welded tuff of the Canelo Hills, which has a K–Ar age of 173±7 m.y. (Hayes and others, 1965, p. M7), appears to be unrepresented inasmuch as the Stevens Mountain extrusives contain albitic plagioclase and anorthoclase and hence are sodium-rich rocks. Assuming that the Stevens Mountain Rhyolite represents the middle rhyolitic unit of the Canelo Hills Volcanics, the age of the Stevens Mountain is Early Jurassic or Late Triassic.

LOWER CRETACEOUS(?) ROCKS

WHITCOMB QUARTZITE

NAME AND TYPE AREA

Quartzite containing lenses of rhyolitic tuff in the upper part overlies the Rodolfo Formation west of Helmet Peak, from Whitcomb Hill (fig. 5) northward for about three-quarters of a mile. This formation, which is faulted off at both ends, is here named the Whitcomb Quartzite, and the exposures at Whitcomb Hill are designated the type area.

GENERAL DESCRIPTION, DISTRIBUTION, AND THICKNESS

The Whitcomb Quartzite is very light gray well-sorted fine- to medium-grained indistinctly bedded orthoquartzite that contains lenses of medium-light-gray flinty rhyolitic tuff in the upper part. About three-fourths of the formation is quartzite, which is resistant to erosion and forms a low ridge whose highest point is Whitcomb Hill. Small generally sill-like but locally discordant bodies of andesite cut the formation.

The Whitcomb overlies the Rodolfo Formation and underlies the Angelica Arkose. Both contacts are disconformities in the type area. The lower contact is described in the discussion of the Rodolfo Formation (p. D22). The upper contact is well exposed at one place and is clearly depositional. The Angelica Arkose here lies with no apparent angular discordance on a rhyolite tuff unit of the Whitcomb and contains a few pebbles of the tuff. Along the strike, the Angelica truncates a small tongue of quartzite and another lens of tuff, indicating that the contact is a disconformity.

The total thickness of the Whitcomb ranges from about 300 feet to nearly 600 feet in a distance of less than a mile between the faults that bound its type outcrops. The variation is due mostly to lateral thinning and thickening of the lower tuff-free quartzite that seems to have resulted from the undulatory surface on which the formation was deposited. Some variation is attributable to undulation in the upper contact. There is no indication that the formation is wedging out in either direction.

About 450 feet of quartzite, here assigned to the Whitcomb, crops out on a small hill in the alluvial plain 4½ miles east of Helmet Peak in sec. 10, T. 17 S., R. 13 E. The base of the quartzite is not exposed. Its top is a gradational contact with conglomerate which, as pointed out later (p. D26), seems best interpreted as a local basal conglomerate of the Angelica Arkose.

LITHOLOGY

Quartzite makes up 65–85 percent of the type Whitcomb. The remainder is rhyolitic tuff, occurring in lenticular beds 10 to perhaps as much as 150 feet thick in the upper half of the formation. The uppermost unit is tuff at most places.

The quartzite is well-sorted fine- to medium-grained quartz sandstone cemented by silica. Freshly broken surfaces have a rough subconchoidal fracture and are very light gray to grayish pink. Weathered surfaces are yellowish gray, grayish orange, or light brown and are locally coated with black desert varnish. Bedding planes are obscure. However, some weathered surfaces show a distinct lamination because of more desert varnish on alternate thin layers. The lamination, which is not apparent on fresh fracture, has almost the same dip as the formation as a whole but is oblique in strike and evidently represents crossbedding.

Constituents of the quartzite discernible with a hand lens are vitreous quartz, sparse disseminated specks of black iron ore, and grains of chalky white feldspathic material. Thin sections show rounded and subrounded detrital grains of quartz, 0.2–0.3 mm in diameter, whose interstices are filled with quartz in optical continuity with the worn grains. A film of dust generally separates worn grain from overgrowth. Quartz makes up 90 percent or more of the rock. The remainder consists of feldspathic grains sericitized and argillized beyond recognition, zircon, tourmaline, iron ores, and local wisps and pockets of sericite between the grains. The rock is a well-sorted orthoquartzite.

The rhyolitic tuff is a medium-light-gray to pinkish-gray, hard, compact rock in which phenocrysts of feldspar and quartz 0.5–3 mm long are easily discernible in a flinty aphanitic groundmass. Outcrops generally lack evident bedding or planar structure of any kind and could easily be mistaken for intrusive porphyry. At a few places on freshly broken and moistened surfaces, however, relict vitroclastic texture in the groundmass has been detected with a hand lens.

In thin section, vitroclastic texture is generally conspicuous despite complete devitrification. Pumice fragments and shards, which have axiolitic structure in the best preserved specimens, are moderately compacted and molded under and over phenocrysts and small rock fragments. Phenocrysts make up 15–20 percent of the rock and consist of sodic plagioclase (An_{5-10}), microperthite, quartz, and sparse pseudomorphs of muscovite and iron oxides after biotite. The rock fragments are mostly rhyolitic rock but include some accidental fragments of thoroughly recrystallized quartzite. Devitrified glass, which makes up most of the rock, is readily and strongly stained by cobaltinitrite solution and appears to be almost wholly potassium feldspar and quartz. On the basis of these properties, the rock is classed as rhyolitic welded tuff.

The quartzite east of Helmet Peak, assigned to the Whitcomb, is mostly well-sorted fine- to medium-grained nearly pure quartzite that weathers medium light gray with a brownish to purplish cast. Some beds contain disseminated coarse well-rounded frosted grains of quartz and medium to coarse subangular grains of fresh alkali feldspars and felsic volcanic rock. According to the terminology of McKee and Weir (1953), the unit is thin to thick bedded, commonly thinly laminated, and locally crossbedded and cross laminated on a medium to large scale. It contains a little detrital tourmaline like the type Whitcomb but on the whole is less pure and less well sorted. Tuff beds are lacking, but the presence of unweathered volcanic detritus indicates a dual source for the unit and suggests that there may have been nearby volcanic activity at the time of deposition.

CONTACTS

The contact of the Whitcomb Quartzite with the underlying Rodolfo Formation is a disconformity which is evident in outcrop because of the abrupt and major change in lithology. From a distance it can be approximately located along the west flank of a low ridge formed by the quartzite.

The contact of the Whitcomb with the overlying Angelica Arkose is a disconformity in the type area west of Helmet Peak. The disconformity is not clearly marked topographically but is easily recognized in outcrop. Locally the contact is gradational, if my interpretation of outcrops east of Helmet Peak is correct. Here the contact is placed where pebble and cobble conglomerate at the base of the Angelica becomes dominant. The contact defined in this way is actually rather sharp although each formation contains sparse thin interbeds characteristic of the other in a zone a few tens of feet thick.

AGE AND CORRELATION

The problem of age and correlation of the Whitcomb Quartzite is difficult and as yet not satisfactorily resolved. Two possible interpretations are as follows:

1. The Whitcomb correlates with the Stevens Mountain Rhyolite and therefore is pre-Cretaceous in age (Early Jurassic or Late Triassic). Both these formations display the unusual assemblage of rhyolite tuff and orthoquartzite that obviously represents a mature sediment, and both lie on correlative Triassic formations. Thus, lithology and stratigraphic position support a correlation. However, the two formations have a very different proportion of quartzite and rhyolite; also, the underlying formations are somewhat different lithologically. The Stevens Mountain has a gradational basal contact whereas the Whitcomb has a disconformity at the base. Correlation of the two formations would require lateral variations in lithology and local disconformity, which are certainly possible in a basin filled with sedimentary and volcanic rocks.
2. The Whitcomb is a general correlative of volcanic units assigned to the basal part of the Lower Cretaceous sequence in mountain ranges to the east (Gilluly, 1956, p. 68–70; Hayes and Raup, 1968; Drewes, 1968). The stratigraphic position of the Whitcomb is compatible with this interpretation, and a lithologically similar quartzite unit occurs in the overlying Angelica Arkose. Though the type Whitcomb has a disconformable upper contact, the quartzite assigned to the Whitcomb east of Helmet Peak has a gradational upper contact with conglomerate that I think must be of Cretaceous

age and could well represent the Glance Conglomerate. The preponderance of evidence favors this interpretation, and the Whitcomb is therefore assigned to the Early Cretaceous(?).

LOWER CRETACEOUS ROCKS

ANGELICA ARKOSE

NAME, TYPE LOCALITY, AND GENERAL DESCRIPTION

The name Angelica Arkose is here applied to a sequence of drab arkosic rocks about 5,000 feet thick that overlies the Whitcomb Quartzite with local disconformity and underlies the Demetrie Volcanics with angular unconformity. The formation crops out in several places, covering a total area of about 2 square miles, in the geologically complex outer part of the pediment east and northeast of the Sierrita Mountains. The chief outcrop area lies south and west of Helmet Peak (fig. 5). Other outcrops are in two small hills 4.5 miles east of Helmet Peak and also in low hills 5.5–6.8 miles to the south in the area west, south, and southeast of the Senator Morgan mine (fig. 2).

The formation, as pieced together from these isolated exposures, consists of a basal conglomerate member, a middle arkose and siltstone member, and an upper arkosic grit and conglomerate member. The basal conglomerate is a highly lenticular pebble and cobble conglomerate which is absent in some places but more than 500 feet thick in others. The middle member is a thin-bedded sequence, as much as 2,000 feet thick, of well-sorted light-olive-gray arkosic sandstone and greenish-gray to grayish-red siltstone. The upper member is a thick-bedded sequence, several thousand feet thick, of poorly sorted light-gray to light-brown arkosic grit and pebble conglomerate containing some gray siltstone and locally a little light-gray limestone and quartzite.

The Angelica Arkose is named for its exposures along Angelica Wash. The composite type locality is in this wash in secs. 10 and 11, T. 17 S., R. 12 E. (fig. 5), where the middle part of the formation is exposed; 4.5 miles east of Helmet Peak in sec. 10, T. 17 S., R. 13 E. (fig. 2), where the basal member is exposed; and just west of the Angelica Wash locality and southwest of the No. 6 thrust fault (fig. 5) in the S½ secs. 10 and 11 and the SW¼ sec. 12, T. 17 S., R. 12 E., where the upper part of the formation crops out.

In the Angelica Wash locality, the basal contact is a disconformity separating the middle sandstone and siltstone member from the underlying Whitcomb Quartzite. A few small pebbles of the Whitcomb occur in the lowermost sandstone beds. In the locality east of Helmet Peak, the basal conglomerate member is in conformable contact with the underlying quartzite. Thus, if my identification of formations in the locality east of Helmet Peak is correct, deposition was continuous east of Helmet Peak while the Whitcomb was being eroded in the Angelica Wash area. Presumably some deformation followed deposition of the Whitcomb and caused the basal contact of the Angelica to be conformable in some places and disconformable in others.

Identification of rocks in the locality east of Helmet Peak as Whitcomb Quartzite and Angelica Arkose, on which this interpretation depends, is based on lithology and on the presence of conglomerate at the base of the Angelica at one other place. South of the Senator Morgan mine near the Duval Road, conglomerate at least 500 feet thick that has been metamorphosed to hornfels underlies lithologically typical Angelica Arkose with poorly exposed but apparently conformable contact. The base of this conglomerate unit is concealed. The conglomerate east of Helmet Peak is stretched and foliated but not metamorphosed to hornfels. It overlies the quartzite with gradational contact, and on a nearby hill it underlies a flow or sill of distinctive amygdaloidal andesite virtually identical in hand specimen and thin section with andesite found by Harald Drewes (oral commun., 1968) in the Bisbee Group in the Santa Rita Mountains and interpreted by him as intrusive. Above the andesite is about 300 feet of brownish-gray arkosic sandstone and pebble conglomerate, whose lithology suggests a transitional zone between the conglomerate and the arkosic sandstone and siltstone in the lower part of the Angelica in Angelica Wash. A fault may be concealed under alluvial deposits between Helmet Peak and the nearby hill, but none is required by the geometric relations; and a large fault in this position is unlikely because the attitudes, both of the beds and of the distinct foliation, and the stretching at a large angle to the attitudes are the same in the two hills. The steep dip of the beds and of the pervasive foliation strongly indicates that the beds predate at least part of the Laramide orogeny. Among the known stratigraphic sequences in the region that fulfill this requirement, the Whitcomb and Angelica sequence provides the closest lithologic match.

LITHOLOGY

BASAL CONGLOMERATE MEMBER

The basal conglomerate is characterized by ill-sorted subrounded pebbles and cobbles tightly bound in a matrix of ill-sorted coarse-grained sandstone, which is generally medium gray on fresh fracture and brownish gray on weathered surface. The clasts are mostly silicic and intermediate volcanic rocks but also include some quartzite, graywacke, chert, limestone, felsic porphyry, aplite, and vein quartz. All the clasts probably came from pre-Angelica Mesozoic and Paleozoic rocks now exposed in the region. The sandstone matrix makes up 20–50 percent of the typical conglomerate and grades laterally and vertically into small sandstone lenses within the unit. Minor interbeds of fine-grained fairly well sorted sandstone and shale are scarce.

The effects of metamorphism are evident in all exposures of the unit. The original lithology of the clasts has been considerably obscured by thermal metamorphism and hydrothermal processes in the outcrops, west and south of the Senator Morgan mine, which are next to a large Laramide pluton. East of Helmet Peak the unit is stretched and foliated at a large angle to the plane of the beds but has not been thermally metamorphosed.

MIDDLE ARKOSE AND SILTSTONE MEMBER

At the type locality, near Angelica Wash, the middle member comprises about 2,000 feet of arkosic sandstone and siltstone in sharply defined beds generally less than 2 feet thick. The sandstone ranges from fine to coarse grained and is predominantly well sorted. In most exposures the rocks are light olive gray to medium gray on fresh fracture, but locally the siltstone and fine-grained sandstone are pale red to grayish red.

The sandstone consists of subangular grains of quartz (generally 40–45 percent), feldspar (25–35 percent), rock fragments (1–5 percent) and accessory heavy minerals tightly cemented in several different ways. In the predominant olive-gray types, the interstitial material is mostly epidote, presumably formed by metamorphism of a calcareous matrix. Overgrowths of quartz on the worn quartz grains are generally present and locally make up much of the cement. Sericite and chlorite, representing argillaceous matrix material, make up a small percentage of the rock generally and as much as 20–25 percent of some of the fine-grained grayish-red sandstones. According to Pettijohn's (1957, p. 291) classification, the sandstone is mostly arkose but grades locally to feldspathic graywacke.

In the sand fraction, albitic plagioclase is as much as three times as abundant as potassium feldspar. The rock grains consist of rhyolite from tuff beds in the Whitcomb Quartzite and cryptofelsite and andesite from the older Mesozoic formations.

Most of the sandstone beds are less than a foot thick, but a few coarse-grained beds are as much as 10 feet thick. Lamination due to slight differences in grain size or color is common. Some individual beds have normal grading, others reversed grading, and still others a combination of the two. As a result, textural variations have proved of little use in distinguishing tops from bottoms of beds. Many beds are lenticular and fill scours in underlying beds. The resulting channel structures and sparse crossbedding are the best indication of the top direction.

Siltstone, though less abundant than sandstone, forms many interbeds generally less than a foot thick. The rock is massive to weakly fissile argillaceous siltstone. It locally contains disseminations or laminae of fine sand having the same mineralogy and mineral proportions as the associated sandstone beds. The siltstone interbeds in much-epidotized sandstone are generally light greenish gray. Where epidotization was less intense, they are generally grayish red and slightly calcareous.

The middle member of the Angelica varies laterally in thickness and lithology. In the hills west and south of the Senator Morgan mine, where the member has normal lithology, it is less than 1,000 feet thick. An apparent pinching out in the southeastern part of this area is probably due to shearing out of beds. In the reference section 4.5 miles east of Helmet Peak, only the lower 300 feet of the middle member is exposed above the basal conglomerate. The middle member here consists of brownish-gray arkosic sandstone and pebble conglomerate in lenticular beds 2 inches to 10 feet thick—the proportion of conglomerate decreasing from about 70 percent at the bottom to about 10 percent at the top. The sandstone in the upper part is generally well sorted and locally laminated like the middle-member sandstone near Angelica Wash. Apparently these beds are a transitional facies between the basal conglomerate and the sandstone-siltstone facies at Angelica Wash.

UPPER ARKOSIC GRIT AND CONGLOMERATE MEMBER

Along Angelica Wash the upper member of the Angelica Arkose consists of about 1,600 feet of light-gray to light-brown arkosic grit and pebble conglomerate containing many interbeds of siltstone. These rocks lie with sharp but interfingering contact on the finer grained, better sorted, and thinner bedded rocks of the middle member, and they are cut off at the top by faults. As the result of the interfingering relationship, the upper member thickens several hundred feet toward the northeast at the expense of the lower member in a distance of less than half a mile. The coarse detritus thus did not come from the southwest; local evidence provides no basis for appraising other possible source directions.

Grit, here defined as coarse-grained ill-sorted sandstone containing disseminated granules and small pebbles, is the most abundant rock in the upper member. This grit is light gray to medium light gray on fresh fracture. Its constituent particles are mostly subangular and commonly range in size from granules to silt within the same hand specimen. Two specimens examined in thin section consist of 45–55 percent quartz, 15–25 percent feldspar, 5–10 percent rock fragments, and 15–25 percent calcareous silty matrix. In these specimens, grains of potassium feldspar and of plagioclase are about equally abundant, unlike the lower unit where plagioclase is predominant.

The grit contains lenses of conglomerate consisting of poorly sorted pebbles, granules, and sand cemented by calcite. Well-rounded pebbles of quartzite and less rounded ones of coarse-grained leucogranite are conspicuous in the rock. Other clasts are quartz, feldspar, and fine-grained igneous and sedimentary rocks. The granite pebbles are lithologically identical with much of the Jurassic granite now exposed in the Sierrita Mountains and undoubtedly came from that formation.

Interbeds of siltstone and fine- to medium-grained sandstone are common in the grit and conglomerate. These finer grained rocks are light olive gray to brownish gray, fairly well sorted, feldspathic, and calcareous. The ratio of potassium feldspar to plagioclase grains is about 1:1, as in the associated grit.

Bedding in the upper member is distinct. The grit and conglomerate units are 15–50 feet thick. They are not graded but commonly show crossbedding and scour-and-fill structure. The finer grained units are as much as 25 feet thick but are mostly 1–15 feet thick.

At the locality southwest of the No. 6 thrust fault (fig. 5), about 3,000 feet of beds consists mostly of light-gray feldspathic grit generally similar to beds in the upper part of the section along Angelica Wash. However, this grit is less distinctly bedded and commonly contains more fine-grained detrital matrix. Lenses of pebble conglomerate are fairly common, particularly in the lower part. There are also beds of light-gray fine-grained graywacke and dark-gray siltstone and mudstone that have been metamorphosed to hornfels. A conspicuous ridge-forming quartzite unit several hundred feet thick occurs in the lower part of the sequence, and a few lenticular units of locally fossiliferous limestone occur in the middle and upper parts. Thin-bedded grayish-red siltstone, shale, and fine-grained arkose are found in the top few hundred feet.

The sequence is assigned to the upper member of the Angelica Arkose because of general lithologic similarity of the principal rock types, but it does not correlate in detail with beds at the Angelica Wash locality. Either the sequence is younger than any beds exposed along Angelica Wash or it is a different facies of partly or wholly time-equivalent beds juxtaposed by the No. 6 thrust fault. In either case, the rocks clearly predate the major unconformity at the base of the Demetrie Volcanics (fig. 5).

Conglomerate, composed of subangular to rounded pebbles and granules in a matrix of light-gray ill-sorted sandstone,. makes up 5–10 percent of the lower part of the sequence as lenses a few inches to a few feet thick. The clasts consist of silicic and sparse andesitic volcanic rocks, quartzite, feldspathic sandstone and siltstone, granite, micropegmatite, and silicic porphyry. All the clasts appear to have come from Triassic and Jurassic formations now exposed in the Sierrita Mountains. The sandstone matrix is invariably feldspathic and commonly of the subgraywacke type. The percentage of the matrix in the conglomerate is highly variable, and the lenses grade vertically and laterally into grit.

Feldspathic sandstone of several types is present in the sequence. The predominant type is coarse-grained ill-sorted feldspathic grit having the same provenance as the conglomerate. The rock resembles the grit in the upper part of the section along Angelica Wash, but the beds are thicker and are not crossbedded. No calcite or other chemical cement has been detected in thin section, its place being taken by fine-grained sericite, quartz, potassium feldspar, and a little chlorite, apparently derived from argillaceous silt. Potassium feldspar is slightly more abundant than plagioclase in the thin sections examined. The grit and conglomerate in the lower part of the sequence are associated with some fairly thick units of medium- to fine-grained indistinctly bedded graywacke. This rock is light gray with yellow and olive hues. It is distinguished from the grit by its finer texture and more abundant sericitic matrix. Very different in lithology are relatively thin bedded fine- to medium-grained feldspathic sandstone and siltstone beds that interfinger with and overlie a limestone unit at the top of the sequence. These rocks are well sorted and commonly pale red to grayish red. The sandstone contains little argillaceous material and is characteristically cemented by calcite. These beds at the very top of the sequence resemble parts of the lower member along Angelica Wash.

The quartzite, which occurs in a single thick unit low in the sequence (fig. 5), is fine grained and not distinctly bedded. It is light gray on fresh fracture and yellowish gray to dark yellowish orange and light brown on weathered surfaces. In thin section the sand grains are seen to be subangular to rounded, fairly well sorted, and closely packed. Quartz makes up about 95 percent of the grains, and the remaining grains are potassium feldspar, sericitized plagioclase(?), iron ores, silicic volcanic rock, and siltstone. The cementing material, which makes up about 20 percent of the rock, is mostly microcrystalline sericite and quartz. Obviously the quartzite is a much more mature sedimentary rock than the associated grit, conglomerate, and graywacke. Its contacts with these rocks are not exposed and therefore could be fault contacts or disconformities. However, no direct evidence of either faulting or disconformity could be found, and the quartzite is assumed to be part of the same sedimentary sequence because the lithology of underlying and overlying rocks is the same and because the bedding and contacts of the quartzite appear to be parallel to bedding in the adjacent rocks.

Siltstone has been metamorphosed to hornfels and occurs in beds a few feet thick between some of the grit units; it is a minor and generally inconspicuous component of the sequence. The rock is medium gray to dark gray and homogeneous looking except for scarce soft white spots about 0.5 mm in diameter. In thin section some silt and very fine sand composed of quartz, alkali feldspars, and an opaque mineral may be seen in an abundant matrix of very finely crystalline and weakly foliated material in which sericite and green biotite are the only recognizable constituents. The white spots visible in some hand specimens are altered anhedral andalusite or cordierite loaded with inclusions of the matrix material. The rock is evidently metamorphosed argillaceous siltstone.

Units consisting of thin-bedded limestone, sandstone, and siltstone as much as 200 feet thick occur locally in the middle and upper parts of the sequence (fig. 5). The principal occurrence is about half a mile south of Helmet Peak, and another smaller occurrence, considerably lower stratigraphically, is about a quarter of a mile southwest of Whitcomb Hill. The limestone beds finger out laterally in distances of hundreds to several thousands of feet and, therefore, they have proved of limited use as stratigraphic markers, either individually or collectively. Only a very few thin beds of limestone and calc-silicate hornfels have been found outside the two areas mentioned.

The limestone is in lenticular beds a few inches to several feet thick. It is finely to coarsely crystalline and medium gray to light gray on fresh fracture. Sand and silt are common as disseminations or in laminae and cross laminae. South of Helmet Peak, the rock contains recrystallized pelecypod and gastropod shells, concentric algal(?) heads as much as 6 inches in diameter, and brown-weathering silicified ostracodes. Where ostracodes and detrital material are abundant, weathered surfaces are light olive gray, yellowish brown, and even brownish black; elsewhere they are medium gray to light gray, like the fresh rock.

CONTACTS

The disconformable and probable gradational contacts of the Angelica Arkose with the underlying Whitcomb Quartzite are described in the section on the Whitcomb Quartzite (p. D25). The contact of the Angelica with the overlying Demetrie Volcanics is an angular unconformity. This unconformity is not expressed topographically but is easily recognized on the ground, where the steep-dipping light-colored sedimentary beds of the Angelica are truncated at a large angle by dark-colored andesitic breccia of the Demetrie.

AGE AND CORRELATION

Fossils found in the Angelica Arkose are very poorly preserved and not diagnostic. The pelecypods and gastropods are indeterminable as to type (J. B. Reeside, written commun., 1958), and the ostracodes are of a fresh-water type common in Upper Jurassic and younger sedimentary rocks (I. G. Sohn, in Cooper, 1960, p. 69). The minimum age of the Angelica is fixed geologically by the unconformably overlying Demetrie Volcanics of Late Cretaceous age.

The Angelica Arkose and the Amole Arkose of W. H. Brown (1939) in the Tucson Mountains are very similar in lithology and are undoubtedly general correlatives. Both resemble the Bisbee Group, in the Whetstone, Empire, and northern Santa Rita Mountains, which is subdivided into five formations (Finnell, 1970). These five formations become less distinct and more like the Amole toward the west and have not been recognized west of the Santa Cruz River. The Angelica Arkose is here correlated with this sequence and is assigned to the Early Cretaceous.

UPPER CRETACEOUS ROCKS

DEMETRIE VOLCANICS

NAME AND TYPE LOCALITY

A thick sequence of andesitic and dacitic breccias and flows that locally contains conglomerate and rhyolite tuff is exposed along and to the west of Demetrie Wash (fig. 6) and was named for that geographic feature (Thoms, 1967). The type locality is west of the wash, in a belt that extends from the NW¼ sec. 15 to the SW. cor. sec. 21, T. 18 S., R. 12 E.

As first pointed out by Courtright (1958), parts of the Demetrie Volcanics are very similar to a unit designated the Silver Bell Formation in the Silver Bell Mountains 45 miles to the northwest; and later, Lynch (1966) and Lootens (1966) used the name Silver Bell for the rocks in the Sierrita Mountains. As these rocks include types not reported in the Silver Bell Mountains, the name Demetrie Volcanics is preferable and therefore adopted.

GENERAL DESCRIPTION, DISTRIBUTION, AND THICKNESS

The Demetrie lies with angular unconformity on rocks as young as the Angelica Arkose and as old as the Ox Frame Volcanics (figs. 5, 6). It locally has a basal conglomerate, tens to hundreds of feet thick, composed of debris from the underlying rocks. The local conglomerate units finger out laterally into unbedded andesitic breccia. Where conglomerate is missing, the breccia lies directly on the older rocks and contains at most only sparse fragments of them. The breccia and sporadic unbrecciated flows of andesite and dark dacite make up most of the formation and are the only rocks at many places. In the type locality, however, the massive ridge-forming lower rhyolitic tuff member averages about 750 feet in thickness and occurs about 1,000 feet above the base of the formation; and the upper rhyolitic tuff member, a thinner unit, occurs near the top (fig. 6). The lower rhyolitic member is largely welded tuff, whereas the upper one is bedded ash-fall material associated with conglomerate. The upper contact of the Demetrie Volcanics comprises several unconformities, the oldest of which is at the base of the Red Boy Rhyolite (fig. 4).

The Demetrie is the most widely distributed Mesozoic formation in the Sierrita Mountains; its outcrops are found southwest of Helmet Peak and in a belt about 18 miles long and as much as several miles wide around the south and west sides of the range. The formation tends to be recessive topographically and is generally poorly exposed in low hills, pediments, and slopes supported by more resistant rocks.

The thickness and lithology of the Demetrie Volcanics are highly variable laterally. This variability is unquestionably due in part to the considerable relief of the prevolcanic surface, in part to the local sources of the materials that make up the formation, in part to erosion of the formation in pre-Red Boy time, and perhaps in part to deformation during the period of Demetrie volcanism.

On the basis of outcrop width, fairly uniform strike, and steep dip evident at a few widely spaced places, the thickness in the type locality is thought to be about 8,000 feet. The true thickness may be less inasmuch as stratigraphic markers are few and parts of the formation could be repeated by unrecognized folds and faults. With due allowance for such possible repetition, the formation must be thousands of feet thick in this area. It thins and pinches out beneath the Red Boy Rhyolite toward the core of the range, which appears to have been the site of a topographic high at the time of deposition.

LITHOLOGY

CONGLOMERATE

The local basal conglomerates of the Demetrie vary in lithology both vertically and laterally. In general, the rock is characterized by poorly rounded pebbles, cobbles, and boulders of one or several of the locally subjacent formations in a matrix of fine-grained poorly sorted material apparently from the same source. Thus, in the type locality, the detritus is very largely from the Ox Frame Volcanics and Mesozoic intrusive rocks, whereas on the west side of the range, detritus from the Stevens Mountain Rhyolite and Tascuela Redbeds is commonly abundant, and a unit in the intervening area is composed entirely of detritus from Jurassic granite. The conglomerate grades upward and laterally into andesitic breccia, largely by interbedding and interfingering and, in part, by the appearance and upward increase in abundance of intraformational andesitic fragments.

The matrix of the basal conglomerate is characteristically ill sorted like the larger fragments. Near Demetrie Wash it is generally light-gray to greenish-gray graywacke. On the west side of the range, it is commonly red mudstone, whose color and texture are probably due to a substantial increment from the Tascuela Redbeds.

Interbeds of graywacke, siltstone, and mudstone are common in the thicker conglomerate units. These beds are generally like the matrix of the conglomerate in color, texture, and composition.

The basal conglomerate in the type locality could be part of a tongue of sedimentary rock of regional

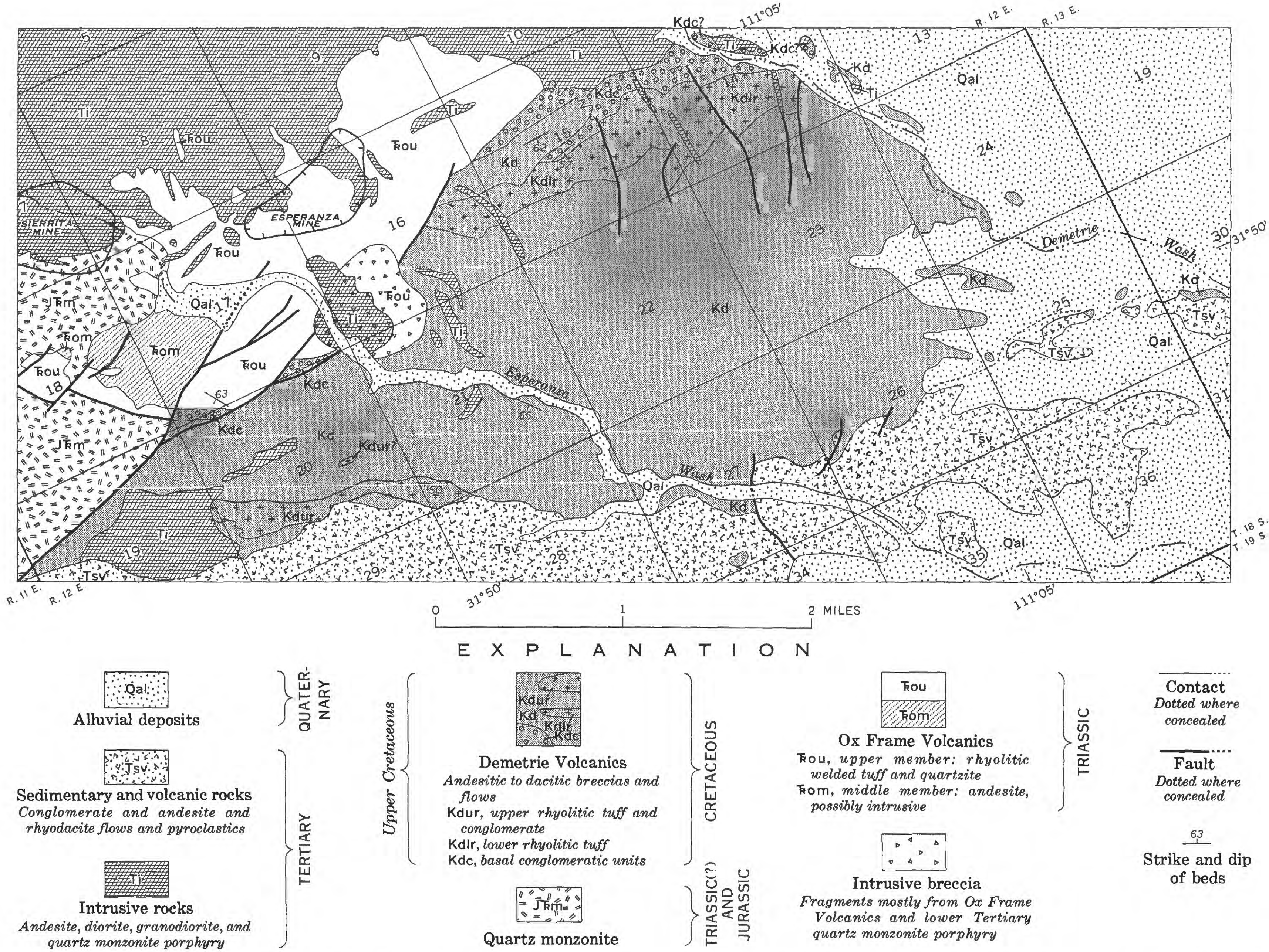


FIGURE 6.—Geologic sketch map of the Esperanza mine area. Geology mapped, 1957–68; base from U.S. Geological Survey Twin Buttes 15-minute quadrangle, 1957.

extent. The unit fingers out to the west but thickens to the east, and near Demetrie Wash it occupies the entire stratigraphic interval beneath the lower rhyolitic tuff member (fig. 6). The lower part of the conglomerate, like basal units elsewhere, is characterized by poorly rounded, locally derived clasts. Toward the east this rock is overlain by interbedded siltstone, pebbly and cobbly graywacke, and conglomerate consisting of better rounded clasts which are lithologically more diverse. The clasts, which range in size from granules to boulders as much as 5 feet in diameter, consist of fine- to coarse-grained arkose, possibly from the Angelica Arkose, biotite granite, and diorite of uncertain source. The granite and diorite fragments suggest parts of the local Precambrian complex, but fragments of Paleozoic rock have not been recognized. In general, the heterogeneous conglomeratic unit lacks intraformational clasts. The unit is bounded on the east by intrusive Paleocene granodiorite and Quaternary alluvial deposits.

ANDESITE AND DACITE

Well-indurated andesitic breccia is the most widespread rock in the formation. The breccia consists of angular to subrounded, granule- to boulder-sized fragments of andesitic rock in a clastic andesitic matrix. Where least altered, the rock is dark greenish gray to grayish purple on fresh fracture and weathers to brown hues. Over extensive areas it is fairly light greenish gray as a result of intense propylitization, and in some smaller patches it is nearly white as a result of later alteration to pyrite and colorless silicates, apparently largely sericite, clay, and quartz. The primary texture of the rock is gradually obscured with increasing alteration.

The breccia is poorly sorted and only very rarely bedded. Except for alteration effects, it is homogeneous looking in outcrop. The constituent fragments ordinarily have 15–35 percent phenocrysts, 0.5–3.0 mm long, of white feldspar and less abundant dark pseudomorphs after mafic minerals in an aphanitic groundmass. Secondary minerals such as epidote and chlorite are commonly discernible in hand specimen but macroscopic quartz is very rare. In thin section the feldspar phenocrysts are locally identifiable as normally zoned andesine, largely or wholly altered to an aggregate of albite, epidote, calcite, and other minerals. The mafic pseudomorphs consist of variable proportions of iron oxides, chlorite, and epidote; they locally have the form and habit of hornblende and biotite. The groundmass is commonly pilotaxitic and consists of microlites of plagioclase, tiny acicular mafic pseudomorphs, specks of iron ore, and interstitial cryptocrystalline material. Quartz is perceptible in some specimens as irregular blebs in the groundmass and as a constituent of vesicle fillings. The potassium feldspar content of the cryptocrystalline material is highly variable, as the staining of thin sections and rock slabs with cobaltinitrite solution indicates. Thus, in spite of its generally homogeneous appearance, the rock probably ranges in composition from andesite to trachyandesite and dacite.

The matrix of the breccia is clastic material similar in composition to the fragments. Thoms (1966, p. 147–150) regarded it as tuff and the rock as tuff-breccia. In the hand specimens and thin sections of the predominant unbedded breccia that I have examined, however, the matrix lacks discernible pumice, shards, or other recognizable airborne ejecta and looks like the ill-sorted detrital matrix of volcanic mudflow or the crushed matrix of flow breccia formed in viscous lava flows.

Flow breccia, volcanic mudflow, and tuff-breccia are probably all present, but are not everywhere distinguishable from each other. Rocks believed to be flow breccia have clasts of petrographically uniform andesite in a clastic matrix of the same material, whereas those believed to be mudflow commonly have fragments of several kinds of andesite in a matrix that contains sparse grains of quartz and other minerals not found in the fragments. This suggests an epiclastic origin, but the lack of bedding and sorting is unlike a normal water-laid deposit. At some places, particularly on the southwest side of the range, beds of andesitic conglomerate are intercalated with this kind of breccia. A lens of dacitic tuff and tuff-breccia about 100 feet thick underlies an unusual brown dacitic flow along Esperanza Wash 1.6 miles south of the Esperanza mine. The pyroclastic rock has the same composition as the flow, which is described in the following paragraph. The tuff and tuff-breccia are well bedded, unlike most of the breccia in the Demetrie Volcanics.

Lava flows, apparently of little lateral extent, are associated with breccia several miles west of Demetrie Wash, southwest of Helmet Peak, and perhaps elsewhere. The flows resemble the associated breccia petrographically but are massive. A common type is greenish-gray to grayish-purple andesitic rock with pilotaxitic texture. West of Demetrie Wash there are also pale-brown to brownish-gray flows containing more silica in which phenocrysts of quartz, plagioclase, and mafic minerals are readily discernible with a hand lens in an aphanitic flinty groundmass. The phenocrysts are 0.5–3.0 mm long and make up about half the rock. In thin section, they are seen to include resorbed quartz, largely saussuritized andesine (about An_{35}), locally a little anorthoclase, olive-green hornblende, chloritized biotite, and the common accessories magnetite, apatite, and zircon. The groundmass is dusty-brown cryptocrystalline material having an aggregate index of refraction less than that of Canada balsam. This rock and the associated tuff and tuff-breccia are certainly as felsic as dacite.

RHYOLITIC TUFF MEMBERS

The two rhyolitic tuff members are conspicuous stratigraphic markers within the Demetrie Volcanics. They are generally white to yellowish gray on weathered surfaces in contrast with the darker colors of the rest of the formation. The members are readily traced for 1–2 miles in the type locality, where they are cut off laterally by faults, a diorite intrusion, and an unconformity. Probably the lower member laps out laterally against the topographic high that appears to have been present in the Sierrita Mountains area in Demetrie time.

The lower rhyolitic member, which averages about 750 feet in thickness, consists of ash-flow tuffs and subordinate ash-fall tuffs. The tuffs vary somewhat in lithology because of differences in the mode of deposition and in the abundance and nature of included rock chips, but as a whole they are very similar in appearance. They are all well-indurated rocks, generally medium gray to medium light gray on fresh fracture and yellowish gray on weathered surfaces. Hand specimens of all but scarce thin crystal tuff layers show sparse tiny phenocrysts and angular fragments of quartz and feldspar in an aphanitic flinty matrix; the phenocrysts are 1 mm or less in longest dimension and rarely make up as much as 5 percent of the rock.

In thin section, the phenocrysts are seen to include quartz, plagioclase, sanidine, and locally anorthoclase. The quartz is largely in angular fragments, but it also occurs as bipyramidal and resorbed crystals. The plagioclase consists of albite and oligoclase, both of which appear quite fresh in some of the sections examined. Sanidine and anorthoclase are generally less abundant than plagioclase. Small books of brown biotite that is almost completely altered to muscovite, sphene, and opaque material occur locally. Accidental grains of orthoclase and microcline perthite, probably derived from a granitic rock, are found in some specimens; there are also abundant lithic fragments that range in size from fine ash to very small blocks. Most of the fragments are devitrified rhyolite and are similar in composition to the rest of the rock but display flow banding, vitroclastic and eutaxitic structure, and spherulitic and other distinctive devitrification textures. These fragments are evidently accessory; that is, they represent previously consolidated volcanic rock torn from the volcanic vent by the same eruption that yielded the juvenile constituents of the tuff. Some accidental fragments of granite, aplite, and andesite are also present.

The matrix of the tuff consists of devitrified shards, pumice fragments, and dust. The devitrification products are coarser than those in many tuffs and appear to be almost entirely quartz and alkali feldspar. As this material is predominant, the rock as a whole is classified as rhyolite.

The rock is cut by tiny quartz-pyrite veinlets and commonly contains a little disseminated pyrite and microscopic streaks and patches of disseminated sericite. Presumably these features are due to the widespread early Tertiary alteration and mineralization in the area.

The best exposed section of the lower rhyolitic member is along a dry wash three-quarters of a mile southeast of the Esperanza mine. Here the tuff lies on a lens of conglomerate that contains fragments of the Ox Frame Volcanics and Jurassic granite and aplite. The upper part of the conglomerate has a tuffaceous matrix and contains at least one bed of rhyolite tuff. Overlying the conglomerate is about 90 feet of fine-grained indistinctly bedded vitric and crystal-lithic tuff that contains a few lapilli-bearing beds. Evidently this material is of ash-fall origin. Above it is about 120 feet of massive, apparently structureless lapilli-bearing tuff which contains, at the base, a 1-foot-thick much-compacted eutaxitic vitric tuff. Above another thin unit of fine-grained indistinctly bedded tuff is another massive lapilli-bearing tuff, much like the one below, which makes up most of the member. Eutaxitic structure is weakly expressed on weathered surfaces by narrow lenticular depressions, presumably due to flattened pieces of pumice that have weathered out. The shards and tiny pieces of pumice are little compacted in the single thin section examined, however. Apparently at this locality the member consists of two ash flows, each underlain by ash-fall material.

A few feet of conglomerate consisting of reworked debris from the tuff here separates the lower member from the overlying andesitic breccia. This conglomerate is evidently intraformational and is not present everywhere along the contact.

The upper rhyolitic member is fine-grained white argillized tuff. Parts are well bedded and evidently of ash-fall origin. Hand specimens show sparse small grains of quartz, altered feldspar, and rarely tiny hexagonal plates of golden altered biotite in a soft white matrix. The predominant constituent to be seen in thin section is argillized vitric ash, which occurs both as sand-sized grains that locally display relict spherulitic and vitroclastic structure and as fine-grained interstitial dust and poorly preserved shards. Primary minerals other than quartz have been completely altered to clays, calcite, fine-grained dusty quartz, and other minerals. The unit clearly represents felsic volcanic ash which may or may not have the same composition as the lower rhyolitic member.

CONTACTS

The basal contact of the Demetrie Volcanics is a major unconformity easily recognized in outcrop by the basal conglomerate locally present in the formation and, where the conglomerate is absent, by the abrupt appearance of andesitic breccia lying with structural discordance on commonly lighter volcanic, sedimentary, and plutonic rocks. The recessive topographic expression of the Demetrie and its common dark hues on fresh and weathered surfaces are of some aid in approximately locating the contact from a distance.

The contact of the Demetrie with the overlying Red Boy Rhyolite is a very rarely exposed unconformity. Where exposed on the southwest side of the mountains near Papago Well (fig. 2), the contact is almost perpendicular to bedding in the Demetrie. As the contact is tight, apparently unfaulted, and virtually parallel to layering in the adjacent tuff breccia of the Red Boy, it has the characteristics of an angular unconformity. However, its dip (about 55°) is much steeper than that indicated by its trace on the topography, and the parallelism of contact and layering in the Red Boy is not what would be expected from onlap against a local steep slope. Possibly a local intrusive phase of the Red Boy here occupies an intra-Red Boy fault, as tuff identical with the extrusive material occurs in small demonstrably intrusive bodies in the Demetrie Volcanics as pointed out later (p. D35). Regardless of whether the exposed contact is depositional or intrusive, the Red Boy in this area has the map pattern of a gently dipping sheet that bevels definitely steeper dipping Demetrie in places and lies in large part on pre-Demetrie rocks.

At most places the Demetrie–Red Boy contact is in a narrow concealed belt which, at least locally, is underlain by a soft unit of decomposed Demetrie; this underlying unit contains blocks and tuffaceous matter of Red Boy Rhyolite in its upper part. Evidently the Red Boy was deposited unconformably on a weathered surface, and its early ejecta were incorporated with erosion products derived from the older rocks. The top of the Demetrie is placed where Red Boy material first becomes evident. This contact is not sharply defined but can be located within a few feet stratigraphically. From a distance, the approximate position of the contact is marked in most places by an abrupt change in slope due to the Red Boy's great resistance to erosion.

AGE AND CORRELATION

The age of the Demetrie Volcanics can be approximated from geologic relations in the Sierrita Mountains. The formation is in angular unconformity on rocks as young as the Angelica Arkose and hence is not older than Late Cretaceous. It is overlain by the Red Boy Rhyolite and is cut by intrusive bodies of diorite, granodiorite, and quartz monzonite. The age of the Red Boy is still uncertain, but some radiometric ages are available for the intrusive rocks. Biotite from a large granodiorite pluton that cuts the Demetrie has yielded concordant K–Ar ages that average 60 m.y. (Paleocene), and the same age was obtained on biotite in a vein that cuts an adjacent but older diorite pluton. Obviously the diorite in this mass and presumably in another mass that cuts the Demetrie was emplaced before the vein, but how long before is not known. The radiometric data and geologic relations confine deposition of the Demetrie within the Late Cretaceous to Paleocene interval.

Volcanic rocks very similar to the Demetrie in lithology and stratigraphic position are common in southeastern Arizona and southwestern New Mexico as shown by the descriptions and correlations of Richard and Courtright (1960), Jones, Hernon, and Moore (1967, p. 59–61), and Hayes and Drewes (1968). Included are the Silver Bell Formation of Richard and Courtright, the lower dacitic breccias and flows of the Salero Formation in the Santa Rita Mountains, the lower andesitic part of the Bronco Volcanics near Tombstone, and mostly unnamed andesitic to dacitic breccias and flows at many other places at least as far north as Christmas, Ariz., and as far east as the vicinity of Silver City, N. Mex. Although these rocks may not be strictly contemporaneous or parts of a once-continuous sheet, they are undoubtedly general correlatives. Richard and Courtright recognized that they were deposited after the Laramide orogeny had started and tentatively assigned them to the early Tertiary. Recent evidence indicates that some and perhaps all of them are of Late Cretaceous age.

From the vicinity of Silver City, N. Mex. (Jones and others, 1967, p. 59–61), westward as far as Christmas, Ariz., the Demetrie-like rocks lie unconformably on fossiliferous beds of early Late Cretaceous (Colorado) age; and in western New Mexico they are overlain unconformably by subaerial deposits that contain plant fossils dated as Late Cretaceous (Elston, 1960). The indicated Late Cretaceous age of the Demetrie-like rocks is supported by evidence found southeast of the Sierritas where these rocks overlie deposits as young as the Upper Cretaceous Fort Crittenden Formation and underlie welded tuff dated as 72 m.y. (Drewes, 1968, p. C11, C12). On this indirect basis, the Demetrie Volcanics are here assigned to the Late Cretaceous.

RED BOY RHYOLITE

NAME, TYPE LOCALITY, AND GENERAL DESCRIPTION

In accordance with the usage of Thoms (1966, 1967), the name Red Boy Rhyolite is here adopted for a sequence, 700 to perhaps 1,000 feet thick, of gray to pale-red rhyolitic flows and pyroclastic rocks that unconformably overlies the Demetrie Volcanics and unconformably underlies gravel and basaltic andesite of middle Tertiary age. The type locality is on the south slope of Red Boy Peak (fig. 4), where the Demetrie–Red Boy relationship is well displayed.

The Red Boy crops out almost continuously in a belt more than 9 miles long and as much as 2.5 miles wide extending from the alluvial cover south of Papago Well (fig. 2), northeastward into the Sierrita Mountains. Its total area of outcrop is about 10 square miles. As the formation is very resistant to erosion, it forms conspicuous foothills athwart the broad pediment south of the mountains, and it caps several high peaks, including Red Boy Peak, Placer Peak, and Keystone Peak, which is the highest peak in the range (fig. 4). The exposures in the high part of the range are in a complex graben probably formed in part during deposition of the Red Boy.

The formation is characterized by massive well-indurated rhyolitic tuff and tuff-breccia containing intercalated rhyolitic flows and locally having a thin basal conglomerate. The formation also includes a volcanic neck and associated small irregular intrusions lithologically like the tuff and a few dikes lithologically like the flows. The rhyolitic rocks grade laterally from an argillized facies south of the Sierrita Mountains to a hard metamorphosed facies in the core of the range. The argillized rocks are generally pinkish gray to pale red and weather grayish orange, whereas the metamorphosed rocks are medium gray on fresh fracture and lighter gray on weathered surfaces. The change in color and hardness takes place in a broad zone in the approximate latitude of Lobo Peak (fig. 4).

The rhyolite is characterized by phenocrysts of quartz and feldspar in an aphanitic matrix, which is hard and flintlike in the gray facies but fairly soft and commonly somewhat porous looking in the argillized facies. Both facies contain units tens to hundreds of feet thick of nonbedded and nonsorted lapilli tuff and tuff-breccia which contain pieces of devitrified pumice and numerous accessory and accidental rock fragments. These units have most of the characteristics of ash-flow tuff although compaction, foliation, and eutaxitic structure are generally obscure in outcrop and typical axiolitic devitrification structure is generally lacking in thin section (Ross and Smith, 1961). Fine-grained bedded ash-fall tuff is sparse. Flows, recognized only in the gray facies, are locally banded but are mostly massive and commonly difficult to distinguish from pyroclastic rock in outcrop.

Fine-grained dark andesite, in the form of small dikes, plugs, and apparently extrusive bodies, occurs in the Red Boy Rhyolite, particularly north of the type locality. No andesite is found in the type locality. It is very scarce farther south and is rarely well exposed.

A probable volcanic vent filled with rhyolitic tuff is found about a mile south of Red Boy Peak. Here a mass of tuff 1,200–1,700 feet in diameter forms Lobo Peak, a steep necklike hill which rises about 500 feet above a pediment cut on the Demetrie Volcanics. The contact surrounding the tuff mass is not exposed, and the topographic relations permit the mass to be interpreted as an erosional remnant of the extrusive tuff sheet, which it resembles lithographically (fig. 7). The almost inevitable first im-

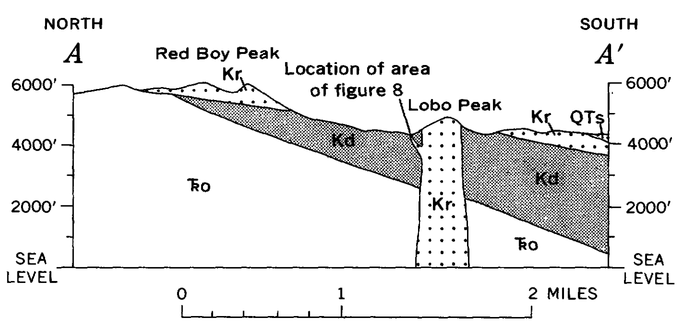


FIGURE 7.—Cross section through Red Boy Peak and Lobo Peak (line of section shown in fig. 4). **QTs**, Quaternary and Tertiary sedimentary rocks; **Kr**, Red Boy Rhyolite; **Kd**, Demetrie Volcanics; Ŧo, Ox Frame Volcanics.

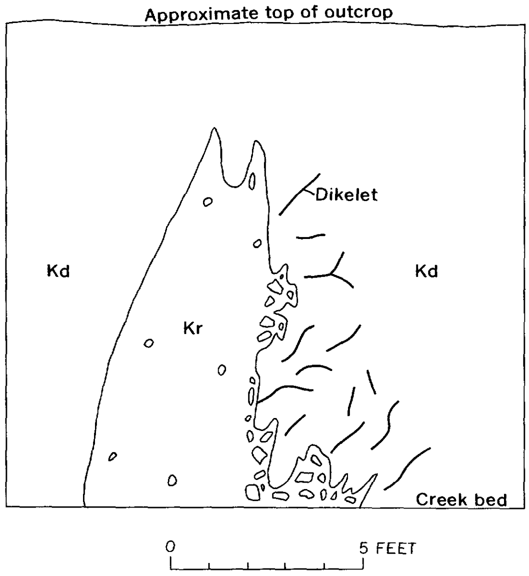


FIGURE 8.—Field sketch showing andesite breccia of the Demetrie Volcanics (Kd) intruded by tuff of the Red Boy Rhyolite (Kr), in nearly vertical north wall of Ox Frame Canyon just north of Lobo Peak. Dikelets of rhyolite tuff in the Demetrie and blocks of andesite breccia in the Red Boy shown schematically.

pression that the mass has a transgressive necklike form is probably correct, however, as lithologically identical tuff is found in small intrusive bodies in the Demetrie Volcanics nearby. One of perhaps a dozen known intrusions of this kind is illustrated in figure 8. Most of the rhyolite in this exposure is lapilli tuff containing scarce fragments of the Demetrie and other formations. The irregular part on the right is full of lapilli and blocks of the Demetrie, and thin irregular dikelets of the tuff are found as much as several feet from the main mass. The intrusive tuff is identical in lithology with that on Lobo Peak—even regarding the presence of xenoliths of granite aplite which must have come from below and which are rare in the extrusive tuff now preserved. I conclude that the tuff on Lobo Peak was emplaced by the same intrusive mechanism and fills a vent that opened to the surface upon which the extrusive tuff was deposited. Presumably, some of the extrusive rhyolite in the formation came from this vent.

LITHOLOGY

The basal conglomerate of the Red Boy Rhyolite where present is a few feet to a few tens of feet thick. On the south slope of Red Boy Peak, the basal unit is poorly indurated and poorly bedded conglomerate that consists of subangular pebbles, cobbles, and boulders of rhyolite and andesite apparently derived from the Demetrie, Ox Frame, and Red Boy formations in an ill-sorted brown matrix containing rhyolitic ash. No basal conglomerate was found where the Red Boy overlies the Ox Frame Volcanics; but it is present, at least locally, where the Red Boy overlies Jurassic granite and Triassic(?) and Jurassic quartz monzonite (secs. 34 and 35, T. 17 S., R. 11 E.). Here the Red Boy has an unusually steep dip and is largely fault bounded. Locally it consists of a basal unit of medium-gray, well-bedded, well-indurated, and commonly foliated pebble conglomerate and graywacke that contain granules and pebbles of the subjacent intrusives. Other constituents are fragments of rhyolite and graywacke from the Ox Frame Volcanics and rhyolitic material probably from early Red Boy eruptions. The rhyolitic rocks of the Red Boy include a considerable variety of tuffs and tuff-breccias, a possible lahar, and some intercalated lenticular flows and intrusive rocks.

Lava flows, which provide the best indication of overall mineral composition, have been identified in the Red Boy Rhyolite at a few places west and north of Lobo Peak. They locally show planar and contorted flow bands and even flow breccia structure, but more commonly they are homogeneous and massive. Hand specimens are characterized by as much as 25 percent phenocrysts of quartz and feldspar, 1–3 mm in diameter, in an aphanitic chertlike groundmass whose color ranges from light to medium gray, light olive gray, and light brownish gray. Thin sections from a thick flow near the top of the high ridge west of Tank Canyon (fig. 4) show large embayed crystals and clots of quartz, albite, and sanidine, scarce small books of biotite, tiny crystals of magnetite and leucoxene, and traces of apatite and zircon in a cryptocrystalline to microcrystalline groundmass. The albite is flecked with sericite, the sanidine is slightly turbid and has a larger optic angle than commonly found in that mineral ($2V$ estimated to be 20°–50°, optic sign negative), and the biotite is largely altered to muscovite and leucoxene. The groundmass, where little altered and coarse enough to be resolved under the microscope, consists mostly of quartz and potassium feldspar and contains dispersed flakes of mica.

Lapilli tuff and tuff-breccia, in nonbedded and nonsorted units tens to hundreds of feet thick, are very distinctive and widespread rocks in the Red Boy Rhyolite. These rocks consist of well-consolidated ash which resembles the flows in composition but which contains numerous pieces of devitrified pumice and rock fragments as large as blocks

(>32 mm). Most of the rock fragments are gray, pink, brown, and red-purple rhyolitic rock and, in thin section, have the characteristics of flows, welded tuffs, and nonwelded tuffs. Accidental fragments of andesite and other rocks are less abundant. The juvenile constituents of the tuff look different in the two alteration facies of the formation. South of the mountains, the pumice fragments are represented by yellowish-green to white clay and the ash fraction is dull-pink, red, or brown argillized material that contains crystals and crystal fragments of quartz, albite, and sanidine of the same types as those in the flows. North of Lobo Peak, pumice fragments and ash are difficult to distinguish, inasmuch as both are represented by hard chertlike material that is generally medium gray or greenish gray.

The argillized tuff south of the mountains is mostly massive but locally has a weak eutaxitic structure due to the parallel arrangement of pumice plates. The gray northern facies also appears massive at most places but locally shows a faint foliated eutaxitic structure on some weathered surfaces and on some freshly broken and moistened surfaces. Thus, the tuff has the principal field characteristics of ash-flow tuff (Ross and Smith, 1961, p. 18–26), which is welded toward the north and nonwelded toward the south.

Thin sections of the tuff confirm its pyroclastic origin and increasing compaction toward the north. Many of the juvenile crystals are broken into sharply angular fragments, and the once-glassy material shows poorly preserved vitroclastic texture. Very little compaction is evident in thin sections of the argillized facies examined, although the internal porosity of the pumice has been obliterated by argillization. Compaction foliation in the northern gray facies is much more apparent in thin section than in hand specimen. The pumice fragments are deformed into subparallel thin lenses that are molded over and under mineral and rock fragments. The rock fabric in the northern area is that of welded tuff, but only rarely is there even the faintest suggestion of axiolitic structure in the devitrified pumice and shards. Apparently the ash flows were sufficiently hot and rich in volatiles to weld locally but not to form normal devitrification textures. It is possible of course that original devitrification textures have been erased by later metamorphism, but this seems unlikely inasmuch as the pumice fragments are finely crystalline and the relict axiolitic, spherulitic, and plumose devitrification structures are preserved in some of the contained rock fragments. The argillized pumice in the southern area lacks the relict structure of any earlier devitrification products and probably remained in the glassy state until it was argillized, presumably by weathering in Quaternary time.

Fine-grained, well-sorted, and locally bedded rhyolitic tuff is a minor constituent of the formation. Thoms (1966, p. 163) described well-stratified light-gray slightly friable tuff at a locality about 2 miles southwest of Red Boy Peak that consists mostly of crystals and crystal fragments, 0.1–1.0 mm in size, of quartz and alkali feldspars in a matrix of microlitic debris. I have observed fine-grained indistinctly bedded tuffs at a few places in streambeds southeast and south of this locality and other tuffs without apparent bedding within the gray facies of the formation in the core of the range.

A possible volcanic mudflow is present in a canyon bottom several miles south-southwest of Red Boy Peak. This rock consists of subrounded pebbles, cobbles, and boulders of rhyolite and more rarely andesite in an abundant friable matrix of rhyolitic debris. Boulders of andesite breccia from the Demetrie Volcanics as much as 4 feet in diameter occur in this rock. The unit is near the bottom of the formation and could be part of the basal conglomerate. A few lenses of rhyolite conglomerate stratigraphically higher in the formation are intercalated with lapilli tuff and tuff-breccia on the high peak 0.3 mile north of Red Boy Peak.

The Red Boy Rhyolite is more metamorphosed and altered in the center of the Sierrita Mountains than it is farther south. The tuffs south of the mountains are pervasively argillized but otherwise virtually undeformed and unaltered, whereas those to the north within the mountains show the effects of metamorphism and alteration as well as greater primary compaction. The effects of metamorphism are generally apparent only in thin section and include strain and rupture of phenocrysts, microfaulting, and microveining oblique to earlier compaction foliation. The principal vein and replacement minerals are quartz, chlorite, and potassium feldspar(?). In Laramide shear zones the rock has been converted to well-foliated and commonly lineated mylonite containing tiny augen of quartz and feldspar. Hand specimens of the mylonite commonly resemble much-compacted welded tuff, whereas thin sections are clearly cataclastic. The mineral augen show such strain effects as undulatory extinction, mortar structure, and granulated rims and tails. Other foliate features are small flat lenses of granoblastic quartz and alkali feldspar and intervening similar but finer grained material that contains oriented tiny crystals of biotite and tourmaline. The potassium feldspar in the augen is largely orthoclase perthite presumably formed by annealing of the original sanidine.

The Red Boy is slightly metamorphosed where it comes closest to Laramide plutons, and it is mineralized in two widely separated areas. Southwest of Red Boy Peak in the SE¼ sec. 21, T. 18 S., R. 11 E., the formation is cut by narrow quartz veins containing a little galena, sphalerite, chalcopyrite, chalcocite, and oxidized iron and copper minerals; and northeast of Red Boy Peak in Ox Frame Canyon (near boundary of secs. 3 and 10, T. 18 S., R. 11 E.), the formation is locally altered and contains veinlets and disseminations of pyrite and oxidized iron and copper minerals.

The northern gray facies of the Red Boy Rhyolite resembles in many respects the rhyolitic rocks in the Ox Frame Volcanics. Of some aid in distinguishing the two formations are the common lithic lapilli in the Red Boy and the quartzite beds in the Ox Frame. In addition, there is a greater abundance and variety of intrusive igneous rocks in the Ox Frame. However, I believe that quartz phenocrysts provide the best basis for making the distinction. The Red Boy generally contains quartz phenocrysts large enough (1–3 mm) to be readily seen in hand specimen, whereas the Ox Frame contains quartz phenocrysts that large only in sparse and generally thin units. The "quartz-eye" criterion is not infallible, but seems to be valid at least in the larger areas of outcrop. It yields a reasonable map pattern and assigns to the Red Boy rocks whose stratigraphic relations are compatible with this assignment but are incompatible with assignment to the Ox Frame. For example, it reveals the Red Boy in angular unconformity on the Ox Frame near the head of Ox Frame Canyon (SE¼ sec. 3, T. 18 S., R. 11 E.), and farther north (SE¼ sec 34, T. 17 S., R. 11 E.) it shows the Red Boy having a basal conglomerate that lies unconformably on post-Ox Frame quartz monzonite.

CONTACTS

The basal contact of the Red Boy is an angular unconformity cut on the Demetrie Volcanics, Ox Frame Volcanics, and Mesozoic intrusive rocks. The contact with the Demetrie is easily recognized and is described in the section dealing with that formation. The contact with the Ox Frame is generally obscure because the Ox Frame is also resistant to erosion, is largely rhyolite, and rarely shows distinct bedding. The Red Boy has no known basal conglomerate where it overlies the Ox Frame. Criteria which help to locate the contact include angular discordance and those discussed in the preceding paragraph. The location of the basal contact is readily apparent where the underlying rock is plutonic and is further marked, at least locally, by a basal conglomerate containing fragments of the Demetrie, the Ox Frame, and other pre-Red Boy formations.

The upper contact of the Red Boy on the south flank of the Sierrita Mountains is an easily recognized angular unconformity with overlying unconsolidated Holocene alluvium or with weakly consolidated Tertiary gravel and basaltic andesite flows of middle Tertiary age. The upper contact at most places is the present erosion surface.

AGE AND CORRELATION

The age of the Red Boy Rhyolite must be intermediate between that of the underlying Demetrie Volcanics and overlying sedimentary and volcanic rocks of middle Tertiary age. Indirect field evidence suggests that the formation predates Laramide plutonism and mineralization in the area. The Red Boy is cut by andesite dikes and plugs petrographically like those of early Tertiary age. Several faults and shear zones that cut the Red Boy are intruded by unfaulted and unsheared granodiorite that forms a large pluton whose K–Ar age is Paleocene (about 60 m.y.). Rocks much like the Red Boy in lithology and apparent stratigraphic position have been dated by the K–Ar method in at least five mountain ranges in southeastern Arizona. The results are shown in the following table:

Stratigraphic unit and locality	Mineral analyzed	Number of analyses	Apparent age (m.y.)	Reference
Mount Lord Ignimbrite of Watson (1964), Silver Bell Mountains	Alkali feldspar	1	60	Mauger (1966).
Cat Mountain Rhyolite of W. H. Brown (1939), Tucson Mountains	do	2	66–70	Bikerman and Damon (1966).
Roskruge Rhyolite, Roskruge Mountains	do	1	69	Bikerman (1967).
Do	Plagioclase	1	66	Do.
Do	Biotite	9	69–74	Do.
Rhyodacite welded tuff in upper part of Salero Formation, Santa Rita Mountains	do	1	73	Drewes (1968).
Volcanics of Jones Mesa, Canelo Hills	do	1	72	S. C. Creasey (written commun., 1964).

Biotite, which is an argon-retentive mineral, gives the best indication of the true age of the formations. The feldspars seem to have lost argon and hence yielded younger apparent ages. For example, a single sample from the Roskruge Rhyolite yielded ages of 72.6 and 72.2 m.y. for the biotite, 68.8 m.y. for the alkali feldspar, and 66.3 m.y. for the plagioclase (Bikerman, 1967, table 1, sample 8). The discrepancies in this sample are almost within the limits of analytical error and are not very serious. The apparent age of 60 m.y. for the Mount Lord Ignimbrite is misleadingly low, however. This rock predates quartz monzonite whose biotite has yielded ages of 67.1 m.y. where fresh, 65.5 m.y. where mineralized, and 63.4 m.y. where mineralized and leached (Mauger, 1966). Clearly the Mount Lord is little, if any, younger than the other dated units. As the Cretaceous-Tertiary boundary is now closely defined at 63 m.y. ago in the K–Ar time scale (Folinsbee and others, 1963), the dated units and presumably the Red Boy Rhyolite also are of Late Cretaceous age.

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