Mesozoic Stratigraphy of the Mule and Huachuca Mountains, Arizona

GEOLOGICAL SURVEY PROFESSIONAL PAPER 658-A

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By PHILIP T. HAYES

MESOZOIC STRATIGRAPHY IN SOUTHEASTERN ARIZONA

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Descriptive stratigraphy of Triassic, Jurassic, and Cretaceous volcanic and sedimentary rocks

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MESOZOIC STRATIGRAPHY OF THE MULE AND HUACHUCA MOUNTAINS, ARIZONA

By PHILIP T. HAYES

ABSTRACT

Triassic and Jurassic strata in the report area are confined to the Huachuca Mountains, where they are included in the Canelo Hills Volcanics and in a presumably equivalent unit of generally altered strata, which is informally referred to as siliceous volcanic rocks of the Huachuca Mountains. Both units range in thickness from wedge edges to several thousand feet and rest on an erosion surface of considerable relief carved on Paleozoic rocks. The Canelo Hills Volcanics are locally subdivided into a lower member, which consists dominantly of volcanic sediments and tuffs, a rhyolitic lava member, and an upper, welded tuff member.

Lower Cretaceous strata in both the Huachuca and the Mule Mountains are assigned to the Bisbee Group, whose constituent formations are all well exposed in the Mule Mountains, where principal reference sections are designated for each. The Glance Conglomerate, at the base of the group, overlies older rocks on an erosion surface of major relief; its thickness is variable, from 0 to more than 3,600 feet, and it contains a mapped volcanic member in the Huachucas. The Morita Formation, made up mostly of red mudstone and siltstone and pinkish-gray feldspathic sandstone, is 2,600–4,2000 feet thick. The Mural Limestone, of marine origin, is divided into two informal members and ranges in thickness from about 300 to about 800 feet. The Cintura Formation, which is lithologically similar to the Morita, ranges in thickness from an erosional wedge edge to more than 2,000 feet.

Upper Cretaceous strata, represented by the Fort Crittenden Formation, are present only in the Huachucas, where they lie unconformably on the Bisbee Group. The formation, as much as 2,000 feet thick, consists dominantly of conglomerates in the lower part and of variegated mudstones and drab graywackes in the upper part.

INTRODUCTION

This report describes the lithologies and field relations of layered Mesozoic rocks in the Mule and Huachuca Mountains, Ariz. (fig. 1). Mesozoic strata of the Mule Mountains, all Lower Cretaceous, were studied in 1960 by Edwin R. Landis and me while we were mapping the southern part of the range. Field data on the much more complete Mesozoic sequence (Triassic and Jurassic, Lower and Upper Cretaceous) of the Huachuca Mountains were gathered by me during the mapping of those mountains from 1962 to 1965. George C. Cone assisted in the measurement of Cretaceous rocks in the Huachucas. Field interpretations benefited from the observations of many of my colleagues, particularly Harald Drewes, Robert B. Raup, and Frank S. Simons, all of whom have been working concurrently with me on related projects in areas to the north and west. The geologic maps of the Mule (Hayes and Landis, 1964) and the Huachuca Mountains (Hayes and Raup, 1968) should be aids to the reader of this report.

GEOLOGIC SETTING

Pre-Mesozoic rocks in the area studied include units of Precambrian and Paleozoic age. The oldest rocks are in the Mule Mountains; they are assigned to the Pinal Schist and are presumed to be older Precambrian in age. Older Precambrian rocks of the Huachuca Mountains are all granitic and are presumably somewhat younger than the Pinal Schist. Younger Precambrian sedimentary rocks, found less than 40 miles to the north in the Little Dragoon Mountains (Cooper and Silver, 1964, p. 36–43), are absent from this area. Here, older Precambrian rocks are overlain on a major unconformity of low relief by as much as 6,000 feet of dominantly marine Paleozoic sedimentary formations, which represent the Cambrian, Devonian, Mississippian, Pennsylvanian, and Permian Systems. In both the Mule and the Huachuca Mountains, Paleozoic and older rocks locally show the effects of normal faulting and vertical uplift prior to the onset of Mesozoic deposition.

Mesozoic rocks in the area consist of sedimentary, volcanic, and intrusive igneous rocks. Pre-Cretaceous layered rocks of Mesozoic age are dominantly volcanic and are confined to the Huachucas, where they are as much as several thousand feet thick. These layered rocks were invaded by a pluton of Jurassic age, the Huachuca Quartz Monzonite. A pluton of similar age, the Juniper Flat Granite, invaded pre-Mesozoic rocks in the Mule Mountains. In both ranges, Lower Cretaceous strata, 1–2 miles thick, represented by the Bisbee Group, overlie these Jurassic plutons and older rocks on an unconformity of considerable relief. In the Huachuca

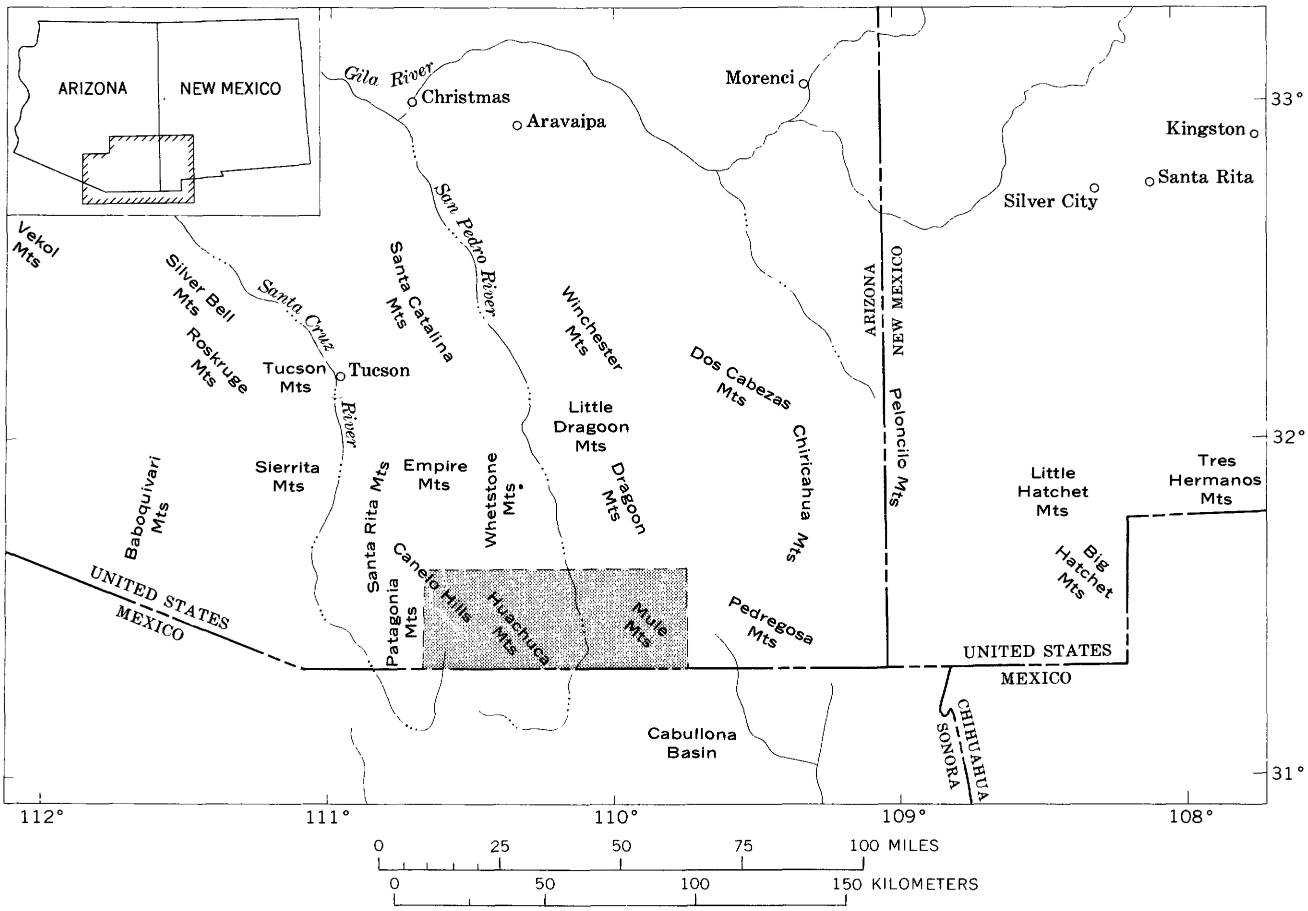


Figure 1.—Index map of southeastern Arizona and adjacent areas, showing location of Mule and Huachuca Mountains and other features mentioned in text. Area of figure 2 stippled.

Mountains, the Bisbee Group and older rocks were folded and thrust faulted before deposition of several thousand feet of Upper Cretaceous strata. The Upper Cretaceous in the Huachucas has itself been sharply folded.

Rocks and deposits younger than Mesozoic layered rocks consist of igneous rocks and continental sedimentary deposits. In the Huachuca Mountains, and to a lesser extent in the Mule Mountains, Cretaceous and older rocks have been intruded by a variety of hypabyssal igneous rocks, which probably were emplaced during late phases of Laramide deformation. Adjacent to the Huachuca Mountains on the north and northeast are orogenic sediments of early and middle Tertiary age that antedate the late Cenozoic uplift of the present ranges. The youngest deposits in the area consist of basin fill and alluvium that postdate the latest faulting and the mountain uplift.

The Mule and Huachuca Mountains are distinctly different in structural character. The Mule Mountains are basically a large faulted and intruded northwest-trending anticline. Most of the faults in the range are high angle and pre-Cretaceous in age, and major igneous bodies are also pre-Cretaceous. Except in the southeast end of the mountains, where Cretaceous rocks have been sharply folded and dislocated along a southwest-dipping low-angle fault, Cretaceous rocks have been deformed very little. The dominant structural features of the east side of the Huachuca Mountains are a series of related northeast-dipping thrust or reverse faults of post-Early Cretaceous age. Mesozoic strata on the west side of the range have been sharply upturned and folded, and large areas of nearly vertical or overturned beds are prevalent. Stratigraphic relations in Mesozoic rocks in the Huachucas, therefore, are more difficult to interpret than they are in the Mule Mountains.

The two ranges are separated by alluvium of the 12-mile-wide San Pedro River valley (fig. 2), and the tectonic relationships between the ranges and the structure beneath the valley are conjectural. Probably the valley is basically grabenlike, and the Mesozoic rocks of the two ranges are not significantly farther apart or closer together than during deposition. However, the possibility that there has been a considerable relative change in position by large-scale strike-slip faulting in the valley or by thrust faulting cannot be entirely ruled out at the present time.

TRIASSIC AND JURASSIC STRATA

Volcanic rocks and a subordinate amount of sedimentary rocks of Triassic and Jurassic age occur only in the Huachuca Mountains, where they are assigned to the Canelo Hills Volcanics and to a generally correlative volcanic unit informally referred to as siliceous volcanic rocks of the Huachuca Mountains (Hayes and Raup, 1968).

CANELO HILLS VOLCANICS

NAME AND TYPE LOCALITY

The Canelo Hills Volcanics were named by Hayes, Simons, and Raup (1965) for exposures in the Canelo Hills (fig. 2). In that area the formation was subdivided into three informal members, all of which are recognized in the Huachuca Mountains.

GENERAL DESCRIPTION AND DISTRIBUTION

The three members of the Canelo Hills Volcanics are: A lower member of dominantly volcanic sedimentary rock and subordinate amounts of interlayered rhyolitic tuff and lava, 0 to more than 1,900 feet (600 m) thick; a rhyolitic lava member, at least 1,000 feet (300 m) thick; and, at the top, a welded tuff member, locally more than 500 feet (150 m) thick. In places the lower two members contain exotic blocks [1] of Paleozoic rocks.

All three members of the formation occur in several square miles of faulted exposures on and near Lone Mountain (fig. 2) on the southwest side of the Huachucas. The rhyolitic lava and welded tuff members also underlie about a square mile (2½ sq km) at the south end of the mountains south of the drainage course in Montezuma Canyon. A very small fault sliver of the formation is present between Bear and Joaquin Creeks about 3 miles (5 km) south of Lone Mountain. Rocks that are tentatively assigned to the mixed volcanic and sedimentary member are poorly exposed in several patches at the north end of the Huachuca Mountains between Pyeatt Ranch and Fort Huachuca. Poorly exposed siliceous volcanics that underlie about a third of a square mile (1 sq km) east of Peterson Peak in the central part of the range are also tentatively assigned to the Canelo Hills Volcanics.

[1] The term "exotic block" as used here refers to allochthonous material from older rock, usually measurable in hundreds or thousands of feet, which is enclosed in autochthonous volcanic or sedimentary rock.

LITHOLOGY

LOWER MEMBER

Volcanic sedimentary rocks make up at least two-thirds of the lower member of the Canelo Hills Volcanics in the Lone Mountain area, and siliceous tuffs and felsites make up the remainder. The thickest preserved sequence is well exposed in the eastern part of sec. 27, T. 23 S., R. 19 E., where, however, both the base and the top of the member are missing along faults and where at least one strike fault within the member may cut out more of the section. In rising sequence, this incomplete section is made up of: About 700 feet (210 m) of interbedded pebble-and-cobble conglomerate, tuffaceous sandstone and feldspathic graywacke, and minor amounts of red-hued siltstone and mudstone; nearly 300 feet (90 m) of pale-reddish-purple tuff, most of which is welded; more than 100 feet (30 m) of conglomerate interbedded with minor amounts of tuffaceous sandstone; more than 200 feet (60 m) of dominantly grayish red and pale-reddish-purple welded and nonwelded tuff; and nearly 600 feet (180 m) of conglomerate interbedded with subordinate amounts of sandstone and siliceous tuffs and felsophyres.

The conglomerate in the member is made up of angular pebbles and cobbles of siliceous volcanic rocks and sparse fragments of Paleozoic rocks set in a matrix of tuffaceous sandstone or feldspathic graywacke. The volcanic fragments in the conglomerate are all identifiable as lithologic types present in the Canelo Hills Volcanics or in the Mount Wrightson Formation of the Santa Rita Mountains (Drewes, 1968). Bedding in the conglomerate is massive. Locally, some conglomerate beds rest on intraformational unconformities with relief measurable in many tens of feet.

The sandstone in the member is mostly moderate red feldspathic graywacke, some of which is tuffaceous and some of which is conglomeratic (fig. 3). Most sandstone is cross-laminated and occurs in beds as much as several feet thick.

The mudstone in the member is moderate red to very dark red, and most of it is silty. At one locality, well-developed mudcracks were noted in mudstone that is interbedded with sandstone.

Most tuff in the member is welded, but little is densely welded. It is typically pale reddish purple, pale red, grayish red, grayish pink, grayish orange pink, light gray, or light brownish gray. Most is fine grained and contains scattered crystals of quartz, sanidine, microcline, and biotite. Lithic and vitric fragments are sparse in most tuff beds but are abundant in a few (fig. 4).

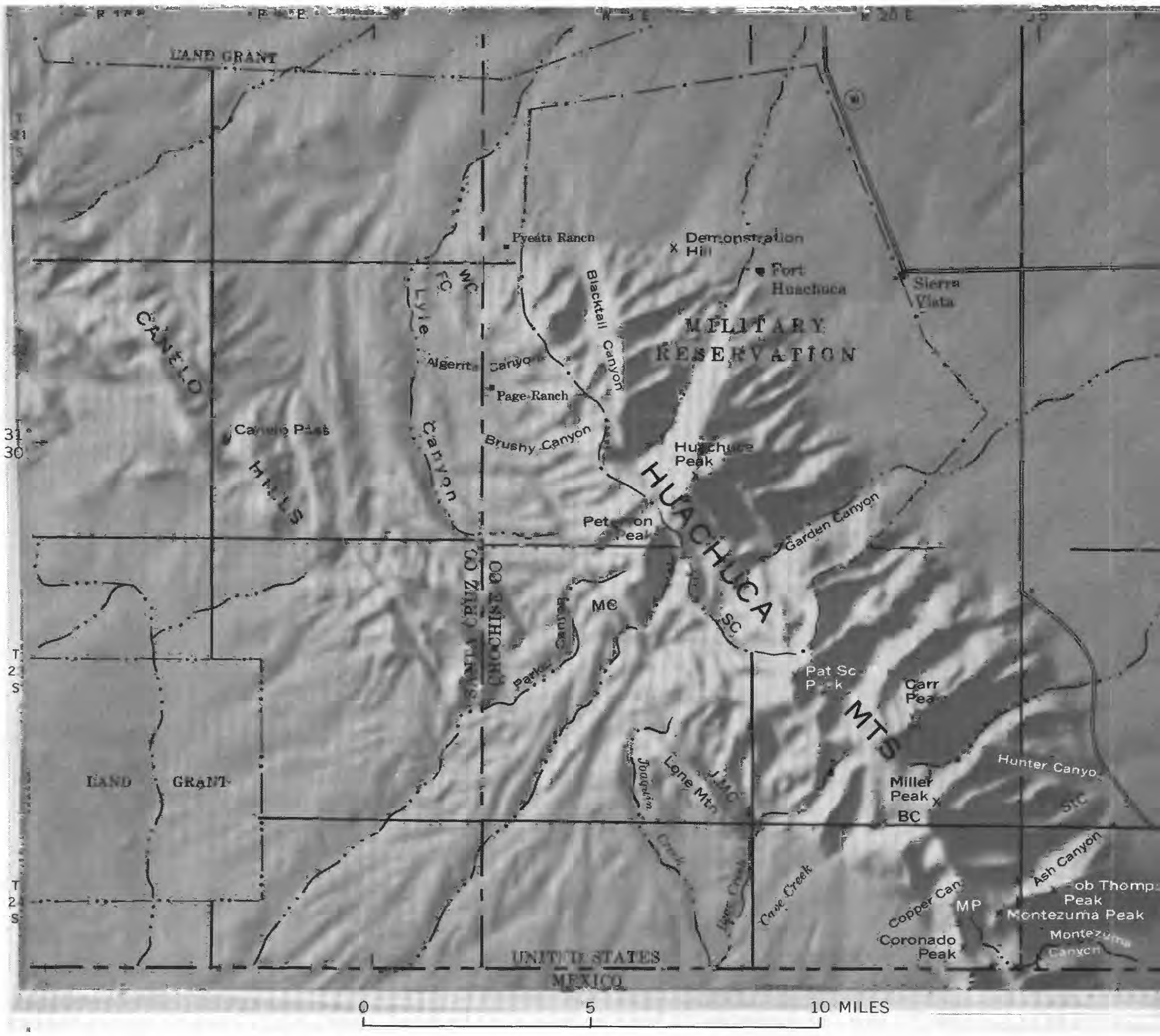
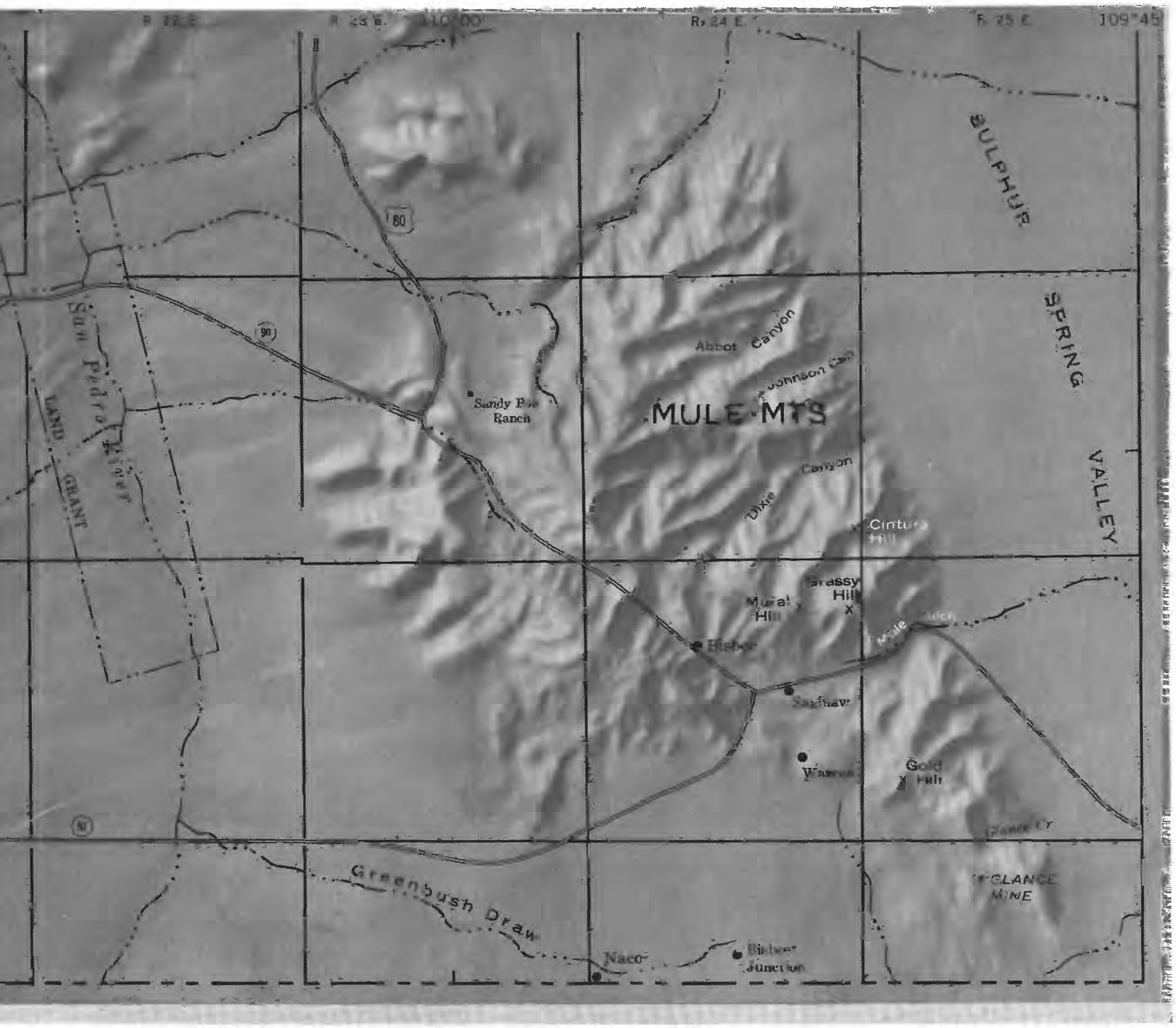


Figure 2.—Huachuca and Mule Mountains vicinity, showing geographic features mentioned in text. In Huachuca Moun
Sawmill Canyon; StC, Stump Canyon; WC, Wood



BC, Blind Canyon; FC, Ferosa Canyon; LMC, Lone Mountain Canyon; MC, Merritt Canyon; MP, Montezuma Pass; SC,
on. See figure 1 for location of area.

Felsite is present only in the upper part of the lower member in the Lone Mountain area, where it occurs in lenticular beds up to 10 feet (3 m) thick. It is a very fine grained grayish-orange-weathering rock containing scattered chalky phenocrysts of feldspar, and it is believed to be lava.

The lower member of the Lone Mountain area is virtually identical with that of the southeastern end of the Canelo Hills, only 2–3 miles (4 km) to the northwest, except that in the Canelo Hills area, brecciated exotic blocks as much as 1,000 feet (300 m) long and 200 feet (60 m) wide of Permian limestone and quartzite are included in the member.

Rocks tentatively assigned to the lower member of the Canelo Hills Volcanics in the Pyeatt Ranch vicinity are similar to those of the Lone Mountain area, but include minor limestone conglomerate and thin units of strongly flow laminated rhyolite very much like some in the overlying rhyolite lava member of the formation. Also included are several exotic blocks of Permian limestone in a red mudstone matrix. Pale-grayish-purple biotite-rich tuff exposed in a draw north of the Kino Spring fault, about half a mile southeast of Demonstration Hill and west of the main post on the Fort Huachuca Military Reservation, is tentatively assigned to the lower member of the Canelo Hills Volcanics because of its similarity to tuff in the member at Lone Mountain and in the Canelo Hills. However, similar tuff is also known in the Pantano Formation of Tertiary age (Finnell, 1970) in its type locality north of the Empire Mountains (fig. 1), and such an age is definitely possible for the tuff near Demonstration Hill.

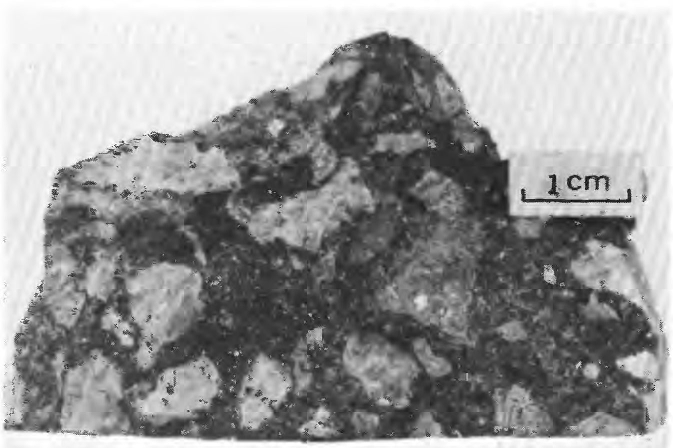


FIGURE 3.—Specimen of conglomeratic sandstone from lower member of Canelo Hills Volcanics. The abundant angular pebbles and granules were derived from siliceous volcanic rocks.

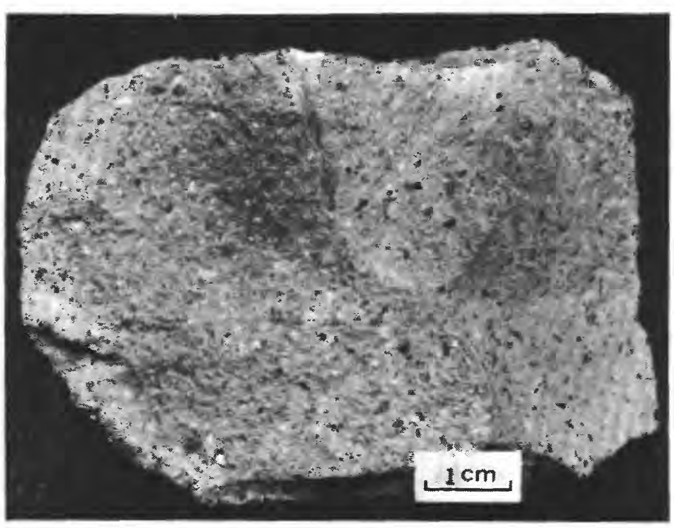


FIGURE 4.—Specimen of fine-grained biotite-rich tuff from lower member of Canelo Hills Volcanics.

RHYOLITIC LAVA MEMBER

The rhyolitic lava member of the Canelo Hills Volcanics in the Lone Mountain area is characterized by pale, varicolored, generally flow banded, sparsely porphyritic rhyolitic lava, but it also contains a few layers of tuff. South of Montezuma Canyon, the member contains minor amounts of sandstone and conglomerate like those in the lower member. Lava in the rhyolitic lava member is commonly pale to moderate red, grayish red, grayish orange, or light gray, but some is yellowish gray to moderate brown. Prominent flow layering (fig. 5), much of it highly contorted, is conspicuous in most of the lava, and much of the lava is brecciated. Gray spherulites a few centimeters in diameter and lithophysae as much as 1 foot (30 cm) across

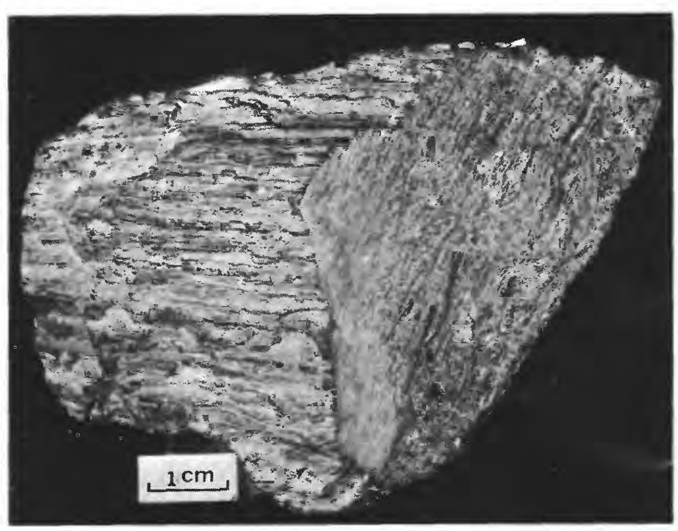


FIGURE 5.—Specimen (with polished surface on right) of finely flow layered rhyolite from rhyolitic lava member of Canelo Hills Volcanics.

are abundant in some flows. The few tuff beds in the member are generally similar to the pale-red welded tuff of the overlying member.

The lavas contain scattered phenocrysts of cloudy sanidine 1–2 mm across, and some also have sparse phenocrysts of quartz, sodic plagioclase, and (or) altered biotite. Phenocrysts make up less—ordinarily much less—than 10 percent of the rocks. In thin section, the groundmass is seen to be a patchily devitrified, usually spherulitic, crinkly flow-layered glass.

No chemical analysis of lava from the Huachuca Mountains area was made, but an analysis of typical lava from the nearby Canelo Hills indicates that the lava is very high in silica (79.7 percent). The calculated CIPW norm for the rock shows potassium feldspar far in excess of plagioclase. The rock may have been secondarily enriched in silica, but the sample can be definitely classified as a high-potassium rhyolite.

The lava member at Lone Mountain and south of Montezuma Canyon contains scattered elongate exotic blocks, some of which are thousands of feet long, of upper Paleozoic sedimentary rocks. Similar blocks in the lava member of the Canelo Hills have been described (Simons and others, 1966, p. D14–D16). As in the Canelo Hills, the blocks in the Huachucas are thoroughly fractured internally and seem to be bedding-plane slabs whose bedding is roughly parallel to the layering of the enclosing lavas. Simons, Raup, Hayes, and Drewes (1966, p. D16) concluded that the blocks most likely were transported on or within lava flows.

WELDED TUFF MEMBER

The welded tuff member of the Canelo Hills Volcanics consists almost entirely of moderate-red to grayish-red to pale-red or grayish-pink crystal-rich rhyolite tuff. Most of it is densely welded and so massive that bedding is almost unrecognizable, but locally the attitude is indicated by the orientation of pumice lentils. Some of it shows crude columnar jointing. The basal part of the unit is less densely welded, and locally it either contains large blocks of the underlying rhyolitic lava or is interbedded with lava. In the Montezuma Canyon area, the upper tens of feet of tuff seem to be tuff breccia consisting of angular welded tuff fragments set in a tuffaceous matrix.

The welded tuff contains conspicuous and abundant 1½- to 3-mm phenocrysts of clear quartz and pink to white feldspar and less abundant phenocrysts of biotite (fig. 6); less conspicuous constituents are pumice lapilli and lithic fragments. In thin section, the densely welded tuff is seen to consist of euhedral crystals, embayed grains, and fragments of quartz and cloudy perthitic potassium feldspar, together with much-altered biotite and lithic fragments set in a matrix of completely devitrified bent and compacted glass shards and highly flattened axiolitic pumice lentils.

No chemical analyses were obtained of welded tuff from the Huachuca Mountains, but one from the Canelo Hills has been reported (Hayes and others, 1965, p. M6). The rock is very high in silica (78.1 percent), and potassia is greatly in excess of soda and lime combined. Like the underlying rhyolite lava, the welded tuff can be classified as a high-potassium rhyolite.

THICKNESS

The thickness of the Canelo Hills Volcanics and of the three members is highly variable within short distances. Locally, in the central and northern parts of the Huachucas, the formation is absent, and Paleozoic rocks are overlain unconformably by Cretaceous strata. The maximum true thickness of the Canelo Hills Volcanics within the Huachucas is unknown, because in the Lone Mountain area, where it appears to be thickest, there are obvious omissions due to faulting. The lower member is at least 1,900 feet (600 m) thick, but the base and top are both faulted off; the rhyolitic lava member is at least 1,000 feet (300 m) thick, but the base is missing; the welded tuff member is at least 500 feet (150 m) thick and is perhaps much thicker. In the exposures south of Montezuma Canyon, the lower member seems to be missing, the rhyolitic lava member is perhaps 500 feet (150 m) thick, and the welded tuff member is roughly half as thick. In the central part of the exposures east of Peterson Peak, the rocks tentatively assigned to the Canelo Hills Volcanics reach a thickness of roughly 1,500 feet (450 m), but within about half a mile in both directions they thin to a wedge edge.

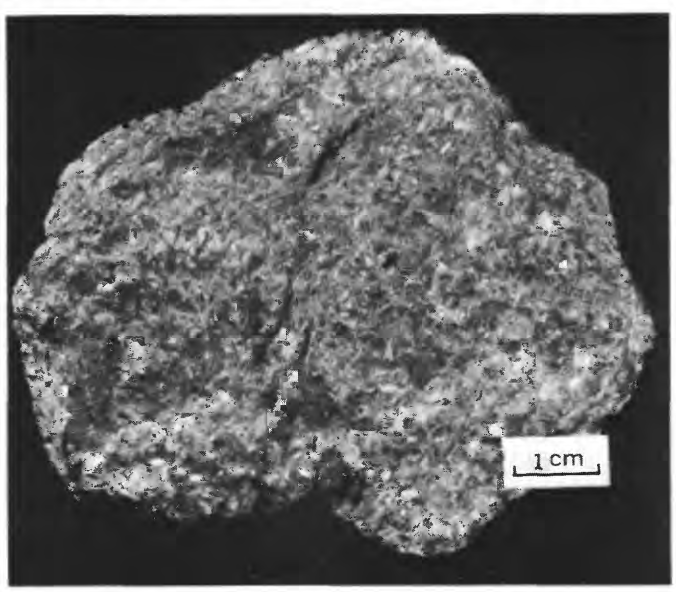


FIGURE 6.—Specimen of crystal-rich welded tuff from welded tuff member of Canelo Hills Volcanics.

STRATIGRAPHIC RELATIONS

The stratigraphic relations between the upper two members of the Canelo Hills Volcanics and between those members and younger and older rocks can be readily established in the Huachuca Mountains area; the relations of the lower member to the other two members or to other rocks are inferred on the basis of relations observed in the nearby Canelo Hills. The inferences are summarized following a description of the observable relations in several local areas.

In the Montezuma Canyon area (fig. 2), the lower member is apparently absent; the rhyolitic lava member unconformably overlies what is believed to be a bedrock outcrop of a part of the Naco Group that is of Early Permian age. The outcrop of Permian rock could be the upper part of an exotic block included in the lava member, but it is a large outcrop, and the rock in it does not appear to be internally brecciated as are most large exotic blocks in the region. The rhyolitic lava member is overlain with a sharp paraconformable contact by the welded tuff member. The welded tuff member, in turn, is unconformably overlain by the Glance Conglomerate of the Bisbee Group of Early Cretaceous age.

In the Lone Mountain area and in the southeastern end of the Canelo Hills, the lower member is everywhere in fault relation to the other two members. The base of the rhyolitic lava member, thus, is also not exposed. Large outcrops of rock of the Naco Group at the apparent base of rhyolitic lava exposures on the north side of Lone Mountain are interpreted to be exotic blocks. The welded tuff member in these areas, as in the Montezuma Canyon area, overlies the rhyolitic lava member, and at one locality on Lone Mountain it is unconformably overlain by the Glance Conglomerate.

Near Canelo Pass, about 6 miles (10 km) from exposures of the lower member in the southeastern part of the Canelo Hills and 11 miles (18 km) from its exposures on Lone Mountain, the lower member unconformably overlies Permian rocks, and the welded tuff member overlies the lower member with paraconformable contact; the rhyolitic lava member is absent. The lower member of the Canelo Pass area is correlated on the basis of strong lithologic similarities with strata assigned to the same unit in the Lone Mountain area.

These observations and correlations indicate that: In the Montezuma Canyon area, the Canelo Hills Volcanics consist of two members, the rhyolitic lava member below and the welded tuff member above; in the Canelo Pass area, the formation consists of two members, the dominantly sedimentary member below and the welded tuff member above; and, in the intermediate Lone Mountain and southeastern Canelo Hills areas, the formation consists of three members, the dominantly sedimentary lower member, the middle rhyolitic lava member, and the upper, welded tuff member. On the assumption that these members are correctly correlated from area to area, any one of at least three conclusions is possible: (1) the rhyolitic lava member pinches out northwestward from Lone Mountain, and the lower member pinches out southeastward, due either to nondeposition or to erosion; (2) the two members intertongue with one another in some way; or (3) a combination of the first two. There is no compelling evidence in the Huachuca Mountains area that would favor any one of these alternatives.

AGE

The age of the Canelo Hills Volcanics must be determined solely on the basis of geologic relations and radiometric methods inasmuch as no fossils of stratigraphic significance have been found in the formation. Fossil wood collected from the lower member in NW¼ sec. 27, T. 23 S., R. 19 E., is of indeterminate identity and age, but its presence suggests that fossil pollen may yet be found in one of the mudstone or nonwelded tuff beds of the lower member.

Geologic relations described in the preceding section are sufficient only to indicate that the Canelo Hills Volcanics are younger than Lower Permian rocks and older than Lower Cretaceus rocks.

Two radiometric age determinations have been obtained for welded tuffs in the formation. A potassium-argon age determination of 173±7 m.y. (million years) for virtually unaltered biotite from densely welded tuff of the welded tuff member in the Canelo Hills has been previously reported (Hayes and others, 1965, p. M7). An age of 144±4 m.y. was determined by H. H. Mehnert, R. F. Marvin, and Wayne Mountjoy of the U.S. Geological Survey (written commun., July 7, 1965) for bronzed biotite from a less densely welded tuff in the lower member in sec. 35, T. 23 S., R. 19 E., of the Lone Mountain area. Inasmuch as both ages are undoubtedly minimum ages owing to possible argon losses, the older one must be closer to the actual age of the rock for which it was determined. Hence, the welded tuff member is considered to be of probable Early Jurassic age. The rhyolitic lava and lower members could also be of Early Jurassic age or could be as old as Triassic or Late Permian from the evidence available. However, from a regional viewpoint, it seems reasonable to make a lithologic correlation of the lower member with the Gardner Canyon Formation of the Santa Rita Mountains, which can be assigned a Triassic age on the basis of a 192 m.y. lead-alpha age determination of zircon from a dacite flow (Drewes, 1968, p. C7). Considering all the above, the welded tuff member of the Canelo

Hills Volcanics of the Huachuca Mountains area is probably of Early Jurassic age, and the lower member is most likely of Late Triassic or Early Jurassic age; the age of the rhyolitic lava member, of course, is intermediate between the ages of the other two members.

CONDITIONS OF DEPOSITION

The Canelo Hills Volcanics were clearly deposited in a continental environment in an area of high relief. The exotic blocks in the lower member in the nearby Canelo Hills and in the rhyolitic lava member there and in the Huachucas are evidence of this relief. The conglomerates in the lower member probably represent fan gravels deposited at the foot of high hills or mountains, and the finer sediments in the member are probably dominantly stream deposits. The great thickening of the welded tuff member from about 250 feet near Montezuma Canyon to about 500 feet in the Lone Mountain area and to at least 6,400 feet locally in the Canelo Hills (Hayes and others, 1965, p. M4) suggests that the vent area for the volcanics was in the vicinity of the present Canelo Hills.

SILICEOUS VOLCANIC ROCKS OF THE HUACHUCA MOUNTAINS

GENERAL DESCRIPTION AND DISTRIBUTION

The siliceous volcanic rocks of the Huachuca Mountains, possibly as much as 4,000 feet thick, are mostly volcaniclastic rocks, although some lava and minor clastic sedimentary rock are present in the unit. Characteristic of the unit are abundant exotic blocks and megabreccias of Paleozoic sedimentary rock.

These rocks are confined to the southern part of the mountains, where they occur in eastern, central, and western structural blocks. Exposures in the eastern block, a northeastward-tilted block between two northeast-dipping thrust faults, are on the north and east slopes of Miller Peak and the slopes of Carr Peak (fig. 2), on the north and east slopes of Bob Thompson Peak, and above the east base of the mountains between Stump and Hunter Canyons. In the central block, the volcanics occur in a faulted roof pendant in the Huachuca Quartz Monzonite between Montezuma Peak and the head of Ash Canyon. The volcanics in the western block dip southwestward and crop out in a series of exposures on and southwest of the central drainage divide of the mountains from the head of Sawmill Canyon to near Montezuma Pass. Some of the rocks in this western block were only tentatively mapped as siliceous volcanics of the Huachuca Mountains; they could almost as well have been assigned, with question, to the Canelo Hills Volcanics.

LITHOLOGY

The siliceous volcanics of the Huachuca Mountains in the western structural block consist largely (about 75 percent) of pale-red to grayish-red quartz latite to rhyodacite tuff and contain some felsite, flow-banded lava, and sedimentary rock.

The tuff bears a general resemblance to that in the welded tuff member of the Canelo Hills Volcanics, but it also has some distinct differences: the tuff in the volcanics of the Huachuca Mountains does not seem to be as densely welded as that in the Canelo Hills Volcanics; it has a noticeably lower content of quartz phenocrysts; it contains much more sodic plagioclase than potassium feldspar; and it seems to contain more lithic fragments.

Generally, the felsite is sparsely porphyritic and is mostly pale reddish purple. Phenocrysts of sodic plagioclase are dominant over those of potassium feldspar, in some places greatly so, and quartz as phenocrysts is sparse to absent. In thin section, the groundmass appears to be almost entirely devitrified glass that has little or no detectable flow structure.

Rare flow-banded siliceous lava in the unit is grayish red purple to grayish purple. The flow banding is crude but conspicuous, as are the spherulites. Phenocrysts of sodic plagioclase are sparse; other phenocrysts are absent. In thin section, the groundmass is seen to be almost entirely devitrified glass with well-developed flow structure.

Sedimentary rock is a very minor constituent of the siliceous volcanics of the Huachuca Mountains, except in the upper end of Sawmill Canyon where the unit laps onto an ancient hill of limestone of Permian age. In that area, the basal few feet of the volcanic unit adjacent to the limestone consists of angular limestone cobble conglomerate, which grades laterally and vertically into angular volcanic-pebble conglomerate, tuffaceous sandstone, siltstone, and mudstone. The finer rocks and the sand matrix of the volcanic-pebble conglomerate are all moderate red. Sedimentary rocks similar to these are present in the lower member of the Canelo Hills Volcanics.

The siliceous volcanic rocks of the Huachuca Mountains have been somewhat epidotized in the central structural block, where they occur in a roof pendant. The alteration, in general, is not so severe that the rocks cannot be directly compared to those of the western structural block. In the central block, however, tuff is greatly dominant, felsite is very sparse, flow-banded lava is apparently absent, and sedimentary rock consisting only of sandstone, siltstone, and mudstone is sparse.

In the eastern structural block, the rocks have been more intensely propylitized than in the central structural block and, where adjacent to thrust faults, have been rather thoroughly sheared. As a consequence, they are not immediately recognizable as belonging to the same unit. However, close hand-lens inspection of the rock reveals that nearly all the rock is tuffaceous material closely similar in texture to tuff in less altered exposures of the unit. Minor amounts of epidotized siltstone and hornfels were also observed.

Exotic blocks derived from Paleozoic sedimentary formations are abundant in the siliceous volcanics of the Huachuca Mountains in all three structural blocks. These exotic blocks range from unmapped blocks a few feet long to blocks, mapped by Hayes and Raup (1968), that are several thousand feet long and several hundred feet thick. The largest mapped blocks, however, are probably composites of several smaller blocks and, thus, may more properly be termed "megabreccia lenses." All the exotic blocks and the bedding within them, as well as the megabreccia lenses, appear to be approximately alined with the crude layering of the enclosing volcanics. The sedimentary material, generally limestone or dolomite, within the exotic blocks is, in most places, finely to coarsely brecciated internally.

THICKNESS

The siliceous volcanic rocks of the Huachuca Mountains are an estimated 2,500±500 feet (800±150 m) thick northeast of Miller Peak, where neither base nor top is exposed; the exposed volcanics are estimated to be 3,000–4,000 feet (900–1,200 m) thick in the vicinity of Pat Scott Peak, where the base of the unit is faulted. Less than 1 mile (1½ km) north of Pat Scott Peak the unit is absent; its stratigraphic position is marked by an unconformity between Paleozoic and Cretaceous strata.

STRATIGRAPHIC RELATIONS

Siliceous volcanic rocks of the Huachuca Mountains unconformably overlie undifferentiated Permian rocks of the upper part of the Naco Group on the north slope of Bob Thompson Peak and between Stump and Hunter Canyons (Hayes and Raup, 1968). Rocks tentatively assigned to the volcanic unit also unconformably overlie the Naco Group on the west side of the mountains between Cave Creek and Copper Canyon and lap onto an ancient hill of Colina Limestone of Permian age in the upper reaches of Sawmill Canyon.

The volcanics are unconformably overlain by the Glance Conglomerate of Early Cretaceous age between Cave Creek and Sawmill Canyon. In the Montezuma Peak–Ash Canyon area, the volcanics have been intruded and altered by the Huachuca Quartz Monzonite.

AGE

Stratigraphic relations described in the preceding section, along with the existence of abundant exotic blocks and megabreccias of Permian rocks, confirm that the siliceous volcanic rocks of the Huachuca Mountains are post-Early Permian in age and that they are older, probably considerably older, than the Glance Conglomerate of Early Cretaceous age. The rocks are, as a matter of fact, older than the Huachuca Quartz Monzonite. Biotite from that quartz monzonite in NW¼ sec. 7, T. 24 S., R. 21 E., was assigned a potassium-argon age of 164±6 m.y. by R. F. Marvin, H. H. Mehnert, and Violet Merritt of the U.S. Geological Survey (written commun., Nov. 7, 1968), indicating a Jurassic age for that rock. On this basis, then, the siliceous volcanics are no younger than Early Jurassic and could be as old as Triassic.

CONDITIONS OF DEPOSITION

The conditions of deposition of the siliceous volcanics of the Huachuca Mountains were probably basically the same as those postulated for the Canelo Hills Volcanics.

CRETACEOUS STRATA

BISBEE GROUP

A sequence of Lower Cretaceous rocks more than 5,000 feet thick underlies more than half the area of the Mule Mountains (Gilluly, 1956; Hayes and Landis, 1964). Dumble (1902) recognized the age of these strata and named them the "Bisbee beds." Ransome (1904) assigned group status to the Bisbee and distinguished four formations within the group, all, except for the Morita, with type localities in the southern part of the Mule Mountains. In ascending order, these are the Glance Conglomerate, Morita Formation, Mural Limestone, and Cintura Formation (fig. 7). Stoyanow (1949) made exhaustive fossil collections from the Bisbee Group in the Mule Mountains area and proposed further refinements in the stratigraphy. Hayes and Landis (1961), however, found Stoyanow's units unsuitable for mapping and retained Ransome's basic stratigraphy.

The presence of many thousands of feet of Lower Cretaceous rocks on the west side of the Huachuca Mountains has been known for decades, but very little about them has been previously reported in the published literature. Stoyanow (1949, p. 30) reported on some Early Cretaceous fossils collected in the mountains. Brief descriptions of the formations of the Bisbee Group in the Huachucas based on early stages of the present investigation were made by Brown, Davidson, Kister, and Thomsen (1966, fig. 3). Schafroth (1968) summarized unpublished descriptions by William R. Moran.

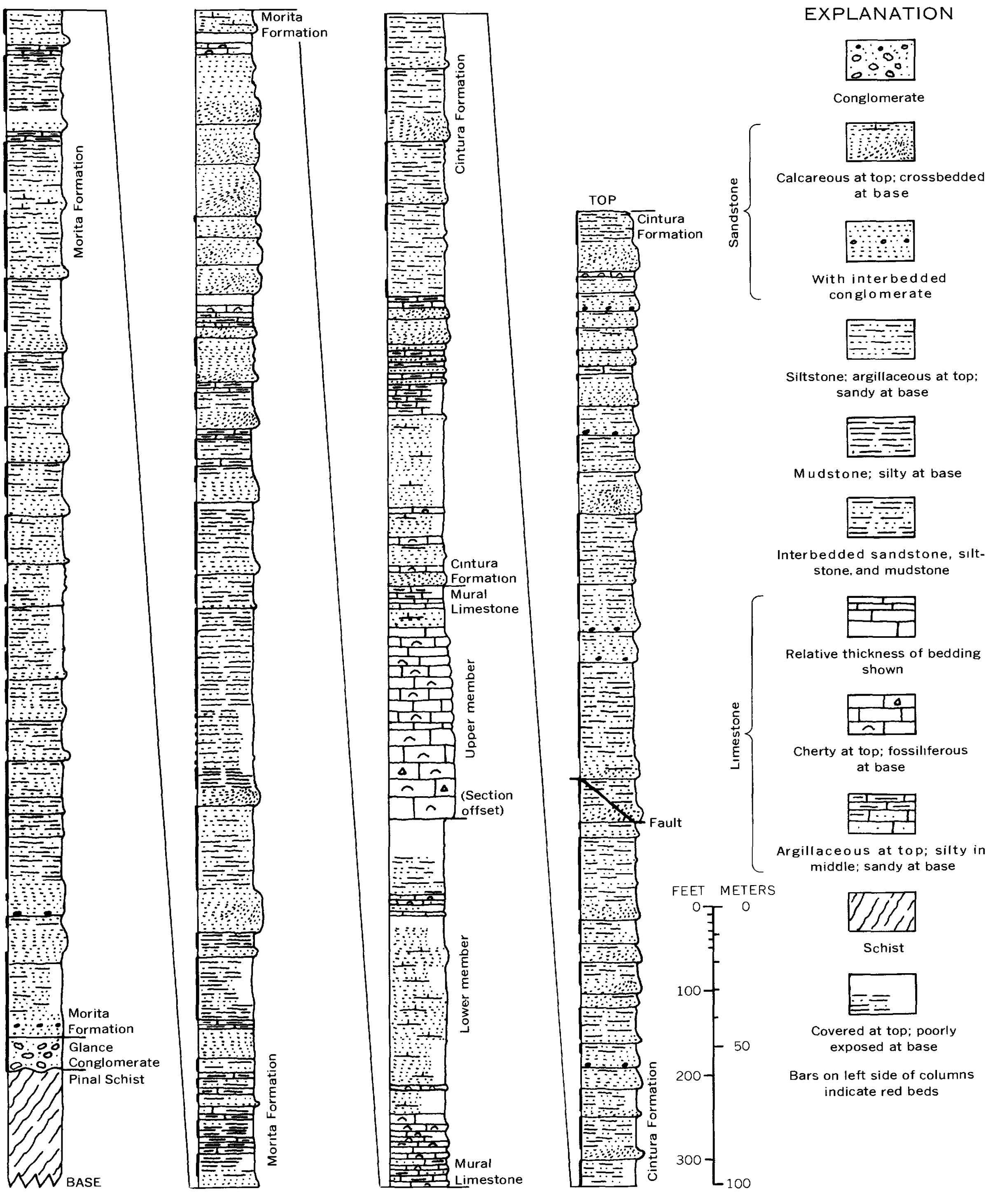


FIGURE 7.—Graphic section of the several formations of the Bisbee Group in the Mule Mountains. The Glance Conglomerate, Morita Formation, and lower member of the Mural Limestone were measured on a spur below Mural Hill between NE¼NW¼NE¼ sec. 15 and SE¼NE¼NE¼ sec. 10, T. 23 S., R. 24 E. The upper member of the Mural Limestone and the Cintura Formation were measured northward from SE¼SW¼SE¼ to NW¼ sec. 12, T. 23 S., R. 24 E., and thence eastward to the top of the hill in NW¼NW¼NE¼ sec. 7, T. 23 S., R. 25 E.

Descriptions of the individual formations of the Bisbee Group in the Mule and Huachuca Mountains are given below followed by notes on heavy-mineral studies and the age and conditions of deposition of the group as a whole.

GLANCE CONGLOMERATE

NAME AND PRINCIPAL REFERENCE SECTION

The Glance Conglomerate was named by Ransome (1904, p. 56) for a station (in NE¼NW¼ sec. 4, T. 24 S., R. 25 E.) on a now-long-abandoned railroad near the Glance mine (fig. 2) in the Mule Mountains, but no type section for the formation was designated. The hill on which the Glance mine shaft is located may appropriately be considered his type locality, but because the top of the formation is absent, a suitable section cannot be measured there. A section of the Glance measured in the NW¼NE¼ sec. 15, T. 23 S., R. 24 E., where the formation is much thinner than at the type locality, is here presented as the principal reference section of the formation (fig. 7).

GENERAL DESCRIPTION AND DISTRIBUTION

The Glance Conglomerate in the Mule Mountains is a basal conglomeratic formation that rests on a highly irregular erosion surface cut on rocks ranging in age from Precambrian to Jurassic. The formation there varies widely in thickness (from 0 to at least many hundred feet) and in the composition of the poorly sorted detrital clasts that make it up. In the Huachuca Mountains and vicinity, the formation is similar to that in the Mule Mountains area, except that in most places in the Huachucas it is thicker and contains a mapped volcanic unit of lavas of intermediate composition (Hayes and Raup, 1968); thin unmapped lava units are also found locally in the conglomerate. In the vicinity of Cave Creek (fig. 2), there seems to be some intertonguing of lavas and conglomerate. As in the Mule Mountains, the basal conglomerates are reflective of the underlying bedrock, which in the Huachucas includes earlier Mesozoic volcanics as well as Jurassic granitic rock, Paleozoic sedimentary rocks, and Precambrian crystalline rocks.

The principal exposures of Glance Conglomerate in the Mule Mountains area are in a broad outcrop band south of Gold Hill (fig. 2). The Glance also crops out extensively for several miles northwest and southeast of Warren. A third important outcrop band, where the Glance is much thinner, extends northwest from near Saginaw along Mule Gulch to near the Sandy Bob Ranch area in the northwestern part of the mountains. The Glance is also exposed on a thrust plate near the mouth of Glance Creek.

In the Huachuca Mountains, the Glance is completely exposed in the northern part of an irregular and considerably faulted outcrop band that extends about 14 miles (23 km) northwestward from the Mexican border south of Coronado Peak to a point about 2 miles (3 km) northwest of Peterson Peak (fig. 2). Along most of its length, this band of exposures is on the west flank of the range; but for about 3 miles (5 km) between the head of Garden Canyon and Pat Scott Peak it forms the crest, and for about 1½ miles (2½ km) at the south end of the range, where it is crossed by the road over Montezuma Pass, it lies along the crest. Apparently complete exposures of the formation are also present at two localities near the north end of the Huachucas. Partial exposures of the Glance are present in fault slices at many other localities, of which the most instructive are south of the mountains in the lower reaches of Bear and Cave Creeks.

LITHOLOGY

MULE MOUNTAINS

The Glance Conglomerate in the Mule Mountains is characteristically made up of poorly sorted and poorly rounded cobbles and pebbles bound in a matrix of reddish-brown sandy and silty mudstone. The composition, size, and degree of sorting and rounding of its clasts vary both vertically and laterally and are strongly controlled by the lithology and local relief of the underlying surface.

Clasts in the basal few feet of the formation are generally angular or poorly rounded, and their composition directly reflects that of the underlying formation, whether it be limestone, schist, or granite. Most clasts near the base of the formation are cobbles and pebbles, but boulders up to 1 foot (30 cm) in diameter are not uncommon locally. Higher in the formation, clasts are smaller, subrounded to subangular, and more varied in composition, but nowhere were fragments recognized that appear to have been derived from any formation not now exposed at the surface somewhere in the Mule Mountains. The Glance grades upward through a thin transition zone of conglomeratic sandstone and siltstone into the Morita Formation.

Bedding planes are generally obscure. In most places the attitude of the bedding can only be determined approximately by sensing the attitude of horizons of change in clast size or a change in clast lithology.

Texturally, the poorly sorted conglomerate of the Glance is nearly identical with the Quaternary alluvial fan deposits along the present mountain fronts (fig. 8).

FIGURE 8.—Boulders of Glance Conglomerate (left) adjacent to cut of well-indurated Quaternary alluvial gravel derived from Paleozoic rocks (right) near north end of Huachuca Mountains, showing the striking similarity of the two. Large boulder left of center is about 3 feet (1 m) high.

HUACHUCA MOUNTAINS

Conglomerate in the lower part of the Glance Conglomerate in the Huachuca Mountains has the same broad lithologic character as the Glance in the Mule Mountains. The composition of the clasts in the basal part of the Glance is strongly controlled by the underlying rocks. In the northern part of the mountains, where the Glance rests on carbonate and sandstone beds of Permian age, its clasts are largely made up of limestone, dolomite, and sandstone; and in the southern part of the mountains, where it generally rests on volcanic rocks of Triassic and Jurassic age, its clasts are dominantly made up of volcanic rocks. Locally, in Blind Canyon, the Glance rests on the Huachuca Quartz Monzonite of probable Jurassic age and is made up of cobbles of that rock. Quartz monzonite detritus is also a major constituent locally near the junction of Cave and Bear Creeks, where the actual base of the formation is missing along a fault.

Conglomerate that overlies the mapped volcanic unit in the Huachucas is similar in general to the lower conglomerate but tends to be more poorly sorted compositionally and better sorted texturally. Unlike the lower conglomerate, it contains an abundance of volcanic debris, and its base may be a minor intraformational unconformity.

Volcanic rocks included in the Glance Conglomerate in the Huachuca Mountains are made up of very dusky red to grayish-purple lavas of intermediate composition that, in general, are not very resistant to erosion. Locally, as it does near Pyeatt Ranch at the north end of the mountains, the member contains thin lenses of conglomerate. Near the south end of the mountains, the member contains numerous large exotic blocks of Paleozoic limestone; a few small blocks were noted elsewhere. The exotic blocks at the south end of the mountains are as much as 1,500 feet (450 m) long and are mostly derived from the Concha Limestone of Permian age. These blocks have been described in some detail by Simons, Raup, Hayes, and Drewes (1966, p. D16–D17). A small unmapped exotic block in Blacktail Canyon at the north end of the mountains was derived from the Abrigo Formation of Cambrian age.

Most of the volcanic rocks are porphyritic; they usually contain scattered phenocrysts of chalky plagioclase, mostly 1–3 mm long and rarely 5 mm long; locally, they also contain small phenocrysts of altered amphibole. Some nonporphyritic volcanics are vesicular or amygdaloidal. Amygdules in the vicinity of Peterson Peak are 1–2 mm across and are of calcite and possibly other minerals (fig. 9). Flow breccia is the dominant rock type near the south end of the mountains, but it is sparse elsewhere.

In thin section, most of the lavas are seen to have a microlitic groundmass that shows conspicuous flow structure; some are vitrophyric. Kaolinized feldspar is the predominant mineral in the groundmass, and most of it appears to be sodic plagioclase. Dark minerals, now largely altered to chlorite and iron oxides, make up from 5 to 25 percent of the groundmass of most samples and average about 15 percent. Traces or very low percentages of disseminated quartz are visible in most sections.

A rapid-rock chemical analysis of one of the less altered darker colored samples of lava from near the north end of the mountains, made by Paul Elmore, Sam Botts, and Lowell Artis of the U.S. Geological Survey (written commun., Oct. 23, 1964) yielded the following results:

	Percent		Percent
SiO_2	59.1	K_2O	2.8
Al_2O_3	16.7	H_2O	2.07
Fe_2O_3	5.6	TiO_2	1.0
FeO	1.5	P_2O_5	.73
MgO	2.8	MnO	.09
CaO	1.3	CO_2	.19
Na_2O	5.9		

The CIPW norm calculated from these results showed:

	Percent
Quartz	9.7
Orthoclase	16.5
Albite	49.9
Anorthite	.5
Enstatite	7.0
Iron oxides and ilmenite	8.1

On the basis of this norm, the rock might be classified as a trachyandesite. However, the presence of nearly 10

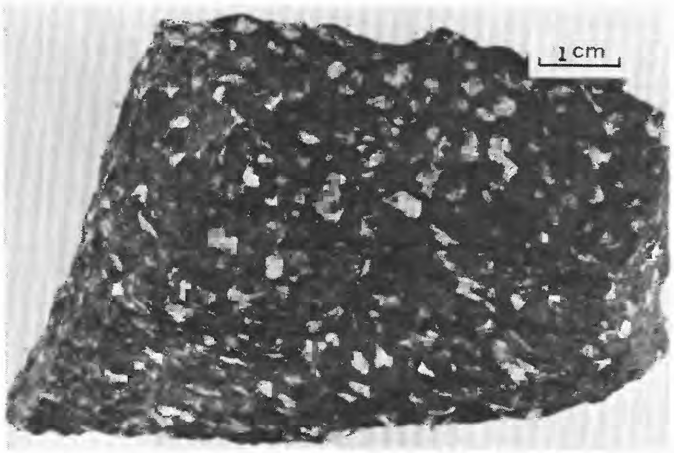


FIGURE 9.—Specimen of rhyodacitic(?) lava from the volcanic unit of the Glance Conglomerate, showing calcite amygdules.

percent quartz in the norm suggests that the rock may be more properly classified as rhyodacite, in spite of the apparent absence of quartz in thin section.

THICKNESS

The thickness of the Glance Conglomerate is highly variable, reflecting, in large part, the relief of the surface upon which it was deposited. In general, the formation is much thicker in the Huachuca Mountains than in the Mule Mountains.

In the Mule Mountains in all exposures north of Mule Gulch (fig. 2), where the large west-trending Dividend fault of pre-Cretaceous age is located, the Glance is less than 100 feet (30 m) thick or is locally absent. South of this area the sub-Glance topography is highly irregular, and the formation ranges in thickness from a few feet to at least several hundred feet.

The thickness of the Glance Conglomerate in the Huachuca Mountains as scaled from the geologic map (Hayes and Raup, 1968) ranges from less than 300 feet (90 m) about 2 miles (3 km) north of Peterson Peak, where the volcanic unit is absent, to more than 3,600 feet (1,100 m) at the head of Garden Canyon, where the volcanic unit is more than 1,000 feet (300 m) thick (fig. 10). South of the vicinity of Pat Scott Peak, the formation seems to maintain a fairly consistent thickness of about 2,000 feet (600 m), but the mapped volcanic unit ranges from about 200 feet (60 m) to nearly 1,500 feet (460 m). Near the north end of the mountains, the formation is about 1,150 feet (350 m) thick, and about 750 feet (230 m) is assigned to the volcanic unit. The volcanic unit, where present, is underlain by a basal conglomerate that is as much as 2,000 feet (600 m) thick in Sawmill Canyon. The upper conglomerate unit is about 750 feet (230 m) thick in the central part of the range near Peterson Peak and is apparently much thicker near Coronado Peak, where the top is not exposed; it is absent at the north end of the range and locally near Bear and Cave Creeks.

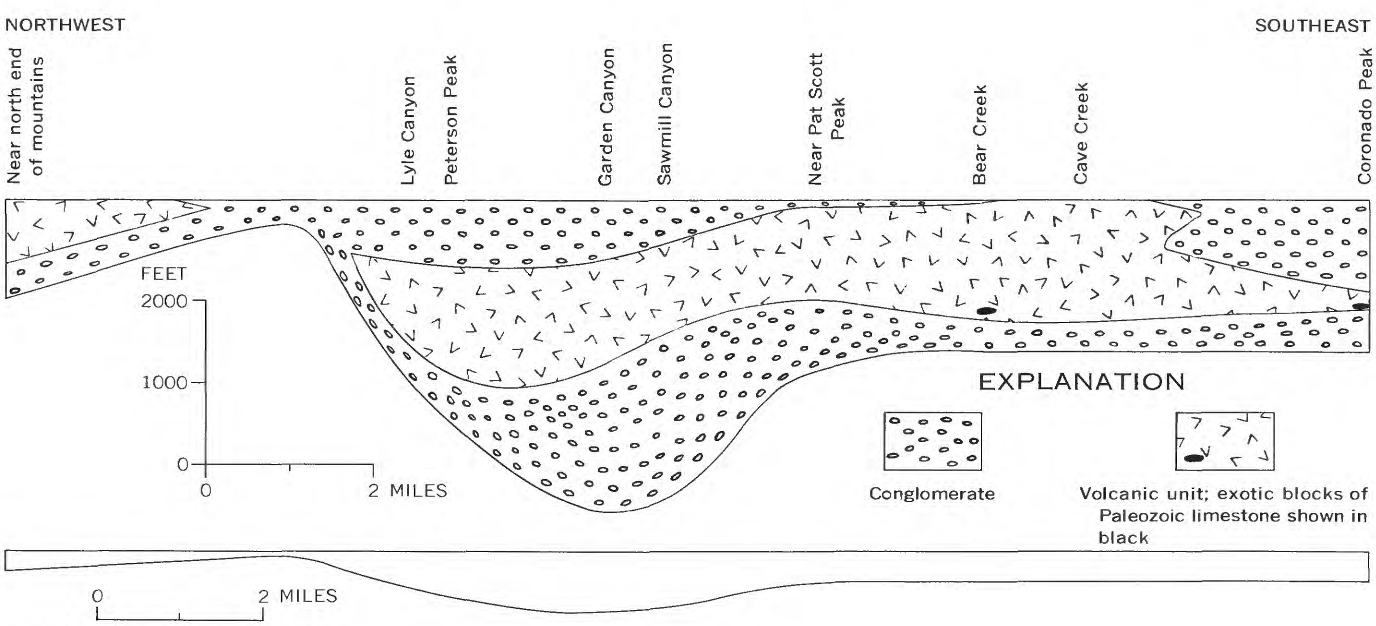


FIGURE 10.—Diagrammatic section of Glance Conglomerate in the Huachuca Mountains, showing relief of pre-Glance surface and variations in thickness of the Glance and its members. Localities at top of section are shown in figure 2.

CONTACTS

The basal contact of the Glance Conglomerate is a major unconformity, which in places is of great relief. Although the constituent clasts of the basal few feet of the formation are in nearly all places derived from the underlying formation, the contact, with one exception, is easily recognized on the outcrop. The exception is east of Coronado Peak in the Huachuca Mountains where the Glance rests on tuff breccia of the welded tuff member of the Canelo Hills Volcanics. In that area, the contact is arbitrarily placed where the breccia seems to have been sufficiently reworked to be included in the Glance.

The Glance is transitional upward into the Morita Formation, but the arbitrary contact can generally be located within a few feet, at the most. It is placed at the top of the highest granule-conglomerate bed above which conglomerate is a subordinate lithology. In most places, thin beds of pebble conglomerate are present tens or hundreds of feet up in the Morita Formation, but these cause no confusion. Locally in the Huachucas the contact is sharp where conglomerate is absent, and the Morita rests on volcanics of the Glance.

CONDITIONS OF DEPOSITION

The Glance Conglomerate was deposited in an area of high relief that, in the vicinity of the present Huachuca Mountains at least, may still have been intermittently rising during deposition. The conglomerates in all but the uppermost part of the formation are believed to represent locally derived fan and colluvial gravels—fan gravels where thick and adjacent to buried high areas, and colluvial gravels where thin high on the flanks and over the tops of high areas. Although not located in the field, there must have been a volcanic vent area in the vicinity of the present Huachuca Mountains, as indicated by the volcanic unit there. The presence of exotic blocks of Paleozoic rock in the volcanics at the south end of the mountains further suggests that areas of high relief were present nearby at the time of the volcanic activity. The possible intraformational unconformity at the top of the volcanic unit in the Huachucas may represent minor crustal instability in the area during part of Glance time. By the end of Glance time, the deposits of the formation had effectively buried the local hills and mountains in their own debris, and the uppermost Glance gravels and finer sediments were largely alluvial deposits derived from somewhat more distant sources, probably to the north and northwest. These uppermost Glance beds are believed to represent piedmont deposition that was transitional into a subaerial deltaic environment to the southeast.

MORITA FORMATION

NAME AND PRINCIPAL REFERENCE SECTION

The Morita Formation was named by Ransome (1904, p. 56) for the Morita Hills in Mexico just south of the Mule Mountains. Ransome (1904, p. 64) measured a stratigraphic section of the formation through its "excellent exposures north and east of Bisbee." A stratigraphic section measured during the present study up a long spur from the NW¼NE¼ sec. 15 to the SE¼ NE¼ sec. 10, T. 23 S., R. 24 E., is designated as the principal reference section (fig. 7).

GENERAL DESCRIPTION AND DISTRIBUTION

The Morita Formation, 2,600–4,200 feet (850–1,280 m) thick, is made up mostly of repeated sequences of pinkish-gray feldspathic sandstones that grade upward into massive grayish-red siltstones and mudstones. Mudstone and siltstone are dominant in most of the formation, but resistant ledges of sandstone are dominant in the upper 300 feet (90 m).

The Morita Formation crops out extensively in both the Mule and the Huachuca Mountains. It underlies a broad outcrop band that extends along the east side of the Mule Mountains from their north end southward to the international border. The formation is poorly exposed in another area east of Bisbee Junction (fig. 2), and the basal beds are present in a smaller outcrop patch southwest of Gold Hill. In the Huachuca Mountains, the Morita crops out along the crest of the range for about 4 miles (6½ km) at the northwest end and along the west side of the range for about another 9 miles (15 km) southeastward to near the canyon of Bear Creek (fig. 2). In these exposures along the west side, the formation has been intruded by many sills that range in thickness from a few feet to several thousand feet. Important exposures of the entire formation are west of the north end of the Huachuca Mountains around Woodyard Canyon and south of the central part of the range in the lower Bear Creek vicinity. The Morita is also incompletely represented in a fault block between Huachuca and Miller Peaks and in other fault blocks in the Cave Creek and Montezuma Canyon areas. Rocks that are questionably assigned to the Morita are exposed along the range front fault at the northeast foot of the Huachucas.

LITHOLOGY

The Morita Formation is made up almost entirely of pinkish-gray to pale-red feldspathic sandstones and grayish-red siltstones and mudstones; pebble conglomerate, greenish-gray claystone, and impure limestone are minor constituents. Typically, beds of the coarsest sandstone rest with sharp scour-and-fill contact on underlying units of siltstone or mudstone and grade upward into finer sandstone, thence into siltstone and mudstone. Although this pattern varies, it seems to reflect a crudely cyclic or, at least, repetitious sequence of deposition. Beds of fine siltstone to mudstone make up slightly more than half of the formation in the Mule Mountains and roughly four-fifths of the formation in the Huachucas, but sandstone is dominant in the upper several hundred feet in both ranges. Thin units of greenish-gray claystone are found throughout the formation in the Mule Mountains but seem to be most common in the middle part; they occur only in the upper part of the formation in the Huachucas. The few thin beds of impure limestone occur only in the top 600 feet (180 m) in both ranges. Thin beds of pebble conglomerate are locally present in the basal few hundred feet in both ranges.

The coarser sandstone beds in the formation are also the most resistant and the lightest colored. On fresh fracture, they are mostly pinkish gray but range to pale red and grayish red purple; weathered outcrops range from moderate yellowish brown to yellowish gray. Beds are generally a foot to several feet thick, but very thin or massive beds are also found. Most sandstone is thinly laminated and much is cross-laminated. Texturally, the coarser sandstone is, in general, moderately well sorted and medium grained, but coarse-grained sandstone occurs sparingly. The grains are mostly subrounded. Petrified wood is locally present in abundance in some of the coarser sandstone beds.

The very fine grained sandstone, which typically grades downward into the coarser sandstone and usually grades upward into siltstone, is less resistant and darker in color than the coarser sandstone. Most of it is grayish red, but some beds are grayish red purple and greenish gray. Bedding is obscure, and laminations are not evident. Textural sorting does not differ systematically from that in the coarser sandstone, but the grains tend to be subangular to angular.

Grain composition of 22 samples of sandstone from the Morita principal reference section in the Mule Mountains and of five samples from the Huachuca Mountains was determined by thin-section point counting. Quartz makes up from 57 to 91 percent of 24 of the 27 samples studied and from 5 to 13 percent of the remaining three samples. Feldspar makes up from 1.5 to 40 percent of the samples studied and averages about 11 percent; there is no apparent systematic change in feldspar content from the base to the top of the formation. The ratio of plagioclase to total feldspar, however, does increase from an average of about 20 percent in the Mule Mountain samples to about 33 percent in the Huachuca samples. The total percentage of sand-size rock fragments, opaque grains, and silt and mud matrix varies widely but averages about 10 percent. The average sandstone (fig. 11) and the dominant sandstone type in the formation is subarkose or feldspathic sandstone, as defined by Pettijohn (1957, p. 291); a small percentage of the sandstone is arkose and subgraywacke.

The dominant fine siltstone and mudstone of the Morita are characterized by their distinctively and uniformly grayish red color on fresh and weathered surfaces and by their lack of well-defined bedding or conspicuous sedimentary structures. Closely spaced joint planes that have no relation to the faint bedding are so common that determination of bedding attitudes is very difficult where interbeds of other lithologies are absent. These rocks were only studied megascopically, but they appear to range from muddy siltstone to silty mudstone. Clay minerals are probably dominant, but quartz and other minerals apparently are important constituents. Irregular subspherical white calcitic concretionary nodules are conspicuous in some siltstone and mudstone units.

Beds of greenish-gray calcareous or dolomitic claystone make up only a small fraction of the Morita but may be of significance in regional correlations. This claystone, like the grayish-red mudstone, lacks conspicuous bedding or other sedimentary structures. Thin-section study of two samples and insoluble residue

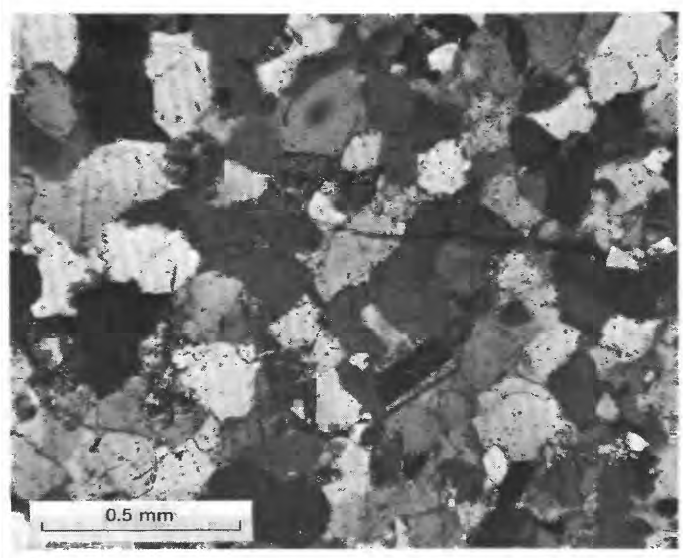


FIGURE 11.—Photomicrograph of typical feldspathic sandstone (under crossed nicols) from principal reference section of Morita Formation. Cementing material is largely quartz (boundaries of some original grains can be seen). Such sandstone is common in both the Morita and the Cintura Formations but is not found in the Fort Crittenden Formation. (See figure 15.)

determinations of three samples disclose that 25–75 percent of the rock consists of undetermined clay minerals, 10–50 percent of calcite to calcareous dolomite, 10–20 percent of quartz silt, and in one sample, about 20 percent of disseminated chert.

Thin beds of medium-gray sandy and argillaceous oyster-bearing limestone occur in the upper part of the Morita. Because they are similar to the more abundant limestone in the lower part of the overlying Mural Limestone, they are not described here.

THICKNESS

The thickness of the Morita in the principal reference section in the Mule Mountains is 2,605 feet (855 m). Ransome (1904, p. 64) reported a thickness of 1,800 feet (550 m) at the same locality. Our measurement was rechecked carefully and is reported here with confidence. Gilluly (1956, p. 73) measured roughly 3,000 feet (900 m) of Morita in the northern part of the Mule Mountains, about 5 miles (8 km) north of the principal reference section. The formation is 4,200 feet (1,280 m) thick on the west side of the Huachuca Mountains, where measured along Bear Creek in secs. 1 and 12, T. 24 S., R. 19 E. (fig. 12), and is very nearly the same thickness where roughly measured in Merritt Canyon in secs. 4 and 5, T. 23 S., R. 19 E. It thins northward from Merritt Canyon, and in the Woodyard Canyon area in sec. 1, T. 22 S., R. 18 E., it is estimated to be only about 3,000 feet (900 m) thick.

CONTACTS

The basal contact of the Morita Formation is described in the section on the Glance Conglomerate. The contact with the overlying Mural Limestone is gradational and is placed at the base of the lowest sequence of interbedded drab mudstones and impure limestones that overlies a series of conspicuous sandstone ledges at or very near the top of the Morita. Although scattered fossiliferous limestone and drab mudstone beds similar to those found in the lower part of the Mural are present in the upper several hundred feet of the Morita, they are greatly subordinate to the sandstone beds typical of the Morita. Limestone is conspicuously more abundant in the lower part of the Mural, and the sandstones in that formation are more calcareous and less resistant than those of the Morita. The grayish-red mudstone and siltstone of the Morita are very sparse in the Mural Limestone. On the steep dip slopes on the west side of the Huachucas, the basal mudstones and limestones of the Mural are not well exposed, but the sandstone ledges of the upper part of the Morita are apparent in most places and allow a close approximation of the position of the contact.

CONDITIONS OF DEPOSITION

The Morita Formation probably represents deposition on a slowly subsiding subaerial deltaic plain. The sandstone beds that rest in a cut-and-fill relation on underlying siltstone and mudstone units are believed to represent channel deposits of meandering streams that flowed across the plain, and the intervening siltstone and mudstone units are believed to represent interfluvial flood deposits. The thin impure oyster-bearing limestone beds in the upper part of the Morita undoubtedly were deposited in brackish waters that intermittently flooded the delta from an advancing sea to the southeast.

In lithologic detail and in cyclicity of lithologies, the Morita Formation is strikingly similar to the Old Red Sandstone of Britain (Allen, 1964) and to the Catskill Formation of New York State (Friedman and Johnson, 1966), both of which have been interpreted as ancient delta deposits.

MURAL LIMESTONE

NAME AND PRINCIPAL REFERENCE SECTION

The Mural Limestone was named by Ransome (1904, p. 56) for Mural Hill (fig. 2) in the Mule Mountains northeast of Bisbee. Although he did not map them separately, Ransome (1904, p. 67) recognized two distinct members of the formation. Stoyanow (1949, p. 6) proposed that only the upper member be known as the Mural Limestone and that the name Lowell Formation be applied to beds included by Ransome in the lower member of the Mural and in the upper part of the Morita Formation. In a more recent report, Hayes and Landis (1961, p. B126) pointed out the general unsuitability of the Lowell Formation as a map unit, and the limits of the Mural Limestone as originally proposed by Ransome are followed here.

No precisely located type section for the Mural Limestone has previously been established. Ransome (1904, p. 67) reported thicknesses for the lower and upper parts of the Mural when he named the formation, but he did not state where the measurements were made. Presumably they were made near Mural Hill. The lower member of the Mural was measured, during the present work, high on the southwest side of Mural Hill in the NE¼NE¼ sec. 10, T. 23 S., R. 24 E. A much more satisfactory section of the upper member of the Mural Limestone than that on Mural Hill was measured in the SW¼SE¼ sec. 12, T. 23 S., R. 24 E., about 2 miles (3 km) southeast of Mural Hill. These sections of the two members of the Mural are considered together as the principal reference section of the formation (fig. 7).

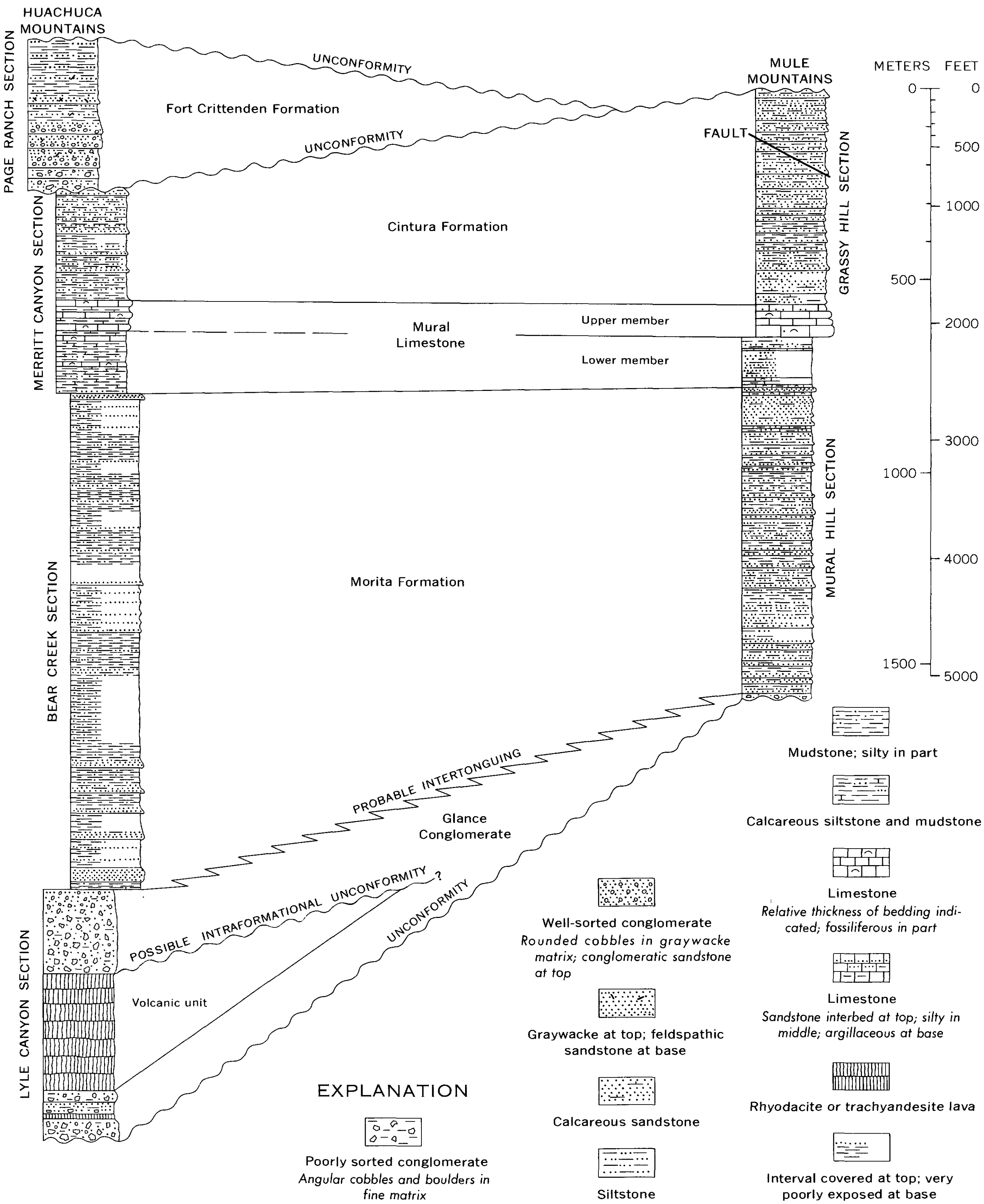


FIGURE 12.—Generalized columnar sections of Cretaceous rocks in Huachuca and Mule Mountains, showing correlations of formations between the two ranges.

GENERAL DESCRIPTION AND DISTRIBUTION

The Mural Limestone, 300–800 feet (90–250 m) thick, is divided into two members of roughly equal thickness: a lower member made up of fairly nonresistant drab calcareous mudstones, impure fossiliferous limestones, and friable calcareous siltstones and sandstones; and an upper member made up of thick beds of gray limestone which, in the Huachucas, are interbedded with a roughly proportionate amount of drab calcareous mudstone and siltstone. These members were mapped separately in the Mule Mountains by Hayes and Landis (1964) and as one map unit in the Huachucas by Hayes and Raup (1968).

In the Mule Mountains, the Mural Limestone is exposed from base to top only in the northeastern part of the range in an outcrop band, locally offset by faults, that extends north about 5 miles (8 km) from Mural Hill to Johnson Canyon (fig. 2) and southeast from Mural Hill to the east edge of the mountains. Parts of the formation are exposed in several places along the southeasternmost edge of the mountains, in several small hills surrounded by Quaternary deposits in the Sulphur Spring Valley, along the international boundary south of Bisbee Junction, and in a small fault slice southeast of Gold Hill.

The Mural is exposed in nearly continuous outcrops along the west side of the Huachuca Mountains for about 13 miles (20 km) from near their north end southeastward to the vicinity of Bear Creek (fig. 2). It is also well exposed south of the mountains in discontinuous outcrops between the Joaquin Creek vicinity and Copper Canyon, and is poorly exposed near Ferosa Canyon west of the north end of the mountains.

LITHOLOGY

LOWER MEMBER IN MULE MOUNTAINS

About half of the lower member of the Mural Limestone in the Mule Mountains is made up of pale-yellowish-brown to light-olive-gray-weathering fine to very fine grained calcareous sandstone that generally occurs in poorly outcropping beds less than 1 foot thick. On fresh fracture, most of the sandstone is medium gray to medium light gray. Most of the sandstone, like that of the Morita, is feldspathic. Fossil molluscan debris is abundant in some beds.

Calcareous and generally platy to shaly siltstone makes up roughly one-fourth of the lower member; some is sandy and some is argillaceous. The siltstone, like the sandstone, is medium gray to medium light gray and weathers olive gray to pale yellowish brown. It is rarely well exposed.

Very impure medium-gray fossiliferous limestone that typically weathers to a mottled light olive gray and medium gray makes up most of the remainder of the lower member in the Mule Mountains. The limestone is nearly all very silty, and most is somewhat sandy and argillaceous. The abundant fossils consist largely of oysters and other molluscan debris bound in a micritic matrix. Some of the limestone occurs in beds as much as 3 feet (1 m) thick that hold up weak discontinuous ledges, but much of it is thin bedded and is poorly exposed in slopes.

LOWER MEMBER IN HUACHUCA MOUNTAINS

More than half of the lower member of the Mural Limestone in the Huachucas consists of pale-olive to greenish-gray very calcareous silty mudstone. This lithology is gradational into olive-gray to pale-yellowish-brown-weathering platy to shaly calcareous siltstone. Layers containing abundant light-brownish-gray calcareous nodules are commonly present in the more massive mudstone. Interbedded with this mudstone and siltstone, but making up only a small part of the member as a whole, are thin beds of very fossiliferous impure limestone similar to that common in the member in the Mule Mountains.

Pale-yellowish-brown to light-olive-gray-weathering fine to very fine grained calcareous sandstone similar to that which makes up much of the member in the Mule Mountains is also present in the Huachuca Mountains area but is very subordinate to mudstone and siltstone.

Pale-red to pale-reddish-brown slightly calcareous silty mudstone to siltstone makes up the remainder of the member in the Huachucas. Mudstone and siltstone of this color are sparse in this member in the Mule Mountains.

UPPER MEMBER IN MULE MOUNTAINS

Throughout the Mule Mountains area, the upper member of the Mural Limestone consists almost entirely of medium-light-gray-weathering limestone in relatively thick beds that hold up resistant cliffs or ridges. Locally, a few thin beds of fine-grained calcareous sandstone are intercalated in the upper part of the member. Most of the limestone is conspicuously rich in molluscan fossil debris, and some beds are rich in Foraminifera of the genus *Orbitolina*. Scattered nodules of reddish-brown-weathering chert are present in some beds. The limestone is mostly medium dark gray on fresh fracture and typically yields a strongly fetid odor when freshly broken. In thin section, the limestone appears to be largely micritic, but irregular patches and veinlets of sparry calcite are usually present. Most of the limestone is highly calcitic, but of seven samples analyzed by the versenate method in U.S. Geological Survey laboratories, one proved to be dolomitic. The average calculated calcite: dolomite ratio is 92:8. The percentage of insoluble residue ranged from less than 1 percent to about 6 percent in six of the samples and was about 28 percent in the other. The residue is dominantly quartz silt.

The thickness and nature of the bedding in the upper member of the Mural vary considerably, both vertically and laterally, in the Mule Mountains. Southward from a point about 1 mile (1½ km) north of Mural Hill, beds in the lower half of the member are typically from 2 to 20 feet (0.6 to 6 m) thick; whereas in the upper half of the member, few beds are more than 5 feet (1.5 m) thick, and many are only inches thick. Very thick reefoid lenses are locally present in the lower part of the member in small outliers about 2 miles (3 km) east of the mountains near U.S. Highway 80. One of these is more than 40 feet (12 m) thick but thins to nearly a wedge edge is less than 500 feet (150 m) laterally along the outcrop (fig. 13). In the northern part of the mountains, beds in the lower part of the member are typically only 2–5 feet (0.6–1.5 m) thick, whereas beds in the upper part are locally as much as 20 feet (6 m) thick.

UPPER MEMBER IN HUACHUCA MOUNTAINS

About two-thirds of the upper member of the Mural Limestone in the Huachuca Mountains area is made up of medium-gray- to medium-light-gray-weathering micritic-skeletal to skeletal-micritic limestone that occurs in beds 1–4 feet (0.3–1.2 m) thick. Unweathered rock is medium to medium dark gray and usually yields a fetid odor when freshly broken. Molluscan debris is common in some layers, and the foraminifer *Orbitolina* may be found in the upper part of the member. Interbedded with the limestone throughout the member, but proportionately more abundant in the upper part, are yellowish-gray to greenish-gray calcareous shale and siltstone and minor amounts of light-olive-gray argillaceous limestone.

FIGURE 13.—Reefoid lens, or bioherm, in upper member of Mural Limestone in NW¼ sec. 1, T. 24 S., R. 25 E., about 2 miles east of Mule Mountains. Rudistids are abundant in the massive bed, which is about 40 feet (12 m) thick, on the right. The bed thins and grades into several thin beds of bioclastic limestone toward the left (west).

THICKNESS

The thickness of the Mural Limestone ranges from about 500 to about 650 feet (150–200 m) in the Mule Mountains and from about 300 to about 800 feet (90–250 m) in the Huachuca Mountains area.

The entire formation has been measured at three localities in the Mule Mountains, and the lower member has been measured at three additional localities. At Abbot Canyon, about 7 miles (11 km) north-northeast of Bisbee, the Mural Limestone is 517 feet (157 m) thick; 340 feet (103 m) is in the lower member, and 177 feet (54 m) is in the upper member (Gilluly, 1956, p. 74). About 3 miles (5 km) northeast of Bisbee, in the S½ sec. 35, T. 22 S., R. 24 E., the formation is 615 feet (187 m) thick; 395 feet (120 m) is in the lower member, and 220 feet (67 m) is in the upper member. In Mule Gulch, about 4½ miles (7 km) east of Bisbee in the N½ sec. 18, T. 23 S., R. 25 E., the Mural is 646 feet (197 m) thick; 372 feet (113 m) is in the lower member, and 274 feet (84 m) is in the upper. In the principal reference section on Mural Hill, the lower member is 432 feet (132 m) thick, and near the south end of the mountains in the NE¼ sec. 14, T. 24 S., R. 25 E., it is 329 feet (100 m) thick. In a restudy of a section measured by Stoyanow (1949, p. 8–12) near Bisbee Junction, in the S½ sec. 14, T. 24 S., R. 24 E., the lower member was determined to be about 360 feet (110 m) thick (Hayes and Landis, 1961, p. B126). There is no evidence from these thicknesses of any consistent unidirectional change in thickness of the lower member of the Mural in the Mule Mountains, but there is a definite suggestion of general southward thickening of the upper member.

In the Huachuca Mountains, the Mural Limestone in the bottom of Merritt Canyon in the NE¼ sec. 8, T. 23 S., R. 19 E., is 800 feet (243 m) thick, with 540 feet (164 m) in the lower member and 260 feet (79 m) in the upper (fig. 12). The formation was not measured across the poorer exposures in the northern part of the mountains or west of the north end of the mountains, but it is apparently no more than about 300 feet (90 m) thick in that area, and most of that thickness is in the upper member. Most of the lower member apparently grades laterally northward into beds of Morita-like lithology.

CONTACTS

The basal contact of the lower member of the Mural Limestone is described in the section on the underlying Morita Formation.

The contact between the upper and lower members of the Mural, where mapped separately in the Mule Mountains, is conformable but sharp. It is placed where the nonresistant calcareous sandstones and siltstones and impure limestones of the lower member give way to the more resistant relatively pure limestones of the upper member.

The contact of the Mural with the overlying Cintura is gradational and is placed at the top of a limestone bed above which sandstone is dominant over limestone and below which limestone is dominant over sandstone. Within the Mule Mountains, this choice of contact rarely causes difficulty; in most areas, there is little question as to which bed should be considered the top of the Mural. In the Huachucas, some yellowish-gray shale and siltstone of the type present in the upper member of the Mural is arbitrarily assigned to the Cintura, as are scattered limestone beds as much as 3 feet (1 m) thick that are found tens of feet above the sequence of predominant limestones.

CONDITIONS OF DEPOSITION

The Mural Limestone is a marine deposit. The lower member, made up of mixed and interbedded terrigenous sediments and carbonates, represents the pulsating northwestward advance of the sea over the subaerial deltaic plain represented by the Morita Formation.[2] The upper member of the Mural represents shelf carbonate deposition. Rudistid reef mounds flourished locally in the area of the present Mule Mountains, which was well offshore, beyond any significant influx of terrigenous sediment. At the same time in the area of the present Huachuca Mountains, which was undoubtedly closer to the shoreline, terrigenous sediments were intermittently spread over the sea floor.

CINTURA FORMATION

NAME AND PRINCIPAL REFERENCE SECTION

The Cintura Formation was named by Ransome (1904, p. 56) for Cintura Hill (fig. 2), about 4½ miles (7 km) northeast of Bisbee in the Mule Mountains. Ransome did not indicate precisely where he measured the Cintura Formation, but it was, no doubt, somewhere between Mule Gulch and Dixie Canyon near the east edge of the mountains. During the present investigation, a section was measured from the SE¼ sec. 12, T. 23 S., R. 24 E., northward along a spur toward Grassy Hill to near the north line of sec. 12 and thence eastward a short distance to a prominent white quartzite bed. The remainder of the section was measured upward from the same bed on the opposite side of a fault along the north edge of the NW¼NE¼ sec. 7, T. 23 S., R. 25 E. It is proposed that this section be taken as the principal reference section of the Cintura Formation (fig. 7).

GENERAL DESCRIPTION AND DISTRIBUTION

The Cintura Formation, about 1,800 feet (550 m) thick in the Mule Mountains and possibly more than 2,000 feet (600 m) thick locally in the Huachucas, can be pictured as a crude mirror image of the Morita Formation. Like the Morita, it is made up mostly of repeated sequences of pinkish-gray sandstone that grades upward into massive grayish-red siltstone and mudstone, and, like the Morita, mudstone and siltstone are slightly dominant over sandstone in the formation as a whole. Resistant ledges of sandstone, however, greatly dominate finer grained rock in the basal several hundred feet of the Cintura, whereas sandstone dominates the upper several hundred feet of the Morita; the few limestone beds present in the Cintura are in the lower part, whereas those in the Morita are in the upper part.

The Cintura Formation is exposed in dip slopes on the east flank of the Mule Mountains from Johnson Canyon on the north to about 2 miles (3 km) southeast of Mule Gulch on the south, a distance of nearly 8 miles (13 km). Near the north end of the Huachuca Mountains, on the west side, its outcrops underlie several square miles in the vicinity of Algerita Canyon (fig. 2). It also crops out in the core of an anticline in the Lyle Canyon vicinity about 1 mile (1½ km) northwest of the Algerita Canyon outcrop area. A discontinuous, but locally well exposed, outcrop band southwest of the Huachuca Mountains extends for about 6 miles (10 km) southeastward from the vicinity of Merritt Canyon to the upper part of Lone Mountain Canyon. Other exposures around the core of an anticline are present south of the Huachucas between Joaquin Creek and Copper Canyon.

LITHOLOGY

The lithology of the Cintura is so similar to that of the Morita, except in the relative stratigraphic positions of dominant lithologic types noted above, that there is no need to repeat detailed descriptions of the lithologic types here. Indeed, there is probably no rock type in either formation that is not represented in the other. Were it not for the presence of the Mural Limestone between the two formations and the transitional beds in the upper part of the Morita and the lower part of the Cintura, it would be extremely difficult, if not impossible, for the field geologist to distinguish between them. Even most of the few fossil forms found near the Mural Limestone in the two formations are insufficiently diagnostic to be of value. However, Stoyanow (1949, p. 10) has described fossil species from beds in the Mule Mountains, considered here as the upper part of the Morita,

[2] Evidence that the sea advanced from the east and south is the fact that limestones of marine origin equivalent to the Mural are thicker in those directions and are thinner or absent in areas to the north and west (Hayes and Drewes, 1968, p. 55).

that probably would not occur as high as the Cintura. Pebble-and-cobble conglomerate previously reported in the Cintura of the Huachuca Mountains (Brown and others, 1966, fig. 3) is now excluded from the formation and is included in the lower part of the overlying Fort Crittenden Formation of Late Cretaceous age.

THICKNESS

The total original thickness of the Cintura is not preserved in the Mule Mountains; the stratigraphically highest east-dipping beds are covered by Quaternary alluvial deposits of the Sulphur Spring Valley. We measured about 1,830 feet (560 m) of Cintura where the exposed section appears to be the thickest. This compares closely to the 1,800 feet (550 m) reported by Ransome (1904, p. 69) in the same area.

It is also very doubtful that the original depositional thickness of the Cintura is preserved in the Huachuca Mountains area, where the Cintura Formation is overlain along an erosional unconformity by much younger Cretaceous rocks or by Cenozoic deposits. Where measured in Merritt Canyon in the E½ sec. 8, T. 23 S., R. 19 E., about 930 feet (282 m) of the formation is preserved (fig. 12), and in all exposures south of that area, the formation seems to range from about 1,000 feet (300 m) to 1,400 feet (425 m) in thickness. To the north of Merritt Canyon the preserved thickness beneath Upper Cretaceous strata is much more variable. In Brushy Canyon, about 4 miles (6½ km) north of Merritt Canyon, the Cintura is probably less than 500 feet (150 m) thick, whereas a little more than 1 mile (1½ km) farther north, in the Algerita Canyon area, the Cintura is apparently more than 2,000 feet (600 m) thick. Even farther north, in the vicinity of Ferosa Canyon west of the north end of the mountains, there is very little Cintura preserved beneath Upper Cretaceous rocks, and locally it is absent. A thickness of 2,750± feet (840 m), previously reported for the Cintura (Brown and others, 1966, fig. 3) on the basis of early phases of the present study, is excessive in that it includes strata at the top that are now known to be Upper Cretaceous beds that rest unconformably on the Cintura.

CONTACTS

The basal contact of the Cintura is described in the section on the Mural Limestone. The upper contact, except where the Cintura is overlain by Quaternary alluvium, is not exposed in the Mule Mountains.

The contact of the Cintura with the overlying Fort Crittenden Formation in the Huachuca Mountains vicinity is an unconformity. The significance of the unconformity is not everywhere immediately obvious, inasmuch as the Fort Crittenden Formation is largely made up of terrigenous sediments, many of which are superficially similar to those in the Cintura. Moreover, the beds on either side of the contact are in most places nearly parallel, and the bases of most sandstone units within the Cintura are disconformities and have channel relations with underlying mudstone and siltstone units. In detail, however, the unconformable nature of the contact is readily apparent. In nearly all places, the basal bed of the Fort Crittenden Formation is a distinctive conglomerate made up of well-rounded pebbles to cobbles of rock derived from the Bisbee Group and older rocks. There is no conglomerate resembling it in the Cintura Formation. Locally, the basal Fort Crittenbeds are pebble-bearing graywackes unlike the much cleaner feldspathic sandstones of the Cintura. In the vicinity of Algerita Canyon, near the north end of the mountains, the basal Fort Crittenden conglomerate is a nonresistant angular fanglomeratic-type conglomerate made up mostly of fragments derived from the Bisbee Group and set in a matrix of reworked Cintura mudstone and siltstone.

In some areas of limited outcrop it may be difficult to distinguish mudstones of the Fort Crittenden from those of the Cintura, but there are differences worth noting here. In general, the Fort Crittenden mudstones are more variegated, and even the red-hued mudstones of the Fort Crittenden are generally paler than those in the Cintura. Furthermore, the Fort Crittenden mudstones typically display much more fissility, or shaliness, than do most mudstones of the Cintura.

CONDITIONS OF DEPOSITION

The Cintura Formation is interpreted to represent subaerial deposition on a prograding delta. Conditions must have been very similar to those during Morita deposition, except that the sea was rapidly retreating southeastward away from the region rather than advancing slowly toward it.

HEAVY-MINERAL CONTENT

Heavy-mineral separates mounted in Aurochlor were prepared from 38 samples taken from the base of sandstone units in the Bisbee Group of the Mule Mountains. In addition, seven heavy-mineral slides were prepared from samples collected from widely separated stratigraphic horizons in the Huachuca Mountains for purposes of comparison with the heavy-mineral zonation in the Mule Mountains. Until separates from several sections of equivalent rocks elsewhere in the region are made and examined, the data gathered from the Bisbee of the Mule and Huachuca Mountains are only of limited value. However, certain substantial differences between the heavy-mineral suites from different parts of the type sections were noted, and these are summarized here along with comments on their possible significance. Figure 14 graphically shows the differences in relative concentrations of several heavy minerals in the Bisbee Group.

Zircon is present in every sample examined. Most of the zircon occurs as well-abraded crystals, but a few terminated crystals are present in most samples. Clear zircon is dominant in all samples, but a pink variety is also present in most. In the Mule Mountains, pink zircon consistently makes up more than 20 percent of total zircon in all samples from the top 700 feet (210 m) of the Morita Formation through the basal 850 feet (255 m) of the Cintura Formation; no such zonation is evident for the few samples from the Huachucas. In their report on the age of zircon grains in sedimentary rocks, Houston and Murphy (1965) concluded that most pink zircon grains in Cretaceous rocks between Montana and northern Arizona and New Mexico were derived from Precambrian source rocks and that colorless zircon grains were more likely derived from Mesozoic plutonic rocks.

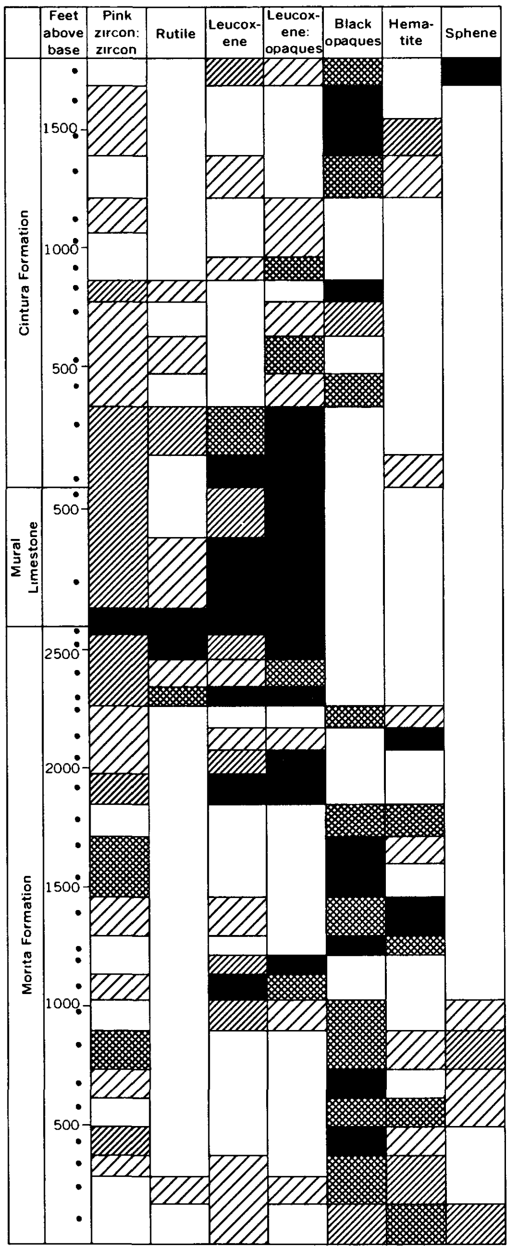


FIGURE 14.—Relative abundance of selected heavy minerals in sandstones in the principal reference sections of the formations of the Bisbee Group. Dots in "Feet above base" column show positions of beds sampled. Degree of shading indicates degree of relative abundance of minerals; unpatterned area shows where mineral abundance or ratio is in lowest 20 percentile of that mineral; black area shows where mineral abundance or ratio is in highest 20 percentile of that mineral.

Leucoxene is also present in all samples but consistently makes up from 17 to 47 percent of the heavy-mineral particles from the top 350 feet (105 m) of the Morita through the basal 300 feet (90 m) of the Cintura; lower in the Morita and higher in the Cintura, the percentage of leucoxene is much more variable, ranging from 2 to 51. Hematite, however, which is present in most samples, is consistently low where leucoxene is high. Hematite ranges from 0 to 7 percent where leucoxene is high and from about 1 to 30 percent elsewhere. Black opaque grains, probably mostly magnetite and (or) ilmenite, tend, like hematite, to be sparsely concentrated in the middle part of the group.

Sphene was noted only in samples from the basal 1,000 feet (300 m) of the Morita and from a sample collected about 1,760 feet (532 m) above the base of the Cintura, the stratigraphically highest point sampled in the formation. Rutile, however, is present mostly in the middle part of the group.

Tourmaline and yellow metallic sulfide(?) grains are present in most samples, but no consistent differences in their concentrations in various parts of the group are evident. However, in two samples from the Cintura Formation in the Huachucas, tourmaline is much more abundant than zircon, whereas this is not true for any samples from the Bisbee Group in the Mule Mountains.

Apatite is present in most slides. It is most abuandant in samples from the lower part of the Morita Formation of the Huachucas.

Trace amounts of garnet and possibly corundum are present in a few samples.

In summary, heavy-mineral suites from the lower part of the Morita Formation and the upper part of the Cintura Formation are similar to one another but differ noticeably from those in the middle part of the group, within a few hundred feet stratigraphically of the Mural Limestone. These differences reflect changes in the gross lithology of the group. Whether they indicate contributions from a different source area, greater distances of transport, diagenetic differences, differences in environment of deposition, or a combination of these is speculative at the present time. Recent studies by Davies and Moore (1969) on the dispersal of Mississippi River sediments into the Gulf of Mexico indicate that distance of transport has little effect on heavy-mineral distribution. Diagenetic differences probably are important in the ratio of leucoxene to black iron oxides and hematite.

FOSSILS AND AGE

The Glance Conglomerate, the lower 2,000 feet (600 m) of the Morita Foundation, and the upper 1,700 feet (515 m) of the Cintura Formation are virtually devoid of fossils, but shallow-water marine fossils, chiefly mollusks, are abundant in impure limestone beds in the upper 600 feet (180 m) of the Morita, in both members of the Mural Limestone, and in impure limestone beds in the basal 100 feet (30 m) of the Cintura Formation. Fossils from the Bisbee Group in the Mule Mountains were studied in considerable detail prior to the present investigation, and only a few previously unreported species were collected from that range during this study. Previous collections have also been reported from the Huachucas, and these are supplemented by four new collections.

MULE MOUNTAINS

Limited collections, made by Ransome (1904, p. 70) "chiefly from the Mural limestone," were studied by T. W. Stanton (in Ransome, 1904, p. 70), who said that fossils from most of the horizons correspond in large part with fauna from the Glen Rose Formation (upper part of Trinity Group) of Texas and that possibly the upper part of the Mural is equivalent in part to the Fredericksburg Group of Texas. Extensive collections made and studied by J. B. Reeside, Jr. (in Gilluly, 1956, p. 83–86), from the lower member of the Mural Limestone and the upper part of the Morita Formation in the northern part of Mule Mountains indicated that that part of the sequence there is referable to the upper part of the Trinity Group of Texas. Stoyanow (1949, p. 36) made a detailed study of the fauna from the same stratigraphic interval near the Mule Mountains along the Mexican border, where he found several species of ammonites and other fossils not found farther north in the Mule Mountains. On the basis of his findings, he correlated beds that are placed in the upper 575 feet (175 m) of the Morita Formation and the basal 90 feet (27 m) of the lower member of the Mural Limestone with the upper part of the Aptian Stage of Europe, thus indicating equivalence to the lower part of the Trinity Group for these beds. Several species of the foraminiferal genus *Orbitolina* collected and examined by Douglass (1960) from the upper member of the Mural Limestone in and near the Mule Mountains confirm the Glen Rose age of this unit.

In conclusion, the upper 600 feet (180 m) or so of the Morita Formation and about the lower one-fourth of the lower member of the Mural Limestone may be correlated with the lower part of the Trinity Group; the remainder of the Mural Limestone is of late Trinity age, although the uppermost part may be as young as Fredericksburg. The Glance Conglomerate and the lower part of the Morita Formation are probably older than the Trinity, but I doubt that they are pre-Aptian. Probably the Cintura Formation is as young as the Fredericksburg Group and possibly, in part, as young as the Washita Group.

Previously unreported fossils from the Bisbee Group of the Mule Mountains collected during this study include: *Dictyoconus floridanus*, collected from 199 feet (61 m) above the base of the upper member of Mural Limestone in the principal reference section (R. C. Douglass, written commun., Oct. 3, 1960); *Caprinella?* sp. from 204 feet (62 m) above the base of the upper member of the Mural in the principal reference section (W. A. Cobban, written commun., Aug. 2, 1960); and *Trochactaeon* sp. from the lower member of the Mural in a tributary to Dixie Canyon (W. A. Cobban, written cummun., Aug. 2, 1960). A small dinosaur(?) bone fragment detected in a conglomeratic bed in the upper part of the Cintura Formation has not yet been extracted.

HUACHUCA MOUNTAINS

Imlay (1944, p. 1037) reported the occurrence of *Exogyra arietana*, a Washita form that was reportedly collected in 1893 by a member of the International Boundary Commission from "the summit of the next to the highest peak in the Huachuca Mountains." This would be Carr Peak, which, as shown by Hayes and Raup (1968), is capped by a klippe of Mississippian limestone. However, the fossil probably was collected from some other point in the Huachuca Mountains, and, if so, it most likely came from the Mural Limestone, as used in this report. The Mural is present on the mountain crest in the N½ sec. 21, T. 22 S., R. 19 E. (projected). There is no place where younger sedimentary rocks are exposed on the crest of the range nor are younger rocks known on any significant peak.

Stoyanow (1949, p. 30) identified "*Ostrea ragsdalei* Hill and numerous specimens of *Glauconia* aff. *G. branneri* (Hill)" from collections that almost certainly were made from the Mural Limestone, as designated in this report. He stated that his collections were from "Parker Canyon," which is probably the same as that labeled Merritt Canyon on the geologic map (Hayes and Raup, 1968), and not the same as the canyon now labeled Parker Canyon. Stoyanow (1949, p. 30) assigned an undoubted Glen Rose age to the host strata.

A collection (USGS Mesozoic loc. D3800) made during this study from the upper part of the lower member of the Mural in the bottom of Merritt Canyon in the Huachuca Mountains (fig. 2), in the NW¼NE¼ NE¼ sec. 8, T. 23 S., R. 19 E., probably came from very nearly the same locality as the collections made by Stoyanow. Concerning collection D3800, W. A. Cobban (written commun., Oct. 1, 1962) wrote:

> This lot consists of pieces of poorly preserved oysters, gastropods, and a colonial coral. One fragment of a pelecypod, possessing some radial folds, possibly represents an *Exogyra* something like *E. clarki* Shattuck from the Washita Group of Texas. The bits of gastropods resemble genera known from the Fredericksburg and Washita of Texas.

Another collection made from the lower member of the Mural Limestone in the NW¼ sec. 11, T. 24 S., R. 19 E., was determined by Ralph W. Imlay (written commun., July 5, 1963) to consist of "internal molds of the pelecypod, *Trigonia*, and of an ammonite that shows a little resemblance to the Lower Cretaceous genus *Parahoplites*," which he believed were inadequate for a definite age determination.

A third collection (USGS Mesozoic loc. D3881), made from along Bear Creek in the NW¼NE¼SW¼ sec. 12, T. 24 S., R. 19 E., contains, according to W. A. Cobban (written commun., Nov. 20, 1962):

Serpula sp.
Ostrea sp.
Trigonia cf. *T. cragini* Stoyanow

Trigonia cragini Stoyanow, a pelecypod, originally was described from specimens found in a part of the Lowell Formation of Stoyanow (1949) of the Bisbee Junction area, that is here considered to be the highest part of the Morita Formation. These beds were considered by Stoyanow to be of Aptian Age.

A collection (USGS colln. f23001) from the same locality in Bear Creek and another collection (USGS colln. f23000) made from near the top of the Mural in the SW¼SW¼NW¼ sec. 23, T. 23 S., R. 19 E., contain specimens of *Orbitolina*, according to R. C. Douglass (written commun., Mar. 14, 1963). Douglass (1960) had previously stated that the maximum known range of *Orbitolina* on a worldwide basis is from the Neocomian (early Early Cretaceous) to the Cenomanian (earliest Late Cretaceous) but that in North America the genus is apparently confined to the Albian (late Early Cretaceous).

These faunal data rather definitely point to a late Early Cretaceous age for the Mural Limestone in the Huachuca Mountains. A late Trinity to Fredericksburg age seems most probable, although faunal elements ranging from early Trinity to Washita age are present. On the whole, the faunal evidence tends to substantiate the lithologic correlation with the type Mural Limestone of the Mule Mountains. On the basis of stratigraphic position, then, the Morita and Cintura Formations of the Huachucas must be virtually synchronous with those formations in the Mule Mountains. It is possible, however, that at least the basal 1,000 feet of the thicker Morita of the Huachucas may be older than the basal Morita of the Mules. If that is true, the Glance Conglomerate of the Huachucas is probably older than that of the Mules Mountains. This might be especially true of the volcanic unit and underlying conglomerate of the Glance of the Huachuca Mountains. These might well be of early Early Cretaceous age.

FORT CRITTENDEN FORMATION

Rocks of Late Cretaceous age, represented by the Fort Crittenden Formation, are exposed in four outcrop areas adjacent to or within 2 miles (3 km) of the southwest side of the Huachuca Mountains (Hayes and Raup, 1968); they are not preserved in the Huachuca Mountains themselves or in the Mule Mountains.

NAME AND REFERENCE SECTION

The Fort Crittenden Formation was named by Stoyanow (1949, p. 59) for exposures near the abandoned fort of that name on the southeast flank of the Santa Rita Mountains (fig. 1), and it has since been redefined slightly by Drewes (1968), who designated a reference section.

GENERAL DESCRIPTION AND DISTRIBUTION

The Fort Crittenden Formation of the Huachuca Mountains vicinity, where it may locally be more than 2,000 feet (600 m) thick, can be divided into two informal members: a basal conglomeratic member that generally underlies low rounded hills, and an upper less resistant shale member of variegated pastel shales and subordinate amounts of graywackes. The two members were not mapped separately by Hayes and Raup (1968).

The formation is most extensively exposed in a 5-mile-long north-northwest-trending outcrop band about 1 mile west of the north end of the mountains near Lyle Canyon (fig. 2) and several of its west-flowing tributaries. It also crops out in Merritt Canyon above the Montezuma Pass–Canelo road, just north of the west end of Lone Mountain, and along the axis of a syncline in the Bear Creek area, south of the mountains.

LITHOLOGY

BASAL CONGLOMERATIC MEMBER

The basal conglomerate member of the Fort Crittenden Formation is made up dominantly of conglomerate but contains some sandstone, siltstone, and mudstone.

The most conspicuous and characteristic lithologic type, although not everywhere the most abundant, is a fairly resistant rounded-cobble conglomerate. The clasts in this conglomerate are well-rounded stream-worn cobbles and pebbles derived from the more resistant older rock types of the region such as Cambrian, Permian, and Lower Cretaceous quartzites and sandstones, siliceous lavas and welded tuffs of Triassic and Jurassic age, and Jurassic quartz monzonite; limestone pebbles and cobbles are present but rare. The matrix of the conglomerate is poorly sorted olive-brown graywacke. Individual conglomerate beds typically grade upward into cross-laminated olive-brown graywacke that, in most places, contains layers of scattered siliceous pebbles. Locally, the graywacke grades upward into silty shale. In most localities, there are at least two or three distinct conglomerate units that are in channel or cut-and-fill relation with underlying conglomerate, graywacke, or shale.

Relatively nonresistant fanglomerate-type conglomerates containing angular cobbles derived almost entirely from rocks of the immediately underlying Bisbee Group occur locally in the extensive northern outcrop area, beneath the characteristic rounded-cobble conglomerates. The matrix of these conglomerates is dominantly reworked Bisbee-like pale-red siltstone and mudstone. These, like the overlying rounded-cobble conglomerates, are repetitious and are typically channeled into underlying rocks and grade upward into feldspathic sandstone and pale-red siltstone and mudstone. Where the Fort Crittenden Formation was measured near Brushy Canyon, it comprises about 190 feet (58 m) of the angular-cobble conglomerate and associated rocks at the base, 165 feet (50 m) of interbedded angular- and rounded-cobble conglomerate, and 245 feet (75 m) of the rounded-cobble conglomerate and associated graywacke at the top of the member.

SHALE MEMBER

Medium-gray silty shale that weathers to pale olive, dusky yellow, pale yellowish brown, or pale red makes up more than two-thirds of the shale member of the Fort Crittenden Formation; the remainder consists of sandstone and siltstone. The shale of the member in most places is decidedly fissile, but locally it is massive claystone. With careful search, many outcrops yield specimens of the gastropod genus *Physa.* Fossil wood is locally distributed in the shale.

Sandstone in the shale member occurs in units that range in thickness from barely 1 foot (25 cm) to more than 50 feet (15 m) and that typically rest with sharp contact on underlying shale and grade upward into siltstone and thence into an overlying shale unit. The sandstone, which usually weathers to a dusky yellow, is medium to fine grained and poorly sorted. Sparse well-rounded siliceous pebbles are commonly present near the base of the sandstone units. Cross-lamination is conspicuous in some beds.

Several thin sections of sandstone were examined, but inasmuch as they all appeared to be similar in composition, only two were point counted. They showed 17½ and 32½ percent quartz, 18 and 26 percent plagioclase feldspar, 15 and 16 percent potash feldspar, 29½ and 7 percent rock fragments, 2 and 2½ percent altered amphibole and pyroxene, 1 and 1 percent opaques, and 16½ and 15 percent matrix of calcite, sericite, limonite, and clay. In Pettijohn's (1957, p. 291) classification, these are both feldspathic graywackes. The sandstone of the Fort Crittenden (fig. 15) is much dirtier in composition than the typical subarkose of the Bisbee Group, is generally more yellow or olive hued, and in general is not as resistant as the sandstone in the Bisbee; thus it is not difficult to distinguish between the two, except in exposures in which only a few beds can be seen.

THICKNESS

The Fort Crittenden Formation is not entirely exposed in the vicinity because the upper part either has been removed by erosion or has been covered by alluvial deposits of late Tertiary or Quaternary age. About 1,275 feet (390 m) was measured along the south edge of sec. 13, T. 22, S., R. 18 E., in a small canyon tributary to Brushy Canyon (fig. 11). There, the basal conglomeratic member is about 600 feet (182 m) thick. In Merritt

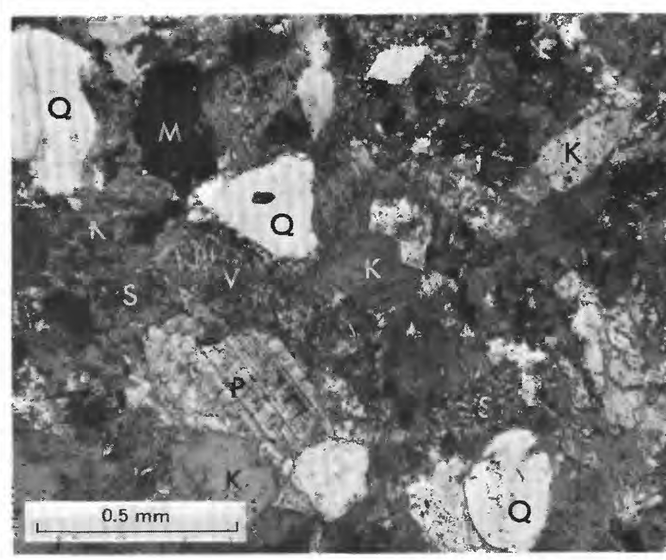


FIGURE 15.—Photomicrograph of typical feldspathic graywacke (under crossed nicols) from the Fort Crittenden Formation. Grains are of quartz (Q), plagioclase (P), potassium feldspar (K), sedimentary rock (S), volcanic rock (V), and magnetite (M). Matrix is largely mud. Graywacke such as this is sparse in the Bisbee Group. (See figure 11.)

Canyon, about 1,160 feet (353 m) of the formation was measured, and about 500 feet (150 m) was in the basal conglomeratic member. There may be nearly 2,000 feet (600 m) of the formation present north of Lone Mountain. Much less is present in Bear Creek.

CONTACTS

The basal contact of the Fort Crittenden is described under the Cintura Formation. The upper contact in the Huachuca Mountains area is a major unconformity overlain by late Tertiary and Quaternary gravels.

AGE

The Fort Crittenden Formation of the Huachuca Mountains area is correlated on the basis of lithology and stratigraphic position with the Fort Crittenden Formation of the Santa Rita Mountains area, which is known to be of Late Cretaceous age (Drewes, 1968). *Physa* and petrified wood, the only fossils yet found in the formation in the Huachucas, are not very diagnostic of age; but the same fossils are found in the formation in its reference section in the Santa Ritas. The Fort Crittenden Formation must also be correlative in part with the Upper Cretaceous Cabullona Group of Taliaferro (1933) known in the Cabullona Basin of Sonora, Mexico (fig. 1).

CONDITIONS OF DEPOSITION

Rocks of the Fort Crittenden Formation were deposited in a variety of continental environments. The angular-cobble conglomerates, locally present at and near the base of the formation, are apparently fan gravel deposits derived from nearby highlands. The rounded-cobble conglomerates are almost certainly cemented stream gravels that were transported several, and perhaps tens, of miles (as reflected by the rounding, sorting, and scarcity of limestone clasts), from mountainous source areas during flood stages of one or more sizeable rivers. The graywackes in the upper part of the formation are interpreted to represent fluvial sands derived from the same source areas during a more mature stage of the geomorphic cycle. The shales of the upper part of the formation may represent floodstage deposition on the flood plain of a broad river valley. Perhaps this valley drained southeastward toward the area of the present Cabullona Basin of Sonora (fig. 1), where the thick Cabullona Group of Taliaferro (1933), which is considered equivalent to the Fort Crittenden Formation, is preserved.

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