Mesozoic depositional history of southeastern Arizona

Philip T. Hayes and Harold Drewes

1978, pp. 201-207. https://doi.org/10.56577/FFC-29.201

in:

Land of Cochise (Southeastern Arizona), Callender, J. F.; Wilt, J.; Clemons, R. E.; James, H. L.; [eds.], New Mexico Geological Society 29 th Annual Fall Field Conference Guidebook, 348 p. https://doi.org/10.56577/FFC-29

This page is intentionally left blank to maintain order of facing pages.

MESOZOIC DEPOSITIONAL HISTORY OF SOUTHEASTERN ARIZONA

PHILIP T. HAYES and HARALD DREWES
U.S. Geological Survey
Denver, Colorado

INTRODUCTION

The area considered herein is roughly between Tucson and the southeastern corner of Arizona (fig. 1). It lies between the Mexican Border and latitude 32°15' N., and between New Mexico and longitude 111°15' W.

Interpretations of stratigraphic relations and regional correlation of Mesozoic rocks in this region are complicated by the lack of datable fossil material in most of the units and by structural complexities; since late Early Permian time, various parts of the region apparently have been subjected to about six episodes of faulting and nearly as many episodes of plutonism. Recently, however, much has been learned about these Mesozoic rocks by professors and students from universities, geologists associated with the minerals industry, and U.S. Geological Survey geologists. This paper is basically an updated version of an earlier paper (Hayes and Drewes, 1968). Although most of the conclusions reached in that paper are unchanged, some of the unnamed units referred to in that paper have been named, units probably correlative to units described in that paper have been found in additional localities, some tentative conclusions of that paper have been made more certain while others have been abandoned, and the worldwide geologic time scale has been revised. The data presented herein are largely presented in much more detail in Cooper (1971), Drewes (1971), Hayes (1970a, 1970b), and Simons (1972). We have also drawn from many older or less detailed recent reports. We obviously are heavily indebted to all of these previous workers, but are ourselves responsible for the interpretations presented here.

Our correlations (fig. 2) are based on analysis of local geologic relations, on paleontologic data of variable usefulness, on radiometric age determinations of variable reliability, on some petrologic studies, and on the assumption that major geologic events must have some degree of regional continuity. In our earlier paper we followed Holmes' (1965) time scale for most of the Mesozoic but used the more refined scale of Gill and Cobban (1966) for the Late Cretaceous. That time scale is shown on the left edge of the correlation diagram, and the time scale of Van Eysinga (1975) is shown on the right edge.

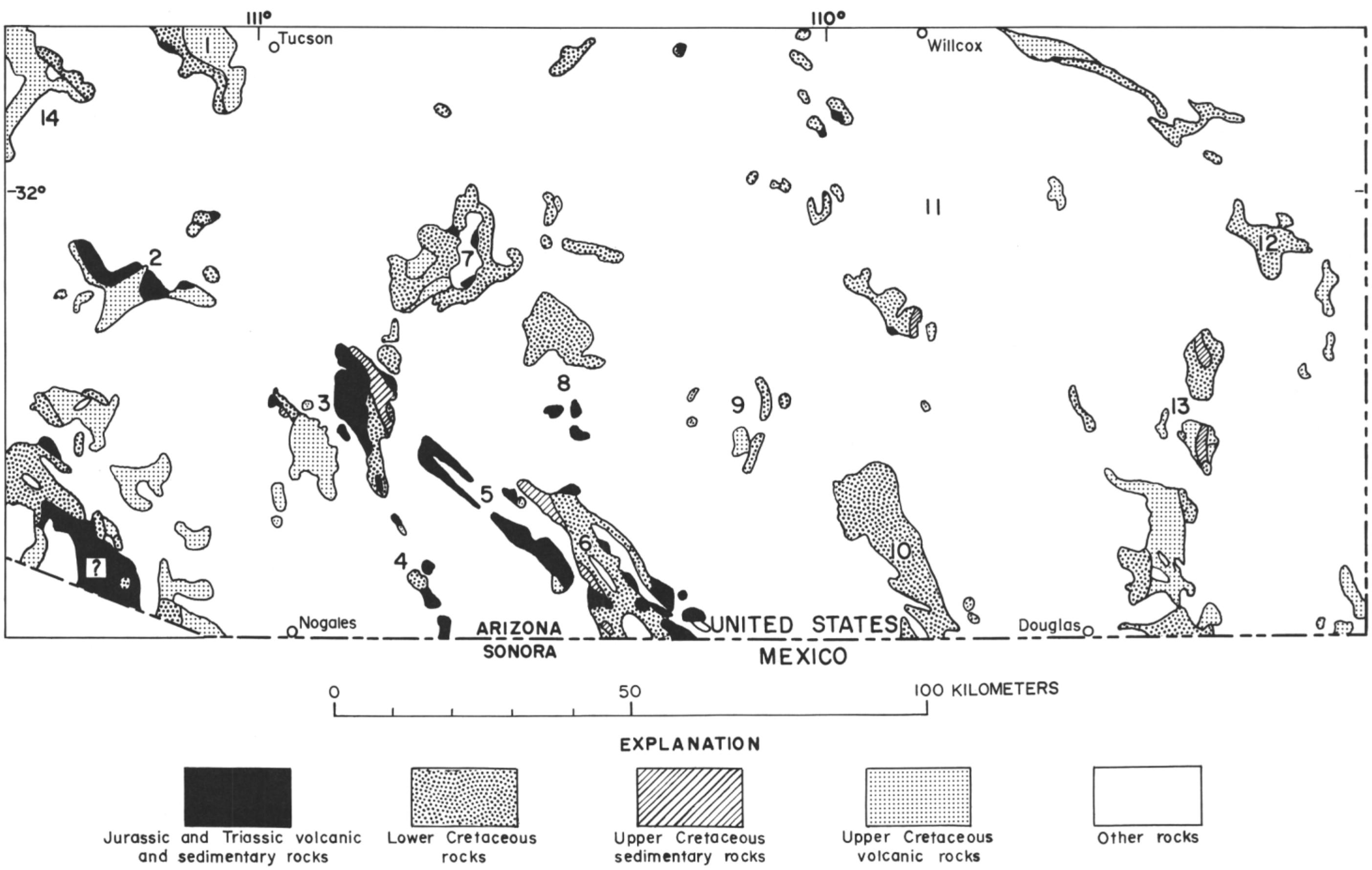

Figure 1. Map showing distribution of Mesozoic volcanic and sedimentary rocks in southeastern Arizona. (1) Tucson Mtns.; (2) Sierrita Mtns.; (3) Santa Rita Mtns.; (4) Patagonia Mtns.; (5) Canelo Hills; (6) Huachuca Mtns.; (7) Empire Mtns.; (8) Whetstone and Mustang Mtns.; (9) Tombstone Hills; (10) Mule Mtns.; (11) Dragoon Mtns. area; (12) Chiricahua Mtns.; (13) Pedregosa Mtns.; (14) Roskruge Mtns.

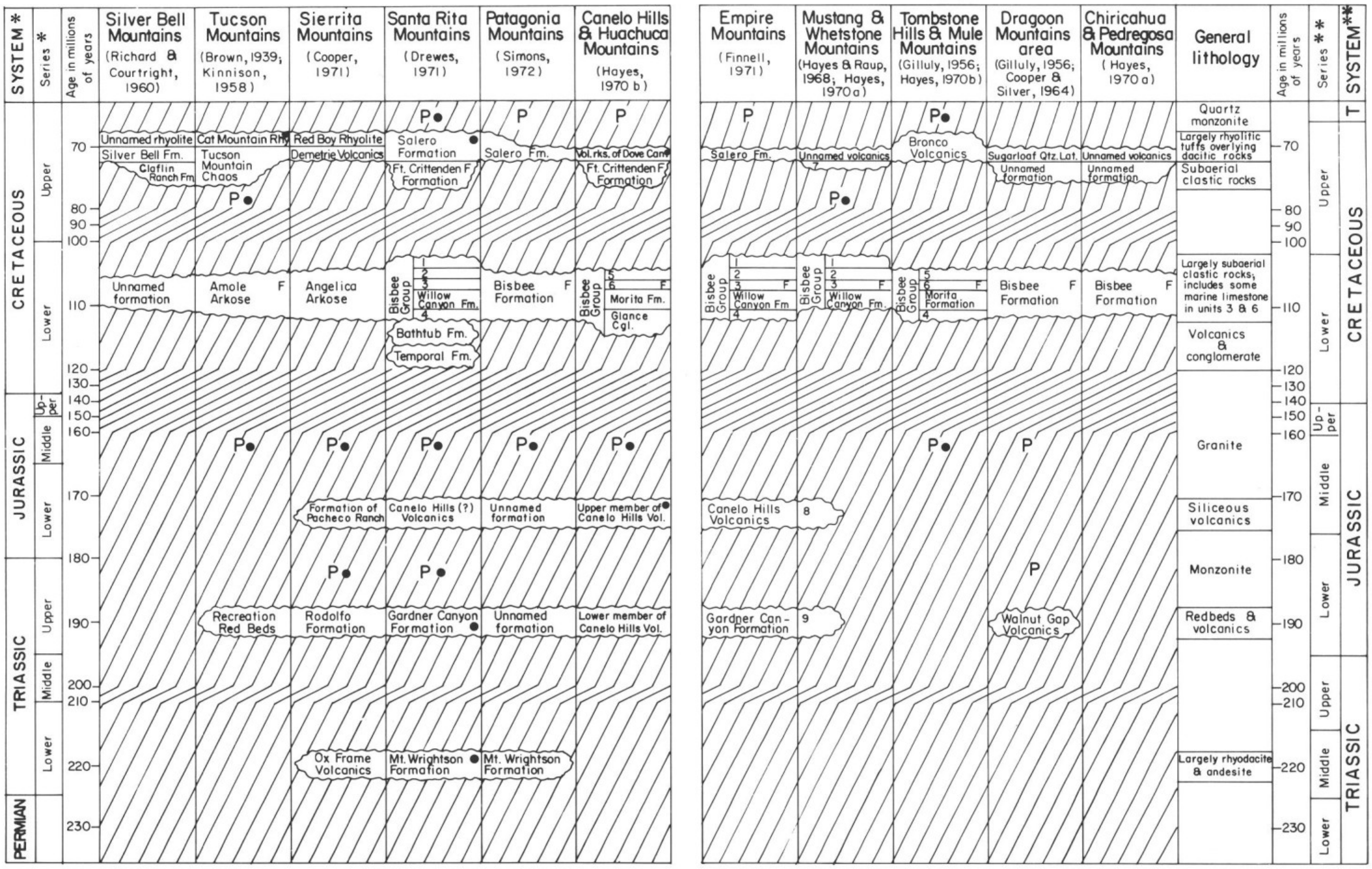

*Figure 2. Correlation chart of Mesozoic rocks in southeastern Arizona. Localities, except for Silver Bell Mountains, are shown on Figure 1. *, time scale used by Hayes and Drewes (1968); **, time scale used by Van Eysinga (1975); (P) plutonic and associated rocks; (F) fossil-bearing rocks; ●, ratiometrically dated rocks. Numbers within chart: (1) Turney Ranch Formation; (2) Schellenberger Canyon Formation; (3) Apache Canyon Formation; (4) Glance Conglomerate; (5) Cintura Formation; (6) Mural Limestone; (7) sedimentary rocks of Rose Tree Ranch; (8) rhyolite in Canelo Hills Volcanics; (9) red beds at base of Canelo Hills Volcanics. Note changes in time scale indicated by pitch of diagonal lines.*

REGIONAL SETTING

Pre-Mesozoic rocks of southeastern Arizona include Precambrian metamorphic, plutonic and sedimentary rocks that are unconformably overlain by about 1,500 m of Paleozoic marine sedimentary rocks ranging in age from Middle Cambrian to late Early Permian. The Mesozoic sequence is unconformably overlain by volcanic and sedimentary rocks of Cenozoic age.

The Mesozoic rocks have a composite maximum thickness of about 12,000 m. They include rhyolitic to andesitic volcanic rocks, sedimentary rocks largely of subaerial origin and some marine beds. Plutonic rocks were intruded in Triassic(?), Jurassic and Late Cretaceous time but are here considered only in connection with their age relation to sedimentary and volcanic rocks. The Mesozoic rocks are treated here in three major divisions separated from each other and from older and younger rocks by major unconformities: (1) Triassic and Jurassic rocks, (2) Lower Cretaceous rocks, and (3) Upper Cretaceous rocks.

Permian-Triassic Unconformity

Marine Paleozoic rocks are separated from subaerial Mesozoic rocks by a widespread unconformity. The youngest Paleozoic formation preserved anywhere beneath the unconformity is the Rainvalley Formation of Permian age in and near the Mustang Mountains, but in places much older rocks lie immediately beneath the unconformity. The oldest Mesozoic rocks inferred to overlie the Permian-Triassic unconformity are included in a volcanic sequence, at least the middle part of which is of Triassic age. The basal contact of these volcanics has not been seen, but the local relief in the Santa Rita Mountains may have been great, for a lens of cobble conglomerate in the sequence contains some clasts of Precambrian granitic rock. The oldest Mesozoic rocks actually in depositional contact with Permian rocks in known exposures are red beds of presumed Late Triassic or Early Jurassic age in the Canelo Hills. The local relief on the erosion surface there may not have been great, inasmuch as the contact irregularities are minor, no basal conglomerate is present, and the lowest chert pebbles of Paleozoic origin in conglomerates intercalated in the red beds are well rounded. On the other hand, the red beds at several places in the Canelo Hills contain exotic blocks of Permian rock interpreted by Simons and others (1966) to be landslide debris from nearby hills. In the Huachuca Mountains Triassic or Jurassic volcanics overlie normally faulted Paleozoic rocks.

MESOZOIC DEPOSITIONAL HISTORY

Triassic and Jurassic Rocks

Three major units, two of them largely consisting of volcanic rocks and the third a medial red-bed unit, make up the oldest major division of Mesozoic rocks. These rocks are most abundant in the western part of the region, mainly in relatively small, faulted areas.

The older volcanic rocks, about 3,000 m thick, are typically represented by the Mount Wrightson Formation in the Santa Rita Mountains. Most of these volcanic rocks are rhyodacite, but andesitic rocks are common in the lower and upper fourths of the formation. Minor conglomerate is intercalated in the middle of the formation, and sandstone and quartzite lenses are scattered throughout and are abundant toward the top. The rhyodacite is intensely indurated and about half of it is finely flow-laminated. The rhyodacite contains, in addition to thick lava flows, welded tuff and agglomeratic tuff facies. The andesitic rock includes some vesicular flows and local pillow lavas. The larger lenses of sandstone and quartzite have sweeping crossbedding of the eolian type; grains are well sorted, largely well rounded and mostly of foreign origin but are admixed with locally derived volcanic detritus.

Similar rocks in a slightly thinner sequence form the Ox Frame Volcanics of the Sierrita Mountains and occur at several localities in the Patagonia Mountains.

The medial red-bed unit is typified by red beds of the lower member of the Canelo Hills Volcanics (Hayes and others, 1965) in the Canelo Hills, the similar Gardner Canyon Formation in the east-central part of the Santa Rita Mountains, and the Rodolfo Formation in the Sierrita Mountains. The Gardner Canyon Formation is estimated to be 600 m thick. The red beds consist of thick-bedded to massive mudstone and siltstone in which some sandstone, conglomerate and volcanics are intercalated. The pebbles of the conglomerate are chiefly chert (derived from Paleozoic formations) and volcanic material (presumably derived from the above-described Mount Wrightson Formation and similar rocks). The volcanic rocks in the red-bed unit are generally pale reddish-purple, finely porphyritic latite, dacite or andesite tuffs, flows and breccias.

Somewhat similar and possibly equivalent units occur in the Empire Mountains, in the Mustang Mountains, in the northern end of the Santa Rita Mountains and on the west and southwest flanks of the Sierrita Mountains. The Recreation Red Beds of Brown (1939) in the Tucson Mountains probably also represent the unit. The Walnut Gap Volcanics of the Little Dragoon Mountains area (Cooper and Silver, 1964) contain red beds which are provisionally correlated with these rocks.

These possibly correlative units vary in proportions of components. Red beds are a very minor constituent of the Walnut Gap Volcanics, whereas no true volcanic rocks—only volcanic sediments—are present in the unit on the west side of the Sierritas. The rocks in the Empire and Tucson mountains are less massive than those in the Canelo Hills and in the Gardner Canyon Formation. The rocks of the northern end of the Santa Rita Mountains contain more sandstone, grit and conglomerate than siltstone.

The youngest of the major units of Triassic and Jurassic age, with a composite thickness in excess of 2,000 m, is the upper part of the Canelo Hills Volcanics. These rocks have been recognized only in the Canelo Hills and the west flank of the Huachuca Mountains. Probable equivalents occur in the Mustang Mountains, may be represented by the formation of Pacheco Ranch (Drewes and Cooper, 1973) on the west side of the Sierrita Mountains, and possibly are represented in the Patagonia, Santa Rita and Empire mountains. The upper member consists of silicic flows, tuffs and some clastic rocks. The rhyolitic lava resembles the flow-laminated volcanic rocks of the Mount Wrightson Formation, but field relations in the Canelo Hills indicate that it is younger than red beds whose clasts include flow-laminated rhyolitic rock. Radiometric dates also indicate that the upper part of the Canelo Hills Volcanics is younger than the volcanic rocks of the Mount Wrightson Formation.

Age

The Mount Wrightson Formation is considered to be older than the Gardner Canyon Formation on the basis of a lead-alpha age determination of 220 m.y. made for volcanic rock in the Mount Wrightson Formation (fig. 2) and on the fact that the Gardner Canyon Formation, which has yielded a considerably younger lead-alpha age (fig. 2), in places contains cobbles of flow-banded volcanic rock identical in appearance to that in the Mount Wrightson Formation. Furthermore, the Ox Frame Volcanics on the west side of the Sierrita Mountains, which we believe to be equivalent to the Mount Wrightson Formation, are in depositional contact with Paleozoic rocks and are overlain by beds of the Rodolfo Formation which are tentatively correlated with the Gardner Canyon Formation. The age of the Mount Wrightson Formation is further supported by the fact that monzonite that is intrusive into the formation has yielded a lead-alpha age of 184(±) m.y. The monzonite, in turn, was intruded by a granite that has been dated by the potassium-argon and lead-alpha methods as of Middle Jurassic age (fig. 2).

Red beds of the lower member of the Canelo Hills Volcanics are considered to be older than rocks of the upper member of the Canelo Hills Volcanics on the basis of field relations (Hayes and others, 1965) and of a still-younger radiometric age in the overlying volcanics that was determined by a potassium-argon date for biotite from welded tuff (fig. 2). A minimum age for the Recreation Red Beds, which we correlated with the red beds of the Canelo Hills Volcanics and the Gardner Canyon Formation, is indicated by a potassium-argon date of 150 m.y. for an andesite porphyry that has intruded the formation (Damon and others, 1967). In several areas, superposition of beds alone dates many of these rocks as post-Early Permian and pre-late Early Cretaceous; in the Santa Rita Mountains, inclusion of clasts of the Triassic Mount Wrightson Formation in the Gardner Canyon Formation show the Gardner Canyon to be Late Triassic or younger.

Jurassic-Cretaceous Unconformity

Jurassic plutonic activity was followed by pronounced uplift and deep erosion to produce the Jurassic-Cretaceous unconformity. This unconformity places Cretaceous rocks on Jurassic granite in the Santa Rita, Patagonia, Huachuca, Dragoon and Mule mountains, and on other Triassic and (or) Jurassic rocks in the Sierrita, Huachuca and Empire mountains, in the Dragoon Mountains area, and possibly in the Tucson Mountains. Relief on the unconformity is considerable in many areas; it amounts to hundreds of meters in the Mule Mountains, and is at least 300 m locally in the Santa Rita and Huachuca mountains. Arkosic conglomerate filling old canyons in those ranges is at least as coarse as the most recent piedmont gravel in the same areas.

Lower Cretaceous Rocks

During Early Cretaceous time two groups of rocks were deposited in the region: (1) an older relatively local group of volcanic and associated sedimentary rocks, and (2) a younger, widespread, thick group of sedimentary rocks, the Bisbee Group and its correlatives.

Volcanic and Associated Sedimentary Rocks

Volcanic and sedimentary rocks of the older group are the combined Temporal and Bathtub formations, each about 600 m thick, of the southeastern flank of the Santa Rita Mountains. Rocks similar in lithology and comparable in age to at least the youngest part of the sequence in the Santa Ritas occur in the Glance Conglomerate of the Bisbee Group (Hayes, 1971b) in the Huachuca Mountains. In the Santa Rita Mountains, these rocks consist of roughly equal amounts of epiclastic rock, rhyolitic tuffs and flows, and andesitic or dacitic volcanics. A minor unconformity separates the two formations there, and the basal part of each formation contains lenticular and locally very thick bodies of coarse conglomerate. Some of these conglomerates are arkoses derived wholly of detritus of Jurassic granite; others contain abundant Precambrian granitic rocks. Such deposits indicate the large amounts of local uplifting and presumably faulting that occurred between Middle Jurassic and earliest Cretaceous time.

The volcanic rocks are also highly lenticular. Some groups of andesitic flows or volcanic breccia as much as 300 m thick extend only 3 to 5 km. Most rhyolitic rock is tuff and tuff breccia, but some welded tuff and lava are present. The volcanic rocks are everywhere so intensely altered that radiometrically datable minerals are destroyed, and zircon sufficiently abundant to provide material for dating was found only in a tuff immediately overlying Jurassic granite. A Jurassic date determined thereon, while not impossible considering the large range of possible error assigned the results, is suspect because of the likelihood that the tuff flow could have picked up its zircon from granite grus over which it flowed.

In the Huachucas, this sequence of volcanic rocks and conglomerates rests unconformably on the Canelo Hills Volcanics, is apparently conformable with overlying rocks in the Bisbee Group, and thus is dated geologically as of probable Early Cretaceous age.

Bisbee Group and Correlative Rocks

Sedimentary rocks of Early Cretaceous age are widely distributed in southeastern Arizona (fig. 1) and are 3,000 m thick or more in some areas. Throughout the region they are made up largely of clastic sediments deposited in a subaerial environment, but rocks of marine origin make up a significant part of the sequence in the southeastern part of the region. Locally, thick conglomerates at the base of the sequence are dominantly fanglomerates. Most of the Lower Cretaceous strata, however, are believed to represent part of a large delta complex on the margin of a sea that existed to the southeast, mostly in Mexico. In the northwest, marine rocks are supplanted by brackish-water facies and the continental rocks are more arkosic. For the purposes of this paper is is convenient to divide the region into southeastern, northeastern, southwestern, central and northwestern areas.

Southeastern area

In the Mule Mountains and Huachuca Mountains (Hayes, 1970b), all of the Lower Cretaceous strata are assigned to the Bisbee Group, which is made up of four formations: the Glance Conglomerate at the base, the Morita Formation, the Mural Limestone, and the Cintura Formation. The Morita and Cintura Formations are made up mostly of repeated sequences of pinkish-gray, arkosic, cross-laminated sandstones that grade upward into massive grayish-red siltstones and mudstones. The Mural Limestone is a fossiliferous marine unit. The Bisbee Group is as much as 1,700 m thick in the Mule Mountains and ranges from nearly 1,800 m to about 3,000 m thick in the Huach ucas.

In the Pedregosa and southern Chiricahua mountains, the Bisbee Formation is about 2,400 m thick and is divisible into four units that, except for the greater prevalence of marine rocks, are roughly comparable to the formations in the Mule Mountains (Epis, 1952).

Northwestern area

In the Dragoon (Gilluly, 1956), Little Dragoon (Cooper and Silver, 1965), and Dos Cabezas (Sabins, 1957) mountains, no significant marine units are present and the Bisbee can be treated as a formation similar in lithology to the Morita and Cintura Formations of the Mule Mountains; a distinct basal conglomerate member is generally present. The formation may be more than 4,500 m thick at one locality in the Dragoon Mountains.

Southwestern area

About 1,000 m of rocks assigned to the Bisbee Formation are present in the Patagonia Mountains (Simons, 1972). Bisbee-like rocks are also present in ranges to the west of the Patagonias.

Central area

Rocks that are correlative in large part with the Bisbee Group of the Mule Mountains are present in the Whetstone Mountains and were called the Bisbee(?) Formation by Creasey (1967). The sequence there is at least 2,000 m thick and may be hundreds of meters thicker; it was divided into four stratigraphically distinct subunits by Tyrrell (1957) and Schafroth (1968). The four units in ascending order are the Willow Canyon, Apache Canyon, Shellenberger Canyon and Turney Ranch formations. Schafroth (1968) and Hayes (1970a) correlated the Willow Canyon Formation with the Morita Formation, the Apache Canyon Formation with the Mural Limestone, and the Shellenberger Canyon Formation with the Cintura Formation; the Turney Ranch Formation was considered to be younger than the Cintura. The rocks of the Whetstone Mountains are generally similar to those in the Mule Mountains but apparently represent a more landward facies. Marine limestone is rare, but thin-bedded limestone of fresh- to brackish-water origin is relatively abundant in the Apache Canyon Formation. Much of the sandstone in the Whetstones is more arkosic than to the southeast.

The Lower Cretaceous sequence in the Empire Mountains (Finnell, 1971) and in the northern part of the Santa Rita Mountains (Drewes, 1971) is similar to that in the Whetstones, and the same subunits are recognizable. In the northern part of the Empires, the basal hundreds of meters of the sequence is in apparent onlap relations with what T. L. Finnell (oral commun., 1967) believes was a rising highland of Precambrian rock (see Bilodeau, this guidebook).

Northwestern area

Hundreds of meters of strata in the Tucson Mountains in the Amole Arkose of Brown (1939) are very similar to Lower Cretaceous strata of the Whetstone, Empire and northern Santa Rita mountains and are undoubtedly general correlatives. Rocks similar to the Amole Arkose are present in the Angelica Arkose of the Sierrita Mountains (Cooper, 1971) and in the Cocoraque Formation of the Roskruge Mountains (Heindl, 1965).

Age

Collections of marine invertebrates from the Mural Limestone in and near the Mule Mountains and reported on by T. W. Stanton *(in* Ransome, 1904), Stoyanow (1949), J. B. Reeside, Jr. *(in* Gilluly, 1956) and Douglass (1960) strongly indicate a correlation of the Mural with the Trinity Group of Texas. Fossils collected by Stoyanow (1949) and during our studies from the Mural in the Huachuca Mountains also indicate a Trinity age, as do fossils from limestones in the Bisbee Group in the Pedregosa Mountains. The entire Bisbee Group in those areas may represent much of Aptian and Albian time. Fossils reported by Tyrrell (1957) in the Whetstone Mountains and by Stoyanow (1949) in the Patagonia Mountains also suggest an Albian age. Fossils collected by Brown (1939) and Kinnison (1958) from the Amole Arkose in the Tucson Mountains are not as definitive; correlation in part, if not all, of that formation with the similar strata of the Whetstones is done on the basis of lithology.

Mid to Late Cretaceous Unconformity

Uplift and erosion again followed deposition of the Bisbee Group and equivalent rocks. A mid- to Late Cretaceous unconformity has been described in southeastern Arizona by Darton (1925), Epis (1952) and Gilluly (1956). Such an unconformity is demonstrable in the Santa Rita, Huachuca and Pedregosa mountains and in the Canelo Hills, where sedimentary rocks of Late Cretaceous age overlie the Bisbee and contain fragments of Bisbee, gently truncate some beds at the top of the Bisbee, or truncate faults in the Bisbee. In other areas, Upper Cretaceous volcanic rocks overlie gently to isoclinally folded Lower Cretaceous rocks.

In many areas the relief of the mid to Late Cretaceous unconformity is not large, for little of the upper part of the Bisbee, as it is known in the type section, is missing. In other areas, however, as in the Serrita Mountains, rocks of Jurassic and probably Triassic age underlie Upper Cretaceous volcanic rocks (Cooper, 1971). Similarly, at the north end of the Empire Mountains, Upper Cretaceous volcanic rocks overlie rocks assigned to the Precambrian (Finnell, 1971). Inasmuch as Upper Cretaceous basal conglomerates in many places contain clasts identifiable as having been derived from Triassic, Jurassic and even Paleozoic rocks, other areas probably exist, that are either not exposed or not yet discovered, in which Lower Cretaceous rocks had been removed before Upper Cretaceous rocks were deposited.

Upper Cretaceous Rocks

Lower Sedimentary Sequence

Sedimentary rocks of Late Cretaceous age lie with slight (and local?) angular unconformity upon the Bisbee Group and lie with probable conformity beneath latest Cretaceous volcanic rocks in a few ranges in the region. This sequence of rocks, though locally of great thickness, is not as widely distributed as are the Lower Cretaceous rocks or the Upper Cretaceous volcanic rocks.

The best known of these Upper Cretaceous sedimentary rocks are included in the Fort Crittenden Formation of the east side of the Santa Rita Mountains (Drewes, 1971). At the base of the sequence there, unconformable with the underlying Bisbee Group, is a lenticular conglomerate made up dominantly of well-rounded cobbles of lower Mesozoic volcanic and sedimentary rocks. Above this is a 160-m-thick sequence of gray shale and subordinate siltstone in which are found a varied fauna including fresh-water mollusks, fish, turtles and dinosaurs of Santonian to Maestrichtian Age (Miller, 1964). Above this fossiliferous shale unit in the Adobe Canyon area is more than 1,800 m of variable grayish-red and brown conglomerate, arkosic sandstone and subordinate shale. High in the unit are several thin rhyolitic tuff beds.

The Fort Crittenden Formation also overlies the Bisbee Group on the west side of the Huachuca Mountains. Locally conglomerates are dominant in the basal 180 m of the unit. These are overlain by a sequence, at least 210 m thick, of shale and graywacke that contains fresh-water mollusks similar to those in the shale and sandstone of the Santa Rita Mountains.

Discontinuous exposures of the Fort Crittenden Formation extend for several kilometers along the northeast side of the Canelo Hills. There conglomerates similar to those in the upper part of the Fort Crittenden Formation of the Santa Ritas overlie the shale and siltstone member. On the southwest side of the Canelo Hills, beds of sandstone, conglomerate, shale and minor tuff are overlain by Upper Cretaceous andesite breccia. These may represent the top of the Fort Crittenden Formation.

In the Rucker Canyon area of the Pedregosa and Chiricahua mountains, Epis (1952) described a sequence at least 1,200 m thick that consists dominantly of well-rounded conglomerates that rest unconformably on the Bisbee Group and appear to grade up into andesites. Those conglomerates, which are derived from the Bisbee and from Paleozoic formations, are undoubtedly roughly equivalent to the Fort Crittenden Formation.

Part of the Bisbee Formation as mapped by Gilluly (1956) between Courtland and South Pass in the Dragoon Mountains contains beds of volcanic-clast conglomerate and may also be correlative with the Fort Crittenden Formation.

Local thin conglomerate units at the base of the Tucson Mountain Chaos of Kinnison (1959) occur in a similar stratigraphic position in the Tucson Mountains and are here considered as possible equivalents to beds high in the Fort Crittenden Formation. Richard and Courtright (1960) have previously correlated the Tucson Mountain Chaos with thin conglomerate and breccia units that locally appear conformably beneath Upper Cretaceous andesites in the Empire Mountains and elsewhere in the region.

The Fort Crittenden Formation of the Huachuca and Santa Rita mountains is similar to, and was probably once coextensive with, dated Upper Cretaceous strata described by Taliaferro (1933) in the Cabullona area in Mexico, several kilometers southwest of Douglas, Arizona.

The presence of terrestrial vertebrates and fresh-water invertebrates, together with the character and distribution of the conglomerates and other sediments, suggests that the Fort Crittenden Formation and correlative strata were deposited locally in subaerial valleys cut on the Bisbee Formation or Group and older rocks after an orogenic episode. The principal drainage direction was probably southeastward toward the Late Cretaceous Mexican geosyncline.

Upper volcanic sequence

The youngest of the major units of Mesozoic rock consists of distinctive andesite to dacite breccia, rhyodacite tuff and welded tuff, and a little sedimentary rock, having a combined thickness of as much as 1,400 m. These rocks, the Salero Formation, conformably overlie the Fort Crittenden Formation in the Santa Rita Mountains (Drewes, 1971); volcanic strata in the Pedregosa Mountains (Epis, 1952) also conformably overlie rocks correlative with the Fort Crittenden Formation. In other areas, presumably old high areas between the major valleys in which the Fort Crittenden Formation and correlatives were deposited, the volcanic rocks unconformably overlie Lower Cretaceous or older rocks. Our regional correlations of these Upper Cretaceous volcanic units are basically similar to earlier correlations by Richard and Courtright (1960), although they considered the rocks to be of Tertiary age. Our chief contribution here is to briefly describe these rocks in areas not described by them (Richard and Courtright, 1960).

The Salero Formation of the Santa Rita Mountains contains a basal member of dacitic breccia and rhyodacitic welded tuff and a capping unit of sedimentary and tuffaceous rock. In ascending order, there is as much as 120 m of flows, 300 m of dacitic breccia, 360 m of rhyodacitic welded tuff and at least 650 m of sedimentary and tuffaceous rock. The dacitic breccia grades laterally into an arkose and arkosic conglomerate facies, where it overlies a rugged old erosion surface cut on granite. The fragments in the breccia are set in a matrix of pulverized dacitic material, and scattered throughout the dacitic debris are blocks of exotic material as much as 450 m across. Similar exotic blocks appear in a correlative andesitic or dacitic breccia in the Tucson Mountains, the Tucson Mountains Chaos. Similar breccias are characteristic of the Demetrie Volcanics in the Sierrita Mountains, volcanic rocks of Dove Canyon in the Canelo Hills (Simons, 1972), the lower parts of the Sugarloaf Quartz Latite and Bronco Volcanics of the Dragoon Mountains region (Gilluly, 1956), and andesites mapped by Epis (1952) in the Pedregosa Mountains. Such breccias are also present in the Empire Mountains (Finnell, 1971).

The overlying rhyodacite welded tuff of the Salero Formation is a brownish-gray to greenish-gray massive unit in which separate cooling units have not been recognized. It is a crystal tuff with abundant, commonly chloritized book biotite. Similar welded tuff forms the Cat Mountain Rhyolite of Brown (1939) in the Tucson Mountains. Nonwelded rhyolite tuff of the Red Boy Rhyolite in the Sierrita Mountains and the upper parts of the Sugarloaf Quartz Latite and Bronco Volcanics of the Dragoon Mountains region are probably equivalent. Tuff in a similar stratigraphic position also occurs in the Empire Mountains.

The lowest member of the Salero Formation seems to have few counterparts in the region. The uppermost member, however, underlies an area in the extreme southwestern part of the Santa Rita Mountains and is found in the Ruby quadrangle west of Nogales. The uppermost member consists of alternating tuffaceous sandstone, volcanic conglomerate, tuff breccia, agglomerate and some red beds, largely metamorphosed to hornfels by intrusives of late Late Cretaceous age.

Samples of these Upper Cretaceous volcanic rocks from the Tucson and Santa Rita mountains, Canelo Hills, and elsewhere have been dated using the potassium-argon method by Bikerman and Damon (1966) and by U.S. Geological Survey laboratory personnel (fig. 2). The dates obtained verify the inferred Late Cretaceous age of at least the volcanic rocks of the Salero Formation, which conformably rest on the Fort Crittenden Formation of known Late Cretaceous age.

The youngest Mesozoic rocks of the region are plutonic rocks, commonly diorite or granodiorite but including some coarse-grained quartz monzonite. Their emplacement was followed in the Paleocene and Eocene by intrusion of more quartz monzonite, granodiorite and, commonly, quartz latite porphyry, including many of the ore-associated bodies of the region.

SUMMARY

The Mesozoic history of southeastern Arizona was complex and varied. In Triassic and Early Jurassic time, the region experienced at least two periods of volcanic activity, apparently separated by a period of plutonism. A more widespread period of plutonism and uplift ensued in Middle Jurassic time. During Late Jurassic and earliest Cretaceous time, the region was subjected to erosion. After a brief period of local volcanic activity, the late Early Cretaceous sea advanced from the south and southeast and the region received deposition of a thick deltaic sequence. In early Late Cretaceous time, regional uplift and another phase of orogeny occurred. The resulting mountainous area was eroded and fluviatile sediments were deposited in valley areas tributary to the sea to the southeast. Widespread volcanic activity followed and was finally succeeded by another episode of plutonism at the end of the Cretaceous.

REFERENCES

Bikerman, Michael, and Damon, P. E., 1966, K/Ar chronology of the Tucson Mountains, Pima County, Arizona: Geol. Soc. America Bull., v. 77, p. 1225-1234.

Brown, W. H., 1939, The Tucson Mountains—An Arizona Basin Range type: Geol. Soc. America Bull., v. 50, p. 697-759.

Cooper, J. R., 1971, Mesozoic stratigraphy of the Sierrita Mountains, Pima County, Arizona: U.S. Geol. Survey Prof. Paper 658-D, 42 p.

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

Creasey, S. C., 1967, Geologic map of the Benson quadrangle, Cochise and Pima Counties, Arizona: U.S. Geol. Survey Misc. Inv. Map 1-470.

Damon, P. E., and others, 1967, Correlation and chronology of ore deposits and volcanic rocks; Annual progress report No. COO-689-76 to Research Division, United States Atomic Energy Commission: Unpublished report by Geochemical Section, Geochronology Laboratories, Tucson, Univ. Ariz., 82 p.

Darton, N. H., 1925, A resume of Arizona geology: Arizona Univ. Bull. 119, Geol. Ser., no. 3, 298 p.

Douglass, R. C., 1960, The foraminiferal genus Orbitolina in North America: U.S. Geol. Survey Prof. Paper 333, 50 p.

Drewes, Harald, 1971, Mesozoic stratigraphy of the Santa Rita Mountains, southeast of Tucson, Arizona: U.S. Geol. Survey Prof. Paper 658-C, 81 p.

Drewes, Harald, and Cooper, J. R., 1973, Reconnaissance geologic map of the west side of the Sierrita Mountains, Palo Alto Ranch quadrangle, Pima County, Arizona: U.S. Geol. Survey Misc. Field Stud. Map MF-538.

Epis, R. C., 1952, Geology of the Pedregosa Mountains, Cochise County, Arizona [Ph.D. dissertation] : Berkeley, Univ. California, 263 p.

Finnell, T. L., 1971, Preliminary geologic map of the Empire Mountains quadrangle, Pima County, Arizona: U.S. Geol. Survey Open-File Map, 2 sheets.

Gill, J. R., and Cobban, W. A., 1966, The Red Bird section of the Upper Cretaceous Pierre Shale in Wyoming: U.S. Geol. Survey Prof. Paper 393-A, 73 p.

Gilluly, James, 1956, General geology of central Cochise County, Arizona: U.S. Geol. Survey Prof. Paper 281, 169 p.

Hayes, P. T., 1970a, Cretaceous paleogeography of southeastern Arizona and adjacent areas: U.S. Geol. Survey Prof. Paper 658-B, 42 p.

1970b, Mesozoic stratigraphy of the Mule and Huachuca Mountains, Arizona: U.S. Geol. Survey Prof. Paper 658-A, 28 p.

Hayes, P. T., and Drewes, Harald, 1968, Mesozoic sedimentary and volcanic rocks of southeastern Arizona: Arizona Geol. Soc. Guidebook III, p. 49-58.

Hayes, P. T., and Raup, R. B., 1968, Geologic map of the Huachuca and Mustang Mountains, southeastern Arizona: U.S. Geol. Survey Misc. Inv. Map 1-509.

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

Heindl, L. A., 1965, Mesozoic formations in the Comobabi and Roskruge Mountains, Papago Indian Reservation, Arizona: U.S. Geol. Survey Bull. 1194-H, 15 p.

Holmes, Arthur, 1965, Principles of physical geology, 2d ed.: New York, The Ronald Press, 1288 p.

Kinnison, J. E., 1958, Geology and ore deposits of the southern section of the Amole mining district; Tucson Mountains, Pima County, Arizona [M.S. thesis] : Tucson, Univ. Ariz., 123 p.

---- 1959, Chaotic breccias in the Tucson Mountains, Arizona: Arizona Geol. Soc. Guidebook II, p. 48-57.

Miller, H. W., Jr., 1964, Cretaceous dinosaurian remains from southern Arizona: Jour. Palentology, v. 38, p. 378-384.

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

Richard, K. E., and Courtright, J. H., 1960, Some Cretaceous-Tertiary relationships in southeastern Arizona and New Mexico: Arizona Geol. Soc. Digest, v. 3, p. 1-7.

Sabins, F. F., Jr., 1957, Stratigraphic relations in Chiricahua and Dos Cabezas Mountains, Arizona: Am. Assoc. Petroleum Geologists Bull., v. 41, p. 466-510.

Schafroth, D. W., 1968, Stratigraphy of some Cretaceous formations of southeastern Arizona: Ariz. Geol. Soc. Guidebook III, p. 59-67.

Simons, F. S., 1972, Mesozoic stratigraphy of the Patagonia Mountains and adjoining areas: U.S. Geol. Survey Prof. Paper 658-E, 23 p.

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

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

Taliaferro, N. L., 1933, An occurrence of Upper Cretaceous sediments in northern Sonora, Mexico: Jour. Geology, v. 41, p. 12-37.

Tyrrell, W. W., Jr., 1957, Geology of the Whetstone Mountains area, Cochise and Pima Counties, Arizona [Ph.D. dissertation] : New Haven, Yale Univ., 171 p.

- Van Eysinga, F. W. B., 1975, Geological time table, 3rd ed.: