Cretaceous Paleogeography of Southeastern Arizona and Adjacent Areas

GEOLOGICAL SURVEY PROFESSIONAL PAPER 658-B

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By PHILIP T. HAYES

MESOZOIC STRATIGRAPHY IN SOUTHEASTERN ARIZONA

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Brief descriptions of local Cretaceous sequences—their correlation, interpretation, and economic potential

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1970

UNITED STATES DEPARTMENT OF THE INTERIOR

WALTER J. HICKEL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

Library of Congress catalog-card No. 74-607329

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 50 cents (paper cover)

CONTENTS

ILLUSTRATIONS

CRETACEOUS PALEOGEOGRAPHY OF SOUTHEASTERN ARIZONA AND ADJACENT AREAS

By PHILIP T. HAYES

ABSTRACT

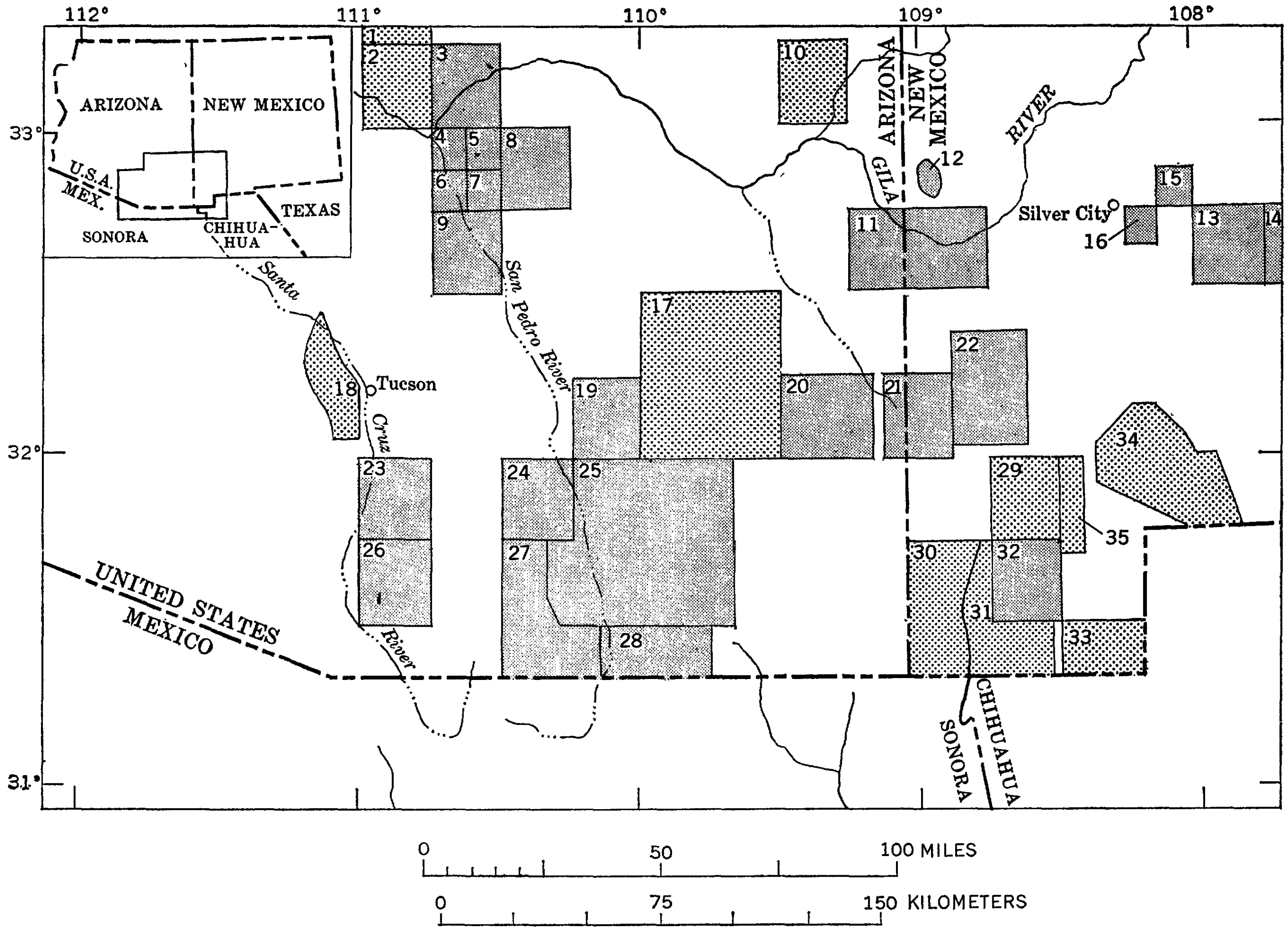
The surface geology and topography of the report region at the beginning of Cretaceous time were diverse. During early Early Cretaceous time, the region was shedding sediments southeastward toward a sea in Mexico, and some volcanic activity occurred in a part of southeastern Arizona. By early Aptian time, the sea had advanced northwestward nearly to Arizona, and the region became the locus of coastal-plain sedimentation. By Albian time, the sea had advanced into Arizona and may have made connection with Pacific waters across northern Sonora. Later in Albian time, this connection may have been broken, and prograding deltaic sedimentation pushed the sea southeastward out of Arizona. Near the end of Early Cretaceous time, general tilting of the region caused the seas to retreat from areas south of Arizona and to advance northward across much of New Mexico and westward into Arizona north of lat 32°30′ N. Compressional tectonism is late Turonian time made southeastern Arizona a mountainous source area for sediments transported northwestward to the sea. By early Campanian time, broad valleys in this mountainous area were receiving largely fluvial sediments from the surrounding mountains. The region was the scene of widespread volcanism in late Campanian and probably Maestrichtian time. This was followed by plutonism and tectonism of the Laramide orogeny at the end of the Cretaceous and beginning of the Tertiary.

This sequence of events is interpreted from the Cretaceous strata preserved in southeastern Arizona and adjacent areas and from the probable relations of these strata to Cretaceous strata of surrounding regions. The oldest Cretaceous rocks in southeastern Arizona are volcanics and associated sedimentary rocks assigned an early Early Cretaceous age. These are succeeded mostly south of lat 32° N. by the Bisbee Group and correlatives of late Early Cretaceous age—a thick sequence of rocks that is largely of marine origin toward the east and of continental origin toward the west. Strata of early Late Cretaceous age in Arizona are found only in areas north of about lat 32°30′ N. and are represented by the Pinkard Formation and correlatives of near-shore continental and marine origin. Upper Upper Cretaceous sedimentary rocks dominantly of fluvial origin, represented by the Fort Crittenden Formation and correlatives, are only locally present and are in unconformable relation with earlier Cretaceous strata. Conformably overlying these strata are the Salero Formation and correlatives made up dominantly of andesitic and rhyolitic volcanics.

Most Cretaceous strata in southeastern Arizona are only of modest economic value or potential, but the youngest are commonly altered and locally contain disseminated copper deposits. Limestones of the Bisbee Group are locally quarried, and some of them offer possibilities as reservoir rocks for oil and gas.

INTRODUCTION

Much new information on Cretaceous rocks and their relations to other rocks has been gathered in the past several years as a result of geologic mapping by the U.S. Geological Survey in twelve 15-minute quadrangles in the area south and southeast of Tucson, Ariz. This principal study area, which includes the Sierrita, Santa Rita, Empire, Whetstone, Patagonia, Huachuca, and Mule Mountains, was mapped by J. R. Cooper, S. C. Creasey, Harald Drewes, T. L. Finnell, E. R. Landis, R. B. Raup, F. S. Simons, and me (fig. 1). This work, supplemented by data from the literature and my observations on Cretaceous localities in nearby areas in Arizona, New Mexico, Sonora, and Chihuahua makes it possible for the first time to present a coherent, though very imperfect, history of Cretaceous events in southeastern Arizona and adjacent areas. The imperfection of the story is due to several factors: (1) although Cretaceous rocks crop out in most ranges in the region, these exposures are separated by much more extensive areas where Cretaceous rocks either have been removed by post-Cretaceous erosion or have been buried by younger deposits that, to date, have been virtually unpenetrated by drill holes; (2) Cretaceous rocks in many areas outside our area of mapping have been only superficially examined; (3) in many areas throughout the region, Cretaceous rocks have been faulted, folded, and, in places, altered to such an extent that they are particularly subject to misinterpretation; and (4) great thicknesses of the Cretaceous sequence in the region, particularly toward the west, are devoid of fossils that are useful for precise stratigraphic zonation. Some of these factors offer nearly in-



1. Ransome (1904)
2. Ransome (1923)
3. Willden (1964)
4. Krieger (1968d)
5. Krieger (1968a)
6. Krieger (1968c)
7. Krieger (1968b)
8. Simons (1964)
9. Creasey (1967a)
10. Lindgren (1905)
11. Morrison (1965)
12. Griggs and Wagner (1966)
13. Elston (1957)
14. Jicha (1954)
15. Jones, Hernon, and Moore (1967)
16. Pratt (1967)
17. Cooper (1960)
18. Brown (1939)
19. Cooper and Silver (1964)
20. Sabins (1957a)
21. Gillerman (1958)
22. Flege (1959)
23. Drewes (1970b)
24. Creasey (1967b)
25. Gilluly (1956)
26. Drewes (1970a)
27. Hayes and Raup (1968)
28. Hayes and Landis (1964)
29. Zeller (1958b)
30. Wrucke and Bromfield (1961)
31. Zeller (1962)
32. Zeller and Alper (1965)
33. Zeller (1958a)
34. Bromfield and Wrucke (1961)
35. Lasky (1947)

FIGURE 1.—Southeastern Arizona and adjacent areas, showing areas for which large-scale (1:62,500 or larger) geologic maps have been published. Shading indicates relatively recent detailed mapping; stippling indicates reconnaissance, preliminary, or relatively old mapping.

surmountable difficulties, but others will be overcome as new areas are studied in detail, as existing and newly developed methods of sedimentary analysis and correlation are applied to the rocks, and as drill holes penetrate Cretaceous rocks in areas where they are now covered by younger deposits.

In this report, my interpretations of the Cretaceous history of the region, illustrated by a series of paleogeographic maps, are presented first. The paleogeographic maps are drawn without regard to variously postulated large thrust or strike-slip displacements in the region in the belief that even if post-Cretaceous displacements measurable in tens of miles did occur, such displacements would only change the configuration of some features and would not invalidate the overall patterns presented. The paleogeographic interpretations are followed by a description of the regional stratigraphic framework that has evolved and upon which the paleogeographic interpretations are largely based. Following this are summary descriptions of Cretaceous rocks at many localities throughout the region that form the basis for the stratigraphic framework. In these descriptions are found most of the references to the numerous papers and unpublished data from which I have so freely drawn. At the end of the report are comments on the economic geology of Cretaceous strata in the region.

PALEOGEOGRAPHY

PRE-CRETACEOUS SURFACE

The surface geologic and topographic features of southeastern Arizona and adjacent areas at the end of the Jurassic Period and beginning of the Cretaceous Period were diverse (fig. 2). They resulted from Triassic and Jurassic faulting, plutonism, volcanism, and erosion in different parts of the region. Southeastern Arizona, in general, was positive late in Jurassic time and was a source area for sediments now represented by the Morrison Formation of northern Arizona (Harshbarger and others, 1957, p. 51–57). Southeastern Arizona probably also contributed sediments eastward to Chihuahua and western Texas to a seaway whose sediments are now preserved as the Malone Formation (Albritton and Smith, 1965, p. 37–38). Sediments from the region may also have been shed southwestward to western Sonora, where Upper Jurassic sedimentary rocks may still be preserved in the vicinity of El Antimonio (fig. 4). The topography in the southeastern

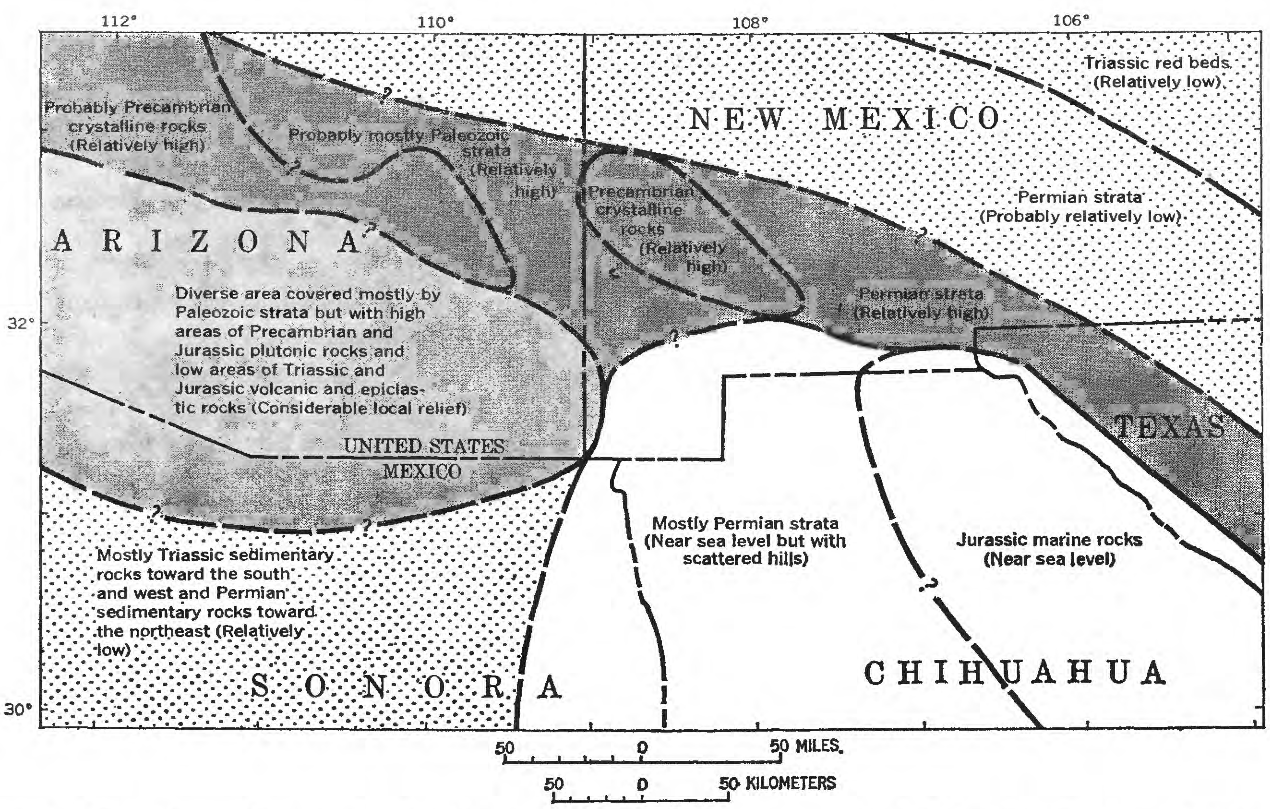


FIGURE 2.—Paleogeology and topography of southeastern Arizona and adjacent areas at end of Jurassic and beginning of Cretaceous time.

Arizona positive region was irregular, particularly toward the west. Local relief there, which was measurable in many hundreds or even thousands of feet, was controlled largely by the character and structure of the underlying rocks.

The rocks exposed at the beginning of Cretaceous time were greatly diverse in age and character (fig. 2). Over a large part of the region, gently tilted and little-faulted dominantly carbonate rocks of Permian age, which had been eroded into a gently rolling topography, were at the surface. In southernmost Arizona, however, there were many topographically low areas underlain by volcanic or epiclastic rocks of Triassic and Jurassic age and topographically high areas held up by plutonic rocks of the same ages or by uplifted blocks of older Paleozoic or Precambrian rocks. In western New Mexico between lat 32° and 33° N. there was a broad west-northwesterly trending upwarped area largely underlain by Precambrian granitic rocks. A similar high area can be postulated to the west in Arizona, but evidence for it is less compelling.

EARLY CRETACEOUS PALEOGEOGRAPHY

The positive area that existed in southeastern Arizona at the outset of the Cretaceous Period probably remained virtually unchanged through about the first half of Early Cretaceous time and continued to shed sediments southeastward to a seaway in Mexico. This seaway may have advanced from the Gulf of Mexico to northern Chihuahua by late Neocomian time (fig. 3*A*). At about this time in southeastern Arizona, there was local volcanic activity in the vicinity of the present Sierrita, Santa Rita, and Huachuca Mountains (fig. 4), as indicated by the presence of volcanics in the quartzite of Whitcomb Hill in the Sierrita Mountains area, in the Temporal and Bathtub Formations in the Santa Rita Mountains, and in the Glance Conglomerate in the Huachuca Mountains (fig. 5). Low areas in these ranges and probably elsewhere were the sites of fanglomerate deposition during the same general time interval.

By early Aptian time, the sea had advanced to a position closer to Arizona, and coastal-plain sediments were deposited in extreme southwestern New Mexico and extreme southeastern Arizona (fig. 3*B*). These sediments are preserved in the Hell-to-Finish Formation of Zeller (1965) in the Big Hatchet Mountains of New Mexico, in the basal part of the Howells Ridge Formation in the Little Hatchet Mountains of New Mexico, and in beds low in the Bisbee Formation or Group in several places in extreme southeastern Arizona (fig. 5). Farther west in southeastern Arizona, fanglomerate deposition, now represented in several ranges by the Glance Conglomerate, continued in valleys in foothill areas adjacent to the old mountainous area farther west. The Etholen Conglomerate and generally equivalent Torcer Formation of the Sierra Blanca area in western Texas (fig. 4) are interpreted by Albritton and Smith (1965, p. 45) to have been deposited near a shoreline and may have been deposited at about this same time of seaway expansion in early Aptian time.

Westward and to a lesser extent northward and probably eastward, general but irregular seaway expansion continued through Aptian time; and by the beginning of Albian time, the seaway may have made connection with Pacific waters across northern Sonora (fig. 3*C*). The general but irregular westward advance of the sea from southwestern New Mexico into southeastern Arizona is interpreted from correlations of rocks of the Bisbee Group and equivalents discussed on pages B9–B15 Marine limestones are much thicker in southwestern New Mexico than in southeastern Arizona and apparently occur at a stratigraphically lower position. That the sea may have made connection with Pacific waters, at least in late Aptian time, is indicated by the presence of fossils of Pacific affinities noted by Stoyanow (1949, p. 50–58) in rocks of Aptian age in the Mule Mountains area, and by the presence of Bisbee-like rocks of Aptian and Albian age as far west as the Santa Ana–Altar area (fig. 4) in Sonora (Popenoe and others, 1960, p. 1517–1518).

The maximum advance of the sea into southwestern Arizona occurred in early Albian time (fig. 3*C*). Marine waters then advanced as far west as the position of the present Patagonia Mountains and as far north as the northern part of the present Chiricahua Mountains (fig. 4). Flood-plain sediments probably of the same age were deposited as far northwest as the present Roskruge Mountains, but areas as far west as the present Vekol Mountains apparently remained slightly positive throughout Early Cretaceous time. Brackish-water sediments were deposited on the flood plain in areas as far northwest as the present Tucson Mountains. This is indicated by limestones that contain brackish-water fossils in the Amole Arkose of Brown (1939). (See fig. 5.) Even as late as early Albian time, mendip hills of older bedrock projected through the coastal-plain sediments in the vicinity of the present Whetstone and Empire Mountains. At this time of maximum advance, rudistid reefs and biostromes flourished in shallow off-shore waters in the vicinity of the present Mule Mountains and in areas to the east that extend into New Mexico. Fossil rudistid banks of the same age are preserved in the Campagrande Formation of the Sierra Blanca area of western Texas (Albritton and Smith, 1965, p. 62). Conglomerate and interbedded limestone mapped beneath the Cox Sandstone by King, King, and Knight (1945) in the Hueco Mountains northwest of the Sierra Blanca area may have been deposited near the shoreline of the early Albian sea.

By middle Albian time (as represented by rocks equivalent to the Fredericksburg Group of Texas), the sea had apparently retreated from southeastern Arizona and probably from western Sonora as well, but it seems to have remained briefly in southwestern New Mexico (fig. 3*D*), as indicated by marine fossils of probable Fredericksburg age near the top of the U-Bar Formation of Zeller (1965) (fig. 5). The Cintura Formation and equivalents in southeastern Arizona of this general age are interpreted to have been deposited on the subaerial part of a prograding delta. Later in middle Albian time, continental deltaic sedimentation extended across the New Mexico Pandhandle and is now represented by the lower parts of the Corbett Sandstone and the Mojado Formation of Zeller (1965). The regression of the sea from Arizona may have been due more to a slight northeastward tilting of the region than to a eustatic lowering sea of level. This is indicated by the fact that marine sediments of Fredericksburg age spread northward and eastward over areas in western Texas not covered by older Cretaceous marine sediments (Albritton and Smith, 1965).

General northeastward regional tilting continued into late Albian and early Cenomanian time (as represented by rocks equivalent to the Washita Group of Texas). By this time, sedimentation had apparently ceased altogether in southernmost Arizona and Sonora, and the seas spread over much of New Mexico and into eastern Arizona north of lat 32°30′ N. (fig. 3*E*). This latter transgression is represented by the Beartooth Quartzite and Colorado Formation and equivalents of New Mexico and by part of the Pinkard Formation of Arizona (fig. 5). Marine sedimentation resumed briefly during part of this time in southeastern New Mexico, as indicated by the presence of marine fossils of Washita age in the upper part of the Mojado Formation of Zeller (1965) in the Big Hatchet Mountains area.

During most of Turonian time (as represented by rocks equivalent to the Eagle Ford Shale of Texas), conditions presumably remained much as they were during late Albian and Cenomanian time, when seas covered much of New Mexico and northeastern Arizona while southeastern Arizona and Sonora remained emergent.

EARLY LATE CRETACEOUS DISTURBANCE

The first pulses of the Piman phase (Drewes, 1968) of the Laramide orogeny in southeastern Arizona took place sometime before mid-Late Cretaceous time. This disturbance consisted of compressional tectonism that, in the position of the present Huachuca Mountains (fig. 4), thrust faulted rocks of the Bisbee Group and, in the position of the present Empire Mountains and elsewhere, isoclinally folded those rocks into northwest-trending structures before the onset of deposition of the Fort Crittenden Formation and younger units.

The disturbance cannot be precisely dated. Although it could have taken place steadily or intermittently throughout Turonian, Coniacian, and Santonian time, I think it is more probable, on the basis of broad regional evidence, that the tectonism occurred largely or entirely in late Turonian time (fig. 3*F*). Mountains uplifted during the disturbance may thus have been the source for the detrital sediments of the Gallup Sandstone of late Turonian age, the basal formation of the Mesaverde Group, which spread far northeastward in northwestern New Mexico over lower Turonian marine shales. An unconformity described by Dane (1960, p. 53–55) at the base of beds of Niobrara age in northwestern New Mexico and southwestern Colorado indicated submarine erosion in that area in late Turonian time that may have been roughly coincident with tectonism in southeastern Arizona. Similarly, at many localities in western Texas, the top of the Eagle Ford Shale of Turonian age has been interpreted as a surface of subaerial erosion or marine planation (West Texas Geol. Soc. 1959, p. 37). Such a hiatus is also apparent in southern California where Turonian or younger rocks rest locally on rocks of Albian age but more commonly on rocks of Neocomian or older age (Popenoe, 1954).

LATE LATE CRETACEOUS PALEOGEOGRAPHY

After the tectonism of postulated late Turonian age, southeastern Arizona was an eroding mountainous area, and, probably through Coniacian, Santonian, and into Campanian time it was a prime source area for the continental sediments of the Mesaverde Group of New Mexico and northeastern Arizona (fig. 3*G*). Sediments probably also were shed east-southeastward during this time across a low plain toward western Texas and Chihuahua.

Early in late Campanian time, the seas made a last major advance toward southeastern Arizona owing either to a general subsidence of much of the Western United States and Mexico or to a eustatic change in sea level (fig. 3*H*). This advance is recorded in northwest-

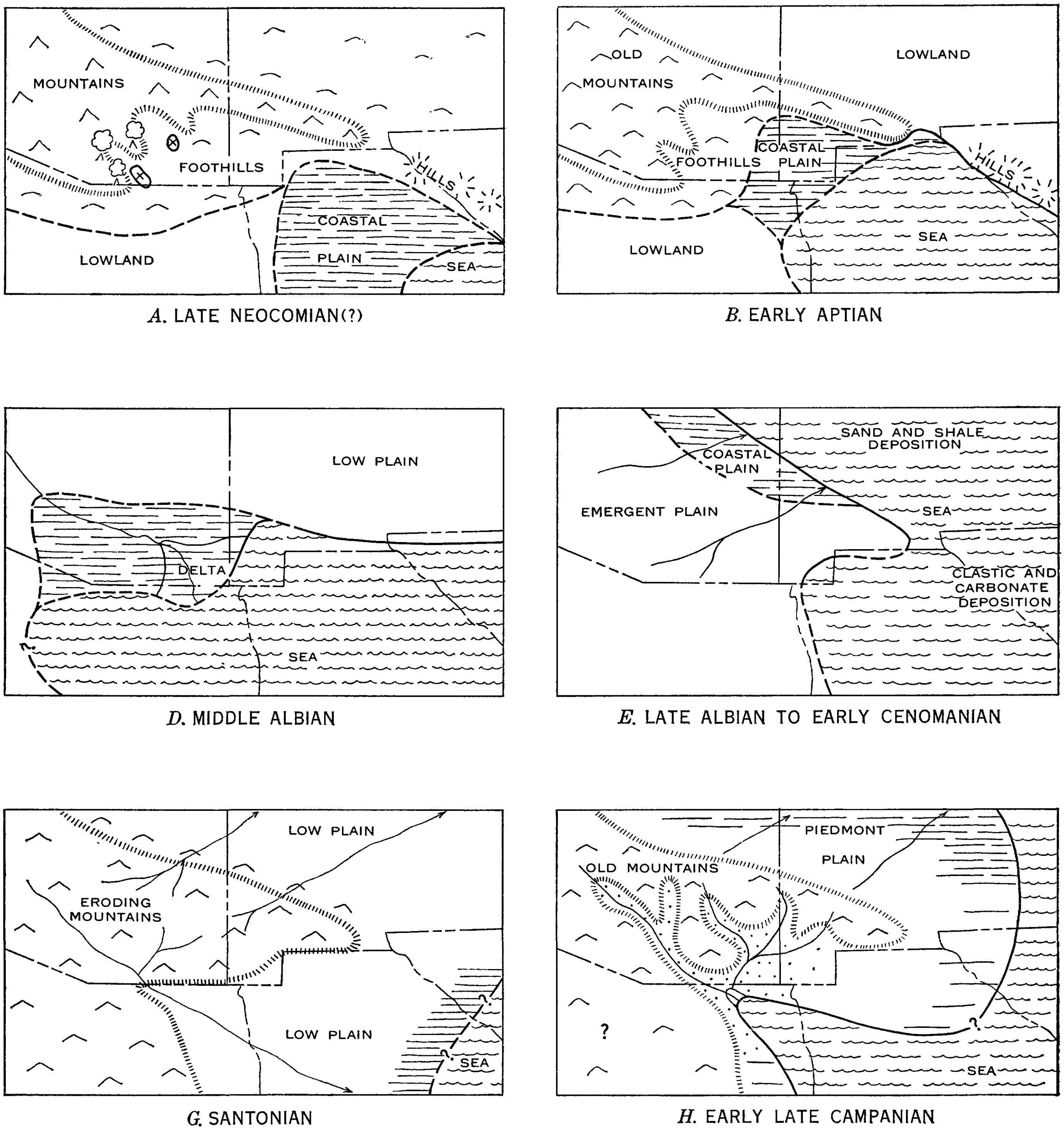
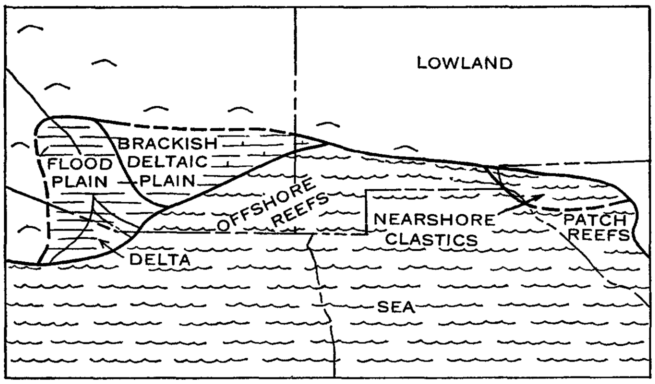
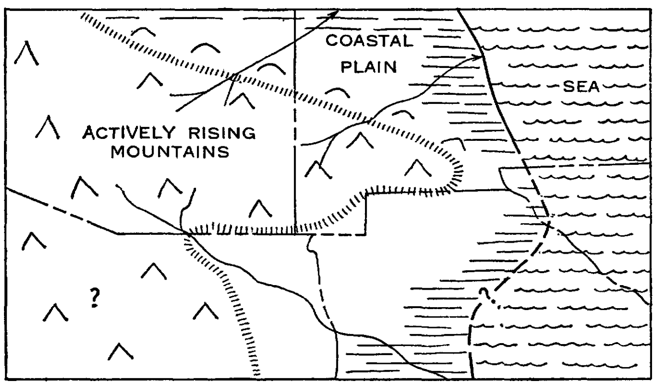


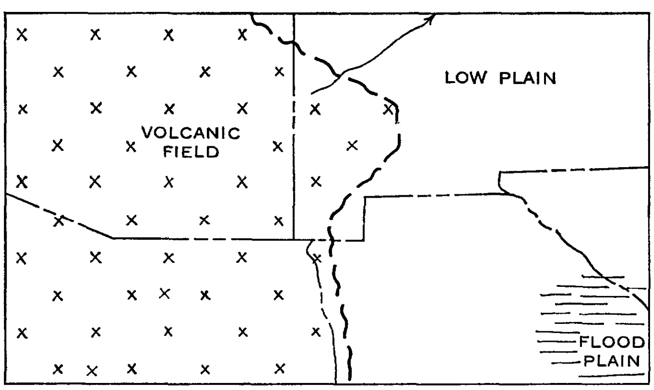
Figure 3.—Paleogeographic maps of southeastern Arizona and adjacent areas during the Cretaceous.



C. EARLY ALBIAN



F. LATE TURONIAN



I. LATEST CAMPANIAN

ern New Mexico by the Lewis Shale. A northwestward advance of the sea may have extended to the vicinity of the present Cabullona Basin in Sonora (fig. 4), where the Cabullona Group of Taliaferro (1933) (fig. 5) was deposited. This thick group of rocks, though largely of fluvial origin, contains fossils of brackish-water invertebrates that may have thrived in an estuarine environment. Broad but deep intermontane valleys in southeastern Arizona and southwesternmost New Mexico, tributary to the estuary, locally received great thicknesses of dominantly fluvial sediments ranging in composition from clays to conglomerates; intermittently, fanglomerates derived from bordering mountains were deposited in the valley areas. These valley sediments in Arizona and southwestern New Mexico are now represented by the Fort Crittenden Formation and its equivalents. Between the valley areas were low mountains that supplied sediment to the valleys and to the seas beyond.

Near the end of Campanian time, the seas once again receded far to the east; and southern Arizona, southwestern New Mexico, and much of Sonora became the scene of widespread volcanic activity (fig. 3*I*) which initiated the later stages of the Piman phase of the Laramide orogeny.

LATEST CRETACEOUS–EARLIEST TERTIARY OROGENY

The later stages of the Piman phase of the Laramide orogeny in southeastern Arizona and adjacent areas in late Campanian time were heralded by the extrusion of vast quantities of andesitic volcanics over a wide area (fig. 3*I*). This volcanism is recorded by the lower part of the Salero Formation and its many correlatives (fig. 5). Seismic activity accompanying the volcanism must have caused great slope instability in the remaining mountainous areas. This is indicated by megabreccias in several areas, as epitomized by the Tucson Mountain Chaos of Kinnison (1959) in the present Tucson Mountains (fig. 4). The volume of andesitic lavas extruded was so great that they may have once covered most areas of older bedrock. The extrusion of andesitic volcanics was followed, at least in areas west of long 110° W. by the explosive extrusion of great volumes of rhyolitic tuffs, as recorded by the upper part of the Salero Formation and its correlatives. In some areas, there was crustal deformation between the extrusion of the andesitic and rhyolitic volcanics. During this period of volcanism, southern Arizona and surrounding country was a source of the continental sediments preserved in the Fruitland and Kirtland Formations of northwestern New Mexico and in the upper part of the locally preserved Aguja Formation of western Texas and equivalents in Chihuahua.

During Maestrichtian time, mainly between 65 and 69 million years ago, the crustal rocks of southeastern Arizona and surrounding areas were intruded by numerous plutonic bodies, chiefly of diorite, granodiorite, and quartz monzonite. During this time, too, the area was a source for continental sediments deposited in areas far to the northeast and east. The end of Cretaceous time in southeastern Arizona was a time of

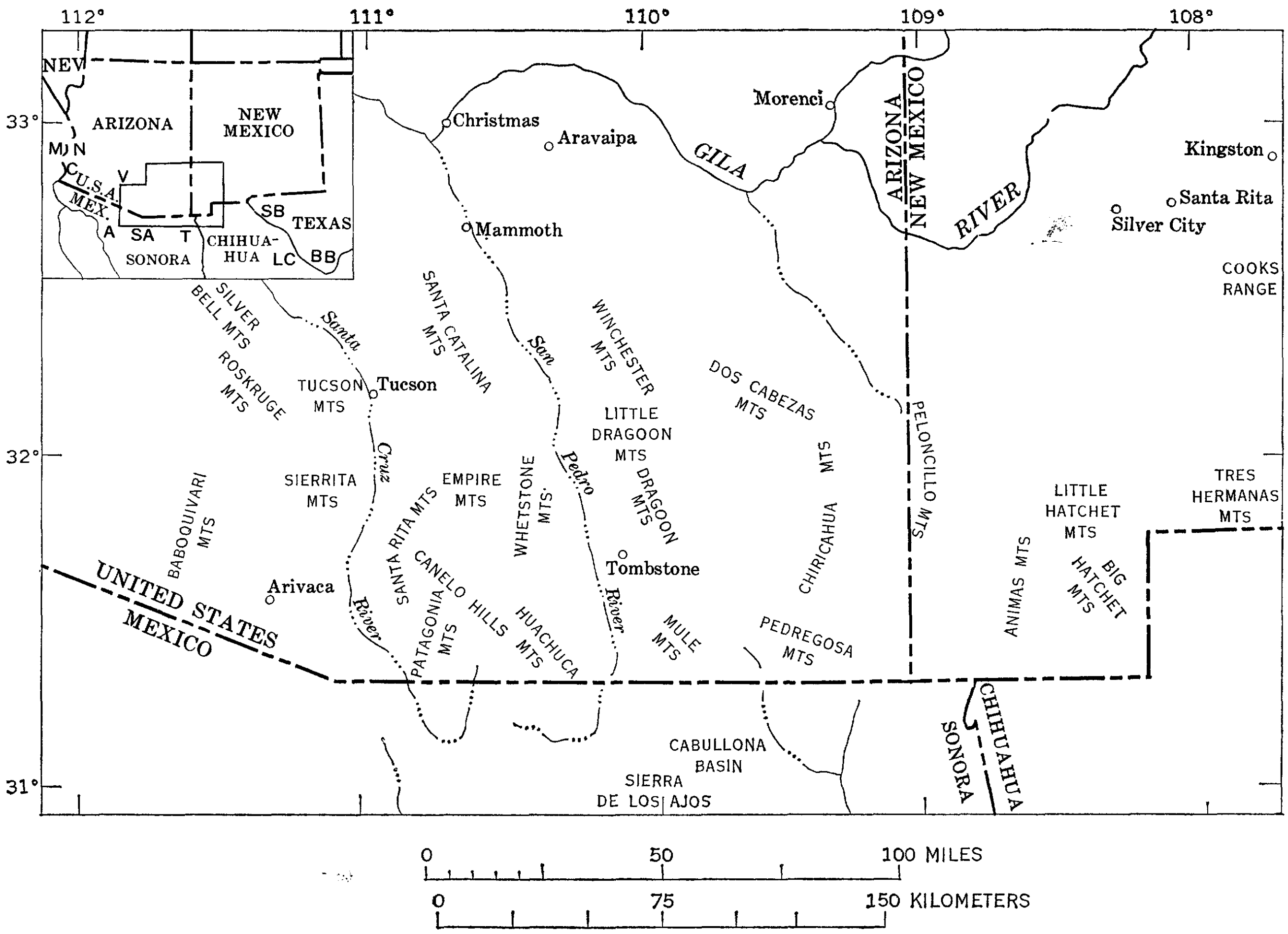


FIGURE 4.—Map of southeastern Arizona and adjacent areas, showing location of geographic features mentioned in text. Letters on inset map refer to localities in outlying regions: M, McCoy Mountains, Calif.; N, New Water Mountains, Ariz.; C, Castle Dome Mountains, Ariz.; V, Vekol Mountains, Ariz.; A, El Antimonio, Sonora; SA, Santa Ana–Altar area, Sonora; T, El Tigre, Sonora; SB, Sierra Blanca area, Texas; LC, Lower Rio Conchos area, Chihuahua; BB, Big Bend area, Texas.

relative quiescence in which there was local volcanic activity and sedimentary deposition in low areas prior to the onset of the Helvetian stage of the Laramide orogeny in early Tertiary time (Drewes, 1968).

REGIONAL STRATIGRAPHY

GEOLOGIC SETTING

Southeastern Arizona is a part of the Basin and Range physiographic province and as such is characterized by numerous elongate mountain ranges of widely variable structure and rock constituents separated by larger areas of intermontane valleys and basins. Exposures of rocks older than late Tertiary are mostly in the ranges, whereas late Tertiary and younger rocks are largely in intermontane basins.

The oldest rocks in the region are widely distributed metamorphic rocks of early Precambrian age generally assigned to the Pinal Schist; in many areas these were intruded by plutonic rocks, dominantly granite to quartz diorite, which are also early Precambrian. These crystalline rocks are locally overlain in the northern part of the region (but not in the southern part) by dominantly clastic sedimentary rocks assigned to the Apache Group and Troy Quartzite and by diabase—all of late Precambrian age.

Paleozoic rocks in the region, more than 1 mile (1,600 m) thick in some ranges, are nearly all sedimentary strata of marine-shelf origin. Cambrian, Devonian, Mississippian, Pennsylvanian, and Permian strata are present in ranges throughout the region; Ordovician strata are present only near the east edge of the region; and Silurian strata are not present anywhere in southeastern Arizona.

Pre-Cretaceous Mesozoic rocks of the region include volcanic, sedimentary, and plutonic rocks. Volcanic and associated sedimentary rocks, assigned to a number of local formations, occur only in the western part of the region, where they are locally distributed but are thousands of feet thick in places. Plutonic rocks ranging from granite to diorite are present in several ranges in the central and western parts of the region but are not known in the easternmost ranges.

Rocks younger than Cretaceous layered rocks include plutonic rocks of latest Cretaceous and early Cenozoic age, hypabyssal rocks of early and middle Cenozoic age, volcanics of early, middle, and late Cenozoic age, and continental sedimentary rocks of middle and late Cenozoic age.

Structural features of the region are of many ages and are diverse in character, but only those of Mesozoic and Cenozoic age that had an effect on the original distribution and character of Cretaceous rocks or that have since affected their distribution are of concern here.

The principal Triassic and Jurassic structural features are normal faults, some with displacements of thousands of feet. The largest of these has a west-northwest trend, but faults with other trends are known.

Structures of Late Cretaceous and early Cenozoic age are largely of compressional origin and include thrust and reverse faults, tear faults, and sharp folds. Trends are variable, but a majority of folds have northwest-trending axes.

The major middle and late Cenozoic structural features in the region are the large, generally northerly trending, range-front faults (now largely buried by later basin-fill deposits) that border the present ranges.

LOWER CRETACEOUS VOLCANICS

Volcanic rocks assigned an Early Cretaceous age are known in the area covered by this report (fig. 4) in and near three ranges—the Huachuca, Santa Rita, and Sierrita Mountains of southeastern Arizona. Unnamed volcanics that were tentatively assigned to the Lower Cretaceous by Gilluly (1956, p. 68–69) in the Dragoon Mountains of Arizona are here (p. B28) thought more likely to be of Triassic or Jurassic age, and a volcanic unit in the Little Hatchet Mountains of New Mexico that was assigned in Early Cretaceous age by Lasky (1947) is here (p. B31) considered to be of Late Cretaceous age. Lower Cretaceous volcanics may be present in the Baboquivari Mountains and elsewhere but have not yet been identified as such.

The volcanics of the region that are assigned an Early Cretaceous age are included in the Glance Conglomerate of the Bisbee Group in the Huachuca Mountains, in the Temporal and Bathtub Formations in the Santa Rita Mountains, and in the quartzite of Whitcomb Hill in the Sierrita Mountains area (fig. 5). None of the formations have been dated on the basis of radiometric or fossil evidence but have been assigned to the Lower Cretaceous on the basis of their relations to rocks of known age. Conglomerate beneath volcanics in both the Glance of the Huachucas and the Temporal of the Santa Ritas rests on surfaces of profound relief carved on granitic rocks as young as Jurassic, as determined on the basis of radiometric dating, and the quartzite of Whitcomb Hill rests with apparent disconformity on rocks assigned to the Triassic. The upper contact of the Glance volcanics of the Huachucas is parallel but may be disconformable. The overlying conglomerate grades upward into rocks known to be of late Early Cretaceous age. The Bathtub Formation, which overlies the Temporal Formation in the Santa Rita Mountains, is overlain with slight unconformity by the upper Lower Cretaceous Bisbee Group. The quartzite of Whitcomb Hill in the Sierrita Mountains area has a locally disconformable and locally gradational contact with the arkose of Angelica Wash which is assigned a late Early Cretaceous age. These relations all suggest a closer relation of these volcanic-bearing units to upper Lower Cretaceous rocks than to any of the Triassic or Jurassic rocks beneath them.

Although these volcanics of Early Cretaceous age all occur in a rather restricted part of southeastern Arizona and although it seems reasonable to assume that all were formed during the same general period of volcanism, the rocks are quite different in three ranges, and no specific correlations are implied. The volcanics in the Glance Conglomerate in the Huachucas are rhyodacitic lavas and flow breccias interbedded with conglomerates; the volcanics of the Temporal and Bathtub Formations include tuffs and lavas and range in composition from andesite to rhyolite; and the volcanics of the Whitcomb Hill unit are rhyolitic tuff lenses in predominant quartzite.

BISBEE GROUP AND CORRELATIVES

Rocks of late Early Cretaceous age that are referred to as the Bisbee Group (or Bisbee Formation where it has not been formally divided into units of formation rank) are present in southeastern Arizona, southwestern New Mexico, and northern Mexico between longs 108° and 111° W. and between lats 31°10′ and 32°30′ N. Rocks that are considered general time-stratigraphic correlatives of the Bisbee are not known to the north of the above-defined area but are present as much as 36 miles (58 km) to the west and much greater distances to the southwest, south, and east.

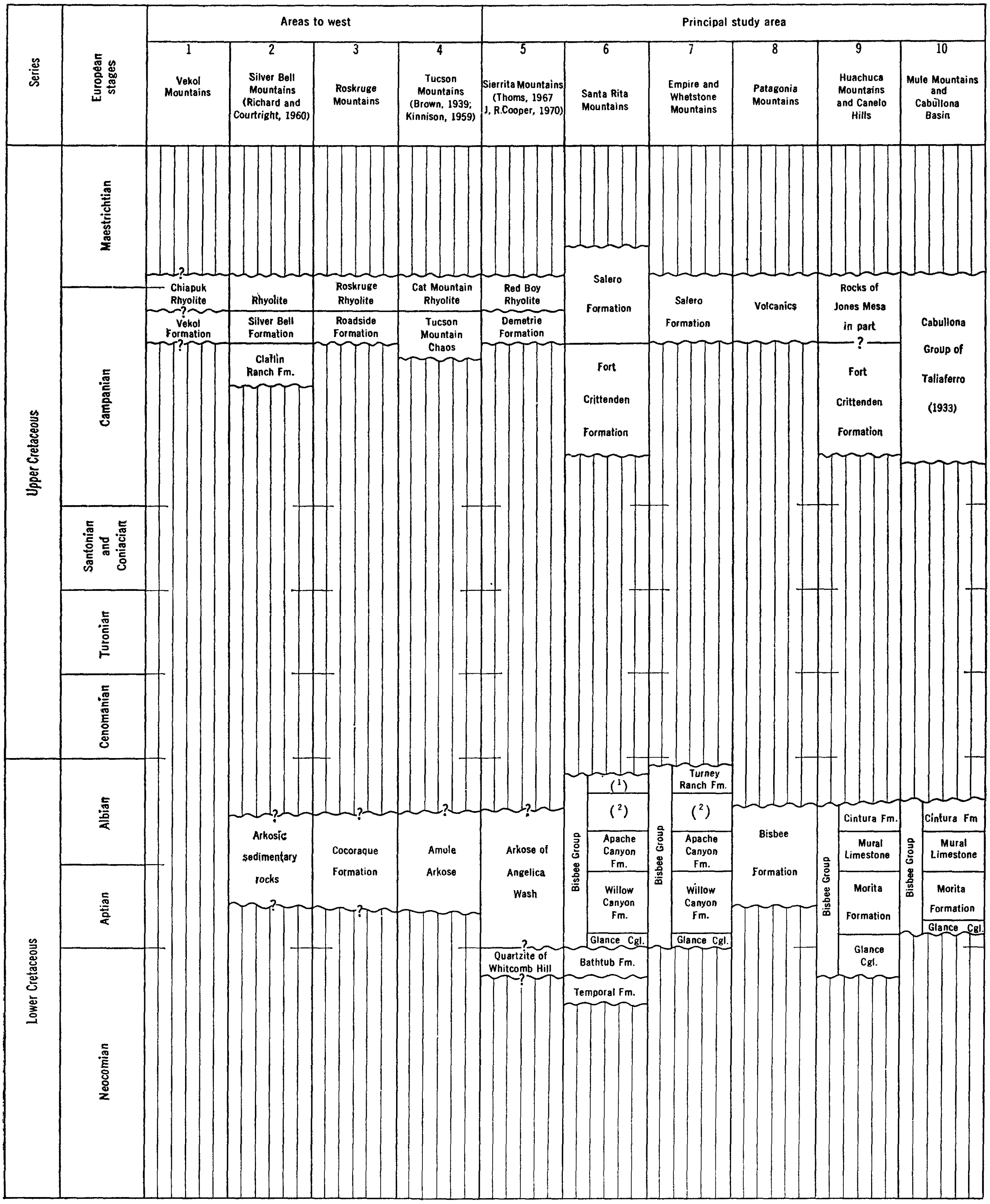
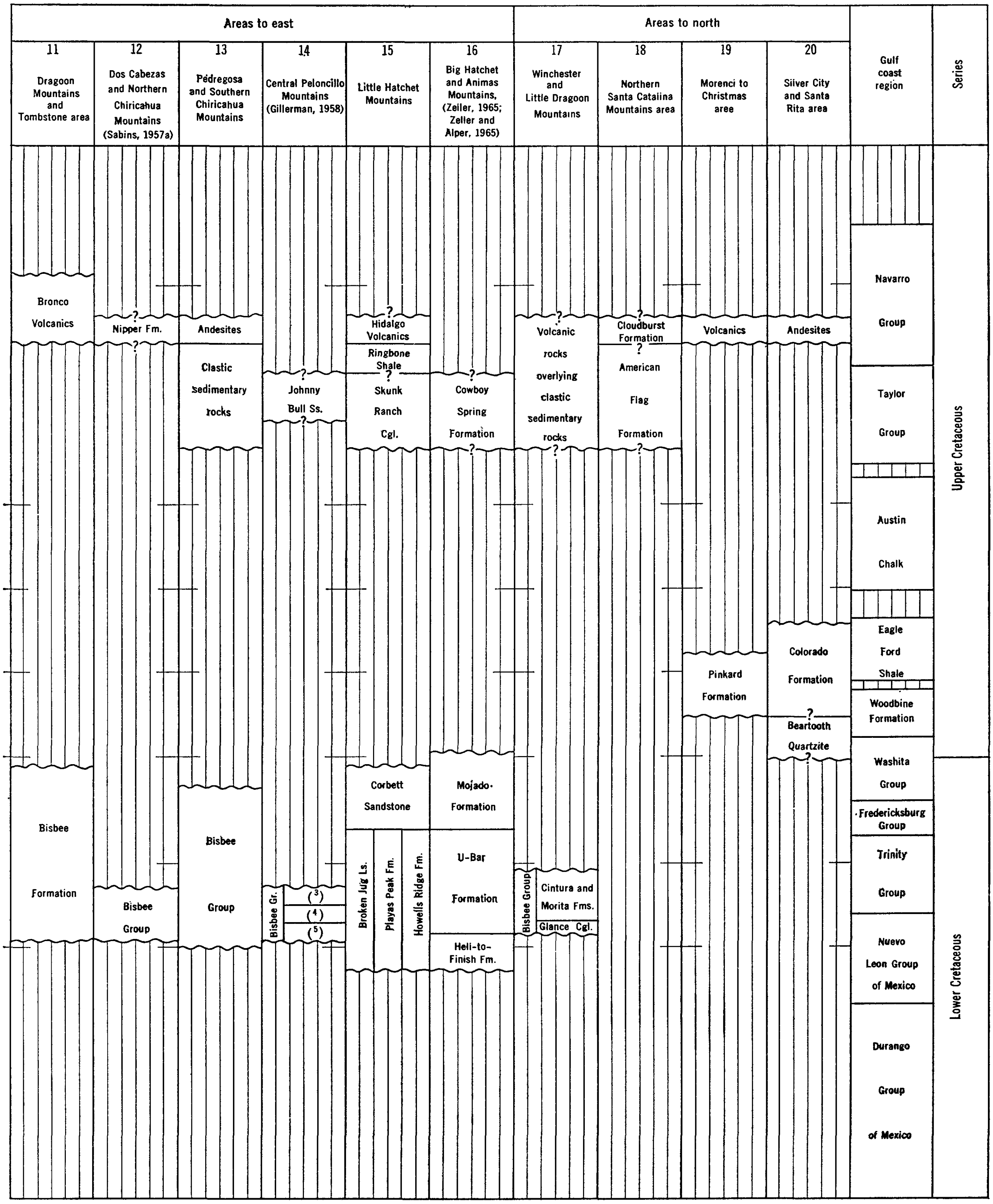


Figure 5.—Correlation chart of Cretaceous formations in southeastern Arizona and southwestern New Mexico, showing their inferred time relations with the European stages and with Cretaceous strata of the gulf coast region. Footnotes: (1) Turney



Ranch Formation, (2) Shellenberger Canyon Formation, (3) Still Ridge Formation, (4) Carbonate Hill Limestone, and (5) McGhee Peak Formation.

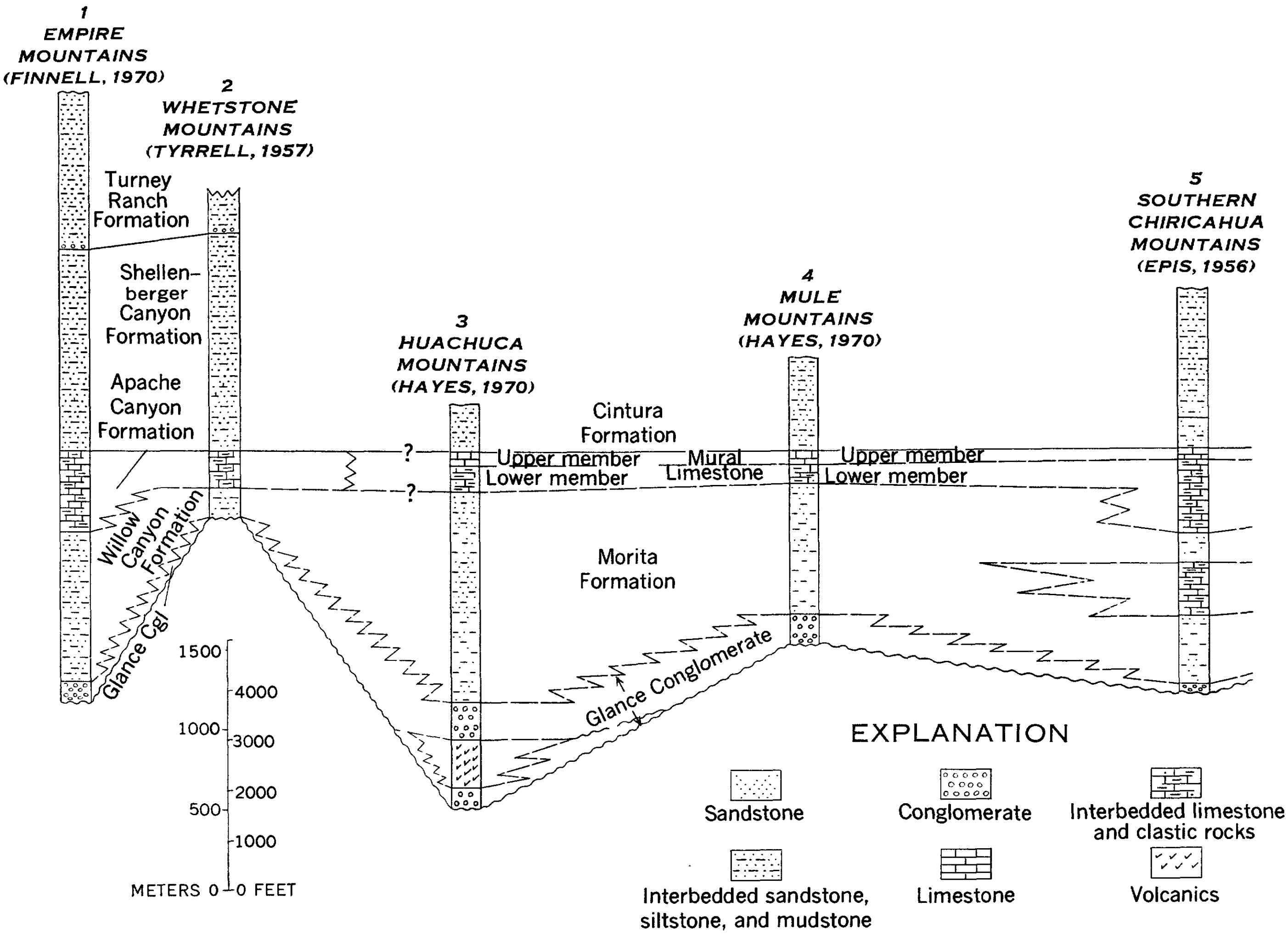


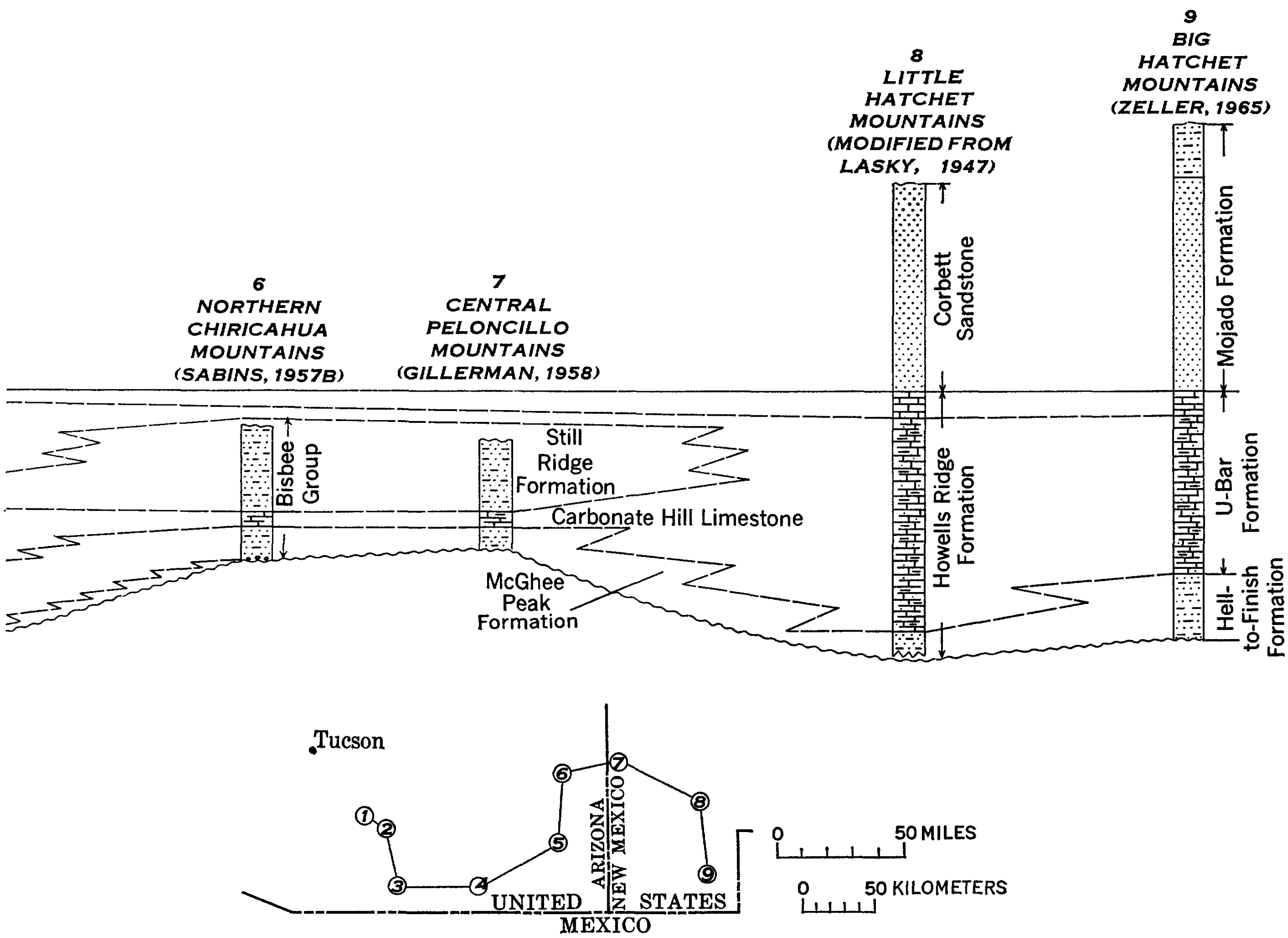
FIGURE 6.—Line of columnar sections, showing inferred correlations of rocks of Bisbee Age from the Empire Mountains, Ariz., to the Big Hatchet Mountains, N. Mex.

The thickness of the Bisbee is extremely variable both regionally and locally owing to the great local relief of the underlying surface and to the variable amounts of early Late Cretaceous erosion (fig. 6). It has a maximum known thickness of about 15,000 feet (4,500 m) in the Empire Mountains area and in the Dragoon Mountains (fig. 4), but it rarely exceeds 10,000 feet (3,000 m) in thickness in other areas.

The Bisbee changes markedly in facies from east to west and from south to north. In its southeasternmost outcrops, most of the lower half of the Bisbee is made up of relatively thick bedded and relatively pure limestones of marine origin, and much of the remainder of the Bisbee is made up of quartzose or slightly feldspathic sandstone interbedded with shales. But the proportion of limestone decreases westward, and the carbonates present in the northwesternmost sections are relatively thin bedded or platy and are generally silty or argillaceous. Sandstones in the group are increasingly feldspathic or arkosic westward.

Range-to-range correlation of lithologic divisions within the Bisbee can generally be no better than tentative. Better correlation is precluded partly by the virtual absence of diagnostic fossil species in western sections and the sparsity or absence of such fossils in thick parts of eastern sections, partly by regional facies changes and intertonguing, and partly by structural complexities that cause uncertainties in establishing the proper sequence in some areas. As a result of these difficulties, only one formational division name has been used in more than three ranges; many names have been used in a single range. Most of the correlations presented here must be considered tentative. They are based on the scant fossil data available, on lithology, and on known and interpreted trends in facies and thickness.

Conglomerate is present at the base of the Bisbee in nearly all areas. It is called the Glance Conglomer-



ate in most areas in Arizona where the Bisbee is of group rank (fig. 5). The thickness, age, and lithologic makeup of the conglomerate at the base of the Bisbee vary both locally and regionally (fig. 5). Local variations are due to the very irregular nature of the underlying surface, particularly in western areas. In some of these areas, the Glance Conglomerate may range in thickness from zero (over old topographic highs) to many hundreds or even thousands of feet within a few miles. Obviously the age of the conglomerate on or near the tops of high areas is somewhat younger than that deposited in intervening low areas. The thickness of conglomerate at the base of the Bisbee in eastern areas is rarely more than tens of feet.

Fortunately, one sequence of distinctive beds a few hundred feet thick in the middle part of the Bisbee of most areas appears to be widely correlative and forms at least a tentative basis for correlating beds above and below. The critical sequence is the upper member of the Mural Limestone in the Mule Mountains. This member consists dominantly of relatively thick bedded and relatively pure limestone which at several horizons is replete with species of the foraminifer *Orbitolina*; rudistid-rich bioherms and biostromes also are characteristic. Fossil evidence indicates that the member is correlative with the upper part of the Trinity Group and possibly with the lowest part of the Fredericksburg Group of Texas.

The Mural Limestone in the Mule Mountains is correlated with the *Orbitolina*-bearing Mural Limestone in the Huachuca Mountains to the west (fig. 6). Although of the same age there, the Mural in the Huachucas is somewhat thinner bedded, and the entire formation thins northward within the range.

Correlation of the upper member of the Mural Limestone in the Mule Mountains with rocks in the Pedregosa–southern Chiricahua Mountains area to the east (fig. 4) is less certain because in the latter area limestone units occur through several thousand feet of the Bisbee. However, only the highest few hundred feet of limestone in that area is relatively pure and thick bedded, is known to bear *Orbitolina*, and contains rudistid bioherms. On the basis of these facts, the highest few hundred feet of limestone in the Bisbee in the Pedregosa–southern Chiricahua area is correlated with the upper member of the Mural Limestone in the Mule Mountains. Lower limestones in the Pedregosa area are presumed to pinch out westward and to be time equivalents of nonmarine clastic beds in the Morita Formation in the Mule Mountains (fig. 6).

Farther eastward and northward in the northern Chiricahua Mountains and in the central Peloncillo Mountains are units made up of relatively impure and relatively thin bedded limestone. These units are only a few hundred feet above the base of the Bisbee and have not yielded *Orbitolina.* The limestone unit in the Peloncillos—the Carbonate Hill Limestone of Gillerman (1958)—has yielded a fauna of probable Aptian age and is thus apparently older than the upper member of the Mural Limestone. Both limestone units are probably correlative with limestone units low in the sequence in the southern Chiricahua Mountains area (fig. 6, cols. 5, 6, 7). Possibly sediments equivalent to the Mural Limestone were never deposited in the Peloncillo Mountains or northern Chiricahua Mountains areas, but it is equally possible that they were removed by erosion in early Late Cretaceous time.

Farther east, in the Little Hatchet and the Big Hatchet Mountains of New Mexico, limestone is the dominant lithology through several thousand feet of stratigraphic section. In the Big Hatchet Mountains, this thick limestone section makes up the U-Bar Formation of Zeller (1965). Beds in the upper several hundred feet of the U-Bar most closely resemble the upper member of the Mural Limestone in both age and lithology. The beds are thick to massive, contain rudistid bioherms, are *Orbitolina* bearing, and were considered by Zeller (1965, p. 66) to be of late Trinity and Fredericksburg(?) age. On the assumption that the upper few hundred feet of the U-Bar Formation of Zeller (1965) is approximately equivalent to the upper member of the Mural Limestone, the lower several thousand feet of the U-Bar, which is largely of Aptian age (Zeller, 1965, p. 66), would then be equivalent to most of the Morita Formation and the lower member of the Mural Limestone of the Mule Mountains (fig. 6). As explained in detail in a later section of this report (p. B31), the Howells Ridge Formation, Playas Peak Formation, and Broken Jug Limestone in the Little Hatchet Mountains probably are faulted repetitions of the same unit. These formations, like the U-Bar Formation of Zeller (1965), are very thick dominantly limestone units whose upper few hundred feet is characterized by thick-bedded to massive rudistid-bearing bioherms and *Orbitolina*-bearing beds. Because of their fossil content and lithology, these upper parts are correlated with the upper member of the Mural Limestone (fig. 6).

Correlation of the Mural Limestone northwestward with rocks of the Bisbee Group in the Whetstone, Empire, and Santa Rita Mountains is not certain. It is here considered likely that the Apache Canyon Formation in and near those ranges is correlative with the Mural Limestone (fig. 6). Limestone units in the Apache Canyon, in general, are much different from those in the Mural in that the Apache Canyon limestones are thin bedded to platy and argillaceous and have yielded brackish-water fossils. However, in its southernmost exposures in the Whetstone Mountains—the exposures closest to the Huachuca Mountains—limestone units in the Apache Canyon are relatively thick bedded. The northernmost exposures of Mural Limestone in the Huachuca Mountains contain thinner bedded limestone than is typical in exposures farther south. If this correlation is correct, the Morita Formation in the Mule and Huachuca Mountains must be a general correlative of the lithologically similar Willow Canyon Formation in the Whetstone, Empire, and Santa Rita Mountains (fig. 6).

The Mural Limestone apparently pinches out northward from the Mule Mountains. Thin beds of limestone having little resemblance to the Mural are present in the very thick Bisbee Formation in the Dragoon Mountains and in the undivided Morita and Cintura Formations in the Little Dragoon Mountains. These beds must be thin northwestward extensions of some of the many limestone beds present in the lower half of the Bisbee Formation in the Pedregosa–southern Chiricahua Mountains area, but no specific correlations are possible now.

Farther west, thin beds of fresh- or brackish-water limestone are present in the arkose of Angelica Wash in the Sierrita Mountains vicinity and in the Amole Arkose of Brown (1939) in the Tucson Mountains. The parts of those units in which limestone beds occur may be generally equivalent to the Apache Canyon Formation. The Cocoraque Formation in the Roskruge Mountains area, still farther west, is considered to be a general equivalent of the Amole Arkose but contains no limestone.

The Cintura Formation, which gradationally overlies the Mural Limestone in the Mule and Huachuca Mountains, is considered on the basis of stratigraphic position to correlate with the formations that gradationally overlie the units here correlated with the Mural Limestone. The Cintura is thus considered roughly correlative with the Mojado Formation of Zeller (1965) in the Big Hatchet Mountains area; with the Corbett Sandstone in the Little Hatchet

Mountains; with the Shellenberger Canyon Formation and possibly in part with the overlying Turney Ranch Formation in or near the Whetstone, Empire (see p. B22), and Santa Rita Mountains; and with the upper parts of the arkose of Angelica Wash in the Sierrita Mountains vicinity and the Amole Arkose of Brown (1939) in the Tucson Mountains (fig. 5).

All these units that are considered correlative with the Cintura Formation consist mostly of interbedded sandstone, siltstone, and shale or mudstone; most contain thin impure limestone beds in their lower parts. The sandstone units are typically in channel relation with underlying siltstone or mudstone; most of them are cross-laminated and grade upward into finer beds. The sequence is interpreted to represent dominantly fluviatile deposits of the subaerial portion of a delta that prograded eastward over the Mural Limestone and its correlatives. Beds of marine origin near the top of the Mojado Formation of Zeller (1965) in the Big Hatchet Mountains may represent a minor westward transgression of the seas that did not extend far west of the area in the present Big Hatchet Mountains. Rocks in western Texas of Fredericksburg and early Washita age that are general equivalents of the Cintura Formation are of marine origin.

The clastic sediments preserved in the Bisbee probably were derived primarily from western source areas and secondarily from northern and local source areas. This concept follows naturally from the conclusion that the seas represented by marine limestones of the Bisbee transgressed from the southeast, and it is supported by the westward change in composition of sandstones in the group. Little petrographic work has been done on sandstones of the Bisbee in New Mexico, but sandstone beds of the Mojado Formation in the Big Hatchet Mountains area are dominantly quartzose, and a few are slightly feldspathic (Zeller, 1965, p. 68). Sandstones of the Corbett Sandstone of the Little Hatchet Mountains are similar. To the west in the Mule and Huachuca Mountains, the average feldspar content of 42 samples examined in thin section exceeds 11 percent; most samples are feldspathic sandstone or subarkose according to the classification of Pettijohn (1957, p. 291). The average feldspar content of eight samples from the Bisbee in the Santa Rita Mountains exceeds 23 percent, and the average of nine samples from the arkose of Angelica Wash in the Sierrita Mountains vicinity, farther west, is about 27 percent. Most samples from the Angelica Wash strata are classifiable as true arkoses. The percentage of rock fragments and fine detrital matrix in the Bisbee sandstones also tends to increase westward.

The total age range of the rocks of the Bisbee Group is uncertain because the lowest and highest parts of the sequence are barren of closely datable fossils. However, on the basis of fairly reliable age assignments for the middle part of the group and lithologic correlations with the more completely dated Cretaceous rocks of the Big Hatchet Mountains, an approximation can be made for the total age range of the Bisbee in most areas. In the type area of the Bisbee Group in the Mule Mountains, fossil evidence indicates that rocks in the Morita Formation about 600 feet (180 m) below the Mural Limestone are equivalent to strata in the lower part of the Trinity Group of Texas, that the Aptian-Albian boundary is in the lower part of the lower member of the Mural Limestone, and that the uppermost part of the Mural Limestone is of late Trinity age or may be as young as the Fredericksburg Group of Texas (p. B18). The Carbonate Hill Limestone of Gillerman (1958) in the central part of the Peloncillo Mountains, which is here correlated approximately with strata in the lower part of the Morita Formation, has yielded a fauna of Aptian age (p. B29). Fossils from the U-Bar Formation of Zeller (1965) in the Big Hatchet Mountains area indicate that strata within 1,200 feet (360 m) of the base of the formation are of Trinity age, that the Aptian-Albian boundary is roughly 1,000 feet (300 m) below the top of the formation, and that the uppermost part of the U-Bar may be as young as the Fredericksburg Group of Texas (Zeller, 1965, p. 64–66). Fossils from the upper 1,086 feet (332 m) of the Mojado Formation of Zeller (1965) in the Big Hatchet Mountains area indicate a middle or late Washita (of Texas) age. From these faunal data and the regional lithologic correlations made in this report, it seems probable that the Bisbee Group represents most of Aptian and Albian time. It is possible, of course, that rocks high in the Bisbee Group in western areas, such as the Turney Ranch Formation in or near the Whetstone, Empire, and Santa Rita Mountains, are as young as early Late Cretaceous and that lowest rocks of the Bisbee in some areas may be as old as the Neocomian.

PINKARD FORMATION AND CORRELATIVES

Strata of early Late Cretaceous age, generally referred to the Pinkard Formation, unconformably overlie Paleozoic rocks in areas north of lat 32°55′ N. in southeastern Arizona. Strata of similar age and lithology in southwestern New Mexico north of lat 32°20′ N. are referred to the Colorado Formation. The Colorado Formation overlies the Beartooth Quartzite (or probable equivalents of earliest Late Cretaceous age or possibly of latest Early Cretaceous age) with apparent conformity, and it overlies Paleozoic or Precambrian rocks unconformably.

The Pinkard and Colorado Formations are distinctly different in lithology from any Cretaceous strata farther south in southeastern Arizona and probably have no age equivalents there (fig. 5). They are made up chiefly of sandstones and shales of shallow-water marine origin but include some continental coastal-plain and lagoonal sediments. Fossils from these formations indicate that they are age equivalents of the Graneros Shale and Greenhorn Limestone in southeastern Colorado and thus are roughly equivalent to the lower part of the Mancos Shale in northwestern New Mexico and northeastern Arizona (Cobban and Reeside, 1952). The Pinkard and Colorado Formations apparently represent rocks near the southwestern wedge edge of the thick Upper Cretaceous sequence of the western interior of North America and have little relation to Cretaceous rocks farther south.

FORT CRITTENDEN FORMATION AND CORRELATIVES

The Fort Crittenden Formation, of late Late Cretaceous age, occurs only in the Santa Rita Mountains–Canelo Hills–Huachuca Mountains (fig. 4) area. It is as much as thousands of feet thick and consists dominantly of conglomerate, sandstone, and shale of continental origin but includes thin tuff beds in its upper part. The formation unconformably overlies folded and faulted strata of the Bisbee Group and is overlain with apparent conformity by the dominantly volcanic Salero Formation. On the basis of vertebrate and nonmarine invertebrate fossils and apparently conformable relations with the overlying radiometrically dated volcanics of the Salero Formation, the Fort Crittenden Formation is presumed to be of early Campanian age. Rocks of the Fort Crittenden appear to be dominantly of fluvial origin but may include some beds deposited in lakes and marshes.

The Fort Crittenden probably is equivalent to part or all of the Cabullona Group of Taliaferro (1933) in the Cabullona Basin area of Sonora, Mexico. Rocks of this group, which have yielded dinosaur bones of Late Cretaceous age, are similar in general to rocks of the Fort Crittenden, but rocks of the Cabullona Group contain proportionately much less conglomerate and more sandstone and shale (p. B18). My interpretation is that the Fort Crittenden Formation and the Cabullona Group of Taliaferro (1933) were once coextensive and that the Cabullona Group was deposited farther from the source area.

Rocks lithologically similar to parts of the Fort Crittenden Formation occur with apparently conformable relations beneath probable Upper Cretaceous volcanics in several other areas in southeastern Arizona and southwestern New Mexico. These include the Claflin Ranch Formation of Richard and Courtright (1960) in the Silver Bell Mountains area, the American Flag Formation in the northern part of the Santa Catalina Mountains, the Ringbone Shale in the Little Hatchet Mountains area, and unnamed units in the southern part of the Winchester Mountains and in the Pedregosa–southern Chiricahua Mountains area. All these units are considered to be roughly correlative with the Fort Crittenden.

Two additional rock units that have been included as upper formations of the Bisbee Group, but which are here considered as likely general equivalents of the Fort Crittenden Formation, are the Johnny Bull Sandstone of Gillerman (1958) in the central Peloncillo Mountains and Skunk Ranch Conglomerate in the Little Hatchet Mountains area. Neither formation is overlain by Upper Cretaceous volcanics, but both seem to be lithologically more similar to the Fort Crittenden Formation than to underlying parts of the Bisbee Group. The Skunk Ranch Conglomerate has a disconformable basal contact, but the basal contact of the Johnny Bull Sandstone appears to be conformable.

The Cowboy Spring Formation of Zeller and Alper (1965) in the Animas Mountains may also be partly equivalent to the Fort Crittenden (p. B30).

In many other areas in the region, the Fort Crittenden Formation or correlative rocks are absent and Upper Cretaceous volcanics disconformably or unconformably overlie older rocks. Some of these areas, such as the Empire Mountains and Tombstone vicinity, lie directly between areas where the Fort Crittenden or similar rocks are present. I believe that rocks correlative with the Fort Crittenden are absent in these areas due to nondeposition and that the Fort Crittenden Formation and correlatives were deposited in broad valleys between mountainous highlands.

Even though there are many differences between the rocks of the Fort Crittenden Formation and correlatives and rocks of the Bisbee Group, it is difficult to distinguish between the two in places. Both units contain clastic rocks of fluvial origin which locally contain an abundance of fossil wood and which may contain fresh-water mollusks, but in the region discussed here, only the Bisbee contains limestone and other rocks of marine origin along with marine and brackish-water fossils. This does not preclude the possibility of fresh-water limestone in the Fort Crittenden or its correlatives, but none has been recognized to date. Relatively well sorted conglomerates which contain rounded stream-worn clasts and poorly sorted fanglomerate-type conglomerates which contain more angular locally derived clasts can be found in both units; but the poorly sorted conglomerates are much more common in the Bisbee, and the well-sorted conglomerates are greatly dominant in the Fort Crittenden and correlatives. Sandstones are also helpful in distinguishing the two. Average sandstone in the Bisbee ranges from slightly feldspathic in the east to arkose in the west, although occasional beds of graywacke are present; most sandstone samples from the Fort Crittenden and correlatives are lithic or feldspathic graywacke or subgraywacke, although some arkose is present. (See Pettijohn, 1957, p. 291.) Rock colors, particularly of shales, may also be helpful in distinguishing the two units. Although both units contain rocks of red and green hues, red-hued rocks are more characteristic of the Bisbee whereas green- to olive-hued rocks are more common in the Fort Crittenden. There are other subtle differences in lithologic characteristics in the two units, but the ones enumerated above are most obvious and therefore most useful.

SALERO FORMATION AND CORRELATIVES

The Salero Formation in the Santa Rita and Empire Mountains is as much as 5,000 feet (1,500 m) thick and is composed of andesitic to dacitic rocks overlain by rhyolitic welded tuff which in turn is overlain by a dominantly clastic sedimentary member. The andesitic to dacitic rocks in the lower part of the formation locally have layers containing exotic blocks of older rock. The Salero overlies the Fort Crittenden Formation with apparent conformity where that formation is present, or unconformably overlies the Bisbee Group where the Fort Crittenden is absent. On the basis of a radiometric age determination of the rhyolitic tuff and the formation's apparently conformable relations with the Fort Crittenden Formation, the Salero is probably late Campanian and possibly earliest Maestrichtian in age (p. B24). The Salero has been intruded by rocks radiometrically dated as very late Cretaceous and is overlain by a variety of rocks assigned to the Tertiary or Quaternary.

Andesitic rocks very similar in lithology to those of the lower part of the Salero and in similar relations to older Cretaceous rocks are widely distributed in southeastern Arizona and southwestern New Mexico. At many localities west of long 110° W., these are overlain by rhyolitic tuffs, some of which have been radiometrically dated as late Campanian or Maestrichtian. Andesitic rocks in the region that are considered as at least approximate correlatives of the lower part of the Salero Formation include the Silver Bell Formation of Richard and Courtright (1960) in the Silver Bell Mountains area, the Demetrie Formation of Thoms (1967) in the Sierrita Mountains vicinity, most of the Tucson Mountain Chaos of Kinnison (1959) in the Tucson Mountains, the Roadside Formation in the Roskruge Mountains area, the Vekol Formation in the Vekol Mountains, the Cloudburst Formation in the Santa Catalina Mountains area, the lower part of the Bronco Volcanics in the Tombstone area, the Nipper Formation of Sabins (1957a) in the Chiricahua Mountains, the Hidalgo Volcanics in the Little Hatchet Mountains, and unnamed rocks in many other areas (fig. 5).

Rhyolitic tuffs in the region that are considered correlatives of the rhyolitic tuffs of the Salero Formation include the Cat Mountain Rhyolite of Brown (1939) in the Tucson Mountains, the Red Boy Rhyolite of Thoms (1967) in the Sierrita Mountains, the Roskruge Rhyolite in the Roskruge Mountains, the upper part of the Bronco Volcanics in the Tombstone area, possibly part or all of the Sugarloaf Quartz Latite in the Dragoon Mountains area, unnamed rocks at the top of the Cabullona Group of Taliaferro (1933) in the Cabullona Basin area in Sonora, and an unnamed rhyolite in the Silver Bell Mountains.

Units comparable to the upper part of the Salero Formation in the Santa Rita Mountains have not been identified elsewhere in the region.

DESCRIPTIONS OF LOCAL SEQUENCES

PRINCIPAL STUDY AREA

MULE MOUNTAINS, ARIZ., TO CABULLONA BASIN, SONORA

(Fig. 5, col. 10)

Many thousands of feet of strata of Cretaceous age are exposed in continuous outcrops that extend about 40 miles (65 km) south-southeastward from the north end of the Mule Mountains, Ariz., to the south edge of the Cabullona Basin, Sonora (fig. 4). Rocks in all but the south end of this large outcrop area are of Early Cretaceous age and are assigned to the Bisbee Group. At the south end, separated from the Bisbee Group by a major west-northwest-trending fault, is the Upper Cretaceous Cabullona Group of Taliaferro (1933).

The Bisbee Group, named for the city of Bisbee in the Mule Mountains, is divided, in ascending order, into the Glance Conglomerate, the Morita Formation, the Mural Limestone, and the Cintura Formation, all of which have principal reference sections in the Mule

Mountains. The following descriptions of the formations of the Bisbee Group, except as otherwise noted, are taken from Hayes (1970).

The Glance Conglomerate is a poorly sorted angular boulder to granule conglomerate whose thickness and lithologic detail are strongly controlled by the relief and lithology of the underlying surface. The Glance rests unconformably on a surface of high relief carved on Precambrian metamorphic rocks, Paleozoic sedimentary rocks, and Jurassic granite. In the Mule Mountains, it ranges in thickness from wedge-edges over buried high areas to many hundreds of feet; and according to Taliaferro (1933), it is as much as 2,500 feet (750 m) thick in Sonora just north of the Cabullona Basin. Conglomerate near the base of the formation is made up of clasts derived from the immediately underlying rocks, whatever they may be, whereas higher in the formation the clasts are of more diverse origin but are all of rock types now exposed at the surface somewhere in the Mule Mountains. The Glance, which is increasingly fine grained toward the top, grades upward into the Morita Formation.

The Morita Formation, 2,600–3,000 feet (800–900 m) thick in the Mule Mountains and, according to Taliaferro (1933), as much as 5,000 feet (1,500 m) thick just north of the Cabullona Basin, is made up mostly of repeated sequences of pinkish-gray feldspathic sandstone that grades upward into grayish-red siltstone and mudstone. Siltstone and mudstone are dominant in most of the formation, but sandstone is dominant in the upper part. The formation, which grades upward into the Mural Limestone, contains a few thin units of impure fossiliferous limestone in the upper part.

The Mural Limestone, 500–700 feet (150–215 m) thick, is divided into lower and upper members. The lower member consists of interbedded calcareous mudstone, impure fossiliferous limestone, and friable calcareous siltstone and sandstone, whereas the upper member is made up dominantly of relatively thick bedded limestone. High in the upper member, which grades upward into the Cintura Formation, are interbeds of pinkish-gray feldspathic sandstone.

The Cintura Formation, as much as 1,830 feet (570 m) thick, is lithologically similar to the Morita Formation. It contains a few thin beds of fossiliferous limestone in the lower part.

Stratigraphically useful fossils from the Bisbee Group in the area have been collected only from horizons in the upper part of the Morita Formation and from the Mural Limestone. On the basis of these, about the upper 600 feet (180 m) 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 of Texas; most of the remainder of the Mural Limestone is correlated with the upper part of the Trinity Group; and the uppermost part may be of late Trinity age or may be as young as the Fredericksburg Group of Texas. Probably the Glance Conglomerate and lower part of the Morita Formation are older than the Trinity, but they are probably not pre-Aptian. The Cintura Formation may correlate largely with the Fredericksburg Group and may, in part, be as young as the Washita Group of Texas.

The Cabullona Group of Taliaferro (1933) was divided by him into five conformable formations which, in ascending order, are the Snake Ridge Formation, the Camas Sandstone, the Packard Shales, a unit informally called the upper red beds, and an unnamed rhyolite tuff. The following descriptions are based on the work of Taliaferro (1933) and a visit I made in 1967 with Harald Drewes and Amador Osoria, then a geologist with the Mexican government.

The Snake Ridge Formation, more than 3,000 feet (600 m) thick, consists of polymictic conglomerate, pale-yellowish-brown to light-gray locally pebbly sandstone, and pale-yellow, pink, and gray shale. Petrified wood and fresh-water mollusks are abundant in some beds, and dinosaur bones were found in the upper part of the formation.

The Camas Sandstone, 1,220 feet (370 m) thick, consists of crossbedded largely tuffaceous sandstone with minor interbedded pale-red and pale-green shale.

The Packard Shales, 1,800–2,500 feet (550–750 m) thick, is made up dominantly of greenish-gray shale with minor interbedded standstone and bentonite. The formation contains carbonized plant fragments and fresh-water mollusks.

The upper red beds, more than 2,000 feet (600 m) thick, is made up mostly of pale-red shale and pale-red to light-gray sandstone but contains very minor siliceous tuff in thin beds.

The rhyolite tuff, as much as 800 feet (250 m) thick, is made up of white to gray siliceous tuff.

The Late Cretaceous age assignment of the Cabullona Group of Taliaferro (1933) is based on identification of dinosaur bones from high in the Snake Ridge Formation and on lithologic resemblances of all but the rhyolite tuff unit to rocks of the Upper Cretaceous Fort Crittenden Formation in the Santa Rita and Huachuca Mountains in Arizona. The plant remains and fresh-water mollusks in the group are not useful for close dating, and none of the tuff of the group has been dated by radiometric methods. According to Taliaferro (1933,

p. 28), "The evidence afforded by the dinosaur remains, although perhaps not conclusive, indicates that the beds belong to the upper part of the Upper Cretaceous and are probably Senonian." This tentative age assignment allows a correlation with the Fort Crittenden Formation and suggests that the Cabullona Group is younger than the Pinkard Formation in the Morenci area or the Colorado Formation in the Silver City area, New Mexico (fig. 5). The rhyolite tuff unit at the top of the Cabullona Group may be equivalent to rhyodacitic tuff in the upper part of the Salero Formation in the Santa Rita Mountains and correlatives. If this is the case, it is notable that there are no andesitic rocks conformably beneath the rhyolitic tuffs in the Cabullona Basin as are found in most parts of the region.

HUACHUCA MOUNTAINS AND CANELO HILLS

(Fig. 5, col. 9)

Cretaceous strata, totaling many thousands of feet in thickness, are exposed in discontinuous outcrops throughout the length of the northwest-trending Huachuca Mountains and are also extensively exposed in the similarly trending Canelo Hills to the west and northwest (fig. 4). Lower Cretaceous rocks, all assigned to the Bisbee Group, are prevalent in the Huachucas, whereas Upper Cretaceous rocks assigned to the Fort Crittenden Formation and unnamed units are prevalent in the southern Canelo Hills. The following brief description of the Cretaceous in the Huachucas is taken from Hayes (1970), and the description of the Cretaceous in the Canelo Hills is derived from unpublished data of my own and of Robert B. Raup and Frank S. Simons.

The Bisbee Group in the Huachuca Mountains, as in the Mule Mountains, is divided in ascending order into the Glance Conglomerate, the Morita Formation, the Mural Limestone, and the Cintura Formation; only the Cintura is represented in the Canelo Hills area. The Morita and Cintura Formations in the Huachucas are basically similar to those formations in the Mules; but the Glance Conglomerate in most areas in the Huachucas contains a volcanic member not present in the Mules, and the Mural Limestone in the Huachucas is somewhat different from that in the Mules.

The Glance Conglomerate in the Huachuca Mountains is divided into lower and upper conglomerate units and a middle volcanic unit. In the northern part of the range, the volcanic unit is locally absent, and the two conglomerate units are indistinguishable. In the southern part, the upper conglomerate unit is locally absent. The lower conglomerate unit, like the Glance Conglomerate in the Mule Mountains, is a poorly sorted angular boulder to granule conglomerate whose thickness and lithologic detail are strongly controlled by the relief and lithology of the underlying surface. It rests uncomformably on a surface of high relief carved on Paleozoic sedimentary rocks, Triassic and Jurassic volcanic rocks, and Jurassic quartz monzonite. The lower conglomerate, where distinguishable from the upper conglomerate, ranges in thickness from about 300 feet (90 m) to nearly 2,000 feet (600 m). The volcanic unit is made up of very dusky red to grayish-purple generally porphyritic rhyodacitic lava and flow breccias that locally contain exotic blocks as much as several hundred feet long of limestone locally derived from Paleozoic formations. The unit ranges in thickness from 0 to nearly 1,500 feet (460 m). The upper conglomerate is similar to the lower but contains debris derived from the volcanic member. The base of the upper unit is interpreted to be a minor intraformational unconformity. The thickness of the upper conglomerate ranges from 0 to at least 750 feet (230 m). The total thickness of the Glance Conglomerate in the Huachuca Mountains ranges from about 300 feet (90 m) near the north end of the range to about 3,600 feet (1,100 m) in the central part of the range.

The Morita Formation in the Huachuca Mountains is very similar to that in the Mule Mountains but contains a somewhat lower proportion of sandstone in the Huachucas. Its thickness in the Huachuca Mountains ranges from about 3,000 feet (900 m) in the northern part to about 4,200 feet (1,280 m) in the central part.

The Mural Limestone in the Huachuca Mountains, as in the Mule Mountains, can be divided into lower and upper members. The lower member in the Huachucas is basically similar to that in the Mules but contains a somewhat higher proportion of mudstone and a lower proportion of sandstone. The upper member in the Huachuca Mountains is made up of thinner bedded limestone than the upper member in the Mule Mountains and is interbedded with calcareous shale and siltstone and argillaceous limestone which together make up about one-third of the member. Thickness of the Mural in the Huachuca Mountains ranges from about 300 feet (90 m) near the north end of the mountains to about 800 feet (250 m) in the central part.

The Cintura Formation in the Huachuca Mountains and Canelo Hills area is basically similar to that in the Mule Mountains. Thickness of the formation in the Huachuca Mountains, zero to apparently more than 2,000 feet (600 m), is highly variable due to the effects of faulting and erosion that transpired after deposition of the Cintura and before deposition of the overlying Fort Crittenden Formation of Late Cretaceous age. Thickness of the formation in the Canelo Hills is unknown inasmuch as the base is not exposed there.

Fossil collections of stratigraphic value from the Bisbee Group in the Huachuca Mountains have all come from the Mural Limestone. Considered together these indicate a late Trinity to Fredericksburg age for the formation there, and they fairly well substantiate the lithologic correlation of the Mural in the Huachuca Mountains with that in the Mule Mountains. Presumably, the generally thicker sequence of rocks beneath the Mural in the Huachuca Mountains indicates that the Glance there, especially the volcanic unit and lower conglomerate, is probably older than the Glance in the Mule Mountains and that it might well be of early Early Cretaceous age.

A sequence of conglomerate, sandstone, and shale referred to the Fort Crittenden Formation unconformably overlies the Bisbee Group on a surface of low local relief in a series of interrupted exposures on the southwest side of the Huachuca Mountains and on the northeast side of the Canelo Hills. The formation, as it occurs here, can be divided into three informal members that grade into one another vertically and probably laterally. At the base is a conglomeratic member, next above it is a shale member, and above that is the upper conglomeratic member.

The basal conglomeratic member of the Fort Crittenden, which ranges in thickness from tens of feet to as much as 600 feet (180 m), is made up of conglomerate, conglomeratic graywacke, siltstone, and mudstone. The conglomerate, set in graywacke matrix, is mostly made up of well-rounded pebbles and cobbles of resistant sandstones and volcanic rocks. Shale and siltstone are like those in the shale member.

The shale member is made up largely of pale-olive to yellowish-brown or pale-red fissile shale and massive claystone but contains many beds of dusky-yellow locally pebbly graywacke. Fresh-water mollusks are locally common near the base of the member. The top of the member is not exposed on the southwest side of the Huachuca Mountains, but the unit is at least 650 feet (200 m) thick there and according to R. B. Raup (oral commun., 1969) is about 1,200 feet (365 m) thick locally on the northeast side of the Canelo Hills.

The upper conglomeratic member is present only on the northeast side of the Canelo Hills. It is generally similar in lithology to the lower conglomerate member except that its pebbles and cobbles are not as well rounded and its bedding locally is more conspicuous. At least 2,700 feet (825 m) of the member, whose top is nowhere preserved at the surface, is present in the area (R. B. Raup, oral commun., 1969).

Cretaceous rocks younger than the Fort Crittenden Formation are not in contact with that formation on the northeast side of the Canelo Hills; but on the west side are strata, informally referred to as "volcanic and sedimentary rocks of Jones Mesa" by Hayes and Raup (1968), that probably include correlatives of the upper part of the Fort Crittenden Formation and the lower part of the Salero Formation as well as sedimentary rocks and interbedded tuffs of Jurassic age. The lowest exposed part of this sequence of strata, whose base is missing along a fault, consists of at least several hundred feet of pale-pink to yellowish-brown feldspathic sandstone, minor similarly colored siltstone and shale, and a 20- to 50-foot-thick bed of light-gray biotite-rich tuff. These lower beds were once considered as possible equivalents of the upper part of the Fort Crittenden Formation (Hayes and Drewes, 1968, p. 56); but on the basis of a potassium-argon age determination of 165 ± 6 m.y. (million years) for biotite from welded tuff in the beds (from SW¼NW¼, sec. 25, T. 23 S., R. 18 E.) made by R. F. Marvin, H. H. Mehnert, and Violet Merritt of the U.S. Geological Survey (written commun., Sept. 23, 1969), the beds are now believed to be of Jurassic age. These Jurassic beds are overlain by a conglomeratic unit whose thickness is unknown because of internal faulting but which is probably at least 1,000 feet (300 m). This conglomeratic unit is dominantly siliceous material in a tuffaceous or feldspathic sandstone matrix in the lower part and is dominantly andesitic material in a graywacke matrix in the upper part; interbedded with the conglomerate is poorly exposed drab shale, olive graywacke, and at least one 30-foot-thick (9 m) bed of light-gray tuff. The conglomeratic unit apparently grades upward into a unit, probably at least 2,000 feet (600 m) thick, of dominantly gray crystal-lithic welded and nonwelded tuff and tuffaceous sandstone. High in this unit are interbeds of grayish-green to olive andesitic mulflow, lava, agglomerate, and conglomerate.

Biotite separated from a welded tuff in the upper unit of the Jones Mesa rocks yielded a potassium-argon age of 72 m.y. (S. C. Creasey, written commun., 1964). This unit is similar in age and general lithology to the Salero Formation in the Santa Rita Mountains and is considered correlative. The underlying conglomerate unit probably represents the Fort Crittenden Formation which there lies uncomformably on Jurassic beds with the Bisbee Group missing.

PATAGONIA MOUNTAINS

(Fig. 5, col. 8)

Sedimentary rocks of Early Cretaceous age are preserved in a triangular outcrop area of about 3 square miles on the east slope of the Patagonia Mountains, and volcanic rocks of probable Late Cretaceous age are preserved in a separate outcrop area at the north end of the range. The Lower Cretaceous rocks are considered correlative with the Bisbee Group but are not formally divided and therefore are referred to as the Bisbee Formation. These rocks were formerly assigned by Stoyanow (1949) to the Molly Gibson Formation. The Upper Cretaceous volcanics are probably equivalent to much of the Salero Formation. The brief descriptions that follow are summarized from preliminary data obtained from work in progress by F. S. Simons.

The Bisbee Formation in the Patagonia Mountains is at least 2,200 feet (670 m) thick and rests disconformably on a unit of dominant silicic volcanics of probable Triassic age. Above a basal conglomerate made up of detritus from the underlying volcanics is roughly 900 feet (275 m) of very fine grained clastic rocks that have been thoroughly altered to hornfels near a large intrusive body. Above that is a sequence nearly 1,400 feet (425 m) thick, of dominant siltstone and mudstone and subordinate sandstone and limestone. The siltstone and mudstone range from variably hued gray to pale purple and are commonly calcareous. Sandstone, relatively more abundant in the lower part of the 1,400-foot-thick sequence, is varicolored and generally feldspathic or arkosic. Limestone, relatively more abundant in the middle part of the sequence, occurs mostly in units less than 5 feet thick, is generally silty or sandy, and is rich in molluscan debris. Some tuffaceous material occurs in the upper part. The top of the Bisbee is cut out by faults in the area.

Fossils from the Bisbee Formation in the Patagonia Mountains are considered by R. W. Imlay of the U.S. Geological Survey (written commun., 1967) to indicate a correlation of their containing rocks with the Trinity Group of Texas. This supports the correlation with the type Bisbee Group in the Mule Mountains.

Rocks, of unknown thickness, that are lithologically similar to and probably correlative with the lower part of the Salero Formation in the Santa Rita Mountains are present around the north end of the Patagonia Mountains. Because of their proximity to the Salero in the Santa Ritas, the rocks are not described here. Rocks analogous to the Fort Crittenden Formation are not known in the Patagonia Mountains.

WHETSTONE AND EMPIRE MOUNTAINS

(Fig. 5, col. 7)

Lower Cretaceous rocks are extensively exposed in and near the Whetstone and nearby Empire Mountains (fig. 4), and rocks of Late Cretaceous age occur in the Empires. The Lower Cretaceous Bisbee Group in the Whetstone Mountains was divided into several new formations by Tyrrell (1957). Creasey (1967b), who mapped the Whetstone Mountains, did not use Tyrrell's formations but included all the Lower Cretaceous strata in the Bisbee(?) Formation. Finnell (1970) has adopted Tyrrell's formations, with some modifications for use in the Empire Mountains area. Finnell's usage is followed here, but the following brief descriptions of the Bisbee Group in the Whetstone and Empire Mountains are taken from all three workers. Descriptions of the Upper Cretaceous rocks in the Empires are taken from unpublished data of T. L. Finnell.

The Bisbee Group is divided, in ascending order, into the Glance Conglomerate and the Willow Canyon, Apache Canyon, Shellenberger Canyon, and Turney Ranch Formations. The group rests on a surface of widely variable relief carved on Permian rocks in the Whetstone Mountains and on rocks ranging in age from Precambrian to Triassic in the Empire Mountains area. As a result of the great local relief of the underlying surface, the thickness of the Glance is extremely variable. Locally, near the north end of the Empire Mountains, the Willow Canyon, Apache Canyon, and basal one-third of the Shellenberger Canyon Formations grade laterally into a thick conglomeratic sequence assigned to the Glance that was deposited around the margins of a very high area underlain by Precambrian crystalline rocks. There, the upper two-thirds of the Shellenberger Canyon Formation rests on the Glance Conglomerate.

The thickness and lithology of the Glance Conglomerate in these ranges, as in the Mule and Huachuca Mountains, is strongly controlled by the topography and lithology of the underlying surface. In the Whetstone Mountains and the southern part of the Empire Mountains, its clasts are largely derived from the Paleozoic formations which underlie it, and its thickness ranges from less than a foot to 400 feet (120 m). In the area around the north end of the Empire Mountains, in the vicinity of the above-mentioned high area made up of Precambrian crystalline rocks, the Glance is as much as 5,600 feet (1,700 m) thick, and its clasts are largely derived from the Precambrian. The Glance is overlain by the Willow Canyon Formation with gradational contact.

The Willow Canyon Formation consists predominantly of alternating units of sandstone and siltstone, but in the upper 300 feet (90 m) it includes subordinate thin beds of silty limestone and calcareous sandstone. Sandstone in the formation is light yellowish gray, light pinkish gray, and light yellowish brown, arkosic, crossbedded, and locally conglomeratic. The siltstone is commonly dark reddish brown in the lower two-thirds of the formation and commonly olive gray to greenish gray in the upper one-third. The Willow Canyon ranges in thickness from 0 to 570 feet (175 m) in the Whetstone Mountains and from 0 to at least 3,000 feet (900 m) in the Empire Mountains. The Willow Canyon is overlain by the Apache Canyon Formation with gradational contact.

The Apache Canyon Formation in the Empire Mountains and in the northern part of its main outcrop belt in the Whetstone Mountains consists of interbedded thinly laminated dark-gray silty limestone, dark-gray fissile shale, calcareous siltstone, and arkosic sandstones; one thin gypsum bed can commonly be found in the lower part. In the southern part of the Whetstones, limestone makes up a larger percentage of the formation, and most of it is lighter gray, thicker bedded, and not thinly laminated as it is to the north. In the Whetstone Mountains, the Apache Canyon is 550–740 feet (167–225 m) thick. In the Empire Mountains the formation is locally at least 1,600 feet (490 m) thick, and laterally it grades completely into the Glance Conglomerate near the north end of the range.

The Shellenberger Canyon Formation consists of interbedded shale, siltstone, sandstone, and some limestone. The shale and siltstone are commonly shades of olive brown, olive gray, greenish gray, and reddish brown. The sandstone is olive brown, olive green, olive gray, and pinkish gray, fine to very coarse grained, arkosic, massive to crossbedded, and lenticular. Some sandstone beds are conglomeratic at the base. Limestone, mainly restricted to the lower 1,300 feet (395 m) of the formation, is mostly thinly laminated and dark gray, but two beds about 1,000 and 1,300 feet (300 and 395 m) above the base are distinctive brown-weathering sandy limestone rich in molluscan debris. The formation generally ranges in thickness from 3,950 to 4,330 feet (1,200 to 1,320 m), except near the north end of the Empire Mountains where the basal 1,000 feet (300 m) grades laterally into the Glance Conglomerate over a Precambrian high. The Shellenberger Canyon Formation is comformably overlain by the Turney Ranch Formation.

The Turney Ranch Formation, at least 3,200 feet (975 m) thick, consists of pale-red siltstone and shale alternating with light-pinkish-gray to pale-orange medium- to coarse-grained arkosic crossbedded sandstone.

The fossils closely diagnostic of age that have been found in the Bisbee Group in these ranges are dinosaur bones from between 1,000 and 1,300 feet (300 and 395 m) above the base of the Shellenberger Canyon in the Empire Mountains and the clam *Trigonia* n.sp. from about 800 feet (240 m) above the base of the Shellenberger Canyon in the Whetstone Mountains. The dinosaur bones are considered by Miller (1964, p. 378) to be Early Cretaceous, and the *Trigonia*, considered with accompanying invertebrates, indicates, according to Tyrrell (1957, p. 111), a late Early Cretaceous age (late Trinity or early Fredericksburg). Although a general correlation of the Bisbee Group in these ranges with that in the Huachuca and Mule Mountains seems certain, correlation of individual formations is more tenuous. On the basis of lithologies and known facies trends in the various ranges, the Apache Canyon Formation is tentatively considered to approximately correlate with the Mural Limestone (fig. 6). The Willow Canyon Formation, then, is considered a rough correlative of the Morita Formation, and the Shellenberger Canyon Formation is believed to be roughly equivalent to the Cintura Formation. The Turney Ranch Formation may be younger than any part of the Bisbee Group in the Mule or Huachuca Mountains, but on the basis of its lithology it is believed to properly belong to that group rather than being correlative with any of the known Upper Cretaceous formations of the region. Although the above correlations are favored here, a case could be made for correlating the Turney Ranch with the Cintura, which it resembles; for correlating at least the basal part of the Shellenberger Canyon with the Mural; and for correlating both the Apache Canyon and Willow Canyon Formations with the Morita.

Rocks that are correlated with the Upper Cretaceous Fort Crittenden Formation are locally exposed west of the north end of the Empire Mountains, and probable correlatives of the younger Upper Cretaceous Salero Formation are more widely exposed in the Empires; no Upper Cretaceous strata have been recognized in the Whetstone Mountains. The rocks correlated with the Fort Crittenden Formation include conglomerate, conglomeratic graywacke, and olive mudstone. These overlie isoclinally folded beds of the Turney Ranch and Shellenberger Canyon Formations with sharp angular unconformity. Elsewhere in the range, the Bisbee Group is overlain by a thick series of conglomerate, andesitic breccia, and rhyolitic tuff that is very similar to the Salero Formation in the

Santa Rita Mountains. As in the Santa Rita Mountains, the Salero in the Empire Mountains locally contains large exotic blocks of older formations.

SANTA RITA MOUNTAINS

(Fig. 5, col. 6)

Formations assigned to the Cretaceous System in the Santa Rita Mountains (fig. 4) include the local Temporal and Bathtub Formations, which are dominantly volcanic units of early Early Cretaceous age; the Bisbee Group of late Early Cretaceous age, which is divided into the same formations as in the Empire and Whetstone Mountains; and the Fort Crittenden and Salero Formations of late Late Cretaceous age. The older two formations are exposed only in the southern part of the mountains. The Bisbee Group occurs in many outcrop areas but is most extensively exposed in the northern part of the range. The Fort Crittenden occurs in several places, but its most informative exposures are in the southeastern part of the range. The Salero Formation also occurs in several areas but is most completely exposed to the southwest. The following descriptions of Cretaceous strata in the Santa Rita Mountains are abstracted from Drewes (1970c).

The Temporal Formation, 1,000–2,000 feet (300–600 m) thick, is divided into three members. The lower member is rhyolitic to andesitic tuff, welded tuff, lava flows, and poorly sorted conglomerate. The middle member is conglomerate, rhyolitic tuff, and porphyritic latite flows. The upper member is boulder and cobble conglomerate, rhyodacite breccia, and lenses of other volcanic rock. Locally, the lower two members grade laterally into a thick unit of andesitic flows and volcanic breccia. The Temporal Formation rests on a surface of considerable relief carved in granite dated by two radiometric methods as Jurassic. The Temporal is overlain by the Bathtub Formation with a general disconformity but locally with slight angular unconformity.

The Bathtub Formation also consists of volcanic and sedimentary rocks divided into three members and is 1,500–2,300 feet (460–700 m) thick. The lower member is poorly sorted boulder conglomerate and volcanic sandstone. The middle member is rhyolitic tuff breccia and andesitic lava. The upper member is largely dacite volcanic breccia but contains some rhyolitic tuff and lava. The Bathtub Formation is overlain with slight unconformity by the Glance Conglomerate of the Bisbee Group.

The Glance Conglomerate in the Santa Rita Mountains, as the basal conglomeratic unit of the Bisbee Group, is basically similar to the Glance in the ranges to the east and southeast. In most areas in the Santa Rita Mountains, the formation is only a few tens to a few hundred feet thick, but locally it is as much as 1,500 feet (450 m) thick. Clasts in the conglomerate range from pebbles to boulders and are derived in large part from the nearest underlying formation, whatever it may be. The Glance rests on rocks as old as Precambrian granodiorite and as young as the Bathtub Formation of an assigned Early Cretaceous age; it locally rests on one of several Paleozoic formations. The Glance grades upward into the Willow Canyon Formation and locally intertongues with that formation.

The Willow Canyon Formation in the Santa Rita Mountains, about 2,200 feet (670 m) thick, is similar to the same formation in the Empire Mountains. It consists dominantly of interbedded arkosic sandstone and siltstone and contains scattered thin conglomeratic units in the lower part and thin impure limestone beds in the upper part. The formation contains a higher proportion of coarser clastic rock toward the west than toward the east. It is overlain by the Apache Canyon Formation with an arbitrary gradational contact.

The Apache Canyon Formation in the Santa Rita Mountains, 1,500–2,000 feet (450–600 m) thick, is made up largely of siltstone and mudstone with interbeds of fine-grained arkosic sandstone and arkose; an important subordinate lithology which allows correlation with the Apache Canyon in the Empire Mountains area, is limestone. Limestone in the formation is either thinly platy laminated rock or blocky fracturing calcarenite. Pebble conglomerate occurs sparingly in the Apache Canyon. The formation is gradationally overlain by the Shellenberger Canyon Formation.

Less than 1,000 feet (300 m) of the basal part of the Shellenberger Canyon Formation is represented in the Santa Rita Mountains. Here, as in the Empire Mountains, the formation is made up of dark-colored siltstone and shale with intercalcated beds of olive-brown sandstone and minor limestone. The upper part of the Shellenberger Canyon and its contact with the presumably overlying Turney Ranch Formation are not exposed in the Santa Ritas.

A maximum of about 1,500 feet (450 m) of beds assigned to the Turney Ranch Formation is exposed in the Santa Rita Mountains. These beds consist dominantly of grayish-red siltstone interbedded with subordinate but conspicuous lenses of generally resistant feldspathic sandstone. The base of the Turney

Ranch is not exposed in the Santa Ritas. The formation is overlain with slight angular unconformity by the Fort Crittenden Formation.

Fossils found to date in the Bisbee Group in the Santa Rita Mountains are dominantly of brackish-water origin and are only sufficient to indicate a Cretaceous age. The formations of the group are assigned to the Lower Cretaceous on the basis of regional lithologic correlations.

The oldest Upper Cretaceous strata in the Santa Rita Mountains are assigned to the Fort Crittenden Formation, whose reference section is in the southeastern part of the range. There, the Fort Crittenden rests with slight angularity on the Turney Ranch Formation. The Fort Crittenden, which is as much as 5,500 feet (1,670 m) thick, is divided into five informal members in its reference section. The members, in ascending order, are: (1) A shale member, a few feet to 550 feet (170 m) thick, which consists dominantly of olive-gray shale but contains a thin lenticular basal conglomerate and a medial pelecypod-bearing siltstone unit; (2) a red conglomeratic member, as much as 1,000 feet (300 m) thick, made up of about 35 percent pebble and cobble conglomerate derived from the Bisbee Group and older rock, 50 percent sandstone (subarkose to subgraywacke), and 15 percent siltstone and mudstone; (3) a brown-weathering conglomerate member, 2,030 feet (620 m) thick where measured, made up of 10–40 percent pebble and cobble conglomerate derived largely from granitic rocks, 20–50 percent arkosic sandstone, and 20–30 percent siltstone and mudstone; (4) another red conglomerate member, at least 1,400 feet (425 m) thick, that is similar to the lower one except that it contains considerable sedimentary breccia derived largely from the Bisbee Group; and (5) rhyolitic tuff, about 65 feet (20 m) thick, that is intercalated within the upper red conglomerate. Rocks on the west side of the Santa Rita Mountains that are assigned with little doubt to the Fort Crittenden Formation are conformably overlain by the Salero Formation.

Fossil fresh-water invertebrates, vertebrates including dinosaurian remains, and wood from the shale member of the Fort Crittenden Formation collectively indicate a late Late Cretaceous (Santonian to Maestrichtian) age and perhaps more likely late than early in this interval. The following evidence for a late Campanian age for the upper part of the apparently conformably overlying Salero Formation suggests that the type Fort Crittenden may, then, be of early Campanian age.

The Salero Formation conformably overlies the Fort Crittenden Formation only locally on the west side of the Santa Rita Mountains. Elsewhere in the range, it unconformably overlies a surface of some relief carved on a Jurassic granite. The Salero, with a composite maximum thickness of about 5,000 feet (1,500 m), is divided into four vertically sequential members and a fifth member that is a lateral facies, largely of one of the sequential members. The sequential members include a lower member of dacitic flows and tuff breccia, 400 feet (120 m) thick; an exotic-block-bearing member with a dacitic volcanic matrix, 1,000 feet (300 m) thick; a rhyodacite welded tuff member at least 1,200 feet (360 m) thick; and an upper member, estimated to be 2,000–2,500 feet (600–750 m) thick, containing conglomerate, agglomerate, tuff, quartzite, and red beds. The fifth member is an arkosic fanglomerate that is largely a lateral facies of the welded tuff member and partly of the upper member. The Salero Formation has been intruded by plutonic rocks radiometrically dated as latest Cretaceous and Paleocene and is unconformably overlain by Cenozoic deposits.

A biotite separate from the welded tuff member yielded a potassium-argon age of 72±2 m.y., which, according to Gill and Cobban (1966, p. A35), indicates a late Campanian age for the member. This age assignment is supported by a potassium-argon date of 67 m.y. for biotite from a diorite that has intruded the Salero Formation. These data and the apparently conformable position of the Salero above the Fort Crittenden Formation indicate that the Salero is probably late Campanian and possibly earliest Maestrichtian in age.

SIERRITA MOUNTAINS

(Fig. 5, col. 5)

Rocks that are tentatively assigned to the base of the Cretaceous System in the Sierrita Mountains vicinity are included in the quartzite of Whitcomb Hill (Cooper, 1970). This unit, which ranges in thickness from about 300 feet (90 m) to nearly 600 feet (180 m), is made up of very light gray well-sorted orthoquartzite that contains lenses of medium-light-gray flinty rhyolitic tuff in the upper part. The unit rests with apparent disconformity on the formation of Rodolfo Wash of Triassic age and is overlain with a locally disconformable and locally gradational contact by the arkose of Angelica Wash of Early Cretaceous age. The locally gradational contact with the Angelica Wash rocks suggests an approximate correlation of the quartzite of Whitcomb Hill with one of the volcanic units assigned to the base of the Cretaceous in the Santa Rita Mountains (the Bathtub or Temporal Formation) and with volcanic rocks in the Glance Conglomerate in the Huachuca Mountains. Assignment of an Early Cretaceous age to the quartzite of Whitcomb Hill remains tentative, however, because of the strong lithologic resemblance of the unit to the Stevens Mountain Rhyolite of Thoms (1967) in the west side of the Sierrita Mountains, a unit which, with good reason, is assigned a Triassic or Jurassic age.

Cretaceous strata are present in disconnected outcrops in various parts of the Sierrita Mountains. The following brief descriptions of these rocks are summarized from Cooper (1970) and Thoms (1966, 1967).

Above the quartzite of Whitcomb Hill in the Sierrita Mountains vicinity is the arkose of Angelica Wash. At one locality, ill-sorted metamorphosed conglomerate, which probably represents the basal part of the Angelica Wash strata, rests on the Whitcomb Hill strata with a gradational contact. At other localities, where the conglomerate is absent, the Angelica Wash strata rest on the Whitcomb Hill strata with a disconformable contact.

The arkose of Angelica Wash is lithologically different in its two principal outcrop areas, and the rocks exposed in the two areas may represent different facies of equivalent strata or different parts of the formation. The latter interpretation is favored by Cooper (1970). As interpreted by him, the lower 2,000 feet (600 m) of Angelica Wash strata consists dominantly of thin- to medium-bedded arkose with subordinate interbedded siltstone that, where not significantly altered, is generally grayish red and slightly calcareous. Above the arkose and siltstone is 1,600 feet (485 m) of feldspathic grit and pebble conglomerate. The grit and conglomerate unit thickens to the northeast at the expense of the underlying arkose and siltstone. The upper several thousand feet of the Angelica Wash strata contains feldspathic sandstone and grit, pebble conglomerate, orthoquartzite, argillite, and limestone. The limestone beds are lenticular and contain pelecypods, gastropods, algal(?) heads, and fresh-water ostracodes that are of little use in dating.

Cooper (1970) has noted the great similarity in lithology of the arkose of Angelica Wash to the Amole Arkose of Brown (1939) in the Tucson Mountains and the similarity of both of these units to parts of the Bisbee Group in the Santa Rita Mountains. Possibly the upper part of the Angelica Wash strata, whose pebble conglomerates have a graywacke matrix and whose limestones are apparently of fresh-water origin, is equivalent to the Upper Cretaceous Fort Crittenden Formation in the Santa Ritas, but correlation with the Lower Cretaceous Bisbee Group is favored here. Most of the sandstones of the arkose of Angelica Wash are intermediate in composition between the typical graywackes of the Fort Crittenden Formation and the feldspathic sandstones of the Bisbee Group in areas to the east. Regional facies changes within the Bisbee indicate a marked thinning of marine elements westward, and the absence of true marine limestones in the Sierrita Mountains equivalents is to be expected as is the transition into more feldspathic or arkosic sandstone. The arkose of Angelica Wash is overlain by the Demetrie Formation of Thoms (1967) with angular unconformity. This fact, incidentally, indirectly strengthens the correlation of the arkose of Angelica Wash with the Bisbee Group rather than with the Fort Crittenden Formation in that the Demetrie is correlated with little hesitation with the lower part of the Salero Formation, a unit which conformably overlies the Fort Crittenden in the Santa Rita Mountains and which unconformably overlies the Bisbee Group in the Empire Mountains.

The Demetrie Formation of Thoms (1967), the next formation younger than the arkose of Angelica Wash in the Sierrita Mountains, is a several-thousand-foot-thick sequence of andesitic to dacitic breccias and flows locally containing conglomerate and rhyolite tuff. Richard and Courtright (1960) and later workers correlated rocks included in the Demetrie with their Silver Bell Formation in the Silver Bell Mountains area, and that correlation is accepted here.

The youngest layered rock assigned a Cretaceous age in the Sierrita Mountains is the Red Boy Rhyolite of Thoms (1967). The Red Boy, whose maximum thickness is probably less than 1,000 feet (300 m), is made up dominantly of massive rhyolite tuff and tuff breccia. The formation overlies the Demetrie Formation of Thoms (1967) with apparent angular unconformity, is overlain with angular unconformity by gravel and basaltic andesite lava of middle or late Tertiary age, and has been intruded by andesite dikes and plugs that are petrographically like known lower Tertiary andesite dikes and plugs of the range. These geologic relations and compositional similarities, as previously suggested by Richard and Courtright (1960), clearly indicate correlation of the Red Boy Rhyolite with the Cat Mountain Rhyolite of Brown (1939) in the Tucson Mountains and, thus, with the upper part of the Salero Formation in the Santa Rita Mountains.

AREAS TO WEST

TUCSON MOUNTAINS

(Fig. 5, col. 4)

In the central and northern Tucson Mountains (fig. 4), the Cretaceous sequence as described by Brown (1939) consists of a lower volcanic member, the Recreation Redbeds, and the Amole Arkose; the Amole Arkose is 2,275 feet (695 m) thick in one measured section. On the basis of a potassium-argon age determination for andesite prophyry intruding the Recreation Redbeds (Damon and others[1]) and regional correlations (Hayes and Drewes, 1968), the Recreation Redbeds and underlying volcanics are now considered to be of Triassic age. The Amole Arkose yielded a sparse fauna considered by A. A. Stoyanow (Brown, 1939, p. 719) to be of Late Cretaceous age but which, on the basis of further collections, was considered by J. B. Reeside, Jr. (McKee, 1951), to be probably Early Cretaceous. The Amole Arkose as seen in its type area is very similar in many lithologic details to rocks of the Bisbee Group of known Early Cretaceous age in the Empire and northern Santa Rita Mountains and is here believed to be an approximate correlative.

In the southern Tucson Mountains, Kinnison (1958) studied the Amole Arkose of Brown (1939) and reported ostracodes from the lower part of the sequence that are no younger than Early Cretaceous, but he found pollen no older than Late Cretaceous in the upper part. Possibly these pollen-bearing Upper Cretaceous beds in the southern part of the mountains are unconformable on underlying parts of the Amole and are younger than any Amole in the type area. They may be more closely allied to Upper Cretaceous sedimentary rocks known elsewhere in the region.

In the central and northern Tucson Mountains, the Tucson Mountain Chaos of Kinnison (1959), 330 feet (100 m) thick in one section, rests with angular unconformity on the Amole Arkose of Brown (1939) of probable Early Cretaceous age and is overlain with apparent conformity by the Cat Mountain Rhyolite of Brown (1939). Except for a local basal conglomerate member, the Tucson Mountain Chaos consists of a chaotic jumble of exotic blocks of dominant Cretaceous and Paleozoic rocks set in an andesitic matrix, and it is very similar to the exotic-block-bearing member of the Salero Formation in the Santa Rita Mountains. The Cat Mountain Rhyolite is a welded tuff unit, at least 800 feet (240 m) thick, which has been dated by the potassium-argon method as 65.6 and 70.3 m.y. (Bikerman and Damon, 1966, p. 1232)—dates comparable to that obtained for biotite from a sample of the lithologically similar welded tuff member of the Salero Formation (p. B24). There is little doubt that the Tucson Mountain Chaos and the Cat Mountain Rhyolite are comparable in age to the Salero.

[1] Damon, P. E., and others, 1967, Annual Progress report C00–689–76 to Research Division, United States Atomic Energy Commission; Correlation and chronology of ore deposits and volcanic rocks: Tucson, Arizona Univ., Geochem. Section, Geochronology Labs., unpub. rept.

ROSKRUGE MOUNTAINS

(Fig. 5, col. 3)

On the east side of the Roskruge Mountains (fig. 4), about 10 miles (16 km) west of the Tucson Mountains, is a sequence of gray-green arkose and graywacke, gray quartzite, red and gray mottled mudstone, and pebble conglomerate, estimated to be about 2,000 feet (600 m) thick, which was named the Cocoraque Formation by Heindl (1965a). He noted the lithologic similarity of the formation to the Amole Arkose of Brown (1939) in the Tucson Mountains. In view of regional relations, a correlation of the two units seems reasonable. The base of the Cocoraque is not exposed. The formation is unconformably overlain by the Roadside Formation.

The several-thousand-foot-thick Roadside Formation, consisting of andesitic and dacitic breccias and flows and beds of pebbly mudstone to boulder conglomerate and breccia, was stated by Heindl (1965a, p. H11) to be equivalent to the Claflin Ranch and Silver Bell Formations of Richard and Courtright (1960) in the Silver Bell Mountains area. The overlying Roskruge Rhyolite, possibly as much as 4,000 feet (1,200 m) thick, yielded radiometric dates of about 70 to 72 m.y. (Bikerman, 1967) and was tentatively correlated by Heindl (1965a, p. H14) with the Cat Mountain Rhyolite of Brown (1939) in the Tucson Mountains. The Roadside Formation and the Roskruge Rhyolite together are probably equivalent to the Salero Formation in the Santa Rita Mountains.

SILVER BELL MOUNTAINS

(Fig. 5, col. 2)

A sequence of arkosic sedimentary rocks of unknown thickness comprises the oldest known Cretaceous unit in the Silver Bell Mountains area (fig. 4). These rocks have not been described in detail or have I seen them, but presumably they are equivalent to the Cocoraque Formation in the Roskruge Mountains area and, hence, are probably of Early Cretaceous age. Relations with younger Cretaceous rocks in the area are uncertain.

The Claflin Ranch Formation of Richard and Courtright (1960) in the Silver Bell Mountains area, when named, was described as resembling the Tucson Mountain Chaos of Kinnison (1959) in the Tucson Mountains "except for the absence of large limestone blocks," and the two units were correlated with one another.

The Silver Bell Formation of Richard and Courtright (1960), dominantly andesitic breccias, overlies their Claflin Ranch Formation and is overlain by "pyroclastics and ignimbrites" that were correlated with the Cat Mountain Rhyolite of Brown (1939) in the Tucson Mountains. All these units are probably generally correlative with the Salero Formation in the Santa Rita Mountains.

VEKOL MOUNTAINS

(Fig. 5, col. 1)

The Mesozoic rocks in the Vekol Mountains area (fig. 4) were described by Heindl (1965b). He suggested no definite correlation of units there with Lower Cretaceous formations to the east, but he did note the general similarity of the Phonodoree Formation in the Vekol Mountains area to the much thicker Recreation Redbeds of Brown (1939) in the Tucson Mountains. If the two formations are indeed correlative and the Recreation Redbeds are Triassic in age, as is now believed likely (p. B26), then there may be no Lower Cretaceous in the Vekol Mountains, because the Vekol Formation, which overlies the Phonodoree, is most probably correlative with Upper Cretaceous volcanics in areas to the east. Very possibly, Lower Cretaceous rocks related genetically to the Bisbee Group were never deposited as far west in Arizona as the Vekol Mountains.

The Vekol Formation, 2,000–3,000 feet (600–900 m) thick, includes lenses of conglomerate, gray-green pebbly arkose and graywacke, green and maroon mudstone, and beds of quartzite, arkosic quartzite, aphanitic claystone, and minor interlayered andesite. Heindl (1965b) compared gray-green and purplish-gray volcanic conglomerate beds in the Vekol Formation with those in the Claflin Ranch and Silver Bell Formations of Richard and Courtright (1960), although he implied no correlations. The Vekol Formation is overlain by the Chiapuk Rhyolite which Heindl (1965b) considered to be contemporaneous with the Cat Mountain Rhyolite of Brown (1939) in the Tucson Mountains. It is here considered possible, if not probable, that both the Vekol Formation and the Chiapuk Rhyolite are general equivalents to the Salero Formation in the Santa Rita Mountains (fig. 5).

OTHER AREAS

Strata of definite or probable Cretaceous age occur in several other ranges within 60 miles (100 km) west of the Santa Cruz River but have not yet been studied in any detail. In the several small ranges south of the Sierrita Mountains, extensive areas have been mapped in reconnaissance (Wilson and others, 1969) as being underlain by Cretaceous sedimentary and volcanic rocks, and Harald Drewes and I have briefly examined several of these areas. We believe that rocks mapped as Cretaceous sedimentary rocks a few miles southeast of Arivaca (fig. 4), near Oro Blanco, represent correlatives of the Lower Cretaceous Bisbee Group, that rocks mapped as Cretaceous sedimentary rocks south and west of Arivaca more likely belong to the Triassic System, and that rocks mapped as Cretaceous andesite north of Arivaca represent correlatives of the Upper Cretaceous Salero Formation.

In the Baboquivari Mountains, Heindl and Fair (1965) described strata of probable Mesozoic age, but they did not suggest any definite correlations with Cretaceous or other Mesozoic rocks to the east. Accompanied by Harald Drewes, I have walked over the sequence in the Baboquivaris and, on the basis of that brief visit, am unable to make definite correlations, but the following possibilities are presented. The Ali Molina Metamorphic Complex probably contains the oldest of the Mesozoic(?) strata in the range, and these may be equivalent to Triassic volcanics known in the Sierrita and Santa Rita Mountains (Hayes and Drewes, 1968). The Pitoikam Formation, about 9,200 feet (2,800 m) thick, was suggested by Heindl and Fair (1965, p. I6) to be partly equivalent to the Ali Molina, and I believe that all or most of the Pitoikam could certainly be of Triassic and (or) Jurassic age. The Chiltepines Member at the top of the Pitoikam, however, bears some resemblance to the Bisbee Group in areas to the east, and it may be a sourceward equivalent of the Bisbee. The overlying Mulberry Wash Volcanic Formation, 3,000 feet (900 m) thick, is largely volcanic and could be either Triassic and (or) Jurassic or Upper Cretaceous. The Chiuli Shaik Formation, about 2,000 feet (600 m) thick, has lithologies in common with the Salero Formation and seems to be a likely correlative. In conclusion, it seems that in the Baboquivari Mountains, correlatives of the Bisbee Group, if present, belong to a more landward and sourceward facies than the Bisbee in areas to the east and that equivalents of the Fort Crittenden Formation, if present, are of a more volcanic facies than the Fort Crittenden in areas to the east.

AREAS TO EAST

DRAGOON MOUNTAINS AND TOMBSTONE AREA

(Fig. 5, col. 11)

In the Dragoon Mountains (fig. 4) and a few miles to the west in the Tombstone area is a thick sequence of rocks similar in lithology to the combined Glance Conglomerate, Morita Formation, and Cintura Formation in the Mule Mountains that was described in detail by Gilluly (1956, p. 76–82) and called the Bisbee Formation. Although a few impure fossiliferous limestone beds are present in the sequence, no lithologic equivalent of the Mural Limestone is present. However, there is little doubt that the Bisbee Formation in the Dragoon Mountains vicinity is a general landward equivalent of the Bisbee Group in the Mule Mountains. Gilluly (1956, p. 78) estimated that the formation is about 15,000 feet (4,500 m) thick in the east-central part of the range.

Beneath the Bisbee Formation in the South Pass area in the Dragoon Mountains is an unnamed sequence of exotic-block-bearing volcanic rocks. Gilluly (1956, p. 68) described these rocks as "chiefly andesite and rhyolitic pyroclastic rocks but with some interbedded flow breccias" and, with some evidence, tentatively regarded them as Cretaceous; he suggested, however, that they could be Triassic or Jurassic. The rocks resemble volcanics here regarded as Lower Cretaceous in the Glance Conglomerate in the Huachuca Mountains, but they also resemble the Walnut Gap Volcanics in the Little Dragoon Mountains area which Cooper and Silver (1964, p. 72–73) regarded as Triassic or Jurassic and which Hayes and Drewes (1968) regarded as Late Triassic. Inasmuch as volcanics of Triassic and Jurassic age seem to have a wider distribution in southeastern Arizona than volcanics of Early Cretaceous age, the volcanics in the South Pass area are here tentatively considered to be Triassic or Jurassic. If they are Cretaceous, they are the northernmost known occurrence of Lower Cretaceous volcanics in southeastern Arizona.

In the Tombstone area, the Bronco Volcanics, estimated to be 5,000–6,000 feet (1,500–1,800 m) thick (Gilluly, 1956, p. 88), unconformably overlies deformed strata of the Bisbee Formation. The Bronco is made up of andesitic breccia in the lower part and dominant quartz latite and quartz latite tuffs above. The formation has been intruded by the Schieffelin Granodiorite whose age, according to the potassium-argon method of dating, is 72 m.y. (Creasey and Kistler, 1962). The Bronco, formerly assigned a Cretaceous or Tertiary age, is very likely equivalent to the Upper Cretaceous Salero Formation in areas to the west.

The Sugarloaf Quartz Latite in and near the southeast side of the Dragoon Mountains, as described by Gilluly (1956, p. 90–93), is comparable in lithology to the upper part of the Bronco Volcanics. The Sugarloaf was assigned the same general age as the Bronco by Gilluly, and it seems probable that much, if not all, of the Sugarloaf is equivalent to at least the upper rhyodacitic part of the Salero Formation. This correlation is bolstered by a potassium-argon age determination (R. F. Marvin, H. H. Mehnert, and Violet Merritt, written commun., 1969), of 72.8±2.5 m.y. for biotite separated from welded tuff which was collected by Harald Drewes from the type locality of the Sugarloaf.

DOS CABEZAS AND NORTHERN CHIRICAHUA MOUNTAINS

(Fig. 5, col. 12)

The Bisbee Group in the Dos Cabezas and northern Chiricahua Mountains (fig. 4) was described by Sabins (1957b), who recognized the Glance Conglomerate at the base and an undivided upper part. The Glance, which unconformably overlies Permian strata, ranges in thickness from 20 to perhaps 1,000 feet (6 to perhaps 300 m), and the clasts that comprise it vary considerably in composition. Above the Glance, Sabins measured 700 feet (212 m) of siltstone and associated coarser clastics, 220 feet (67 m) of interbedded limestone, siltstone, and shale that pinch out northwestward in the Dos Cabezas, and 1,650 feet (500 m) of sandstone and siltstone. The top of the Bisbee is missing due to erosion throughout the area. I suspect that all the exposed strata above the Glance Conglomerate are general equivalents to the Morita Formation in the Mule Mountains (fig. 6). The limestone member may be approximately equivalent to impure limestones far beneath the probable equivalent of the upper member of the Mural in the Pedregosa Mountains (p. B29).

North of the Dos Cabezas Mountains, strata equivalent to the Bisbee Group are apparently absent, probably due to nondeposition.

The Nipper Formation of Sabins (1957a) along the east side of the Chiricahua Mountains consists of andesitic flows, volcanic conglomerates, and associated sediments and is a probable equivalent of the lower part of the Salero Formation and correlatives. The Nipper Formation lies with angularity on Lower Cretaceous and Paleozoic rocks and is overlain by the Faraway Ranch Formation of Enlows (1951), which was tentatively assigned a mid-Tertiary age by Fernandez and Enlows (1966, p. 1028).

PEDREGOSA AND CENTRAL AND SOUTHERN CHIRICAHUA MOUNTAINS

(Fig. 5, col. 13)

The Bisbee Group as it occurs in the Pedregosa Mountains (fig. 4) and adjoining parts of the southern Chiricahua Mountains has been described by Epis (1956). There the Glance Conglomerate is 30–150 feet (9–45m) thick. It is overlain by 1,350 feet (950 m) of beds assigned to the Morita Formation. Above that are 3,120 feet (950 m) of interbedded marine and nonmarine strata that at various horizons have similarities to both the Morita Formation and the lower member of the Mural Limestone in the Mule Mountains. Calcareous algae from limestones in the lower part of this sequence are believed by Konishi and Epis (1962) to indicate a tropical marine environment within the lower littoral and upper infralittoral zones. Above those beds is 200 feet (60 m) of *Orbitolina*-bearing marine limestone that is here correlated with the upper member of the Mural Limestone in the Mule Mountains (fig. 6). This limestone is overlain by 3,200 feet (970 m) of beds assigned by Epis (1956) to the Cintura Formation. For reasons discussed in the second following paragraph, I believe that the highest 500 feet (150 m) of these strata assigned to the Cintura is probably of late Late Cretaceous age and approximately correlative with the Fort Crittenden Formation in the Huachuca and Santa Rita Mountains.

A previously undescribed sequence of strata correlative with the Bisbee Group was examined in reconnaissance during the present study along the Snowshed Trail on the east side of the central Chiricahua Mountains. There, above a thin basal conglomerate resting unconformably on Permian strata, is an estimated 4,500 feet (1,350 m) of strata somewhat similar to the basal 4,500 feet of beds described by Epis (1956) in the Pedregosa Mountains, except that the strata contain abundant interbedded dark-gray shale and less limestone. Above these strata are some thick-bedded marine limestone beds, one of which yielded a fossil identified by W. A. Cobban (written commun., 1960) as *Trigonia* cf. *T. stolleyi* Hill. *Trigonia stolleyi* is a Trinity form that was identified by Stoyanow (1949) from beds in the Mule Mountains area that are here considered to be a part of the lower member of the Mural Limestone.

Epis (1956) described a largely conglomerate sequence that is as much as 4,000 feet (1,200 m) thick and lies between the Bisbee Group and overlying propylitized andesites in the Pedregosa Mountains area. The conglomerates are made up of generally well rounded pebbles, cobbles, and occasional boulders derived from the Bisbee Group and various Paleozoic formations. Epis (1956) reasonably considered these conglomerates as approximate correlatives of the Cabullona Group of Taliaferro (1933) in Sonora and of the Skunk Ranch Conglomerate in the Little Hatchet Mountains in New Mexico. Possibly, the top 500 feet (180 m) of the poorly exposed underlying strata assigned by Epis (1956) to the Cintura Formation of the Bisbee Group is also of Late Cretaceous age. These uppermost strata assigned to the Cintura by Epis resemble much of the sandstone and shale of the Cabullona Group of Taliaferro and some beds in the Fort Crittenden Formation. They include at several horizons, thin conglomeratic sandstone beds that contain debris apparently derived from the Bisbee Group and include at least one bed of volcanic conglomerate. As stated by Epis (1956), the contact between the Bisbee Group and Upper Cretaceous strata must be "an unconformity of considerable significance, although * * * strata above and below it generally have the same strike and dip."

An estimated 2,500 feet (750 m) of andesitic flows, agglomerates, breccias, and tuff breccias in the Pedregosa Mountains, described by Epis (1956), gradationally overlies the thick sequence of sedimentary rocks of probable Late Cretaceous age. These volcanics are similar in lithology and stratigraphic relations to the Salero Formation in the Santa Rita Mountains and are undoubtedly approximately correlative. Epis (1956, p. 180) tentatively correlated these andesites in the Pedregosa Mountains with similar andesites in the Christmas (fig. 4) and nearby Stanley districts that Richard and Courtright (1960) have since correlated with their Silver Bell Formation in the Silver Bell Mountains area.

PELONCILLO MOUNTAINS, N. MEX. AND ARIZ.

(Fig. 5, col. 14)

Gillerman (1958) described the Bisbee Group in the central Peloncillo Mountains in New Mexico (fig. 4), a few miles east of the New Mexico–Arizona State line. At the base, resting on an erosion surface of considerable relief carved on Paleozoic rocks, is the McGhee Peak Formation of Gillerman (1958), 370 to about 600 feet (110 to about 180 m) thick, which includes some conglomerate at the base but is generally comparable to the 700 feet (210 m) of strata above the Glance Conglomerate in the Dos Cabezas and northern Chiricahua Mountains. Above the McGhee Peak is the Carbonate Hill Limestone of Gillerman (1958), which is probably about 225 feet (68 m) thick. It has yielded a fauna of Aptian age and was correlated by Gillerman (1958) with the Quajote Member of the Lowell Formation of Stoyanow (1949)—part of the lower member of the Mural Limestone of this report. It is here correlated on the basis of lithology with the limestone unit in the Bisbee Group in the Dos Cabezas and northern Chiricahua Mountains (fig. 6). Above the Carbonate Hill Limestone is the Still Ridge Formation of Gillerman (1958), which is 685 feet (208 m) thick in one section. This unit, which includes some limestone, may also be somewhat older than the upper member of the Mural Limestone in the Mule Mountains (fig. 6). The Still Ridge Formation is overlain by the Johnny Bull Sandstone of Gillerman (1958), which is more than 1,000 feet (300 m) thick.

This unit was conjecturally assigned to the Lower Cretaceous by Gillerman but is here believed to be of possible late Late Cretaceous age and, hence, not properly a part of the Bisbee Group. The formation contains a siliceous pebble conglomerate bed near the apparently conformable base and includes much dark-colored subgraywacke interbedded with lighter colored sandstones and brown shales. Although the formation has yielded no fossils, the nature of the thin conglomerate units and the subgraywacke suggests a possible correlation with the Fort Crittenden Formation and equivalents rather than with the Bisbee Group.

On and near the west side of the southern Peloncillo Mountains in Arizona, just north of the United States–Mexico border, rocks mapped as the Bisbee Formation by Cooper (1959) have not been studied in detail but have some features that are worthy of note. The base of the formation, poorly exposed in very limited outcrops, consists of a few feet of limestone cobble and pebble conglomerate resting unconformably on Permian strata. Not far above the base is an unusual massive graywacke that contains pebbles and cobbles of volcanic rock, the easternmost known occurrence of volcanic cobbles in the lower part of the Bisbee. Above this, the Bisbee in the southern Peloncillo Mountains area seems to be similar to that in the Pedregosa Mountains in that marine limestone beds interbedded with sandstones and mudstones of probable fluviatile origin occur within a few hundred feet of the base and are found through perhaps several thousand feet of section. Some limestone beds high in the sequence are thick and massive and appear to be biohermal; these may be equivalent to the upper part of the type Mural Limestone in the Mule Mountains.

BIG HATCHET AND ANIMAS MOUNTAINS, N. MEX.

(Fig. 5, col. 16)

A thick sequence of Lower Cretaceous rocks in the Big Hatchet Mountains area of southwestern New Mexico (fig. 4) was described in detail by Zeller (1965). The lowest stratigraphic unit, 1,274 feet (388 m) thick, is the Hell-to-Finish Formation of Zeller (1965), consisting dominantly of mudstone and siltstone with subordinate arkose and limestone; there is conglomerate at the base. Above the Hell-to-Finish is the dominantly limestone U-Bar Formation of Zeller (1965), which is about 3,500 feet (1,060 m) thick. The formation has yielded a rather rich fauna of mollusks and *Orbitolina* and is considered to be of Aptian and Albian age. As suggested by Zeller (1965), a general correlation of the upper part of the formation with the Mural Limestone in the Mule Mountains is reasonable (fig. 6). Overlying the U-Bar is the Mojado Formation of Zeller (1965). The lower 4,109 feet (1,253 m) of the formation consists chiefly of unfossiliferous sandstone and shale and may be approximately equivalent to the Cintura Formation in the Mule Mountains. The upper 1,086 feet (331 m) of the Mojado consists of sandstone and shale and calcareous beds which yield marine fossils that are considered to be of middle to late Washita age and thus may be younger than any Lower Cretaceous strata assigned to the Bisbee Group elsewhere in this report. They may be closely related to strata of very early Late Cretaceous age known farther north in the Silver City–Santa Rita area of New Mexico.

In the Animas Mountains, west of the Big Hatchet Mountains, Zeller and Alper (1965) recognized the Hell-to-Finish, the U-Bar, and the Mojado Formations; these are overlain by a conglomeratic unit, the Cowboy Spring Formation of Zeller and Alper (1965). In the Animas Mountains, the Hell-to-Finish Formation is extremely variable in thickness owing to relief on the underlying surface carved in Permian rocks. The U-Bar Formation is only about one-half as thick as it is in the Big Hatchet Mountains area as a result, according to Zeller and Alper (1965), of its deposition over an actively rising anticline. The Cowboy Spring Formation was described as conformably overlying the Mojado Formation and was assigned a late Early Cretaceous or early Late Cretaceous age. Zeller and Alper (1965) also noted that some observers have suggested that the formation may be correlative with the lithologically similar Skunk Ranch Conglomerate in the Little Hatchet Mountains. This correlation was not accepted by Zeller and Alper (1965) because of the presumed Trinity age of the Skunk Ranch and the apparently conformable relations of their Cowboy Spring Formation on the post-Trinity Mojado Formation. Inasmuch as I believe that the Skunk Ranch Conglomerate is of late Late Cretaceous age (see p. B31) and inasmuch as rocks of this age in many places in the region overlie Lower Cretaceous rocks with parallel but disconformable contact, it is here suggested that the Cowboy Spring Formation may indeed be equivalent to the Skunk Ranch and may be of late Late Cretaceous age.

LITTLE HATCHET MOUNTAINS, N. MEX.

(Fig. 5, col. 15)

All the Cretaceous strata of the structurally complex Little Hatchet Mountains in New Mexico (fig. 4) were considered to be of Early Cretaceous age and were included in the Bisbee Group by Lasky (1947, p. 16–26). The sequence there, as described by him in ascending order, includes (1) the Broken Jug Limestone, as much as 5,000 feet (1,500 m) thick but whose base is not exposed; (2) the *Physa*-bearing Ringbone Shale, as much as 650 feet (200 m) thick, which in most places rests on the Broken Jug with an erosional unconformity with possible relief of more than 2,000 feet (600 m); (3) the Hidalgo Volcanics, with a maximum thickness that may exceed 5,000 feet (1,500 m) and which overlies the Ringbone with a disconformable but nearly parallel contact; (4) the Howells Ridge Formation, about 5,000 feet (1,500 m) thick, which is lithologically very similar to the Broken Jug Limestone and is described as overlying the Hidalgo Volcanics with a disconformable contact having a relief of at least 1,200 feet (350 m); (5) the conformably overlying Corbett Sandstone, about 4,000 feet (1,200 m) thick; (6) the Playas Peak Formation, more than 3,000 feet (900 m) thick, which is similar in lithology to the Broken Jug Limestone and Howells Ridge Formation and which overlies the Corbett with a contact described as disconformable; and (7) the Skunk Ranch Conglomerate, which contains boulders derived from both Cretaceous and Paleozoic formations and which overlies the Playas Peak with a disconformable contact. The total composite thickness of the Bisbee Group as described by Lasky is about 26,000 feet (8,000 m).

Although the general high quality of Lasky's (1947) work in the Little Hatchets is not questioned, I consider it very likely that at least two of the disconformities described by Lasky (1947) in the sequence are strike faults and that the section has been repeated. Zeller (1965, p. 73–75) expressed serious suspicions about the validity of the sequence as described but offered no suggestions as to what he believed were the actual relations. I have visited the Little Hatchet Mountains briefly three times and, although I did not walk out the possible fault contacts, I crossed them at several points. On the basis of those visits to the area and of lithology, fauna, and regional stratigraphic relations, a reconstruction of the sequence in the Little Hatchet Mountains is tentatively offered here. Even though my interpretation of the sequence in the range is used in making my regional paleogeographic interpretations, it is not now proposed that formal changes should be made in the stratigraphic terminology of the area until someone has completed a detailed restudy of the area. However, the term Bisbee Group is not used in the Little Hatchet Mountains in this paper.

If the "disconformable contacts" at the base of the Howells Ridge and Playas Peak Formations are indeed faults, as I believe they are, then the Broken Jug Limestone, Howells Ridge Formation, and Playas Peak Formation probably are actually the same formation. All are similar in lithology and contain very similar *Orbitolina*-bearing faunas of Trinity age. All can then be correlated with the lithologically and faunally similar U-Bar Formation of Zeller (1965) in the nearby Big Hatchet Mountains area (fig. 5). The Corbett Sandstone, which conformably overlies the Howells Ridge, can then be correlated with the lithologically nearly identical lower 4,000 feet (1,200 m) or so of the Mojado Formation of Zeller (1965).

The Ringbone Shale, which overlies the Broken Jug Limestone in the northern part of the range with erosional unconformity, I believe is approximately correlative with the Fort Crittenden Formation in southeastern Arizona and should not be considered as a Bisbee Group equivalent. At the base of the Ringbone is a conglomerate containing debris derived from Lower Cretaceous rocks. In the shales are fossil remains of the gastropod *Physa* which are also locally abundant in the Fort Crittenden Formation. The shales in the Ringbone are much more similar to those in known Upper Cretaceous rocks in southeastern Arizona and Sonora than to Lower Cretaceous shales in the region. Richard and Courtright (1960) previously postulated a post-Bisbee age for the Ringbone Shale.

The Skunk Ranch Conglomerate, which overlies the Playas Peak Formation in the southern part of the Little Hatchet Mountains with erosional unconformity, contains debris derived from Lower Cretaceous and Paleozoic rocks. The Skunk Ranch may be a thick equivalent of conglomerates at the base of the Ringbone. Very reasonably, Epis (1956) considered the Skunk Ranch to be a general correlative of the Upper Cretaceous Cabullona Group of Taliaferro (1933).

The Hidalgo Volcanics which disconformably overlie the Ringbone Shale are here considered approximately equivalent to the lower part of the Salero Formation in southeastern Arizona. On the basis of lithologic similarity and an interpretation of the geologic relations similar to that made here, Richard and Courtright (1960) tentatively correlated the Hidalgo Volcanics with their Silver Bell Formation in the Silver Bell Mountains area, a formation that is here correlated with the lower part of the Salero Formation.

In summary, if the section in the Little Hatchet Mountains is reconstructed as proposed here, there is a sequence of Lower Cretaceous rocks, about 9,000 feet (2,750 m) thick (with the base not exposed), that is closely comparable to the sequence in the Big Hatchet Mountains and that can be reasonably correlated with sections to the west in southeastern Arizona. Above the

Lower Cretaceous rocks are formations that appear to be similar to and correlative with Upper Cretaceous formations in southeastern Arizona.

OTHER AREAS

Cretaceous rocks crop out in several other areas in southwestern New Mexico. In some of these areas, the rocks are so similar to those in nearby areas already described that no further description is useful here, and in some areas the rock exposures are so limited that they are of little value in regional interpretations. The Cretaceous rocks along the west side of the Tres Hermanas Mountains, however, are worthy of brief mention.

In the Tres Hermanas Mountains, both the upper and lower contacts of the Cretaceous rocks are fault zones, and therefore the total thickness is unknown; but Kottlowski and Foster (1962, p. 2097) measured 1,530 feet (486 m) of exposed beds between the faults which, in ascending order, they described as follows: 374 feet (114 m) of chert conglomerate, arkosic to quartzose sandstone, pale-red siltstone, and gray silty limestone; 395 feet (120 m) of gray coarsely crystalline massive limestone with scattered lenses of limestone-pebble conglomerate near the top; about 35 feet (11 m) of sandstone; 318 feet (97 m) of limestone-pebble to boulder conglomerate; 70 feet (21 m) of sandstone and chert conglomerate; and 338 feet (103 m) of sparsely fossiliferous gray limestone. Poorly preserved pelecypods from the limestone indicate an Early Cretaceous age, and the rocks were compared by Kottlowski and Foster (1962, p. 2096) to the Lower Cretaceous limestones in the Big Hatchet and the Little Hatchet Mountains. No doubt they are generally correlative and are of Aptian and (or) early Albian age.

This incomplete sequence in the Tres Hermanas Mountains is significant because of the presence of so much conglomerate in the limestone interval. It suggests that the Tres Hermanas area was very near a relatively high and rugged coastline in Aptian and early Albian time.

AREAS TO NORTH

WINCHESTER AND LITTLE DRAGOON MOUNTAINS

(Fig. 5, col. 17)

Rocks assigned to the Bisbee Group and mapped as two units—the Glance Conglomerate and the undivided Morita and Cintura Formations—are present in the southern part of the Little Dragoon Mountains (fig. 4) and in the nearby Gunnison and Steele Hills (Cooper and Silver, 1964, p. 73–76). There is some suggestion that the Glance Conglomerate, which locally may exceed 1,000 (300 m) feet in thickness, interfingers southward with finer clastic sediments. The combined Morita and Cintura Formations are at least 2,500 feet (760 m) thick in the area and may be much thicker. The rocks in the Little Dragoon area locally appear to be similar to the Bisbee Formation in the Dragoon Mountains but elsewhere may more closely resemble the Bisbee in the Whetstone and Empire Mountains area.

Rocks assignable to the Bisbee have not been recognized north of the Steele Hills and are presumably absent due to nondeposition.

Cooper and Silver (1964, p. 76–78) described a sequence, estimated to be 4,000 feet (1,200 m) thick, of feldspathic sandstone, siltstone, conglomerate, and a few small lenses of rhyolitic tuff and flow breccia that crop out in several places along the base of the Winchester Mountains. The well-rounded conglomerates in the lower sequence contain fragments of diverse rocks including limestone conglomerate believed to represent the Glance Conglomerate. Probably, the sequence of sedimentary rocks is of Late Cretaceous age and is a general equivalent of the Fort Crittenden Formation. It is overlain by about 950 feet (290 m) of dominantly andesitic rocks. The andesitic rocks are probably approximately equivalent to the lower part of the Salero Formation. Cooper and Silver (1964, p. 78) assigned a Cretaceous(?) age to all these unnamed rocks.

NORTHERN SANTA CATALINA MOUNTAINS AREA

(Fig. 5, col. 18)

The American Flag Formation, named and described by Creasey (1967a, p. 41–44) for exposures on the northeast slopes of the Santa Catalina Mountains (fig. 4), is a sequence more than 2,000 feet (600 m) thick of graywacke, olive-hued siltstones, and conglomerates with well-rounded pebbles to boulders probably derived from Paleozoic and Precambrian rocks. The formation has yielded the fresh-water mollusks *Unio* and *Viviparus*. Where I viewed the formation, it has many lithologic characteristics that are similar to those of the Fort Crittenden Formation, and it is therefore considered to be a probable general equivalent. It was assigned a Cretaceous(?) age by Creasey (1967a, p. 42). The formation rests unconformably on Mississippian strata; no older Cretaceous rocks are known in the area.

A few miles north of the Santa Catalina Mountains, near Mammoth, the Cloudburst Formation, as described by Heindl (1963, p. E5–E13) and Creasey (1967a, p. 49–55), is a possible general equivalent of at least the lower part of the Salero Formation. Assigned a Late(?) Cretaceous or early Tertiary age by Creasey (1967a), it consists of conglomerates and andesitic to latitic flows. The formation was correlated by Creasey (1967a, p. 10) with similar rocks in the Christmas area which overlie lower Upper Cretaceous sedimentary rocks and which were correlated by Richard and Courtright (1960) with their Silver Bell Formation in the Silver Bell Mountains area.

MORENCI TO CHRISTMAS AREA

(Fig. 5, col. 19)

Cretaceous rocks that are very different in character from those in areas to the south are present at several localities between Morenci and Christmas north of lat 32°55′ N. in Arizona (fig. 4).

The Cretaceous strata at Morenci were first described by Lindgren (1905, p. 73–74), who named them the Pinkard Formation; they have not been studied in detail since. At Morenci, the Pinkard Formation rests with erosional unconformity on Mississippian limestone and is unconformably overlain by Tertiary rocks. About 200 feet (60 m) of strata at the base of the formation is preserved there. It consists of dark fissile shale and some sandstone and has yielded marine fossils that indicate a Colorado or early Late Cretaceous age.

In the Deer Creek area a few miles east of Christmas, Cretaceous strata containing coaly beds were examined first by Walcott (1885) and have since been described to some extent by Campbell (1904), Ross (1925), and Willden (1964) but have never been formally named. Willden (1964) divided these rocks into two unnamed units, a lower sedimentary unit and an upper volcanic and sedimentary unit, which are separated by a "widespread erosional unconformity with a small angular discordance at some places." The lower sedimentary unit of the Christmas area, as much as 500 feet (150 m) thick, is similar to the Pinkard Formation in the Morenci area, but it contains some thin coaly beds in the lower part and some higher conglomerate beds that were derived mostly from lower Paleozoic and upper Precambrian rocks. Marine invertebrate fossils and plant fossils from the unit indicate an early Late Cretaceous age, the same as that of the Pinkard Formation. The unit rests unconformably on Pennsylvanian rocks.

The unnamed volcanic and sedimentary unit is apparently at least 3,000 feet (900 m) thick locally. It was subdivided by Willden (1964, p. E27) into (1) a basal unit several hundred feet thick of andesitic agglomerate, mudflows, and flow breccias; (2) a unit as much as 300 feet (90 m) thick of conglomerate, sandstone, mudstone, and tuff; (3) a unit at least 1,000 feet (300 m) thick of andesitic agglomerate, mudflows, tuff, and flow breccias; and (4) an upper unit at least 1,000 feet (300 m) thick of andesitic flow breccias, agglomerate, and mudflows. According to Creasey (1967a, p. 55) these rocks "were intruded by a quartz diorite porphyry whose isotopic age by the K/Ar method using biotite is 63 million years." This volcanic and sedimentary unit was correlated by Richard and Courtright (1960) with their Silver Bell Formation in the Silver Bell Mountains and by Creasey (1967a, p. 55) with the Cloudburst Formation in the northern Santa Catalina Mountains area. Both correlations seem reasonable.

Cretaceous strata in the Aravaipa area (fig. 4) were most recently described by Simons (1964). Rocks referred by him to the Pinkard Formation are as much as 1,000 feet (300 m) thick and are intermediate in lithologic character between the Pinkard Formation in the Morenci area and the lower sedimentary unit in the Christmas area; they apparently contain no coaly beds and much less conglomerate than sandstone, siltstone, and shale. Unconformably overlying the Pinkard Formation are the Williamson Canyon Volcanics—andesitic and dacitic rocks probably at least 2,500 feet (750 m) thick that undoubtedly represent the unnamed volcanic and sedimentary unit in the Christmas area. Simons (1964, p. 47) noted the close similarity of rocks in the Williamson Canyon Volcanics to rocks in the lower part of the Bronco Volcanics in the Tombstone area but made no definite correlation. On the basis of accumulated regional evidence, such a correlation certainly seems reasonable. Krieger (1968b) assigned a Late Cretaceous and (or) Tertiary age to the Williamson Canyon Volcanics.

SILVER CITY–SANTA RITA AREA, NEW MEXICO

(Fig. 5, col. 20)

Two sedimentary formations of Cretaceous age are recognized in the Silver City–Santa Rita area: the Beartooth Quartzite at the base and the overlying Colorado Formation. These units were first defined by Paige (1916) and have since been mapped by various workers in surrounding areas, most recently by Jones, Hernon, and Moore (1967). The following brief descriptions of these formations and of the overlying andesitic volcanics of probable Cretaceous age are taken largely from these two sources and partly from a general summary paper by Kottlowski (1963).

The Beartooth Quartzite rests unconformably on rocks ranging in age from Precambrian to Permian and is overlain with apparent conformity by the Colorado Formation. It is 50–140 feet (15–48 m) thick and consists largely of fine to very fine grained thin-bedded to massive locally crossbedded sandstone.

The Colorado Formation, possibly as much as 2,000 feet (600 m) thick locally, comprises a lower shale member about 200 feet (60 m) thick and an upper, sandstone member. The shale member consists of dark-gray generally fissile partly sandy shale that contains a few beds of fine-grained sandstone. The sandstone member consists of an alternating series of shale, sandstone, and mudstone beds. The top of the Colorado Formation in the area is an erosional unconformity.

Marine invertebrate fossils from the middle of the shale member support a correlation with the Graneros Shale of northeastern New Mexico and Colorado and thus suggest a late Cenomanian age (Cobban and Reeside, 1952). Fossils from the lower part of the sandstone member indicate a correlation with the Greenhorn Limestone in northeastern New Mexico and Colorado.

Fossils useful for dating have not been found in the Beartooth Quartzite or in the upper part of the sandstone member of the Colorado Formation. Darton (1928, p. 38), however, correlated the Beartooth on the basis of lithology and stratigraphic position with the Sarten Sandstone in the Cooks Range, about 30 miles (50 km) east-southeast of Santa Rita, which has yielded a fauna considered to be correlative with the Washita or Fredericksburg Groups of Texas. Because of their apparent conformity with the overlying Colorado Formation, the Beartooth Quartzite and the Sarten Sandstone are most likely of late Washita (early Cenomanian) age. Thus, they both may be equivalent to the upper part of the Mojado Formation of Zeller (1965) in the Big Hatchet Mountains (fig. 5). The upper part of the sandstone member of the Colorado Formation must be younger than the Greenhorn and may represent much of Turonian time.

The oldest rocks unconformably overlying the Colorado Formation are unnamed andesitic breccias, lavas, and agglomerates of probable Late Cretaceous age. These rocks are similar in lithology and general stratigraphic position to the Salero Formation in southeastern Arizona and are probably approximately equivalent. According to Callaghan (1953), they may also be equivalent to altered and mineralized andesitic and latitic breccias in the Kingston area, New Mexico, 25 miles (40 km) farther east.

OUTLYING REGIONS

SONORA, MEXICO

In Sonora, Mexico, Cretaceous sedimentary and volcanic rocks, few of which have been studied in detail, are present at many localities. Lower Cretaceous rocks similar in general to the Bisbee Group in southeastern Arizona occur in several areas in northern Sonora within 75 miles (110 km) of the United States–Mexico border. Rocks of similar age, but which contain interbedded volcanics in increasing amounts westward, are present at several localities in east-central Sonora between 110 and 185 miles (180 and 300 km) south of the border. Other than the rocks of the Cabullona Group of Taliaferro (1933) already described (p. B18), Upper Cretaceous sedimentary rocks are not known in Sonora. Uppermost Cretaceous volcanics may be widely distributed but, if so, have not generally been distinguished from Cenozoic volcanics.

In the Sierra de los Ajos (fig. 4), both the Glance Conglomerate and the Morita Formation of the Bisbee Group are present according to Imlay (1939, p. 1736–1737). The Glance there is at least 5,000 feet (1,500 m) thick, and the Morita, though not measured, is at least several thousand feet thick. The Morita is similar to the Morita of the Mule Mountains in Arizona, except for the presence of a coal bed several thousand feet above the base.

Imlay (1939, p. 1733–1735) also described Lower Cretaceous rocks in the El Tigre area, about 50 miles (80 km) south of the United States–Mexico border near long 109°10′ W. He measured 2,850 feet (870 m) of Cretaceous strata there between an unconformable contact with upper Paleozoic limestone at the base and an unconformable contact with Tertiary conglomerates at the top. The Cretaceous sequence—which consists of interbedded sandstone, shale, and limestone bearing marine invertebrate fossils of Aptian age—seems to be similar, in general, to the basal several thousand feet of the Bisbee Group in the Pedregosa Mountains and in the southern part of the Peloncillo Mountains in Arizona.

In the Santa Ana–Altar area in northwestern Sonora, mollusks that Popenoe, Imlay, and Murphy (1960, p. 1517–1518) considered as most likely of Albian age have been collected by various workers from several localities. At one of these localities, 8 miles (13 km) west of Santa Ana, I examined the rocks and found that they resemble rocks of the Bisbee Group in southeastern Arizona. Tentatively, these rocks are considered as western equivalents of at least the Albian part of the Bisbee Group.

Rocks of Cretaceous age at several localities in east-central Sonora, between 110 and 185 miles (180 and 300 km) south of the United States–Mexico border, were described by King (1939). In that region, the Cretaceous strata overlie sedimentary rocks of Triassic and Jurassic age and are overlain by volcanics of probable Tertiary age. Toward the east (near long 109° W.), the Cretaceous is represented by many thousands of feet of fossiliferous marine strata of Albian age, the upper half of which contains some interbedded andesite and agglomerate. Toward the west, according to King (1939, p. 1659), "the limestones thin out, the clastic sedimentary rocks thicken and contain great quantities of volcanic detritus, and there are thick lava flows."

SOUTHWESTERN ARIZONA

Sedimentary sequences of unequivocal Cretaceous age have not been identified in southwestern Arizona although they probably exist. The westward thinning of Cretaceous sedimentary sequences in the ranges west of the Santa Cruz River and the apparent absence of Cretaceous sedimentary strata in the Vekol Mountains (p. B27), however, suggest that any Cretaceous sedimentary sequences that may be present in southwestern Arizona probably have no direct relation to those in the southeastern part of the State.

Wilson (1933, p. 79–80) briefly described a sequence, estimated to be more than 1,000 feet (300 m) thick, that consists dominantly of greenish-gray shale and apparently unfossiliferous limestone and subordinately of sandstone and conglomerate to which he assigned a Cretaceous(?) age in the Castle Dome Mountains (fig. 4). He stated that the rocks were practically identical with those in a sequence about 25 miles (40 km) to the north in the New Water Mountains. I have seen some of these rocks in the New Water Mountains and similar strata in other nearby ranges and believe they may be approximately equivalent to a thick series of moderately metamorphosed strata in the McCoy Mountains, about 50 miles (80 km) west of the New Waters in California, from which E. C. Beaumont (oral commun., 1968) collected fragments of dichotoledenous plant fossils that C. B. Read stated (oral commun., 1969) can be no older than Albian.

Volcanic rocks, largely andesitic, that have been assigned a Cretaceous age occur in many places in southwestern Arizona (Wilson and others, 1969). Many of these may be general equivalents of the Upper Cretaceous Salero Formation in southeastern Arizona.

NORTHERN ARIZONA AND NEW MEXICO

Cretaceous strata in northern Arizona and New Mexico differ greatly from those in southeastern Arizona. However, certain major events that took place in Cretaceous time affected the regimens of sedimentation and erosion in both regions, so the Cretaceous rocks in the northern region merit a brief summary description here.

The oldest Cretaceous rocks in this northern region are represented by the Burro Canyon Formation, which occurs only in northeasternmost Arizona and northwesternmost New Mexico (Craig and others, 1955, p. 160). The Burro Canyon gradationally overlies the Morrison Formation of Late Jurassic age and has yielded nonmarine fossil vertebrates, invertebrates, and plant remains of Aptian or Trinity aspect from its upper part (Simmons, 1957, p. 2526). The formation is truncated southward by a post-Burro Canyon and pre-Late Cretaceous erosion surface (Craig and others, 1955, p. 161). The Burro Canyon may well be an age equivalent of at least a part of the Bisbee Group in southeastern Arizona; however, I believe that the two units were never physically connected across the intervening region but that this intervening region was an upland source area that may have contributed sediments to both units.

Unconformably overlying the Burro Canyon Formation, where it remains, and Jurassic or older strata elsewhere throughout northern Arizona and New Mexico, is a thick sequence of both marine and nonmarine formations that represents, with only a few minor breaks, all of Cretaceous time from late Albian or early Cenomanian through the Maestrichtian. Numerous papers of both local and regional scope have been written about the lithologies, ages, correlations, environments of deposition, and intertonguing relations of the many stratigraphic units involved. Although outdated in part, the regional correlation paper of Cobban and Reeside (1952) probably remains the best general reference for the region as a whole.

The lowest formations in this nearly complete sequence of Upper Cretaceous and uppermost Lower Cretaceous strata contain rocks of marine origin deposited in late Albian, Cenomanian, and early Turonian time in or near the margins of a shallow sea that advanced from the east and northeast. Rocks deposited during the early phases of this initial advance are roughly correlative with the uppermost part of the Mojado Formation in the Big Hatchet Mountains area of southwestern New Mexico, with the Beartooth Quartzite and Colorado Formation in the Santa Rita–Silver City area of New Mexico, and with the Pinkard Formation in the Morenci-Christmas area in Arizona.

From late Turonian until early Campanian time, there was a general eastward and northeastward regression of the seas (interrupted by minor transgressions) from northern Arizona and northwestern New Mexico which resulted in deposition of the largely continental rocks of the Mesaverde Group in those areas while marine shales were being deposited in northeastern New Mexico. There are no known time equivalents of these rocks in southernmost southeastern Arizona. This area probably was an eroding upland from which was derived some of the detrital sediment preserved in the Mesaverde Group.

Another major transgression of the sea into northwestern New Mexico took place in Campanian time and resulted in deposition of the Lewis Shale. The Lewis may be an approximate correlative of the Fort Crittenden Formation in southeastern Arizona and of the Cabullona Group of Taliaferro (1933) in Sonora.

The final eastward and northeastward regression of the Cretaceous sea from northern Arizona and New Mexico began in late Campanian time and resulted in the deposition of regressive sandstone deposits and overlying continental sediments. The regressive sandstones are the Pictured Cliffs Sandstone in northwestern New Mexico and the somewhat younger Trinidad Sandstone in northeastern New Mexico; the overlying continental sediments are preserved in the Fruitland and Kirtland Formations and younger rocks in northwestern New Mexico and in the Vermejo Formation in northeastern New Mexico. The lower of these rocks, at least, are probably approximate time-equivalents of the Salero Formation and correlatives in southeastern Arizona.

WESTERN TEXAS AND ADJOINING AREAS

Cretaceous rocks are widely distributed in western Texas and in adjacent parts of Mexico and central Texas. These rocks are too far removed from southeastern Arizona to require detailed description in this report, but a brief summary of their ages and lithologies is pertinent.

Rocks of Neocomian age are not known to be definitely present in western Texas but apparently are present in the lower Rio Conchos area and elsewhere in northern Chihuahua (fig. 4). The rocks of presumed Neocomian age in Chihuahua, the Las Vigas Formation of Scott (1940), are dominantly red and gray shales interbedded with sandstone and thin layers of limestone (King and Adkins, 1946, p. 284).

The oldest Cretaceous strata in western Texas are in the Etholen Conglomerate and Torcer Formation, both largely of marine origin, which Albritton and Smith (1965) believed might be equivalent to one another, at least in part. These formations have not yielded fossils that allow an unequivocal age assignment. The Torcer Formation overlies the Malone Formation of Late Jurassic age with apparent conformity and underlies the Yucca Formation with apparent conformity; the Yucca Formation, in turn, conformably underlies rocks of definite early Albian age (Albritton and Smith, 1965, p. 38, 50, 52). Because marine rocks of Neocomian age are not present in any direction, except possibly to the south, the Etholen Conglomerate and Torcer Formation are here tentatively considered to be of early Aptian age and the Yucca Formation of late Aptian age although a Neocomian age for the lower of these is possible.

Rocks of marine origin that are equivalent to the Trinity, Fredericksburg, and Washita Groups in central Texas and are assigned to various formations are widely distributed in western Texas and have been most recently described in detail by Albritton and Smith (1965), King (1965), and Maxwell, Lonsdale, Hazzard, and Wilson (1967); and their occurrence in northern Chihuahua has been summarized by Córdoba (1969). These formations were deposited in seas that transgressed from the south, and only the younger formations are present in northern parts of western Texas.

Cretaceous strata younger than those correlative with the Washita Group are very sparsely preserved in westernmost Texas, but in the Big Bend area, nearly all the Upper Cretaceous is represented (Maxwell and others, 1967). There, all Upper Cretaceous strata older than late Campanian are of marine origin, whereas rocks of late Campanian and Maestrichtian age are continental sandstones and shales that contain some coal beds. The lower of these rocks of continental origin, represented in the upper part of the Aguja Formation, are here considered to be roughly equivalent to the Salero Formation in southeastern Arizona.

ECONOMIC GEOLOGY OF CRETACEOUS STRATA

The layered Cretaceous rocks are only of limited direct economic importance at present and seem to offer only a modest potential for future importance.

Although in many mineralized areas in the region the plutonic bodies responsible for introducing mineralizing solutions are younger than most of the Cretaceous layered rocks, strata older than the Salero Formation and equivalents seem to have been very poor host rocks for base-metal mineralization. The andesites of the Salero and equivalents, on the other hand, have been altered at many localities, and some contain disseminated copper deposits of value. The chief value in understanding the stratigraphy of the older Cretaceous rocks in these areas is in the interpretation of the local structure and geologic history. In areas such as Bisbee in the Mule Mountains, the principal base-metal mineralization is of pre-Bisbee age (Bryant and Metz, 1966, p. 202–203), and sandstones in the Bisbee Group contain trace amounts of base-metal ore minerals but not to the degree that they have importance as fossil placers.

Limestone from the Mural Limestone is presently quarried, for use in copper smelters, from a locality just east of the Mule Mountains in Arizona and from another locality just south of the Mule Mountains in Sonora. In several areas east of the Mule Mountains, the Mural Limestone might be a good source of cement rock if economic factors should warrant its exploitation.

The fossil reef-mounds or bioherms present in the Mural Limestone and correlatives in southeasternmost Arizona and to the east in New Mexico might, under proper structural conditions, serve as reservoir rocks for oil or gas in some of the intermontane basins. Other rocks in the Cretaceous sequence appear to be far too impermeable to be good potential reservoir rocks for hydrocarbons or to serve as good aquifers for ground water.

REFERENCES CITED

Albritton, C. C., Jr., and Smith, J. F., Jr., 1965, Geology of the Sierra Blanca area, Hudspeth County, Texas: U.S. Geol. Survey Prof. Paper 479, 131 p.

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

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

Bromfield, C. S., and Wrucke, C. T., 1961, Reconnaissance geologic map of the Cedar Mountains, Grant and Luna Counties, New Mexico: U.S. Geol. Survey Mineral Inv. Field Studies Map MF–159.

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

Bryant, D. G., and Metz, H. E., 1966, Geology and ore deposits of the Warren mining district, *in* Titley, S. R., and Hicks, C. L., eds., Geology of the porphyry copper deposits, southwestern North America: Arizona Univ. Press, p. 189–203.

Callaghan, Eugene, 1953, Volcanic rocks of southwestern New Mexico, *in* New Mexico Geol. Soc. Guidebook 4th Field Conf., Oct. 1953: p. 143–144.

Campbell, M. R., 1904, The Deer Creek coal field, Arizona: U.S. Geol. Survey Bull. 225, p. 240–258.

Cobban, W. A., and Reeside, J. B., Jr., 1952, Correlation of the Cretaceous formations of the Western Interior of the United States: Geol. Soc. America Bull., v. 63, no. 10, p. 1011–1043.

Cooper, J. R., 1959, Reconnaissance geologic map of southeastern Cochise County, Arizona: U.S. Geol. Survey Mineral Inv. Field Studies Map MF–213.

——— 1960, Reconnaissance map of the Willcox, Fisher Hills, Cochise, and Dos Cabezas quadrangles, Cochise and Graham Counties, Arizona: U.S. Geol. Survey Mineral Inv. Field Studies Map MF–231.

——— 1970, Mesozoic stratigraphy of the Sierrita Mountains, Pima County, Arizona: U.S. Geol. Survey Prof. Paper 658–D (in press).

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.

Córdoba, D. A., 1969, Mesozoic stratigraphy of northeastern Chihuahua, Mexico, *in* Córdoba, D. A., Wengerd, S. A., and Shomaker, John, eds., Guidebook of the border region: New Mexico Geol. Soc., 20th Field Conf., Oct. 23–25, 1969, p. 91–96.

Craig, L. C., and others, 1955, Stratigraphy of the Morrison and related formations, Colorado Plateau region, a preliminary report: U.S. Geol. Survey Bull. 1009–E, p. 125–168.

Creasey, S. C., 1967a, General geology of the Mammoth quadrangle, Pinal County, Arizona: U.S. Geol. Survey Bull. 1218, 94 p.

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

Creasey, S. C., and Kistler, R. W., 1962, Age of some copper-bearing porphyries and other igneous rocks in southeastern Arizona, *in* Short papers in geology, hydrology, and topography: U.S. Geol. Survey Prof. Paper 450–D, p. D1–D5.

Dane, C. H., 1960, The boundary between rocks of Carlile and Niobrara age in San Juan Basin, New Mexico and Colorado: Am. Jour. Sci., v. 258–A (Bradley volume), p. 46–56.

Darton, N. H., 1928, "Red beds" and associated formations in New Mexico; with an outline of the geology of the State: U.S. Geol. Survey Bull. 794, 356 p.

Drewes, Harald, 1968, The Laramide orogeny of Arizona southeast of Tucson [abs.]: Geol. Soc. America Cordilleran Section Program 64th Ann. Mtg., Tucson, 1968, p. 52–53.

——— 1970a, Geologic map and sections of the Mount Wrightson quadrangle, Santa Cruz and Pima Counties, Arizona: U.S. Geol. Survey Misc. Geol. Inv. Map I–614 (in press).

——— 1970b, Geologic map of the Sahuarita quadrangle, southeast Tucson, Pima County, Arizona: U.S. Geol. Survey Misc. Geol. Inv. Map I–613 (in press).

——— 1970c, Mesozoic stratigraphy of the Santa Rita Mountains, southeast of Tucson, Arizona: U.S. Geol. Survey Prof. Paper 658–C (in press).

Elston, W. E., 1957, Geology and mineral resources of Dwyer quadrangle, Grant, Luna, and Sierra Counties, New Mexico: New Mexico Bur. Mines and Mineral Resources Bull. 38, 86 p.

Enlows, H. E., 1951, The igneous geology of Chiricahua National Monument, Arizona [summary]: Tulsa Geol. Soc. Digest, v. 19, p. 105–107.

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

Fernandez, L. A., Jr., and Enlows, H. E., 1966, Petrography of the Faraway Ranch Formation, Chiricahua National Monument, Arizona: Geol. Soc. America Bull., v. 77, no. 9, p. 1017–1030.

Finnell, T. L., 1970, Formations of the Bisbee Group, Empire Mountains quadrangle, Pima County, Arizona, *in* Cohee, G. V., Bates, R. G., and Wright, W. B., Changes in stratigraphic nomenclature by the U.S. Geological Survey, 1968: U.S. Geol. Survey Bull. 1294–A, 55 p.

Flege, R. F., Jr., 1959, Geology of the Lordsburg quadrangle, Hidalgo County, New Mexico: New Mexico Bur. Mines and Mineral Resources Bull. 62, 36 p.

Gill, J. R., and Cobban, W. A., 1966, The Red Bird section of the Upper Cretaceous Pierre Shale in Wyoming, *with a section on* A new Echinoid from the Cretaceous Pierre Shale of eastern Wyoming, by P. M. Kier: U.S. Geol. Survey Prof. Paper 393–A, 73 p.

Gillerman, Elliot, 1958, Geology of the central Peloncillo Mountains, Hidalgo County, New Mexico, and Cochise County, Arizona: New Mexico Bur. Mines and Mineral Resources Bull. 57, 152 p.

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

Griggs, R. L., and Wagner, H. C., 1966, Geology and ore deposits of the Steeple Rock mining district, Grant County, New Mexico: U.S. Geol. Survey Bull. 1222–E, p. E1–E29 [1967].

Harshbarger, J. W., Repenning, C. A., and Irwin, J. H., 1957, Stratigraphy of the uppermost Triassic and the Jurassic rocks of the Navajo country [Colorado Plateau]: U.S. Geol. Survey Prof. Paper 291, 74 p.

Hayes, P. T., 1970, 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, *in* Titley, S. R., ed., Arizona Geol. Soc. Southern Arizona Guidebook 3, 1968: p. 49–58.

Hayes, P. T., and Landis, E. R., 1964, Geologic map of the southern part of the Mule Mountains, Cochise County, Arizona: U.S. Geol. Survey Misc. Geol. Inv. Map I–418.

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

Heindl, L. A., 1963, Cenozoic geology in the Mammoth area, Pinal County, Arizona: U.S. Geol. Survey Bull. 1141–E, p. E1–E41.

——— 1965a, Mesozoic formations in the Comobabi and Roskruge Mountains, Papago Indian Reservation, Arizona: U.S. Geol. Survey Bull. 1194–H, 15 p.

——— 1965b, Mesozoic formations in the Vekol Mountains, Papago Indian Reservation, Arizona: U.S. Geol. Survey Bull. 1194–G, 9 p.

Heindl, L. A., and Fair, C. L., 1965, Mesozoic(?) rocks in the Baboquivari Mountains, Papago Indian Reservation, Arizona: U.S. Geol. Survey Bull. 1194–I, 12 p.

Imlay, R. W., 1939, Paleogeographic studies in northeastern Sonora [Mex.]: Geol. Soc. America Bull., v. 50, no. 11, p. 1723–1744.

Jicha, H. L., Jr., 1954, Geology and mineral deposits of Lake Valley quadrangle, Grant, Luna, and Sierra Counties, New Mexico: New Mexico Bur. Mines and Mineral Resources Bull. 37, 93 p.

Jones, W. R., Hernon, R. M., and Moore, S. L., 1967, General geology of Santa Rita quadrangle, Grant County, New Mexico: U.S. Geol. Survey Prof. Paper 555, 144 p.

King, P. B., 1965, Geology of the Sierra Diablo region, Texas, *with* Special determinative studies of Permian fossils, by L. G. Henbest, E. L. Yochelson, P. E. Cloud, Jr., Helen Duncan, R. M. Finks, and I. G. Sohn: U.S. Geol. Survey Prof. Paper 480, 185 p.

King, P. B., King, R. E., and Knight, J. B., 1945, Geology of Hueco Mountains, El Paso and Hudspeth Counties, Texas, 1945: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 36, 2 sheets.

King, R. E., 1939, Geological reconnaissance in northern Sierra Madre Occidental of Mexico: Geol. Soc. America Bull., v. 50, no. 11, p. 1625–1722.

King, R. E., and Adkins, W. S., 1946, Geology of a part of the lower Conchos Valley, Chihuahua, Mexico: Geol. Soc. America Bull., v. 57, no. 3, p. 275–294.

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

——— 1959, Chaotic breccias in the Tucson Mountains, Arizona, *in* Arizona Geol. Soc. Guidebook 2, Apr. 1959: Arizona Geol. Soc. Digest, 2d Ann., p. 48–57.

Konishi, Kenji, and Epis, R. C., 1962, Some early Cretaceous calcareous algae from Cochise County, Arizona: Micropaleontology, v. 8, no. 1, p. 67–76.

Kottlowski, F. E., 1963, Paleozoic and Mesozoic strata of southwestern and south-central New Mexico: New Mexico Bur. Mines and Mineral Resources Bull. 79, 100 p.

Kottlowski, F. E., and Foster, R. W., 1962, Pre-Tertiary strata of Tres Hermanas Mountains, Luna County, New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 46, no. 11, p. 2090–2098.

Krieger, M. H., 1968a, Geologic map of the Brandenburg Mountain quadrangle, Pinal County, Arizona: U.S. Geol. Survey Geol. Quad. Map GQ–668.

——— 1968b, Geologic map of the Holy Joe Peak quadrangle, Pinal County, Arizona: U.S. Geol. Survey Geol. Quad Map GQ–669.

——— 1968c, Geologic map of the Lookout Mountain quadrangle, Pinal County, Arizona: U.S. Geol. Survey Geol. Quad. Map GQ–670.

——— 1968d, Geologic map of the Saddle Mountain quadrangle, Pinal County, Arizona: U.S. Geol. Survey Geol. Quad. Map GQ–671.

Lasky, S. G., 1947, Geology and ore deposits of the Little Hatchet Mountains, Hidalgo and Grant Counties, New Mexico: U.S. Geol. Survey Prof. Paper 208, 101 p.

Lindgren, Waldemar, 1905, The copper deposits of the Clifton-Morenci district, Arizona: U.S. Geol. Survey Prof. Paper 43, 375 p.

McKee, E. D., 1951, Sedimentary basins of Arizona and adjoining areas: Geol. Soc. America Bull., v. 62, no. 5, p. 481–505.

Maxwell, R. A., Lonsdale, J. T., Hazzard, R. T., and Wilson, J. A., 1967, Geology of Big Bend National Park, Brewster County, Texas: Texas Univ. Pub. 6711, 320 p.

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

Morrison, R. B., 1965, Geologic map of the Duncan and Canador Peak quadrangles, Arizona and New Mexico: U.S. Geol. Survey Misc. Geol. Inv. Map I–442 [1966].

Paige, Sidney, 1916, Description of the Silver City quadrangle, New Mexico: U.S. Geol. Survey Geol. Atlas, Folio 199, 19 p.

Pettijohn, F. J., 1957, Sedimentary rocks [2d ed.]: New York, Harper & Bros., 718 p.

Popenoe, W. P., 1954, Mesozoic formations and faunas, southern California and northern Baja California [Mexico], [Pt.] 3 *in* Chap. 3 *of* Jahns, R. H., ed., Geology of southern California: California Dept. Nat. Resources Div. Mines Bull. 170, p. 15–21.

Popenoe, W. P., Imlay, R. W., and Murphy, M. A., 1960, Correlation of the Cretaceous formations of the Pacific Coast (United States and northwestern Mexico): Geol. Soc. America Bull., v. 71, no. 10, p. 1491–1540.

Pratt, W. P., 1967, Geology of the Hurley West quadrangle, Grant County, New Mexico: U.S. Geol. Survey Bull. 1241–E, 91 p.

Ransome, F. L., 1904, Description of the Globe quadrangle [Ariz.]: U.S. Geol. Survey Geol. Atlas, Folio 111, 17 p.

——— 1923, Description of the Ray quadrangle [Ariz.]: U.S. Geol. Survey Geol. Atlas, Folio 217, 24 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.

Ross, C. P., 1925, Geology and ore deposits of the Aravaipa and Stanley mining districts, Graham County, Arizona: U.S. Geol. Survey Bull. 763, 120 p.

Sabins, F. F., Jr., 1957a, Geology of the Cochise Head and western part of the Vanar quadrangles, Arizona: Geol. Soc. America Bull., v. 68, no. 10, p. 1315–1341.

——— 1957b, Stratigraphic relations in Chiricahua and Dos Cabezas Mountains, Arizona: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 3, p. 466–510.

Scott, Gayle, 1940, Cephalopoda from the Cretaceous Trinity group of the south-central United States: Texas Univ. Pub. 3945, p. 969–1106.

Simmons, G. C., 1957, Contact of Burro Canyon formation with Dakota sandstone, Slick Rock district, Colorado, and correlation of Burro Canyon formation: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 11, p. 2519–2529.

Simons, F. S., 1964, Geology of the Klondyke quadrangle, Graham and Pinal Counties, Arizona: U.S. Geol. Survey Prof. Paper 461, 173 p.

Stoyanow, Alexander, 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, no. 1, p. 12–37.

Thoms, J. A., 1966, The geology and ore deposits of the Tascuela area, Sierrita Mountains, Pima County, Arizona: Michigan Univ. unpub. Ph. D. thesis.

——— 1967, The geology and ore deposits of the Tascuela area, Sierrita Mountains, Pima County, Arizona [abs.]: Dissert. Abs., sec. B, v. 27, no. 7, p. 2420B–2421B.

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

Walcott, C. D., 1885, Deer Creek coal field, White Mountain Indian Reservation, Arizona: U.S. 48th Cong., 2d sess., S. Ex. Doc. 20, p. 2–7.

West Texas Geological Society, 1959, Geology of the Val Verde Basin and field trip guidebook, Nov. 1959: 118 p.

Willden, Ronald, 1964, Geology of the Christmas quadrangle, Gila and Pinal Counties, Arizona: U.S. Geol. Survey Bull. 1161–E, 64 p.

Wilson, E. D., 1933, Geology and mineral deposits of southern Yuma County, Arizona: Arizona Bur. Mines Bull. 134, Geol. ser. 7 (Univ. Bull., v. 4, no. 2), 236 p.

Wilson, E. D., Moore, R. T., and Cooper, J. R., 1969, Geologic map of the State of Arizona: Arizona Bur. Mines and U.S. Geol. Survey.

Wrucke, C. T., and Bromfield, C. S., 1961, Reconnaissance geologic map of part of the southern Peloncillo Mountains, Hidalgo County, New Mexico: U.S. Geol. Survey Mineral Inv. Field Studies Map MF–160.

Zeller, R. A., Jr., 1958a, Reconnaissance geologic map of Dog Mountains quadrangle: New Mexico Bur. Mines and Mineral Resources Geol. Map 8 [1959].

——— 1958b, Reconnaissance geologic map of Playas fifteen-minute quadrangle: New Mexico Bur. Mines and Mineral Resources Geol. Map 7 [1959].

——— 1962, Reconnaissance geologic map of southern Animas Mountains: New Mexico Bur. Mines and Mineral Resources Geol. Map 17.

——— 1965, Stratigraphy of the Big Hatchet Mountains area, New Mexico: New Mexico Bur. Mines and Mineral Resources Mem. 16, 128 p.

Zeller, R. A., Jr., and Alper, A. M., 1965, Geology of the Walnut Wells quadrangle, Hidalgo County, New Mexico: New Mexico Bur. Mines and Mineral Resources Bull. 84, 105 p.

INDEX

[Italic page numbers indicate major references]

U.S. GOVERNMENT PRINTING OFFICE: 1970