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CENOZOIC GEOLOGY OF ARIZONA—A 1960 RESUME

By

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ABSTRACT

A framework for Cenozoic geology in Arizona is set up by defining four groupings of rocks and three structural provinces.

The four groupings include sedimentary, volcanic, intrusive, and metamorphic rocks, in varying combinations, and are referred to by their general ages—(1) late(?) Mesozoic to early(?) Tertiary, (2) early middle(?) Tertiary, (3) late middle(?) Tertiary, and (4) Tertiary and Quaternary. The late(?) Mesozoic age is included because the earliest Tertiary deposits seem to be a continuation of deposition that began in Mesozoic time. The groupings generally are separated by widespread erosion surfaces.

The three structural provinces are delineated largely on the distribution, intensity, and interplay of compressional deformation of Mesozoic and Cenozoic age and high-angle faulting and folding of late Cenozoic age. One structural province includes the northeastern part of the State and consists principally of mildly deformed Paleozoic to Cenozoic deposits that are largely unaffected by late Cenozoic faulting and folding. The second structural province includes the western and southern parts of the Colorado Plateau where mildly deformed Paleozoic and Mesozoic rocks were deformed further by late Cenozoic faulting and folding. The third structural province includes southern and western Arizona where late Cenozoic warping and faulting were superposed on intensely deformed and intruded Mesozoic to middle(?) Tertiary rocks and structures.

Deformation, particularly in southern and western Arizona, was almost continuous from Mesozoic through Cenozoic time, and the groupings are nearly everywhere separated by well-developed angular or erosional unconformities. Regionally, the unconformities represent multiple local erosion surfaces that probably overlap in part and are only generally contemporaneous.

Cenozoic rocks in Arizona are characterized by rapid lateral and vertical variation, reflecting the localization of deformation, relief, erosion, and deposition. Except for a small area in southwesternmost Arizona, all the deposits are continental. Sedimentary deposits were laid down in narrow to broad, shallow to deep basins, commonly of interior or poorly integrated drainages; however, many of the well-developed erosion surfaces represent integrated regional drainage. Widespread vulcanism occurred intermittently, particularly in southern and central Arizona, and the rocks range in composition from rhyolite to basalt. Many fine-grained intrusive bodies are closely related to the volcanic rocks. Coarse-grained intrusive rocks, principally of late(?) Mesozoic to early(?) Tertiary age, occur in many parts of southern Arizona and are local centers of mineralization and metamorphism.

CENOZOIC GEOLOGY OF ARIZONA—A 1960 RESUME[1/]

By

L. A. Heindl

The Cenozoic record of Arizona was considered for many years to be restricted largely to the latest one-third of the era—Miocene time and later. This interval, roughly 25 million years long, included much volcanic activity and the basin-and-range deformation with its accompanying alluvial and lacustrine deposition and spectacular erosion. The next older record was believed to be represented by rocks of Cretaceous or Cretaceous(?) age. With only a few exceptions, the approximately 50-million-year period between the Cretaceous(?) and the Miocene(?) appeared to be a sort of blank during which little more than the deformation and erosion of Cretaceous(?) and older rocks were presumed to have occurred. Work during the past 20 years has filled in part of this gap and also has given a more refined insight into the younger one-third of the Cenozoic than was had before. Some of the rocks previously considered to belong to the late Cenozoic have been shown to be older; some of the rocks of Cretaceous(?) age apparently are Tertiary. In short, our understanding of the Cenozoic has begun to broaden. The papers in this volume represent some of the studies made of the Cenozoic of Arizona during the past 10 years. The areas discussed in these reports are shown on figure 1.1.

This resume of the Cenozoic era is based on a synthesis of both earlier and more recent work, papers presented in this volume, and unpublished data. My debt to the many geologists who have given freely of their experience and thought, particularly John F. Lance, is gratefully acknowledged. However, the responsibility for the interpretation presented here is mine.

GENERAL GEOLOGIC SETTING

Cenozoic time represents only the last 70 million years, or about 2 percent of the approximately 3-billion-year history of the Earth. Whatever occurred during the Cenozoic must be set within the general framework of the regional relationships and their geologic history.

The older Precambrian rocks of Arizona consist principally of schist and granite that were deformed predominantly into northeast-trending structures. These rocks were beveled to a remarkably uniform surface on which the younger Precambrian and Paleozoic rocks, mostly marine deposits, were laid down during a time of predominantly broad crustal fluctuations. During early Mesozoic time moderately thick sequences of mostly continental rocks were deposited in northern Arizona. In the southern and western parts of the State, however, lower Mesozoic rocks are absent or unrecognizable as a result of

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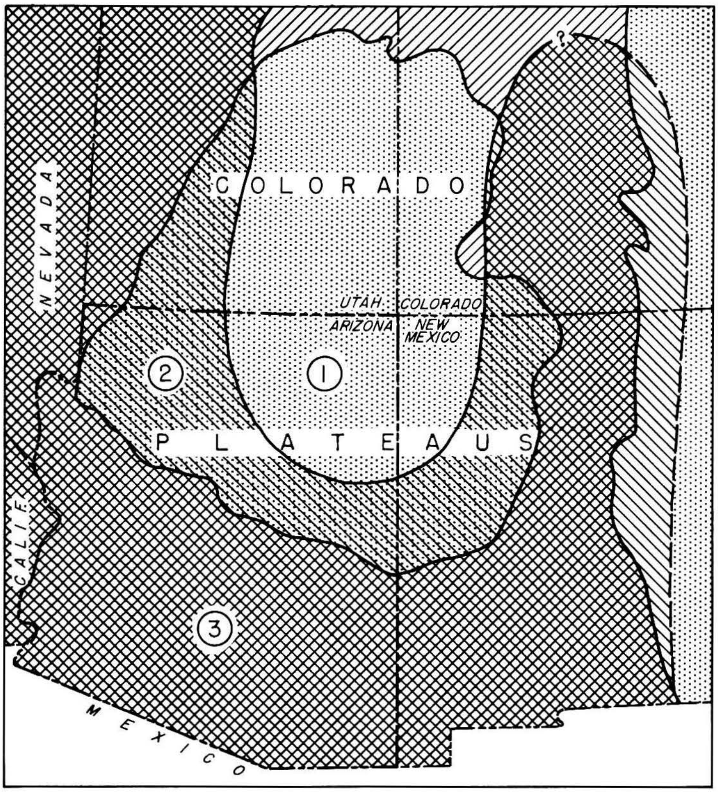
1/ Publication approved by the Director, U. S. Geological Survey.

alteration due to large-scale intrusions. In late Mesozoic time northern Arizona was part of a broad northerly slope of the Rocky Mountain geosyncline; contemporaneously, southern and western Arizona was in a zone whose southeastern part was sinking to form the Sonoran geosyncline while its western part apparently was being extensively deformed and intruded. The destruction of the Sonoran geosyncline in southern Arizona and the contemporaneous uplift of northeastern Arizona are considered to mark the earliest events considered typical of Cenozoic time in Arizona. Epeirogenic movement continued through most of Cenozoic time and at a few places appears to be nearly contemporaneous with folding and faulting associated with the present basin-and-range topography.

Arizona comprises parts of two strikingly different physiographic regions, the Colorado Plateaus and the Basin and Range provinces (fig. 1.1). These are separated by a structural and topographic high, the Mogollon Highlands, that arcs from east-central to northwestern Arizona. North and east of this high, the country is characterized by the extensive plains, broad mountains, and deep canyons of the Colorado Plateau. To the south and west the land is studded with small, discontinuous mountain ranges that stand abruptly above the adjacent basins. Generally, these two physiographic provinces have been presumed to reflect two different structural provinces, but in reality they form parts of three.

The three structural provinces are based largely on the distribution, intensity, and interplay of various episodes of Mesozoic and Cenozoic deformation (fig. 1.2). The first structural province, which occupies the northeastern part of the State, is characterized principally by mildly deformed Paleozoic to Cenozoic deposits that have been largely unaffected by Late Cretaceous and early Tertiary and late Cenozoic faulting and warping. The second structural province includes that part of the Colorado Plateau whose mildly deformed Paleozoic, Mesozoic, subsequently deposited and Cenozoic beds were deformed by late Cenozoic faulting and folding, much of it monoclinal. In general, the north-south part of the boundary between the two regions is just east of the Kaibab uplift. The third structural province includes southern and western Arizona; in this province late Cenozoic warping and high-angle faulting were superposed on intensely deformed and intruded Mesozoic to middle(?) Tertiary rocks and structures.

The principal episodes of structural deformation which these structural provinces represent were initiated in Mesozoic time, although some of the northwest-southeast and north-south trends aline roughly with those of Precambrian structures, and the deformation that began in the Mesozoic continued into the Cenozoic. During early Mesozoic time Arizona was divided into two distinct regions separated by the Mogollon Highlands. These features generally coincide with the Colorado Plateaus and Basin and Range provinces and the highlands between them. Although the term Mogollon Highlands originally was used for a Triassic structural and physiographic feature (Harshbarger and others, 1957), the name has come to be applied to the high central part of Arizona without being restricted to any particular time. During Mesozoic and Cenozoic time the Colorado Plateaus part of Arizona was uplifted but only moderately deformed; in contrast, southern and western Arizona was depressed and deformed intensely and was intruded and in part metamorphosed. Distinctions between lower Mesozoic, Laramide (Late Cretaceous and early Tertiary), and middle(?) Tertiary deformations in southern and western Arizona have been made only locally and their regional relationships are not clearly understood. In late Cenozoic time widespread broad folding and high-angle normal faulting were superposed on the earlier structures throughout much of southern, central, and western Arizona.



EXPLANATION

Rocks affected largely by only moderate Late Cretaceous and early Tertiary deformation

Rocks affected intensely by Late Cretaceous and early Tertiary deformation

Rocks affected by late Cenozoic basin-and-range type of normal faulting and warping

Structural provinces in Arizona

1 Structural province affected largely by only moderate Late Cretaceous and early Tertiary deformation

2 Structural province affected by moderate Late Cretaceous and early Tertiary deformation and by late Cenozoic basin-and-range type of normal faulting and warping

3 Structural province affected by intense Late Cretaceous and early Tertiary deformation and by late Cenozoic basin-and-range type of normal faulting and warping

Figure 1.2—Arizona and adjacent States showing structural provinces in Arizona and areas affected by different intensities of Late Cretaceous and early Tertiary deformation and by late Cenozoic basin-and-range type of normal faulting and war ping. (Areas of deformation modified from Eardley, 1951).

The areal distribution of the different episodes of deformation as expressed by the State's three structural provinces, and the division of the State into two physiographic provinces have resulted in some curious anomalies. For example: The physiographic provinces reflect the older intervals of deformation more distinctly than they do the younger, or late Cenozoic, deformation. Also, the basin-and-range topography in Arizona is not the reflection of just basin-and-range faulting, but the superposition of high-angle faulting and warping upon an earlier rugged terrain developed on intensely deformed and intruded Mesozoic to middle(?) Tertiary rocks. Again, the high-angle faulting, commonly considered to be the distinctive characteristic of the Basin and Range province, is equally well developed in parts of the Colorado Plateaus province, although it is displayed differently there because it involves moderately rather than intensely deformed rocks. Thus some of the anomalies are largely semantic: High-angle normal, "basin-and-range" faulting is not restricted to the Basin and Range province, and the Basin and Range province in Arizona is only partly the result of high-angle normal faulting.

The gross structural relationships in Arizona deserve a few additional comments. Since Mesozoic time the most obvious displacement of rocks in Arizona has been vertical, although the vertical movement in many places may have been only a component of the total movement. The largest vertical displacement has occurred along the zone between the little deformed Colorado Plateau and the intensely deformed southern and western parts of the State. This zone, referred to here as the Mogollon Highlands, forms the structural and topographic backbone of the State. On either side the terrain is lower than in the Mogollon Highlands, and the northeast part is generally lower structurally than the southern and western parts. Thus, if the surface of the early Precambrian rocks is taken as a datum, the southern and western parts of Arizona are characterized by a series of irregular blocks that step down from the general vicinity of the Mexican boundary to a low immediately south and west of the Central Highland. Along the Central Highland the surface of the early Precambrian rocks abruptly rises several thousand feet, and then slopes gently north and east toward the basins in the central part of the Colorado Plateaus. A southwest-northeast profile along this datum suggests a tilted fault block rising above a badly disrupted graben. The evolution of these structural relationships, which have so greatly influenced Cenozoic events, is probably one of the least understood facets of Arizona geology.

The Cenozoic sedimentary and volcanic rocks of the Colorado Plateau are largely late Cenozoic, Pliocene, and Pleistocene in age. However, the early and part of middle Tertiary time is represented by the volcanic Datil Formation and associated nonvolcanic sediments in east-central Arizona. These units locally are more than 2,000 feet thick, nearly flat lying, and appear to correlate with the Baca Formation in New Mexico (Willard, 1959). Except in east-central Arizona, erosion was predominant during most of early and middle Tertiary time. In contrast, the Cenozoic in southern Arizona was a time of intermittent but nearly incessant deformation, vulcanism, erosion, deposition, and intrusion. Locally, the Cenozoic deposits in southern Arizona total at least 15,000 feet in thickness and, depending on their local histories, may be either deformed practically beyond the point of recognition as sediments or are nearly undisturbed. Figure 1.3 is a synoptic diagram showing the general ages, types of rocks, and intervals of deformation and erosion in Arizona.

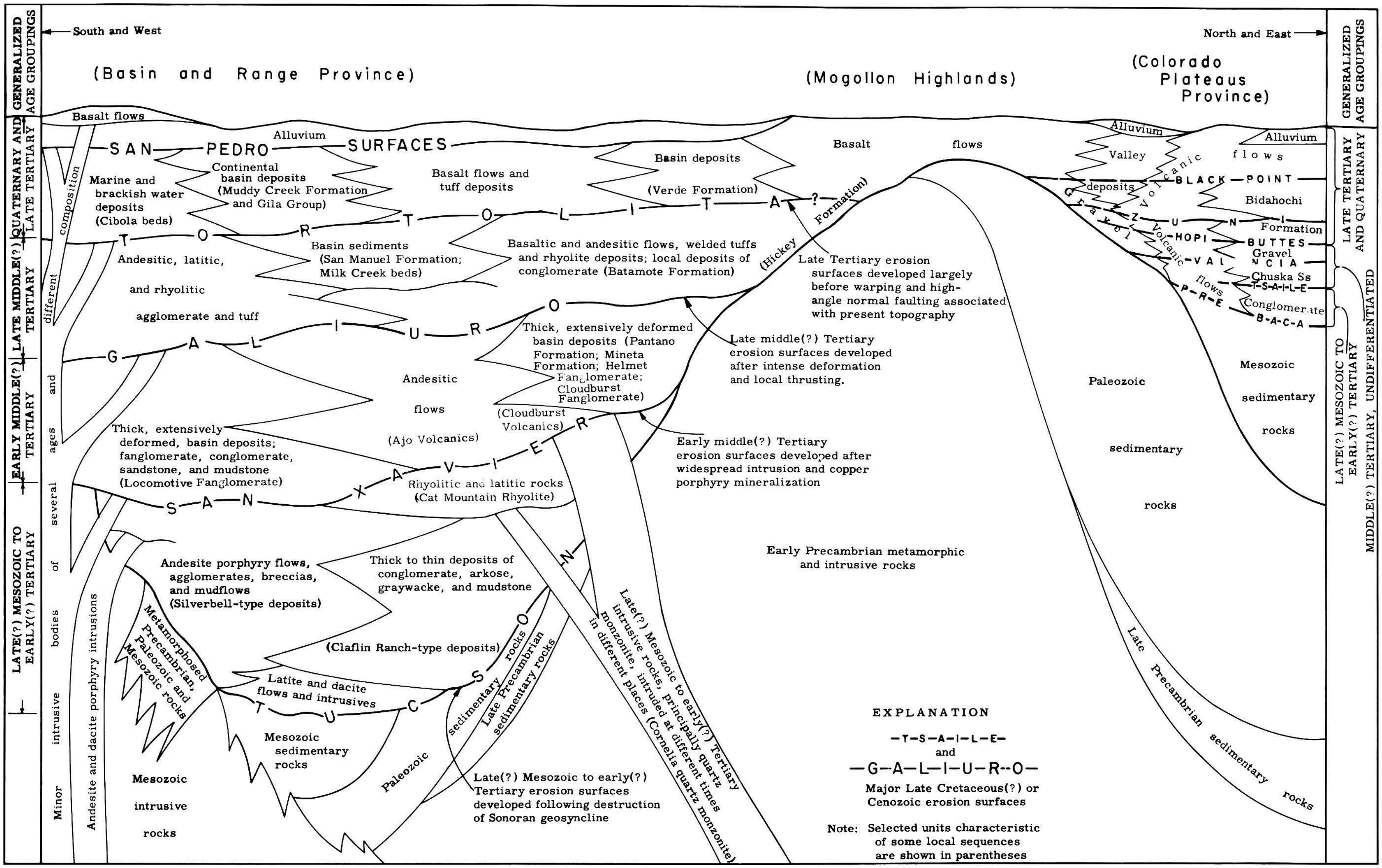


Figure 1. 3. --Synoptic diagram showing the general sequence of geologic events of the Cenozoic era in Arizona.

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CENOZOIC HISTORY

The Cenozoic rocks in southern and western Arizona reflect almost continuous deformation since late Mesozoic time. In contrast, the Cenozoic history of the Colorado Plateau was almost placid. The Mogollon Highlands form a transitional zone. In this report the Cenozoic rocks and the youngest Mesozoic rocks of Arizona are divided arbitrarily into four groupings, which are, from oldest to youngest: (1) late(?) Mesozoic to early(?) Tertiary, (2) early middle(?) Tertiary, (3) late middle(?) Tertiary, and (4) late Tertiary and Quaternary. The groupings are based principally on stratigraphic position, similarity of lithology and degree of deformation, and a few vertebrate fossils. The degree of deformation is not a consistent means for distinguishing units, but it has been useful in many reconnaissance studies and will continue to be so until detailed investigations provide more reliable criteria. In general, the groupings represent stages in the development of the region rather than ages, but it is convenient to identify them by the generalized time interval during which they were deposited or implaced. Not all stages are everywhere present; neither are they necessarily of similar regional importance, nor do they represent similar intervals of time.

The age assignments of the groupings are broad because the ages of the groupings are probably not identical in all parts of the State and because there are only five localities where pre-Pliocene Cenozoic rocks have been dated in southern Arizona—two widely separated Miocene fossil localities, one questioned Eocene locality, and two radioactive determinations. So far, only Pliocene or more recent fossils have been reported from Cenozoic rocks in northeastern Arizona. The age "late(?) Mesozoic" is included because the rocks of the oldest grouping are part of an apparently continuous sequence of deposition spanning the Mesozoic-Cenozoic boundary.

In most places the rocks of the groupings are distinctive, and the groupings are separated by well-marked angular unconformities. Locally, however, strata apparently belonging to two or more groupings may be conformable. The unconformities are similar at so many localities that their development appears to be associated with the regional structural development. On the other hand, an individual surface may represent erosion around a local center of deformation and be the time equivalent of some nearby sequence of deposits. The regional unconformities shown on figure 1.3 are diagrammatic and represent compound or multiple, more or less contemporaneous erosion surfaces.

Although structural deformation determined the principal characteristics of Cenozoic rocks, the rocks were also affected by the climate, which influenced conditions of erosion, drainage, and deposition. Red hues in the earlier Cenozoic sedimentary rocks contrast with the browns and grays of later materials, and the change appears to parallel the general climatic shift from humid to arid regimens described by R. Y. Anderson in this volume. The effects of Pleistocene and possibly Recent glaciation on sedimentation in the Southwest pose a moot question that deserves at least as much study as it has had speculation. Alternation of erosion and deposition of late Cenozoic rocks in some parts of Arizona appear to be cyclical; in other parts, however, deposition was continuous through some, if not all, glacial fluctuations. The sedimentary materials in such areas doubtless reflect the changing climate and eventually may provide a continuous record of faunal and floral changes in this region from Pliocene through Quaternary time.

In some areas the four groupings appear to represent generally contemporaneous stages of deformation, erosion, deposition, vulcanism, and, in part, intrusion. Some deposits of Miocene age in western Arizona appear to be similar lithologically to Pliocene and younger rocks in southeastern Arizona. The most recent stages of thrusting in western Arizona are older than those in eastern Arizona. Similarly, the physiography of western Arizona, with its broad plains and small ranges, seems to represent a later stage in erosional development than the physiography in the southeastern part of the State, with its rugged mountains and generally dissected valleys. It is almost as if the various structural and associated events of Arizona's Cenozoic history began somewhere to the west or southwest of the State; with time they progressed north and east, becoming younger and weaker toward the core of nearly undeformed rocks that forms the Colorado Plateau.

Late(?) Mesozoic and Early(?) Tertiary

The rocks of the late(?) Mesozoic and early(?) Tertiary grouping appear to be almost entirely restricted to the southern and western parts of Arizona, although remnants of some widespread deposits underlying the White Mountains and Datil volcanic fields in east-central Arizona belong in this interval. A few exposures of early(?) Tertiary deposits crop out on the Colorado Plateau bordering the Mogollon Highlands region. The Chuska Sandstone, once considered to be of possible Eocene age, is now believed to be younger. Some deposits in the vicinity of Lake Mead (Longwell, 1936) also may belong in the late(?) Mesozoic and early(?) Tertiary grouping.

The rocks of late Mesozoic and early Tertiary are not discussed in any paper in this volume. Much of the work showing the stratigraphic significance of these rocks has been by Courtright (1958), Kinnison (1959), Richard and Courtright (1960), Willard (1959), and Cooley and Akers (1961).

In southern Arizona, the rocks assigned to this grouping consist principally of coarse- to fine-grained continental sedimentary deposits and a variety of volcanic rocks. These rocks overlie the Tucson surface which truncates Paleozoic and some Cretaceous and Cretaceous(?) strata and are unconformably overlain by early middle(?) Tertiary and younger deposits. The volcanic rocks are characterized by, but not limited to, dark-maroon andesite porphyry. The sedimentary rocks range from boulder conglomerate, including megabreccia, to mudstone and commonly include abundant fragments of andesite porphyry and related volcanic rocks. The deposits interfinger and differ in sequence and composition from place to place. At many points the sequence is capped by rhyolitic tuff and agglomerate, similar to the Cat Mountain Rhyolite of Brown (1939). These rhyolitic rocks are the youngest rocks intruded extensively by quartz monzonite and associated with copper porphyry mineralization in the State.

The following units have a probable late(?) Mesozoic and early(?) Tertiary age: Silver Bell and Claflin Ranch Formations and related rocks in central Pima County (Courtright, 1958; Heindl, 1960; Richard and Courtright, 1960); the Bobcat Hill Conglomerate and related andesite (Gillerman, 1958), the Nipper Formation (Sabins, 1957), the Bronco volcanics and underlying conglomerate in southeastern Arizona (Gilluly, 1956); the Tucson Mountain Chaos and associated rocks west of Tucson (Kinnison, 1959); and, perhaps, the lower part of the Artillery Formation (Lasky and Webber, 1949), the Tertiary(?) rocks older than the Moss Porphyry (Ransome, 1923) in west-central Arizona, and the Black Canyon and Boulder Wash Groups (Longwell, 1936) in northwestern Arizona.

The internal structure and the stratigraphy of the rocks of this interval are complex. Lateral and vertical variations are rapid; local angular unconformities within the sequence are common; and faulting, intrusion, deformation, and metamorphism further complicate field relationships. In many places the rocks themselves have sedimentary, volcanic, or intrusive characteristics simultaneously, or rocks of different origin may appear to grade into each other.[1/] In spite of their variety, complex internal relationships, lack of dated beds, and discontinuity of exposures, the late(?) Mesozoic and early(?) Tertiary rocks appear to represent a distinct phase in the history of southern Arizona, and in the field they can be recognized by their very heterogeneity and complexity.

The age of these deposits is problematic. In southeastern Arizona, they are demonstrably post-Early Cretaceous and in some areas, post-Late Cretaceous. To the west and north, however, they become difficult to separate from lithologically similar deposits of reported Cretaceous or Late(?) Cretaceous age. Some similar deposits, long considered to be of Cretaceous(?) age, are now suspected of being older, possibly as old as Jurassic. Consequently, this sequence of sedimentary and volcanic rocks in western, southern, and central(?) Arizona may represent parts of Jurassic through early(?) Tertiary time, whereas in southeastern Arizona the sequence may represent only the latest Cretaceous and early(?) Tertiary, or just early Tertiary, time. These relationships are shown diagrammatically in figure 1.4. Some of the rocks of this interval are lithologically similar to the McCrae and Baca Formations of New Mexico which contain Cretaceous dinosaur and Eocene mammal fossils (Kelley and Caswell, 1952).

The late(?) Mesozoic and early(?) Tertiary rocks in southern and western Arizona were laid down in local continental basins at a time of intense, but probably highly localized, volcanic, intrusive, and tectonic activity. The deposits appear to have been laid down in basins around local centers of deformation and vulcanism. The distribution of these deposits suggests that they were deposited in a broad structurally depressed area bounded by two major west-northwest-trending zones of uplift—one along the southwest front of the present Colorado Plateau to the north, and the other a nearly parallel region of uplift along the Arizona-Sonora, Mexico, boundary. The predominant drainage of the region was probably in part southeast into the expanded Late Cretaceous and retreating early Tertiary seas of the Gulf of Mexico and, in part, to the west, into the Pacific Ocean across southern California. The erosion surfaces developed by these drainage systems are called collectively the San Xavier surface.

In contrast to those of southern and western Arizona, the rocks of late Mesozoic and early(?) Tertiary time were deposited rather uniformly across the northeastern part of the State. The distribution of the early(?) Tertiary rocks

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1/ Ed. Note: The general confusion of these rocks provoked graduate students at the University of Arizona in the early "fifties" into referring to them as the "Cretaceous, Choke-sob" and J. H. Courtright vividly expressed the frustration of identifying some forms by calling them the "illusive intrusive," but never in print.

in this region, although only imperfectly known because only a few remnants of the deposits remain, appears to be restricted to the northeastern margins of the Mogollon Highlands. The Late Cretaceous and early(?) Tertiary deposits represent the breakup of the western shelf area of the Rocky Mountain geosyncline into basins and areas of uplift in the Laramide time. Marine deposits of Late Cretaceous age in the northeasternmost part of the region grade into and intertongue with continental rocks to the southwest. The nonvolcanic continental deposits probably transgress time lines into the early(?) Tertiary and may correlate with the Baca Formation of New Mexico. In east-central Arizona these sediments consist of siltstone, sandstone, and conglomerate containing pebbles to boulders composed of granite, quartzite, and chert apparently derived from the Mogollon Highlands region.

Early Middle(?) Tertiary

Early middle(?) Tertiary time, in general, was a period of events similar to those in early(?) Tertiary time. The deposits of this interval in southern Arizona, however, form distinctive units, and these deposits and the probably contemporaneous but less well-known units on the Mogollon Highlands are both separated from younger rocks by well-developed, widespread erosion surfaces.

The northern part of the Colorado Plateau continued to be an area of erosion that was being drained toward the north and east. Along the north slopes and on the eastern part of the Mogollon Highlands in Arizona, however, volcanic rocks, probably belonging in the early middle(?) Tertiary grouping, were being deposited. The deposits form the Datil Formation, which consists of interbedded rhyolite and andesite flows, tuff, and sediments derived from volcanic sources. The lower sedimentary parts of the Datil probably grade upward from the underlying nonvolcanic sediments tentatively assigned to the late(?) Mesozoic and early(?) Tertiary grouping. The Datil was deformed, and subsequent erosion formed a surface called the Valencia by Cooley and Akers (1961). During early middle(?) Tertiary time, intermittent vulcanism, chiefly basaltic eruptions, occurred in many areas in the southern Colorado Plateau and Mogollon Highlands.

The Mogollon Highlands continued as a high during the early middle(?) Tertiary interval. In part, the area was built up by the eruption of volcanic rocks that make up the Datil Formation; in part it was remnant of the high that developed during late(?) Mesozoic and early(?) Tertiary time, possibly further uplifted by renewed deformation. A barrier, and a moderately high and continuous one, must be inferred to have existed between the northeastern and southwestern parts of the State to explain the discontinuity between the deposition and erosion of the two regions. Southern Arizona was an area of rugged relief around local(?) centers of uplift and deposition in restricted basins. Although drainage in northern Arizona was to the north and east, no fragments derived from rocks in southern Arizona have been identified, which suggests that drainage in the State did not extend through the Mogollon Highlands to southern Arizona.

In southern Arizona, the early middle(?) Tertiary rocks lie unconformably on the San Xavier surface cut on late(?) Mesozoic and early(?) Tertiary and older rocks and are overlain unconformably or grade into younger deposits. The basal part of the early middle(?) Tertiary sequence commonly contains large Precambrian granitic boulders, attesting to the intense deformation and deep erosion that preceded its deposition.

A large part of the early middle(?) Tertiary rocks in southern Arizona consists of thick sequences of fanglomerate deposits and andesitic flows. Intrusive rocks are minor. The fanglomerate and andesitic deposits crop out widely, and in many areas they are distinctive because of their brick-red to red-brown color, which contrasts with the maroon or gray of deposits of the late(?) Mesozoic and early(?) Tertiary interval. The andesitic flows are commonly fine grained and massive, but locally they contain distinctive large tabular feldspar phenocrysts.

The best known representatives of the early middle(?) Tertiary sequences are the Locomotive Fanglomerate and Ajo volcanics in the Ajo vicinity (Gilluly, 1946), the Cloudburst Formation in the San Manuel area (Wilson, 1957), the Helmet Fanglomerate (Cooper, 1960) and Pantano Formation of Tolman and Brennan south of Tucson, and the Mineta Formation of Chew east of Tucson. The Pantano and Mineta Formations are described in this volume.

The small intrusions assigned to this interval transect the early middle(?) Tertiary deposits and are overlain by younger rocks. These bodies range in composition from rhyolitic to mafic. Commonly they are fine-grained porphyries, although some, such as the Samaniego Granite of Wallace (1955) in the Santa Catalina Mountains, are coarse grained and similar in appearance to some Precambrian rocks in the area. Some of the sedimentary sequences are mineralized and others are not. As of this writing, it has not been determined whether the mineralized units are older than the unmineralized, or whether they represent effects of local hydrothermal alteration associated with nearby intrusions.

The general age of the early middle(?) Tertiary rocks is assumed to be Oligocene to middle Miocene on the basis of probable lower Miocene rhinoceros fragments from the Mineta Formation (Chew, 1952; Wood, 1959) and camel fragments from the Muggins Mountains (Lance and Wood, 1958). The age of the Samaniego Granite has been determined tentatively by the strontium-rubidium method to be about 30 + 3 million years (Giletti and Damon, 1961), or possibly late Oligocene. However, the spatial relationship of the Samaniego Granite to other rocks of early middle(?) Tertiary age is not known.

The rocks of the early middle(?) Tertiary interval were deposited in an environment and in areal distribution similar to that of the late(?) Mesozoic and early(?) Tertiary rocks. Vulcanism was common. The topography during the early part of this interval was probably not unlike that of today, but the mountains probably were higher, the valleys broader, and their positions did not coincide everywhere with those of the present. Some ancient basins extended beyond the limits of the present basins and included areas where mountain ranges, such as the Galiuros, now stand; other old ranges, such as the ancestral Santa Catalinas, existed in much their present location. The area was disturbed by recurrent differential uplift, but by the end of the interval, the mountains were largely worn down and buried. The rhinoceros, found in the Mineta Formation of Chew (1952b) at a place well up on the sides of the Rincon Mountains, apparently died near the margin of a large lake and his body floated out to be buried in fine-grained lake-bottom muds. The interval of uplift came to a close with folding and thrusting, again probably local in extent at any given time. The period of erosion that followed resulted in the cutting of the Galiuro surface upon which the rocks of the late middle(?) Tertiary interval were deposited.

Late Middle(?) Tertiary

The massive accumulation of bedded volcanic flows and associated deposits, which form such a prominent part of the landscape in southern and central Arizona, are the principal rocks of the late middle(?) Tertiary grouping. Deposition of some volcanic flows and thin alluvium also occurred in parts of northeastern Arizona.

Andesitic and basaltic flows are the predominant rocks of this grouping. Lesser amounts of rhyolitic pyroclastic rocks and alluvial deposits also form a part, and in some areas a conspicuous part, of the sequence. The volcanic flows and associated alluvial deposits spread out from many centers and built up broad domes, highlands, and widespread tablelands.

In southern Arizona, upper middle(?) Tertiary flows rest on the Galiuro surface; in northern Arizona, the rocks were laid down on the Hopi Buttes surface, which had formed during the early stages of the Colorado and Little Colorado River drainage systems (Cooley, 1958).

At many places in southern, western, and central Arizona, the volcanic rocks of this interval show a general threefold pattern—a lower sequence of andesitic to latitic flows and pyroclastic deposits; a middle sequence, not everywhere present, of rhyolitic or dacitic deposits, characteristically welded tuff; and the upper sequence of thin black basaltic and andesitic flows which caps many ranges in southern Arizona. At other places, especially in the Mogollon Highlands, basalt may occur at the base of or throughout the sequence of andesitic and rhyolitic deposits. Channel and valley deposits, sometimes of considerable thickness, occur locally through the volcanic sequence, but are perhaps best developed at the base.

Volcanic rocks tentatively assigned to the lower andesitic sequence include the Pearce and S O volcanics in Cochise County (Gilluly, 1956), the Sneed Andesite near Ajo (Gilluly, 1946), and at least a part of the Hickey Formation in central Arizona (Anderson and Creasey, 1958). The rhyolitic sequence includes such deposits as the Rhyolite Canyon Formation (Enlows, 1955), Weatherby Canyon Ignimbrite (Gillerman, 1958), and possibly the dacite near Ray (Ransome, 1923). The Batamote Andesite in the Ajo area (Gilluly, 1946) is typical of the upper sequence of flows. Alluvial deposits include the Whitetail Conglomerate, the steeply dipping beds above the dacite in the vicinity of Ray (Ransome, 1923), and the alluvial deposits in the hanging wall of the San Manuel fault in the San Pedro River valley (Schwartz, 1953; Heindl, in preparation). Some of the alluvial deposits of this interval in central Arizona are described by Charles St. Clair in this volume.

During this interval the basin-and-range type of deformation developed extensively, and the Colorado Plateaus province was elevated prominently above southern and western Arizona. Local compressional deformation continued in southeastern Arizona. The zones of structural weakness along the southern and western fronts of the Colorado Plateau became sites of deep south- and west-draining canyons in which thick alluvial and volcanic sequences subsequently were laid down before the end of this interval (Melton, 1960). In part, the present valleys coincide with these valleys; in part, they do not, and the thick alluvial and volcanic beds laid down in the ancient valleys now form parts of the present mountain ranges.

The general age of these deposits ranges from late Miocene to early Pliocene. One radioactive date of 14.3 million years has been obtained from rhyolitic tuff near the base of deposits of this interval (Sabels, 1959), and early Pliocene fossils occur near the top of a tilted sedimentary sequence (Bryant, 1951; Hook, 1950). Both localities are in the Mogollon Highlands. Some of these fossiliferous sediments and related deposits are described by St. Clair in this volume.

The Chuska Sandstone, which occurs as a large erosional remnant near the northeast corner of the State, consists of fluvial and eolian deposits and a few bentonitic beds. The fluvial part of the Chuska appears to have been laid down by southward-flowing streams (Repenning, Lance, and Irwin, 1958) on the Tsaile surface (Cooley, 1958), and the eolian part was deposited by southwest winds (Wright, 1956). The Chuska was truncated by the Zuni and older erosion surfaces (Cooley, 1958; Repenning, Lance, and Irwin, 1958; also see Cooley's paper in this volume).

Although the Chuska Sandstone is currently assigned to the Pliocene(?) and tentatively correlated with the lower member of the Bidahochi Formation (Repenning, Lance, and Irwin, 1958), lithologic and geomorphic data suggest that the Chuska Sandstone is older (Wright, 1956; Cooley, 1958). The relationship of the Chuska Sandstone, laid down by southward-flowing streams, to the Datil Formation and the physiographic history of the Colorado Plateau is not known. However, it represented a reversal in the direction of regional drainage on the Colorado Plateau from the north to the northeast-flowing drainages that were present during the early Cenozoic.

Late Tertiary and Quaternary

The deformation associated with the extrusion of great volumes of volcanic material continued into the late Tertiary (middle and late Pliocene) and Quaternary. During an early stage of the deformation, the depressed areas in southern Arizona were eroded to the Tortolita surface by south- and southwest-flowing streams (Melton, 1960). The Tortolita surface probably is an integration of many local surfaces and is most prominently exposed as high rock-floored passes transverse to the chains of mountain ranges. It also is exposed underlying deposits of alluvial and volcanic rocks in valleys tributary to the Gila River. The Tortolita surface represents a generally unrecognized period of integrated drainage during which erosion locally dissected rocks of the upper middle(?) Tertiary interval down to and below the Galiuro surface. The Tortolita surface was largely covered by late Tertiary deposits. In many areas where it has subsequently been exhumed, the Tortolita surface, modified slightly by erosion, forms the bedrock pediments so frequently discussed in the literature of Arizona as a feature contemporaneous with or younger than the alluvial deposits of the valley fills.

As basin-and-range folding and faulting continued, the relief increased and through-flowing streams were dammed or diverted by uplifted blocks, volcanic flows, or accumulations of alluvial debris. The process may have been gradual or nearly instantaneous; where it was gradual, the stream gradients were reduced and much of the valley-fill material was accumulated before the integrated drainages were completely disrupted. Only the uppermost deposits of most intermontane basins represent deposition in basins of internal drainage. With few exceptions in Arizona, the valley-fill deposits of this interval are rarely more than about 3,000 feet thick (McKee, 1951). The reported 7,000-foot thickness of alluvium in San Simon Valley in southeasternmost Arizona (Sabins, 1957) is excessive because the rock below about 2,500 feet is tuff, not alluvium.

In western Arizona, some of the basins were open to the ancient Gulf of California until about the beginning of Quaternary time, and marine or brackish water deposits extended to a few tens of miles north of Yuma (Wilson, 1933). In northeastern Arizona, lake, stream, and volcanic deposits of the Bidahochi Formation intermittently filled broad basins behind uplifted parts of the Colorado Plateau and the Mogollon Highlands during most of Pliocene time. By Pleistocene time or earlier, the lake had topped its dam and drained out along the course of the ancestral Colorado River. Deformation and regional uplift and tilting continued intermittently. In northern Arizona, the uplift, in conjunction with the drainage of the lake in northeastern Arizona, resulted in the formation of the Zuni and Black Point surfaces and led to the dissection that helped cut the Grand Canyon. In southeastern Arizona, uplift and tilting triggered deposition of coarse alluvial fans along the margins of many basins.

The valley-fill deposits in the intermontane basins are perhaps best represented by the Gila Group (Gilbert, 1875; Heindl, this volume and in preparation) in southeastern Arizona and the Muddy Creek Formation (Longwell, 1928) in northwestern Arizona. These are predominantly of Pliocene and early Pleistocene age, although locally some deposits may represent continuous deposition since late Miocene time. On the Colorado Plateau the principal deposits are the lake beds and stream deposits of the Bidahochi Formation and the more or less contemporaneous extrusive rocks from various volcanic centers. In the southwestern border region of the plateau, the deposits of this interval are alluvial and volcanic, filling more or less well-defined shallow valleys or deep basins. Alluvial deposits in southeastern Arizona are discussed in this volume by Van Horn and Heindl, and some of the geomorphic features of the Colorado Plateau are described by Cooley.

Drainage patterns during this interval changed as a result of basin filling, local deformation and regional uplift, and local damming by volcanic flows. The end of the interval was predominantly one of degradation, but the process was not continuous. The Willcox basin in southeastern Arizona and the Red Lake area in northwestern Arizona are still basins of internal drainage, and in many areas in southwestern Arizona the degree of incisement in the central parts of the basins appears to be small. Elsewhere in southern and western Arizona, degradation alternated with aggradation and rapid incisement with pedimentation, resulting in the broadly stepped appearance of many of Arizona's basins. The cycle of degradation is best known from the San Pedro Valley (Bryan, 1926) and is referred to informally as the San Pedro cycle of erosion. During the cycle, several levels of erosion surfaces were developed on late Tertiary and early Quaternary deposits, but there is only a general similarity between the surfaces in different valleys. Climatic factors may have influenced the formation of multiple erosion surface, but they do not appear to be adequate to explain the range in the relief or the varying numbers of surfaces in different valleys.

Terrace, flood-plain, and channel deposits along the entrenched streams and pediment gravels, and finer grained materials laid down on broad surfaces are the principal deposits associated with late Pleistocene and Recent time. During late Pleistocene and Recent time, glaciers scored and deposited in small areas in the highest parts of the State—in the San Francisco Mountains near Flagstaff (Sharp, 1942) and in the White Mountains (M. A. Melton, oral communication, 1960). Although vulcanism was not so prominent during this interval as it was earlier, volcanic flows and tuffaceous deposits were erupted intermittently and occur widely over the State. The most recent eruption has been dated elegantly by Smiley (1958) as starting after the growing season ended, probably in September, A. D. 1064. The last large earthquake, associated with a 30-foot displacement along a fault scarp just south of the International boundary with Mexico, occurred in 1883 (Gianella, 1960). The last widespread major floods were in 1905.

Note: References cited are included in a single section covering all papers in this volume.

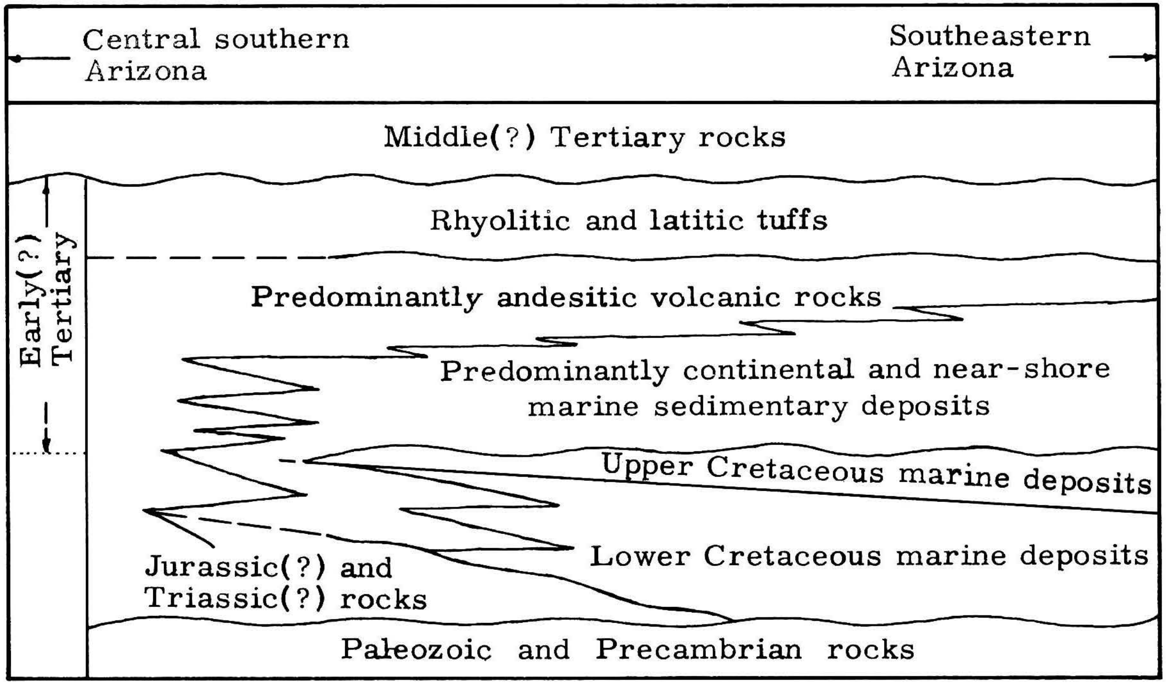

Figure 1.4. --Synoptic diagram showing inferred relationship of Mesozoic and early(?) Tertiary rocks in southern Arizona.