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STRATIGRAPHY OF THE BIG HATCHET MOUNTAINS AREA, NEW MEXICO

By

ROBERT A. ZELLER, JR.

A CONDENSATION BY EDWARD E. KINNEY

Editor's Note: This condensation of *New Mexico Bureau of Mines and Mineral Resources Memoir 16* was prepared by Edward E. Kinney following the untimely death of Robert A. Zeller, Jr.

Although most of the illustrations and many of the details of stratigraphic descriptions have been omitted in order to present the paper in the Guidebook, it is hoped that the essence of Zeller's conclusions are contained herein. The reader who is interested in the details is referred to the unabridged memoir by Zeller (1965). Also, a list of references is found in the original memoir; references are cited at appropriate places within this condensation, but a bibliography is not included here because of space limitations.

Eroded Precambrian crystalline rocks were inundated by the early Paleozoic sea, which advanced from the southwest. More than 1500 feet of Cambrian and Ordovician rocks were deposited. Any deposited Silurian rocks were removed by pre-Late Devonian erosion. An unbroken 1800-foot sequence of Devonian and Mississippian rocks accumulated, followed by a brief erosional break. About 3500 feet of Pennsylvanian and early Permian limestone was laid down in an unbroken sequence. This was followed by deposition of more than 4000 feet of Permian rocks. The 10,000 feet of Paleozoic rocks, most of which are shallow-water marine limestone and dolomite, are the accumulations of more than one geosynclinal sea that reached this area at different times.

No Triassic or Jurassic rocks are preserved in this area. Fragmentary evidence of early Mesozoic history in the region indicates granitic intrusion, weak folding and faulting, and subaerial erosion. In Early Cretaceous time, the sea advanced from the south; a red-bed formation was deposited along the border of the sea. As the sea covered the area, 5000 feet of shallow-water marine sediments accumulated. After retreat of the sea, more than 5000 feet of terrestrial sediments accumulated in the Big Hatchet Mountains area.

Orogeny succeeded Cretaceous deposition, and the rocks of the area were strongly deformed by folds, high-angle faults, and overthrust faults. Elsewhere in the region, the intrusion of plutonic rocks caused metamorphism of sedimentary rocks. Though folding and faulting were strong in parts of the area of this study, satisfactory sections were preserved.

Following the orogeny, the region was above sea level and was eroded. Detritus accumulated on the flanks of residual high areas. Then volcanism started, and the region was covered by several thousand feet of volcanic flows, agglomerates, and tuffs. Finally, high-angle faulting and gentle tilting caused the uplift of mountain blocks with respect to the valley blocks; erosion produced the present land forms and created the excellent exposures of forma-

tions.

Problems of placing system and series boundaries are present here as in many areas. Notable of the problems are those between the Cambrian and Ordovician, the Devonian and Mississippian, the Mississippian and Pennsylvanian, and between the series in the Cretaceous section. Several factors contribute to the problems. This is a relatively unknown region in which few paleontologic studies have been made. Many fossils have not been studied and are new forms whose ages and stratigraphic ranges are not known. Fossils occur together here that have not been found together elsewhere. In many instances, the faunas near a boundary in this project have not been collected or studied in sufficient detail to determine on which side of the boundary they belong. It seems axiomatic that the closer a fossil is found to a time boundary in a little-studied area, the greater the uncertainty as to which side of the boundary it should lie. However, as far as interpreting the stratigraphy of the region is concerned, such boundary problems do not seriously influence conclusions.

PRECAMBRIAN ROCKS

Paleozoic sedimentary rocks in the Big Hatchet Mountains area rest upon an erosion surface carved deeply in Precambrian rocks. The principal exposures of Precambrian rocks are on the small hills north of the highway in Hatchet Gap, on the southern end of the Little Hatchet Mountains, on the hill north of the mouth of Chaney Canyon on the west side of the Big Hatchet Mountains, and at the base of exposures in secs. 20 and 29, T. 30 S., R. 15 W. on the east side of the Big Hatchets. Other small exposures of Precambrian rock in fault blocks do not show the pre-Paleozoic erosion surface.

A mass of Precambrian quartzite, which was intruded by Precambrian granite, is exposed on the first hill north of the highway in Hatchet Gap. The Paleozoic Bliss Formation rests upon the quartzite for about 100 feet along the contact. Elsewhere on this hill and in other parts of the area where the unconformity is exposed, Paleozoic rocks rest upon Precambrian granite.

The Precambrian quartzite is massive but in places shows bedding laminae. It is medium gray on fresh fracture and weathers brown.

The granite is coarsely crystalline, porphyritic, and altered. Fresh granite is medium gray, and the weathered surfaces are brown and rough. The granite is less resistant than overlying Paleozoic rocks and, except for bold outcrops in Hatchet Gap and in the Little Hatchet Mountains, the rock is seldom exposed. Veins of milky quartz cut the Precambrian quartzite and granite; quartz veins are not found cutting younger sedimentary rocks of the immediate area.

Evidence of Precambrian age of the granite and quartzite is conclusive. Exposures of the erosion surface upon which Paleozoic rocks were deposited are abundant, and the character of the contact can be decisively determined. Late Cambrian brachiopods are found in beds 100 feet above the unconformity in the Hatchet Gap section.

The intrusive nature of the contact between the granite and quartzite, whether the quartzite be a large xenolith or a roof pendant of the pluton, proves that the quartzite is older than the granite and thus is of Precambrian age.

PRE-LATE CAMBRIAN UNCONFORMITY

The earliest Paleozoic rocks of the area, the Bliss Formation, rest with profound unconformity upon Precambrian rocks. Though fossils of specific age significance have not been found in the lower part of the Bliss, beds 100 feet above the unconformity have early Franconian (middle Late Cambrian) fossils.

Throughout southern New Mexico and southeastern Arizona, early Paleozoic sandstone rests unconformably upon Precambrian rocks. The ages of the first fossils that appear above the unconformity become progressively younger eastward—Middle Cambrian in central Cochise County, Arizona; Late Cambrian in the Chiricahua and Big Hatchet Mountains; and Early Ordovician at El Paso, Texas.

In the Big Hatchet Mountains area, the pre-Bliss erosion surface has at least several tens of feet of relief, which is visible in Chaney Canyon and Hatchet Gap. Relief may have been greater, as indicated by the great size of boulders in basal Bliss beds and by sharp changes in lithology and thickness of the Bliss Formation over short distances.

CAMBRIAN AND ORDOVICIAN SYSTEMS

In the area of this study, the position of the Cambrian-Ordovician boundary is not precisely known and may lie within the upper part of the Bliss Formation. Rocks of these systems are divided into three formations. The basal arenaceous beds are assigned to the Bliss Formation; the predominantly limestone sequence above is called the El Paso Formation; and the upper unit of dolomite is assigned to the Montoya Dolomite.

BLISS FORMATION

The basal Paleozoic arenaceous formation in the Franklin Mountains east of Fort Bliss, Texas, was originally named the Bliss Sandstone by Richardson (1904, p. 27). Kelley and Silver (1952, p. 33-34) summarized the history of use of the formation name and proposed that the name be changed from Bliss Sandstone to Bliss Formation.

West of the Big Hatchet Mountains, principally in Arizona, the basal Paleozoic sandstone is called the Bolsa Quartzite.

The Bliss Formation is exposed in four places in the area. In the Sierra Rica, several outcrops are found on the south sides of the hills in secs. 31 and 32, T. 29 S., R. 14 W. In Hatchet Gap, exposures are seen on the tops and southwest slopes of the three hills north of the highway. On the east side of the Big Hatchet Mountains, a belt of exposures extends southeastward from sec. 20 to sec. 33, T. 30 S., R. 15 W. On the west side of the range, the formation crops out on the top and north side of the small ridge that lies north of the mouth of Chaney Canyon.

Along the east side of the Big Hatchet Mountains, the formation has little sandstone and consists largely of sandy dolomite and shale. Here the formation is nonresistant and is incompletely exposed in gullies and in small outcrops at the base of the range.

Erosion of the pre-Bliss surface probably took place subaerially rather than under sea. Subaerial erosion would account for the sharp irregularities of the surface more readily than would marine erosion.

The Bliss Formation is a marine deposit probably formed along the shoreline of an advancing sea.

No interruption in sedimentation is apparent between the Bliss and El Paso Formations.

Though fossils are rare in the Bliss Formation, a significant brachiopod fauna was found in the Hatchet Gap section. It occurs above the white quartzite in thin-bedded gray and brown arkosic and dolomitic sandstone 102 feet above the base of the formation.

EL PASO FORMATION

Originally, Richardson (1904, p. 29), in naming the El Paso Limestone for exposures in the Franklin Mountains north of El Paso, Texas, included all limestone of Ordovician age in the formation. Later, he (Richardson, 1909, p. 3) divided the Ordovician limestone of the Franklin Mountains into two formations, stating that "the name El Paso is retained for the lower formation which contains Lower Ordovician fossils."

In the Big Hatchet Mountains, the name El Paso Formation is used for the rocks lying between the highest sandy dolomite bed of the Bliss Formation and the lowest bed of the Montoya Dolomite in which quartz sandstone lenses are present.

The El Paso Formation is exposed on the west side of the Sierra Rica and in the northern part of the Big Hatchet Mountains. In the Sierra Rica, the formation occurs only in an overthrust plate, mainly in the hills in secs. 31, 32, and 33, T. 29 S., R. 14 W.

In the Big Hatchet Mountains, an exposed band of El Paso Formation somewhat complicated by faults extends from sec. 13, T. 30 S., R. 16 W. southeastward to sec. 33, T. 30 S., R. 15 W. The formation also crops out on the north side of Chaney Canyon.

The lower part of the formation, composed of dolomite and dolomitic limestone, is nonresistant and forms moderate slopes. The upper part is composed of more massive limestone and is more resistant. Elsewhere, erosion of the

upper beds has developed a bluff-and-terrace topography where massive beds form the bluffs and thin-bedded limestones form the terraces.

In the Big Hatchet Mountains, the El Paso Formation has an abundance of fossils, including trilobites, cephalopods, gastropods, cystoids, sponges, and algae.

The age of the El Paso Formation here, as elsewhere in southern New Mexico, is Canadian (Early Ordovician). In the Big Hatchet Mountains area, El Paso deposition took place during nearly all of Canadian time with the following possible exceptions: During earliest Canadian time the upper Bliss may have been deposited instead of the lower El Paso; minor hiatuses may be present in the El Paso; and any beds of latest Canadian age deposited in the upper El Paso may have been removed during the time of the El Paso—Montoya disconformity.

POST-EL PASO-PRE-MONTOYA DISCONFORMITY

The contact between the El Paso Formation and the Montoya Dolomite is an unconformity in the Big Hatchet Mountains as it is in south-central New Mexico. Kelley and Silver (1952, p. 50-54) recognized a pre-Montoya erosion surface cut upon the El Paso in the Caballo Mountains. Kottlowski et al. (1956, p. 18) noted an unconformity between the El Paso and Montoya in the San Andres Mountains. In these ranges, pre-Montoya karst erosion produced cavities in the upper El Paso beds.

The age of the highest identified fossils in the El Paso of the Big Hatchet Mountains is equivalent to that of the Jefferson City, which is late but not latest Canadian. The age of the lowest identified fossils in the Montoya of the Big Hatchets is late Champlainian (Middle Ordovician) or early Cincinnati (Late Ordovician).

Evidence of karst erosion in the El Paso under the pre-Montoya surface in south-central New Mexico shows that the surface in that region emerged above sea level. However, in the Big Hatchet Mountains, where some erosion occurred between El Paso and Montoya deposition, there is little indication that the area was above the sea and subjected to subaerial erosion.

MONTOYA DOLOMITE

Richardson (1904, p. 29) originally included all Ordovician beds of the Franklin Mountains with the El Paso Limestone. Later, he (1909, p. 3-4) divided the Ordovician rocks into two formations and retained the name El Paso for the lower unit in which he found a lower Ordovician fauna. The upper formation, in which he recognized a later Ordovician fauna, he named the Montoya Limestone. Dunham (1935, p. 42-43) recognized the dolomitic composition of the formation in the Organ Mountains, and therefore used the name Montoya Dolomite.

The Montoya Dolomite, like the El Paso Formation, is confined in distribution in this area to the west side of the Sierra Rica and the northern part of the Big Hatchet Mountains.

In the Sierra Rica, the Montoya Dolomite is found only in a thrust sheet. Its principal exposures are on the north

sides of the hills in secs. 31 and 32, T. 29 S., R. 14 W.

In the Big Hatchet Mountains, the formation is most prominently exposed in a belt extending diagonally across the range from southeast to northwest in secs. 19, 29, 30, 32, and 33, T. 30 S., R. 15W.

The Montoya Dolomite, composed principally of massive dolomite, is more resistant than formations above and below. It commonly forms ridges between the moderately resistant El Paso Formation and the nonresistant Percha Shale. Along the belt of exposures cutting diagonally across the Big Hatchet Mountains the Montoya, which dips southwestward under the Percha Shale, forms a cuesta that bounds the deep valley eroded on soft Percha Shale.

PRE-LATE DEVONIAN UNCONFORMITY

In this area, the Percha Shale of Late Devonian age rests upon an erosion surface cut upon Montoya Dolomite. The hiatus represented by the unconformity includes the time from Late Ordovician to Late Devonian. No angularity is noted between beds below and above; the contact is a plane surface with no channel cuts or irregularities. A thin basal sandstone of the Percha found in some exposures may represent reworked, insoluble detritus derived from the weathering of pre-Percha rocks.

In south-central New Mexico, an Early Devonian unconformity is found that undoubtedly corresponds to the later Devonian unconformity of southwestern New Mexico. Devonian deposition commenced earlier in south-central New Mexico than in the southwestern area, but by Late Devonian time, deposition extended over all of southern New Mexico.

The Late Devonian unconformity cuts deeper into the sedimentary sequence west of the Big Hatchet Mountains. In the Peloncillo Mountains, Gillerman (1958, p. 26) found the Percha Shale resting upon the El Paso and a few possible remnants of the Montoya. The unconformity continues into southeastern Arizona where the Late Devonian Martin Limestone lies upon the Cambrian Abrigo Limestone. In central Arizona, the Late Devonian erosion surface is cut into Precambrian rocks.

Throughout most of southern New Mexico, the Montoya Dolomite is overlain by the Fusselman Dolomite of Silurian age. At the type locality of the formation in the Franklin Mountains, Kottlowski et al. (1956, p. 27) report a thickness of about 840 feet for the Fusselman. Kelley and Bogart (1952, p. 1646) report a thick section of Fusselman in the Florida Mountains. In the Sacramento, San Andres, and Caballo Mountains, the Fusselman Dolomite thins northward and pinches out in each range because of post-Fusselman erosion. From the regional distribution and southward thickening of the Fusselman Dolomite, one might expect it to be present in the Big Hatchet Mountains, but the formation is absent here.

The absence of Fusselman Dolomite in the Big Hatchet Mountains may be due to nondeposition or to pre-Percha erosion. In view of the regional thickening of the Fusselman in the direction of the Big Hatchet Mountains, its absence here is most probably due to pre-Percha erosion.

DEVONIAN SYSTEM

In the Big Hatchet Mountains, about 300 feet of shale lies between the Montoya Dolomite of Ordovician age and the Escabrosa Limestone of Mississippian age. The few fossils found in the formation in the Big Hatchet Mountains have not been determined as to age, but from regional considerations, the formation here is thought to be Late Devonian. Such a shale formation is found in the same stratigraphic position in other ranges in southern New Mexico where it is commonly called Percha Shale, a name that was first applied to the formation by Gordon and Graton (1907, p. 92).

In the Chiricahua Mountains of southeastern Arizona, Sabins (1957, p. 475-480) described the Upper Devonian Portal Formation, which consists of about 300 feet of interbedded shale and limestone. The formation lies between the Ordovician rocks and the massive Escabrosa Limestone.

PERCHA SHALE

The Percha Shale is exposed in two locations in the area, one in the prominent valley that cuts the northern part of the Big Hatchet Mountains diagonally from northwest to southeast in secs. 19, 20, 30, and 32, T. 30 S., R. 15 W., and the other on the southwestern slope of the northernmost peak of the Big Hatchet Mountains, principally in sec. 13, T: 30S., R.16 W.

The soft Percha Shale is sandwiched between resistant formations, and therefore, where the rocks have moderate dips, erosion reduces its exposures to valleys lying between ridges. Its occurrences are covered with alluvium except for a few exposures in deep gullies. The most complete exposure of the formation is in Mescal Canyon.

The age of the Percha Shale in the Big Hatchet Mountains is not known from direct evidence. Fossils are rare. A fish plate was found in the basal sandstone bed; three specimens of *Conularia* sp. and several linguloid brachiopods were found in the middle of the formation. These fossils at present have no specific age significance.

Elsewhere in southern New Mexico where significant fossils are present, the age of the Percha is close to the Devonian—Mississippian boundary.

The Percha in the Peloncillo Mountains is generally similar to the Percha of the Big Hatchet Mountains except that at the former locality, as in the Portal Formation of the Chiricahua Mountains, it contains more limestone and has a thick bed of black fissile shale above its base. Black fissile shale found near the base of the Percha in the Big Hatchet Mountains may correspond to the black shale units found in the Peloncillo and Chiricahua sections.

MISSISSIPPAN SYSTEM

ES CABROSA LIMESTONE

In the Big Hatchet Mountains, the limestone of Mississippian age that overlies the Percha Shale closely resembles the Escabrosa Limestone of southeastern Arizona and is quite different from the Mississippian formations of southcentral New Mexico.

Ransome (1904, p. 42-44) named the formation from Escabrosa Ridge, which lies about one mile southwest of

Bisbee, Arizona. He summarizes the lithology as follows: "The characteristic rocks of the Escabrosa formation are rather thick-bedded, nearly white to dark gray, granular limestones, which close examination often shows to be made up very largely of fragments of crinoid stems."

The most prominent exposure of Escabrosa Limestone in the Big Hatchet Mountains stretches diagonally from southeast to northwest across the northern part of the range. Along most of this band, the upper part of the formation forms a sheer cliff more than 500 feet in height. This cliff is one of the outstanding topographic features of the range, and the Escabrosa is one of the greatest cliff-formers of the area.

The rock sequence from Percha into typical massive Escabrosa is transitional with no obvious breaks. Changes upward are gradual from shale to shale interbedded with limestone to limestone. The age of the Percha in the region and presumably in the Big Hatchet Mountains is very Late Devonian. Fossils from high in the lower member of the Escabrosa are of Early Mississippian age. Thus, lithologic and faunal evidence indicates continuous deposition from Late Devonian Percha to Early Mississippian Escabrosa in the Big Hatchet Mountains.

Fossils, though not abundant, are found throughout most parts of the formation. These include brachiopods, solitary corals, crinoids, trilobites, bryozoans, cephalopods, Archimedes, and fish teeth.

PARADISE FORMATION

The Paradise Formation, named by Stoyanow (1926, p. 316-318) for exposures near Paradise, Arizona, in the Chiricahua Mountains, is limited in distribution to southeastern Arizona, southwestern New Mexico, and northwestern Chihuahua. The Paradise may be related to the Helms Formation of southeastern New Mexico and western Texas.

The Paradise Formation, consisting mainly of tan-weathered, thin-bedded elastic limestone and tan shale, lies conformably upon the gray-weathered, massive Escabrosa Limestone and is overlain with erosional unconformity by gray-weathered, medium-bedded Horquilla Limestone. It is one of the distinctive lithologic units of the region.

The largest exposure of the Paradise Formation in the Big Hatchet Mountains is in a diagonal northwest-trending band paralleling lower Paleozoic formations in the northern part of the range. Northeast of this band, it crops out in several small areas along the north and northeast sides of the range where later normal faults have placed it in contact with older formations.

The formation is also exposed on the south side of Chaney Canyon. From here southward for a mile along the west side of the range it is distributed in a pattern complicated by tight folding and faulting. Along the eastern flank of the range, the formation crops out in a number of places from near the mouth of Sheridan Canyon southward. In the Sierra Rica, it is found in a small exposure in NW 1/4 sec. 32, T. 29 S., R. 14 W.

The formation is thin bedded and nonresistant. Commonly, its exposure forms a swale between the bluffs of

resistant limestone below and above. Identification of the Paradise is facilitated by its orange-brown or tan color, its nonresistance, its abundance of oolitic and fossiliferous limestone, and its position between two resistant gray limestone formations.

The Paradise fauna is rich both in quantities of fossils and in variety of forms. Marine invertebrate fossils include corals, bryozoans, crinoids, brachiopods, pelcypods, scaphopods, gastropods, cephalopods, and trilobites. Land plant fossils which I have recognized include *Calamites*, *Lepidodendron*, and *Stigmaria*.

In all places, the Paradise Formation has been cut by erosion before deposition of later rocks. Perhaps the Helms and Paradise Formations were once a continuous succession of rocks, but the younger Helms Formation was removed from southwestern New Mexico and southeastern Arizona by this period of erosion.

POST-PARADISE-PRE-HORQUILLA UNCONFORMITY

In the Big Hatchet Mountains, the contact between the Paradise Formation and the overlying Horquilla Limestone is an erosional unconformity. There is no obvious angularity between the beds above and below the contact.

A hiatus is undoubtedly present at the unconformity. Its magnitude depends upon the age of rocks above and below. The uppermost beds of the Paradise are probably of Chester age; the age of lowermost Horquilla beds is not known at present.

In the Sierra Boca Grande to the east, the unconformity is more obvious than in the Big Hatchet Mountains. There the unconformity progressively cuts out several hundred feet of the upper Paradise in half a mile.

Throughout the entire region, there is an erosional unconformity at the base of the Pennsylvanian System. In the Caballo Mountains, Kelley and Silver (1952, p. 91-92) found that the base of the Pennsylvanian section rests upon an erosion surface having a maximum stratigraphic relief of about 500 feet; Pennsylvanian rocks rest upon beds ranging from lower Upham to Lake Valley. Farther north, Pennsylvanian rocks rests upon Precambrian rocks. In the San Andres Mountains (Kottlowski et al., 1956, p. 35), Pennsylvanian rocks rest with erosional unconformity upon various Mississippian beds.

West of the Big Hatchet Mountains in central Cochise County, Arizona, Gilluly, Cooper, and Williams (1954, p. 15) recognized a disconformity between Pennsylvanian and Mississippian rocks. In the Chiricahua Mountains, Sabins (1957, p. 485-486) found that the contact between the Paradise Formation and the Horquilla Limestone is a minor disconformity indicated by an abrupt lithologic change and a hiatus representing late Chester time.

Thus, the contact between the Paradise Formation and the Horquilla Limestone in the Big Hatchet Mountains is an erosional unconformity. The Mississippian—Pennsylvanian boundary may or may not lie at this contact. Throughout the region, the unconformity is recognized at the base of rocks identified as Pennsylvanian.

PENNSYLVANIAN AND PERMIAN SYSTEMS

NACO GROUP

The predominantly carbonate rocks of the Pennsylvanian and Permian Systems in the Big Hatchet Mountains are readily divisible into formations based upon gross lithologic differences. These formations bear less resemblance to the upper Paleozoic formations of other parts of New Mexico or western Texas than to those of southeastern Arizona. In gross lithology, they match remarkably well those of central Cochise County, southeastern Arizona, as defined by Gilluly, Cooper, and Williams (1954).

Ransome (1904, p. 44) named the Naco Limestone from the Naco Hills in southeastern Arizona.

Gilluly, Cooper, and Williams (1954) divided the Naco Group into six formations, which, from oldest to youngest, are Horquilla Limestone, Earp Formation, Colina Limestone, Epitaph Dolomite, Scherrer Formation, and Concha Limestone. All these formations are recognized in the Big Hatchet Mountains and are described below.

HORQUILLA LIMESTONE

The Horquilla Limestone is the thickest and one of the most resistant and widely exposed Paleozoic formations in the region. It is exposed in the Big Hatchet Mountains, the Little Hatchet Mountains (Dane and Bachman, 1961), the Animas Mountains (Zeller, 1958a, 1962), Antelope Pass in the Peloncillo Mountains (Dane and Bachman, 1961), the Cedar Mountains, the Sierra Rica, and the Sierra Boca Grande and other ranges in northwestern Chihuahua. In the Big Hatchet Mountains where its exposures cover half the range, the greatest area of outcrop is in the eastern half; it extends from the northern to the southern tip of the range. In the southwestern and western parts, it is found in many thrust plates. Scattered exposures occur along the flanks of the northern third of the range, on the northernmost peak of the mountains, and on the isolated hill south of the highway in Hatchet Gap. Small exposures of Horquilla Limestone are found in a thrust plate on the northwestern spurs of the Sierra Rica.

The Horquilla Limestone is resistant to erosion and forms most of the bold peaks and ridges that make up the backbone of the Big Hatchet Mountains. Thick, massive, biohermal reefs locally present in the middle and upper parts of the formation account for the great cliffs found on Big Hatchet Peak and on other peaks in the center of the range. In the southcentral part of the mountains, local 200-foot shale beds between massive reef limestones in the upper part of the formation result in gentle slopes steepening upward to moderately high limestone-capped mountains. The lower third of the formation, and also the upper part in places where not complicated by reefs or local shale beds, is characterized by alternating thin and thick beds that form moderately steep mountain slopes with frequent ledges. Exposures of this lithology are characterized by light-colored and regularly stratified beds.

The Horquilla Limestone rests upon an erosion surface cut upon the Paradise Formation; the contact is distinct and sharp. Brown-weathered sandstone, oolitic limestone,

and shale of the Paradise contrast with the light-gray-wheathed limestone of the overlying Horquilla.

The Horquilla Limestone in the Big Hatchet Mountains ranges from latest Mississippian (Chester) age or earliest Pennsylvanian (Morrow) age, through Pennsylvanian, and into early Permian (Wolfcamp) age.

The fauna is rich and varied and includes fusulinids, brachiopods, gastropods, cephalopods, bryozoans, corals, crinoids, pelecypods, and sponges. Calcareous algae, "f u-coidal" markings, rare trilobites, and large four-inch barbed echinoid spines are also found. Exhaustive collections of fusulinids were made because they are abundant and are of greatest value for zoning. Other fossils were collected where obvious or from intervals where fusulinids are lacking.

UPPER HORQUILLA FACIES

In the area of the Big Hatchet Mountains, the upper two-thirds of the Horquilla Limestone, embracing rocks of the upper Des Moines, Missouri, Virgil, and Wolfcamp Series, is complicated by basin, reef, and shelf facies (Zeller, 1960). These facies and the indicated depositional environments are similar to those in the Permian rocks of western Texas and southeastern New Mexico. Principles described by King (1942) and by Newell et al. (1953) for the latter area are applicable to the area of the Big Hatchet Mountains.

Detailed study of basin, reef, and shelf relationships in southwestern New Mexico is retarded by several factors. Complete exposure of the Horquilla Limestone is found only in the Big Hatchet Mountains, and exposures of parts of the formation are found in widely separated localities. In many places, the formation was involved in post-Horquilla structural deformation which contorted original sedimentary features. Projection of reef and basin facies southward is retarded by meager knowledge of the Horquilla Limestone and its equivalents in Mexico.

The significance of the reef and associated facies was realized after completion of the field work and after the deep test well was drilled southwest of the range in 1958. Thus, certain data that would aid in the understanding of these problems were not collected. A concentrated study of the upper Horquilla facies within the region would be of value.

During late Pennsylvanian and Wolfcamp time, the region including southwestern New Mexico, southeastern Arizona, northwestern Chihuahua, and northeastern Sonora was the site of marine deposition. Subsidence was greater here than in neighboring areas, a fact that is indicated by the thick deposits of marine rocks found here compared to the thinner sections of rocks of the same age found in surrounding areas. Kottlowski (1959, p. 150) shows that the thickness of the Pennsylvanian section in the Pedregosa Mountains of southeastern Arizona is about 2500 feet, the same as that of the Pennsylvanian part of the Horquilla Limestone measured in the Big Hatchet Mountains.

Areas of even greater subsidence within the region produced local basins (analogous to the Delaware basin of western Texas). Areas between such local basins were the sites of deposition from an epicontinental sea and may be defined as shelf areas.

Such a local basin was discovered in the upper Horquilla Limestone in the well drilled by Humble Oil & Refining

Company southwest of the Big Hatchet Mountains. Corresponding beds that crop out as extremely massive limestone on Big Hatchet Peak and southeastward along the crest of the range represent biohermal reefs along the basin margin. Medium-bedded limestones east of the reefs lie in the shelf area.

The rock typically found in shelf areas is regularly bedded, light-colored limestone composed chiefly of fossil shell detritus. Even though the rock is composed mostly of shell remains, its light color indicates that bituminous matter is very minor.

EARP FORMATION

The Earp Formation crops out in the southwestern part of the Big Hatchet Mountains. Its greatest area of exposure is on the floor of South Sheridan Canyon and in the topographic basin between Sheridan Wells and Sheridan mine. The Earp is exposed in several of the small canyons trending northwest from Sheridan Wells and in the long canyon extending from Hell-to-Get-to-Tank to a mile south of Big Hatchet Peak. It crops out through nearly the full length of Mine Canyon. In the steep, west-sloping area between Little Tank and Hell-to-Get-to-Tank, the formation is exposed in several bands where it has been involved in imbricate thrust faulting. Here, as in central Cochise County, Arizona, the Earp Formation served as a weak stratum along which thrusting of sheets of massive Horquilla Limestone occurred.

As the Earp Formation is less resistant to erosion than enclosing formations, canyons or valleys have been cut in areas of its exposure. Most of the canyons in the southwestern interior of the mountains were formed by erosion of southeast-trending belts of the Earp Formation. Since the formation is weak and occupies canyon floors, it is covered with alluvium, except for exposures in deep gullies and outcrops of certain resistant beds. Where typically exposed, the Earp Formation occupies canyons bounded by high mountains of Horquilla Limestone on one side and lower ridges of Colina Limestone and Epitaph Dolomite on the other.

The Earp Formation was measured in the Hale Tank section which lies about half a mile northwest of Hale Tank. Here the formation is most completely exposed and is not faulted.

The lower part of the formation is commonly faulted against the upper part of the Horquilla Limestone, which results in the removal of a small amount of section. In the Hale Tank section, the basal bed is brown limestone-granule conglomerate, but elsewhere the basal beds consist of thin, brown siltstone interbedded with light gray, soft claystone. The contact between the Horquilla Limestone and the Earp Formation is usually sharp with no interbedding of the limestone and siltstone-claystone lithologies. However, a thin bed of dolomite siltstone lies 16 feet below the contact in the Hale Tank section.

Fossils in the Earp Formation are rare. In the Hale Tank section fossils, including ostracods and fragments of high-spined gastropods, were found only in bed 27. Ostracods collected were examined by I. G. Sohn, who (written com-

munication, 1955) reported that the genera represented have stratigraphic range of Mississippian through Permian.

COLINA LIMESTONE

In the Big Hatchet Mountains, the Colina Limestone is exposed only in the southwestern part. As it overlies the Earp Formation, its distribution is similar to that of the Earp except that it occupies the updip sides and rims of canyons in which the Earp is found. In addition, it is found in several narrow outcrop belts on the steep southwestern slopes of the range.

Because the Colina Limestone is medium bedded, it is only moderately resistant to erosion. It ordinarily is carved by erosion into high hills and spurs intermediate between canyons formed on the Earp Formation on one side and high hills and mountains formed of resistant higher Permian formations on the other side. In some places, the Colina is less resistant to erosion, and alternating thin and medium beds form stepped hillsides. In other places, it becomes more massive, forming several prominent bluffs. A prominent and persistent 25-foot bed, which may be distinguished by a 15-inch stratum near its middle, commonly forms a cliff near the base of the formation and is a useful marker bed throughout much of the range. This is unit 3 of the Lower Sheridan Tank section.

The fauna of the Colina Limestone consists mostly of bellerophontid and high-spined gastropods and large echinoid spines and plates. No fusulinids or brachiopods were found, although they were diligently sought. The few fossils collected have not been identified, and therefore the exact age of the formation is unknown. However, since the formation lies in the interval between late Wolfcamp fusulinids in the Horquilla Limestone and Leonard fusulinids in the Concha Limestone, the age of the Colina Limestone is either late Wolfcamp or Leonard.

EPITAPH DOLOMITE

The Epitaph Dolomite is exposed only in the southwestern part of the Big Hatchet Mountains in the area bounded on the northeast by South Sheridan Canyon, on the southwest and south by the foot of the range, and on the north approximately by lat. $31^{\circ} 37' N$. Unfaulted exposures along the southwestern side of South Sheridan Canyon are the best for study. A long belt of faulted exposures of the formation extends northwestward from near the head of Bighorn Canyon.

The formation is moderately resistant to erosion and therefore crops out on relatively high hills and mountains. Slopes on the formation are craggy and moderately steep, but cliffs are rare. Thinner beds in the lower half produce bluff-and-terrace slopes.

No fossils were found in the Epitaph Dolomite, which lies between the upper Horquilla Limestone of Wolfcamp age and the Concha Limestone of Leonard age. As the lithology is more closely allied to the overlying Concha Limestone, the Epitaph Dolomite is likely to be of Leonard age. In the Gunnison Hills, Arizona, Williams (Gilluly, Cooper, and Williams, 1954, p. 41) shows that the Epitaph Dolomite is probably of Leonard age.

In spite of the lack of fossils in the formation in the Big Hatchet Mountains, the Epitaph Dolomite may be correlated with confidence with the formation in the type area in the Gunnison Hills, southeastern Arizona, on the basis of similar lithology and its position in the stratigraphic succession.

Correlation of the Epitaph with the Yeso has three points in its favor. First, both contain evaporite deposits interbedded with red shale, siltstone, and sandstone. Second, the ages of each are approximately the same; the Epitaph may be either Wolfcamp or Leonard in age, but it is most likely Leonard. The Yeso Formation in the San Andres Mountains and in southeastern New Mexico (Kottlowski et al., 1956, p. 59-60) is classified as Leonard age. And third, they each underlie sequences of thin beds of sandstone overlain by limestone that probably correlate with one another.

SCHERRER FORMATION

In the Big Hatchet Mountains, the Scherrer Formation is between 5 and 20 feet in thickness. Though this is too thin to be properly classed as a formation, it is nevertheless called a formation here because it cannot be properly included with either formation above or below and because it is a distinct division of the Naco Group in the type area. However, for geologic mapping in the Big Hatchet Mountains, it is grouped with the Concha Limestone.

The distribution of the Scherrer Formation is similar to that of the upper Epitaph Dolomite. It is nonresistant and is commonly concealed. The Scherrer is described in the Upper Sheridan Tank section, and it is shown graphically in the Upper Sheridan Tank and the Mine Canyon sections.

The formation is characterized by medium- and fine-grained, subrounded, quartz sand in a limestone matrix. In most places, the proportion of sand is great and the formation becomes a white, calcareous, quartz sandstone. However, the sand concentration and the thickness vary, and where the formation is 20 feet thick, several beds of quartz sandstone are interbedded with sandy limestone. The limestone is similar to that of the overlying Concha Limestone.

The basal contact of the Scherrer is sharp in the Big Hatchet Mountains, as it is in the type section in the Gunnison Hills of southeastern Arizona. Gilluly, Cooper, and Williams (1954, p. 28) remark that although the contact is knife-sharp in the type section and that it ". . . obviously represents a great change in conditions of deposition, no evidence of either angular or erosional unconformity was detected." This observation applies as well to the contact in the Big Hatchet Mountains.

Evidence from the Sierra Boca Grande in Mexico suggests that the basal contact of the Scherrer is conformable and does not represent a regional disconformity. In that range, the Scherrer consists of sandstone with a faintly purple color. A few thin strata of identical purplish sandstone occur in the upper 400 feet of the Epitaph Dolomite. Within the Scherrer, there are thin beds of Epitaph-like dolomite. Commingled Epitaph and Scherrer lithologies indicate a normal contact. This evidence from Mexico and the lack of evidence of a regional disconformity in New Mexico and Arizona suggest that the basal contact of the

Scherrer is conformable even though the contact is sharp in most places.

The upper contact of the Scherrer is also conformable. In the Big Hatchet Mountains, as in the type section in Arizona, quartz sand gradually diminishes upward as the proportion of limestone increases. In the Big Hatchet Mountains, the contact was chosen at the level where obvious quartz sand disappears.

As no fossils were found in the formation, its age in the Big Hatchet Mountains is not definitely established. Like the Earp, Colina, and Epitaph, the Scherrer lies in the interval between Wolfcamp- and Leonard-age rocks. The conformable relationship of the Scherrer with the overlying Concha of Leonard age suggests that the Scherrer also is of Leonard age.

CONCHA LIMESTONE

The Concha Limestone, which overlies the Scherrer Formation, was named by Gilluly, Cooper, and Williams (1954, p. 29) for Concha Ridge in the Gunnison Hills of southeastern Arizona. Williams, in discussing the fauna of the formation, recognized that the Concha Limestone is probably equivalent to the Chiricahua Limestone, which was first recognized by Stoyanow in 1926 and named by him in 1936 (Stoyanow, 1926, p. 318-319; 1936, p. 532-533).

The Concha Limestone crops out in two northwesterly-trending belts in the southwestern part of the Big Hatchet Mountains. One belt caps the ridge between South Sheridan Canyon and Bighorn Canyon; it extends down the dip slope of the ridge to the floor of Bighorn Canyon and is terminated by a fault at the head of the canyon. It is covered by valley fill on the south end of the ridge. The other belt caps the ridge on the west side of Bighorn Canyon and extends southwestward down the dip slope to the edge of the mountains. It extends northwestward along the foot of the range for about five miles in exposures narrowed by faulting and valley fill. A portion of this belt was offset by a high-angle fault, which accounts for the Concha on the ridge principally in the northeastern part of sec. 4, T. 32 S., R.15 W.

The Concha Limestone is moderately resistant and forms the tops and dip slopes of several ridges. Where exposed on ridge tops, it weathers into small bluffs, and on the dip slopes its alternating thin and medium beds weather into a gentle step topography.

The Concha is readily recognized throughout the region by its distinctive lithology. The outstanding features are the abundance of chert nodules and silicified robust productids and the lavender color of much of the chert. The field term used for the formation was "cherty limestone." The fauna of the Concha Limestone is rich in silicified brachiopods.

The Concha Limestone of the Big Hatchet Mountains is correlated with the "Chiricahua" Limestone of the Peloncillo Mountains, the "Chiricahua" Limestone and Concha Limestone of the Chiricahua Mountains, and the Concha Limestone of central Cochise County, Arizona, because of its position above the Scherrer Formation, its nearly identical and distinctive lithology, and the general aspect of its fauna.

POST-PALEOZOIC—PRE-CRETACEOUS UNCONFORMITY

The contact between Paleozoic rocks and the overlying Lower Cretaceous rocks is seen in a few small exposures in the southwestern part of the Big Hatchet Mountains. Here the conglomerate and red beds of the Hell-to-Finish Formation rest upon the Concha Limestone. The Hell-to-Finish Formation is regarded as Early Cretaceous in age.

The contact is an erosional unconformity representing a hiatus that includes post-Leonard Permian, Triassic, Jurassic, and possibly earliest Cretaceous time. The red-bed lithology above the contact contrasts sharply with the gray limestone and dolomite below. In the Big Hatchet Mountains, no angular divergence is seen between beds above and below the contact. Erosion prior to deposition of the Hell-to-Finish Formation cut deeply into the Concha Limestone and produced a surface of great relief. Such relief is indicated by the difference in thickness of Concha Limestone preserved below the contact in two nearby measured sections. The basal bed of the Hell-to-Finish Formation resting on the contact is conglomerate composed of chert granules, fusulinid-bearing chert pebbles, and limestone and dolomite pebbles—all derived by erosion of the Concha Limestone.

In the well drilled by Humble Oil & Refining Company about five miles southwest of the surface exposures of Concha Limestone, several cavities ranging from 3 to 27 feet in height were encountered within the upper 85 feet of the Concha Limestone. These are apparently solution cavities which formed below the pre-Cretaceous erosion surface by karst erosion.

The contact between the Concha Limestone and the basal Cretaceous beds, which undoubtedly are equivalent to the Hell-to-Finish Formation, is exposed at Rancho las Palmas in Mexico about 18 miles south of the Big Hatchet Mountains. There the contact is an angular unconformity.

About 18 miles west-northwest of the exposures of Concha Limestone in the Big Hatchet Mountains, the pre-Cretaceous erosion surface is seen in the Animas Mountains (Zeller, 1962). Here it was cut into the lower part of the Colina Limestone and the upper part of the Earp Formation; the Epitaph, Scherrer, and Concha were removed by erosion. In this restricted area, deposition was upon an anticline that started its growth prior to Cretaceous sedimentation, and a slight angular divergence is visible between beds below and above the unconformity (Zeller and Alper, 1965).

The unconformity is visible in the Sierra Boca Grande east of the Big Hatchet Mountains. Lower Cretaceous rocks rest upon an erosion surface cut to varying depths upon Concha Limestone, and no angular discordance is noted between the Permian and Cretaceous beds.

In the Peloncillo Mountains, Gillerman (1958, p. 46-47) found the same unconformity at the base of the Cretaceous rocks. The pre-Cretaceous surface had cut into the Earp Formation and higher Permian rocks. In some places, beds above and below the unconformity are parallel, but elsewhere angular discordance is seen.

The pre-Cretaceous unconformity is found throughout

southeastern Arizona. Ransome (1904, p. 57-58) recognized the structure in the Bisbee area. Gilluly (1956, p. 67-68) found the unconformity in the northern end of the Mule Mountains, the Tombstone Hills, and the Dragoon Mountains. He shows that here, as at Bisbee, strong orogenic disturbance occurred between deposition of the Paleozoic and Cretaceous rocks and that erosion removed amounts of the section ranging downward from Epitaph Dolomite to Precambrian schist. Taliaferro (1933, p. 19-21) shows that in Sonora about 25 miles southwest of Douglas, Arizona, the unconformity is angular. Sabins (1957, p. 502-506) found that in the Chiricahua and Dos Cabezas Mountains, the unconformity is angular and that, in places, Cretaceous sediments have filled valleys formed upon the deeply dissected erosion surface.

Lower Cretaceous limestone is exposed in many ranges in western Texas, and where the basal contact is seen, it rests unconformably upon the Hueco Formation. Thus, the pre-Cretaceous unconformity is recognized in southwestern New Mexico, in southeastern Arizona, in western Texas, and in neighboring parts of Mexico.

From the Big Hatchet Mountains area toward the north, Lower Cretaceous sections progressively thin and disappear (the Little Hatchet Mountains sections are excluded from this statement for reasons mentioned later). In the Burro Mountains area, rocks interpreted as Late Cretaceous in age are found resting unconformably upon Paleozoic and older rocks. These facts imply that while the area of southwestern New Mexico and southeastern Arizona was receiving Early Cretaceous sediments, areas bordering this depositional basin on the north were still positive. Gradually, the limits of the basin advanced northward and successively younger beds were deposited upon the erosion surface. The pre-Late Cretaceous unconformity in the Burro Mountains therefore may be continuous with the pre-Early Cretaceous unconformity to the south.

Orogeny affected the region during the hiatus between Concha and Hell-to-Finish deposition. Angularity of the pre-Cretaceous unconformity in some exposures is evidence of this activity. Deformation in southeastern Arizona may have been stronger than in the area of the Big Hatchet Mountains because in Arizona the unconformity is angular and cuts more deeply into the geologic column. Near the Big Hatchet Mountains angular discordance at the unconformity is seen only in two areas, and elsewhere Cretaceous beds rest with concordance upon Concha Limestone. However, the arkose of the Hell-to-Finish Formation shows that deformation was strong near the Big Hatchet Mountains. Angular grains of quartz and fresh, pink feldspar in the formation were derived from a nearby elevated granitic mass, which was exposed following orogenic activity but which is now concealed.

CRETACEOUS SYSTEM

Lower Cretaceous rocks crop out in many of the ranges of southeasternmost Arizona, southwesternmost New Mexico, and adjoining areas in Mexico. Upper Cretaceous rocks, which have not been identified in this restricted region, are known only in the peripheral zone extending from south-central Arizona to north of Lordsburg and Deming, New

Mexico, and to El Paso, Texas. Only Lower Cretaceous rocks are recognized in the area covered by this report. Prior to initiation of the present study, Lower Cretaceous rocks of the region were given detailed attention by Ransome (1904) and Stoyanow (1949) near Bisbee, Arizona, and by Lasky (947) in the Little Hatchet Mountains.

In the area covered by this report, Lower Cretaceous rocks are exposed in the Sierra Rica and in Mojado Pass south of the Big Hatchet Mountains. Because the rocks in the Sierra Rica are faulted and silicified, complete and satisfactory stratigraphic sections are lacking. In Mojado Pass, exposures are more complete and less deformed. Therefore, detailed study of Lower Cretaceous rocks was confined to Mojado Pass.

Here about 10,000 feet of sedimentary rocks are exposed that rest upon an erosion surface cut upon Permian Concha Limestone and that are truncated by an erosion surface formed before Tertiary deposition. Fossils prove Early Cretaceous age for all but the lowermost beds, but even though index fossils are lacking in these beds, their conformable relationship with overlying Lower Cretaceous beds indicates their probable Early Cretaceous age.

The Lower Cretaceous section in Mojado Pass lends itself to a natural threefold division based upon gross lithology. Each division, an excellent mapping unit, is designated as a formation. Because problems prevent identification or correlation of these formations with other described formations in the region, the Lower Cretaceous formations of Mojado Pass are here assigned new names. Problems of correlation and interpretation of the Lower Cretaceous rocks are discussed later.

The Lower Cretaceous sequence in the area of the Big Hatchet Mountains is divided into the following new formations: the lower, Hell-to-Finish Formation, which is a clastic unit composed mainly of red arkosic sandstone and red shale; the middle, U-Bar Formation, which is predominantly limestone; and the upper, Mojado Formation, which consists mostly of sandstone and shale.

HELL-TO FINISH FORMATION

The Hell-to-Finish Formation is exposed in several places on the southern and southwestern flanks of the Big Hatchet Mountains. The largest and most complete exposure extends from about a quarter of a mile north of Hell-to-Finish Tank to the south side of the hill south of the tank. This hill is capped with Tertiary fanglomerate, but the Hell-to-Finish Formation crops out on all sides.

The Hell-to-Finish Formation on the southern flank of the Big Hatchet Mountains rests upon the irregular erosion surface cut upon the Concha Limestone. Relief on the surface was probably as much as 1000 feet in a mile. Where the Hell-to-Finish Formation was deposited in deep depressions in the erosion surface, it is thick; where the formation was deposited on topographic highs, it is thin. Although the formation is characterized by red elastic sediments, a great variety of rock types is present. Such varied Ethology is not surprising in view of the deposition upon a surface of such high relief.

The bulk of the Hell-to-Finish Formation consists of shale, mudstone, and siltstone which are soft and seldom exposed. The shale is mostly red, although some beds are reddish brown and others are green.

The elastic lithology of the Hell-to-Finish Formation is transitional upward with the marine limestone lithology of the U-Bar Formation.

The probable age of the formation may be surmised from indirect evidence. The formation is overlain conformably by the U-Bar Formation in which the earliest identified fossils are of Early Cretaceous Aptian age.

From Concha to Hell-to-Finish time, the area had a long history of which little record remains. The angular unconformity found in places at the base of the Cretaceous bed and the arkosic composition of the Hell-to-Finish Formation are evidence of mountain-building activity during the long hiatus. Regional evidence shows that as the Mexican sea advanced, successively younger beds were deposited. Terrestrial sediments of the Hell-to-Finish Formation were deposited as the Big Hatchet area started subsiding and the Cretaceous sea approached from the south; when the sea reached the area, the marine U-Bar Formation was deposited.

The Hell-to-Finish Formation and equivalent red-bed formations in the region represent a facies of terrestrial rocks that was deposited near the margin of the advancing Cretaceous sea prior to marine deposition. Deposition was probably in river deltas and flood plains close to the coast, and as the sea approached, the upper beds were probably deposited in estuaries. Advance of the sea was rapid; had it been slow, the elastic beds would have been reworked and quartz sandstone would have been deposited instead of arkose.

U-B AR FORMATION

The U-Bar Formation is here named for exposures on U-Bar Ridge, the prominent synclinal ridge that lies off the southwestern flank of the Big Hatchet Mountains. The formation consists of the dominant limestone part of the Lower Cretaceous section that lies above the red beds of the Hell-to-Finish Formation and below the sandstone of the Mojado Formation.

In the Sierra Rica, the U-Bar Formation occurs in two northwest-trending outcrop bands duplicated by a fault in approximately the six sections of the northeasternmost corner of the Big Hatchet Peak quadrangle.

Except for the massive reef limestone near the top of the formation and several 100-foot-thick units of massive calcarenite near the middle, the formation consists of thin alternating beds of limestone and shale.

The U-Bar Formation rests conformably upon the Hell-to-Finish Formation.

The U-Bar Formation has a rich and varied marine fauna, which includes pelecypods, gastropods, echinoids, corals, ammonites, nautiloids, and foraminifers. Fossils that are abundant and obvious, such as *Ostrea*, are usually long ranging forms that are useless for precise age determination or for zoning the formation. Rare but useful fossils, such as ammonites, are very difficult to find and, when found, many are too poorly preserved to be serviceable.

The age of the U-Bar Formation may be summarized as

follows: In terms of European stages, it ranges from Aptian to early and possibly middle Albian. In terms of Gulf Coastal Plain terminology, it ranges through Trinity and probably into Fredericksburg. The Aptian--Albian boundary lies near the contact between the oyster limestone and limestone-shale members; the Trinity—Fredericksburg(?) boundary is close to the contact between the limestone-shale and reef limestone members.

Correlation of the U-Bar Formation with other Lower Cretaceous limestone formations in the region is complicated because of the several similar limestone formations in the Little Hatchet Mountains. To which one or ones does the U-Bar Formation correlate? Until correlation of the Cretaceous formations is possible between the Big Hatchet and Little Hatchet Mountains only a short distance apart, correlations of the region cannot be firmly established.

MO JADO FORMATION

The Mojado Formation, the uppermost division of the Lower Cretaceous sequence in the Big Hatchet Mountains area, is here named for Mojado Pass in which it is exposed. It consists of more than 5000 feet of interbedded sandstone and shale that rests conformably upon the limestone of the U-Bar Formation and that is overlain with angular unconformity by Tertiary fanglomerate.

Within the area covered by this report, the formation is exposed in Mojado Pass south of the Big Hatchet Mountains and in the Sierra Rica.

The Mojado Formation was probably deposited on the coastal plain of the Cretaceous sea. Argillaceous sediments were deposited upon flood plains and sands were deposited in stream channels which migrated laterally.

The Lower Cretaceous formations of Mojado Pass south of the Big Hatchet Mountains cannot be correlated with the Lower Cretaceous formations as interpreted by Lasky (1947) in the Little Hatchet Mountains a short distance to the north.

Lasky (1938, p. 535) found that certain lithologies and faunas are repeated through the section in the Little Hatchet Mountains. He noted, for instance, that "There are four zones of massive limestone, perhaps of reef origin, containing many specimens of the foraminifer *Orbitolina*, the mollusks *Toucasia* and rudistids, and perhaps less commonly the large gastropod *Tylostoma*. . . ." After considering the possibility of fault repetition, he concluded that the repetition was not due to faulting but instead to normal deposition (Lasky, 1938, footnote, p. 535). According to his (1947) determination, the entire sequence was deposited during Trinity time and had a total thickness of between 17,000 and 23,000 feet; as much as 17,000 feet of rock was deposited during the Glen Rose part of the Trinity. He attributed this tremendous thickness of rocks to deposition in a rapidly subsiding geosyncline.

Lasky's stratigraphic sequence in the Little Hatchet Mountains is viewed with suspicion because of two major regional observations. The first is that the total thickness of the section seems excessive. Many observers are reluctant to believe that as much as 21,000 feet of rock was deposited in the relatively short time span of the Trinity. Furthermore,

this thickness does not fit the regional pattern of progressive thinning of the Lower Cretaceous from south to north.

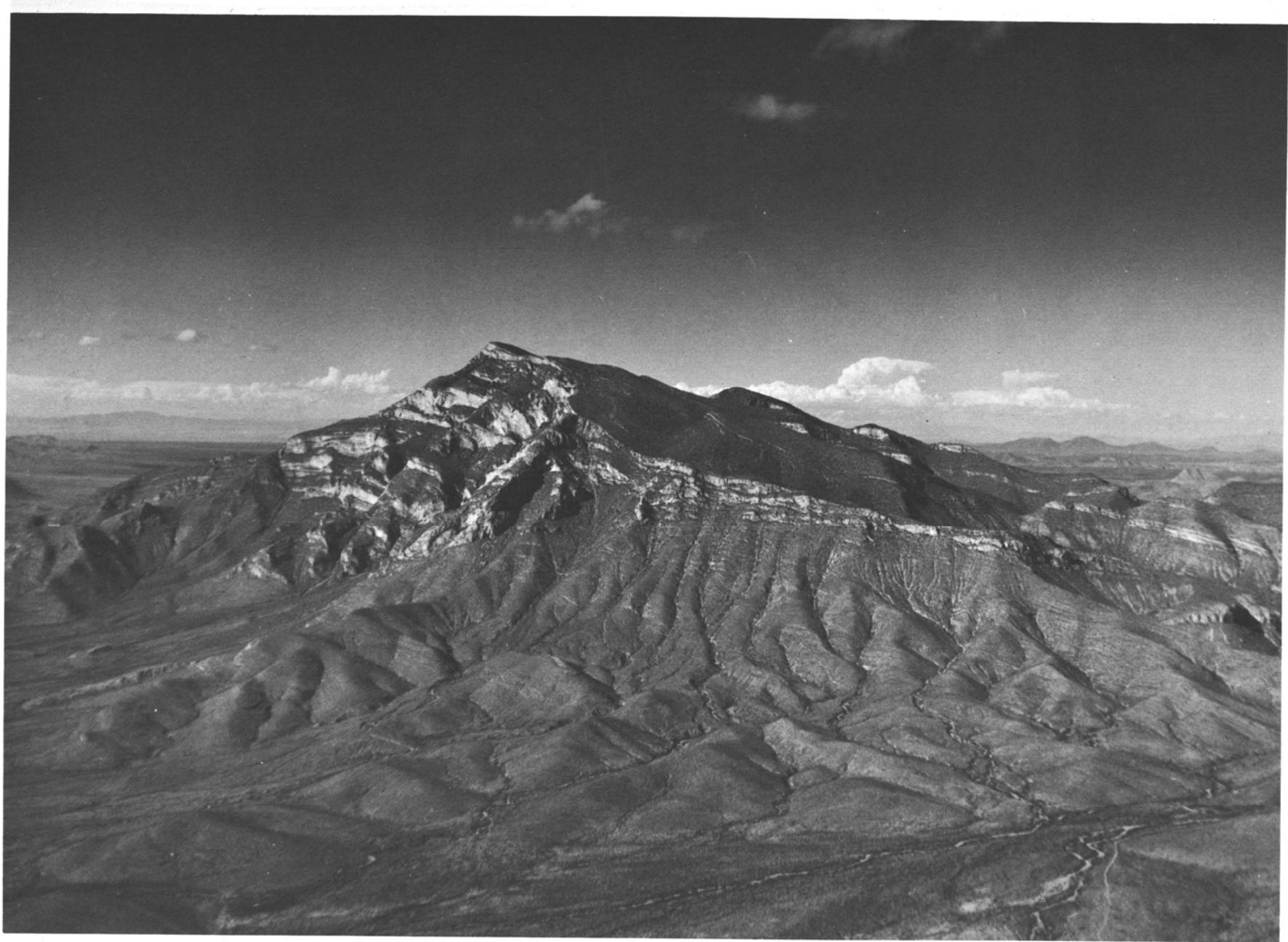
A second regional observation makes the Little Hatchet stratigraphic sequence suspect. In the chief areas where Lower Cretaceous rocks have been studied in the region, the lithologic sequence is divisible into three gross divisions: a lower sandstone and shale unit, a middle limestone unit, and an upper sandstone and shale unit. This threefold division is recognized in Mojado Pass, in the Sierra Rica, at Bisbee, in the northern Chiricahua Mountains, and in the central Peloncillo Mountains. As index fossils have not been found in the upper and lower elastic units of the region, except for the Mojado Formation, their precise ages are not known. However, index fossils from the middle limestone units of all studied sections are of the same age—Trinity and possibly Fredericksburg. Such similarity of lithology and age suggests correlation that further suggests a simple gross Early Cretaceous history for the region. As subsidence of the Mexican geosyncline started here and the

sea advanced from the south, the lower terrestrial elastics were deposited along the coast. As subsidence continued and the shallow Mexican sea invaded the region, the limestone of the middle unit was deposited. And as the rate of subsidence slackened, terrestrial deposits from the north were brought to the region by streams and the upper elastic unit was deposited as the sea retreated. The fact that the Little Hatchet stratigraphic section does not fit this regional picture casts doubt on its validity.

Although such regional observations are useful in suggesting that something is amiss in the Little Hatchet stratigraphic section as presently interpreted, the answers can be found only by further field study in the Little Hatchet Mountains. Solution of the stratigraphic puzzle in the Little Hatchet Mountains should simplify regional Cretaceous stratigraphy and may permit regional correlation of formations.

		Big Hatchet Mtns. (after Zeller)	Northwest Chihuahua Mexico (after Diaz & Navarro)	Southeast New Mexico
CENOZOIC	Quaternary	Alluvium		
MESOZOIC	Tertiary	Fanglomerate		
Cretaceous	Upper			
		Mojado Fm. 5195'		
	Lower	U-Bar Fm. 3500'		
		Hell-to-Finish Fm. 1274'	Las Vigas	
Permian	Permian	Concha Limestone 1376'	Concha Ls. 590' (179m)	San Andres Ls. 1360'
		Scherrer Sandstone 20'	Scherrer Ss. 10' (3m)	Glorieta Ss. 40'
		Epitaph Dolomite 1500'	Epitaph Dolomite 1553' (472m)	Yeso Fm. 2000'
		Colina Limestone 440'	Colina Limestone 609' (185m)	
		Earp Fm. 997'	Earp Fm. 707' (215m)	Abo Fm. 1100'
	Pennsylvanian	1500'	1030' (308m)	Wolfcamp Series 1000'
		Horquilla Limestone 2100'	Horquilla Ls. 2515' (764m)	Virgil Series
				Missouri Series
				Des Moines Series
				Atoka Series
PALEOZOIC	Mississippian	Paradise Fm. 318'	Paradise Fm. 352' (107m)	Helms or Barnett Fm. 100'
		Escabrosa Fm. 1261'	Hachita Fm. 296' (90m)	
			Keating Fm. 109' (33m)	Limestone 500'
	Devonian	Percha Shale 280'		Woodford Shale 100'
				Limestone 1000'
	Silurian			Fusselman Dolomite 600'
	Ordovician	Montoya Dolomite 385'		Montoya Dolomite 900'
				Simpson Sandstone 200'
		El Paso Limestone 1070'		Ellenburger Dolomite 450'
	Cambrian	Bliss Sandstone 250'		Bliss Sandstone 80'
	Precambrian	Precambrian		Precambrian

Stratigraphic nomenclature chart showing usage in Big Hatchet Mountains area, adjacent Mexico, and southeast New Mexico. Compiled by Edward E. Kinney.



Big Hatchet Peak. View toward northnortheast. Prominent overthrust fault at base of massive Pennsylvanian and Permian Horquilla reef limestones lying on younger Colina, Epitaph, and Colina Formations.

(Photograph by Zeller)



Animas Peak in the Animas Mountains. View northeast from N.M. Highway 338 near Gray Ranch headquarters in the Animas Valley. Most of the rocks exposed in the Animas Mountains are Tertiary volcanics with gentle dips.
(Photograph by Wengerd)