



The Yucca Formation - Early Cretaceous continental and transitional environments, southern Quitman Mountains, Hudspeth County, Texas

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THE YUCCA FORMATION—EARLY CRETACEOUS CONTINENTAL AND TRANSITIONAL ENVIRONMENTS, SOUTHERN QUITMAN MOUNTAINS, HUDSPETH COUNTY, TEXAS

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LOCAL GEOLOGIC SETTING

The Quitman Mountains are part of an extensive range, 104 kilometers long, which includes the Malone Mountains to the north in Hudspeth County, Texas, and the Sierra Cieneguilla to the south in the Mexican state of Chihuahua. Structurally the range lies on the eastern side of the Chihuahua Tectonic Belt in which Laramide deformation is typified by overturning and thrust-faulting to the northeast. An inferred high-angle normal fault borders the Quitman Mountains on the southwestern side, intersecting the strike of the Yucca Formation at a low angle. Major normal faulting appears not to have taken place on the northeast side of the Quitmans, where the sedimentary strata dip beneath the bolson deposits. The region is physiographically placed in the Basin and Range Province (Mexican Section).

Quitman Gap forms a narrow pass between the northern and southern Quitmans and divides the mountains into two lithologically contrasting parts—primarily Tertiary igneous rocks to the north and Cretaceous sedimentary rocks to the south.

The northern Quitmans are composed of silicic, coarsely crystalline plutonic rocks such as granite, monzonite and syenite and slightly older, fine-grained volcanic rocks such as rhyolite and trachyte. The volcanic rocks are believed (Huffington, 1943) to have collapsed into the plutonic mass during its intrusion. A zone of contact metamorphism occurs in the sedimentary rocks adjacent to the intrusive bodies and is observed in prospect pits and arroyos between Quitman Gap and the mountains to the north. Metasedimentary strata include metasandstone and hornfels, with minor amounts of marble. Typical minerals in the zone of contact metamorphism are actinolite, epidote, garnet, wollastonite, scapolite, tremolite, limonite, and quartz. Sulfides and other ore minerals have been reported as replacements in the sedimentary rocks and in fissure veins associated with the metamorphic aureole. Nickel, uranium, and scheelite, as well as silver and gold have also been discovered in small quantities (Huffington, 1943). The age of the volcanic activity, intrusion, and metamorphism is early to mid-Tertiary.

The southern Quitman Mountains comprise Cretaceous sedimentary strata for the most part, including large volumes of sandstone and shale, and smaller amounts of limestone. Structurally the southern Quitmans are a block-faulted, thrust-faulted, nearly recumbent anticline and syncline (Jones, 1968; Jones and Reaser, 1970). Jurassic evaporites acted as a décollement zone during much of the Laramide deformation in the Chihuahua Tectonic Belt (Haenggi and Gries, 1970). Evaporites have not been found in the Quitmans but may occur in the subsurface. Reaser (1974) believed that the set of structural-geomorphic features from the Malone Mountains south-southeastward to the Cuchillo Parado on the Rio Conchos forms a major structural element of the eastern Chihuahua Tectonic Belt, similar to and parallel with the La Mula-Sierra Blanca Range to the east, reflecting regional Laramide compres-

sion, tilting, and gravity sliding to the northeast. Regional structural history has been summarized also by Haenggi and Gries (1970).

REGIONAL LATE MESOZOIC HISTORY

During the late Mesozoic, a narrow arm of the Mexican seaway developed in central and eastern Chihuahua, and extended southward into the state of Coahuila. This depositional basin, called the Chihuahua Trough, was bordered on the east by an extensive continental landmass, the western edge of which is termed the Diablo Platform, and on the west by the Plataforma de Aldama of presently unknown extent.

Marine Jurassic rocks preserved in several sierras of northern Chihuahua and in the Malone Mountains northwest of the Quitmans contain faunas and rocks suggestive of shallow-water, neritic, and transitional environments of deposition (Albritton and Smith, 1965).

During Early Cretaceous time, the northern end of the Chihuahua Trough disintegrated into a region of local uplifts and depositional basins, trapping considerable amounts of siliciclastic and calciclastic materials in southernmost New Mexico, Arizona, and northern Chihuahua. Along the east side of the Chihuahua Trough, however, sedimentary accumulation was less localized and Cretaceous rocks regionally thicken from the Diablo Platform into central Chihuahua, where thicknesses up to 6,300 m may be present above a poorly known pre-Cretaceous surface.

THE YUCCA FORMATION

The Yucca Formation is an Early Cretaceous sequence of red, predominantly siliciclastic strata occurring in the Chihuahua Trough beneath an assemblage of Aptian marine carbonate rocks or lagoonal equivalents, the marine beds possibly representing the first major advance of the Cretaceous sea into Trans-Pecos Texas (Campbell, 1968). The Yucca is overlain by the Bluff Mesa Formation (Aptian) which is mostly of marine origin. The Yucca is correlated with a red terrigenous sequence called the "Las Vigas lithosome" (Haenggi, 1966) in Chihuahua.

A regional plot of the thicknesses of the Las Vigas lithosome, according to Haenggi (1966), indicates a maximum estimated value of 1,320 m near El Cuervo in east-central Chihuahua, and suggests regional lithosomal asymmetry with onlap toward the east onto the western edge of the continental platform. Thus the strata represented in the lithosome appear to form a wedge-shaped assemblage of sedimentary layers constituting a large portion of the Cretaceous sedimentary record in the eastern Chihuahua Trough.

The Yucca Formation in the Quitman Gap area is overturned and the strata generally dip to the west or are nearly vertical. In Quitman Gap, I measured and described 1,617 m of the Yucca Formation and, like Jones (1968), considered the formation to be divisible into upper, middle, and lower members. Jones (1968) used the

term "Mountain Formation" for these beds, correlating them with the Las Vigas and Navarrete Formations to the south in Chihuahua. Eastward the Yucca Formation crops out in the Devil Ridge, including Yucca Mesa and Bluff Mesa; in the Red Hills; and in the Indio Mountains, each area exhibiting lithologic varieties similar (but not identical) to the Yucca at Quitman Gap.

One of the main problems in Yucca stratigraphy is the presence of thrust faults in the Devil Ridge area to the east. Movement along some of the faults has placed quite different facies adjacent to each other, thereby making correlation on a bed-by-bed basis difficult. The present report gives emphasis to the Yucca Formation in the southern Quitman Mountains.

The Yucca Formation in the Quitman Mountains is, for the most part, composed of red sandstone, and gray and red-brown mudstone, locally conglomeratic; it reflects a major episode of uplift and erosion of the nearby western edge of the continental platform, where a wide variety of metamorphic and sedimentary rocks was exposed. In the Quitmans the terrigenous wedge is sandwiched between comparatively minor carbonate sequences, representing relative structural inactivity in the source area and decreased sediment production. Environmental interpretations of these rocks by previous geologists show considerable variance (Table 1).

I believe that two environmental associations, transitional and continental, are indicated by the rocks and fossils found in the Yucca Formation in the southern Quitman Mountains:

1. Coastal plain lacustrine, bay, and lagoonal conditions represented mainly by microcrystalline carbonate rocks, oncolitic limestone-pebble conglomerate, and fine-grained siliciclastic beds, and
2. Coastal plain fluvial environments typified by alternating fining-upward sequences of medium- and fine-grained, red, siliciclastic beds, constituting the bulk of the formation.

Lower Member

The lower member of the Yucca Formation at Quitman Gap is at least 189 m thick (base not exposed) and consists mainly of thin beds of laminated to massively bedded, dove-gray micrite, silty micrite, microspar, and calcisiltite, characteristically weathering pale yellow and light tan. Hard calcitic and siliceous fine-grained sandstones and relatively soft pink to red mudstones are common. Most of the rock layers are approximately 1.2 to 1.8 m thick. A 15-cm-thick bed of oolitic and pisolitic limestone is exposed near the base of the section in Quitman Gap; echinoderm spines occur in this layer.

Other fossils occurring in a few of the limestone beds, include charophyte gyrogonites (a fresh-water alga), oncolites, and other algal forms. One limestone bed contains thin-shelled pelecypods and small high-spined gastropods. Ostracod shells are common, having smooth carapaces and occurring mainly in the beds of micrite. Turtle remains and unidentified bone fragments are rare. As a whole, the member is not very fossiliferous, either in terms of numbers of specimens or species diversity.

Middle Member

The middle member of the Yucca Formation exposed at Quitman Gap has a thickness of 1,100 m. The member is composed of cyclic repetitions of siliceous, cross-bedded, slightly conglomeratic sandstone overlain by soft, red, slightly muscovitic siltstone and mudstone. The paired assemblage of lower sandstone and upper mudstone forms what is termed a "cyclothem" (figs. 1 and 2). At Quitman Gap, 91 of the 96 cyclothem occur in the middle member. Statistical data on cyclothem are given in Table 2 in which two thickness modes are evident: 6.6 m ($n = 75$) and 23.1 m ($n = 21$). Sedimentary structures and petrography of the lower strata differ considerably from those of the upper strata in a single cyclothem and are discussed in some detail.

Table 1. Environmental interpretation of the Yucca and equivalent formations.

Author, Date	Location	Stratigraphic Terminology	Interpretation
Taff, 1891	Yucca Mesa Bluff Mesa Quitman Mts.	Yucca Beds Mountain Beds	Shallow, marine shoreline deposits (p. 732)
Burckhardt, 1930	Northern Mexico	Las Vigas Mountain Beds	Littoral and subcontinental facies (table 12)
Adkins, 1932	Sierra Blanca Quitman Mts. Mexico	Yucca Mountain Las Vigas	Marginal facies: fluvial, palustrine, littoral, lagoonal, deltaic and brackish deposits (p. 261, 292)
Smith, 1940	Devil Ridge Area	Yucca	Bay; neritic and littoral facies (p. 606)
Huffington, 1943	Quitman Mts.	Yucca	Marginal and nearshore neritic deposits (p. 1000)
Underwood, 1962	Indio Mts. Devil Ridge	Yucca	Littoral and transgressive (p. 81)
Bridges, 1962	Placer de Guadalupe	Las Vigas	Nonmarine
Milton, 1964	Sierra del Alambre	Las Vigas	Shallow marine (p. 35)
Albritton and Smith, 1965	Sierra Blanca Quitman Mts.	Yucca	Shallow marine, nearshore (p. 51)
Haengi, 1966	El Cuervo	Navarrete Las Vigas	Nonmarine (lagoonal) and marine (p. 154) Nonmarine (terrestrial) and marine (p. 162)
Gries, 1970	Sierra de la Parra	Navarrete Las Vigas	Nearshore (p. 22) Nearshore (p. 24)
This paper	Quitman Mts.	Yucca	Lagoonal, bay, fluvial, lacustrine

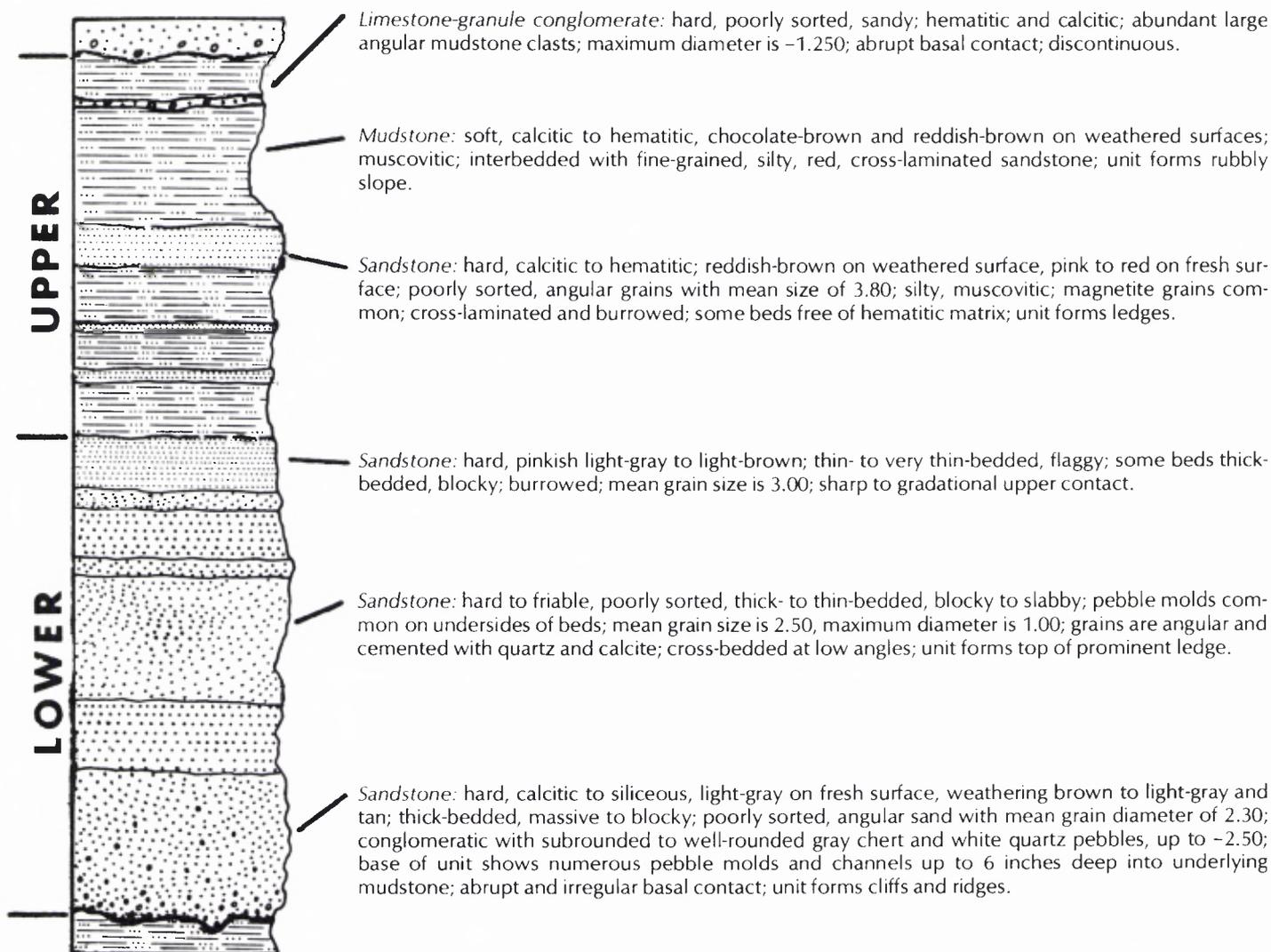


Figure 1. Lithologic details of a cyclothem, middle member, Yucca Formation at Quitman Gap. Field data from beds 640 m above base of member. Interval is 7.5 m thick.

Basal Cyclothem Strata—The basal sandstone or conglomerate beds of the cyclothem erosionally truncate the uppermost mudstone beds of the underlying unit. Relief at the contact is low and the basal surfaces of the cyclothem are gently convex downward. Sandstones of the lower portion of the cyclothem generally pinch out along strike, rarely forming outcrops more than 600 m long.

Small channels (runnels) filled with polymictic conglomerate or conglomeratic sandstone are common along the basal contacts and, in the overturned sequences, the fillings are displayed as narrow sinuous ridges on the dip-slopes of the resistant strata (fig. 3). Most of the runnels are approximately 15 cm deep and 30 to 40 cm wide. Determination of the orientations of 48 runnels indicates a clear northwest-southeast direction. Thin discontinuous lenses of red mudstone (1-3 cm thick) interrupt the relatively coarse-grained cross-bedded units.

Large-scale, trough cross-bedding (pi-type of Allen, 1963) is well developed in basal parts of typical cyclothem. The angles of discordance are large between the laminae of superposed cross-bed sets. Set lengths average approximately one meter. Simple cross-bedding (McKee and Wier, 1953, or xi-type of Allen, 1963) prevails in the upper part of the sandstone in the lower segment of the cyclothem, where the angles of discordance become much less

and the lengths of the sets increase to as much as 3 m. Rarely, the basal strata of the cyclothem display only simple cross-bedding.

Flat bedding and horizontal laminations, with rib-and-furrow structures, burrows, trails, and rootlets(?) are common in the upper meter of the sandstones in the lower set of strata (fig. 3). Micrite nodules occur near the top of the lower set of beds in each cyclothem and typically weather out to form a "Swiss cheese" appearance on the outcrop.

Upper Cyclothem Beds—Layers of mudstone, siltstone, and very fine-grained sandstone make up most of the upper beds of the cyclothem (fig. 1). These beds contain quartz as the principal framework constituent with cements of quartz, calcite, and siderite, and with varying proportions of hematite and sericite matrix. Carbonate minerals generally increase toward the tops of the cyclothem.

Thin lenticular beds of well-sorted, very fine-grained, silty sandstone normally show ripple-drift and horizontal laminations. Distorted laminations, small-scale scour and fill, small-scale trough cross-bedding, and lenticular laminations also occur. Lunate, linguoid, and low-crested ripple marks are abundant (fig. 4).

Thin beds composed of sand-size clasts of hematitic, sericitic mudstone embedded in a matrix of hematitic quartz silt are com-

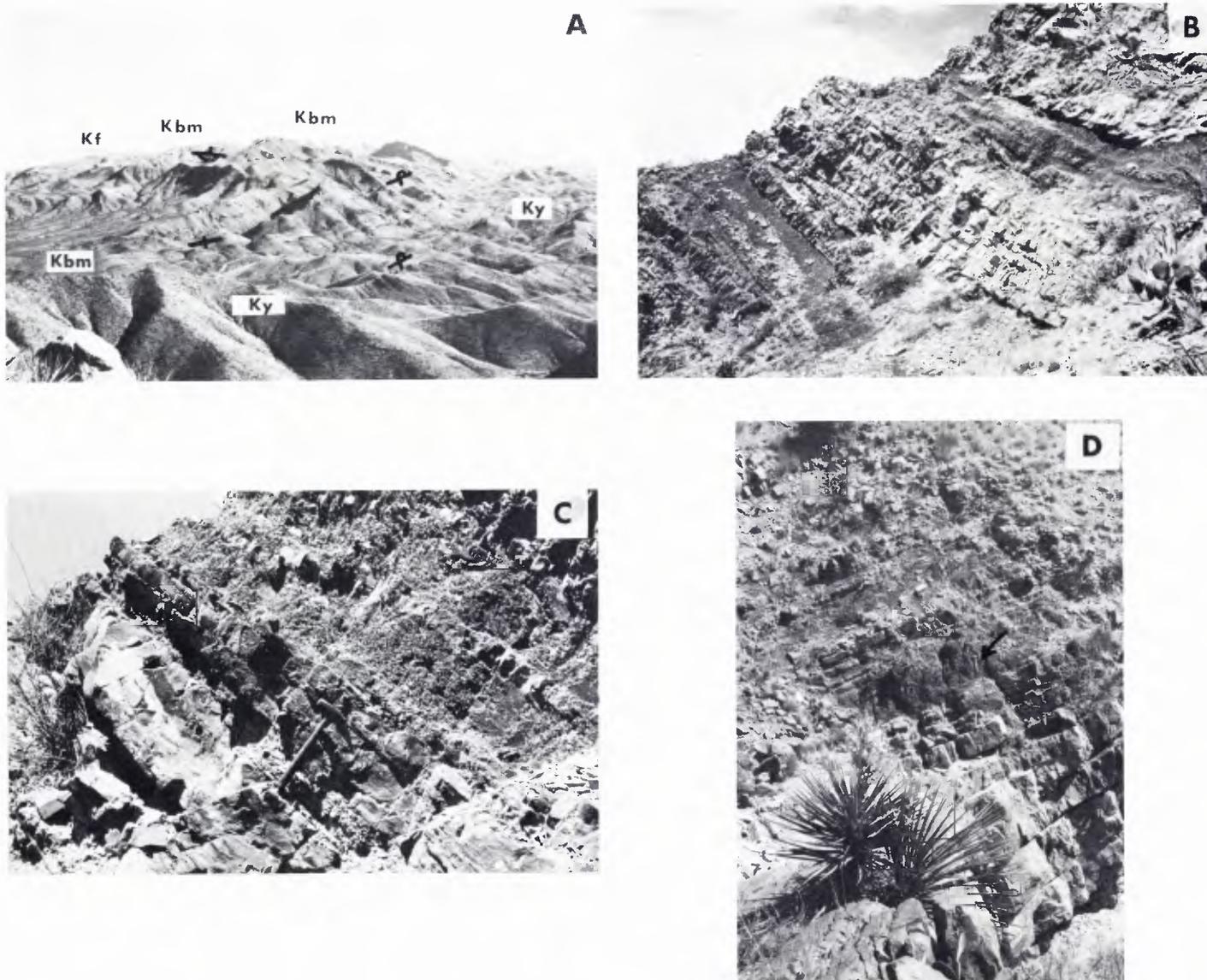


Figure 2. Yucca Formation, southern Quitman Mountains.

- A. Southward view across Quitman Gap from high point in northern Quitmans. Foothills to right formed by Yucca Formation (Ky) most of which is vertical or overturned. Limestones in Bluff Mesa Formation (Kbm) form prominent cliffs and ridges, some beds overturned more than 180 degrees, and thrust-faulted over right-side-up Cox and Finlay (Kf) Formations. East-west dimension on photograph is approximately 6.5 km.
- B. Middle member, near Indian Hot Springs. Alternating sequences of light-colored, ledge-forming sandstone beds of point bar environment and dark-colored, slope-forming mudstone beds of floodbasin environments. Sandstone bed in center of photograph is approximately 9 m thick.
- C. Close-up view of some strata shown in B above. Hammer is 35.5 cm long.
- D. Typical fluvial cyclothem, like those shown above, midway along length of southern Quitmans. Medium-grained sandstone at base, overlain by very fine-grained blocky sandstone, which, in turn, is overlain by slope-forming siltstone and mudstone. Hammer at center.

mon. The clasts are normally poorly sorted and the beds thoroughly indurated, relative to the salty mudstone that makes up most of the upper section of a cyclothem.

Silt- and sand-filled mudcracks occur in some mudstone beds and, at Quitman Gap, mudcracks were observed in association with small burrows (average diameter = 1.2 cm). Some of the burrows occur in pairs where they penetrate bedding surfaces (fig. 4).

Bone fragments, presumably of dinosaurs, occur sparsely in the mudstone. Oncolites are rare (fig. 4). Petrified wood is abundant in a few zones, particularly near the top of the member.

Cyclothem Petrography. The lower strata in a typical cyclothem contain (in order of increasing abundance) sandy conglomerate, conglomeratic sandstone, and sandstone. Conglomeratic units can be categorized in three types according to pebble lithology: (1) rounded red, black, gray and (rarely) green chert, white vein quartz, a few limestone clasts (containing Paleozoic fossils) and low-grade metamorphic rock fragments, (2) pebbles of micrite and microsparite, a few oncolites which contain filamentous and spongy blue-green algae, and rarely, charophyte debris, and (3) mixtures of these pebble types. Clasts of subround to angular red

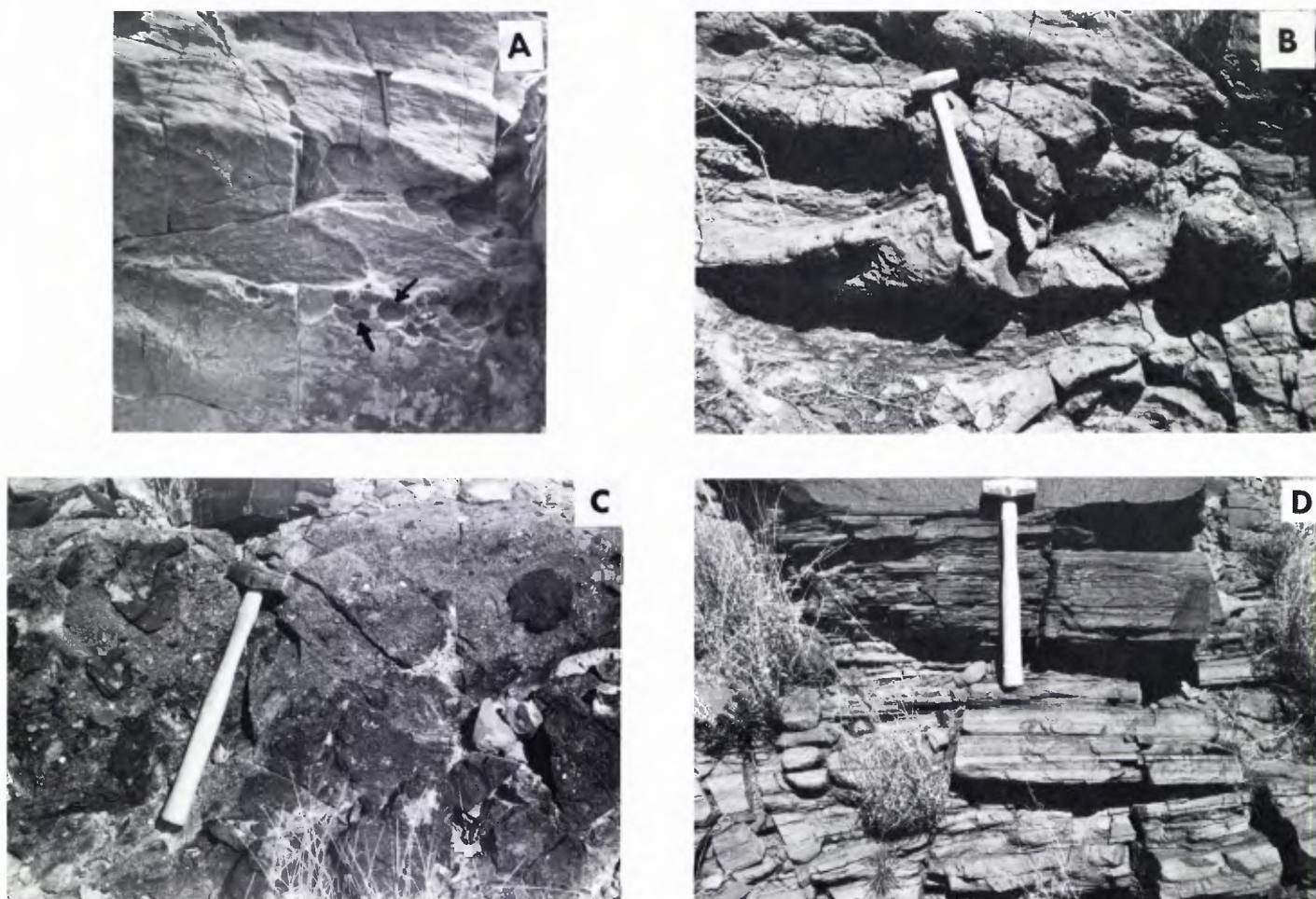


Figure 3. Sedimentary structures in basal beds of fluvial cyclothem, Middle Member, Yucca Formation, Quitman Gap.

A. Filled runnels on base of vertical sandstone bed. Note gravel molds formed by erosion of mudstone clasts.

B. Runnel-fillings on base of vertical sandstone bed.

C. Subround to angular sandstone clasts on base of vertical conglomeratic sandstone bed.

D. Horizontal lamination in muddy sandstone, underlain by fine-grained sandstone showing low-angle cross-bedding. Uppermost strata in lower sandy portion of cyclothem.

mudstone and sandstone having diameters of up to 20 cm occur in most of the conglomeratic units and, where these clasts have weathered out of the matrix, molds have formed. The gravel molds are most common in, but not restricted to, the lower strata of the cyclothem and probably represent penecontemporaneous erosion. Sorting of the particles in conglomeratic beds is generally poor; grains in sandstone beds are commonly moderately to moderately well sorted.

Sand-sized quartz grains are mainly monocrystalline and strained, showing strongly undulose extinction and deformation lamellae. Well-rounded monocrystalline grains with straight extinction are rare in the Yucca. Angular to well-rounded polycrystalline quartz grains are abundant.

Chert grains are plentiful, well-rounded to subangular, and some display a faint orientation of intercrystals, suggesting slight metamorphism. Particles of chert are especially common in coarse sand and gravel sizes. Subangular chalcedony occurs in small amounts.

Examination of stained thin sections indicates a scarcity of microcline or orthoclase. Fresh to highly altered grains of angular albite and oligoclase, showing various degrees of seritization and vacuolization, are present but not common. Plagioclase abundance seems to decrease southward in the Quitmans. Subhedral to euhedral

crystals of authigenic albite occur commonly in limestone clasts and beds, particularly in or near fossil algae.

Several varieties of medium-gray, angular to subrounded, weakly to incipiently metamorphosed rock fragments were observed. Many are schistose and chloritic; others show sericite shreds interspersed in micro- to cryptocrystalline quartz matrices. Meta-

Table 2. Cyclothem Thicknesses*
(in meters)

	Mean	Standard Deviation	Range	Number Measured
<i>Mode I</i>				
Cyclothem	6.6	2.8	2.1-12.9	75
Lower beds	3.6	2.2	0.6- 9.0	75
Upper beds	3.7	2.2	1.2- 9.9	75
<i>Mode II</i>				
Cyclothem	23.1	6.5	13.5-37.5	21
Lower beds	11.6	7.9	2.4-28.5	21
Upper beds	11.7	6.1	2.1-22.2	21
			Total	96

*Based on a measured section in Quitman Gap (Campbell, 1968).

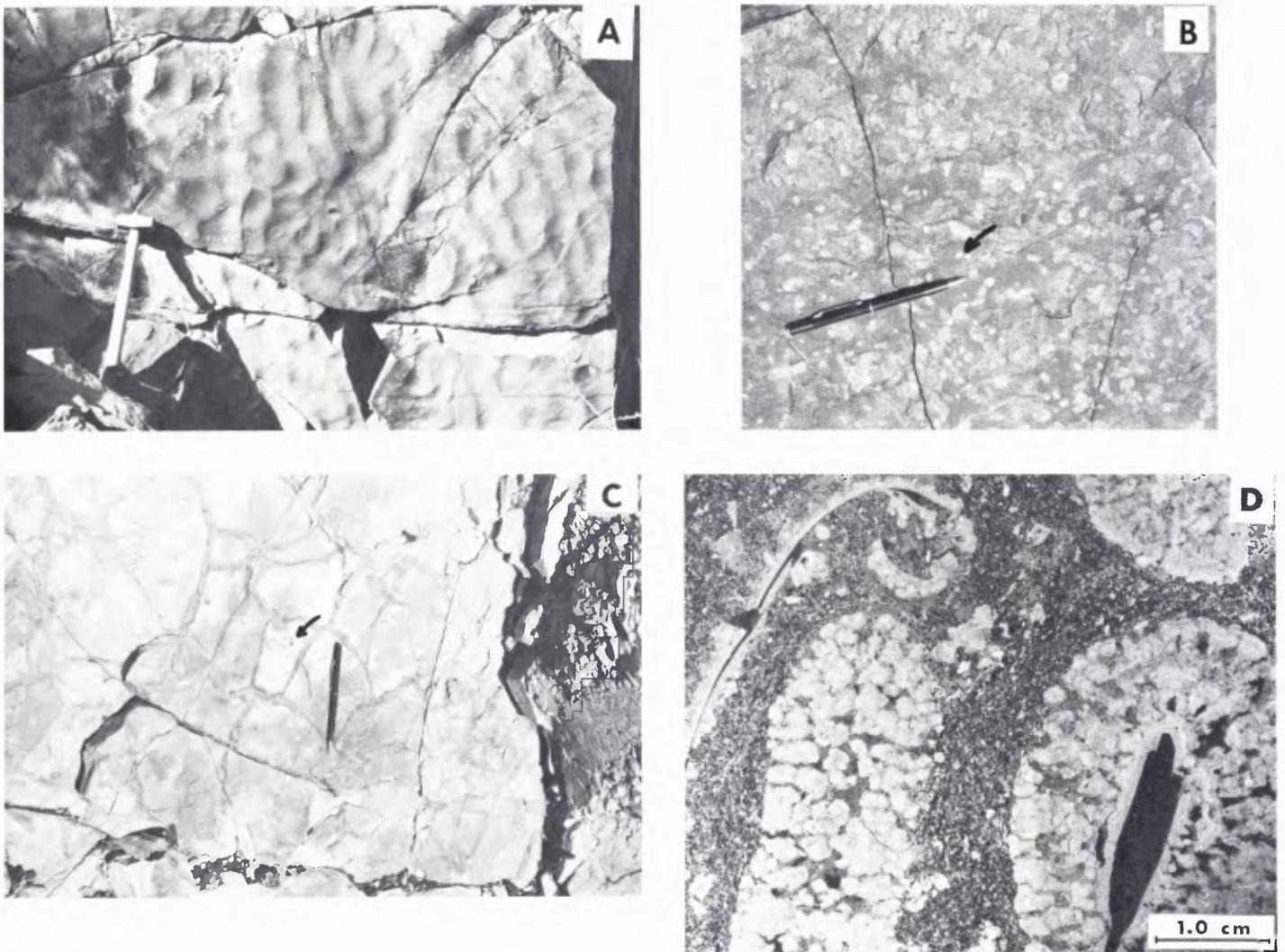


Figure 4. Miscellaneous sedimentary features of fluvial cyclothems in middle member.

- A. Casts of linguoid ripples on base of vertical sandstone bed, near Indian Hot Springs.
 B. Burrow-fillings, some paired, on bedding surface of sandstone in lower beds of cyclothem. Pencil is 15 cm long. Quitman Gap.
 C. Sand-filled desiccation cracks in clayey siltstone bed in upper part of cyclothem. Quitman Gap.
 D. Negative print of thin section showing oncolite in quartzose matrix. Note concentric pattern of algal laminations and encrusted river clam(?) shell. Upper middle member, Indian Hot Springs.

morphic rock fragments are relatively common in fine-grained sandstones.

Angular to rounded clasts of sandstone and sandy mudstone occur in the coarse-grained sandstone and conglomerate beds. Clast size ranges from fine sand to boulder. The clasts normally contain terrigenous grains similar, if not identical, to those of the matrix.

Limestone grains in the sandstones are lithologically identical to those in the gravel sizes.

Heavy mineral grains are generally well-rounded tourmaline, zircon, and magnetite. Muscovite flakes are common on bedding surfaces. Pyroxene and hornblende are virtually absent.

Coarse-grained rocks such as sandstones and conglomerates are cemented with quartz and calcite. Sandstones commonly exhibit coalescent quartz overgrowths and pore fillings of unaltered chlorite. Some of the quartz grains exhibit hematitic dust beneath the quartz overgrowths. Siltstones contain various amounts of matrix rich in calcite, dolomite, fresh chlorite (iron-rich), sericite, and hematite.

Sandstone petrography indicates a mixture of resistate minerals (quartz and chert) and labile constituents (soft metamorphic rock fragments and limestone clasts). Petrographically, they are classified as submature sublitharenites (Folk, 1974). Detailed petrographic work on clays and heavy minerals remains to be done.

Upper Member

The upper member of the Yucca Formation is 328 m thick at Quitman Gap and 135 m thick at Indian Hot Springs, 32 km to the southeast along strike. The member is composed principally of soft, medium- to dark-gray marl; resistant micrite; silty micrite; and calcitic siltstone. Limestone beds are characteristically cream-colored, yellowish tan, and beige. Green knobby nodules of micrite, exhibiting septarian cracks are abundant; the cracks commonly contain quartz, calcite, and chlorite. A few thin discontinuous beds of sandy, oncolitic, limestone-pebble conglomerate locally interrupt the generally fine-grained aspect of the member.

Fossils are much more abundant, in a relative sense, in the upper member (fig. 5) than in the underlying members. Charophyte

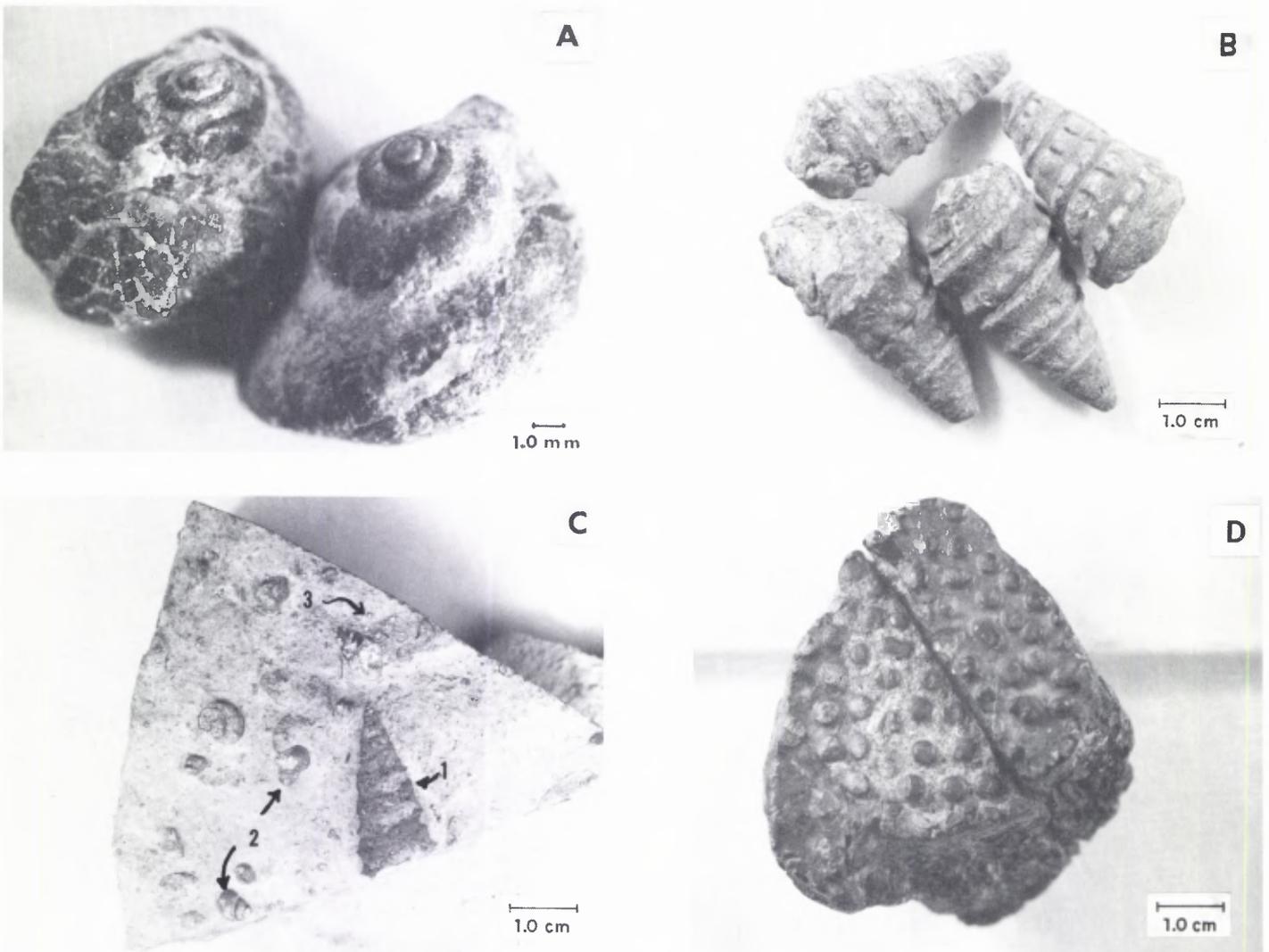


Figure 5. Fossils in the Yucca Formation.

- A. Small oblate gastropods, *Valvata* sp.(?) from mudstone in upper member, Indian Hot Springs.
- B. *Cassiope branneri* (Hill), a gastropod from the upper member, Indian Hot Springs vicinity. External molds showing double rows of coarse tubercles characteristic of the species.
- C. Weathered surface of limestone showing (1) *Cassiope branneri* (Hill), (2) *Hydrobia* sp.(?), and (3) charophyte gyrogonites. Upper member, Indian Hot Springs area.
- D. Carapace fragment of beaded-shell turtle from limestone bed in upper member, approximately 8 km north of Indian Hot Springs. Note rounded stubby projections on specimen surface.

debris (generally considered a fresh-water alga) and oncolites are relatively abundant. Remains of small ornithiscian dinosaurs and beaded-shell turtles are common. Petrified coniferous wood is abundant in some zones, occurring in some localities as logs with lengths up to two meters. Pelecypods and gastropods, suggestive of fresh-water environments, are locally numerous in certain limestone beds. Some of the limestone beds in the upper 6 m of the formation contain pelecypods and gastropods, and suggest the influence of a not-too-distant sea. Descriptions of fossils in the Yucca Formation can be found in Campbell (1968).

Provenance

Regional study of the Yucca Formation reveals increase in grain size to the east. Schist, metamudstone, and limestone fragments, relatively abundant in the Yucca of the Indio Mountains, suggest a nearby source; the well-rounded quartz, chert, and metaquartzite,

however, may represent more than one cycle of erosion and deposition. Precambrian rocks of the Van Horn region are likely local sources for some of the detritus in the Yucca Formation; however, since the Yucca is a part of the Las Vigas lithosome comprising a volume of approximately 205,000 km³ (Haenggi, 1966), additional sources seem necessary. The Wichita Paleoplain (Hill, 1901), a pre-Cretaceous surface of erosion extending over much of Texas and Oklahoma, may have been veneered with materials derived principally from the Ouachita-Marathon structural belt. Partial destruction of the western edge of the Wichita Paleoplain by ordinary erosional processes, during the Late Jurassic and Early Cretaceous resulted in deposition of clastic materials along the southern and western flanks of the Paleoplain (Haenggi, 1966; DeFord, in Yeager, 1960). Additional petrographic studies of rocks in the Las Vigas lithosome and strata beneath the Yucca equivalents on the Paleoplain may yield data that will permit a precise interpretation.

DEPOSITIONAL ENVIRONMENTS AND HISTORY

Lower Member

During the Early Cretaceous, when the Diablo Platform was topographically low and supplying minor amounts of coarse-grained sediment to the Chihuahua Trough, materials making up the lower member of the Yucca Formation were deposited in shallow bays and lagoons on a gently sloping coastal plain. Laminated siltstone and calcisiltite, pink mudstone, marl, and micrite suggest the predominance of quiet-water environments. Several beds rich in charophyte remains indicate that the water was fresh, alkaline, shallow, warm, and slowly moving. Fragments of beaded-shell turtles, small thin-shelled ostracods, valvulid and cerithiid gastropods, and a few scattered oyster shells also suggest fresh to slightly brackish water. Echinoderm spines and plates, found in only one limestone bed near the base of the exposed section at Quitman Gap, indicate local incursion of marine water. A limestone bed, 15 cm thick near the base of the exposed member, contains abundant oolites and pea-size pisolites, suggesting shallow-water agitation, perhaps along a lagoonal shoreline.

Fine-grained siliciclastic strata near the top of the member, exhibiting burrows and cross-laminae, may represent small-scale deltaic accumulations deposited by low-gradient streams as they entered the bays and lagoons. Low-grade metamorphic and sedimentary rocks on the Diablo Platform (western edge of the Wichita Paleoplain) supplied the terrigenous materials. Climate during the deposition of the exposed lower member is interpreted to have been semi-arid. Fossils readily providing an age assignment for the lower member have not been found in the Quitman Gap area. Age of the lower member is tentatively regarded as Neocomian, based on correlation with 1) the Navarrete Formation which crops out in the Sierra del Alambre 40 km to the south in Chihuahua (Haenggi and Gries, 1970), and 2) the Alcaparra Formation in the Sierra de la Alcaparra 110 km to the west (Torres, 1969).

Middle Member

A gradual increase in sand percentage and maximum particle size, and the appearance of clearly defined two-part cyclothem characterize the transition from bay and lagoonal environments to fluvial conditions represented by the strata of the middle member. The cyclothem record repetitive migration of river and associated floodplain environments formed on a low-lying coastal alluvial plain and reflect major differential tectonism between the source area to the east and the Chihuahua Trough.

Poorly bedded sandy conglomerates and conglomeratic sandstones at the base of the typical cyclothem contain materials of extra-basinal derivation, as well as materials originating by bank caving of penecontemporaneous cohesive sediments and by reworking of sediments formed in nearby dried mud puddles. The relatively coarse-grained conglomerates may have formed on scour surfaces (Allen, 1962) within or near thalweg channels.

Most of the sandstones in the lower part of the cyclothem exhibit moderate- to high-angle, trough cross-stratification, suggesting deposition in migrating channel bars and point bars of meandering streams. The sandstones in the basal part of the cyclothem represent off-lapping deposits of point bars, which accumulated by lateral accretion of bedload sediments transported in both high- and low-intensity, lower flow regimes of highly sinuous rivers. Flat-bedded sandstone, also common in the basal units, probably formed in lower portions of upper flow regimes of the streams.

Thin discontinuous beds of red mudstone (1-3 cm thick) within

the basal sandstones are interpreted as clay drapes and indicate deposition of suspended material during waning flood stages.

Large, whole and slightly abraded oncolites; clasts of limestone containing blue-green algae in the limestone-pebble conglomerates; and calcarenites of the otherwise siliciclastic red-bed sequence of the middle member suggest the contemporaneity of nearby carbonate-producing environments and incorporation of these materials into the fluvial system.

The upper beds of the typical cyclothem contain fine-grained muddy deposits of floodplain environments, including mudstones of flood-basin swales and abandoned channels, and relatively well sorted, cross-laminated sandstones of natural levees, crevasse splays, and sandy mudstone of overbank sheet floods.

Graded sandstone beds, composed of angular hematitic mudstone clasts and having a sharp erosive base may reflect the flood-related processes of scouring and reworking of penecontemporaneous iron-rich deposits which had formed in relatively low areas between the meander belts on the alluvial plains.

Thin discontinuous siliciclastic and calciclastic conglomerates (25-50 cm thick) within beds of mudstone were deposited by relatively high-velocity streams, perhaps during catastrophic flooding. Locally, relatively quiet- and clear-water lacustrine conditions are inferred from thin beds of silty and sandy microsparite and calcisiltite, some of which exhibit birdseye structures and clotted textures, and rarely contain charophytes, ostracods, and blue-green algal clasts. Knobby nodules of micrite which occur abundantly in the mudstone beds may indicate development of calcareous soil horizons on the floodplains.

Upon regional uplift of the source area, the streams increased their loads and gradients to such an extent that, near the boundary of the depositional basin and source terrain, the rivers were locally braided, deposits from which are represented in the red-beds of the Yucca Formation in the Indio Mountains. Coalescence of these deposits along a line roughly parallel to the edge of the source terrain produced a narrow depositional belt herein termed a "proximal piedmont alluvial plain." To the west in the vicinity of the southern Quitmans, wide areas of alluvial flats developed where stream gradients were relatively low and aggradation occurred as a result of repetitive down-valley and lateral migration of meandering rivers . . . a "distal alluvial plain." The middle member of the Yucca (red-bed facies), which is correlated with the Las Vigas Formation in Chihuahua, is, consequently, part of a very extensive and voluminous alluvial wedge that formed along the eastern edge of the Chihuahua Trough.

Repeated regional uplift of the source area is implied by the fact that extensive erosion was required to supply the large volume of sediment represented in the Las Vigas lithosome (Haenggi, 1966). The relatively coarse-grained nature of these poorly to moderately sorted sediments, and the common presence of labile constituents, suggest that erosion and deposition were rapid. Transportation distance for the labile constituents was relatively short. Climate during the deposition of the middle member is interpreted to have been sub-humid to semi-arid.

Fluctuations in stream gradients and competencies on the alluvial plains could have been eustatically as well as structurally controlled. The tectonism responsible for the large-scale influx of terrigenous debris into the Chihuahua Trough, I believe, was probably a combination of regional epeirogenic uplift and pronounced flexing or faulting along the Diablo Platform border.

Upper Member

As the influx of sediment decreased, lacustrine and bay environments were again formed on the low coastal plain. Fine-

grained sandstone and mudstone, and interbedded calcisiltite, micrite, and powdery marl were deposited. The limestones commonly contain fresh-water fossils comprising mainly small snails and charophyte debris that are abundant in some strata. The lakes were probably warm, sunlit, alkaline, and shallow. A few beds of fining-upward, sandy limestone-pebble conglomerate, containing fresh-water fossils within the clasts and in the matrix, mixed with siliceous constituents such as ordinary quartz, chert, and metamorphic rock fragments, suggest infrequent fluvial redeposition of carbonate materials derived from nearby penecontemporaneous lacustrine environments.

Echinoid fragments, large gastropods, and oysters in the sandstones and sandy limestones of the upper 6 m of the member at Quitman Gap suggest incursions of seawater, perhaps as tidal effects in shoal areas of shallow bays. Also present in the upper 6 m of the member are beds of micrite, rich in charophyte debris, probably indicating quiet, relatively fresh-water deposition in lakes or, perhaps, lagoons. Evaporite beds were not observed. Thus, the upper portion of the member reflects transitional to normal marine conditions, abundantly evidenced by fossils and sedimentary structures in the overlying Bluff Mesa Formation.

Climatically, conditions during the deposition of the upper member of the Yucca were probably somewhat more arid than those during the deposition of the middle member red-beds.

Age of the upper member is Aptian, based on identification of charophyte remains belonging to the genus *Atopochara* by R. E. Peck (letter, 1965). Subsequent examination by the writer suggests strong similarity to *Atopochara trivolis* Peck. Aptian ammonites occur in the lower beds of the Bluff Mesa Formation which overlies the Yucca.

Alluvial Models and Comparisons

Alluvial models proposed by Bernard and Major (1963), Allen (1974), Potter (1967), LeBlanc (1972) and Walker (1975) have been helpful in the interpretation of the red-bed facies of the Yucca Formation. The Yucca appears to show striking lithologic similarity to the Devonian Catskill facies, Buddy's Run Member, in the New York Appalachians (Allen and Friend, 1968) and the Carboniferous Wamsutta Formation of eastern Massachusetts (Stanley, 1968).

Allen (1974b) recognized three intergrading types of pedogenic carbonate nodule units preserved primarily in the upper parts of cyclothems of the lower Old Red Sandstone, and after comparison with Recent units, believed them to have accumulated in the C horizons of soils in warm to hot climates with moderately low seasonal rainfall. Petrographic and field observations indicate that the numerous knobby nodules of micrite in the Yucca are very similar except that the abundant calcite- or silt-filled tubes, thought by Allen to be animal burrows or root channels occurring in the nodule zones in the Old Red Sandstone, seem to be relatively uncommon in the equivalent Yucca cyclothem interval.

Eight models of fluvial sequence geometry, employing assumptions relating allocyclic and autocyclic controls, and incorporating carbonate paleosols with their temporal and geomorphic implications, were defined by Allen (1974b). Two models seem in many respects to apply to some of the facies of the Yucca, assuming pedogenic origin for the numerous micrite nodule zones:

Model "2B," descriptive of the lower Yucca in the Indio Mountains, is characterized by short, lateral-horizontal river movements via avulsion on alternate sides of alluvial cones on alluvial plains; there are relatively few carbonate paleosols; the river may migrate perpendicular to its course, broadly parallel with the fall line. Evidence for fluvial migration parallel to the fall line in the Yucca Formation has not been found.

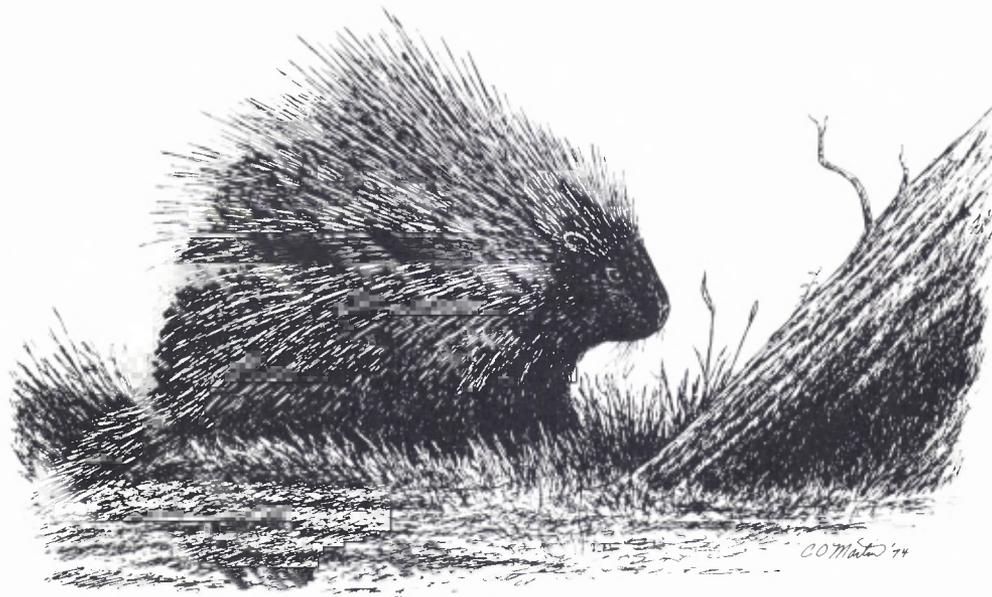
Model "3," similar to the red-bed facies in the Quitman Mountains and Red Hills, involves lengthy lateral-horizontal movements of the river; there is nearly random avulsion and shifting of the stream course via crevassing on the alluvial plain; carbonate paleosols are common.

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Porcupine, *Erethizon dorsatum*.