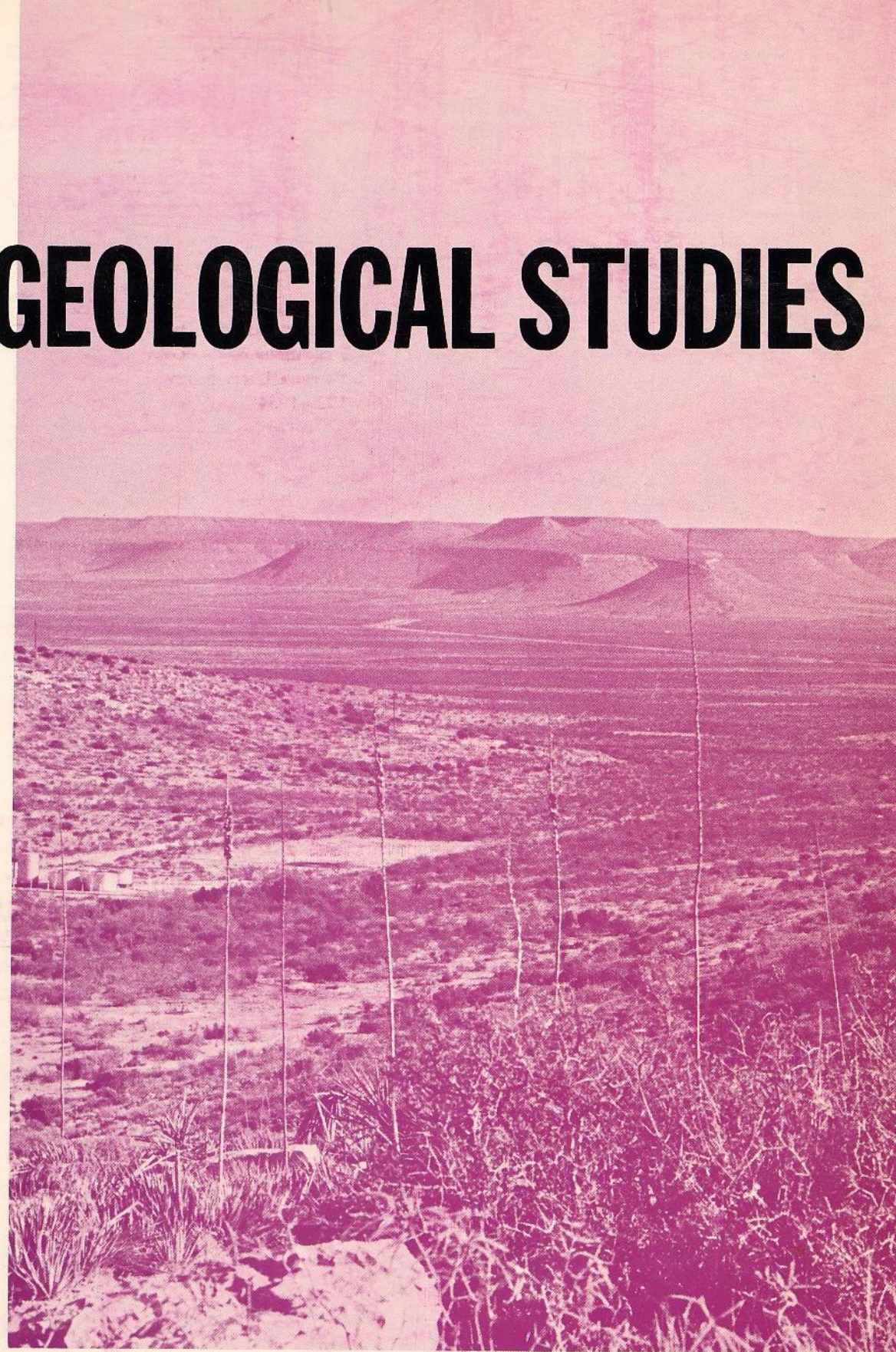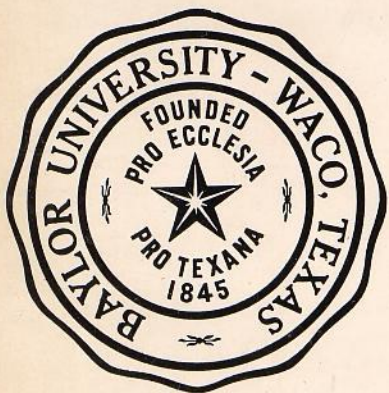# BAYLOR GEOLOGICAL STUDIES

SPRING 1972
Bulletin No. 22

*The Geomorphic Evolution
of the Pecos River System*

RONNY G. THOMAS

"Creative thinking is more important than elaborate equipment--"

FRANK CARNEY, PH.D.
PROFESSOR OF GEOLOGY
BAYLOR UNIVERSITY
1929-1934

Objectives of Geological Training at Baylor

The training of a geologist in a university covers but a few years; his education continues throughout his active life. The purposes of training geologists at Baylor University are to provide a sound basis of understanding and to foster a truly geological point of view, both of which are essential for continued professional growth. The staff considers geology to be unique among sciences since it is primarily a field science. All geologic research including that done in laboratories must be firmly supported by field observations. The student is encouraged to develop an inquiring objective attitude and to examine critically all geological concepts and principles. The development of a mature and professional attitude toward geology and geological research is a principal concern of the department.

The Geomorphic Evolution
of the Pecos River System

Ronny G. Thomas

Baylor Geological Studies

CONTENTS

ILLUSTRATIONS

The Geomorphic Evolution
of the Pecos River System

Ronny G. Thomas

ABSTRACT

The geomorphic evolution of the Pecos River was controlled by a sequence of tectonic events of both regional and local extent. The events are recorded in the Pecos Valley by alluvial deposits, cave systems, and anomalous valleys.

The earliest ancestral Pecos River is represented by the Iraan-Rio Grande sub-basin in Texas. This portion of the river, entrenched into the Edwards-Stockton Plateau, is of Eocene age and dates from uplift of the San Juan Mountains of New Mexico and Colorado in Laramide time. It was probably one of a network of rivers responsible for the deposition of an early Tertiary (pre-Ogallala) alluvial veneer over the study area. This river extended from the Rio Grande to the San Juan Mountains.

The existence of a pre-Ogallala Pecos River in the vicinity of Roswell and Carlsbad, New Mexico is suggested by the cave systems in the Guadalupe Mountains. The presence of quartzose gravels in cave fillings suggests the existence of a pre-Ogallala cave system which required a valley deeper than the present Pecos Valley, since buried by alluviation.

The presence of basal Ogallala quartzose conglomerates along the Pecos and Black rivers in the area of Roswell and Carlsbad, New Mexico and quartzose gravels on top of the Guadalupe Summit Peneplain and in cave fillings suggests a predominately southward flow of quartzose material from the source area in the San Juan Mountains during Ogallala deposition.

The Pecos River during Ogallala deposition was probably one of a network of southward-flowing rivers responsible for Ogallala deposition. The Pecos River of that time necessarily extended as far north as the sediment source area in the San Juan Mountains.

During late Ogallala deposition (late Teritary-early Pleistocene) the Guadalupe, Sacramento and Sangre De Cristo mountains were uplifted. This beheaded the ancestral Pecos River in the area of Sierra Blanca and may have diverted the upper ancestral Pecos into the Tularosa Basin. The beheaded Pecos was deprived of a large volume of water and became a headward eroding stream migrating laterally eastward on the more resistant east-dipping limestones of the Permian San Andres Formation.

During Late Pleistocene a tributary of the headward- and eastward-migrating Pecos River captured the upper ancestral Brazos River which occupied a valley in the present position of the upper Pecos River above Fort Sumner, New Mexico. The upper Canadian River also appears to have been a tributary of the ancestral Pecos River at that time. Much of the basin area now drained by these streams was diverted into the Pecos River until the upper Pecos was captured by the headward-eroding Canadian River. This complex and long history, culminating in these stream captures, established the Pecos River in its present course.

INTRODUCTION[1]

PURPOSE

The geomorphic evolution of the Pecos River (fig. 1) is a complex problem involving a series of anomalous valleys collectively called the Pecos Valley. The valley is entrenched into surfaces of differing ages. In the

south near Pecos, Texas the Pecos River flows on a Quaternary surface which slopes to the base of the Cretaceous escarpment at Iraan, Texas. The river then flows through a deep narrow valley which is entrenched into the Edwards-Stockton Plateau (Pl. I, figs. 2, 3). In the dissected High Plains area north of Carlsbad, the river has exposed basal Ogallala conglomerates (Bretz and Horberg, 1949a) in the valley

---

[1] A thesis submitted in partial fulfillment of the requirements for the M.S. degree in Geology, Baylor University, 1971.

Scale 0 — 50 — 100 — 150 — 200 Miles
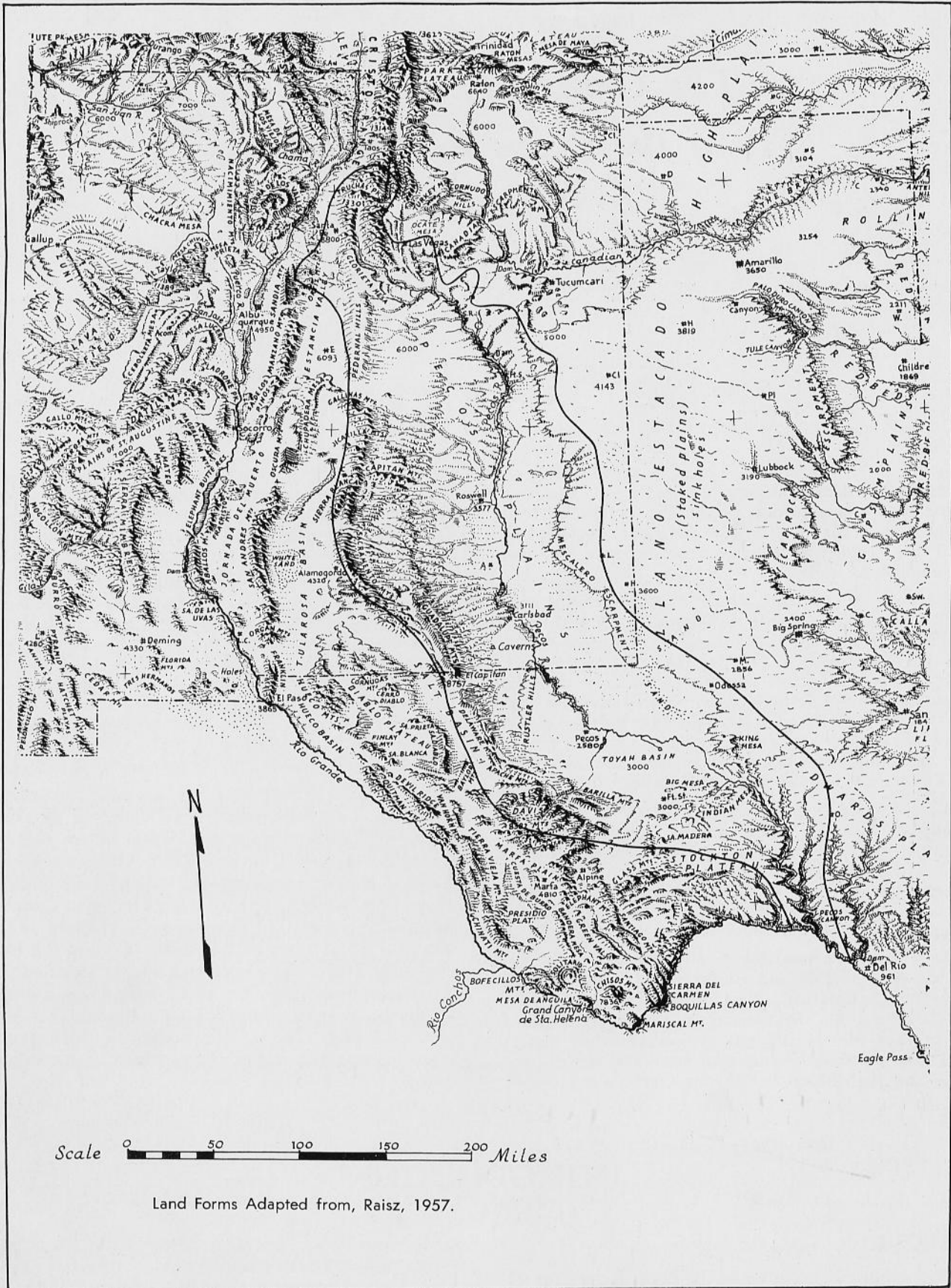
Land Forms Adapted from, Raisz, 1957.

Fig. 1 Index map showing present drainage of the Pecos River.

floor 1300 feet below the present Ogallala surface.[2] This suggests that the river flows in an exhumed valley older than the Ogallala (Pliocene) beds in the vicinity of Carlsbad. However, the present river and its valley must be younger than Ogallala because Ogallala sediments once extended across the area of the present basin. From Carlsbad to Fort Sumner, New Mexico the Pecos River is in alignment with the upper Canadian River, which suggests that the upper Canadian River originally may have been a tributary to the Pecos River (fig. 1, Pl. I).

These and other anomalies led to interest in the present problem. The purpose of this investigation, therefore, was to establish a reasonable sequence of events in the development of the present Pecos River drainage system.

LOCATION

The Pecos River originates in southwest Mora County, New Mexico at the confluence of the Rito de los Chimayosos, Rito del Padre and Jaroso Canyon. From this junction it trends 820 miles southward through San Miguel, Torrance, Guadalupe, DeBaca, Chavez, and Eddy counties, New Mexico and Loving, Reeves, Ward, Crane, Upton, Pecos, Crockett, Terrell and Val Verde counties, Texas. Towns and cities along the course include Pecos, Santa Rosa, Fort Sumner, Roswell and Carlsbad, New Mexico and Pecos, Iraan, Sheffield and Langtry, Texas. Major tributaries of the Pecos River are the Gallinas River, Pintada Creek, Alamogordo Creek, Arroyo del Macho, Rio Hondo, Rio Penasco and the Black River in New Mexico and Toyah Creek, Howards Creek, and Independence Creek in Texas. The Pecos River joins the Rio Grande, as a major tributary, 12 miles southeast of Langtry, Texas (fig. 1, Pl. I).

The Pecos River basin is surrounded by several drainage basins. On the north, the basin is bounded by basins of Canadian River tributaries; on the east, by the eastward drainage of the Llano Estacado; on the west, by tributaries of the upper Rio Grande and the internal drainage of the Salt Basin, Tularosa Basin and the Estancia Valley; and on the south, by the Rio Grande valley southeast of El Paso, Texas (fig. 1).

The Pecos River valley has long been used as a transportation route, first by the Apache and Comanche Indians, then by the early Spanish explorers, trappers, and buffalo hunters, then by the American settlers and is presently the route of U. S. Highway 285 from Santa Fe, New Mexico, to Sanderson, Texas (Fulton, 1954). The valley includes portions of the Basin and Range, Southern Rockies, High Plains and Edwards Plateau physiographic provinces. Physiographic features in the drainage area include the Glass, Davis, Apache, Delaware, Guadalupe and Sacramento Mountains, Pedernal Hills, Sangre De Cristo Mountains and the Mescalero Escarpment (fig. 1).

---

[2] I question that the quartz gravel at channel level in the Pecos Valley is Ogallala *in situ*. In the Ogallala stratigraphy there is reason to challenge that.—J. C. Frye.

METHOD

The method of study included: (1) a review of previous works related to the area of study; (2) an inventory of physiographic and geologic features, and hydrology of the present Pecos River basin; (3) compilation of a geologic map of the present basin, based on existing topographic and geologic maps, to determine the possible contribution to the river of each stratigraphic unit and the routes of possible ancestral stream courses; (4) collection and comparison of gravel samples from older erosional and depositional surfaces and the Pecos River basin to determine the possible sources of Pecos gravels and the relative ages of contributing surfaces related to the basin; (5) review of the geochronology of the structural events within the area of study to determine their possible effects on the direction of stream courses; and (6) comparison of characteristics of the present Pecos River and the postulated ancestral Pecos River. Regional literature related to this problem was relied upon heavily and was very important in gaining a general and working knowledge of the study area and adjacent areas.

Topographic and geological maps of the study area and field reconnaissance were used to identify erosional and depositional surfaces, possible sites of capture of other drainage, major stream deflections and valley anomalies.

ACKNOWLEDGMENTS

PREVIOUS WORKS

Literature on the geomorphic evolution of the Pecos River is largely speculative and uncertain (Baker, 1916). Previous studies have been more descriptive than interpretative and generally the problem has been considered as a side issue of another study (Fiedler and Nye, 1933; Bretz and Horberg, 1949).

The first study dealing solely with the Pecos Valley was by H. H. Harrington (1890) who considered the soil and waters of the Pecos Valley in Texas and concluded that the alkali content of the river water was such that it could be best utilized for irrigation purposes.

W. F. Cummins (1891) in a survey of the Llano Estacado in Texas included a brief summary of the

Fig. 2. Pecos Valley near Iraan, Texas (viewed from the west). The mesas of the Edwards-Stockton Plateau in the background are 500-600 feet above the valley floor, which is veneered with Ogallala gravels.
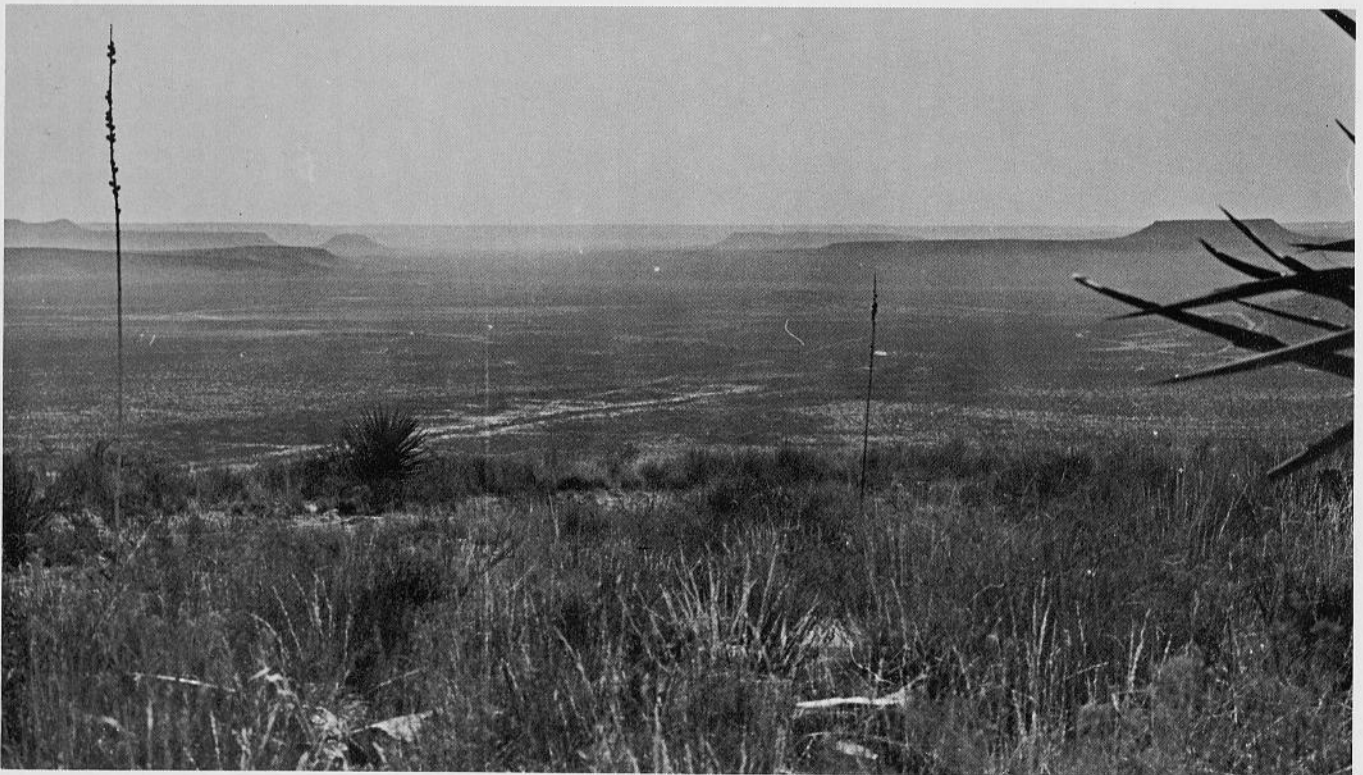

Fig. 3. Pecos Valley, as seen from Southwest Mesa (10 miles south of McCamey, Texas), looking south toward the Edwards-Stockton Plateau. These mesas rise 300-350 feet above the projected level of the Ogallala Formation.

land west of the Llano Estacado including the Pecos Valley. He delt principally with the soils and economy of the region of the Pecos Valley.

The first truly geomorphic work on the Pecos River was by C. L. Baker (1916) who described the Pecos plain as a gently sloping surface from the walled sides of the Pecos Valley to the river floor. This he described as veneered with Pleistocene and Recent gravels with few exposures of bedrock. The Pecos River from the Toyah Basin northward was considered by Baker to be youthful and to date from early Pleistocene. He suggested that the progressive northward extension of the Pecos eventually beheaded the ancient eastward flowing Brazos River and other streams which once drained eastern New Mexico. Baker also recognized that the lower reaches of the Pecos, where it is incised into the Edwards Plateau must be older than the northern Pecos. He suggested that the lower Pecos dates from the time of the Balcones faulting.

In 1925 Willis Lee described the Pecos Valley in southeastern New Mexico as a succession of broad shallow depressions which can be attributed only in part to surface erosion. Lee believed the chief mechanism of formation of these basins to be local subsidence due to the removal by solution of soluble rock of the Chalk Bluff Formation near the surface.

Charles V. Theis (1932) in a report on groundwater in Curry and Roosevelt counties, New Mexico called the Portales Valley (figs. 4, 5) a buried abandoned stream valley. Theis stated that excellent groundwater supplies were obtained from the unconsolidated Ogallala Formation, of late Tertiary age, over most of the area, and from the valley fill, of Quaternary age, in Portales Valley.

Fiedler and Nye (1933, p. 13) described six planar surfaces descending from the crest of the Sacramento Mountains to the Pecos River—from the highest to the lowest, the Sacramento Plain, the Diamond A Plain, the gravel-capped mesas, the Blackdom terrace, the Orchard Park terrace, and the Lakewood terrace. The Sacramento and Diamond A plains are mainly erosional surfaces; the Diamond A Plain is largely an exhumed surface of the San Andres Formation and the younger rocks. The Sacramento Plain, which is developed on the limestones of the Permain San Andres Formation, is the highest erosional surface on the east flank of the Sacramento Mountains. The gravel-capped mesas and the Blackdom, Orchard Park, and Lakewood terraces were described as construction plains of alluvium deposited by the Pecos River and its tributaries.

Albritton and Bryan (1939) in a study of the Quaternary stratigraphy of the Trans-Pecos region described three alluvial formations, in descending order Kokernot, Calamity, and Neville. Though all the units described are Quaternary in age, as established by finds of mammoth bones, the Neville was considered to be early Pleistocene, correlative with the Durst Silts of the Abilene area.

Though not related directly to geomorphic history, hydrologic studies of the modern Pecos are also significant since they contribute the only truly quantitative information on erosional rates, competence and capacity of streams in the area of study. The United States Geological Survey regularly publishes discharge records for the Pecos River. The 1937-1939 floods on the Pecos in New Mexico were the largest on record, reaching 55,200 sec-ft at Santa Rosa, New Mexico.

Studies of the Rio Grande are also significant to this study since the chronology of both rivers is intricately related. W. A. Price (1941) suggested that an abandoned valley six to eight miles wide paralleling the Rio Grande and thirty-five miles to the north of it in Jim Hogg and Willacy counties, Texas may have been cut by the Pecos River. The valley may have been abandoned when the Pecos was captured by the Rio Grande near Laredo. Price suggested the valley was structurally controlled by the Reynosa Cuesta.

Five cyclical erosional surfaces were recognized in the Pecos Valley of New Mexico by Morgan and Sayre (1942). These in topological order are:

1. The Sacramento Plain. This is an erosional surface in the Sacramento Mountains to the west of the Pecos Lowland that is correlated with the constructional surface of the Ogallala formation in the Llano Estacado.

2. The Diamond A-Mescalero Plain. Diamond A is the name applied to the surface on the west side of the Pecos Valley and Mescalero to the corresponding surface on the east side. The Diamond A surface is a pediment that lies from 400 to 1300 feet below the level of the Sacramento Plain; the Mescalero Plain on the east side of the Pecos Valley is the much more extensive of the two pediments. It was estimated by Morgan (1942) that close to 95 per cent of the excavation that has taken place in the Pecos basin was accomplished during the Diamond A-Mescalero erosion cycle, which he believed covered a very considerable part of Pleistocene time.

3. Along the Pecos River below the Diamond A-Mescalero surface are three gravel-capped pediments named from highest to lowest the Blackdom, Orchard Park, and Lakewood terraces (Thornbury, 1965, p. 316).

Based on discovery of Marmota *flaviventris obscura,* Stearnes (1942) suggested that the life zones of southeastern New Mexico had been lowered 1,000 to 4,500 feet during Wisconsin time. The marmot described is akin to species presently restricted to the timberline country of Colorado. The localities described were in the Tularosa Basin and the Guadalupe and Manzano mountains.

Evans and Meade (1944) in a study of the Quaternary of the High Plains of Texas concluded that the deposition of the Ogallala of Texas and New Mexico spanned a time from late Tertiary to early Quaternary. They also concluded the lake deposits of the High Plains date from Nebraskan time. This appears to agree with the previous suggestion by Baker (1916) that the upper reaches of the Pecos developed during the Pleistocene.

Bretz and Horberg (1949a) suggested that the "quartzose conglomerate" fill along the Pecos depression correlates with the basal Ogallala. They made field studies of Ogallala remnants both east and west of the Pecos River. Gravel remnants at various elevations over a wide area in southeastern New Mexico are related to a once extensive cover of High Plains Ogallala deposits. They also suggested that an ancestral Pecos depression, probably formed jointly by warping and solution collapse, existed in pre-Ogallala
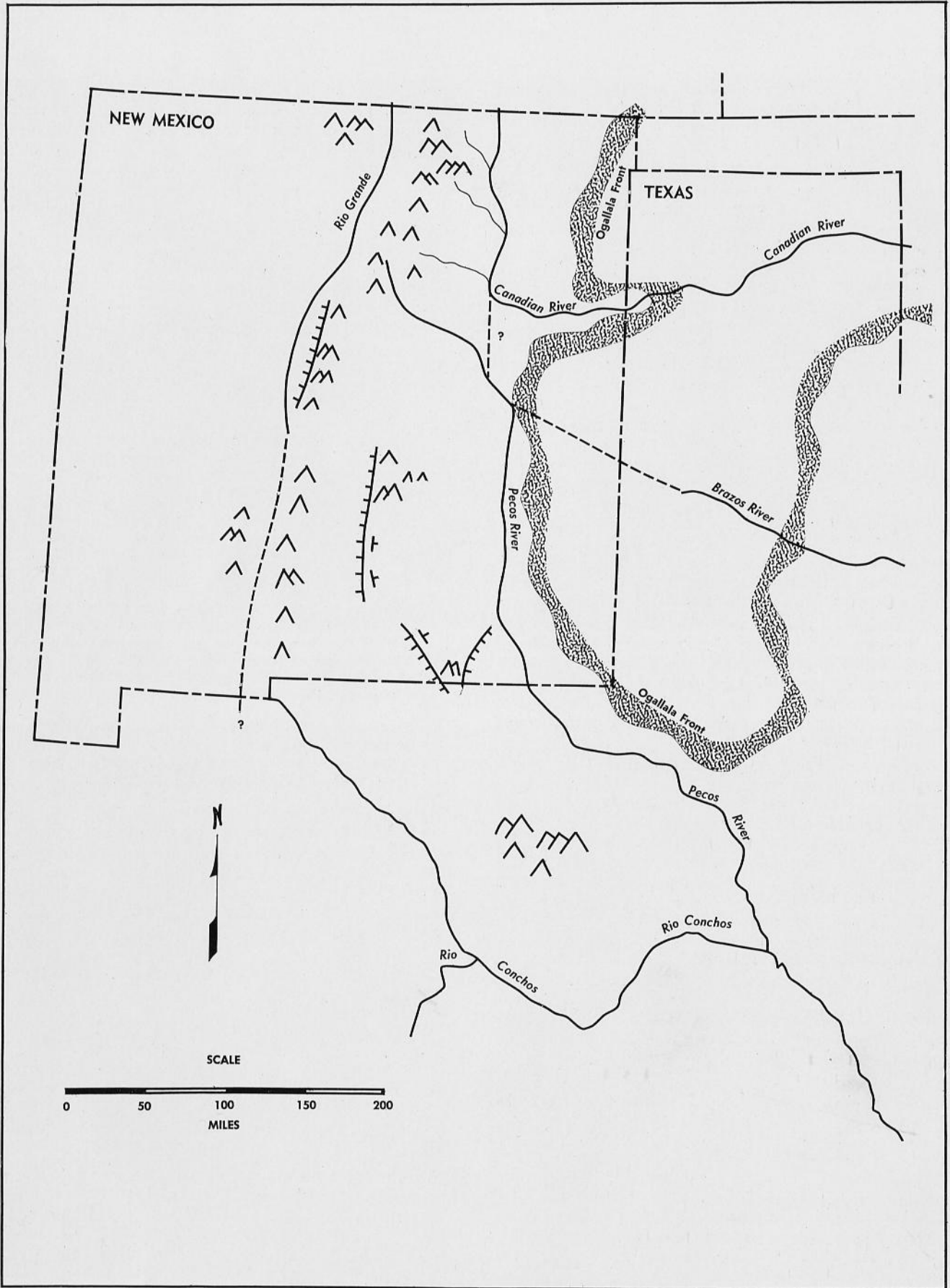
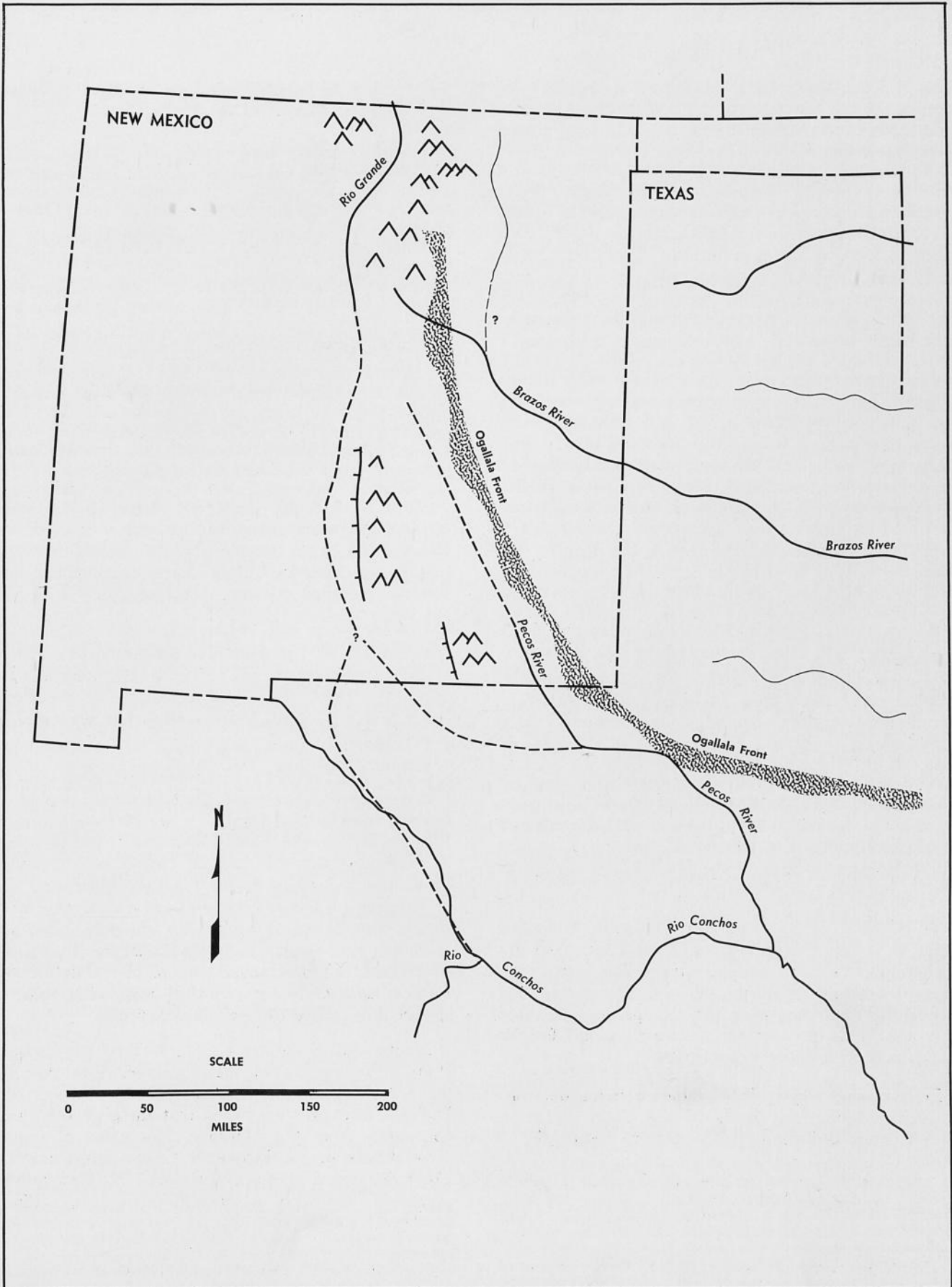Fig. 4. Postulated drainage of the Pecos River—Late Pleistocene.

Fig. 5. Postulated drainage of the Pecos River—Middle Pleistocene.

time, and that the present depression, enlarged by re-
treat of the cap rock escarpment and modified by later
deformation and solution subsidence, is in large part a
resurrected feature.

Galloway (1956) in agreement with Theis (1932)
described the Portales Valley as a pre-Ogallala Brazos
River which included as its headwaters the upper Pecos
River. The valley was then filled by Pleistocene alluvia-
tion. The headwaters portion of the stream was
captured near Fort Sumner by the Pecos River, cut-
ting off the flow of water to Portales Valley causing
it to be abandoned.[3]

The history of the formation of the High Plains
(Ogallala) is critical to the reconstruction of the drain-
age history of the Pecos River. The most significant
recent contributions in this area are those of Frye and
Leonard (1957). In their study of the margin of the
High Plains they concluded that an arid period in late
Pliocene resulted in the formation of the Ogallala cap
rock of the High Plains. They also reported that a
mild humid climate prevailed over a late mature ero-
sional topography in early Neogene. This was followed
by a uniform drying period until semiarid conditions
were reached by the end of Tertiary. A trend toward
a more humid climate began in the Pleistocene and was
accompanied by stream incision and minor alluviation.
This trend climaxed in Kansan time and was followed
by progressive desiccation. At present the climate ap-
proaches the condition described for the late Tertiary
plain.

Frye and Leonard (1957a), in correlating the Og-
allala of Texas to the Ogallala of the Great Plains,
dated initial deposition of Ogallala as late Miocene and
deposition completed by the end of Pliocene. They also
dated the initial erosion of the High Plains surface as
Pleistocene based on eolian fill.

W. S. Mott (1959) dated the Sacramento Mountains
uplift as middle Tertiary. The Ogallala was then de-
posited by consequent streams forming the Sacramento
Plain. Sometime following this the Sacramento and
Guadalupe mountains were further uplifted and tilted
eastward. This provided the structural control for the
formation of the upper Pecos River.

Leonard and Frye (1962) studied the geomorph-
ology and molluscan faunas of the Pecos River in
Texas. Four pedimented surfaces were described:

Surface I—graded to the late Tertiary Ogallala
          drainageways.

Surface II—graded to a lower level early Pleisto-
           cene channel of the Pecos River.

Surface III—graded during early Wisconsin time
            to a level only slightly above the present Pecos
            River.

Surface IV—developed during latest Wisconsin and
           Recent represented as a terrace of highly fos-
           siliferous deposits in which the present Pecos
           River is incised.

Molluscan fauna were found only in association with
the last two surfaces. Leonard and Frye concluded that
the Pecos River dates from late Tertiary.

Frye and Leonard (1964) in studying the Southern
High Plains of Texas concluded that the Ogallala in
that region was deposited during the Pliocene.[4]

The United States Geological Survey (1966) pub-
lished water quality and surface water data for the
Pecos River from sample stations located at Orla,
Girvin, and Shumla, Texas. These data include flow
records, chemical content, dissolved solids load and
silt load.

Lewand (1967) in a study of the geomorphic history
of the Leon River of central Texas concluded that the
ancestral Brazos River was beheaded by the Pecos
River in central New Mexico, as earlier suggested by
Baker (1916).

C. L. Byrd (1971) concluded that deposition of
Uvalde Gravels of central Texas occurred within an
interval from earliest Ogallala (late Miocene) to early
Pleistocene. On the basis of distribution and petrology
he concluded that the Uvalde Gravel was deposited
contemporaneously with the Ogallala Formation and
is Neogene in age (Miocene-Pliocene). Byrd (*idem.*
p. 19) also described lag gravels of white, pink, and
yellowish vein quartz atop the Callahan Divide, ap-
proximately 200 feet above the projected High Plains
surface, apparently lags from a much older alluvial
surface, not related to Ogallala deposition.

Menzer and Slaughter (1971) in their petrographic
study of kyanite-bearing metaquartzite, silica-cemented
orthoquartzite and chert pebbles and cobbles in the
Dallas, Texas area suggested that these gravels prob-
ably came from the Manzano Mountains of central
New Mexico or the Sangre De Cristo Range near the
Colorado border. They also speculated that these gravels
represent the lag of a more extensive High Plains
blanket.

---

[3]The Galloway statement indicates the same conclusion reached
by Byron Leonard and me last summer. The oldest Pleistocene
we could find there is Kansan. The valley is cut several hundred
feet below the base of the Ogallala (as shown on Thomas' map)
to the Pecos Valley east of Ft. Sumner.—J. C. Frye.

[4]Applicable here is Frye & Leonard (1968) Late Pleistocene
Lake Lomax in western Texas in "Means of Correlation of
Quaternary successions," Vol. 8, VII INQUA Congress, Univ.
of Utah Press, p. 519-534.—J. C. Frye.

THE PECOS RIVER BASIN

The valley of the Pecos River extends from Mora County, New Mexico to Val Verde County, Texas. The overall basin length is 550 miles. The area of the present Pecos basin is approximately 42,500 square miles. The maximum basin width, 135 miles, occurs across the dissected High Plains area just north of Roswell, New Mexico where it is bounded by the Sacramento Mountains on the west and the Mescalero Escarpment on the east (fig. 1, Pl. I).[5]

The elongate Pecos basin is bounded on the west by the Stockton Plateau; the Glass, Davis, Apache, Delaware, Guadalupe, and Sacramento mountains; the Pedernal Hills and the Santa Fe range of the Sangre De Cristo Mountains. On the east, the divide follows the western edge of the Edwards Plateau, the Mescalero Escarpment, the low tablelands between the Pecos River and the tributaries of the Canadian River and the Rincon range of the Sangre De Cristo Mountains. To the south the Pecos River flows into the Rio Grande which drains southeast into the Gulf of Mexico (fig. 1).

Physiographically, the Pecos basin can be divided into five sub-basins:

(1) *Cowles-Ribera Sub-basin.* The upper basin from Cowles to Ribera, New Mexico is an area of high relief. The topography is mountainous and the high mountain streams of the Pecos Baldy area coalesce to form the Pecos River. The stream valleys in this section are deeply entrenched into the Pennslyvanian and Precambrian rocks of the Sangre De Cristo Mountains. The divides between the Pecos River and the tributaries of the Rio Grande and upper Canadian rivers are formed by high ridges of the mountains (fig. 6, Pl. I).

(2) *Ribera-Fort Sumner Sub-basin.* The basin from Ribera to Fort Sumner, New Mexico is a region of rough topography where the Pecos River and its tributaries are entrenched into Triassic rocks. This area includes the Pecos Valley and the sub-basins of the Gallinas River and Pintada Creek. The divides between tributaries of the Pecos River and the Canadian River are indistinct and occur on tablelands cut by occasional wind gaps. The divide between the Pecos River and Laguna del Perro is low-lying and ill-defined (fig. 6, Pl. I).

(3) *Fort Sumner-Carlsbad Sub-basin.* The basin from Fort Sumner to Carlsbad, New Mexico is an area of low relief. The Pecos River and its principal tributaries, the Arroyo del Macho, Rio Hondo, Rio Penasco and the Black River flow over Permian and Triassic rocks forming a rolling plains topography dissected by the eastward flowing tributaries. The divide between the Pecos River and the internal drainage of the Tularosa Basin extends along the crest of the Sacramento Mountains. The eastern divide of the Fort Sumner-Carlsbad sub-basin is the Mescalero Escarpment which separates the Pecos River from the eastward drainage of the High Plains.[6] The Blackdom, Orchard Park and Lakewood terraces described by Fielder and Nye (1933) are constructional plains of alluvium deposited by the Pecos River in this section of the basin, where the Pecos River meanders through a broad valley of Quaternary fill (figs. 1, 6; Pl. I).

(4) *Carlsbad-Iraan Sub-basin.* The basin from Carlsbad, New Mexico to Iraan, Texas is an area of extensive low-lying plains. In this section the river is a meandering stream in a broad shallow valley floored by Quaternary sediments.[7] In this sub-basin the divide between the Pecos River and the eastern drainage of the High Plains is ill-defined. On the west the Pecos basin is separated from the Salt Basin by the Davis, Apache and Delaware mountains (figs. 1, 6; Pl. I).

(5) *Iraan-Langtry Sub-basin.* The basin from Iraan to Langtry, Texas is a narrow valley deeply entrenched into a high tableland of Cretaceous rocks. Within the deep valley the Pecos River meanders on Quaternary sediments.[8] This sub-basin includes the main Pecos Valley and the tributary basins of Howards and Independence creeks. The divides between Pecos tributaries and the Rio Grande occur on highlands of the Stockton Plateau. The divides between the Pecos and Devils rivers occur on highlands on the Edwards Plateau (figs. 1, 2 6; Pl. I).

STRATIGRAPHY

Stratigraphy of the Pecos basin is significant to the reconstruction of basin history. Siliceous gravels contributed to the sediment load of the Pecos River (thus to depositional surfaces within the Pecos basin) and provide evidence for establishing a sequence of events in basin development. The stratigraphic units of importance in the Pecos basin include rocks of Precambrian, Permian, Triassic, Cretaceous, Tertiary and Quaternary age.

---

[5]The map, Pl. I, is in error on part of the area shown as "Q" west of Ft. Sumner. Although there are five Pleistocene terraces on the west side of the valley, four of which contain good molluscan faunas, and one of which was dated 17,180±140 (ISGS-91), there is a sizable patch of High Plains surface underlain by positive Ogallala. We have studied a well-exposed section south of Yeso where the Ogallala gravels are on bedrock at a level well above the highest of the five Pleistocene terraces. Although we could quibble over details, I think this is the only major disagreement we would have with the map. (Incidentally, the other radiocarbon date we got last summer was 18,100±370 (ISGS-92) from a terrace fauna 3.7 miles northeast of Bob Crosby Bridge, northeast of Roswell).—J. C. Frye.

[6]If the term "Mescalero Escarpment" is used to mean the escarpment held up by Ogallala, there's quite a stretch southeast of Ft. Sumner where it does not exist. The surface next below the Ogallala surface in a wide area is extensively covered by Kansan deposits that contain a strong caliche soil profile—Yarmouth Soil—in the top, and in some places holds up a significant escarpment.—J. C. Frye and A. Byron Leonard.

[7]In the segment of Pecos Valley between Pecos, Texas, and Iraan there are some patches of definite Ogallala (e.g., Leonard and Frye, 1962) from which we got some fragmentary *Biorbia papillosa* and which is clearly topographically higher than the three Pleistocene surfaces that we described. Also, much of the surface, particularly on the south side of the river, is strongly pedimented.—J. C. Frye.

[8]In significant parts of this segment the Pecos River is flowing, with a strong gradient, on bedrock rather than meandering on Quaternary sediments.—J. C. Frye.
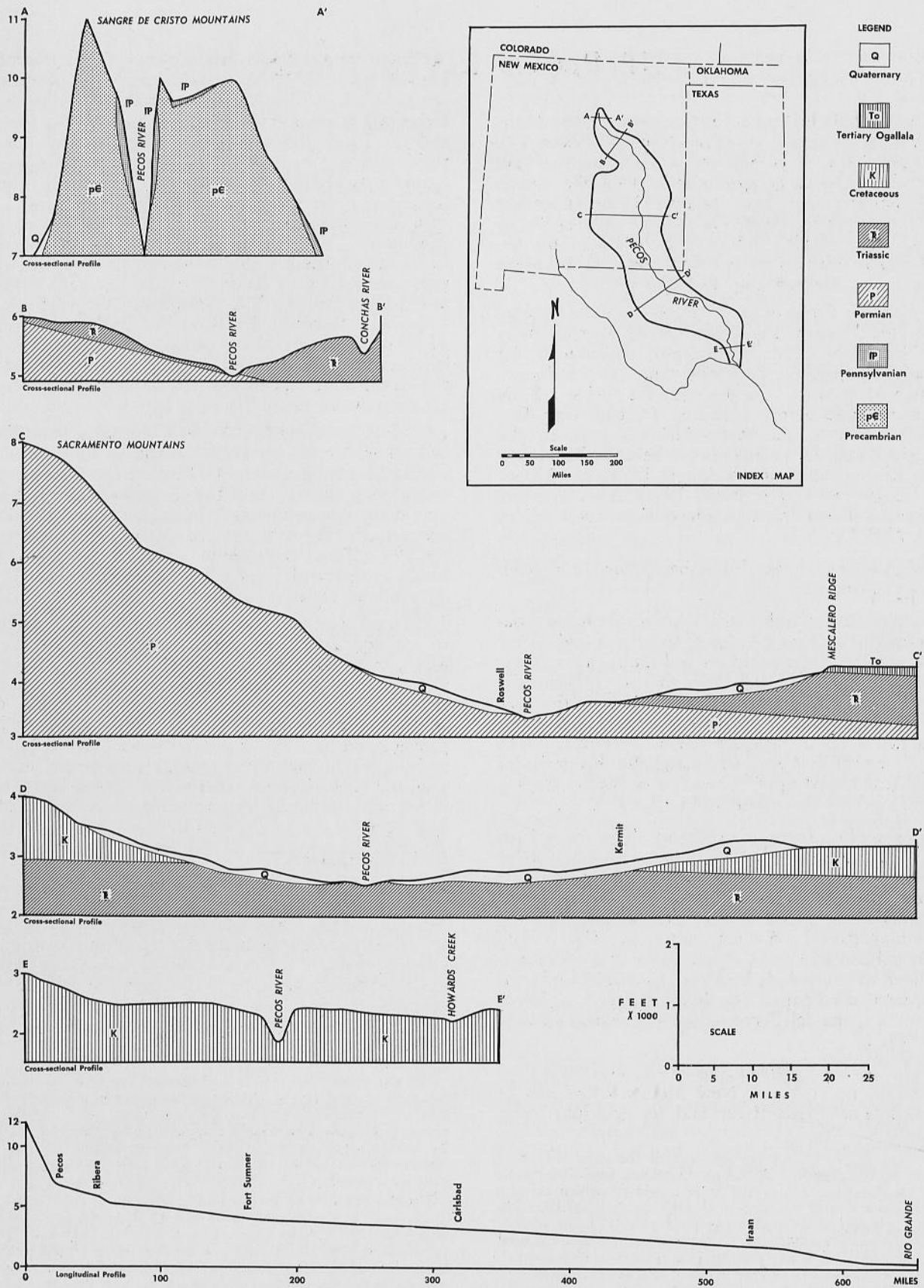
Fig. 6. Cross valley and longitudinal profiles of the Pecos River.

Precambrian rocks supplied the gravels of the High Plains and, through reworking, those of the terraces and floodplains of the Pecos. Permian rocks, largely limestone, are exposed over the greatest area in the basin and, because of their regional dip and resistance to erosion, are a significant factor in the progressive positions of the stream channel. Triassic rocks, chiefly red shale and evaporites, are widely exposed in the basin and may have localized valley formation through solution and collapse. Cretaceous rocks, principally limestone, preserve a history of earlier (pre-Pecos) drainage, and hence aid in interpretation of the geomorphic history of the lower Pecos River. Histories of the Tertiary Ogallala Formation and of scattered remnants of a pre-Ogallala fluvial formation are often enigmatic, but closely related to events of the history of the ancestral Pecos River. Quaternary sediments, chiefly sand and gravel, are represented by terraces or valley fill.

Small areas of outcrop of Jurassic, Pennsylvanian, Mississippian, Devonian, Silurian, Ordovician, and Cambrian rocks occur in the basin, but are of little direct significance in interpreting the evolution of the river system.

PRECAMBRIAN

Outcrops of Precambrian rock in the Pecos Valley are confined to the Sangre De Cristo Mountains and the Pedernal Hills of New Mexico (Pl. I).

Precambrian rocks are exposed widely in the Sangre De Cristo Mountains of northern New Mexico (fig. 6, Pl. I). They consist of the Ortega and Vadito formations and Embudo Granite. The Ortega Formation consists of 10,000 feet of quartzite, staurolite schist, muscovite-quartz-biotite phyllite and black carbonaceous phyllite. The Vadito Formation, resting unconformably on the Ortega Formation, contains conglomerate, metarhyolite felsites, minor muscovite-quartz-biotite phyllite and hornblende-andesine amphibolite schist. Pegmatites, vein quartz, and hydrothermal mineralization are related to intrusion of the Embudo Granite into the Ortega and Vadito rocks (Miller *et al.*, 1963, p. 1, 7-14).

The low Pedernal Hills of Torrance County, New Mexico expose Precambrian rock composed of fine-grained quartzite containing some argillitic laminae, schist, gneiss and granite (Stipp, 1952, p. 5).

PERMIAN

Permian rocks are exposed over a larger area of the basin than are rocks of any other age. They crop out in the Glass and Delaware mountains of Texas, and the Guadalupe and Sacramento mountains and the Pecos Valley of New Mexico (Pl. I). The Permian units of greatest importance to this study are the San Andres Limestone and the Chalk Bluff Formation.

The San Andres Limestone is 800-1200 feet thick, composed of massive black limestone, dolomitic limestone with included sandstone, anhydrite and redbeds, and forms the eastern slopes of the Sacramento Mountains and the northern portion of the Guadalupe Mountains. East of the Sacramento Mountains the San

Andres Limestone is overlain by the Chalk Bluff Formation, about 1,000 feet thick, consisting of redbeds, anhydrite, dolomitic anhydrite, sandstone, and dolomitic limestone (Lang, 1937, p. 850-856).

The Chalk Bluff Formation is transitional with the Grayburg Formation in the Guadalupe Mountains, which is in turn overlain by the Whitehorse Group, composed of the Queen, Seven Rivers, Yates and Tansill formations. The Whitehorse Group is correlative to and transitional with the Capitan reef limestone of the Guadalupe Mountains which grades laterally into the Bell Canyon Formation of the Delaware Basin. The San Andres Limestone is equivalent in age to the Goat Seep Limestone of the Guadalupe Mountains. The upper units of the Permian section include the Castile Anhydrite, Salado Halite and the Rustler Formation, which are overlain unconformably by Triassic beds (Stipp *et al*, 1952, p. 11).

TRIASSIC

Triassic rocks of the Dockum Group crop out in the Pecos Valley along the Pecos River from Artesia to the Sangre De Cristo Mountains in New Mexico. Other outcrops of Triassic rocks occur in the Sacramento and Capitan mountains and near Pecos, Texas. Formations of the Dockum Group exposed in the study area are the Santa Rosa Sandstone and the Chinle Formation (Dane and Bachman, 1965).

The Santa Rosa Sandstone is 200-300 feet thick and consists of gray and red sandstone and lenses of red shale and conglomerate (Hendrickson and Jones, 1952, p. 23-24). Overlying the Santa Rosa Sandstone are redbeds of the Chinle Formation, consisting of a thick series (250-350 feet thick) of red shales and thin interbedded sandstones (*idem*).

CRETACEOUS

Cretaceous rocks in the study area preserve the earliest history of the Pecos drainage. Cretaceous rocks were once present in a continuous depositional surface from the Cordilleran uplift in the Western United States (Eardley, 1962). This surface of early Cretaceous rocks was, therefore, the last clearly pre-Pecos surface before tectonic movements in the study area initiated the development which ultimately resulted in the formation of the present Pecos Valley.

Cretaceous rocks crop out in the study area on the Edwards-Stockton Plateau region of Texas and on the north end of the Sacramento Mountains in New Mexico (Pl. I). The Cretaceous system is represented by the Comanche Series in the Edwards-Stockton Plateau area and the Mesa Verde Group, Mancos Shale and the Dakota Sandstone in New Mexico (Dane and Bachman, 1965; Darton *et al.*, 1937).

The groups of the Comanche Series of the Edwards-Stockton Plateau are the Washita, Fredericksburg and Trinity groups. The Trinity Group consists of alternating limestone and marl with some sandstone. The Fredericksburg Group consists of massive rudist limestone and marl. The Washita Group consists of massive limestone and marl (King 1935, p. 237-241).

Fig. 7. Bluff formed by Basal Ogallala conglomerate at Locality 29 on the Black River near Malaga, New Mexico, more than 1000 feet below the projected level of the High Plains surface.

Fig. 8. Basal Ogallala conglomerate at Locality 29 on the Black River. The dark gravels in the photograph are mostly quartzite and jasper. In addition, limestone pebbles are common in the conglomerate at this locality.

The Mesa Verde Group, which crops out around Sierra Blanca and Sacramento mountains, is about 2,100 feet thick and consists of sandstone, shale, and marl (Pike, 1947, p. 9-11). The Mancos Shale, about 400 feet thick, consists of sandy marine shale, cross-bedded sandstone and quartzose sandstone (Dane and Bachman, 1957, p. 181-196). The Dakota Sandstone, on the eastern slope of the Sangre De Cristo Mountains, is a prominent cliff-forming unit averaging about 100 feet in thickness and consisting largely of fine- to medium-grained cross-laminated sandstone (Waage, 1953, p. 11-26).

TERTIARY

Rocks of Tertiary age in the study area include the Ogallala Formation of the High Plains and Pecos Valley and remnants of apparent pre-Ogallala fluvial sediments found on the Stockton Plateau and on King Mountain in Texas (Pl. I). The Ogallala Formation has been described in some detail by Frye (1970). Parts of his regional review are as follows:

> The Ogallala Formation, of Pliocene and late Miocene age, extends from north to south through the Great Plains region for 800 miles, and has a maximum extent of 300 miles from east to west. . . . Throughout this region it is either exposed at the surface or is mantled with only relatively thin deposits of eolian sands and silts or by shallow pond deposits. As the Ogallala contains significant quantities of sand and of sand and gravel and is generally underlain by older rocks of much lower permeability, it is the most extensive and usable aquifer of the Great Plains province.

> The High Plains surface is underlain by, and takes its form from, the Ogallala Formation. This vast area stands as a plateau above adjacent topography that is lower to both east and west, except in part of Nebraska. However, at the southern limit of the High Plains the Cretaceous rocks rise above the Ogallala surface, locally leaving it in the position of a terrace. At the northern edge of the formation, the erosional surface developed on the Ogallala merges with the adjacent erosional topography developed on older stratigraphic units.

> The character of the Ogallala deposits demonstrates that they are primarily the product of stream action, probably locally supplemented by eolain activity and periodically interrupted by widespread soil development. Furthermore, the basal part of the formation consists of a series of fills in separate valleys that, in general, trended from west to east. Coalescence of the alluvial fills from one valley to another gradually took place as the individual divides were buried in the progressively thickening alluvial fills. The final integration of this extensive plain of alluviation, permitting an essentially unrestricted lateral migration of stream channels, occurred during the late phase of Ogallala deposition. Some elements of the former bedrock topography (particularly in west-central Texas) were probably never buried by Ogallala deposits. The resultant coalescent plain, marked only by depositional constructional topographic features, maintained the equilibrium sufficiently long to permit the strong development of the 'Ogallala climax' soil.

> The Ogallala Formation ranges in thickness from a feather edge to more than 500 feet; in texture, from coarse gravel and sand, through sand and silt, to marl and clay; in induration, from loose and friable to compact and, locally, cemented with both calcium carbonate and silica; and, in color, from white or light gray to tan, olive gray and red-brown. However, in spite of these extreme ranges some clearly recognizable vertical and regional, trends in
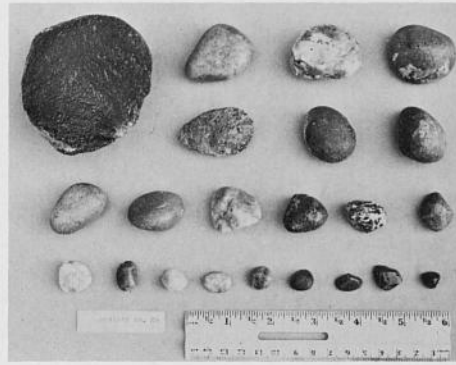

Fig. 9. Gravel samples from Locality 29. The gravels consist of red, black, and gray chert, white and pink vein quartz, white gray-to-black, purple and banded quartzite, white orthoquartzite, granite and rhyolite.

> physical character can be used for stratigraphic correlation (Frye, 1970, p. 5-7, 10).

Bretz and Horberg (1949b) suggested that the quartzose conglomerate on the west side of the Pecos River, previously mapped as Pleistocene age, may be basal Ogallala. These conglomerates are found in a strip 10-20 miles wide mostly west of the Pecos River from Seven Rivers to Roswell and another area that extends south from Carlsbad to the Black River (locs. 7, 8, 9, 14, 18, 24, 29; figs. 7, 8, 9, 10, 11, 12). The quartzose conglomerate ranges in thickness from a feather edge to more than 300 feet and consists of clay, silt, sand, gravel, and conglomerate. In both areas the conglomerate appears to be thickest a few miles west of the Pecos and to thin abruptly to the east and more gradually to the west. Nearly everywhere it is slumped and deformed (Hendrickson and Jones, 1952, p. 24-25).

There is what appears to be a pre-Ogallala depositional surface preserved on highlands in the Pecos basin. Scattered residual gravels have been found on the Stockton Plateau and on King Mountain near McCamey, Texas (locs. 2, 3, 25, 26). These gravels consist of vein quartz, jasper, and quartzite. At one locality on King Mountain a quartzite cobble was found embedded in a caliche bed. Byrd (1971) also described siliceous gravels, older than the Ogallala Formation, atop the Callahan Divide near Merkel, Texas, which may be remnants of the same or a similar pre-Ogallala formation.

Eocene deposits of the Cub Mountain Formation, cropping out on the east flank of Sierra Blanca consist of beds of pale-yellow to gray coarse-grained quartzose sandstones, with lenses of quartzite and chert-pebble conglomerate (loc. 28). Thickness of the formation is greater than 500 feet. It uncomformably underlies Tertiary rocks and unconformably overlies the Cretaceous Mesa Verde Group. This formation may be as old as latest Cretaceous or as young as Miocene (Bodine, 1956, p. 1, 8-11).

If these Eocene deposits are correlative, they too may be remnants of a once extensive alluvial plain much older than Ogallala. Dane and Bachman (1965) have mapped the Cub Mountain and Baca formations in the Sierra Blanca and in an east-west line of outcrops in west-central New Mexico in the Datil and Gallinas mountains.

Fig. 10. Bluffs, formed by basal Ogallala conglomerate, overlooking the Pecos River at Herradura Bend. Here the Ogallala rocks are exposed 900-950 feet below the projected High Plains surface.

QUATERNARY

Quaternary deposits of the Pecos Valley include the Lakewood, Orchard Park and Blackdom terrace deposits (Fiedler and Nye, 1933), the Mescalero Sands in New Mexico and Pleistocene terraces along the Pecos River in Texas (Pl. I).

Deposits of the Recent Lakewood terrace consist chiefly of silts and interbedded lenses of gravel and sand, ranging in thickness from 5-30 feet. Underlying the Lakewood terrace are the Pleistocene Orchard Park and Blackdom terraces consisting of beds of silt and sand, ranging in thickness from a few feet to 20 feet (Morgan, 1938, p. 13-14).

The Mescalero sands are dune sands that mantle most of the area from the Pecos River to the Mescalero Escarpment (fig. 13).[9] These dune sand deposits reach thicknesses of 60 feet (Hendrickson and Jones, 1952, p. 26).

Quaternary deposits of the Texas portion of the Pecos Valley form an extensive plains area from the New Mexico-Texas state line to the Edwards-Stockton Plateau. They also form the flat flood plain area of the Pecos Valley from Iraan to the Rio Grande. These deposits consist of alluvial clay, sand, silt, and gravel along the Pecos River and dune sand near the edge of the High Plains.

---

[9] The "Mescalero Sands" at some places east of the Pecos River overlie the extensive intermediate surface that is generally covered by Kansan age deposits which contain a strong caliche soil profile in the top.—J. C. Frye.

GEOLOGIC STRUCTURE

The Cowles-Ribera sub-basin of the Pecos basin is developed on Pennsylvanian and Precambrian rocks in the Sangre De Cristo Mountains. The river is controlled by block faulting and warping and is confined to a narrow symmetrical valley (fig. 6, Pl. I). The steep gradient in this section of the river is also attributed to the high relief of the mountains.

The Ribera-Carlsbad portion of the Pecos basin is developed on Permian and Triassic beds that dip gently eastward into the Permian basin from the block faulted Delaware, Guadalupe and Sacramento mountains. The formations which have influenced the topography most are the Castile Anhydrite, the Salado Halite, and the Rustler Limestone of the Permian Ochoa Series. The Pecos Valley may have originated at least partly because of the solubility of these formations, and solution phenomena are widespread (Morgan, 1942). The wide western flank of the basin is developed on the resistant San Andres Limestone of Permian age. The narrower eastern flank of the basin is developed on the less resistant Chalk Bluff Formation, also of Permian age, and on Triassic redbeds (fig. 6). The upper portion of the Pecos basin is, therefore, asymmetrical (fig. 6). The length and number of eastward draining tributaries and the apparent eastward migration of the Pecos River have been controlled largely by the existence of the less resistant Chalk Bluff Formation and Dockum redbeds overlying the eastward dipping resistant San Andres Limestone (Pl. I).

The Carlsbad-Rio Grande portion of the Pecos basin, which developed on Quaternary and Cretaceous units, is symmetrical in cross-profile (fig. 6). From the New Mexico-Texas state line to Iraan, the Pecos Valley is developed on Quaternary alluvial deposits exposed on four pediment surfaces sloping into the Pecos River (Leonard and Frye, 1962). From Iraan to the Rio Grande, the Pecos basin has steep valley walls developed in the Lower Cretaceous units which dip gently southeastward at 5 to 10 feet per mile (King, 1930) (figs. 2, 3).

The gradient of the Pecos River varies widely among the sub-basins. In the section from the headwaters to Ribera it is 110 to 115 feet per mile. From Ribera to Fort Sumner it averages 25 to 30 feet per mile; from Fort Sumner to Carlsbad it is 6 to 6.5 feet per mile; from Carlsbad to Iraan again 6 to 6.5 feet per mile; and from Iraan to the Rio Grande it is 10 to 12 feet per mile (fig. 6). The change in gradient at Fort Sumner is in the suggested area of capture of the ancestral Brazos River by the Pecos River (Baker, 1916; Theis, 1932; Galloway, 1956; Lewand, 1969) (figs. 4, 5) and this may explain at least part of the change. Another significant change in gradient occurs just below Iraan (6 to 6.5 feet per mile to 15 to 20 feet per mile) where the river encounters resistant Cretaceous rocks.

RIVER STATISTICS

Flow and sediment records of the present Pecos River are significant to this study since they indicate the competence and capacity of an existing stream in the area of study under conditions perhaps not radically different than those throughout much of the past. They give a measure of erosional and sediment transport rates in the basin under study.

Average discharge of the Pecos River within the basin above Pecos, New Mexico is 70,865 acre-feet per year, recorded at Pecos. The maximum annual discharge at this station over a 20 year period was 208,900 acre-feet in 1941; the minimum, 20,110 acre-feet in 1951. Average discharge of the Gallinas River, a major tributary of the Pecos River, at Montezuma, New Mexico is 10,935 acre-feet per year. The maximum discharge recorded at that station over a 20 year period was 63,540 acre-feet in 1941; the minimum was 756 acre-feet in 1953. At Alamogordo Dam, below the Fort Sumner to Ribera section of the Pecos basin, the average discharge is 167,521 acre-feet per year. The maximum discharge recorded over a 20 year period was 382,600 acre-feet per year; the minimum was 65,760 acre-feet in 1954. Average discharge at Carlsbad, the southern end of the Carlsbad to Fort Sumner section of the basin, is 172,195 acre-feet per year. The maximum discharge recorded over a 20 year period was 1,388,000 acre-feet in 1941, the minimum was 25,160 acre-feet in 1953. At Comstock, Texas, in the lower basin, the average discharge recorded over a 12 year period was 2,109,330 acre-feet in 1954; the minimum was 104,340 acre-feet in 1952 (New Mexico State Engineers, 1959; Stout *et al.*, 1961).

In these flows, the maximum recorded flood discharge of the Pecos River, 55,200 sec-ft, was recorded at Santa Rosa, New Mexico in the 1937-1939 floods (U. S. Geol. Survey, 1939).

Erosion rates in the Pecos basin are difficult to determine, but useful estimates have been determined. Leopold *et al.,* (1966) determined the erosion rate of the Arroyo de los Frijoles, small watershed just northwest of Santa Fe, New Mexico, to be approximately 0.015 feet per year (Leopold *et al.,* 1966, p. 237-239). Schumm (1963) reporting on the disparity between present rates of denudation and orogeny determined the rates of denudation in an area of 10 inches or less of effective precipitation (typical of the larger portion of the Pecos Valley) to be 0.29 feet per 1,000 years or 1 foot every 3,400 years. Hence the existing valley in the Ribera-Carlsbad and Iraan-Langtry sections (where the river is most deeply entrenched) would have been excavated in 3,060,000 to 4,420,000 years, since the middle Pliocene period. The calculations are only rough approximations. However, this rate of excavation seems inadequate to correlate with other aspects of the postulated history, erosional rates were higher, or river flow was greater.[10]

EVIDENCE OF THE EARLY HISTORY OF THE PECOS RIVER

In considering the evolution of a river system there are many forms of evidence which may be used. These include alluvial deposits, valley form, river patterns, structural patterns, hydrologic data, physiographic expression, etc.

As evidence of Pecos River history this study relies heavily on relationships between erosional and depositional surfaces within and adjacent to the Pecos Valley, physiography of the valley, structural tectonics of the Pecos basin (as expressed by stratigraphic units and tectonic events) and possible source areas for siliceous gravels.

Within and adjacent to the Pecos Valley there exists an apparent pre-Ogallala surface represented by siliceous lag gravels high above the Ogallala Formation of the High Plains. High lag gravels also exist on the summit peneplains of the Guadalupe and Sacramento

---

[10]Climatic data from several sources, and most strikingly from the molluscan faunas, demonstrate that precipitation rates at times during the Pleistocene were several times the present. In the paper Byron Leonard and I are now working on, we have overwhelming evidence for a much higher precipitation rate as recently as 17,000-18,000 B.P. I wonder if the slow erosion rates quoted have any meaning in the over-all history of the Pecos.—J. C. Frye.

Fig. 11. Gravel samples from Locality 7 in the Yeso Hills. These gravels, derived from a conglomerate, consist of chert, dark gray-to-black quartzite and vein quartz.
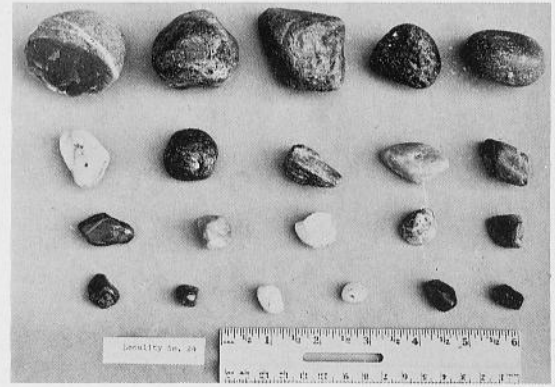

Fig. 12. Gravel samples from Locality 24 on Highway 13, 6 miles west of Hagerman, New Mexico. These gravels derived from a conglomerate capping the mesas in that area consist of gray-to-black chert; white and pink vein quartz; jasper; banded, red, purple and gray-to-black quartzite.

mountains. Basal conglomerates of the Ogallala Formation occur west of the Pecos River at river level 1300 feet below the High Plains surface.[11] Siliceous rocks, similar in petrology to siliceous gravels of the pre-Ogallala and Ogallala formations occur in the Pedernal, Manzano and San Juan mountains. Abandoned valleys apparently once connected the Pecos River above Fort Sumner in New Mexico to the Brazos River of Texas and more recently the north-south flowing portion of the upper Canadian River to the upper Pecos River. Each of these evidences will be considered in turn.

PRE-OGALLALA HISTORY

The pre-Ogallala history includes both erosional and depositional events, evidence of which is preserved in the form of remnantal surfaces. The correlation of these surfaces is an attempt to establish the existence of a once continuous and widespread early Tertiary depositional surface in the study area.

Church and Hack (1939) described the plateau-like surface of San Pedro Mountain in the northwestern part of the Jemez Mountains of New Mexico as a remnant of an exhumed erosion surface, overlain by a thin veneer of chert, with underlying gravel. The chert and gravel beds are a part of Tertiary beds which thicken eastward and extend across the northern spurs of the Jemez Mountains. These rocks are correlative with the El Rito, Abiquiu Tuff and Santa Fe formations (Pliocene-Pleistocene) found in the Rio Grande depression. The erosional surface, formed during late Cretaceous and early Tertiary, is exposed on the summit of San Pedro Mountain where the late Tertiary deposits have been eroded away. This erosional surface is also present on Cerro Pedernal (fig. 14) north of the Jemez Mountains.

Barker (1958) described the La Jarita Mesa-Jawbone Mountain highland in the Las Tablas area of northern New Mexico. This highland, part of the San Juan Mountains, consists of the La Jarita Mesa (which

[11] I question that these gravels are Ogallala *in situ,* 1300 feet below the High Plains surface.—J. C. Frye.

ranges in altitude from 8,000 to 9,000 feet) (fig. 15); Kiawa Mountain, a monadnock that rises 1,000 feet above La Jarita Mesa; Tusas Mountain, another monadnock that is 10,100 in height; and Jawbone Mountain, another monadnock (10,860 feet in height).

The presence of monadnocks above a lower consistent erosional surface suggests two definite erosional surfaces and probably a third in the San Pedro and San Juan Mountains. These are represented by (1) the peneplained surface atop the monadnocks, (2) the peneplained surface atop the La Jarita Mesa, and (3) the present level of erosion.

This interpretation is further supported by the presence of two depositional surfaces: (1) the pre-Ogallala surface, and (2) the Ogallala Formation (Miocene to Pliocene). Remnants of a pre-Ogallala depositional surface are found on the Callahan Divide, on the Stockton Plateau of Texas, and in the Sacramento Mountains of New Mexico.

Byrd (1971, p. 19) described pebble-sized lag gravels of white, pink, and yellow vein quartz and some chert strewn in cultivated fields atop the Callahan Divide 15 miles southwest of Merkel, Texas. These lag gravels are approximately 200 feet higher than the projected Ogallala High Plains surface.

The Ogallala Formation in the southern portion of the High Plains slopes into the base of the Cretaceous escarpment and appears to extend into the entrenched Pecos Valley of the Edwards-Stockton Plateau area. Siliceous gravels are found on the Cretaceous highlands 400-450 feet above the valley floor (locs. 2, 3, 8, 25). On King Mountain about 6 miles north of McCamey, Texas (loc. 23), gravels of white vein quartz and black and light yellowish quartzite embedded in a caliche bed are found at an elevation of 3,150 feet, 450 feet above the Quaternary surface sloping into its base from the north. Other localities are on the Stockton Plateau (locs. 25, 26) where a few dark quartzite and rhyolite pebbles were found scattered on the highlands (fig. 16).

Sharps (1963) and (Sharps and) Freeman (1965) mapped old gravels in Terrell, Brewster, and Val Verde counties near the mouth of the Pecos River. These old gravels were interpreted as Rio Grande terraces. The

Fig. 13. Mescalero Escarpment and Mescalero Sands east of Roswell, New Mexico. This escarpment marks the western limit of the High Plains.
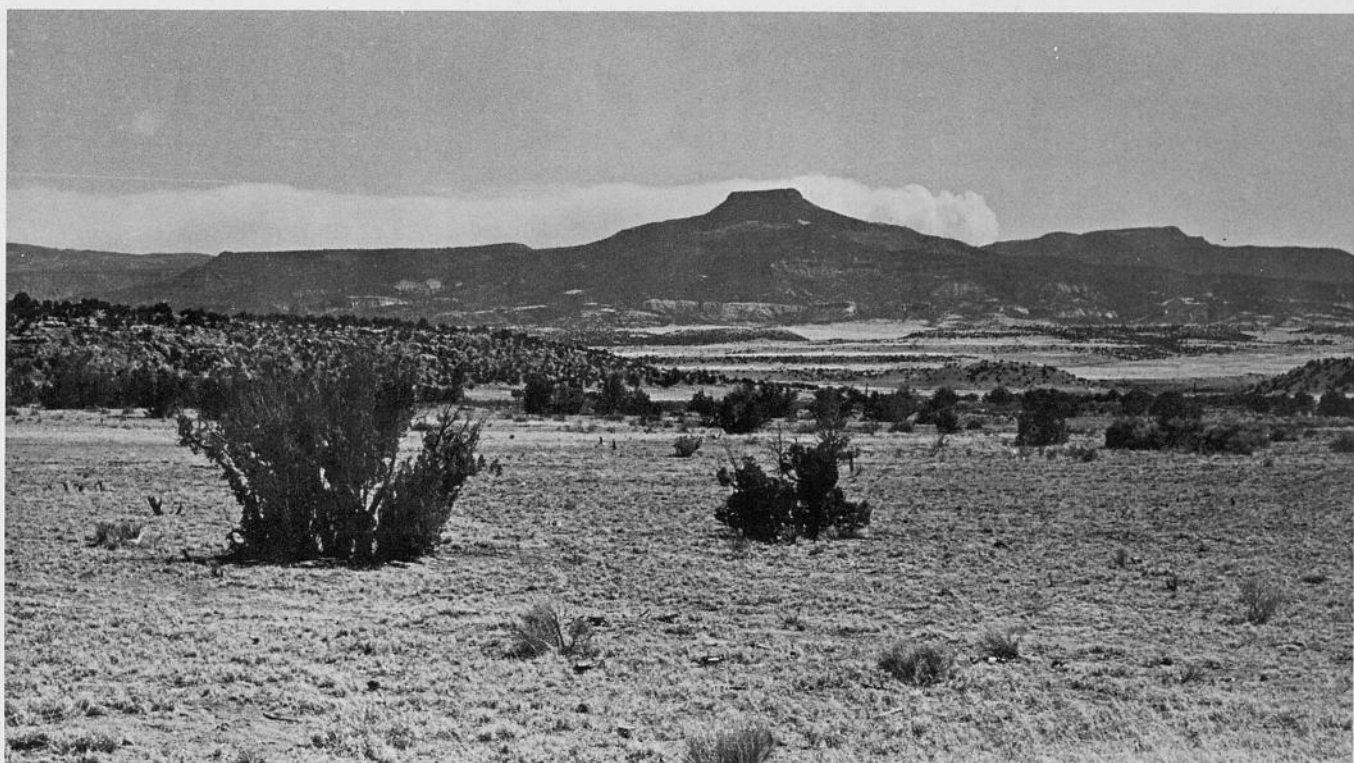

Fig. 14. Cerro Pedernal (viewed from the north), a monadnock above the La Jarita Mesa north of the Jemez Mountains. This monadnock reflects the development of two pedimented surfaces before the present cycle of erosion. The "cloud" in the photograph is smoke from a forest fire in Jemez crater in June of 1971.
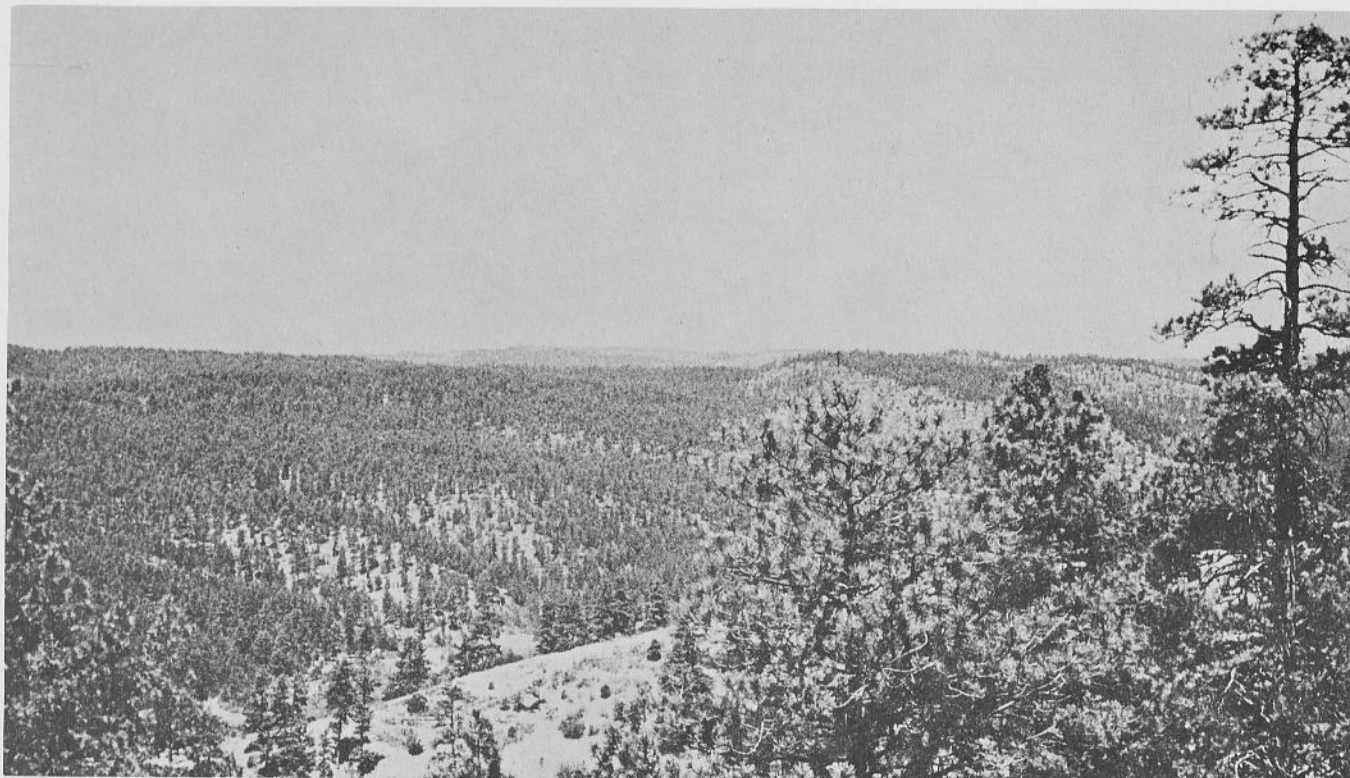
Fig. 15. La Jarita Mesa (viewed from the east) in the Las Tablas region. This is an area of extensive Precambrian outcrop, a pediment surface of a previous erosional cycle, correlated with the alluvial plain of the Ogallala Formation of the High Plains.

Fig. 16. Old gravels atop the Stockton Plateau on the Billings Ranch, Locality 15. These gravels consist of chert, vein quartz, quartzite and volcanics. These gravels are 250-300 feet above the Pecos River. At other localities they are 600-700 feet above the Rio Grande.

gravels, consisting of white and pink vein quartz, black, red and purplish quartzite, chert, limestone and volcanics are 300-600 feet above the Pecos River and Rio Grande. The Rio Grande which did not cut through the Franklin Mountains until middle to late Pleistocene (Kottlowski, 1958) is an unlikely candidate for deposition of these high gravels. The gravels are composed of volcanics of the Davis Mountains and are deposited on top of the Cretaceous units.[12] They may instead have been transported to their present position by tributaries of an early Tertiary Conchos-Pecos River (fig. 16).

The Pecos River, Conchos River and the Rio Grande from Presidio, Texas to the mouth of the Pecos River are deeply entrenched into the rocks of the Stockton Plateau and Big Bend area. The rivers had to be in their present position before uplift began. Uplift apparently began during Eocene as suggested by the angular unconformity between the top of the Eocene nonvolcanic (Hannold Hill) and Eocene basal volcanic (Canoe) units (Maxwell *et al.,* 1965). By late Eocene coarse conglomerates of the Chisos Formation had also been deposited. The Rio Grande, in the section from El Paso to Presidio, Texas, was not present before Pleistocene time (Kottlowski, 1958); therefore, the Rio Conchos and Pecos River were the only major streams present in that area during late Eocene time.

Reeside (1924) described conglomerates containing jaspery quartz, chert, vein quartz, quartzite, hard sandstone, weathered andesite and other igneous rocks in the Paleocene-Eocene McDermott, Ojo Alamo, Animas and Wasatch formations and the Nacimiento Group of the San Juan Basin of Colorado and New Mexico, which flanks the San Juan Mountains on the west.

The Eocene Wilcox and Claiborne groups of the Texas Gulf Coastal Plain, 300-600 miles southeast of the San Juan Mountains, contain lenses of gravel of vein quartz, quartzite, jasper and chert mixed with considerable thickness of sandstone and shale (Dumble, 1903).

The possible correlation of these Paleocene-Eocene deposits vaguely suggests a depositional surface extending from the rising Laramide Mountains to the Gulf Coast during that period. The southern portions of this postulated surface may have extended across the area of New Mexico and Texas.

SOURCE AREA

The deposition of siliceous gravels of the Ogallala and pre-Ogallala Formation raises questions concerning source, tectonics and time. The postulated source of Ogallala gravel has generally been the easternmost ranges of the Laramide uplift (Plummer, 1932, p. 667-680).

The eastern ranges include the Sangre De Cristo, Pedernal Hills, Sacramento, Guadalupe and Delaware

mountains. However, rocks exposed in the Sangre De Cristo Mountains consist largely of granite, gneiss and schist, rocks not widely present in Ogallala deposits. The Pedernal Hills, though they expose both quartzite and granite, were apparently once covered by the Ogallala Formation. The Sacramento Mountains are composed largely of limestone, a rock type not common to the Ogallala Formation of the High Plains. In addition, the Sangre De Cristo, Sacramento, and Guadalupe mountains were apparently uplifted during early to middle Pleistocene.

Regions with lithology to match the Ogallala (vein quartz, jasper, and quartzite) include the Ladrone, Los Pinos, Manzano, Sandia, San Pedro, Nacimiento mountains of New Mexico, and San Juan Mountains of Colorado (fig. 1). These ranges are on the east and west sides of the Rio Grande depression, a structural depression developed by block faulting in late Pliocene and Pleistocene time. During Tertiary time, this may have been an extensive area of exposure of Precambrian quartzites, quartz, jasper, granite, gneiss and schist at an altitude adequate to encourage eastward transport of gravels to the High Plains.

West of the Rio Grande depression Precambrian rocks are exposed on the Ladrone, Nacimiento and San Juan mountains. The Ladrone Mountains consist of Precambrian granite, quartzite, gneiss, schist (Kuellmer, 1963, p. 10; Northrop, 1961, p. 49).

Barker (1958) estimated a thickness of 21,100 to 35,000 feet of Precambrian rocks exposed in the Las Tablas quadrangle in the southern San Juan Mountains of New Mexico. These rocks include Kiawa Mountain quartzite; the Moppin Metavolcanic Series (consisting of greenschist, amphibolite, and quartzite conglomerate); Ortega Quartzite; and Precambrian metarhyolites, granodiorites, granite, gneiss, and pegmatite. This appears to have been the principal source of the quartzose rocks of the Ogallala Formation.

East of the Rio Grande depression Precambrian rocks are exposed in the Sandia, Manzano and Los Pinos mountains, capped by Pennsylvanian rocks. The Manzano and Sangre De Cristo mountains were not contributors to the early Ogallala alluviation as these mountains would have presented barriers to a source area sufficient in size and volume to have supplied the amount of quartzitic material necessary for the pre-Ogallala and Ogallala formations.

Lewand (1969) and Menzer and Slaughter (1971) on the basis of petrographic comparison suggested the Manzano and Sangre De Cristo mountains of New Mexico as the source area of the quartzitic gravels derived from the Ogallala Formation found in the Brazos and Leon River basins of central Texas and Dallas and Tarrant counties, Texas. The volume of quartzite and quartz in the present Southern High Plains is, at a minimum, over 1,080 cubic miles (38,600 square miles bounded roughly by the eastern and western escarpment and covered by approximate average of 150 feet of Ogallala). The area east of the present Southern High Plains projected by Byrd (1971, p. 14) includes an additional 990 cubic miles (71,00 square miles inside an area bounded by McLean, Texas; Durant, Okla-

---

[12]I agree with the general concept. Byron Leonard and I found some alluvial deposits, and fragmentary fossils, at a high level on the Edwards many years ago. However, don't be misled by the height above the Pecos channel of some of the intermediate gravels in Val Verde County because the gradient of the Pecos is greatly increased in that stretch and is clearly quite young in its lower part. Also, we got a few fossils from that intermediate level (not published) that indicate Pleistocene.—J. C. Frye.

homa; Dallas, Texas; Junction, Texas and Rankin, Texas covered by an average 75 feet of Ogallala (75 feet assumed as median between 150 feet of present Ogallala and feather edge to the east). The projected area west of Mescalero Escarpment includes another 400 cubic miles (14,500 square miles) inside an area bounded by Hassel and Estancia, New Mexico and the Guadalupe Mountains covered by 150 feet of projected Ogallala (much less than the actual value because the Pecos Valley fill is not included). The minimum total volume of material represented by the Ogallala Formation is approximately 2,470 cubic miles of material. The *maximum* area of Precambrian outcrop in the Manzano Mountains is not over 125 square miles. To have furnished that much material the Manzano Mountains would have to have been 19.5 miles high, which seems somewhat excessive. Further, the largest area of Precambrian outcrop is on the west side of the block faulted mountain and is largely overlain on the east by Pennsylvanian rocks. The Manzano Mountains appear to be a youthful mountain range, too small and too recent to account for a significant part of Ogallala sediments.

The Sangre De Cristo Mountains also appear to be youthful and lithologically unsuited to provide the vast volume of quartzose sediments of the Ogallala Formation. The quartzose Precambrian outcrops are confined to small areas on the high peaks or to the bottoms of the low valleys (Miller, *et al.*, 1963). These outcrops are clearly inadequate to have contributed significant quantities of material to the Ogallala Formation.

Quartzitic gravels derived from the Manzano and Sangre De Cristo mountains were probably not extensively transported until early-middle Pleistocene upon the formation of the Rio Grande depression by block faulting. Formation of the Rio Grande depression and its surrounding mountain ranges would have terminated the movement of quartzitic gravels from the postulated primary source area in the San Juan, Nacimiento, Ladrone, Los Pinos, Manzano, and Sandia area complex. The San Juan Mountains region of Colorado and New Mexico seems to be the area of major contribution.

OGALLALA WEST OF THE PECOS RIVER

Bretz and Horberg (1949a) describe *in situ* conglomerates on the west side of the Pecos River along the base of the Guadalupe escarpment and on the east slope of the Sacramento Mountains. They thought these conglomerates to be correlative and interpreted them as basal Ogallala. These conglomerates cap the Yeso Hills (loc. 7; fig. 11), form bluffs along the Black River around Herradura Bend (loc. 9; fig. 10), and along the lower Rio Penasco (Bretz, 1949) and cap hills over a large area west and southwest of Roswell (locs. 8, 24; figs. 12, 17). They also described basal Ogallala on the Pedernal Hills (loc. 5) and at several other localities around Vaughn, New Mexico west of the Pecos River as described by Bretz (1949).

On the east flank of the Sacramento Mountains, the Sacramento Plain is the highest recognized erosional surface. Remnants of the essentially flat surface are preserved in a belt along the crest of the range (where elevations are 8,400 to 8,500 feet in altitude) from Ruidoso southward to within a few miles of Cloudcroft. South of Cloudcroft the surface ranges in elevation from 9,200 to 9,600 feet near the crest of the Sacramento Mountains and from 8,200 to 8,600 feet near its eastern limits. This surface slopes eastward 70-75 feet per mile. Projected to the east at this gradient, the surface would be far below the level of the Llano Estacado. However, the degree of preservation of the surface and the nature of lag gravels preserved on it suggest that the Sacramento Plain was once continuous with the Llano Estacado (Fiedler and Nye, 1933, p. 97).

There is considerable difference in the degree of uplift of the northern Sacramento Mountains (around Sierra Blanca) and the southern portions of the range. The southern portion is 1,500 to 2,000 feet higher. This difference in uplift may account for the steeper gradient of the southern portion of the Sacramento surface.

Remnants of a Guadalupe summit peneplain are present over large areas of the Guadalupe Mountains (New Mexico). The peneplain is well preserved in the area between Rattlesnake and Slaughter canyons 3 to 5 miles southwest of Carlsbad Caverns (loc. 10). In this area at the head of Nuevo Canyon there are cave fillings of foreign pebbles consisting of quartzite, chert, jasper, and vein quartz (figs. 18, 19, 20).

These cave fillings indicate a previous higher erosional surface and the presence of a scarp before the deposition of quartzose gravels.[13] Bretz (1949) suggested this in his discussion on the age of the Guadalupe caves; as follows:

> Every Guadalupe cave examined has yielded what seems to be incontrovertible evidence that it antedates the present erosional cycle and therefore antedates the making of the existing reef scarp and the lowland east of it. Three of the caves are but little below the trace of the former oldland, which now survives only in isolated flattish summits. One cave records a vadose stream whose vigorous current found escape much below the level of the gravel flat abutting against the base of the reef scarp. For this escape, a post-peneplain Pecos Valley deeper than the present one seems required (Bretz, 1949, p. 460).

Horberg (1949) working with Bretz in the area stated that Carlsbad and other caverns antedate the present topography and are believed to be related to a pre-Ogallala cycle of erosion.

Boyd (1958) suggested that the stream responsible for McKittrick Canyon wind gap was beheaded by late Pliocene or early Pleistocene faulting. Dark Canyon, which has deep entrenched meander scars of the Serpentine Bends, also appears to have been beheaded by the same faulting.

ABANDONED VALLEY

Portales Valley in Curry and Roosevelt counties, New Mexico was first recognized as an abandoned stream valley by Baker (1916). He traced the valley

---

[13]See earlier comments about Bretz interpretation of Pecos history. These apply as well to cave history.—J. C. Frye.

southward into Texas, near the present Brazos River drainage system.

Theis (1932) also described Portales Valley as an abandoned stream valley. He believed that a stream having the same course as the Pecos River above Fort Sumner continued southeastward across the area of the High Plains through Portales Valley to the present course of the Double Mountain Fork of the Brazos River. At some time during Pleistocene the Pecos River extended headward and captured the portion of the then Brazos River above Fort Sumner. The old valley, cut off from its headwaters, was consequently filled with later Quaternary sediments (Theis, 1932, p. 113-114).

In describing the Portales Valley, Theis stated:

(1) It is a broad continuous depression extending from the northwestern escarpment of the Llano Estacado on the present Pecos River drainage basin probably to the drainage basin of the Brazos River in Texas. It is thus comparable in some respects with the valleys of major streams which at present rise in the Rocky Mountain and flow across the Great Plains—as, for example, the valley of the Canadian River. The present divide between the Pecos River drainage system and the southeastward drainage, which crosses this broad valley west of Melrose and is indistinguishable without accurate levels, shows that the valley is older than the present drainage system. (2) Encroachment by the Pecos River upon eastward-flowing streams of the Llano Estacado is manifested in the same vicinity by Alamosa Creek. This creek, which has its headwaters in the extreme northwest tip of the Llano, flows southeastward for about 25 miles and then turns abruptly southwestward to join the Pecos River. (3) The low

gradient of the valley, which is less than 10 feet to the mile whether measured along the present surface or along the buried red-bed channel, shows that the valley was cut by a large stream. (4) The basal deposits of Portales Valley, as seen south of Melrose and near Little Salt Lake, consist of coarse, crossbedded gravel, showing the evidence of strong stream currents, such as apparently could not be engendered by local run-off (Theis, 1932, p. 114).

Galloway (1956) agreed with Theis (1932) that the Pecos River had captured its headwaters from the former Brazos River, but he also suggested that the Portales Valley may have been occupied by a pre-Ogallala stream and was, therefore, an exhumed feature before it was beheaded by the Pecos River during Pleistocene.[14]

The southward flowing portion of the upper Canadian River may also have originally been a tributary to the Pecos River. The Canadian River makes an abrupt turn from a southward flowing stream to an eastward flowing stream near Conchas Dam, New Mexico, suggesting the possibility of stream piracy in that area. In addition, the upper Canadian is in alignment with the Pecos River south of Fort Sumner and roughly in alignment with the postulated drainage through Portales Valley (Theis, 1932). In the area of Santa Rosa and Cuervo, New Mexico on the ill-defined divide between the Pecos and Canadian rivers is what appears to be a remnant of a north-south valley later filled by Ogallala sediments. This leads to the suggestion that the upper Canadian River may have been a tributary of the pre-Ogallala Brazos River as suggested by Galloway (1956).

RECONSTRUCTION OF THE ANCESTRAL PECOS RIVER

In reconstructing the drainage of the Pecos River, the time of beginning must be the formation of the initial surface on which drainage originated. The Pecos River flows southward over an area that once was covered by extensive southeastward dipping Cretaceous deposits. Upon regional uplift of this area development of a drainage system was imminent.

Correlations of high surfaces (p. 20) suggest that by early Tertiary time there was uplift in the San Juan Mountains area of southwestern Colorado which initiated a period of sediment formation and alluviation. During this period southward drainage was dominant in the Pecos region and the ancestral Pecos River was probably one of the drainage systems responsible for this earliest alluviation. Regional southward dip of Lower Cretaceous rocks in the study area, as a consequence of and contemporaneous with the uplift of the Laramide San Juan Mountains, apparently was the controlling factor in determining the initial stream course of an ancestral Pecos River (fig. 1). This stream, rising in the area of southwestern Colorado, apparently drained southward and eastward across areas now occupied by the northern Rio Grande de-

pression, Estancia Valley, Pedernal Hills, the Sacramento and Guadalupe mountains and the Edwards-Stockton Plateau and eventually into the Gulf of Mexico (fig. 21). It was apparently during this time that the Pecos River began entrenchment into the Edwards-Stockton Plateau. The lower part of this canyon is preserved below McCamey and flow through this section appears to have been continuous since that time. The area of southern alluviation (Southern High Plains) and the apparent funneling of drainage across the Edwards-Stockton Plateau suggest that the ancestral Pecos may have been the principal southward drainage at that time. The course of the Pecos below Langtry is uncertain, but it may have joined an ancestral Conchos River before entering the Gulf of Mexico, as suggested by the apparent Eocene age of the

---

[14]The concept of the Portales Valley as a Kansan valley, subsequently pirated in its headwaters by the Pecos River, fits all we know about the area. However, the idea that the Portales Valley is an exhumed earlier valley does *not* fit the data from the Ogallala along the margins of the bedrock valley or the deposits in the floor of the present valley. As quoted, we agree with Theis but not Galloway.—J. C. Frye and A. Byron Leonard.

Fig. 17. Capitan Mountains (viewed from the south) with Diamond A Plain and gravel-capped mesas extending westward undisturbed past the base of the range.

Pecos River, Conchos River and Rio Grande below Presidio, Texas (p. 23).[15]

Following early Tertiary alluviation there was a change to denudation. The source area remained stable. Development of a pre-Ogallala valley in the lower portions of the present Pecos basin was suggested by Bretz and Horberg (1949). The presence of siliceous pebbles and gravels in cave fillings on the Guadalupe summit peneplain (p. 24), which was apparently lowlying at this time, suggests that there was an ancestral low land east of the caverns area in the vicinity of Carlsbad. The stream course probably extended from the San Juan Mountains southward along the course described for earliest Pecos drainage, but by this time it flowed in a valley instead of on a plain of alluviation. At the southern end, the river, entrenched in its present

[15]At this point let me suggest a possible analogy with the Colorado piedmont. In Colorado the Ogallala was graded westward to an erosion surface across the soft rocks in front of the Front Range, and to the erosion surface at 9,000-11,000 feet in the crystallines of the Rockies. After the early Pleistocene warping, lateral drainage readily incised in the weak rocks in front of the Front Range and produced drainage parallel to the mountain front. Therefore, a west-facing scarp held up by Ogallala faces this erosional lowland in front of the Rockies. The drainage is mostly south to north, directly across the trend of the Ogallala streams, and the deposits capping the highest elements in this lowland (well below the projected Ogallala surface) are all mid- to late-Pleistocene in age. The only streams that have maintained themselves across this stretch are the Platte and Arkansas rivers. Although far less clear cut in the case of the Pecos, the analogy seems to me to be very good for part of the valley.—J. C. Frye.

course, joined with the ancestral Conchos River to enter the Gulf of Mexico (fig. 22).

The Precambrian quartzites of the San Juan Mountains are the apparent source of the siliceous gravels of the pre-Ogallala formations. The earliest drainage, that which first distributed gravels from the Laramide ranges, had to rise from that area.

During this period the ancestral Brazos River may have occupied a channel in the upper Pecos basin (Galloway, 1956) which apparently extended northwestward across the area now occupied by the Sangre De Cristo Mountains into the San Juan region (fig. 22). This ancestral Brazos served as a major southeastward drainage toward the area of the present High Plains of Texas.

South of the ancestral Brazos River there appears to have been a low divide between the ancestral Pecos River and the eastward drainage of the pre-Ogallala High Plains area (Leonard and Frye, 1962; Cronin, 1969), apparently developed on an extension of the Edwards Plateau which formed the highlands of the divide.

During early Miocene time there was renewed uplift in the San Juan Mountains and Ogallala alluviation began. The basal Ogallala west of the Pecos River and the cave fillings in the Guadalupe Mountains (Bretz and Horberg, 1949) were deposited at the beginning of this phase. The position of the ancestral Pecos River north of the present Edwards-Stockton Plateau is uncertain but may have extended as in the past,

Fig. 18. Quartzose conglomerates existing as cavern fill, from the rimrock of the mouth of Slaughter Canyon, Locality 11, Guadalupe Mountains, New Mexico.

northward across the area of the Guadalupe and Sacramento mountains, Pedernal Hills, Estancia Valley, Rio Grande depression and the lower end of the San Juan Mountains into the source area during this time. The area west and northwest of the present Pecos basin was probably covered by the vast network of ephemeral streams necessary to deposit the thick alluvial cover of the Ogallala Formation of the Southern High Plains (fig. 23).

Eastward flow of the streams during early Ogallala time (Plummer, 1932; Frye and Leonard, 1957a) would not have delivered gravel to the southern part of the High Plains, since the gravel source was northwest. To deliver quartzitic gravels from the San Juan Mountains of southwestern Colorado to the Southern High Plains, direction of flow had to be south to south 30° east from the easternmost ranges of the southern San Juan Mountains. Later, some gravels may have been dispersed to the east as the High Plains surface was slowly built up by material moving generally southward along the area of the Pecos basin to the Southern High Plains. Southeastward-draining rivers such as the ancestral Brazos River flow through Portales Valley (Theis, 1932; Galloway, 1956) and evidently were principal distributors of deposits to the northern part of the Southern High Plains (fig. 24).

During late Pliocene and early Pleistocene time tectonic movement began to shape the Pecos basin into its present form. Uplift of the Sacramento and Sangre De Cristo mountains started abruptly, halting transport of gravels to the Pecos River drainage from the primary source area in the San Juans and cut off the flow of water into the Pecos River from the area of the present upper Rio Grande depression, and perhaps diverted it into the Tularosa Basin, filling that basin with sediment. The mountains adjacent to the Tularosa Basin seem insufficient to supply the entire volume or nature of material filling the basin. The lower course of the ancestral Rio Grande may have been across the area of the Delaware Mountains of Texas into the Pecos, as a tributary entering north of the Edwards-Stockton Plateau or across the area of the present Diablo Plateau and Quitman Mountains, as a tributary of the Conchos River south of the Edwards-Stockton Plateau (fig. 5).

During this period the newly beheaded Pecos River, extending northward only to the Sacramento Mountains or perhaps a little farther, was controlled by a new set of factors. It was then exhuming an older valley in the southern region below Roswell, previously filled by Ogallala Formation. The stream bed now on the resistant limestones of the eastward-dipping Permian San Andres Formation began downdip migration stripping away the less resistant overlying Chalk Bluff Formation (Fiedler and Nye, 1933). Headward erosion continued to the north in the direction of Fort Sumner, New Mexico, perhaps following a route dictated by pre-Ogallala valleys. The Sangre De Cristo Mountains became the source area for the later Ogallala deposits.

The ancestral Brazos River (Udden, Baker, and Böse, 1916; Theis, 1932; Galloway, 1956) flowed through Portales Valley and transported material from the Sangre De Cristo Mountains (fig. 5).[16] The upper Canadian River appears to have been a tributary of the ancestral Brazos River during this time (fig. 5). By middle to late Pleistocene time the Pecos River system had taken on an appearance much as it is today.

Headward erosion and eastward lateral migration led to the capture of the upper ancestral Brazos River somewhere in the vicinity of Fort Sumner, New Mexico (Udden, Baker, and Böse, 1916; Theis, 1932; Galloway, 1956) (fig. 4). The Portales Valley, deprived of flow, was abandoned. The upper Brazos River and its tributaries, possibly including portions of the present upper Canadian River, were diverted into the Pecos River (fig. 4).

The present upper Canadian drainage apparently was captured from the early Pecos River by the eastward flowing lower Canadian River. Thus a substantial part of the Pecos River headwaters was diverted (fig. 4).[17]

Additional uplift in the Pecos Valley and adjacent Sangre De Cristo, Sacramento, Capitan, Guadalupe, Delaware, Davis, and Barilla mountains, and subsidence in the Tularosa and Salt basins shaped the western side of the Pecos basin. Erosion along the western scarp of the Llano Estacado (High Plains) and deposition of the Mescalero and Monahans sands and the development of Quaternary sedimentary plain between Carlsbad, New Mexico and Iraan, Texas developed during this latest state of basin evolution. At the close of this period the Pecos had the pattern it has today (fig. 25).

SPECULATIONS

During the progress of any regional study, certain speculations develop, based on factors and observations coincidental to the study. These cannot often be supported adequately by the evidence at hand, yet have value simply as possibilities for further consideration. Therefore, included are a series of speculations and conjectures which were born during the progress of this report, and which may be of interest to others. They are offered as statements, though they cannot be defended and they remain puzzles to the writer.

1. The lower part of the Miocene-Pliocene Santa Fe Formation of the Rio Grande depression, the Carson Conglomerate (Just, 1937) of the San Juan Mountains and Rio Grande depression are isolated remnants of a once continuous Ogallala surface, preserved by the block faulting which formed the Rio Grande depression.

2. The northern part of the Sacramento Mountains is relatively stable when compared to the southern part as suggested by Triassic, Cretaceous, and Eocene rocks yet surrounding Sierra Blanca. Paleozoic rocks of the southern range occur at higher elevations than the Mesozoic rocks around Sierra Blanca because of late Tertiary block faulting.

3. Rio Grande drainage is difficult to reconstruct. The lower part of the river and perhaps the upper part of the river are probably very old, yet the section below El Paso and above the Rio Conchos is quite young. It appears possible that the Rio Grande during its first development was the headwater section of the ancestral Pecos River (p. 27) (figs. 21, 22, 24).

Even after uplift of the Sangre De Cristo, Pedernal and Sacramento mountains and the Rio Grande was diverted into the Tularosa Basin it was still, in effect, a tributary of the Pecos River, whether or not it rejoined the Pecos across the area of the Delaware Mountains above the Edwards-Stockton Plateau as a tribu-

tary of the Conchos-Pecos River. During this period of time it may have contributed fill to the Tularosa Basin.

Later uplift in the area of the San Andres and Oscura mountains and Chupadera Mesa may have diverted the Rio Grande into the Joranado del Muerto. During this relatively short period of occupation the Rio Grande may have been flowing into pluvial lakes of northern Mexico (Kottlowski et al., 1956). This diversion may have resulted in essentially the present river pattern in which the Pecos is a tributary to the larger Rio Grande, though the final diversion through the Southern Franklin Mountains may have been somewhat later.

4. The monadnocks seen in the Front Ranges of the Colorado Rockies are apparently remnants of the pediment surface over which Ogallala alluvial deposits moved during Miocene and Pliocene time. The Sangre De Cristo Mountains are the southern extension of the Front Ranges of Colorado. If these ranges were uplifted at the same time (late Ogallala or early Pleistocene time) uplift would have been after the development of a pediment surface, in and east of the source area. Since the source area of the siliceous material of the Southern High Plains is in the San Juan Mountains, this suggests that the source for the Northern High Plains would be west of the Front Ranges of Colorado.

---

[16]The dating may be even later as the Portales Valley contrains extensive Kansan deposits, and may have had through drainage even later.—J. C. Frye.

[17]The speculative drainage history maps (figs. 4, 5, 21-24) are interesting, to say the least. The southeast trend of Ogallala drainage fits what we know except that the high area south of Midland is not covered by Ogallala (in spite of some maps); the Ogallala as a high terrace along the Pecos in Pecos County is not a continuation of the Ogallala north of the Midland "high." In the Big Spring area and southeast Garza County, the Ogallala occupies abandoned valleys and is in a terrace position trending east-southeast (note Frye and Leonard, 1968). There is evidence that during Kansan time there was southwest drainage in the extreme southern part of the Texas High Plains, not conclusive but intriguing because such a pattern would have put additional Kansan drainage into the lower Pecos. I'm not suggesting changes in the maps although I disagree in detail. The evidence is far from conclusive.—J. C. Frye.

Fig. 19. Collapse breccia with quartzose gravels from Lowe's Ranch, Locality 10, Guadalupe Mountains, New Mexico.

CONCLUSIONS

1. The Pecos River below Iraan, Texas, the Rio Conchos, and the Rio Grande from Presidio, Texas to the mouth of the Pecos are entrenched into the structure of the Big Bend and the Stockton Plateau. These structures are as old as the plateau uplift, which appears to have been mid-late Eocene as suggested by the angular unconformity between the Hannold Hill Formation and the Canoe Formation, the boulder conglomerates of the upper Eocene Chisos Formation, and mammalian fossils found in these Eocene formations (Maxwell *et al.*, 1967, p. 102-137).

2. An early Tertiary (pre-Ogallala) alluvial surface covered the study area. Remnant lag gravels of this once extensive surface, unrelated to the Ogallala Formation, are on the Callahan Divide, King Mountain, and the Stockton Plateau.

3. The Pecos Valley in the region of Carlsbad and Roswell, New Mexico is an exhumed feature. The presence of basal Ogallala conglomerates along the Pecos and Black rivers suggests 1300 feet of Ogallala valley fill. Bretz and Horberg (1949) suggested the necessity of a valley deeper than the present Pecos Valley to allow for the formation of the cave systems in the Guadalupe Mountains.

4. The source area of the siliceous gravels of the Ogallala and pre-Ogallala formations appears to have been the San Juan Mountains of northern New Mexico and southwestern Colorado. The 21,000-35,000 feet of Precambrian outcrop in the Las Tablas region of northern New Mexico and other areas of Precambrian outcrop in the San Juan Mountains are petrographically the same as the siliceous gravels of the Ogallala and pre-Ogallala formations. The milled pediment surface on Precambrian outcrop appears extensive enough to supply the siliceous material of the Southern High Plains.

5. Drainage responsible for deposition of the Ogallala and pre-Ogallala formation was predominantly southward. Siliceous gravels derived from the San Juan Mountains are present in basal Ogallala conglomerates along the Black River south of Carlsbad, New Mexico. To reach that locality the Pecos River and other drainage would have extended as far north as the San Juan Mountains and stream flow would have been southward.

6. Uplift of the Sacramento, Los Pinos, Manzano, Sandia, and Sangre De Cristo mountains of New Mexico occurred during the last stages of Ogallala deposition. If these mountains had been present during Ogallala deposition, southward and eastward movement

of siliceous material from the source area in the San Juan Mountains would have been blocked.

7. An ancestral Brazos River in the position of the present upper Pecos River was captured by the Pecos near Fort Sumner, New Mexico during late Pleistocene. The buried abandoned Portales Valley which is in alignment with the upper Pecos River and the Brazos River in Texas—described by Udden, Baker, and Böse, (1916), Theis (1932), and Galloway (1956)—was the connecting route.

8. The upper Canadian River appears to have been a tributary of the upper Pecos River. The upper Canadian apparently joined the Pecos in the vicinity of a wind gap near Santa Rosa, New Mexico that appears to be a valley remnant which was later filled by the Ogallala Formation or by gravels derived from the Ogallala Formation (fig. 25).

Fig. 20. Gravel samples from Lowe's Ranch Locality 10. Guadalupe Mountains, New Mexico. These gravels consist of chert, gray-to-black and banded quartzite, and white and pink vein quartz.

REFERENCES

ALBRITTON, CLAUDE C. and BRYAN, KIRK (1939) Quaternary stratigraphy in the Davis Mountains, Trans-Pecos Texas: Geol. Soc. America Bull., v. 50, p. 1423-1474.

ALCORN, REX, Chm. (1954) Guidebook of southeastern New Mexico: New Mexico Geol. Soc., Fifth Field Conference, 209 p.

BAKER, C. L. (1916) in Review of the geology of Texas: Univ. Tex. Bull. 44 by Udden, J. A.; Baker, C. L.; and Böse, Emil.

BARKER, FRED (1958) Precambrian and Tertiary geology of Las Tablas Quadrangle, New Mexico: New Mexico Bur. of Mines and Min. Res. Bull. 45, 104 p.

BARTRAM, JOHN G. (1937) Upper Cretaceous of Rocky Mountain area: Am. Assoc. Petrol. Geol. Bull., v. 21, pt. 2, p. 899-913.

BODINE, M. W., JR. (1956) New Mexico Bur. of Mines and Min. Res. Circ. 35 (cited in Keroher, 1966).

BOYD, D. W. (1958) Permian sedimentary facies, central Guadalupe Mountains, New Mexico: New Mexico Bur. Mines and Min. Res. Bull. 49, 100 p. (cited in Parks, 1962).

BRETZ, J. HARLAN (1949) Carlsbad Caverns and other caves of the Guadalupe Block, New Mexico: Jour. Geology, v. 57, p. 447-463.

BRETZ, J. HARLAN and HORBERG, LELAND (1949a) The Ogallala Formation west of the Llano Estacado: Jour. Geology, v. 57, p. 477-490.

——————(1949b) Caliche in southeastern New Mexico: Jour. Geology, v. 57, p. 491-511.

BYRD, CLIFFORD L. (1971) Origin and history of the Uvalde Gravels of central Texas: Baylor Geological Studies Bull. 20, 48 p.

CHURCH, F. S. and HACK, J. T. (1939) An exhumed erosion surface in the Jemez Mountains, New Mexico: Jour. Geology, v. 47, p. 613-629.

CRONIN, JAMES G. (1969) Ground water in the Ogallala Formation in the Southern High Plains of Texas and New Mexico: U.S. Geol. Survey Hydrologic Investigation HA-330, 9 p.

CUMMINS, W. F. (1891) Report on the geography, topography, and geology of the Llano Estacado or Staked Plains: Geol. Survey Texas 3rd. Ann. Rept., p. 127-223.

DANE, C. H.; WANEK, A. A.; and REESIDE, J. B., JR. (1957) Reinterpretation of section of Cretaceous rocks in Alamosa Creek valley area, Catron and Socorro counties, New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 41, p. 181-196.

DANE, CARLE H. and BACHMAN, GEORGE O. (1965) Geologic map of New Mexico: U.S. Geol. Survey.

DARTON, N. H.; STEPHENSON, L. W.; and GARDNER, JULIA (1937) Geologic map of Texas (Stone, G. W., ed.): U.S. Geol. Survey.

DUMBLE, E. T. (1903) Geology of southwestern Texas: American Institute of Mining Engineers, v. 33, p. 914-987.

EARDLEY, A. J. (1962) Structural geology of North America (2nd. ed.): Harper and Row, New York, 742 p.

EVANS, GLEN L. (1956) The Llano Estacado: Guidebook of the eastern Llano Estacado and adjoining Osage Plains: West Texas Geol. Soc. and Lubbock Geol. Soc., 102 p.

EVANS, GLEN L. and MEADE, GRAYSON E. (1944) Quarternary of the Texas High Plains: Univ. Tex. Bull. 4401, p. 485-507.

FIEDLER, A. G. and NYE, S. S. (1933) Geology and ground water resources of the Roswell artesian basin, New Mexico: U.S. Geol. Survey Water Supply Paper 639, 372 p.

FOSTER, R. W. (1959) Precambrian rocks of the Sacramento Mountains and vicinity in Guidebook of the Sacramento Mountains: Soc. Econ. Paleont. and Mineralog., Permian Basin Sec., and Roswell Geol. Soc., p. 137-153.

FREEMAN, V. L. (1964) Geologic map of the Indian Wells Quadrangle, Terrell and Brewster counties, Texas: U.S. Geol. Survey Map I-395.

——————(1964) Geologic map of the Langtry Quadrangle, Val Verde County, Texas: U.S. Geol. Survey Map I-422.

——————(1964) Geologic map of the Shumla Quadrangle, Val Verde County, Texas: U.S. Geol. Survey Map I-424.

——————(1965) Geologic map of the Bakers Crossing Quadrangle, Val Verde County, Texas: U.S. Geol. Survey Map I-434.

FRYE, JOHN C. (1970 The Ogallala Formation—A review: Ogallala Aquifer Symposium, Texas Tech Univ., Special Rept. 39, 14 p.

FRYE, JOHN C. and LEONARD, A. B. (1957a) Studies of Cenozoic geology along eastern margin of Texas High Plains, Armstrong to Howard counties: Univ. Tex. Bureau Econ. Geol., Rept. Inv. 32, 62 p.

——————(1957b) Ecological interpretations of Pliocene and Pleistocene stratigraphy in the Great Plains region: Am. Jour. Sci., v. 225, p. 1-11.

——————(1959) Correlation of the Ogallala Formation (Neogene) in western Texas with type localities in Nebraska: Univ. Tex., Bureau Econ. Geol. Rept. Inv. 39, 46 p.

——————(1964) Relation of Ogallala Formation to the Southern High Plains in Texas: Univ. Tex., Bureau Econ. Geol, Rept. Inv. 51, 25 p.

FULTON, MAURICE G. (1954) Adventure and exploits of Pecos pioneers (Stipp, T. F. et al., eds.): Fifth Field Conference of the New Mexico Geol. Soc., p. 70-83.

GALLOWAY, SHERMAN E. (1956) Geology and ground-water resources of the Portales Valley area, Roosevelt and Curry counties, New Mexico: Unpublished master's thesis, Univ. New Mexico.

HARRINGTON, H. H. (1890) Soils and waters of the upper Rio Grande and Pecos valleys of Texas: Geol. Survey Tex. Bull. 2, p. 23

HENDRICKSON, G. E. and JONES, R. S. (1952) Geology and ground-water resources of Eddy County, New Mexico: New Mexico Bur. Mines and Min. Res. Ground-water Rept. 3, 250 p.

HORBERG, LELAND (1949) Geomorphic history of the Carlsbad Caverns area, New Mexico: Jour. Geology, v. 57 (5), p. 464-476.

HUFFINGTON, R. M. and ALBRITTON, C. C., JR. (1941) Quaternary sands on the Southern High Plains of western Texas: Amer. Jour. Sci., v. 239, p. 325-338.

JICHA, HENRY L. (1954) Geology and mineral deposits of Lake Valley Quadrangle, Grant, Luna, and Sierra counties, New Mexico: New Mexico Bur. Mines and Min. Res. Bull. 37, 93 p.

JUST, EVAN (1937) Geology and economic features in the pegmatites of Taos and Arriba counties, New Mexico: New Mexico Bur. Mines and Min. Res. Bull. 13, 73 p. (cited in Dane and Bachman, 1965).

KEROHER, GRACE C. (1966) Lexicon of geologic names of the United States for 1936-1960: U.S. Geol. Survey Bull. 1200, pt. 1, 2, and 3, 4341 p.

KING, P. B. (1930) Geology of the Glass Mountains, Texas: Univ. Tex. Bull. 3038, 245 p.

———————(1935) Outline of structural development of Trans-Pecos Texas: Am. Assoc. Petrol. Geol. Bull., v. 19, p. 221-261.

———————(1942) Permian of west Texas and southeastern New Mexico: Am. Assoc. Petrol. Geol. Bull., v. 26, p. 535-763.

———————(1948) Geology of the southern Guadalupe Mountains, Texas: U.S. Geol. Survey Prof. Paper 215, 183 p.

KOTTLOWSKI, FRANK E. (1958) Geologic history of the Rio Grande near El Paso in Guidebook of the Franklin and Hueco Mountains, Texas: West Texas Geol. Soc., p. 46-54.

KOTTLOWSKI, FRANK E.; FLOWER, ROUSSEAU H.; THOMPSON, M. L.; and FOSTER, ROY W. (1956) Stratigraphic studies of the San Andres Mountains, New Mexico: New Mexico Bur. Mines and Min. Res. Memoir 1, 132 p.

KUELLMER, FREDERICK J. (1954) Geologic section of the Black Range at Kingston, New Mexico: New Mexico Bur. Mines and Min. Res. Bull. 33, 100 p.

———————(1963) Guidebook of the Socorro region New Mexico: New Mexico Geol. Soc., 14th Field Conference, 240 p.

LANG, W. B. (1937) The Permian formations of the Pecos Valley of New Mexico and Texas: Am. Assoc. Petrol. Geol. Bull., v. 21, p. 833-898.

LEE, WILLIS T. (1925) Erosion by solution and fill: U. S. Geol. Survey Bull. 760, p. 107-121.

LEONARD, A. B. and FRYE, J. C. (1962) Pleistocene molluscan faunas and physiographic history of Pecos Valley in Texas: Univ. Tex., Bureau of Econ. Geol. Rept. Inv. 45, 42 p.

LEOPOLD, LUNA B.; EMMETT, WILLIAM W.; MYRICK, ROBERT M. (1966) Channel and hillslope processes in a semiarid area, New Mexico: U.S. Geol. Survey Prof. Paper 352-G, p. 193-253.

LEWAND, RAYMOND L., JR. (1969) The geomorphic history of the Leon River: Baylor Geological Studies Bull. 17, 27 p.

MAXWELL, ROSS A.; LONSDALE, JOHN T.; HAZZARD, ROY T.; and WILSON, JOHN A. (1967) Geology of Big Bend National Park, Brewster County, Texas: Univ. Texas Pub. 6711, 320 p.

MEINZER, O. F. and HARE, R. F. (1915) Geology and water resources of the Tularosa Basin, New Mexico: U.S. Geol. Survey Water Supply Paper 343.

MENZER, F. J., JR. and SLAUGHTER, B. H. (1971) Upland gravels in Dallas County, Texas, and their bearing on the former extent of the High Plains physiographic province: Tex. Jour. Sci., v. 22, (2, 3), p. 217-222.

MILLER, J. P.; MONTGOMERY, ARTHUR; and SUTHERLAND, P. K. (1963) Geology of part of the Southern Sangre De Cristo Mountains, New Mexico: New Mexico Bur. Mines and Min. Res. Memoir 11, 106 p.

MORGAN, ARTHUR M. (1938) Geology and shallow water resources of the Roswell artesian basin, New Mexico: U.S. Geol. Survey and State Engineers of New Mexico, 95 p.

———————(1942) Solution-phenomena in the Pecos Basin: Am. Geophys. Union Trans., v. 23, p. 27-35.

MORGAN, ARTHUR M. and SAYRE, A. N. (1942) Geology and groundwater in The Pecos River Joint Investigation: The National Resources Planning Board, p. 28-38. (cited in Thornbury, 1965).

MOTT, W. S. (1959) Geomorphology of the east side of the Sacramento Mountains, New Mexico in Guidebook, Sacramento Mountains of Otero County, New Mexico: Soc. Econ. Paleont. Mineralog., Permian Basin Sec., and Roswell Geol. Soc., p. 223-233.

NEW MEXICO ENGINEERS (1959) Hydrologic summary, New Mexico stream flow and reservoir content, 1888-1954: Technical Rept. 7, State Engineers Office, Santa Fe, 326 p.

NORTHROP, STUART A. (1961) Guidebook of Albuquerque County: New Mexico Geol. Soc., 12th Field Conference, 199 p.

OLIVE, W. W. (1957) Solution-subsidence troughs, Castile Formation of Gypsum Plain, Texas and New Mexico: Geol. Soc. Am. Bull., v. 68, p. 351-358.

PARKE, R. P. (1962) Field trip Guidebook of the Permian of the central Guadalupe Mountains, Eddy County, New Mexico (Wilde, Garner et al., eds.): Hobbs, Roswell, and West Texas Geol. Socs., 116 p.

PIKE, WILLIAM S., JR. (1947) Intertonguing marine and nonmarine Upper Cretaceous deposits of New Mexico, Arizona, and southwestern Colorado: Geol. Soc. Amer. Memoir 24, 103 p.

PLUMMER, F. B. (1932) Cenozoic geology of Texas: Univ. Texas Bull. 2323, v. 2, pt. 3, p. 519-818.

PRAYE, LLOYD C. (1959) Guidebook for joint field conference in the Sacramento Mountains of Otero County, New Mexico (J. Rex Alcorn, chm.): Soc. Econ. Paleont. Mineralog., Permian Basin Sec., and Roswell Geol. Soc., 306 p.

PRICE, ARMSTRONG (1941) Abandoned Pecos Valley across Reynosa Cuesta, south Texas (abst.): Geol. Soc. America Bull., v. 52, 2006 p.

REESIDE, JOHN B. (1924) Upper Cretaceous and Tertiary Formations of the western part of the San Juan Basin, Colorado and New Mexico: U.S. Geol. Survey Prof. Paper 134, 70 p.

ROSWELL GEOLOGICAL SOCIETY (1957) Slaughter Canyon, New Cave, and Capitan Reef exposures, Carlsbad Caverns National Park: Guidebook Field Trip no. 10, 19 p.

———————(1960) Northern Franklin Mountains, southern San Andres Mountains, with emphasis on Pennsylvanian stratigraphy: Guidebook, 160 p.

SCHUMM, S. A. (1963) The disparity between present rates of denudation and orogeny: U.S. Geol. Survey Prof. Paper 454H, 13 p.

SELLARDS, E. H.; ADKINS, W. S.; and PLUMMER, F. B. (1933) Geology of Texas, v. I, stratigraphy: Univ. Tex. Bull. 3232, 1007 p.

SHARPS, J. A. (1963) Geologic map of the Malvado Quadrangle, Terrell and Val Verde counties, Texas: U.S. Geol. Survey Map I-382.

SHARPS, J. A. and FREEMAN, V. L. (1965) Geologic map of the mouth of Pecos and Feely Quadrangle, Val Verde County, Texas: U.S. Geol. Survey Map I-440.

STARK, J. T. (1956) Geology of the south Manzano Mountains, New Mexico: New Mexico Bur. Mines and Min. Res. Bull. 34, 46 p.

STEARNS, CHARLES E. (1942) A fossil marmot from New Mexico and its climatic significance: Am. Jour. Sci., v. 240, p. 867-878.

STIPP, T. F. (1952) Guidebook of the Pedernal positive element and the Estancia Basin, Torrance and northern Lincoln counties, New Mexico (Huffmyer, J. R. et al., eds.): Roswell Geol. Soc. Field Trip no. 7, 39 p.

STIPP, T. F.; MATCHUS, E. J.; HUFFMYER, J. R., eds. (1952) Surface structures of the foot hill region of the Sacramento and Guadalupe mountains, Chaves, Eddy, Lincoln, and Otero counties, New Mexico: Guidebook of the Roswell Geol. Soc. Field Trip no. 6, 14 p.

STOUT, IVAN M.; BENTZ, LURA C.; and INGRAM, H. WAYNE (1961) Silt load of Texas streams; A compilation report June 1889-September 1959: Texas Board of Water Engineers, Bull. 6108, 236 p.

THEIS, CHARLES V. (1932) Report on the ground water in Curry and Roosevelt counties, New Mexico: Tenth Biennial Report, State Engineer of New Mexico, p. 99-160.

THORNBURY, WILLIAM D. (1965) Regional geomorphology of the United States: John Wiley, New York, 609 p.

TROWBRIDGE, A. C. (1923) A geologic reconnaissance in the Gulf Coastal Plain of Texas near the Rio Grande: U.S. Geol. Survey Prof. Paper 131D, p. 85-117.

UDDEN, J. A.; BAKER, C. L.; and BÖSE, EMIL (1916) Review of the geology of Texas: Univ. Texas Bull. 44, p. 84-88.

UNITED STATES GEOLOGICAL SURVEY (1939) Floods in the Canadian and Pecos River basins of New Mexico: Water-Supply Paper 842, 66 p.

———————(1966) Water resources data for Texas: Part 2, Water quality records, 312 p.

WAAGE, KARL M. (1953) Refractory clay deposits of south-central Colorado: U.S. Geol. Survey Bull. 993, 104 p.

WEST TEXAS GEOLOGICAL SOCIETY (1965) Geology of the Big Bend area, Texas: Field Trip Guidebook, 196 p.

NEW MEXICO

TEXAS

N

Rio Conchos

Pecos River

Rio Conchos

SCALE

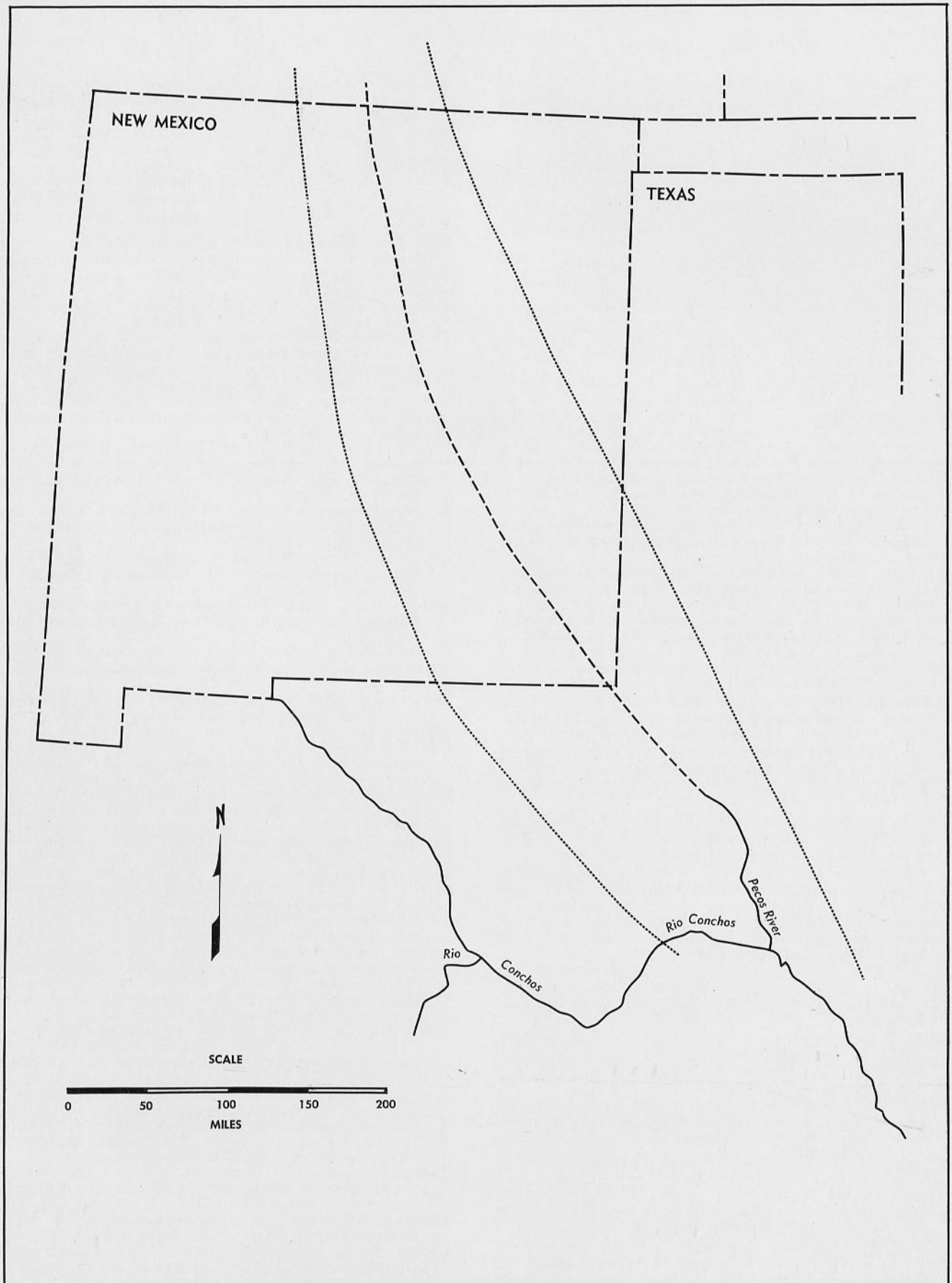0   50   100   150   200

MILES

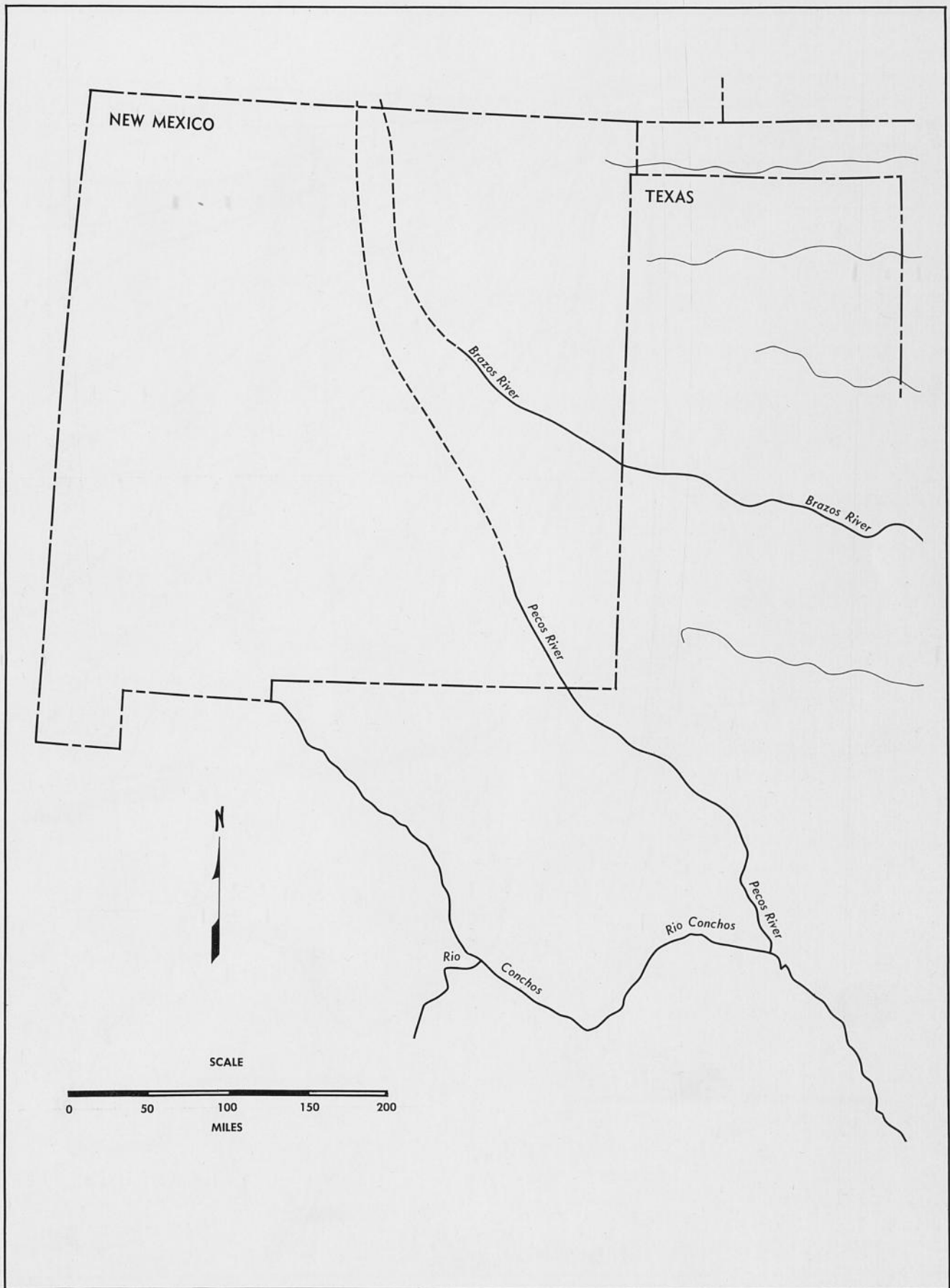Fig. 21. Postulated drainage of the Pecos River—Laramide.

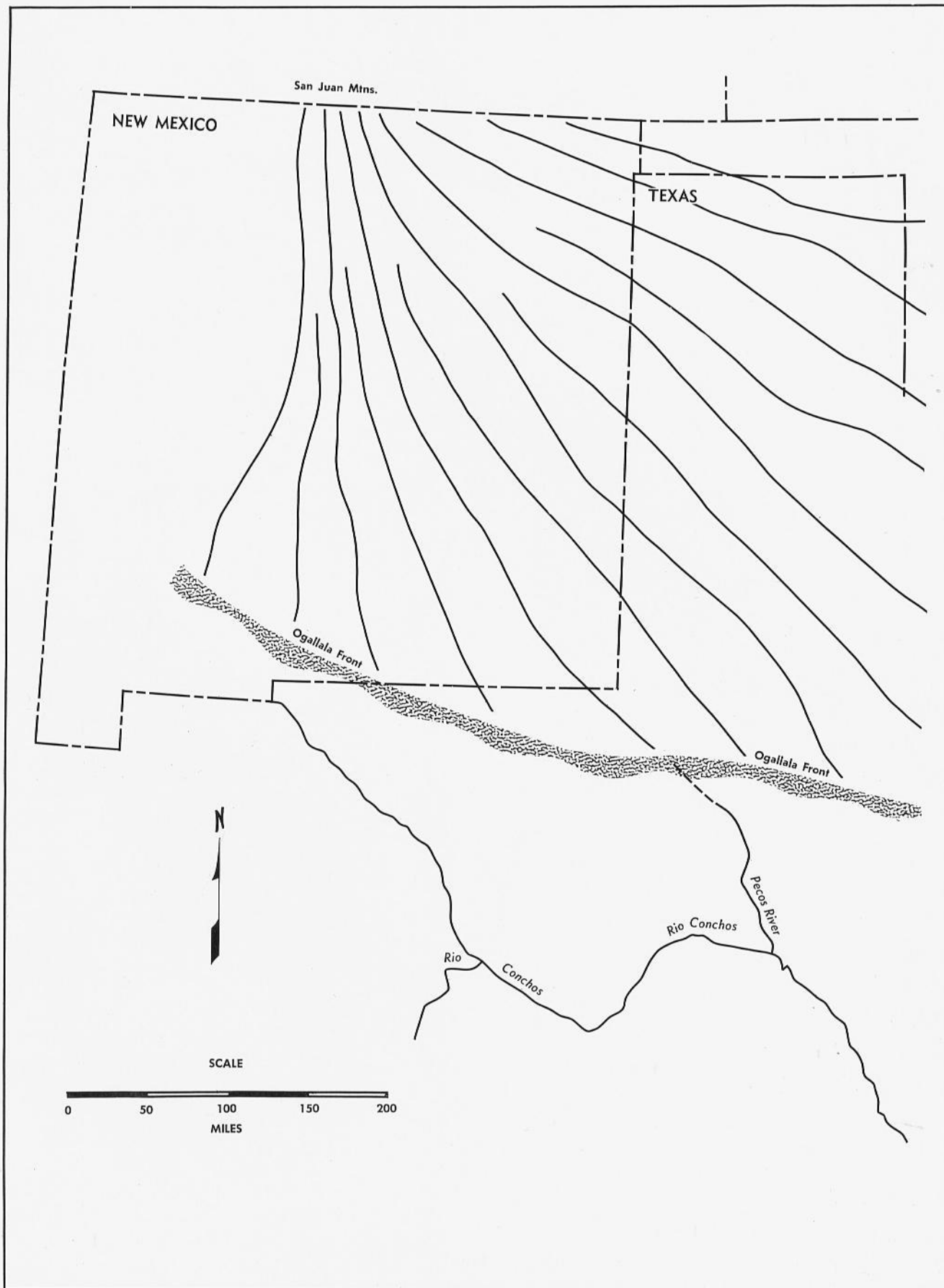Fig. 22. Postulated drainage of the Pecos River—Early Tertiary.

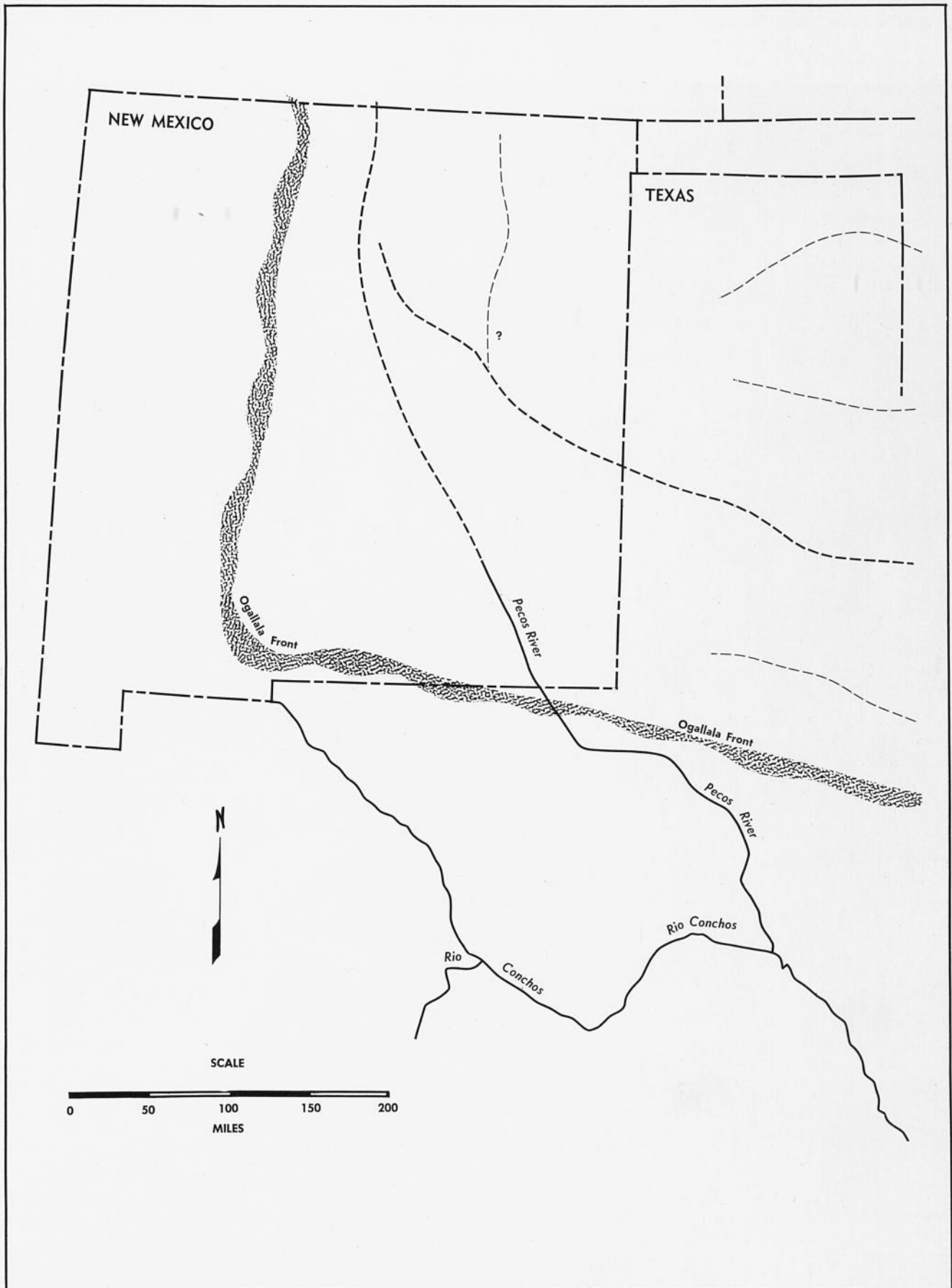Fig. 23. Postulated drainage of the Pecos—Late Tertiary.

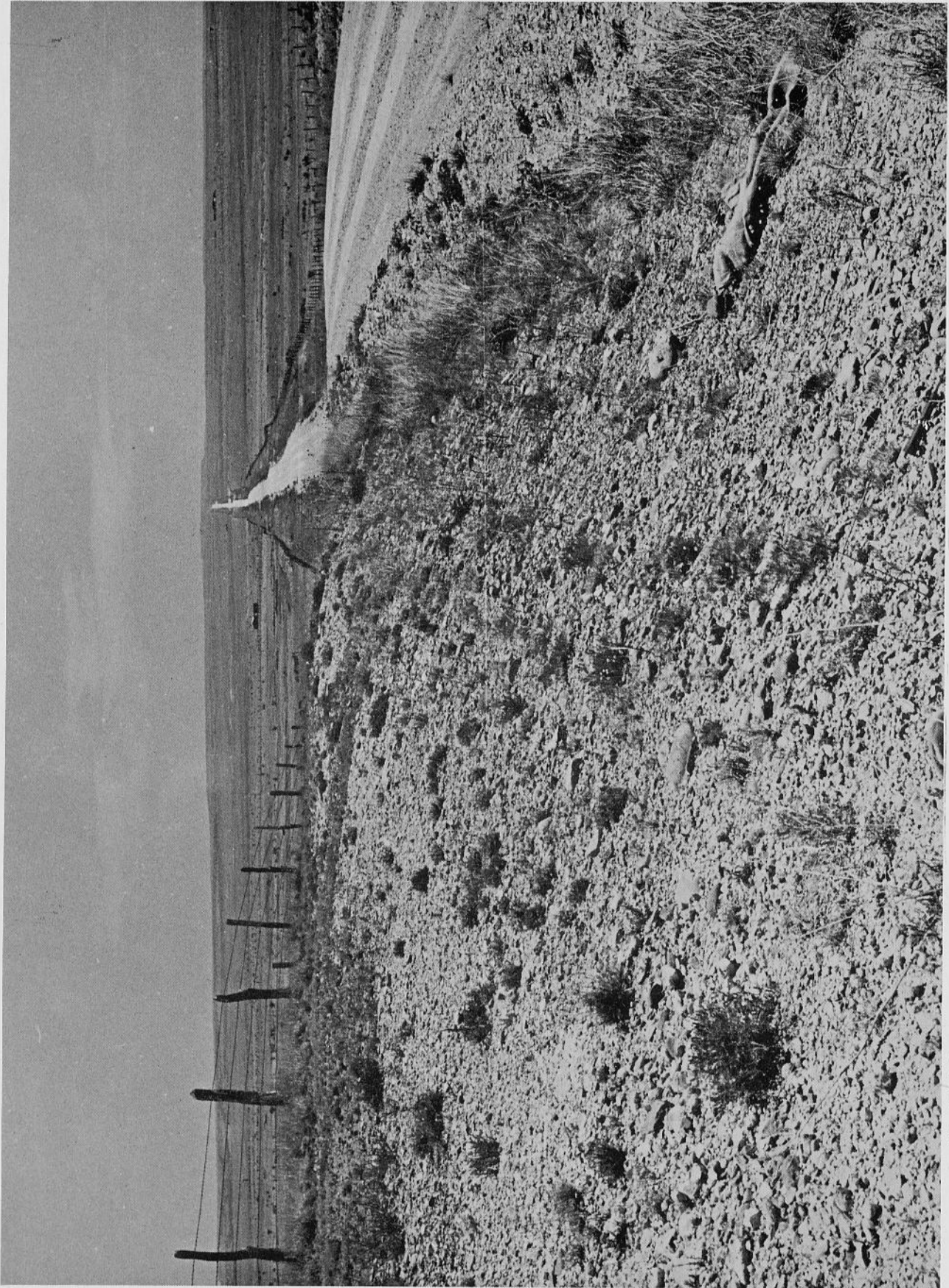Fig. 24. Postulated drainage of the Pecos River—Late Tertiary-Early Quaternary.

Fig. 25. Wind gap between tributaries of the Canadian and Pecos rivers near Santa Rosa, New Mexico (Locality 22). The gravels in the photograph are from the Ogallala Formation, and appear to be filling from a pre-Ogallala north-south valley. This is a postulated route from the upper Canadian River to the Pecos River, before piracy diverted the upper Canadian River into its present course.

APPENDIX

LOCALITIES

Locality coordinates taken from United States Geological Survey 1:250,000 topographic maps.

LOCALITY 1

Tower Hill 1 mile south of Highway 180, 18 miles east of Carlsbad, Eddy County, New Mexico (31° 28′ N; 103° 50′ W). Siliceous content: gravel-sized chert, jasper, and quartzite derived from caliche-capped hills.
Condition: well rounded.

LOCALITY 2

Scattered residual siliceous pebbles on Fade-Away Ridge approximately 6.5 miles south of junction of Highway 82 and 360, 13 miles east of Artesia, Eddy County, New Mexico (32° 44′ N; 104° 13′ W).
Siliceous content: pebble-sized chert, jasper, vein quartz and quartzite.
Condition: well rounded.

LOCALITY 3

Road cut in the Mescalero Escarpment 4 miles west of Caprock on Highway 380, Chaves County, New Mexico (32° 25′ N; 103° 47′ W).
Siliceous content: pebble-sized vein quartz derived from caliche of the Ogallala Formation.
Condition: well rounded.

LOCALITY 4

Tolar, Roosevelt County, New Mexico (34° 27′ N; 103° 56′ W). Erosional interruption of the Llano Estacado's western scarp. More than 150 square miles of the Llano Estacado's drainage have been captured from a southeastern course into Texas to become a southwest drainage tributary of the Pecos River.

LOCALITY 5

Basal Ogallala exposed in road cut 2 miles west of Negra on Highway 60, Torrance County, New Mexico (34° 41′ N; 105° 34′ W).
Siliceous content: scattered quartzose pebbles are embedded in caliche (Bretz and Horberg, 1949, p. 482).

LOCALITY 6

Basal Ogallala outcrop on the east flank of Pedernal Mountains 17 miles northwest of Encino, Torrance County, New Mexico (34° 39′ N; 105° 36′ W) (Bretz and Horberg, 1949).

LOCALITY 7

Basal Ogallala exposed in road cut 28 miles southwest of Carlsbad, Eddy County, New Mexico, on Highway 62 (32° 01′ N; 104° 28′W).
Siliceous content: pebble-sized chert, dark gray to black quartzite, and vein quartz.
Condition: well rounded.

LOCALITY 8

Basal Ogallala exposed in gravel pit 100 yards west of gravel road 9 miles west of Malaga, Eddy County, New Mexico (32° 12′ N; 104° 13′ W).
Siliceous content: pebble-sized chert, light gray to black quartzite and vein quartz.
Condition: well rounded.

LOCALITY 9

Bluff over the Pecos River at Herradura Bend held up by Basal

Ogallala 10 miles southeast of Carlsbad, Eddy County, New Mexico (32° 19′ N; 104° 06′ W).
Siliceous content: pebble- and cobble-sized chert, quartzite, orthoquartzite, and vein quartz.
Condition: well rounded.

LOCALITY 10

Scattered siliceous gravels and collapse breccia at Lowe's Ranch service road 3 miles southwest of Carlsbad Caverns entrance (32° 09′ N; 104° 30′ W).
Siliceous content: pebble- and gravel-sized chert; gray-black and banded quartzite, white and pink vein quartz.
Condition: rounded.

LOCALITY 11

Conglomerate solution cavity fill in the rimrock at the mouth of Slaughter Canyon 9 miles southwest of Carlsbad Caverns, Eddy County, New Mexico (32° 60′ N; 104° 40′ W).
Siliceous content: pebble-sized chert, red and gray to black quartzite and white vein quartz.
Condition: rounded.

LOCALITY 12

Scattered siliceous pebbles on Ares Peak at the head of Dunaway Draw 35 miles west-southwest of Carlsbad, Eddy County, New Mexico (32° 17′ N; 104° 48′ W).
Siliceous content: foreign schist and chert pebbles (Bretz and Horberg, 1949, p. 486).

LOCALITY 13

Summit peneplain in the Pickett Hill area 23 miles west of Carlsbad Caverns, Eddy County, New Mexico (32° 11′ N; 104° 50′ W) (King, 1948).

LOCALITY 14

Basal Ogallala exposed in road cut on Highway 62 2.2 miles southwest of White's City, Eddy County, New Mexico (32° 08′ N; 104° 22′W).
Siliceous content: pebble-sized white vein quartz and gray to black quartzite and white orthoquartzite.
Condition: rounded.

LOCALITY 15

Gravel-capped hilltops overlooking Pecos River on Billing's Ranch, 14 miles northeast of Langtry, Val Verde County, Texas (29° 52′ N; 101° 25′ W).
Siliceous content: pebble, gravel, cobble and boulder-sized chert, vein quartz, quartzite, and volcanics.
Condition: rounded.

LOCALITY 16

Scattered pebbles at Towersite on Yates Mountain, 4 miles southwest of Iraan, Pecos County, Texas (30° 52′ N; 101° 56′ W).
Siliceous content: pebble-sized chert, vein quartz and quartzite.
Condition: well rounded.

LOCALITY 17

Pecos River terrace gravels exposed in road cut on Highway 80, 2 miles west of Barstow, Ward County, Texas (31° 27′ N; 103° 25′ W).
Siliceous content: pebble- and gravel-sized chert, vein quartz, quartzite, and orthoquartzite.
Condition: well rounded.
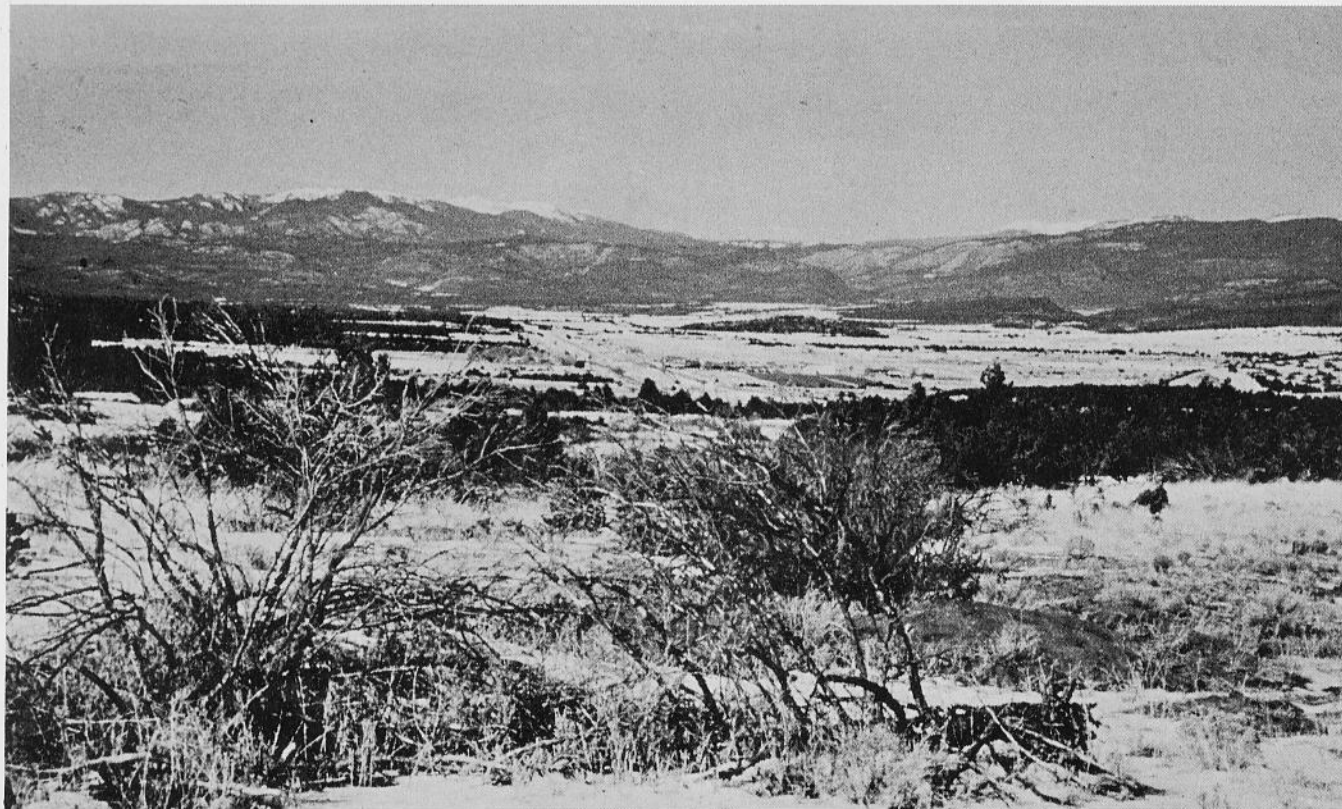
Fig. 26. Pecos Valley (viewed from the south) at Pecos, New Mexico. Pecos Baldy, where the Pecos River rises, is the snow-capped peak in the center.

LOCALITY 18

Siliceous gravels exposed in road cut and adjacent hilltops on Highway 380, 16 miles west of Roswell, Chaves County, New Mexico (33° 22′ N; 104° 29′ W).
Siliceous content: gravel-sized chert, vein quartz and quartzite.
Condition: rounded.

LOCALITY 19

Scattered siliceous pebbles on the Mescalero Plain adjacent to Highway 380, 18 miles east of Roswell, Chaves County, New Mexico (33° 25′ N; 104° 12′ W).
Siliceous content: pebble-sized chert, white and pink vein quartz and quartzite.
Condition: well rounded.

LOCALITY 20

Water well Roswell, Chaves County, New Mexico (32° 24′ N; 104° 17′ W).
Quartzose conglomerate is penetrated by numerous wells in Roswell Basin (Bretz and Horberg, 1949, p. 483).

LOCALITY 21

Water well in Carlsbad, Eddy County, New Mexico (32° 25′ N; 104° 14′ W).
Quartzose conglomerate is penetrated by numerous wells in Roswell Basin (Bretz and Horberg, 1949, p. 483).

LOCALITY 22

Basal Ogallala exposed in road cut on Highway 156 12 miles east of Santa Rosa, Guadalupe County, New Mexico (34° 57′ N; 104° 39′ W).
Siliceous content: gravels, cobble- and boulder-sized chert, pink and white vein quartz, gray-black and green quartzite, banded quartzite and laminated micaceous quartzite and granite.
Condition: rounded.

LOCALITY 23

Isolated orthoquartzite gravels atop King Mountain 6 miles northeast of McCamey, Upton County, Texas (31° 12′ N; 102° 09′ W).
Siliceous content: pebble- and gravel-sized white vein quartz and white orthoquartzite.
Condition: well rounded.

LOCALITY 24

Conglomerate exposed in road cut and adjacent hilltop on Highway 13, 15 miles west of Hagerman, Chaves County, New Mexico (33° 05′ N; 104° 06′ W).
Siliceous content: pebble, gravel, and cobble-sized gray to black chert, white and pink vein quartz, jasper, banded, red, purple and gray to black quartzite.
Condition: well rounded.

LOCALITY 25

Scattered siliceous gravels on high surface adjacent to Highway 2400, 2 miles east of JCT 2400 and McKee Creek, 21 airline miles northeast of Sanderson, Terrell County, Texas (30° 27′ N; 102° 07′ W).
Siliceous content: pebble-sized chert, white orthoquartzite and rhyolite.
Condition: chert and ortoquartzite—rounded; rhyolite—angular.

LOCALITY 26

Creek bed at low-water crossing on gravel road one-half mile north of Highway 2400, 8 miles east of JCT 2400 and 285, 19 airline miles north of Sanderson, Terrell County, Texas (30° 18′ N; 102° 19′ W).
Siliceous content: granule- and pebble-sized chert, quartz and rhyolite.
Condition: rounded.

LOCALITY 27

Scattered gravels on top of southwest mesa 3 miles east of Highway 305, 7 miles south of McCamey, Crockett County, Texas (31° 03′ N; 102° 06′ W).
Siliceous content: pebble- and gravel-sized chert and gray orthoquartzite.
Condition: well rounded.

LOCALITY 28

Outcrop of Eocene Cub Mountain Formation in a roadcut on Highway 380, 10 miles east of Carrizozo, Lincoln County, New Mexico (33° 35′ N; 105° 40′ W).

Siliceous content: pebble- and gravel-sized vein quartz and gray to black quartzite embedded in quartzose sandstone.
Condition: rounded.

LOCALITY 29

Bluffs formed by Basal Ogallala along the Black River 100 yards north of gravel road 2 miles west of Malaga, Eddy County, New Mexico (32° 13′ N; 104° 07′ W).

Siliceous content: gravel- and cobble-sized red, black and gray chert; white and pink vein quartz; white, gray to black, purple and banded quartzite; white orthoquartzite, granite and rhyolite.
Condition: rounded.

INDEX

BAYLOR GEOLOGICAL
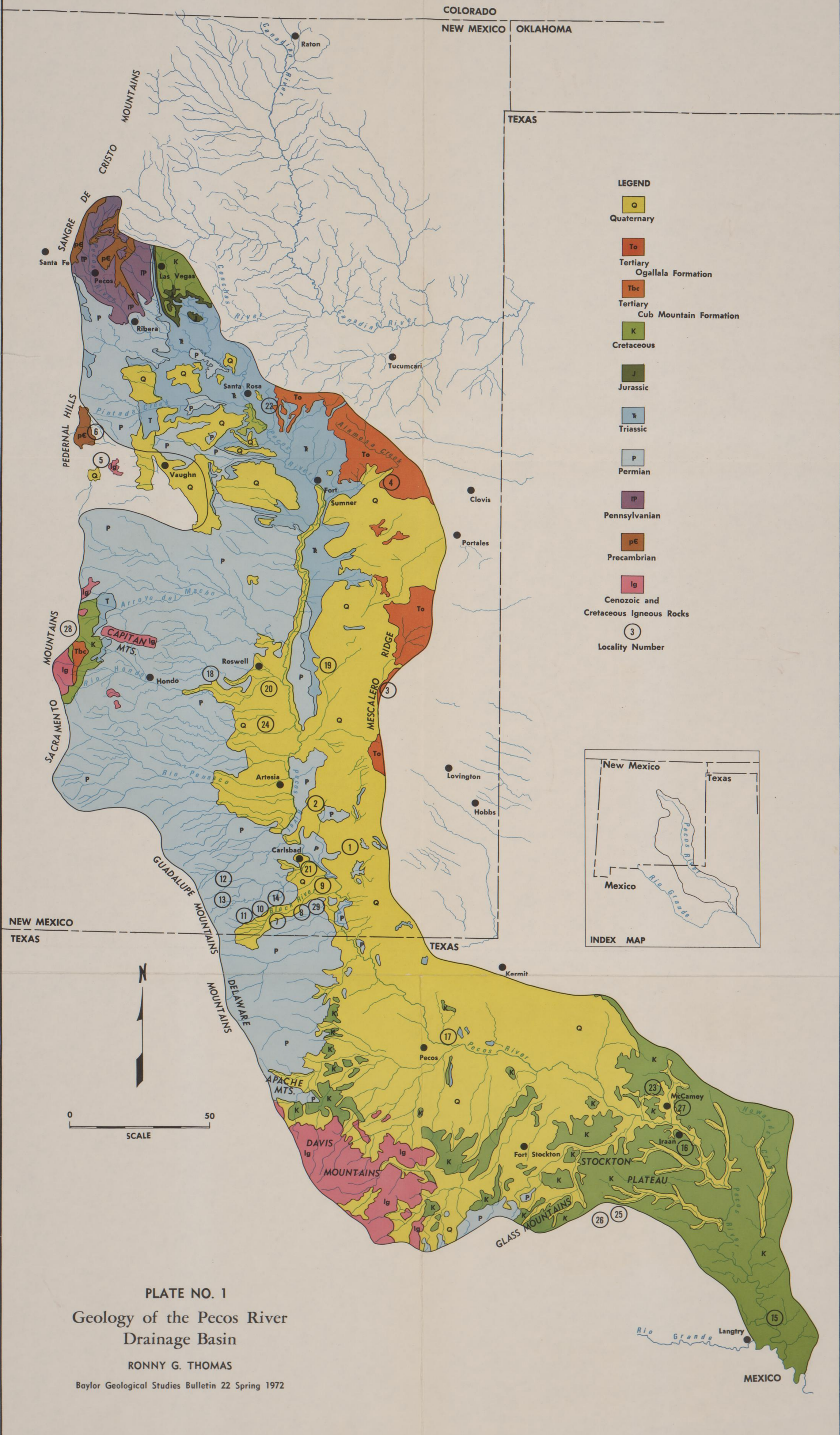# PUBLICATIONS*

Baylor Geological Studies

1. Holloway, Harold D. (1961) The Lower Cretaceous Trinity aquifers, McLennan County, Texas: Baylor Geological Studies Bull. No. 1 (Fall). Out of print.
2. Atlee, William A. (1962) The Lower Cretaceous Paluxy Sand in central Texas: Baylor Geological Studies Bull. No. 2 (Spring). $1.00 per copy. Out of print.
3. Henningsen, E. Robert (1962) Water diagenesis in Lower Cretaceous Trinity aquifers of central Texas: Baylor Geological Studies Bull. No. 3 (Fall). $1.00 per copy. Out of print.
4. Silver, Burr A. (1963) The Bluebonnet Member, Lake Waco Formation (Upper Cretaceous), central Texas—A lagoonal deposit: Baylor Geological Studies Bull. No. 4 (Spring). $1.00 per copy.
5. Brown, Johnnie B. (1963) The role of geology in a unified conservation program, Flat Top Ranch, Bosque County, Texas: Baylor Geological Studies Bull. No. 5 (Fall). $1.00 per copy. Out of print.
6. Beall, Arthur O., Jr. (1964) Stratigraphy of the Taylor Formation (Upper Cretaceous), east-central Texas: Baylor Geological Studies Bull. No. 6 (Spring). $1.00 per copy.
7. Spencer, Jean M. (1964) Geologic factors controlling mutation and evolution—A review: Baylor Geological Studies Bull. No. 7 (Fall). $1.00 per copy. Out of print.

Urban geology of Greater Waco. A series on urban geology in cooperation with Cooper Foundation of Waco.
8. Part I: Geology (1965) Geology and urban development by Peter T. Flawn; Geology of Waco by J. M. Burket: Baylor Geological Studies Bull. No. 8 (Spring). $1.00 per copy.
9. Part II: Soils (1965) Soils and urban development of Waco by W. R. Elder: Baylor Geological Studies Bull. No. 9 (Fall). $1.00 per copy.
10. Part III: Water (1966) Surface waters of Waco by Jean M. Spencer: Baylor Geological Studies Bull. No. 10 (Spring). $1.00 per copy.
11. Part III: Water (1966) Subsurface waters of Waco by H. D. Holloway: Baylor Geological Studies Bull. No. 11 (Fall). $1.00 per copy.
12. Part IV: Engineering (1967) Geologic factors affecting construction in Waco by R. G. Font and E. F. Williamson: Baylor Geological Studies Bull. No. 12 (Spring). $1.00 per copy.
13. Part V: Socio-Economic Geology (1967) Economic geology of Waco and vicinity by W. T. Huang; Geology and community socio-economics—A symposium coordinated by R. L. Bronaugh: Baylor Geological Studies Bull. No. 13 (Fall). $1.00 per copy.
14. Part VI: Conclusions (1968) Urban geology of greater Waco—Summary and recommendations by Editorial Staff: Baylor Geological Studies Bull. No. 14 (Spring). $1.00 per copy.

15. Boone, Peter A. (1968) Stratigraphy of the basal Trinity (Lower Cretaceous) sands, Central Texas: Baylor Geological Studies Bull. No. 15 (Fall). $1.00 per copy.
16. Proctor, Cleo V. (1969) The North Bosque watershed, Inventory of a drainage basin: Baylor Geological Studies Bull. No. 16 (Spring). $1.00 per copy.
17. LeWand, Raymond L., Jr. (1969) The geomorphic evolution of the Leon River System: Baylor Geological Studies Bull. No. 17 (Fall). $1.00 per copy.
18. Moore, Thomas H. (1970) Water geochemistry, Hog Creek basin, Central Texas: Baylor Geological Studies Bull. No. 18 (Spring). $1.00 per copy.
19. Mosteller, Moice A. (1970) Subsurface stratigraphy of the Comanchean Series in East Central Texas: Baylor Geological Studies Bull. No. 19 (Fall). $1.00 per copy.
20. Byrd, Clifford Leon (1971) Origin and history of the Uvalde Gravel of Central Texas: Baylor Geological Studies Bull. No. 20 (Spring). $1.00 per copy.
21. Brown, Thomas E. (1971) Stratigraphy of the Washita Group in Central Texas: Baylor Geological Studies Bull. No. 21 (Fall). $1.00 per copy.
22. Thomas, Ronny G. (1972) The geomorphic evolution of the Pecos River system: Baylor Geological Studies Bull. No. 22 (Spring). $1.00 per copy.

Baylor Geological Society

101. Type electric log of McLennan County. 1"-100'; 1"-50'-$2.00.
102. Reptile charts—Comparison of flying and swimming reptiles. $0.10 each. Comparison of the dinosaurs. $0.10 each.
103. Guide to the mid-Cretaceous geology of central Texas, May, 1958. Out of print.
104. Location map of logged wells in McLennan County, 1959. 1"-1mile. Out of print.
105. Layman's guide to the geology of central Texas, 1959. Out of print.
106. Collector's guide to the geology of central Texas, 1959. Out of print.
107. One hundred million years in McLennan County, 1960. Out of print.
108. Cretaceous stratigraphy of the Grand and Black Prairies, 1960. Out of print.
109. Popular geology of central Texas, west central McLennan County, 1960. Out of print.
110. Popular geology of central Texas, Bosque County, 1961. Out of print.
111. Popular geology of central Texas, northwestern McLennan County, 1961. Out of print.
112. Popular geology of central Texas, southwestern McLennan County and eastern Coryell County, 1962. Out of print.
113. Upper Cretaceous and Lower Tertiary rocks in east central Texas, Fred B. Smith, Leader, 1962. Out of print.
114. Precambrian igneous rocks of the Wichita Mountains, Oklahoma, Walter T. Huang, Leader, 1962. Out of print.
115. Why teach geology? A discussion of the importance and cost of teaching geology in high schools, junior colleges and smaller 4-year institutions. Free upon request. 27 pp. (1961).
116. Popular geology of Central Texas: The hill country—McLennan, Coryell and Bosque counties, 1963. $1.00 per copy. Revised.
117. Shale environments of the mid-Cretaceous section, Central Texas—A field guide. Leaders—Beall, A. O.; Johnson, C.F.; and Silver, B. A.; 1964. $2.00 per copy.
118. Geology and the city of Waco—A guide to urban problems, 1964. $2.00 per copy.
119. The Bosque watershed. Geology of the Bosque River basin, 1966. Out of print.
120. Valley of the giants. Lower Comanchean section of the Paluxy River basin, 1967. Out of print.
121. The Hog Creek watershed. Environmental study of a watershed, 1968. $1.00 per copy.
122. The Waco region. Geologic section of the area around Lake Waco, McLennan County, Texas, 1968. $1.00 per copy. Out of print.
123. Mound Valley. A physiographic study of Central Texas, 1969. Out of print.
124. The Bosque watershed (revised). Geology of the Bosque River basin, 1969. Out of print.
125. Lampasas Cut Plain. Geomorphic evolution of the Lampasas Cut Plain, southwest of Gatesville, 1970. $1.00 per copy. Out of print.
126. Middle Bosque Basin. Geology of the Middle Bosque drainage basin, 1970. $1.00 per copy. Out of print.
127. Geology of the Trinity Group in the type area. A professional level guide, 1970. $4.00 per copy.
128. The Walunt Prairie, 1971. $1.00 per copy.

LEGEND

- Q — Quaternary
- To — Tertiary Ogallala Formation
- Tbc — Tertiary Cub Mountain Formation
- K — Cretaceous
- J — Jurassic
- Tr — Triassic
- P — Permian
- IP — Pennsylvanian
- p€ — Precambrian
- Ig — Cenozoic and Cretaceous Igneous Rocks
- ③ — Locality Number

INDEX MAP

New Mexico — Texas — Mexico
Pecos River — Rio Grande

COLORADO
NEW MEXICO | OKLAHOMA
TEXAS

Map labels: Raton, Santa Fe, Pecos, Las Vegas, Ribera, Tucumcari, Santa Rosa, Vaughn, Fort Sumner, Clovis, Portales, Roswell, Hondo, Artesia, Lovington, Hobbs, Carlsbad, Kermit, Pecos, Fort Stockton, McCamey, Iraan, Langtry

Geographic features: SANGRE DE CRISTO MOUNTAINS, PEDERNAL HILLS, SACRAMENTO MOUNTAINS, GUADALUPE MOUNTAINS, DELAWARE MOUNTAINS, APACHE MTS., DAVIS MOUNTAINS, GLASS MOUNTAINS, STOCKTON PLATEAU, CAPITAN MTS., MESCALERO RIDGE

Rivers/creeks: Canadian River, Conchas River, Pintada Creek, Pecos River, Alamosa Creek, Arroyo del Macho, Rio Hondo, Rio Peñasco, Black River, Rio Grande, Howards Creek

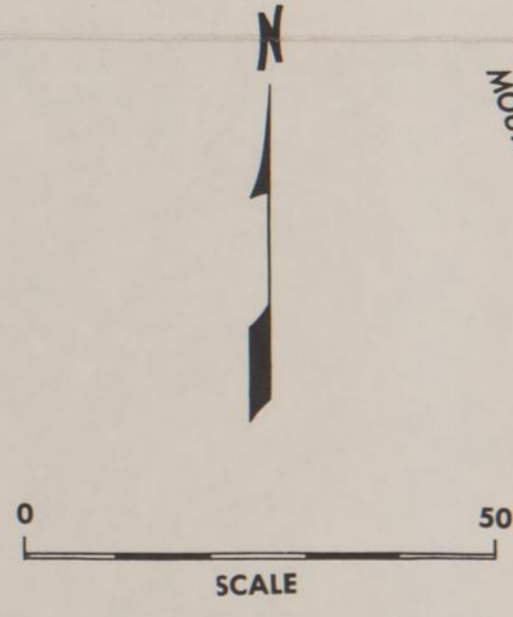NEW MEXICO
TEXAS

N

0 — SCALE — 50

PLATE NO. 1

Geology of the Pecos River Drainage Basin

RONNY G. THOMAS

Baylor Geological Studies Bulletin 22 Spring 1972