BUREAU OF ECONOMIC GEOLOGY
The University of Texas
Austin 12, Texas

Peter T. Flawn, Director

Report of Investigations—No. 45

Pleistocene Molluscan Faunas and Physiographic History of Pecos Valley in Texas

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Errata

Page--

263, line 26: "Wilson et al. (1927)" should read "Wilson et al. (1957)"

263, line 27: "Gardner (1953)" should read "Gardner (1933)"

266, line 1: "Ackerman Formation" should be in regular heavy letters

267, last major heading: "Betheden Formation" should be in regular heavy letters

267, last line: "Lithology. 25 feet, locally absent." should read "Bauxitic and kaolinitic clay; lignite."

286, line 1: "Squirrel Creek Formation" should read "Squirrelcreek Formation"

Please correct your copy

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Illustrations

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A. BYRON LEONARD[1] and JOHN C. FRYE[2]

ABSTRACT

Studies of physiographic relations and of fossil molluscan faunas made in the Pecos River valley region (Val Verde County to the Texas–New Mexico border) reveal extensive, well-pedimented surfaces southwest of the river extending from the Davis Mountains to near the present channel. These surfaces are described as Surface I, graded to the late Tertiary Ogallala drainageways; Surface II, graded to a lower level early Pleistocene channel of Pecos River and extensively pedimented during Illinoian time; Surface III, graded during early Wisconsinan to a level only slightly above the present channel of Pecos River; and Surface IV, developed during latest Wisconsinan and Recent as a terrace of highly fossiliferous deposits in which the Pecos River is presently incised. No molluscan fossils were observed in the sediments of Surface I; meager collections in alluvial sediments underlying Surface II confirm its Pleistocene(?) age; adequate collections of fossil mollusks from alluvial sediments beneath Surface III are characteristic of early Wisconsinan, and the uniquely rich faunas in deposits below Surface IV are characteristic of post-Twocreekan (post-Bradyan) assemblages. Physiographic features of Pecos River valley are illustrated by generalized profiles and photographs; the 33 localities from which fossil mollusks were collected are indicated on a location map, the species included in each local molluscan faunal assemblage are shown on a chart, and each species is illustrated photographically.

INTRODUCTION

The Pecos River extends generally southeasterly across southwestern Texas from the New Mexico line to its junction with the Rio Grande on the Mexican border. The complex valley through which the river flows in Texas is an extensive region from which Pleistocene fossil molluscan faunas are virtually unknown, and from which detailed information on the physiographic history and the stratigraphy of the surficial deposits is sparse. During August 1958 and June 1959 the writers undertook a reconnaissance of Pleistocene fossil mollusks of the Pecos Valley region. Snail faunas had previously been described (Frye and Leonard, 1957) as far south as northern Glasscock County, and general Pleistocene correlations had been made from farther north in western Texas southward into Howard County, thus furnishing a point of departure for southwestward correlations.

Although fossil snails have been obtained from 33 localities within the Pecos Valley region (fig. 1) a significant geographic gap still exists between the faunas previously reported (Frye and Leonard, 1957) in Howard and Martin counties and the most northeasterly localities here reported from Crane, Pecos, and Crockett counties. Furthermore, many of the faunas of the Pecos Valley region are not clearly definitive as to age and correlation.

It is the purpose of this paper to report only upon the Pleistocene fossil mollusks obtained from this region and to present a tentative outline of the physiographic his-

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tory of the Pecos Valley in Texas. A detailed discussion of Pleistocene stratigraphy is not attempted because of the paucity of adequate exposures, lack of detailed knowledge of physiographic surfaces, lack of clearly recognizable lithologic criteria such as volcanic ash beds and buried soils, and present inadequate knowledge of the faunas.

The work on which this report is based was done under the auspices of the Bureau of Economic Geology of The University of Texas and is part of a broader project on late Cenozoic geology in western and northern Texas.

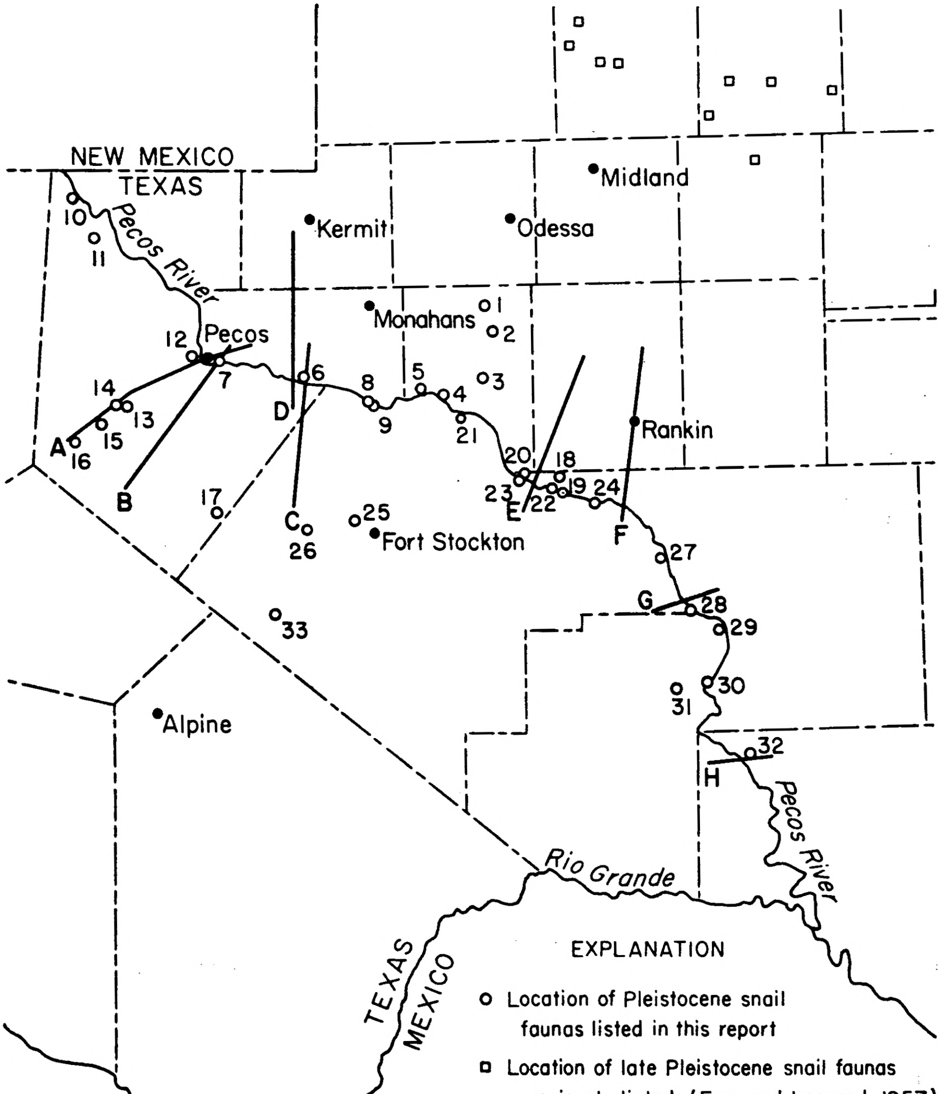


FIG. 1. Map of a part of southwestern Texas showing localities from which fossil mollusks are listed and position of generalized cross-profiles in figure 2.

PHYSIOGRAPHY

The region of the middle part of the Pecos Valley is sufficiently distinct in land forms and climate that it has long been recognized (Fenneman, 1931) as a distinctive physiographic section. Upstream from Upton County, Texas, it is a semiarid plains region, characterized by gently sloping and relatively undissected surfaces, and broken at places by mesas of various sizes that rise sharply above the regional plain. Southwest of the Pecos River the assemblage of sloping surfaces rises gradually toward the southwest to the flank of the Davis Mountains.

Even though it is a semiarid plains region, the character of the topography contrasts markedly with that of the adjacent High Plains surface and with the broad flat uplands of the Edwards Plateau (Pl. I). This contrast in topography coincides with a contrast in geology. The High Plains are regionally underlain by, and topographically reflect the character of, the late Tertiary Ogallala formation, and the upland surfaces of the Edwards Plateau are all underlain by resistant limestones of Cretaceous age. In contrast, the Pecos Valley, northwestward from Crane County, is underlain by Triassic and Permian rocks with scattered outliers of more resistant Cretaceous rocks (Sellards, Adkins, and Plummer, 1933). For the most part these more rapidly erodible Triassic and Permian rocks are covered by a relatively thin veneer of Pleistocene, and locally late Tertiary, deposits.

The physiography adjacent to the lower Pecos River contrasts strongly with that adjacent to the middle segment of the valley. Along the lower course of the Pecos River the main valley is a much less conspicuous element of the regional topography. It is a relatively narrow portion of the drainage basin and displays more characters in common with the basin of Devils River, to the east, than it does with its own basin farther upstream in Texas.

The channel of the Pecos River across Texas descends from an elevation of nearly 2,900 feet to less than 1,300 feet at its junction with the Rio Grande. Although the character of the valley and its local gradient change radically from place to place (figs. 2 and 3) the channel is near bedrock throughout the entire distance across Texas. The striking influence of the local bedrock on valley configuration is graphically shown in figures 2 and 3. On figure 2, the generalized cross-profiles (*see* fig. 1 for locations) A through D are in an area where the bedrock is relatively nonresistant Triassic and Permian, whereas the topography shown in generalized cross-profiles E through H is controlled by more resistant limestones of Cretaceous age.

The same relationship of topography to bedrock control is shown in figure 3 by the generalized profiles drawn parallel to the trend of the Pecos River and approximately 10 miles on either side of the channel. Here, these flanking profiles roughly simulate the gradient of the channel through the belt underlain by Triassic and Permian rocks but radically depart from it in the area where the belt of Cretaceous rocks crosses the valley.

The effect of local bedrock on channel gradient is also shown in figure 3. In the 50-mile segment nearest the mouth of the river, which is entirely within Cretaceous rocks, the gradient of the valley flat is approximately 12 feet per mile, whereas for the next 150 miles upstream the gradient of the valley flat is less than 5 feet per mile. It is significant that within the first 50 miles after the valley has entered Cretaceous limestone, the gradient does not appreciably exceed 5 feet to the mile.

The strong contrast in valley morphology associated with bedrock stratigraphy can perhaps be best expressed by descriptions of the valley slopes. In the belt of Triassic and Permian outcrop the valley is strongly asymmetrical. A distinct valley wall (Pl. I, A and F) occurs north of the river from Loving County across Ward County and part of Crane County. This north valley wall generally is little more

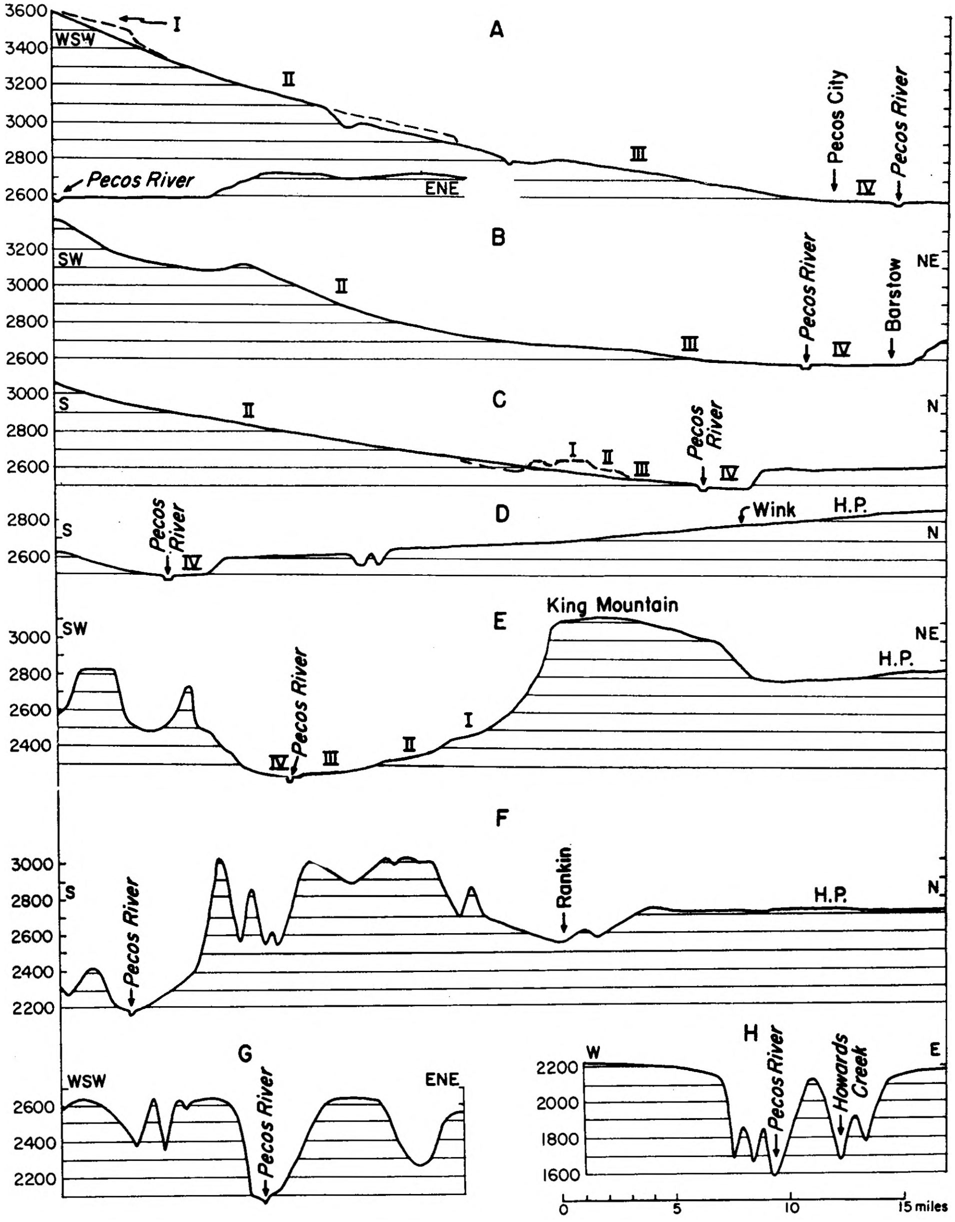


FIG. 2. Generalized and schematic cross-profiles of the Pecos Valley region of Texas. Based on 100-foot contour interval, 1:250,000-scale maps of Pecos, San Angelo, Fort Stockton, and Sonora areas issued by U. S. Geological Survey.

than 100 feet in height, but throughout a significant part of the distance Triassic rocks are exposed below capping Cenozoic deposits. The valley wall generally lies from 1 to 5 miles from the Pecos River channel.

In this area the south valley side slope presents a consistent contrast with the north valley side slope. In eastern Reeves County and northwestern and north-central Pecos County, pediments of regional proportion extend southward from the Pecos channel bank (Pl. I, D; fig. 2) and in some areas extend as an almost unbroken sloping surface for more than 30 miles to the south and southwest to a point where they approach the flank of the Davis Mountains. Although locally interrupted by mesas of Cretaceous limestone (Pl. I, E), the pediment surfaces generally rise to elevations of more than 1,000 feet above the channel of Pecos River. The extreme is represented by a complex of integrated pediment surfaces that may be traced continuously southwestward from the Pecos River channel into northern Brewster County where pediment surfaces stand at elevations more than 1,500 feet above channel level.

In this area the asymmetry of the valley is accented by the northeastward extension, from the low crest of the north valley wall, of an almost unbroken upland surface that is indistinguishable from the northward adjacent parts of the High Plains. This lack of a northward physiographic boundary contrasts with the imposing mountain fronts that serve as a southwestern terminus to the more steeply rising pediment surfaces to the south.

The strong asymmetry of the valley and the extensive pediment surfaces are both abruptly reduced where Pecos River enters the outcrop of Cretaceous limestones west of McCamey. Progressively narrower pediments persist for more than 50 miles downstream from McCamey, but it is the gravity slope and free-face slope elements that dominate the topography. Through this stretch the valley, even though sharply constricted near McCamey, progressively narrows downstream (fig. 2, E, F, G).

Downstream from southwestern Crockett County the valley becomes a sharply incised trench (fig. 2, H) lacking all but the most rudimentary flanking pediments (Pl. I, B). In this segment of greatly steepened gradient (fig. 3) the valley floor is dominated by alluvial fans, built at and below the mouths of entering tributaries, that have been dissected and partly cut away by the main stream. The partial destruction of the medium- to coarse-textured fan deposits has produced locally prominent unpaired terraces. At other places the stream flows directly on bedrock and is flanked by an insignificant strip of alluvium. The

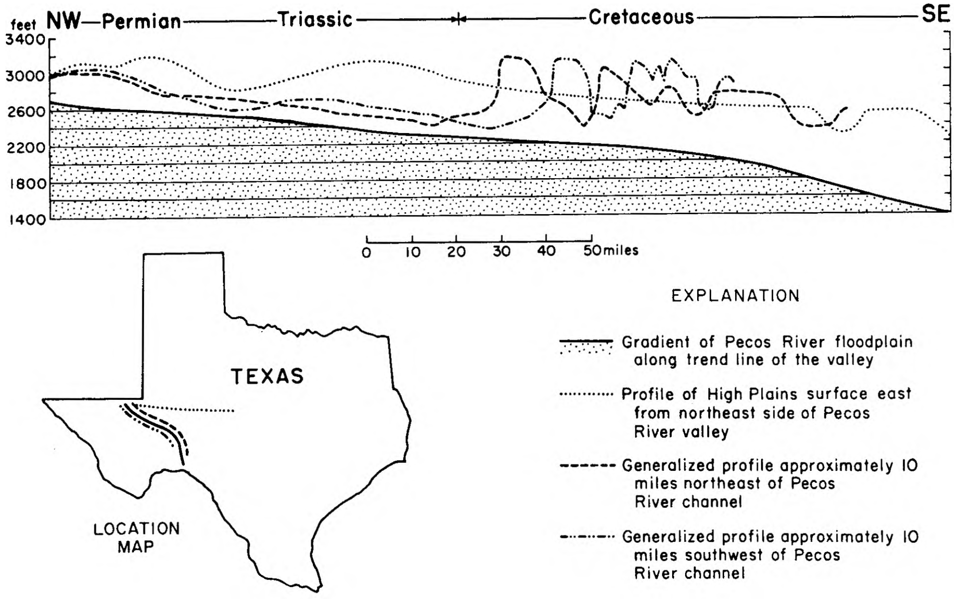


FIG. 3. Profile of Pecos Valley flat along trend line of valley; profiles 10 miles each side of the channel; and profile of High Plains surface to north. Based on 100-foot contour interval, 1:250,000-scale maps of Pecos, San Angelo, Fort Stockton, and Sonora areas issued by U. S. Geological Survey.

absence of flanking pediments coincides with the segment of greatly steepened valley gradient.

Late Cenozoic Physiographic Development

In spite of the many uncertainties in the interpretation of late Cenozoic history of the Pecos Valley in Texas, it nevertheless seems desirable to present an outline of its inferred history as background to understanding the Pleistocene fossil molluscan faunas to be described. Northward from this part of Texas extends the vast plateau surface called the High Plains. The surface of this plateau is generally underlain by sediments of the late Tertiary Ogallala formation. This formation ranges in thickness from a few feet to more than 500 feet and has been correlated into the panhandle region of Texas and northward across Kansas and Nebraska (Frye and Leonard, 1957, 1959). It reached its culmination of sedimentation by mid-to late-Pliocene time. Although locally thin Ogallala formation persists to the crest of the north wall of the Pecos Valley (Pl. I, A, F), it is generally thin, discontinuous, and patchy southwest from Howard County. The continuous extent of the topographic surface, or physiographic datum defined by the High Plains, however, can be traced in Midland, Ector, Winkler, Ward, Crane, and Upton counties, where it is in part a constructional and in part an erosional surface. In the southwestern part of this area the continuation of this late Tertiary surface is extensively veneered with relatively young Pleistocene deposits, but in southern Howard, Glasscock, and Upton counties (fig. 2, E, F) large mesas and buttes capped by resistant Cretaceous limestones stand several hundred feet above it. It is evident that this late Tertiary coalescent alluvial plain, that engulfed all former topography for hundreds of miles to the north, became, in this area, a lowland plain below the remnants of a higher surface that had been cut earlier on the Cretaceous limestones.

In Crane, Ector, Ward, and Winkler counties the gradient or slope of the High Plains surface shifts to a southerly direction. This transition from an east-southeast slope to a southerly slope takes place in an indistinctly definable belt along a northwest-southeast-trending zone across Ector County where Cretaceous rocks are at or near the surface. This vaguely defined divide continues into northwestern Upton County and appears to be continuous with the high Cretaceous bedrock including King Mountain near McCamey. Because of inadequate exposures, it has not been possible to determine whether or not this divide zone consistently lacks Ogallala deposits, but it is apparent that at least in Ector and Winkler counties the physiographic continuity of the High Plains surface is uninterrupted across it.

This shift in High Plains surface slope strongly suggests a southward drainage trend of the late Tertiary alluviating streams along the north side of the middle Pecos Valley and a drainage outlet to the southeast in the general position of the lower Pecos River basin. The continuity of the surface and lack of locally distinguishable expression of a divide, together with the possibility of discontinuous Ogallala deposits across the area, indicate the integrated nature of the High Plains erosional-depositional surface and suggest that the Ector County late Tertiary divide was of no greater significance than other divide areas that have been recognized occurring on the High Plains surface to the north.

Granting the continuity of the High Plains surface across Ector County, the late Tertiary coalescent alluvial plain clearly was terminated on the southwest by the toe of the extensive pediments rising to the flanks of the Davis Mountains. Thus, in late Tertiary time the highest pediment surfaces to the southwest were in a flanking position to the southernmost through-flowing drainage line of the High Plains complex. However, southeastward from eastern Crane County this was not the case as the Pecos Valley was no longer integrated with the High Plains complex but was isolated from the plains by the essentially continuous higher bedrock Cretaceous upland (figs. 2 and 3). That an ancestral late Tertiary Pecos River existed across the Cretaceous bedrock area nevertheless is indicated by (1) the suggested correlation of the highest pediment level containing well-developed pisolitic limestone on its surface into the narrowed Pecos Valley south of McCamey, by (2) the requirement of a southeasterly drainage outlet as control for the extensively developed pediments as well as an outlet for the late Tertiary alluviating streams across Crane, Ward, and Winkler counties, and by (3) scattered remnants of alluvial deposits on relatively high bedrock at a few places in Val Verde County. The position of the late Tertiary Pecos River southeastward from eastern Pecos County may have departed markedly from that of the present stream and it seems probable that much of the entrenchment of the drainage of northeastern Terrell, southwestern Crockett, and western Val Verde counties took place during the Pleistocene.

The Pleistocene history of the northern half of the Pecos Valley in Texas, although obscure in detail, seems evident in its major aspects. It is probable that in general this segment of the channel has been lowered no more than 300 feet below its late Tertiary level. It is evident that the extensive region including much of Pecos and Reeves counties has existed as a complex of pediment surfaces at least since mid-Tertiary time and that the control of these pediments has been by through-flowing drainage in a position relatively near the present position of Pecos River. Pediment veneers have consisted of coarse colluvium interspersed with strips of alluvium along streams flowing generally toward the northeast and serving as local control for their own systems of flanking pediments. Significant areas of unconsumed upland exist as mesas, or inselbergs, in the eastern part of this region of pediment complex, and some small areas of Ogallala formation are thought to be present in northwestern Pecos County and adjacent Reeves County.

The sequence of pediment surfaces is difficult to determine because of the many local control levels. A suggested sequence has been arrived at for the area southwest from the city of Pecos, and these surfaces tentatively have been correlated throughout the region (fig. 2). For ease of discussion the recognized surfaces have been numbered by Roman numerals from highest to lowest.

Surface I was observed only in relatively small areas and generally adjacent to pediment heads. It is our judgment that Surface I is the late Tertiary surface, contemporaneous in its climax development with the High Plains to the northeast and the remnants of Ogallala, in which a few fragmentary *Biorbia* seeds have been observed, in northwestern Pecos County. If our correlation of this surface into eastern Pecos County is correct (fig. 2, F), it indicates that the narrow late Tertiary pediment along the eastern part of the Pecos Valley was significantly lower than the High Plains surface to the north of the Cretaceous divide. This suggests a steeper gradient on the late Tertiary streams along the Pecos Valley than obtained along the High Plains streams farther north in Texas.

Surface II constitutes the most extensive surface of Reeves and western Pecos counties. It is veneered by several generations of deposits that suggest several cycles of activity. The sediments range in composition from coarse-textured, cross-bedded stream gravels that are judged to be the result of streams that crossed the pediment surfaces, to unoriented, poorly sorted, and locally caliche-cemented colluvium. The position of this surface, distinctly below Surface I, the presence of sparse snail shells (*Succinea*) in the youngest of the multiple generations of pediment veneer, and its position above more richly fossiliferous deposits lead to the conclusion that it is pre-Wisconsinan Pleistocene in age. Its development may have taken place during the first half to two-thirds of Pleistocene time, and may have been controlled by a relatively stable stream position that was maintained by the resistant rocks downstream. One or more of the broad sags that cross Ward and Crane counties, entering the Pecos Valley from the north, may have been produced by southward to south-southwestward-flowing streams during the more humid early Pleistocene (Frye and Leonard, 1957a) and thus be contemporaneous with this extensive pedimented surface south of the Pecos River.

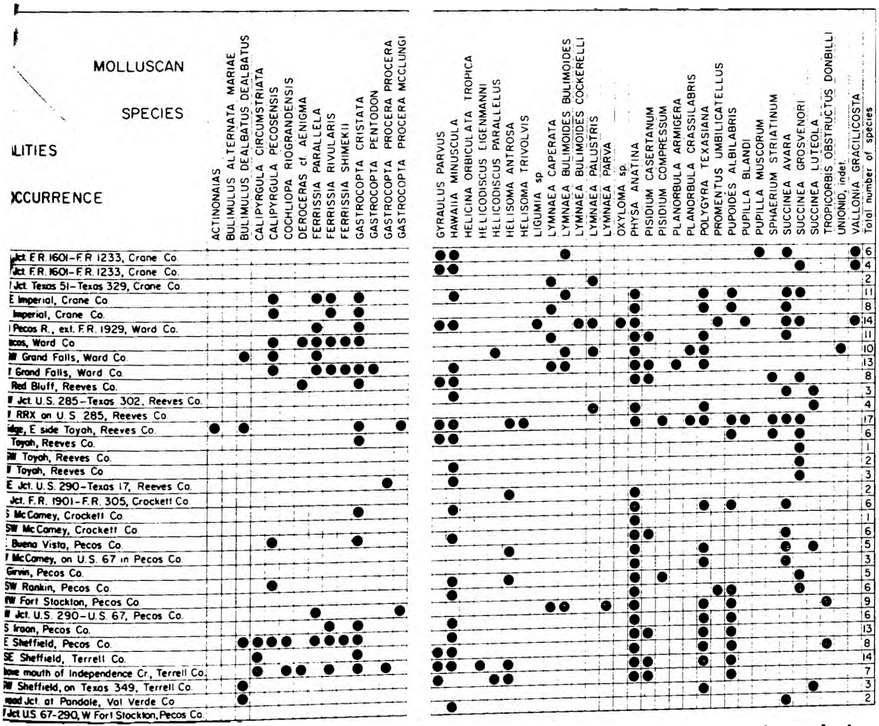
Surface III is generally distinguished from Surface II only by a change in the angle of slope, but locally a low pediment wall has been observed separating the two surfaces. In areal extent it is only a small fraction of the size of Surface II. At many places its pediment toe is accordant with the alluvial deposits of tributary streams and of the Pecos. Although a few fossil snail shells have been found in the pediment veneers of this surface, most of the faunas attributed to this level were collected from the associated alluvial deposits (Pl. I, C) that were formed by streams flowing down the pediment slope. These streams controlled the development of their local flanking pediments, and they in turn were controlled by the position of Pecos River. It is possible that one or more of the sags entering Pecos Valley from the north across Ward and Crane counties were contemporaneous with Surface III rather than with a late phase of the development of Surface II. The age of Surface III is not firmly established. Mos[illegible] is early Wisconsinan, although i[illegible] sible that it may be older w[illegible] Pleistocene.

Surface IV is of relatively m[illegible] tent and consists mostly of the fl[illegible] of Pecos River and its major tr[illegible] (Pl. I, A). In some places Su[illegible] includes narrow flanking pedim[illegible] are continuous with the flood-plai[illegible] and are distinguished from Surfa[illegible] a change in the angle of slope. T[illegible] molluscan faunas reported from t[illegible] were collected from channel-ba[illegible] sures of the alluvial deposits. The[illegible] deposits, particularly downstrea[illegible] central Ward County, constitute tw[illegible] of fill separated by a distinct but r[illegible] immature soil. The uppermost cy[illegible] have been periodically receiving a[illegible] from overbank flooding during [illegible] times. An age of late Wisconsinan [illegible] cent is indicated for the deposits bel[illegible] face IV because of (1) their activ[illegible] plain situation, (2) their confor[illegible] existing stream gradients, and (3) t[illegible] molluscan faunas they have yielded.

In general the Pleistocene his[illegible] Pecos Valley from Loving to C[illegible] counties has been characterized by [illegible] sive pedimentation, whereas from C[illegible] County to the mouth of the river [illegible] Verde County it has been character[illegible] sharp valley incision.

ssil molluscan faunas discussed in ly were collected by Frye and in the summer of 1958 and in the ; summer by Leonard and Tong-who concentrated their attention liferous deposits exposed in the banks of Pecos River. The 33 lo-rom which fossils were collected ributed from Val Verde County y 32) to northern Reeves County y 10) near the Texas–New border. As indicated earlier, fossil g localities are indeed rare in the leistocene sediments that consist of alluvial deposits now beveled by, ied beneath, an almost unbroken of pediment slope colluvium. More rous exposures and more abundant in faunas were found in deposits to be Wisconsinan in age; in fact, t abundant and populous exposures post-Twocreekan terrace deposits, h Pecos River is presently incised, from the northwestern corner of Val Verde County to near the southern border of New Mexico.

In local exposures where fossil mollusks were sparse, collections were made by hand-picking, but Leonard and Ho employed the wet-screening method extensively in making their collections from the channel bank exposures in Pecos River. All fossil mollusks discussed in this report are housed in the collections of late Cenozoic and Recent Mollusca at The University of Kansas (all catalogue numbers refer to these collections), except representatives deposited with The University of Texas Bureau of Economic Geology, Austin, Texas. A grant from the National Science Foundation (NSF-G3481) to the senior author also assisted in the support of the study. The writers take this opportunity to acknowledge the able assistance of Mr. Tong-yun Ho, graduate student at The University of Kansas.



4. Chart showing fossil molluscan faunas collected from Pecos Valley region of Texas during d 1959.

Physiographic History of Pecos Valley in Relation to Fossil Molluscan Faunas

Several features of the physiographic development of Pecos River valley deserve further comment here, inasmuch as they have profoundly affected in the past both the nature and numbers of molluscan populations as well as the preservation of molluscan shells as fossils. Alluvial deposits and the pediment slope veneers that cover them, underlying Surface I and Surface II (Pl. I, F; fig. 2), are not generally exposed, but at a few places pits and roadside excavations are sufficient to develop a generalized picture of the nature of the sediments beneath these surfaces.

Surface I, judged to be late Tertiary in its primary development, flanks the Davis Mountains to the northeast; exposures relatively near the mountains, observed along U. S. Highway 67 northeast of Alpine, Texas, show the presently well-pedimented and essentially unbroken surface to be underlain by extremely coarse clastics, consisting of boulders up to several feet in diameter, cobbles, gravel and sand, with only minor increments of fine sediments. At other localities, however, the sediments underlying this surface exposed in a few gravel pits and roadside excavations consist of cobbles up to several inches in diameter, gravel and sand, with lentils and minor strata of sandy silt. Admitting the paucity of exposures of the alluvial and colluvial materials underlying Surface I, it is nevertheless possible to deduce that the ancestral Surface I presented a shallow-incised coarse-textured topography, graded to the southernmost through-flowing Ogallala drainageway, and contemporaneous in development with the locally well-preserved Ogallala formation (Pl. I, A, D) on the eastern flank of the valley of Pecos River. Episodes of pedimentation during the latest Tertiary and again during the latter half of the Pleistocene have beveled and veneered Surface I so perfectly that exposures of the underlying sediments are almost completely limited to those produced by the activities of man. These have been made (unfortunately, from the view of the stratigraphic paleontologist) in search of gravels for construction and road materials, thus failing to expose the finer alluvial sediments that must have been deposited by streams flowing out of the Davis Mountains. On the northeastern flank of Pecos Valley, sediments approximately equivalent in age to the stream deposits under Surface I consist of graveliferous Ogallala formation, from which a few fragmentary seeds, but no fossil mollusks, have been recovered. Under these circumstances, it is not now possible to develop any knowledge of molluscan faunas related to the pre-pedimented phase of development of Surface I, since the depositional environment of channel gravels is generally inimical to the preservation of fossil mollusks.

Only meager exposures of the alluvial sediments underlying Surface II were observed, but these were sufficient to indicate the presence of a former shallowly stream-dissected topography that was graded to an early Pleistocene ancestral Pecos River at a somewhat lower level than that existing in late Tertiary time. It is judged that Surface II was initiated by stream dissection of Surface I in response to a lowered local base level and increased precipitation, followed by smoothing by pedimentation in response to the same local base level but decreased precipitation. Although the average particle size of the clastics is noticeably reduced, consisting of cobbles of igneous rocks from the Davis Mountains, reworked caliche from Surface I materials, gravel, sand, and increased amounts of fine sand and silt, the depositional environment was not favorable to the preservation of fossil mollusks. At a few places, such as Locality 33, a few gastropods of a kind not known to occur in late Tertiary faunas (*Succinea*) were helpful in identifying this as the oldest of the Pleistocene surfaces. Again, lacking all but graveliferous exposures, no concept of the contemporary molluscan faunas associated with the integrated stream pattern across the pre-pedimented Surface II topography is yet possible, but deposits in Crane County (Localities 1, 2) are judged to be at least approximately equivalent in age to alluvial deposits underlying Surface II. There is no way at present of ascertaining, however whether or not the molluscan fossils reported from the Crane County localities give much insight into the nature of contemporary faunas associated with Surface II on the southwestern flank of the Pecos Valley, since local environmental conditions there may well have been significantly different.

As already noted, Surface I and Surface II are now well pedimented, a surficial veneer of colluvial materials having beveled across the ancient shallowly incised coarse-textured topography. The surficial aspect of Surface I and Surface II is now generally unbroken and unrelieved, although active transport of relatively fine sediments still continues in this almost desert climate under a scant cover of vegetation.

Although the time of the initiation of the colluvial blanket now veneering Surfaces I and II is difficult to determine with accuracy, it is judged that on Surface II it dates from the smoothing of the stream-textured topography caused by the trend toward greater aridity that characterizes the latter half of the Pleistocene. Unfortunately, there is no molluscan faunal control, since colluviated clastics, especially those containing the cobbles, gravels, and sands characterizing the deeper parts of these veneers, are scarcely conducive to the preservation of molluscan shells. Moreover, there is reason to judge on other grounds that climatic deterioration contemporary with the initiation of pedimentation may have seriously reduced molluscan populations. Frye and Leonard (1957, p. 28) showed that the broad expanses of "cover sand" on the High Plains of northwestern Texas are Illinoian in age and eolian in origin. They deduced, from the nature of the deposit and observations on eolian movement of sands in nearby areas, that the cover sands were spread as a generally uniform sheet by activity of the wind acting on a surface scantily provided with scattered clumps of vegetation. The important consideration here is the evidence of arid conditions in Illinoian time in this part of Texas. The writers propose that the initial shift from an integrated stream pattern on Surface II began with the trend toward arid climatic conditions in western Texas in Illinoian time; it is obvious, of course, that pedimentation has generally continued into Recent time, although there may well have been minor fluctuations toward an integrated stream pattern on these surfaces during pluvial intervals. The pediment veneers reflect a *trend* toward the present-day arid climate in the Trans-Pecos region, inasmuch as the deeper parts of the veneers contain, at least locally, extremely coarse clastics, while surficial materials under transit today scarcely ever exceed the size of medium to fine sand, and the predominant clastic is silt. The gradual and continuous reduction in particle size of the pediment veneers, from the deeper to surficial materials, reflects the general climatic deterioration in this region, with consequent reduction in competency of run-off waters to move sediments down slope, since changes in gradient seem not to be sufficiently significant to account for observed differences in grain size.

Best observed exposures of Surface III sediments, rather than being under the pediment surface itself, consisted of alluvial deposits equivalent to Surface III, represented by segments of stream deposits incised below the level of Surface II. Representative of these deposits are those shown on Plate I, C; nearby at Toyah, Reeves County, a rather abundant and varied fossil molluscan fauna (fig. 4, Locality 13), judged to be early Wisconsinan, was obtained. The sediments in question indicate that an environment conducive to molluscan life existed along the stream courses that crossed Surface III. In the deposits the preponderant clastic is grayish-tan to rustytan silt, containing some fine to medium sand and small increments of clay, and having in places thin lenticular beds of gravel. The presence in the contained faunas of unionid and sphaeriid pelecypods, as well as series of aquatic pulmonate gastropods, indicates that relatively permanent streams characterized the topography of Surface III, while abundant terrestrial gastropods attest an adjacent vegetative cover significantly better than that existing locally today.

If judgments that Pleistocene pedimentation of the southwestern slopes of the Pecos Valley began in Illinoian time are sound and if the writers' judgments that molluscan faunas recovered from deposits associated with Surface III are early Wisconsinan in age are reasonable, then the presence of stream deposits such as those discussed above, points to a revival of an integrated, though quite coarse-textured, stream pattern in the area during early Wisconsinan time. It is entirely possible, if not probable, that climatic deterioration and consequent trend toward pedimentation did not reach its peak until post-Twocreekan time, and that the unrelieved pediment surfaces forming the conspicuous topographic feature of the southwestern Pecos Valley did not reach their final form until very late Pleistocene time. As has been stated earlier, lacking faunal control, the segments of time represented in the pediment veneers remain unknown except in broad generalities.

The sediments containing a faunal locality in Ward County (Locality 6) represent, in the writers' judgment, the equivalent of Surface III on the northeastern flank of the Pecos Valley.

By far the most generally and abundantly fossiliferous of the sediments studied were those below Surface IV, which is developed as a late Pleistocene (post-Twocreekan) terrace, often a mile or more in width, and exposed in the channel banks of Pecos River. From near the northwest corner of Val Verde County to well above the city of Pecos, Reeves County, the channel banks of Pecos River expose above low-water stage 20 to 25 feet of the sediments of Surface IV, although locally (Pl. I, A) the channel is cut below these sediments into Triassic bedrock. Except for 2 to 4 feet of Recent overwash consisting of fine to medium sand and very little silt, the channel bank deposits are involved in a weakly developed but distinctly zonal soil. In such an exposure studied in detail in the right bank of the Pecos River above the mouth of Independence Creek on the Chandler ranch in northeastern Terrell County (Locality 30), in the left bank of Pecos River, 1 mile east of the city of Pecos in Ward County (Locality 7), and elsewhere, the A-horizon is a black, sandy, friable silt, 18 inches to 2 feet in thickness. It seems never to have been completely leached of carbonates as it contains mollusk shells, but it has in addition been enriched by carbonate from the overwash sediments above. The B-horizon, although displaying little textural contrast, ranges locally from 18 inches to 2½ feet in thickness; the sediments are red brown to reddish tan, have a typical prismatic structure (although clay enrichment is slight), and contain fossil shells. The zone of lime enrichment, varying from yellow tan to grayish tan, is abundantly fossiliferous, and is profusely infiltrated with diffused carbonate or with soft caliche nodules. The thickness exposed ranges up to 18 feet, but since it was observed that the zone of lime accumulation locally extended several feet below low-water level, the exact maximum thickness has not been determined.

The nature of the molluscan faunas and their large population numbers, together with the deeply humic-stained sediments immediately underlying Surface IV, indicate that during the deposition of this late Pleistocene alluvium the Pecos River was essentially a slack-water stream flanked by back swamp marshes from central Reeves County to northeastern Terrell County. Elsewhere in western Texas and across the High Plains in general, all available evidence points to a trend toward aridity following Twocreekan time. One of the factors that contributed to the choking of the Pecos River, and the production of a local environment highly favorable to mollusks in the near vicinity of the channel, was the decline in competency of the stream with the well-documented increasing aridity. However, at least as important as regional climatic control would seem to be that imposed by variations in resistance to erosion of individual Cretaceous bedrock strata at or near the nickpoint in the deep entrenchment of Pecos River in central Val Verde County. This sensitivity of Pecos River to control by the regimen of the lower reaches of the river is indicated by the fact that the lime-accumulation zone of Surface IV sediments has in the recent past been more deeply incised than at present. Further evidence of this control is seen in the fact that Surface II represents a complex of pediment surfaces that cannot be correlated with individual glacial stages. although there is good reason to judge that physical phenomena associated with both the Nebraskan and the Kansan stage, and possibly part of the Illinoian stage of the Pleistocene, are represented in the development of this surface.

In summary, pediment veneers have destroyed or buried all but extremely scant evidence of pre-Wisconsinan molluscan faunas in the Pecos Valley region. Since Surface I has evidently been subjected to at least two cycles of pedimentation, little hope remains of recovering significant fossil molluscan faunas from beneath this surface. The sediments under Surface II, also almost completely obscured by a pediment veneer, offer almost no exposures except those produced by the work of man, and these, for reasons previously elucidated, are not likely sites in which to find fossil mollusks, and in fact only extremely rare examples have been found. Fairly adequate faunal collections have been made from deposits correlatable with Surface III, and, as noted, sediments beneath Surface IV are richly fossiliferous.

Still another aspect of the physiographic development of Pecos River valley that has significantly affected at least the preservation of formerly existing fossil molluscan faunas is the apparent shift of the channel of the ancestral Pecos River toward the northeast. Almost nothing remains of any but late Pleistocene terrace materials on the northeastern flank of the valley.

Finally, the unusual ecological and paleontological features of the post-Twocreekan Pecos River deserve comment, Whatever the complex of factors that reduced the competency of Pecos River during this segment of time, the result was the production of a narrow band of extremely favorable habitat for mollusks at a time when regional ecological conditions were badly deteriorated. Surface IV sediments along the Pecos River are unique in the Great Plains for their rich and varied molluscan faunas. There is evidence, based, however, on a single fossiliferous outcrop (Locality 6). that ecological conditions in the near vicinity of the Pecos were favorable to mollusks in early Wisconsinan time, but this is not at all unusual, since rich early Wisconsinan faunas are the rule rather than the exception. not only in Texas, but elsewhere.

Annotated Check List of Fossil Molluscan Species

Class LAMELLIBRANCHIATA

Order PRIONODESMACEA

Family UNIONIDAE (d'Orbigny)

Subfamily LAMPSILINAE

Genus ACTIONONAIS Fisher and Crosse

ACTIONONAIS sp.

Pl. IV, fig. 14

At Locality 13, at the east edge of the village of Toyah, Reeves County, in sediments exposed in the banks of a generally dry gully, numerous but poorly preserved shells of an unidentified species of *Actiononais* were found associated with *Pisidium compressum*, *Sphaerium striatinum*, several species of aquatic pulmonate gastropods, and an assemblage of terrestrial gastropods. The assemblage is characteristic of a stream, although the fine texture of the sediments suggests one without strong currents. The deposit is judged to be early Wisconsinan.

Genus LIGUMIA Swainson
LIGUMIA sp.
Pl. IV, fig. 12

A rich population of a species of *Ligumia* was found in creek bank exposures at Locality 6, Ward County. The shells are poorly preserved, but it is likely that they represent some form of *L. recta*. Associated with them was another, unidentified unionid mussel (Pl. IV, fig. 13) and several species of aquatic gastropods as well as an assemblage of terrestrial snails. No unionid mussels were found in deposits judged to be older than early Wisconsinan. The Toyah locality (no. 13) is almost certainly early Wisconsinan; Locality 6 may possibly be somewhat younger but probably not significantly so.

Order TELEODESMACEA
Family SPHAERIDAE
Genus SPHAERIUM Scopoli
SPHAERIUM STRIATINUM (Lamarck)
Pl. IV, figs. 15, 16

This small sphaeriid clam was found at Localities 10, 12, and 13. It was nowhere abundant, but most numerous specimens were found at Locality 10. The living species is widely distributed in North America, from northern Canada to Central America. Living populations are found in a variety of habitats, including large and small streams, as well as lakes and ponds. The two localities near Toyah, Reeves County, indicate a sluggish stream, while the sediments at Locality 10 near Red Bluff, northern Reeves County, are relatively coarse and strongly cross-bedded, indicating vigorous stream action. Some of the specimens listed by Frye and Leonard (1957, fig. 9) as *Sphaerium* sp. from localities in northwestern Texas may be referred to *striatinum*.

Genus PISIDIUM Pfeiffer
PISIDIUM CASERTANUM (Poli)
Pl. IV, figs. 19, 20

This small clam was found at Localities 7, 9, 10, 21, 28, 30, and 31, that is to say, over much of the area under consideration. So far as known, these are all stations in Wisconsinan deposits; elsewhere (Taylor, 1960) *P. casertanum* has been reported from deposits ranging in age from early Pliocene to Recent. The species is tolerant of many habitats, including most aquatic situations except deep water. It is widely distributed over the world, and in the Western Hemisphere from Alaska to southern South America. The shells respond to local conditions, tending to become heavier in stream habitats and more delicate in pond situations. A majority of the shells obtained from Surface IV deposits are notably thin-shelled, especially those near the top of the terrace, supporting the judgment that Pecos River was a sluggish stream at the conclusion of the building of Surface IV.

PISIDIUM COMPRESSUM PRIME
Pl. IV, figs. 17, 18

Pisidium compressum is a small clam, with a characteristic trigonal shell. It is distributed in deposits ranging in age from early Pleistocene to Recent and has been reported as a fossil by Leonard (1950, fig. 4) and by Taylor (1960, p. 48) from localities ranging from western Iowa to southern Kansas. Living populations prefer running water, but the species may be found in well-aerated ponds. In the two localities (nos. 13, 24) reported here, *P. compressum* was not abundant but was more numerous at Locality 13, at Toyah, Reeves County.

Class GASTROPODA
Subclass PROSOBRANCHIA
Order ARCHAEOGASTROPODA
Family HYDROBIIDAE
Genus CALIPYRGULA Pilsbry
CALIPYRGULA PECOSENSIS Leonard and Ho
Pl. II, fig. 6

Calipyrgula pecosensis Leonard and Ho, 1960, Nautilus, vol. 73, p. 125, pl. 12, figs. 1-3.

The type locality of this minute branchiate gastropod is in Surface IV sediments exposed in channel bank of Pecos River, 3.5 miles northeast of Imperial, in Crane County (Pl. I, A; fig. 4, Locality 4). This snail is known from many localities in Surface IV exposures in the channel banks of Pecos River from Sheffield, Terrell County, to central Reeves County. It is almost everywhere abundant in this stretch of Pecos River, in late Pleistocene deposits, but has not been found living. It seems to have had a habitat preference for slack-water streams, or ponds and oxbow lakes; below Sheffield it is abruptly replaced in Surface IV sediments by *Calipyrgula circumstriata* that probably had different habitat requirements.

CALIPYRGULA CIRCUMSTRIATA Leonard and Ho

Pl. II, fig. 5

Calipyrgula circumstriata Leonard and Ho, 1960, Nautilus, vol. 73, p. 125, pl. 12, figs. 1–3.

The type locality of this minute hydrobiid gastropod is in the Surface IV deposits situated a quarter of a mile above the mouth of Independence Creek on the Chandler ranch, Terrell County, Texas (Locality 30). Shells were also abundant in a similar exposure on the W. C. Dunlap ranch, 12 miles south-southeast of Sheffield, Terrell County, and a few shells were found in a Surface IV exposure about 3 miles east of Sheffield, Terrell County. The abrupt replacement of *Calipyrgula pecosensis* by *C. circumstriata* in this stretch of Pecos River suggests that the latter was an inhabitant of clear, fast water, especially since it is associated in the localities of occurrence with fossil *Cochliopa riograndensis* that also lives in good populations in Independence Creek. Careful search, however, failed to reveal living examples of *C. circumstriata* in Independence Creek or elsewhere.

Genus COCHLIOPA Stimson

COCHLIOPA RIOGRANDENSIS Pilsbry and Ferriss

Pl. II, figs. 7–9

Cochliopa riograndensis Pilsbry and Ferriss, Leonard and Ho, 1960, Nautilus, vol. 73, p. 127, pl. 12, figs. 4–7, text figs. 1–4.

This small branchiate gastropod was found at two localities (nos. 28 and 30) both below Surface IV sediments in the channel banks of Pecos River in Terrell County, where it was associated with *Calipyrgula circumstriata* and other species. However, at Locality 29, where *C. circumstriata* was abundant, no *Cochliopa riograndensis* occurred.

C. riograndensis was found living in Independence Creek, both on the Chandler ranch near the mouth of the stream and also farther upstream, where it was common under stones and pieces of driftwood in the quieter parts of this cool, fast-flowing creek. This constitutes a northern extension of the range of this species, it having been previously reported from southern Val Verde County near the Rio Grande.

Family HELICINIDAE

Genus HELICINA Lamarck

HELICINA ORBICULATA TROPICA Pfeiffer

Pl. III, figs. 13–15

The figured specimen of this species was not collected in the Pecos River valley but in late Pleistocene deposits in Kinney County, west of Brackettville. It may well occur either living or as a fossil in the Pecos Valley region, but the writers did not find it there.

Subclass PULMONATA

Order BASOMMATOPHORA

Family LYMNAEIDAE

The family Lymnaeidae comprises a large group of aquatic pulmonate gastropods of such variable nature that attempts at a systematic arrangement of the several kinds has given rise to much confusion and controversy. Extremes of treatment range from recognition of nearly a dozen genera and well over 100 species in North America to the recognition of a single genus and no more than seven species. The biological verity probably lies somewhere between these extremes. However, inasmuch as many of the apparently important taxonomic features, especially those separating the many named genera, are to be found in the soft anatomy, it is deemed advisable to take a conservative attitude toward fossil shells. Therefore, all kinds reported here are assigned to the genus *Lymnaea*; the shells are so variable that there is sufficient hazard in assigning fossil shells to named species.

LYMNAEA BULIMOIDES BULIMOIDES (Lea)

Pl. IV, fig. 4

Lymnaea bulimoides as one form or another ranges from middle Pleistocene to Recent. Baker (1911, p. 211) indicates that *bulimoides* east of the Rocky Mountains are referable either to *L. b. cockerelli* or *L. b. techella*; the Pecos River valley specimens, except those at Locality 6, seem best to conform to the typical species. The characters of the inner lip, the more slender last whorl, and longer spire seem to exclude these shells from *L. b. cockerelli.*

Pilsbry (1896, p. 96) has noted that *L. bulimoides* is capable of considerable resistance to dessication and cites an example in which many individuals survived after being packed in dry cotton for 45 days.

LYMNAEA BULIMOIDES COCKERELLI Pilsbry

Pl. IV, fig. 5

At Locality 6, south of Pyote in Ward County, more than 60 specimens assignable to this subspecies were collected. The temporal distribution extends only from late Pleistocene to Recent. It is a common living gastropod in several Great Plains states, where it thrives in more or less ephemeral pools. It has not been found living in the Pecos River valley. *L. b. cockerelli* is obviously adapted to withstand long periods without open water, although it occasionally occurs in perennial ponds. It seems never to occur in streams.

LYMNAEA CAPERATA Say

Pl. IV, fig. 1

Lymnaea caperata occurs at Localities 3, 5, 9, and 26; the species was especially abundant at Locality 26 near Fort Stockton, Pecos County, where it occurred with less abundant *L. parva.* Like other species of *Lymnaea* found as fossils in Pecos Valley deposits, *L. caperata* is tolerant of a variety of habitat conditions. Distributed in a broad belt across North America, it thrives in small, often ephemeral pools, and is capable of withstanding the lack of open water for months.

LYMNAEA PARVA Lea

Pl. IV, fig. 3

A few snails of this species were found in the deposits at Locality 26, west of Fort Stockton, Pecos County. This small gastropod lives in damp situations near open water, rather than in it as do most species of *Lymnaea. L. parva* lives today in populations distributed from James Bay to southwestern United States. As a fossil it exists from lower Pleistocene to Recent. The Pecos Valley deposits are notably lacking in small species of *Lymnaea*; neither *Lymnaea parva* nor *L. dalli* seems to be living in Pecos Valley region today, although adequate studies of the living molluscan fauna are lacking.

LYMNAEA PALUSTRIS (Muller)

Pl. IV, fig. 2

Lymnaea palustris was found at Localities 3, 6, 8, 12, and 26 (fig. 4). The species was nowhere numerous, but the wide distribution of localities of occurrence indicates that it was once a common inhabitant of the Pecos Valley. It does not, of course, occur in the living fauna of the region but is widely distributed in North America from Canada to New Mexico and in the Northern Hemisphere generally. It is a highly variable animal and most of the subspecies names applied to it seem to reflect little more than local variation.

As a fossil, *Lymnaea palustris* occurs from the Kansan to Recent; Frye and Leonard (1957, fig. 7) reported it from Kansan localities in Garza and Lubbock counties, Texas.

Family PLANORBIDAE

Genus HELISOMA Swainson

HELISOMA ANTROSA (Conrad)

Pl. II, fig. 3, 4

Helisoma antrosa was found at six localities (nos. 13, 18, 22, 25, 30, 31) but was nowhere numerous, no more than six examples having been recovered at any single locality. For this reason, no attempt is made to assign these specimens to a named variety, as limits of variation cannot be determined. Living *H. antrosa* is widely distributed in the northern part of the United States and Canada and occurs with less frequency in middle and southern parts of the United States. Fossils of *H. antrosa* occur from early Pleistocene to Recent and are common in lower Pleistocene deposits on the Great Plains (Leonard, 1950; Frye and Leonard, 1957; Taylor, 1960).

H. antrosa occurs in large and small streams and seems to be especially adapted to creeks, but in northern United States it occurs in deep lakes.

HELISOMA TRIVOLVIS (Say)

Pl. II, figs. 1, 2

Helisoma trivolvis is the largest planorbid snail occurring in Texas, either living or fossil. In the present study it was found only at Locality 13, at Toyah in Reeves County, but it has been reported in the High Plains region of Texas and elsewhere on the High Plains (Leonard, 1950; Frye and Leonard, 1957; Taylor, 1960) as a common Pleistocene fossil. The living species is widely distributed in North America, especially in the northern half, although either this or some closely related species is common in the southern states.

Helisoma trivolvis prefers quiet, even stagnant water but is found in the quieter parts of swift streams. It seems to have great ability to resist periods of dessication, and large populations may appear in roadside pools and other small and ephemeral bodies of water.

Genus PLANORBULA Haldeman

PLANORBULA ARMIGERA (Say)

Pl. II, figs. 10–12

A single specimen of *Planorbula armigera* was found at Locality 9, 3 miles southwest of Grandfalls, Ward County, where it occurred with other aquatic pulmonate gastropods as well as *Calipyrgula pecosensis* and an assemblage of terrestrial snails.

Planorbula armigera has a wide distribution in North America, from northern Canada to Louisiana and Georgia, but is not known west of the Rocky Mountains. It is a typical inhabitant of small pools and marshes. If our analysis of the ecology of deposition of Surface IV sediments is reasonable, *P. armigera* should have thrived in these back swamp situations, and it is not known why no more shells were found.

PLANORBULA CRASSILABRIS (Walker)

Pl. II, figs. 13–15

At Locality 8 southwest of Grandfalls, Ward County, was found a single example of *Planorbula crassilabris*; two examples were recovered from the deposits at Locality 13, at Toyah, Reeves County. At each of these localities *P. crassilabris* was associated with unionid mussels, numerous sphaeriids, and several species of aquatic pulmonate gastropods.

Within the aperture (in old individuals, sometime deeply within) of both *P. armigera* and *P. crassilabris* is to be found a series of excrescences or lamellar denticles. The two species differ in the characters of these lamellae; *crassilabris* is a smaller snail than *armigera* but the reproductions on Plate II, not being to the same scale, give the illusion that this is not the case. The living species is known from Michigan, Iowa, and neighboring states where it occurs in ponds and small pools.

Genus PROMENETUS Baker

PROMENETUS UMBILICATELLUS (Cockrell)

Pl. II, figs. 19–21

A few shells assigned to this species were collected at each of the two localities (nos.

6 and 24), the first in Ward County, the other in Pecos County. *P. umbilicatellus* is known from late Pliocene to Recent deposits in the High Plains; the living form is primarily distributed in the northern part of central United States and in Canada. It lives in quiet waters, especially those in which there is a good growth of aquatic vegetation. It has been reported from the southern High Plains by Leonard (1950, p. 18) and by Taylor (1960, p. 60), and an unassigned species of *Promenetus* was reported by Frye and Leonard (1957) from the High Plains region of western Texas.

Genus GYRAULUS Charpentier

GYRAULUS PARVUS (Say)

Pl. II, figs. 22–24

This tiny planorbid snail occurred in nine widely distributed localities (nos. 1, 2, 6, 10, 13, 14, 29, 30, 31) but was not abundantly represented at any individual outcrop. *Gyraulus parvus* has been reported as a fossil from late Pliocene to Recent in the southern Great Plains (Taylor 1960, p. 58).

The living species is an inhabitant of quiet waters, such as small ponds or the quieter edge situations in streams. It is most often associated with heavy growth of aquatic plants. It is not now living in Texas, but occurs widely east of the Rocky Mountains from Alaska and northern Canada to Florida.

Genus TROPICORBIS Pilsbry and Brown

TROPICORBIS OBSTRUCTUS (Morelet)

Pl. II, figs. 16–18

Two specimens of *Tropicorbis obstructus* were found in Surface IV sediments at Locality 29 on the Dunlap ranch about 12 miles south-southeast of Sheffield, Terrell County, and a single individual was recovered from the deposits at Locality 26, west of Fort Stockton, Pecos County.

The genus *Tropicorbis* is widely distributed from southern United States through Central America and South America as far south as Argentina. It is a conspicuous element of the aquatic pulmonate fauna of the West Indies. *T. obstructus* lives in southern Texas and Louisiana along the humid coastal areas but is not now known to be living in the Pecos Valley region.

The three specimens collected resemble closely the subspecies *T. o. donbilli* of Tristam, but the lack of good series of shells is basis for not assigning these individuals to a subspecies.

Family ANCYLIDAE Menke

Genus FERRISSIA Walker

FERRISSIA PARALLELA (Haldeman)

Pl. III, figs. 16, 17

Shells of this ancylid gastropod were collected at Localities 4, 6, 7, 8, 9, 26, and 28, the number of individuals varying from one to ten at different collecting stations. The species has been reported as a fossil from many localities on the Great Plains (Leonard, 1950; Taylor, 1960) from early Pleistocene to Recent deposits.

The living form of the species is distributed from southeastern Canada to the central part of the United States but is not known to be living in Texas. It is adapted to living in quiet waters, where it lives on the smooth stems of plants or upon old bottles and metal cans.

FERRISSIA RIVULARIS (Say)

Pl. III, figs. 20, 21

Ferrissia rivularis was found at seven localities (nos. 4, 5, 7, 9, 27, 28, and 30); it was most abundant at Locality 9, southwest of Grandfalls, Ward County where a large series of individuals was collected. Fossil shells have been reported from late Pliocene (Taylor, 1960, p. 61) to Recent deposits, but shells are not common in the Great Plains region in deposits younger than early Pleistocene, except for those reported here.

Ferrissia rivularis lives in streams on stones and other smooth hard objects, such as the shells of unionid mussels.

FERRISSIA SHIMEKI Pilsbry

Pl. III, figs. 18, 19

This tiny ancylid occurred at Localities 7, 9, and 28 and was notably abundant at Locality 9, 3 miles southwest of Grandfalls, Ward County. The large series of specimens available and the unique characters of this minute ancylid shell leave no doubt of its identity, although it was a surprise to find it in the Pecos River valley. To the writers' knowledge *F. shimeki* has not been previously reported as a fossil, the nearest locality of living colonies being in central Kansas.

Ferrissia shimeki is an inhabitant of quiet waters, such as the edges of small ponds where it may be found on stones, old bottles, and other smooth, hard objects, occasionally on cattails, and often on smooth leaves, such as those of the cottonwood. Large populations may sometimes be found in lily ponds in gardens near homes or in public parks, although the means by which these colonies become established is not clear. It is likely that they are dispersed in commerce by the sale of water lilies and other aquatic ornamental plants.

Family PHYSIDAE Dall

PHYSA ANATINA Lea

Pl. III, fig. 22

Physa anatina occurs at a majority of the localities reported here (fig. 4), and at some of them in huge numbers. The species currently inhabits the southern High Plains and is common in and around stock tanks in the Pecos Valley region. It also occurs in the Pecos River, especially in quiet water near the border of the stream or where there are mats of vegetation. It is also fairly common in small tributary creeks, including those that are usually dry for several months each year.

As a fossil, *Physa anatina* occurs in the southern High Plains from late Pliocene to Recent deposits. Identification of fossil shells is often hazardous, inasmuch as it is known that the living forms respond readily to local environmental conditions, and a stock introduced into a new environment may change in a few generations so much as to be almost unrecognizable.

Order STYLOMMATOPHORA

Family POLYGYRIDAE

Genus POLYGYRA Say

POLYGYRA TEXASIANA (Moricand)

Pl. III, figs. 7–9

Polygyra texasiana occurs at about half the localities studied but was not abundant at any of them. Our specimens are closely similar to the subspecies *texasensis* of Pilsbry (Pilsbry, 1940, p. 619) but lack of long series did not permit us to assess individual variation as we should have desired. The subspecies *texasensis* occurs in Val Verde County in the lower reaches of Pecos River valley. According to Pilsbry (1940, p. 20), this snail lives under the fallen leaves of yucca or beneath prostrate yucca plants. Although not numerous, because of its relatively large size, it forms a conspicuous element of the terrestrial aspect of Pecos Valley faunas.

Polygyra texasiana was reported from late Kansas deposits in Woodward County, Oklahoma, by Leonard (1950, p. 35) ; this may be the same species as those described by Taylor (1960, p. 82) from southwestern Kansas as *Polygyra rexroadensis*, but Taylor's specimens have not been seen by the writers.

Family BULIMULIDAE

Genus BULIMULUS Leach

BULIMULUS DEALBATUS DEALBATUS (Say)

Pl. IV, fig. 6

Bulimulus dealbatus dealbatus is essentially a southern snail, but it ranges as far north as north-central Kansas. To our knowledge, it is not known living in the Pecos Valley region but is common in central Texas. In our collections it occurs, never in large numbers, at Localities 8, 13, 28, 31, and 32, which would indicate from its distribution that it was once common in Pecos Valley.

Bulimulus d. dealbatus is well adapted to arid climates, although it is not confined to them. In times of drouth it seals the aperture of the shell with mucous to some object, such as the stem of a plant, and will survive many months in this position.

BULIMULUS ALTERNATUS MARIAE (Albers)
Pl. IV, fig. 7

The figured specimen is from Kinney County; no fossils of *Bulimulus alternatus mariae* were found in our collections in the Pecos River valley region, but inasmuch as living colonies occur in central Val Verde County, it is likely that the species will be found as a late Pleistocene fossil in the region. It is a conspicuous snail, often more than an inch in length. The living individuals observed in Val Verde County were an almost immaculate white.

Family ZONITIDAE
Genus HAWAIIA Gude
HAWAIIA MINUSCULA (Binney)
Pl. III, figs. 10–12

Hawaiia minuscula is one of the most ubiquitous gastropods of fossil and living molluscan faunas on the Great Plains, and the same is true in the Pecos Valley. The species occurs at more than half of the localities studied, at some of them in large numbers. *H. minuscula* is distributed over much of North America and is found in the West Indies. It is adaptable to a wide range of habitat situations and is one of the rather limited number of terrestrial gastropods that survived the period of extermination of many gastropods on the Great Plains toward the end of the Pleistocene. Living specimens were not found in Pecos River valley, but fresh shells were seen in drift in Pecos River.

Hawaiia minuscula is known in the Great Plains region as a fossil in early Pliocene to late Pleistocene deposits.

Family LIMACIDAE
Genus DEROCERAS
DEROCERAS AENIGMA Leonard
Pl. II, fig. 27

The object figured is the internal shell of a slug. Similar shells have been found in deposits in the Great Plains region, ranging from early to late Pleistocene in age, but since these internal shells bear few characters, it is not possible to say whether all are actually those of the same species, as no living slug is known to which the shells may be referred.

Shells assigned to *Deroceras aenigma* occur at Localities 7, 10, and 30. Although nothing is known of the animal, it may be presumed that it lived in moist situations of the kind to which the naked and unprotected slugs are adapted.

Family ENDODONTIDAE
Genus HELICODISCUS Morse
HELICODISCUS PARALLELUS (Say)
Pl. III, figs. 1–3

Helicodiscus parallelus is another of the minute terrestrial gastropods widely distributed over North America and capable of surviving ecological situations too rigorous for most snails. It is one of the few snails that can live in the high, dry grasslands in the more arid parts of the Great Plains, but it occurs more abundantly beneath decaying logs and in leaf mold beneath patches of trees or shrubs.

Although *Helicodiscus parallelus* is usually a common fossil in deposits ranging in age from middle to late Pleistocene, it was found only at Localities 8 and 31, at each of which it was represented by a few individuals.

The shell is easily recognized in spite of its small size by its coin shape and conspicuous parallel raised striations.

HELICODISCUS EIGENMANNI Pilsbry
Pl. III, figs. 4–6

Helicodiscus eigenmanni is represented in our collections only by two shells collected at Locality 30, where it occurs in Surface IV sediments in the channel banks of Pecos River on the Chandler ranch in Terrell County. It is a common element of the living gastropod fauna of Texas and Mexico, although it ranges as far north as Colorado. The shells of *H. eigenmanni* resemble those of *H. parallelus* but are usually more robust, and the internal denticles, which are usually too deeply placed to be observed in the shells of *parallelus*, are situated (when present) near the aperture.

Living colonies of *H. eigenmanni* are known from the vicinity of Devils River in Val Verde County, but no living individuals were observed in the middle reaches of Pecos River valley.

Family SUCCINEIDAE

Genus OXYLOMA

OXYLOMA sp.

Pl. IV, fig. 11

A single, badly damaged shell that is judged to belong to some species of *Oxyloma* was found at Locality 6, in western Ward County near the Pecos River. Even the generic assignment is purely tentative.

Genus SUCCINEA Draparnaud

The species in the genus *Succinea* and related genera in the family Succineidae can be diagnosed only with accuracy by means of characters associated with the soft anatomy. It is well known that the shells are notoriously unreliable as clues to species. Therefore, in the following three accounts, the use of specific names is designed only to give some concept of the size and form of the shell; it is entirely probable that none of these actually belong to the species whose names are used with them.

SUCCINEA GROSVENORI Lea

Pl. IV, fig. 8

Shells resembling in size and general form those of recognized *Succinea grosvenori* were found at eleven localities (fig. 4). Similar shells occur on the Great Plains as fossils in deposits ranging in age from Nebraskan to late Pleistocene and geographically from western Iowa to Texas (Leonard, 1950, p. 24). According to Pilsbry (1940, p. 819), the species ranges widely over North America, but since few anatomical studies have been made, there is room for considerable doubt that many of the shells reported to be *grosvenori* actually belong to that species.

Members of the genus *Succinea* are often found in moist situations, but they are by no means restricted to such habitats. We have found them in Texas, aestivating on rocky cliffs, far from water and in open sunlight where the local temperature was extremely high. Such aestivating individuals can be activated months later by placing them in a moist chamber.

SUCCINEA LUTEOLA Gould

Pl. IV, fig. 9

At four localities (nos. 11, 12, 22, 32) shells closely resembling those of *Succinea lutelola* occurred in our collections. As noted above, there is little assurance that these shells belong to the species of which the name is here used. *S. luteola* is known, however, in colonies on the high land west of Devils River, Val Verde County, and in arid places in Arizona and New Mexico (Pilsbry, 1940, p. 828), and it may be that the shells reported here are actually *S. luteola.*

SUCCINEA AVARA Say

Pl. IV, fig. 10

At eleven localities (fig. 4) shells of small *Succinea* resembling those of *Succinea avara* were collected; it is almost a certainty that these shells constitute a complex of species, because it is well known that several of the smaller kinds that resemble *avara* as far as the shell is concerned, are anatomically different enough to constitute not only different species but different genera of Succineidae (Miles, 1958). However, small shells of this sort are numerous in many early to late Pleistocene deposits in the Great Plains region of western Texas and elsewhere on the Great Plains farther north.

Family PUPILLIDAE

Genus GASTROCOPTA Wollaston

GASTROCOPTA PENTODON (Say)

Pl. III, fig. 29

A single specimen of *Gastrocopta pentodon* was found at Locality 9, in sediments beneath Surface IV, 3 miles southwest of Grandfalls, Ward County. Although *G. pentodon* ranges from eastern United States and Canada to Mexico through a wide variety of habitat situations, the narrow band of humid ecological conditions near the Pecos River in post-Twocreekan time seems to have been unsuitable for it. *G. pentodon* generally inhabits uplands, and most often timbered areas.

It is not well known as a fossil, but Frye and Leonard (1957, fig. 9) reported it from several High Plains localities of early Wisconsinan deposits in western Texas.

GASTROCOPTA PROCERA PROCERA (Gould)

Pl. III, fig. 27

A few specimens of *Gastrocopta procera* having the characters of the typical species were collected at Localities 17 and 30; it occurred at both stations with *Gastrocopta cristata*, which was much more abundant. *G. procera* is not a common Pleistocene fossil. Frye and Leonard (1957) did not report it from their studies along the High Plains escarpment; however, Leonard (1950, p. 32) reported the species from late Kansan localities in central Kansas and in northwestern Oklahoma, and Taylor (1960, p. 67) listed *G. procera* from early Pleistocene localities in southwestern Kansas.

The living form of the species is distributed widely in the southern part of the United States, a little farther north than the general latitude of the Ohio River. Its habitat is usually situated in woodlands, but a small clump of trees is sufficient to harbor a colony.

GASTROCOPTA PROCERA MCCLUNGI(?) (Hanna and Johnston)

Pl. III, fig. 28

Only two individuals assignable to this subspecies were found, one each at Localities 13 and 26. Inasmuch as the shells were not well preserved, the identity of these shells is doubtful.

GASTROCOPTA CRISTATA (Pilsbry and Vanatta)

Pl. III, fig. 26

Gastrocopta cristata occurred at nearly half of the localities studied (fig. 4) and at many of them was found in abundance. *G. cristata* is a common Pleistocene fossil in the Great Plains region. It occurs in late Kansan deposits distributed from western Iowa to southwestern Kansas (Leonard, 1950, p. 32) and was reported from many localities along the escarpment of the High Plains region of Texas by Frye and Leonard (1957); stratigraphically, it ranges there from Kansan to late Pleistocene. *G. cristata* is a part of the gastropod fauna of southwestern United States; it is highly adapted to arid conditions.

Genus PUPOIDES Pfeiffer

PUPOIDES ALBILABRIS (Adams)

Pl. III, fig. 25

Pupoides albilabris, one of the largest pupillid snails of the region, was found at 12 localities among the 33 studied (fig. 4). The species is widely distributed east of the Rocky Mountains and in the West Indies. Although elsewhere it occupies various habitat situations, including some very humid ones, *P. albilabris* is one of the few common snails in the short-grass environment on the Great Plains, where it endures long periods of severe dessication and extremely high temperatures.

P. albilabris is a common fossil in the Great Plains region, where it occurs in deposits ranging in age from lower Pliocene to late Pleistocene (Leonard, 1950, p. 29; Taylor, 1960, p. 74). The shell of this species, especially in western populations, is heavy and ruggedly constructed, which probably improves its chances of being preserved as a fossil.

Genus PUPILLA Leach

PUPILLA BLANDI Morse

Pl. III, fig. 23

Pupilla blandi occurs in our collections at Locality 6 and Locality 13; it was especially numerous at Locality 6 in early Wisconsinan sediments near the Pecos River in western Ward County. Along with *Pupilla muscorum*, it is a common loess fossil in the more northern Great Plains and in the Mississippi Valley. Also, like *Pupilla muscorum*, *P. blandi* was eliminated from Great Plains molluscan faunas just before or during the Bradyan interval. It ranges from Kansan deposits to early Wisconsinan deposits generally over the Great Plains region, from western Iowa to Texas.

PUPILLA MUSCORUM (Linne)

Pl. III, fig. 24

A moderately good series of shells of *Pupilla muscorum* was recovered from deposits in northern Crane County (Locality 1). *P. muscorum*, an old-world species that first appears in the Great Plains region in Kansan deposits, is widely distributed as a fossil from western Iowa to southwestern Texas. As noted above, it does not occur in late Pleistocene deposits in this geographical region. The stratigraphic and geographic distribution of *P. muscorum* has been discussed by Leonard (1950, p. 28); Frye and Leonard (1957) reported this fossil from numerous localities in their studies of Pleistocene fossiliferous deposits of the High Plains region of western Texas.

Family VALLONIDAE

Genus VALLONIA Risso

VALLONIA GRACILICOSTA Reinhardt

Pl. II, figs. 25, 26

Vallonia gracilicosta was found at three localities in the Pecos Valley region (nos. 1, 2, and 6). This species in the midcontinent region is one of the most numerous and widespread of molluscan fossils, from Nebraskan to early Wisconsinan, but does not occur in post-Twocreekan sediments in the region. Its occurrence in the Pecos Valley region is, however, much less widespread and populations much less abundant than is true farther north on the High Plains. Leonard (1950) discussed the occurrence of *V. gracilicosta* in Kansan deposits, and Frye and Leonard (1957) reported its occurrence in numerous Pleistocene localities along the High Plains escarpment, where the deposits ranged from Kansan to early Wisconsinan. *V. gracilicosta* vanished from most of the Great Plains region after Twocreekan time, although it occurs in northern Nebraska (Taylor, 1960, p. 77) and elsewhere to the northwest. In the montane areas it ranges down to New Mexico, and to the northeast into Minnesota (Pilsbry, 1948, p. 1028).

Age and Correlation of Fossil Molluscan Faunas

No previous attempts have been made to study in an organized and systematic manner the stratigraphic paleontology of the late Cenozoic in the Pecos River valley region of Texas. This fact, the lack of detailed topographic maps for the region, and the relatively short time that was available for field study, make certain aspects of this report little more than a reconnaissance. Nevertheless, we judge that several conclusions are justified by the facts available.

Although no fossil mollusks were collected from beneath Surface I, we are convinced that it is late Tertiary in origin because (1) it is graded to the drainageway that deposited the graveliferous sediments of the Ogallala formation on the south flank of the High Plains, capping in many places the east bluff of Pecos River valley (Pl. I, A, D, F); (2) it forms the highest erosional surface below the Cretaceous uplands (Pl. I, E); and (3) the collection of fossil mollusks at Locality 33 shows definitely that the next lower surface (Surface II) is Pleistocene. Surface I developed as an extensive pediment during latest Tertiary, and although locally dissected and somewhat lowered during early Pleistocene time, it is now well graded and veneered with colluvium except for widely spaced intermittent drainageways. We judge Surface I, although somewhat lowered, to be a relatively intact late Tertiary surface.

Inasmuch as the shells at Locality 33 come from alluvial sediments underlying Surface II, it is demonstrated that it is Pleistocene in origin, and since the fossil molluscan faunas from the alluvial sediments underlying Surface III are characteristic early Wisconsinan assemblages, it follows that the cutting of Surface II represents a complex history that probably extended through all Pleistocene time to the end of the Kansan stage. Climatic deterioration in the region in Illinoian time is judged to have eliminated an integrated drainage pattern from this surface and developed the extensive coalescent pediments and their surficial veneers to essentially their present form. Surface II, although perhaps slightly lowered, has been essentially stabilized since its development during the Illinoian.

The sediments at Localities 1 and 2 in northern Crane County are here tentatively correlated with those underlying Surface II. The molluscan faunas do not offer conclusive evidence on this point. However, a synthesis of the available data places the weight of the evidence in favor of these sediments being Kansan in age. The elements of the argument are as follows: (1) although the fossil molluscan fauna is not conclusively characteristic of Kansan assemblages, there are no faunal elements that exclude it from such an assemblage; (2) the sediments from which the fossils were collected occur in a topographic situation consistent with an alluvial valley fill from the north, graded to the same local base level that controlled Surface II; and (3) the deposits in which the fossils are incorporated are sandy marls, indicating a well-watered local contemporary terrain. The deposits at Localities 1 and 2 do not fit the conditions which almost certainly prevailed during the extended period of arid climate known to have characterized the Illinoian stage in the region. Finally, local physiographic relations seem to exclude these deposits from being early Wisconsinan, as it is extremely difficult to explain the presence of sluggish streams and/or ponds in this situation persisting from the time that local drainage was integrated with the Kansan Pecos until the time that the Pecos had reached its early Wisconsinan level.

Correlation of fossil molluscan faunas in alluvial sediments beneath Surface III on the southwestern flank of the Pecos River valley with fossil molluscan assemblages recovered from terrace remnants on the northeastern side of the valley are much more certain, and there is, moreover, little doubt that these faunas are early Wisconsinan. As examples of molluscan faunal assemblages that bear out this judgment we cite those from Locality 13 near Toyah, Reeves County, and the assemblage from Locality 6 in western Ward County. The assemblages are typologically similar, both reflect essentially the same ecological conditions, and both contain representatives of the genus *Pupilla*, characteristic of early Wisconsinan faunas and absent from post-Twocreekan sediments. Furthermore, the deposits at Locality 6, except for lack of colluvial veneer, correlate topographically with the general level of Surface III and exist in the form of a terrace, distinctly distinguishable physiographically from the terrace here designated Surface IV.

Fossil molluscan faunas contained in the sediments below Surface IV, except for the Recent mollusks in the overwash sediments above the weakly developed soil, are certainly latest Wisconsinan and judged to be post-Twocreekan in age. This age assignment is based on topographic position, the terrace being the lowest and obviously the youngest present in the Pecos River valley; the relatively unweathered state of the deposits; and the rich molluscan fauna contained in it, that lacks representatives of *Pupilla* and other kinds of mollusks known to have disappeared from the southern Great Plains and adjoining regions before the deposition of post-Twocreekan terraces.

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Plates I–IV

PLATE I

Some geologic features of the Pecos River valley

A. View northeast across Pecos River, 3.5 miles northeast of Imperial, in Crane County, Texas; fossil Locality 4 (1958). Fauna collected from deposits under Surface IV in middle distance; Triassic rocks exposed in channel of Pecos River below fossiliferous sediments. Northeast bluff of Pecos Valley, in distance, capped by Ogallala formation, and Triassic rocks are exposed in lower part of bluff.

B. Cemented colluvium of early Wisconsinan pediment veneer, 2 miles below Pandale in Pecos River valley, Val Verde County, Texas (1958).

C. Cut bank along Salt Draw, 4½ miles northeast of Toyah, Reeves County, Texas (1958). Early Wisconsinan snail fauna occurs in the deposits below Surface III; fauna is similar to that collected farther south at Locality 13. The deposit consists of gray clayey silts and sands, with a few thin lenses of gravel. Surface III here is a narrow terrace below the truncated edge of Surface II that yielded snails farther south. Locally, a very narrow terrace of Surface IV occurs (not shown in view) that yielded sparse *Succinea.*

D. North across pediment Surface III toward Pecos River, 14 miles west of Grandfalls, in Pecos County, Texas (1958). This smooth, ungullied, colluvial veneered surface extends several miles north to within a few hundred yards of Pecos River channel where a narrow Surface IV terrace occurs at a slightly lower level. Fauna Locality 6 occurs in the truncated edge of the early Wisconsinan sediments below this surface near the river. Southward, the unbroken Surface III truncates Surface II with a distinct but low-angle change of slope, as shown by sections B and C on figure 2. Under the sparse cover of vegetation, unconcentrated sheet wash, although incapable of producing gullies, maintains active transit of the surficial materials.

E. Pediment pass on Surface I, looking south-southeast, 2.3 miles south-southeast of Girvin, Pecos County, Texas (1958). The upland mesas are developed on Cretaeous rocks, and the high elements of pediment Surface I, as shown here, are cut surfaces on Cretaceous bedrock; this cut pediment surface grades imperceptibly downward to a veneered surface, and in northern Pecos County thin remnants of Ogallala formation occur on the lower elements of this surface. Surface I is identified throughout a vertical distance of approximately 1,000 feet (fig. 2) without physiographic discontinuity.

F. Ogallala formation on Triassic rocks exposed in road cut through north valley wall of Pecos Valley, along Farm Road 1053, 4½ miles northeast of Imperial, in Crane County, Texas (1958).

A

B

C

D

E

F

PLATE II

Fossil mollusks from the Pecos River valley region of Texas

(Magnifications are approximate)

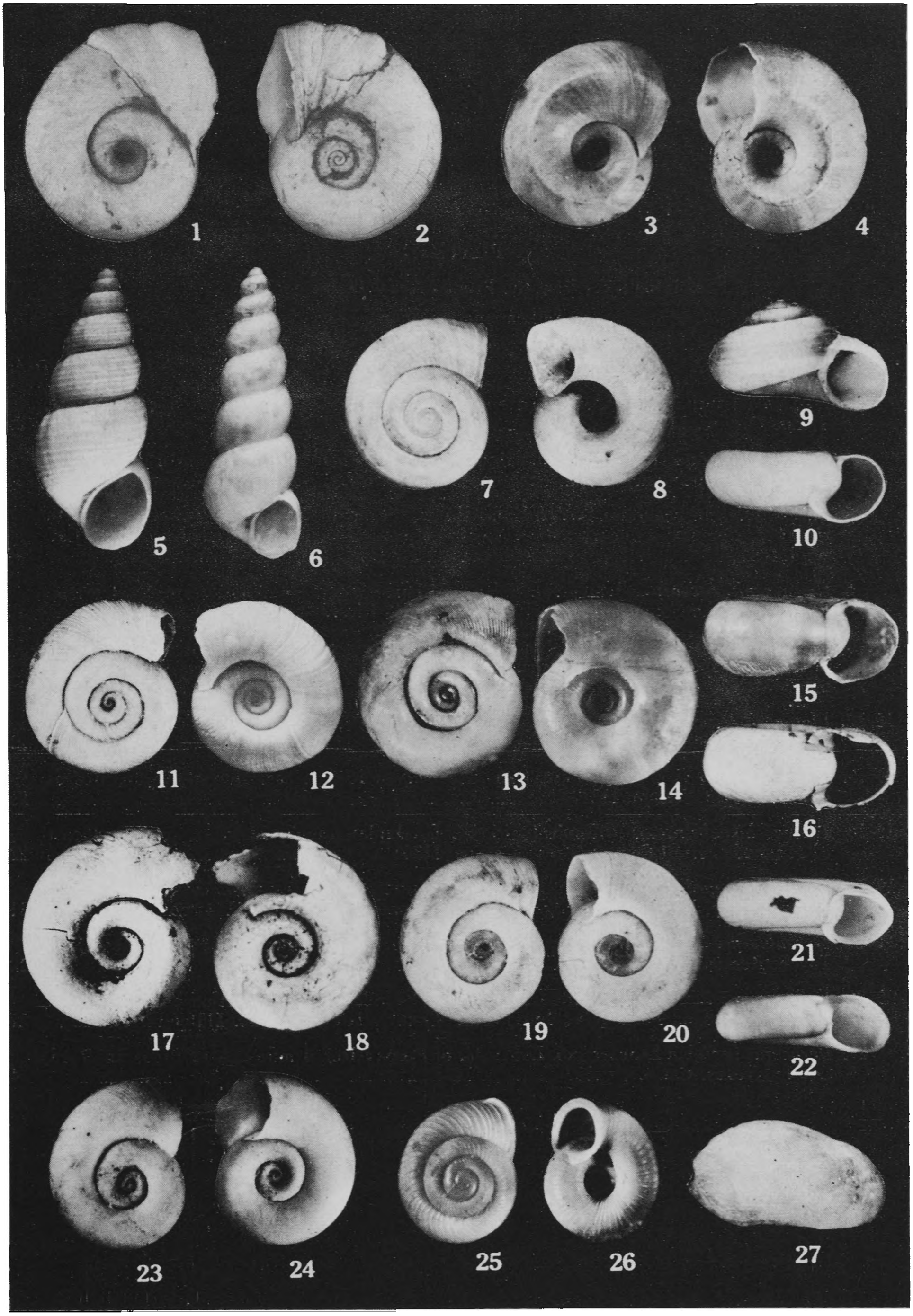
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PLATE III

Fossil mollusks from the Pecos River valley region of Texas

(Magnifications are approximate)

FIGURES— PAGE

1–3. *Helicodiscus parallelus* (Say), x8. Twenty miles south of Sheffield, in Terrell County, Texas, at State Highway 349 crossing of Independence Creek. Cat. no. 11132 24

4–6. *Helicodiscus eigenmanni* Pilsbry, x8. Right bank of Pecos River, one-fourth mile above mouth of Independence Creek, Chandler ranch, Terrell County, Texas. Cat. no. 11313 24

7–9. *Polygyra texasiana* (Moricand), x3. Right bank of Pecos River, one-fourth mile above mouth of Independence Creek, Chandlei ranch, Terrell County, Texas. Cat. no. 11324 23

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24. *Pupilla muscorum* (Linné), x8. Caliche pit, 7.8 miles north of junction of Farm Roads 1601 and 1233 in Crane County, Texas. Cat. no. 11231 27

25. *Pupoides albilabris* (Adams), x8. Right bank of Pecos River, one-fourth mile above mouth of Independence Creek, Chandler ranch, Terrell County, Texas. Cat. no. 11321........ 26

26. *Gastrocopta cristata* (Pilsbry and Vanatta), x8. Pecos River at U.S. Highway 290 bridge, 3 miles southeast of Sheffield, Pecos County, Texas. Cat. no. 11308 26

27. *Gastrocopta procera procera* (Gould), x8. Eleven miles east-southeast of junction of U.S. Highway 290 and State Highway 17, on Barilla Creek, Reeves County, Texas. Cat. no. 11102 26

28. *Gastrocopta procera mcclungi* (?) (Hanna and Johnston), x8. East end of bridge, east side of Toyah, Reeves County, Texas. Cat. no. 11215 26

29. *Gastrocopta pentodon* (Say), x8. Three miles southwest of Grandfalls, Ward County, Texas. Cat. no. 11309 25

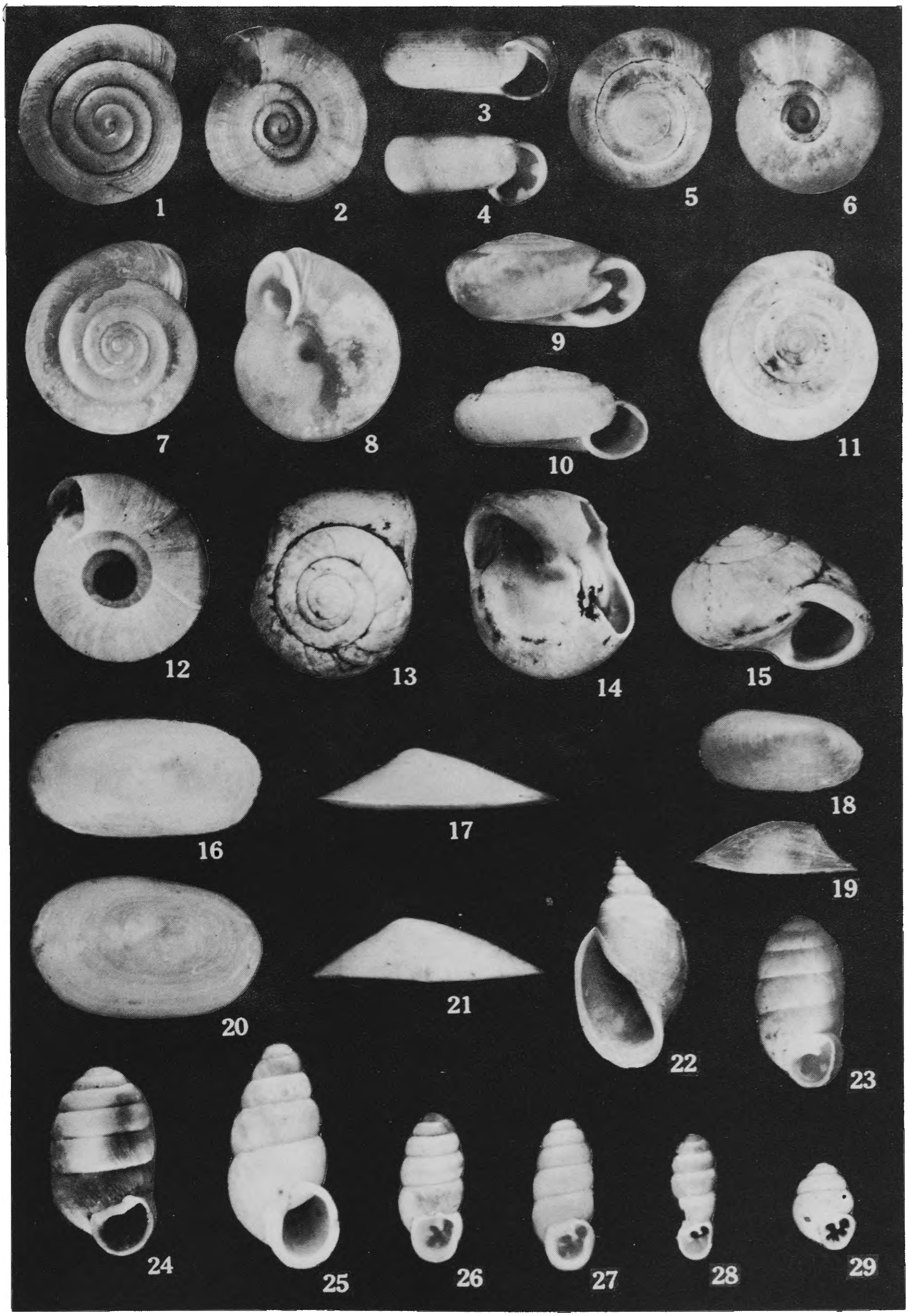
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PLATE IV

Fossil mollusks from the Pecos River valley region of Texas

(Magnifications are approximate)

FIGURES—		PAGE
1.	*Lymnaea caperata* Say, x6. Six and one-half miles west of junction of U.S. Highway 290–67 with U.S. Highway 285, Fort Stockton, Pecos County, Texas. Cat. no. 11187	20
2.	*Lymnaea palustris* (Müller), x3. Two miles northwest of U.S. Highway 285 railroad crossing, Pecos, Reeves County, Texas. Cat. no. 11208	20
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6.	*Bulimulus dealbatus dealbatus* (Say), x2. Two miles north of road junction in Pandale, on Ozona road, Val Verde County, Texas. Cat. no. 11155	23
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11.	*Oxyloma* sp., x3. Seven-tenths mile north of Pecos River, extension of Farm Road 1927, Ward County, Texas. Cat. no. 11165	25
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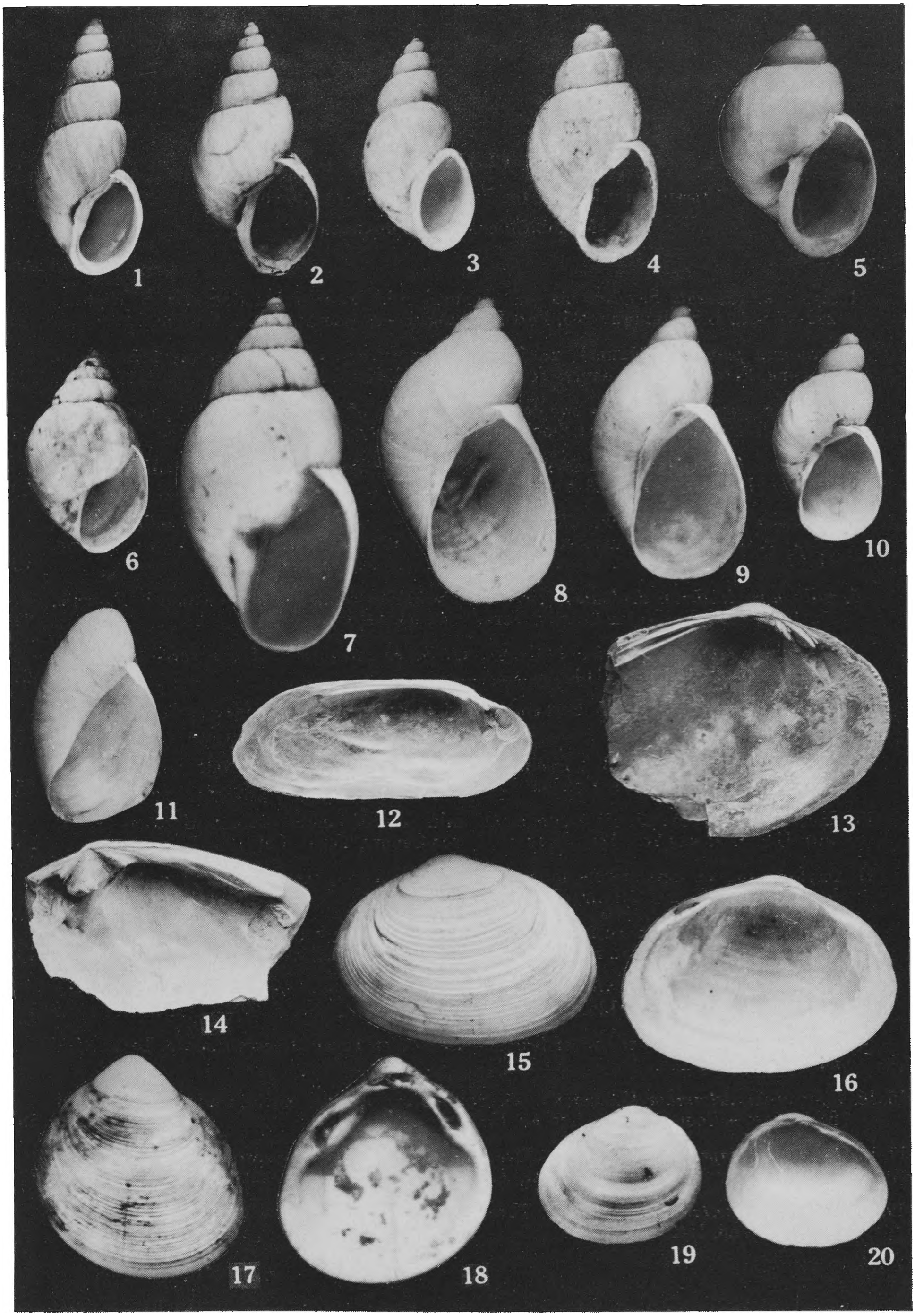
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