PALEOCLIMATIC RECONSTRUCTION BASED ON MOLLUSCAN (GASTROPODA; PELECYPODA) ENVIRONMENTAL INDICATORS--LATE QUATERNARY OF NORTHWESTERN TEXAS

by

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ABSTRACT

Paleoecologic interpretation of fossil molluscan faunas provides a basis for indirect reconstruction of paleoclimates. Terrestrial and aquatic mollusks are abundant in late Quaternary sedimentary deposits of the western Rolling Plains of Texas. These taxa compose a succession of distinct faunal assemblages. Most mollusks represented in late Pleistocene to middle Holocene assemblages of the region are absent from the modern fauna. However, none of the extirpated species are extinct. Their distribution has merely been reduced such that at present, these taxa are found north, east, or in montane areas west of the Southern High Plains and Rolling Plains. Because they are living species their environmental requirements (habitat and climate) are relatively well known. Environments that sustain these mollusks today are presumed to have existed in northwestern Texas in the past. Ecologic conditions throughout the Pleistocene and Holocene Epochs can be inferred by tracing the range of environmentally sensitive taxa through radiocarbon-dated stratigraphic sequences. Allowance is made for local variations owing to facies changes and temporary modifications of habitat. Conditions in this region during the late Pleistocene favored diverse molluscan faunas. By comparison, the living fauna is depauperate and virtually restricted to species with broad environmental tolerances. Climatic and ecologic change was gradual, affecting different species at different times. Regional extirpation of a number of species with comparable ecologic requirements indicates a profound change in environment probably related to climate. Data from three well-constrained stratigraphic sections permit refinement of existing paleoclimatic reconstructions. Climatic variations during the Holocene have taken two related but somewhat independent paths. A summer warming trend that began in the latest Pleistocene greatly increased temperatures by about 8,000 yr b.p. A similar trend toward desiccation was accelerated between 8,000 and 6,000 yr b.p., until essentially modern conditions were attained 3,000 yr b.p. Other, comparatively minor fluctuations of the regional paleoclimate are evident as well.

INTRODUCTION

Recent investigations in the western Rolling Plains have disclosed thick, laterally extensive Quaternary deposits containing abundant fossil mollusks and local concentrations of vertebrate remains (Dalquest, 1964; Neck, 1978; Johnson and others, 1982; Caran and others, 1985). More than fifty finite radiocarbon dates provide adequate chronologic control for investigation of these deposits (Caran and Baumgardner, 1985a). Stratigraphic, pedologic, and paleontologic evidence permits reconstruction of the regional, late Quaternary paleoclimate. Molluscan faunas are particularly useful paleoenvironmental indicators. Over the time interval of interest (latest Pleistocene to Holocene, the past 100,000 yr), mollusks in this region have been demonstrably conservative; no significant evolutionary trends are evident and no species have become extinct. In contrast, it was during this period that much of the Rancholabrean mammal fauna became extinct. Consequently, paleoclimatic inferences based on mammals alone would necessarily draw on assumed and often unsatisfactory analogies to existing related taxa.

Despite its relative conservatism the regional molluscan fauna has experienced a gradual loss of taxa since the late Pleistocene, although all species extirpated locally survive elsewhere. The remaining fauna consists of taxa adapted to a broad range of habitats and climatic conditions, along with a few specialized forms surviving in relict habitats. Analysis of the fossil molluscan assemblages affords an ideal basis for paleoenvironmental reconstruction.

Molluscan faunas described in this study were initially discussed by Neck (1978), Johnson and others (1982), Caran (1984), and Neck and Fullington (1985). Sediment was sampled in bulk at measured sections with suitable chronostratigraphic control. These samples were processed by flotation, screening, and washing, employing methods similar to those of Allen and Cheatum (1961, p. 295, 296) and Johnson and others (1982, p. 119, 120). Recovered mollusks were carefully identified and counted (Cheatum and Allen, 1965; Neck,

1978; Neck and Fullington, 1985). A summary of these data is presented in accompanying tables 1-4.

REGIONAL GEOLOGIC SETTING

The western Rolling Plains is the moderately dissected Triassic, Permian, and Quaternary terrane immediately east of the Caprock Escarpment, the eastern boundary of the Southern High Plains of Texas (fig. 1). Quaternary deposits discontinuously cover more than 7,800 km^2 (3,000 mi^2) of the western Rolling Plains, across a zone 50 km (30 mi) wide (Caran and others, 1985). The late Quaternary history of the region is recorded in these deposits. Climatic variations during this period are reflected in the stratigraphy and paleofauna.

The basal component (informally designated component 1) of the regional Quaternary section consists of alluvial-fan deposits that spread eastward from the retreating Caprock Escarpment (Caran and others, 1985). These coarse-clastic deposits overlie an eroded and structurally deformed unconformity on Triassic, Permian, and, locally, Tertiary (Ogallala Formation) strata. Deformation of the older strata resulted from karstic subsidence owing to dissolution of Permian salt at relatively shallow depth, generally less than 150 m or 500 ft (Gustavson and others, 1982). Subsidence has continued to the present and locally affects the entire Quaternary section.

Overlying the basal coarse-clastic deposits are discrete lenses of fine-grained lacustrine sediment composing the middle component (component 2) of the regional Quaternary section (Caran and others, 1985). These lake beds accumulated in small subsidence basins the floors of which dropped beneath the local water table. Perennial lakes were created and simultaneously isolated from most sources of coarse sediment. The lakes provided habitat for a diverse assemblage of aquatic mollusks and other organisms. Terrestrial mollusks were carried into the lakes by the limited centripetal runoff within these small closed basins.

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The lacustrine deposits are succeeded stratigraphically by the heterogeneous upper component (component 3) of the section (Caran and others, 1985). Fluvial and eolian sediment (gravel, sand, and clayey silt) accumulated rapidly but sporadically, permitting intermittent development of soils. Many of these soils werre buried and preserved, as were remains of terrestrial and aquatic mollusks.

STUDY AREAS

Lake Theo Archeological Site

The Lake Theo archeological site (41BI70) is a Paleoindian (Folsom, Plainview) and Archaic occupation area in Caprock Canyons State Park, Briscoe County (fig. 1). A moderately thick sequence of fluvial and eolian deposits of component 3 was exposed here in a steep cutbank of Holmes Creek (now impounded to form Lake Theo), and in archeological excavations. Figures 2 and 3 summarize the deposits at this site which include poor exposures of component 2(?) and 1, as well. The stratigraphy and pedology of the Lake Theo section were described previously by Johnson and others (1982), who also discussed the archeological materials and paleofauna and their radiocarbon age.

Mollusks from this site were described by Neck (1978), Johnson and others (1982), and Caran (1984). Caran and Neck (1984) reported several new radiocarbon dates based on analyses of organic humates from this section. Figure 4 illustrates the stratigraphic and chronologic range of mollusks collected there.

Edwards Farm Site

The Edwards farm site, also known as the Quitaque local fauna site, is an important Rancholabrean vertebrate locality along Quitaque Creek in Motley County (fig. 1). Basal sands and gravels (component 1), an irregularly eroded and locally truncated lens of

lacustrine clay (component 2), and upper sands and gravels (part of component 3) are exposed in gullies on the northern bank of the broad intermittent stream (fig. 5).

Dalquest (1964) originally described this locality and its vertebrate fauna. Dalquest (1985) supplemented these data and revised the nomenclature as needed. Cheatum and Allen (1965) reported an extensive molluscan fauna from the Edwards farm site (table 1) but did not provide details regarding the stratigraphy of units sampled. Caran and Baumgardner (1985b) described the section from which Dalquest collected vertebrates (fig. 5). Cheatum and Allen's collection of mollusks probably was obtained from this same local section. A thicker, more complete sequence of lacustrine deposits is preserved nearby. Mollusks from lacustrine strata above those shown in figure 5 were identified by Neck and Fullington (1985) and are listed in table 2. Questionable finite and infinite radiocarbon dates were obtained from analyses of samples from the section shown in figure 5, as described by Dalquest (1964) and Caran and Baumgardner (1985a).

Smith Farm Site

The Smith farm site in southern Briscoe County is a critical locality for understanding the regional Quaternary section. At this site a long deep tributary of Los Lingos Creek provides excellent exposures. Strata of components 2 and 3 are represented in the measured section shown in figure 6. Basal sands and gravels of component 1 are exposed south of this section, as are Permian siltstones underlying the entire Quaternary sequence.

Caran and Baumgardner (1985c) described the stratigraphy of this important site. A series of finite radiocarbon dates were obtained through analyses of samples from the section illustrated in figure 6 (Caran and Baumgardner, 1985a). Neck and Fullington (1985) identified mollusks from most of the lacustrine strata (units 5-10, fig. 6); these mollusks are listed in table 3.

MOLLUSKS AS PALEOENVIRONMENTAL INDICATORS

Previous Investigations

A number of investigators have shown that mollusks are useful indicators of paleoenvironment (habitat and climate) in the western Rolling Plains and Southern High Plains. Frye and Leonard (1963), Pierce (1975), Neck (1978), Johnson and others (1982), and Caran (1984) have reconstructed conditions existing regionally during the Pleistocene and Holocene Epochs by interpreting molluscan paleofaunas. Such interpretations are based on extension of the environmental tolerances of living mollusks to fossil representatives of the same taxa. Analogies of this kind have been called transfer functions by Imbrie and Kipp (1971). Vertebrate remains from most sites in the region have not proven diagnostic (Dalquest, 1964, 1985; Johnson and others, 1982), and few usable palynological records have been obtained (S. A. Hall, written communication, 1985).

Lowe and Walker (1984, p. 155) proposed a rationale for interpretation of environments of the past based on paleontologic indicators. Some of their assumptions, condensed and paraphrased here, constitute useful criteria for evaluating the homology of paleoecologic and modern ecologic relationships:

1) The origin (taphonomy) of a fossil assemblage is understood;

2) A fossil assemblage is representative of the death assemblage and has not been biased by differential exclusion or destruction of original constituents, or contamination with older or younger material;

3) The fossil remains can be identified to a sufficiently low taxonomic level to permit application of uniformitarian principles; and

4) The distribution and environmental requirements of fossil organisms have valid analogues in those of modern plants and animals.

Sources of Error

Although mollusks generally provide a reliable basis for paleoclimatic reconstruction there are ways in which error can be introduced. Differential preservation or recovery of shell may lead to underrepresentation or deletion of taxa from a faunal assemblage, and mistaken assessment of paleoenvironment. Large samples increase the probability that comparatively rare taxa are recorded. Fewer individuals and species of mollusks are listed in table 3, unit 7, than in table 4. Both samples were collected from unit 7, but that reported in table 4 was much larger. This variation in procedure illustrates how techniques can affect results.

Of primary concern is whether shells are preserved. Shell can be crushed or weathered during exposure, or dissolved by organic and carbonic acids in soils. Rapid burial generally increases chances for preservation but can cause shells to be broken if the sediment is relatively coarse compared to the size of the shells. Boekelman (1935) demonstrated the importance of collecting shell fragments. Equally important is the recovery of very small mollusks that may be difficult to separate from fine-grained matrix. In some taxa shells are thin and delicate but most are reasonably durable, particularly if they are completely filled with fine sediment during burial. Filling inhibits crushing and may reduce the possibility of sedimentary reworking, the displacement of shells either areally or stratigraphically (into younger strata).

Reworking can be a problem in some instances. Johnson and others (1982, table 4) note that one specimen of Cionella lubricella (Porro) had been eroded from strata low in the Lake Theo section and later redeposited in a younger unit. This resulted in an apparent, but fictitious, anomaly in the local range of this taxon. An obvious discontinuity of this kind signals probable reworking and contamination of younger strata. The appearance of a fossil also may give evidence of this process. The shell may be abraded by erosion and secondary transport. Or, it may be wholly or partly coated with adhering

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particles of older matrix or cement, or mineral or organic stains unlike those of other specimens in a given stratum. Reworking would result in overestimation of the age of strata from which reworked fossils are recovered, or underestimation of the age of the fossils. In contrast, burrowing, root action, and soil cracking may move fossils downward in a stratigraphic section, although burrowing by some insects and large animals also can bring older sediment and shells to the surface or higher in the section. Floods, winds, and perhaps animals may even transport shells into areas far outside their normal habitat or distribution (Pierce, 1975; Neck, 1984).

An even more important source of error is the natural variability in any environment. The upper ("young") end of the stratigraphic range of a mollusk may represent its final appearance in an area because conditions such as climate had become intolerable. But it also could mean that the local habitat had changed. For example, an area may undergo normal ecological succession whereby one association of plants gradually gives way to another, perhaps changing the available habitat of a small invertebrate like a land snail. Or there may be a local catastrophic event such as a prairie fire that would kill almost all land mollusks, or a flood that would kill or temporarily displace most aquatic mollusks in the affected area. If a given species were later to reestablish itself its local range would be discontinuous, but not because of reworking. Neither succession nor localized catastrophes are as significant as a major and essentially "permanent" change in climate, yet it may be difficult to differentiate these causes in some instances, especially if an interpretation is based on the fauna of a single section.

Facies substitutions can occur, as well. A lotic or fast-flowing stream may afford suitable habitat for a given mollusk. But evulsion could cause a channel segment to be abandoned. Water would pool in the abandoned reach, providing lentic or still-water conditions unsuitable for mollusks that occupied the flowing stream. The channel segment may fill in entirely and become dry land. Aquatic mollusks could not then occupy that site, not because of a major secular change in climatic conditions but because the environment

is dynamic and simply establishes a new local habitat. This particular sequence of events actually may have occurred at the Lake Theo site. Therefore, the paleoclimatic interpretation for this site emphasizes the terrestrial gastropods (fig. 4) because they are less susceptible to changes in stream conditions than are aquatic mollusks.

An additional source of error is linked to relict faunas. For example, a shaded canyon with ground-water seepage may shelter a mesic-adapted species long after climatic changes (desiccation and higher temperatures) have eliminated it from other parts of the region. This single refuge might then be a contemporary source of shells that could be flushed downstream by heavy rains. Fluvial deposits lower in the drainage basin would incorporate a climatic indicator of conditions no longer existing at the point of deposition. The shells would not have been reworked and need not have been transported great distances. Neck (1984) concluded that minute species were most likely to contaminate a local paleofauna in this manner. Investigators may reduce errors of this type by weighing the evidence of large species most heavily. Even more important are (1) the stratigraphic distribution of taxa, (2) the depositional environment (flood deposit, upland soil, etc.) of strata in which the fossils are found, and (3) the existence of nearby sources of contamination at the time of deposition. These observations should allow the investigator to evaluate the possibility of faunal mixing.

Deliberate effort must be made to recognize and differentiate possible causes of apparent stratigraphic range extension, discontinuity, and compression. Each of these false signals would result in incorrect interpretation of conditions during deposition of a given stratum incorporating molluscan remains. The most important solution is to examine multiple stratigraphic sections, looking for correlative changes over a large area. If a mollusk disappears from the record of an entire region a major environmental change may be indicated.

PALEOCLIMATIC INTERPRETATION

Lake Theo Site

The molluscan faunas described here provide a firm basis for reconstructing the regional paleoclimate of the Holocene and latest Pleistocene Epochs. These faunas are well-constrained stratigraphically and chronologically. Figures 2 to 4 summarize the Quaternary stratigraphic, chronologic, and paleontologic record of the Lake Theo site, based on data from Neck (1978), Johnson and others (1982), Caran (1984), and Caran and Neck (1984). The temporal range of these taxa corresponds to findings of regional studies by Pierce (1975) and Neck (1984). Anomalous, isolated or discontinuous occurrences of some taxa (Strobilops texasiana, Rabdotus dealbatus, Gastrocopta armifera, Strobilops labyrinthica, Gastrocopta holzingeri, and Discus cronkhitei) within the section probably are statistical artifacts, in part related to limited recovery of shells of some of these species. All are known to have occupied the region in the late Pleistocene (Pierce, 1975).

The breaks in molluscan ranges do not coincide with major stratigraphic zonations (fig. 2). Sampling procedures may account for part of this apparent dichotomy (Johnson and others, 1982, tables 4 and 5). However, that part of the section in which faunal transitions are evident is relatively uniform geologically. All stratigraphic units between numbers 4 and 9 inclusive (younger than 11,000 yr b.p.) appear to be related to episodic overbank deposition of silty sand, followed by intervals of stability in which soils formed. There is relatively little indication of facies variation through the upper half of the section, from which most of the fossil mollusks were recovered; whereas the lower half (unit 3 and below, older than 11,000 yr b.p.) indicates a transition from active to inactive fluvial channel and eventually to relatively distal floodplain and terrace (Caran, 1984; Caran and Neck, 1984). The modern and ancestral drainage basins of Holmes Creek are very small, so it is unlikely that "exotic" faunal elements intruded the local assemblages.

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Comparison of figure 4 and table 5, together with interpretation of the genetic stratigraphy and geomorphology of the Lake Theo site indicate that through most of the Holocene the area was wooded riparian habitat with nearby grasslands, particularly in the middle to late Holocene. Carychium exiguum, Cionella lubricella, Pupilla muscorum, Gastrocopta holzingeri, Nesovitrea electrina, and Discus cronkhitei inhabit woodlands near water, and all are represented in strata approximately 8,000 years old and older. Subsequently, these species disappeared from the region and generally have a northern or montane western distribution today. Riparian woodlands persisted at the site to the present, as indicated by Strobilops labyrinthica, S. texasiana, Gastrocopta armifera, Euconulus fulvus, Vertigo ovata, and Helicodiscus parallelus, among others. Most of these taxa were eliminated from the regional fauna by about 3,000 years ago, and the extant Gastrocopta armifera and Vertigo ovata are restricted to mesic (damp) microhabitats sustained by ground-water seepage. Both G. armifera and V. ovata were common and very widespread in the late Pleistocene and early Holocene. These latter six species generally characterize the eastern half of the U.S. and are dependent on moist conditions. The remaining taxa included in figure 4 occupy either riparian woodlands or grasslands, and most are extant. There probably has been a reduction in tree cover and perhaps a change in composition of the woodlands since the early Holocene. But the overall habitat is little changed locally because of its proximity to at least intermittent drainage.

Yet mollusks composing distinct assemblages in the fossil record (fig. 4) have been extirpated, and in a systematic manner. The modern distribution and ecology of these species indicates that climatic change was the most likely cause of the gradual loss of molluscan taxa from the local fauna. The timing of the loss of assemblages that have overlapping modern distributions reveals a distinctive, two-part climatic transition. Those species that today are found in cooler climates to the north or to the west at higher elevations were the first to disappear (fig. 4). Presumably, they were unable to tolerate long hot summers or unstable winters that inhibited continuous hibernation. Most of these

taxa were gone by about 8,000 yr b.p., in the very early Holocene. Other species require wet conditions like those of areas farther east, although a few of these taxa continue to occupy mesic microhabitats within or near the Rolling Plains. The eastern species survived the warming trend of the early Holocene but were displaced by progressive aridity about 3,000 yr b.p. Holliday and others (1983) present a somewhat different interpretation of the mid- to late-Holocene paleoclimate but conclude that by the middle Holocene the climate of the adjacent Southern High Plains had become increasingly dry. The living molluscan fauna of the area is depauperate compared to older Quaternary faunas and consists of species tolerant of a warm dry climate or a moist but highly restricted microenvironment.

Edwards and Smith Farms Sites

The faunas of the Edwards and Smith farms sections, in contrast to that of the Lake Theo site, are dominated by aquatic species (tables 1-4). Lacustrine environments were widespread throughout the region during the late Pleistocene, from about 40,000 to 10,000 yr b.p. (Caran and others, 1985). Emergent ground water turned karstic subsidence basins into perennial lakes with small surface-drainage areas. The water was still or nearly so. It is unlikely there was significant contamination of the local paleofaunal assemblage with allochthonous material. Reworking generally requires water turbulence, and an extensive drainage network would be needed for long-distance transport of contemporary or reworked fossil shells. Conditions within the lakes were relatively stable with little influx of terrigenous sediment. Slight fluctuations of the water table alternately inundated or exposed the lake margins.

The Edwards and Smith farms sections are similar in many respects, although some of the lacustrine strata at the Edwards site may be somewhat older than those at the Smith site. Radiocarbon analyses of organic humates from sediment near the bottom of the lacustrine section at the Edwards farm yielded two infinite dates exceeding 35,000 to 38,000 yr b.p. (fig. 5; Caran and Baumgardner, 1985a). Dalquest (1964) previously had

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reported radiocarbon ages of mussel (Uniomerus tetralasmus) shells from the same part of the section. These dates were finite, ranging from 25,000 to 37,000 yr b.p.; but radiocarbon analyses of freshwater-mollusk shell are notoriously unreliable (Caran and Baumgardner, 1985a). An internally reinforced series of finite dates was obtained from analyses of lacustrine sediment at the Smith farm (fig. 6). These dates range from about 15,000 to 25,000 yr b.p., representing the ages of the uppermost to middle strata, respectively. Assuming the dates are accurate the age of the lowermost lacustrine strata at the Smith farm can be extrapolated to about 35,000 yr. This may be 5,000 to 15,000 yr younger than the lowest lacustrine strata at the Edwards farm, or perhaps even younger.

Direct comparison of molluscan faunas of the Edwards and Smith farms sites is complicated by possible difference in age and some uncertainty regarding the precise stratigraphic interval sampled by Cheatum and Allen (1965). The fauna described by these authors (as emended, table 1) is extensive. Fully half are terrestrial species, the balance, including three pelecypods, being aquatic. The exact number of individuals of each taxon was not reported but relative abundance was indicated. Terrestrial forms generally were incidental to a dominantly aquatic population. This is consistent with the interpretation that beds of clay reportedly sampled by Cheatum and Allen (1965, p. 4) are the lacustrine strata (unit 3 of fig. 5) at the Quitaque local fauna site of Dalquest (1964, 1985), as recognized by Caran and others (1985).

Fossil mollusks of the Edwards farm site are listed in tables 1 and 2. Those in table 2 were collected from the upper part of the lacustrine component of the local section. Correlative strata were eroded prior to deposition of unit 2 in figure 5. This figure illustrates strata exposed at the Quitaque local fauna locality, approximately 0.25 km (0.15 mi) southwest of the point where the mollusks described in table 2 were collected. In aggregate the mollusks of tables 1 and 2 compose a diverse assemblage. Some of the aquatic taxa, particularly the lymnaeids Fossaria and Stagnicola, the planorbids Gyraulus and Promenetus umbilicatellus, and perhaps Physella and Aplexa hypnorum, are

characteristic of intermittent or ephemeral water bodies today. These species may have occupied shallows along the margins of the small lake at this site.

The rest of the aquatic taxa are diagnostic or suggestive of quiet perennial water with an abundance of broad-leaved aquatic vegetation. However, at least the main body of the lake was not stagnant. Well-oxygenated waters are implied by the relative abundance of the pelecypods and the presence of _Valvata tricarinata_. In addition, the model proposed by Caran and others (1985) stipulates that the lakes were maintained by emergence of ground water, necessarily implying a high regional water table. Stratigraphic evidence indicates little runoff and terrigenous matter entered the lake. Therefore, the terrestrial mollusks can be assumed to have occupied lakeside woodlands, the preferred habitat of most of these species today (table 5).

The molluscan fauna of the Smith farm site is analogous to that of the Edwards farm localities, but is not so diverse. It too is dominated by aquatic taxa in terms of the number of specimens recovered (tables 3 and 4). This is especially evident in table 4 which represents the species derived from a very large sample processed as a test of the separation technique. Comparison of table 3, unit 7, with table 4 (also representing unit 7) indicates that many more individuals and several additional species were found by laborious treatment of a large volume of matrix (approximately 15 kg or 35 lb). But in this instance the overall interpretation of paleoenvironment was not affected.

All of the aquatic mollusks represented at the Smith farm site are characteristic of shallow quiet water with abundant submerged aquatic vegetation. Remains of the macrophytic alga _Chara_ sp. are particularly common at this locality (Caran and others, 1985) and may have supported the large population of snails. (No clams have been found there.) Three species completely dominate the fauna, _Gyraulus parvus_, _G. circumstriatus_, and _Stagnicola exilis_, in order of decreasing abundance. Neck and Fullington (1985) reported that the examples of _Stagnicola exilis_ in these samples lack malleations or dents resulting from buffeting by waves or currents, an indication that the water was still or slow

moving. Most of the aquatic taxa including the dominant species can occupy ephemeral water bodies, but local stratigraphic evidence does not support this environmental interpretation of the lake.

A more likely explanation is that water in the shallow lake may have been relatively concentrated in dissolved solids conveyed to the surface by ground water. Clays within the lacustrine deposits (units 5-10, fig. 6) are highly calcareous and Chara actively secreted calcium carbonate (Caran and others, 1985). There is little available information regarding the water quality preferred by various mollusks. Yet the low faunal diversity and other evidence noted previously suggest that water chemistry, rather than intermittency, was the primary factor controlling biota at the Smith farm site. Permian evaporites at shallow depths are a ready source of dissolved solids. A high water table is all that is necessary to account for the stratigraphic and paleontologic anomalies at this site.

A number of aquatic species represented in faunas of the Edwards and Smith farms are absent from the region today. These taxa include: Valvata tricarinata; Cincinnatia cincinnatiensis; Fossaria dalli; Stagnicola caperata; S. elodes; S. exilis; Aplexa hypnorum; Armiger crista; Gyraulus circumstriatus; Promenetus exacuous; P. umbilicatellus; Ferrissia rivularis; Sphaerium rhomboideum; Pisidium casertanum; P. compressum; P. nitidium; and perhaps Physella gyrina. Almost all these species are now found in cooler climates at higher elevations to the west, or significantly farther north. Several are typically cold-water species, especially Valvata tricarinata, Aplexa hypnorum, and Armiger crista. Valvata tricarinata is not known to occur in waters warmer than 17°C (63°F). The temperature of phreatic ground water generally approaches mean air temperature. The modern mean air temperature of the western Rolling Plains probably would afford marginal conditions for V. tricarinata, but summer extremes and the virtual absence of suitable habitat probably combined to eliminate this taxon entirely.

Reconstruction of paleotemperatures on the basis of aquatic mollusk ecology is somewhat tenuous. There is strong circumstantial evidence that elimination of cold-

adapted taxa by the late Pleistocene-early Holocene resulted, at least in part, from increased summer temperatures and, perhaps, fluctuating winter temperatures. More direct evidence supports the claim that aridity increased during the Holocene. The near complete disappearance of ground-water lakes from the western Rolling Plains indicates markedly lowered water tables. Dissection of the terrain by integrated drainage may have enhanced dewatering of the shallow aquifer (Caran and others, 1985) but the majority of this effect must be related to reduced and seasonally redistributed precipitation. In combination the faunas of the Edwards and Smith farms sites indicate persistence of wet, cool conditions throughout the latest Pleistocene.

SUMMARY

The abundant, diverse molluscan paleofaunas of late Quaternary deposits in the Rolling Plains serve as ideal indicators of paleoenvironment and, in turn, paleoclimate. Stable, wet, and somewhat cooler conditions characterized at least the last 30,000 yr of the Pleistocene. Near the beginning of the Holocene, temperatures began to rise rapidly. Species whose modern range lies north or at higher elevations to the west were extirpated regionally by about 8,000 yr b.p. From then until about 3,000 yr b.p. desiccation intensified, eliminating eastern species and driving some formerly widespread taxa into isolated mesic microenvironments. These trends culminated in the temperate, subhumid to subarid climate of today. Careful examination of the paleontologic record and its stratigraphic and chronologic context form the basis for this plausible reconstruction of past environments. Paleoecologic data also corroborates regional stratigraphic and geomorphic interpretations linked to paleoclimate.

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Table 1. Molluscan remains from Edwards farm site (Quitaque local fauna locality).
(Cheatum and Allen, 1965, p. 4, revised to conform to nomenclature of table 5)

Vallonia gracilicosta	Aplexa hypnorum
Vallonia parvula	Armiger crista
Pupilla muscorum	Gyraulus circumstriatus
Pupoides albilabris	Gyraulus parvus
Gastrocopta armifera	Helisoma anceps
Gastrocopta cristata	Planorbella trivolvis
Gastrocopta pentodon	Promenetus umbilicatellus
Gastrocopta procera	Ferrissia rivularis
Gastrocopta tappaniana	Sphaerium striatinum
Vertigo ovata	Pisidium compressum
Strobilops texasiana	Uniomerus tetralasmus
Succinea sp.	Cincinnatia cincinnatiensis
Discus cronkhitei	Fossaria dalli
Helicodiscus eigenmanni	Fossaria obrussa
Helicodiscus parallelus	Stagnicola caperata
Helicodiscus singleyanus	Stagnicola elodes
Stenotrema leai	Physella virgata
Valvata tricarinata	Physella gyrina

Table 2. Molluscan remains from Edwards farm site (eastern fenceline locality).

(Neck and Fullington, 1985, table 3)

Species	Number of specimens
Carychium mexicanum	5
Vallonia gracilicosta	9
Vallonia parvula	4
Pupoides albilabris	2
Gastrocopta cristata	5
Vertigo ovata	9
Succinea sp.	2
Discus cronkhitei	3
Helicodiscus singleyanus	5
Euconulus trochulus	8
Zonitoides arboreus	1
Stagnicola exilis	94
Aplexa hypnorum	10
Gyraulus parvus	14
Promenetus exacuous	15
Sphaerium rhomboideum	6
Pisidium casertanum	34
Pisidium nitidum	25

Table 3. Molluscan remains from Smith farm site.

(Neck and Fullington, 1985, table 4)

Species	Specimens in each stratigraphic unit (numbered)					
	6	7	8	9	10	Total
Carychium mexicanum	1			5		6
Vallonia parvula				4		4
Pupilla muscorum	2					2
Pupoides albilabris	1	1				2
Vertigo milium		1	8			9
Succinea sp.	2					2
Euconulus trochulus	2					2
Stagnicola exilis		9	4		13	
Fossaria obrussa	2	4		3		9
Gyraulus circumstriatus		29	29		7	65
Gyraulus parvus		17	34	5	8	64
Promenetus exacuous			4			4

Table 4. Molluscan remains from Smith Farm, unit 7.

(Neck and Fullington, 1985, table 5)

Species	Number of specimens
Pupilla muscorum	1
Gastrocopta cristata	2
Gastrocopta tappaniana	7
Vertigo ovata	4
Stagnicola exilis	129
Fossaria obrussa	47
Fossaria dalli	7
Aplexa hypnorum	1
Gyraulus circumstriatus	281
Gyraulus parvus	981
Armiger crista	34
Promenetus exacuous	92
Promenetus umbilicatellus	35

Table 5. Paleoenvironmental significance of molluscan faunas.

Taxon[1]	Modern status[2]	Indicated paleoenvironment[3]
Class Gastropoda, snails		
Terrestrial snails		
Family CARYCHIIDAE		
Carychium exiguum (Say)	Absent (New Mexico)	Wooded lakeside, riparian woodland, or damp woodland
C. mexicanum Pilsbry	Extant?	Marsh, lakeside, or riparian area
Family CIONELLIDAE		
Cionella lubricella (Porro)	Absent (Guadalupe Mountains of Trans-Pecos region, Texas and New Mexico)	Moist shaded slope with leaf litter, riparian woodland, or moist prairie
Family VALLONIIDAE		
Vallonia gracilicosta (Reinhardt)	Extant	Riparian woodland, damp woodland with leaf litter or downed wood, or cool savannah
V. parvula Sterki	Extant	Riparian woodland with leaf litter, or damp woodland
Family PUPILLIDAE		
Pupilla muscorum (Linnaeus)	Extant (as sinistral subspecies P. m. sinistra)	Woodland with leaf litter, or grassy hillside (some subspecies)
Pupoides albilabris (C. B. Adams)	Extant	Essentially any upland habitat: arid brushland, semiarid grassland, or humid forest
Gastrocopta armifera (Say)	Extant	Woodland with leaf litter, or riparian woodland within a canyon
G. cristata (Pilsbry and Vanatta)	Extant	Upland prairie, wooded slope, or riparian area
G. pellucida (Pfeiffer)	Extant	Prairie with scattered woody vegetation within valley
G. pentodon (Say)	Extant	Shaded slope near water, or prairie near water
G. procera (Gould)	Extant	Sparse woodland, prairie, or brushland
G. tappaniana (C. B. Adams)	Extant	Shaded slope near water
Vertigo milium (Gould)	Extant	Riparian woodland, marsh, or near perennial water
V. ovata Say	Extant	Shaded slope near water
Family STROBILOPSIDAE		
Strobilops labyrinthica (Say)	Absent (Guadalupe Mountains of Trans-Pecos region, Texas and New Mexico)	Damp woodland with leaf litter or downed wood
S. texasiana (Pilsbry and Ferriss)	Absent (eastern Texas, or Guadalupe Mountains of Trans-Pecos region, Texas and New Mexico)	Damp woodland with leaf litter or downed wood
Family SUCCINEIDAE		
Succinea cf. S. avara (Say)	Extant	Wide range of terrestrial habitats (species generally found in damp areas)

Table 5 (cont.)

Taxon[1]	Modern status[2]	Indicated paleoenvironment[3]
Family ENDODONTIDAE		
Discus cronkhitei (Newcomb)	Absent (New Mexico)	Damp woodland with leaf litter
Helicodiscus eigenmanni Pilsbry	Extant	Shaded woodland, lakeside, or riparian area
H. parallelus (Say)	Absent (Oklahoma)	Damp woodland with leaf litter
H. singleyanus (Pilsby)	Extant	Damp woodland with leaf litter
Family ZONITIDAE		
Nesovitrea electrina (Gould)	Absent (New Mexico)	Woodland with leaf litter or downed wood
Hawaiia minuscula (Binney)	Extant	Woodland with leaf litter or downed wood, or prairie
Euconulus trochulus (Say)	Extant	Woodland
E. fulvus (Muller)	Absent? (New Mexico)	Damp shaded woodland with leaf litter
Zonitoides arboreus (Say)	Absent (New Mexico)	Woodland or riparian area
Family BULIMULIDAE		
Rabdotus dealbatus (Say)	Extant	Riparian woodland, prairie, or savannah
Family POLYGYRIDAE		
Stenotrema leai (Binney)	Absent (eastern Texas)	Riparian woodland or damp woodland with leaf litter
Aquatic snails		
Family VALVATIDAE		
Valvata tricarinata (Say)	Absent (Nebraska)	Large perennial lake with abundant broad-leaved aquatic vegetation; water temperature $\leq$ 63°F ($\leq$17°C)
Family HYDROBIIDAE		
Cincinnatia cincinnatiensis (Anthony)	Absent? (Oklahoma)	Stream, probably with slow to moderate flow and abundant diatoms, algae, and broad-leaved aquatic vegetation
Family LYMNAEIDAE		
Fossaria dalli (Baker)	Absent (southern New Mexico)	Shallow pond or marsh
F. obrussa (Say)	Extant	Shallow ephemeral pond or marsh
Stagnicola caperata (Say)	Absent (Colorado)	Intermittent stream or ephemeral pond
S. elodes (Say)	Absent (New Mexico)	Intermittent stream or ephemeral pond
S. exilis (Lea)	Absent (Kansas)	Intermittent stream or ephemeral pond
Family PHYSIDAE		
Physella gyrina (Say)	Absent? (Arkansas)	Permanent water or area of vernal flooding adjacent to permanent water
P. virgata Gould	Extant	Virtually any aquatic habitat
Aplexa hypnorum (Linnaeus)	Absent (northern Nebraska)	Area of vernal flooding adjacent to permanent water; intermittent stream or ephemeral pond; small perennial stream or lake (occasionally)

Table 5 (cont.)

Taxon[1]	Modern status[2]	Indicated paleoenvironment[3]
Family PLANORBIDAE		
Armiger crista (Linnaeus)	Absent (Minnesota)	Shallow ephemeral pond, marsh, or intermittent stream, probably with abundant broad-leaved aquatic vegetation
Gyraulus circumstriatus (Tryon)	Absent (New Mexico)	Shallow ephemeral pond or marsh
G. parvus (Say)	Extant	Probably still water with abundant aquatic vegetation; wide range of aquatic habitats
Helisoma anceps (Menke)	Extant	Perennial water (pond, lake, stream, or river)
Planorbella trivolvis (Say)	Extant	Perennial water (pond, lake, or stream) with moderate to abundant aquatic vegetation
Promenetus exacuous (Say)	Absent (northern New Mexico)	Still or slow-moving water with abundant aquatic vegetation; wide range of aquatic habitats
P. umbilicatellus (Cockerell)	Absent (northern New Mexico)	Ephemeral pond or intermittent stream with abundant aquatic vegetation
Family ANCYLIDAE		
Ferrissia rivularis (Say)	Absent (New Mexico)	Perennial stream (species generally attaches to stones but can attach to empty clam shells)

Class Pelecypoda, clams

Freshwater fingernail clams

Taxon	Modern status	Indicated paleoenvironment
Family SPHAERIIDAE		
Sphaerium rhomboideum (Say)	Absent (northern United States)	Perennial lake, pond, or slow-moving stream with muddy substrate
S. striatinum (Lamarck)	Extant	Small or medium-sized perennial stream
Pisidium casertanum (Poli)	Extant	Small or medium-sized intermittent or perennial stream (species often found near springs)
P. compressum Prime	Extant	Small or medium-sized perennial stream (species often found near springs)
P. nitidum Jenyns	Extant	Shallow perennial stream

Freshwater mussel

Taxon	Modern status	Indicated paleoenvironment
Family UNIONIDAE		
Uniomerus tetralasmus (Say)	Extant (very restricted in this region historically)	Still or moving water (species tolerates dry substrates for extended periods)

Table 5 (cont.)

[1]Authorities for nomenclature and order of presentation: terrestrial snails--Burch (1962), Cheatum and Fullington (1973), Fullington and Pratt (1974), and Hubricht (1983); aquatic snails--Fullington (1978), Burch (1982); fingernail clams--Burch (1972), Clarke (1981); mussels--Burch (1973). Species within a given genus are listed alphabetically.

[2]Extant = living in western Rolling Plains today. Absent = not living in western Rolling Plains today. The area closest to the western Rolling Plains where each absent taxon can be found living today is noted parenthetically. Authorities for modern distribution of taxa: terrestrial snails--Taylor (1960), Burch (1962), Pierce (1975), Neck (1978, 1984), Neck and Fullington (1985); aquatic snails--Taylor (1960), Pierce (1975), Fullington (1978, 1979), Burch (1982), Neck and Fullington (1985); fingernail clams--Burch (1972), Clarke (1981); mussels--Burch (1973), authors.

[3]Authorities for habitat requirements of living taxa: terrestrial snail--Taylor (1960), Cheatum and Allen (1965), Pierce (1975), Neck (1978, 1984), Neck and Fullington (1985); aquatic snails--Fullington (1978), Neck and Fullington (1985); fingernail clams--Heard (1979), Clarke (1981); mussels--Clarke (1981), authors.