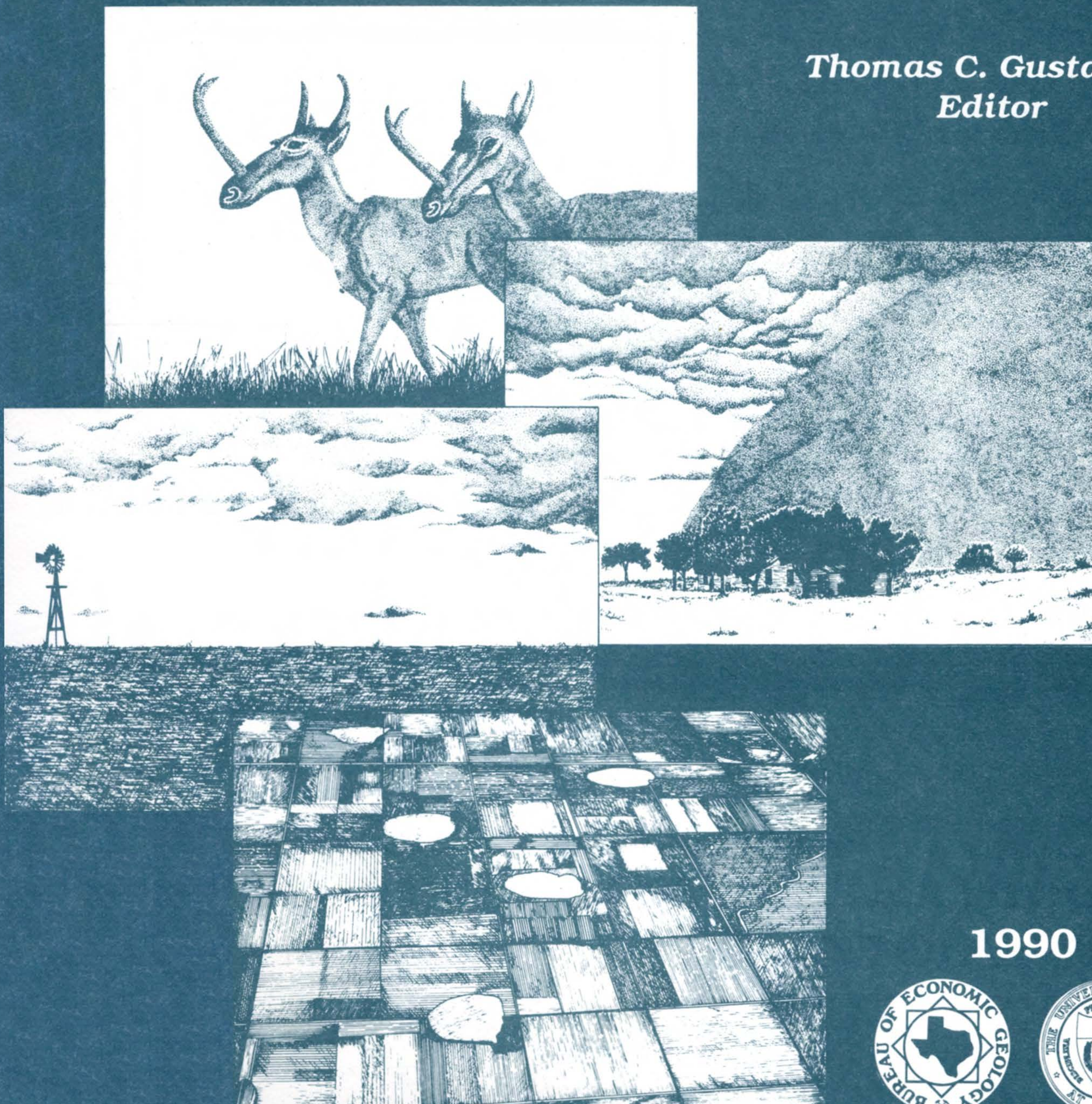
Guidebook 24

TERTIARY AND QUATERNARY STRATIGRAPHY AND VERTEBRATE PALEONTOLOGY OF PARTS OF NORTHWESTERN TEXAS AND EASTERN NEW MEXICO

Thomas C. Gustavson
Editor



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Cover:

Illustrations, symbolic of the range of research described in this volume, are (clockwise from top left): paleontology represented by the fossil mammal *Synthetoceras tricornatus*; depositional processes and eolian stratigraphy represented by a dust storm; stratigraphy, hydrology, and geomorphology represented by playas incised into the High Plains; and hydrology represented by a windmill on the High Plains. Line drawings by Jamie H. Coggin.

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Introduction

T. C. Gustavson, V. T. Holliday, and G. E. Schultz

This field guide summarizes recent interpretations of the upper Cenozoic stratigraphy of parts of the Southern High Plains and Rolling Plains in northwestern Texas and eastern New Mexico. Processes that formed lacustrine basins, which pond surface water on the High Plains that is recharged to the Ogallala aquifer, are also described. Field trip stops were selected to illustrate the depositional facies and paleosols of Cenozoic formations, Cenozoic local faunas, and lacustrine basins. Eolian facies (loess and sheet sands) and calcic paleosols that characterize the Quaternary Blackwater Draw Formation and the upper part of the Neogene Ogallala Formation (Group) are emphasized (Stops 1, 2, 4, 6, 7, 9, 11, 12, and 13) (fig. 1). Fluvial facies in the Ogallala Formation are described from exposures at both the east and northwest erosional limits of the unit (Stops 3, 6, 10, 12, and 13). Sections in the Ogallala, Blanco, and Quaternary Tule Formations containing local vertebrate faunas of Clarendonian age (Stops 6 and 14), Hemphillian age (Stops 3, 6, 15, 16, and 17), Blancan age (Stop 5) and Irvingtonian age (Stop 8) are described (locations of Stops 14–17 are given on separate maps). Evidence of the geomorphic processes of subsidence induced by piping and subsidence related to dissolution of $CaCO_3$, which led to the development of lake basins on the High Plains, is discussed at Stop 2.

Keywords: Blackwater Draw, field trip guidebooks, High Plains, New Mexico, Ogallala, paleosols, playas, Quaternary, stratigraphy, Tertiary, Texas, vertebrate paleontology

Regional Geologic Setting

Structural Development

The Palo Duro Basin, which underlies part of the Texas Panhandle and eastern New Mexico is bounded by the Amarillo Uplift–Wichita Mountains trend on the northeast and by the Matador Arch–Roosevelt Uplift on the south (fig. 2). To the west the Palo Duro and Tucumcari Basins are bounded by the Pedernal and Sierra Grande Uplifts. To the north the Dalhart and Anadarko Basins are separated by the Cimarron Arch. These positive structural elements resulted from faulting and uplift that began during the Paleozoic, perhaps as early as the Late Cambrian (Birsa, 1977).

During the Pennsylvanian and Early Permian, tectonic movement along the Amarillo Uplift and Matador Arch controlled sedimentation and facies distribution in the Palo Duro Basin (Dutton and others, 1979). Epeirogenic uplift during the Triassic resulted in the terrestrial basin that contains the Dockum Group (McGowen and others, 1979). By Cretaceous time the region had subsided below sea level. Epeirogenic movements continued into the Tertiary and resulted in uplift of Cretaceous marine strata to more than 940 m (3,100 ft) above sea level in the study area (Eifler, 1968; Gable and Hatton, 1983; Budnik, 1984).

Nontectonic deformation, in the form of regional subsidence induced by extensive dissolution of Permian bedded salt, has occurred beneath large parts of the Southern High Plains and surrounding areas (Gustavson and others, 1980, 1982; Johnson, 1981; Gustavson and Budnik, 1985; Gustavson and Finley, 1985; DeConto and Murphy, 1986; Gustavson, 1986a, b; Reeves and Temple, 1986; Boyd and Murphy, 1987; McGookey and others, 1988). Several of the lacustrine basins on the High Plains may have formed partly from dissolution-induced subsidence during the late Tertiary or Quaternary (Baker, 1915; Gustavson and Budnik, 1985; Gustavson and Finley, 1985; Reeves and Temple, 1986). Other arguments suggest that dissolution beneath the High Plains occurred during the Triassic and could not have affected Tertiary or Quaternary lacustrine basins (DeConto and Murphy, 1986).

Stratigraphy

During the early Paleozoic, episodes of deposition on shallow marine shelves alternated with periods of erosion in the vicinity of the

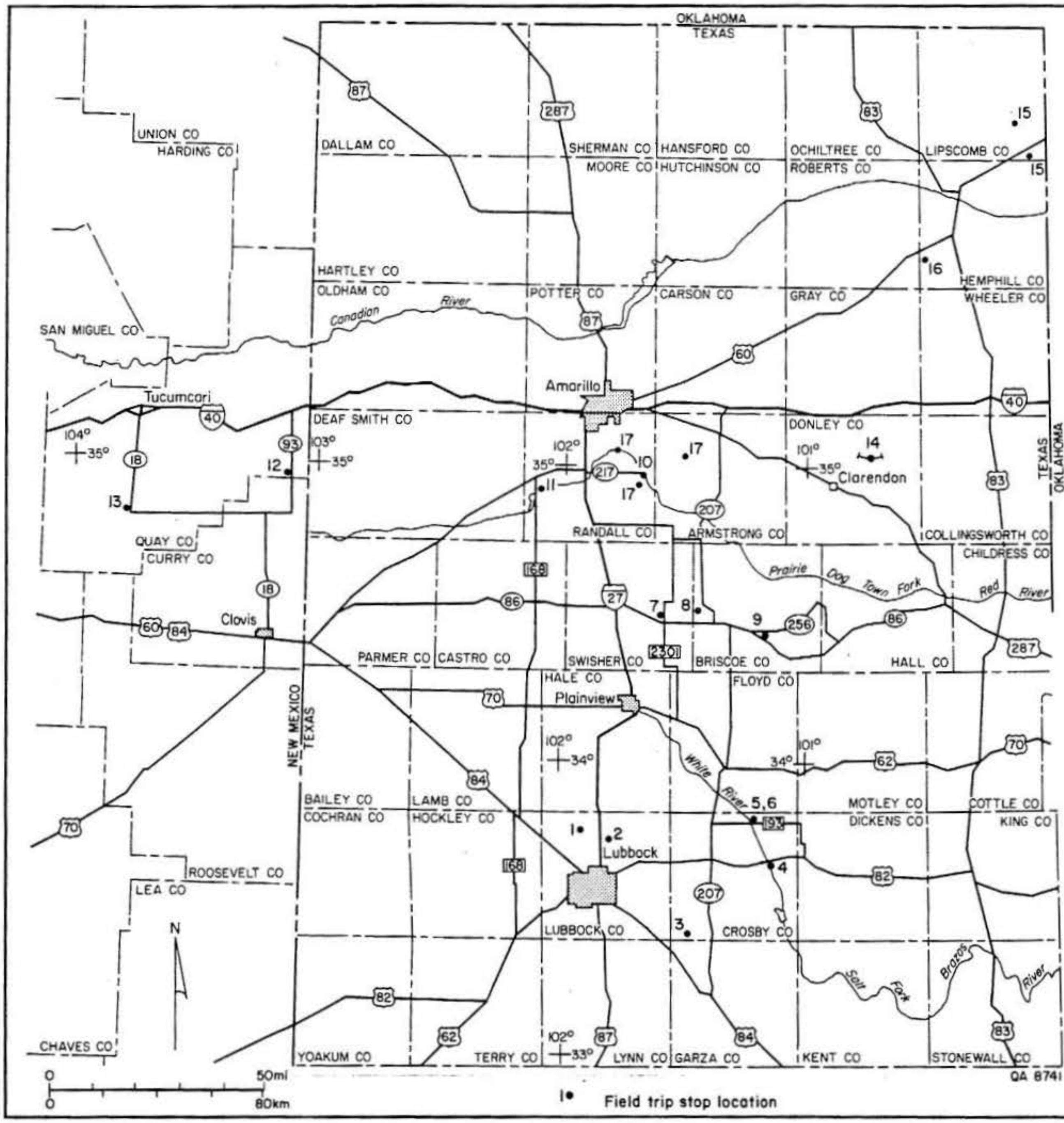

Figure 1. Location of Field Trip Stops 1 through 17 in Texas and eastern New Mexico.

Texas Panhandle and eastern New Mexico. Terrigenous clastics, informally called granite wash, were derived from, and deposited as fan deltas near, the Matador Arch and Amarillo Uplift during the Pennsylvanian and Early Permian as a result of uplift of these features (Handford and Dutton, 1980). Marine sedimentation during the Late Pennsylvanian and Early Permian was dominated by shelf-margin carbonates while the deeper parts of the basin were being filled by fine-grained terrigenous clastic sediments. During the middle and Late Permian a wide, low-relief marine shelf developed, and salt, anhydrite, dolomite, limestone, and red beds were deposited (Presley, 1979a, b, 1980a, b; McGillis and Presley, 1981;

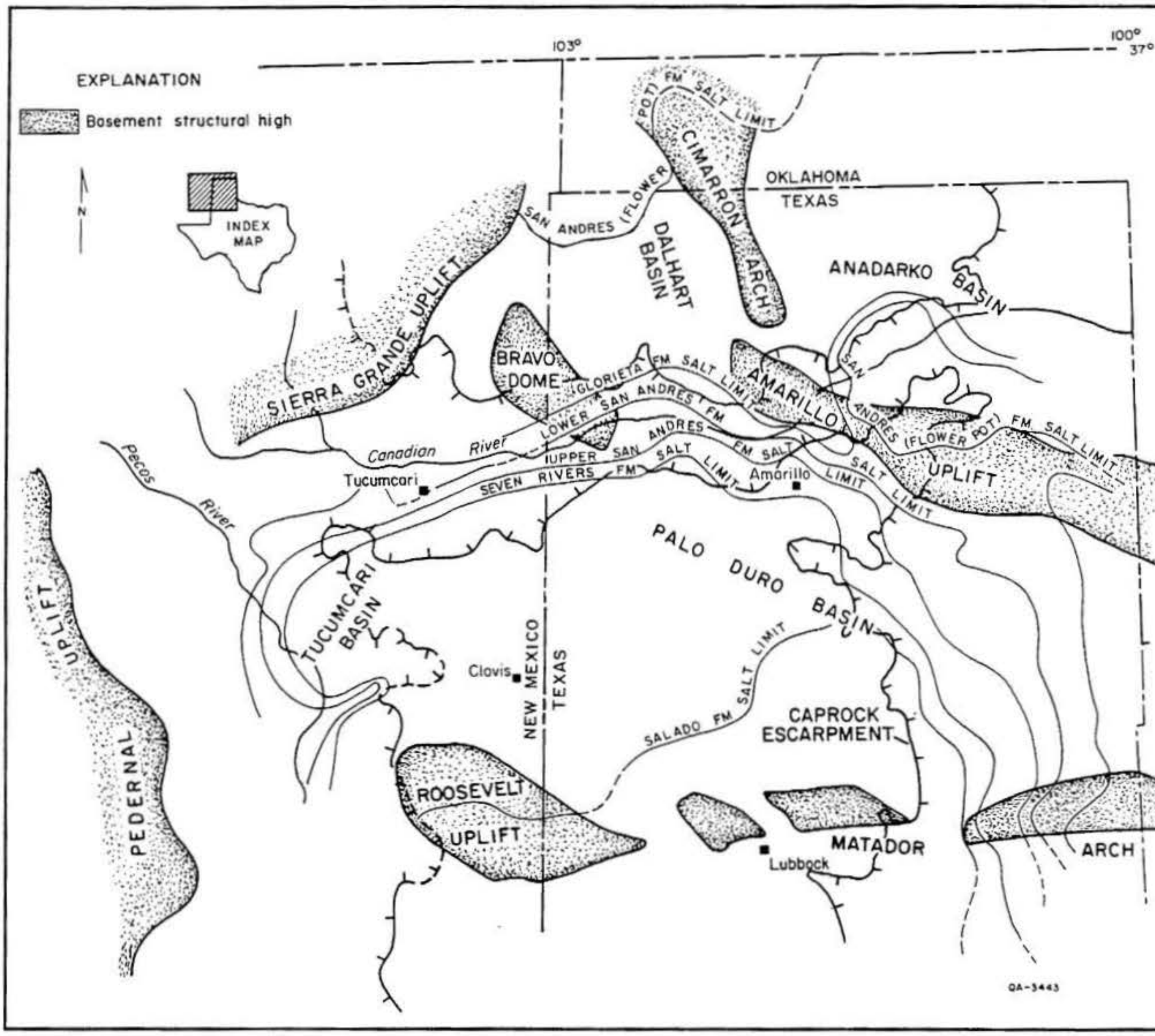

Figure 2. Major structural elements, Texas Panhandle and surrounding areas. After Nicholson (1960). Limits of Permian bedded salts are closely associated with structural margins of Palo Duro Basin; lines illustrate updip limit of Permian bedded salt. Each of these units (Salado-Glorieta Formations) has lost substantial thicknesses of salt. Collectively, the salt-limit lines approximate a zone of salt dissolution that rims west, north, and east margins of Palo Duro Basin. Structurally high salt units are most likely to be affected by salt dissolution (Gustavson and Finley, 1985).

Hovorka and others, 1985; Fracasso and Hovorka, 1986).

Fluvial, deltaic, and lacustrine sandstones and mudstones of the Triassic Dockum Group unconformably overlie Permian strata (McGowen and others, 1979). Locally in eastern New Mexico Jurassic marine strata unconformably overlie the Dockum Group. In the Texas Panhandle and parts of eastern New Mexico, Lower Cretaceous Edwards Limestone also unconformably overlies the Dockum Group. During the Late Cretaceous and early Tertiary, extensive erosion exposed Triassic, Jurassic, and Lower Cretaceous strata. Fluvial and eolian sediments of the Neogene Ogallala Formation overlie the Tertiary erosional surface (Seni, 1980; Winkler, 1984, 1985, 1987; Gustavson and Holliday, 1985; Gustavson and Winkler, 1988; Wilson, 1988). Locally, upper Pliocene lacustrine deposits of the Blanco Formation and Cita

Canyon lake beds overlie the Ogallala Formation (Holliday, 1988). The Quaternary Blackwater Draw Formation, which is composed primarily of eolian sediments, overlies the Ogallala Formation as well as the Pliocene lacustrine formations (Holliday, 1984, 1988; Gustavson and Holliday, 1985; Machenberg and others, 1985). Lacustrine sediments of the Tule Formation are interbedded with sediments of the Blackwater Draw Formation (Gustavson and Holliday, 1985; Schultz, 1986). Thick, widespread Quaternary eolian, fluvial, and lacustrine deposits, containing sediments eroded from the Caprock Escarpment, overlie Triassic and Permian strata on the Rolling Plains at the foot of the Caprock Escarpment (Caran and Baumgardner, 1990).

Hydrogeology

Studies of the hydrology of the Palo Duro Basin indicate that the lower, or Wolfcampian brine, aquifer is separated from aquifers in the overlying Ogallala Formation and Dockum Group by an aquitard containing Upper Permian evaporites and salt-cemented terrigenous clastics. Regional flow of the Wolfcampian aquifer is toward the northeast (Smith and others, 1983). Ground-water movement through the evaporite aquitard is minimal; flow is to the east and southeast (Dutton, 1983). Ground water in the unconfined Ogallala aquifer and in the Dockum aquifer also flows toward the east and southeast (Dutton and Simpkins, 1986; Nativ, 1988). Recharge of the Ogallala is primarily from surface water ponded in small playa-lake basins on the High Plains (Osterkamp and Wood, 1987; Wood and Osterkamp, 1987; Nativ, 1988). Numerous fresh-water springs, which mark discharge points of the Ogallala and Dockum aquifers, lie along the Caprock Escarpment at the base of the Ogallala Formation and to a lesser extent at the base of sandstones in the Dockum Group (Brune, 1981). A preliminary model of ground-water movement from west to east across the eastern Caprock Escarpment suggests that fresh water from the Ogallala Formation leaks downward into the zone of salt dissolution in Permian strata (fig. 2) and eastward beneath the Rolling Plains (Simpkins and Fogg, 1982). Springs discharge brines derived from dissolution of halite in several areas east of the escarpment (U.S. Army Corps of Engineers, 1975; Richter and Kreitler, 1986). Na-Cl ground waters from the salt dissolution zone beneath the Southern High Plains have ^{14}C ages of less than 16,200±3,500 yr and 23,500±1,000 yr and salinities of 95,000 to 68,000 ppm (Dutton, 1987).

Geomorphology and Physiography

Field trip stops are located on the High Plains, Canadian River Breaks, Rolling Plains, and eastern Caprock Escarpment, which separates the High Plains from the Rolling Plains (fig. 3). Regional physiography is largely controlled by subsidence resulting from dissolution of Permian salt. For example, the Canadian and Pecos River valleys overlie areas where as much as 200 m (660 ft) of Permian salt has been dissolved (fig. 2). These valleys were probably formed by diversion of Tertiary drainage due to dissolution and subsidence (Gustavson and Finley, 1985; Gustavson, 1986a).

The Southern High Plains, which is primarily underlain by the Blackwater Draw Formation, has a flat, low-relief surface partly covered with small playa-lake basins. Playa-lake basins as well as some of the larger lake basins have been variously attributed to deflation, dissolution of salt or soil carbonate, compaction, or animal activity (Gilbert, 1894; Baker, 1915; Evans and Meade, 1945; Reeves, 1972; Gustavson and others, 1980; Reeves and Temple, 1986; Osterkamp and Wood, 1987). Drainage of the High Plains is mostly internal into these lake basins. Widely separated draws having narrow drainage basins slope to the east and southeast. Adjacent draws do not have common drainage divides but are separated by broad interfluves containing numerous playa-lake basins.

The relief of the Caprock Escarpment is maintained by resistant calcretes and silicified zones of the Ogallala Formation and resistant sandstones of the Dockum Group and Permian Quartermaster Formation. The escarpment parallels and overlies the west margin of the zone of extensive dissolution of Permian bedded salt (Gustavson and others, 1981; Gustavson and Finley, 1985).

The Rolling Plains is developed primarily on easily eroded Permian strata of the Quartermaster and Whitehorse Formations (Bath, 1980; Gustavson and others, 1981; Gustavson, 1986b; Simpkins and Gustavson, 1987), and is locally highly dissected by modern streams. In most upland areas, however, topography is rolling; hence the name Rolling Plains. Drainage on the Rolling Plains tends to parallel the margins of subsurface salt units undergoing dissolution,

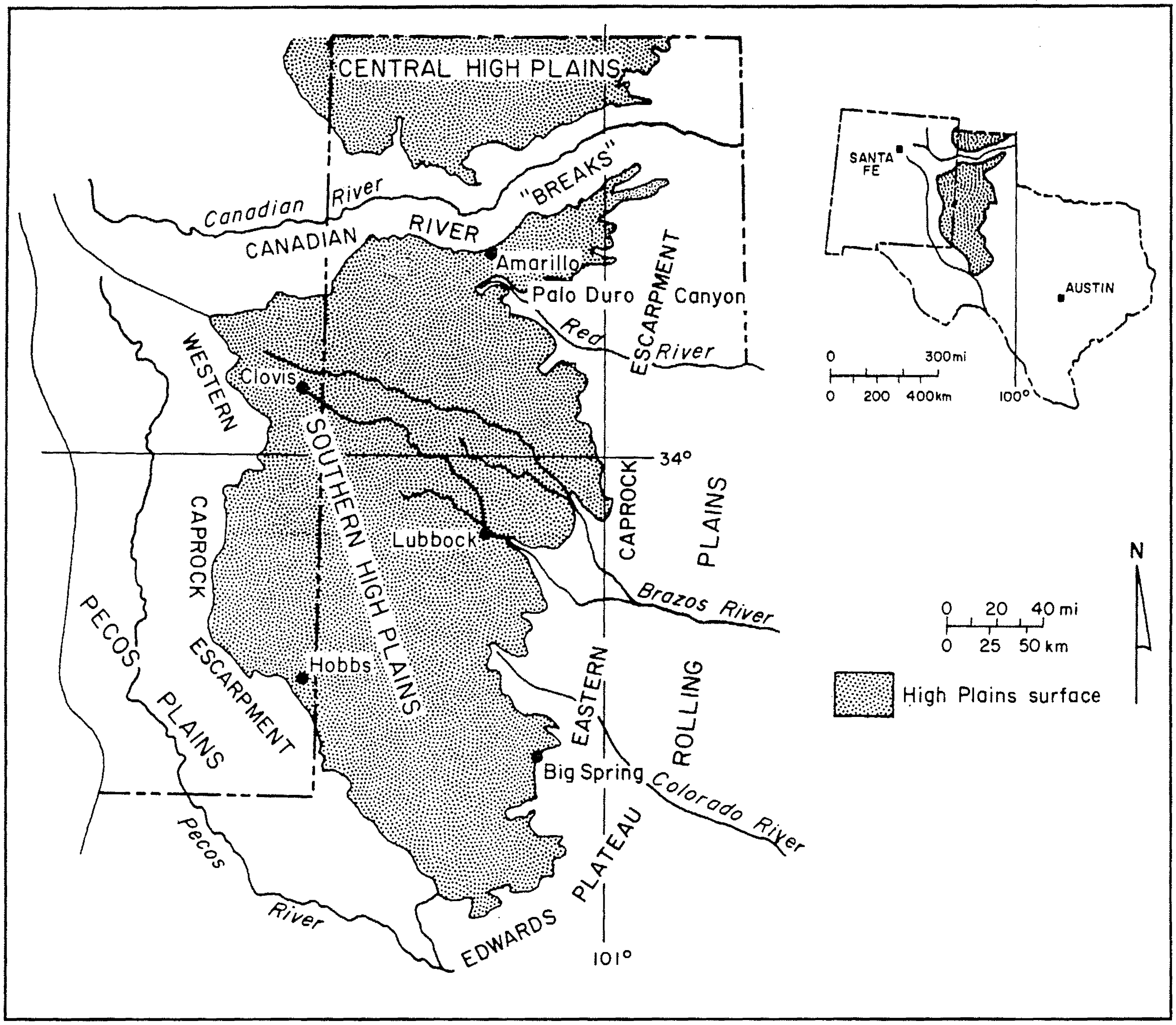

Figure 3. Physiography of parts of Southern and Central High Plains and surrounding area in Texas and New Mexico.

and karst features resulting from dissolution-induced subsidence are common (Simpkins and others, 1981; Gustavson and others, 1982; Gustavson and Finley, 1985).

Climate

Climate in the Texas Panhandle and eastern New Mexico is continental semiarid to subhumid (30 to 55 cm [12 to 22 inches] annual precipitation), and mean annual precipitation varies widely (Orton, 1964; U.S. Department of Commerce, 1978a, b). Approximately 75 percent of the annual precipitation occurs between the end of March and the beginning of October. Annual pan evaporation is approximately 158 cm (62 inches) (Kier and others, 1977). Rapid temperature changes and large ranges in daily and annual temperature are characteristic of the region (Orton, 1964). The calcic soils that are developing in the Texas Panhandle and eastern New Mexico are caused partly by the climatic conditions of the area and partly by the influx of $CaCO_3$ contained in eolian dust and rainfall solutes (Jenny, 1941; Machette, 1985).

Middle Tertiary Erosional Surface

Permian, Triassic, and Cretaceous strata underlie the middle Tertiary erosional surface beneath the High Plains. A structure-contour map on the base of the Ogallala Formation (High Plains aquifer) (fig. 4) can closely approximate this surface because in most areas the base of the High Plains aquifer is the base of the Ogallala Formation. However, small parts of the Triassic Dockum Group are locally included in the High Plains aquifer.

Paleotopographic elements are clearly discernible in many areas, and aligned groups of V-shaped contour lines that point upslope indicate a system of major paleovalleys (fig. 4). These relationships are clear on the part of the erosional surface that underlies the Southern High Plains; however, much of the area that underlies the Central High Plains, which lies north of the Canadian River Valley, has been affected by subsidence resulting from salt dissolution, and pre-Ogallala erosional topography is no longer identifiable (Gustavson and Finley, 1985). In the Southern High Plains, paleostream segments appear to have flowed to the southeast over parts of the paleosurface. In northern Hale, southern Swisher, and southern Castro Counties, a major paleovalley contained streams that flowed west to east. This paleovalley extends northwestward into southeast Quay County, New Mexico. In southeast Deaf Smith and southwest Randall Counties, Texas, a paleostream divide lies 150 m (500 ft) above the paleostream valley in north Hale County (fig. 4). Other divides are in southeast Hale and central Floyd Counties.

Ogallala Formation (Stops 3, 4, and 9 through 17)

The Miocene–Pliocene Ogallala Formation covers much of the Great Plains, extending more than 1,200 km (800 mi) from South Dakota to Texas, including most of northwestern Texas and parts of eastern New Mexico (fig. 5). In Texas and eastern New Mexico, the Ogallala was deposited unconformably on Permian, Triassic, Jurassic, and Cretaceous strata. Thickness of the Ogallala reflects the paleotopography on the underlying middle Tertiary erosional surface and varies from less than 30 m (100 ft) to more than 150 m (500 ft) beneath most of the Southern High Plains. Locally, above subsidence basins induced by salt dissolution (Gustavson and others, 1980; Gustavson and Finley, 1985), thicknesses may exceed 235 m (800 ft). Typically, however, areas of thick accumulations lie in paleovalleys, and thin accumulations overlie paleotopographic divides.

The Ogallala Formation was first described by Darton (1899) in Nebraska. Baker (1915) recognized that the upper Cenozoic deposits of the Texas Panhandle resulted from uplift and erosion of the Rocky Mountains to the west and that these deposits were primarily fluvial and to a lesser extent eolian.

Most authors, including Johnson (1901), Sellards and others (1932), Smith (1940), Bretz and Horberg (1949a, b), Frye and Leonard (1964), Frye (1970), Seni (1980), and Reeves (1984b), thought that the Ogallala Formation in Texas and New Mexico contained primarily fluvial sediments and that the fluvial part originated either as a series of deposits from ephemeral streams or as a great alluvial plain (bajada). It was commonly accepted that an erosional surface containing deep, wide valleys was buried during the late Tertiary and that the present High Plains surface was a reflection of the depositional slope of the Ogallala. In general, the importance of eolian sedimentation has not been recognized. However, Evans and Meade (1945), Reeves (1972), Hawley (1984), Gustavson and Holliday (1985), Winkler (1987), and Gustavson and Winkler (1988) described substantial eolian sections in the Ogallala.

Some recent studies in the Texas Panhandle emphasize that the depositional environment of the Ogallala Formation was similar to that of both modern and ancient wet alluvial fans. Seni (1980) compared the Ogallala to the Kosi River fan in Nepal and India (Gole and Chitale, 1966). The distal portion of the Kosi fan is fine grained, consisting mostly of sand and fine sand. Seni (1980) thought the texture of the Kosi fan and its large size (15,400 to 20,500 km^2 [6,000 to 8,000 mi^2]) made it a suitable modern analog of the Ogallala Formation. Reeves (1984b) suggested several ancient analogs including the sandstone deltaic facies of the Van Horn Formation, Texas (McGowen and Groat, 1971), the East Rand fan of the Witwatersrand Basin, Africa (Pretorius, 1974), and the Salt Wash Member of the Morrison Formation (Mullens and Freeman,

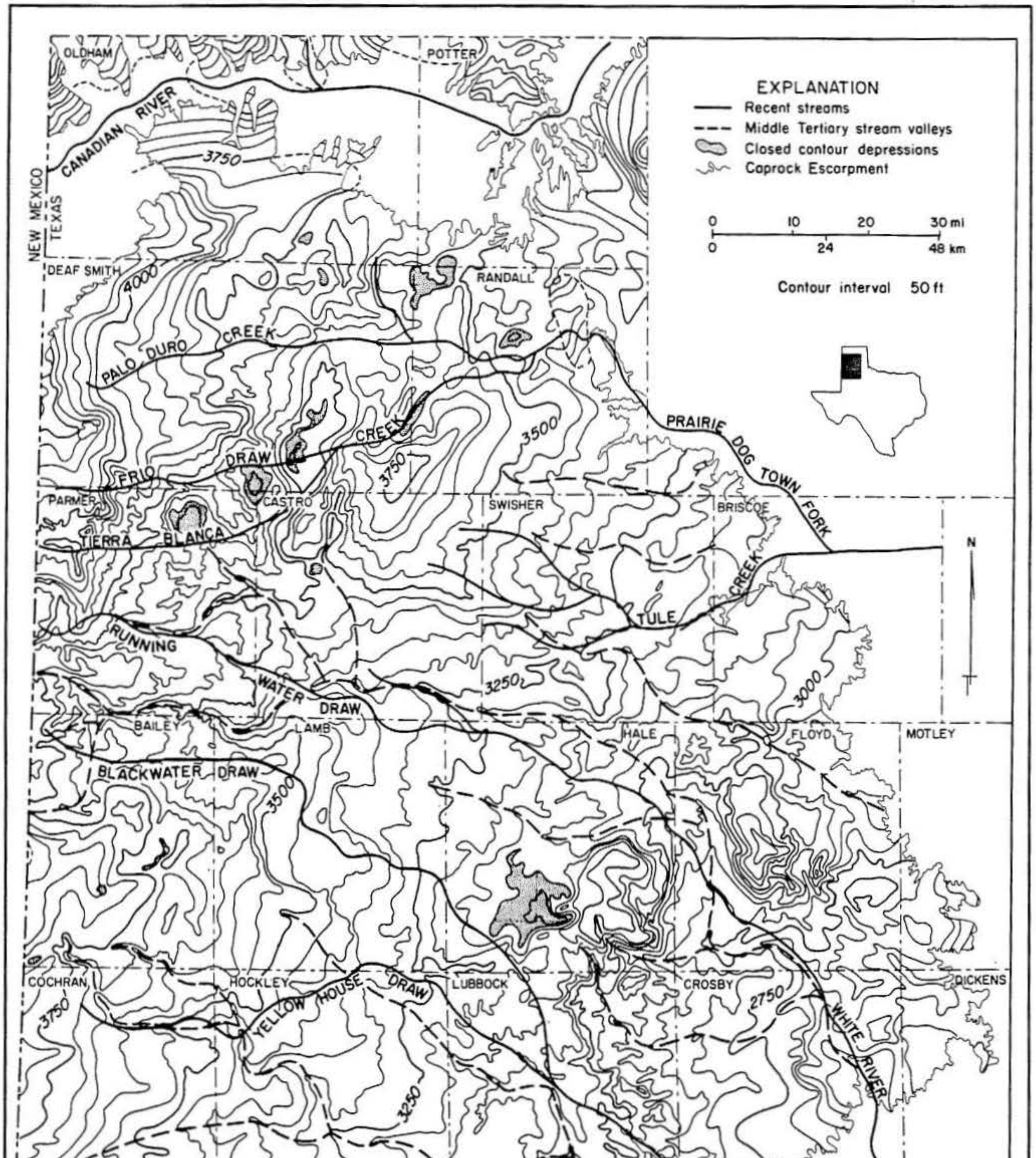

Figure 4. Structure-contour, or paleotopographic, map on base of Ogallala Formation. Derived from Knowles and others (1982) for Texas part and Cronin (1969) for New Mexico part. Paleostreams are interpreted from contour V's pointing upslope. Modern drainage superimposed to show similarity between modern and paleodrainage. After Gustavson and Finley (1985).

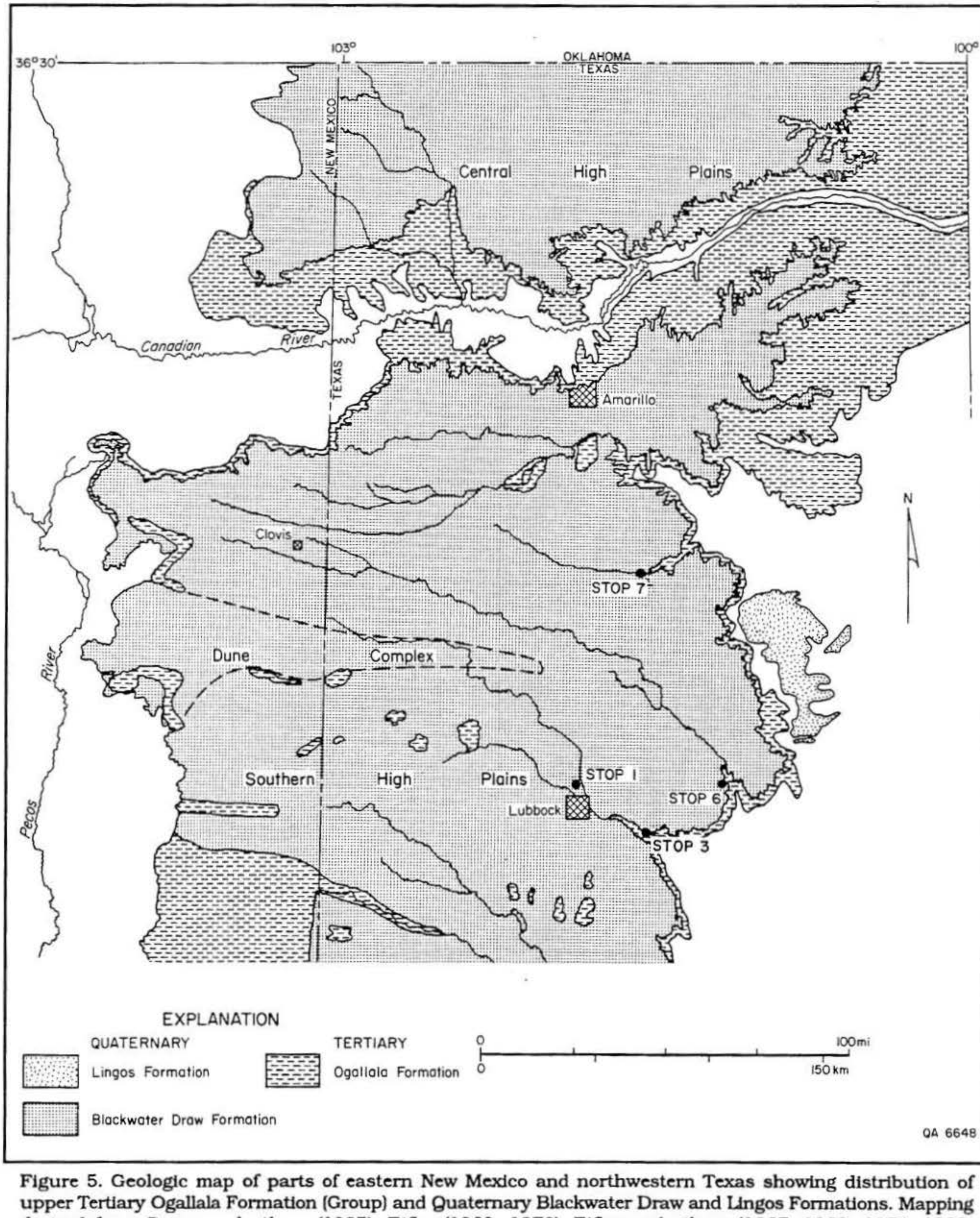

Figure 5. Geologic map of parts of eastern New Mexico and northwestern Texas showing distribution of upper Tertiary Ogallala Formation (Group) and Quaternary Blackwater Draw and Lingos Formations. Mapping derived from Caran and others (1985), Eifler (1969, 1976), Eifler and others (1967, 1968, 1974, 1983, 1984), Eifler and Fay (1970), and Eifler and Reeves (1974, 1976, 1977).

1957), as well as an additional modern analog, the Riverine Plain, Australia (Schumm, 1968).

Gustavson and Holliday (1985), Winkler (1985), and Gustavson and Winkler (1988) suggested that fluvial facies of the Ogallala were similar to deposits of recent intermittent high-energy braided streams of variable water and sediment discharge (McKee and others, 1967) and that the fine-grained eolian part of the Ogallala resembled eolian sand sheets (Fryberger and others, 1979; Kocurek and Neilson, 1986).

Fluvial sections of the Ogallala, commonly overlain by eolian sections, lie along the axes of broad pre-Ogallala paleovalleys that trend southeastward across the middle Tertiary erosional surface. Upland sections, consisting predominantly of eolian sediments, are high on the flanks or crests of paleodrainage divides. Calcic paleosols are present throughout much of the Ogallala, and vertebrate fossil assemblages indicate a savannalike environment (Winkler, 1985; Gustavson and Winkler, 1988). These relationships indicate that the Ogallala Formation was not deposited as a wet alluvial fan (Seni, 1980) but rather as a series of alluvial valley fills, which are interbedded with and overlain by eolian sediment (Gustavson and Winkler, 1988) laid down in an arid to semiarid climate.

The abrupt cessation of fluvial sedimentation in the Ogallala Formation suggests a diversion of streams flowing across the Ogallala landscape. This interpretation is consistent with the suggestions by Gustavson and Finley (1985) and Gustavson (1986a) that most Ogallala drainage systems were diverted during the Tertiary to form the Pecos and Canadian Rivers.

The thick eolian sections overlying paleostream divides represent a long period of intermittent eolian sedimentation. The eolian sediments in the lower parts of these sections may have been derived from ephemeral sandy, braided Ogallala streams. However, the upper parts of the eolian sections overlying the interfluves, as well as the eolian portions overlying the paleovalley fills, may have had different source areas. Streams on the High Plains had been diverted to form the Pecos and Canadian Rivers, and the floodplains of these rivers became sources of eolian sediment.

The end of deposition of the Ogallala Formation is marked by the development of the massive Ogallala Caprock caliche (calcrete) (fig. 6). According to Darton (1899), the Caprock caliche "is clearly a secondary deposit, formed after the deposition of the sediments that it binds together, by the precipitation of . . . calcium carbonate dissolved in ground water." Darton (1899) thought that caliches were the product of carbonate deposition by evaporation of shallow ground waters drawn near the surface by capillary action. Although his interpretation of the process by which caliche forms is now recognized as incorrect, Darton (1899) correctly observed that caliches form only in arid and semiarid areas and, therefore, that climatic conditions during the late Cenozoic were like those of the present.

Elias (1931) asserted that the Caprock caliche in Wallace County, Kansas, contained an alga (*Chlorellopsis bradleyi* Elias) that required a permanent body of water for its growth. On the basis of the presence of the alga, he postulated a lacustrine environment for the deposition of the Caprock caliche. Many objected to this hypothesis, including Smith (1940), who argued that a widespread lake on the High Plains was improbable because it would have required reducing the tilt of the High Plains to nearly horizontal during deposition of the lake beds and then returning the High Plains to an easterly tilt of 2 to 2.5 m/km (10 to 12 ft/mi).

Bretz and Horberg (1949a, b) identified and described the formation of caliche as a pedogenic process. On the basis of petrographic analyses of pisolitic parts of the Caprock caliche, Swineford and others (1958) established that it predominantly developed by soil-forming processes. The work of Smith (1940), Bretz and Horberg (1949a, b), Brown (1956), and Swineford and others (1958) essentially ended the controversy over the origin of the Caprock caliche. Although many authors have discussed the various attributes of the Caprock caliche, pedogenic and ground-water calcretes and silcretes within the Ogallala, especially those at the base of the formation, have been either ignored or mentioned only briefly. The development of thick, laminated, brecciated, and recemented pisolitic calcretes such as the Ogallala Caprock caliche requires extended periods of landscape stability, at least several hundred thousand years (Bachman and Machette, 1977; Gile and others, 1981). Apparently neither extensive deposition nor erosion occurred in the High Plains during formation of the Ogallala Caprock.

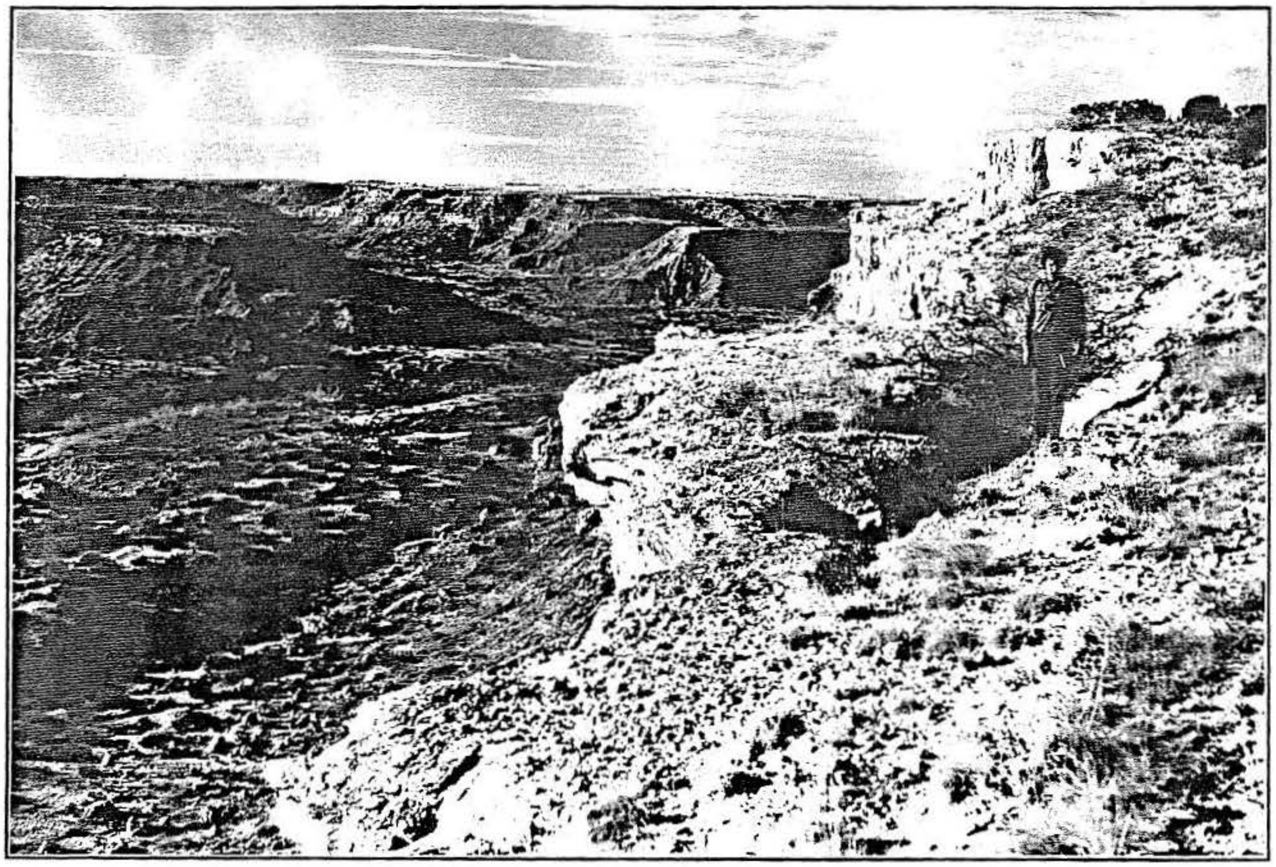

Figure 6. View toward north of northeast rim of Palo Duro Canyon. The Caprock Escarpment is partly supported by erosionally resistant units including Caprock caliche (calcrete), which is present near top of escarpment. Figure is standing on lower of two calcretes, which locally make up Caprock caliche.

Blanco Formation (Stop 5)

The upper Pliocene Blanco Formation is exposed in the walls of Blanco Canyon in Crosby County, Texas, where it rests unconformably on the Ogallala Formation (Bridwell Formation of the Ogallala Group of Evans, 1956, 1974, and Winkler, 1985). Similar units exposed along the valley of Yellow House Draw in Lubbock, Texas, have been correlated with the Blanco Formation at Blanco Canyon. Blanco deposits are a localized lacustrine-basin accumulation according to Evans and Meade (1945), although a fluvial origin was advocated by Gidley (1903a), Matthew (1924a), and Frye and Leonard (1957). More recently both lacustrine and fluvial facies have been identified (Pierce, 1973). Near the center of the basin, Blanco strata mostly contain very fine sand, primary dolostone, and magnesium-rich clays (attapulgite and sepiolite) and only minor amounts of sheetwash gravel. Near the margin of the basin, limestone and coarser clastics, including caliche gravel and cobbles in arroyo fans, are found, whereas dolostone and magnesium-rich clays become rarer. The Blanco Formation is capped by a Stage IV calcrete (see Machette, 1985, for descriptions of calcrete stages) and is in turn overlain unconformably by the Quaternary Blackwater Draw Formation (Holliday, 1988).

Although the Blanco Formation in Blanco Canyon is overlain unconformably by the Blackwater Draw Formation, elsewhere it may be interbedded with that formation. A 1-m-thick lens of pinkish-orange very fine silty sand that appears similar to sediment of the Blackwater Draw Formation is interbedded with the Blanco Formation (?) in a quarry approximately 10 km northwest of Lubbock and on the north side of U.S. Highway 84. If this material is in fact a lens of Blackwater Draw sediments interbedded with the Blanco Formation, then the lower part of the Blackwater Draw is coeval with at least part of the Blanco Formation.

The age of the Blanco Formation is based mainly on fossil vertebrates, tephrochronology, and magnetic stratigraphy. Vertebrate remains that make up the Blanco Local Fauna are thought to be a fauna of late Blancan (late Pliocene) age. The Blanco Formation strata are overlain by the Blackwater Draw Formation, which contains the Guaje Volcanic Ash (~1.4 Ma old [Izett, 1977], 1.77 Ma old [Boellstorff, 1976]) near the base of the formation. The Blanco Ash lies near the middle of Blanco strata and has been dated at 2.8±0.3 Ma (Boellstorff, 1976). Paleomagnetic studies of the Mount Blanco section including both ash beds have determined that the entire section is reversely magnetized (Lindsay and others, 1975), indicating that the Mount Blanco section and the Blanco Local Fauna lie in the lower Matuyama (reversed) magnetic interval and are between 1.4 and 2.4 Ma old. Consequently, although the Blanco Local Fauna is late Pliocene, the uppermost strata of the Blanco Formation may in fact be Pleistocene in age.

Blackwater Draw Formation (Stops 1, 6, and 7)

The Blackwater Draw Formation is the principal surficial deposit of most of the High Plains of Texas and New Mexico and supports the lucrative agricultural industry of the region (fig. 5). The unit is a sheetlike body of sediment that varies in texture from sandy in the southwest to clayey in the northeast (fig. 7) and varies in thickness from a feather edge in the south and southwest to at least 27 m in the north and northeast (Reeves, 1976). Given the extent (roughly 100,000 km^2) and economic importance of the Blackwater Draw Formation, the relatively little research on its age and depositional origin is surprising. Frye and Leonard (1957) were the first to study these deposits formally. They used the informal term "cover sands" for this sediment, considering it to be of "Illinoian" age because it apparently was stratigraphically above lacustrine sediments of "Kansan" age (the Tule Formation) and below lacustrine sediments of "Wisconsinan" age (the Tahoka Formation). They acknowledged that the "cover sands . . . may include more than one age of deposit" (Frye and Leonard, 1957, p. 28). They identified the eolian Judkins Formation (Huffington and Albritton, 1941), which lies adjacent to the southwest part of the Texas High Plains, as part of the complex called "cover sands," concluding that the cover sands were of eolian origin, probably derived from the Pecos River valley to the west and southwest. Frye and Leonard (1964, 1965) also identified a strongly developed soil formed in the upper part of the cover sands as a "Sangamon soil."

Reeves (1976) proposed that the informal term "cover sands" be replaced by the formal designation "Blackwater Draw Formation"; he thought the unit had been deposited during the Illinoian. Reeves also noted that the term "Sangamon soil" should not be applied to the regional surface soil because of evidence of multiple soil-formation periods. Reeves (1976, p. 222) also identified a "thin cover of loess" overlying the Blackwater Draw Formation in the northeast portion of the Llano Estacado (Southern High Plains).

Several other investigations shed new light on the physical properties, age, and origin of the Blackwater Draw Formation. The mineralogy of selected soils at the surface of the Blackwater Draw Formation was studied by Allen and others (1972). The coarse fraction of the sediments contains primarily quartz and some feldspar, and the clay minerals are dominantly smectite and illite. Seitlheko (1975) provided the first quantitative data on textural variation of the surface soil of the Blackwater Draw Formation and presented several significant conclusions. He clearly showed, for example, that the Blackwater Draw Formation fines from southwest to northeast, which supports the hypothesis that the sediments originated in the Pecos Valley and were deposited by wind. Furthermore, Seitlheko showed that the silty and clayey sediments in the northeast portion of the area are the result of this downwind fining and not a separate "loess cover." Allen and Goss (1974) and Hawley and others

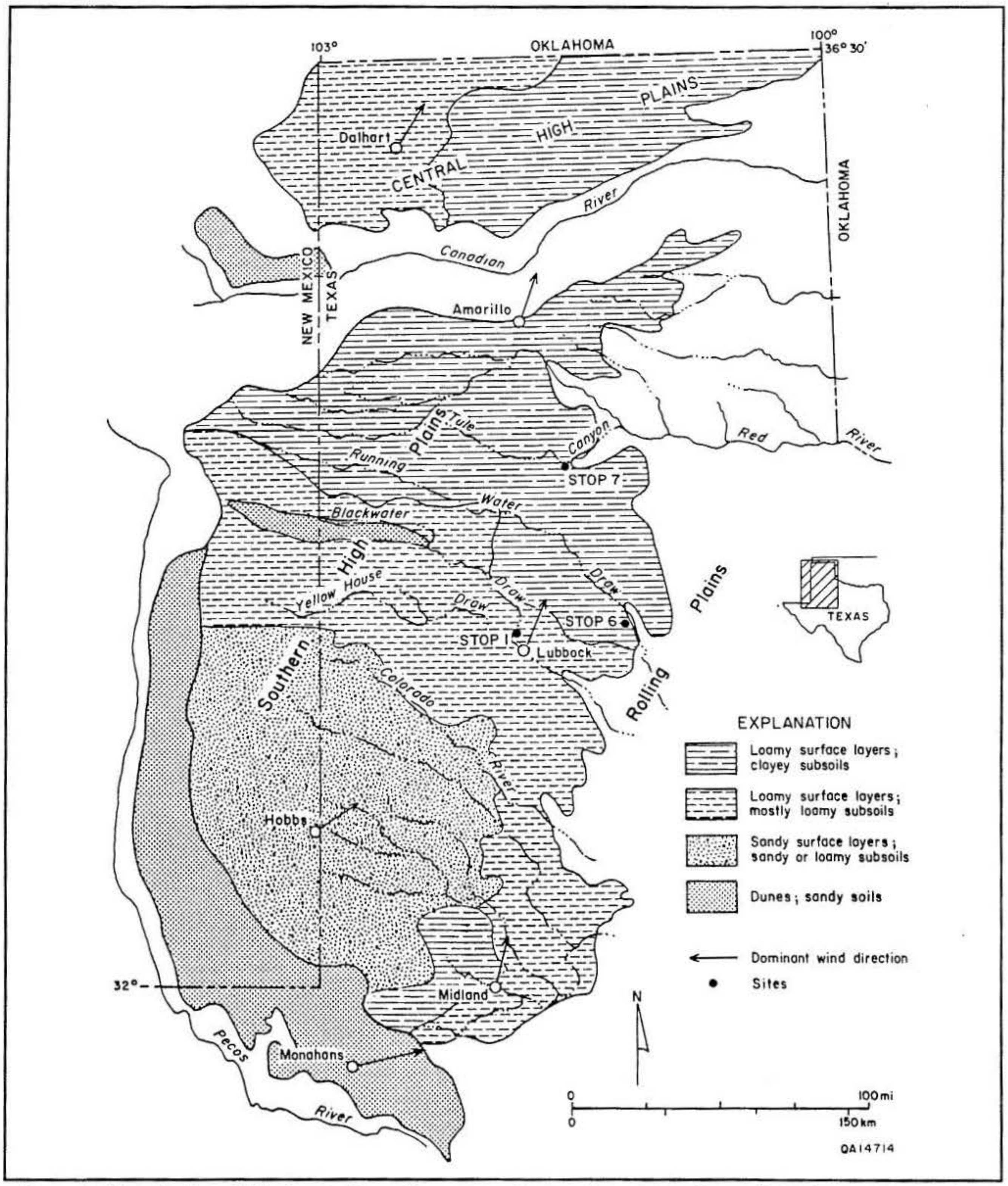

Figure 7. Distribution of Blackwater Draw Formation, showing fining of surface soils to the northeast. After Chepil and others (1964) and Godfrey and others (1973). Coarsest soils occur east and north of the Pecos and Canadian Rivers, suggesting that these may be the source areas for at least the upper part of Blackwater Draw Formation. Modern dominant wind directions shown.

(1976) recognized that, locally, the Blackwater Draw Formation may contain as many as seven well-developed soils, including the surface soil, indicating that the formation contains a number of individual layers, each deposited episodically. Limited absolute age control, discussed more fully at the individual stops and in Holliday (1989, in press) suggests that deposition took place throughout much of the Pleistocene.

A preliminary paleomagnetic study of the lowermost of five buried soils in the Blackwater Draw Formation near Bushland, Texas (approximately 66 km [10 mi] west of Amarillo), demonstrates that the remnant magnetization, apparently acquired during pedogenesis, is dominantly reversed. This suggests that the soil formed during the last reversed-polarity epoch, which ended about 0.79 m.y. B.P. (E. E. Larson, personal communication, 1984).

Tule Formation (Stop 8)

The Pleistocene Tule Formation is exposed around the margin of Mackenzie Reservoir at the boundary of Swisher and Briscoe Counties, Texas. These strata occupy a large erosional basin and unconformably overlie both the Triassic Dockum Group and the Miocene–Pliocene Ogallala Formation. Stratigraphy of the Tule Formation was discussed by Evans and Meade (1945), Frye and Leonard (1957), Reeves (1976), and Schultz (1986). Tule Formation sediments generally have been interpreted as lacustrine deposits, although Frye and Leonard (1957) thought they were fluvial. The presence of thin limestone and dolostone beds and laminated, horizontally bedded mudstones strongly suggests that the Tule Formation is lacustrine.

Evidence of the age of these beds recently has been reviewed by Schultz (1977c; 1986; Stop 8, this guidebook, p. 60). On the basis of vertebrate remains and the presence of Lava Creek B Ash near the top of the Tule Formation and the Cerro Toledo-X Ash near the base of the formation (Izett, 1977; Izett and Wilcox, 1982), Schultz suggested that the Tule beds span most of the Irvingtonian Mammal Age (early and middle Pleistocene). Previously, Evans and Meade (1945) referred to these beds as middle Pleistocene, whereas Frye and Leonard (1957) thought they were Kansan in age.

The Clarendon Fauna and the Clarendonian Land Mammal Age (Stop 14)

Establishment of "Provincial" and "Land Mammal" Ages

The Texas Panhandle is significant in Tertiary vertebrate paleontology and biostratigraphy because it contains the type localities of faunas upon which the Wood and others (1941) committee based three of the Provincial Ages for the Tertiary: the Clarendonian (Stop 14), the Hemphillian (Stops 15 through 17), and the Blancan (Stop 5). The first two were identified on the basis of fossils collected from the Ogallala Formation, whereas the Blancan is based on the local fauna from the white lacustrine basin-fill deposits at "Mt. Blanco" and the adjoining draws, near the "old rock house," north of Crawfish Draw, Crosby County, Texas (Wood and others, 1941, p. 12).

These Provincial Ages, like the others for the Tertiary, were based on first and last appearances of mammalian genera in North America as well as on "index" genera restricted to the age and on other genera common during or characteristic of the age. The ages were not defined in relation to epochs or the European standard, although approximate equivalents were indicated. Stirton (1936a) thought the ages of the three type faunas from Texas were early, middle, and late Pliocene, respectively. A study of the European Tertiary (Berggren and Van Couvering, 1974) indicates correlations different from those of Stirton (1936a) and Wood and others (1941). It now appears that the Clarendonian is late Miocene, the Hemphillian is latest Miocene to earliest Pliocene, and the Blancan is equivalent to most of the Pliocene; the views of earlier workers (for example, Gidley, 1903a; Osborn and Matthew, 1909) have thus been vindicated.

Savage (1962) and Evernden and others (1964) redesignated the original "Provincial Ages" as "North American Land Mammal Ages." They also argued against the use of the term "ages" in referring to the equivalent continental deposits or "stages," as had originally been allowed by the Wood and others (1941) committee. The committee did not have substantial or explicit lithostratigraphic or biostratigraphic control including measured and described sections, vertical ranges, and geographic distribution of taxa.

Wilson (1967) noted that, whereas the taxonomic criteria for each age as proposed by the Wood committee were thought to be generally applicable throughout North America, the current basis for correlation was largely the degree of evolutionary advancement, migration of Old World mammals into North America, and the negative evolutionary criterion of extinction. Tedford and others (1987) later used first appearances of immigrant genera, as well as extinction of certain taxa, to refine and subdivide the "Land Mammal Ages" of the late Tertiary.

Introduction, Historical Background, and Type Locality

The Clarendonian Provincial Age was originally described by Wood and others (1941, p. 12) as "based on the Clarendon local fauna (and member?) near Clarendon, Donley County, Panhandle of Texas" (fig. 1). The name "Clarendon local fauna" (Clarendon Fauna, this guidebook), in turn, has been applied to an aggregate of fossil vertebrate species, mostly mammalian, collected since 1892 from a number of localities scattered over a 100-km² (40-mi²) area immediately north of the Salt Fork of the Red River and north and east of the town of Clarendon, Texas (fig. 42) (Stop 14). Clarendon lies on the east edge of the Southern High Plains (Llano Estacado) at an elevation of 816 m (2,719 ft) above sea level. Fossils from this area were first collected and reported by Cope (1893), who referred to the beds containing them as the "Loup Fork," an obsolete term once applied to upper Tertiary strata in Nebraska (see Osborn and Matthew, 1909, p. 84, and Simpson, 1933, p. 101, for a summary of the history of the terms "Loup River" and "Loup Fork").

The term "Clarendon beds" was proposed by Gidley (1903a, p. 632), who made extensive collections of vertebrate fossils for the American Museum of Natural History from 1899 through 1901, but the name never gained general application. The fossil beds are now recognized as facies of the Ogallala Formation, having been placed in this formation by Stirton (1936a, p. 181), who thought they were lower Pliocene. Unfortunately, no comprehensive study or description of the Clarendon Fauna has ever been published, although single species have been described in short papers or in large publications dealing with certain taxonomic groups. In addition, papers on other "early Pliocene" (now Miocene) faunas have occasionally referred to fossils from the Clarendon Fauna. At present, about 30 fossil-producing sites are known from the area just north of the Salt Fork of the Red River (fig. 42). Detailed biostratigraphic analyses have not been done on most of these sites, but available faunal evidence indicates that most of them are about the same age, a few slightly younger.

Webb (1969a) attempted to revise the Clarendonian Mammal "Age" and to establish the biostratigraphic basis for its identification as a time-rock unit (stage) by selecting a section described by Cummins (1893) as the type section. The following description and section are quoted from Cummins (1893, p. 204):

> On the ranch of Mr. Stanton, twelve miles west of the town of Clarendon on the Mobeetie road is a very favorable locality for the collection of characteristic vertebrate fossils of this bed. Prof. Cope and myself visited that locality and made a very interesting collection, which have [sic] been described and figured by him, providing beyond question that the beds are Loup Fork. They are underlaid by the Triassic [Permian, actually]. The upper part of the section [which is given below] is probably the Goodnight beds. No fossils were found at the place where the section was made, but I conclude that they are later, upon stratigraphic and lithological reasons.
>
> The Loup Fork is composed of alternating beds of bluish and almost pure white sand. The fossils were in a fine state of preservation and were easily obtained. Most of the samples we collected were picked up on the surface, as at only one place did we attempt to secure any by excavation and that only in a small way, but were well paid for our labor in finding excellently preserved specimens.
>
> The following section was made at this place, showing the relation of the Loup Fork beds to the overlying strata:

1.	Whitish sandy clay	20 feet
2.	Sandy clay, with many rounded siliceous pebbles of different sizes	20 feet
3.	Yellowish sand	40 feet
4.	Indurated white sand	40 feet
5.	Yellow sandy clay, with the sand more or less predominating in places. In places the sand is hardened, while in others the clay is more or less concretionary	250 feet
6.	Alternating beds of bluish clay and white sand (Loup Fork)	30 feet
		400 feet

Unfortunately, Webb did not (and, in fact, could not) present a detailed biostratigraphic analysis of this section but instead gave a composite faunal list of mammals known from the various localities north and northeast of Clarendon and west of Goldston, a small ghost town 14 km (9 mi) north of Clarendon. This list was incomplete, however, because several published records, including that of *Paratoceras macadamsi* (Frick, 1937) and *Teleoceras fossiger* Cope (Johnston, 1937a), were omitted, not to mention the unpublished specimens in the larger collections from the area that would have added more taxa to the list. Finally, the faunal list does not take into account the possibility that the fossils may have come from different stratigraphic levels or zones.

Cummins' locality fails to meet the criteria of a type section on several counts. The precise location at which he measured his section cannot be determined from the published data, and the beds were not described adequately to be recognized in the field. The Stanton Ranch apparently covered a large area at the time and the reference to "twelve miles west of the town of Clarendon on the Mobeetie road" is certainly in error because Mobeetie is northeast of Clarendon. The old Mobeetie road probably followed the route of State Highway 70 north across the Salt Fork at least as far as the intersection with the Country Club Road at Goldston. Fossil-producing sites are common in the vicinity of the old Goldston schoolhouse, and it is likely that Cummins actually meant 19 km (12 mi) "north" and not "west." The local relief around Goldston is less than 60 m (200 ft), and Cummins' 122-m (400-ft) section must either represent an error in measurement or be a composite made over a considerable distance.

Whereas it seems impossible to refine or redescribe Cummins' "type section" in terms of recent stratigraphic knowledge of the area, the designation of a "type locality" based on the fauna collected by Cummins and Cope and reported by Cope (1893) is possible. Examination of these fossils at the Texas Memorial Museum, The University of Texas at Austin, indicates that most, if not all, were collected at the adjacent Dilli and Charles Risley ranch localities near the head of Turkey Creek, 1.6 km (1 mi) north and 1.6 km (1 mi) east of Goldston, and about 16 km (10 mi) north of Clarendon. Characteristics such as the preservation and dark brown color of the bone as well as the concretionary matrix enclosing it are similar to those of fossils collected later from these localities by workers from the University of California and West Texas State University.

At present, the Clarendon Fauna is used as a biostratigraphic zone in correlation, although it lacks proper characterization (Tedford, 1970, p. 693) and is among the poorest known of Clarendonian faunas. Precise biostratigraphic analysis is difficult in the region because rock sequences are too sparsely fossiliferous and too incomplete to determine local range zones of species. There are about 30 fossil sites known, but many are too widely separated to be easily correlated. Fossiliferous beds often cannot be traced laterally because of poor exposures, removal by erosion, rapid changes in channel and floodplain facies, or complete isolation in sinkhole deposits. Nevertheless, physical correlation between some sites is possible; faunal similarities may aid in the correlation of others. Recent stratigraphic and faunal studies based on the large quarry samples in the Frick collection in New York indicate that most of the reported faunas come from the more fossiliferous lower levels in the region (for example, MacAdams, Grant, Risley, Farr and Bromley localities), although a few sites (for example, Gidley's 3-Toed Horse Quarry) appear to represent slightly younger stratigraphic levels (Tedford and others, 1987).

Another difficulty encountered in defining the Clarendonian Stage is the lack of direct superpositional relationship with subjacent or superjacent stages in the type area (Tedford, 1970, p. 693). In addition, the original definition of the Clarendonian as a Provincial Age depended heavily on the first occurrence of

Table 1. Correlation chart of Clarendonian and Hemphillian faunas of the Great Plains.

EPOCH	LAND MAMMAL AGE		AGE (Ma)	TEXAS	OKLAHOMA	KANSAS-COLORADO	NEBRASKA		SOUTH DAKOTA
PLIOCENE	HEMPHILLIAN	LATE	5	Axtel, Christian Ranch, and Currie Ranch	Virgil Clark, etc., Gravel Pits			↑	
MIOCENE	HEMPHILLIAN	LATE		Coffee Ranch (=Miami), Goodnight	Optima (=Guymon)	Edson and Rhino Hill (Kansas)			
MIOCENE	HEMPHILLIAN	EARLY	6	Box T		Wray (Colorado)	Cambridge (=Ft. 40) Oshkosh Feltz Ranch		
MIOCENE	HEMPHILLIAN	EARLY	7	Higgins (=Sebits Ranch)					
MIOCENE	HEMPHILLIAN	EARLY	8	V. V. Parker Pits	Arnett (=University of Oklahoma Adair Ranch Quarry=Port of Entry)			Upper Snake Creek Faunas	
MIOCENE	HEMPHILLIAN	EARLY			Capps = Neu = Pratt				
MIOCENE	CLARENDONIAN	LATE	9	Cole Highway Pit Clarendon (Gidley's 3-Toed-Horse Quarry)	Durham		*Leptarctus* Quarry and Xmas-Kat channels		
MIOCENE	CLARENDONIAN	EARLY	10	Exell and Coetas Creek Clarendon (MacAdams, Grant, Risley, Farr, Bromley)	Laverne (=Beaver)	WaKeeney (Kansas)	Minnechaduza		Big Spring Canyon, Mission, & Wolf Creek
MIOCENE	CLARENDONIAN	EARLY	11	Lapara Creek (from Gulf Coast)				↓	
MIOCENE	BARSTOVIAN	LATE	12				Burge		

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taxa, many of which are not known from the type Clarendon Fauna. Webb (1969a, p. 15) stated, however, that this situation, although not ideal, presents no real problem because the Clarendon Fauna is diversified enough to permit correlation elsewhere in the same biological province with sections in which relevant superpositional relationships can be established. In north-central Nebraska, for example, the equivalent of most of the Clarendon Fauna is the Minnechaduza Fauna (early Clarendonian), which includes all local faunas from the lower part of the Ash Hollow Formation (Caprock Member). In this region, subjacent and superjacent faunas are present, and Webb (1969a) extended the concept of the Clarendonian downward to include the Burge Fauna (now considered late Barstovian) in the Burge Sand Member of the Valentine Formation and upward to include the *Leptarctus* Quarry (late Clarendonian) in the high stream channels that cut into the Caprock Member of the Ash Hollow (table 1). Beneath the Burge Sands are older sediments in the Valentine Formation that also contain late Barstovian faunas (see Skinner and Johnson, 1984, for a review of the Tertiary stratigraphy and fossil vertebrates from north-central Nebraska).

Age and Correlation

The Clarendonian Land Mammal Age represents a span of late Miocene time from about 11.7 to about 9 Ma ago; the division between "early" and "late" Clarendonian occurs at about 10 Ma (table 1; Tedford and others, 1987). At present, the Clarendon Fauna is thought to include taxa and sites of both early and late Clarendonian age, thus correlating with earlier Ash Hollow faunas of north-central Nebraska and south-central South Dakota (Skinner and others, 1968, p. 404; Skinner and Johnson, 1984). Most of the Clarendon faunal localities appear to be early Clarendonian and to represent Minnechaduza age equivalents, whereas a few, such as Gidley's 3-Toed Horse Quarry, are somewhat younger and seem to correlate best with the late Clarendonian *Leptarctus* Quarry and the Xmas-Kat channel assemblages (Tedford and others, 1987). Other Clarendonian faunas in the Great Plains Province include the Big Spring Canyon (Gregory, 1942), Mission (Macdonald, 1960), and Wolf Creek (Green, 1956) Local Faunas of South Dakota, the Upper Snake Creek Faunas (in part) of Nebraska (Matthew, 1924b; Skinner and others, 1977), the Wakeeny Local Fauna of Kansas (Wilson, 1968), the Laverne (=Beaver) Local Fauna of Oklahoma (Hesse, 1936a), the Exell (Dalquest and Hughes, 1966) and Coetas Creek (Patton, 1923; Schultz, 1977a, b) Local Faunas from the north Texas Panhandle, and the fauna of the Couch Formation from the south part of the Texas Panhandle (Evans, 1949, 1956; Winkler, 1985, 1987). The Lapara Creek Fauna of the Texas Gulf Coastal Plain (Patton, 1969) is early Clarendonian. Correlation of these faunas and, hence, of their respective provinces is made possible by a high degree of similarity between their respective taxa, especially of the horses. Refined correlation of Clarendonian faunas of the Great Plains or Gulf Coastal Plain with the Cerrotejonian and Montediablan Mammalian Stages of the Pacific Coast Province (Savage, 1955a) is more difficult because of greater geographic differences and distances and because there are fewer shared taxa. In general, however, the early and late Clarendonian faunas of the Great Plains and Gulf Coastal Plain correlate with the Cerrotejonian and Montediablan Stages, respectively (Tedford and others, 1987).

The Hemphillian Land Mammal Age, Texas Panhandle and Adjacent Oklahoma (Stops 15 through 17)

Introduction

The Hemphillian Provincial Age was originally described by Wood and others (1941, p. 122) as being "based on the Hemphill member of the Ogallala, which includes both the Hemphill Local Fauna from the Coffee Ranch Quarry and the Higgins Local Fauna, Hemphill County, Panhandle of Texas" (the Higgins Local Fauna is actually in Lipscomb County, Texas [fig. 1]). The "Hemphill Member" is not recognizable as a distinct lithologic unit, however, and is an obsolete term. It represents an upgrading of the term "Hemphill beds" proposed by Reed and Longnecker (1932, p. 20): "Since these beds, according to the fauna, represent a heretofore undescribed formation of the Lower Pliocene, the name *Hemphill beds* is here given to them to be applied as a faunal horizon." They thought the fauna was intermediate in age between Clarendon and Blanco Faunas and described about two dozen fossil sites from various levels within the section, most of which produced only a few specimens. Their Locality 20 at the Coffee Ranch was the most productive site and later became the type faunal locality for the Hemphillian Land Mammal Age (Evernden and others, 1964).

Age and Correlation

The Hemphillian represents a span of time from about 9 to about 4.5 Ma ago, and it is now possible to distinguish between early and late Hemphillian faunas. This division, which occurs at about 6 Ma, is marked by the extinction of many genera characteristic of the Clarendonian chronofauna and by the appearance of new immigrant taxa, as described in the following section. Early Hemphillian faunas may be further subdivided into "early early" (approximately 9 to 7 Ma ago) and "late early" (approximately 7 to 6 Ma ago). The Coffee Ranch (=Miami) Local Fauna (type Hemphillian) dates to the beginning of the "late" Hemphillian, however.

Until recently the Hemphillian Land Mammal Age was thought to be of middle Pliocene age (Wood and others, 1941). According to correlations by Berggren and Van Couvering (1974), the Hemphillian ended about 4.5 Ma ago and therefore straddles the Miocene–Pliocene boundary at about 5 Ma.

In Lipscomb County, Texas, in the northeast corner of the Panhandle and in adjacent Ellis County, Oklahoma, a sequence of faunas ranging in age from late Clarendonian to latest Hemphillian can be placed in stratigraphic succession. These and other important Hemphillian faunas of the region are described in Stops 15, 16, and 17, this guidebook, p. 95 through 114.

Faunal Turnover in the Hemphillian

The Texas Panhandle and adjacent areas of Oklahoma provide an excellent sequence of Late Tertiary faunas that document the significant changes in the vertebrate faunas of the Southern High Plains from early Clarendonian to latest Hemphillian time. Many of the taxa cited by Wood and others (1941) as characteristic of these ages are present in the faunas of the region.

Wood and others (1941) thought the genera *Agriotherium, Dipoides, Ilingoceros,* and *Plesiogulo* were index fossils of the Hemphillian Provincial Age, which also saw the first appearance of ground sloths, *Lutravus, Machairodus,* and *Taxidea* (*Pliotaxidea*), and the last appearance of *Aphelops, Blastomeryx, Mylagaulus, Osteoborus, Pliauchenia, Pliohippus, Prosthennops, Sphenophalos,* and *Teleoceras. Hypolagus, Megatylopus, Nannippus,* and *Neohipparion* were also thought to be characteristic of this age.

Recent work in vertebrate paleontology has tended to downplay the importance of index fossils and has extended or restricted the geological range of certain taxa. For example, *Dipoides, Nannippus,* and *Hypolagus* are known from the Blancan, and the latter genus, as well as *Megatylopus* and *Neohipparion,* are known to occur in the Clarendonian. *Blastomeryx* had disappeared by the end of Clarendonian time, whereas *Osteoborus* is now restricted to the Hemphillian. The most current analysis of Neogene land mammal ages and their characteristic taxa and evolving chronofaunas is that of Tedford and others (1987). Because the Hemphillian lasted about 4 to 5 Ma, it is possible to identify important differences between early and late Hemphillian faunas. Early Hemphillian faunas (for example, Arnett of Oklahoma, Higgins and Box T of Texas, and Cambridge [=Ft. 40] of Nebraska) include an admixture of Clarendonian holdover genera such as *Epicyon, Leptarctus, Barbourofelis, Procamelus, Aepycamelus, Cranioceras, Pseudoceras, Calippus, Cormohipparion,* and *Pliohippus* and new genera such as *Amebelodon, Nimravides, Osteoborus, Indarctos, Eomellivora, Machairodus, Pliometanastes,* and *Thinobadistes.* Late Hemphillian faunas (for example, Coffee Ranch and Goodnight of Texas, Optima (=Guymon) of Oklahoma, and Edson and Rhino Hill of Kansas) lack many of these Clarendonian and early Hemphillian genera and are marked by the first appearance of *Megalonyx, Plesiogulo, Agriotherium, Rhynchotherium, Alforjas,* and *Dinohippus.* Latest Hemphillian faunas (for example, Axtel and Christian Ranch of Texas and Yepomera and Ocote of Mexico) have more advanced species of *Dinohippus, Astrohippus, Agriotherium,* and *Osteoborus,* as well as the first appearance of genera more typical of the Blancan.

Blanco Formation (Stop 5)

History of Investigations and Interpretations

The earliest work in the Blanco Canyon area is that of W. F. Cummins, who in 1890 applied the name Blanco Canyon Beds (shortened by him to "Blanco Beds" in 1892) to all the post-Cretaceous deposits of the High Plains of Texas (see Cummins, 1890, 1891, 1892, 1893). Cummins thought these deposits had been laid down in a great inland "sea" or lake. Fossils he collected were sent for identification to E. D. Cope, who later accompanied Cummins in the field. In 1900 and 1901, J. W. Gidley (1903a) made extensive fossil collections from the Blanco for the American Museum of Natural History and concluded that the beds were of limited extent and that they represented a valley deposit of an aggrading stream. He wrote that "the occasional beds of diatomaceous earth are easily accounted for by supposing that there were in this ancient valley occasional ponds filled with clear water, enduring for various periods of time, partially or totally isolated from the stream that ran through the valley." Matthew (1924a) also thought the Blanco was a stream valley deposit but thought that the light-colored, fossil-bearing strata were a channel facies that interfingered with the bordering, reddish-brown Pliocene sands and clays that he took to be a floodplain facies of the Blanco: "The Blanco beds were deposited in a broad and shallow slowly aggrading stream valley with a slow-flowing, probably intermittent stream of about the type of the present Blanco Creek. The valley would be partly occupied then as now by abandoned stream channels forming ponds and muck holes."

Evans and Meade (1945, p. 492) believed the Blanco beds (Stop 5, this guidebook, p. 44) "to be lacustrine deposits laid down in broad shallow basins rather than deposits of a large stream valley." Their main lines of evidence were

(1) The coarser clastics of the Blanco beds are of indigenous origin, consisting of pebbles derived from the hard caliche cap rock of the surrounding Pliocene. These coarser materials occur on the shallow-lying marginal slopes, while the finer-grained sediments occupy the central and deeper-lying parts of the basin. This arrangement is the same as in existing playas of the region and is the reverse of the condition found in stream-laid deposits.

(2) The main body of exposed beds is well-stratified, some of the beds being traceable across most of the exposed areas.

(3) The types of sediments, particularly the bentonitic clays, fresh-water limestones, and the more localized beds of diatomite are indicative of quiet water deposition.

(4) No evidence exists along Blanco Canyon or its tributaries of a connecting filled valley segment between the two areas of Blanco beds or of an extension of such a valley either above or below these areas.

The geologic history of the Blanco basin as interpreted by Evans and Meade (1945, p. 492) and Evans (1948, p. 617–619) can be summarized as follows:

(1) After an alluvial plain developed in middle or late middle Pliocene time, a period of nondeposition occurred during which climatic conditions were dry enough to favor the development of an extensive caliche zone near the surface of the High Plains.

(2) Following the caliche development, basins formed to depths of 18 or 21 m (60 or 70 ft), possibly as a result of deflation, which would require a dry climate and appreciable time. That a caliche caprock existed before basins developed is substantiated by the presence of caliche pebbles and boulders in the basal member of the Blanco section.

(3) The essentially unbroken sequence of lacustrine strata composing the Blanco beds indicates nearly continuous deposition in permanent or nearly permanent bodies of water for a period long enough for the basins to fill almost to the level of the surrounding plains. Such permanent lakes would seem to require a sustained period of moist climate.

(4) After the filling of the Blanco basins, or perhaps during the last stages of filling, thin deposits of eolian silt, sand, and volcanic ash were laid down, which were later eroded and largely removed by wind. A widespread mantle of windblown sands and silts was then laid down over the surrounding plains and across the eroded surface of the basin deposits to form the present-day plains surface. The wind-eroded remnants of unaltered ash and loess as well as the overlying, probably eolian sands indicate the return of more arid conditions following the relatively humid Blancan stage.

Frye and Leonard (1957, p. 20–21) argued against Evans and Meade's interpretation of the environmental history of the Blanco beds, citing as evidence the conspicuous absence of aquatic mollusks and certain types of vertebrate fossils such as fish and amphibians, all of which would have been present had a large permanent lake existed under humid climatic conditions for any extended period. They argued that "all the known facts . . . point to alluviation by streams of very low gradient flowing across a semiarid terrain."

Frye and Leonard (1957, p. 20–21) then went on with their claim:

> That the Blanco was deposited by fluviatile mechanisms is attested by local channel deposits, including large abraded cobbles of Ogallala caprock, but the general fine texture of the sediments points with equal clarity to stream regimen of low gradient. Such a stream or streams, shifting, anastomosing, and with extremely unstable bottom conditions seems to account for the absence of fossil aquatic mollusks, which are unable to survive under such conditions. An unstable stream regimen likewise would account for the lack of fishes, amphibians, and aquatic turtles, the extreme paucity [absence] of beaver remains, and the lack of rodents with affinities to the muskrats.
>
> Contemporary semiaridity of the local climate seems almost self-evident. Had a humid local environment prevailed during deposition of the Blancan beds, whether by lacustrine or by fluviatile mechanisms, the surrounding plain would certainly have supported some kind of terrestrial molluscan fauna, the shells of which would have been carried into the Blancan sediments by tributary streams. The absence of such molluscan remains, the lack of fossil amphibians or fossil microtine rodents—animals that might be expected to have thrived on the plains under humid climatic conditions—sustain the deduction of a semiarid, rather than a humid, contemporary environment.

Pierce (1974), on the basis of his mineralogical and sedimentological studies supplemented by a study of pollen, diatoms, and ostracodes, concluded that the Blanco beds were deposited in a large playa lake during an arid to semiarid climatic interval. Deposition, which occurred during latest Pliocene or earliest Pleistocene (pre-Nebraskan) time, was marked by two episodes, one very short, of semipermanent to permanent water accumulation in a closed basin. This basin may have originated in the shallow depression of an abandoned Pliocene drainage channel and may have been enlarged by deflation.

Palynological studies by Pierce (1974) reveal a bimodal flora containing a few aquatic or riparian species such as hazel, willow, and pondweed, and a larger, more diverse, semiarid flora composed of grasses, cactus, saltbush, ragweed, juniper, Mexican chokecherry, and salt cedar. Diatoms from the Blanco Ash/diatomite unit are generally tolerant of alkaline environments and include species that can tolerate a subaerial (above water) habitat and that, while preferring calcium-rich environments, are capable of withstanding extreme drought and great variations in mineral concentrations. Invertebrates are rare; only one species of ostracode, *Candona paracaudata*, has been identified. No mollusks were recovered from the Blanco by Pierce, although Dalquest (1975, p. 45) mentions that a few aquatic snails are found in the sandy mud beneath the diatomite along with abundant fossils of reeds and aquatic plants.

Pierce (1974, p. 16) concluded that

> the flora and fauna strongly support a semiarid to arid climatic interpretation. The apparent absence of fishes, aquatic turtles and mollusks suggests that water accumulation was generally intermittent and transitory. While the basal sand and cyclic units suggest seasonal water accumulation, only very rare diatoms have been recovered from this unit. The lacustrine sands of the main bone bed zone, below the diatomite, can be interpreted as at least seasonal water on the basis of the ostracode species recovered. Candonid ostracodes are normally spring bloomers. Their occurrence suggests an early spring precipitation maximum. The flora of the diatomite unit also suggests only seasonal water accumulation, although semipermanent water may have accumulated at this time. The absence of an invertebrate fauna in the diatomite is not surprising, considering the highly leached character of this unit. Above the diatomite, there is little indication of other than intermittent ponding, with sepiolite-rich immature paleosols comprising the dominant lithology. . . . The absence of the pollen of conifers, apparently ubiquitous during all pluvial periods of the Pleistocene, and the restricted invertebrate fauna suggests strongly that the Blanco beds accumu-

> lated during late Pliocene or earliest (pre-Nebraskan) Pleistocene time. The distinctive climatic reversal of the Nebraskan Glaciation marked by a significant floral change, is not indicated.

Studies by Dalquest (1975) support the concept of deposition under arid or semiarid conditions and contradict Evans and Meade's concept of a permanent or partly permanent lake occupying a closed depression of considerable extent. Dalquest also observed, among other things, the discontinuity of some of the minor strata, which is in strong contrast to the even, uniform sediments typical of the deflation basins of West Texas, as described by Evans and Meade (1945). He stated (p. 5–6) that

> the bentonitic clays and freshwater limestones indicate still waters, but these might have occupied low areas or small, temporary depressions after floods or heavy rains. This type of deposition occurs today in arid areas. The diatomite, however, definitely is a lacustrine deposit. The sandy mud deposit beneath the diatomite beds can often be traced laterally for 100 yards or more away from the diatomite itself. The deposits are clearly recognizable as pond deposits by their evenness and uniformity of sediments, and by their contained fossils. Remains of aquatic plants are abundant, and some few fossil aquatic snails also occur. The ponds, however, were shallow and apparently limited to areas of a few acres. No fish or aquatic turtle remains have been found, and fossil wood and hackberry seeds are usually as abundant as fossils of emergent vegetation. It should be emphasized that these deposits within the Blanco sediments are readily recognized as lacustrine. . . . The absence of fossils of aquatic vertebrates and the varied nature of the sediments in the Blanco Formation argue against a closed depression occupied by a lake. It seems more likely that the deposits accumulated in a shallow, drained rather than closed basin, formed by stream erosion or deflation. Coarser materials were deposited on the valley slopes, but floods or mudflows carried some gravels far out into the valley. Slope wash and wind-blown materials filled the basin, the materials being sorted and reworked by wandering shallow streams during wet intervals. Heavy rains, perhaps seasonal, carried clay materials that accumulated in low areas. Dry intervals permitted accumulation and leaching of carbonates into sands and clay deposits to form the calcareous limestones and caliche.

Stop 1: Blackwater Draw Formation Type Locality

V. T. Holliday

The Quaternary Blackwater Draw Formation type section, northwest of New Deal, Texas, contains four buried soils plus the surface soil. The buried soils are similar to, but better developed than, the surface soils of the central Southern High Plains: Paleustalfs and Paleustolls of the Amarillo-Acuff-Mansker soil association.

The type section of the Blackwater Draw Formation lies in a roadcut northwest of New Deal in north Lubbock County on the west side of Blackwater Draw 8 km (5 mi) north of farm-to-market road (FM) 1294 and approximately 3.5 km (2.2 mi) west of Interstate Highway 27 (figs. 1 and 8). The section is about 10 m (30 ft) thick—the modern High Plains surface at the top and the Ogallala Caprock caliche at the base (fig. 9, table 2). The Blackwater Draw Formation is the "Illinoian cover sand" of Frye and Leonard (1957). Reeves (1976) proposed the formation name for the deposits, and Gustavson and Holliday (1985), Holliday (1989, in press), and Holliday and Gustavson (in press) showed that the sediments accumulated throughout most of the Quaternary.

There are two striking features about the type section: (1) its general homogeneity and (2) the number of strongly developed buried soils (fig. 9). The overall color, texture, and structure of the section are relatively uniform. Close inspection, however, reveals that the section contains at least four buried soils in addition to the modern surface soil (fig. 10). The overall homogeneity of the section is due to the soils having about the same degree of pedologic expression: reddish-brown color (2.5YR to 5YR hues), moderate to strong prismatic structure containing common films of illuvial clay on the ped faces, and Stage II to III calcic horizons (after Gile and others, 1966). No A or C soil horizons are apparent other than the A horizon of the surface soil, and no primary sedimentary structures are preserved.

The buried soils are similar to the well-developed, regional surface soils of the central portion of the Southern High Plains: Paleustalfs and Paleustolls of the Amarillo-Acuff-Mansker soil association (Godfrey and others, 1973). At this stop the surface soil has a thick, reddish-brown (5YR hues) argillic horizon (50 to 149 cm; table 2) and a dominantly coarse prismatic structure. Clay films are apparent on ped faces and are common in thin section. Below the argillic horizon is a Stage III calcic horizon (149 to 290 cm). The boundary between the argillic and calcic horizons is abrupt and subhorizontal, similar to a depositional contact. Such an abrupt boundary is typical of the regional surface soils, however, and is pedogenic. All characteristics of this soil indicate that it is well developed.

Morphologically, the buried soils are more strongly developed than the surface soil (table 2). At least some parts of each profile exhibit (1) 2.5YR hues, (2) more continuous and thicker clay films on ped faces, (3) a higher percentage of clay films in thin section, and (4) an angular blocky structure. The blocky structure apparently is due to higher illuvial clay content, suggested by the abundant clay films.

The morphologies of the calcic horizons in the buried soils are somewhat similar to one another but distinctly different from those in the surface soil. The buried calcic horizons are expressed either as patchy films and coats on ped faces, generally the vertical faces, or as vertically oriented, rootlike nodules about 1 to 3 cm thick. These nodules appear to follow the joints between prismatic peds, and this morphology is sometimes informally referred to as "ladder structure" (McGrath, 1984, p. 131) (fig. 11). Some think ladder-matrix carbonate horizons represent recalcified argillic horizons (for example, McGrath, 1984). Some evidence shows that these horizons represent formerly extensive calcic horizons that underwent dissolution. The upper boundaries of the ladder-matrix calcic horizons are commonly horizontal and abrupt. This suggests that the horizons were originally similar to the surface-soil calcic horizon but were subsequently subjected to dissolution, carbonate concentrating along veins (ped faces?) and forming nodules. Illuvial clay is common in and on peds between carbonate

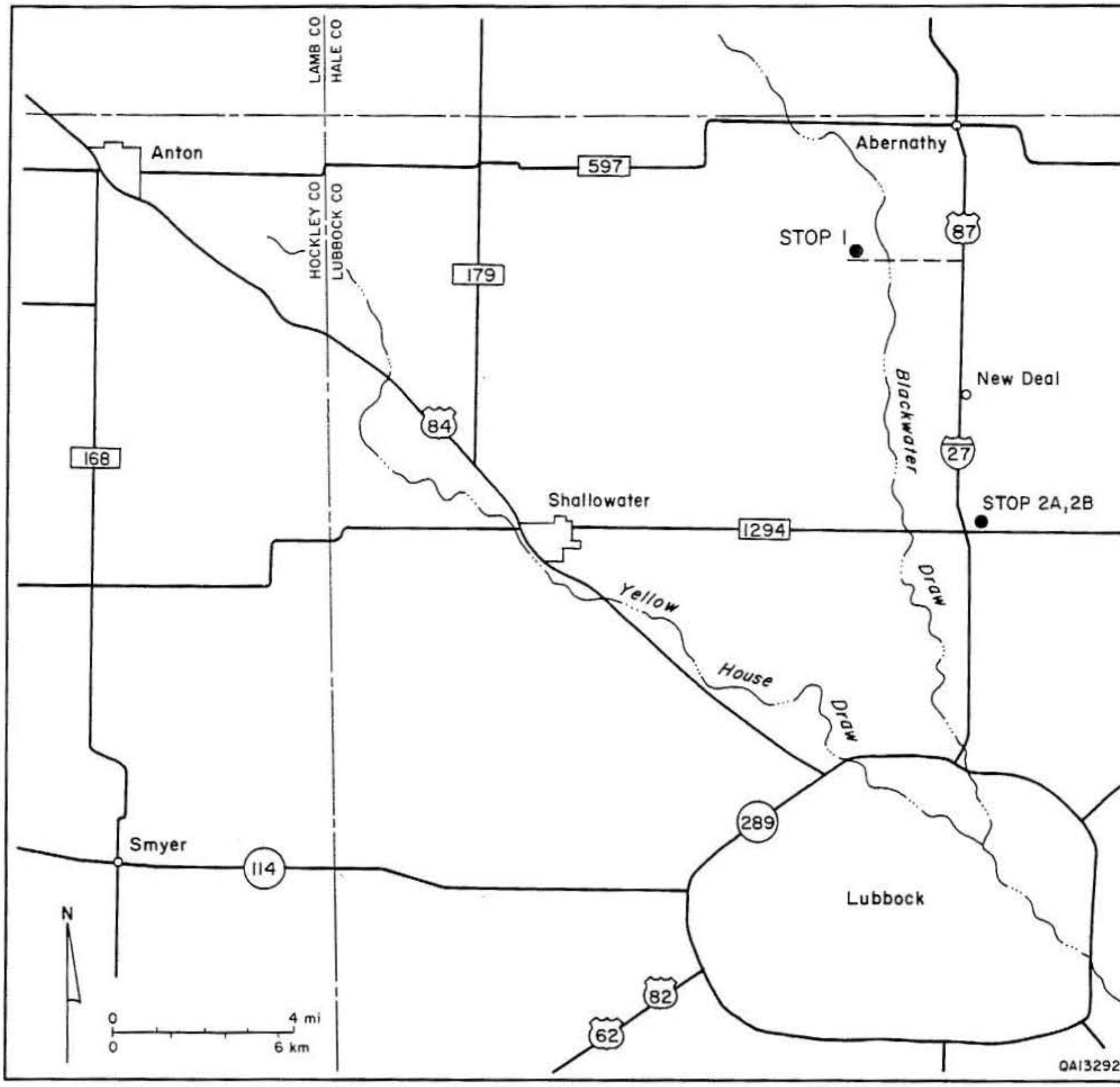

Figure 8. Map of Lubbock, Texas, area showing Field Trip Stops 1, 2A, and 2B. Derived from Lubbock Sheet, U.S. Geological Survey (1:250,000 series). See figure 1 for location.

nodules in the ladder-matrix horizons, but such clay is not apparent in the surface-soil calcic horizon. This would further suggest that clay illuviation accompanied or followed carbonate dissolution.

Two K horizons (zones dominated by $CaCO_3$ accumulation) are exposed at the bottom of the section (table 2). The K1b4 (upper K horizon of the fourth buried soil) horizon is a massive, nonindurated calcic horizon, probably representing a buildup of carbonate that was the result of the impermeable nature of the underlying calcrete. The K2mb4 (lower K horizon, indurated, of the fourth buried soil) is a silicified calcrete, probably the Caprock caliche at the top of the Ogallala Formation.

One exception to the strong pedologic expression in the type section of the Blackwater Draw Formation exists. At the east end of the roadcut (fig. 9; table 2), on the floor of Blackwater

Table 2. Soil descriptions, Blackwater Draw Formation type section (fig. 1).*

*Profile 1***

Horizon	Depth (cm)	Color: Dry	Color: Moist	Texture	Structure	Consistence: Dry	Consistence: Moist	Reaction	Boundary	Remarks
Fill	0–33									
A	33–50	5YR3/4	5YR3/3	SC (SCL+)	2csbk		f	non	cw	
BAt	50–63	5YR3/4	5YR3/3	SC (SCL+)	1cpr 2csbk	h		non–se	cw	
Btk1	63–95	5YR3.5/6 5YR7/4 (ped faces with carbonate)	5YR3/4 5YR4/4	SCL	2cpr 2cabk	h		se es	cw	Common very fine carbonate films and threads; many thin clay films.
Btk2	95–127	5YR3/6	5YR3.5/4	SCL	2cpr 2cabk	h		non–se es	cw	Few carbonate threads and films; many thin clay films.
Btk3	127–149	5YR3/8	5YR3/6	SCL	3cpr 2cabk	h		non–se ev	aw	Very few threads and films; common thin clay films.
Bk1	149–215	5YR6/4 (matrix) 7.5YR8/2 (max. carbonate)	5YR5/6 7.5YR7/4		m	h		ev ev	gw	Stage III; 60% carbonate bodies and concretions; few burrows.
Bk2	215–242	7.5YR5/8 (matrix) 7.5YR8/3 (carbonate)	5YR5/7 7.5YR7/4	L	1csbk		f	 ev	cw	30% carbonate bodies (no thin sections).
Bk3	242–290	7.5YR5/8 (matrix) 7.5YR8/3 (carbonate)	5YR5/7 7.5YR7/4	L	1csbk		f	es	gw	Fewer than 20% carbonate bodies and concretions; groups of carbonate bodies and concretions occur in distinct zones.

*Abbreviations for soil profile descriptions: **Texture:** S = sand, SC = sandy clay, SL = sandy loam, SCL = sandy clay loam, L = loam, C = clay, Si = silty, f = fine, and + = clayey. **Structure:** Grade: 1 = weak, 2 = moderate, and 3 = strong. Type: sbk = subangular blocky, abk = angular blocky, pr = prismatic, pl = platy, m = massive, sg = single grain, g = granular, part = parting, c = coarse, and f = fine. **Consistence:** Dry: h = hard, sh = slightly hard, vh = very hard, xh = extremely hard, and so = soft. Moist: f = friable. **Reaction: (w/dilute HCl):** non = noncalcareous, se = slightly effervescent, e = effervescent, es = strongly effervescent, and ev = violently effervescent. **Boundary:** Distinctness: a = abrupt, c = clear, g = gradual, and d = diffuse. Topography: s = smooth, w = wavy, i = irregular. **Remarks:** carbonate = calcium carbonate, vert. = vertically, horiz. = horizontally, cont. = continuous, max. = maximum, and diam. = diameter.*

***NOTE: 5–10 m east of this profile; carbonate in Bk2 and Bk3 occurs as distinct bodies 5–10 cm vertical and 3–5 cm horizontal. Bodies equal in 20–30% of horizon.*

Table 2. (cont.)

Profile 2

Horizon	Depth (cm)	Color Dry	Color Moist	Texture	Structure	Consistence Dry	Consistence Moist	Reaction	Boundary	Remarks
0 depth equivalent to Bk2, Bk3 (180–290 cm) of Profile 1.										
Btk1b1	110–155	2.5YR3/6	2.5YR3/4 (matrix)	SC (SCL+)	3cabk	h		e	ci	Max. carbonate 119–121 cm; w/tongues of max. carbonate producing irregular boundaries; Stage III. Carbonate is massive (same area); common thin clay films.
		5YR8/3	5YR7/4 (carbonate)		m			ev		
Btk2b1	155–200	2.5YR3/6	2.5YR3/4 (matrix)	SC (SCL+)	1mpr 2mabk	h		e	cw	Stage II–III. Carbonate (50%) as large (50–70 mm) patches and bodies; many fine clay films; very few 1- to 2-mm Mn? patches.
		5YR8/3	5YR7/4 (carbonate)					ev		
Btk3b1	200–220	5YR4/8	5YR3/6 (matrix)	SCL	2cabk	h		e	ci	Stage II. Carbonate occurs as 30–50% (20–50 mm) patches and bodies.
		5YR8/2	5YR7/4 (carbonate)					ev		
Btkb2	220–295	2.5YR3/6	2.5YR3/6 (matrix)	SC (SCL+)	3mabk	h		non–se	aw	Carbonate occurs as veins 5–15 cm wide and as much as 50 cm deep from overlying horizons; also few subhorizontal veins 1 cm thick; massive carbonate; many cont. clay films; few 1- to 4-mm dendritic Mn?
		5YR8/2	5YR7/4 (carbonate)		m					

Profile 3

Horizon	Depth (cm)	Color Dry	Color Moist	Texture	Structure	Consistence Dry	Consistence Moist	Reaction	Boundary	Remarks
0 depth equivalent to base of Profile 2.										
Btk1b3	0–27	5YR5/8	5YR5/8 (matrix)	SCL	1mpr 2msbk	h		e–es	cw	
		5YR8/4	5YR7/4 (carbonate)					ev		
Btk2b3	27–57	2.5YR4/8	2.5YR4/8 (matrix)	SCL	1mpr 2msbk	h		e–es	cw	
		5YR8/3	5YR7/4 (carbonate)					ev		
Btk3b3	57–110	5YR8/4	5YR8/4 (matrix)	SCL	1mpr 2msbk	h		e–es	cs	
		5YR9/1	5YR7/6 (carbonate)					ev		

Table 2. (cont.)

Profile 3 (cont.)

Horizon	Depth (cm)	Color		Texture	Structure	Consistence		Reaction	Boundary	Remarks
		Dry	Moist			Dry	Moist			
Btk4b3	110–164	5YR5/8	5YR5/8 (matrix)	SCL	1mpr 1msbk	h		s–es	cs	
		5YR8/3	5YR7/4 (carbonate)					ev		
Btk5b3	164–195	5YR5/8	5YR5/8 (matrix)	SCL	1mpr 1msbk	h		s–es	gw	
		5YR8/4	5YR8/4 (carbonate)					ev		
Bktb3	195–250	5YR9/1	7.5YR8/3 (carbonate)	SCL	m	h		ev	cw	Stage III; only locally present.
Btb4	250–315	5YR4/8	5YR4/8	SCL	1mpr 2sbk	h		ped faces s ped int. none		Very few carbonate bodies 2.5 cm diam. Rare Mn nodules on ped faces. Thin section collected.

Profile 4

Horizon	Depth (cm)	Color		Texture	Structure	Consistence		Reaction	Boundary	Remarks
		Dry	Moist			Dry	Moist			
0 depth is probably equivalent to Btb4 (250 cm) of Profile 3.										Most carbonate coats and films are on ped faces.
Btk1b4	0–75	5YR4/8	5YR3/6 (matrix)	SCL	1cpr	h		non–se	cw	30% carbonate films and coatings, few nodules 1–5 cm in diam. Stage II. Many to cont. thin clay films on ped faces.
		5YR8/2	5YR7/3 (carbonate)		2cabk			ev		
Btk2b4	75–110	5YR4/8	5YR3/6 (matrix)	SCL+	2cpr	h		non–se	cw	20% patches and threads carbonate. Stage I–II cont. thin clay films.
		5YR8/1	5YR7/3 (carbonate)		3cabk			ev		
Btk3b4	110–155	5YR4/8	5YR3/6 (matrix)	SCL+	2cpr	h		non–se	cw	10% carbonate films on ped faces. Many thin clay films on ped faces.
		5YR8/1	5YR7/3 (carbonate)		2csbk			ev		
Btk4b4	155–225	5YR4/8	5YR3/6	SCL	1cpr 2csbk	h		non–se		Fewer than 10% carbonate films and threads on ped faces.

Table 2. (cont.)

Profile 5

Horizon	Depth (cm)	Color: Dry	Color: Moist	Texture	Structure	Consistence: Dry	Consistence: Moist	Reaction	Boundary	Remarks
A	0–26	7.5YR3/4	7.5YR2/3	fSL	1msbk g 2mg	so		e	cs	
BA	26–51	7.5YR3.5/4	7.5YR3/4	fSL+	1csbk	sh		e	cs	Some very weak prisms.
Bw	51–75	7.5YR 4/4	7.5YR 3/4	fSL+	1mpr 2msbk	sh		es	cw	Few 1- to 2-mm clasts of carbonate, probably slope wash.
Btk1	75–101	5YR5/6	5YR4/6	SCL	1msbk	sh		ev	cw	10% carbonate threads common 1- to 3-mm carbonate clasts; some with coating of secondary carbonate; weak Stage I.

NOTE: 5YR5/6 [above] and 5YR4/6 [below] may be one thick horizon.

Horizon	Depth (cm)	Color: Dry	Color: Moist	Texture	Structure	Consistence: Dry	Consistence: Moist	Reaction	Boundary	Remarks
Btk2	101–120	5YR4/6	5YR4/6 (matrix)	SCL	1msbk	sh		ev	ci	Weak Stage I. 10% carbonate threads; common 1- to 3-mm carbonate clasts, some w/coatings of secondary carbonate.
2Btk3	120–155	5YR4/6 5YR8/3	5YR4/6 (matrix) 5YR6/4 (carbonate)	SCL+	1msbk		f*	ev	ci	Many carbonate films and threads; very common pockets and lenses of 1- to 5-mm carbonate clasts, commonly coated and/or cemented by secondary carbonate; weak Stage II.

NOTE: Horizons 75–155 cm dip to east (toward Blackwater Draw). Soil 0–155 cm is probably Holocene Valley fill. ~Lubbock Lake soil.

Horizon	Depth (cm)	Color: Dry	Color: Moist	Texture	Structure	Consistence: Dry	Consistence: Moist	Reaction	Boundary	Remarks
3Btkb4	155–225	5YR 4/8 5YR9/1	5YR 3/6 (matrix) 5YR8/3 (carbonate)	SCL+	1cpr 2csbk		firm	non-se ev	aw	Blackwater Draw Formation; Stage I carbonate, ~20% films, threads along ped faces.
K1b4	225–385	5YR9/1	5YR8/2		m			ev	ai	Upper ±10 cm has some laminar structure; common 2- to 5-mm carbonate concretions.
K2mb4	385+									Ogallala Caprock?

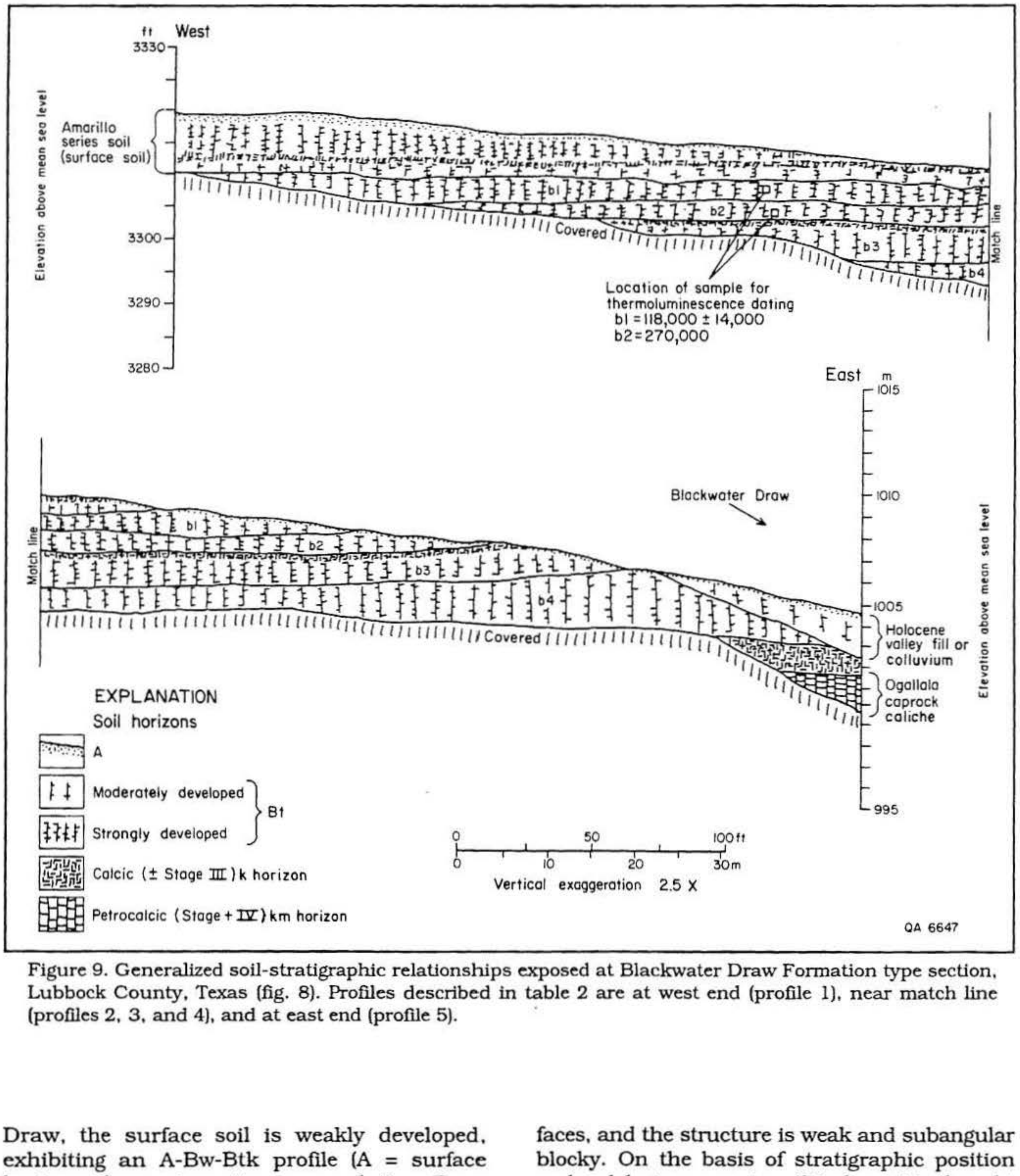

Figure 9. Generalized soil-stratigraphic relationships exposed at Blackwater Draw Formation type section, Lubbock County, Texas (fig. 8). Profiles described in table 2 are at west end (profile 1), near match line (profiles 2, 3, and 4), and at east end (profile 5).

Draw, the surface soil is weakly developed, exhibiting an A-Bw-Btk profile (A = surface horizon of organic matter accumulation; Bw = weak B horizon, subsurface zone of leaching or illuviation, or both; Btk = B horizon containing illuvial clay and carbonate). Some clay films are apparent in thin section. Although the hues in this soil are 7.5YR to 5YR, the soil is not thought to be as well developed as others in the section because there are no clay films on ped faces, and the structure is weak and subangular blocky. On the basis of stratigraphic position and pedologic expression, this deposit is thought to be a middle Holocene valley fill commonly found in the draws in the region (Holliday, 1985a, b).

As yet, there is no firm age control on the soils or sediments at the section. Two thermoluminescence (TL) ages are available: 118±14 Ka B.P. (Alpha 1750) from the Btk1b1 horizon

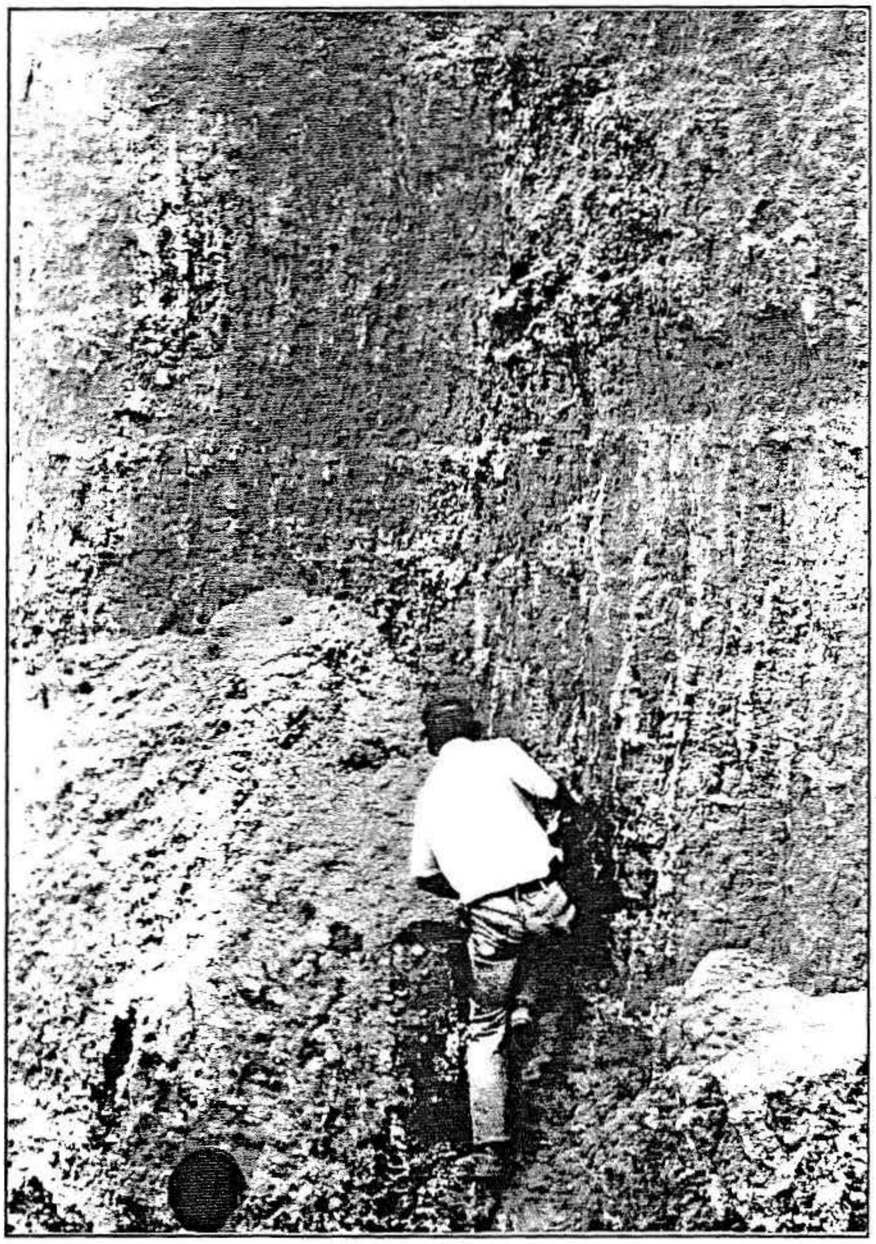

Figure 10. View of type section of Blackwater Draw Formation (profile 4), Lubbock County, Texas (fig. 8). Note presence of several well-developed buried soils.

(table 2, profile 2) and greater than 270 Ka B.P. (Alpha 1751) from the Btkb2 horizon (table 2, profile 2). Stratigraphic studies from other localities (Gustavson and Holliday, 1985; Holliday, 1990) suggest that these ages are within the correct order of magnitude of the age of the respective deposits.

A number of inferences can be made concerning the depositional history and soil stratigraphy of the Blackwater Draw Formation on the basis of observations at this section and the sedimentological data of Seitlheko (1975) discussed in the Introduction (p. 11). The Blackwater Draw Formation is clearly composed of a number of individual eolian deposits, fining downwind from southwest to northeast, each strongly modified by pedogenesis, but the original thickness and total number of these units are difficult to determine. At the type section there are at least five layers, and at the

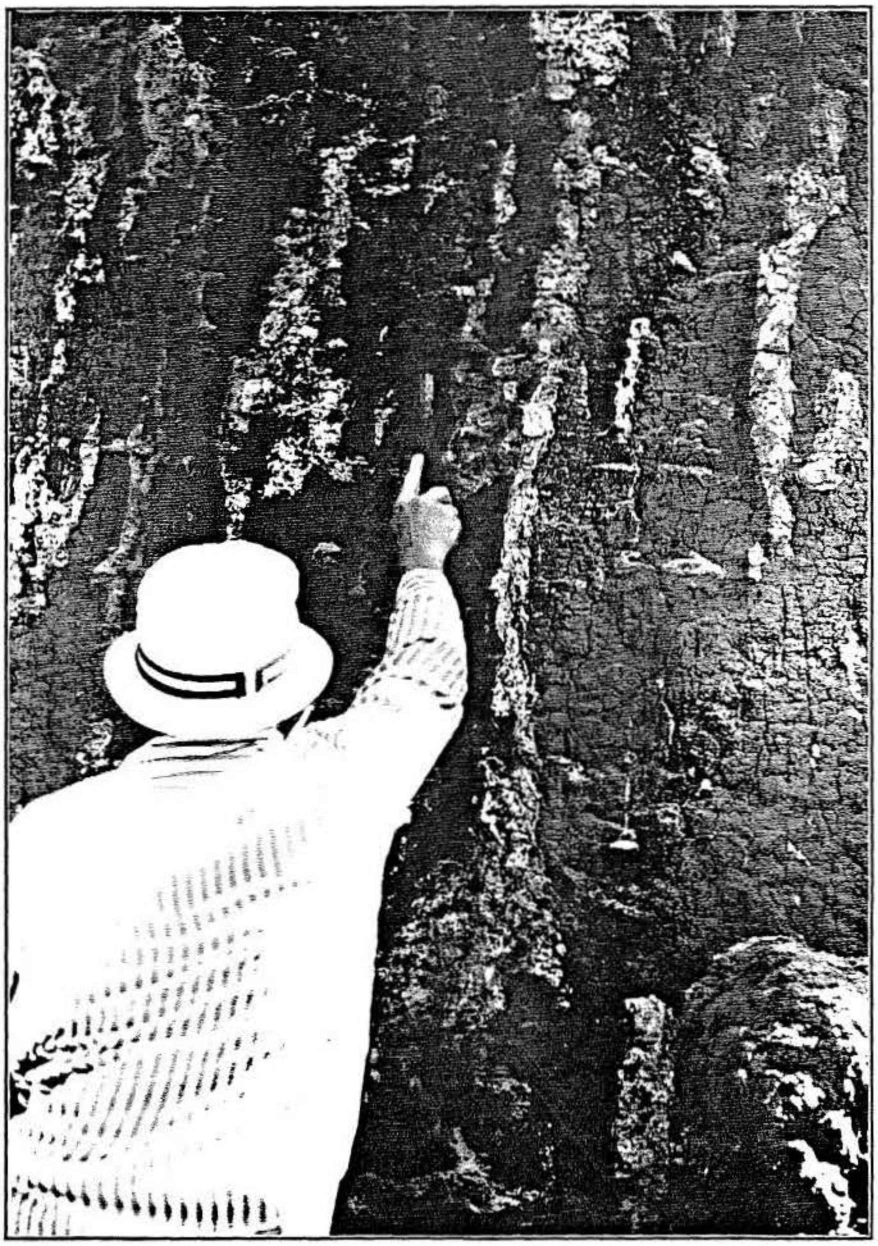

Figure 11. Ladder structure where $CaCO_3$ nodules follow joints between peds (McGrath, 1984).

Bushland site, near Amarillo, there are at least seven layers (Allen and Goss, 1974; Holliday, in press). Erosion prior to burial of each layer is suggested by the varying number of buried soils in each section, the absence of buried A horizons, and the presence of unconformable contacts.

Available data indicate that the general depositional model for development of the Blackwater Draw Formation is cyclic. Each cycle, which began with an interval of eolian deposition followed by nondeposition, landscape stability, and soil formation, may have ended with an interval of erosion. Wind has probably been the dominant geomorphic and sedimentologic agent of the region throughout late Cenozoic time, although at any given time wind erosion and sedimentation probably operated concurrently with pedogenic processes, as is happening today. During the course of a single cycle, however, different processes dominated from time to time. During depositional periods, material derived from the Pecos Valley would blow onto the High Plains at a rate faster than erosion or pedogenesis, resulting in deposition of a more or less continuous sheet of eolian sediment across the area. Sedimentation would then slow, erosion would remain minimal, and a soil would form in the eolian sheet. Enough time would elapse to allow formation of a well-developed soil similar to the surface soil of the area. Erosion by wind deflation would then follow, destroying the lateral continuity of the eolian sediment in many areas. In other places the more easily eroded A horizon would be removed down to the more resistant Bt horizon. The erosion would occur immediately before, or perhaps be coeval with, early stages of the subsequent depositional event. After several such cycles the result would be a stack of sedimentary units disconformably overlying one another, varying in number from one section to the next, but each unit exhibiting similar pedologic properties. Given the similarities between the buried soils and surface soil, the paleoenvironment associated with the buried landscapes probably was similar to that of the late Quaternary: a generally semiarid environment dominated by grasslands.

Stop 2A: Gentry Playa: Origin by Hydrologic Processes

W. R. Osterkamp

The floor of a playa-lake basin exposed in Gentry Pit 3 km (2 mi) north of the Lubbock airport has persisted and expanded largely through hydrologic processes, especially by piping and dissolution of soil carbonate adjacent to and beneath the playa floor.

One of the finest cuts exposing near-surface rocks in the central Southern High Plains is at Gentry Pit, about 3 km (2 mi) north of Lubbock International Airport and immediately northeast of the intersection of FM Road 1294 and Interstate Highway 27 (figs. 1, 8). Gentry Pit is one of several large borrow pits that supplied fill from playa areas for construction of Interstate 27. The pit is U-shaped in plan view and thereby provides exposures of the uppermost Ogallala Formation and overlying rocks along eight different quarry faces in the playa basin. In a region where topographic relief is low and road cuts are uncommon, the walls of Gentry Pit (fig. 12) provide (1) exceptional exposures of local geology and (2) insights into the hydrologic and geomorphic processes active beneath and adjacent to playa floors.

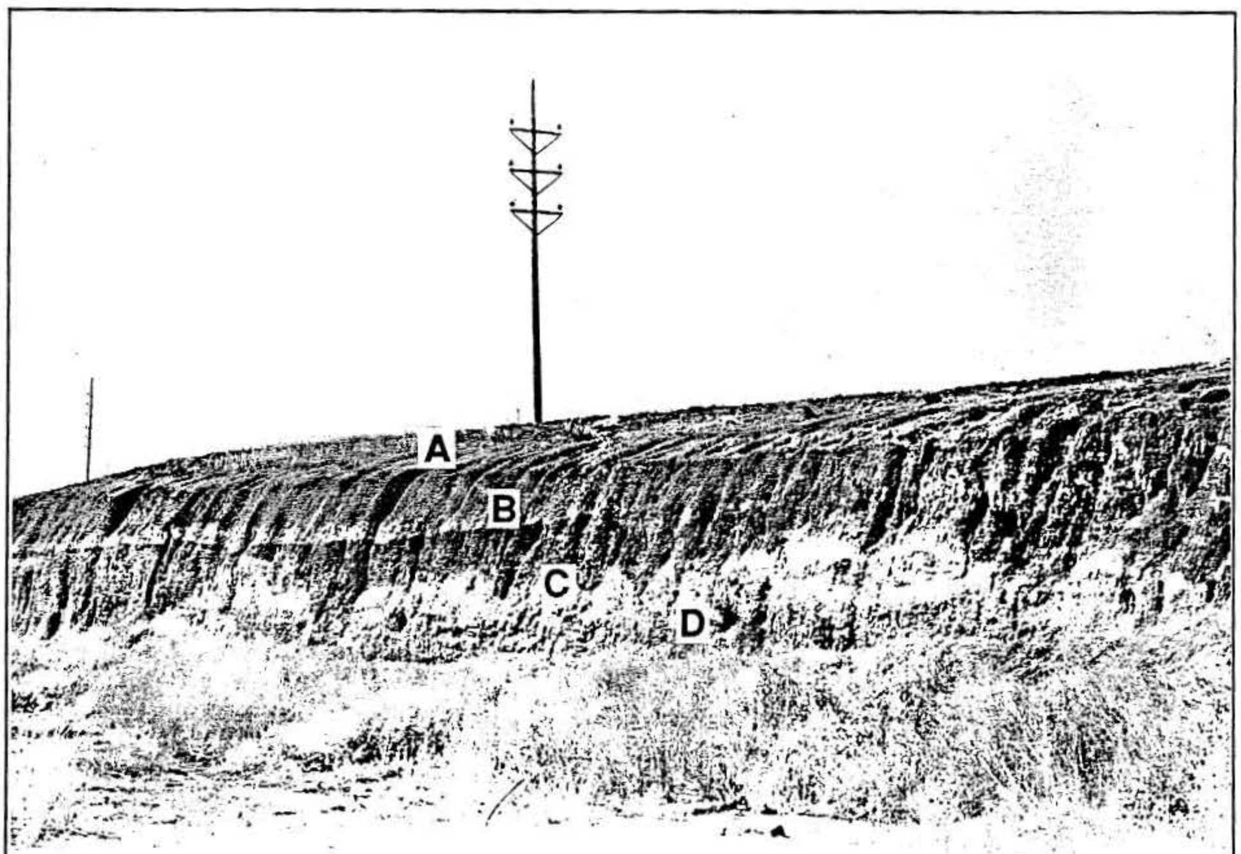

Figure 12. Quarry face in central part of Gentry Pit. (A) Randall Clay, (B) Blackwater Draw Formation, (C) Ogallala Formation Caprock caliche (calcrete), and (D) erosion surface on Caprock caliche.

Geology

Several interpretations of stratigraphy at sites such as Gentry Pit have been proposed. (For example, see the description by V. T. Holliday of Stop 2B, p. 36, this volume.) A section at the southwest corner of Gentry Pit measured by C. C. Reeves (personal communication, 1983, 1984) contains, in descending order: (1) about 1 m (3 ft) of Randall Clay, a dark organic lacustrine deposit typical of playa bottoms in this part of the Southern High Plains, (2) 1 m (3 ft) of eolian sand, probably blown into the playa from the southwest, (3) about 3 m (10 ft) of generally light colored sand, silt, and clay of the Tahoka Formation (Evans and Meade, 1945), and (4) about 2.5 m (8 ft) of sand, silt, and clay of the Double Lakes Formation, commonly cemented with carbonates and iron oxides (Reeves, 1976).

Stratigraphers further divided the Pleistocene Tahoka and Double Lakes Formations into one or more members (see summary by Reeves, 1976). Most of these divisions were based at least partly on differentiation of evaporite depositional environments of playa bottoms or of variations in geochemical environments within playa basins. For simplicity, the beds at Gentry Pit are here assigned only to the Randall Clay and underlying playa deposits, the Blackwater Draw Formation, and the Ogallala Formation (fig. 12); lithologic variations within the formations are considered here in terms of inferred hydrologic and geochemical processes.

Randall Clay and Underlying Playa Deposits

The fine-grained, dark organic sediments that occupy playa bottoms, including that of Gentry playa, are mapped as a Vertisol (Udic Pellustert), but are actually Pleistocene to Recent lacustrine fills of the playa depressions (Holliday, 1983, p. 110). Samples collected at playas west and northeast of Lubbock contained an average of 49 percent clay, mostly as montmorillonite and illite and smaller amounts of kaolinite; 23 percent silt; and 28 percent sand (Allen and others, 1972). Found mostly in the clay-size fraction, organic material near the surface may be as much as 5 percent of sample weight. Comparisons of particle-size distribution and chemical analyses of playa deposits with those of upland soils (Allen and others, 1972) suggest that the Randall Clay is derived from local sources by eolian deposition and overland transport during storm runoff.

At Gentry Pit the Randall Clay and underlying playa deposits (fig. 12) reached a thickness of about 8 m (26 ft) in the excavated center of the playa. Carbon-isotope analyses indicate that ages of the deposit range from about 1 Ka near the surface to about 10 Ka near the base. Presence of late Pleistocene horse and mammoth teeth from a leached zone at the base of the playa deposits (Tahoka equivalent of Evans and Meade, 1945) supports these dates. Pollen analyses of the deposits (T. A. Ager, U.S. Geological Survey, personal communication, 1982) suggest relatively persistent dry grassland conditions. A lack of corrosion on pollen grains from the playa deposits indicates that reducing conditions prevailed through much or all of the last 10 Ka.

Blackwater Draw Formation

At Gentry Pit and other playas in the area, the Randall Clay and related lacustrine beds are inset into iron-oxide-stained eolian sand and silt of the Blackwater Draw Formation (Reeves, 1976) that are as much as 27 m (90 ft) thick. At Gentry Pit, exposures of the Blackwater Draw Formation (fig. 12) range from about 1 to 5 m (3 to 16 ft) in thickness, a result of deposition on the irregular erosion surface of the underlying Ogallala Formation. On the basis of exposures about 100 km (60 mi) north of Lubbock that contain Lava Creek B Ash, the basal Blackwater Draw Formation seems to exceed 0.6 Ma in age, but the presence of at least four buried soils containing pedogenic caliche zones in the type section near Gentry Pit (fig. 8) suggests that deposition continued into the Holocene (Gustavson and Holliday, 1985).

Ogallala Formation

The Ogallala Formation, containing the largest aquifer of the Southern High Plains (Knowles and others, 1982), formed principally during the Miocene from detritus eroded from the Southern Rocky Mountains. Accumulation of fluvial Ogallala sediment ceased following piracy of mountain runoff by the Pecos and Canadian Rivers at about the end of the Miocene (Gustavson and Finley, 1985; Gustavson,

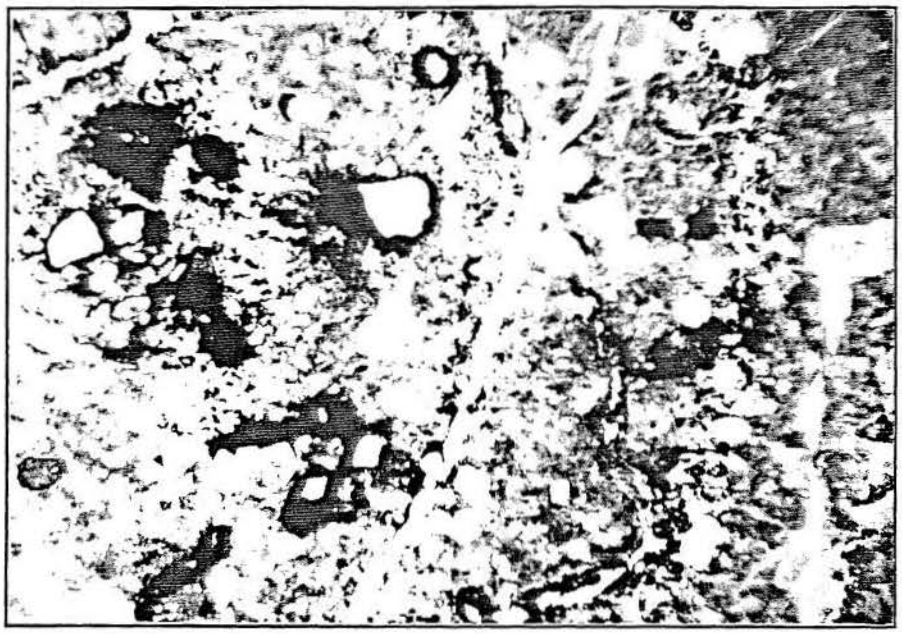

Figure 13. Photomicrograph (50×) of Blackwater Draw Formation sample showing microfabrics and linings of manganese oxides within open tubes (pipes?), evidence that these structures are probably pathways for infiltrating ground water. Photograph by R. G. Deike.

1986a), but substantial eolian sand and silt in the upper Ogallala Formation suggest that limited deposition may have continued after cutting by the Pecos and Canadian Rivers. The massive, 1- to 3-m-thick (3- to 10-ft) Ogallala Caprock caliche (calcrete) (fig. 12, C), which in most places caps the Ogallala Formation, probably formed during an extended period of landscape stability after the cutoff of water and sediment from the west.

The Ogallala Formation varies in thickness from about 30 to 150 m (100 to 500 ft) and generally fines upward. Calcretes are present throughout the formation, those in the lower part having possibly resulted from deposition by ground water (Gustavson and Holliday, 1985) and those in the upper unsaturated part having formed pedogenically.

Hydrology

On the Southern High Plains most recharge to the High Plains aquifer (principally the Ogallala Formation) occurs by infiltration of water ponded in playas; it is chiefly through hydrologic processes that the floors of playa basins are inferred to persist and expand (Osterkamp and Wood, 1987; Wood and Osterkamp, 1987). At Gentry Pit the effects of water movement can be seen at different scales of space and time.

Downward movement of water through the unsaturated zone beneath Gentry playa is indicated by (1) geochemical zonations in and beneath the lowermost Randall Clay, (2) microfractures in the uppermost Blackwater Draw Formation, and (3) carbonate dissolution in the Blackwater Draw and Ogallala Formations. The nearly white leached zone at the base of the playa deposits typically contains less than 40 percent clay, as well as iron and manganese oxides. At the base of the leached zone is 1 to 2 cm (0.4 to 0.8 in) of platy iron oxide. In the uppermost Blackwater Draw Formation concretions containing large amounts of manganese are common, especially at the southwest corner of Gentry Pit. Petrographic studies of the Blackwater Draw Formation (R. G. Deike, U.S. Geological Survey, written communication, 1984) show that beneath the edges of Gentry Pit playa, conduits less than a millimeter (0.04 inch) in diameter are probably pathways for infiltrating ground water. Conduit linings of manganese oxides and iron-rich authigenic clay suggest relatively long-term unsaturated-zone movement of ground water through the microfractures (fig. 13). Extensive caliche dissolution is apparent in exposures of the Caprock caliche in north-central Gentry Pit (fig. 12). Near the center of the playa, excavation failed to cut any identifiable Caprock caliche.

Short-term indications of infiltration from Gentry or other playas that have not been excavated include the following: (1) *Lack of evaporites in the Randall Clay and lack of high dissolved-solids content in ponded playa water.* If ponded water did not infiltrate, evaporation would concentrate salts in the Randall Clay and lake water; however, none of the small playas in the Lubbock to Amarillo area, including Gentry playa, exhibit salt buildup. (2) *Relatively rapid water-level declines during ponding.* When playas fill following precipitation, lake levels typically decline much faster than can be explained by evaporation alone (Wood and Osterkamp, 1984a, b). (3) *Piping.* The capacity for piping is demonstrated by numerous pipes at the walls of Gentry Pit. Natural pipes that are inferred to transmit water downward from the edges of natural playas have been found northwest of Amarillo.

Stop 2B: Gentry Playa: Origin by Geomorphic Processes

V. T. Holliday

Erosional contacts between the Blackwater Draw Formation and playa sediments and the lack of evidence of subsidence indicate that a playa basin exposed in Gentry Pit was formed by surface erosion, most likely deflation.

The small shallow basin of an ephemeral lake or playa, which is exposed in Gentry Pit, appears to be one of the thousands of similar basins that dot the Southern High Plains (figs. 1 and 8). The origins of these basins have long been the subject of debate. Some may be polygenetic, but Reeves (1966) presented a convincing case that the basins are primarily the result of wind deflation. More recently Wood and Osterkamp (1984a, b), Osterkamp and Wood (1987), and Osterkamp (Stop 2A, this guidebook, p. 32) proposed that some of the basins may have been caused by eluviation, micropiping, and carbonate dissolution in the Blackwater Draw and Ogallala Formations.

However, as in any scenario of basin development, the following field observations must be considered: (1) at Gentry Pit and other lake basins, the Blackwater Draw Formation is not deformed below the basin; beds are horizontal to subhorizontal; (2) calcic and petrocalcic zones within and below the Blackwater Draw Formation may have been removed or altered, but the sediments and other pedologic features show no evidence of significant deformation; (3) the contact between the lake sediments and the Blackwater Draw Formation, moreover, is clearly disconformable; and (4) the lake sediments rest in a basin cut into the Blackwater Draw Formation. Erosion thus seems to have been a significant agent in the development of the basins, and wind erosion the most likely mechanism.

The playa sediments are the typical clayey deposits high in organic matter found in most of the smaller lake basins in the region. The soil formed in the deposits is mapped as the Randall Clay, the only Vertisol mapped in the area (Udic Pellustert). In about the middle of the Randall Clay section, on the southwest (upwind) side of the basin (and exposed in the southwest corner of the pit), is a wedge of reddish, sandy, apparently eolian sediment that pinches out toward the center of the basin.

Osterkamp (Stop 2A, this guidebook, p. 32) secured radiocarbon ages of about 10 Ka and 1 Ka B.P. on organic matter from the lower and upper portions of the Randall Clay, respectively, on the south wall of the pit. An assay of 5,730±60 yr B.P. (SMU-1375) is also available on organic-rich sediments from about the middle of the section, just below the wedge of eolian sand. These dates demonstrate that the basin slowly filled with organic-rich clay throughout the Holocene, although a brief interval of eolian sedimentation occurred in the middle Holocene. A similar episode of eolian activity is recorded in draws and dunes in the region (Gile, 1979; Holliday, 1985a).

Older lake sediments containing interbedded olive-green clay and sand, well-exposed along the south wall of the pit, underlie the dark clay. Fragments of mammoth tusk and late Pleistocene horse were found in the sand. The older lake sediments are probably the Tahoka Formation, judging from their lithology and stratigraphic position. The assignment of such stratigraphic terminology can be misleading, however, because olive-hued lacustrine clays are also abundant in the Pliocene Blanco Formation and lower Pleistocene Tule Formation.

The sediments and soils of the Blackwater Draw Formation at the north end of the pit are typical of the region (see Stop 1, p. 22). Postdepositional and postpedogenic alterations of the Blackwater Draw Formation are apparent under the playa sediments, however. There is some gleying; manganese nodules are abundant (table 3), and the calcic horizons have undergone solution and reprecipitation.

Table 3. Soil description, Gentry Pit (south end of "peninsula"). See table 2 (p. 24) for definition of symbols.

Horizon	Depth (cm)	Color Dry	Color Moist	Texture	Structure	Consistence	Reaction	Boundary	Remarks
Ap	0–17		10YR3/1	C	1mpl	f	non	cw	0- to 94-cm, moist.
ACl	17–54		10YR3/1	C	1msbk	f	non	aw	Common slickensides.
AC2	54–94		10YR4/2	C	1mpr& 3csbk	f	non	cs	Wetting front boundary?
AC3	94–129	10YR5/2	10YR4/2	C	3cabk	vh	non	d	
AC4	129–169	10YR5/2	10YR4/2	C	1mpr& 3cabk	xh	non	d	Colors approach 2.5Y.
AC5	169–226	10YR5/2	10YR4/2	C	1mpr& 3cabk	xh	non	d	Common slickensides.
AC6	226–279	10YR5/2	10YR4/2	C	1mpr& 3cabk	xh	non	cs	
Bg	279–309		2.5Y5/2	C	2msbk	f	non	cs	
2Cl	309–328	5Y6/2	5Y6/3	SCL	1msbk part.	f	non	aw	
2C2	328–378	5Y7/3	5Y6/2	SCL	1mpr part. to 2mpl	sh	non	aw	Many dendritic, thin Mn-Fe coats on ped surfaces in upper third; mid. third common; lower third many (w/metallic luster).
2C3	378–380	5Y7/3	5Y6/3	SCL	1pl	h	non	aw	
3Btgcbl	380–434	5Y7/3	5Y6/3	SC	2mpr& 2mabk	h	non	dw	Blackwater Draw Formation; gleying along ped surfaces and channels; upper 12 cm dominated by Mn-Fe staining throughout peds; many splotches have metallic luster—this grad. decr. w/depth; at about 30 cm begin picking up few 1-cm Mn concretions (5PB 3/1).
3Btgbl	434+	5YR5/6 (5Y7/2)	5YR4/6 (5Y6/3)	SCL	2mpr& 2msbk	h	es		Gleying along ped faces and channels, generally oriented vertically; few to common coarse red mottles in gley matrix to common gley mottles in red matrix.

NOTE: 0–279 cm have dry weather crack fillings; long, sinuous 2–3 cm wide; 7.5YR5/6(d), 4/6(m); also common organic coatings on ped faces & along crack fillings.

Stop 3: Ogallala Formation (Group) Exposed at Janes Quarry

D. A. Winkler

Coarse-grained fluvial sediments of the upper Tertiary Ogallala Formation (Group), deposited by braided streams, subsequently filled the Slaton paleovalley near Slaton, Texas. These sediments contain an early Hemphillian Land Mammal Age fauna.

Janes Quarry contains evidence of one of the most interesting episodes in the faunal and depositional record of the Ogallala on the Southern High Plains (figs. 1 and 14). Early mapping in Yellow House Canyon by Glen Evans (1940's, 1950's) and Carl Chelf (personal communications, 1984) identified a band of gravels along the south edge of the canyon east of the city of Slaton. These sediments were best exposed in the area now occupied by the Janes Gravel Company quarry. Outcrops at Janes Quarry contain interbedded massive and trough crossbedded sand to boulder gravel at least 18 m (60 ft) thick (figs. 14 and 15). Many troughs are on the order of 1 m (3.3 ft) high and several meters wide. Megaclasts of paleovalley wall rock weighing many tons and as much as 3 m (10 ft) long lie within the gravel deposit (Reeves, 1984a). Evans (1949, 1956) identified two mappable formations within the Ogallala Group in Yellow House and Blanco Canyons: the Couch Formation and the overlying Bridwell Formation (Winkler, Stop 4, this guidebook, p. 41). The sediments at Janes Quarry differ markedly from those in most of the other Ogallala deposits in these canyons and are not clearly assignable to

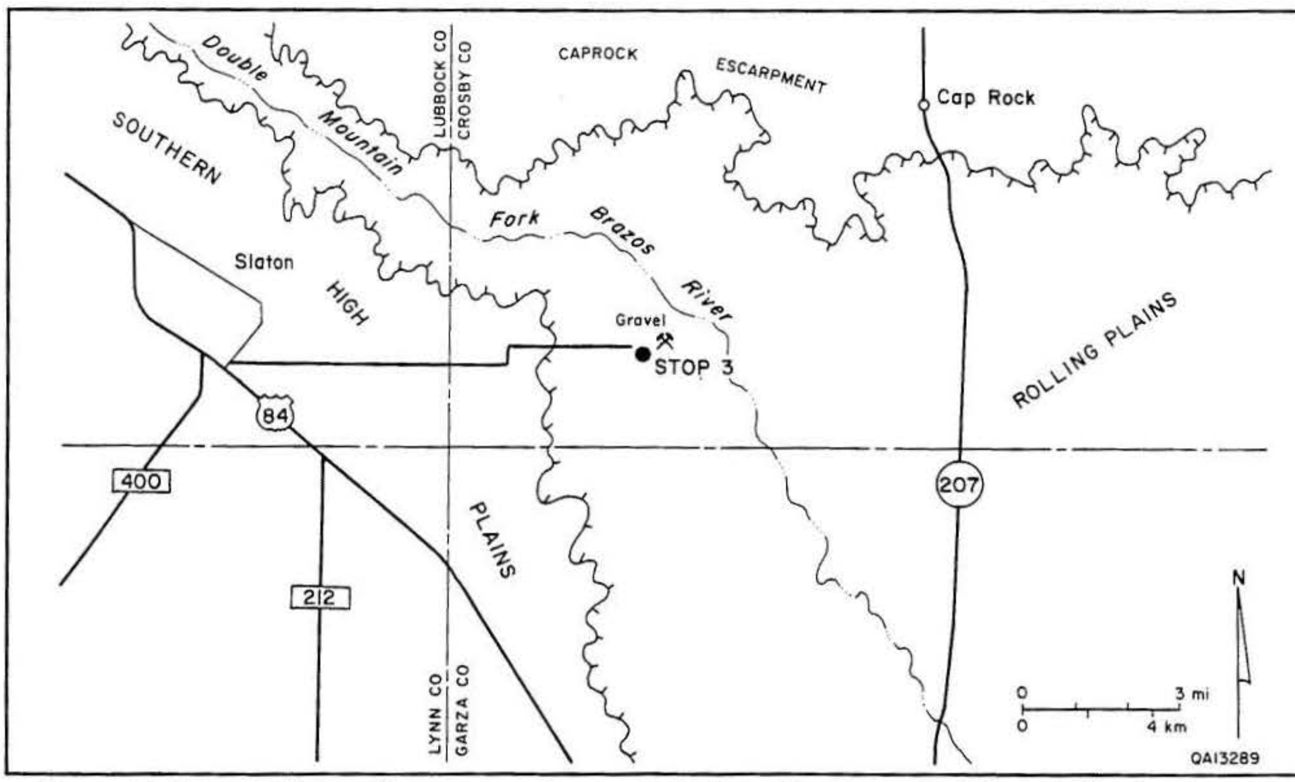

Figure 14. Map of Slaton, Texas, area showing Field Trip Stop 3. Derived from Lubbock Sheet, U.S. Geological Survey, (1:250,000 series). See figure 1 for location.

Figure 15. Coarse-grained, imbricated gravels of the upper Tertiary Ogallala Formation (Group) exposed at Janes Quarry near Slaton, Texas. Pencil is 14 cm (5.5 inches) long.

either formation on the basis of lithology. Hydrologic studies have shown that the gravels at Janes Quarry can be traced for miles in the subsurface (figs. 4, 16) and pass near the city of Slaton (Cronin, 1969; Knowles and others, 1984). The fluvial channel facies at Janes Quarry fill a deeply incised sinuous paleovalley termed "the Slaton paleovalley" (Reeves, 1984b; Winkler, 1985; Gustavson and Winkler, 1988). The stratigraphic placement of the valley-fill facies cannot be clearly determined only by their superposition.

During his initial work in Yellow House Canyon, Carl Chelf noted vertebrate fossils in the gravels and commented that the deposit, though in contact with Triassic rocks, may not represent the earliest Ogallala deposits in the area (Chelf letter on file, 1959, Texas Memorial Museum, Austin). Work on a new part of the quarry in the late 1970's led to the discovery of a productive bone bed near the top of the valley-fill deposit. Proctor (1980) described an unusual concentration of fossils representing a population of gomphotheres (primitive relatives of elephants), estimated to number in the hundreds. Gomphotheres are most abundant in the bone bed, but the fauna also includes horses (*Cormohipparion, Nannippus*), camels, and large carnivores (*Epicyon*, cat), as well as aquatic turtles (Winkler, 1985). Fossils appear dominantly as isolated, rounded bones and teeth in a unit of sandy pebble gravel. The suite of animals found at Janes Quarry is restricted to the early Hemphillian Land Mammal Age (late Miocene, or 6–9 Ma) (Winkler, 1985). This is the only confirmed representation of that time in the Yellow House and Blanco Canyon areas (and, in fact, south of Lipscomb County, Texas [Schultz, 1977b]).

The Slaton channel is topographically lower than any other Ogallala sediments in Yellow House Canyon. However, the presence of early Hemphillian mammals in the deposit, as well as superposition of reddish, finer grained Bridwell Formation sediments (upper Ogallala) in the channel fill, indicates that this valley probably was incised and certainly was filled during the middle of the time that the Ogallala

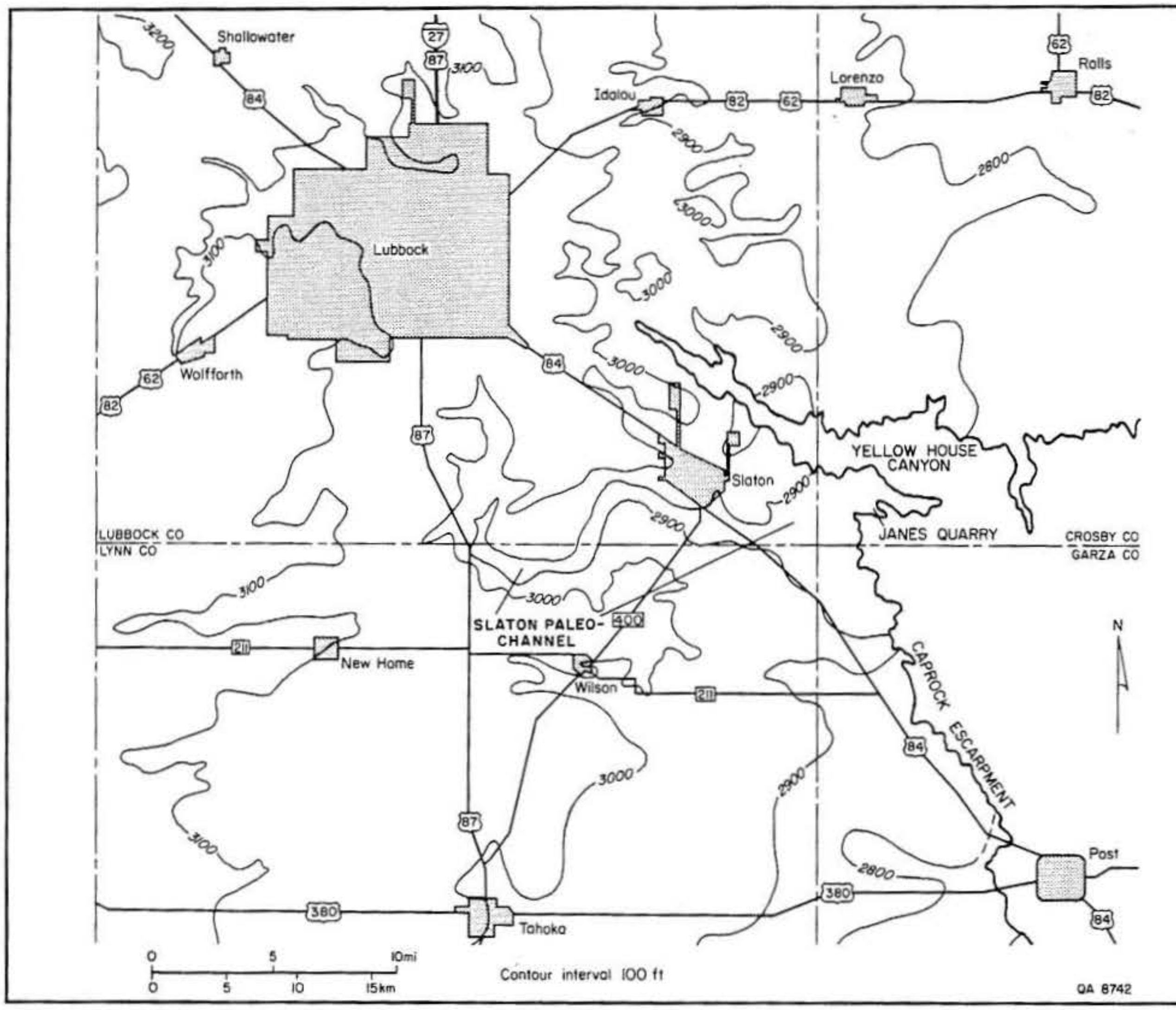

Figure 16. Structure-contour map of approximate elevation of base of High Plains aquifer for parts of Crosby, Garza, Lubbock, and Lynn Counties, Texas. From Knowles and others (1982). This surface essentially coincides with erosional surface that underlies Ogallala Formation. Janes Quarry lies within Slaton paleochannel.

was being deposited (Winkler, 1985). The sediments that the valley is cut through include the upper Couch Formation, which contains early Clarendonian Age mammals (10–11 Ma) in Blanco Canyon (Winkler, 1985). Only the top of the Slaton channel fill has produced age-diagnostic fossils, so its base is not directly dated.

The Slaton channel represents a time of valley incision through older Ogallala sediments that was followed by vigorous filling and then abandonment. Such valley cutting contrasts sharply with more widespread and continuous aggradation by smaller ephemeral streams and eolian processes indicated in the rest of the Ogallala on the Southern High Plains (Winkler, 1985). This unusual geomorphic situation is reflected in the unusual fauna dominated by gomphotheres. Previous models identified the Slaton channel deposits and two or three other large valley fills that cross the Texas Panhandle as deposits of major trunk streams that fed sediment to areas of the High Plains throughout Ogallala deposition (Seni, 1980; Reeves, 1984b). Biostratigraphic evidence indicates that the Slaton paleovalley was a source of sediment for only part of the time during which the Ogallala was deposited.

Stop 4: Type Section of the Couch and Bridwell Formations (Ogallala Group) at Blanco Canyon, Silver Falls Area

D. A. Winkler

In the Blanco Canyon area the lower Couch Formation, which contains Clarendonian mammal remains, consists of sandy sediments of flashy-discharge braided streams. The overlying Bridwell Formation, which contains Hemphillian mammal remains, records deposition by flashy-discharge braided streams and eolian processes.

Ogallala deposits in the area of Blanco and Yellow House Canyons received little attention from pioneering geologists working in the Panhandle (figs. 1 and 17). In contrast, the deposits and fossils of the Blanco beds in Blanco Canyon were described as early as the late 1800's (Cope, 1892a, 1893). The first attention given to the Ogallala in this area was related to the search for vertebrate fossils. In the early 1940's Porter Montgomery and Grayson Meade from Texas Tech University and Glen Evans from the Texas Memorial Museum, University of Texas, Austin, made the first recorded collections of fossils and began stratigraphic work in the canyon areas. Other collections of fossils were made for the University of California from

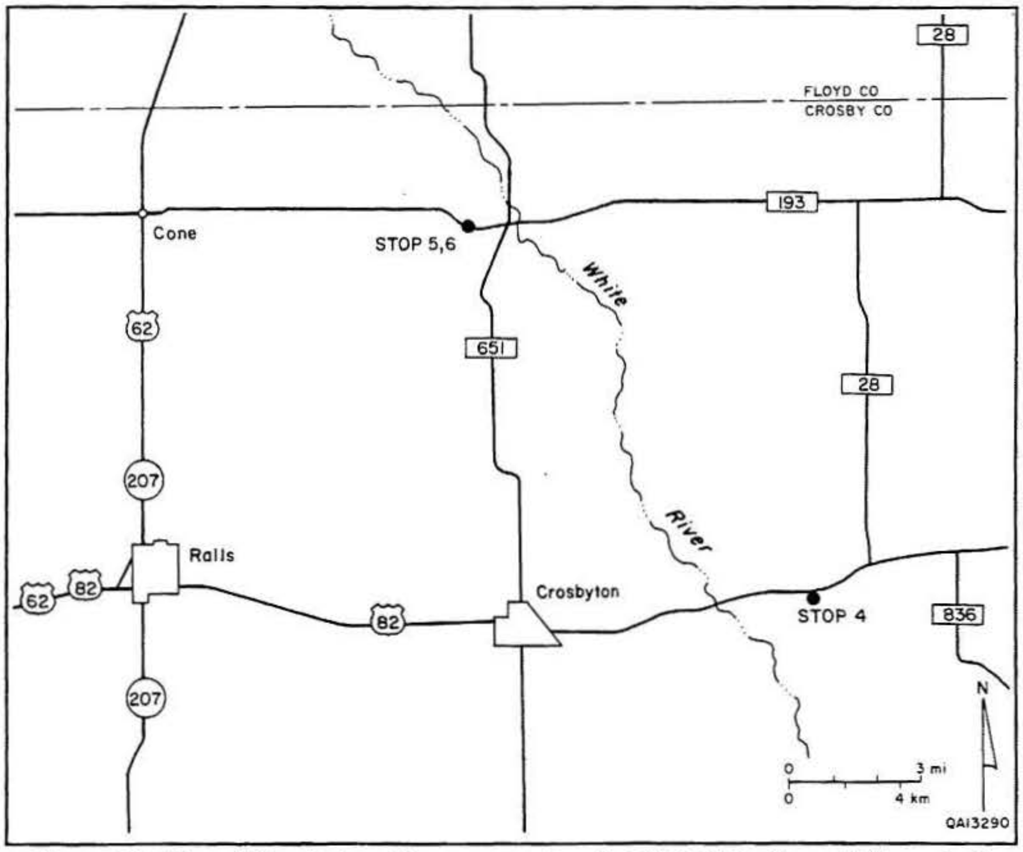

Figure 17. Map of Crosbyton, Texas, area showing Field Trip Stops 4 through 6. Derived from Lubbock Sheet, U.S. Geological Survey (1:250,000 series). See figure 1 for location.

Yellow House Canyon (Johnston and Savage, 1955). Carl Chelf also collected fossils from Yellow House Canyon that are now in the Texas Memorial Museum.

Pioneering stratigraphic work on the Ogallala in the canyons was reported by Evans (1949, 1956, 1974) in a series of field guides. Frye and Leonard (1957, 1959) measured sections in the area for their regional work on the Ogallala of the Panhandle. Reeves (1972, 1984b) and Seni (1980) described general depositional histories of the Ogallala including the southern canyon area. Evans (1949, 1956) proposed that two formations composed the Ogallala Group in Blanco Canyon—the Couch and Bridwell Formations (see Winkler, 1985). The type area of the two formations was designated along the south side of U.S. Highway 82 approximately 4 km (2.5 mi) east of Silver Falls in Blanco Canyon (Evans, 1949, 1956). The Couch Formation contains a lower fluvial-dominated section in Blanco Canyon and an upper unit of massive pink silty sand (fig. 18). The lower Couch is dominated by greenish gray and buff sands. Only the upper part of the Couch Formation is found in Yellow House Canyon. The Bridwell Formation is redder in outcrop than the Couch because of deep red clays intercalated with buff sands.

The Ogallala Group in Blanco and Yellow House Canyons has produced vertebrate fossils from the Clarendonian and Hemphillian Land Mammal Ages. The age of the deposits is, therefore, bracketed between approximately 11 and 5 Ma (Winkler, 1985). Like much of the Ogallala in Texas, the fauna was dominated throughout that time by large, savanna-adapted animals, especially horses and camels (Schultz, 1977b).

The fluvial sediments of the lower Couch Formation unconformably overlie the Triassic Dockum Group in outcrops along the south side of U.S. 82, 4 km (2.5 mi) east of the Silver Falls crossing (fig. 18). Clarendonian mammals have been found in nearby outcrops of the lower Couch and appear as isolated, transported bones and teeth. The sediments are dominated by horizontally bedded sand containing subordinate large-scale trough crossbedding. The lower Couch represents basal valley fills of flashy-discharge to sandy ephemeral streams.

The upper Couch Formation is clearly visible along the south side of U.S. 82 west of Silver Falls. Here the upper Couch consists of about 11 m (36 ft) of massive pink silty sand that contains abundant pedogenic carbonate nodules (Winkler, 1985). At the type section a thick laminar carbonate lies at the top of the upper Couch; however, northward in Blanco Canyon, the carbonate layer is overlain by at least 10 more meters of massive pink silty sand. Outcrops along U.S. 82 and farther north along FM 2591 contain vertebrate skeletons. Many of the specimens are isolated, articulated skeletons that show signs of desiccation and subaerial weathering before burial. The bedding of the upper Couch, the presence of carbonate nodules, the fine grain size, and the mode of vertebrate-fossil preservation all support an eolian origin for the unit (Winkler, 1987). Deposition resulted from bed-load saltation of sand and suspension transport of finer particles. Thus the unit has characteristics of both loess and eolian sand sheets.

Bridwell Formation sediments overlie the upper Couch on an erosive contact. The Bridwell contains lenticular packages of horizontally bedded and trough crossbedded sands containing armored mud balls. These lenses alternate with massive silty sands and red clays. The formation is 51 m (168 ft) thick at the type section, inclusive of the caprock (Winkler, 1985). Paleosols are common in the Bridwell Formation, as shown by carbonate development, and the formation is bounded above by the Caprock caliche. Remains of Late Hemphillian mammals have been found at several Bridwell sites in Blanco Canyon, including the roadcut on the north side of U.S. 82 on the west descent into the canyon. The Bridwell Formation records alternating episodes of deposition by high-energy, variable-discharge streams and by eolian processes. No fossils have been found in the Bridwell that are younger than late Miocene (approximately 5.0 Ma old).

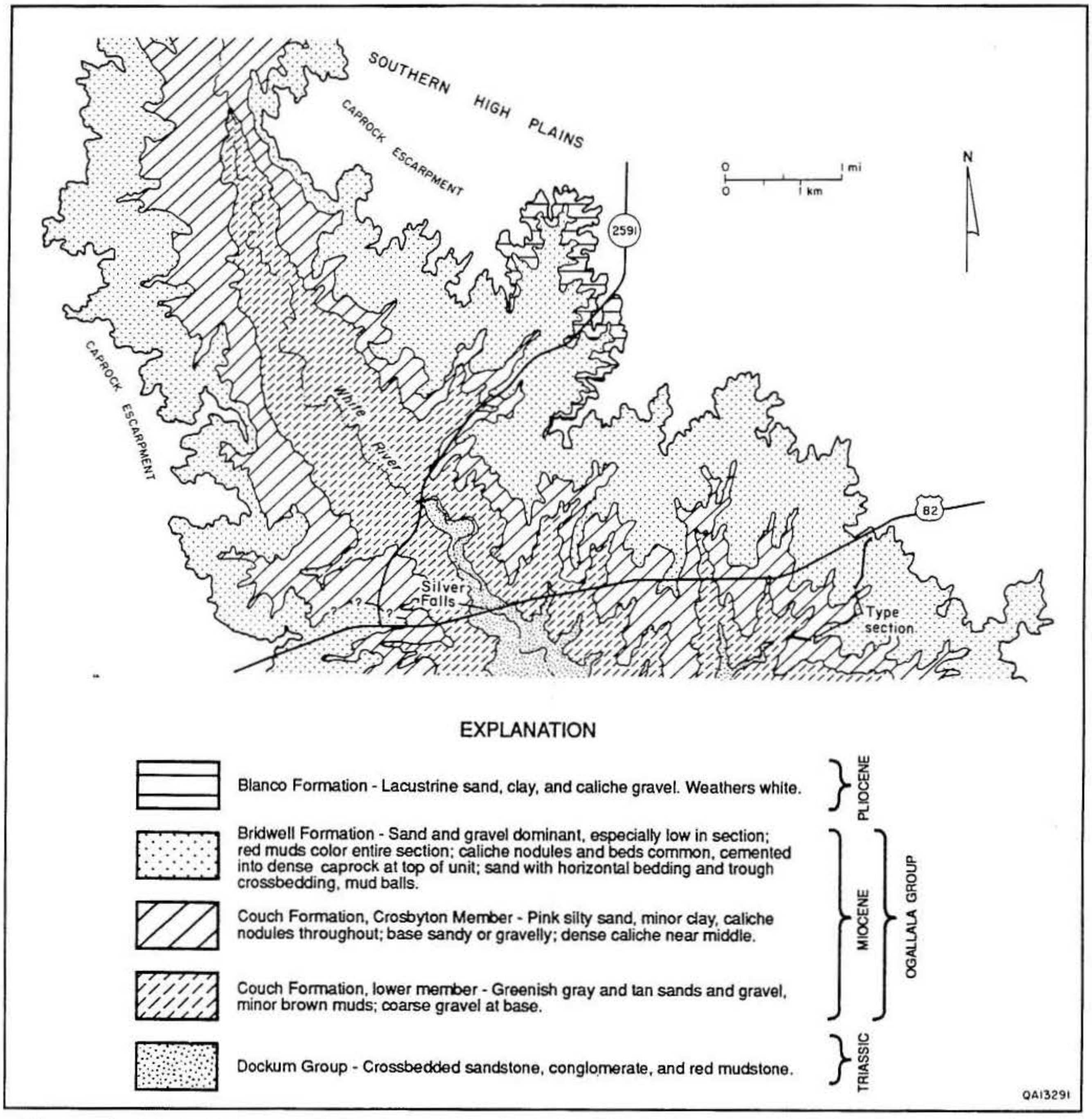

Figure 18. Geologic map of type area of Couch and Bridwell Formations (Ogallala Group) in Blanco Canyon, Texas. From Winkler (1985).

Stop 5: Blanco Local Fauna and the Blancan Land Mammal Age

G. E. Schultz

The Blanco Local Fauna of Crosby County, Texas, which is the type fauna of the Blancan Land Mammal Age, existed under conditions that are similar to those of the Southern High Plains at present.

The Blanco Local Fauna, named for Mount Blanco, a small erosional remnant and local landmark, is the type fauna of the Blancan Land Mammal Age of North America (Wood and others, 1941) (figs. 1, 17, and 19 through 22; table 4). Most of the vertebrate fossils have come from deposits exposed in the upper canyon walls on the north side of Crawfish Draw 3.2 km (2 mi) west of its junction with the White River and 16 km (10 mi) north of Crosbyton. The quarries or fossil localities are on the J. S. Bridwell Ranch southwest of the junction of

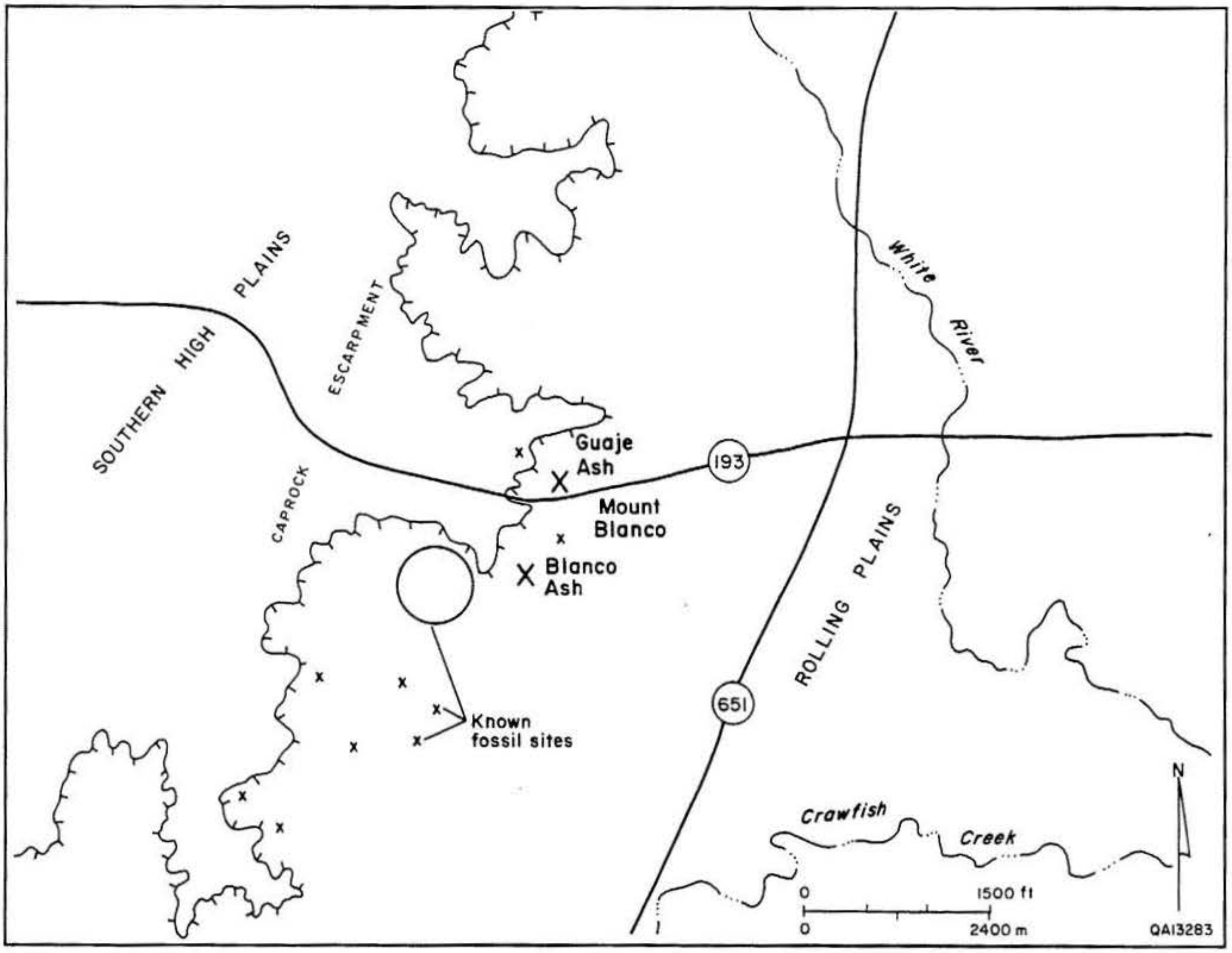

Figure 19. Map showing locations of Blanco Local Fauna sites and volcanic ash beds, Crosby County, Texas (Field Trip Stop 5). Small x's and circled area indicate known fossil sites; large x's are ash beds. Scale 1:24,000. See figure 1.

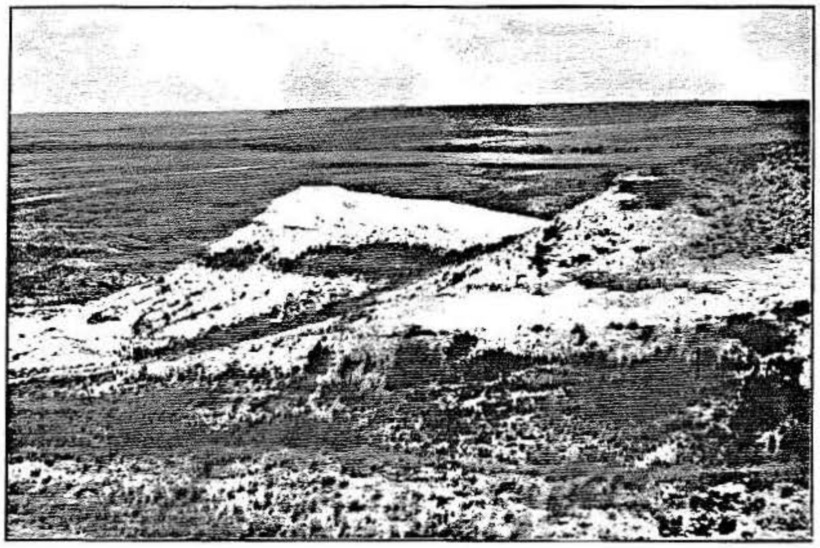

Figure 20. Mount Blanco, view toward southeast. Blanco Canyon and High Plains surface in distance. Crosby County, Texas.

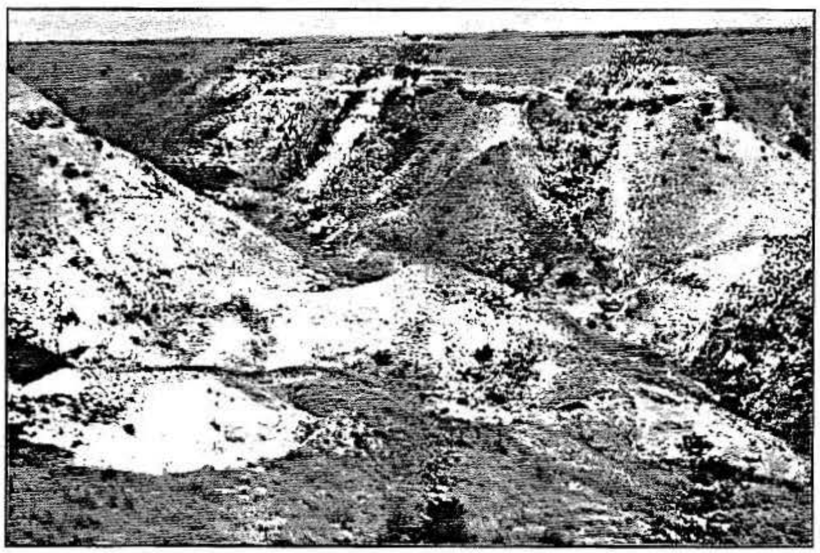

Figure 21. Blanco Formation, Crosby County, Texas. High Plains surface in distance.

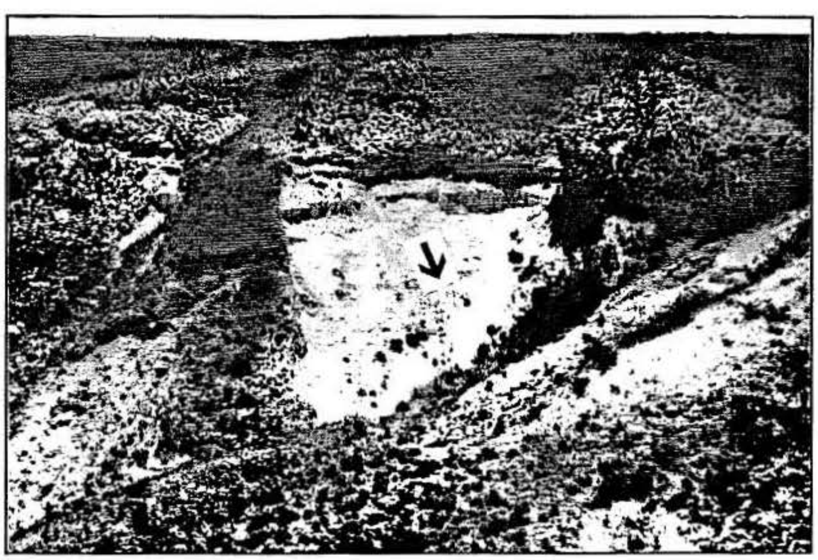

Figure 22. Blanco Formation showing Blanco volcanic ash, Crosby County, Texas. Ash bed (arrow) about 8 m (25 ft) below Guaje Ash.

Table 4. Faunal list of Blanco Local Fauna, Crosby County, Texas.

Class Reptilia
- Order Chelonia
  - Family Testudinidae
    - * *Geochelone campester* Hay - tortoise
    - * *Gopherus pertenuis* (Cope) - tortoise

Class Aves
- Order Ralliformes
  - Family Rallidae
    - ** *Creccoides osbornii* Shufeldt - rail

Class Mammalia
- Order Insectivora
  - Family Soricidae
    - *Sorex taylori* Hibbard - shrew
  - Family Talpidae
    - * *Scalopus (Hesperoscalops) blancoensis* Dalquest - mole
- Order Chiroptera
  - Family Molossidae
    - Bat near *Tadarida*
- Order Edentata
  - Family Megalonychidae
    - * *Megalonyx leptostomus* Cope - ground sloth
  - Family Mylodontidae
    - *Glossotherium* near *chapadmalensis* Kraglievich - ground sloth
  - Family Glyptodontidae
    - ** *Glyptotherium texanum* Osborn - glyptodont
- Order Rodentia
  - Family Sciuridae
    - *Paenemarmota barbouri* Hibbard and Schultz - marmot
    - *Spermophilus* sp. (large) - ground squirrel
    - *Spermophilus* sp. (small) - ground squirrel
    - *Spermophilus* cf. *S. howelli* (Hibbard) - ground squirrel
  - Family Geomyidae
    - *Geomys* sp. - pocket gopher
  - Family Heteromyidae
    - *Perognathus* cf. *P. rexroadensis* Hibbard - large pocket mouse
    - *Perognathus* cf. *P. pearlettensis* Hibbard - small pocket mouse
    - *Prodipodomys* cf. *P. centralis* (Hibbard) - kangaroo rat
  - Family Cricetidae
    - *Peromyscus* near *kansasensis* Hibbard - deer mouse
    - *Reithrodontomys* sp. - harvest mouse
    - *Baiomys* sp. - pygmy mouse
    - *Calomys (Bensonomys)* sp. - neotropical mouse
    - *Onychomys* sp. - grasshopper mouse
    - *Neotoma* cf. *N. quadriplicatus* (Hibbard) - wood rat
    - *Sigmodon medius* Gidley - cotton rat
- Order Lagomorpha
  - Family Leporidae
    - *Pewelagus dawsonae* White - rabbit
    - *Hypolagus* sp. - rabbit
    - *Sylvilagus* cf. *S. hibbardi* White - cottontail rabbit

** *Holotype of genus*
* *Holotype of species*

Table 4. (cont.)

Order Carnivora
- Family Hyaenidae
  - ?*Chasmaporthetes johnstoni* (Stirton and Christian) - hyena
- Family Felidae
  - ?*Homotherium* sp. - saber-toothed cat
  - * *Felis* (*Dinofelis*) *palaeoonca* Meade - large cat
  - *Felis* cf. *F. lacustris* Gazin - small cat
- Family Canidae
  - ** *Borophagus diversidens* Cope - bone-eating dog
  - *Canis lepophagus* Johnston - coyote
- Family Mustelidae
  - ** *Canimartes cumminsii* Cope - extinct mustelid
  - *Spilogale rexroadi* Hibbard - spotted skunk
  - *Taxidea* sp. - badger

Order Proboscidea
- Family Gomphotheriidae
  - *Stegomastodon mirificus* (Leidy) - short-jawed mastodon
  - * *Rhynchotherium praecursor* (Cope) - gomphothere mastodon

Order Artiodactyla
- Family Tayassuidae
  - * *Platygonus bicalcaratus* Cope (including *P. texanus* Gidley) - peccary (holotypes)
- Family Camelidae
  - ** *Blancocamelus meadei* Dalquest - long-legged camel
  - *Camelops* cf. *C. traviswhitei* Mooser and Dalquest - camel
  - * *Gigantocamelus spatulus* (Cope) - giant camel
  - * *Hemiauchenia blancoensis* (Meade) - llama
- Family Cervidae
  - *Odocoileus* cf. *O. brachyodontus* Oelrich - deer
- Family Antilocapridae
  - Antilocaprid sp. - pronghorn

Order Perissodactyla
- Family Equidae
  - * *Nannippus phlegon* (Hay) - small 3-toed horse
  - * *Equus* (*Dolichohippus*) *simplicidens* (Cope) - zebrine horse
  - * *Equus* (*Asinus*) *cumminsi* Cope - small asslike horse

FM 651 and FM 193 in Blk. 3, Eastland C.S.L. (Capital School Lands) Survey No. 1, Crosby County, Texas (U.S. Geological Survey [USGS], Floydada S.E. 7.5-minute topographic quadrangle) (fig. 19). Two other fossil sites are on the R. B. Smith Ranch on the slopes of the first reentrant north of FM 193 (same topographic map). Another exposure of Blanco deposits, somewhat smaller and less fossiliferous, lies 13 km (8 mi) to the southeast on the east side of White River Canyon about 9.7 km (6 mi) northeast of Crosbyton (USGS Crosbyton 7.5-minute quadrangle). No discernible stratigraphic tie exists between deposits in this area and those on the Bridwell Ranch. Meade (1945, p. 519) gives more detailed locations for these fossil quarry sites, although his map (Meade, 1945, p. 510) is in error. The main group of quarries is actually about 0.4 km (0.25 mi) west of their plotted positions on his map. These locations have been corrected on a map by Dalquest (1975, p. 8).

Geology

According to Evans and Meade (1945), the Blanco deposits are a localized basin accumulation and are predominantly of lacustrine origin, although a fluviatile origin has been advocated by Gidley (1903a), Matthew (1924a), and Frye and Leonard (1957). The best exposures of these white beds are along the upper walls of White River Canyon (Blanco Canyon) and Crawfish Draw for a distance of about 4 km (2.5 mi), where they unconformably overlie the reddish-brown sands and clays of the Bridwell Formation (locally defined equivalent of the upper part of the Ogallala Group). The Blanco Formation is in turn overlain by eolian sands, silts, and caliche of the Blackwater Draw Formation Quaternary age (Reeves, 1976).

Evans and Meade (1945, p. 491) stated that "the Blanco beds consist mainly of well-bedded, light gray, calcareous sands and clays with some fresh-water limestones, tufa, diatomite, and coarse gravels. The finer-grained materials make up the main body of the deposits but grade marginally to coarser sand and gravel." They described the following section, located 1,067 m (3,500 ft) south of FM 193 and near the mouth of Crawfish Draw:

		Thickness in feet
10.	Bentonitic clay, greenish gray, sandy in upper part	10.0
9.	Sands, gray to light greenish gray, containing calcareous nodules	4.7
8.	Diatomaceous earth, light gray; varies in thickness from 1 foot to more than 5 feet at this section	1.0
7.	Bentonitic clay, sandy	9.4
6.	Caliche, gray, jointed	6.8
5.	Bentonitic clay, calcareous and sandy	6.2
4.	Fresh-water limestone, thin flaggy beds, reeflike tufa masses locally present	6.0
3.	Clay, gray, calcareous	2.0
2.	Sand, light greenish gray, massive	12.5
1.	Clay, light tan to greenish	2.0
		60.6

In this and six other sections measured at intervals over an outcrop distance of about 2.4 km (1.5 mi), Evans and Meade identified 10 to 12 beds and noted a range in thickness of 17 to 22 m (56 to 74 ft) for the Blanco sequence. Changes in thickness and facies of individual beds are visible along the outcrop.

Recent geological studies of the Blanco Formation by Pierce (1974) detailed clay, carbonate, and silicate mineralogy by X-ray diffraction and use of thin sections, along with supplementary textural analysis of insoluble residues. Pollen, diatoms, and invertebrates were also studied. Pierce found that near the center of the basin, the Blanco beds mostly contain very fine sand, primary dolomite or dolostone, and magnesium-rich clays (attapulgite and sepiolite) and only small amounts of sheetwash gravel. Near the margin of the basin, limestone and coarser clastics, including caliche gravel and cobbles in arroyo fans, are found, whereas dolostone and magnesium-rich clays become rarer. Pierce also discovered that the Blanco Ash (Izett and others, 1972; Boellstorff, 1976) (fig. 22), which is restricted to the northwest part of the basin, can be traced laterally into the prominent diatomite unit that overlies some of the main fossiliferous strata in the lower part of the formation. This diatomite unit and its lateral facies equivalent, a dense, laminated limestone, provide a useful marker bed throughout the west part of the basin, where they form a boundary between dolomitic carbonates below and highly contorted laminated calcitic carbonates above. Pierce noted a disconformity between these laminated caliches and the overlying eolian cover sands, which contain the Guaje Ash (Izett and others, 1972) that is exposed in the roadcut of FM 193 (fig. 23).

The vertebrate fauna reported by Dalquest (1975) and earlier workers is dominated by grazing herbivores such as glyptodonts, gomphothere mastodons, camels, antilocaprids, and horses, although some browsers are represented, including ground sloths and deer. Peccary probably required some brush or woodland cover, which may have grown along streams and ponds and in shaded valleys. Aquatic vertebrate remains are absent, with the exception of one alligator tooth. Rodents include pocket mice, kangaroo rats, ground squirrels, cotton rats, and gophers—indicating semiarid grassland habitats. No arvicoline rodents are present. Dalquest (1975, p. 46) concluded that "the Blanco local fauna represents one rather uniform habitat: grassy plains with narrow belts of trees fringing watercourses and in the shaded parts of valleys. Conditions were almost identical to those of the High Plains and Texas Panhandle today where not modified by agriculture."

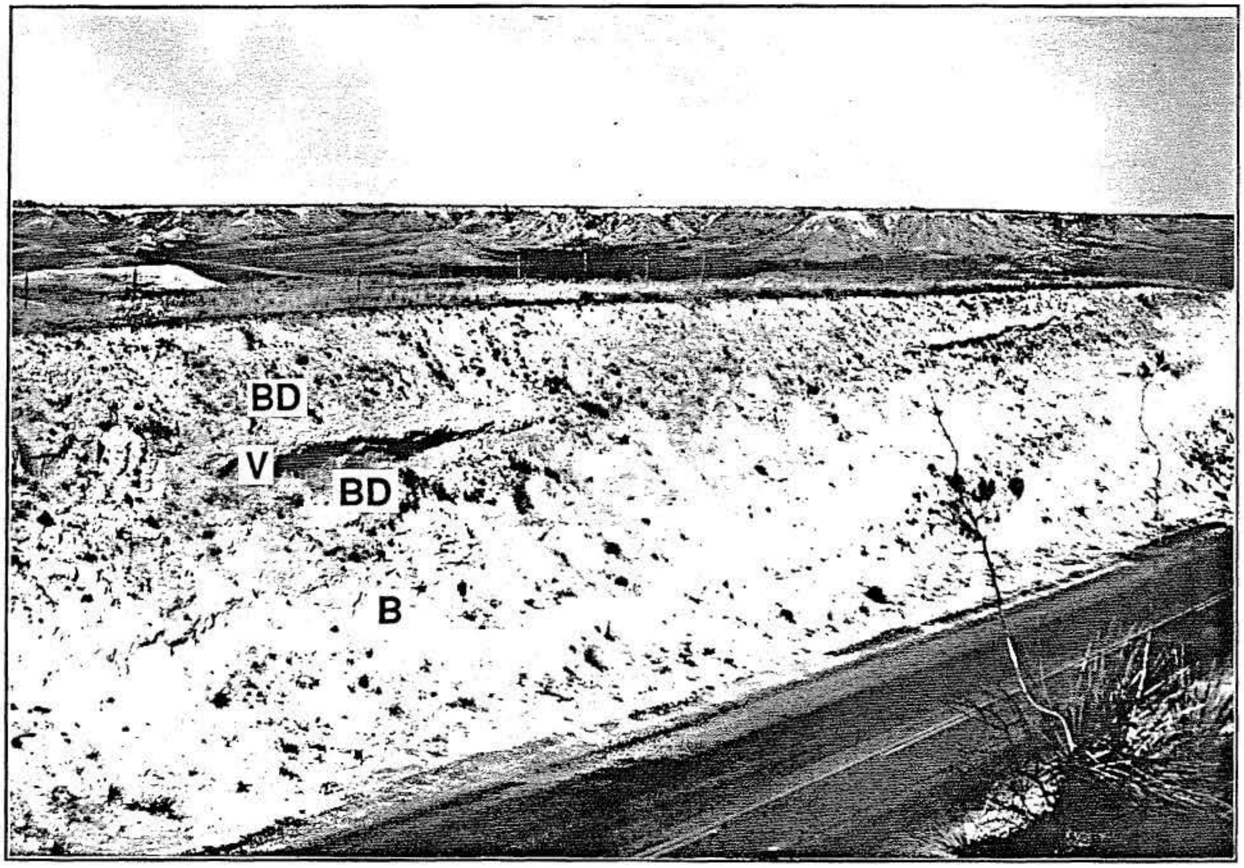

Figure 23. View of Blackwater Draw Formation (BD) overlying Blanco Formation (B) at type section of Blanco Formation. The 1.4-Ma-old Guaje volcanic ash (V) is underlain by approximately 1 m (3 ft) of Blackwater Draw Formation sediments.

History of Fossil Collecting

A number of institutions have collected from the Blanco beds, and many new species have been described (table 4). The first specimens, now at the Texas Memorial Museum, The University of Texas at Austin, were described by Cope (1892a, b, c, d, e, f, g; 1893). They include the type specimens of a land tortoise, a ground sloth, a bone-crushing dog, a small mustelid, a mastodon, a peccary, a giant camel, and two horses. The American Museum of Natural History expeditions under Gidley obtained additional material, including a nearly complete carapace of *Glyptotherium texanum* described by Osborn (1903) and restudied by Gillette and Ray (1981) and a peccary, *Platygonus texanus*, described by Gidley (1903b) but later synonymized with *P. bicalcaratus* Cope (Hibbard and Riggs, 1949, p. 843).

Most of the fossil material consists of isolated bones, teeth, and jaws that are commonly fragmentary. Notable exceptions include the glyptodont carapace just mentioned, as well as two partial skeletons of the zebrine horse *Equus* (*Dolichohippus*) *simplicidens* (formerly *Plesippus*) collected from a white clay bed by Matthew and Simpson for the American Museum in 1924 (Matthew, 1924c, 1926; Simpson, 1951). The small 3-toed horse, *Nannippus phlegon*, is known from articulated leg bones as well as from partial skulls, lower jaws, and teeth (Dalquest and Donovan, 1973; MacFadden and Waldrop, 1980; MacFadden, 1984a). *Nannippus phlegon* apparently was a highly cursorial, antelopelike grazer.

During the early 1940's, Meade collected a representative sample of the fauna for the University of Texas, Austin (Meade, 1945). Of interest are the type skull and jaws of a large cat, *Felis* (*Panthera*) *palaeoonca*, which Meade considered to be a jaguar but which Kurten (1972) assigned to the Old World genus *Dinofelis*. Of interest, too, are the remains of about 18 individuals of the giant camel, *Gigantocamelus spatulus*, which Meade collected from one quarry. Although no articulated skeletons were found, there were several articulated skulls and jaws and a number of articulated leg bones. According to Meade (1945, p. 514), these fossils may represent a herd of camels that ventured into the shallow waters of an ancient lake and were trapped or were overcome by carnivores at the edge of the water. *Gigantocamelus* has been reviewed recently by Breyer (1976) and Harrison (1985). Meade also described a new species of llamalike camel, *Tanupolama blancoensis*, now assigned to the genus *Hemiauchenia* (Webb, 1974; Breyer, 1977, 1983). And he collected a jaw fragment of the giant ground squirrel, *Paenemarmota*, later described by Hibbard (1950, p. 137) and Repenning (1962). An incisor of this rodent was misidentified by Meade (1945) as that of a beaver, *Procastoroides*. There is no beaver in the Blanco Fauna.

Errors in identification of taxa and much controversy and speculation have occurred, in part, because some of Cope's type specimens were lost for a time. A proper understanding of the nature of *Borophagus*, for example, was not possible until the type of *B. diversidens* was relocated (VanderHoof, 1936) and a complete skull was found and described by Dalquest (1969a). Of note also is the varied treatment given the mastodons, which include the rather common short-jawed *Stegomastodon*, which lacks lower tusks, and the much less common lower tusked mastodons assigned to various genera including (currently) *Rhynchotherium* (Osborn, 1923, 1924, 1936; Savage, 1955b). Another problem concerns the proper identification of the several camels present and the correct association between limb and foot elements and dentitions. Dalquest (1969a, 1975) dealt admirably with these and other problems. For example, he coined the genus *Blancocamelus* for the large, long, slender metapodials to which Meade had applied the name *Leptotylopus percelsus*—a nomen nudum borrowed from an unpublished manuscript by Matthew. Meade was not aware that Matthew had intended the name for a small species of camel now recognized as *Hemiauchenia blancoensis*. *Blancocamelus* was reviewed by Harrison (1985).

The most recent additions to the Blanco Local Fauna are the microvertebrates collected by Dalquest (1975) from several quarry sites. These fossils, though few in number, include a shrew, a mole, a bat, two rabbits, and a variety of rodents. The rodents are primarily grassland prairie forms such as gophers, kangaroo rats, pocket mice, ground squirrels, cotton rats, and other cricetines. Arvicoline rodents, beavers, otters, fish, amphibians, small pond turtles, and other forms indicative of aquatic or moist environments are absent except for a single tooth of a large alligator. Turtles are represented only by the large land tortoise, *Geochelone*.

Dalquest placed most of his collection in the museum at Texas Tech University in Lubbock, which also has some of the material described by Meade. There is also a small collection at West Texas State University and one in the Panhandle-Plains Historical Museum in Canyon.

Age of the Blanco Fauna

The Blanco beds disconformably overlie deposits of the Ogallala (Bridwell) Formation, which locally have produced late Hemphillian fossils, and they are disconformably overlain by unfossiliferous eolian silts and sands of the Quaternary Blackwater Draw Formation. The age of the Blanco Local Fauna has been based mainly on the evidence of the fossil vertebrates supplemented more recently by studies of volcanic ash petrography and magnetic stratigraphy.

The fauna is a mixture of typical Blancan genera such as *Borophagus*, *Stegomastodon*, *Gigantocamelus*, and *Dolichohippus*, as well as longer ranging genera such as *Camelops*, *Platygonus*, and *Hemiauchenia*, which survived through most or all of the Pleistocene, and also a few carryovers from the Hemphillian such as *Nannippus*, *Rhynchotherium*, and *Hemiauchenia* (table 4). Early workers such as Gidley, Matthew, and Osborn assigned a Pliocene age to the fauna. Meade (1945) identified typical Pleistocene genera and assigned an early Pleistocene age to the fauna. Meade's conclusion, along with evidence that the deposits presumably formed in a humid climate (probably during a glacial stage), indicated to Evans and Meade (1945) that the Blanco beds were of Nebraskan age.

The apparent absence of a molluscan fauna in the Blanco led Hibbard (1958) to conclude that the age of the fauna was Aftonian interglacial because, in his experience, faunas that lived in southwest Kansas during glacial periods under moist climatic conditions commonly included abundant mollusks. Frye and Leonard (1957) accepted a Nebraskan age for the Blanco Local Fauna but ascribed the absence of mollusks as well as fish, amphibians, and aquatic turtles to an unstable stream regimen.

Meade (1945, p. 516–519) argued that not only the Blanco Local Fauna, but Blancan faunas in general, were of early Pleistocene age. Later authors, for a time, thought the Blancan Age had spanned the late Pliocene through the early Pleistocene. They accepted Meade's assignment of an early Pleistocene age for the Blanco Local Fauna, but not, as he had intended, for all Blancan faunas (Dalquest, 1975, p. 46).

Recent studies indicate that warm Blancan faunas such as the Sand Draw Local Fauna of Nebraska (Skinner and others, 1972) and those from southwest Kansas studied by Hibbard, which were once thought to be interglacial, are of pre-Nebraskan age. Thus, the current consensus is to return the Blancan wholly to the Pliocene, which, according to current dating techniques, probably extended from about 5 Ma ago to less than 2 Ma ago.

Although precise zoning of faunas within the Blancan probably is not attainable on faunal evidence alone, most workers think the Blanco Local Fauna is a late Blancan fauna, considerably younger than the Rexroad Fauna of Kansas or the Hagerman Fauna of Idaho and more closely related to the Red Light and Cita Canyon Faunas of Texas. This age assignment is supported by the presence in all three faunas of the ground sloth *Glossotherium* and the glyptodont *Glyptotherium*, both of which are late Blancan immigrants from South America (see Lundelius and others, 1987, for correlation chart). Dalquest (1975, p. 46) noted that "the absence of microtine (arvicoline) rodents and aquatic mammals from the Blanco makes correlation with other Blancan local faunas difficult, for most known Blancan local faunas are from more northern areas, where microtines are abundant and beavers and otter are present." He assigned an early Blancan age to the Blanco Local Fauna, however, and stressed the similarity between it and the Rexroad Fauna of Kansas, yet recognized that *Hesperoscalops* and *Stegomastodon* are represented in each fauna by different species. Savage (1955b) thought the Rexroad *Stegomastodon* was more primitive than *S. mirificus* from Blanco and Cita Canyon. The Blanco mole, on the other hand, may or may not be more primitive than the Rexroad species.

A 30-cm-thick (1-ft) volcanic ash bed exposed in the roadcut just northwest of Mount Blanco has been dated at 1.4±0.2 Ma using the fission-track method on glass shards and has been correlated with the Guaje Pumice Bed of the Jemez Mountains, New Mexico (Izett and others, 1972; Izett, 1981). This ash bed, however, lies near the surface in the upper part of the Blackwater Draw Formation that disconformably overlies the Blanco Formation (Holliday, Stop 6, fig. 23, this guidebook, p. 52; Holliday, 1988). The ash is separated from the lower fossiliferous part of the Blanco Formation by 9 m (30 ft) or more of partly calichified strata. The Guaje Ash thus furnishes a minimum date for the underlying Blanco Formation and, hence, for the Blanco Local Fauna.

Another ash bed, the Blanco Ash, is about 10 cm (4 inches) thick and lies about 7.5 m (25 ft) below the Guaje Ash; both ashes are exposed in the first large reentrant south of FM 193 just west of Mount Blanco (fig. 22). The uranium content of the Blanco Ash is too low to permit fission-track dating by means of zircons (G. A. Izett, personal communication, 1976), but Boellstorff (1976, p. 65) obtained a glass shard fission-track date of 2.8±0.3 Ma for this ash. Boellstorff (1976, p. 57) obtained a date of 1.77±0.44 Ma for the Guaje Ash using the same method. The Blanco Ash overlies the fossil-bearing unit of the Blanco Formation and thus suggests an age in excess of 2.8 Ma for the Blanco Local Fauna.

Lindsay and others (1975, p. 114) determined from paleomagnetic studies that the entire Mount Blanco section, including both ash beds, is reversely magnetized. The 1.4-Ma age of the Guaje Ash and the absence of a normal magnetic polarity zone beneath the ash in the Blanco section indicated to them that the Blanco Local Fauna must appear in the lower Matuyama (reversed) magnetic chron, which dates between 1.4 and 2.4 Ma in age.

Additional references to the geology or fauna at Mount Blanco may be found in Gidley (1901, 1907), Hay (1908), Osborn (1918), Matthew (1925), Matthew and Stirton (1930a, b), Stirton and VanderHoof (1933), Stirton (1936a), Gazin (1937), VanderHoof (1937), Evans (1949, 1956), Johnston and Savage (1955), Auffenberg (1962b), Webb (1965), Hirschfeld and Webb (1968), Schultz (1977a, c), Richey (1979), Kurten and Anderson (1980), Holliday (1988), and Holliday (Stop 6, this guidebook, p. 52).

Stop 6: Age of the Lower Blackwater Draw Formation at Blanco Canyon

V. T. Holliday

The 1.4-Ma-old Guaje Ash is interbedded with sediments of the lower Blackwater Draw Formation at Blanco Canyon. A buried soil in the Blackwater Draw Formation separates the Guaje Ash from the underlying Pliocene Blanco Formation.

In north Crosby County the Blackwater Draw Formation is exposed on the west side of Blanco Canyon in a roadcut of FM 193, about 1.2 km (0.8 mi) west of the intersection with FM 651 (figs. 1, 17). The Blackwater Draw Formation is about 5 m (17 ft) thick and rests on the lacustrine sediments of the Blanco Formation. The 1.4-Ma-old Guaje Ash, derived from the Jemez volcanic field in New Mexico (Izett and others, 1972), is exposed about 4 m (13 ft) below the surface within sediments of the Blackwater Draw Formation (Holliday, 1988) (fig. 23).

The Blanco Formation comprises the lower 4 m (13 ft) of the section exposed in the roadcut (fig. 24). Locally, the Blanco Formation is as much as 14 m (46 ft) thick, and near the center of the ancient Blanco basin the unit is as much as 27 m (90 ft) thick (Pierce, 1973). In the roadcut, the upper Blanco Formation is a highly contorted olive clay that has common vertical and horizontal joints. The sediments are folded into a series of broad anticlines and synclines. Within the trough of each downwarp is a pocket of reddish sand as much as 1 m (3 ft) thick.

A subhorizontal, strongly developed pedogenic calcrete (Km horizon) has formed across the tops of the upfolds in the Blanco clay and across the tops of the pockets of reddish sand (table 5). The calcrete is apparent at the top of the Blanco Formation throughout the area. The Km horizon is as much as 1 m (3 ft) thick, is locally pisolitic, and has sporadic thin carbonate laminae at the top. This calcrete is, therefore, a Stage IV calcic horizon (Gile and others, 1966), probably related to a soil formed in the overlying sediments.

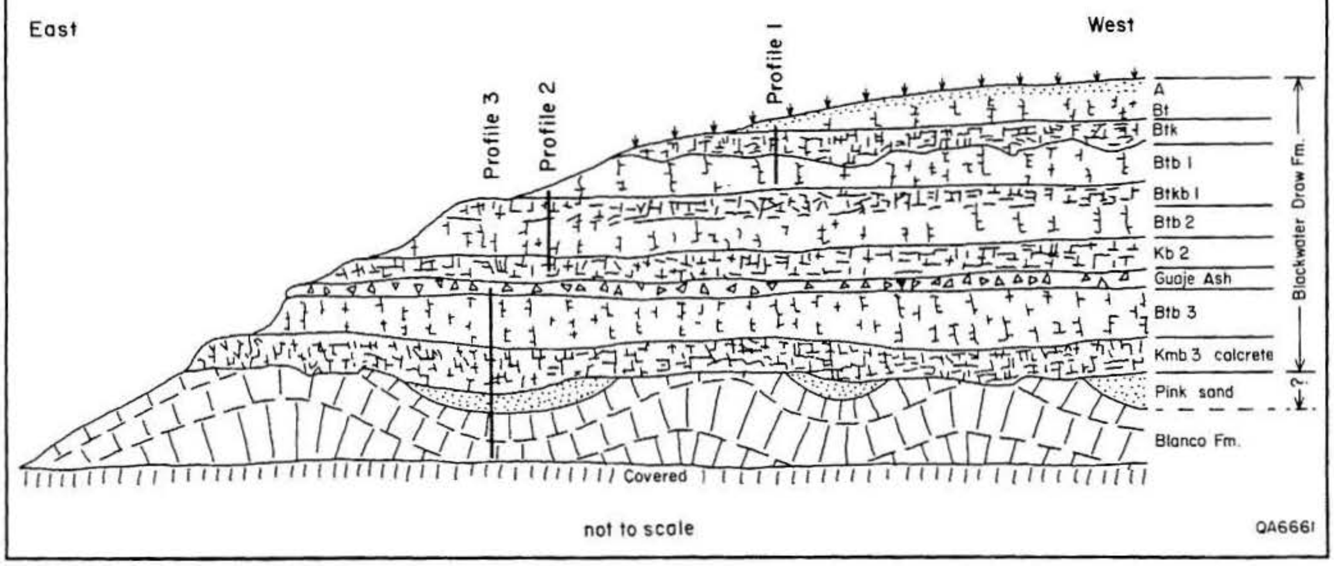

Figure 24. Schematic composite drawing of upper Cenozoic strata exposed at Blanco Formation type section (not to scale) and generalized soil stratigraphy. Detailed soil descriptions given in table 5; symbols identified in figure 9. See figure 17 for location.

The entire section above the calcrete is thought to be the Blackwater Draw Formation because it is a reddish-brown sandy deposit disconformably overlying the Blanco Formation, as described by Frye and Leonard (1957) and Reeves (1976). Furthermore, it is identical stratigraphically, lithologically, and pedologically to the type section of the Blackwater Draw Formation (Holliday, Stop 1, this guidebook, p. 22).

The Blackwater Draw Formation at Mount Blanco contains three buried soils (b1, b2, b3, top to bottom) plus the present surface soil, and it can be subdivided using the soils and the Guaje Ash. The ash lies about 1 m (3 ft) above the base of the Blackwater Draw Formation. Below the ash is the lowermost buried soil (b3), which lies below the ash in many other exposures in the area. The soil includes a Bt horizon exhibiting 5YR hues, well-expressed prismatic to subangular-blocky structure, and the previously described Km horizon formed at the top of the Blanco Formation (table 5). In the Bt horizon films of illuvial clay are common on ped (an individual aggregate of soil) faces and are common in thin section as coats on quartz sand grains and the walls of voids (table 5). Opaque material, probably illuvial opal, is common in thin section. Silica derived from weathering of overlying ash was probably translocated into the Bt horizon.

The ash zone includes a layer of pure ash as much as 30 cm (1 ft) thick overlying a zone of mixed ash and sand as much as 50 cm (1.6 ft) thick. The ash rests disconformably on the b3 soil. The thickness of the ash layer varies considerably throughout the area and is absent at the west end of the roadcut.

Above the ash are two buried soils (b1, b2) and the present surface soil. The number and continuity of buried soils in the Mount Blanco area are unknown. The surface soil (not described) at the west end of the roadcut, away from the edge of Blanco Canyon, is typical of the strongly developed surface soil of the region, having a Bt-K or Btk profile and being classified as a Paleustalf. The Bt horizon is about 1 m (3 ft) thick, exhibiting 5YR hues, a prismatic to subangular-blocky structure, and clay films common on ped faces. Illuvial clay is also common in thin section, clay films coating quartz sand grains. The upper portion of the zone of carbonate accumulation is a laminar K horizon (K [lam]) about 10 cm (4 inches) thick. Below the K horizon is a Btk horizon with ladder-matrix morphology (fig. 11). The K-Btk horizon crops out as a ledge at the east end of the roadcut (fig. 23) where erosion along the walls of Blanco Canyon have removed the upper part of the profile.

The two buried soils above the ash are each about 1.2 m (4 ft) thick and contain Bt horizons having morphologies identical to that of the surface soil (table 5). The b1 soil also has a ladder-matrix Btk horizon, which appears to have formed in the upper part of the b2 soil. The b2 soil has a Stage III–IV K horizon formed just above the zone of pure Guaje Ash. The parent material for the K horizon may have contained some reworked ash, judging from its low bulk density, fine sand texture, and the gradual boundary between the K horizon and the ash layer. Both carbonate horizons crop out as ledges at the east end of the roadcut.

This section has clearly shown that eolian accretion of the Blackwater Draw Formation began before 1.4 Ma ago and was episodic throughout the Quaternary, as indicated at the type section (Holliday, Stop 1, this guidebook, p. 22). As also indicated at the type section, the morphologies of the buried soils are similar to that of the surface soil and are therefore indicative of a generally semiarid grassland.

Table 5. Soil descriptions, Blanco Formation type section near Mount Blanco (figs. 1, 10). See table 2 (p. 24) for definition of symbols.

Profile 1

Horizon	Depth (cm)	Color Dry	Color Moist	Texture	Structure	Consistence Dry	Consistence Moist	Reaction	Boundary	Remarks
A & B	0–25	7.5YR4/4	7.5YR3/4	SCL	1cpr& 2msbk				aw	Holocene? Remnant of Amarillolike soil? Undivided; thin A (few cm).
K(lam)	25–35	5YR8/2	5YR7/3		m	xh		ev	aw	Laminar zone.
K	35–85	5YR8/4	5YR7/5		m	h		ev	cs	Stage III; common, very hard carbonate segregations as much as 3 mm diam.
Btk	85–102	5YR6/4	5YR6/6	SCL	m	sh		ev(k)	cw	Stage II–III; common threads, bodies, & hard carbonate concretions.
Btk1b1	102–159	5YR5/6	5YR4/6	SCL	1fsbk	sh		ev(k)	aw	Common areas as much as 15 cm wide of soft carbonate and hard carbonate bodies; few Mn splotches on carbonate; colors for Bt; Bt has few Mn splotches, common thick clay films; structure disrupted by areas of carbonate.
Btk2b1	159–195+	5YR5/6	5YR4/6	SCL	1fsbk	sh		ev(k)		This horizon is very distinctive as it weathers, forming a "caliche bench" in outcrop; in this section it is 2d bench down (1st=K); common very hard carbonate bodies as much as 15 cm wide; few Mn patches.

Profile 2

Horizon	Depth (cm)	Color Dry	Color Moist	Texture	Structure	Consistence Dry	Consistence Moist	Reaction	Boundary	Remarks
	0–70									This is equal to beveled-off Btk2b1.
Bkb1	70–120	5YR8/2 5YR8/3	5YR7/4 5YR7/4		m	vh		ev(k)	cw	5YR8/2 = ped interiors; 5YR8/3 = exteriors; on weathering zone fractures in vertical sections as much as several cm in width & blocks as much as several cm in height; almost platy; common Mn patches; Bt material few mm wide and few cm high.

NOTE: "ev(k)" indicates reaction of carbonate bodies; matrix is otherwise noncalcareous.

Table 5. (cont.)

Profile 3

Horizon	Depth (cm)	Color		Texture	Structure	Consistence		Reaction	Boundary	Remarks
		Dry	Moist			Dry	Moist			
Btk1b2	120–180	5YR8/2 5YR8/3	5YR7/4 5YR7/4		m	vh		ev(k)	cw	Very similar to Bkb1; carbonate bodies are elongate, several cm wide, spaced 5–10 cm apart; carbonate weathering into very hard "pillars" common, thick clay films.
Btk2b2	180–240	5YR8/2	5YR7/4		m	vh		ev(k)	cw	As above; fewer clay films.
Kb2		5YR8/3	5YR7/4							Massive Stage III–IV w/no laminar zone; well-expressed to left (E) of Profile 2; as much as 50 cm thick.
2C1b2		N8	N8		mpl	vh		non	aw	Clean ash (Guaje); 0–30 cm thick.
3C2b2	0–20	5YR8/4	5YR7/6		m	vh		e	aw	Reworked ash; as much as 50 cm thick; few Mn patches.
3Btk1b3	20–40	5YR7/4	5YR6/6	fSCL	1fpr& 3msbk	vh		ev(k)	cs	Carbonate bodies as much as 1 cm thick formed along vert. and horiz. ped faces = "ladder structure."
3Btk2b3	20–100	5YR6/6	5YR5/8	fSCL	2fpr& 3msbk	vh		ev(k)	aw	Lower buried soil? Thickness varies—locally as much as 1 cm; carbonate as coats on ped faces; some "ladder structures."
3Kmb3		7.5YR8/1	7.5YR6.5/3			xh			cw	Massive Stage IV; as much as 1 m thick; locally see effects of dissolution; formed in Blanco clay and locally pink sand (3Ckb3).
3Ckb3		5YR8/2	5YR6/4	S	m	xh		ev	aw	Found in troughs of folded Blanco clay; locally as much as 1 m thick.
4Rb3		N9	5YR8/1	C	m	xh		ev		Blanco Formation; secondary carbonate locally common; highly contorted; considerable vertical and horizontal jointing.

Stop 7: Age of the Blackwater Draw Formation Exposed at Tule Creek, Texas Panhandle

V. T. Holliday

Eolian sediments of the Blackwater Draw Formation exposed along Tule Creek in east Swisher County, Texas, are interbedded with the 0.62-Ma-old Lava Creek B volcanic ash.

Another exposure of the Blackwater Draw Formation lies in Swisher County, 19 km (12 mi) east-southeast of Tulia, on the south side of Tule Canyon (figs. 1, 25). The locality is in a roadcut of FM 2301, 2 km (1.2 mi) north of State Highway 86. In the exposure are fine-grained eolian sediments containing the 0.62-Ma-old Lava Creek B (=Pearlette Type O) volcanic ash (Izett and Wilcox, 1982), which is overlain by lacustrine sediments of the Tule Formation. The eolian sediments containing the ash are Blackwater Draw Formation (fig. 26) because, by definition, the Blackwater Draw Formation includes eolian sediments overlying the Tule Formation (Frye and Leonard, 1957; Reeves, 1976).

The Blackwater Draw Formation is more than 4 m (13 ft) thick in this exposure (table 6, fig. 27). The upper 1.47 m (4.9 ft) of the section contains the well-developed modern surface soil exhibiting A-Bt-Bk horizons, reddish-brown (7.5YR) hues, a moderate structural development, and a Stage III calcic horizon. From 67 to 147 cm (2.2 to 4.9 ft) (Btk2 horizon) there is well-expressed Bt material below the calcic horizon at 40 to 67 cm (1.3 to 2.2 ft) (Btk1 horizon), suggesting either a buried soil or a formerly deeper surface profile. Soil development in the 170- to 275-cm (5.6- to 9.2-ft) zone, related either to the surface soil or to the possibly buried soil noted previously, occurred in material that probably contained abundant volcanic ash. This is indicated by low bulk density, massive structure, and some silica coatings. The zone of pure ash underlies the soil and varies in thickness from a feather edge to about 30 cm (1 ft). The ash buried about 90 cm (3 ft) of Blackwater Draw Formation, which also has a well-developed soil exhibiting a Bt horizon, 7.5YR hues, moderate structural development, and a thin Stage IV calcic horizon (table 6).

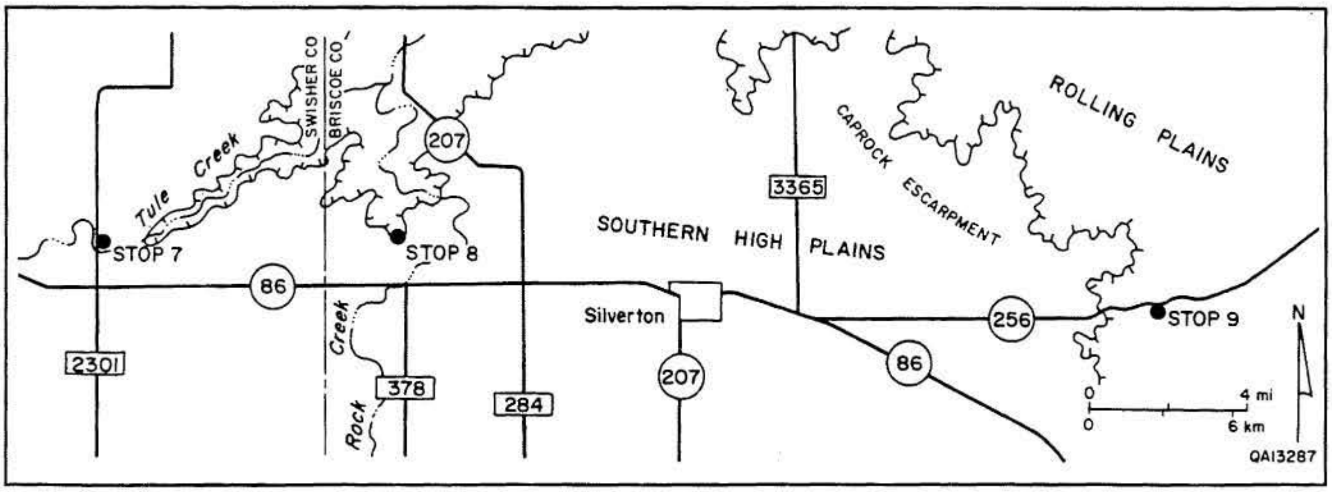

Figure 25. Map of Silverton, Texas, area showing Field Trip Stops 7 through 9. Derived from Plainview Sheet, U.S. Geological Survey (1:250,000 series). See figure 1 for location.

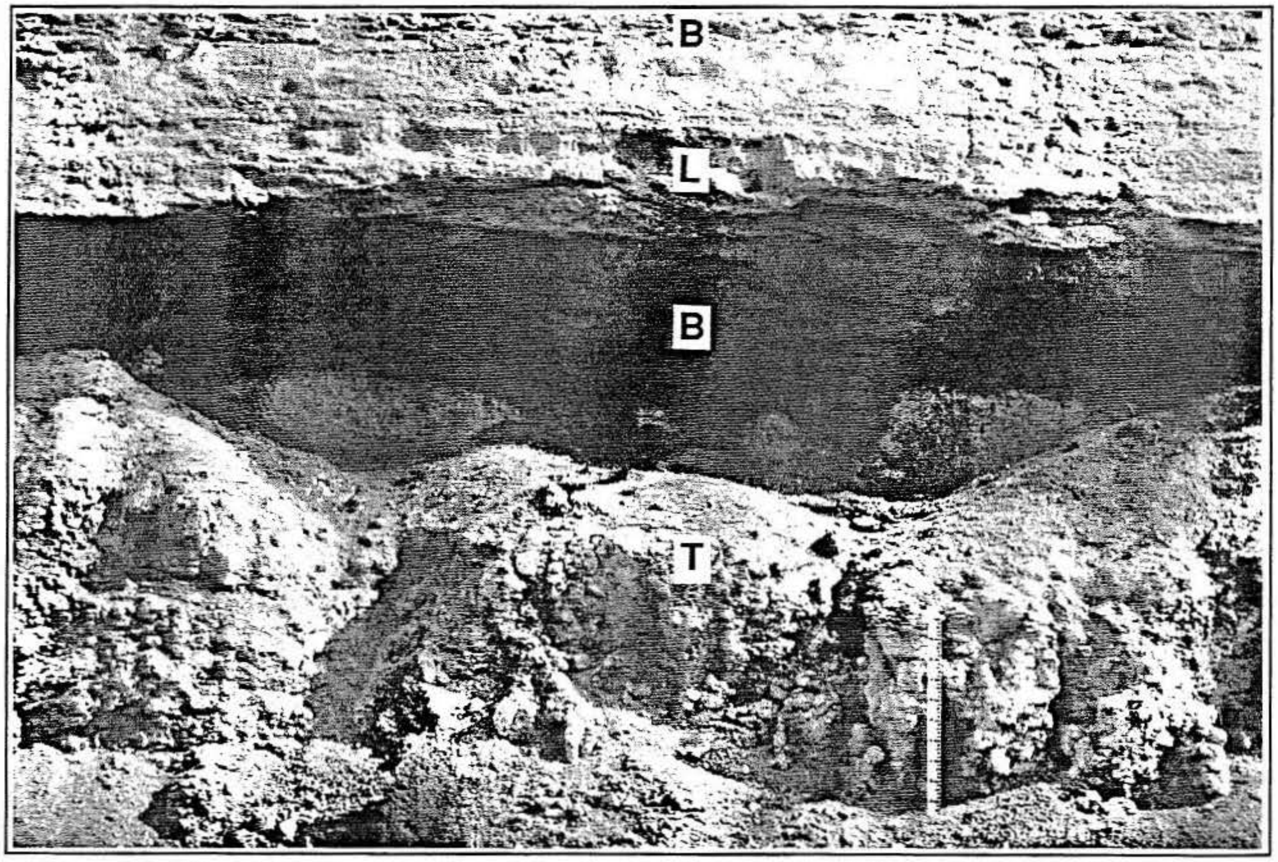

Figure 26. View of Quaternary Blackwater Draw (B) and Tule (T) Formations. See figure 25 for location. In this exposure Blackwater Draw Formation contains 0.62-Ma-old Lava Creek B volcanic ash (L) and overlies Tule Formation. (Scale bar = 1 m.)

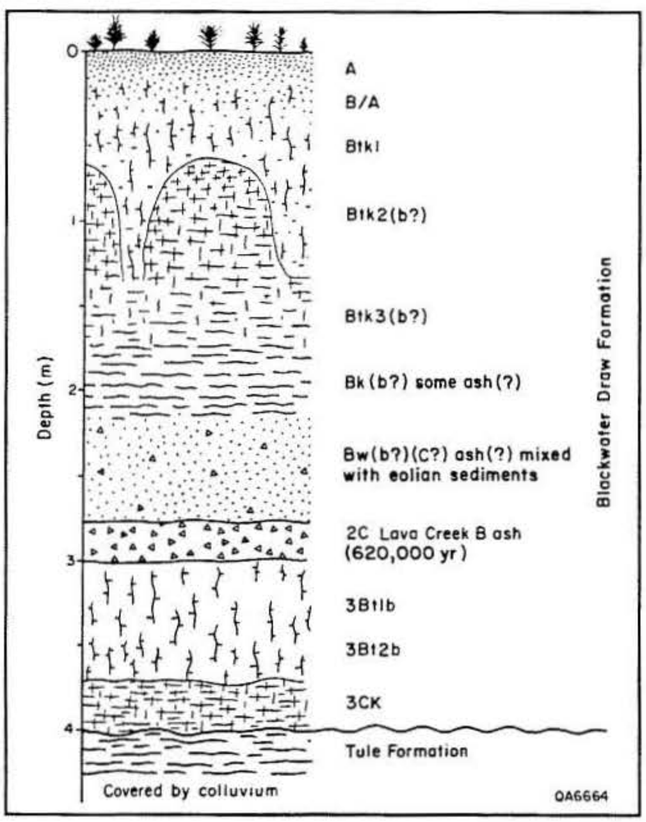

Figure 27. Schematic drawing showing soil-stratigraphic relationships of Blackwater Draw and Tule Formations in a roadcut on the east side of State Highway 2301 south of Tule Creek, Swisher County, Texas.

Table 6. Soil descriptions, Tule Basin type section (fig. 1). See table 2 (p. 24) for definition of symbols.

Profile 1

Horizon	Depth (cm)	Color		Texture	Structure	Consistence		Reaction	Boundary	Remarks
		Dry	Moist			Dry	Moist			
A	0–17	7.5YR5/3	7.5YR3/3	SiCL	1msbk 3fgr	sh		es	cs	10–20% granules are pinkish in color as if brought up from the B horizon. (Bioturbation?)
B/A	17–40	7.5YR6/3	7.5YR4.5/4	SiC	1msbk 3fgr	sh		es	cs	Very weak prisms evident; granules seem to be a mixture of overlying A and underlying B.
Btk1	40–67	7.5YR5/6 (matrix) 7.5YR9/1 (carbonate)	7.5YR4/6 7.5YR7/4	SiC	1mpr 2msbk	sh		es ev	ci	20% 1–20 cm bodies soft $CaCO_3$; $CaCO_3$ films on ped faces and lining root channels (profile is benched at 67 cm).
Btk2 (b?)	67–147	7.5YR4/6 (matrix) 7.5YR9/1 (carbonate)	7.5YR4/6 7.5YR8/3	CL	1msbk m (pockets of granular material)	h sh		e ev	cw	Massive Stage III carbonate with tongues of B material occurring in zones 10–30 cm wide and as much as 70 cm deep; in some areas of roadcut, massive caliche begins as high as B/A horizon; tongues of B material begin at Btk1; few very thin clay films. ~50% tongues of B material connect w/underlying B horizon.
Btk3 (b?)	147–170	7.5YR5.5/4 (matrix) 7.5YR9/1 (carbonate)	7.5YR4/4 7.5YR8/2		2mpl m	vh xh		non ev	ai	Similar to B horizon above but only 30–40% carbonate here, in masses as much as 40 cm across; common thin Mn coats. 30–40% 1- to 2-mm granules of carbonate throughout B horizon.
Bk (b?)	170–208	7.5YR6/4 (matrix)	7.5YR5/6		3cpl	eh		non	ai	Carbonate occurs as continuous lens 1–2 mm thick all across plate; low bulk density material (ash).
2Bw (b?)	208–275	7.5YR7/3	7.5YR4/6	fSL no clay	m	sh– h		non	ai	Low bulk density, contains some volcanic ash; very weakly sbk. 10% silica threads along root channels and as veins. Profile 2 platy zones together occur across the outcrop face in a broadly undulating zone.

Table 6. (cont.)

Profile 2

Horizon	Depth (cm)	Color		Texture	Structure	Consistence		Reaction	Boundary	Remarks
		Dry	Moist			Dry	Moist			
2C		7.5YR8/1	7.5YR7/3		m					Ash layer, varies in thickness from a feather edge to ~30 cm. Ash occurs in irregular masses; weathered.
3Bt1b	0–50	7.5YR6/3	7.5YR4/4	SiL	1cpr 3cabk	h		non	cs	Structure is coarsest near the top. Few very thin clay films on ped faces (maybe bleached out A?).
3Bt2b	50–75	7.5YR5/5	7.5YR4/6	SiL	1fpr 3msbk	h		non	cw	Fewer than 10% threads and film of silica on ped faces and lining root channels. Probably a mixture of Tule Formation lake beds and secondary carbonate. Common thin clay films on ped faces.
3Ckb	75–90	7.5YR7/4	7.5YR7/4	SiC	m	h		ev	d	Stage VI.

STOP 8: Biostratigraphy and Volcanic Ash Deposits of the Tule Formation, Briscoe County, Texas*

G. E. Schultz

Along the East Fork of Rock Creek, on the Mayfield, McDaniel, and Martin Ranches, the Tule Formation of early and middle Pleistocene age is well exposed in a 45-m (150-ft) thick section. Near the base of the formation, which rests disconformably on Triassic red beds, a reversely magnetized 1.2- or 1.3-Ma-old volcanic ash bed derived from the Jemez Mountains in New Mexico lies at a level where Blancan and Irvingtonian vertebrates coexist (Martin Ranch Local Fauna). In the upper part of the section, the classic Rock Creek Local Fauna and the Equus scotti *Quarry are overlain by a Cudahy molluscan and microvertebrate fauna (Mayfield Ranch Local Fauna) covered by the normally magnetized 0.6-Ma-old Lava Creek B (=Pearlette Type O) volcanic ash. A younger molluscan fauna appears in sediments above this ash.*

Vertebrate fossils of Pleistocene (Irvingtonian) age have been found at scattered localities in the Tule Formation for many years. Most of them have been collected near the head of the East Fork of Rock Creek, a north-draining tributary of Tule Canyon (figs. 25, 28). The earliest collections were made by W. F. Cummins between 1889 and 1892 and by E. D. Cope in 1892. Cope (1893) referred to the fossil-bearing strata as "*Equus* Beds" and described numerous significant forms, including the holotypes of what are now known as *Gopherus hexagonata, Gopherus laticaudata, Camelops sulcatus, Hemiauchenia macrocephala*, and *Equus semiplicatus*. J. W. Gidley collected fossils for the American Museum of Natural History from 1899 through 1901 and described the first specimen of *Equus scotti* from the now-famous horse quarry (Gidley, 1900, 1901). He thought the fauna belonged to the "Sheridan Beds" of Pleistocene age (Gidley, 1903a).

At present, two principal quarries or fossil sites are recognized:

(1) The Sloth-Camel Quarry (Rock Creek Local Fauna) is on the west bank of the East Fork of Rock Creek near its head, 0.4 km (0.25 mi) north of the Rock Creek store at the junction of State 86 and FM 378; 11 km (7 mi) west of Silverton and 3.2 km (2 mi) east of the west county line in the NW 1/4, SW 1/4, sec. 208, Blk. G-M, Denison and SE Ry. Co. Survey; Briscoe County, Texas (fig. 28) (Troxell [1915a, p. 614] erroneously gave the location as sec. 207). The quarry is on land owned by Mrs. Roy Mayfield.

(2) The *Equus scotti* (=Horse) Quarry is on the south side of a short east-draining tributary of the East Fork of Rock Creek, 1.2 km (0.75 mi) north of the Rock Creek store in the center, NE 1/4, sec. 213, Blk. G-M, Denison and SE Ry. Co. Survey; Briscoe County, Texas (fig. 28) (Troxell [1915a, p. 614] erroneously gave the location as sec. 208). The site is on land owned by Bill McDaniel. Locations of both quarries are depicted on the USGS Rock Creek 7.5-minute topographic quadrangle map.

At the Sloth-Camel Quarry, which is frequently flooded by waters of a stock tank, fossils are found mainly in a 1.2-m-thick (5-ft-thick) bed of yellowish-gray, semi-indurated sandstone that forms a small knoll on the west side of Rock Creek just west of the Mayfield Ranch house and south of the earth dam. A smaller outcrop of the same bed lies across the creekbed to the east. The quarry was worked extensively in 1912 by Lull and Troxell for Yale University. The Rock Creek Local Fauna (Cope, 1893, 1895; Hay, 1908, 1924; Lull, 1915; Troxell, 1915a, b; Johnston, 1937b; Hibbard, 1953; Quinn, 1957; Dalquest, 1964; Kurten, 1967; Nowak, 1979; Kurten and Anderson, 1980; Schultz, 1986) is

*Modified from Gustavson (1986b)

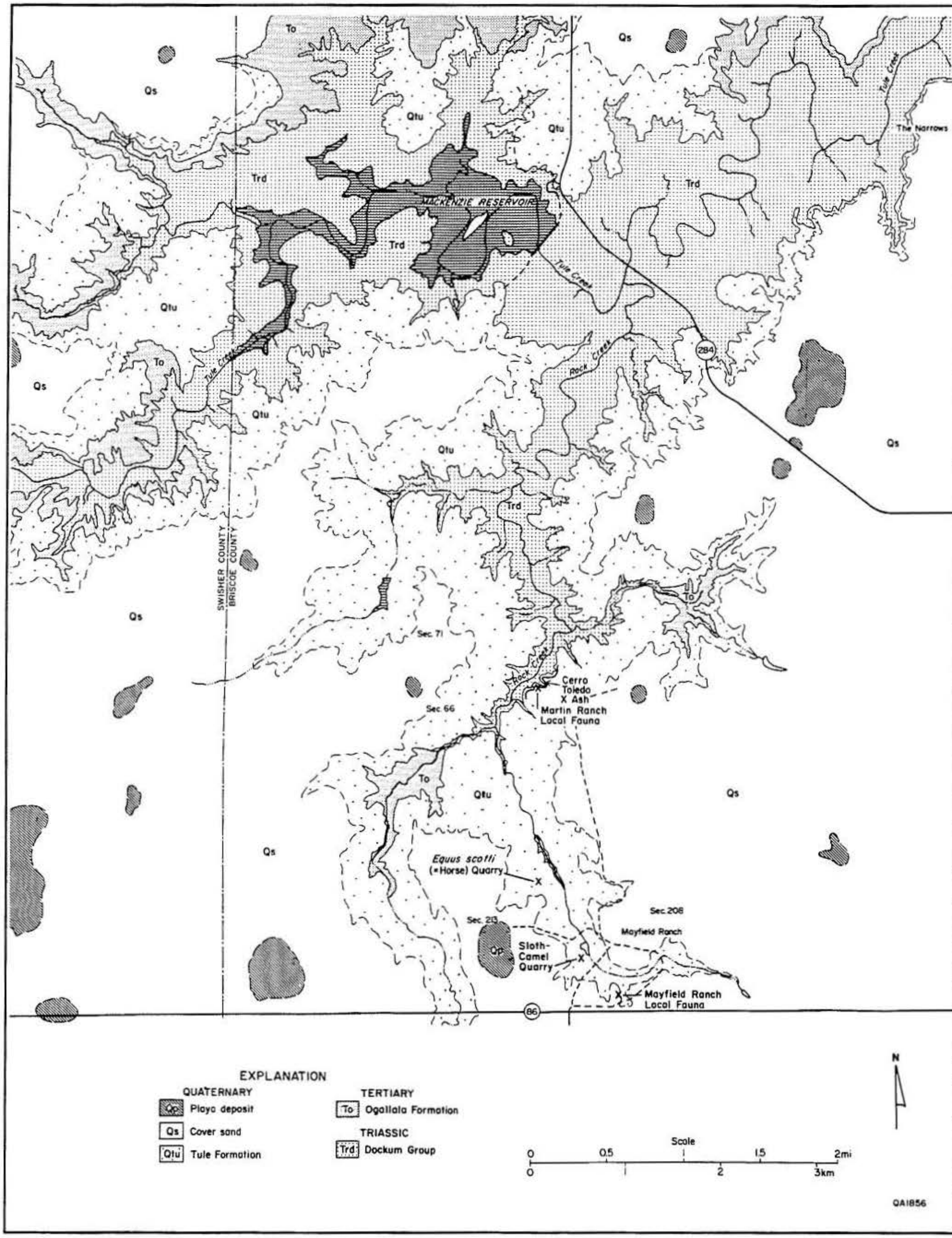

Figure 28. Geologic map of parts of Cope Creek and Rock Creek Quadrangles. Stop 8 is at Sloth-Camel Quarry and Horse Quarry. See figures 1, 25, and 41 for location within Texas Panhandle.

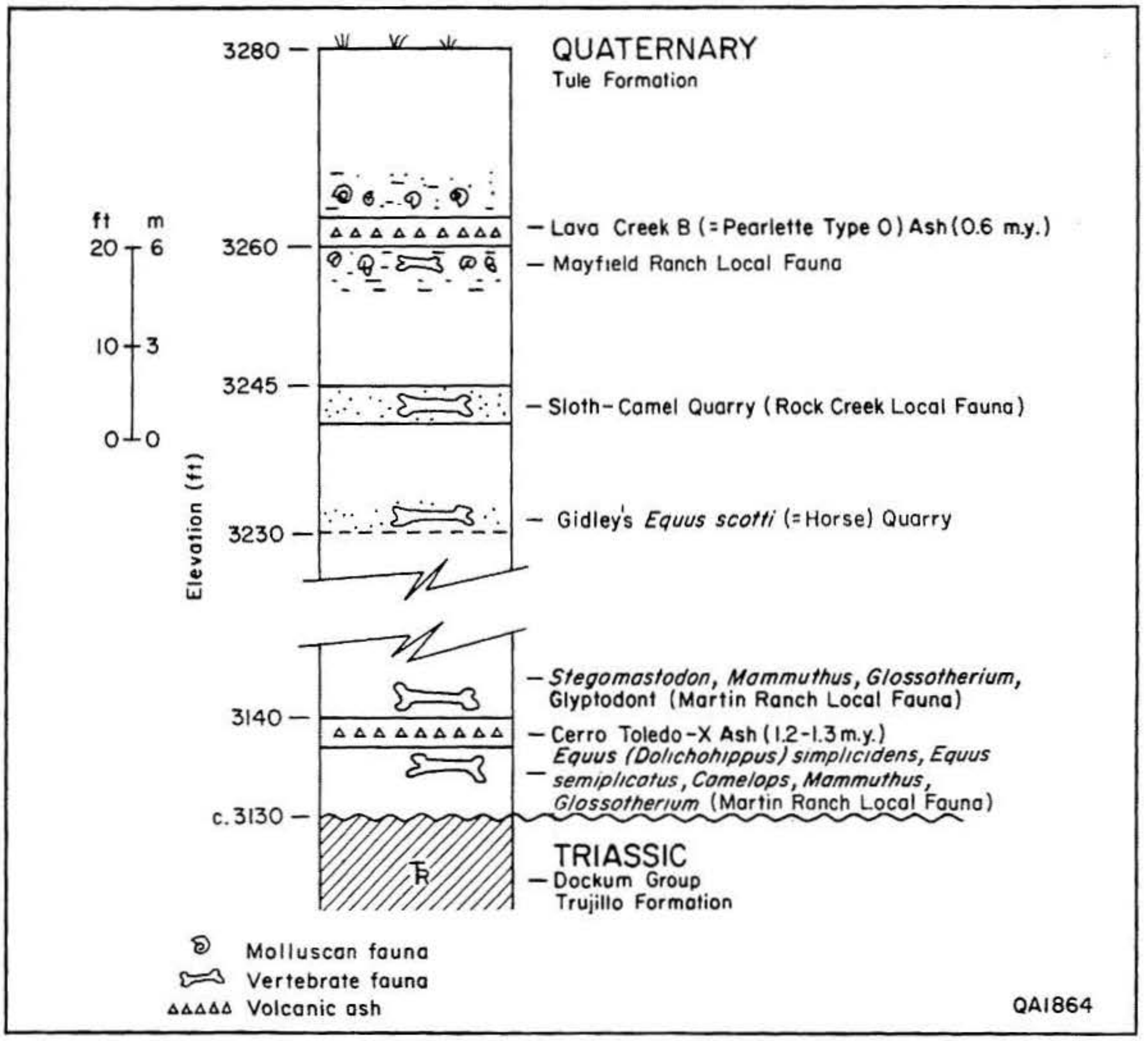

Figure 29. Biostratigraphic section of Tule Formation along East Fork of Rock Creek, Mayfield Ranch, Briscoe County, Texas.

dominated by large- and medium-sized grazers but includes a few browsers and semibrowsers and several carnivores. The following taxa are present: Testudinidae (giant land tortoises), including possibly *Geochelone campester* and Cope's holotypes of *Gopherus hexagonata* and *Gopherus laticaudata; Glossotherium harlani* (ground sloth); *Sylvilagus* sp. (cottontail rabbit); *Canis armbrusteri* (extinct wolf); *Canis latrans* (coyote); *Protocyon texanus* (a dog of South American affinities and origin); *Arctodus simus* (giant short-faced bear); *Mammuthus imperator* (mammoth); *Platygonus* sp. (extinct peccary); *Camelops sulcatus* (large extinct camel); *Hemiauchenia macrocephala* (extinct llama); *Hayoceros falkenbachi* (extinct pronghorn); *Soergelia* (formerly *Preptoceras*) *mayfieldi* (primitive muskox of Old World affinities and origin); and the horses *Equus scotti* and *E. calobatus*. *E. calobatus* (holotype based on long slender metapodials) is probably referable to Cope's *E. semiplicatus* (holotype based on teeth).

Upstream to the southeast, the sloth-camel bed is overlain by reddish-buff silts and greenish-gray clays. Less than 0.4 km (0.25 mi) to the southeast, just south of the Mayfield house, in a small tributary draw that enters Rock Creek from the south (fig. 28), the greenish-gray clay is overlain by a normally magnetized 1-m-thick (3-ft) bed of Lava Creek B (=Pearlette Type O) volcanic ash derived from the Yellowstone region and dated at 0.62 Ma (Izett, 1977;

Izett and Wilcox, 1982). The base of the ash lies nearly 5 m (15 ft) above the top of the Sloth-Camel Quarry (fig. 29). Greenish-gray clays just beneath the ash contain a molluscan and microvertebrate fauna (Mayfield Ranch Local Fauna) similar to that described by Hibbard and Dalquest (1966) (Vera Local Faunule) in Knox and Baylor Counties, Texas, and similar to the Cudahy Fauna in southwest Kansas described by Hibbard (1944, 1976), Paulson (1961), and others. Cudahy-type faunas, which contain numerous microtine and cricetine rodents, as well as shrews, have been collected at a number of sites in the High Plains from sediments beneath the Lava Creek B Ash and are, therefore, older than 0.62 Ma. At the Mayfield Ranch, a thin caliche unit, which directly overlies the ash bed, can be traced downstream to a point about 5 m (15 ft) above the Sloth-Camel Quarry where the ash is absent, thus demonstrating that the Rock Creek Local Fauna is somewhat older than the Mayfield Ranch Local Fauna. Green- and rust-colored sands above the caliche unit contain a few snails of late Pleistocene age.

The *Equus scotti* Quarry is 0.8 km (0.5 mi) northwest of the Sloth-Camel Quarry and nearly 5 m (15 ft) lower in the section (fig. 29). Since Gidley first described this horse in 1900, a number of more or less complete skeletons have been collected and are now in the American Museum of Natural History, Yale Peabody Museum, and Panhandle-Plains Historical Museum, Canyon, Texas. Johnston (1937c, p. 460) stated that the skeletons "were found in a fine consolidated white cross-bedded sand containing granules of calcium carbonate and lying about 75 cm (30 inches) below a 2.5-cm (1-inch) continuous horizontal stratum of bluish-green clay, which underlies several feet of compact, semiconsolidated gray sand showing no signs of crossbedding. This bed is overlain by a rather tough layer of green shale, which forms the surface."

About a mile north of the *Equus scotti* Quarry, on the M. G. Martin Ranch, in the NE 1/4, sec. 66, and the SE 1/4, sec. 71, Blk. A, Arnold and Barrett Survey, in Briscoe County, Texas (fig. 28 and USGS Cope Creek 7.5-minute topographic quadrangle map), Izett (1977) identified a reversely magnetized volcanic ash (Cerro Toledo X) that was dated at about 1.2 or 1.3 Ma on the basis of correlation with the Cerro Toledo rhyolite in the Jemez Mountains source area near Santa Fe, New Mexico (Izett, 1977, 1981; Izett and others, 1981; Izett and Wilcox, 1982). This ash, which lies about 36 m (120 ft) below the Lava Creek B Ash, lies at or near the base of the Tule Formation and, in places, rests directly on Triassic red beds of the Trujillo Formation (fig. 29). Blancan and Irvingtonian vertebrates including *Equus* (*Dolichohippus*) *simplicidens*, *Equus semiplicatus*, *Camelops* sp., *Stegomastodon barbouri* (Madden, 1986), *Mammuthus* sp., *Glossotherium* sp., and *Glyptotherium* sp. coexist below, at, or slightly above the level of the ash, and the fauna (Martin Ranch Local Fauna) is similar to the Gilliland Fauna from the Seymour Formation in Knox and Baylor Counties, Texas (Hibbard and Dalquest, 1966). The lower part of the Tule Formation is well exposed on the Martin Ranch and consists primarily of buff to pale reddish-brown, fine silty sands locally cemented by calcium carbonate and containing lenses of caliche pebbles near the base. The lower half of the formation in this area contrasts strongly with the upper half, which is dominated by greenish-gray to pale-yellow silty sands and clays.

In addition to the fossils collected from the immediate Rock Creek drainage, several other significant discoveries have been made in the area. Gidley (1903a) reported a partial skeleton of *Mammuthus* from the head of Tule Canyon about 11 km (7 mi) west of the *Equus scotti* Quarry in Swisher County. This specimen was later described by Osborn (1942). Matthew (1920) reported the discovery of the hind part of the skeleton of a giant short-faced bear (*Arctodus simus*) 3.2 km (2 mi) north of the horse quarry. This specimen, now in the American Museum of Natural History, was described by Kurten (1967). An undescribed humerus and some upper teeth of this bear from the Sloth-Camel Quarry are in the Panhandle-Plains Historical Museum, Canyon, Texas. G. E. Schultz collected a diverse Cudahy-type microvertebrate and molluscan fauna from a diatomite bed beneath a thick deposit of Lava Creek B Ash in Deadman's Creek, a tributary of Tule Canyon in Swisher County, 8 km (5 mi) northwest of the *Equus scotti* (=Horse) Quarry.

On the basis of fossil evidence, it is possible to draw some conclusions about the paleoenvironment of the Tule Basin during a part of the Irvingtonian Land Mammal Age from about 1.3 to about 0.6 Ma ago. The predominance of large and medium-sized grazers such as horses, camels, proboscideans, and muskoxen at one or more levels in the section indicates an abundance of grasses in the vicinity, whereas the presence of browsers and semibrowsers (peccary, pronghorn, and possibly the large camel) indicates the presence of shrubs and, possibly, scattered small trees. Taller grasses may have dominated the lower slopes, and shorter grasses may have dominated better drained high ridges and divides. The structure of the teeth of *Platygonus*, the peccary suggests a diet of coarse vegetation or browse, whereas the pronghorn probably roamed the open grassy upland, feeding on forbs, shrubs, browse, and some grass. Although primarily a grazer, *Camelops*, having a long neck and long legs, was probably an occasional browser (Kurten and Anderson, 1980, p. 305). The ground sloth, *Glossotherium*, generally considered a grassland species, probably fed on grass and small shrubs and may have used its claws to dig up roots (Kurten and Anderson, 1980, p. 144). *Arctodus simus*, the giant short-faced bear, and *Protocyon texanus*, the South American dog, were highly predaceous carnivores; the former undoubtedly preyed upon the sloth and other large herbivores. Today cursorial (running) canids such as the wolf and the coyote range successfully through a variety of habitats; the Rock Creek species probably roamed through broken, open country or grasslands.

Vegetation now in the region could not sustain the abundant and diverse fauna that lived in the Rock Creek area during Irvingtonian time. Development of grasslands, indicated by abundance of herbivores, required greater and more dependable rainfall than the unpredictable and sporadic amounts received in this semiarid region today. More abundant rainfall is clearly indicated by the numerous fresh-water mollusks, rodents, and shrews of the Mayfield Ranch Local Fauna, remains of which are found in the clayey and diatomaceous pond deposits. Mild, frost-free winters are suggested by the presence of the giant land tortoises (Hibbard and Dalquest, 1966, p. 12–13).

STOP 9: Upper Tertiary Ogallala Formation Eolian Strata at the Caprock Escarpment, East of Silverton, Texas

T. C. Gustavson

Approximately 38 m (125 ft) of eolian sediment of the Ogallala Formation is exposed in the Caprock Escarpment near Silverton, Texas. Eolian sediments were deposited as loess and sand sheets and contain numerous calcic paleosols.

The Ogallala Formation is exposed in a roadcut, herein called the Silverton section, on State Highway 256 between 18.5 and 19.3 km (11.5 and 12 mi) east of Silverton, Texas (figs. 1, 25). The base of the section is at an elevation of approximately 907 m (2,975 ft), and the formation extends 38 m (125 ft) to an elevation of approximately 945 m (3,100 ft). Ogallala sediments in the Silverton section (fig. 30) unconformably overlie weathered and fractured mudstones of the Triassic Dockum Group.

Stratigraphic Descriptions

Locally, narrow channels (1 to 1.5 m [3 to 4.5 ft] deep) are filled with sandy carbonate-cemented gravel at the base of this section of the Ogallala Formation (fig. 31 [Note that symbols used in this figure, as well as in figures 34, 35, 38, and 40, are described in figure 32]). Gravel clasts as much as 13 cm (5 inches) long are mostly quartzites and other metamorphics, vein quartz, and fine-grained igneous rocks. Primary sedimentary structures are not preserved, and gravel clasts appear to float in a fine-grained matrix. Carbonate cement in this unit has been silicified locally.

The remaining 36 m (119 ft) of the Silverton section consists of grayish-orange-pink (5YR 7/2), fine to very fine sand that appears similar to fine and very fine sand sequences in the Buffalo Lake section and in the upper parts of the Bellview and Ragland sections (Gustavson, Stops 1, 2, and 3, this guidebook, p. 22, 32, and 38, respectively). No primary sedimentary structures were identified in this section. Well-rounded frosted sand grains and pinkish-gray carbonate (calcrete) nodules as much as 5 cm (2 inches) in diameter are present throughout much of the section. At least four massive (Stage IV?) pedogenic calcretes (Bachman and Machette, 1977) are present in the lower 17 m (56 ft) of this section. The upper 19 m (63 ft) of this exposure includes numerous paleosols preserved as concentrations of carbonate nodules or as slightly darker (moderate-red-brown [10R4/6] to pale-red-brown [10R5/4]) and slightly clay-rich Bt horizons. Only a few of these paleosols are illustrated in figure 31.

The top 3.5 m (11.6 ft) of the Silverton section is a massive pinkish-gray (5YR8/1) to grayish-orange-pink (5YR7/2) Stage VI calcrete, the Ogallala Caprock caliche. The calcrete is laminated but does not appear to be brecciated or pisolitic. Large areas of dense carbonate fracture conchoidally.

Facies Interpretations

The shallow, widely separated gravel-bearing channels at the base of the Silverton section represent fluvial deposition, but the lack of preserved sedimentary structures and the sparseness of these deposits precludes additional interpretation.

The upper 36 m (119 ft) of the Silverton section is similar to the Buffalo Lake section (Stop 11, p. 72) and probably represents eolian deposition, judging from the texture of these sediments and from the presence of rounded to subrounded frosted grains. Primary sedimentary structures were destroyed partly by bioturbation and partly by the disruption of sediments during soil-forming processes, mainly precipitation of carbonate. The numerous preserved paleosols represent periods of landscape stability followed by influxes of additional eolian sediment. Although few root structures are preserved in

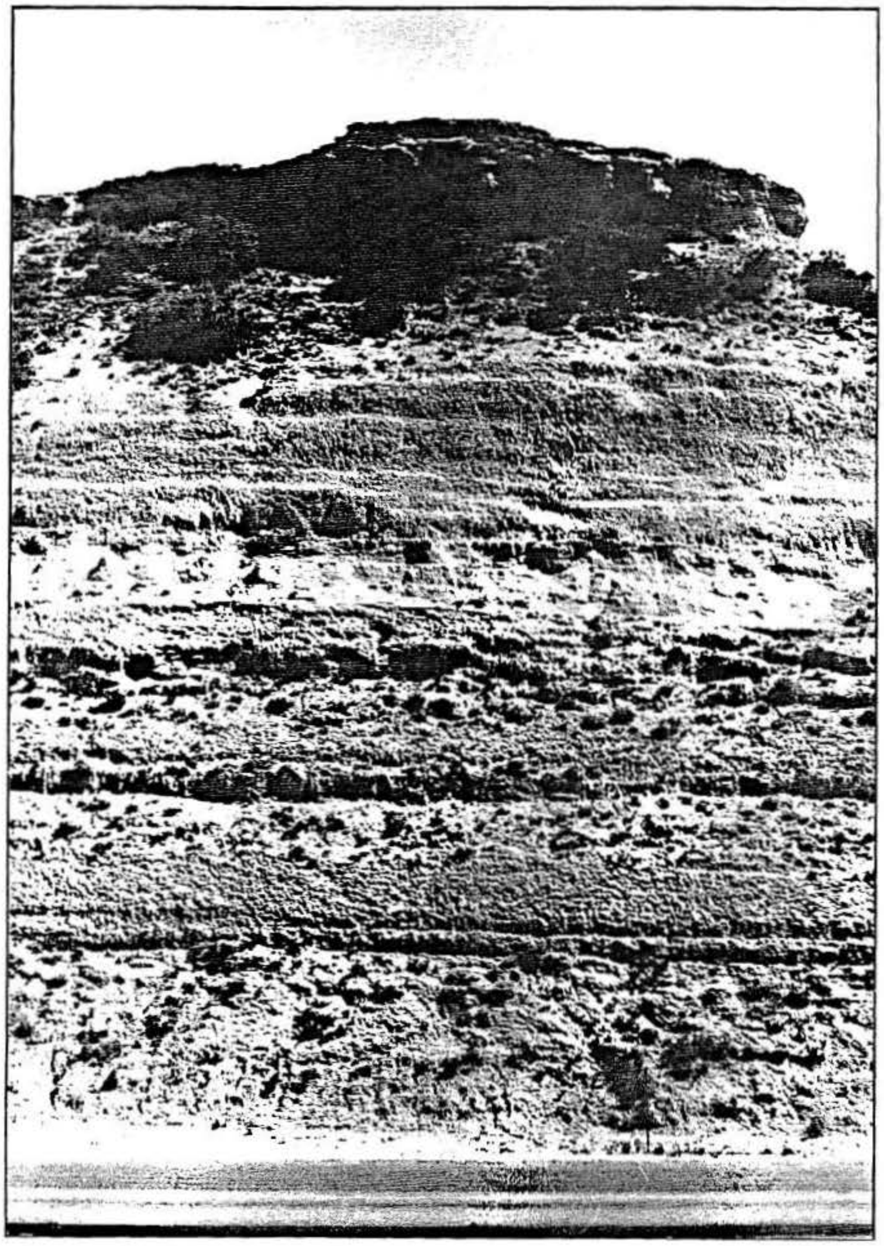

Figure 30. View of upper Tertiary Ogallala Formation exposed along State Highway 256 at Caprock Escarpment, approximately 19 km (12 mi) east of Silverton, Texas. The Ogallala contains numerous buried calcic soil horizons in addition to Caprock caliche that marks top of Ogallala Formation. Section is approximately 20 m (65 ft) high.

this section, the landscape stability indicated by development of paleosols also suggests that the Ogallala surface was vegetated. The Caprock caliche that marks the top of the Ogallala Formation is a Stage VI (see Machette, 1985, for descriptions of stages of development for calcretes) pedogenic calcrete and represents an extended period of landscape stability.

Cementation

The lower 1.5 to 2 m (4.5 to 6 ft) of the Silverton section is a calcrete composed of carbonate-cemented sand and gravel. Gravel clasts appear to float in the fine-grained carbonate matrix. The lack of brecciation and lamination of carbonate deposits, characteristics

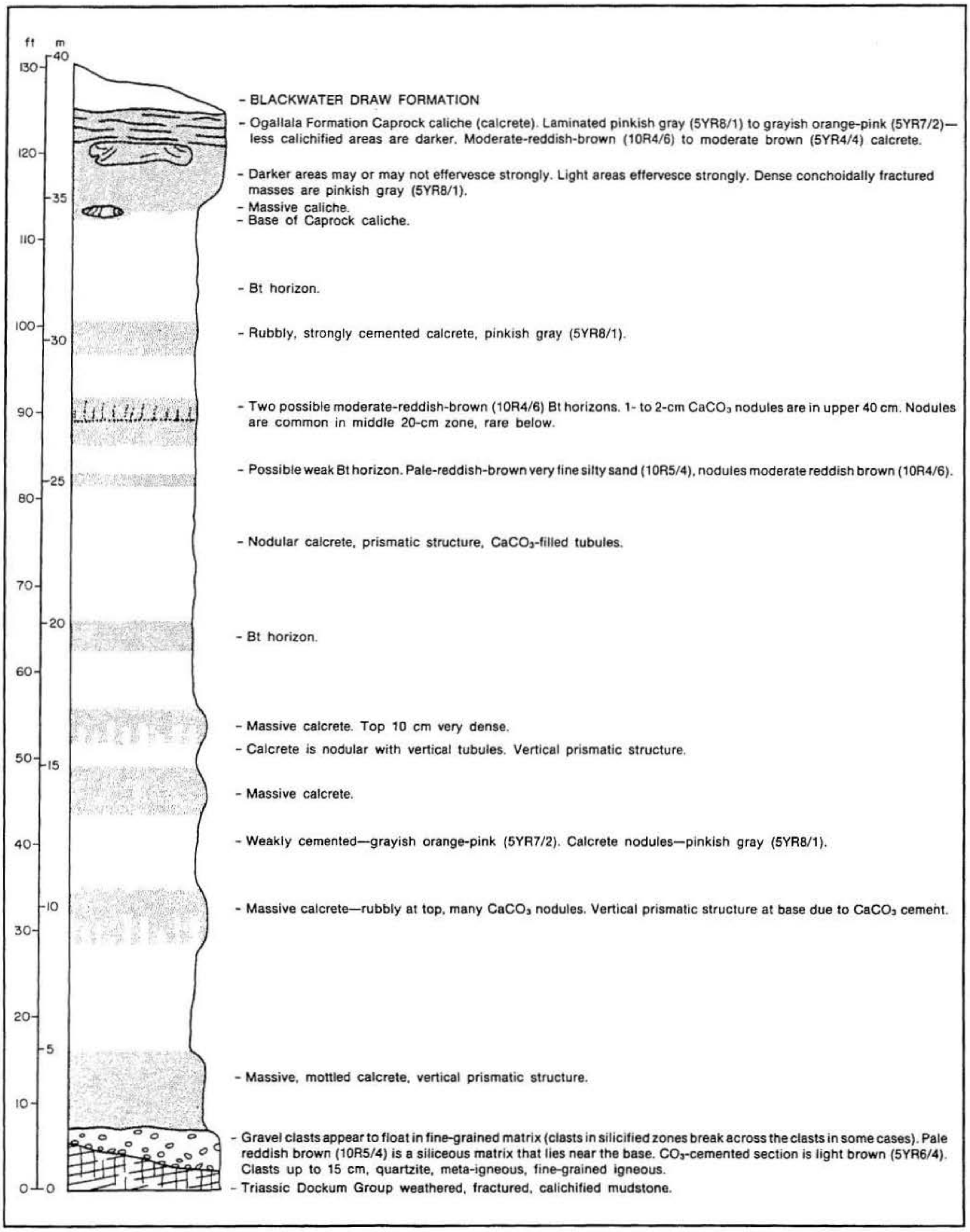

Figure 31. Composite profile of Ogallala Formation exposed along State Highway 256, approximately 19 km (12 mi) east of Silverton, Texas. Symbols for sedimentary structures described in figure 32. Field observations noted to right of column.

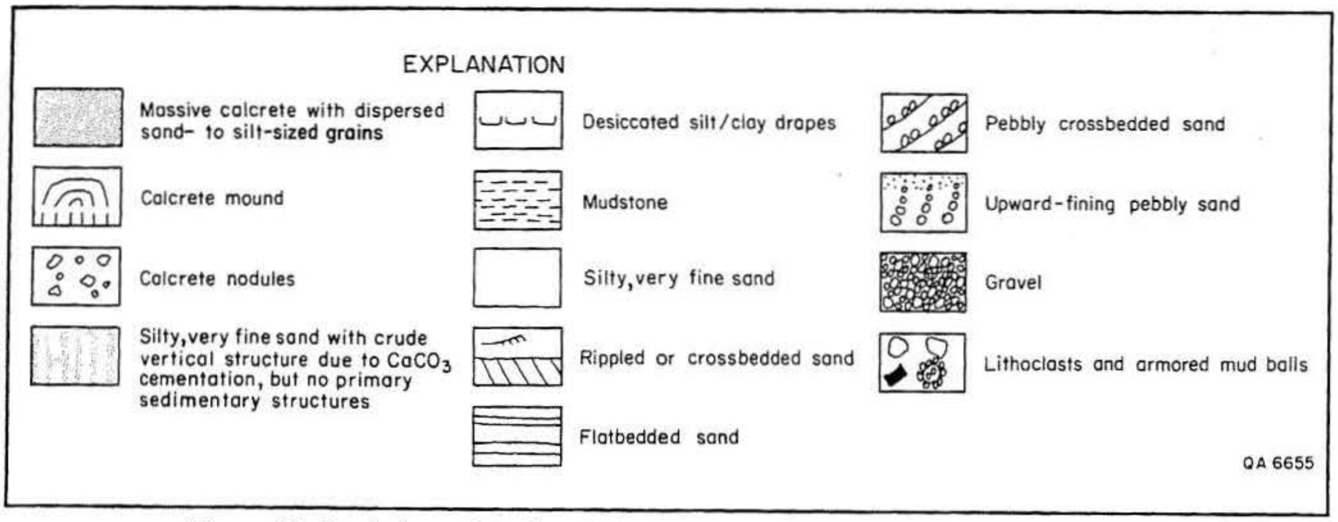

Figure 32. Symbols used in descriptive sections in figures 31, 34, 35, 38, and 40.

generally attributable to pedogenic calcretes, suggests that this is a ground-water calcrete. Locally, this carbonate cement has been replaced by silica. The remainder of the section is moderately to slightly carbonate cemented. This cement is mostly the result of pedogenic processes and consists of carbonate films along ped faces, carbonate nodules, and pedogenic calcretes.

Age

No datable materials were observed at the Silverton section.

STOP 10: Upper Tertiary Ogallala Formation Strata at the Caprock Escarpment, Palo Duro Canyon State Park, Texas

T. C. Gustavson

The upper Tertiary Ogallala strata exposed in the Caprock Escarpment at Palo Duro Canyon State Park contain eolian sediments deposited as sheet sands and loess and fluvial sediments deposited by braided streams. Pedogenic calcretes lie within the eolian section and ground-water calcretes lie within the fluvial section.

The Ogallala Formation is exposed in a roadcut, herein called the Palo Duro Canyon State Park section, along the park entrance road where the road crosses and begins to descend the Caprock Escarpment (figs. 1, 33). The Ogallala Formation unconformably overlies Triassic Dockum Group mudstone at an approximate elevation of 1,015 m (3,330 ft) (fig. 34). Beneath the middle Tertiary erosional surface that separates these two units, Dockum Group light-olive-gray (5Y6/1) mudstone is weathered to yellowish gray (5Y7/2) to a depth of 1.5 m (5 ft).

Stratigraphic Description

Basal Ogallala sediments in the Palo Duro Canyon State Park section contain rounded pebble- to cobble-sized, partly carbonate cemented gravel composed of quartzite and igneous and various fine-grained metamorphic clasts. These gravels lie in shallow narrow channels 1 to 2 m (3 to 6 ft) deep. Neither volcanic clasts nor primary sedimentary structures were identified in this unit. Calcium carbonate (caliche) nodules are preserved in the cemented zones.

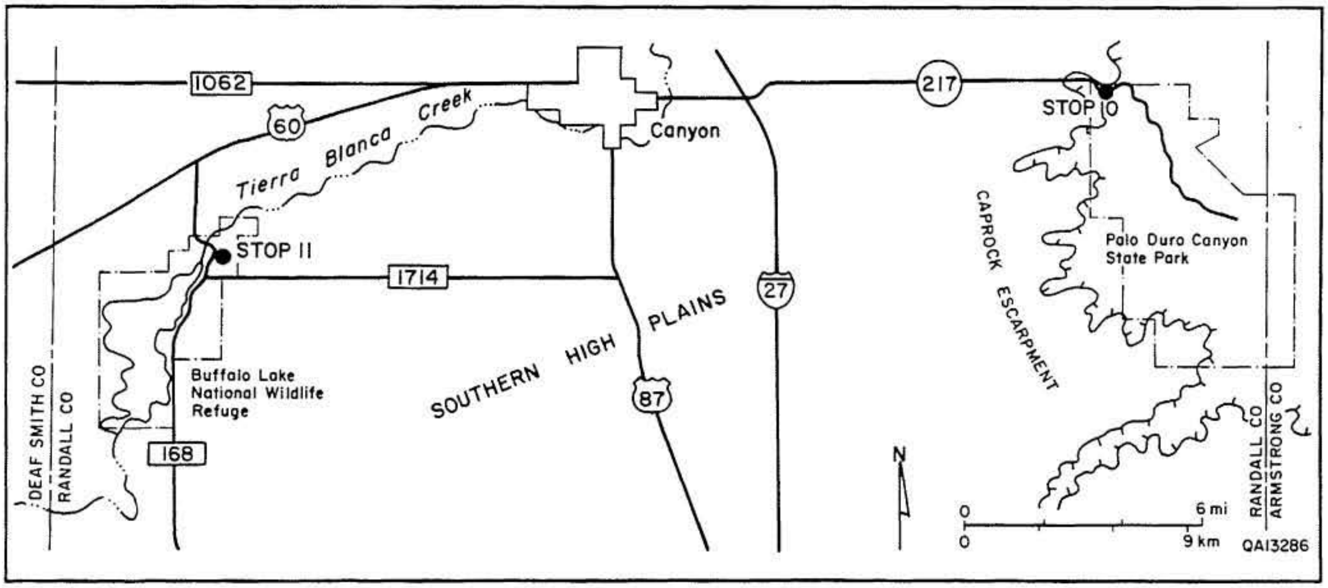

Figure 33. Map of Canyon, Texas, and vicinity, showing Field Trip Stops 10 and 11. Derived from Plainview Sheet, U.S. Geological Survey (1:250,000 series). See figure 1 for location.

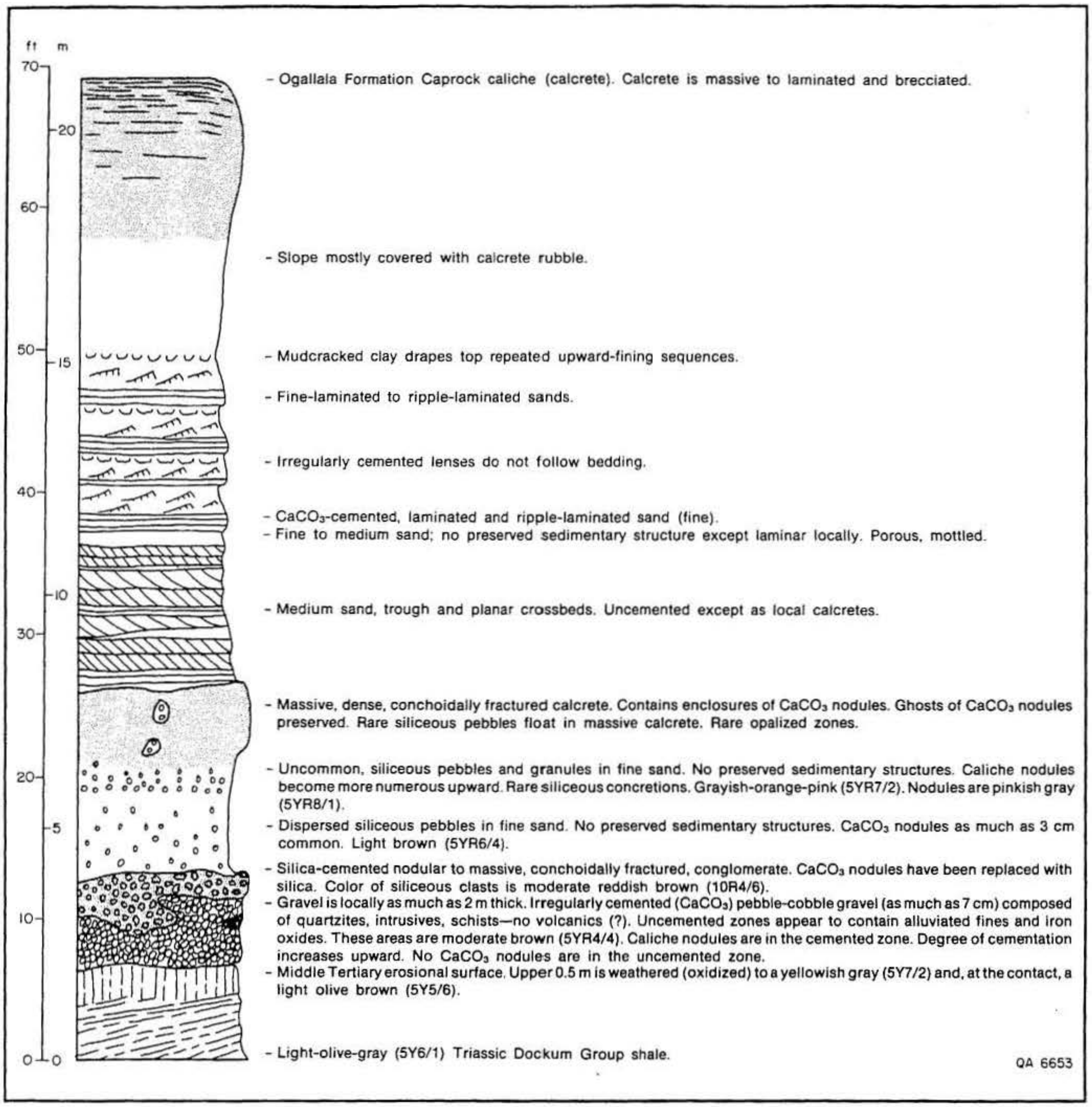

Figure 34. Vertical composite profile of Ogallala Formation exposed at Caprock Escarpment along entrance road to Palo Duro Canyon State Park, 26 km (16 mi) east of Canyon, Texas. Symbols for sedimentary structures described in figure 32. Field observations noted to right of column.

Overlying the basal gravel is 4 m (13 ft) of fine to very fine sand containing dispersed siliceous pebbles. No preserved sedimentary structures are present within this section. Calcium carbonate (caliche) nodules as much as 3 cm (1.2 inch) in diameter are common. The lowest 1 to 1.5 m (3 to 5 ft) is carbonate cemented and contains caliche nodules. The basal cemented zone forms an erosionally resistant layer that can be seen throughout the Palo Duro Canyon area. Locally this basal unit contains siliceous nodules or is entirely silicified. Silicified parts are nodular to massive, moderate brown (10R4/6), and they fracture conchoidally.

Ghosts of caliche nodules are identifiable within the silicified zone, but the nodules also have been silicified. The silicified zone is fractured, and locally fracture faces are partly covered with opal films.

The upper 2 m (6 ft) of this unit is strongly carbonate cemented, forming a massive conchoidally fracturing calcrete. Uncemented enclosures of fine sand and carbonate nodules are present. Ghosts of carbonate nodules remain, along with rare dispersed siliceous pebbles.

Above the calcrete lies 12 m (40 ft) of horizontally bedded, crossbedded, and ripple-laminated sand. This section fines upward from medium sand at the base to fine sand near the top; the thickness of crossbeds also diminishes upward from 20 to 30 cm (8 to 12 inches) at the base to 2 to 10 cm (0.8 to 4 inches) near the top of the exposure. Silty clay drapes showing evidence of desiccation overlie upward-fining ripple-laminated sequences. This sequence does not contain calcium carbonate (caliche) nodules.

This part of the section is poorly cemented, although local case hardening occurs where the surfaces of some strata are carbonate cemented. Lenses of carbonate-cemented sand (ground-water calcretes) are also present.

Overlying the fluvial section described previously is a 3.5-m (12-ft) section covered with colluvium. The top of the section exposes a weathered and extensively fractured part of the Caprock caliche.

Facies Interpretations

The lack of preserved primary sedimentary structures in the lower 6.75 m (22.3 ft) of the Palo Duro Canyon State Park section (fig. 34) makes interpreting the environments of deposition difficult. The channel-filling rounded gravel clasts at the base of the section were probably deposited by small, possibly braided, streams. Except for a few dispersed gravel-sized clasts, the 4 m (13 ft) of fine to very fine sand overlying the gravel is similar in grain size to eolian material described in the Silverton, Buffalo Lake, Bellview, and Ragland sections (Gustavson, Stops 9, 11, 12, and 13, this guidebook, p. 65, 72, 75, and 79, respectively). The absence of primary sedimentary structures and the presence of caliche nodules indicate that the section has been altered by pedogenic processes and perhaps has been bioturbated. The presence of pedogenic caliche nodules in this part of the section suggests that a stable landscape and a slow rate of accumulation of sediment prevailed when the nodules were being formed.

The lower part of the 5.5-m-thick (18-ft) sequence of fluvial sediments in the middle of the Palo Duro Canyon State Park section consists primarily of planar and trough crossbeds and horizontal beds. Ripple cross-stratification and silt/clay drapes are missing. The sedimentary structures present probably represent superimposed bars similar to those preserved in a Platte River type (Smith, 1970) of sandy braided stream.

The upper part of the fluvial sequence of the Palo Duro Canyon State Park section includes numerous upward-fining sequences capped by ripple cross-stratification and silt/clay drapes showing evidence of desiccation. These structures suggest deposition during repeated flood events by high-energy, shallow sandy braided streams exhibiting highly variable water and sediment discharge, similar to the flood events at Bijou Creek, Colorado (McKee and others, 1967).

Cementation

Several episodes of cementation have probably affected the Palo Duro section. Two ground-water calcretes are present near the base of the section. The base of the Ogallala section is strongly carbonate cemented to a thickness of about 2 m (6 ft). Ground-water calcretes do not display any of the characteristics of pedogenic calcretes. Although ghosts of pedogenic carbonate nodules are present, the basal calcrete is not laminated and does not appear to be fractured and recemented. Clasts of the original sediment in this section may have been slightly dispersed by the cementation process but are not excluded from the calcrete. Locally this calcrete has been silicified. A second calcrete lies about 2 m (6 ft) above the basal calcrete and is similar in character. In addition, numerous individual beds within the fluvial section are cemented by calcium carbonate to form thin, discontinuous ground-water calcretes.

Age

No datable materials were observed in this section.

STOP 11: Upper Tertiary Ogallala Formation at the Caprock Escarpment, Buffalo Lake National Wildlife Refuge, Texas Panhandle

T. C. Gustavson

About 25 m (83 ft) of Upper Tertiary Ogallala Formation eolian sediments are exposed at the Buffalo Lake National Wildlife Refuge, Texas. These strata were extensively modified by pedogenic processes that formed calcic soils.

The Ogallala Formation is exposed in a roadcut, herein called the Buffalo Lake section, on the southeast side of FM 168, in the Buffalo Lake National Wildlife Refuge, approximately 5 km (3 mi) south of Umbarger, Texas (figs. 1, 33). The base of the section is at an elevation of about 1,103 m (3,620 ft), 0.3 km (0.25 mi) east of the Buffalo Lake dam. Triassic Dockum Group strata exposed at the base of the section contain brecciated sandstones and mudstones that dip approximately 20° SW (fig. 35). Fractures are filled with carbonate-cemented fragments of Dockum strata. The upper 1 to 1.5 m (3 to 5 ft) contains brecciated mudstones partly displaced by laminated calcium carbonate (calcrete). This may be a remnant of a pedogenic calcrete developed at the middle Tertiary erosional surface on Dockum strata.

Stratigraphic Description

A massive, 2.2-m-thick (7-ft) calcrete lies at the base of the Ogallala Formation (fig. 35). The calcrete is locally brecciated and silicified, silicification boundaries cutting across breccia clasts. Rare quartzite pebbles are dispersed in the calcrete.

Overlying the calcrete is 21 m (70 ft) of fine to very fine pinkish-gray (5YR8/1) to light-brown (5YR6/4) sand and silt. No primary sedimentary structures are preserved in this sequence, although numerous white carbonate (calcrete) nodules are present throughout the section. A crude vertical columnar structure is present throughout most of this sequence that apparently reflects differential carbonate cementation along soil ped faces. The slightly resistant areas are more heavily carbonate cemented. Opalized, downward-branching tubules, apparently representing silicified root traces, are present locally. Several paleosols are present as pedogenic carbonate horizons near the top of the section (fig. 36), where the number and size of calcrete nodules increase. The pedogenic Ogallala Caprock caliche, approximately 2.5 m (8.2 ft) thick, lies at the top of the section. The upper part is massive and intensely fractured. No secondary laminations were observed.

Facies Interpretation

Dockum strata below the middle Tertiary erosional surface appear to have undergone pedogenesis, which resulted in the development of pedogenic calcrete. If so, then the middle Tertiary erosional surface in this locale was stable long enough for a mature soil profile to develop.

There is no evidence of fluvial deposition at the Buffalo Lake section. The 21 m (70 ft) of Ogallala Formation sediments exposed at the Buffalo Lake section is predominantly fine to very fine silty sand. Some sand grains are frosted and well rounded. The presence of frosted, well-rounded sand grains and the texture of these sediments suggest that the entire section was deposited by eolian processes in a way similar to the deposition of the upper parts of the Ragland and Bellview sections (Stops 12 and 13). The large percentage (commonly 40–70%) of fine to very fine sand is too coarse for loess, but the presence of a significant proportion of silt- and clay-sized (30–60%) material supports a premise of loess deposition. Preserved root traces, paleosols, and caliche nodules, as well as the absence of preserved primary sedimentary

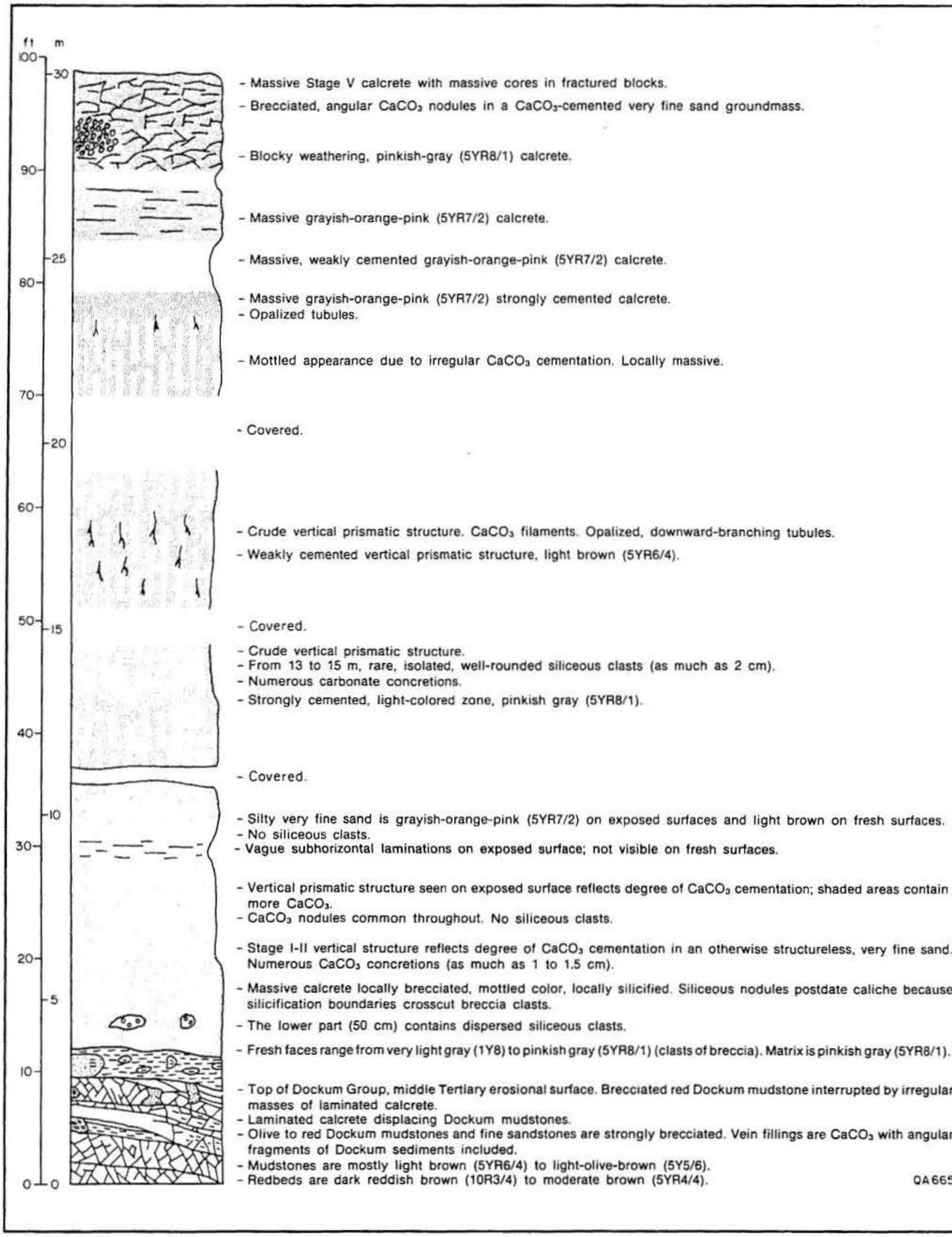

Figure 35. Composite profile of Ogallala Formation exposed along FM 168 in Buffalo Lake National Wildlife Refuge, 5 km (3 mi) south of Umbarger, Texas. Symbols for sedimentary structures described in figure 32. Field observations noted to right of column.

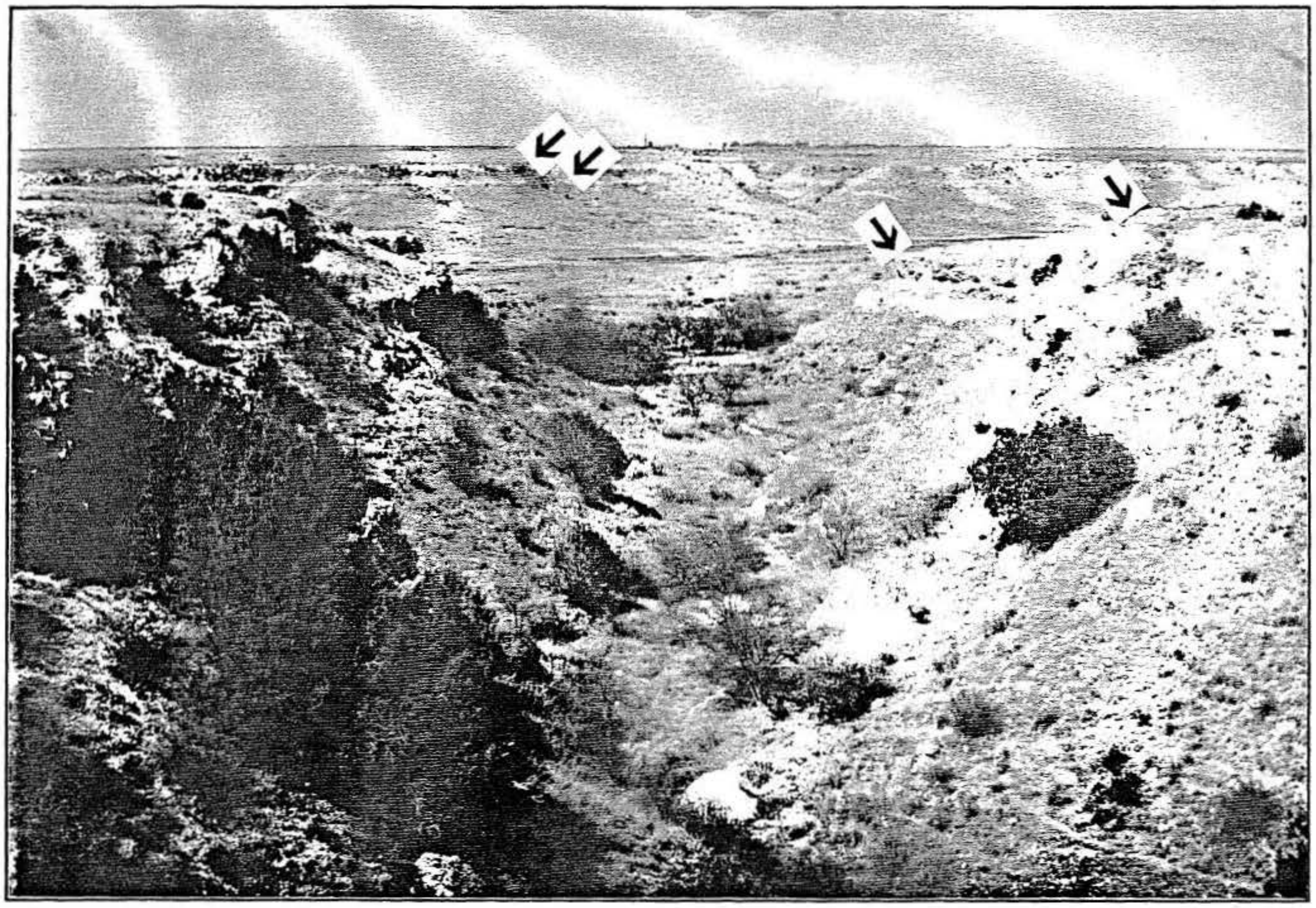

Figure 36. View to north across valley of Tierra Blanca Creek, Buffalo Lake National Wildlife Refuge. Three resistant buried calcretes are exposed in valley wall of Tierra Blanca Creek; two are almost continuous near top of valley side, and the third is discontinuously exposed. See arrows.

structures, suggest slow accumulation of sediment on a stable landscape. The combination of sand-, silt-, and clay-sized material suggests that mixed eolian processes account for deposition of this section. Examples of modern analogs are loess deposition (Miller and others, 1984) and deposition as sand sheets (Fryberger and others, 1979; Kocurek and Neilson, 1986).

Cementation

The entire Buffalo Lake section is weakly cemented by calcium carbonate. Carbonate nodules, probably resulting from pedogenic processes, are scattered throughout the section. Near the base of the section lies a 2-m-thick (6-ft) calcrete that is partly silicified and massive. Although there is little evidence of brecciation and recementation of carbonate clasts, no other characteristics suggest that this basal Ogallala calcrete is pedogenic in origin. The calcrete is apparently the result of precipitation of calcium carbonate from ground water.

Age

No datable materials were found in this section.

STOP 12: Upper Tertiary Ogallala Formation at the Caprock Escarpment, North of Bellview, New Mexico

T. C. Gustavson

Upper Tertiary Ogallala Formation strata exposed at the Caprock Escarpment 13 km (8 mi) north of Bellview, New Mexico, consist of a lower fluvial section overlain by eolian sediments. The eolian sediments have been modified by the development of numerous calcic paleosols, and the fluvial sediments were deposited by high-energy ephemeral braided streams.

The Ogallala Formation is exposed in a roadcut, herein called the Bellview section, at the Caprock Escarpment approximately 13 km (8 mi) north of Bellview, New Mexico, on New Mexico State Highway 93 (figs. 1, 37). About 29 m (96 ft) of Ogallala Formation strata is exposed at the Caprock Escarpment (fig. 38). The Ogallala Formation at the Bellview section rests unconformably on weathered and faulted Triassic Dockum Group strata. Clastic dikes in the Dockum are filled with basal Ogallala sediments.

Stratigraphic Description

Overlying the middle Tertiary unconformity is a 1-m-thick (3.3-ft) sequence of angular to subangular gravel overlain by a light-brown

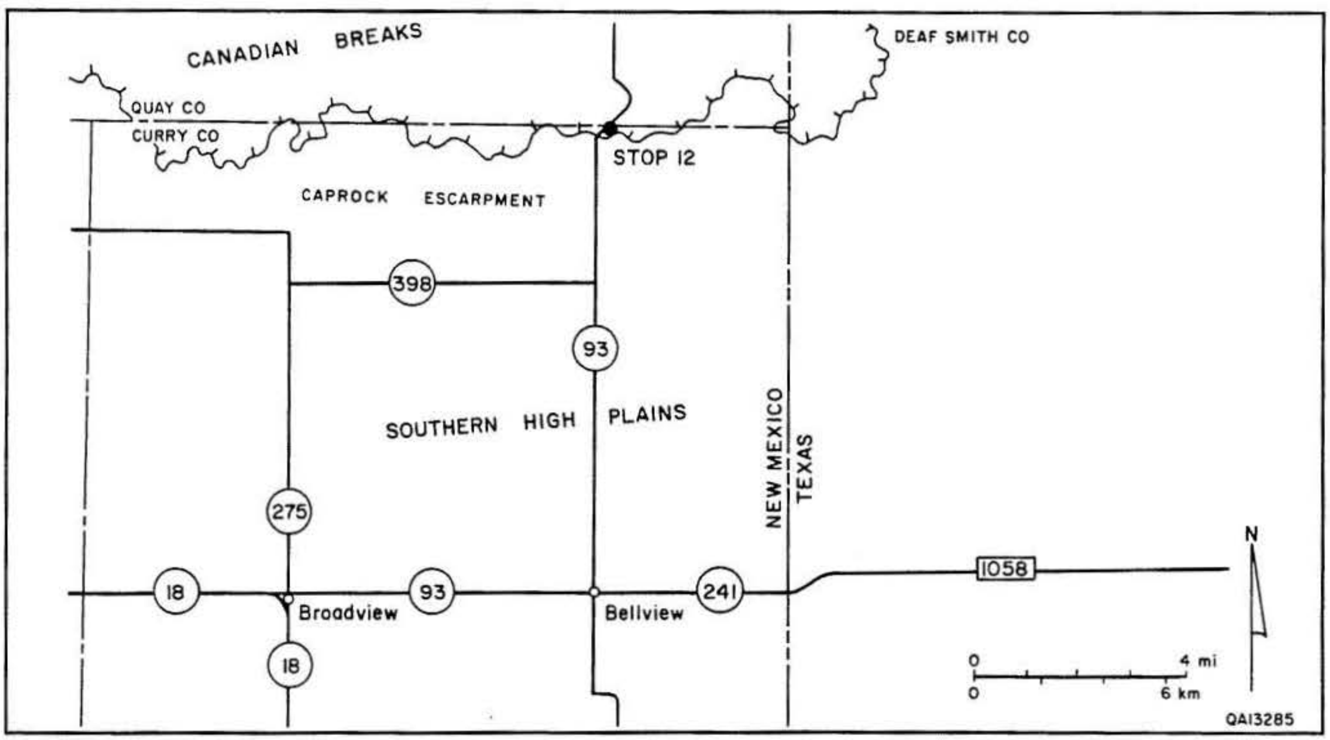

Figure 37. Map of parts of Quay and Curry Counties, New Mexico and Deaf Smith County, Texas, showing Field Trip Stop 12 at Caprock Escarpment. Derived from Clovis Sheet, U.S. Geological Survey (1:250,000 series). See figure 1 for location.

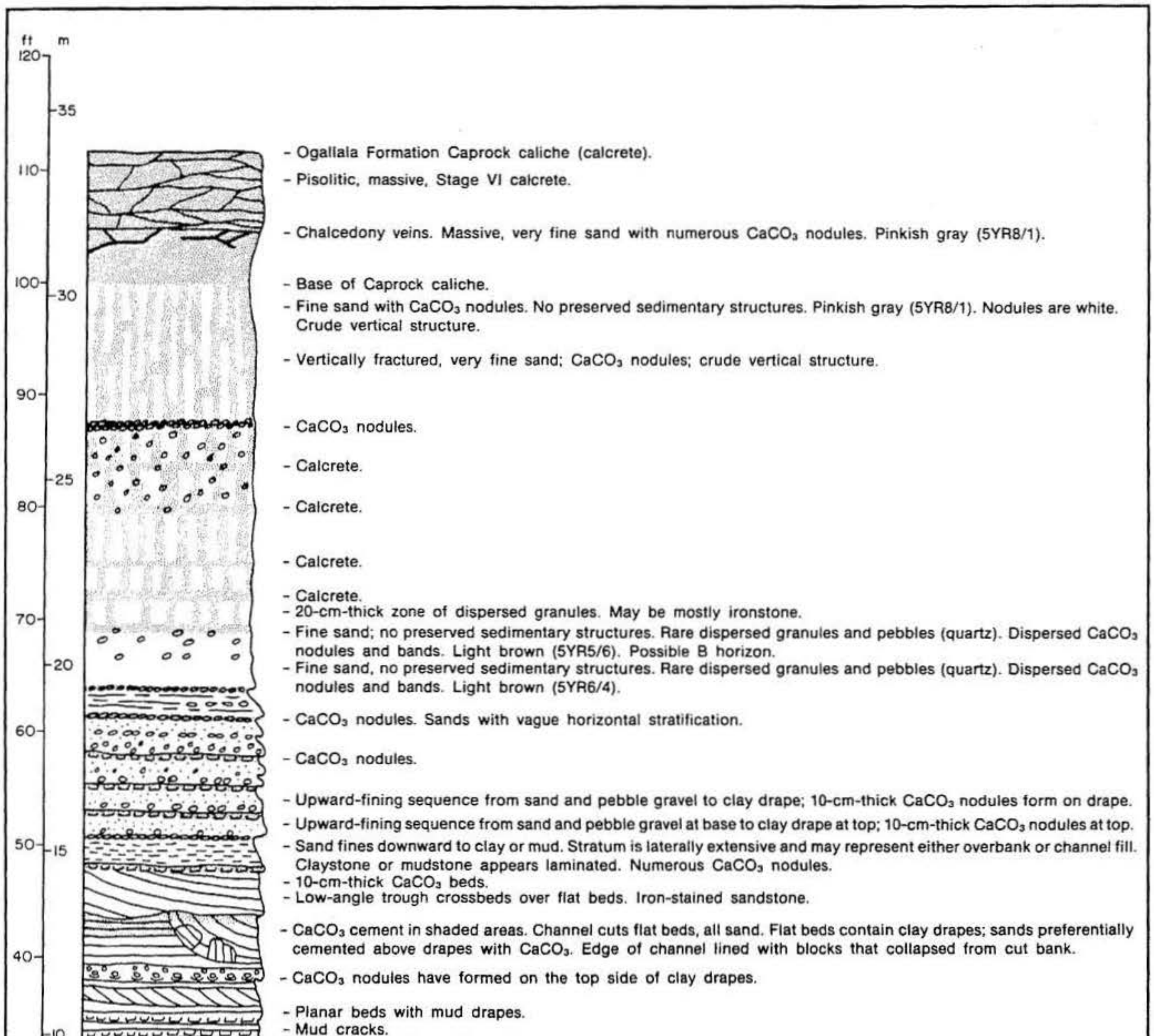

Figure 38. Composite profile of Ogallala Formation exposed at Caprock Escarpment along New Mexico State Highway 93, 13 km (8 mi) north of Bellview, New Mexico. Symbols for sedimentary structures described in figure 32. Field observations noted to right of column.

(5YR5/6), sandy clay loam (fig. 38). Color and texture suggest that this is a buried B soil horizon. No primary sedimentary structures are preserved in this unit. Most of the gravel clasts therein are angular to subangular fragments of plinthite (iron-cemented sand) or silicified valves of the Cretaceous pelecypod *Gryphaea*.

Unconformably above the paleosol lies 10 m (33 ft) of flatbedded and crossbedded pebbly sands (fig. 38). Channel cutbanks at 7 and 12 m (23 and 40 ft) are preserved in this sequence. Blocks of collapsed bank material, lithoclasts, and armored mud balls lie in the channel fills. Overlying this sequence of pebble sands is a third channel (at 15 m [49 ft]) filled by 0.75 m (2.5 ft) of laminated carbonate-cemented mudstone. In turn this channel fill is overlain by numerous 20- to 40-cm-thick (8- to 16-inch) sequences of horizontally bedded pebble gravel or pebbly sand that fine upward to horizontally bedded or crossbedded sand. Generally these sequences are capped by thin silt/clay drapes. Curled edges along mudcracks through the drapes indicate that desiccation occurred after deposition of the sand. Clay drapes are commonly overlain by beds of amorphous, nodular, calcium-carbonate nodules that can reach as much as 10 cm (4 inches) in thickness. No clastic sedimentary material is in these nodules.

The upper 14.8 m (49 ft) of the Bellview section differs markedly from the underlying strata and predominantly contains fine to very fine pinkish-gray (5YR8/1) sand capped by the 4-m-thick (13-ft) Caprock caliche. The fine and very fine sand section has a crude vertical columnar structure, apparently the result of differential carbonate cementation. Carbonate nodules are scattered throughout this part of the section. At about 13 m (43 ft) below the surface, two slightly darker (5YR5/6), light-brown zones preserve a higher clay content and apparently are buried B horizons. At least six buried pedogenic calcretes are indicated by diffuse zones of increased carbonate cement or carbonate nodules. No primary sedimentary structures were preserved in this material.

The massive Caprock caliche that caps the Bellview section is pinkish gray (5YR8/1) and is nearly 4 m (13 ft) thick. The base of the Caprock caliche displays an upward increase in size and number of carbonate nodules. Toward the surface the calcrete becomes more massive. The upper part is a laminated, brecciated, pisolitic Stage VI calcrete (Bachman and Machette, 1977). Numerous chalcedony veins are exposed at about 2 m (6 ft) below the surface.

Facies Interpretation

The fine-grained, clay-rich paleosol overlying a thin zone of angular fragments at the base of the section represents a weathering and soil-forming horizon. The angularity of the coarse fragments suggests accumulation without significant transport. This unit preserves a thin colluvial deposit, modified by pedogenesis, that formed on the middle Tertiary erosional surface before deposition of Ogallala Formation fluvial sediments.

The fluvial sands and gravels exposed at the Bellview section make up channel fills and several upward-fining sequences within a larger upward-fining unit. Horizontally bedded and crossbedded pebbly sands fine upward and are capped by desiccated silt/clay drapes. Channel-fill sequences begin at erosion surfaces and include armored mud balls and rotated slump blocks near the channel floors. These sediments were deposited by streams, the sediment and water discharge of which were highly variable. Each upward-fining sequence capped by a silt/clay drape represents a flood event followed by subaerial exposure. The Bijou Creek and South Saskatchewan River types of sandy, braided, ephemeral streams appear to be modern analogs for these deposits (McKee and others, 1967; Cant and Walker, 1978).

Midway through the Bellview section at approximately 14 m (46 ft), a fundamental change in depositional processes is preserved in the sedimentary record. The upper part of the Bellview section primarily contains fine to very fine sand having no preserved primary sedimentary structures. The development of paleosols in this part of the section is indicated by several preserved pedogenic calcretes and two B horizons. Carbonate nodules (caliche) are abundant throughout the upper part of the section. Grain-size distribution and uniformity of grain size throughout the upper part of the section resemble those of eolian beds of the upper part of the Ragland section (Stop 13, this guidebook, p. 79) and those of the eolian sections of the Ogallala described by Winkler (1985). The stacked paleosols show no evidence of erosion between them, indicating that the surface of accumulation was a stable landscape. The absence of sedimentary structures also suggests bioturbation. The development of pedogenic calcretes and B horizons results from long-term landscape stability during which pedogenic processes have a chance to operate. The presence of both sand and silt fractions suggests that deposition was mixed and probably included eolian sand sheets and loess deposited on a stable grass-covered landscape (see Frye and Leonard, 1957, for discussions of Ogallala flora). As suggested by Fryberger and others (1979) and Kocurek and Neilson (1986), vegetation, particularly grasses, probably plays a significant role in stabilizing eolian sand sheets. Clearly, vegetation would also act as a baffle to stabilize windblown dust.

Ogallala fluvial sediments at the Bellview section differ from those at the Ragland section (Stop 13, this guidebook, p. 79) in several significant ways. The Bellview section is primarily sand, whereas the Ragland section is sand and coarse gravel, especially at the base of the section. Gravel clasts at the Bellview section are mostly fragments of an iron-cemented sand (plinthite), *Gryphaea*, and quartzite pebbles. Plinthite fragments are absent at the Ragland section, and *Gryphaea* are rare. Basic volcanic cobbles are common at the Ragland section but do not appear at the Bellview site. These data indicate that the fluvial systems operating at these two sites during the late Tertiary had significantly different flow regimes and that the sources of sediment available to the two stream systems may also have been significantly different.

Cementation

Carbonate cementation is widespread but variable within the fluvial and colluvial sediments that make up the lower part of the Bellview section. Most of the section is poorly cemented, but some finer grained sand and mud units are moderately well cemented.

Beds of calcium carbonate as much as 10 cm (4 inches) thick have accumulated above thin, mud-cracked silt/clay drapes, which may have retarded the downward flow of ground water. The carbonate beds are nodular and have not incorporated any of the adjacent clastic material. The mechanism by which $CaCO_3$ accumulated is not understood. Pedogenic carbonate nodules form at shallow depths in soils by precipitation from soil waters and in the process of formation exclude most soil particles. Perhaps a similar process accounts for the carbonate beds in this section, but the precipitation of calcium carbonate is apparently from ground water that has percolated somewhat deeper than normal soil-forming depths of 1 to 2 m (3.3 to 6.6 ft).

Age

No datable material was observed at the Bellview section. No basic volcanic clasts were identified at the Bellview section, so the relative age of the section cannot be determined.

STOP 13: Upper Tertiary Ogallala Formation at the Caprock Escarpment, Ragland, New Mexico

T. C. Gustavson

The upper Tertiary Ogallala Formation exposed at the Caprock Escarpment at Ragland, New Mexico, has a lower fluvial section containing coarse gravel deposited by high-energy braided streams. Eolian sediments deposited as loess and sand sheets overlie the fluvial section. Eolian sediments are extensively modified by pedogenesis to form calcic paleosols.

The Ogallala Formation is exposed in a roadcut, herein called the Ragland section, at Ragland, New Mexico, along New Mexico Highway 18, approximately 37 km (23 mi) south of Tucumcari, New Mexico, in a north-facing segment of the Caprock Escarpment (figs. 1, 39). This section exposes approximately 25 m (85 ft) of the Ogallala Formation (fig. 40), which was deposited unconformably on Triassic Dockum Group strata. The base of the section lies at an elevation of approximately 1,458 m (4,785 ft).

Stratigraphic Description

The lower 1.5 m (5 ft) of the Ogallala Formation exposed in the Ragland section is a clast-supported, carbonate-cemented siliceous gravel containing primarily well-rounded volcanics, quartzite, and other fine-grained metamorphic clasts. Intermediate axis lengths of 7 cm (3 inches) are common. Rare angular clasts of Dockum sediment as much as 20 cm (8 inches) long are present, but their angularity, relative softness, and large size indicate they have not been transported any great distance. These basal gravels are horizontally bedded and imbricated, and they compose at least three upward-fining sequences. Calcium carbonate cement occupies most original pore space.

Overlying the basal conglomerate is 7 m (23 ft) of interbedded clast-supported, carbonate-cemented siliceous conglomerates and pebbly sandstones. Conglomerates are horizontally bedded, and clasts are well rounded and imbricated. Upward-fining sequences range in thickness to 0.8 m (2.3 ft). Sandstones are composed of pinkish-gray, pebbly coarse sand preserved as low-angle tangential cross sets. This section

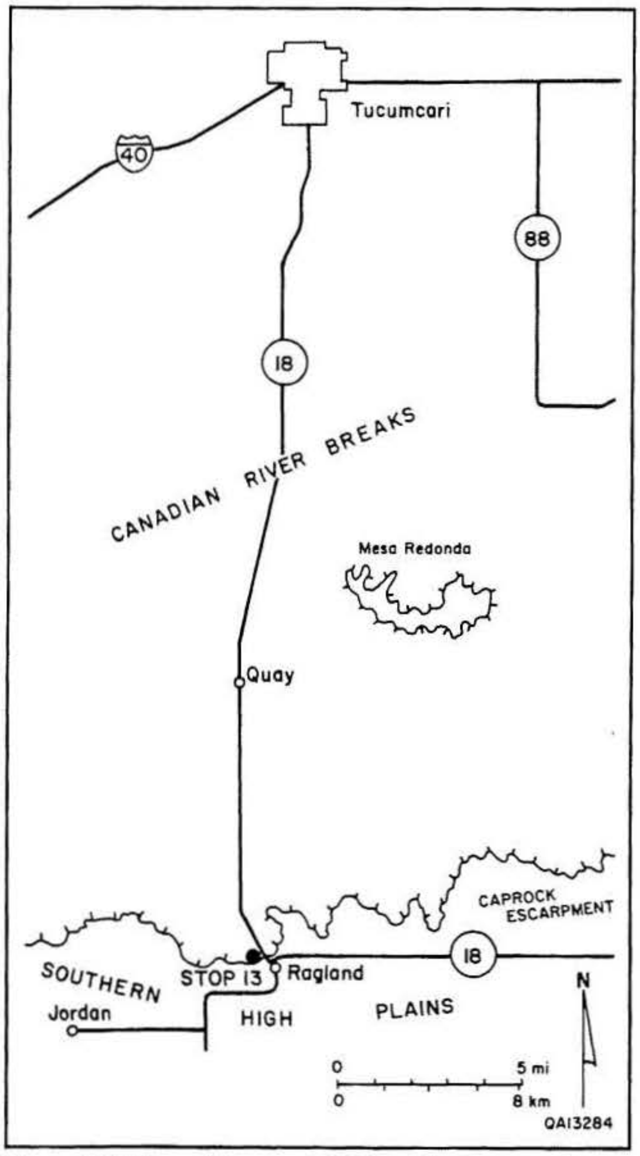

Figure 39. Map of Tucumcari, New Mexico, area (Quay County) showing Field Trip Stop 13. Derived from Clovis and Tucumcari Sheets, U.S. Geological Survey (1:250,000 series). See figure 1 for location.

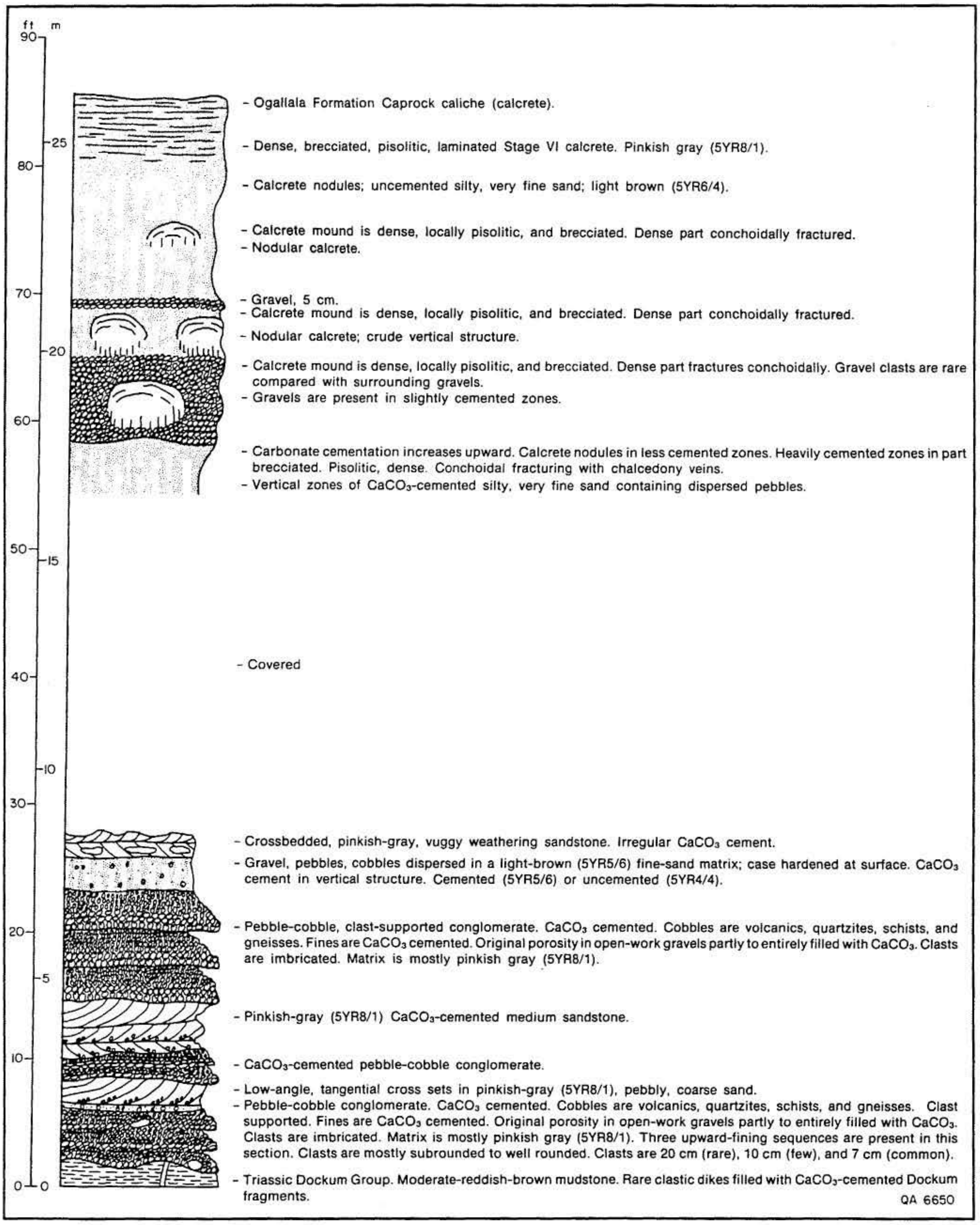

Figure 40. Composite profile of Ogallala Formation exposed at Caprock Escarpment along New Mexico State Highway 18 at Ragland, New Mexico. Symbols for sedimentary structures described in figure 32. Field observations noted to right of column.

is capped by 0.75 m (2 ft) of pinkish-gray, cross-bedded, vuggy weathering, carbonate-cemented sandstone. The apparent paleoflow direction as determined from cross-set orientations was to the southeast.

Overlying approximately 2.4 m (7.9 ft) of section obscured by slope wash is 4 m (13 ft) of interbedded pebbly sand and gravel. No primary sedimentary structures are identifiable. Original sediment appears to have been a pebbly medium sand interbedded with medium gravel (intermediate axis as much as 5 cm [2 inches]). At least two and possibly three zones of pedogenic calcrete (caliche) formed within these sediments. Calcrete development, or carbonate cementation, increases upward. Initially, vertical zones of dispersed carbonate cement resulted in a crude vertical prismatic structure in coarse sands, the carbonate becoming nodular and then massive near the top of this section. The original clastic ground mass is generally excluded from the carbonate nodules. Individual nodules extend in diameter to approximately 2 cm (0.75 inch), increasing upward in number and size. Massive carbonate near the top of this section is partly brecciated, recemented, and pisolitic, and it contains chalcedony in veins. These are the features that characterize calcic soils and pedogenic calcretes (Bachman and Machette, 1977).

Massive calcium carbonate is present as horizontal beds of crude moundlike structures having relatively sharp upper boundaries. Clastics that are part of the original sediments are excluded from the massive carbonate, although minor sand and gravel clasts float in the carbonate mass. The spaces between the mounds are filled with structureless, poorly cemented sand or gravel. The massive carbonate horizons represent at least one Stage IV or V pedogenic calcrete (Bachman and Machette, 1977). The spaces between the mounds probably resulted from carbonate solution forming pitlike features in the calcrete. Later fluvial sedimentation filled the pits, and pedogenesis alternated with carbonate solution to form the second set of calcrete mounds.

The style of sedimentation changes abruptly approximately 16.5 m (55 ft) above the base of this Ogallala alluvial section. The clastic material that comprises the upper 6 m (20 ft) of the Ragland section is primarily pinkish-gray, fine to very fine sand. Many sand grains are rounded and frosted, and no primary sedimentary structures are preserved. Carbonate content increases upward. Carbonate cement deposited preferentially along vertical infiltration pathways has produced a crude vertical or columnar structure. Carbonate nodules increase in size and number upward, grading to a massive 2.2-m-thick (7.3-ft) pedogenic calcrete, the Caprock caliche, at the top of the section. This massive pinkish-gray calcrete is complexly brecciated and recemented at the surface. The upper part is deeply weathered, and the preserved portion is probably equivalent to the Stage VI pedogenic calcrete of Bachman and Machette (1977).

Facies Interpretation

The fluvial sands and gravels exposed in the Ragland section were deposited in a major channel system that contained streams that flowed southeastward across the middle Tertiary landscape (fig. 4). The fluvial deposits fine upward from mostly gravel near the base of the channel to mostly sand near the top. Upward-fining sequences of horizontally bedded gravels overlain by crossbedded sands suggest deposition of superimposed bars by high-energy, high-sediment-load, braided, and flashy-discharge streams. The change from gravel-dominant to sand-dominant facies suggests that at least two modern analogs may apply. These are the Scott River type, coarse-gravel, braided-stream model for the gravel sequences (Boothroyd and Ashley, 1975) and the Donjek River type, sand-and-gravel, braided-stream model for the entire section (Williams and Rust, 1969; Rust, 1972).

The upper 6 m (20 ft) of the Ragland section consists of fine to very fine sand containing rare floating granules or small pebbles. Some sand grains are frosted. The lack of preserved sedimentary structures and the pervasive development of calcic soils and pedogenic calcrete make it difficult to interpret the process by which this part of the section was deposited. However, the presence of frosted grains and the grain size of these sediments suggest deposition by eolian processes.

These fine to very fine sands probably are too coarse to have been deposited entirely from suspension as loess. However, the presence of as much as 50 percent silt- and clay-sized material makes it likely that eolian dust contributed to these sediments. The coarser fraction, especially fine and very fine sand, either moved primarily as material in saltation or became temporarily suspended within a meter or two of the surface. Modern and Wisconsinan analogs are loess or dust deposits (Pewe, 1981; Miller and others, 1984) and sand sheets as described by Fryberger and others (1979) and Kocurek and Neilson (1986). Winkler (1985) described similar silty, fine sand facies southeast of Lubbock, Texas, in his studies of the Ogallala and also attributed their deposition to processes similar to those that deposit loess and sand sheets.

Cementation

Carbonate cementation in the lower, fluvial part of the section increases downward and is irregularly expressed as erosionally resistant lenses in sandy facies. Carbonate cement fills voids between gravel clasts near the contact with the underlying Dockum and partly coats clasts higher in the section. Because no evidence of clast displacement by carbonate cement exists, and because no structures characteristic of pedogenic calcretes were identified, calcretes in the lower part of the fluvial section probably were deposited from ground water.

Age

Because the Ragland section contains neither fossil material nor tephra, the age of these deposits cannot be determined with accuracy. Numerous large, rounded, amygdaloidal basalt cobbles are present in the basal gravels. Basic volcanic flows northwest of the Ragland section in the Ocate and Raton volcanic fields have been dated as 8.3 Ma or younger (Stormer, 1972; O'Neil and Mehnert, 1980). These flows are the nearest extrusive basic volcanics up paleoslope from this section. Either field may be the source of the basic volcanic clasts in the Ragland section; thus the basal portion of the Ogallala here is no older than 8.3 Ma.

STOP 14: The Clarendonian Faunas of the Texas and Oklahoma Panhandles

G. E. Schultz

The Clarendonian faunas of the Texas and Oklahoma Panhandle region are dominated by medium to large grazing mammals. The Exell, Coetas Creek, and Cole Highway Pit Local Faunas of Texas and the Laverne and Durham Local Faunas of Oklahoma also contain a large number of grazing animals, suggesting a parkland or woodland savanna.

Geology and Taphonomy

Most of the Ogallala sediments in the Clarendon, Texas, region (figs. 41, 42) are the unfossiliferous, massive, structureless buff to brown silty eolian sheet sands that are characteristic of the Ogallala elsewhere in the Great Plains. A few places have exposures of coarse, fairly well sorted and loosely consolidated yellow to gray to brown sands and some gravels representing stream-channel deposits. More extensive exposures of fine greenish-gray to brown clay and silt, commonly containing thin flaggy lenses of fresh-water limestone and representing overbank floodplain, backswamp, and "oxbow lake" deposits can also be found. These fluvial deposits are scattered for an east-west distance of about 24 km (15 mi) along ridges and divides and in small tributary draws north of the Salt Fork of the Red River. They demonstrate that eastward-flowing meandering and braided streams flowed here during Clarendonian time.

Some fossils apparently accumulated in ponds, lakes, or marshy areas on grass-covered floodplains (for example, fossils found at MacAdams, Dilli, Risley, Farr, Noble, and Bromley localities [figs. 41, 42]), whereas others, which are broken and waterworn, were buried in the coarser ferruginous sands of stream channels (Quarries 1 through 5 on the Rowe-Lewis Ranch) (figs. 41 through 44). Completely articulated skeletons are rarely found except in sinkhole deposits on the Rowe-Lewis Ranch northeast of Clarendon.

The sinkholes developed as a result of subsurface dissolution of evaporite minerals in the Permian red beds, followed by collapse of the overlying sediments. These sinks were steep walled and filled rapidly with the water and sand that washed into them. Animals that were trapped in them were buried intact. The Frick Laboratory excavated about two dozen horse skeletons and a number of other mammals from the largest of the sinks exposed on the north side of Petrified Creek (Rowe-Lewis Ranch Quarry 7) (fig. 42, site 19). The skeletons, although complete, are difficult to remove from the ferruginous concretionary sandstone matrix that surrounds them. The deposits are easily identified in the field as yellow to brown sand in sharp contact with Permian red beds, which may bend sharply downward around the edge of a sink. Along the south side of Petrified Creek, the sinkhole fillings were more resistant than the surrounding Permian red beds, which have eroded away leaving the sinkhole deposits as high, flat-topped hills capped by flaggy, fresh-water limestones. These have been termed the "Leaf Hills" (fig. 42, sites 14 and 15) because fossil leaf impressions have been found there.

Volcanic ash beds are rare in the Clarendon region. One deposit can be found on the Tom D'Spain Ranch, adjacent to the Rowe-Lewis Ranch. Unfortunately, it does not overlie any fossil-bearing strata but is exposed in the bed of Petrified Creek 0.8 km (0.5 mi) north of Gidley's 3-Toed Horse Quarry (fig. 42, site 16; fig. 45). It is reported (M. F. Skinner, personal communication, 1976) to have contained a skull of *Pseudhipparion*. A sample of volcanic glass from this deposit yielded a glass fission-track date of 8.1±0.5 Ma (J. D. Boellstorff, personal communication, 1977).

Fauna

Fossils have been collected from the Clarendon region for nearly a century. The first collections were made by Cope and Cummins in 1892 for the Texas State Geological Survey

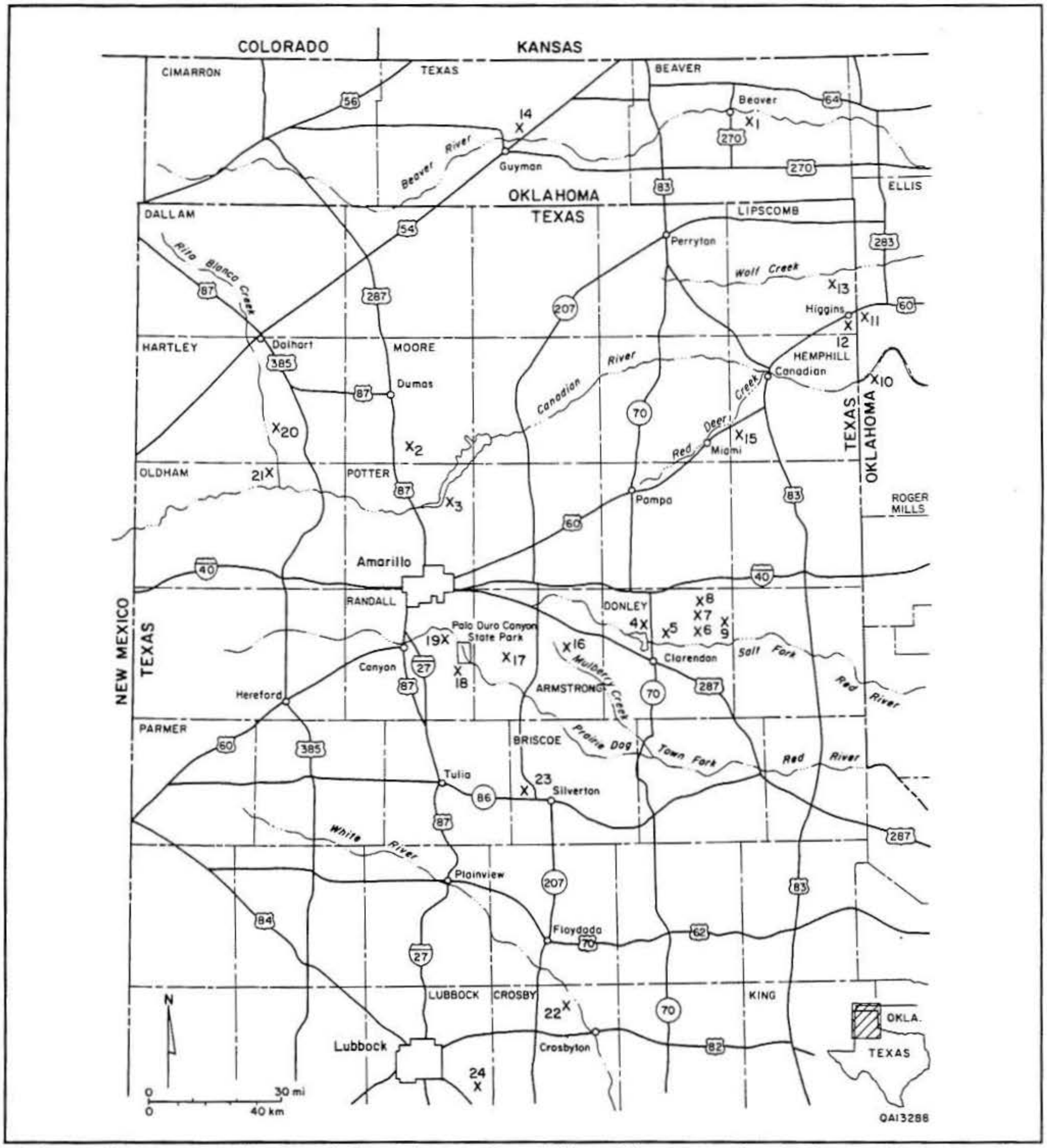

Figure 41. Location of principal Clarendonian, Hemphillian, Blancan, and post-Blancan faunas in the Texas and Oklahoma Panhandles. **Clarendonian:** (1) Laverne (=Beaver), (2) Exell, (3) Coetas Creek, (4) Clarendon (Shannon Ranch, MacAdams, and Grant Quarries), (5) Clarendon (Dilli, C. Risley, A. Risley, Noble=Farr, Bromley Ranches), (6) Clarendon (Lull Quarries), (7) Clarendon (Rowe-Lewis Ranch, Spade Flats, Gidley's 3-Toed Horse Quarry), (8) Clarendon (Whitefish Creek: *Pliohippus fossulatus* skull), (9) Clarendon (Skillet Creek Divide: Gidley's 1901 Mastodon and *Dinocyon* skull), (10) Durham. **Early Hemphillian:** (11) Arnett (=Port-of-Entry Pit) and Capps=Neu=Pratt Pits, (12) Higgins (=Sebits Ranch) and Cole Highway Pit (Late Clarendonian or Early Hemphillian), (13) Box T and V. V. Parker Pits. **Late Hemphillian:** (14) Optima (=Guymon), (15) Coffee Ranch, (16) Goodnight, (17) Christian Ranch, (18) Axtel, (19) Currie Ranch, (20) Rita Blanca Creek, (24) Smart Ranch. **Blancan:** (18) Cita Canyon, (20) Rita Blanca Creek, (21) Red Corral, (22) Blanco. **Post-Blancan:** (23) Rock Creek and *Equus scotti* Quarries, (24) Slaton.

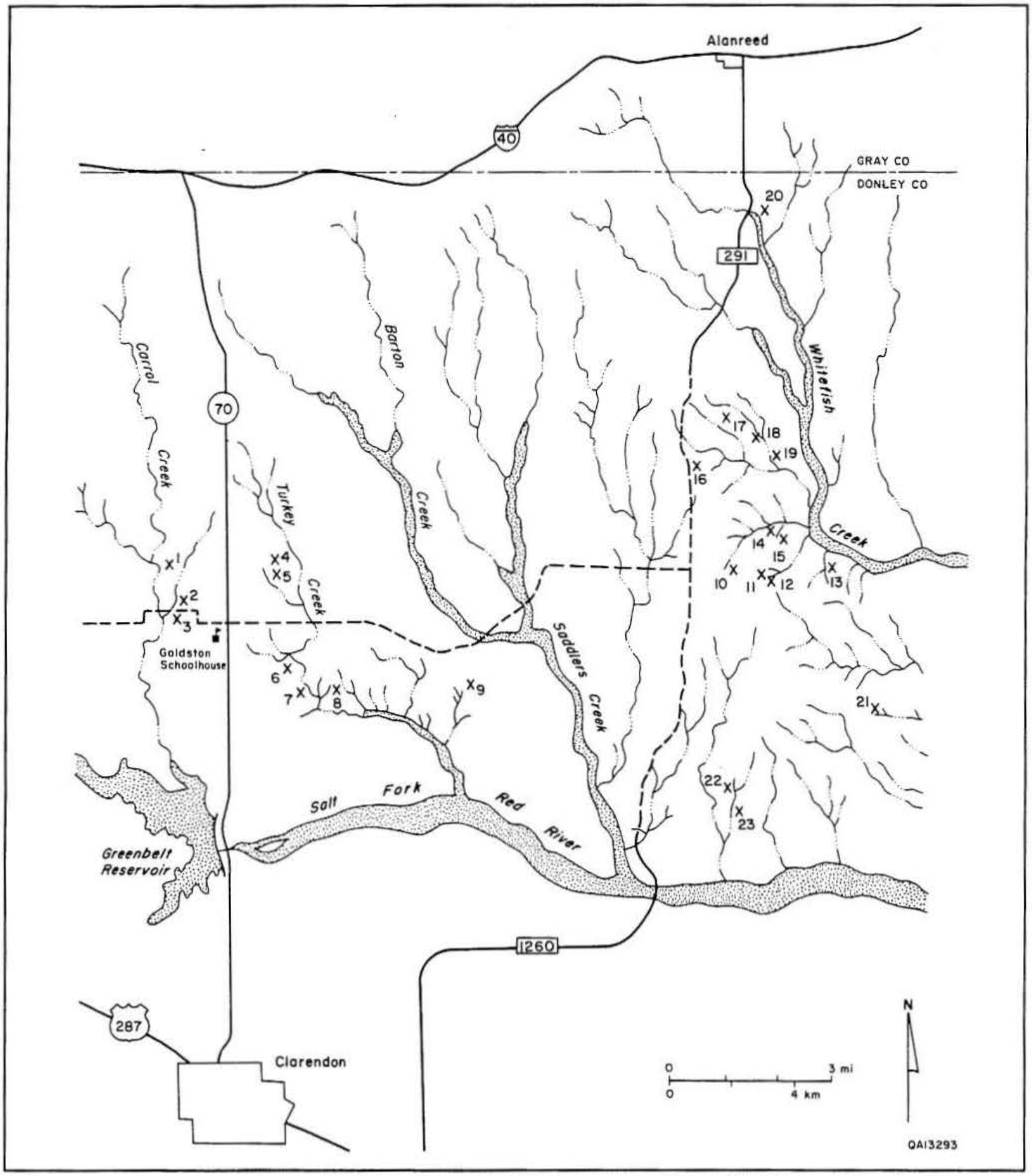

Figure 42. Location of Clarendonian faunal sites in Donley County, Texas. (1) Shannon Ranch, (2) Grant (=Littlefield), (3) MacAdams (=Porter), (4) Dilli (=Cope's loc.?), (5) Charles Risley, (6) Adam Risley (*Pliocyon walkerae* skull), (7) Ward's Creek Bluff Pit, (8) Noble (=Farr), (9) Bromley (*Synthetoceras* type and Gidley's 1899 Mastodon), (10) Lewis (=Rowe) Quarry 1, (11) Lewis Quarries 2 and 3, (12) Lewis Quarries 4 and 5, (13) Lewis Quarry 6, (14) Vaughn Quarry and Leaf Hills 1, 2, and 3, (15) Leaf Hills 4 and 5, (16) Gidley's 3-Toed Horse Quarry (=D'Spain), (17) Lewis Quarry 11, (18) Lewis Quarry 8, (19) Lewis Quarry 7, (20) Stirton and Chamberlain 1939 *Pliohippus fossulatus* skull, (21) Lewis Quarries 9 and 10, (22) Lull Mastodon, (23) Lull Quarry. Skillet Creek Divide (Gidley's 1901 Mastodon and *Dinocyon* skull) not shown on map. Unpublished locality information courtesy of Will Chamberlain of Clarendon, Texas.

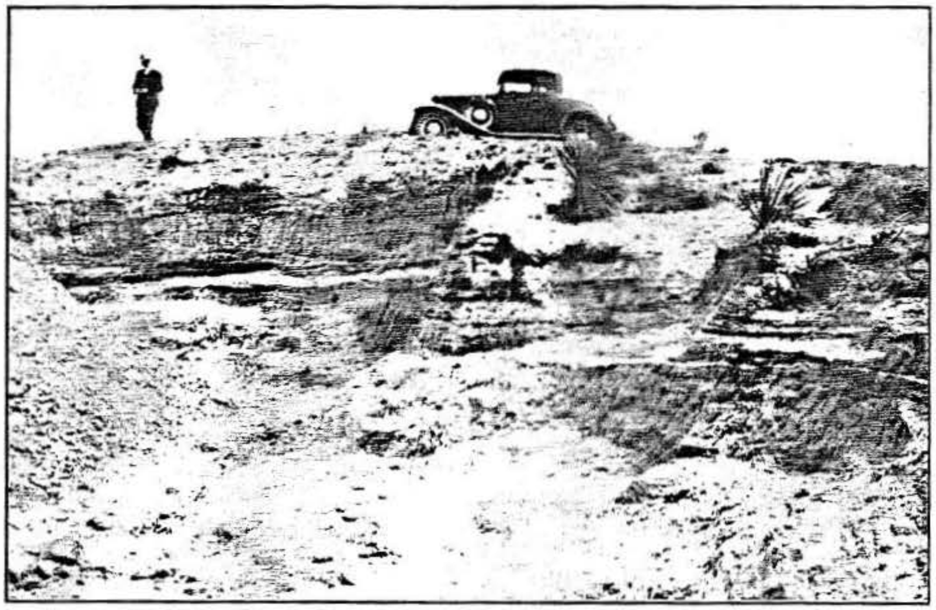

Figure 43. Rowe-Lewis Ranch Quarry 4 (Clarendonian), Donley County, Texas. Quarry produced abundant rhinoceros. Photo courtesy of Panhandle-Plains Historical Museum, Canyon, Texas.

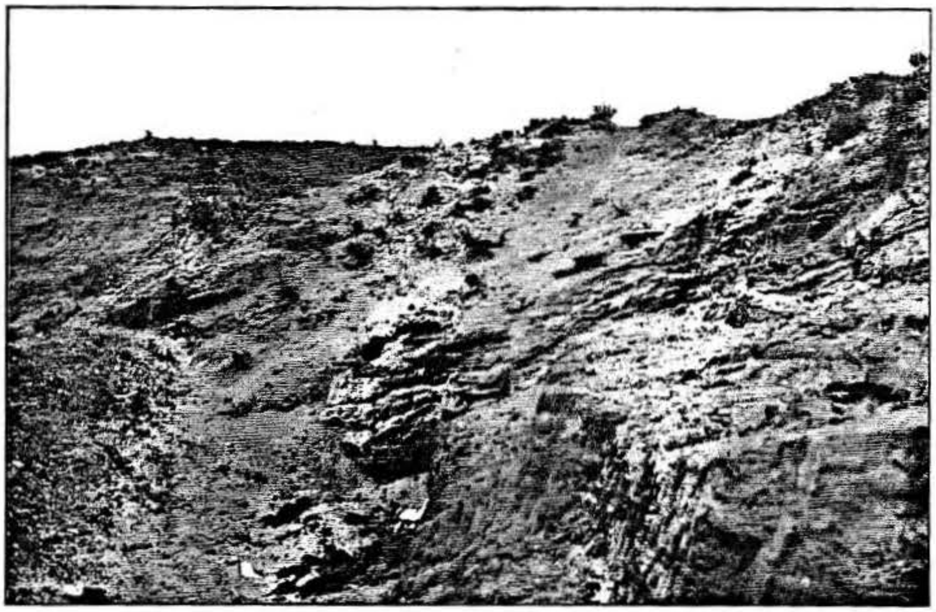

Figure 44. Rowe-Lewis Ranch Quarry 4 (Clarendonian), Donley County, Texas. Photo courtesy of Panhandle-Plains Historical Museum, Canyon, Texas.

(Cope, 1893); these materials are now at the Texas Memorial Museum, The University of Texas at Austin. Gidley collected two mastodons, a large bear-dog skull, and numerous 3-toed horses for the American Museum of Natural History in 1899 and 1901 (Gidley, 1903a). Lull made a small collection for Yale University about 1912. The University of California recovered a sizable collection from several localities in the early 1930's. Works Progress Administration (WPA) crews under the supervision of C. Stuart Johnston collected from several sites for West

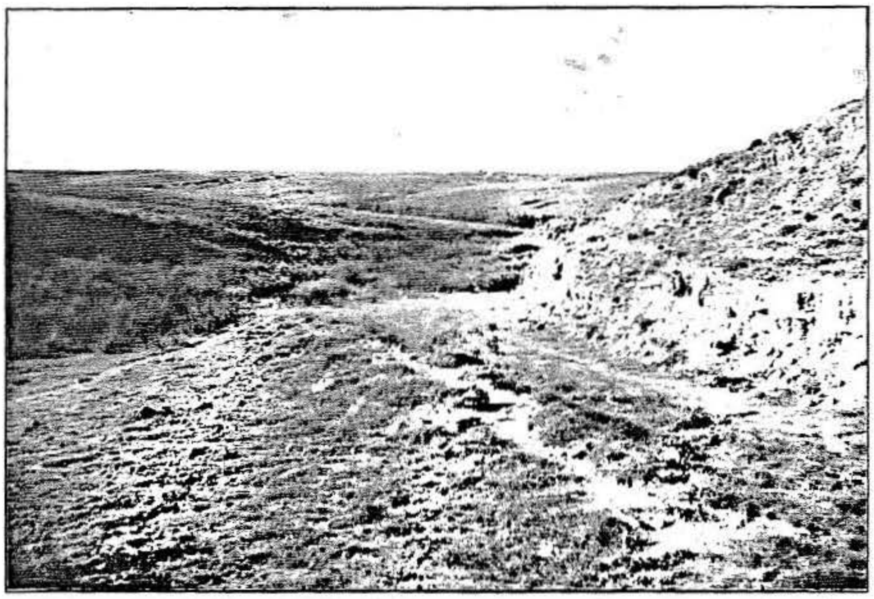

Figure 45. Gidley's 3-Toed Horse Quarry (late Clarendonian), Donley County, Texas.

Texas State University and the Panhandle-Plains Historical Museum, Canyon, Texas. The largest collections from the region were obtained by the Frick Laboratory from about 1929 to 1960 under the supervision of Will Chamberlain, C. H. Falkenbach, and N. Z. Ward. These materials are now part of the American Museum of Natural History collections. Midwestern State University at Wichita Falls, Texas, has a representative collection from several sites, and there is a small collection at Harvard University.

The fauna from the Clarendon region (table 7) is dominated by medium to large grazing mammals. Perissodactyls are the most abundant order and consist of a variety of pliohippine and hipparionine horses having hypsodont teeth and slender legs and ranging in size from a pony-sized *Pliohippus* down to the goat-sized *Calippus regulus*. Also present but rare is *Hypohippus*, last of the browsing horses. The Clarendon horses have been described, discussed, and revised in an extensive literature (Cope, 1893; Gidley, 1907; Osborn, 1918; Johnston, 1937d, 1938; Stirton and Chamberlain, 1939; Quinn, 1955; Webb, 1969a; Forsten, 1975; Skinner and MacFadden, 1977; MacFadden, 1980, 1984a; Webb and Hulbert, 1986; Hulbert, 1987, 1988). According to MacFadden (1984a), the MacAdams Quarry (fig. 42, site 3) contains the largest fossil population of *Hipparion* in North America; there are more than 100 skulls from this quarry in the Frick Collection of the American Museum of Natural History in New York City. Rhinoceroses are represented by *Teleoceras*, a short-legged, robust, hippolike amphibious variety with high-crowned teeth commonly found in stream-channel deposits on the Rowe-Lewis Ranch (fig. 42, sites 11 and 12) (Johnston, 1937a). This animal probably lived around pools and marshes on the floodplains and grazed on adjacent grasslands.

Artiodactyls, the second most abundant order, include a diversity of forms. Camel remains are fairly common, but the group is poorly known and largely unstudied. There are several varieties including large and small species of *Procamelus*, probably a grazer, and the giraffe-camel *Aepycamelus*, a browser with a long neck and an estimated shoulder height of 3.5 m (11.5 ft) (Breyer, 1983; Webb, 1983a; Harrison, 1985). Less abundant but of considerable interest are several ruminants, including dromomerycids and moschids (Frick, 1937), and protoceratids (Stirton, 1932; Frick, 1937; Patton and Taylor, 1971, 1973). One of the most unusual animals is *Synthetoceras tricornatus*, a protoceratid commonly referred to as the "slingshot deer" because of its strange forked rostral horn in addition to its two strongly curved frontal horns. This "deer" was first reported by Stirton (1932) from the Bromley Ranch (fig. 42, site 9), but it is also abundant at the MacAdams Quarry (fig. 42,

Table 7. Composite faunal list—Clarendon Fauna, Donley County, Texas.

Class Osteichthyes
- Order Semionotiformes
  - Family Lepisosteidae
    - *Lepisosteus* sp. - gar (Shannon and Bromley Ranches)

Class Reptilia
- Order Chelonia
  - Family Testudinidae
    - *Geochelone* sp. - large tortoise (Shannon, Bromley, and Rowe Ranches)
    - *Gopherus* sp. - tortoise
  - Family Trionychidae
    - *Trionyx* sp. - soft-shell turtle (Shannon and Bromley Ranches)
  - Family Emydidae
    - Emydid sp. - unidentified pond or river turtles (Shannon, MacAdams, and Noble=Farr Ranches)
- Order Crocodilia
  - Family Crocodilidae
    - *Alligator* sp. - alligator (Shannon and Rowe Ranches)

Class Aves
- Order Anseriformes
  - Family Anatidae
    - Anatid sp. - goose (Noble=Farr Ranch)

Class Mammalia
- Order Rodentia
  - Family Mylagaulidae
    - *Mylagaulus* sp. - burrowing rodent (Noble=Farr, Rowe Ranches)
- Order Carnivora
  - Family Nimravidae
    - *Barbourofelis* cf. *B. whitfordi* (Barbour and Cook) - small, short-legged saber-toothed cat (Rowe Ranch Quarry 7)
  - Family Felidae
    - *Pseudaelurus*? sp. - cat (Adam Risley Ranch)
  - Family Canidae
    - *Aelurodon taxoides* Hatcher - large, wolflike dog (MacAdams Quarry; Grant, Noble=Farr, Bromley, Rowe Ranches)
    - *Epicyon saevus* (Leidy) - medium-sized dog
    - *Tomarctus euthos* (McGrew) - small dog (Noble=Farr, Rowe Ranches)
    - * *Cynarctus fortidens* Hall and Dalquest - raccoonlike dog (holotype from Farr Ranch; also at Adam Risley and Rowe Ranches)
  - Family Amphicyonidae
    - * *Ischyrocyon gidleyi* (Matthew) - bear dog (holotype from Skillet Creek) (includes *Pliocyon walkerae* Johnston and Christian holotype from Adam Risley Ranch)
  - Family Mustelidae
    - *Brachypsalis* sp. (Bromley Ranch)
    - *Leptarctus* sp. (Noble=Farr Ranch)
    - *Mionictis* sp. (MacAdams Quarry)
    - *Sthenictis* sp. (Shannon Ranch)
- Order Proboscidea
  - Family Gomphotheriidae
    - *Gomphotherium productus* (Cope) (Bromley Ranch) (includes the holotype of *G. serridens* from Skillet Creek)
    - * *Tetralophodon fricki* Osborn (holotype from Rowe Ranch)

** *Holotype of genus*

* *Holotype of species*

Table 7. (cont.)

Order Artiodactyla
- Family Tayassuidae
  - *Prosthennops* sp. - peccary (MacAdams Quarry; Noble=Farr and Rowe Ranches)
- Family Merycoidodontidae
  - *Ustatochoerus profectus* var. *studeri* Schultz and Falkenbach - oreodont (MacAdams Quarry; Rowe Ranch)
- Family Camelidae
  - *Aepycamelus* sp. - giraffe camel
  - *Procamelus grandis* Gregory - medium-sized camel (many localities)
  - * "*Procamelus*" *leptognathus* Cope - small camel (holotype from Dilli or Charles Risley Ranch on Turkey Creek)
  - *Protolabis* sp. - small camel
  - ?*Hemiauchenia* sp. - small llamalike camel
- Family Protoceratidae
  - ** *Paratoceras macadamsi* Frick - horned ruminant (holotype from MacAdams Quarry)
  - ** *Synthetoceras tricornatus* Stirton - horned ruminant (holotype from Bromley Ranch; also at MacAdams Quarry)
- Family Dromomerycidae
  - * *Cranioceras clarendonensis* Frick - horned deerlike ruminant (holotype from MacAdams Quarry)
- Family Moschidae
  - * *Longirostromeryx clarendonensis* Frick - small ruminant (holotype from MacAdams Quarry)

Order Perissodactyla
- Family Equidae
  - *Calippus (Grammohippus) martini* Hesse (many localities)
  - *Calippus (Calippus) placidus* (Leidy) (Shannon Ranch)
  - * *Calippus (Calippus) regulus* Johnston (holotype from Grant Quarry; also at Shannon Ranch)
  - *Cormohipparion sphenodus* (Cope) (early Clarendonian from MacAdams Quarry)
  - *Cormohipparion occidentale* (Leidy) (late Clarendonian from Gidley Horse Quarry)
  - *Hipparion tehonense* (Merriam) (MacAdams Quarry)
  - *Neohipparion affine* (Leidy) (MacAdams Quarry)
  - *Pliohippus pernix* Marsh (includes holotypes of *Pliohippus fossulatus* Cope and *Pliohippus pachyops* Cope from Dilli site on Turkey Creek)
  - *Protohippus supremus* Leidy
  - * *Pseudhipparion hessei* Webb and Hulbert (holotype from MacAdams Quarry)
  - *Hypohippus affinis* Leidy - browsing horse (MacAdams Quarry; Grant and Rowe Ranches)
- Family Rhinocerotidae
  - *Teleoceras* cf. *T. fossiger* (Cope) - short-legged hippolike rhinoceros
  - ?*Aphelops* sp. - rhinoceros

site 3) (Patton and Taylor, 1971). Although it is not known from the northern Great Plains, it has been reported from the early Clarendonian Lapara Creek Fauna of the Texas Gulf Coastal Plain and from the early Hemphillian McGehee Local Fauna of Florida (Patton and Taylor, 1971). Other, relatively rare artiodactyls in the fauna include *Cranioceras*, a giraffelike horned browsing ruminant; *Longirostromeryx*, a small chevrotainlike ruminant; *Ustatochoerus*, one of the last oreodonts (Schultz and Falkenbach, 1941); and the peccary *Prosthennops*. The oreodont and peccary, as well as some of the camels and ruminants, were probably mixed feeders that, together with browsers such as *Aepycamelus*, *Hypohippus*, *Cranioceras*, and gomphotheres, inhabited the wooded areas along streams. They were rarely fossilized (Webb and others, 1981; Webb, 1983a).

Other mammalian orders are less abundant in the fauna. Proboscideans are represented by several skulls, jaws, and teeth of sublongirostrine gomphothere mastodons (Cope, 1884, 1889, 1893; Frick, 1933; Osborn, 1936). Carnivores include several reported skulls and jaws of *Ischyrocyon*, a bone-crushing, carrion-eating bear dog (Matthew, 1902; Johnston and Christian, 1941; Webb, 1969a); a raccoonlike dog, *Cynarctus* (Hall and Dalquest, 1962); plus largely undescribed felids (Baskin, 1981, p. 131), mustelids (Harrison, 1981, p. 25), and canids, including *Aelurodon*, a hyenalike dog, and *Epicyon*, a wolflike predator. Small mammals are conspicuously absent, although rodents are represented by the genus *Mylagaulus*.

Lower vertebrates are represented by large land tortoises (Dalquest, 1962) and aquatic turtles, alligators, and gar fish. A few bird bones, such as goose, have been found.

In summary, the fauna seems to be dominated by hypsodont (high tooth-crowned) grazers, some mixed feeders, and a few browsers and predators. Lower vertebrates are mainly aquatic forms.

Paleoecology and Climate

Sedimentological and faunal evidence suggests that the habitat of the Clarendon Fauna was primarily a stream-border environment dominated by medium to large grazing mammals. Occasionally high-energy flow or flood conditions occurred, as indicated by coarse channel deposits, broken, waterworn bone fragments in the channels, and thinly bedded overbank deposits. As a rule, however, quiet-water flow prevailed. Adjacent to the streams were broad, grass-covered floodplains and scattered marshes, ponds, and oxbow or floodplain lakes in which fossils accumulated. Deciduous trees grew mainly along stream borders, but the habitat is best considered a parkland savanna. As a result of salt dissolution in the Permian red beds in the subsurface, sinkholes developed locally where overlying sediments collapsed. These sinkholes served as waterholes but became deathtraps for the animals.

The climate of the region during Clarendonian time probably was mild, subhumid, and somewhat subtropical as indicated by the browsing gomphotheres and by the lowland, floodplain-dwelling, amphibious rhinoceros *Teleoceras*. The presence of alligators implies the existence of warm temperatures, permanent water, and sufficient vegetation for their nests. Permanent fresh water is also indicated by aquatic turtles and the gar *Lepisosteus*. The presence of large land tortoises suggests mild winters (Hibbard, 1960).

Floral evidence from the Clarendon area is limited but supports the climatic model provided by the vertebrates. Cottonwood leaf impressions were collected by the author from the Leaf Hills on the Rowe-Lewis Ranch. From the old Shannon Ranch (fig. 42, site 1) northwest of Goldston, Stirton collected several palm seeds as well as a seed of *Arctostaphylos* (bearberry) and some wood of the ash tree *Fraxinus*. These were reported by Chaney and Elias (1936, p. 13), who also described several other late Tertiary floras from the Great Plains. Comparing the limited Clarendon flora with the extensive one from the Laverne (=Beaver) assemblage in Beaver County, Oklahoma, 217 km (135 mi) farther north (fig. 41, site 1), they concluded that the climate of the Clarendon region was somewhat warmer and less humid than that of the Oklahoma Panhandle during Clarendonian time.

Hibbard (1960, p. 13), considering all available evidence from late Tertiary faunas and floras of the interior Great Plains, concluded that "the majority of the area from southern South Dakota to Texas was a moist, subhumid, subtropical savanna with forests and tall grasses along the river valleys, with chiefly shrubs and tall grasses on the valley walls and on the low divides. Some short grasses may have occurred on the higher and well-drained divides." More recent studies indicate drier conditions for the southern Great Plains than the ones proposed by Hibbard (1960). Webb, largely on the basis of the ungulate fauna, characterized the environment of the Great Plains during late Miocene time as a woodland savanna similar to that of central Africa today (Webb, 1977, 1983a).

The Clarendonian Chronofauna

The Clarendon Fauna is representative of what has been termed the Clarendonian chronofauna (Webb, 1969a, 1977, 1983a; Tedford, 1970). It is a coherent association of species lineages dominated by ungulates that emerged in North America during the late Barstovian Land Mammal Age, about 15 Ma ago, reached its peak in the Clarendonian, and declined by the end of the Hemphillian, around 5 Ma ago. The rise and fall of this late Miocene chronofauna apparently were controlled by a late Cenozoic trend toward cooler and drier climates at temperate latitudes (Webb, 1983a). As forest biomes gave way to parkland savanna, the abundance and diversity of ungulates and the ratio of grazers to browsers increased. Later, the trend toward increasing aridity and the spread of steppe conditions led first to the extinction of virtually all browsers, then to the decimation of grazers, and finally to the wholesale destruction of the chronofauna by the end of Hemphillian time. Hemphillian faunas, especially later ones, show a marked decrease in diversity compared with the Clarendonian faunas. There is a remarkable resemblance between the late Miocene ungulate fauna of North America and the Recent ungulate fauna of the African savanna despite their entirely independent origins (Webb, 1983a).

Exell Local Fauna (=Frick's 4-Way Locality)

The Exell Local Fauna is a small Clarendonian fauna reported by Dalquest and Hughes (1966) from a high cutbank in the headwaters of South Plum Creek, 6.4 km (4 mi) east-northeast of the community of Exell in Moore County, Texas (fig. 41, site 2), about 56 km (35 mi) north of Amarillo in the SW 1/4, sec. 2, Blk. B-26, E. L. and R. R. Ry. Co. Survey. Here the creek has cut into the flanks of several small hills to form a cliff or cutbank 3 to 9 m (10 to 30 ft) high and about 360 m (1,200 ft) long. The exposed rocks include massive sandstones and laminated sandstones and shales varying in color from gray to russet to yellowish brown. The nature of the strata and the waterworn condition of most of the bones indicate a stream-channel and floodplain environment.

The fossils are well preserved and consist mainly of waterworn bone fragments, isolated teeth, and a few jaw fragments of several genera of horses, including *Pseudhipparion, Cormohipparion, Pliohippus,* and *Calippus*. Other mammals represented by one or two lower jaws each include the hyenoid dog *Aelurodon;* a peccary, *Prosthennops;* an oreodont, *Ustatochoerus;* a small ruminant, *Longirostromeryx;* and a rhinoceros referred to the genus *Peraceras*. Other fossils include remains of toads and large and small turtles and a number of sandstone casts of camel tracks that have come loose from the underside of one of the beds. Collections from the site have been made by the Panhandle-Plains Historical Museum, by West Texas State University, and by the Frick Laboratory.

Coetas Creek Fauna

The Coetas Creek Fauna, an assemblage of Clarendonian-age vertebrates, was collected from a small area south of the Canadian River in east Potter County 32 km (20 mi) northeast of Amarillo (fig. 41, site 3). Fossils are found in what was described by Patton (1923, p. 80) as the Coetas Formation, a unit composed of slightly consolidated sands and flaggy, sandy lacustrine limestone that caps the high divides and dips into the valleys of Coetas, Chicken, and Bonita Creeks. Beneath the Coetas Formation lies the Potter Formation, a unit of coarse, partly consolidated sands and gravels locally cemented with calcium carbonate (Patton, 1923, p. 78). Both formations can be considered facies of, or, at best, members of the Ogallala Formation. No vertebrates have been reported from the Potter sands and gravels, but Patton (1923, p. 83) reported *Hipparion* teeth from the Coetas. During the early 1930's, the University of California obtained a small collection from the area (Bivins Ranch Locality V-3103), and in the late 1930's, the Frick Laboratory collected a small but varied fauna including the holotype specimens of two oreodonts, *Ustatochoerus profectus studeri* and *U. major texanus* (Schultz and Falkenbach, 1941). More recent collections have been made by West Texas State University. The largely undescribed fauna consists of oreodonts, camels, small antilocaprids, peccaries, gomphotheres, several horses, including *Pliohippus, Cormohipparion,* and *Pseudhipparion,* rhinoceroses, felids, canids, shore birds, tortoises, and small turtles. The geology of the area was described by Wilson (1988).

Laverne (=Beaver) Local Fauna

The Laverne (=Beaver) Local Fauna is a Clarendonian fauna identified originally (Hesse, 1936a) in several localities on the south side of the Beaver River about 14.5 km (9 mi) east and 4.8 km (3 mi) south of Beaver, Beaver County, Oklahoma (fig. 41, site 1). The fossiliferous beds lie in the "Laverne member" of the Ogallala Formation (Schoff, 1956). They first came to the attention of paleontologists in the 1890's when fossil leaves, diatoms, and a few vertebrates were collected by Cragin (1891) and Case (1894) from northwest-dipping beds of diatomaceous marl on the east bank of Gyp Creek, a north-draining tributary of the Beaver River. The Beaver flora was described by Berry (1918) and Chaney and Elias (1936). Fossil fish remains are found in the diatomaceous marls, and fossil mammals were collected by the University of California in the 1930's and by the University of Kansas in the 1930's and 1940's from gray sandy clays above and below the marls. The sediments were deposited in lakes and ponds and acquired their northwest dip as a result of local structural collapse or subsidence brought on by subsurface salt dissolution in the underlying Permian red beds. Among the more significant vertebrate discoveries are the type specimens of the beaver *Eucastor planus* (Stirton, 1935), the horse *Calippus martini* (Hesse, 1936a), and the turtle *Chrysemys limnodytes* (Galbreath, 1948), as well as a horn core of the antilocaprid *Cosoryx* (Hibbard, 1951). Newer localities about 26 km (16 mi) farther east have yielded fossil fish (Smith, 1962), an alligator (Woodburne, 1959), and mollusks (Leonard and Franzen, 1944; Taylor, 1954; Herrington and Taylor, 1958) now in the University of Michigan collections. More recently the Laverne horses were discussed by Webb (1969a).

The flora described by Chaney and Elias (1936) includes box elder, ash, hackberry, persimmon, sycamore, cottonwood, willow, and elm, as well as cattails and sedges. This variety suggests a grassy floodplain environment with trees confined to the stream borders. The cattails and sedges grew in lakes or ponds on the floodplain. Modern equivalents of the arboreal species live in central to eastern Oklahoma, 290 km (180 mi) or more to the east, where the annual precipitation exceeds 76 cm (30 inches). The annual precipitation in the Beaver area of the Oklahoma Panhandle probably was about 76 to 89 cm (30 to 35 inches) and probably was concentrated during the warmer months, judging from the absence of oak and evergreen trees in the fossil flora. The temperature may have been somewhat warmer than now. The present annual precipitation is about 48 to 51 cm (19 to 20 inches), and the mean annual temperature is 14°C (57°F) (Orton, 1964).

Durham Local Fauna

The Durham Local Fauna is a relatively limited fauna of late Clarendonian age from a locality 3.2 km (2 mi) northwest of the community of Durham south of the Canadian River in the center, SE 1/4, sec. 15, T. 16 N, R. 26 W, Roger Mills County, Oklahoma (fig. 41, site 10). The site was discovered by David Kitts of the University of Oklahoma in 1955 and was worked by that institution the following year.

The geology of Roger Mills County was discussed by Kitts (1959), and the fauna was described by Kitts and Black (1959), with an additional description of *Aelurodon* made later by Kitts (1964). The fauna includes isolated teeth of *Pseudhipparion* and other horses. *Mylagaulus* is represented by several teeth and some limb bone fragments. Most of the remaining taxa are known from jaw fragments and include camel, antilocaprid, oreodont, rodent, and several carnivores. Remains of turtle and snake are also known.

Kitts and Black (1959, p. 27–30) stated that

> the strata from which the fossils were obtained are exposed in a blowout which is about 5,000 square yards in area . . . along the east bank of an intermittent stream which drains north into the South Canadian River at a point about two miles distant. . . . The fossils . . . are contained in two beds, a lower buff sand and lying directly above it a cross-bedded channel sand. The contained fossils do not reveal any age difference in the two beds. . . . The lower bone-bearing bed consists of reddish-buff, fine- to medium-grained massive sand containing calcium carbonate concretions. The deposit is probably of floodplain origin. The abundance of

concretions and the lack of bedding indicate that for a prolonged period in its history the deposit was located at or near the surface and subjected to weathering. The fossil bone recovered from this layer is poorly preserved. . . . The upper bone-bearing bed, which lies unconformably on the buff sand layer, consists of uncemented, crossbedded sand. The sand grains vary in size between fine and very coarse. The deposit contains lenses of clay and clay balls and is locally iron-stained . . . the fossils are rather evenly and sparsely distributed throughout much of the deposit. Almost all of the bone occurs as small fragments which show evidence of having been transported over a considerable distance. About 10 percent of the fossils recovered from this deposit were found in place, the remainder having been picked up on the surface. The channel in which the sand was deposited apparently trended east and west since the degree of crossbedding decreases and the material becomes finer to the north and south. The channel must have been over a hundred feet in width since the deposits are exposed over an area about 100 by 150 feet.

Cole Highway Pit Fauna

The Cole Highway Pit Fauna was recovered from a crossbedded sand and gravel deposit exposed just south of Commission Creek on the east side of FM 1453 about 6.4 km (4 mi) south of Higgins, Lipscomb County, Texas (fig. 46, site 1). The site was quarried by the Frick Laboratory and yielded a limited late Clarendonian or early Hemphillian fauna (unpublished). Fossils at West Texas State University include tortoise, gomphothere, camel, horse, rhinoceros, and a mylagaulid lower jaw.

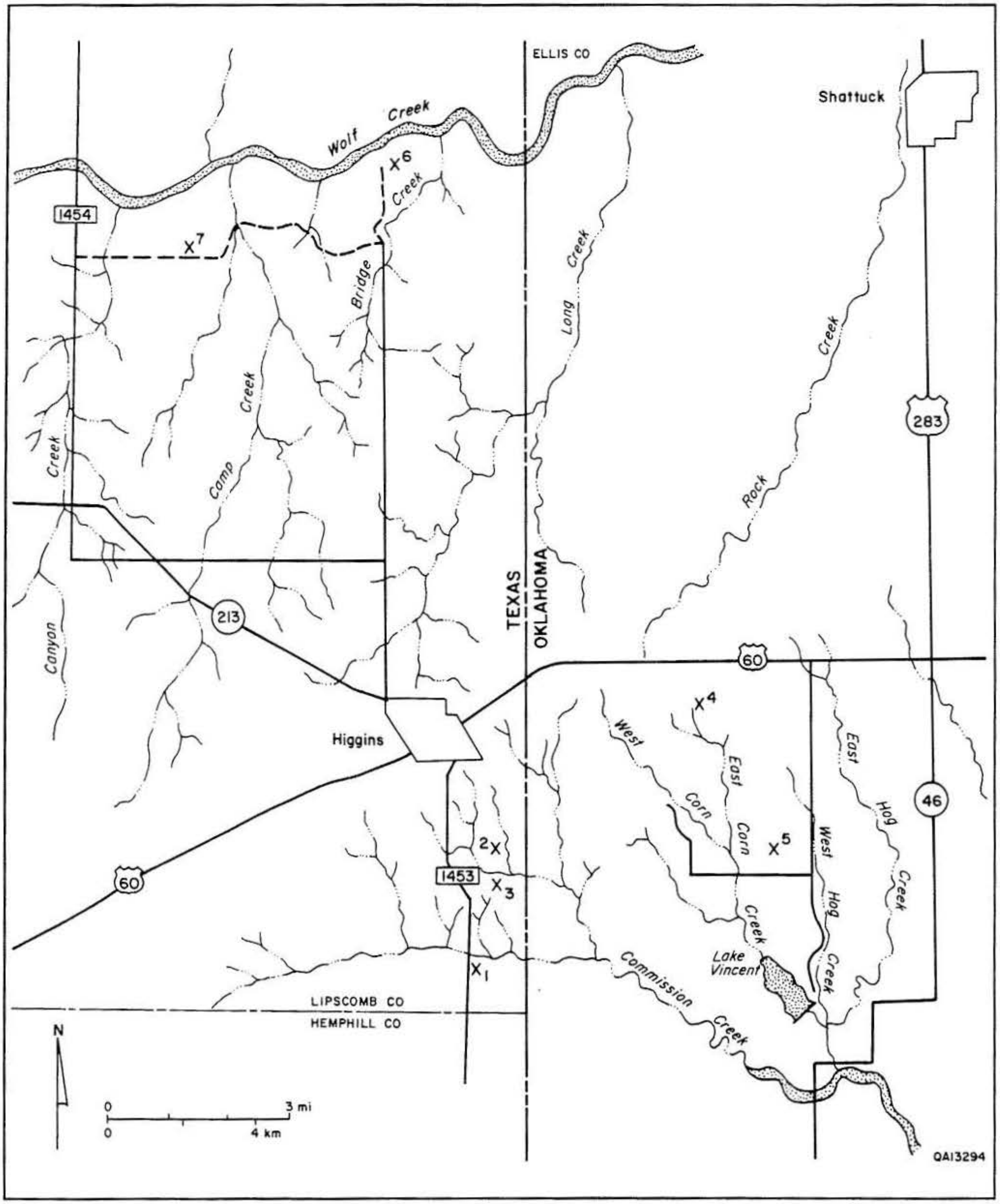

Figure 46. Location of principal late Clarendonian and early Hemphillian faunal sites in Lipscomb County, Texas, and Ellis County, Oklahoma. **Late Clarendonian:** (1) Cole Highway Pit. **Early Hemphillian:** (2) Higgins (Sebits Ranch Locality 24-A), (3) Higgins (Sebits Ranch Locality 24-B), (4) Arnett (University of Oklahoma Adair Ranch Quarry and Frick Laboratory Port-of-Entry Pit), (5) Capps=Neu=Pratt Quarries, (6) V. V. Parker Pits, (7) Box T (Pit 1). Unpublished locality information courtesy of R. H. Tedford and M. F. Skinner, American Museum of Natural History.

Stop 15: Early Hemphillian Faunas of the Texas and Oklahoma Panhandles

G. E. Schultz

Early Hemphillian faunas include the Capps=Neu=Pratt Pits Fauna, the Arnett (=Port-of-Entry Pit) Local Fauna of Ellis County, Oklahoma, and the Higgins (=Sebits Ranch) Local Fauna, V. V. Parker Pits Fauna, and the Box T Local Fauna of Lipscomb County, Texas. These faunas suggest the presence of parkland or woodland savanna.

Capps=Neu=Pratt Pits Fauna

Several shallow excavations were made by the Frick Laboratory in greenish-gray to yellowish-brown clays and silts of an old lake bed. These beds are exposed on the divide between Corn Creek and West Hog Creek about 3.2 km (2 mi) north of Lake Vincent, 4.8 km (3 mi) south of U.S. Highway 60, and 6.4 km (4 mi) east of the Texas–Oklahoma state line in Ellis County, Oklahoma (fig. 46, site 5). The fossil-bearing zone lies low in the local Ogallala section and has produced an earliest Hemphillian fauna of completely articulated skeletons and partial remains of horses such as *Pliohippus* (R. H. Tedford, personal communication, 1977) and *Neohipparion leptode* (MacFadden, 1984a, p. 102) and remains of camels such as *Aepycamelus, Procamelus, Hemiauchenia,* and *Megatylopus* (Breyer, 1983). Although it has not been published, the fauna apparently is older than that of Port-of-Entry Pit, Sebits Ranch (=Higgins), or V. V. Parker Pits (fig. 46). A partial list is given in table 8.

Arnett Local Fauna (=University of Oklahoma Adair Ranch Quarry and the Frick Laboratory Port-of-Entry Pit)

The Arnett Local Fauna (Kitts, 1957, 1965) is an early Hemphillian fauna collected by the University of Oklahoma during the 1930's, 1955, and 1956. The site is located on the L. H. Adair Ranch, 4 km (2.5 mi) east of the Texas–Oklahoma state line and 16 km (10 mi) west of the town of Arnett in the NW 1/4, NW 1/4, sec. 14, T. 19 N, R. 26 W, Ellis County, Oklahoma (fig. 41, site 11; fig. 46, site 4). Excavations extend for several hundred feet along the east wall of a small canyon, East Branch of Corn Creek, which drains south into the valley of the South Canadian River. The Frick Laboratory Port-of-Entry Pit is a continuation of the same deposit, extending for several hundred yards along the east wall of the canyon in the southwest quarter of the same quarter section. The "Hopewell fauna" of Hesse (1936a, p. 68) is probably synonymous with the Arnett Local Fauna, because the old Hopewell schoolhouse was only a mile or two from the Arnett locality.

Kitts (1957, p. 7) stated that

> the section at Arnett consists of unconsolidated fine clayey and silty sands and layers of calcareous "caliche" or "mortar beds" which contain large amounts of fine sand. There are no coarse channel sands or gravels exposed in the area, the coarsest material being a few well rounded caliche fragments of pebble size contained in the sands. The sands were presumably deposited in lakes or upon floodplains. The caliches are probably of secondary origin.
>
> The fossils are sparsely distributed in a bed of fine clayey, silty sand about three feet in thickness. The bones are well mineralized and are hard. All of the specimens are fragmentary and the broken edges are sharp. No articulated specimens were found. After the soft parts had decomposed, the bones were apparently broken and scattered, perhaps by carnivores and scavengers. It is possible that the bones were transported a short distance and deposited in ponds or playa lakes.
>
> Deposits which accumulated in the manner suggested above would certainly not contain the remains of a represen-

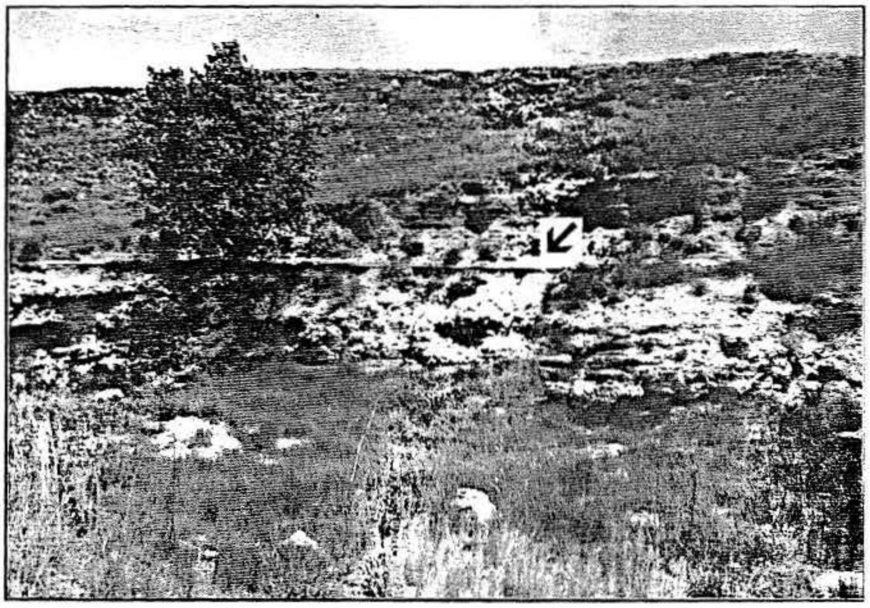

Figure 47. Early Hemphillian Frick Laboratory Port-of-Entry Pit (=Arnett Local Fauna), Ellis County, Oklahoma. Fossils are present at base of exposed section. Note thin white volcanic ash layer marked by arrow in midsection.

tative sample of the fauna living in the area at the time. Mastodonts and large carnivores are by far the most abundant faunal elements preserved, a fact which suggests that the carnivores were preying upon the mastodonts or, particularly in the case of the hyaenoid dogs, feeding upon the carcasses of mastodonts which had died on the flood plain.

There is a striking scarcity of limb bones in the collection, which may be at least partly the result of selective collecting.

At some places a thin calcareous layer overlies the bone-containing sand, and itself contains bone. Where the thin layer of caliche is absent, the base of the massive caliche layer contains bone, which is in some instances surrounded by a thin layer of unconsolidated sand. These facts strongly suggest that the caliche is of secondary origin.

The geologic profile at the Port-of-Entry Pit (fig. 47) is similar to that given by Kitts (1957, p. 6) for the Adair Ranch Quarry. Fossils are found at the base of a 1.2-m-thick (4-ft) gray caliche-cemented sandstone. This is overlain by about 2 m (7 ft) of fine, loosely consolidated brown sand containing a 15-cm-thick (6-inch) bed of white to bluish-gray volcanic ash about 0.6 m (2 ft) from the base. This ash, which has not been dated, also lies above the fossiliferous beds in the Adair Ranch Quarry but was not mentioned by Kitts. Capping the Port-of-Entry Pit strata is a 30-cm-thick (1-ft) gray caliche-cemented sandstone. The slopes above both quarries for about 12 m (40 ft) are mostly grass-covered, gray to tan unconsolidated sands and silts. The canyon rim, however, is composed of 1.5 to 2.4 m (5 to 8 ft) of tan sandy caliche, which weathers into prominent, resistant ledges along most of the valleys in the region.

Among the most interesting elements in the fauna (table 8) are the remains of carnivores, which include lower jaws and other skeletal parts of the large pseudaelurin cat, *Nimravides* cf. *N. thinobates* (Kitts, 1958; Martin and Schultz, 1975; Baskin, 1981). This long-legged predator probably pursued its prey in open country and may have been a scavenger as well (Webb and others, 1981). Also present is the primitive, short-legged, saber-toothed catlike carnivore, *Barbourofelis lovei* (Baskin, 1981) (="*Albanosmilus*? sp." of Kitts, 1957), intermediate in size between the smaller *B. morrisi* from the late Clarendonian Ash Hollow Formation of Nebraska and the larger *B. fricki* from the late early Hemphillian Cambridge Local Fauna of

Table 8. Faunal lists of the early Hemphillian chronofaunal sequence of local faunas in the Texas Panhandle and adjacent Oklahoma.

	A	B	C	D
Class Reptilia				
Order Chelonia				
Family Testudinidae				
Geochelone sp. - large tortoise		?	X	X
Gopherus sp. - tortoise	?	?	X	?
Small pond or river turtle	?			X
Order Squamata				
Family Boidae				
Charina prebottae Brattstrom - extinct boa			X	
Family Colubridae				
Paleoheterodon tiheni Holman - extinct hog-nosed snake			X	
Miocoluber dalquesti Parmley - extinct racer			**	
Coluber or *Masticophis* - racer or coachwhip			X	
Thamnophis cf. *T. sirtalis* (Linnaeus) or *T. proximus* (Say) - extinct garter snake			X	
Class Mammalia				
Order Chiroptera				
Family Vespertilionidae				
Pizonyx wheeleri Dalquest and Patrick - bat			*	
Order Edentata				
Family Megalonychidae				
Pliometanastes cf. *P. protistus* Hirschfeld and Webb - ground sloth				X
Megalonychid sp. - ground sloth			X	
Family Mylodontidae				
Thinobadistes wetzeli Webb - ground sloth				X
Order Rodentia				
Family Mylagaulidae				
Mylagaulus sp. - burrowing rodent			X	
Family Eomyidae				
Kansasimys dubius Wood			X	
undetermined genus and species			X	
Family Sciuridae				
Spermophilus sp. - ground squirrel			X	
Family Geomyidae				
Pliosaccomys higginsensis Dalquest and Patrick - pocket gopher			*	
Family Heteromyidae				
Perognathus sp. - pocket mouse			X	

** Holotype of genus
* Holotype of species
X Occurrence in fauna
? Possible occurrence in fauna
A Capps=Neu=Pratt Pits Local Fauna (Early early Hemphillian—list incomplete
B Port-of-Entry Pit=Arnett Local Fauna
C Higgins=Sebits Ranch Local Fauna
D Box T Local Fauna (Late early Hemphillian)
A and B are in Ellis County, Oklahoma. C and D are in Lipscomb County, Texas.

Table 8. (cont.)

	A	B	C	D
Order Lagomorpha				
Family Leporidae				
Hypolagus vetus (Kellogg) - rabbit			X	
Order Carnivora				
Family Nimravidae				
Barbourofelis lovei Baskin (="*Albanosmilus*" of Kitts, 1957) - short-legged saber-toothed catlike carnivore		X		
Family Felidae				
Nimravides cf. *N. thinobates* (Macdonald) (=*N. catocopis* [Cope] of Burt [1931] - cat)		X	X	X
Machairodus sp. - saber-toothed cat				X
Family Canidae				
Epicyon validus (Matthew and Cook) - large dog		X	X	X
Epicyon mortifer (Cook) - large dog		X		
Osteoborus sp. - large bone-eating dog			X	X
Osteoborus sp. (small *O. cyonoides* of Hesse [1940])			X	
Osteoborus cf. *O. pugnator* (Cook) - bone-eating dog				X
Family Mustelidae				
Eomellivora sp.				X
Leptarctus sp.				X
Sthenictis sp.				X
Family Ursidae				
Indarctos sp. - large bear				X
Order Proboscidea				
Family Gomphotheriidae				
Gomphotherium or *Amebelodon* sp.	X	X		
Amebelodon hicksi (Cook) - long-jawed form			X	
Amebelodon cf. *A. fricki* Barbour - shovel tusker				X
Order Artiodactyla				
Family Tayassuidae				
Prosthennops sp. - peccary		X		
Prosthennops (*Macrogenis*) *graffhami* Schultz and Martin - peccary				X
Family Camelidae				
Aepycamelus sp. - giraffe camel	X	X		
Procamelus sp. - medium-sized camel	X	X		X
Megatylopus sp. - large camel	X	X	X	X
Hemiauchenia sp. (=*Pliauchenia* of Hesse [1940]) - llamalike camel	X	X	X	X
Family Dromomerycidae				
Pediomeryx (*Yumaceras*) cf. *P. figginsi* (Frick) - giraffelike horned ruminant		X	X	X
Family Gelocidae				
Pseudoceras sp. - small hornless ruminant				X
Family Antilocapridae				
Antilocaprine sp. - pronghorn	X	X	X	
Plioceros or *Texoceros* sp. - pronghorn				X
Osbornoceros? sp. - pronghorn				X

Table 8. (cont.)

	A	B	C	D
Order Perissodactyla				
Family Equidae				
Astrohippus sp. - 1-toed horse				X
Calippus sp. - small 1-toed horse				X
Cormohipparion cf. *C. occidentale* (Leidy)		X	X	X
Hipparion sp. - 3-toed horse		X	X	
Hipparion forcei Richey - 3-toed horse				X
Neohipparion leptode Merriam - 3-toed horse	X	X	?	X
Pliohippus sp. - 1-toed horse	X	X	X	X
Pseudhipparion sp. - small 3-toed horse			?	
Family Rhinocerotidae				
Aphelops malacorhinus Cope - rhinoceros			X	
Aphelops sp. - rhinoceros		X		X
Teleoceras cf. *T. fossiger* (Cope) - short-legged hippolike rhinoceros			X	?

Nebraska (Schultz and others, 1970). This short-legged carnivore probably ambushed large ungulates from deep cover (Webb and others, 1981). Canids include the large, massive-jawed *Epicyon validus* and a smaller hyenoid dog, *Epicyon mortifer* (Kitts, 1957). The latter is characterized by reduced but uncrowded premolars, which retain their accessory cusps.

The Arnett Local Fauna includes taxa that are similar or closely related to those in the nearby Higgins (=Sebits Ranch) Local Fauna in Lipscomb County, Texas, 4.8 km (3 mi) southwest of the Arnett locality (for example, *Nimravides, Epicyon validus, Pediomeryx* [*Yumaceras*], and *Aphelops*) (fig. 46, sites 2 and 3). However, at the Sebits Ranch localities, *Barbourofelis* and *Epicyon mortifer* are absent, whereas *Osteoborus* makes its first appearance in the southern Great Plains, represented here by a large and a small species (R. H. Tedford, personal communication, 1977). According to Baskin (1980), *Osteoborus* evolved from a small species of *Epicyon* (*saevus* group) in the early Hemphillian, whereas the genus *Aelurodon* became extinct at the end of the Clarendonian.

The gomphothere in the Arnett Local Fauna has lower incisors that are narrower than those of *Amebelodon hicksi* from Sebits Ranch. The Arnett gomphothere may be similar to the narrow-tusked species from the late Clarendonian Love Bone Bed of Florida, which Webb and others (1981) referred to *Amebelodon* cf. *A. barbourensis*. It possibly represents an undescribed species of *Gomphotherium*.

Among the ungulates, antilocaprines appear for the first time in the southern Great Plains in the Arnett Local Fauna and are present at Sebits Ranch. The camel genera *Aepycamelus* and *Procamelus* make their last local appearance at the Arnett site and are absent at Sebits Ranch (R. H. Tedford, personal communication, 1977; Tedford and others, 1987), although Breyer (1983) assigned to *Procamelus* a metatarsal from the younger Box T Local Fauna. Horses are not abundant in either the Arnett or Higgins (=Sebits Ranch) Local Faunas but include *Pliohippus, Cormohipparion,* and *Neohipparion leptode* (Hulbert, 1987).

Stratigraphic evidence suggests that the Arnett Local Fauna is slightly older than the Higgins (=Sebits Ranch) Local Fauna. The intermediate size of *Barbourofelis lovei* compared with that of *B. morrisi* and *B. fricki* of Nebraska suggests that the Arnett Local Fauna is younger than late Clarendonian and older than late early Hemphillian and is therefore early Hemphillian—

Figure 48. Ogallala Formation mortar beds outcrop in Sleepy Hollow west of Sebits Ranch Locality 24-B (fig. 46, site 3) near Higgins, Lipscomb County, Texas. Photo courtesy of Panhandle-Plains Historical Museum, Canyon, Texas.

probably dating at about 7.5 Ma (table 8). The presence of *Epicyon mortifer, Epicyon validus, Gomphotherium* (or a primitive *Amebelodon*), the camels *Aepycamelus* and *Procamelus*, as well as the limited horse fauna, supports this age assignment.

Higgins (=Sebits Ranch) Local Fauna

The Higgins (=Sebits Ranch) Local Fauna (early Hemphillian) is known from two localities on the old Sebits Ranch southeast of Higgins, Lipscomb County, in the northeast corner of the Texas Panhandle (fig. 41, site 12; fig. 46, sites 2 and 3). The two sites were discovered in 1928 by Reed and Longnecker (1932), who designated them Localities 24-A and 24-B. Locality 24-A is 2.4 km (1.5 mi) south and 1.6 km (1 mi) east of Higgins on the west side of a south-draining tributary of Commission Creek, 0.8 km (0.5 mi) west of the Oklahoma state line near the center, SE 1/4, NE 1/4, sec. 176, Blk. 43, Houston and Texas Central Railroad Survey. Locality 24-B is 0.8 km (0.5 mi) south of Locality 24-A on the south side of Sleepy Hollow, an east-draining tributary of Commission Creek in the center, S 1/2, SE 1/4, sec. 176, Blk. 43. Both sites lie at the same stratigraphic level in gray, unconsolidated to cemented fluvial sands that vary in thickness from 0.9 m (3 ft) at Locality 24-B to 1.8 m (6 ft) at Locality 24-A. The section is better exposed at Locality 24-B (figs. 48 through 50) where the fossil bed is underlain by about 7 m (23 ft) of loose brown silty sand and caliche resting on a cemented brown sand, or mortar bed. The fossil bed is overlain by 1.8 m (6 ft) of loose brown sand capped by another cemented brown sand, or mortar bed about 3 m (10 ft) thick, which, at the quarry, lies 7.5 m (25 ft) below the upland surface. This upper cemented sand forms a prominent ledge along the sides of the primarily grass-covered slopes of the valleys in the region. Locally this ledge occurs at or near the top of the valley walls, whereas elsewhere it slopes downward to crop out at lower elevations on the valley slopes. This ledge is not the true Caprock caliche that occurs at the top of the Ogallala Formation in the Llano Estacado farther west. The area around Higgins lies at a lower elevation in the breaks, or transitional zone between the High Plains and the Low Rolling Plains. The Ogallala here is truncated. The mortar beds are highly cemented sandstones that are found at several different levels in the stratigraphic section in this area.

Fossils were first collected from the two Higgins localities by Reed and Longnecker (1932)

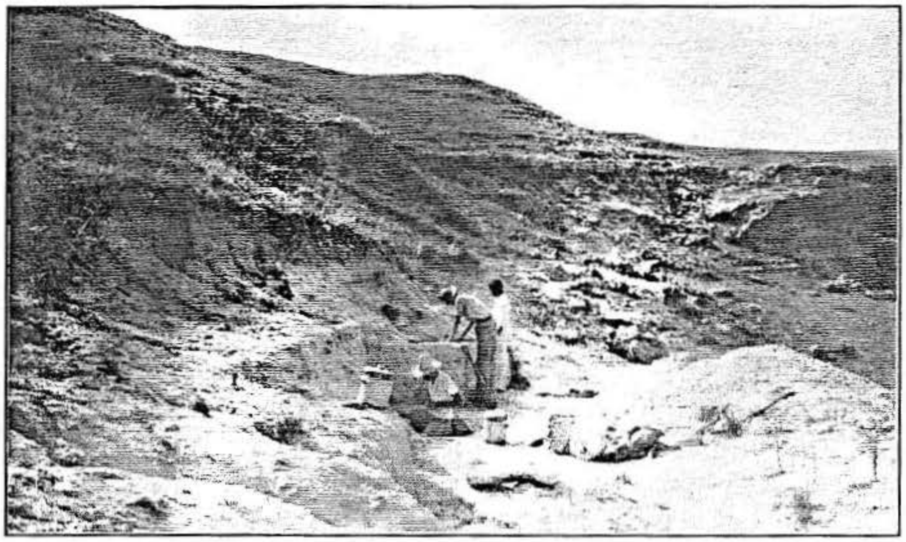

Figure 49. Sebits Ranch Locality 24-B (fig. 46, site 3) (early Hemphillian) near Higgins, Lipscomb County, Texas, in 1937. View to west showing excavation of fossil bed. Photo courtesy of Panhandle-Plains Historical Museum, Canyon, Texas.

Figure 50. Sebits Ranch Locality 24-B (fig. 46, site 3) in 1937. View to east showing excavation of fossil bed. Photo courtesy of Panhandle-Plains Historical Museum, Canyon, Texas.

and by the University of California in 1928, 1929, and 1930. Later collections were made by the Panhandle-Plains Historical Museum of Canyon, Texas, in the late 1930's. The fossils from the two localities are similarly preserved, incomplete, and frequently specifically indeterminate. The fauna (table 8) was described by Hesse (1940). It is dominated by jaws and other skeletal elements of the rhinoceros *Aphelops* (Matthew, 1932) and of the long-jawed gomphothere *Amebelodon*. Less common are carnivores, including the large, massive-jawed canid, *Epicyon validus* (Johnston, 1939a; Webb, 1969b; Richey, 1979) and the large pseudaelurin cat tentatively referred to *Machairodus* by Burt (1931), but later shown to belong to the genus *Nimravides* (Kitts, 1958; Martin and Schultz, 1975). Horses and camels make up a smaller part of the fauna. Of note is the earliest regional occurrence of a megalonychid sloth—its identification based on a single tooth now in the Panhandle-Plains Historical Museum. The large tortoises were mentioned by Brattstrom (1961, p. 550). Five species of snakes (one new) were described by Parmley (1988). A small micromammal fauna was reported by Dalquest and Patrick (1989).

The Higgins Local Fauna includes species that are similar or closely related to species in the nearby Arnett Local Fauna in Ellis County, Oklahoma, 4.8 km (3 mi) northeast of the Higgins localities (for example, *Nimravides, Epicyon validus, Pediomeryx* [*Yumaceras*], and *Aphelops*). However, the small canid in the Higgins Local Fauna identified by Hesse (1940) as *Osteoborus cyonoides* is absent from the Arnett Local Fauna. A larger member of the same genus has been identified from the Higgins site (R. H. Tedford, personal communication, 1977). The gomphothere in the Higgins Local Fauna is *Amebelodon*, whereas that in the Arnett Local Fauna may be referable to *Gomphotherium*. Stratigraphic evidence suggests that the Higgins Local Fauna is slightly younger than the Arnett Local Fauna, although the fauna is still clearly of early Hemphillian age, probably equivalent to the Feltz Ranch Local Fauna of Nebraska (Hesse, 1935a) (table 1). The presence of *Epicyon validus* in the Arnett and Higgins Local Faunas indicates a correlation with part of the Upper Snake Creek locale of Nebraska, which produced the "type" of that species.

V. V. Parker Pits

Several exposures of gray silty sand lie along the south valley wall of Wolf Creek about 14.5 km (9 mi) north of Higgins, Lipscomb County, Texas (fig. 46, site 6). Some of these exposures, which probably represent a single channel deposit, are fossiliferous and were quarried by the Frick Laboratory. The fauna (largely unpublished) includes turtle, large cat, gomphothere, camel, small ruminant, rhinoceros, and several kinds of horse. MacFadden and Skinner (1979) described a lower jaw of the one-toed horse *Hippidion*, the first North American record of this South American genus. The fauna is early Hemphillian and appears to correlate stratigraphically with the fauna from the Arnett (=Port-of-Entry) site.

Box T Local Fauna

The Box T Local Fauna (table 8) is known from several localities 1.6 km (1 mi) south of Wolf Creek on the Vester Smith Box T Ranch, approximately 14.5 km (9 mi) northwest of Higgins, Lipscomb County, Texas (fig. 41, site 13; fig. 46, site 7). The principal quarries are west of the ranch house in the SE 1/4, SE 1/4, sec. 611, Blk. 43, Houston and Texas Central Railroad Survey. Fossils were collected by the Frick Laboratory from unconsolidated stream-channel sands containing abundant clasts of scoriaceous basalt derived from the volcanic highlands of northeastern New Mexico. These clasts may represent the oldest basalts from Raton-Clayton field, which have been dated at about 7.2 Ma B.P. (Stormer, 1972), or they may be derived from the earliest eruptions in the Ocate field west of Springer, New Mexico, which have been dated between 8.1 and 5.5 Ma B.P. (Nielsen and Dungan, 1985). The channel deposits containing these clasts disconformably overlie a massive cemented buff sandstone that presumably is equivalent to the brown sand, or mortar bed, overlying the bone-bearing beds at the Higgins quarries. The fossiliferous beds at the Box T quarries are overlain by 9 to 10.5 m (30 to 35 ft) of rubbly buff sand locally cemented into thin mortar beds near the top (fig. 51).

The fauna is large (table 8), although it is undescribed except for the sloths *Pliometanastes* cf. *P. protistus* (Hirschfeld and Webb, 1968, p. 284) and *Thinobadistes wetzeli* (Webb, 1989), and it is similar to the Higgins (=Sebits Ranch) Local Fauna because it contains *Nimravides, Epicyon validus, Osteoborus* (large and small species), *Amebelodon, Pediomeryx* (*Yumaceras*), and *Aphelops* (R. H. Tedford, personal communication, 1977). However, certain taxa characteristic of the Arnett or Higgins Local Faunas, such as *Barbourofelis, Epicyon mortifer, Aepycamelus*, and possibly *Procamelus*, are absent. Immigrant genera, such as *Machairodus, Indarctos*, and *Eomellivora*, appear for the first time (Tedford and others, 1987), indicating that the fauna is younger than the Higgins (=Sebits Ranch) Local Fauna and thus belongs to the later part of the early Hemphillian (table 8). The Box T Local Fauna probably dates between 6 and 7 Ma ago.

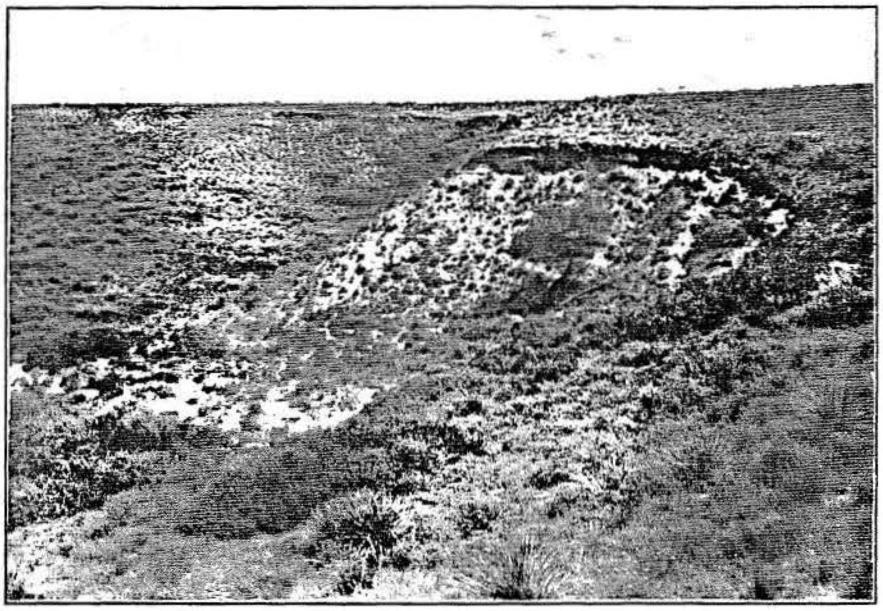

Figure 51. Box T Local Fauna Pit No. 1 (late early Hemphillian), Lipscomb County, Texas. Fossils are present at base of exposed section of Ogallala sediments. Photo courtesy of Panhandle-Plains Historical Museum, Canyon, Texas.

Whereas a complete description of the Box T Local Fauna has not been published, many of the taxa present have been mentioned in the literature, such as the immigrant ground sloths, *Pliometanastes* and *Thinobadistes* from South America (Hirschfeld and Webb, 1968; Marshall and others, 1979; Webb, 1989); the giant bear *Indarctos* (Harrison, 1983, p. 25); the giraffelike browsing ruminant *Pediomeryx* (*Yumaceras*) cf. *P. figginsi* (Webb, 1983b); the camel *Procamelus* (Breyer, 1983); and the horses *Hipparion forcei* (MacFadden, 1984a) and *Neohipparion leptode* (Hulbert, 1987). Breyer (1981) recorded the presence of *Osteoborus, Sthenictis, Prosthennops graffhami*, and *Neohipparion leptode*. The Box T Local Fauna, despite the presence of new immigrant genera and the absence of certain older taxa, demonstrates the persistence of a Clarendonian chronofauna (Webb, 1969a).

The Box T Local Fauna is older and lower in the Ogallala section than the late Hemphillian Coffee Ranch Local Fauna (fig. 41, site 15) and contains the last occurrence of *Nimravides, Leptarctus, Amebelodon* cf. *A. fricki, Calippus, Pliohippus, Pediomeryx* (*Yumaceras*), and the strange Clarendonian immigrant *Pseudoceras*, a small hornless ruminant of the gelocid family. This fauna lacks, however, taxa that appear for the first time in the Coffee Ranch and equivalent faunas, such as *Rhynchotherium, Plesiogulo*, and *Agriotherium* (Tedford and others, 1987). The Box T Local Fauna correlates closely with one of the "Kimball faunas" (Cambridge=Ft-40 Local Fauna) of Nebraska and with the Wray Local Fauna of Colorado, both of which are considered to be late early Hemphillian (Tedford and others, 1987).

The climate in the Texas Panhandle during the time in which the Higgins and Box T Local Faunas lived continued to be mild, and grassland savanna conditions prevailed. The presence of large tortoises suggests a frost-free environment (Hibbard, 1960) and some mammals such as the rhinoceroses (*Aphelops* and *Teleoceras*) and the shovel-tusked gomphothere *Amebelodon* became quite large and apparently fed on the abundant vegetation growing along broad grassy floodplains of the larger river valleys. *Amebelodon* probably used its large lower tusks to shovel up succulent water plants and perhaps roots and bulbs, as suggested by Osborn (1936, p. 333). A well-preserved lower jaw of this gomphothere is recorded from Roberts County, Texas (Gregory, 1945).

STOP 16: Late Hemphillian Faunas of the Texas and Oklahoma Panhandles

G. E. Schultz

The Coffee Ranch and Goodnight Local Faunas of Texas and the Optima Local Fauna of Oklahoma are dominated by mammals adapted to grazing on a grassland savanna or steppe.

Coffee Ranch (=Miami) Local Fauna

The Coffee Ranch Quarry, type locality for the Hemphillian Land Mammal Age, is about 13 km (8 mi) northeast of Miami, 1.6 km (1 mi) east of the Roberts-Hemphill county line and about 150 m (500 ft) north of a county road in the SE 1/4, NE 1/4, NE 1/4, sec. 59, Blk. A-2, H. and G. N. Ry. Co. Survey, Hemphill County, Texas (USGS Lora 7.5-minute topographic quadrangle map) (fig. 41, site 15; fig. 52). The quarry is high in the Ogallala section, and the fauna is thought to be of late Hemphillian age. The site was discovered by Reed and Longnecker in 1928 while they were investigating the geology of Hemphill County for the Rio Bravo Oil Company (Reed and Longnecker, 1932). The University of California obtained specimens collected by them and made additional collections at the site from 1928 to 1930 (UCMP Locality V-2823). The site was worked during the 1930's by the Frick Laboratory, the Denver Museum of Natural History, and West Texas State University. In 1963 and 1964, Midwestern State University began extensive excavations that included screenwashing matrix for microfauna.

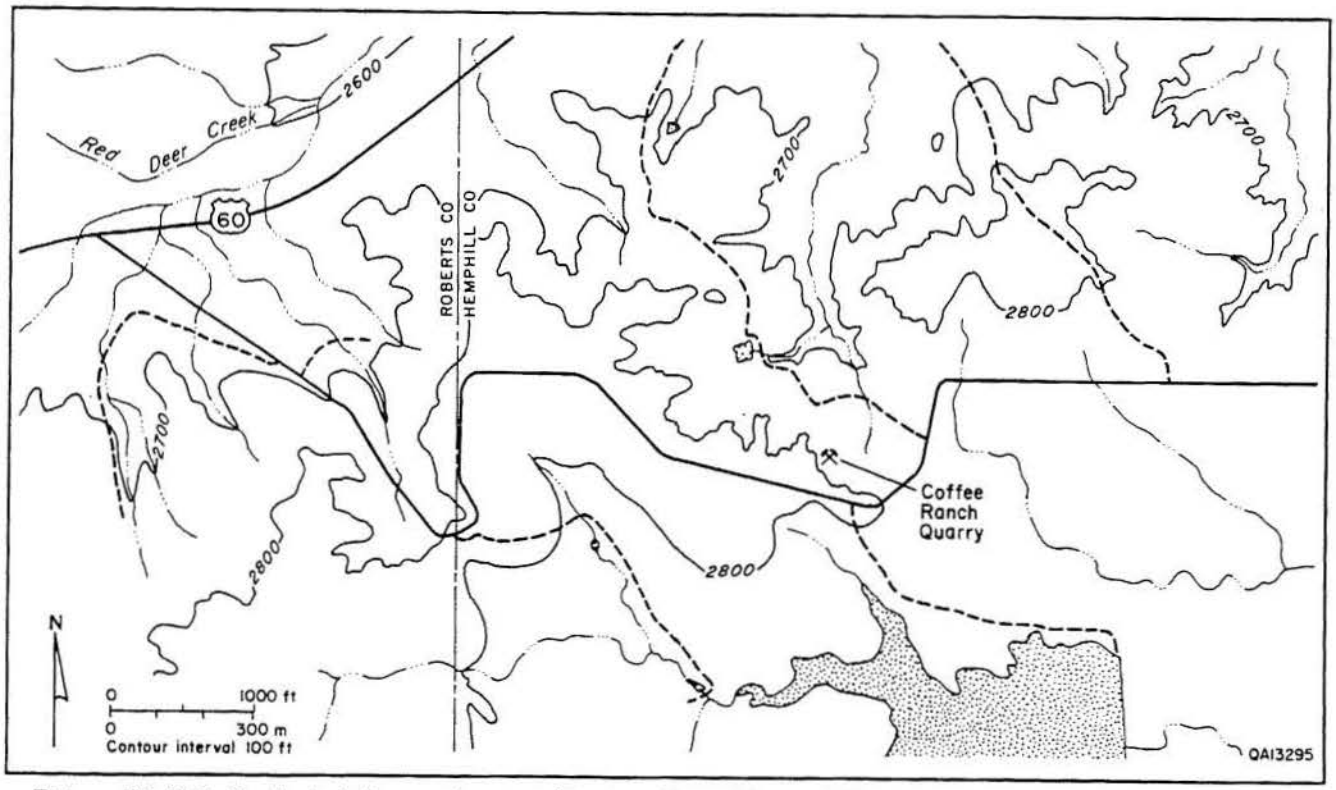

Figure 52. U.S. Geological Survey topographic map (Lora, Texas, 7.5-minute quadrangle) of Coffee Ranch Quarry (type Hemphillian), Hemphill County, Texas. Quarry at gravel pit marked ⚒. Scale 1:24,000. See also figure 41, site 15.

During the past 50 yr or so, an extensive literature has developed on the fauna. Early faunal lists based on the University of California collections appeared in papers by Matthew and Stirton (1930a, p. 367), Reed and Longnecker (1932, p. 66), and Plummer (1932, p. 775). Various papers have dealt with certain taxa in the fauna. Matthew and Stirton (1930b) described a bone-eating dog, *Borophagus cyonoides*, later referred to *Osteoborus* by Stirton and VanderHoof (1933). This was followed by a study (Matthew and Stirton, 1930a) of the fossil horses that includes a description of the type of *Astrohippus ansae* and the referral of three other horse taxa to species described by Cope (1893) from Mulberry Canyon south of Goodnight, Texas. Burt (1931) described the saber-toothed cat now identified as *Machairodus* cf. *M. coloradensis* (the type of *M. catocopis* is properly referred to *Nimravides*, according to Martin and Schultz, 1975). After Matthew's death, Stirton completed an account of the rhinoceroses (Matthew, 1932). Stirton described the type lower jaw of a ruminant, *Pediomeryx hemphillensis* (Stirton, 1936b; Webb, 1983b), gave measurements of a jaw of the antilocaprid *Capromeryx altidens* (Stirton, 1938) and mentioned the rarer carnivores in an abstract (Stirton, 1939). Other contributions include the descriptions of some fragmentary gomphothere material (Frick, 1933, p. 606), duck (Compton, 1934; Brodkorb, 1964, p. 225), bird, and carnivore tracks from the volcanic ash overlying the quarry beds (Johnston, 1937e), the horse *Dinohippus* (Quinn, 1955, p. 43), the camel *Megatylopus matthewi* (Webb, 1965; Harrison, 1985), and the carnivores (Dalquest, 1969b, 1986; Webb, 1969b; Wagner, 1976; Richey, 1979; Harrison, 1981, 1983). The small camels, first mentioned by Gregory (1942), were described by Harrison (1979), Dalquest (1980), and Breyer (1983). The horses were described or reviewed by Dalquest and Donovan (1973), Dalquest (1978, 1981), MacFadden and Waldrop (1980), MacFadden (1984a), and Hulbert (1987). Schultz (1977a) presented a list of the mammals along with a description of the site and comparisons of the fauna with other Hemphillian faunas from Texas and Oklahoma. A recent summary of the fauna including a description of the micromammals was given by Dalquest (1983). Additional micromammals were described by Dalquest and Patrick (1989). The sloth *Thinobadistes* was identified by Webb (1989). The herpetofauna was described by Parmley (1984, 1987). The fauna as currently recognized is listed in table 9.

An important paleoecological analysis of the fauna was done by Shotwell (1955, 1958) using specimens in the University of California collection. From data on abundance of species, minimum number of individuals, and completeness of skeletal representation, he constructed a faunal analysis model by which he assigned taxa to proximal, intermediate, and distal communities. He concluded that the proximal community at the Hemphill site lived in a grassland habitat and was dominated by large grazing herbivores such as horses, camels, rhinoceroses, and deer and by large predators such as the saber-toothed cat and the bone-eating dog. He believed that a more distal community at the site was one of less abundant mammals such as peccary, mastodon, and wolverine inhabiting brush or open woodland.

The climate during the late Hemphillian apparently was somewhat drier than during the Clarendonian or early Hemphillian. The absence of browsers and the reduced diversity of grazers reflect the progressive trend from woodland savanna to steppe that had culminated by the end of Hemphillian time (Webb, 1977, 1983a).

Geology

According to Dalquest (1969b, p. 2), the fossils at Coffee Ranch accumulated in a lake or bog of moderate but unknown area. The lacustrine sediments were then buried under about 9 m (30 ft) of eolian material and are now exposed for about 90 m (300 ft) along the east face of a steep hillside at the head of a northward-draining valley that runs into Red Deer Creek (figs. 52 and 53). The original areal extent of the fossil-bearing strata is uncertain because the east portion has been eroded away, whereas the west margin lies buried in the hillside. Fossil quarrying over the years has undercut the overlying strata, causing large blocks to collapse and obscure much of the outcrop.

The present exposure is lenticular in profile. The following section near the center of the deposit was measured by Dalquest (1969b, p. 2).

Bed	Description	Thickness in feet
8.	Overburden of buffy, sandy clay and soil	25.0
7.	Volcanic ash	9.0
6.	Compact bentonitic clay	2.0

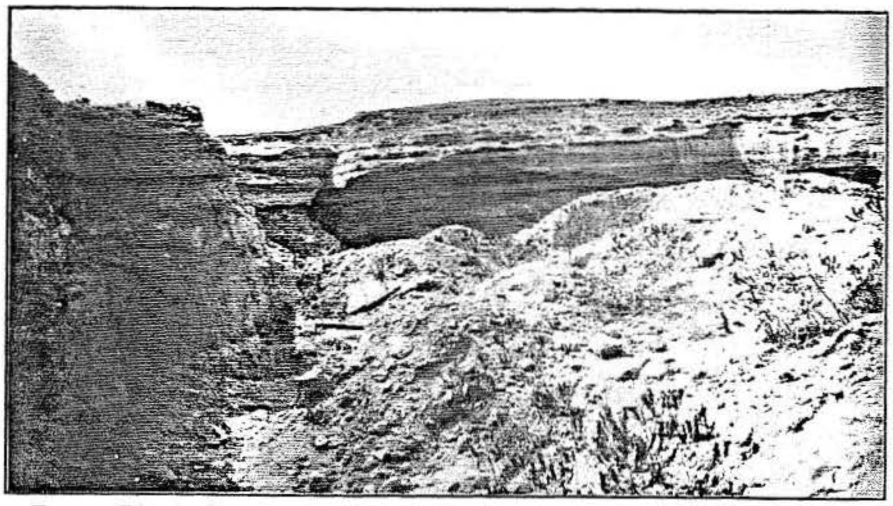

Figure 53. Coffee Ranch Quarry, Hemphill County, Texas, in 1936. (Type locality for Hemphillian Land Mammal Age.) Fossils are present in lower part of section below overhanging ledge of volcanic ash. Photo courtesy of Panhandle-Plains Historical Museum, Canyon, Texas.

Bed	Description	Thickness in feet
5.	Greenish gray sand with some clay	2.0
4.	Reddish brown, sandy clay, variable in thickness in the deposit and with sharp but contorted contact with beds above and beneath	1.0
3.	Greenish sand and sandy clay with some pebble bands and thin calcareous sandstone layers	5.5
2.	Slick, hard reddish brown clay with calcareous crusts and nodules	0.2
1.	Buff-colored aeolian sandy sediments of the Ogallala Formations; bottom not exposed in the area	

Although vertebrate fossils appear in all beds of the lake deposit (Beds 2 through 7), the bulk of the fossils and most of the complete bones have been found in the semiconsolidated greenish sand of Bed 3. Most early collecting seems to have been concentrated in this bed. The bones are white to cream colored, chalky, light and porous but generally well preserved. The dense greenish bentonitic clay (Bed 6) also contains abundant bones, but many are broken. Dalquest (1983) recovered a small but important microvertebrate fauna by screenwashing the clay.

Some concentrations of bone were found in the volcanic ash, but for the most part bones are few and scattered. The ash is thinly bedded, and many of the bedding planes show distinct ripple marks; several contain abundant bird and mammal tracks. Most of the excellent animal tracks described by Johnston (1937e) are found on a single bedding plane that lies approximately 20 cm (8 in) above the base of the volcanic ash and approximately 2.4 m (8 ft) above the main fossil-bearing horizon, which is near the base of the greenish sand of Bed 3. A few tracks have been found above this level. They are unusually clear and well preserved and thus can be easily and accurately measured. The volcanic ash apparently was deposited in shallow water and was in a damp, slightly plastic condition when the tracks were made. Because there is no evidence of erosion or desiccation on this surface, it appears that the tracks were covered by a protecting layer of water-laid ash shortly after they were made. Samples of the ash taken from the base of the deposit were radiometrically dated by Izett (1975, p. 202) using the fission-track method on zircon and hydrated glass shards. Glass-mantled zircon microphenocrysts yielded an age of 6.6±0.8 Ma, and glass shards gave an age of 4.7±0.8 Ma. Boellstorff (1976, p. 65) obtained a glass fission-track date of 5.3±0.4 Ma on glass from this ash.

Table 9. Faunal lists of late Hemphillian local faunas of the Texas and Oklahoma Panhandles.

	A	B	C
Class Osteichthyes			
Order Semionotiformes			
Family Lepisosteidae			
Lepisosteus sp. - gar		X	
Class Amphibia			
Order Urodela (=Caudata) - salamanders			
Family Ambystomatidae			
Ambystoma cf. *A. minshalli* Tihen and Chantell		X	
Class Reptilia			
Order Chelonia			
Family Testudinidae			
Geochelone sp. - large tortoise	X	X	X
Small pond turtle		X	
Order Squamata			
Family Boidae			
Erycinae genus et sp. indet.		X	
Ogmophis pliocompactus Holman		X	
Family Colubridae			
Elaphe nebraskensis Holman - rat or black snake		X	
Lampropeltis similis Holman - king snake		X	
Paleoheterodon tiheni Holman - hog-nosed snake		X	
Paracoluber storeri Holman - racer		X	
Salvadora paleolineata Holman - patch-nosed snake		X	
Order Crocodilia			
Family Crocodilidae			
Crocodilid sp. - crocodile	X		
Class Aves			
Order Falconiformes			
Family Accipitridae			
Accipitrid sp. - hawk		X	
Order Anseriformes			
Family Anatidae			
Nettion bunkeri Wetmore - pond duck		X	
Class Mammalia			
Order Insectivora			
Family Soricidae			
Soricid sp. - shrew		X	
Family Talpidae			
Scalopus (Hesperoscalops) ruficervus Dalquest - mole		•	
Order Chiroptera			
Family Vespertilionidae			
Eptesicus hemphillensis Dalquest - brown bat		•	

•• Holotype of genus
• Holotype of species
X Occurrence in fauna
? Possible occurrence in fauna
A Optima (=Guymon), Texas County, Oklahoma
B Coffee Ranch (=Miami), Hemphill County, Texas
C Goodnight, Armstrong County, Texas

Table 9. (cont.)

	A	B	C
Order Edentata			
Family Megalonychidae			
Megalonyx sp. - ground sloth	X		
Family Mylodontidae			
Thinobadistes sp. - ground sloth		X	
Order Rodentia			
Family Mylagaulidae			
Mylagaulus cf. *M. monodon* (Cope) - burrowing rodent		X	
Mylagaulus sp.	X		
Family Castoridae			
Dipoides sp. - beaver	X		
Family Eomyidae			
Comancheomys rogersi Dalquest		**	
Family Sciuridae			
Spermophilus sp. - ground squirrel		X	
Family Geomyidae			
Progeomys sulcatus Dalquest - pocket gopher		**	
Family Heteromyidae			
Cupidinimus sp.		X	
Perognathus sp. - pocket mouse		X	
Prodipodomys (?) sp. - kangaroo rat		X	
Family Cricetidae			
Paronychomys (?) sp. - grasshopper mouse		X	
Calomys (Bensonomys) coffeyi Dalquest - neotropical mouse		*	
Peromyscus sp. - deer mouse		X	
Prosigmodon sp. - cotton rat		X	
Neotoma (Paraneotoma) minutus Dalquest - wood rat		*	
Order Lagomorpha			
Family Leporidae			
Hypolagus cf. *H. vetus* (Kellogg) - rabbit	X	X	
Order Carnivora			
Family Felidae			
Machairodus cf. *M. coloradensis* Cook - saber-toothed cat	X	X	
Felis proterolyncis Savage - lynx	*	X	
Pseudaelurus hibbardi Dalquest - cat		*	
Adelphailurus sp. - cat	X		
Family Canidae			
Osteoborus cyonoides (Martin) - bone-eating dog	X	X	X
Canis davisi Merriam - coyote	X	X	
Vulpes stenognathus Savage - slender-jawed fox	*	X	
Family Mustelidae			
Plesiogulo marshalli (Martin) - wolverine	X	X	
Pliotaxidea cf. *P. nevadensis* (Butterworth) - small badger	X	X	
Family Procyonidae			
Arctonasua fricki Baskin - coati	*		
Family Ursidae			
Agriotherium coffeyorum Dalquest - large bear	X	*	
Order Proboscidea			
Family Gomphotheriidae			
Rhynchotherium (?) sp. - gomphothere		X	
Family Mammutidae			
Pliomastodon sp. - mastodon	X		

Table 9. (cont.)

	A	B	C
Order Artiodactyla			
Family Tayassuidae			
Prosthennops cf. *P. graffhami* Schultz and Martin - peccary		X	
Prosthennops sp. - peccary	X		
Family Camelidae			
Megatylopus matthewi Webb - large camel	X	•	
Alforjas taylori Harrison - medium-sized camel	X	X	
Hemiauchenia vera (Matthew) - llamalike camel	X	X	
Family Dromomerycidae			
Pediomeryx (Pediomeryx) hemphillensis Stirton - giraffelike ruminant	X	••	
Family Antilocapridae			
Texoceros cf. *T. altidens* (Matthew) - pronghorn	X	X	
Antilocaprid sp. - pronghorn			X
Order Perissodactyla			
Family Equidae			
Dinohippus interpolatus (Cope) - large 1-toed horse	X	X	•
Astrohippus ansae (Matthew and Stirton) - 1-toed horse	X	•	X
Neohipparion eurystyle (Cope) - 3-toed horse		X	X
Neohipparion leptode Merriam - 3-toed horse		X	
Neohipparion gidleyi Merriam - 3-toed horse	X		
Nannippus lenticularis (Cope) - small 3-toed horse or *Nannippus ingenuus* (Leidy)	X	X	•
Nannippus minor (Sellards) - small 3-toed horse		X	
Family Rhinocerotidae			
Aphelops cf. *A. kimballensis* Tanner (or *A. mutilus* Matthew) - rhinoceros		X	
Aphelops sp. - rhinoceros			X
Teleoceras sp. - short-legged hippolike rhinoceros	X	X	

The geologic history of the lake deposits as interpreted by Dalquest (1969b, p. 3) is briefly summarized as follows:

(1) Deposition of sand and dust in the basin of a shallow seasonal lake, forming a sandy mud (Bed 3). Bones of animals that died in or near the lake settled through the mud to rest near the bottom. When the lake was dry, heavy rains washed coarse-grained debris from the nearby caprock hills and cliffs out onto a firm sandy flat, forming layers of pebbles and gravel. These later served as traps that caught bones sinking down through the soft sediments above them.

(2) Deposition of the reddish-brown sandy clay (Bed 4) under somewhat different climatic conditions, when more subaerial exposure of the sediments was occurring.

(3) A brief return to conditions prevalent during Bed 3 time with the deposition of additional greenish sand (Bed 5).

(4) Development of a meadow or bog where small rodents, shrews, and rabbits lived and whose remains became preserved in the bentonitic clay (Bed 6).

(5) Volcanic activity somewhere to the west, which produced a fallout of volcanic dust that settled on slopes and hills about the lake basin. Heavy rains washed the ash into the shallow lake, where it settled to form mud. When the lake periodically became dry, the mud retained ripple marks and footprints of wading animals.

More ash fell and washed into the basin, refilling the lake and covering the hardened layers of ash with new layers of mud, thus preserving bones and footprints. Additional ash and dust washed into the lake until 2.7 m (9 ft) had accumulated and the basin was filled. The fossiliferous deposits were thus sealed beneath the ash.

(6) Deposition of eolian silts and clays and development of soils that overlie the volcanic ash.

Age and Correlation

According to Dalquest (1983), the Coffee Ranch Local Fauna is a unit fauna and represents animals that lived at the site during a relatively brief interval, perhaps a few centuries, during which a closed depression formed and then filled with sediment. The zircon fission-track date of 6.6±0.8 Ma for the ash immediately overlying the fossil-bearing unit may represent a more reliable age for the fauna than do the glass fission-track dates of 5.3±0.4 Ma (Boellstorff, 1976, p. 65) and 4.7±0.8 Ma (Izett, 1975, p. 202), which may be too low because of annealing of the tracks (Izett, personal communication, 1976). Lindsay and others (1975, p. 114; 1984, p. 460) determined that the fossil-bearing sands and the overlying ash are in a thick, normally magnetized polarity zone. They thought the zone represented the lower part of magnetic chron 5 (approximately 5.9 Ma ago) because the ash date indicates that it is older than the Gauss chron (3.3 to 2.4 Ma ago).

Some of the principal late Hemphillian correlative faunas (table 1) include the Optima (=Guymon) Local Fauna of Oklahoma (Hesse, 1936b; Savage, 1941), the Rhino Hill and Edson Local Faunas of Kansas (Harrison, 1983), the ZX Bar Local Fauna in the Upper Snake Creek faunal sequence of northwest Nebraska (Skinner and others, 1977), the Camel Canyon, Redington, Wikieup, and White Cone Local Faunas of Arizona, and the Chamita Local Fauna of New Mexico (Lindsay and others, 1984).

Goodnight Fauna

The term Goodnight Fauna has been used to refer to a small assemblage of fossil mammals of late Hemphillian age discovered by Cummins (1893) and described by Cope (1893) from the upper part of Mulberry Canyon on the Charles Goodnight Ranch in Armstrong County, Texas (fig. 41, site 16). Mulberry Creek is a tributary of the Prairie Dog Town Fork of the Red River. The exact locality from which the fauna was collected has never been recorded and cannot be determined satisfactorily from available accounts of early expeditions in the area. There is some indication that the locality may be about 6.4 or 8.0 km (4 or 5 mi) south or southwest of the town of Goodnight on the north side of Mulberry Canyon. Cummins (1893, p. 201) designated the fossil-bearing strata the "Goodnight beds" and attempted to show stratigraphically that they overlay the "Clarendon beds" farther east. He had distinctly different geologic sections for the north and south sides of the canyon. Gidley (1903a, p. 628) showed that Cummins had misidentified or misinterpreted certain gravel beds in the Clarendon and Mulberry areas and that the strata were essentially the same on both sides of Mulberry Canyon. He then equated the Goodnight and Clarendon beds both faunally and stratigraphically. Later work has shown, however, that the Goodnight Fauna is definitely younger than the Clarendon Fauna, although the Goodnight beds do not represent a distinct lithologic unit in the Ogallala.

The fauna described by Cope (1893) includes isolated horse teeth that are the type specimens of *Dinohippus interpolatus* and *Nannippus lenticularis* as well as specimens referred to *Neohipparion eurystyle*. The lectotype specimen of the latter is actually from the "Falls of the Palo Duro south of Amarillo," which is at the lower end of Lake Tanglewood in Randall County—probably the Currie Ranch Local Fauna site (fig. 41, site 19). A fourth horse in the Goodnight Fauna is apparently *Astrohippus ansae*, described by Matthew and Stirton (1930a) from the Hemphill (=Coffee Ranch) locality. The rhinoceros, *Aphelops*, was also listed in the fauna by Cope. The Cope specimens are now at the Texas Memorial Museum at The University of Texas at Austin.

The Goodnight Fauna is late Hemphillian and, although small, is specifically identical to the Coffee Ranch Local Fauna in Hemphill County (table 9). Subsequent collecting by the Frick Laboratory from several quarries on the McGehee and Hubbard Ranches near Goodnight during the early 1950's enlarged the fauna, but the fossils obtained have not been published.

Optima (=Guymon) Local Fauna

The Optima Local Fauna is a late Hemphillian fauna identified in several localities about 2.4 km (1.5 mi) southwest of Optima, 12 km (7.5 mi) northeast of Guymon, and 90 m (300 ft) north of the Rock Island Railroad right-of-way in secs. 6 and 7, T. 3 N, R.16 E, Texas County, Oklahoma (fig. 41, site 14). According to Savage (1941, p. 692), the fossiliferous deposits are exposed in an escarpment eroded by several small intermittent streams draining southward into the Beaver River. These escarpments are not prominent but are steep, talus-covered slopes and rolling grass-covered hills, probably resulting from loose cementation in the caliche caprock.

The stratigraphic sequence in the small area of the University of Oklahoma quarries consists, according to Savage (1941, p. 693), of more than 0.6 m (>2 ft) of brownish-red sand, grit, and gravel overlain by 1.2 to 2 m (4 to 7 ft) of white quartz sand that grades into grits and gravel in places and contains fossil vertebrates. This unit is overlain by 2 or 2.4 m (7 or 8 ft) of buff to gray clay and silt that is also fossiliferous, and this is capped by 1 to 2 m (3 to 7 ft) of soil and caliche. The coarser deposits are stream-channel deposits. Most of the fossils have been found in small pockets in the white sand, which, according to Hesse (1936b, p. 58), is loose and coarse or cemented into a calcareous grit. Many of the coarse, gravelly pockets are surrounded by a fine reddish-brown fluvial sand. The fossils are buff to white and heavily silicified, but they show traces of calcification and are unusually light and porous. Although incomplete, the specimens show no evidence of being heavily waterworn. Apparently deposition of the fossils was rapid but with little transportation.

Fossils were discovered by the landowner, James English, and reported to the University of California, which collected there in 1929. Additional collections were obtained by the University of Oklahoma and the Frick Laboratory during the 1930's. The California collection was described by Hesse (1936b). The Oklahoma collection was studied by Savage (1941), who described the type specimens of a fox, *Vulpes stenognathus*, and a lynx, *Felis proterolyncis*. A dromomerycid ruminant, *Yumaceras falkenbachi* (=*Pediomeryx hemphillensis*), and an antilocaprid, *Texoceros guymonensis* (=*altidens*), were reported by Frick (1937). In addition, various members of the fauna have been mentioned, described, or revised by other workers in papers devoted to particular taxa such as antilocaprids (Hesse, 1935b; Stirton, 1938), sloths (Hirschfeld and Webb, 1968, p. 245, 286), badgers (Hall, 1944, p. 15; Wagner, 1976, p. 110), wolverines (Harrison, 1981), procyonids (Baskin, 1982), cats (Martin and Schultz, 1975; Harrison, 1983, p. 31), camels (Harrison, 1979; Breyer, 1983), dromomerycids (Webb, 1983b), and horses (MacFadden, 1984a).

Grazing mammals dominate the fauna (table 9), horses forming 80 percent of the Oklahoma collection. Several hundred isolated teeth and numerous jaws and other remains of *Dinohippus interpolatus* and *Astrohippus ansae* are included. Second in importance are the artiodactyls; camels and the antilocaprid, *Texoceros altidens*, are the most numerous. Carnivores are less abundant but varied.

The Optima Local Fauna is similar to that from Coffee Ranch in Hemphill County, Texas. Both are thought to be late Hemphillian (table 9), and the two faunas share many common taxa. The abundance of grazing ungulates in the Optima Local Fauna, as compared with browsing types, indicates that the region was predominantly a broad, open, short-grass country (Savage, 1941, p. 705). The existence of deer, bear, beaver, sloth, fox, and lynx indicates the presence of forested areas, probably on floodplains. Alligator remains suggest that the climate was warmer and more humid than now and that the streams were deeper and more sluggish than present-day streams in the area because alligators prefer quiet, deep waters.

STOP 17: Latest Hemphillian Faunas of the Texas Panhandle

G. E. Schultz

The Axtel Local Fauna of Randall County, Texas, and the Christian Ranch Local Fauna of Armstrong County, Texas, are dominated by grazing mammals adapted to a semiarid grassland savanna or steppe.

Axtel Local Fauna

The Axtel Local Fauna is one of the latest Hemphillian faunas in the Southern High Plains. The site is a quarry located on a promontory of the east wall of Woody Draw, a south-draining tributary of North Cita Canyon about 5.6 km (3.5 mi) south and 19 km (12 mi) east of the town of Canyon and just outside Palo Duro Canyon State Park, Randall County, Texas, in the SE corner, SW 1/4, SW 1/4, sec. 165, Blk. 6, I. and G.N. R.R. Co. Survey (fig. 41, site 18).

Fossils were discovered in 1936 by Donald E. Savage near the bottom of a 1.5-m-thick (5-ft) brown fluviatile sand of limited areal extent. The sand bed rests on red shales of the Triassic Dockum Group and is overlain in turn by 1.8 m (6 ft) of brown caliche-cemented sandstone, 0.3 to 0.6 m (1 to 2 ft) of resinous opal, and a cap of nearly 9 m (30 ft) of massive white caliche (Johnston and Savage, 1955, p. 28).

The fauna, collected by WPA crews for the Panhandle-Plains Historical Museum, was first reported by Johnston (1939b), who described the type specimens of *Osteoborus hilli*, a bone-crushing dog (see also Webb, 1969b; Richey, 1979). Most of the fauna is undescribed, although Johnston and Savage (1955, p. 28) published a faunal list (table 10) and a stratigraphic section of the quarry. Horses are the most abundant forms; there are numerous isolated teeth, jaws, and limb bones of *Dinohippus* cf. *D. mexicanus* and *Astrohippus* cf. *A. stocki*. Mawby (1965, p. 574) described a machairodont and Oelrich (1957, p. 236) and Auffenberg (1962a, p. 630) reported a tortoise, *Geochelone* cf. *G. turgida*.

The Axtel Local Fauna is latest Hemphillian (table 10) but younger than the Coffee Ranch Local Fauna, as indicated by the more advanced horses, camels, and *Osteoborus* (Johnston and Savage, 1955, p. 29) (compare tables 8 and 9). The fauna is equivalent in age to the Christian Ranch Local Fauna (table 10) and several other smaller ones in the Palo Duro Canyon region (fig. 41). Lindsay and others (1975, p. 117) determined that the fauna lies in a zone of normal magnetic polarity, which probably represents chron 5 because of the similarity of the fauna to that from Coffee Ranch. The Coffee Ranch Local Fauna is assigned to chron 5 because the fossil-bearing strata exhibit normal magnetic polarity and because of the radiometric dates obtained on the overlying volcanic ash (Izett, 1975; Boellstorff, 1976).

The climate of the region by latest Hemphillian time already was semiarid as evidenced by a long history of calcic soil development that produced the caliche caprock that underlies the High Plains surface. This caliche overlies the fossil bed at the Axtel site, but at a nearby locality (Currie Ranch, fig. 41, site 19) a small late Hemphillian fauna is sandwiched between two massive caliche beds. Waterworn cobbles of the lower caliche are present in the fossil bed, indicating that caliche formation had already commenced by the time these latest Hemphillian faunas appeared (Johnston and Savage, 1955, p. 33). The absence of rhinoceros from latest Hemphillian faunas and the greatly reduced number of mastodons (*Rhynchotherium*) also suggest a shift toward a drier climate in the region.

Christian Ranch Local Fauna

This latest Hemphillian faunal site is on the Terrell Christian Ranch 15 km (9.5 mi) south and 12 km (7.5 mi) west of Claude, Armstrong County, Texas (fig. 41, site 17) in the SE 1/4, NW 1/4, sec. 4, Blk. 1, I. R.R. Co. Survey. Johnston and Savage (1955, p. 30) gave the following description of the site and its origin:

Fossiliferous exposures lie on a small erosional remnant hill atop a ridge that connects a prominent intracanyon butte, called "Big Mountain" locally, to the east wall of Horseshoe Canyon. Horseshoe Canyon is a large, deep, amphitheater-like southward-draining tributary and is one of the most spectacular sights in the Palo Duro system.

The fossiliferous stratum is a 3- to 10-foot bed of gray sand overlain by a 6-inch to 3-foot bed of gray to white resistant sandy limestone. These two beds constitute a lens 300 feet wide which grades laterally into brown mudstones and sands or sandstones.

The supra-Triassic section found at Horseshoe Canyon is the thickest (about 260 feet) seen at any fossil site in the Panhandle. The brown-colored beds are interpreted as river-floodplain or playa accumulations. Phases of deposition or precipitation of limey material are represented by the light-colored laminae in the lower part of the section and by the massive sandy or silty caliche beds at the top. The gray fossil-bearing lens is believed to have been formed in a spring fed pond or bog area where the finer clastics (silts and clays) were flushed away by some sort of churning action. The gray color was probably developed by the reduction of ferric oxides (the brown and red coloration in the surrounding sediments). This reduction may have been brought about by the accumulation of plants and resultant organic acids in the environs of this more permanent water supply. And in the latest interval of existence of this water hole, calcareous matrix was concentrated and deposited. The aggregation of bones in the gray lens also suggests that here was a spot where animals congregated to drink and feed.

The supra-Triassic section at the site is about 78 m (260 ft) thick. The fossil quarry is about halfway up, or 39 m (130 ft) below the surface of the surrounding plains. Fossils were discovered here in 1930 by Floyd V. Studer, who collected and prepared most of the specimens now in the Panhandle-Plains Historical Museum. The collection, largely undescribed, consists mainly of teeth and jaws of *Astrohippus* cf. *A. stocki* with a smattering of other horses, camels, antilocaprids, peccaries, and carnivores (table 10). Richey (1979) described a lower jaw of *Osteoborus*. An excellent lower jaw of a gomphothere, probably *Rhynchotherium*, was described by Savage (1955b). Additional specimens were obtained by the University of California and the Frick Laboratory in 1953 and by West Texas State University in more recent years.

No paleomagnetic data exist for this site. The fauna, which is latest Hemphillian, resembles that from the Axtel site and other small sites in the Palo Duro area and is more advanced than the one from Coffee Ranch (table 9). The horses suggest a correlation with the late Hemphillian Yepomera fauna of Mexico (MacFadden, 1984b).

Latest Hemphillian Gravel Pits

Several gravel pits in Ellis County, Oklahoma (Miller, Nations, Campbell, and Virgil Clark), occupy deep channels cut into the top of the Ogallala. These have yielded horse teeth (*Astrohippus stocki* and *Neohipparion* cf. *N. eurystyle*) of latest Hemphillian age (Tedford and others, 1987).

Table 10. Faunal lists of latest Hemphillian local faunas of the Texas Panhandle. Modified after Johnston and Savage (1955).

	A	B	C
Class Reptilia			
Order Chelonia			
Family Testudinidae			
Geochelone turgida (Cope) - tortoise	X		
Geochelone sp. - large tortoise		X	X
Testudinid sp. - small tortoise		X	
Class Mammalia			
Order Edentata			
Family Megalonychidae			
Megalonyx sp. - ground sloth	X		
Order Rodentia			
Family Mylagaulidae			
Mylagaulus sp. - burrowing rodent	X		
Family Geomyidae			
Geomys sp. - pocket gopher	X		
Order Carnivora			
Family Felidae			
Machairodus (*Heterofelis*) sp. - saber-toothed cat	X		
Machairodont? - saber-toothed cat		X	
Family Canidae			
Osteoborus hilli Johnston - bone-eating dog	•		
Osteoborus sp. - bone-eating dog		X	X
Canis sp. - coyote-sized form	X		
Canid sp. - small form		X	
Family Mustelidae			
Pliotaxidea sp. - badger	X		
Mephitine sp. - skunk		X	
Family Ursidae			
Agriotherium sp. - bear	X		
Order Proboscidea			
Family Gomphotheriidae			
Rhynchotherium? sp. - gomphothere		X	X
Order Artiodactyla			
Family Tayassuidae			
Prosthennops sp. - peccary	X	X	
Family Camelidae			
Megatylopus? - large camel	X	X	X
Hemiauchenia sp. - llamalike camel	X	X	
Family Antilocapridae			
Hexobelomeryx ? sp. - medium-to-large pronghorn	X	X	
Order Perissodactyla			
Family Equidae			
Dinohippus cf. *D. mexicanus* (Lance) - 1-toed horse	X	X	X
Astrohippus cf. *A. stocki* (Lance) - 1-toed horse	X	X	X
Neohipparion cf. *N. eurystyle* (Cope) - 3-toed horse	X	X	X
Nannippus cf. *N. lenticularis* (Cope) = *Nannipus ingenuus* (Leidy) - 3-toed horse	X		

• Holotype of species
X Occurrence in fauna
A Axtel, Randall County, Texas
B Christian Ranch, Armstrong County, Texas
C Currie Ranch, Randall County, Texas

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