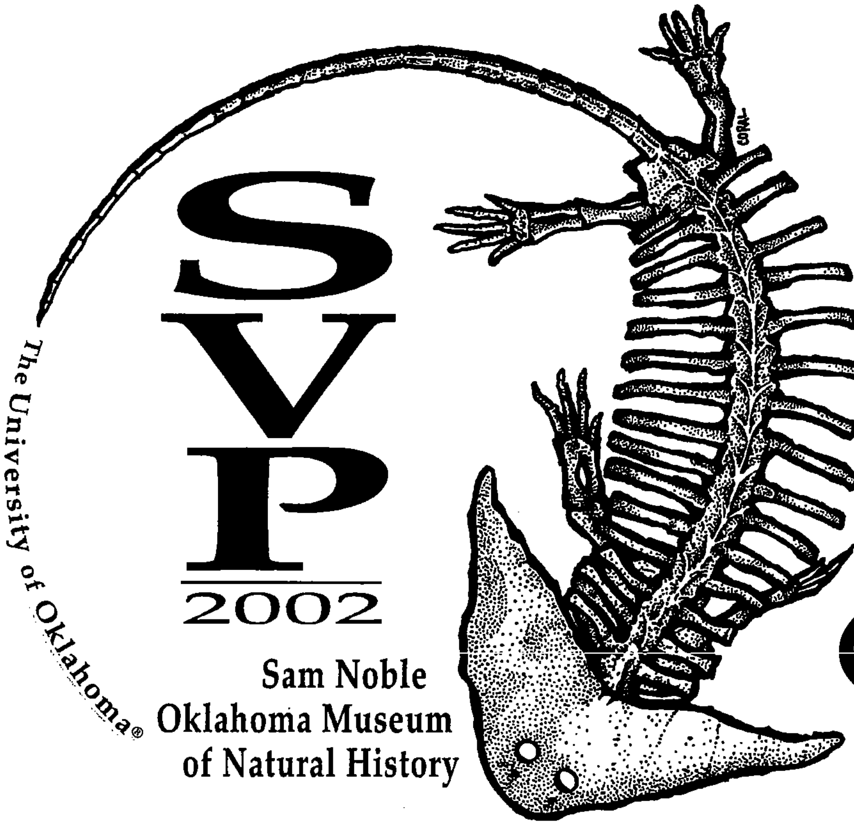

Field Trip Guidebook

62nd Annual Meeting

Oklahoma Geological Survey
Open-File Report 10-2002

Photograph on Front Cover:
Participants in the 1977 North American Paleontological Convention Field Trip to the Texas and Oklahoma Panhandles. Front Row (seated left to right): Gerald Schultz, Bruce MacFadden, Greg Retallack, Kay Behrensmeyer, Jane Voorhies, Judith Van Couvering, Mary Ann Turner. Back Row (standing left to right): Gordon Edmond, John Boellstorff, Richard Tedford, David Webb, Jack Hughes, Lloyd Tanner, Michael Voorhies, Lewis Bremer, King Richey, David Jones, Morris Skinner.

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Field Trip Guidebook

62nd Annual Meeting Norman, Oklahoma

Edited By:

Roger Burkhalter
Nicholas Czaplewski
and
Richard Lupia

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Preface

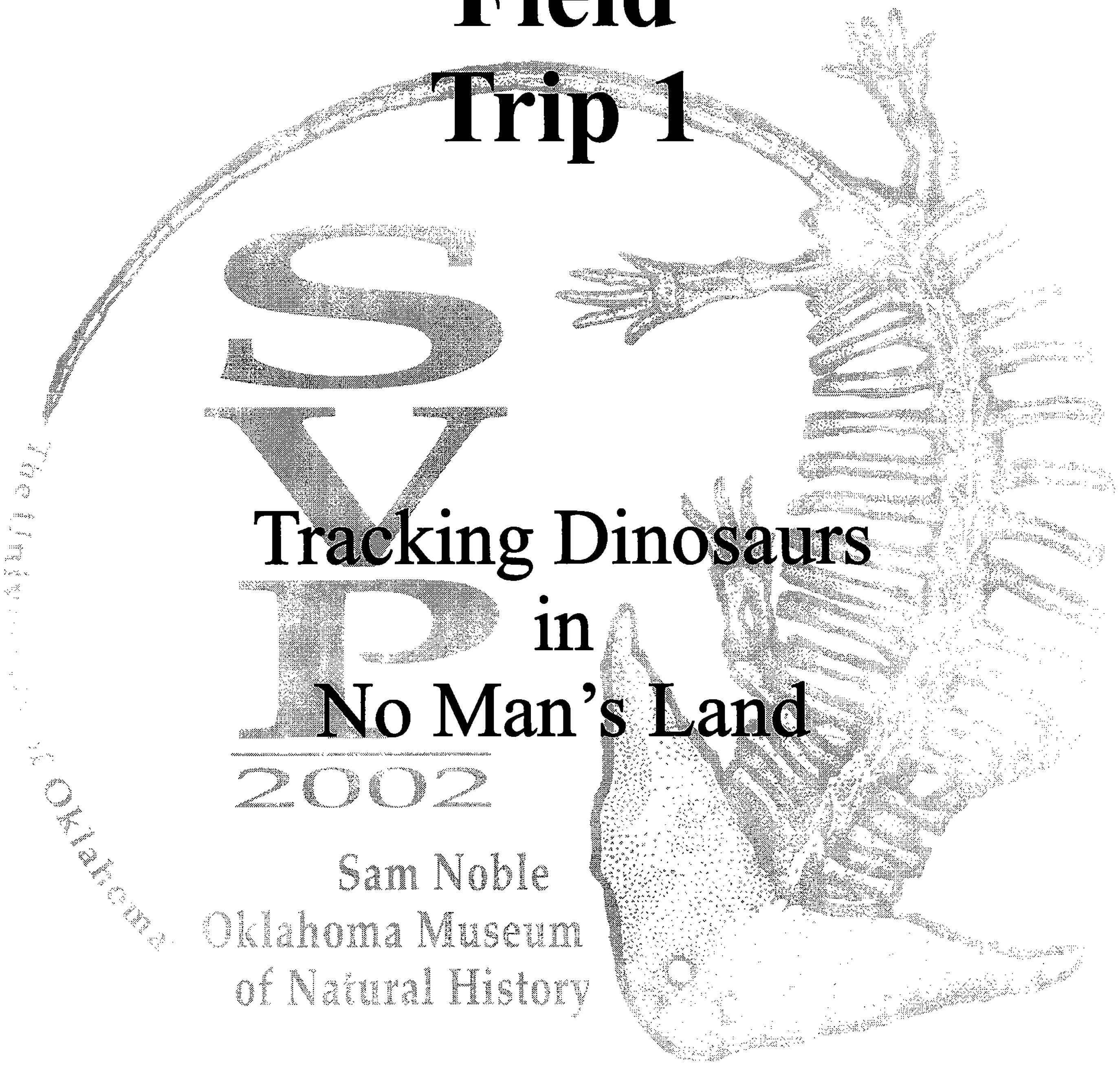
The papers presented in this Oklahoma Geological Survey Open File Report serve as the field trip guidebook for the 62nd Annual Meeting of the Society of Vertebrate Paleontology, hosted by the Sam Noble Oklahoma Museum of Natural History at The University of Oklahoma in Norman, Oklahoma. These contributions summarize the current state of vertebrate paleontology in the southern plains region. The first two papers focus on the Mesozoic, the third paper focuses on the Cenozoic and the fourth and fifth papers focus on upper Paleozoic paleontology.

This Open File Report will be reviewed and re-edited for final publication as an Oklahoma Geological Survey Guidebook series report, available sometime in 2003 from the OGS.

Several individuals combined to make the field trips and this report possible. These include the editors of this report, the field trip leaders and co-leaders, the Host Committee, the SVP Business Office, the Sam Noble Oklahoma Museum of Natural History and Michelle Flood, who worked tirelessly making travel arrangements.

Field
Trip 1

Tracking Dinosaurs in No Man's Land



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A Guide to Tracking Dinosaurs in "No Man's land": Mesozoic Tracksites from the Tri-State area of Colorado, Oklahoma and New Mexico

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ABSTRACT: No less than ten Upper Triassic, seven Upper Jurassic and eighteen mid Cretaceous vertebrate tracksites are known in and around No Man's Land - the tri-state area where northeastern New Mexico meets southeastern Colorado and the Oklahoma panhandle. Each of these three ichnofaunas forms part of a distinct regional facies that needs to be understood in paleoenvironmental and sequence-stratigraphic context. Upper Triassic tracksites provide evidence of the rise of saurischian dinosaurs, including the oldest sauropods in North America, while Upper Triassic non-dinosaurian faunas were still abundant. Upper Jurassic sites provide evidence of classic Morrison sauropod-theropod faunas, with pterosaurs, in lacustrine settings. Mid-Cretaceous ichnofaunas document dinosaur (ornithopod and theropod) and crocodilian activity along the coastal plain of the Western Interior Seaway during the onset of the Cenomanian transgression. The resulting ichnofacies is now famous as the "dinosaur freeway." In addition to these 35 documented sites, we may add at least five Upper Cretaceous tracksites, found to the west of the area, near Trinidad (Colorado) and Raton (New Mexico), that shed light on dinosaur activity and population levels at the K/T boundary.

Three large Upper Triassic sites provide good censuses of Rhaetian vertebrate faunas. They suggest the presence of sauropods, which are not known from skeletal remains, and relatively abundant small theropods and prosauropods, along with other non-dinosaurian reptiles. The Upper Jurassic Purgatoire Valley tracksite remains the largest, mapped dinosaur footprint locality in North America, while a coeval site in Oklahoma reveals the first well-authenticated pterosaur tracks from the Morrison Formation. Two mid-Cretaceous tracksites in New Mexico have provided stimulating debate on two subjects: gregarious behavior among ornithopods of different age groups, and the criteria necessary for discriminating between crocodilian and pterosaurian tracks.

INTRODUCTION

Dinosaur tracks and other fossil footprints are well known from Upper Triassic, Upper Jurassic and Cretaceous sedimentary sequences in and around the Cimarron Valley of the tri-state area, where Colorado, Oklahoma and New Mexico meet. (The Oklahoma panhandle is known as "No Man's Land", Hanners, 1996). Track-bearing outcrops have been reported east of Folsom, New Mexico and downstream to the vicinity of Kenton, Oklahoma (Conrad and others, 1987; Lockley and others, 1993, 1996a,b, 2000, 2001a,b). Cretaceous tracks also occur to the northeast of Kenton, on both sides of the Colorado-Oklahoma border (Lockley and others, 1992; Lockley and Hunt, 1995). The main track-bearing formations with known track types are summarized in Table 1. Tracksites also occur as far south of Kenton as Clayton and Tucumcari, New Mexico.

GENERAL GEOGRAPHICAL AND GEOLOGICAL SETTING

Most of the sites outlined in this guide are situated in the Dry Cimarron Valley in Union County, northeastern-most New Mexico; Cimarron County, at the western end of the Oklahoma Panhandle (No Man's Land); or Baca County, in southeastern-most Colorado (Figure 1). This region is part of the High Plains physiographic province (1200 – 1500 m elevation) and is dominantly prairie with small hidden canyons. Black Mesa, situated almost at the tri-state junction near Kenton, Oklahoma, is the highest point in Oklahoma at 1507 meters. The famous Purgatoire Valley dinosaur tracksite is located in Comanche National Grasslands to the north in Colorado. The Purgatoire River, a tributary of the Arkansas River, eventually meets the Cimarron River at Tulsa, Oklahoma. To the south of the Cimarron Valley, in Union County, various tributaries of the Canadian River (e.g., Rita Blanca and Carrizo) flow

Age and Geological Unit	Track types	References
CRETACEOUS-TERTIARY Raton Formation	Tyrannosaurid, hadrosaurid, ceratopsian, bird and ?turtle	Lockley and Hunt, 1994,1995
CRETACEOUS Dakota Group	Ornithopod and theropod dinosaurs, crocodilians	Lockley and others, 1992, Lockley and Hunt, 1995 Bennett, 1993
LATE JURASSIC Morrison Formation	Theropod, sauropod and pterosaur	Lockley and others, 1992, 1996, 2000, 2001a, Stovall 1938
LATE JURASSIC Summerville Formation	Theropod and pterosaur	Lockley and others, 2001
LATE TRIASSIC Sheep Pen Formation	Theropod, prosauropod, other reptiles	Lockley and others, 1993, 2001b
LATE TRIASSIC Sloan Canyon Formation	Theropod, prosauropod, sauropod, other archosaurs, lepidosauromorphs, and synapsids	Conrad and others, 1987 Lockley and Hunt, 1993, 1995, Lockley et al, 2001b
LATE TRIASSIC Bull Canyon Formation	Unknown tetrapod	Hunt and others, 1993

Table 1. Mesozoic track-bearing units, track types and date sources for tri-state area.

east-southeast through the Kiowa National Grassland near Clayton, where another well-known tracksite is located in Cretaceous sediments at Clayton Lake State Park. Further to the south, near Mosquero, about 64 km north of Tucumcari, is another significant Cretaceous tracksite.

In the west of Union County is the small settlement of Folsom that gives its name to one of the oldest and best-known Native American cultures and associated stone tool industries. Only 10 km southwest of Folsom is Capulin Volcano National Monument, a late Cenozoic cinder cone. Further to the west, towards the Rocky Mountain Front Range around Raton, New Mexico, and Trinidad, Colorado, many famous, iridium-bearing K/T boundary sections have been identified in association with a number of dinosaur and bird tracksites. East of Union County, in Cimarron County, Oklahoma, and Baca County, Colorado there are a surprising number of Late Triassic, Early Jurassic and Cretaceous tracksites.

Throughout most of this area of Union County, significant portions of the Mesozoic section are either missing or significantly condensed. The oldest rocks in the region, exposed in the deeper uplifted parts of the Purgatoire and Cimarron valleys, are Permo-Triassic red beds that have proved difficult to differentiate owing to lack of fossils. Traditionally many were assigned to the Triassic Dockum Group, now reclassified as the Chinle Group (Lucas 1993). In the NE New Mexico and NW Oklahoma area at least six formations have been recognized within the Chinle Group (Lucas, 1993, fig. 5). Of these, only the upper two (Sloan Canyon and Sheep Pen) have yielded tracks, although footprints also have been reported from the older Bull Canyon Formation in east-central New Mexico, near Tucumcari (Hunt and others, 1993).

Above the Chinle Group there is a major break in the succession with most of the Lower and Middle Jurassic interval up to the Entrada Formation missing. The Entrada Formation is exposed only sporadically. Above this we find a thin sequence of the Middle-Late Summerville Formation (formerly called the Bell Ranch Formation) which yields theropod and pterosaur tracks. Above this is a fairly complete section of the Morrison Formation, which is undifferentiated, consisting only of fine-grained Brushy Basin facies (without the "Salt Wash" channel sandstone facies found west of the Front Range).

Above the Morrison Formation the Lower Cretaceous succession consists of the Lytle Sandstone, which contains no tracks; the marine Purgatoire Formation, which also contains no tracks; and the Dakota Group which is rich in tracks (Lucas and others, 1989; Lockley and others, 1992, 2000). In the tri-state area the Dakota Group is divided into the Mesa Rica Sandstone and the overlying Pajarito Formation. Most of the tracks are at or near the contact of these two formations.

IMPORTANT TRACK ASSEMBLAGES

Although there are dozens of tracksites in the tri-state region, they fall naturally into three major groups, or ichnofacies, all of which appear to have regional sedimentological and stratigraphic significance. In strict ichnological terms multiple track or trace fossil assemblages (ichnocoenoses), with similar composition, that occur repeatedly in similar sedimentray facies, can be referred to collectively as an ichnofacies. These are sometimes loosely referred to as ichnofaunas. Broadly speaking, there are three ichnofacies or ichnofaunas, as follows.

Late Triassic Ichnofacies.

There are at least seven Late Triassic tracksites from the Sloan Canyon and Sheep Pen Formations along or near

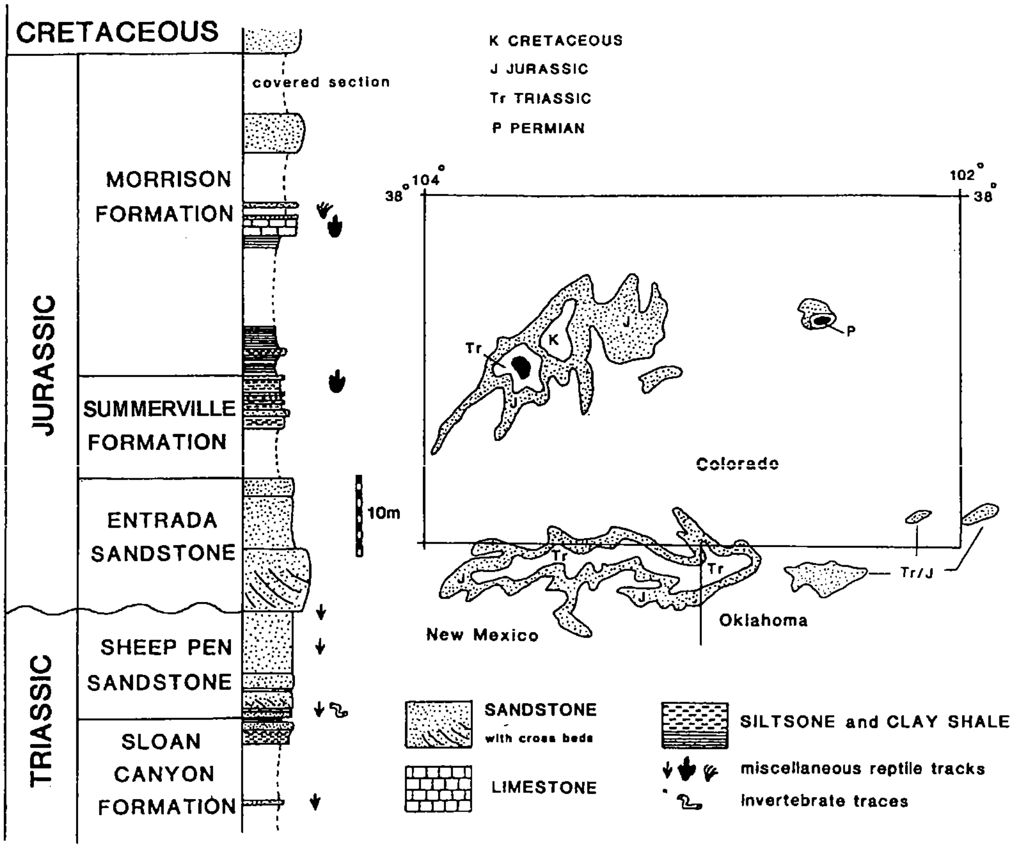


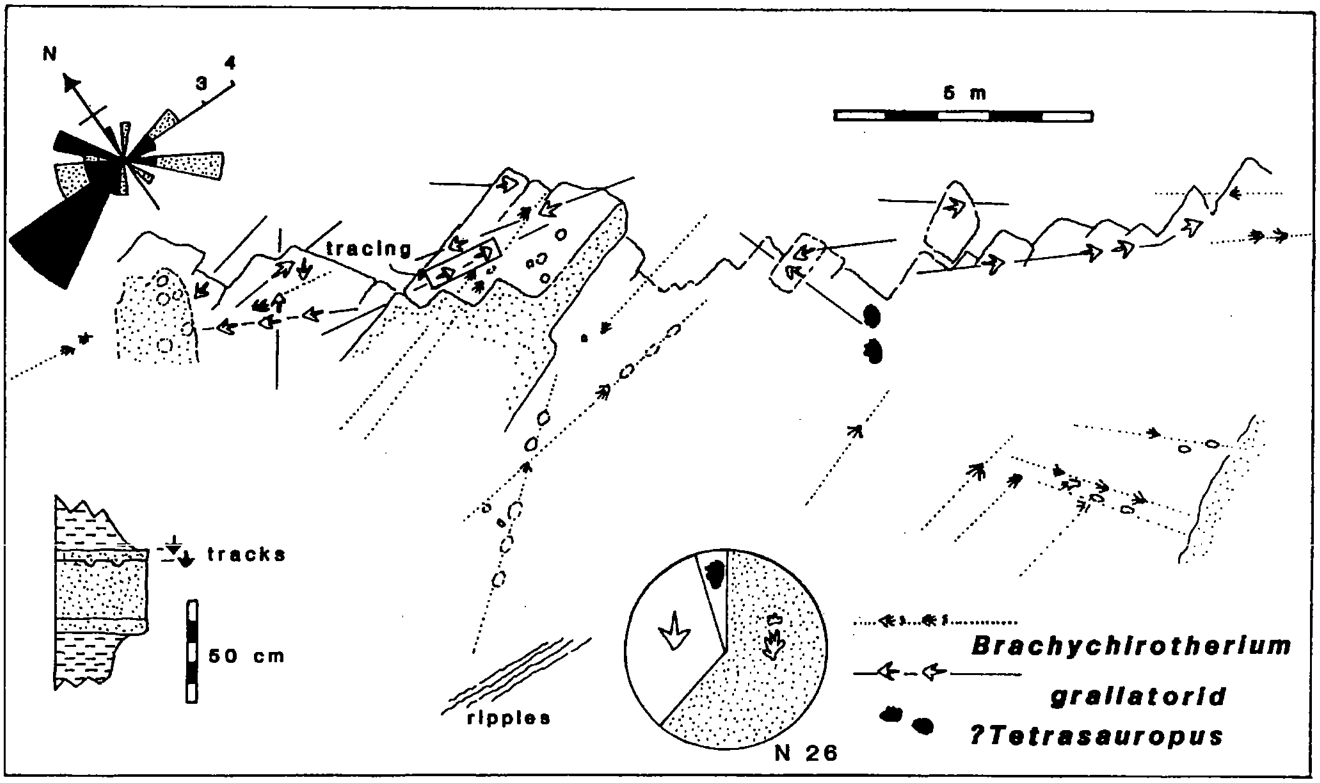
Figure 1. Locality map and Late Triassic-Jurassic stratigraphic section for tri-state area. Modified after Conrad and others (1987). Note that the Bell Ranch Formation is also referred to as the Summerville Formation.

the main axis of the Cimarron Valley between Folsom and Kenton (Union, Cimarron and Baca Counties). In addition there are several tracksites in the stratigraphically equivalent Redonda Formation of Quay County to the south, near Tucumcari. Significant collections from the former region are held in the University of Colorado at Denver collections, and collections from the latter region are held at the Mesalands Dinosaur Museum (Tucumcari) and in the New Mexico Museum of Natural History and Science (Albuquerque).

It has been noted that throughout the outcrop of the Chinle Group, in New Mexico, Texas, Oklahoma, Colorado, Wyoming, Utah and Arizona, there is a very high concentration of tracksites in the uppermost formations and members (Lockley and Hunt, 1995). This is in contrast to a lack of tracksites in all other formations at lower stratigraphic levels. This distribution means that tracks are only common in association with the uppermost of the four

Small *Grallator* (theropod) 33	***Pseudotetrasauropus* (prosauropod) 12**
Large theropod 11	***Tetrasauropus* (?sauropod) 53**
***Brachychirotherium* (about 20)**	***Rhynchosauroides* (many)**
Large therapsid	**Small therapsid/mammal**

Table 2: Census of trackways counted at various sites in the tri-state and Tucumcari areas



Sloan Canyon Tracksite

Figure 2. Map of Sloan Canyon Tracksite. Modified after Lockley and Hunt (1993). Note that treackways tend to run E-W, parallel to ripple crests.

Chinle Group faunochrons (A-D), designated the Apachean land vertebrate faunochron (Lucas, 1998), now considered Rhaetian in age. Such concentration of dozens of tracksites at a particular stratigraphic level suggests some form of sequence-stratigraphic control, and indeed this part of the Chinle Group has been referred to as the Rock Point sequence (Lucas, 1998, Lucas and Huber, 1994) including the aforementioned Redonda, Sloan Canyon, and Sheep Pen formations.

Tracksites known from all of the states listed above (except Texas) have produced rich vertebrate track assemblages represented by tracks attributed to one or more of the following groups: theropods, prosauropods, ? sauropods, non dinosaurian archosaurs, lepidosauromorphs, therapsids and mammals. The most common ichnogenera, corresponding to the first five trackmaking groups listed above, are: *Grallator, Pseudotetrasauropus, Tetrasauropus, Brachychirotherium* and *Rhynchosauroides.*

Recent work on the ichnogenera *Pseudotetrasauropus* and *Tetrasauropus,* originally named on the basis of South African tracks (Ellenberger, 1972, 1974), has led to the conclusion that both prosauropods and true sauropods were present in western North America in the Late Triassic, even though there is no skeletal evidence for the latter group (Lockley and others, 2001b). Details of all sites are given below.

Late Jurassic Ichnofacies

Late Jurassic ichnofacies are known from five sites in the Summerville and Morrison Formations near Kenton, Oklahoma (Lockley and others, 2001a) and two sites in the Morrison Formation in the Purgatoire Valley near Higbee, Colorado (Lockley and others, 1986, 1997). The Summerville sites yield pterosaur and theropod tracks. The Morrison sites yield theropod, sauropod and pterosaur tracks. Sites in the Summerville Formation appear to represent marginal marine deposits associated with the southern shores of a large marine embayment that opened to the north during the Middle to Late Jurassic. Pterosaur tracksites occur in coeval (i.e., Summerville equivalent) deposits in NE Arizona, eastern Utah, western Colorado and Wyoming. Thus, the distribution of these sites is part of a regional picture associated with an early Late Jurassic rise in sea level. Details of all sites are given below.

Mid-Cretaceous Ichnofacies

Mid-Cretaceous ichnofacies in northeastern New Mexico and southeastern Colorado are associated with the latest Albian-early Cenomanian transgression, and form part of a complex of tracksites associated with early transgressive system tract deposits that can be traced from near Tucumcari, New Mexico, to as far north as Boulder, Colorado (Lockley and others, 1992). Such regionally-

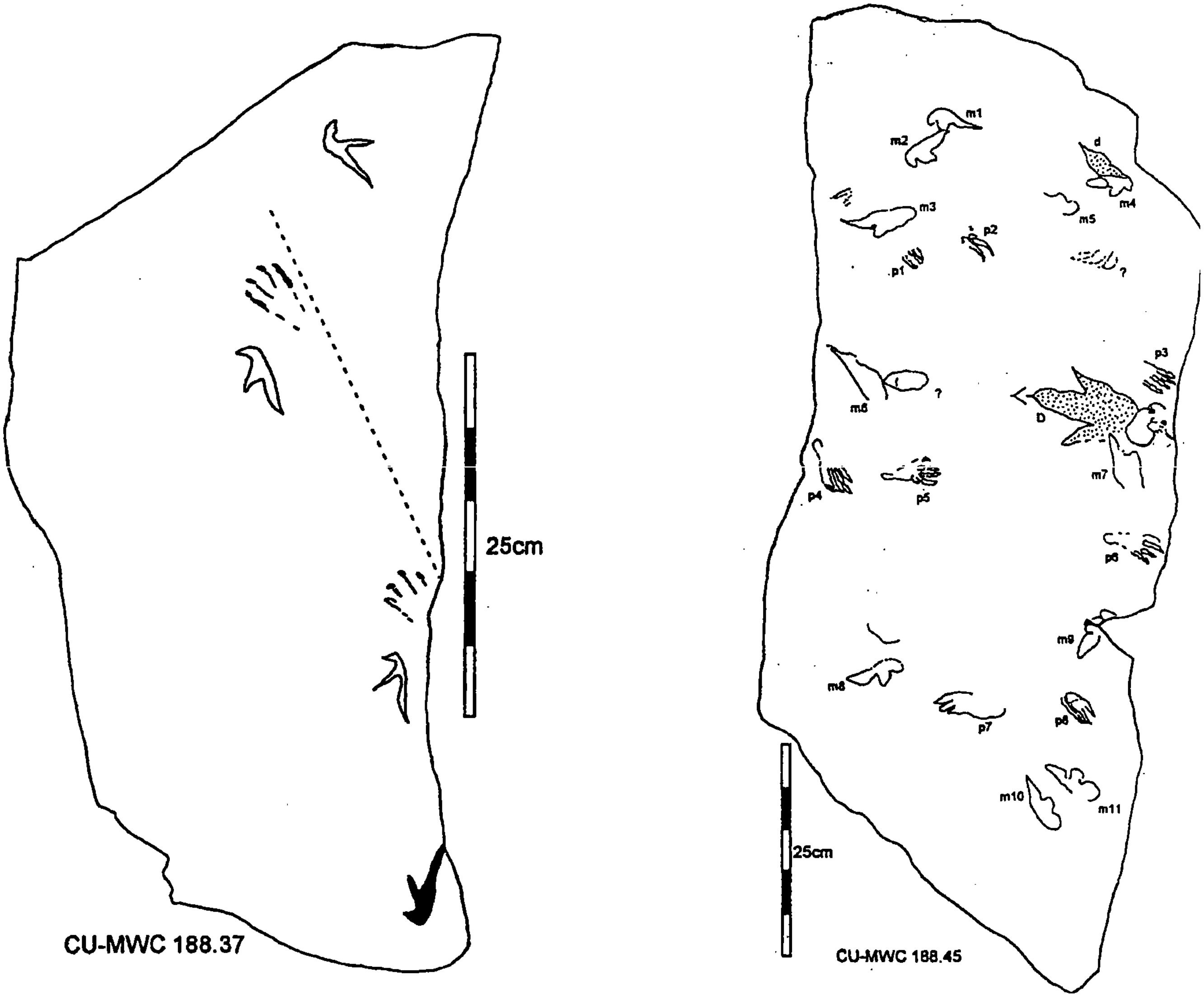


Figure 3. Left: Pterosaur trackway (white) and isolated track (black) from the Summerville Formation (Baca County Colorado) and, right: theropod track (stippled) and pterosaur tracks from the Morrison Formation (near Kenton Oklahoma). Modified after Lockley and others, (2001a)

extensive track-bearing facies have been dubbed "megatracksites" or "dinosaur freeways" (Lockley and Hunt, 1995). More than 30 sites have been recorded at this stratigraphic level at outcrops that cover a minimum geographic area of 30,000 m^2 (about 80,000 km^2). Tracks at these sites can be attributed to bird like ?ornithomimid dinosaurs (ichnogenus *Magnoavipes*), ornithopod dinosaurs (probably iguanodontid, ichnogenus *Caririchnium*), ? ankylosaurid dinosaurs, crocodilians and birds. Details of all sites are given below.

LATE TRIASSIC TRACKSITES

The following list registers seven Late Triassic vertebrate tracksites in the immediate tri-state area. In addition there are at least three more tracksites (Apache Canyon, Mesa Redonda and Bull Canyon) to the south in the Tucumcari area (Lockley and others, 2000, Hunt and others, 2000). The Apache Canyon and Mesa Redonda tracksites are in the Redonda Formation and contain *Grallator* and *Pseudotetrasauropus*. They correlate with the tri-state tracksites. Note that pre-2001 reports do not identify *Tetrasauropus* as a probable sauropod track (see Lockley and others, 2001b). When combining tri-state and Tucumcari area tracksites about 109 dinosaur trackways have been recorded, along with others attributed to archosaurs and other tetrapods (Table 2).

The above survey does not include data from the Bull Canyon Formation tracksite, which occurs in a lower sequence within the Chinle Group. Here we find tracks of at least two quadrupeds assigned to the ichnospecies *Barrancapus cresapi*. The affinities of this trackmaker are unknown. (see Hunt and others, 1993, fig 2).

Summary of Late Triassic tracksites

Not all sites are on private land and not accessed easily. Maps of most sites have been published. The first three listed are large sites that provide useful census data (e.g., Sloan Canyon site)

Sloan Canyon type section:
Union County, New Mexico, (Lockley and Hunt, 1993). Main site reveals at least 26 trackways, attributed to *Brachychirotherium*, grallatorids (theropod) and a single ? sauropod (*Tetrasauropus*): see Figure 2.

Peacock Canyon:
Union County, New Mexico; Sloan Canyon Formation (Conrad and others, 1987; Lockley and Hunt, 1995). This large site has historical significance because, as noted by Conrad and others (1987), two specimens from the site were described (incorrectly) by Baird (1964). The site was first mapped by Lockley (1986), but see Lockley and Hunt (1995) and Lockley and others (2000, 2001b) for updates. The site reveals at least 44 dinosaur trackways attributed to ?sauropods (*Tetrasauropus*), *Pseudotetrasauropus*, and *Grallator*. Also *Brachychirotherium*, many *Rhynchosauroides* and possible synapsid tracks are present.

Furnish Canyon:
Baca County, Colorado; Sloan Canyon Formation (Lockley and others, 2001b). Ten mostly parallel trackways, possibly of ?sauropods (*Tetrasauropus*).

Tucker Ranch site 1 (Lower):
Baca County, Colorado; Sheep Pen Sandstone (Conrad and others, 1987, fig. 8). Small *Grallator* track casts.

Tucker Ranch site 2 (Middle):
Baca County, Colorado; Sheep Pen Formation (Conrad and others, 1987, fig 9). At least eight small *Grallator* trackways and two *Brachychirotherium* trackways.

Tucker Ranch site 3 (Upper):
Cimarron, County, Oklahoma; Sheep Pen Sandstone (Conrad and others, 1987). At least ten small *Grallator* trackways and possible tracks of *Brachychirotherium.*

Wheeler site:
Union County, New Mexico; Sheep Pen Sandstone (Lockley and others, 1993). About ten *Grallator* trackways, a small *Pseudotetrasauropus* trackway and possible therapsid/mammaloid tracks.

Summary of Late Jurassic Tracksites:

Note: unless otherwise stated, all tracksites are on private land.

Furnish Canyon:
Baca County, Colorado; Summerville Formation (Lockley and others, 1996, 2001a) Site reveals only pterosaur tracks (cf. *Pteraichnus*): see Figure 3.

Kenton North:
Cimarron County, Oklahoma; Summerville Formation (Lockley and others, 1996, 2001a). Site reveals two trackways of a large theropod (cf. *Megalosauripus*).

Kenton West 1 :
Cimarron County, Oklahoma; Morrison Formation (Lockley and others, 2001a) Site first reported by West (1978) reveals a slab with many pterosaur tracks (cf. *Pteraichnus*): see Figure 3.

Kenton West 2 :
Cimarron County, Oklahoma; Morrison Formation (Lockley and others, 2001a). Site reveals two small theropod tracks

Stovall site:
Cimarron County, Oklahoma; Morrison Formation (Schoff and Stovall, 1943). Sauropod tracks reported, and site given, but not re-located.

Picketwire Canyonlands:
Las Animas County Colorado; Morrison Formation (Lockley and others, 1986, 1997). This is unquestionably the largest and most significant dinosaur tracksite in the region. Probably the largest continuously mapped site in North America (E-W dimensions of about 350 meters), it reveals more than 100 trackways (about 1300 footprints) attributable to theropods and sauropods. Sauropod tracks include type of *Parabrontopodus mcintoshi* (a narrow-gauge, small manus type) of probable diplodocid affinity (Lockley and others, 1994). Theropod track size and shape variable. Site is remarkable for having a lacustrine, oolite-bearing facies and rich biota of fish, snails, clams (trampled by dinosaurs) charophytes and horsetails. Seasonally open to the public. For information contact the U.S. Forest Service in La Junta, Colorado.

Higbee:
Otero County Colorado; Morrison Formation (Lockley and others, 1986, 1997). Theropod tracks excavated, in 1930s, for Denver Museum of Natural History and Science. Exact site and additional tracks have not be re-located.

Summary of Mid-Cretaceous Tracksites

All the sites listed below in Colorado Oklahoma and New Mexico are in what broadly can be referred to the Dakota group. More specifically however, they are associated, in most cases with the upper part of the Mesa Rica Sandstone or basal Pajarito Formation. The two common dinosaur tracks types are *Caririchnium leonardii* (Lockley 1987) representing an ornithopod, and *Magnoavipes caneeri* (Lockley and others, 2001c) representing an theropod (?ornithomimid). The ornithopod tracks from the whole region have been subjected to statistical analysis that reveals at least three size (or "age") groups (Matsukawa and others, 1999). Crocodilian tracks (cf. *Walteria jeffersoni*) are also reported sporadically. The largest sites are at Clayton Lake State Park and Mosquero Creek. The latter has been studied intensively but is on private land.

Note: unless otherwise stated, all tracksites are on private land.

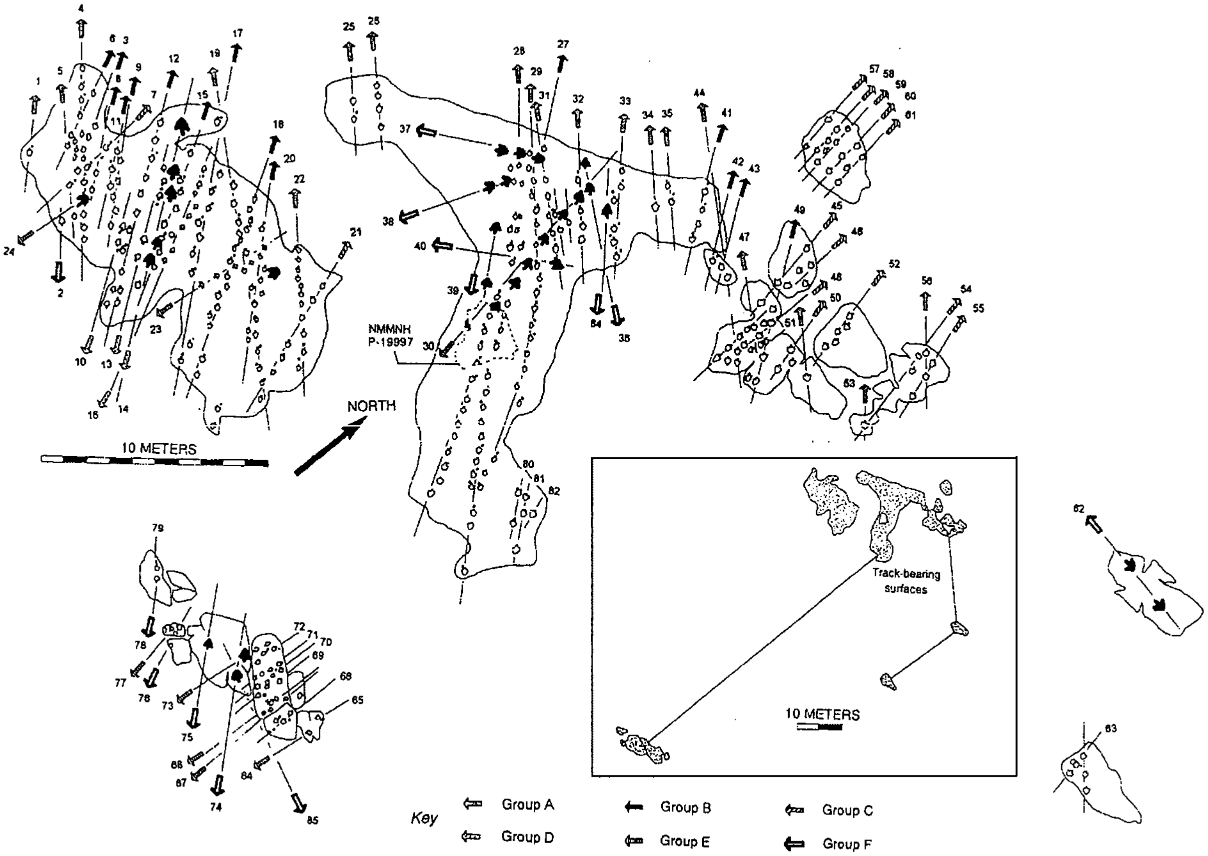


Figure 4. Map of Mosquero Creek tracksite. Modified after Matsukawa and others (in press). Groups A-C comprise 48 trackways heading north and northwest. Groups D-F comprise the remainder (about 37) heading south and southeast.

Ninaview:

Bent County, Colorado; Dakota Group (Lockley and others, 1992). Ornithopod tracks in Denver Museum of Natural History and Science.

Rourke Ranch:

Purgatoire Valley, Las Animas County. (Lockley and Foster, 1997). *?Magnoavipes* track.

Dolores Mission:

Purgatoire Valley, Las Animas County. (Lockley and Foster, 1997). ?Crocodilian swim tracks

Lamar:

Colorado; Dakota Group (Lockley, 1987; Lockley and others, 1992). Trackway excavated in 1940s for Denver Museum of Natural History and Science. Described in detail by Lockley (1987)

Springfield:

Baca County, Colorado; Dakota Group (Lockley and others, 1992). Unconfirmed reports of tracks from this area.

Richardson Ranch:

Baca County, Colorado; Dakota Group (Lockley and others, 1992). Private collection of more than 150 theropod and ornithopod tracks. Several illustrated by Lockley (1987). Single, possible ankylosaur track illustrated by Kurtz and others (2001) could be first from Dinosaur Freeway.

Gallinas Canyon:

Baca County, Colorado; Dakota Group (Lockley and others, 1992, fig. 9). May be source of many Richardson Ranch tracks. Includes ornithopod (*Caririchnium*) and theropod (*Magnoavipes* tracks)

Sand Canyon:

Baca County, Colorado; Dakota Group (Lockley and others, 1992, fig 10). Includes ornithopod (*Caririchnium*) and theropod (*Magnoavipes* tracks)

Pat's Canyon:

Baca County, Colorado; Dakota Group (Lockley and Foster 1997). Includes ornithopod (*Caririchnium*) tracks)

Picture Canyon:

Baca County, Colorado; Dakota Group. National

Grasslands Survey (Lockley and Foster 1997) discovered theropod tracks (cf. *Magnoavipes*: see Lockley and others, 2001c)

South Carizzo Creek:

Cimarron County, Oklahoma; Mesa Rica Sandstone (Lucas and others, 1989) reported several ornithopod tracks (cf. *Caririchnium*), some with manus impressions.

Clayton Lake State Park:

Union County, New Mexico; Mesa Rica Sandstone (Gillette and Thomas, 1989; Lockley and others, 1992). One of the largest exposed tracksite in the region, in the spillway of Clayton lake. This site was originally mapped/ reported by Gillette and Thomas (1985, 1989). Their interpretations of crocodilian tracks as pterosaurian has been questioned (Bennett, 1993) as has their interpretation of web-footed theropods (Lockley and Hunt, 1995).

Mosquero Creek:

Harding County, New Mexico (Lockley and Hunt, 1995: Cotton and others, 1998; Matsukawa et al, in press). This site provides the best evidence for ornithopod (*Caririchnium*) herding in the entire region of the Dinosaur Freeway. The site was mapped by Lockley and Hunt (1995: Figure 4 herein). About 48 trackways are recorded in a single direction (NW), with a total of more than 80 at the site as a whole. Gregarious behavior and speed were analyzed by Cotton and others (1998) with further detailed statistical analysis by Matsukawa and others (in press): see Figure 4.

Mills Canyon:

Harding County, New Mexico; Mesa Rica Sandstone, Lucas and others, (2000) reported several ornithopod tracks (cf. *Caririchnium*).

Cejita de los Comancheros:

Harding County, New Mexico; Mesa Rica Sandstone (Lockley and others, 1992). This site, was first reported by John Holbrook (oral. Communication). Hunt and Lucas (1998, p. 164) also report a site from Harding County.

Farley:

Colfax County, New Mexico; Mesa Rica Sandstone, Lucas and others, (2000) reported several ornithopod tracks (cf. *Caririchnium*) some with manus impressions.

Jaralosa Creek:

Socorro County, New Mexico; Dakota Sandstone (Heckert and Lucas, 1998). This site is somewhat outside the tri-state region considered in this guide, but nay, nonetheless indicate another part of the "dinosaur freeway" suitable for investigation.

Kansas swim tracks:

Kansas; Dakota Group, (McAllister, 1989a,b). For the sake of completeness, mention of a single site in Kansas with purported ornithopod swim tracks (McAllister, 1989a) is included. However, the configuration of the tracks suggests that they may be of crocodilian origin as reported at other localities in the Dakota Group (e.g., Bennett, 1993; Lockley and Hunt, 1995). A map of the slab was published by McAllister (1989b), and the specimen is on display at the museum in Fort Hayes, Kansas.

Summary of Late Cretaceous Tracksites

There are a variety of Late Cretaceous dinosaur tracks reported from the lower part of the Raton Formation between Cimarron New Mexico and Trinidad Colorado. These include tracks attributable to hadrosaurs, ceratopsians, theropods, birds and a possible turtle swim track. Bird tracks also occur in the Tertiary part of the Raton Formation above the K/T boundary (Lockley and Hunt, 1995). By far the most spectacular dinosaur track so far reported is *Tyrannosauripus pillmorei* atributed to the genus *Tyrannosaurus*, probably *T. rex* (Lockley and Hunt, 1994).

The tracks at several sites in this region occur at stratigraphic levels only within 2.00 to 0.37 meters below the K/T iridium layer. Hence they provide evidence that dinosaurs were alive and well until right before the catastrophic event(s) that caused the iridium fallout. Previously there had been unresolved debate about the significance of incomplete dinosaur remains found near the boundary, and several paleontologists had inferred a sub-K/T "3 meter gap" without any remains that were clearly indicative of living dinosaurs. The track evidence reduces the gap to no more than 37 cms.

ACKNOWLEDGEMENTS.

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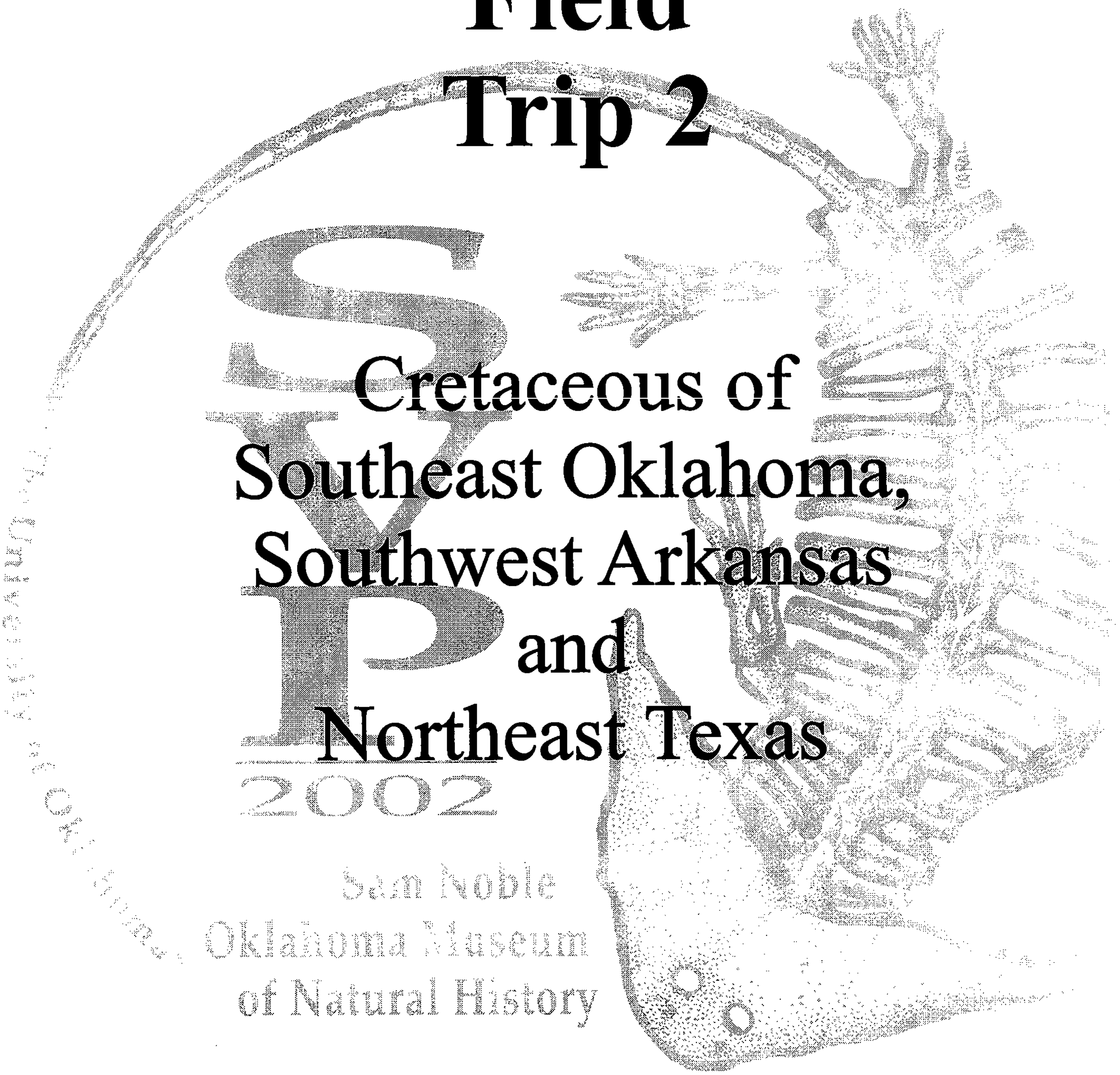
Field Trip 2



Cretaceous of Southeast Oklahoma, Southwest Arkansas and Northeast Texas

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Cretaceous Vertebrates of SE Oklahoma, SW Arkansas and NE Texas

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General Itinerary

Our trip takes us through SE Oklahoma, SW Arkansas and NE Texas (Figures 1, 2, and 3). We will leave Norman, Oklahoma and drive across Paleozoic outcrops in central Oklahoma to Atoka County in the southeastern part of the state, where dinosaur, mammal, lizard and other vertebrates have been collected from the Lower Cretaceous Antlers Sandstone. We will see localities around McCleod Prison, which have recently yielded a new sauropod, *Sauroposeidon*, and other discoveries. The Antlers Sandstone here also has given us the carnosaur *Acrocanthosaurus* (Stovall and Langston, 1950).

After the stops to see the Antlers, we will drive north into the western edge of the Ouachita Mountains and see scenery along the Talimena Parkway, which connects Talihina, Oklahoma with Mena, Arkansas, where we will spend the night. On the second day we will drive east from Mena, with a quick stop to see the Paleozoic rocks of the Ouachitas, to Murfreesboro, Arkansas where we see the onlapping contact with the Lower Cretaceous. In Murfreesboro, we will visit Crater of Diamonds State Park to see a rare kimberlite volcanic pipe emplaced during the Cretaceous Period. A short distance away from Murfreesboro, we will visit Lower Cretaceous outcrops containing sauropod dinosaur footprints and a mixed assemblage of fragmentary dinosaur, turtle and crocodile fossils, and several mammal and lizard specimens. We will see Upper Cretaceous outcrops on the way to Texarkana where we will spend the second night.

On the third day, we will drive west on the Upper Cretaceous outcrop belt of NE Texas to good exposures along the North Sulphur River just south of Paris, Texas. Artificial "canyon-cutting," following straightening of this river channel many years ago, has given us miles of outcropping Upper Cretaceous beds from which ammonite, mosasaur and other vertebrate remains steadily come. From the North Sulphur River stop, we will head back to Norman, Oklahoma, driving on the Lower Cretaceous north of Dallas and then through the Paleozoic section of the Arbuckle Mountains in south-central Oklahoma.

Physiography

The region of our field trip takes us across terrain drained by rivers and streams that generally flow eastward or southeastward toward the Mississippi River (Figure 3). The Canadian River flows east-to-west from northwestern Oklahoma, through the central part of the state near the University of Oklahoma campus, reaching the Arkansas River along Interstate 40 in the east-central edge of the state. The Canadian River and its tributaries drain the area north of the Arbuckle and Ouachita Mountains. As we reach the outcropping Cretaceous in southern Oklahoma, we see the stream drainages flowing southward toward the Red River: Blue River to the west near Tishomingo, Boggy Creek in the area of the dinosaur localities around Atoka and Antlers, and the Kiamichi and Little Rivers of southeastern Oklahoma. After the field stops near Antlers, we will drive up the Kiamichi River drainage from Antlers on Highway 2 to Talihina, Oklahoma, where we will enter the Ouachita National Forest and the Ouachita Mountains. As we see the dramatic views along the prominent ridge road called the Talimena Parkway, connecting Talihina, Oklahoma to Mena, Arkansas, we can look to the south to see headwaters of streams flowing southward into the Gulf Coastal Plain province and to the north to see headwaters of streams flowing north toward the Arkansas River in its broad valley between the Ouachita Mountains and the Ozark Mountains. Rocks in the Ouachita Mountains in southeastern Oklahoma and southwestern Arkansas are predominately Pennsylvanian in age. After our overnight stay in Mena, Arkansas, we will see more gentle terrain along Highway 8 toward the southeast, to Norman, Arkansas and Caddo Gap, Arkansas, where highly folded Early Paleozoic rocks crop out in the "core" of the Ouachita Mountains. We will reach the Gulf Coastal Plain province again south of Caddo Gap, as we cross the contact between

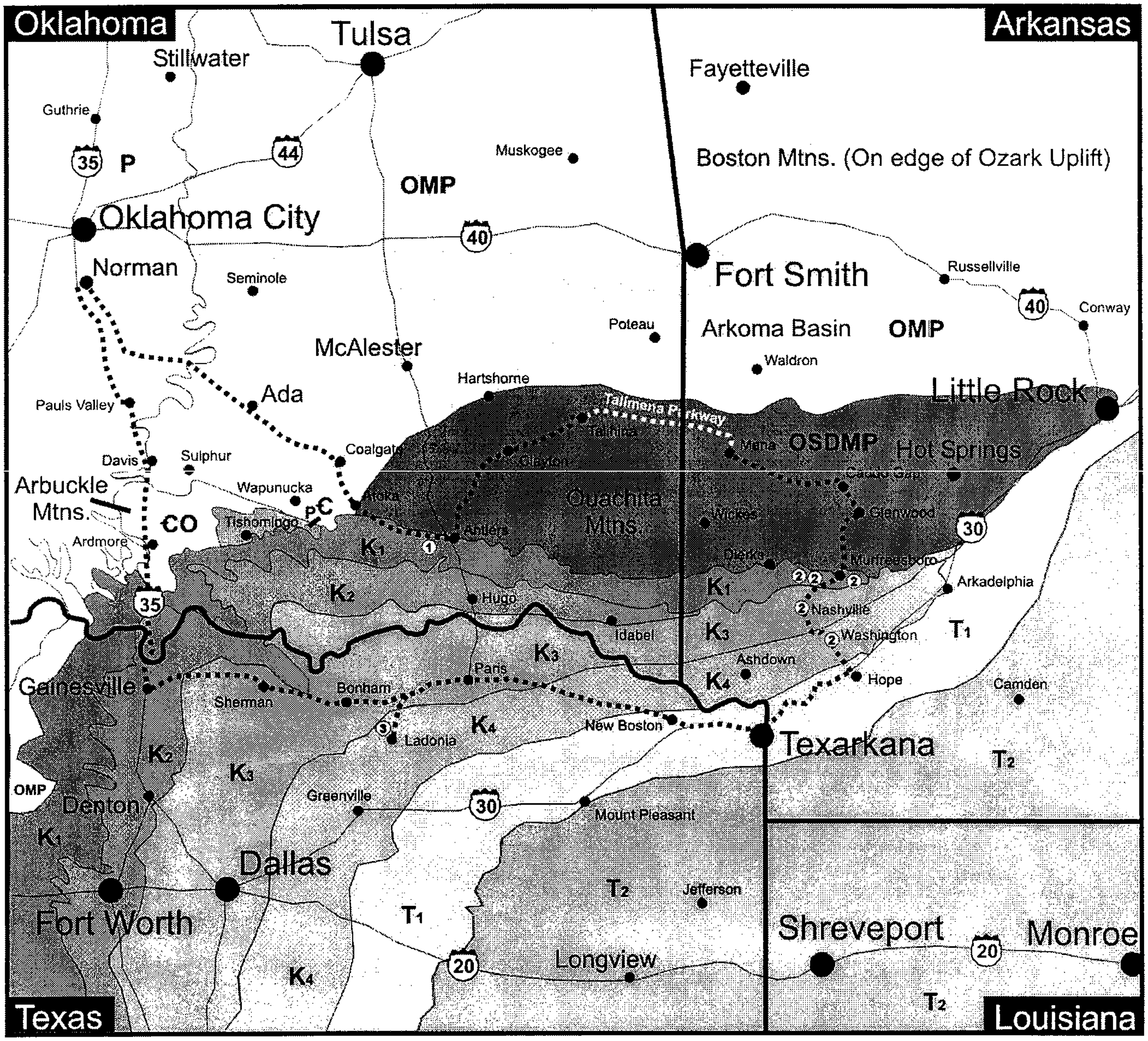

Figure 1 - Route Map / Geologic Map. The Oklahoma geologic map was modified from Branson and Johnson (1972) and the Digital Geologic Maps of Oklahoma series by the USGS (1997 -- See references for specific sheets used.). The Geologic Map of Arkansas by Haley, et al. (1993), was used for Arkansas. For NE Texas, the Sherman and Texarkana sheets of the Geological Atlas of Texas by McGowen, et al. (1967) and Shelby, et al. (1966) were used.

folded Paleozoic Ouachita beds and onlapping Cretaceous deposits. This area is at the edge of the Mississippi Embayment, lying to the east. In fact, the Caddo River, with its headwaters just up from Caddo Gap, flows eastward into the Ouachita River nearby, and the Ouachita continues to the southeast across southern Arkansas and northeastern Louisiana, where it meets the Mississippi River. Similarly, the Little Missouri River, with its headwaters near Mena in the Ouachitas, flows southeastward into the Ouachita River east of our drive. On the southward drive across the Cretaceous outcrop belt to Texarkana, we will cross streams flowing southward toward the Red River, which we cross at Texarkana. Our third day will take us across stream drainages flowing east or north into the Red River along the northern border of Texas. The Sulphur River, where we will make our only stop of the day near Paris, Texas, flows eastward across northeastern Texas, meeting the Red River south of Texarkana. We will catch Interstate 35 north of Dallas and drive across the Cretaceous-Paleozoic contact near Ardmore, and then see folded Paleozoic rocks of the Arbuckle Mountains on the drive up to Norman and the University of Oklahoma campus.

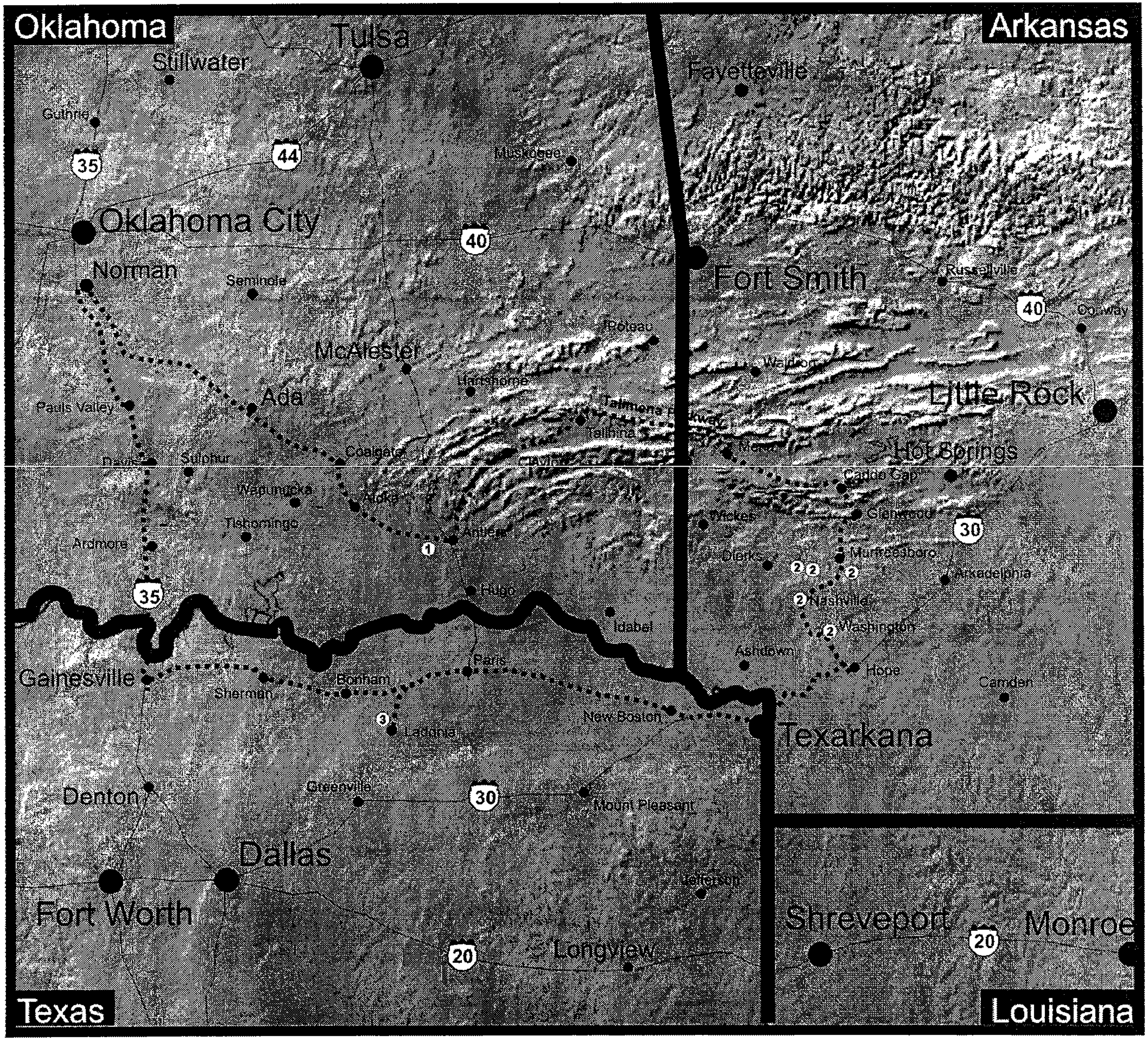

Figure 2 - Shaded Relief Map. Map cropped from digital images available at www.birrell.org (See references for description and source).

Geologic History

The Arbuckle Mountains contain shallow marine and non-marine rocks that accumulated within the Southern Oklahoma Aulacogen that, along with similar rift structures in Trans-Pecos Texas and near the Mississippi Embayment, marked the southern edge of the continent during the Early Paleozoic Era. Thick Cambrian and Ordovician limestone beds typify the Arbuckle Mountains. We will drive near the area where some of the oldest rocks in Oklahoma, the Precambrian Tishomingo Granite, are exposed in the edge of the Arbuckle Mountains (Figure 1).

The Ouachita Mountains contain Paleozoic marine strata that accumulated on and near the margin of the continent as South America and smaller blocks approached from the south. The continent-to-continent collision of the Late Pennsylvanian produced a long fold belt stretching from far southwestern Texas (exposed in the Marathon Uplift near Fort Stockton) through central Texas to the folded rocks now exposed in the Ouachita Mountains. The Ouachita fold belt extends eastward from Arkansas under Mississippi and Alabama, and roughly ties in to the Appalachian fold belt in Alabama. Folding and thrust faulting in the Ouachita Mountains is typical of such tectonic settings (Figure 4). Notably, the Arkansas Novaculite of Devonian to Mississippian age, which we see at Caddo Gap, Arkansas, and the Big Fork Chert of Ordovician age, form prominent, tightly sinuous ridges across the mountains. Younger Paleozoic beds are dominated by the turbidites of the Pennsylvanian Jack Fork

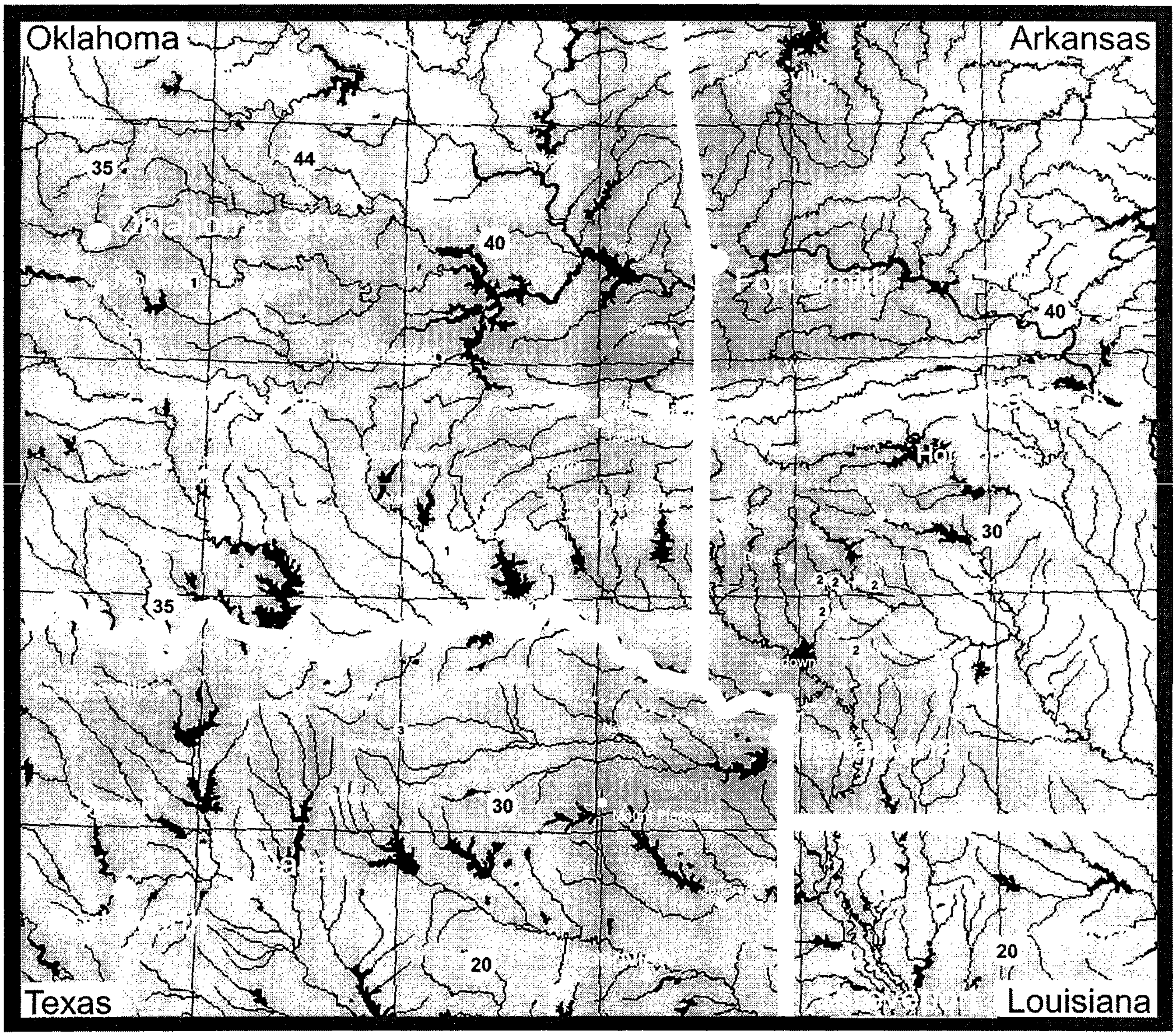

Figure 3 - Physiographic Map with Rivers and Streams. Map prepared using the Interactive Map Browser at www.nationalatlas.gov (National Atlas of the United States; see references for description).

Sandstone and adjacent units, which we will see over much of our drive through the mountains.

Late Triassic-Early Jurassic rifting opened up the Gulf of Mexico along the line marked by the Cretaceous outcrop belt across central Texas, northeastern Texas, and southern Arkansas (See the basal units of the cross section shown in Figure 5). Early stage volcanics and sedimentary deposits are found within graben structures in the subsurface of these areas, and are covered by marginal platform deposits of Jurassic age. Jurassic rocks subcrop beneath Cretaceous strata under Texarkana and in adjacent positions along the margin of the Gulf of Mexico Basin, and thus do not crop out. After a wide shelf of marginal marine clastic and carbonate deposits built up during the Jurassic Period, the continental shelf became even wider during the Cretaceous, as gravel deposits spread across the front of the Ouachita Mountains in the area of the present day Cretaceous outcrop belt. These basal Cretaceous sediments actually wrap around some protruding Paleozoic ridges along the southern edge of the Ouachita Mountains in southeastern Oklahoma and southwestern Arkansas. The Jurassic and Cretaceous is dominated by gravelly material in the area just south of the mountains -- a steady supply of hard clasts, especially from units like the Arkansas Novaculite and Big Fork Chert, eroded as the Ouachita Mountains gradually wore down. Within the Cretaceous section, we see a shifting shoreline record that has been correlated to transgressions and regressions that may be seen around the margin of the Gulf of Mexico Basin and elsewhere. Notably, the "Mid-Cretaceous Unconformity," which we see along the outcrop at the base of the Woodbine Formation (Cenomanian), is a prominent feature in the subsurface and on the outcrop. In the subsurface, we may observe that positive features around the margin of the Gulf

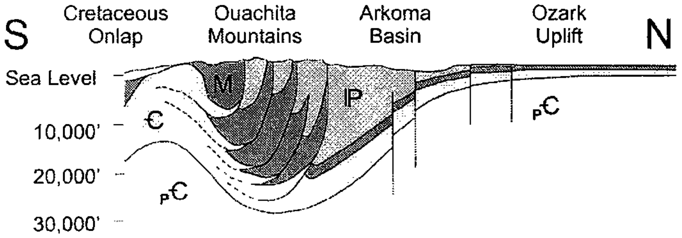

Figure 4 - Cross Section through Ouachita Mtns. of SE Oklahoma to the Ozark Uplift of NE Oklahoma (Redrawn from Branson and Johnson, 1972).

of Mexico (Sabine Uplift of northwestern Louisiana; Monroe Uplift of northeastern Louisiana) were truncated by erosion before the Upper Cretaceous beds were laid down. Volcanic activity during this time also occurred around the margin of the Gulf of Mexico Basin. The onlap of the Upper Cretaceous over older Cretaceous units in southeastern Arkansas reveals the prominent subsidence of the Mississippi Embayment that began during the Late Cretaceous (observe the termination of most Cretaceous units in SW Arkansas on the geologic map in Figure 1). On our drive through Texarkana, we will graze the edge of the Tertiary outcrop belt wrapping around the margin of the Gulf Coastal Plain..

Field Trip Descriptions

Day 1 - From Norman, Oklahoma across Paleozoic Rocks of central Oklahoma to Lower Cretaceous dinosaur-bearing outcrops of southeastern Oklahoma, to the Ouachita Mountains and Mena, Arkansas

As we leave the campus of the University of Oklahoma, we will drive southeast on Highway 3 to Ada, Oklahoma across gently dipping Permian and Pennsylvanian rock units. To the southwest of Ada, there are numerous fault and fold structures on the edge of the Arbuckle Mountains that lie along Interstate 35. In this area southwest of Ada, the oldest rocks exposed in the Arbuckle Mountains, the Precambrian Tishomingo Granite, crop out against Early Paleozoic folded sedimentary rock units (Figure 1). As we continue toward the southeast on

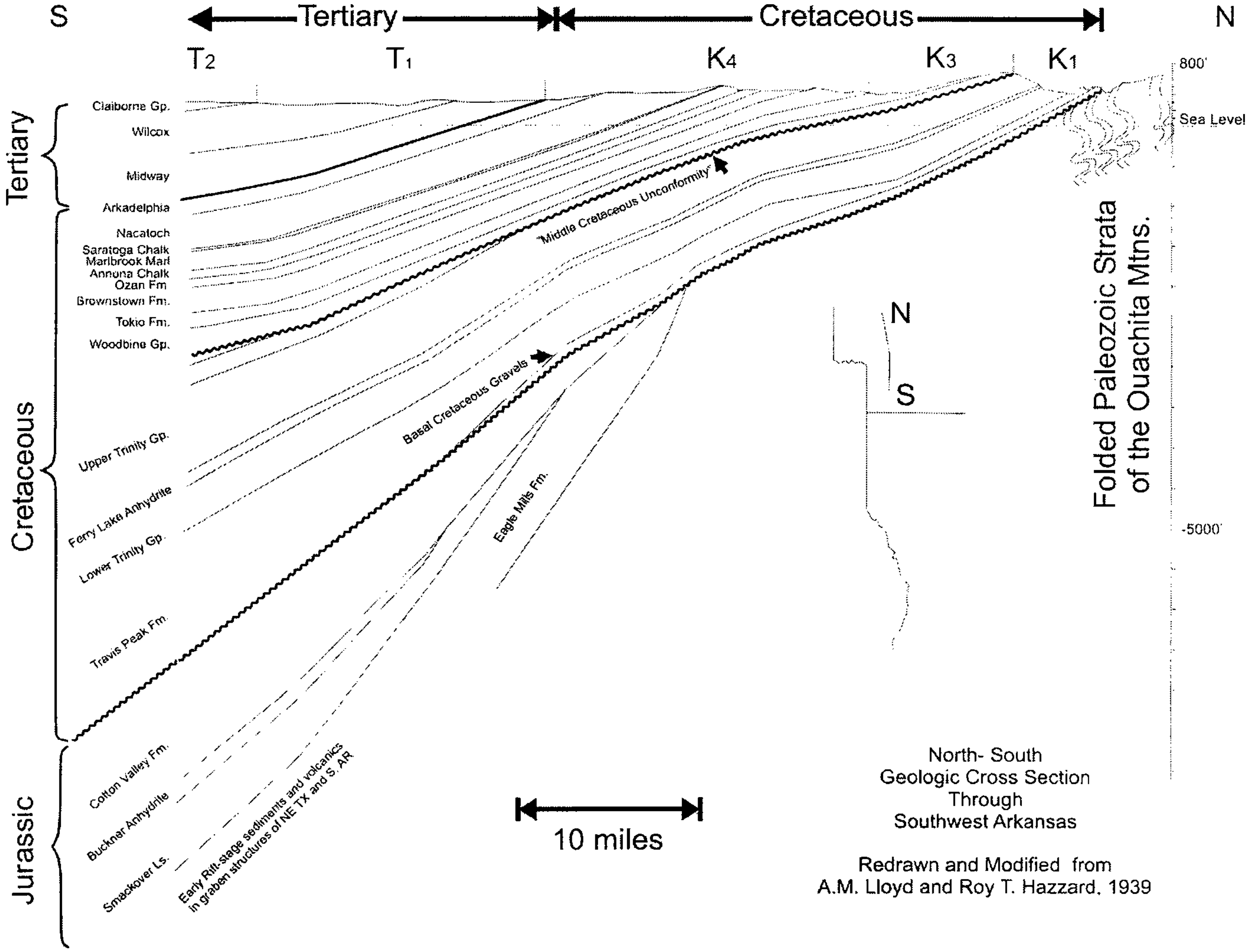

Figure 5 - Cross Section across the northern Gulf Basin in Arkansas (Redrawn from Lloyd and Hazzard, 1939). The cross section begins where Cretaceous gravels cover the flank of the Ouachita Mountains and ends in southern Arkansas, near the Louisiana state line.

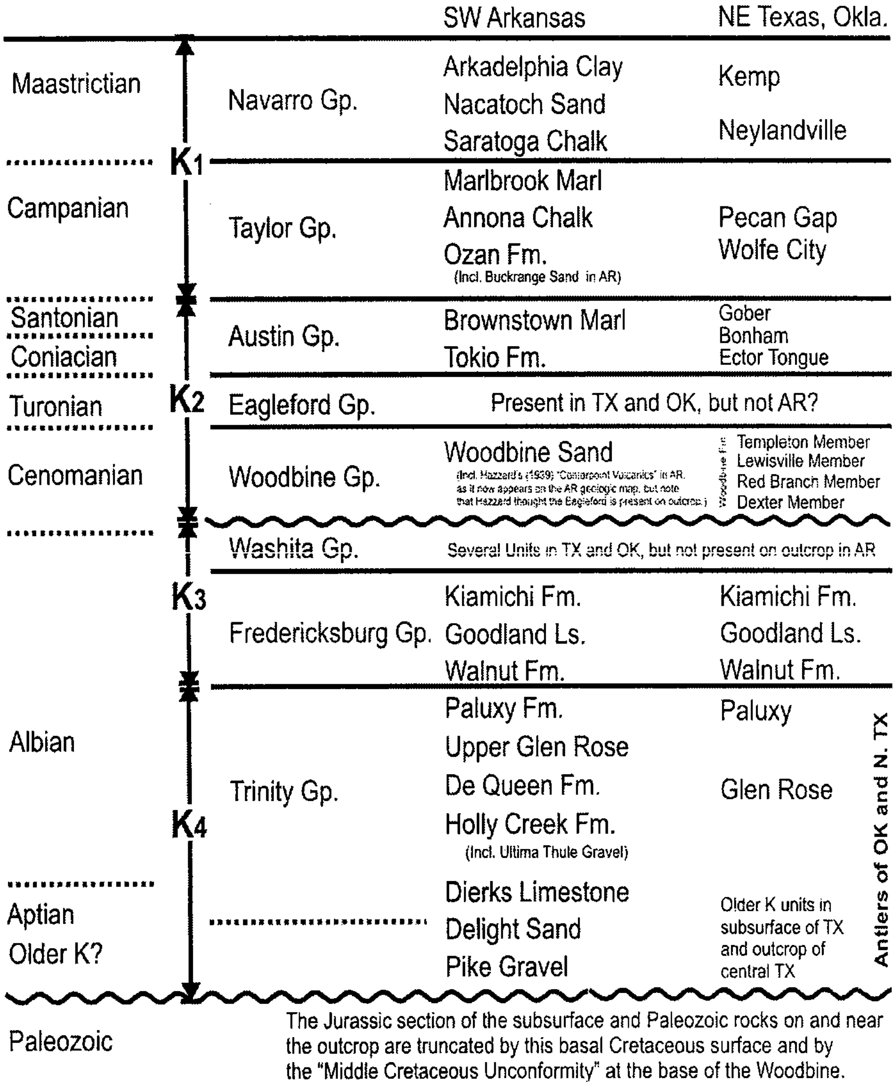

Figure 6 - Stratigraphic Column for the Cretaceous of SW Arkansas and NE Texas.

Highway 3 from Ada, bedrock is Pennsylvanian until we reach the southwestward extent of the Ouachita Mountains at Atoka, Oklahoma, where the basal Cretaceous unit, the Antlers Sandstone, laps onto the Pennsylvanian rocks. We will drive on the Antlers Sandstone to the McCleod Prison locality near Antlers, Oklahoma, where we will see several sites on and near the prison grounds that have yielded *Acrocanthosaurus* and, more recently, a new sauropod, *Sauroposeidon*, multiple *Tenontosaurus* skeletons, and microvertebrates.

Additional information about this stop will be provided by the trip leaders.

Day 2 - From Mena, Arkansas and the Ouachita Mountains across the Cretaceous outcrop belt to Texarkana, Arkansas

As we drive south over the Paleozoic rocks of the Ouachita Mountains we reach the "core" of the mountains at Caddo Gap, Arkansas (Stop 2-1), where vertically dipping Early Paleozoic Rocks are cut through by the Caddo River to form a water gap. As we drive south from Caddo Gap, we will reach the southern flank of the mountains where sub-vertical Late Paleozoic beds crop out around Kirby, Arkansas.

As we continue south from Kirby toward Murfreesboro, we will see the Paleozoic-Cretaceous contact and a gravel pit in the Pike Gravel, the lowest stratigraphic unit in the Cretaceous. Near Murfreesboro, you may notice sandier soils developed on Cretaceous beds higher in the section. The Dierks Limestone (pronounced locally as "Derricks") crops out in a few stream valleys along this stretch of the Cretaceous outcrop belt. Ammonites from the Dierks indicate an Aptian age for this part of the section (Imlay, 1945). More gravel is found in the interval above the Dierks Limestone, for which the local stratigraphic name Ultima Thule Gravel is used. Sandy and silty facies dominate the interval called the Holly Creek Formation. Sedimentary strata in this part of the section lie within the lower part of the Trinity Group, well known for dinosaur footprints in the Hill Country of

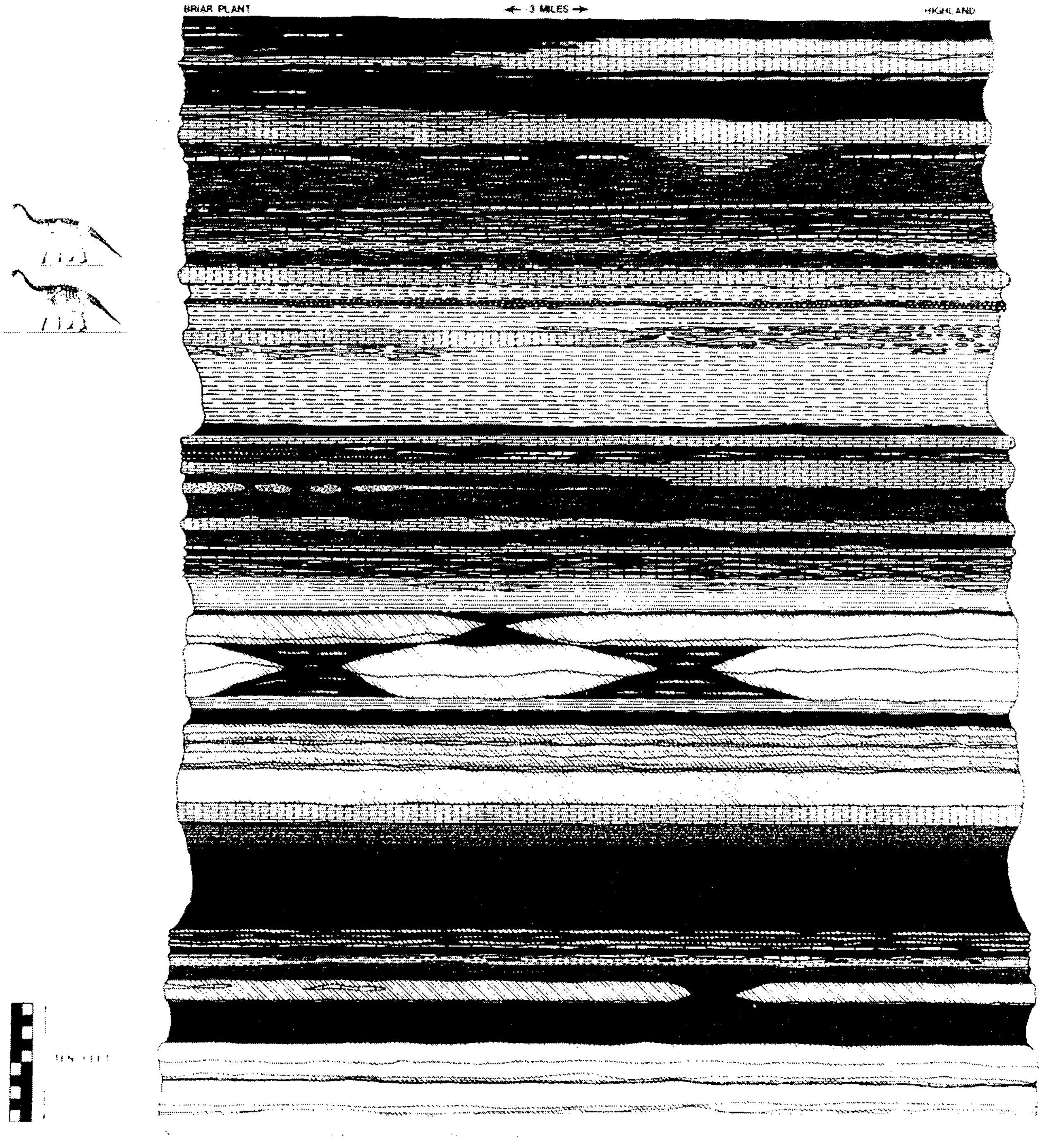

Figure 7 - Measured Section of the De Queen Formation at Highland, Arkansas (Pittman, 1985).

Texas and dinosaur bones in north Texas and southern Oklahoma.

The stratigraphic position of Crater of Diamonds State Park (Stop 2-2), just south of Murfreesboro, is within the Lower Cretaceous Holly Creek Formation. In displays at the state park, you may observe red core samples from the Trinity clastic facies, adjacent to greenish diamond-bearing material associated with the volcanics. From the diamond mine we will drive a short distance southwest of Murfreesboro to the area where gypsum beds are mined from the De Queen Formation, the next unit up-section within the Trinity Group. We will see a nice stratigraphic section in an abandoned quarry near Highland, Arkansas (Stop 2-3) and will also see a larger active quarry at Briar Plant Quarry, located 10 miles north of Nashville, Arkansas (Stop 2-4).

As we drive southward from Briar Plant Quarry to the town of Nashville, we will drive up a ridge and cross the upper contact of the Lower Cretaceous Trinity Group, where it is unconformably overlain by Woodbine-

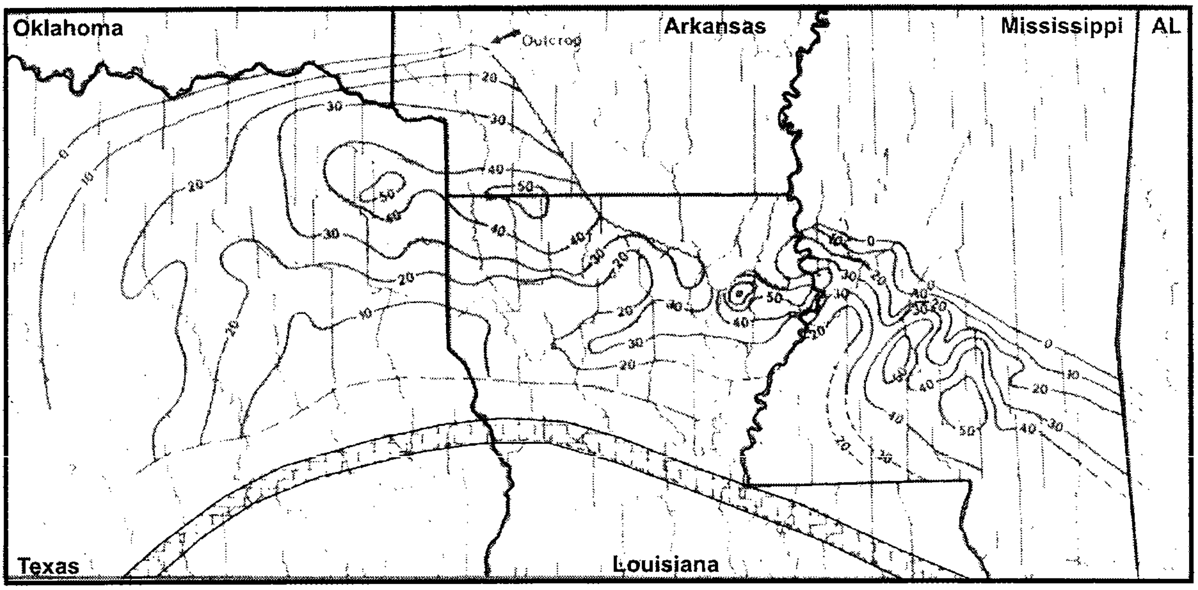

Figure 8 - Map Showing Depositonal Area for the Upper Gypsum Bed in the De Queen Fm. (Pittman, 1985).

equivalent strata (Cenomanian). Capping the ridge we will see large gravel clasts scattered across the pasture land north of Nashville. These gravels are part of the Tokio Formation, which also contains sandy facies with lignitic material. In the town of Nashville (Stop 2-5), we will visit one small outcrop where shark teeth, fish bones, crab claws and other interesting materials come from green micaceous clay that is penetrated by many sandstone dikes. A few miles east of Nashville there is a sand pit where leaf fossils are found in a clay seam within massively cross-bedded sugary sand called the Bingen Sand, a local unit within the Tokio Formation.

As we drive southward from Nashville, we will drive through low-lying terrain where the Brownstown, Ozan, and Marlbrook Formations crop out, and will then come to a prominent cedar tree-covered ridge formed by the outcropping Saratoga Chalk. Fragmentary mosasaur and plesiosaur material has come from the chalky outcrops. South of the Saratoga Chalk outcrop, we will see more relief in a pine tree-covered sandy outcrop of the Nacatoch Formation near the historical town of Old Washington (Stop 2-6). We will stop to see limestone blocks in the foundation walls of the old courthouse building that were mined locally from fossiliferous facies within the Nacatoch Formation.

From Washington, it is just a few miles south to Interstate 30 at Hope, Arkansas, and it is along this stretch that we will pass over the forest-covered youngest Cretaceous beds of the Arkadelphia Formation and the overlying Midway Formation of Tertiary age. We will drive along strike to Texarkana, but much of this drive will be across the wide floodplain of the Red River.

Stop 2-1: Paleozoic Rocks at Caddo Gap, Arkansas

The route from Mena to Caddo Gap crosses Ordovician rocks in the oldest "core" of the Ouachita Mountains. At Caddo Gap the road crosses a thin interval of steeply dipping Devonian to Silurian rocks, including the Devonian-Mississippian Arkansas Novaculite, a hard chert unit that forms a prominent ridge. The Caddo River, which has its headwaters higher in the mountains to the west, cuts through this ridge to form a water gap. From this point, Mississippian and Pennsylvanian units, including thick turbidite intervals, crop out across the southern flank of the

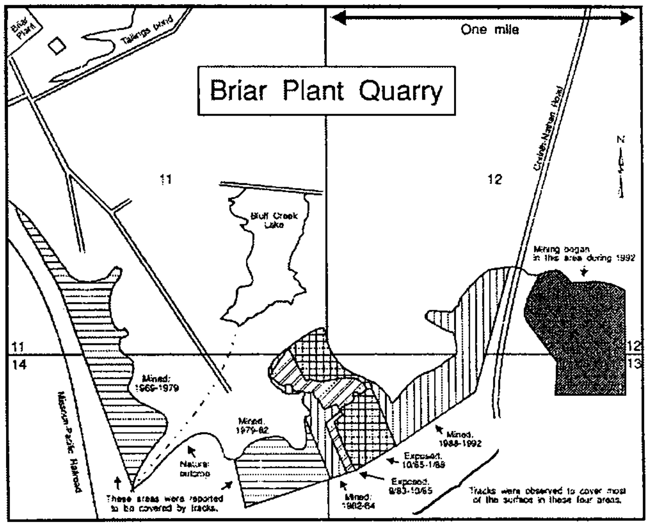

Figure 9 - Map of Gypsum Quarrys at Briar Plant, north of Nashville, Arkansas (From Pittman, 1992), where sauropod dinosaur tracks were observed to cover a limestone bed within the top of the De Queen Formation.

Figure 10 - Aerial Photograph 1 of Sauropod Dinosaur Tracks in the De Queen Fm. at Briar Plant Quarry, north of Nashville, Arkansas (From Pittman, 1992). A wing of the small airplane carrying the photographer is visible in the photograph. Several of the sauropod trackways visible in this photograph had been clean of clay fill before some short sections were molded in fiberglass. Most of the trackways may be observed to lead away from the foreground, but you may be able to several others leading right to left in the foreground. Spot checking on the ground indicated that these trackways lead in the same direction. The natural outcrop of the limestone bed was near the area where the surface is heavily fractured.

Ouachita Mountains. Cretaceous gravels of varying age lap onto these folded Late Paleozoic rocks along the southern edge of the mountains.

Stop 2-2: Crater of Diamonds State Park, Murfreesboro, Arkansas

Diamonds were known to occur in the soils of the area in the 1800s, but were first formally reported in 1907 (Kunz and Washington, 1907). Private mining operations sporadically worked the site, with episodes of legal disputes, during the early 1900s. The state of Arkansas bought the property and made it a state park in 1972. Since 1906, more than 75,000 diamonds have been collected from the area, including the 40.23-carat -Uncle Sam, found in 1924, the largest diamond ever unearthed in the United States. The largest diamond found by "tourists," since the park opened in 1972, is the "Amarillo Starlight," 16.37 carats. Some of the diamonds have been cut to flawless grade, as rated by the American Gem Society. The three most common colors found are white, brown and yellow, in that order.

Robert T. Hill (1888) was first to report vertebrate fossils from the region when he described fish and "saurian" remains from the base of Plaster Bluff, located on the Little Missouri River a short distance from Crater of Diamonds State Park. Hill's fossils probably came from the Holly Creek Formation (Trinity Group), which crops out at the base of Plaster Bluff. The diamond-bearing material is also emplaced within the Holly Creek Formation -- you may observe red-colored clastic sedimentary material in a core sample display at the state park. The Holly Creek Formation consists of red to buff colored siltstone and sandstone, with some gravel lenses and abundant lignitic horizons.

Stop 2-3: Abandoned Gypsum Quarry, Highland, Arkansas

Gypsum beds in the De Queen Formation crop out from Plaster Bluff, near Crater of Diamonds State Park, westward to the abandoned mining areas at Highland and over to and past the currently operating mines at Briar Plant

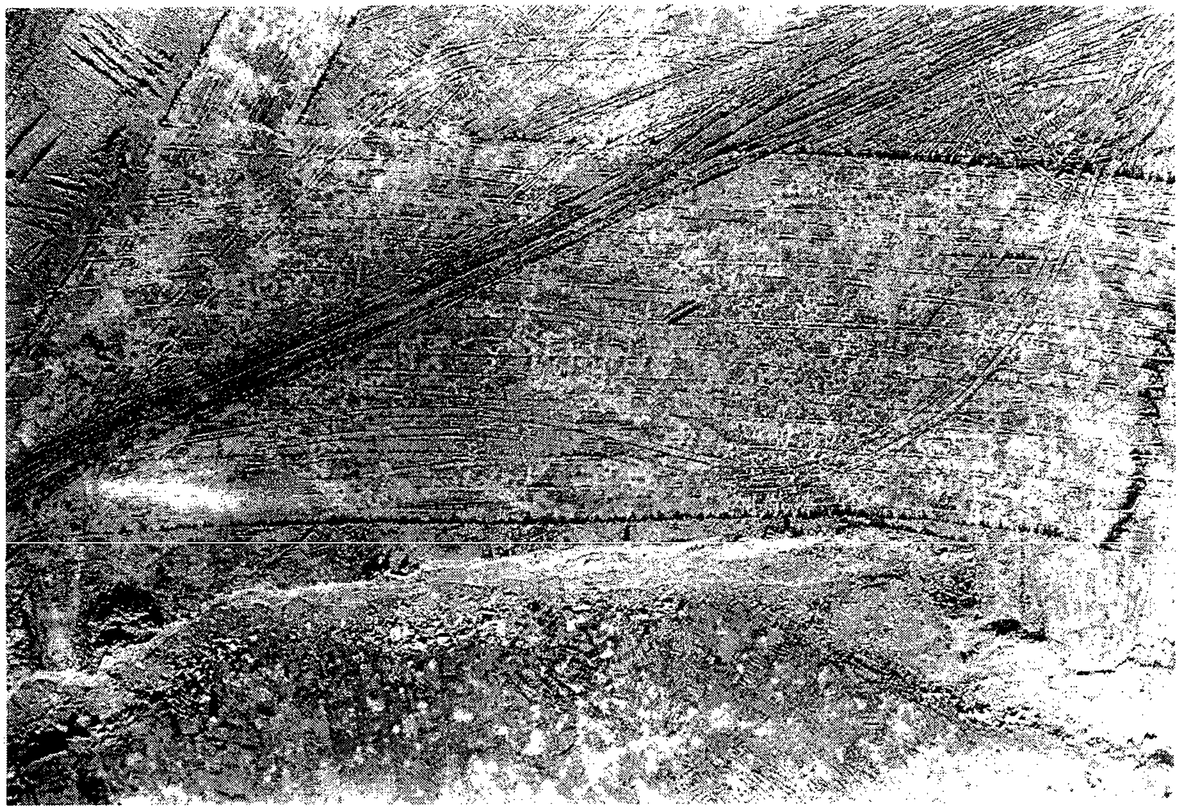

Figure 11 - Aerial Photograph 2 of Sauropod Dinosaur Tracks in the De Queen Fm. at Briar Plant Quarry, north of Nashville, Arkansas (From Pittman, 1992). In this photograph, the same stratigraphic surface of the upper trackbed, visible in Aerial Photograph 1, is shown in an adjacent area. A road grader had scraped clay from the surface, making the clay-filled tracks more visible. You may be able to discern several trackways within the mass numbers of tracks.

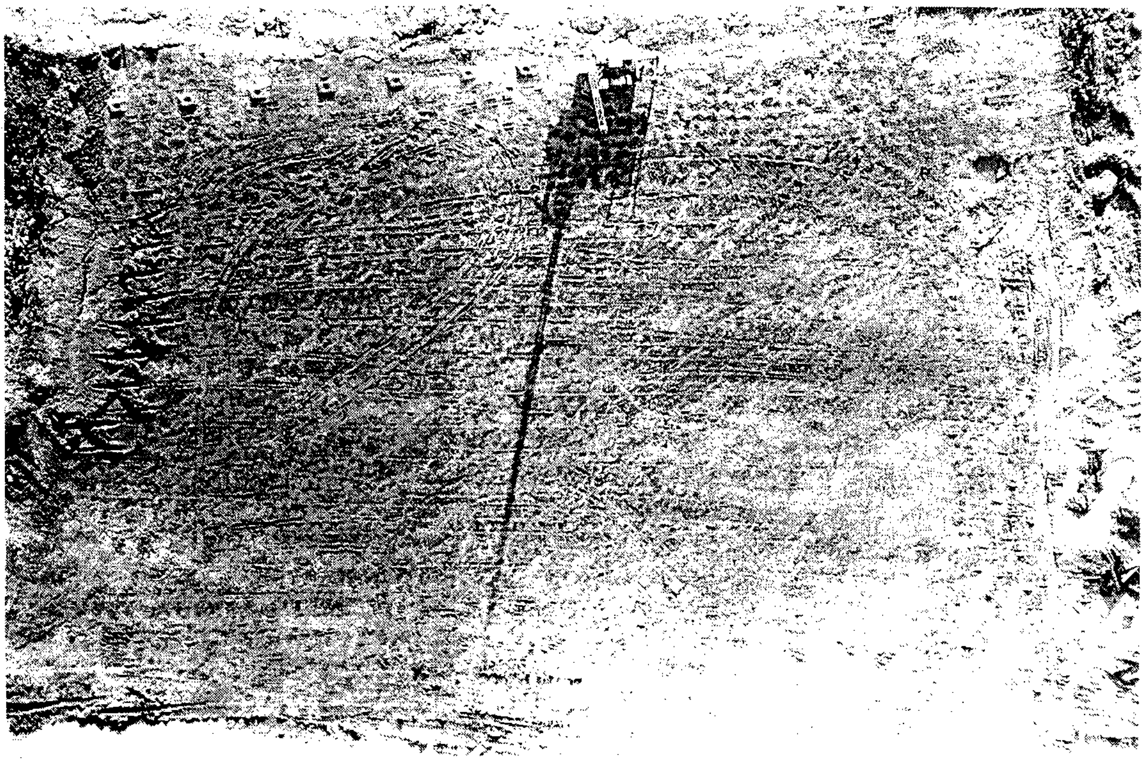

Figure 12 - Aerial Photograph 3 of Sauropod Dinosaur Tracks in the De Queen Fm. at Briar Plant Quarry, north of Nashville, Arkansas (From Pittman, 1992). This is another area showing sauropod dinosaur tracks on the same stratigraphic surface that may be seen to be track-covered in the other two aerial photographs.

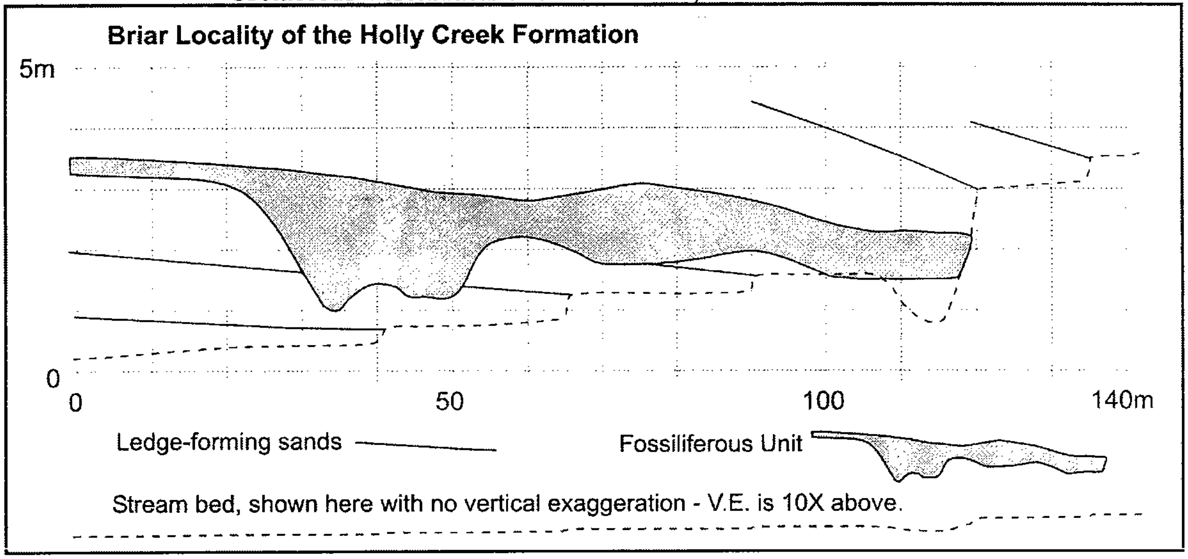

Figure 13 - Stratigraphic Cross Section of a fossiliferous unit in the Holly Creek Fm. at Briar Plant Quarry, north of Nashville, Arkansas (From Pittman, 1992). This diagram shows the beds cropping out in a drainage ditch within the quarry grounds. The fossiliferous bed is dark in color, because of abundant lignite material of the conifer *Pseudofrenelopsis*. Screen-washing has been done of pebbly zones in the lower part of the fossiliferous bed.

Quarry (Stop 2-4). There are several 1-to 2-meter-thick gypsum beds in the lower half of the De Queen Formation, which is about 30 meters in total thickness (Figure 7). In the upper half of the formation, mudstone dominates, with 10-to 40-centimeter-thick limestone strata and thinner-bedded sequences intercalated throughout. The depositional environment of the gypsum beds was shallow subtidal to supratidal. Individual strata may be correlated into the subsurface where they can be traced from the subsurface near Waco, Texas all the way across the Gulf Basin to south Florida (Pittman, 1985). The gypsum beds were deposited within a broad "lagoonal sea" that was cut off repeatedly from the open ocean by a shelf-edge rudist-coral barrier reef running through the subsurface of present-day central Louisiana and adjacent states (Figure 8). The thin beds in the upper half of the De Queen Formation accumulated in a widely shifting nearshore setting. Some of the limestone and clayey mudstone units accumulated in shallow subtidal conditions, but there is evidence of multiple exposure surfaces and desiccation within the section, in the form of mud cracks, salt crystal molds, displacive gypsum nodules, soil horizons and surfaces heavily trampled by sauropod dinosaurs. As at Plaster Bluff, gravels of the Woodbine Formation crop out on top of the De Queen Formation, on a prominent regional angular unconformity that truncates the De Queen and other Lower Cretaceous units east of Plaster Bluff.

Stop 2-4: Briar Plant Quarry, North of Nashville, Arkansas

Briar Plant Quarry is a major gypsum wallboard-producing operation. In fact, it is now the world's largest. The operation started in 1963 by the local timber company Dierks Forests Inc. and has changed hands among several companies during the last twenty years, from Weyerhaeuser Company, to Boral Industries, to J.H. Hardie, to the present owner, British Plasterboard. In the early 1980s, when Weyerhaeuser Company worked the quarry, the mining procedure involved the use of heavy equipment to remove overburden down to the level of several of the thicker limestone beds in the upper half of the De Queen Formation. In this fashion, a prominent ledge and broad expanse of the upper surface of the thickest limestone bed was regularly present in the quarry (See the measured section in Figure 7). The material from this limestone bed down to the top of the gypsum beds was then removed by drilling and blasting, before the actual gypsum material was blasted and removed. Thousands of sauropod dinosaur footprints were found on the ledge-forming limestone bed (Pittman, 1984, 1992; Figure 9). Documentation of the footprints was done by aerial photography (Figure 9 and the aerial photographs in Figures 10, 11, and 12) and some mapping, molding and casting, before mining operations took away the area of the initial discovery. Sauropod footprints were also found on the surface of a sandstone bed about one meter lower in the sequence (Figure 7). Sporadic checking of the quarry has shown that the tracks continue on the surface of the limestone bed in the area that was mined to the east of the Nathan-Corinth road. The mining technique changed in the late 1980s so that the prominent ledge formed by the upper trackbed is no longer present during normal quarrying operations.

With new ownership by British Plasterboard in 2002, all access has been denied to the quarry grounds. Hopefully, negotiations in the coming months will be fruitful so that research may continue.

Within the grounds of Briar Plant Quarry, a plant-rich horizon (Figure 13) near the top of the Holly Creek Formation, just a few meters beneath the lowermost gypsum stratum in the De Queen Formation, has produced

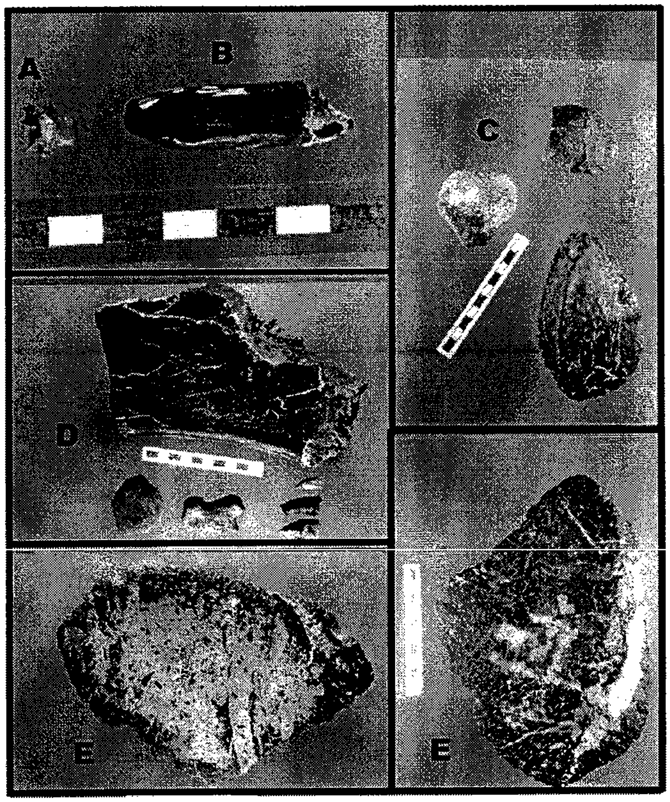

Figure 14 - Larger Fossils from the Holly Creek Fm. at Briar Plant Quarry, north of Nashville, Arkansas. A - Lizard vertebra; B - Sauropod tooth; C - Polecanthid? ankylosaur armor skutes; D - Theropod material, including the distal end of an ischium?, carpal or tarsal?, a manual phalanx, and teeth; E - Polecanthid? ankylosaur armor plate. These fossils were found by periodically prospecting exposures along the outcrop shown in the cross section.

vertebrate fossils, starting with the report by Quinn (1973) of turtle and crocodile material. Frequent outcrop prospecting of this exposure by J. Pittman over the last 20 years has lead to the collection of additional fragmentary material of theropods, sauropods and thryreophoran dinosaurs, as well as more crocodile and turtle material (Figure 14). Screen washing has been productive and promises to yield an important microfauna from this locality. So far, material from washing (Figure 15) includes shark (*Lissodus*), holostean fish (scales, teeth), amphibians (limb elements, vertebrae, jaw fragments), lizards (skull and jaw fragments, vertebrae), crocodiles (teeth, vertebrae and scutes), the turtle *Naomichelys*, dinosaurs (theropod teeth and a phalanx, and a sauropod tooth) and mammals (two teeth). The fossil-bearing stratum is pebbly to clayey, is colored black by abundant lignite, and cuts down more than one meter into underlying siltstones within a horizontal distance of 100 meters. Plant fossils in the unit, which include large trunks of the confier *Pseudofrenelopsis* and its associated wood, cones, and *Classopolis* pollen were described by Stanley (1988).

Stop 2-5: Woodbine Fm. and Tokio Fm. Outcrops, Nashville, Arkansas

You may observe on the geologic map that the Woodbine Formation rests unconformably on various geologic units, ranging from the Kiamichi and Goodland Formations at the Arkansas/Oklahoma line to the De Queen Formation at Briar Plant Quarry and at Plaster Bluff to the east. Eastward from Plaster Bluff the Tokio Formation, in turn, laps over the Woodbine and the Lower Cretaceous units and eventually directly onto Paleozoic rocks to the east. This onlapping relationship marks the position of a

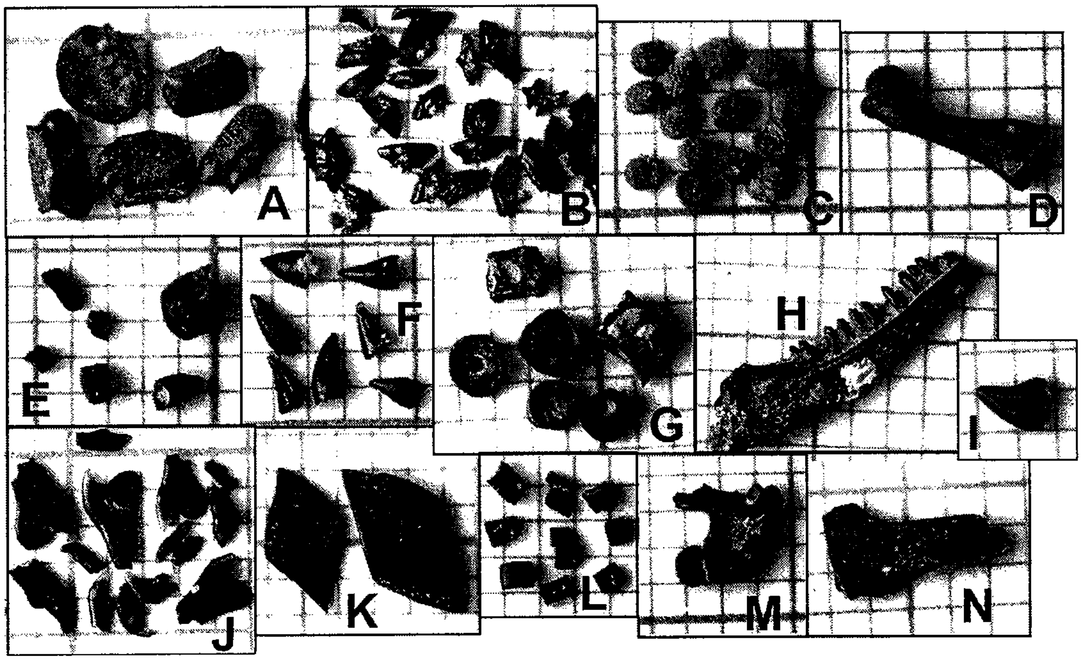

Figure 15 - Fossils found by screen-washing the Holly Creek Fm. at Briar Plant Quarry, north of Nashville, Arkansas. A - elongate, compressed, striated teeth, crocodilian? -- c.f. Atoposauridae; B - *Lissodus sp.*; C - Charophyte oogonia; D - Phalanx?; E - Semionotid fish teeth; F - Conical teeth -- some are crocodilian (c.f Pholidosauridae); some are of semionotid fish; G - Vertebrae; H - Lizard jaw; I - ; J - Pharyngeal teeth; K - Lepisosteid fish scales; L - Fish lepidotrichia; M - Amphibian? vertebra; N - Lizard frontal (broken longitudinally along the midline).

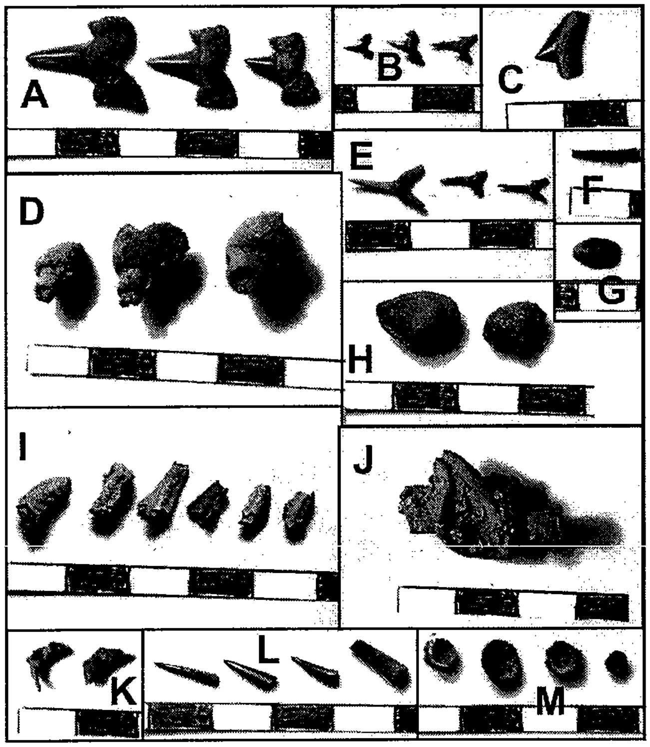

Figure 16 - Fossils from the Tokio Fm. at Nashville, Arkansas. A, *Cretolamna appendiculata*; B, E - *Scapanorhynchus texanus*; C - *Squalicorax falcatus*; D - Gastropod internal molds; F - *Belenostomus* sp. ; G - Shark dermal denticle; H - Pelecypod internal molds; I - Crab claws ; J - Serpulid worm tubes? or burrow fills?; K - *Enchodus*, probably *E. petrosus*; L - *Enchodus* teeth; M - Shark vertebrae.

regional angular unconformity beneath which the Trinity Group and older stratigraphic units subcrop from the outcrop area southeastward into southern Arkansas and northern Louisiana (seen in well logs of the subsurface). This "Middle Cretaceous Unconformity" represents a pre- or within-Cenomanian advance over a widespread erosional surface developed across the northern part of the Gulf Basin passive margin (northeast Texas, northern Louisiana, southern Arkansas). In the outcrop area, the Woodbine and Tokio Formations are mostly terrestrial in nature, with abundant conglomerate. At one locality above Plaster Bluff, lignitic stumps may be observed in place within clayey facies. As we drive southward from the outcrops of the Trinity Group units around Briar Plant Quarry, we will see gravel-covered hills marking the basal sedimentary materials of the Woodbine and Tokio Formations resting atop the "Middle Cretaceous Unconformity." In the town of Nashville, Arkansas, we will see clayey marine facies and overlying cross-bedded sands of the Tokio Formation. Sharks teeth, fish teeth, crab claws and pyritized invertebrates are found within the clayey facies (Figure 16). Well-preserved leaves are found on a clayey seam within cross-bedded sugary sands higher in the section. Lignite is contained in the transitional deposits in-between the marine and non-marine facies. Numerous sandstone dikes can be seen cutting through Tokio claystones in stream channels exposing these beds in and near the town of Nashville. These sandstone dikes are similar to sandstone dikes described in the Woodbine near Waco, Texas (Monroe, 1951).

Stop 2-6: Old Washington State Historic Area, Washington, Arkansas

Washington is a unique, historic Arkansas community conserved and interpreted by Arkansas State Parks in conjunction with the Pioneer Washington Restoration Foundation. From its establishment in 1824, Washington was an important stop on the rugged Southwest Trail for pioneers traveling to Texas. Several of the buildings date to the 1830s and 1840s. James Bowie, Sam Houston and Davy Crockett traveled through Washington. James Black, a local blacksmith, is credited with creating the legendary Bowie Knife here. Later, the town became a major service center for area planters, merchants and professionals. By 1860, Washington and vicinity had 16 doctors, 15 carpenters, nine teachers, nine blacksmiths, three carriage makers, 17 lawyers, 15 merchants, six printers and three hotel keepers. Washington was the Confederate Capital of Arkansas from 1863 - 1865. When the Cairo and Fulton Railroad bypassed the town in 1874, Washington's heyday was ending. The following year, fire destroyed 4½ blocks of the business district. Another fire in 1883 engulfed 24 more businesses.

Preservation efforts began in the 1930s and the place became a state park in 1973. The buildings have been restored and the streets and grounds have been kept intact. Some of the trees in Washington, including catalpa and magnolia, are older than 150 years.

The hilly terrain around Washington is formed by the outcropping Nacatoch Sandstone, which lies above thin fossiliferous limestone beds above a thicker clayey interval. The area is covered by pine forests, but some small exposures may be found locally in creeks near Washington and along roads and railroads nearby. The invasive plant "kudzu" covers the landscape across this terrain to the west in the area of McNab, Arkansas.

Day 3 - From Texarkana, Texas across the Cretaceous outcrop belt of northeastern Texas and the Paleozoic rocks of south-central Oklahoma, and back to Norman, Oklahoma

We will drive due west on Highway 82 to Paris, Texas. We will not see many outcrops along the road, just a few small chalk exposures of Upper Cretaceous units in some of the ditches. On the drive to Paris, Texas, we will cross the K-T boundary west of Texarkana, and then drive down-section across units of the Navarro and Taylor Groups (Campanian - Maastrichtian) to beds at the top of the Austin Group (Coniacian - Santonian). From Paris we will angle south to Ladonia, Texas, located alongside the floodplain of the North Sulphur River, which flows eastward back toward Texarkana. Repeated flooding of farmland in the 1930s lead to a channel straightening

Figure 17 - Stratigraphic section of the Ozan Formation in the bed of the North Sulphur River near Ladonia, Texas. The main marker bed within this part of the section is a reddish-colored condensed interval about 1 foot (0.3m) in thickness, which you may observe beneath Gorden's feet. The upper part of this interval is a muddy, glauconitic, coarse sand unit with numerous black phosphate grains. Many of these phosphate grains are vertebrate teeth and baculite molds.

project. The unforeseen consequence of this channel straightening has been the excisement of a deep and wide channel for many miles along the stretch of the river south of Paris.

Stop 3-1: North Sulphur River, Ladonia, Texas

The large outcrops here result from flood control channelization modifications made to the main stream by the U.S. Army Corps of Engineers many years ago. Straightening and deepening of the channel has produced many high velocity runoff flows as well as lowered the stream base level. These factors have resulted in tremendous headward erosion in the side streams upstream from this reach. As usual, erosion is the paleontologist's friend and the situation has provided an extremely popular area for local and regional fossil collectors. It is such a popular collecting area that it became the subject for a special publication of the Dallas Paleontological Society (McKinzie et al., 2001). Probably the largest single collection of Sulphur River vertebrate fossils is that assembled by Joan Echols during her dissertation work in the area (Echols, 1972) and during the years she taught geology classes at East Texas State University. A faunal list for the Ozan Formation, derived from these sources, is shown at the end of this stop description.

The exposures within walking distance are all within the marine Ozan Formation and were formerly referred to as the Upper Taylor Marl. Although the vast majority of vertebrate fossils here occur as float washed out during peak water discharge, most are derived from a relatively thin stratigraphic interval within the lower part of the Ozan Formation. The main marker bed within this part of the section is a condensed interval about 1 foot (0.3m) in thickness (Figure 17). The lower part of this interval is a sandy nodular bed that weathers to a reddish color (sideritic?), while the upper part is a muddy, glauconitic, coarse sand unit with numerous black phosphate grains. Many of these phosphate grains are vertebrate teeth and baculite molds. Many of the *in situ* vertebrate fossils are immediately associated with this condensed interval. Probably most of the shark fauna is derived from the upper glauconitic unit.

Just downstream (east) of the old Ladonia Bridge, which is about 1 mile upstream of the new Ladonia Bridge, a few very thin, light gray limestone stringers up to 10 cm thick appear about 1.5m above the condensed interval. These stringers increase in number to the west and the total thickness of the marls bracketed by these stringers increases in thickness to 4.2m (Figure 18). Some displaced fossils with adhering bits of light limestone matrix can be related back to this original stratigraphic interval.

Ammonites derived from the condensed interval and a few meters above (Figure 18) were correlated by Cobban (1992) to the ammonite succession in the Western Interior Seaway and thus provide a biostratigraphic age of the interval. These ammonites include:

Pachydiscus paulsoni
Eupachydiscus grossouvrei
Placenticeras sp.
Menabites delawarensis
M. danei
M. vanuxemi
Glyptoxoceras sp. (See Figure 19)
Baculites sp. *(aquilaensis* group*)*
Scaphites sp. *(hippocrepis* group*)*
Trachyscaphites spiniger spiniger
T. densicostatus

They are indicative of a latest Early Campanian or earliest Middle Campanian Stage in a tripartite division of that stage. This is equivalent to a position in or near the *Baculites maclearni* Zone in the Western Interior Seaway, which is approximately equivalent to the Upper Sharon Springs Mbr. of the Pierre Shale in its type area or the lower Mitten Black Shale Mbr. of the Pierre in the Black Hills. The vertebrate faunas of the Sharon Springs and Mitten members in the Black Hills and the Ozan Fm. here share several common elements.

Of additional interest is a distal fragment of a metacarpal of *Ichthyornis* from the Roxton Chalk that is in the East Texas State collection at Univ. of Texas at Austin, Vertebrate Paleontology Laboratory. Also, in that collection are portions of the large marine turtle, *Archelon*, probably from the Pecan Gap Chalk.

Pleistocene floodplain deposits may be seen along the channel exposures. Bluff outcrops of sandy sediment, three to four meters thick, may be observed upstream of the old Ladonia bridge. Mammoth and other vertebrate material

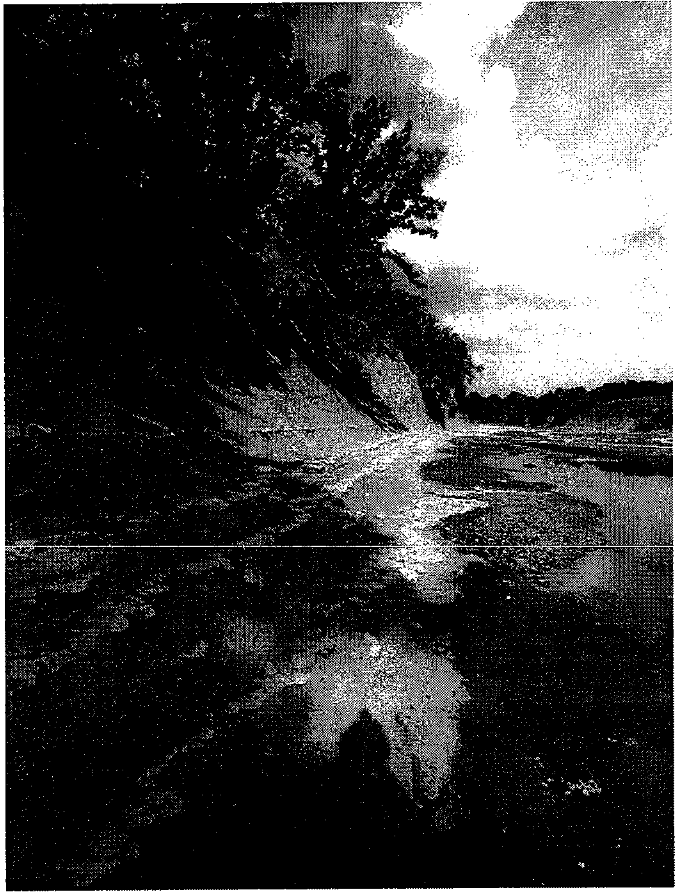

Figure 18 - Near the old Ladonia bridge a few very thin, light gray limestone stringers up to 10 cm thick appear about 1.5m above the condensed interval. These stringers increase in number to the west and the total thickness of the marls bracketed by these stringers increases in thickness to 4.2m. Minor faults offset these beds.

has been collected locally from this interval in stream valleys draining into the North Sulphur River channel. The Pleistocene fossils include (McKinzie et al., 2001):

Alligator mississippiensis
Dasypus bellus
Holmesina septentrionalis
Megalonyx jeffersoni
Castoroides ohioensis
Equus sp.
Tapirus sp.
Camelops sp.
Odocoileus virginianus
Symbos cavifrons
Ursus americanus
Mammut americanum
Mammuthus columbi

VERTEBRATE FAUNAL LIST - OZAN FORMATION
(from McKinzie et al, 2001)

Chondrichthyes
- *Cretolamna appendiculata*
- *Galeorhinus* sp.
- *Gingylymostoma lehneri*
- *Heterodontus canaliculatus*
- *Hexanchus microdon*
- *Lissodus selachos*
- *Lissodus* sp.
- *Paleogaleus* sp.
- *Pararhincodon groessensis*
- *Paranomotodon* sp.
- *Pseudocorax granti*
- *Ptychodus connellyi*
- *Ptychodus latissimus*
- *Scapanorhynchus texanus*
- *Serratolamna serrata*
- *Squalicorax kaupi*
- *Squatina hassei*
- *Squalus* sp.
- *Brachyrhizodus whichitaensis*
- *Dasyatis* sp.
- *Ischyrhiza avonicola*
- *Myliobatis* sp.
- *Onchosaurus pharao*
- *Ptychotrygon agujaensis*
- *Ptychtrygon triangularis*
- *Rhinobatos cassieri*
- *Sclerorhynchus* sp.

Osteichthyes
- *Enchodus ferox*
- *Pachyrhizodus minimus*
- *Pachyrhizodus caninus*
- *Gillicus arcuatus*
- *Saurodon* sp.
- *Xiphactinus audax*
- *Protosphyraena* sp.
- *Anomoeodus barberi*
- *Stephanodus* sp.

Reptilia
- Unid. Turtle
- Unid. Dryosaurid?
- Mosasauridae
  - *Clidastes propython*
  - *Globidens alabamaensis*
  - *Halisaurus* sp.
  - *Platecarpus tympaniticus*
  - *Tylosaurus proriger*
- Unid. Hadrosaur

In addition, the following taxa are among specimens collected by Joan Echols and her associates and students. Formerly at East Texas State University, the vertebrate portion of this collection has been transferred to the Vertebrate Paleontology Laboratory, Texas Memorial Museum, University of Texas at Austin.

Chondrichthyes

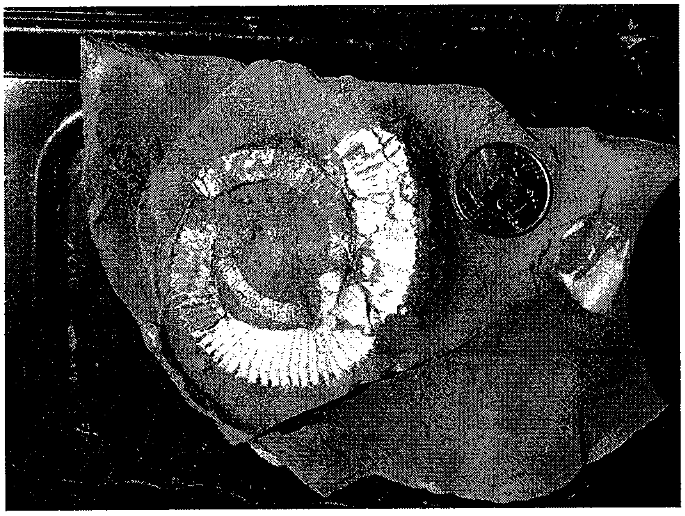

Figure 19 - *Glyptoxoceras* sp. from the condensed interval near the old Ladonia bridge.

Unid. holocephalan?, handwritten id. label says "*Asarotus*"
Osteichthyes
Saurocephalus lanciformis
Reptilia
Testudines
Protostega gigas
Unid. toxocheliid
Plesiosauria
Unid. polycotylid
Mosasauridae
Cf. *Hainosaurus* sp.
Mosasaurus conodon
Mosasaurus maximus

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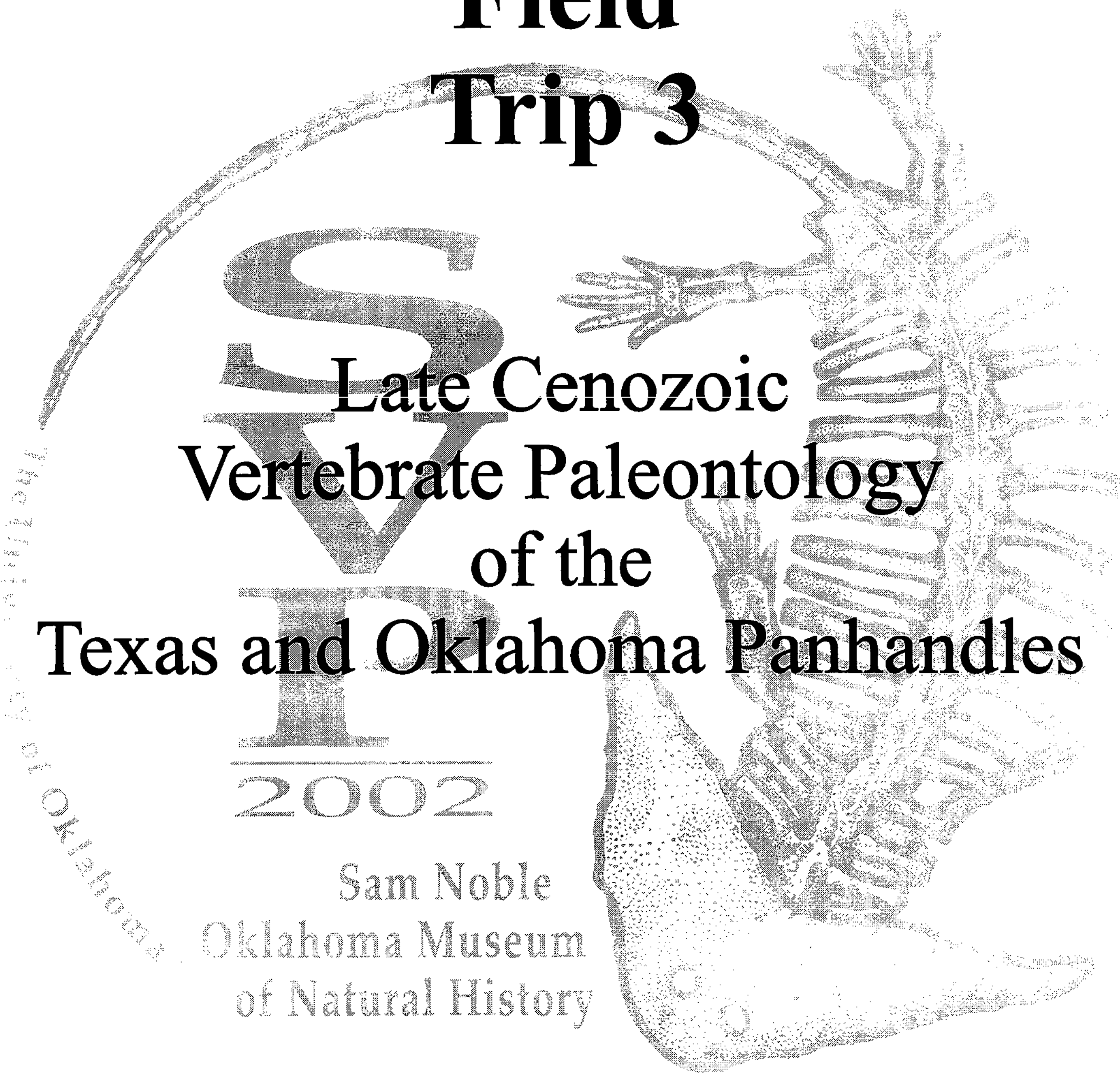
Field Trip 3

Late Cenozoic Vertebrate Paleontology of the Texas and Oklahoma Panhandles



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Panhandle-Plains Historical Museum
Canyon, Texas

KENT SMITH (Co-Leader)
DON WYCKOFF (Co-Leader)
CINDY GORDON (Co-Leader)

Sam Noble Oklahoma Museum of Natural History
University of Oklahoma
Norman, Oklahoma

Participants in the 1977 North American Paleontological Convention Field Trip to the Texas and Oklahoma Panhandles. Front Row (seated left to right): Gerald Schultz, Bruce MacFadden, Greg Retallack, Kay Behrensmeyer, Jane Voorhies, Judith Van Couvering, Mary Ann Turner. Back Row (standing left to right): Gordon Edmond, John Boellstorff, Richard Tedford, David Webb, Jack Hughes, Lloyd Tanner, Michael Voorhies, Lewis Bremer, King Richey, David Jones, Morris Skinner.

Clarendonian and Hemphillian Vertebrate Faunas from the Ogallala Formation (Late Miocene-Early Pliocene) Of the Texas Panhandle and Adjacent Oklahoma

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Abstract.— The Texas Panhandle and adjacent areas of Oklahoma provide an excellent sequence of late Tertiary and Quaternary vertebrate faunas that document the significant changes in fauna, environment and climate of the Southern High Plains during the last 12 Ma. Vertebrate fossils have been recovered from the Ogallala Formation (late Miocene-early Pliocene) in the region for nearly a century, beginning with the collections made by W. F. Cummins and E. D. Cope in the early 1890's. Later collections were made by the American Museum of Natural History, Yale University, the University of California, the Frick Laboratory, the University of Oklahoma, the University of Texas, Midwestern State University, West Texas A&M University and the Panhandle-Plains Historical Museum.

The Ogallala Formation is composed of fluvial silts, sands, gravels, lacustrine deposits and fine eolian sheet sands. Channel sands and the finer silts and clays deposited along floodplains and in small lakes and ponds are locally fossiliferous and have yielded fragmentary remains of horses, camels, rhinoceroses, gomphotheres, carnivores and other mammals. Complete, articulated skeletons have been recovered from sandy deposits that filled ancient sinkholes, which formed because of subsidence due to dissolution of underlying Permian salt beds.

Mammals from the Ogallala Formation are assigned to the Clarendonian and Hemphillian Land Mammal Ages. The Clarendonian Age (about 12.5 to 9 Ma) is represented in the Texas Panhandle by approximately 30 fossil sites north and east of Clarendon in Donley County and by the Coetas Creek and Exell Local Faunas north of Amarillo. The Laverne (=Beaver) and Durham Local Faunas of Oklahoma are also of Clarendonian age. Most of the faunas have not been studied adequately and correlation of the different sites is imprecise. The faunas include abundant grazers, a few browsers and mixed feeders and a variety of carnivores. Significant taxa include the horses *Pliohippus*, *Protohippus*, *Neohipparion*, *Hipparion*, *Cormohipparion*, *Pseudhipparion*, *Calippus* and *Hypohippus*; the camels *Aepycamelus*, *Procamelus* and *Protolabis*; the oreodont *Merychyus*; a peccary; the ruminant artiodactyls *Longirostromeryx*, *Cranioceras* and *Synthetoceras*; gomphothere mastodons; the short-legged, robust rhinoceros *Teleoceras*; and carnivores such as *Aelurodon*, *Paratomarctus*, *Cynarctus*, *Ischyrocyon*, *Leptarctus* and *Barbourofelis*. Lower vertebrates include gars, pond turtles, giant tortoises and alligators. Climate during this time was mild and probably subhumid and savanna conditions prevailed. The more heavily wooded areas would have bordered the major streams.

EarlyHemphillian faunas (about 9 to 6 Ma) include the Higgins (=Sebits Ranch), V. V. Parker and Box T Local Faunas of Lipscomb County, Texas and the Arnett (=Adair Ranch and Port-of-Entry Pit) and Capps=Neu=Pratt Local Faunas of Ellis County, Oklahoma. These faunas, which can be placed in a biostratigraphic sequence, show the continued presence of many typical Clarendonian genera, but with more advanced species. They record the first local appearance of the gomphothere *Amebelodon*, the rhinoceros *Aphelops*, antilocaprines and the carnivores *Nimravides*, *Epicyon haydeni* and *Borophagus*. The Box T Local Fauna is late early Hemphillian and correlates with the Cambridge Local Fauna of Nebraska. It records the appearance of the immigrant carnivore genera *Indarctos*, *Eomellivora* and *Machairodus* and of the sloths *Pliometanastes* and *Thinobadistes*, as well as the last local occurrence of many genera typical of the Clarendonian chronofauna, such as *Nimravides*, *Epicyon*, *Leptarctus*, *Amebelodon*, *Calippus*, *Pliohippus*, *Cormohipparion* and *Hipparion*.

Late Hemphillian faunas (around 6 to 4.5 Ma) include the Coffee Ranch (=Miami), Goodnight, Christian Ranch and Axtel Local Faunas of Texas and the Optima (=Guymon) Local Fauna of Oklahoma. These faunas, postdating a significant mid-Hemphillian extinction event, are characterized by the horses *Dinohippus*, *Astrohippus*, *Neohipparion* and *Nannippus*; the camels *Alforjas*, *Megatylopus* and *Hemiauchenia*; the rhinoceros *Aphelops*; the gomphothere *Rhynchotherium*; the ruminant *Pediomeryx*; and the antilocaprine *Texoceros*. Carnivores include *Machairodus*, *Borophagus* and the immigrant genera *Plesiogulo* and *Agriotherium*. The Coffee Ranch Local Fauna, type fauna of the Hemphillian Age, accumulated in a lacustrine sand that is capped by a volcanic ash that yielded a zircon fission-track date of 6.6 ± 0.8 Ma and glass fission-track dates of 5.3± 0.4 Ma and 4.7 ± 0.8 Ma. Sediments containing the fauna show normal magnetic polarity. The Axtel and Christian Ranch Local Faunas are the latest Hemphillian faunas known from the Texas Panhandle and contain more advanced species of the horse genera found at Coffee Ranch, Goodnight and Optima. Decimation of most browsers and many grazers during the Hemphillian Age, coupled with the development of calcic soil horizons or caliche, document a progressive trend toward aridity and the replacement of savanna by grassland prairie and steppe by the end of that age.

Introduction

In southwestern Kansas and in the Oklahoma and Texas Panhandles, eastward-flowing streams and their tributaries have exposed, over vast areas, strata ranging in age from Permian to Quaternary. South of the Canadian River, in the Texas Panhandle, the Llano Estacado section of the Southern High Plains stands as a high plateau bounded on two sides by locally steep escarpments, which separate it from the Low Rolling Plains to the east and the Pecos Valley of New Mexico to the west (fig. 1). Headwater tributaries of the Red, Pease, Brazos and Colorado Rivers have eroded valleys and, in places, have cut deep canyons into the eastern escarpment. In these canyons, in the "breaks" of the Canadian River and elsewhere along the eastern margin of the High Plains where the transition to the Rolling Plains is more gradual, fossiliferous strata of Triassic and late Cenozoic ages are exposed. During the past century, studies of fossil vertebrates (mostly mammalian) recovered from Quaternary and upper Tertiary strata in these areas have provided significant information about vertebrate evolution, biostratigraphy and paleoecology. Of particular interest are the remarkably well preserved late Tertiary fossils that have been recovered locally from the Ogallala Formation, a vast complex of fluvial sands and gravels, caliche and eolian silt and sheet sand that underlies much of the High Plains from Texas northward to western Nebraska. Other younger Tertiary as well as Quaternary fossils has been recovered from large basin-fill deposits – e.g. Blanco, Tule and Cita Canyon. It is the Ogallala fossils, however, with their geologic and faunal context and their significance to vertebrate paleontology and related fields that constitute the subject of this paper which updates an earlier version by Schultz (1990 a).

The first reported discoveries of vertebrate fossils in the Texas Panhandle were made in the early 1890's by W. F. Cummins and E. D. Cope during explorations for the State Geological Survey of Texas. Cope (1893) reported a number of late Tertiary and Pleistocene mammals, including horses, camels, carnivores and proboscideans, as well as large tortoises, which he collected from the vicinities of Clarendon and Goodnight and from Blanco and Tule Canyons. He also described fragmentary Triassic reptiles from Palo Duro Canyon. During the summers of 1899 through 1901, J. W. Gidley collected fossils from Cope's localities along the eastern edge of the Plains, from Donley County south to Crosby County, for the American Museum of Natural History in New York (Gidley, 1903). Yale University obtained remains of Pleistocene horses, camels, sloths and mammoths from Rock Creek, a tributary of Tule Canyon in Briscoe County (Troxell, 1915a, 1915b; Lull, 1915).

Following the discovery of fossils in the northeast corner of the Texas Panhandle by two petroleum geologists in 1928 (Reed and Longnecker, 1932), the University of California spent several field seasons collecting late Tertiary mammals from localities near Higgins in Lipscomb County (Hesse, 1940) and in Hemphill County (Matthew and Stirton, 1930a, 1930b; Matthew, 1932), as well as near Clarendon in Donley County (Stirton, 1932). Collections also were made in Beaver and Texas Counties, Oklahoma (Hesse, 1936a, 1936b).

During the 1930's, the Frick Laboratory in New York City began collecting Tertiary mammals from several localities in the Texas Panhandle and in adjacent parts of Oklahoma. This activity continued until about 1960 and the collection—the largest and best of its kind—is now housed in the American Museum of Natural History.

Other important collections have been made by institutions within Texas, including The University of Texas at Austin, Midwestern State University at Wichita Falls, Texas Tech University at Lubbock and the Panhandle-Plains Historical Museum and West Texas A&M University at Canyon. In addition, the University of Oklahoma at Norman contains a large collection of late Tertiary mammals from the western part of Oklahoma.

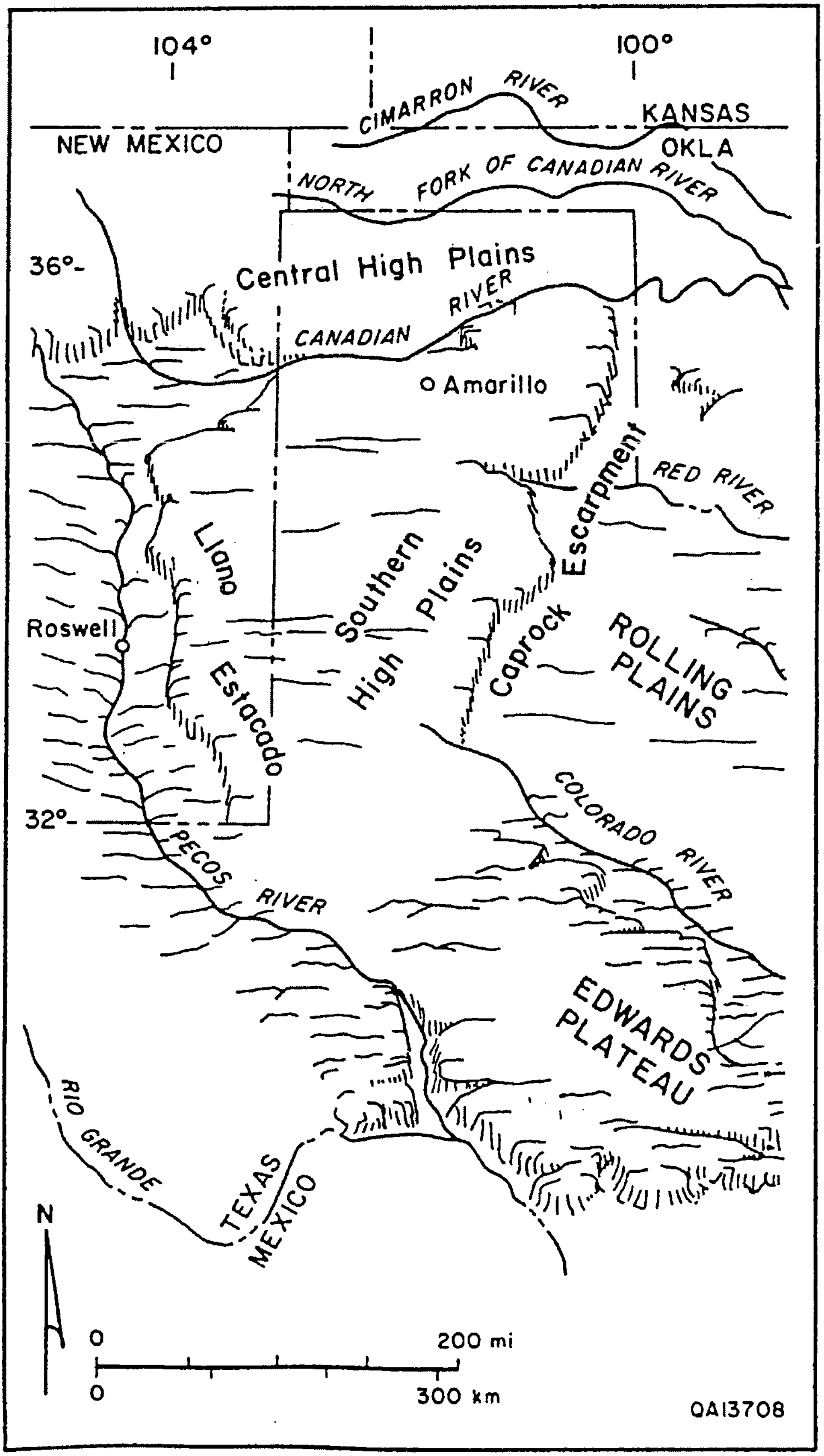

FIGURE 1. Physiographic map of Southern High Plains (Llano Estacado).

The Texas Panhandle is especially significant in late Tertiary mammalian paleontology and biostratigraphy because it contains the type localities of faunas on which Wood and others (1941) based three of their "Provincial" Ages: the Clarendonian, the Hemphillian and the Blancan. The first two are based on fossils from the Ogallala Formation in Donley and Hemphill Counties, respectively, whereas the Blancan is based on a fauna obtained from the white lacustrine basin-fill deposits at "Mt. Blanco" and from 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 others of the Tertiary, were based on first and last appearances of mammalian genera in North America, 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 the Lyellian Epochs, although approximate equivalents were given. Stirton (1936a) considered the ages of the three type faunas from Texas to be early, middle and late Pliocene, respectively, but revisions of the Miocene/Pliocene boundary in Europe (Berggren and Van Couvering, 1974) indicate the Clarendonian is late Miocene, the Hemphillian is latest Miocene to earliest Pliocene and the Blancan is equivalent to most of the Pliocene, thus confirming the views of earlier workers such as Gidley (1903) and Osborn and Matthew (1909).

Savage (1962) and Evernden and others (1964) redesignated the original "Provincial Ages" as "North American Land Mammal Ages." They argued that the term "Age" should not be used for equivalent continental deposits, or "Stages" (as Wood and others [1941] had allowed), without substantial and explicit lithostratigraphic and biostratigraphic control, including measured and described sections as well as vertical ranges and geographic distribution of taxa. The Clarendonian and Hemphillian Ages have been reviewed recently by Tedford and others (1987), who used first appearances of immigrant genera and extinction of certain taxa to refine and subdivide the late Tertiary mammal ages. The Blancan has been reviewed by Lundelius and others (1987).

This paper reviews the major vertebrate faunas of Clarendonian and Hemphillian age recovered from the Ogallala Formation in Texas and Oklahoma and presents a brief history and description of the geographic location and geologic setting of each site. Significant or representative taxa are mentioned in the descriptions of each fauna and, where possible, complete and updated faunal lists are provided for the larger and better-known faunas. Inferences are drawn about the living habits of some of the taxa and about the paleoecology of a particular site. Where possible, biostratigraphic correlations are made with faunas of the region and, in some cases, with well-known faunas that exist elsewhere in the United States. The faunas are discussed chronologically to illustrate progressive changes in chronofauna and paleoecology of the region during a period of time that spanned from about 12.5 to 4.5 Ma.

Much information presented in this paper comes from an earlier field trip guidebook (Schultz, 1977). At the time the guidebook was published, the existing literature was scattered and outdated and many of the fossil sites had not been visited, worked, or studied for many years. The 1977 guidebook attempted to present a state-of-the-art synthesis of published and unpublished information on the faunas of the region. This information was updated by Schultz (1990a; 1990b) and the current contribution has been updated further to include new taxonomic and biostratigraphic data obtained within the last 12 years.

Clarendonian Land Mammal Age and The Clarendon Fauna Of Texas

Introduction, Historical Background and Type Locality

The Clarendonian Provincial Age was defined originally by Wood and others (1941, p. 12) as being "based on the Clarendon local fauna (and member?) near Clarendon, Donley County, Panhandle of Texas" (fig. 2). The name "Clarendon local fauna," in turn, has been applied to an aggregate of fossil vertebrate species, mostly mammalian, collected since 1892 from numerous localities scattered over a 100-km^2 area (40-mi^2) immediately north of the Salt Fork of the Red River and north and east of Clarendon, Texas (fig. 2), on the east edge of the Southern High Plains. Fossils from this area were collected first 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 (Osborn and Matthew, 1909, p. 84; Simpson, 1933, p. 101).

The term "Clarendon beds" was proposed by Gidley (1903) while collecting fossils for the American Museum of Natural History, but the name has not found general application. The fossil beds are recognized now as facies of the Ogallala Formation and were placed in this formation by Stirton (1936a, p. 181), who considered them to be lower Pliocene. Unfortunately, no comprehensive study or description of the Clarendon "fauna" has been published, although single species have been described in short papers or in publications dealing with larger taxonomic groups. In addition, papers on other late Tertiary faunas occasionally have referred to fossils from the Clarendon "fauna." Currently, about 30 fossil-producing sites are known from the immediate area north of the Salt Fork of the Red River (fig. 3). Although detailed biostratigraphic analyses have not been conducted on most of these sites, available faunal evidence seems to indicate that most of them are contemporaneous, although a few are slightly younger than the rest.

Webb (1969a) attempted to revise the Clarendonian Mammal "Age" and to establish a biostratigraphic basis for its recognition as a time-rock unit (Stage) by selecting a section described by Cummins (1893, p. 204) as a type section. Unfortunately, the precise location of Cummins' section on the old Stanton Ranch is not recorded and cannot be recognized in the field, although in all probability it was

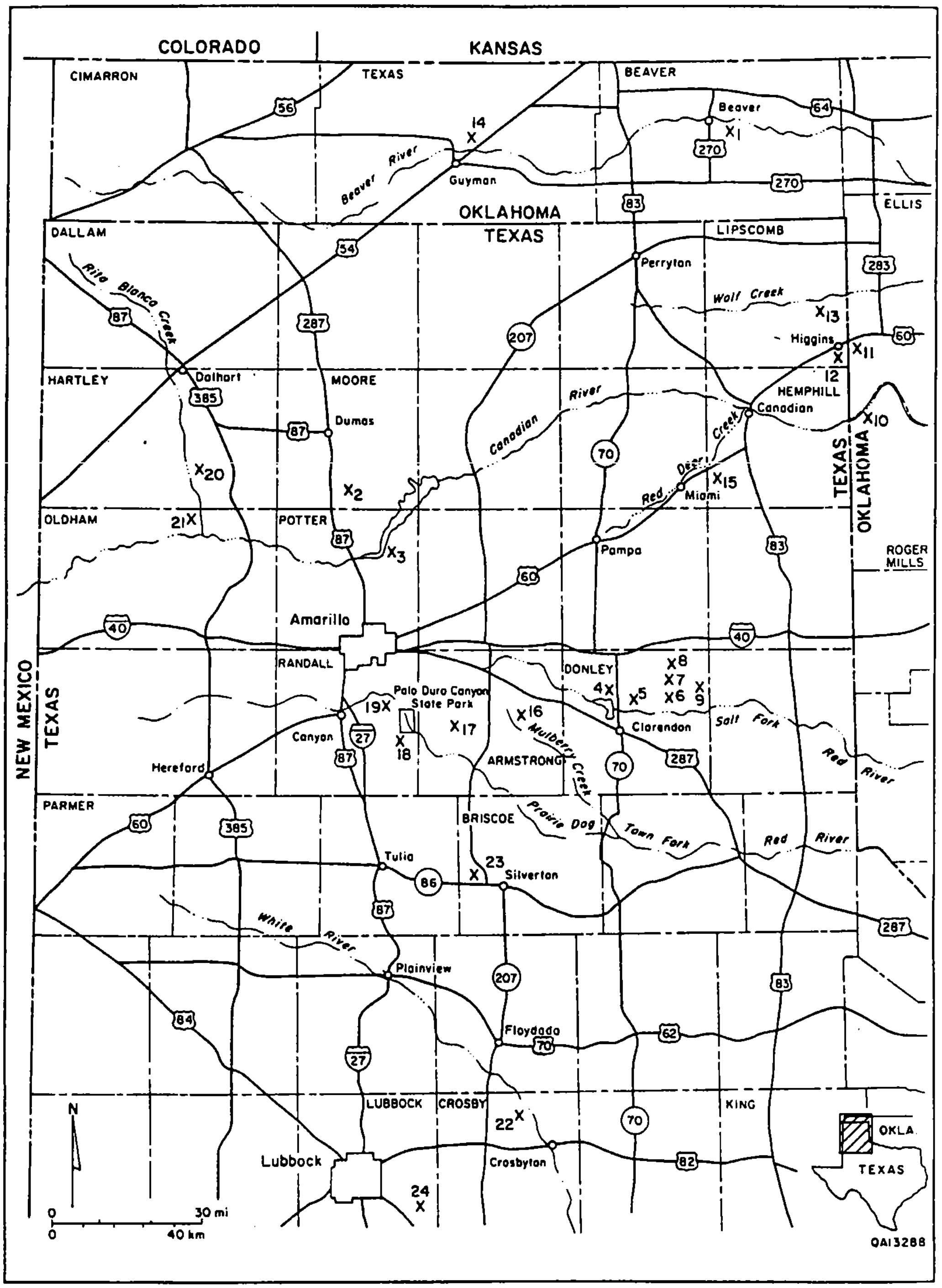

FIGURE 2. Location of principal Clarendonian, Hemphillian, Blancan, and post-Blancan faunas in the Texas and Oklahoma Panhandles. ***Clarendonian:*** (1) Laverne (=Beaver), (2) Exell, (3) Coetas Creek, (4) Clarendon (Shannon Ranch, MacAdams, and Grant Quarries), (5) Clarendon (Dilli, C. Risley, A. Risley, 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.

about 16 km (10 mi) north of Clarendon near the old Goldston schoolhouse (fig. 3). Local topographic relief is less than 60 m (200 ft), so that the 122-m (400-ft) thickness given by Cummins is either in error or else represents a composite section over a larger area.

Although fossils are identified from several localities near Goldston, examination of those reported by Cope (1893) and now housed at the Texas Memorial Museum, The University of Texas at Austin, indicates that most were collected at the adjacent Dilli and Charles Risley Ranch localities near the head of Turkey Creek, about 1.6 km (1 mi) north and 1.6 km (1 mi) east of Goldston and about 16 km (10 mi) north of Clarendon. Color, preservation and matrix are similar to that of fossils collected later from these localities by other institutions.

The Clarendon "fauna" is used now as a faunal unit in correlation, although it lacks proper biostratigraphic characterization (Tedford, 1970, p. 693) and is among the poorest known of Clarendonian faunas. Precise stratigraphic analysis is difficult in the region because rock sequences are too sparsely fossiliferous and too incomplete to determine local range zones of taxa. Many of the more than 30 sites known are separated too widely 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, whereas faunal similarities may aid in the correlation of others. Recent studies based on the large quarry samples in the Frick collection at the American Museum 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 horizons (Tedford and others, 1987).

Additional difficulties in defining the Clarendonian Stage are the lack of direct superpositional relationship with subjacent or superjacent stages in the type area and the absence of certain key taxa in the type fauna. However, the fauna is sufficiently diverse to permit correlation with Clarendonian faunas elsewhere in the Great Plains Province (for example, localities in Nebraska) where such superpositional relationships exist.

Age and Correlation

The Clarendonian Land Mammal Age spans a period of late Miocene time from about 12.5 to 9 Ma; the division between "early" and "late" Clarendonian occurs at about 10 Ma (table 1) (Whistler and Burbank, 1992; Wang and others, 1999). Currently, the Clarendon Fauna is considered to include taxa and sites of both early and late Clarendonian age, thus correlating with faunas from the lower part of the Ash Hollow Formation of north-central Nebraska (Skinner and Johnson, 1984). Most of the fossil sites in the Clarendon area appear to be early Clarendonian and to correlate with the Minnechaduza Fauna of Nebraska (Webb, 1969a; Tedford and others, 1987), whereas a few sites, such as Gidley's 3-toed Horse Quarry, seem to correlate best with the late Clarendonian *Leptarctus* Quarry and the Xmas-Kat channel assemblages of north-central Nebraska (Skinner and Johnson, 1984; Tedford and others, 1987). The Burge Fauna from the Burge Sand member of the Valentine Formation, which underlies the Ash Hollow Formation in north-central Nebraska, was considered by Webb (1969a) to be early Clarendonian but is now regarded as being latest Barstovian (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, 1924; Skinner and others, 1977), the WaKeeney 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, 1977, 1990a) Local Faunas of the northern Texas Panhandle and the fauna of the Couch Formation of the southern Texas Panhandle (Evans, 1949, 1956; Winkler, 1985, 1987, 1990). The Lapara Creek Fauna of the Texas Gulf Coastal Plain (Patton, 1969) is early Clarendonian. These faunas and their respective provinces can be correlated because of a high degree of similarity between taxa, especially between the horses.

Geology and Taphonomy

Most of the Ogallala sediments in the Clarendon, Texas region (figs. 2 and 3) are generally 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, sometimes containing thin flaggy lenses of fresh water limestone and representing overbank floodplain, backswamp and "oxbow lake" deposits can 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 existed there during Clarendonian time.

Some fossils apparently accumulated in quiet ponds, lakes or marshy areas on grass-covered floodplains (for example, fossils found at MacAdams, Dilli, Risley, Farr, Noble and Bromley localities [figs. 2 and 3]), 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. 2 and 3). Completely articulated skeletons are found rarely 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

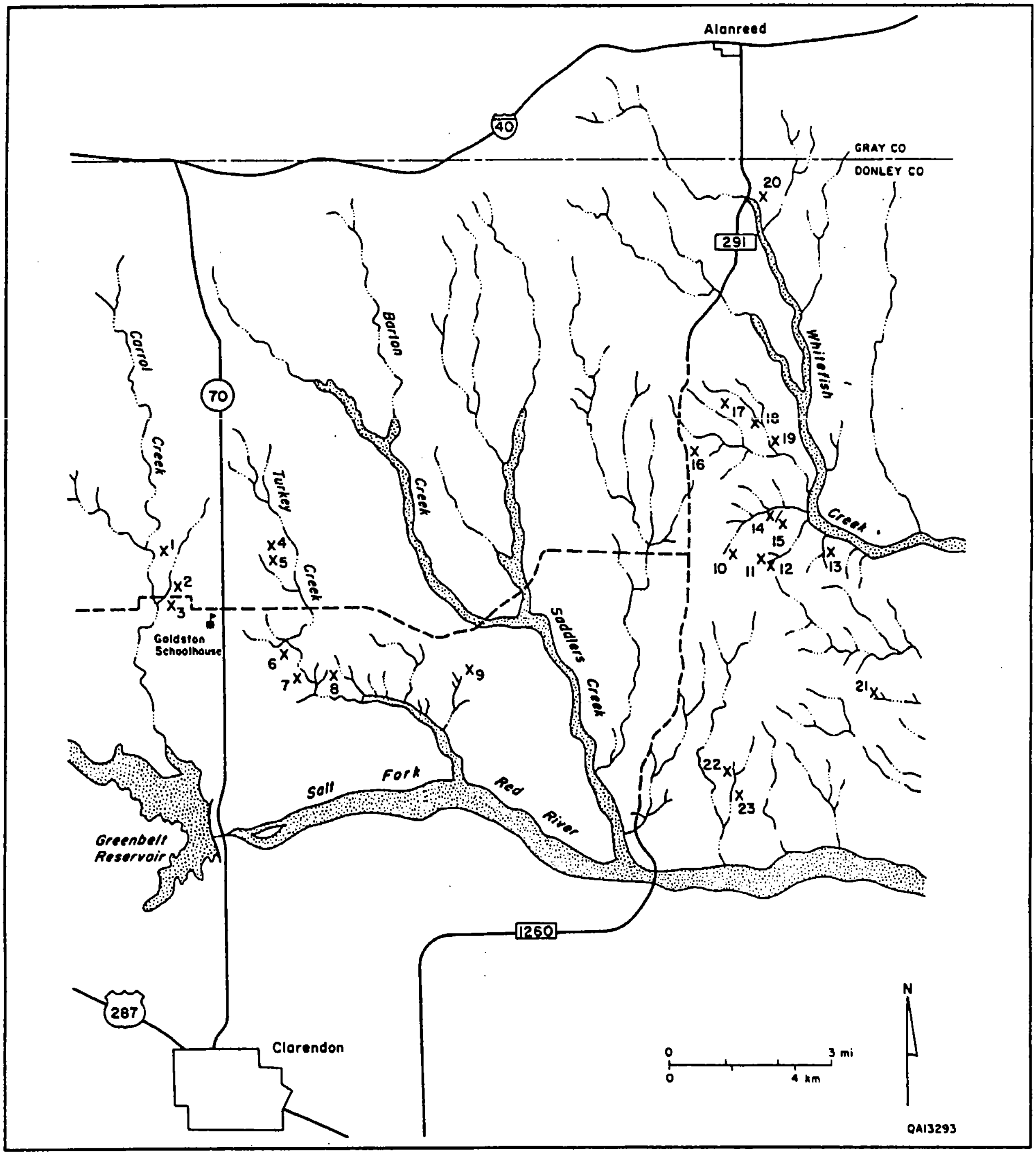

FIGURE 3. Location of Clarendonian faunal sites in Donley County, Texas. (1) Shannon Ranch, (2) Grant (=Littlefield), (3) MacAdams (=Porter), (4) Dilli (=Cope's locality?), (5) Charles Risley, (6) Adam Risley (*Pliocyon walkerae* skull), (7) Ward's Creek Bluff Pit, (8) Noble (=Farr), (9) Bromley (*Synthetoceras* type and Gidley's 1899 Mastodon), (10) Rowe (=Lewis) Quarry 1, (11) Rowe Quarries 2 and 3, (12) Rowe Quarries 4 and 5, (13) Rowe 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) Rowe Quarry 11, (18) Rowe Quarry 8, (19) Rowe Quarry 7, (20) Stirton and Chamberlain 1939 *Pliohippus fossulatus* skull, (21) Rowe Quarries 9 amd 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.

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

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

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. 3, site 19). The skeletons, although complete, are difficult to remove from the ferruginous concretionary sandstone matrix that surrounds them. The deposits are identified easily 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. 3, 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. 3, site 16). It is reported (M. F. Skinner, personal communication, 1976) to have contained a skull of the small horse *Pseudhipparion*. A sample of volcanic glass from this deposit yielded a 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. Cope (1893) reported a camel and several kinds of horse. Gidley collected two gomphothere mastodons, a large bear dog skull and numerous three-toed horses for the American Museum of Natural History in 1899 and 1901 (Gidley, 1903). 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 Texas State College (now West Texas A&M 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. 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 (appendix 1) is dominated by medium to large grazing mammals. Perissodactyls are the most abundant order and consist of over a dozen species of pliohippine and hipparionine horses having hypsodont (high-crowned) 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, 1937a, 1938; Stirton and Chamberlain, 1939; Quinn, 1955; Webb, 1969a; Forsten, 1975; Skinner and MacFadden, 1977; MacFadden, 1980, 1984a, 1998; Webb and Hulbert, 1986; Hulbert, 1987, 1988; Kelly, 1995, 1998). According to MacFadden (1984a), the MacAdams Quarry (fig. 3, 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, hippo-like amphibious variety with high-crowned teeth commonly found in stream-channel deposits on the Rowe-Lewis Ranch (fig. 3, sites 11 and 12) (Johnston, 1937b; Prothero, 1998b). 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; Honey and others, 1998). Less abundant but of considerable interest are several ruminants, including dromomerycids and moschids (Frick, 1937; Webb, 1998; Janis and Manning, 1998a) and protoceratids (Stirton, 1932; Frick, 1937; Patton and Taylor, 1971, 1973; Prothero, 1998a). 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. 3, site 9), but it is also abundant at the MacAdams Quarry (fig. 3, 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 giraffe-like horned browsing ruminant; *Longirostromeryx*, a small chevrotain-like ruminant; *Merychyus*, one of the last oreodonts (Schultz and Falkenbach, 1941; Lander, 1998); and a peccary (Wright, 1998). 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. Browsing proboscideans are represented by several skulls, jaws and teeth of sublongirostrine gomphothere mastodons (Cope, 1884, 1889, 1893; Frick, 1933; Osborn, 1936; Tobien, 1972; Madden and Storer, 1985; Lambert, 1996). Carnivores include several reported skulls and jaws of *Ischyrocyon*, a bone-crushing, carrion-eating bear dog or amphicyonid (Matthew, 1902; Johnston and Christian, 1941; Webb, 1969a; Hunt, 1998). Canids are represented by *Cynarctus*, a raccoon-like dog (Hall and Dalquest, 1962); *Paratomarctus*; *Aelurodon*, a hyena-like dog; and *Epicyon*, a wolf-like predator (Munthe, 1989, 1998; Baskin, 1998; Wang and others, 1999). Less numerous are the largely undescribed felids, the nimravid *Barbourofelis* (Baskin, 1981, p. 131) and mustelids (Harrison, 1981, p. 25). 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 gars. Bones of a few birds have been found (Becker, 1987).

In summary, the fauna is dominated by hypsodont grazers, with some mixed feeders and a few browsers and predators. Lower vertebrates include land tortoises and some aquatic species.

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 and 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 subsided. These sinkholes served as waterholes but became deathtraps for some animals.

The climate of the region during Clarendonian time probably was mild, subhumid and temperate to subtropical, as indicated by the browsing gomphotheres and by the lowland, floodplain-dwelling, amphibious, hippo-like 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, frost-free winters (Hibbard, 1960).

Floral evidence from the Clarendon area is limited but does not contradict 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. 3, 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. One of these is associated with the Laverne (=Beaver) Local Fauna, a vertebrate fauna of Clarendonian age, from Beaver County in the Oklahoma Panhandle, about 217 km (135 mi) north of the Clarendon localities in Donley County, Texas (fig. 2, site 1). This flora includes box elder, ash, hackberry, persimmon, sycamore, cottonwood, willow and elm, as well as cattails and sedges. These plants indicate a grassy floodplain environment, with trees confined to the stream borders and cattails and sedges growing 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 Beaver County 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 flora. The temperature may have been slightly warmer than at present. The present annual precipitation in Beaver County is about 48 to 51 cm (19 or 20 STET) and the mean annual temperature is about 14°C (57°F). Comparing the limited Clarendon flora with the extensive one from Beaver County, Oklahoma, Chaney and Elias (1936) concluded that the climate of the Clarendon region was slightly warmer and less humid than that of the Oklahoma Panhandle during Clarendonian time. The current annual precipitation in Donley County, Texas, is about 55 cm (21.5 inches) and the mean annual temperature is about 15°C (59°).

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, reached its peak in the Clarendonian and declined by the end of the Hemphillian, around 5 Ma. 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. 2, site 2) about 56 km (35 mi) north of Amarillo. 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 hyaenoid dog *Aelurodon*, the bear dog *Ischyrocyon*, a peccary, an oreodont *Merychyus*, 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, West Texas A&M 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 (20mi) northeast of Amarillo (fig. 2, 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) and now re-assigned to *Merychyus novomexicanus* (Lander, 1998). More recent collections have been made by West Texas A&M 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 2, 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 has been 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), alligator (Woodburne, 1959) and mollusks (Leonard and Franzen, 1944; Taylor, 1954; Herrington and Taylor, 1958) now in the University of Michigan collections. More recently, horses of the Beaver Fauna were discussed by Webb (1969a) and Hulbert (1988). A small but diverse microvertebrate fauna including insectivores, bats, lagomorphs and rodents was recovered from the newly recorded Whisenhunt site by Dalquest and others (1996).

Durham Local Fauna

The Durham Local Fauna is a relatively limited fauna of late Clarendonian age (table 1) from a locality 3.2 km (2 mi) northwest of the community of Durham, south of the Canadian River in Roger Mills County, Oklahoma (fig. 2, 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* (now *Epicyon*) made later by Kitts (1964). The fauna, obtained from a crossbedded channel sand, 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.

Cole Highway Pit Fauna

The Cole Highway Pit Fauna was recovered from a crossbedded sand and gravel channel 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. 4, 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 A&M University include tortoise, gomphothere, camel, horse, rhinoceros and a mylagaulid lower jaw.

Hemphillian Land Mammal Age and the Hemphillian Faunas Of Texas and Oklahoma

Introduction

The Hemphillian Provincial Age was defined 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. 2). The "Hemphill member" is not recognizable as a distinct lithologic unit, however and is an obsolete term. It represented an upgrading of the term "Hemphill beds" proposed by Reed and Longnecker (1932, p. 20), who state: "Since these beds, according to the fauna, represent a heretofore undescribed formation of the Lower Pliocene, the name *Hemphill beds* is hereby given to them to be applied as a faunal horizon." They regarded the fauna as being intermediate in age between the Clarendon and the 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 on the Coffee Ranch was the most productive site and later became the type faunal locality of the Hemphillian Land Mammal Age (Evernden and others, 1964).

The Hemphillian represents a span of time from about 9 to 4.5 Ma and it is now possible to distinguish between early and late Hemphillian faunas. This division, which occurs at about 7 Ma, is marked by the extinction of many genera characteristic of the Clarendonian chronofauna and by the

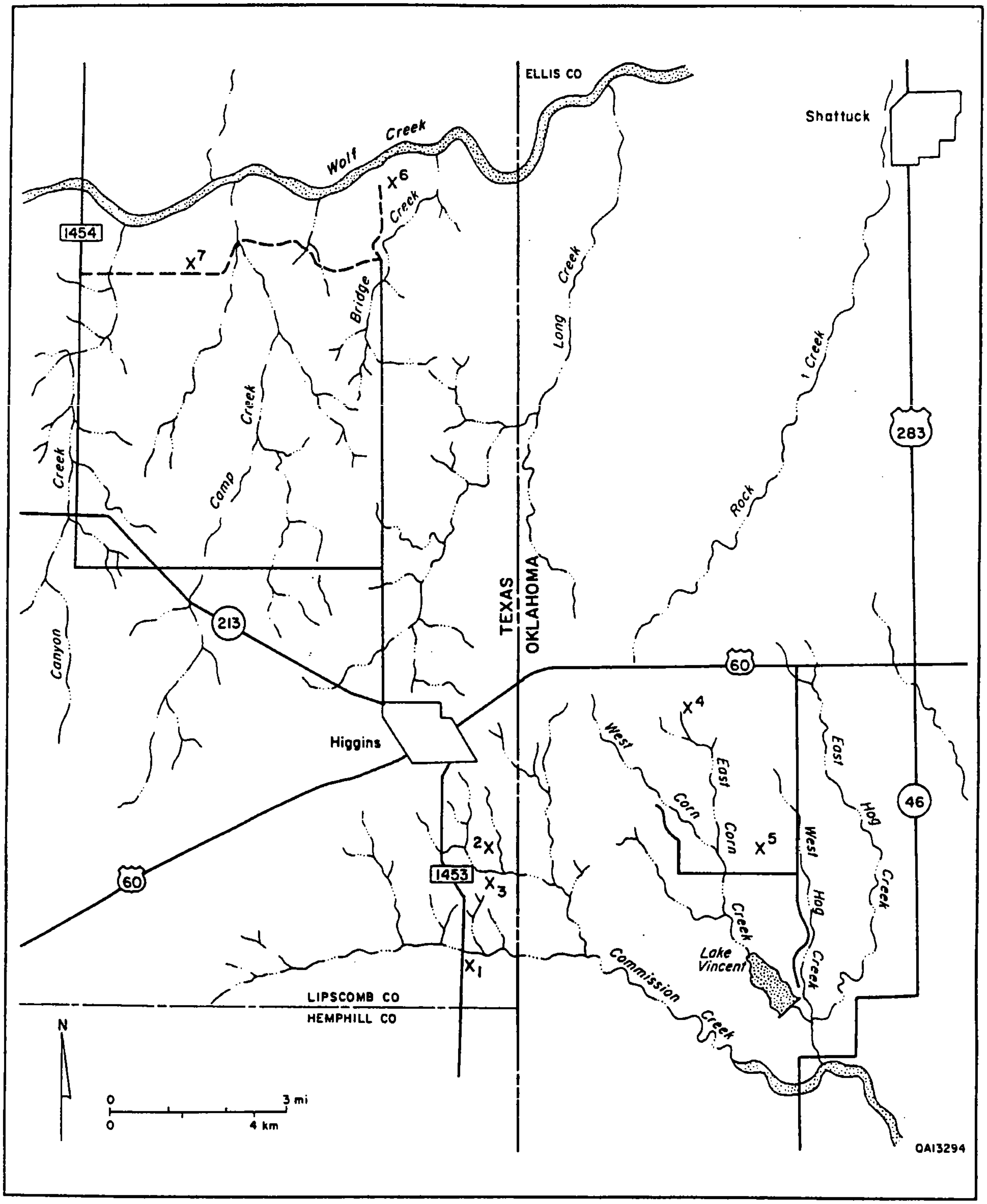

FIGURE 4. Location of principal late Clarendonian and early Hemphillian faunal sites in Lipscomb County, Texas, and Ellis County, Oklahoma. *Late Clarendonian:* (1) Cole Highway Pit. *Early Hemphillian:* (2) Higgins (Sebits Ranch Locality 24-A), (3) Higgins (Sebits Ranch Locality 24-B), (4) Arnett (University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

appearance of new immigrant taxa. Early Hemphillian faunas may be subdivided further into "early early" (approximately 9 to 8 Ma) and "late early" (approximately 8 to 7 Ma). Until recently, the Hemphillian Land Mammal Age was considered to be middle Pliocene age (Wood and others, 1941). According to correlations by Berggren and Van Couvering (1974), the Hemphillian, straddles the Miocene-Pliocene boundary which is currently placed at about 5 Ma and ended about 4.5 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. Most of the larger faunas in this region (for example, Capps=Neu=Pratt, Arnett, Port-of-Entry Pit, Higgins, V. V. Parker and Box T) are of early Hemphillian age (table 1; fig. 4). The Coffee Ranch (=Miami) Local Fauna (type Hemphillian) and the Goodnight Local Fauna from Armstrong County, Texas (fig. 2) date to the beginning of the late Hemphillian (table 1). Latest Hemphillian faunas in the Texas Panhandle include the Axtel Local Fauna in Randall County and the Christian Ranch Local Fauna in Armstrong County (table 1; fig. 2).

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. 4, 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 the Port-of-Entry Pit, Sebits Ranch (=Higgins) or the V. V. Parker Pits (fig. 4). A partial taxonomic list is given in appendix 2.

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 Ellis County, Oklahoma (fig. 2, site 11; fig. 4, site 4). Excavations extend for several hundred feet along the east wall of a small canyon, formed by the 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) noted that the fossils at the Arnett locality were well-mineralized and were sparsely distributed in a bed of fine clayey, silty sand about 0.9 m (3 ft) thick. The bones were fragmentary with sharp broken edges, which suggested to him that they had been scattered by predators and scavengers before final transport to their burial site. He also noted that the fauna was dominated by mastodonts (gomphotheres) and large carnivores, suggesting that the carnivores were preying upon the mastodonts or, in the case of the hyenoid dogs, feeding upon the carcasses of mastodonts that had died on a floodplain.

The geologic profile at the Port-of-Entry Pit (fig. 5) 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 adequately, 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 (appendix 2) are the remains of carnivores, which include lower jaws and other skeletal parts of the large pseudailurin 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 cat-like nimravid *Barbourofelis loveorum* (Baskin, 1981) (="*Albanosmilus*? sp." of Kitts, 1957), which is intermediate in size between the smaller *B. morrisi* from the late Clarendonian Ash Hollow of Nebraska and the large *B. fricki* from the late early Hemphillian Cambridge Local Fauna of 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 haydeni* and the smaller *Epicyon saevus* (Wang and others, 1999).

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 haydeni, Pediomeryx* [*Yumaceras*] and

FIGURE 5. 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.

Aphelops) (fig. 4, sites 2 and 3). However, at the Sebits Ranch localities, *Barbourofelis* and *Epicyon saevus* are absent, whereas *Borophagus* makes its first appearance in the southern Great Plains. According to Baskin (1980), *Osteoborus* (now *Borophagus*) 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 floridanus* from Sebits Ranch. The Arnett gomphothere may represent 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 (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 loveorum* 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—probably dating at about 8.5 Ma (table 1). The presence of *Epicyon saevus, Epicyon haydeni, Gomphotherium,* 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. 2, site 12; fig. 4, sites 2 and 3). The two sites were discovered in 1928 by Reed and Lognecker (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. 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. 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 (fig. 6), 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

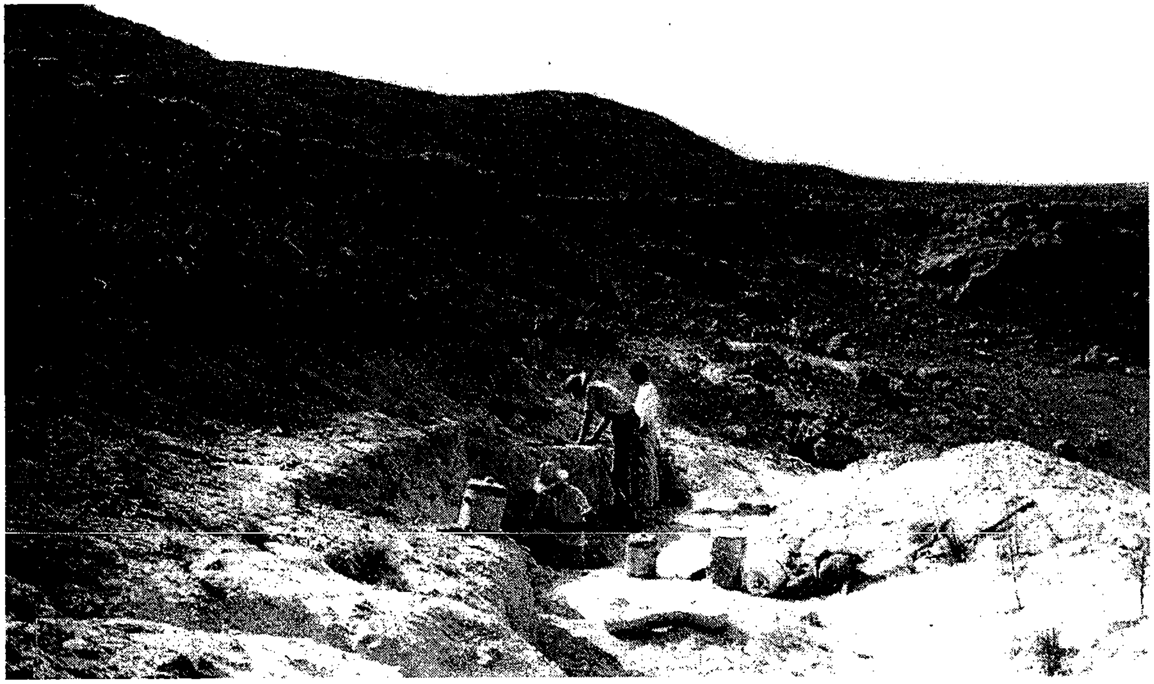

FIGURE 6. Sebits Ranch Locality 24-B (fig. 4, site 3) (early Hemphillian) near Higgins, Lipscomb County, Texas, in 1937. View to west showing excavation of fossil bed. Photo courtesy of Panhandle-Plains Historical Museum, Canyon, Texas.

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 (fig. 7). The area around Higgins lies at a lower elevation in the "breaks," or transitional zone between the High Plains and the Low Rolling Plains to the east. The Ogallala here is truncated. The mortar beds are highly cemented, case-hardened 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) 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 (appendix 2) was described by Hesse (1940). It is dominated by jaws and other skeletal elements of the rhinoceros *Aphelops malacorhinus (*Matthew, 1932) and of the long-jawed gomphothere *Amebelodon.* Less common are carnivores, including the large, massive-jawed canid *Epicyon haydeni* (Johnston, 1939a; Webb, 1969b; Richey, 1979; Wang and others, 1999) and the large pseudailurin 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) and Czaplewski (1993).

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 haydeni, Pediomeryx* [*Yumaceras*] and *Aphelops*). However, the small canid in the Higgins Local Fauna identified by Hesse (1940) as *Osteoborus cyonoides* (now *Borophagus* cf. *secundus*) is absent from the Arnett Local Fauna. 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 haydeni* 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 Local Fauna

Several exposures of gray silty sand lie along the south valley wall of Wolf Creek about 14.5 km (9 mi) north of

FIGURE 7. Ogallala 'caliche caprock' on mesa northwest of Canadian, Texas.

Higgins, Lipscomb County, Texas (fig. 4, 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, the large dogs *Epicyon saevus* and *Epicyon haydeni* (Wang and others, 1999), a 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 (appendix 2) is known from several localities 1.6 km (1 mi) south of Wolf Creek on the Vester Smith Box T Ranch, approximately 14.5 (9 mi) northwest of Higgins, Lipscomb County, Texas (fig. 2, site 13; fig. 4, site 7). 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 the Raton-Clayton field, which have been dated at about 7.2 Ma (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 (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. 8).

Although a complete description of this large fauna (appendix 2) has not been published, many of the taxa present have been described or at least mentioned in the literature. These include the two immigrant ground sloths from South America *Pliometanastes* cf. *P. protistus* (Hirschfeld and Webb, 1968, p. 284; Marshall and others, 1979) and *Thinobadistes wetzeli* (Webb, 1989); the large canids *Epicyon saevus* and *Borophagus* cf. *pugnator* (Wang and others, 1999); the giant bear *Indarctos* (Harrison, 1983, p. 25); a large mustelid *Leptarctus supremus* (Lim and others, 2001); the giraffe-like browsing ruminant *Pediomeryx* (*Yumaceras*) cf. *P. figginsi* (Webb, 1983b); a metapodial assigned to *Procamelus* (Breyer, 1983); and the horses *Hipparion forcei* (MacFadden, 1984a, 1998) and *Neohipparion leptode* (Hulbert, 1987). Breyer (1981) recorded the presence of *Osteoborus* (now *Borophagus*), *Sthenictis, Prosthennops and Neohipparion.*

The Box T Local Fauna is similar to the Higgins (=Sebits Ranch Local Fauna) because it contains *Nimravides, Epicyon, Borophagus, Amebelodon, Pediomeryx* (*Yumaceras*) and *Aphelops* but lacks certain taxa characteristic of the Arnett or Higgins (=Sebits Ranch) Local Faunas such as *Barbourofelis, Aepycamelus* and possibly *Procamelus.* Immigrant genera such as *Machairodus, Indarctos* and *Eomellivora* appear for the first time (Tedford and others, 1987), indicating that the fauna is

FIGURE 8. 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.

younger than the Higgins (=Sebits Ranch) Local Fauna and thus belongs to the later part of the early Hemphillian (table 1) and probably dates about 7.5 Ma. However, despite the presence of new immigrant genera and the absence of certain older taxa, the Box T Local Fauna 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. 2, site 15) and contains the last local 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) (table 1).

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). The large rhinoceroses *Aphelops* and *Teleoceras* probably fed on the abundant vegetation growing along broad grassy floodplains of the larger river valleys. The shovel-tusked gomphothere *Amebelodon* may have used its large lower tusks to shovel up succulent water plants and perhaps roots and bulbs, as suggested by Osborn (1936, p. 333) and also for scraping bark from tree trunks and stripping leaves and twigs from trees as in modern African elephants (Lambert, 1992; Lambert and Shoshani, 1998). A well-preserved lower jaw of this gomphothere is recorded from Roberts County, Texas (Gregory, 1945; Lambert, 1990).

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 and 1.6 km (1 mi) east of the Roberts-Hemphill county line in Hemphill County, Texas (fig. 2, site 15). 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 College (now West Texas A&M University). In 1963 and 1964, Midwestern State University began extensive excavations that included screenwashing matrix for microfauna.

During the past 70 years or so, an extensive literature has

FIGURE 9. 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.

been 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) and now re-assigned to *Borophagus* (Wang and others, 1999). This was followed by a study (Matthew and Stirton, 1930a) of the 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 which include an abundance of the large *Aphelops mutilus* but a scarcity of *Teleoceras* (Matthew, 1932) (see also Prothero and others, 1989). Stirton described the type lower jaw of the ruminant *Pediomeryx hemphillensis* (Stirton, 1936b; Webb, 1983b), gave measurements of the jaw of the antilocaprid *Texoceros altidens* (Stirton, 1938) and mentioned the rarer carnivores in an abstract (Stirton, 1939). Other contributions include the descriptions of some fragmentary *Rhynchotherium* material (Frick, 1933, p. 606), bird and carnivore tracks from the volcanic ash overlying the quarry beds (Johnston, 1937c), a duck (Compton, 1934; Brodkorb, 1964, p. 225; Becker, 1987), the horse *Dinohippus* (Quinn, 1955, p. 43), the camel *Megatylopus matthewi* (Webb, 1965; Harrison, 1985) and the carnivores (Dalquest, 1969, 1986; Webb, 1969b; Wagner, 1976; Richey, 1979; Harrison, 1981, 1983; Miller and Carranza, 1986; Wang and others, 1999). 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, 1998) and Hulbert (1987). Schultz (1977, 1990a) 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 White (1987) and 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 appendix 3.

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 scarcity 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).

According to Dalquest (1969, p. 2), the fossils at Coffee Ranch accumulated in a lake or bog of moderate but unknown areal extent. The lacustrine sediments then were buried under about 9 m (30 ft) of eolian material and now are 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 (fig. 9). The original areal extent of the fossil-bearing strata is uncertain because the east part 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 measured section near the center of the deposit is given by Dalquest (1969, p. 2):

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 (1937c) 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 measured easily and accurately. 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

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
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 eolian sandy sediments of the Ogallala Formation; bottom not exposed in the area	

they were made. Samples of the ash taken from the base of the deposit were dated radiometrically 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.

The geologic history of the lake deposits as interpreted by Dalquest (1969, p. 3) is summarized briefly 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 sealed beneath the ash.
6. Deposition of eolian silts and clays and development of soils that overlie the volcanic ash.

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 FT (fission-track) date of 6.6 ± 0.8 Ma for the ash immediately overlying the fossil-bearing unit probably represents a more reliable age for the fauna than do the glass FT dates which may be too young because of annealing of the tracks. Lindsay and others (1975, p. 114; 1984, p. 460) determined that the fossil-bearing sands and ash are in a thick, normally magnetized polarity zone which they thought represented the lower part of old magnetic chron 5 (approximately 5.9 Ma) because the ash date indicated that it was older than the Gauss chron (3.4 to 2.47 Ma). Based on a revised FT zircon date of 6.8 ± 0.2 Ma, this zone should be zone C3Bn (old C6N) of Cande and Kent (1992, 1995) and not old upperzone C5N. The FT date also is supported by correlation by Perkins (1998) of this ash with the Blacktail Creek ash bed in Idaho (dated at 6.7 ± 0.10 Ma by K-Ar).

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. 2, 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 gave distinctly different geologic sections for the north and south sides of the canyon. Gidley (1903, 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. 2, 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* also was 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 (appendix 3). Subsequent collecting by the Frick Laboratory during the early 1950's from several quarries on the McGehee and Hubbard Ranches on Mulberry Canyon near Goodnight enlarged the fauna but the fossils obtained are largely unpublished. Wang and others (1999, p. 287) reported *Borophagus* *secundus* from the Center Hill Pit, McGehee Place and from the Hubbard Place Quarry but certain other records of this taxon are from Goodnight age equivalent beds about 24 km (15 mi) west of these localities and should not be considered part of the Goodnight Fauna (Cope *senso strictu*) – e.g., Baker Place, Hill Quarry and Christian Pit No. 2, which is older and lower in the same section as the latest Hemphillian Christian Ranch (=Christian Place) Local Fauna.

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, Texas County, Oklahoma (fig. 2, 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 "2 or more feet of brownish-red sand, grit and gravel overlain by 4 to 7 feet 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* (*=T. 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, p. 18; Breyer, 1983), dromomerycids (Webb, 1983b), horses (MacFadden, 1984a; Hulbert, 1987) and rhinoceroses (Prothero and others, 1989).

Grazing mammals dominate the fauna (appendix 3), with 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, with camels and the antilocaprid *Texoceros* being 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 1) 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.

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 (fig. 2, 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).

Collected by WPA Crews for the Panhandle-Plains Historical Museum, the fauna was first reported by Johnston (1939b), who described the type specimens of *Osteoborus hilli* (now *Borophagus*), a bone-crushing dog (see also Webb, 1969b; Richey, 1979; Wang and others, 1999). Most of the fauna is undescribed, although Johnston and Savage (1955, p. 28) published a faunal list (see appendix 4) and a stratigraphic section of the quarry. Horses are the most abundant forms; there are numerous isolated teeth, jaws and limb bones of *Dinohippus mexicanus* and *Astrohippus stockii*. Mawby (1965, p. 574) described a machairodont and Oelrich (1957, p. 236) and Auffenberg (1962, p. 630) reported a tortoise, *Geochelone* cf. *G. turgida*.

The Axtel Local Fauna is latest Hemphillian (table 1) and younger than the Coffee Ranch Local Fauna, as indicated by the more advanced horses, camels and *Borophagus* (Johnston and Savage, 1955, p. 29) (compare appendices 3 and 4). The fauna is equivalent in age to the Christian

Ranch Local Fauna (table 1) and several other smaller ones in the Palo Duro Canyon region (fig. 2). Lindsay and others (1975, p. 117) determined that the fauna lies in a zone of normal magnetic polarity.

The climate of the region by latest Hemphillian time already was semiarid, as indicated 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. 2, 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 already had 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 (=Christian Place) Local Fauna

This latest Hemphillian faunal site is on the Terrell and Tom Christian Ranch 15 km (9.5 mi) south and 12 km (7.5 mi) west of Claude, Armstrong County, Texas (fig. 2, site 17). Johnston and Savage (1955, p. 30) noted that the fossiliferous exposures lie on a small erosional remnant hill atop a ridge that connects a prominent intracanyon butte, locally called Big Mountain, to the east wall of Horseshoe Canyon, a large, deep, southward-draining tributary to Palo Duro Canyon. The fossil-bearing stratum is a 1 to 3 m (3 to 10 ft) bed of gray sand overlain by a thin gray to white resistant sandy limestone. These two beds comprise a lens 100 m (about 300 ft) wide, which grades laterally into brown mudstone and sands or sandstones. The fossil quarry lies about 39 m (130 ft) below the High Plains surface and about the same distance above the contact between the base of the Ogallala Formation and the underlying Triassic Dockum Group. Fossils of late but not latest Hemphillian age equivalent to those of the Goodnight Fauna occur at Christian Pit no. 2 lower in the section.

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 stockii*, with a smattering of other horses, camels, antilocaprids, peccaries and carnivores (appendix 4). Richey (1979) described a lower jaw of *Osteoborus* (now *Borophagus*). An excellent lower jaw of a gomphothere, probably *Rhynchotherium*, was described by Savage (1955). Additional specimens were obtained by the University of California and the Frick Laboratory in 1953 and by West Texas A&M 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 but is more advanced than the one from Coffee Ranch (table 1). 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 stockii* and *Neohipparion* cf. *N. eurystyle*) of latest Hemphillian age (Tedford and others, 1987).

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 fauna 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) considered the genera *Agriotherium, Dipoides, Ilingoceros and Plesiogulo* to be 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*. In addition, *Hypolagus, Megatylopus, Nannippus* and *Neohipparion* also were regarded as being characteristic of this age.

Recent research in vertebrate paleontology 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* disappeared by the end of Clarendonian time, whereas *Osteoborus* has been re-assigned to *Borophagus* which now ranges throughout the Hemphillian and Blancan. The most current analysis of Neogene land mammal ages and their characteristic taxa and evolving chronofaunas is that by Tedford and others (1987). Because the Hemphillian lasted about 4 to 5 My, it is possible to recognize 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, are characterized by 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, Borophagus, 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, are characterized by more advanced species of

Dinohippus, Astrohippus and Borophagus, as well as the first appearance of genera more typical of the Blancan.

Summary and Conclusions

During the past century, fossil vertebrates, especially mammals, have been collected extensively from the Ogallala Formation (late Miocene-early Pliocene) in the Texas Panhandle and adjacent Oklahoma by the American Museum of Natural History, the University of California, the Frick Laboratory of New York, the University of Oklahoma and several Texas institutions. As a result, the region demonstrates a remarkable sequence of vertebrate faunas that spans most of the Clarendonian and Hemphillian Land Mammal Ages. The Clarendonian Age lasted from about 12.5 to 9 Ma and the Hemphillian Age lasted from about 9 to 4.5 Ma.

Clarendonian faunas are represented in more than 30 sites in the region. Most are north and east of Clarendon in Donley County, Texas and a few are north of Amarillo. The Laverne (=Beaver) Local Fauna of Oklahoma is also of Clarendonian age. Most of the faunas have not been studied adequately and correlation of the different sites is imprecise because of limited exposures, rapid facies changes, wide geographic separation of sites and the lack of superpositional relationships of faunas or of faunas and datable volcanic ash beds. However, the Clarendonian faunas of the region are sufficiently diverse to permit general correlations with Clarendonian faunas elsewhere in the Great Plains (for example, faunas of the Ash Hollow Formation in Nebraska) and in the Gulf Coast region, despite the lack of adequate biostratigraphic control for the "type" fauna in Texas.

Clarendonian faunas are characterized by abundant grazers, a few browsers and mixed feeders and a variety of carnivores. Perissodactyls (horses and rhinoceroses) are the most diverse and abundant group of mammals, followed by artiodactyls (camels, peccary and ruminants), carnivores and proboscideans. Lower vertebrates include gars, pond turtles, giant tortoises and alligators. Complete, articulated skeletons of horses and other mammals have been taken from sinkhole deposits in Donley County, but most fossils are fragmentary and occur in fluvial deposits and probably sample primarily the stream border environment. The climate during the Clarendonian was mild and apparently more mesic in the Panhandle than it is today, with savanna conditions prevailing. The more heavily wooded areas would have bordered the major streams.

Early Hemphillian faunas (about 9 to 7 Ma) are found mainly in Lipscomb County, Texas (for example, the Sebits Ranch and Box T localities) and in adjacent Ellis County, Oklahoma (for example, the Adair Ranch and Port-of-Entry Pit). These faunas can be placed in a biostratigraphic sequence and show the continued presence of many typical Clarendonian genera but with more advanced species. They also document the first appearance of certain immigrant genera, primarily carnivores and sloths. Many of these faunas are dominated by large rhinoceroses (*Aphelops*), gomphotheres (*Amebelodon*) and large carnivores (*Epicyon, Nimravides* and *Barbourofelis*). The Box T Local Fauna is late early Hemphillian and records the last local occurrence of many typical Clarendonian genera. The fauna is large and diverse and correlates closely with the Cambridge (=Ft-40) Local Fauna of Nebraska.

Late Hemphillian faunas (about 7 to 4.5 Ma), such as the Coffee Ranch (=Miami) Local Fauna in Hemphill County, Texas and the Optima (=Guymon) Local Fauna in Oklahoma, postdate a significant mid-Hemphillian extinction event that terminated much of the "Clarendonian chronofauna"; these faunas therefore have fewer browsers and a lower diversity of grazing species. The Coffee Ranch Local Fauna, type fauna for the Hemphillian Age, accumulated in a lacustrine sand, which is capped by a volcanic ash of probable Idaho origin that yielded a zircon fission-track date of 6.8 ± 0.2 Ma. Sediments containing the fauna are normally magnetized and may belong to zone C3Bn. The Axtel and Christian Ranch Local Faunas are the latest Hemphillian faunas identified from the Texas Panhandle and contain more advanced species of *Borophagus* and of the horse genera that are found at Coffee Ranch, Goodnight and Optima. During the Hemphillian Age, especially the latter part, the decimation of most browsers and many grazers coupled with the development of calcic soil horizons or caliche, document a progressive trend toward aridity and the replacement of savanna by grassland prairie and steppe.

Much has been learned in recent years about the Clarendonian and Hemphillian faunas of the Texas Panhandle and adjacent Oklahoma. Continued study of Ogallala stratigraphy and sedimentation, along with careful analysis of mammalian fossils from the region (now housed in the American Museum of Natural History, the University of California, The University of Oklahoma, The University of Texas at Austin, Midwestern State University, West Texas A&M University and the Panhandle-Plains Historical Museum), will provide more precise biostratigraphic correlations and better indications of the morphology and environmental preferences of late Tertiary mammals of the Southern High Plains.

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Appendix 1. Composite faunal list – Clarendon Fauna, Donley County, Texas.

(Site records are not complete)

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

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

- Class Aves
  - Order Falconiformes
    - Family Accipitridae
  - Order Galliformes
    - Family Phasianidae
      - Meleagridinae
  - Order Charadriiformes
    - Family Phoenicopteridae
      - *Megapaloelodus* sp.
  - Order Anseriformes
    - Family Anatidae (2 species) (MacAdams and Noble=Farr Ranches)
- Class Mammalia
  - Order Rodentia
    - Family Mylagaulidae
      - *Mylagaulus* sp. (Noble=Farr, Rowe Ranches)
  - Order Carnivora
    - Family Nimravidae
      - *Barbourofelis whitfordi* (Barbour and Cook) (MacAdams, Rowe Q7)
    - Family Felidae
      - *Pseudailurus* or *Nimravides* (Adam Risley Ranch)
    - Family Canidae
      - *Cynarctus crucidens* Barbour and Cook (MacAdams, Adam Risley, Noble=Farr, Rowe Q2 and Q6)
      - *Aelurodon taxoides* Hatcher (MacAdams, Grant, Noble=Farr, Bromley, Rowe Q4 and Q7)
      - *Paratomarctus euthos* (McGrew) (MacAdams, Noble=Farr, and Rowe Q1, Q3, Q6, and Q7
      - *Carpocyon robustus* (Green) (Rowe Q1)

Epicyon saevus (Leidy) (MacAdams and Rowe Q1, Q2, and Q7)
Epicyon haydeni Leidy (Rowe Q1)
Family Amphicyonidae
**Ischyrocyon gidleyi* (Matthew) (Skillet Creek*, also includes type of *Pliocyon walkerae* from Adam Risley, also at MacAdams, Grant, Noble=Farr and Rowe)
Family Mustelidae
Brachypsalis sp. (Bromley Ranch)
Leptarctus sp. (Noble=Farr, and Rowe Q1 and Q2)
Mionictis sp. (MacAdams)
Sthenictis sp. (Shannon Ranch)
Order Proboscidea
Family Gomphotheriidae
Gomphotherium obscurum (Leidy) (Bromley, Skillet Creek, Noble=Farr)
Family indeterminate
Tetralophodon campester Cope (=type of *T. fricki* Osborn from Rowe)
Order Artiodactyla
Family Tayassuidae
Tayassuinae indeterminate (MacAdams, Noble=Farr, Rowe)
Family Merycoidodontidae
Merychyus novomexicanus Frick (MacAdams, Noble=Farr, Rowe Q2)
Family Camelidae
Aepycamelus robustus (Leidy) (MacAdams, Noble=Farr)
Nothotylopus sp. (MacAdams)
Procamelus grandis Gregory (many localities)
**Procamelus leptognathus* Cope status unclear (Dilli or Charles Risley*)
Protolabis heterodontus (Cope)
Family Protoceratidae
***Paratoceras macadamsi* Frick (MacAdams**)
***Synthetoceras tricornatus* Stirton (MacAdams, Adam Risley, Noble=Farr, Charles Risley or Dilli, Bromley**, Rowe Q2 and Q3)
Family Dromomerycidae
**Cranioceras clarendonensis* Frick (MacAdams*, Adam Risley, Noble=Farr)
Family Moschidae
**Longirostromeryx clarendonensis* Frick (MacAdams*, Adam Risley, Noble=Farr, Bromley)
Order Perissodactyla
Family Equidae
Hypohippus affinis Leidy (MacAdams, Grant, Rowe)
**Pseudhipparion hessei*: Webb and Hulbert (MacAdams*, Grant, Charles Risley)
Hipparion tehonense (Merriam) (MacAdams)
Neohipparion affine (Leidy) (MacAdams, Grant, Noble=Farr, Rowe Q1 and Q7)
Cormohipparion occidentale (Leidy) (MacAdams, Grant, Rowe)
Cormohipparion sphenodus (Cope) (MacAdams)
Nannippus sp. (fide MacFadden, 1998)
Protohippus supremus Leidy (MacAdams, Charles Risley)
Calippus placidus (Leidy) (MacAdams, Grant, Shannon, Charles Risley)
**Calippus regulus* Johnston (MacAdams, Grant*, Shannon, Charles Risley, Rowe)
Calippus martini Hesse (MacAdams, Grant, Charles Risley, Rowe)
Pliohippus pernix Marsh (Grant, Charles Risley)
**Pliohippus fossulatus* Cope (MacAdams, Charles Risley or Dilli*, Whitefish Creek)
**Dinohippus? pachyops* (Cope)-status unclear (Charles Risley or Dilli*)
Family Rhinocerotidae
Teleoceras major Hatcher (Noble=Farr, Rowe)
?Aphelops sp.

Symbols: ** Holotype of genus
* Holotype of species

Appendix 2. 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	?
Family Emydidae?				
Small pond or river turtles	?			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 Aves				
Order Falconiformes				
Family Accipitridae		X		
Order Galliformes				
Family Phasianidae			X	
Order Anseriformes				
Family Anatidae				
Anserinae				X
Order Ciconiiformes				
Family Ciconiidae			X	
Class Mammalia				
Order Chiroptera				
Family Vespertilionidae				
Antrozous pallidus Allen (=*Pizonyx wheeleri*)			X	
Order Edentata				
Family Megalonychidae				
Pliometanastes cf. *P. protistus* Hirschfeld and Webb				X
Megalonychid sp.			X	
Family Mylodontidae				
Thinobadistes wetzeli Webb				X
Order Rodentia				
Family Mylagaulidae				
Mylagaulus sp.			X	
Family Eomyidae				
Kansasimys dubius Wood			X	
Undetermined genus and species			X	
Family Sciuridae				
Spermophilus sp.			X	
Family Geomyidae				
Pliosaccomys higginsensis Dalquest and Patrick			*	
Family Heteromyidae				
Perognathus sp.			X	
Order Lagomorpha				
Family Leporidae				
Hypolagus vetus (Kellogg)			X	

Order Carnivora				
Family Nimravidae				
Barbourofelis loveorum (Baskin)(=*Albanosmilus* of Kitts, 1957)		X		
Family Felidae				
Nimravides cf. *N. thinobates* (Macdonald) (=*N. catocopis* of Burt, 1931)		X	X	X
Pseudailurus sp. – fide Martin, 1998		X		
Machairodus sp.				X
Family Canidae				
Carpocyon limosus Webb		X		
Epicyon saevus (Leidy)		X		X
Epicyon haydeni Leidy		X	X	X
Borophagus cf. *B. secundus* (Matthew and Cook)			X	
Borophagus cf. *B. pugnator* (Cook)				X
Family Mustelidae				
Eomellivora sp.				X
Leptarctus supremus Lim, Martin, and Wilson				*
Sthenictis sp.				X
Family Ursidae				
Indarctos oregonensis Merriam, Stock, and Moody				X
Order Proboscidea				
Family Gomphotheriidae				
Gomphotherium?	X	X		
Amebelodon floridanus (Leidy)			X	
Amebelodon cf. *A. fricki* Barbour				X
Order Artiodactyla				
Family Tayassuidae				
Tayassuinae indet.		X		
Prosthennops serus (Cope)			cf?	X
Family Camelidae				
Aepycamelus sp.	X	X		
Procamelus sp.	X	X		?
Megatylopus sp.	X	X	X	X
Hemiauchenia sp. (=*Pliauchenia* of Hesse, 1940)	X	X	X	X
Family Dromomerycidae				
Pediomeryx (*Yumaceras*) cf. *P. figginsi* (Frick)		X	X	X
Family Gelocidae				
Pseudoceras sp.				X
Family Antilocapridae				
Antilocaprine indet.	X	X	X	X
Osbornoceros? sp.				X
Order Perissodactyla				
Family Equidae				
Hipparion sp.		X	X	
Hipparion forcei Richey				X
Neohipparion leptode Merrian	X	X	X	X
Cormohipparion cf. *C. occidentale* (Leidy)		?	?	X
Astrohippus sp.				X
Calippus – large sp.				X
Pliohippus nobilis Osborn	X	X	X	X
Family Rhinocerotidae				
Aphelops malacorhinus Cope		X	X	X
Teleoceras fossiger (Cope)		cf.	cf.	X

Symbols:

**	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 Arnett=Port of Entry Pit 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

Appendix 3. 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
Family Emydidae?			
Small pond turtle		X	
Order Squamata			
Family Boidae			
Erycinae gen. 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	X		
Class Aves			
Order Falconiformes			
Family Accipitridae		X	
Order Passeriformes			
Family Corvidae			X
Order Gruiformes			
Family Rallidae	X		
Order Anseriformes			
Family Anatidae			
Nettion bunkeri Wetmore (or *Anas crecca*) – duck or teal		X	
Class Mammalia			
Order Insectivora			
Family Soricidae			
Soricid sp. indet.		X	
Family Talpidae			
Scalopus (*Hesperoscalops*) *ruficervus* Dalquest		*	

	A	B	C
Order Chiroptera			
Family Vespertilionidae			
Eptesicus hemphillensis Dalquest		*	
Order Edentata			
Family Megalonychidae			
Megalonyx sp.	X		
Family Mylodontidae			
Thinobadistes sp.		X	
Order Rodentia			
Family Mylagaulidae			
Mylagaulus cf. *M. monodon* (Cope)		X	
Mylagaulus sp.	X		
Family Castoridae			
Dipoides sp.	X		
Family Eomyidae			
Comancheomys rogersi Dalquest		**	
Family Sciuridae			
Spermophilus sp.		X	
Family Geomyidae			
Progeomys sulcatus Dalquest		**	
Family Heteromyidae			
Cupidinimus sp.		X	
Perognathus sp.		?	
Prodipodomys? sp.		X	
Family Cricetidae			
Paronychomys? sp.		X	
Calomys (*Bensonomys*) *coffeyi* Dalquest		*	
Peromyscus sp.		X	
Prosigmodon sp.		X	
Neotoma (*Paraneotoma*) *minutus* Dalquest		*	
Order Lagomorpha			
Family Leporidae			
Hypolagus cf. *H. vetus* (Kellogg)	X		
Hypolagus gidleyi White		X	
Order Carnivora			
Family Felidae			
Machairodus cf. *M. coloradensis* Cook	X	X	
Lynx proterolyncis (Savage)	*	X	
Pseudailurus sp. or *Adelphailurus* sp.	X		
Pseudailurus hibbardi Dalquest		*	
Nimravides sp. – fide Martin 1998		X	
Family Canidae			
Borophagus secundus (Matthew and Cook)	X	X	X
Eucyon davisi (Merriam)	X	X	?
Vulpes stenognathus Savage	*	X	X
Family Mustelidae			
Plesiogulo marshalli (Martin)	X	X	
Pliotaxidea cf. *P. nevadensis* (Butterworth)	X	X	
Family Procyonidae			
Arctonasua fricki Baskin	*		
Family Ursidae			
Agriotherium schneideri Sellards	X	X	
Order Proboscidea			
Family Gomphotheriidae			
Rhynchotherium sp.		X	
Family Mammutidae			
Mammut sp.	X		

Order Artiodactyla			
Family Tayassuidae			
Platygonus sp.	X	X	?
Family Camelidae			
Megatylopus matthewi Webb	X	*	
Alforjas taylori Harrison	X	X	
Hemiauchenia sp.	X		
Hemiauchenia vera (Matthew)		X	
Family Dromomerycidae			
Pediomeryx (*Pediomeryx*) *hemphillensis* Stirton	X	**	?
Family Antilocapridae			
Texoceros guymonensis Frick (=*T. altidens*?	**		
?*Texoceros minorei* Frick (=*T. altidens*?)	*		
Texoceros cf. *T. altidens* (Matthew)		X	X
Order Perissodactyla			
Family Equidae			
Dinohippus interpolatus (Cope) (includes *Pliohippus bakeri*)	X	X	*
Astrohippus ansae (Matthew and Stirton)	X	*	X
Neohipparion eurystyle (Cope)	X	X	X
Neohipparion gidleyi Merriam	X		
Neohipparion leptode Merriam		X	
Nannippus lenticularis (Cope) (=*N. ingenuus* of MacFadden)	X	X	*
Nannippus aztecus Mooser		X	
Family Rhinocerotidae			
Aphelops mutilus Matthew	X	X	?
Teleoceras hicksi Cook	X	X	
Teleoceras n. sp. (dwarf)	X		

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

Appendix 4. Faunal lists of latest Hemphillian local faunas of the Texas Panhandle. Modified after Johnston and Savage (1955).

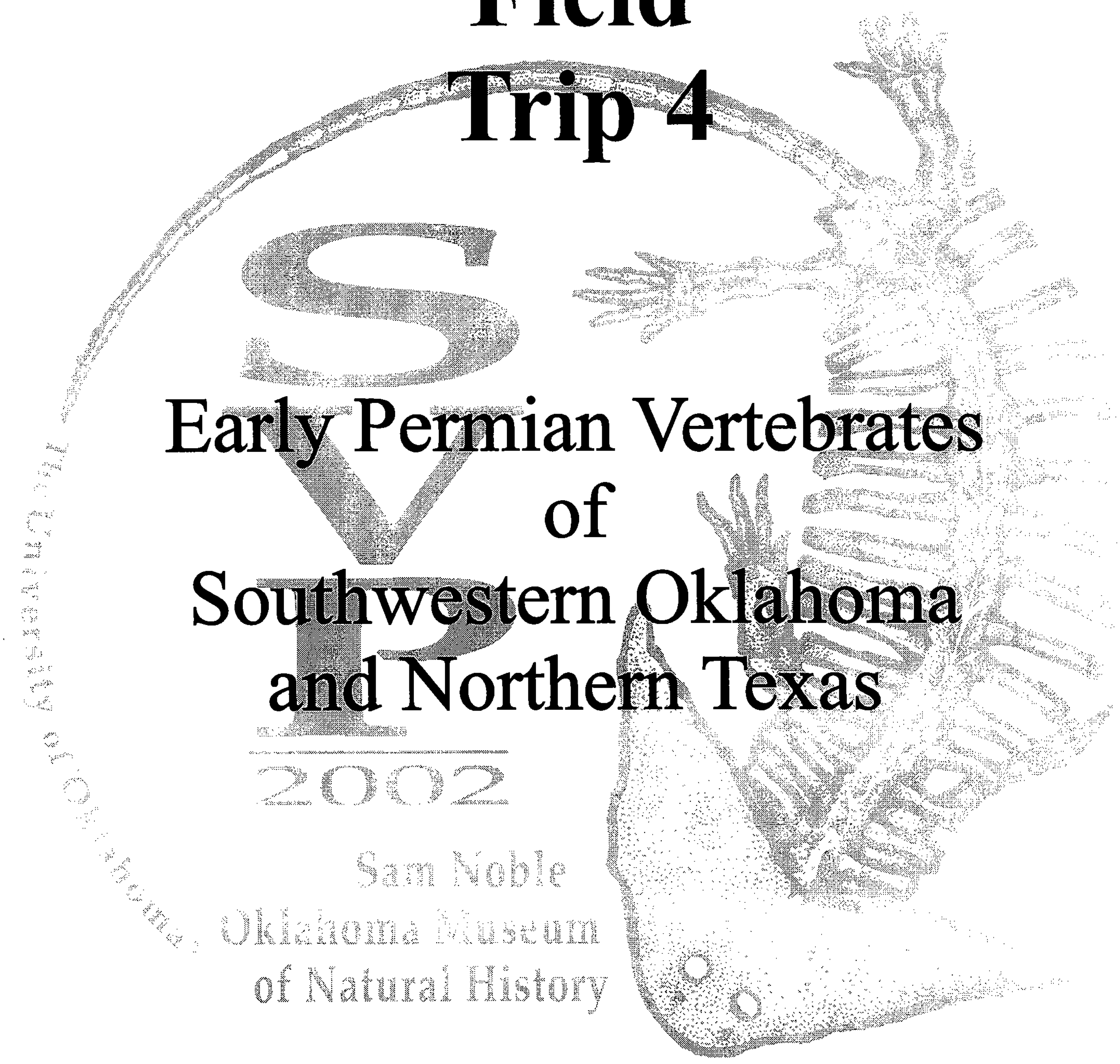
	A	B	C
Class Reptilia			
Order Chelonia			
Family Testudinidae			
Geochelone turgida (Cope) – tortoise	X		
Geochelone sp. – large tortoise		X	X
Testudinid sp. – small tortoise		X	
Class Mammalia			
Order Edentata			
Family Megalonychidae			
Megalonyx sp.	X		
Order Rodentia			
Family Mylagaulidae			
Mylagaulus sp.	X		
Family Geomyidae			
Indet. genus and species	X		
Order Carnivora			

Family Felidae			
Machairodus sp.	X		
Felid indet.		X	
Family Canidae			
Borophagus hilli (Johnston)	*	X	X
Caninae indet. – possibly *Eucyon davisi* (Merriam)	X	X	
Family Mustelidae			
Pliotaxidea sp.	X		
Mephitinae indet.		X	
Family Ursidae			
Agriotherium schneideri Sellards	X		
Order Proboscidea			
Family Gomphotheriidae			
Rhynchotherium? sp.		X	X
Order Artiodactyla			
Family Tayassuidae			
Tayassuinae indet. – possibly *Platygonus* sp.	X	X	
Family Camelidae			
Megatylopus? – large camel	X	X	X
Hemiauchenia sp.	X	X	
Family Antilocapridae			
Hexobelomeryx? sp.	X	X	
Order Perissodactyla			
Family Equidae			
Dinohippus mexicanus (Lance)	X	X	X
Astrohippus stockii (Lance)	X	X	X
Neohipparion eurystyle (Cope)	X	X	X
Nannippus cf. *N. lenticularis* (Cope) (=*N. ingenuus* of MacFadden)	X		
Nannippus aztecus Mooser	?		

Symbols: * Holotype of species
X Occurrence in fauna
A Axtel Local Fauna, Randall County, Texas
B Christian Ranch Local Fauna, Armstrong County, Texas
C Currie Ranch Local Fauna, Randall County, Texas

Field Trip 4

Early Permian Vertebrates of Southwestern Oklahoma and Northern Texas



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Lower Permian Vertebrates From Southwest Oklahoma

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Introduction

Permian sedimentary rocks cover most of the western half of Oklahoma. The succession ranges from a conformable contact with the Pennsylvanian to perhaps the youngest Permian sediments on the continent (Fay and Hart, 1978). These rocks have a combined thickness of at least 2,000 meters in the deepest parts of the Anadarko Basin located in far western Oklahoma.

Permian vertebrate faunas in this area have been studied for nearly 125 years. The earliest discovery in Oklahoma of Lower Permian vertebrates was by W.F. Cummins in the early 1880's during a brief stagecoach stop at Deep Red Run Creek (Stop 3). There, Cummins, working with Cope, collected and later described a new palaeoniscoid fish and two species of *Dimetrodon.* Since that time, there have been a series of researchers studying the Permian faunas in Oklahoma, largely to compliment or supplement similar work in Texas. Olson (1962, 1965, 1967) and Simpson (1979) have compiled the most recent comprehensive surveys of Permian sites in Oklahoma.

General Geologic Setting

During the Permian, a broad, shallow, inland sea covered an area known as the Permian basin (Figure 1). This region encompassed the western one-half of Oklahoma. The Permian basin extended south from west Texas and eastern New Mexico, northward into western Kansas and southeastern Colorado. This area was defined, in part, by the Anadarko, Delaware, Midland, Palo Duro, Hardeman and Dalhart basins and by surrounding uplands. Sedimentation was influenced by basin structure and subsidence. Clastic sediment eroded from the Ouachita lowlands to the east, the Amarillo-Wichita uplift in the center, and the ancestral Rocky Mountains to the west. A maximum of 2,300 meters of sediment was deposited in the basins.

Normal marine water entered into the Permian basin region through the Delaware and Midland basins from open ocean areas to the west and southwest. These waters passed over reefs that fringed the basins and entered into a shallow inland evaporite sea. Freshwater flowed into the basins from surrounding areas and carried clastic sediment and minerals derived from the uplands. In general, clastic sediment was deposited in the alluvial and nearshore margin of the basins and evaporates were deposited in the more central or deeper parts of the basins.

Marine carbonate and clastic units are mostly Wolfcampian in age, although isolated occurrences of fossiliferous Leonardian through middle Guadalupian marine rocks are known. Examples of these include a small outcrop of a marine dolomite in the early Guadalupian Blaine Formation (Fay, 1962) and a marine limestone in the

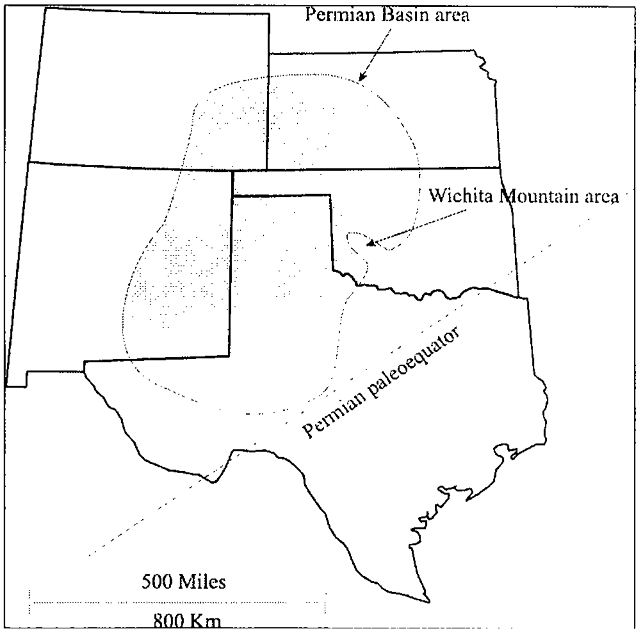

Figure 1. Outline of the Permian basin area during the Lower Permian (modified from Johnson, 1997).

middle Guadalupian Doe Creek Lentil of the Whitehorse Group. These occurrences help to correlate the Permian System of Oklahoma with Texas, Kansas and New Mexico, although large gaps in the marine fossil record accompanied by flora and fauna differences and lateral changes in the terrestrial sediments have frustrated geologists and paleontologists for decades.

An outcrop belt of clastic, terrestrial-derived sediment stretches from north-central parts of Oklahoma southward to north of the Arbuckle Mountains, then south-westward into Texas. It consists of Wolfcampian through early Guadalupian interbedded carbonate, conglomerates, sandstones and shales that outcrop in parallel bands that are progressively younger to the west. Carbonates and conglomerates are more common in the Wolfcampian succession while massive sandstones dominate the younger units.

Evaporite sequences dominate the west-central parts of the state and are of Leonardian to Guadalupian age. The depositional sequence of the evaporites follows a general trend from bottom to top, or from basin margin to center, of dolomite to anhydrite to halite. Dolomite units tend to be thin (5 to 10 cm) and discontinuous; anhydrite (gypsum in outcrop) can be thin and discontinuous or massive (up to several meters thick) and persistent; halite is confined largely to the subsurface and is usually massive (tens of meters to over one hundred meters thick). Interbedded with the evaporite sequences are various shale and sandstone units that may be persistent or grade laterally into dolomite or evaporites. Thinly bedded selenite is typically present in the shale and sandstone units.

Above the youngest evaporite units in the Anadarko Basin are the Ochoan age Doxey Shale and Elk City Sandstone. The Doxey Shale correlates to the Quartermaster Formation and Dewey Lake Formation in Texas; the Elk City Sandstone rests above these formations and is younger than any other Permian units in North America (Fay and Hart, 1978; Johnson, 1976, 1993).

History of Permian Vertebrate Studies in Oklahoma

The first vertebrate fossils described from Oklahoma are, fittingly, from the Permian. In 1888 Cope described *Dimetrodon dollovianus* from collections made in Indian Territory (now Oklahoma) by W.T. Cummins (Stop 3). Other early researchers working in the Oklahoma Permian include Williston (1899), Gould (1900), Case (1902), Moodie (1911) and Smith (1927), all of whom collected mostly in the Lower Permian of north-central Oklahoma. Most of the sites from which these and later researchers studied, including the Orlando Site, McCann Quarry, Waurika Site and others, still yield vertebrate fossils. Many of these sites and the faunas have not been studied since Olson's comprehensive monograph (1967).

Upper Permian sites in Oklahoma are much less common and have received even less study. Olson and Barghusen (1962) and Olson (1965) described the vertebrate faunas from the Chickasha Tongue of the Flowerpot Formation (lower to middle Guadalupian) from several localities. In 1963 Olson found a jaw fragment found in the Elk City Sandstone (Fay and Hart, 1978), making this possibly the youngest Paleozoic vertebrate site in North America.

Field Trip Stop Descriptions

Stop 1. Richards Spur Dolese Quarry

This locality (OMNH V51), in the Slick Hills of southwestern Oklahoma, is the most prolific Paleozoic vertebrate producing site and it is arguably one of the most prolific vertebrate producing sites of any age. A faunal list is given in Table 1. Fossils are found in excavated clays dumped in an area of the active quarry floor. They represent Permian karst fills from fissures in a limestone host rock. The dump areas include a mix of deposits of clay, flowstone, limestones and dolomite not suitable for use by the quarry. These piles are removed periodically to other areas or ground into aggregate. *Watch for loose rock and rattlesnakes in the dump area!*

In 1932, operators of the quarry informed geologists at the University of Oklahoma of large quantities of vertebrate fossils occurring in clay-filled limestone fissures (Gregory and others, 1956). J. Willis Stovall and his students made the initial collections from the site. Subsequent collections from this site over the past 70 years have yielded a large and diverse fauna of nearly 30 taxa. This is the most diverse known assemblage of Paleozoic terrestrial tetrapods (Sullivan and others, 2000). Today, the quarry operation yields few vertebrate remains because the active quarry is below the depth of fossil producing fissures.

The Richards Spur quarry is an active operation. No in situ study of the actual fossil occurrences has been made and very little is known of the taphonomy. An additional two related occurrences of this fauna have been recorded. The first is at a site known as Bally Mountain (also known as Leatherbury's Quarry). This is a much smaller, abandoned Dolese quarry located about 23 miles northwest of Richards Spur. The other site is a small road cut along State Highway 19 to the west of Apache, about 11 miles north northwest of Richards Spur. Both of these localities are much smaller in extent than Richards Spur and workers are not exposing new fissures. Consequently, they do not or have not produced the same abundance of fossil materials. However, because these sites are static, the fossil occurrences and karst features have been studied in considerably more detail (Donovan, 1982; Donovan and Busbey, 1991; Donovan and others, 1989, 1992). Additionally, the fauna represented at Richards Spur and the two known related sites is unique in composition and preservation, making direct comparisons with other Lower Permian localities tenuous.

The fissure deposits occur in a Lower Ordovician limestone host of the Arbuckle Group. The Slick Hills are Cambrian and Ordovician carbonates that unconformably overlie a Cambrian igneous basement. They occur along the

Chondrichthyes	
Xenacanthida	
Xenacanthidae	*Xenacanthus* sp.
Tetrapoda	
Temnospondyli	
Eryopidae:	Unidentified eryopid
Dissorophidae:	*Cacops* cf. *C. aspidophorus* *Doleserpeton annectens* *Tersomius* sp.
Trematopsidae:	Unnamed genus
Batrachomorpha	
Seymouriidae:	*Seymouria* sp.
Lepospondyli	
Aistopoda	
Phlegethontiidae:	*Phlegethontia cf. linearis*
Microsauria	
Gymnarthridae:	*Cardiocephalus peabodyi* *Euryodus primus*
Hapsidopareiontidae:	*Llistrofus pricei*
Amniota	
Parareptilia:	Unidentified parareptile
Eureptilia	
Protorothyrididae:	*Colobomycter pholeter*
Captorhinidae:	*Captorhinus aguti* *Captorhinus laticeps* Large captorbinid *Baeotherates fortsillensis*
Bolosauridae:	*Bolosaurus* sp. *Bolosaurus grandis*
Synapsida:	*Delorhynchus priscus* *Thrausmosatirus serratidens*
Caseidae:	Unidentified caseid
Varanopseidae:	*Mycterosaurus longiceps* Large varanopseid
Diapsida:	Unidentified neodiapsid

Table 1. Richards Spur paleofauna.

exposed portion of the frontal Wichita fault zone. This area was uplifted and underwent deformation during the Pennsylvanian and earliest Permian (Donovan and others, 1992). The Slick Hills (Figure 3) are bounded on the north by the Wichita Valley Fault and, north of the fault, the Anadarko Basin. The Meers Fault bound the hills on the south. South of the Meers Fault are the Wichita Mountains and the Hardeman Basin.

The karst developed in a fine network of fractures and structural linaments related to the deformation of the rock units. Karstification probably began shortly after the host limestone was exposed at the surface in the Pennsylvanian and continued into the Early Permian. Donovan and others (1992), describing the evolution of a fossil cave system at the Bally Mountain site, listed a sequence of five cycles. These include the primarily vadose opening of the fissures by meteoric dissolution; the coating of the fissures by calcite speleothems including flowstone, cave popcorn and stalactites/stalagmites; the phreatic infill of the lower reaches of the fissures; the clastic infilling of the fissures including vertebrate remains; and the final fossilization of the karst by burial beneath Permian alluvium.

This is a simplified sequence based on in situ study of a series of caves or fissures and does not reflect the complexity of the karst entirely. Much work needs to be done at Richards Spur and related sites to determine the origin and genesis of the karst.

Price gave the earliest descriptions of the quarry (Gregory and others, 1956). He notes that on the face of the "old east-facing quarry," now removed, there were vertical fissures varying from a few centimeters to perhaps a meter in width with irregularly curved walls. The fissures were filled with a limestone breccia and pockets of soft blue and yellow clay, all containing fossils. He also noted that the bases of the exposed fissures were not exposed and the tops were open into the soil zones of the hilltop.

The fossils found in the dump area at Richards Spur are subject to weathering. Because the clay readily washes away with water, piles left to weather are typically slumped and fossils are concentrated at the surface. Most collections made at Richards Spur have been made by gathering large grab samples of fossiliferous clay in bags or boxes from the dump area. These samples were then transported back to a lab for processing. Occasionally, articulated or partially articulated specimens were found and collected individually. They usually have been found in newly dumped piles or from fissures with well cemented matrix.

Observations of Richards Spur

Based on three decades of observation and collecting by the authors and informal interviews of quarry workers, many previously undocumented features of these deposits have been noted.

Speleothem lithology

A diverse range of speleothem lithologies can be observed in the Richards Spur dump area. Variations in speleogenesis, fissure or cave morphology, duration of the fissure or cave, and taphonomy are significant because they may control fossil distribution. Lithologies include fossiliferous and unfossiliferous deposits. Donovan and others (1992) list eight types of speleothem calcite deposits based on petrographic analysis of specimens collected at Bally Mountain. These include four types of flowstone, stalactites, stalagmites, cave popcorn, and euhedral precipitates. Detrital deposits, including the fossiliferous clay, are described briefly by Donovan and others (1992) and divided into allochthonous and autochthonous origins. Accessory minerals present in some of the speleothems include hydrocarbon (asphalt), pyrite/marcasite, small blue barite crystals, and small, double terminated quartz crystals.

The calcite speleothems were deposited along the floor, roof and walls of the fissures and caves. These deposits may be up to 0.6 meters thick and typically contain hydrocarbons inclusions (Donovan and others, 1992). The flowstones are rarely interbedded with detrital sediments; most are massive and conform to the shape of fissure or cave walls or floor. Stalactites and/or stalagmites are rare and normally small.

The detrital sediments are quite varied in appearance and texture. They include a minimum of eleven depositional types, based on color and content. Numerous sub-categories of these types based on grain size and accessory mineral content may be present. The deposits include: laminated blue gray clay (fossiliferous or unfossiliferous), massive blue gray clay (fossiliferous or unfossiliferous), brecciated massive blue gray clay (fossiliferous or unfossiliferous), conglomeratic massive blue gray clay (fossiliferous or unfossiliferous), laminated yellow brown clay (typically unfossiliferous) and massive yellow brown clay (fossiliferous or unfossiliferous).

Laminated blue gray and laminated yellow brown clays consist of layers that vary in grain size and/or mineral content (including hydrocarbons). The blue gray clay may contain articulated or partially articulated fossils or disarticulated fossil bones in coarser layers and probably were deposited in relatively quiet areas. The deposition of these clays has not been studied, although some appear to be size sorted. Other deposits appear have oriented fossil long bones, while still other deposits appear unsorted with individual fossil bones unoriented and crossing bedding planes. The fossil assemblages that occur in these types of deposits are typically monotaxic or numerically dominated by a single taxa. Additionally, most of the uncommon taxa appear in these deposits.

The massive blue gray and yellow brown clays deposit are typically coarsening upwards deposits that may have a brecciated upper layer. Fossils found in these deposits are usually unsorted and disarticulated. These may be reworked deposits or the product of the sudden inflow of sediment into a low area.

Brecciated massive blue gray clay is common throughout the dump area, but in some cases may be an artifact of mixing soft, wet clay with gravel piles in the dump area. Many of these deposits contain fossils, as well as increased percentages of accessory minerals, particularly pyrite and marcasite. Fossils are typically disarticulated and fragmentary. Donovan and others (1992) postulated that these breccias were derived from the overlying land surface and represented the final burial and termination of speleogenesis of the fissure deposits.

Conglomerate deposits are fairly uncommon but are often fossiliferous. These conglomerates typically contain flat clay (claystone) pebbles derived from the speleothems themselves. These deposits are usually calcite cemented and contain coarser clastic materials and disarticulated fossils, typically of single taxon. These deposits were possibly the result of a sudden increase in water flow within a closed fissure or cave system that resulted in the redeposition and concentration of fossils.

The only additional common speleothem deposit found throughout this site is one filled with asphalt. Typically, these deposits also contain calcite of either dogtooth spar or rhombohedron crystals. The calcite crystals can be of large size. Some of these crystals grow directly from the walls of the fissures or caves on the host limestone; some are outgrowths from flowstone, while others grow on clay deposits.

Stop 2. Fort Sill Asphalt Pit

This locality (OMNH V243) has been known for nearly as long as Richards Spur, but has received minimal attention. The site is located within the property boundaries of Fort Sill and is subject to control by the U.S. Army. *No collections may be made at this site.*

The asphalt pit is located in the informally named Post Oak sandstone and is of Leonardian age. Two specimens from this site represent well-preserved *Diadectes* sp. fossils that were collected by J. Willis Stovall in 1937 (OMNH 613) and by one of the authors (May) in 1997 (OMNH 35346). Although the site has not been studied, observations demonstrated the presence of *Dimetrodon* and *Trimerorhachis*.

The observed fossils and the two reposited specimen are coated with asphalt. The sandstone is heavily impregnated with asphalt; tar actively seeps from the sandstone in warm weather. The sandstone is predominantly fine grained with some cross bedding. Fossils are found scattered throughout the sandstone as disarticulated elements.

The dating of oil impregnation of the sandstone is an interesting question. Dates for several nearby occurrences of asphalt deposits and of oil migration into younger units fall within the Permian. The question arises whether these animals were trapped by tar (á la La Brea) or did the asphalt migrate into the sandstone after deposition? Further study is needed before any conclusions can be drawn, but this is one of the more interesting and least studied Lower Permian sites in Oklahoma.

Stop 3. Cummins' Deep Red Run Creek

This was the first vertebrate locality discovered in Oklahoma and is the type locality for a palaeoniscoid fish (*Platysomus palmaris*) and two species of *Dimetrodon* (*D. dollovanus* and *D. platycentrus* [= *D. macrospondylus*]) (Case, 1907; Cope, 1888, 1891; Cummins, 1908; Romer and Price, 1940). Cummins found this locality (OMNH V174) during a stagecoach trip from Fort Sill to Fort Auger, in the Indian Territory. A stagecoach stop was made at the water crossing of Deep Red Run Creek and Cummins, scouting the surrounding geology, made the fossil discoveries. This is a large site covering in excess of 100 acres.

Simpson (1979) located an area of highly eroded terrain in the general area along the stagecoach route indicated on early maps of Indian Territory (1875, 1885, and 1906). Many areas of this site have yielded vertebrate fossils.

This site has about 12 meters of typical lower Garber Sandstone exposed in an underfit valley. The site is mud-dominated and contains a few channel deposits. Paleosols are frequent and developed in mud dominated overbank deposits across much of the site. Vertebrate fossils have been found in channel fill conglomerates. This site has not been studied recently, but has potential due to its extensive outcrop area.

Stop 4. Northeast Frederick Site

This site (OMNH V173) has yielded a diverse fauna of mid-upper Leonardian (Garber) vertebrates and plant fossils. It site was described by Simpson (1979) who collected materials from this and one other site as a basis for his unpublished masters thesis (1976).

About 15 meters of typical upper Garber Formation are exposed in a series of washes overlooking a small, unnamed creek. The site is mudstone dominated with a few channel deposits. Lithologies include gray claystone, red mudstone and conglomerates. The mudstone and claystone are weakly fissile, poorly indurated and erode easily. Some areas have extensive outcrops of barite nodules and paleosol development has been observed throughout the section.

Simpson (1976) mapped the fossil occurrences and divided the site into six separate areas that were based mainly on lithologic differences. Currently, the most prolific parts of the site are in Simpson's areas B and C, where erosion is greatest and vegetation is minimal.

Stop 5. East Manitou

This site (OMNH V176) is stratigraphically younger than the NE Frederick site (Stop 4) and the lithologies are quite different. Olson (1967) initially described this site and Simpson (1973, 1974) added to the faunal list and interpreted the paleoecology.

The East Manitou site is located in a roadcut near Lake Frederick and is stratigraphically at the Garber Sandstone-Hennesey Shale contact. Channel fills include massive buff colored sandstones and an overlying thin, well-cemented arkose that yield fossils. The sandstones are weakly cross-bedded and well sorted. The most common fossils are plant remains with occasional organic rich lamina that contain a hash of plant fossils, palaeoniscoid scales and isolated teeth. The arkose contains a variety of vertebrate fossils and petrified logs. Most of the vertebrate fossils in the arkose are disarticulated, although Simpson (1974) found an articulated platysomid in this unit.

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Permian rocks and fossil plants of North-Central Texas

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INTRODUCTION

Lower Permian rocks of North-Central Texas were the source of world-famous reptile and amphibian remains collected during the late 19th and early 20th centuries. More recently, these rocks have yielded abundant and diverse fossil plants. Research by the Smithsonian Institution over the last 15 years is leading toward a comprehensive picture of the Permian rocks, their flora and fauna and the environments of deposition, ecosystems and paleoclimate.

In terms of Permian paleogeography, North-Central Texas was situated on the Eastern Shelf of the Midland Basin (Figure 1). The Midland Basin was a nearly landlocked oceanic basin with waters several hundred meters deep and abrupt shelf margins. The Eastern Shelf was broad and virtually flat, covering much of Central and North-Central Texas. The Ouachita Mountains lay to the east and the Arbuckle and Wichita Mountains to the northeast and north. Streams carried sediment from these source areas across the Eastern Shelf to the Midland Basin. Through time, the basin was filled gradually with sediment, becoming by mid-Guadalupian time a complex of shifting sand dunes, mud flats and alkali flats.

In simplest terms the Lower Permian facies tracts are as follows. Surrounding the Arbuckle and Wichita Mountains are coarse, fluvial sandstones and conglomerates. On the landward part of the Eastern Shelf, red mudstone is prevalent and represents fluvial environments also. On the seaward part of the shelf, red mudstone intergrades with gray and green mudstone, shallow marine limestone, dolomite and gypsum. Within the Midland Basin dark-colored and fine-grained limestone, dolomite, siltstone and dark shale were deposited.

Through time, these facies belts shifted in response to tectonic activity, sea-level changes and other processes. Most dramatically, the Midland Basin shrank as it was filled with sediments derived from the land. By middle Guadalupian time, the basin essentially was filled and its site became a complex of intermittently flooded mud flats, alkali flats and sand dunes. However, because the slope of the Eastern Shelf was so gentle, minor changes in water level of the basin produced large lateral shifts of the shore line. Superimposed on global climatic trends were the local climate changes that took place in response to the unsteady shrinkage of the West Texas inland sea.

Considering the present outcrop belt, the plant and vertebrate collecting grounds of North-Central Texas are dominantly within the upper shelf redbeds facies tract. These rocks grade southward (into Central Texas) and westward (into the subsurface) into the lower shelf facies belt.

Below we describe that part of the section from which significant plant and vertebrate remains have been recovered. These descriptions focus on the factors where we have concentrated our research: basic stratigraphy and depositional environments, fossil plants and paleosols.

Bowie Group

The Bowie Group (Hentz, 1988) comprises terrestrial redbeds that are equivalent to mixed marine and nonmarine rocks of the Cisco Group in Central Texas (Figure 2). Hentz divided the Bowie into two formations in North-Central Texas: the Markley and the Archer City.

Wichita Group

The definition of the Wichita Group varies among geologists, time periods and regions of Texas; but the definition recommended by Hentz (1988) is used here. Hentz defined the Wichita Group in North-Central Texas as the interval of redbeds overlying the Bowie Group and underlying the Clear Fork Group (Figure 2). The Wichita, as used by Hentz, is correlative with marine strata of the Albany Group southward along the outcrop belt.

Markley Formation (Bowie Group). The Markley Formation spans the Virgilian-Wolfcampian boundary (Figure 2). Placement of this boundary within the Markley is uncertain due to a lack of diagnostic fossils. In Central

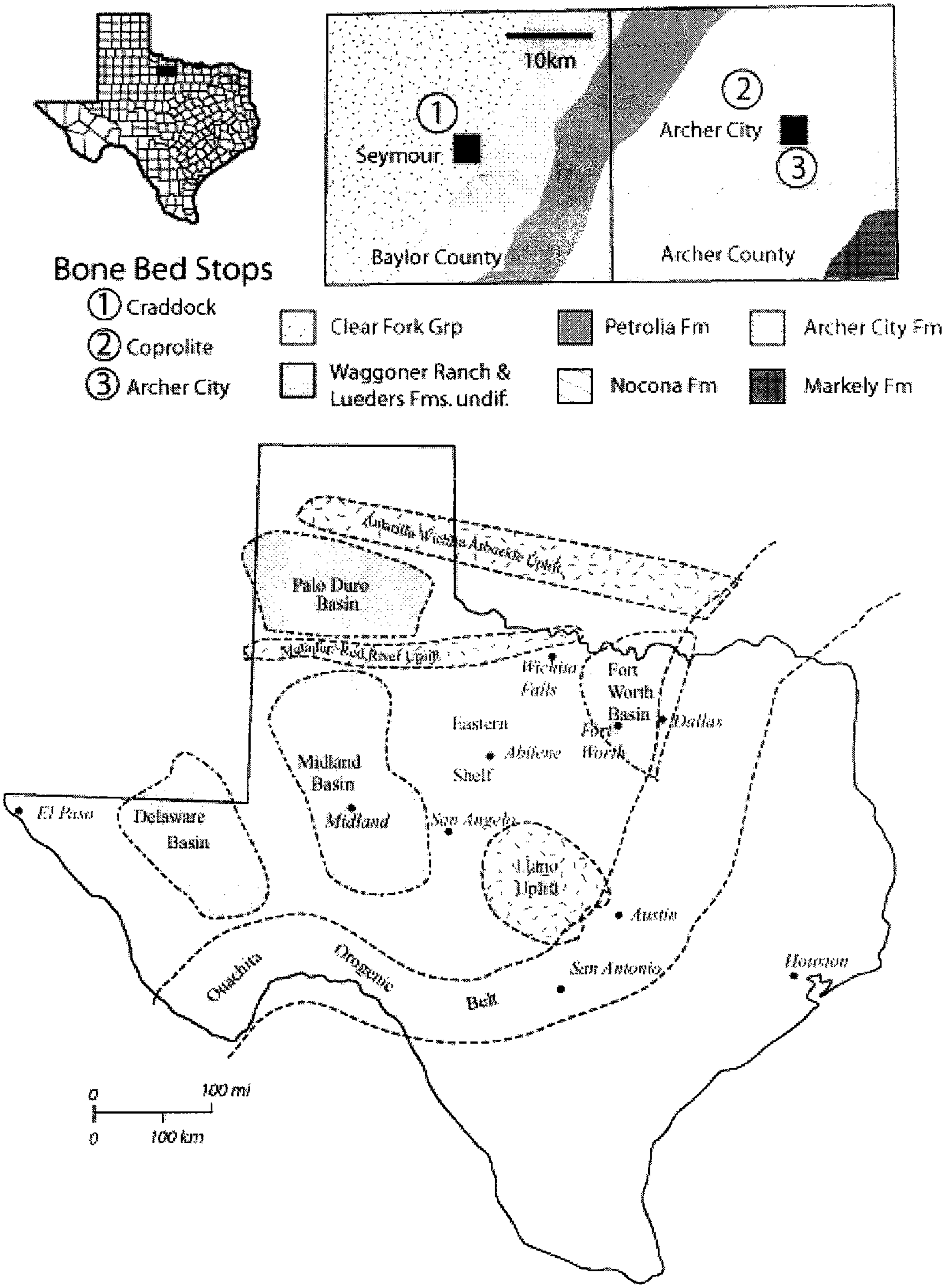

Figure 1. Locality, geologic and tectonic sketch maps of Texas and field trip localities.

Texas, the Virgilian-Wolfcampian boundary is placed in the lower part of the Harpersville Formation on the basis of fusulinids and ammonoids. The equivalent position in North-Central Texas is in the mid-upper part of the Markley.

The Markley and correlative Harpersville are distinguished by the presence of coal. Coal from the Harpersville was mined commercially during the late 19th and early 20th centuries. Coal beds that were mined ranged from about 50 to 125 cm thick and were ranked from subbituminous A to high-volatile B bituminous coal, with high ash and sulfur contents (Evans, 1974). Coal beds in the Markley are highly lenticular and too thin to mine; many are more accurately classified as carbonaceous shale. Subsurface data show that coal zones within the Bowie and Cisco Groups extend at least 140 km basinward from the outcrop belt.

Hook (1989) summarized the stratigraphic distribution of tetrapods from the Bowie and Wichita Groups, as gleaned from published and unpublished reports and field notes of collectors. The Markley Formation has yielded only a few vertebrate collecting sites and low diversity of remains.

Plant-bearing outcrops of the Markley are complex, but similar deposits recur along the outcrop belt from north of the Llano Uplift on the south nearly to the Red River (Texas – Oklahoma border) on the north (Figure 1). In the late 1980s and early 1990s, Smithsonian field parties visited nearly all previously reported plant localities (and discovered many new ones) along this belt and made extensive collections. Work in this interval was curtailed only after the point where the floras became predictable. Here is a typical Harpersville fossil plant succession (from bottom to top):

- Paleosol at the base; tree fern roots present at a few sites.
- White to gray, massive kaolinite bed that varies from a few cm to over a meter thick. The base is erosional. The clay may represent a lag deposit: clays formed as a result of extensive weathering during lowstand and were redeposited in channels during transgression. The flora is almost entirely seed plants, including conifers, cycads, medullosans and *Sphenopteridium.*
- Organic shale or impure coal, ranging in thickness to more than a meter and representing in situ swamp accumulation of peat. The flora includes typical wetland taxa such as *Neuropteris scheuchzeri, Alethopteris zeilleri, Pecopteris* spp., *Lilpopia raciborskii, Asterophyllites equisetiformis and Sigillaria* spp.
- Gray to brown mudstone, locally containing small sandstone lenses; a flood basin deposit. The flora includes *Neuropteris ovata, N. auriculata, Annularia carinata, Sphenophyllum oblongifolium, Pecopteris unita, P.* spp., *Lobatopteris puertolanesis and Psuedomariopteris busquetii.*
- Sandstones and mudstones representing active channel deposits.

The flora and rock succession typical of the Markley persists into the lower part of the overlying Archer City Formation. Fluctuation of base level appears to have been the primary control on deposition and floral communities.

Paleosols of the Markley are best developed in mud- and clay-rich rocks. Lithologic and sedimentary associations indicate that these soils developed upon exposed fluvial floodplains. A common paleosol type in the lower Markley consists of thin (< 75 cm) gray mudstone and claystone with brown and red vermicular mottles. Thin and laminar carbonized root traces or impressions are common. A thin (1 to 20 cm) organic-rich horizon, or histosol, may overlie the mottled mudstone.

Paleosols thicker than 75 cm are less common. Most are composed of red to brown mudstone with angular, blocky structure in the upper part, grading downward to gray, green or buff, massive sedimentary rocks. In the lower and middle parts of the Markley, thicker paleosols typically exhibit an accumulation of either phyllosiclicate clay (argillic horizon; alfisols/ultisols), or iron oxide (oxic horizons or plinthite; oxisols/inceptisols).

Paleosols in the upper Markley become thicker and commonly exhibit sand- and silt-filled desiccation cracks, along with slickensides and wedge-shaped aggregate ("sphene") structures. These paleosols resemble modern vertisols and through time they became a significant component of the Early Permian landscape.

The morphological, mineralogical and chemical characteristics of paleosols in the lower and middle Markley all indicate a humid soil moisture regime. Morphologies indicative of seasonal wetting and drying (such as mud cracks) in the upper Markley suggest a change to a more seasonal, or seasonally water-stressed climate.

Archer City (Bowie Group) and Nocona Formations (Wichita Group). The lithologic transition from the Bowie Group to the Wichita Group is not as marked as it is in their lateral marine correlatives the Cisco and Albany Groups. The Archer City and Nocona Formations are quit similar in appearance on outcrop, Thus they are treated together in this discussion. The Archer City and Nocona Formations, both named by Hentz (1988), comprise the upper part of the Wolfcampian Series in the area of interest. The Wolfcampian-Leonardian boundary is placed within or a short distance beneath the Elm Creek Limestone (top of Nocona), on the basis of the ammonoid fauna.

The Archer City and Nocona are composed dominantly of red and variegated mudstones, along with lenticular yet mappable sandstone bodies. These units differ from the Markley in that coal beds are absent and the sandstones are generally thinner and less continuous (Hentz, 1988).

Paleosols of the lower Archer City are typically red to brown mudstones. Some of these bear blocky structure, along with argillic horizons, which are weak to very strong accumulations of phyllosilicate clay minerals in layers that are mottled in yellow and gray. These soils are classified as alfisols. Other paleosols have wedge-shaped aggregate structure along with slickensides and dessication cracks; these are considered to be vertisols. Carbonate nodules and concretions make their appearance in the upper Archer City and persist throughout the Nocona. Although noncalcareous inceptisols, alfisols and vertisols occur in the Nocona and younger units, the calcareous paleosols remain important through the middle Clear Fork. These changes in soil suggest that the climate became drier, producing a net moisture deficit, around the middle of Archer City deposition. The common occurrence of vertisols is evidence that these soils were seasonally water-stressed.

The Archer City and Nocona Formations both have been highly productive for fossil vertebrates (Hook, 1989). In particular, many "bonebeds" of the Archer City Formation in Archer and Clay Counties have been collected.

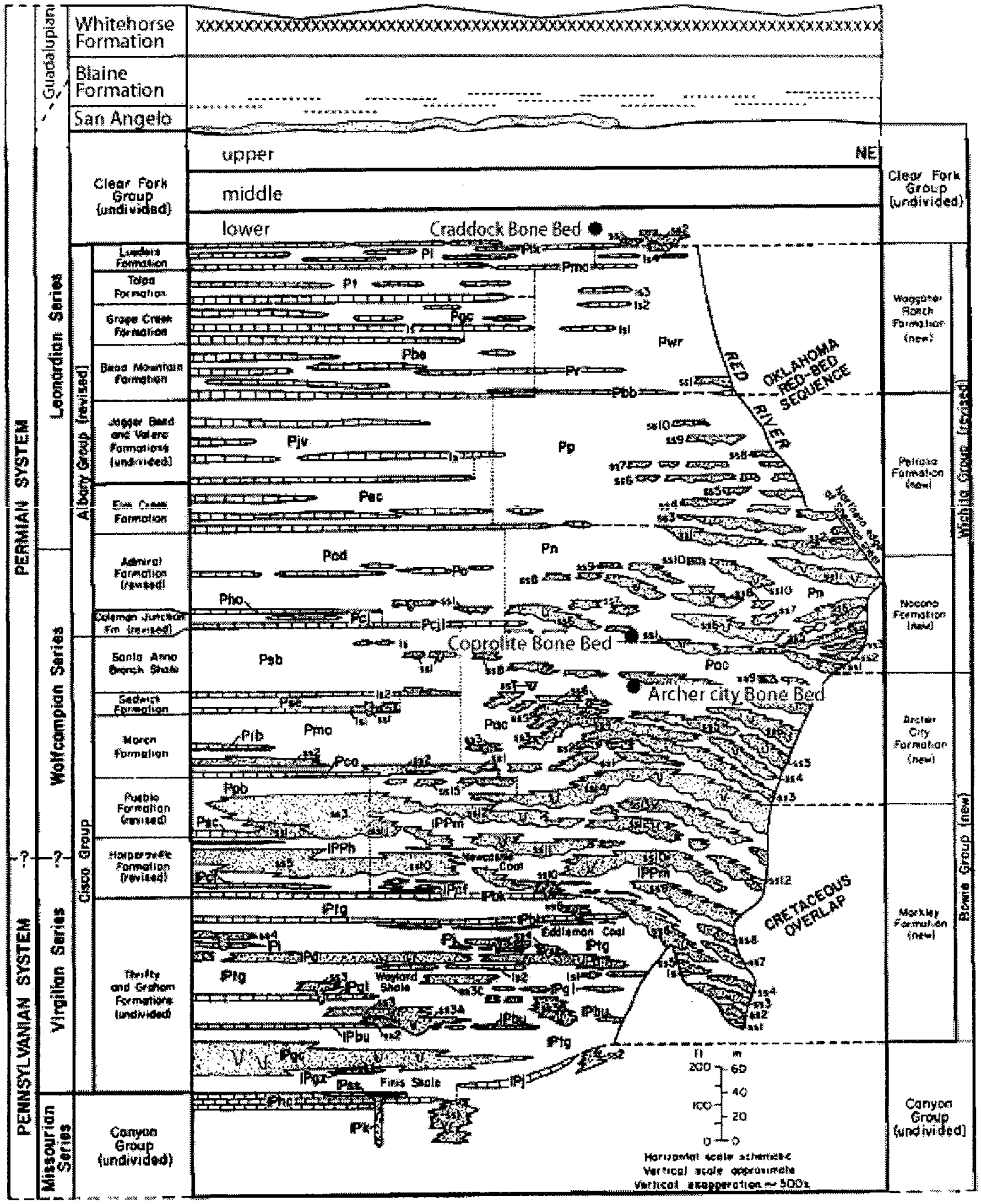

Figure 2. Stratigraphic section showing field trip stops (after Hentz, 1988). Clearfork Group and younger sections added by DSC, not to scale, thickness of units relative.

Although several prolific plant deposits have been discovered in the Archer City and Nocona, generally poor exposures limit prospecting and lithofacies analysis. In general, these plant deposits represent alluvial plain deposits, well removed from marine influences. Most occur in channel-form deposits that probably represent abandoned or sluggish channels of floodplains. In some cases, plant-bearing channel fills are clearly associated with large, meandering streams that deposited extensive belts of sand. The actual plant deposits are generally simple and lithologically uniform, consisting of gray to red mudstone and minor laminated claystone. These contrast with the complex plant-bearing beds of the Markley.

The fragmentary picture that arises is one of gradual change in the floras through the Wolfcampian. The Archer City shares many taxa with the Markley, including *Neuropteris auriculata, Asterophyllites equisetiformis, Sphenophyllum oblongifolium, Lilpopia raciborskii and* tree-fern foliage (locally abundant). These elements become progressively rarer higher in the section. Dominant elements of the flora, especially in the upper part of the Archer City and the Nocona, closely resemble the unusual floras of kaolinite beds in the Markley. These include the peltasperms *Autunia conferta* and *Rachiphyllum schenkii* and the conifers *Walchia spp., Brachyphyllum densum and Ernestiodendron filciforme.* The foliage of cordaites and of the putative cycad *Russelites* also is common. *Odontopteris* is rare and *Taeniopteris,* which is characteristic of Leonardian rocks, is known from a single specimen found nearly at the top of the Nocona.

A progressive trend toward plants more tolerant of seasonal drought appears to be present. Conclusions must be tentative, owing to poverty of collections.

Petrolia and Waggoner Ranch Formations (Wichita Group). These two formations, comprising the upper part of the Wichita Group (Hentz, 1988), are host to several important plant localities.

The Petrolia and Waggoner Ranch contain greater proportions of mudstone and smaller proportions of sandstone than the Nocona and older units. The sandstones are generally thin and tabular, or represent isolated channels rather than meander belts. Several marine carbonate units, notably the Elm Creek and Beaverburk Limestones, extend into North-Central Texas before pinching out northward.

Paleosols resemble those of the Nocona and upper Archer City, except that calcareous nodules and concretions become more common and argillic horizons much less common. A continuing trend toward lower soil moisture and seasonal wet/dry conditions is thereby implied.

The Petrolia Formation has yielded numerous vertebrate remains, whereas the Waggoner Ranch has been less productive. Hook (1989) recorded relatively minor changes in fauna between these and older units and was reluctant to attribute such changes to evolutionary factors versus ecological ones.

Fossil plants, as in older formations, typically are preserved in channel-form settings that probably represent rivers on a coastal plain. Some fossil plants from the Waggoner Ranch may have grown along tidal channels.

A dramatic change in the floral composition takes place immediately above the Elm Creek Limestone, which as previously noted, lies close to the Wolfcampian-Leonardian boundary (Figure 2). The medullosans, such as *Neurpoteris* and *Alethopteris* and other typical elements of Upper Pennsylvanian and Wolfcampian become rare or absent. These are supplanted by a flora rich in pecopterid foliage from tree ferns, gigantopterids, peltasperms, conifers and taeniopterids. Such taxa as *Compsopteris, Gigantopteridium, Cathaysiopteris, Autunia, Walchia, Taeniopteris and Comia* are the prevalent plants.

Lueders Formation (Wichita Group). In its type area north of Abilene, the Lueders is dominantly a marine limestone that is quarried for building stone. Traced northward, the limestone beds gradually wedge out and are replaced by variegated gray, green and red mudstone. Two limestone (or dolomite) members, the Maybelle at the base and the Lake Kemp at the top, persist as far north as Wilbarger County on the Red River. Throughout its extent, the Lueders is 18 to 24 m thick.

Paleosols of the Lueders are red to gray mudstone that have angular blocky or wedge-shaped aggregate structure. Most paleosols contain pedogenic carbonate nodules. Soils with angular blocky structure also exhibit argillic horizons that have rhizoliths. Such superimposition of calcic over argillic horizons is attributed to a change from wet-to-dry soil moisture regimes(Soil Survey Staff, 1975). These relatively rare soil morphologies occur also in the overlying Clear Fork and in Pennsylvanian and Permian rocks of Kansas (Miller et al., 1996).

Fossil plants have been recovered from the Lueders at several localities in Baylor and Wilbarger Counties. The settings are shallow channels, possibly of tidal origin, commonly directly overlying and scoured into the Lake Kemp and Maybelle dolomites. *Wattia, Walchia, ? Brachyphyllum densum,* gigantopterids *and* peltasperms such as *Autunia* are among the common elements.

Clear Fork Group

The Clear Fork includes the classic Texas continental "red beds" renowned for their vertebrate fauna. Like the underlying Wichita and Bowie Groups, the Clear Fork changes from mixed marine and nonmarine strata in Central Texas to almost entirely terrestrial redbeds in North-Central Texas. Three formations, the Arroyo (oldest), Vale and Choza are recognized in the Clear Fork of Central Texas. Although some authors (Olson, 1958, 1989; Olson and Mead, 1982) used these formation names in North-Central Texas as well, we found that the formations are not mappable and use informal divisions only (Figure 2) (Nelson and others, 2001). The primary vertebrate and plant hunting grounds of the Clear Fork are situated in the Wichita Valley of Baylor, Knox, Foard and Wilbarger Counties. Here, the Clear Fork is about 350 m thick and divisible into a lower unit, about 200 m thick, that is rich in vertebrates and plants and an upper unit of 150 m thickness virtually devoid of fossils. The lower, productive beds are largely red mudstone, but contain several intervals of sandstone that represent widespread fluvial meander belts. Plants are found almost exclusively in the channel deposits, which are of several kinds. One is active but generally sluggish channels, in which organic remains are incorporated into siltstone or rarely, fine-grained sandstone of channel bars. Another is abandoned channels or ox-bow lakes, filled with finely laminated claystone. Plant specimens in these claystones are commonly permineralized with iron oxide and preserved in fine anatomical detail. Dipping accretionary sandstone beds, which record the successive accumulation of point bars, represents a third type of channel. Here the fossil plants are generally found in clay-rich sediments that lie between, or above, the inclined sandy layers

Vertebrates are somewhat more widely distributed than fossil plants. The Clear Fork vertebrate fauna is world famous, collected from the late 19th through the middle 20th century by such renowned paleontologists as E.D. Cope, Charles Sternberg, E.C. Case, A.S. Romer and E.C. Olson (see Craddock and Hook, 1989, for an overview of collecting history). Their maps and writings indicate that the richest deposits, including the prolific "bone beds", were dominantly in meander-belt sandstones of the lower and middle Clear Fork. The most productive interval is a unit we informally call the Red Tank sandstone, located 30 to 55 m above the base of the Clear Fork. The Red Tank is also the most productive interval for plants. Other vertebrate collections were made from isolated channel or "pond" deposits at varied stratigraphic levels. In addition, single skeletons have been collected from paleosols and failed aestivation assemblages occur within mudstones.

The upper, barren part of the Clear Fork (Choza Formation of previous authors) comprises extensive tracts of red mudstone that contain thin but widely persistent beds of dolomite and stringers, nodules and thin beds of gypsum. The few channel deposits represent small, local straight to gently sinuous, single-story channels. Meandering channels like those that host plants and vertebrates in the lower Clear Fork are absent. Apparently, the upper Clear Fork represents broad, alkaline mud flats close to the shores of the Midland Basin. This setting was neither conducive to plant and animal life nor to its preservation. Farther south, between Abilene and San Angelo, the upper Clear Fork includes marginal-marine sediments and has produced a few plant assemblages. Also, the well-known tetrapod trackway site of Castle Peak is within this interval.

As for paleosols, the lower Clear Fork contains several examples of calcic horizons superimposed on argillic ones, as seen in the upper Wichita Group. In addition, well-developed noncalcareous and calcareous paleosols that resemble modern entisols, inceptisols, alfisols, vertisols and possibly aridisols are found in the lower and middle Clear Fork. In contrast, paleosols of the upper barren part of the Clear Fork are generally thin, poorly developed and noncalcareous, like modern entisols, inceptisols and vertisols. Several inferences about the paleoclimate can be made. The pedogenic slickensides of the inceptisols and vertisols indicate a seasonal climate in which clays swelled and shrank with changing soil moisture. Calcareous horizons denote extended dry seasons. The transition to thin and poorly developed soils in the upper Clear Fork suggests increasingly arid conditions and sparser vegetation.

The Clear Fork flora, although abundant, is not highly diverse and undergoes a gradual compositional change through time. The flora includes the gigantopterids *Cathaysipoteris, Zeilleropteris and Evolsonia;* the peltasperms *Autunia, Compsopteris and Comia,* the cycadophyte *Taeniopteris,* the conifers *Walchia spp.* and *Ernestiodendron*, cordaite foliage, calamite stems and foliage and locally abundant tree-fern foliage. The enigmatic *Wattia* occurs widely, but is seldom abundant. A few occurrences of *Odontopteris, Sigillaria and Sphenophyllum* have been documented. Overall, the composition of the flora evokes a woody streamside vegetation of shrubs and small trees, together with ferns and rare wetland plants on the poorly drained areas of flood plains away from the channels. The broad, large leaves suggest a humid, but seasonally dry climate.

Pease River Group

The Pease River Group in Texas comprises two formations: the San Angelo Formation (or Sandstone) below and the Blaine Formation above.

San Angelo Formation. The San Angelo contains the only significant sandstone between the middle of the Clear Fork and the top of the Pease River Group. This sandstone, which forms a low escarpment, is correlative with the Duncan Sandstone in Oklahoma and approximately equivalent to the Glorieta Sandstone in New Mexico. In its type area, the San Angelo is as thick as 60 m and is coarse and pebbly, containing rounded quartz and chert pebbles as large as 3 cm. Northward, the sandstone thins and becomes finer grained. Overlying the sandstone is a unit of sandy mudstone, the Flowerpot Mudstone Member (formation in Oklahoma), included in the San Angelo. Total thickness of the San Angelo in North-Central Texas averages about 30 m. Environments of deposition range from fluvial channel to deltaic, tidal mud-flat and sabkha (Smith, 1974).

Paleosols are weakly developed and present generally thin (<50 cm) profiles that show weak angular, blocky to wedge-shaped aggregate structure. These soils are noncalcareous, lack argillic horizons and rarely display root structures. The lack of well-developed soils is rather puzzling in view of the presence of locally abundant fossil plants.

Through extensive prospecting, Olson and Beerbower (1953) located two vertebrate sites in the San Angelo, one in Hardeman and one in Knox County. Both are in the upper San Angelo, or Flowerpot Member. Of seven reptilian genera described by Olson and Beerbower, six were new and the fauna was "notably advanced over that known from the Clear Fork."

Fossil plants are fairly common in the Flowerpot Member and as in older units, occupy abandoned channel deposits. Plants are associated closely with copper mineralization; the latter served as a guide to prospecting (Smith 1974). As detailed in DiMichele et al. (2001), the flora is peculiar, including a number of genera previously known only from Mesozoic rocks. As Olson and Beerbower reported for the vertebrates, San Angelo plants are entirely distinct from those of the Clear Fork.

Blaine Formation. The Blaine Formation of North-Central Texas comprises 180 to 230 m of interbedded red to gray mudstone, gypsum, dolomite and limestone; plus anhydrite and halite in the shallow subsurface. Gypsum and anhydrite beds are especially prevalent in the middle part of the Blaine; some are thicker than 10 m and are mined commercially. Bedding of the Blaine is tabular. Sandstone is virtually absent; only a few shallow channel structures have been observed. Carbonate beds are regionally widespread and serve as mapping markers. They yield marine fossils, largely pelecypods but locally include nautiloids and ammonoids. Based on the latter, age of the Blaine has been interpreted to range from upper Leonardian through the Roadian and, perhaps, Wordian stages of the Guadalupian Series.

Paleosols of the Blaine are, at best, weakly developed.

The only biogenic structures we have observed are burrows found in carbonate rocks and presumably made by marine invertebrates.

We have mapped and prospected extensively in the Blaine but to date, only a single plant locality has come to light. It is in King County, at the position of the Aspermont Dolomite member, about 40 m below the top of the Blaine. The setting is a shallow channel, some 15 m wide and 2 m deep, incised into a thick gypsum bed and filled with greenish-gray mudstone and lenses of dolomite. The flora is dominated by cordaite-like foliage, along with a few gigantopterid leaves and cones of an unknown conifer. This assemblage bears little similarity to any older one from Texas.

Strata younger than the Blaine on the Eastern Shelf have been mapped, described and prospected only in reconnaissance. These rocks comprise fluvial redbeds, eolian silts and sands,and thick layers of gypsum (halite and anhydrite in subsurface). Neither fossil plants nor vertebrates have been reported and the likelihood for finding either appears remote.

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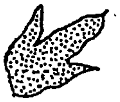

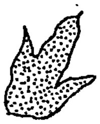

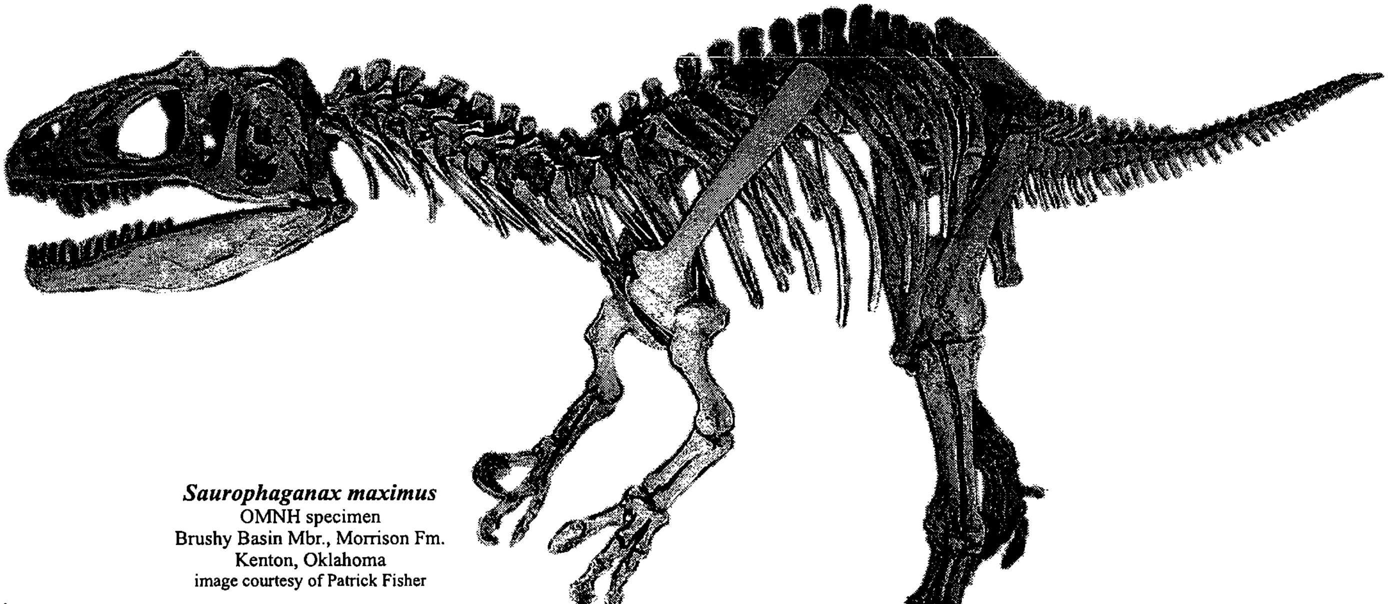

Saurophaganax maximus
OMNH specimen
Brushy Basin Mbr., Morrison Fm.
Kenton, Oklahoma
image courtesy of Patrick Fisher