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On The Cover —

Stigmaria ficoides in Growth Position

The cover photograph shows a well-preserved cast of a common type of Pennsylvanian plant fossil called *Stigmaria ficoides. Stigmaria* is the generic name for the rootlike anchorage structures of trees that grew in vast swamps ~300 million years ago. These dichotomizing rootlike structures represent one of the most common lycopod fossils and generally (but not always) are found in clay layers immediately beneath Carboniferous coal deposits (Taylor, 1981, p. 139).

Stigmaria are rootlike structures that grew out almost horizontally, forking dichotomously, at the base of lycopod trees; they may or may not be true roots. Lateral structures ("rhizoids"), ~0.25 in. in diameter, grew from the main rootlike structures. Although not commonly preserved themselves, the rhizoids left small, round, dimple-like scars on the surface of the *Stigmaria* (clearly visible in the cover photo). Where preserved, the rhizoids appear as narrow, black, carbonaceous ribbons on layers of shale that were probably soil (Taylor, 1981, p. 139).

The primary rootlike structures (axes) radiated horizontally up to 45 ft from the base of the trunk to form an extensive subterranean anchorage system (Taylor, 1981, p. 140). In addition to serving as anchors, the function of these underground plant parts was to absorb nutrients and water. The inset picture on page 119 is a reconstruction of a *Lepidodendron* sp., one of the best-known fossil lycopods, showing the stigmarian root anchorage system (from Stewart, 1983).

As long ago as the middle of the 19th century, Jules Marcou (1856) documented the occurrence of *Stigmaria* in Oklahoma. In his report on an investigation for a feasible railroad route through the

(continued on p. 119)

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Notes

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Paleontological and Archeological Perspectives of Fossil Proboscideans in Oklahoma

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Introduction

In Oklahoma, elephants attract attention. Each year, families flock to Oklahoma City to watch the Barnum and Bailey pachyderms make their run from the railroad unloading dock to the State Fairgrounds. A few years ago, when an elephant escaped from the winter headquarters of a circus near Hugo, Oklahomans in all parts of the State were captivated by the animal's disappearance in the tangled woodlands of Choctaw County. And, for nearly a hundred years, the bones of elephants have intrigued paleontologists and archeologists working in Indian Territory, or what is now Oklahoma. These scholars have studied fossil finds in order to answer questions about the evolution and extinction of elephants in North America. Such questions ordinarily are the purview of paleontologists. However, archeologists, in their study of ancient human societies, were among the first to take a scholarly interest, and they are the principal investigators of fossil elephants found today. The subjects of this survey are Oklahoma's fossil elephant record and the interests of paleontologists and archeologists in it.

A Cursory Review of Elephant Origins and of Their North American Occurrences

Oklahoma's fossil elephants belong to Proboscidea, an order with many forms of animals along the branches of its evolutionary tree; only a few forms occurred in what is now Oklahoma. This order's oldest forms appear to have been heavy-footed, pig-sized mammals called moeritheres (Fig. 1) that lived from southern Asia to northern Africa during the Eocene, some 50 Ma (million years ago) (Shoshani and others, 1996; Tassy, 1996a). From them evolved three or four other lineages, all with skulls showing elongated cranial regions, external nostrils at the very front of the skull, deep lower jaws with a large ascending ramus, and enlarged second lower and upper incisors (Colbert and Morales, 1991, p. 402). Evolutionary trends observable for the order include an increase in size, development of very large size, development of a trunk, and the growth of the second incisors into tusks (Colbert and Morales, 1991, p. 402). By early Miocene times, some 23 Ma, three elephantlike lines are evident in the world's paleontological record: deinotheres in India and Africa; gomphotheres in Africa and Asia; and mastodonts in Africa, Europe, India, and Asia (Colbert and Morales, 1991, p. 400–413; Tassy, 1996b). The gomphothere and mastodont lines are important because they were ancestral to the forms of prehistoric elephants found in Oklahoma.

Gomphotheres were Miocene descendants of moeritheres. Larger than moeritheres, but smaller than modern elephants, gomphotheres were distinguished by

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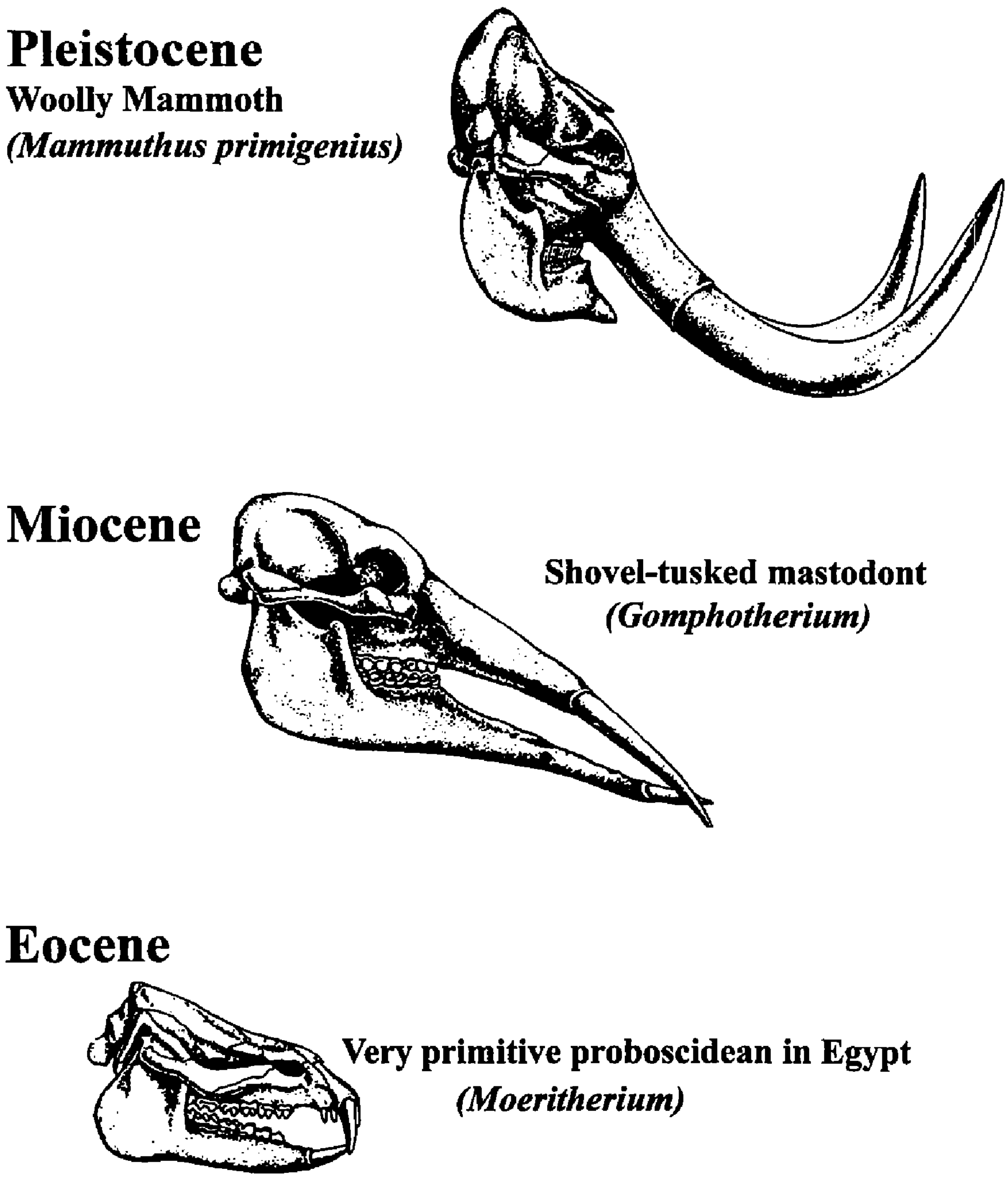

Figure 1. Examples of select forms in the evolution of proboscideans. (Adapted from Frazier and Schwimmer, 1987, fig. 9-95.)

three or more sets of matched cones on their cheek teeth; by two downward pointing tusks formed from second upper incisors; by two short tusks that projected out from elongated lower jaws; and, most probably, by long, flexible trunks (Tassy, 1996b,c). During the Miocene, gomphotheres diversified greatly, some becoming the famous shovel-tusked forms (Fig. 1) believed common to Miocene and Pliocene savannah settings (Colbert and Morales, 1991, p. 405; Guan, 1996; Lambert, 1996; Mazo, 1996; Tassy, 1996a,b). Their successful adaptive radiation enabled gomphotheres to play a key role in the evolution of mastodonts and, later, elephants (Maglio, 1973; Shoshani, 1996). By 14 Ma, a form of gomphothere, which evidently had migrated from Eurasia across the Bering land bridge to North America, was inhabiting the Great Plains and Great Basin (Tedford and others, 1987, p. 159; Webb, 1985, p. 209). Between 12 and 7 Ma, gomphotheres attained their maximum distribution, numbers, and variety in North America (Lambert, 1996, p. 147–148). By late Pliocene times (2.2 Ma), there is evidence of only two varieties of gomphotheres, which persisted through the Pleistocene in the tropics of Central and South America (Kurten and Anderson, 1980, p. 346–348).

Sometime during the Oligocene (>30 Ma), an ancestral form of mastodont developed from gomphotheres (Tobien, 1996). The mastodonts had somewhat larger, stockier bodies than their gomphothere contemporaries, and their cheek teeth—while like those of gomphotheres—had more pronounced crests; they lacked lower tusks, but had larger, curved upper tusks than gomphotheres (Colbert and Morales, 1991, p. 404–407; Tobien, 1996). Although they were never as prevalent as gomphotheres, mastodonts successfully spread from Africa into Europe and Asia. Both gomphotheres and mastodonts immigrated, by way of a land bridge between Alaska and Siberia, to North America at about the same time (mid-Miocene) (Tedford and others, 1987, p. 159; Webb, 1985, p. 209). Mastodonts show little diversity in North America, and their single line of evolution had its most numerous and widespread distribution here between 4.5 and 1.5 Ma (Kurten and Anderson, 1980, p. 343–346). Mastodonts persisted in North America through the Pleistocene.

With their distinctively cusped teeth, gomphotheres and mastodonts were well suited for browsing in forests, woodlands, and savannahs (Lambert, 1992, 1996; Tobien, 1996). Diversity in these two lineages seems to begin to decline in the late Miocene (~8 Ma), a time when there is corresponding evidence for the expansion of grasslands in North America and elsewhere (Lambert, 1996, p. 147–148). About this time, ancestral elephants begin emerging in the paleontological record (Maglio, 1973).

The origins of elephants are believed (Maglio, 1973; Todd and Roth, 1996) to lie in late Miocene and Pliocene Africa, but the ancestry for the three main lineages of elephants can best be traced only to the early Pleistocene (~2 Ma). Two of these lineages are represented by the surviving, but diminishing, species we know today: the African and the Indian forms. Representatives of the now-extinct third line, the mammoths, migrated to and diversified in prehistoric North America (Maglio, 1973; Todd and Roth, 1996).

By early Pleistocene times, mammoths had spread from Africa into Eurasia and eastward along what is now the Arctic border (Maglio, 1973; Van Essen and Mol, 1996). By 1.5 Ma, *Mammuthus meridionalis* was grazing the plains and steppe woodlands of North America (Kurten and Anderson, 1980, p. 350–351). *M. meridionalis* was an imposing beast that stood almost 12 ft tall at the shoulders; it had massive, relatively straight tusks and a high, foreshortened skull. Its descendants, *M. imperator* and *M. columbi*, successfully adapted and thrived in North America until about 11,000 years ago (Dalquest and Schultz, 1992, p. 198–203; Dudley, 1996). *Mammuthus imperator*, which was even larger than *M. meridionalis*, apparently ranged over much of the central and southern parts of the United States during middle to late Pleistocene times (Dalquest and Schultz, 1992, p. 200–201). *Mammuthus columbi*, the last of the *M. meridionalis* line, was distributed across central, western, and southern parts of the United States and northern Mexico (Dalquest and Schultz, 1992, p. 201–203). Perhaps the best known species of mammoth that lived in North America was the woolly mammoth, *Mammuthus primigenius* (Fig. 1). This animal developed from the Eurasian strain of mammoths and was well adapted to tundra and taiga habitats in the Arctic; it immigrated to North America, where it is represented primarily by fossils found in Alaska and Canada (Kurten and Anderson, 1980, p. 353–354). It, too, became extinct about 11,000 years ago.

Actual elephants and their ancestors have teeth well adapted to grazing on dry, dusty grasslands. Upon first viewing, elephant cheek teeth appear to have large, flat surfaces ideal for grinding. While they look flat, especially compared to the teeth of mastodonts and gomphotheres, elephant cheek teeth are composed of vertically aligned plates of alternating hard enamel and softer dentine and cementum (Maglio, 1972). These plates create a chewing surface with many pronounced, low, ridges that enhance shearing more than grinding. These features of elephant's cheek teeth effectively reduce hard seeds and the often gritty (usually silica laden) grasses and forbs of grasslands to digestible fodder (Guthrie, 1984; Maglio, 1972). That some species of mammoths ate grasses and other graminoid plants is known from dung deposits preserved in dry caves in the western United States (Mead and Agenbroad, 1991). Besides being structurally adapted to coarse, gritty foods, elephants' teeth are constantly being replaced. During their lives, elephants grow six sets of cheek teeth. Each set consists of one functional tooth at a time in each quadrant of the jaws (i.e., one tooth in the upper left, one in the upper right, one in the lower left, and one in the lower right) that is replaced sequentially as the previous one is worn out. Thus, elephants are well equipped to feed on gritty, coarse fibers. Such grassland food would have been physically and nutritionally detrimental to browsing herbivores like gomphotheres and mastodonts (Lambert, 1996; Maglio, 1972).

Ancient Proboscideans in Oklahoma

Although it is a long way from any former Siberian-Alaskan land bridge by which proboscideans immigrated to North America, Oklahoma has yielded some of the better clues about the continent's earliest proboscideans. This evidence comes from a few localities in western Oklahoma that have been studied by paleontologists. Western Oklahoma has most of the State's deposits datable to the time that proboscideans began appearing in North America.

The deposits in question comprise the Ogallala Formation. The sand, silt, and gravel of the lower part of the Ogallala Formation was laid down by many sluggish streams that drained the Rocky Mountains during the late Miocene and the Pliocene (Frazier and Schwimmer, 1987, p. 541–543). The sequence of fluvial deposition is complex because the formation actually consists of succeeding fill channels that were eroded into the fill of earlier ones (Gustavson and Finley, 1985; Nativ, 1988; Seni, 1980). The upper part of the Ogallala bears witness to increasing eolian deposition of silt (Osterkamp and others, 1987). Today, the Ogallala Formation underlies the almost featureless, southeast-sloping, High Plains in the panhandles of Texas and Oklahoma; in addition, there are eroded remnants of the Ogallala along the eastern border of the High Plains, which includes Beaver, Harper, Dewey, Woodward, Ellis, and Roger Mills Counties in Oklahoma (Marcher, 1972; Nativ, 1988; Weeks and Gutentag, 1988). Early forms of North American gomphotheres and mastodonts are reported for Ogallala deposits, where erosion has exposed them in Oklahoma's Texas, Ellis, and Roger Mills Counties.

Oklahoma's oldest evidence for proboscideans comes from Ellis County. There, on a ranch southwest of Arnett (Fig. 2), paleontologists from several institutions periodically have excavated and recovered bones of diverse carnivores, along with

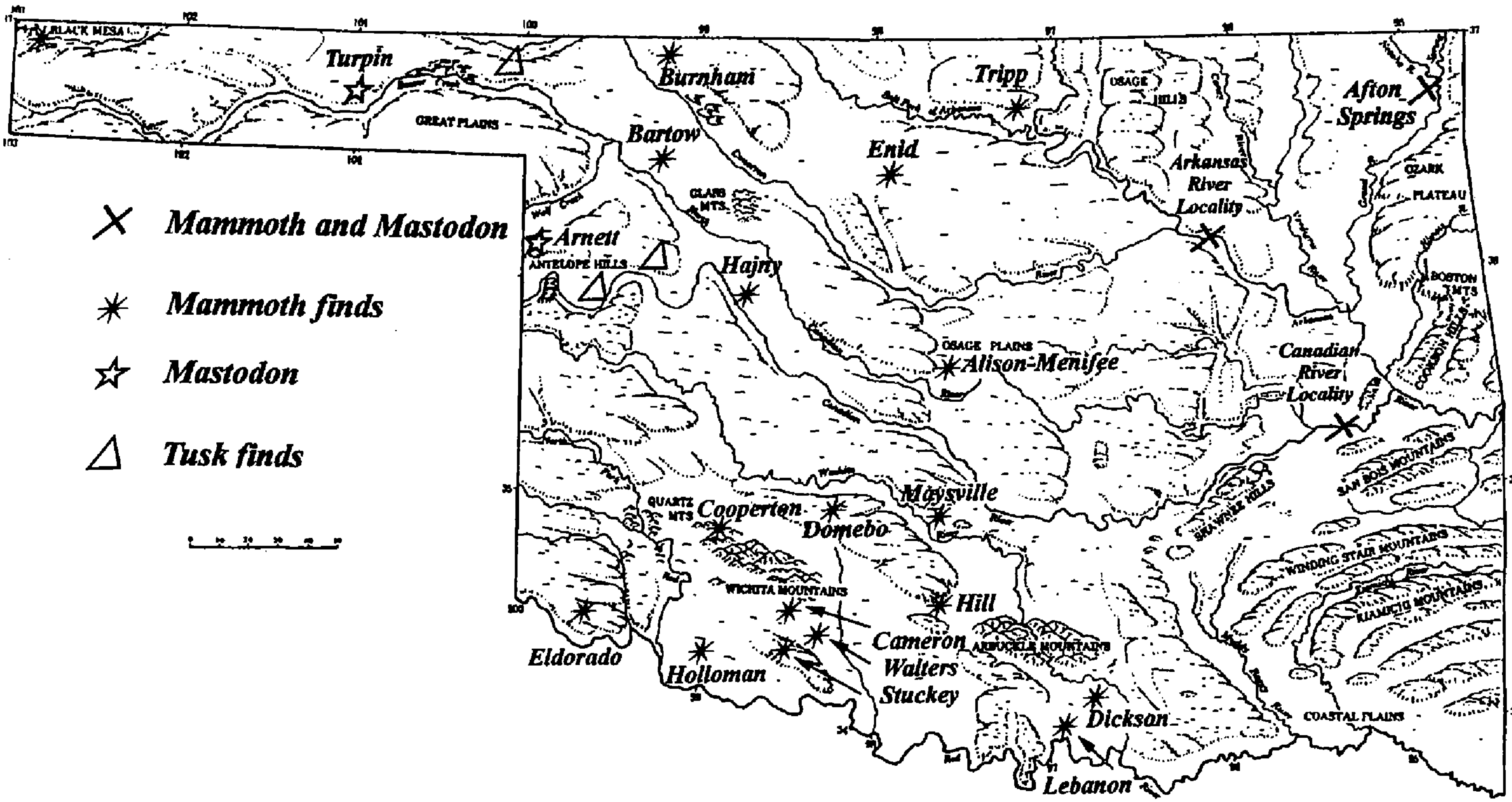

Figure 2. Locations of some of the many proboscidean finds in Oklahoma. (Adapted from Morris and others, 1976, map 5.) County names are shown on Figure 5.

those of horses, camels, antelopelike animals, and *Gomphotherium* sp. (Hesse, 1940; Kitts, 1957, 1965; Savage, 1955). Except for narrow lower tusks, this gomphothere resembles shovel-tusked gomphotheres (e.g., *Amebelodon* sp.) described for other fossil quarries in the Oklahoma and Texas Panhandles (Hesse, 1940; Savage, 1955). The Arnett finds reportedly are well-mineralized, broken with sharp edges, and sparsely scattered through a layer of silty sand that is below a volcanic ash (Kitts, 1957, 1965). Based on similar stratigraphy at other fossil sites in nearby Texas and shared characteristics of certain of the carnivore remains (relative to finds geologically dated elsewhere), the Arnett fossils are estimated to date to about 6–7.5 Ma (Schultz, 1990, p. 72; Tedford and others, 1987). Recently, B. J. Carter and P. A. Ward of Oklahoma State University began fission-track dating of volcanic ash deposits in Oklahoma. They report a date of 9.95 Ma for ash at the Arnett fossil site (Ward, 1991). This age would correlate the Arnett gomphothere with the early late Miocene. To the south, remains of at least one of the shovel-tuskers, *Amebelodon* or *Platybelodon*, have been found near Cheyenne, Oklahoma, based on an unpublished specimen in the Oklahoma Museum of Natural History.

By the mid-Pliocene (3 Ma), an advanced gomphothere called *Stegomastodon* appeared in North America. This form closely resembled the true elephants because it had lost the lower tusks and had a very short mandible (Lundelius and others, 1987). Fragmentary remains of *Stegomastodon* are known from one site in Oklahoma.

Another site in Oklahoma's studied record of early proboscideans is in eroding uplands several miles northeast of Turpin, Texas County (Fig. 2). Excavated in the 1930s and 1940s by paleontologists from the University of Oklahoma and other schools, this location yielded the remains of several early horses along with occasional bones of sloth, alligator, fox, cats, camels, and an early form of mastodont, *Pliomastodon* sp. (Hesse, 1936; Savage, 1941). The bones were mineralized and in water-deposited sand, but, unfortunately, no ash or other datable materials were at hand. The assemblage of animals recovered near Guymon reportedly is similar to an assemblage from Hemphill County, Texas, which is thought to be about 5–6.5 Ma (Savage, 1941; Schultz, 1990, p. 78–79; Tedford and others, 1987, p. 173–175).

Various Oklahoma institutions are known to have examples of early proboscideans, but little, if anything, has been published about these remains. For example, there is a series of reconstructed mandibles of shovel-tusked gomphotheres in the Museum of Natural History of Northwestern Oklahoma State University in Alva; these mandibles include a growth series of *Gomphotherium* sp. from near Arnett. There are broken teeth and tusks of gomphotheres from northern Roger Mills County in the Oklahoma Museum of Natural History at the University of Oklahoma (Norman). These fragments, along with bones of horse and camel, were recovered in 1995 several miles north of Strong City from a gleyed pond deposit, which was exposed by bulldozers preparing a gas-well pad. These are but two of the, as yet, unstudied early proboscidean fossils from western Oklahoma.

Pleistocene Elephant Finds in Oklahoma

Traces of Pleistocene mastodonts and mammoths have been reported from more than 50 Oklahoma locations, and there are probably three times that many unreported finds, such as large bones, tusks, or teeth discovered by individuals while plowing, building ponds, grading roads, or quarrying sand and gravel. Sometimes such a find prompts a telephone call to a nearby museum or college to see if anyone is interested in recovering the fossils. Too often, however, the finder tries to recover the fossil without any expert guidance, and it is broken irreparably. When this happens, little can be learned from the find. Much more information can be gathered when the finder works closely with researchers who are interested not only in preserving the find but also in studying it for what it can reveal about Oklahoma's past landscape, climate, and ecology.

Surprisingly, most studies of Pleistocene elephant finds in Oklahoma have been undertaken and reported by archeologists, not paleontologists. There are exceptions, of course, especially reports of occasional tooth fragments recovered in paleontological screenwashings (Dalquest and Baskin, 1992; Dalquest and Stangl, 1989; Hay, 1924, 1927, p. 283; Starrett, 1956; Stephens, 1960; Wilson, 1972). Nevertheless, for nearly 100 years, Oklahoma's Ice Age elephants have been viewed by archeologists as a means of answering questions about the peopling of North America.

Humans in North America, How Long Ago?

By the late 1800s, two schools of thought had arisen regarding the antiquity of humans in North and South America. On the one hand, some strident amateur archeologists, a few trained anthropologists teaching at Ivy League schools, and quite a few geologists contended that North America had archeological evidence fully as old as the Ice Age artifacts then known for Paleolithic people in Europe (Gifford and Rapp, 1985; Meltzer, 1991; Willey and Sabloff, 1974, p. 52–58). This evidence was mainly chipped stone objects that resembled the hand axes and other implements that European researchers were finding with early human remains, including Neanderthal, known to be older than the last ice age. Opponents of the American evidence were archeologists and physical anthropologists from the U.S. Bureau of American Ethnology and the U. S. National Museum of Natural History (Meltzer, 1983, 1991). These government scholars had several decades of experience gained from examining prehistoric quarries for knappable stone, uncovering diverse kinds of prehistoric camps and villages in the eastern United States, and studying hundreds of prehistoric Indian skeletons; they were convinced that North America's past involved only fully developed human ancestors of the American Indian and that these people had immigrated to North America from Asia only a few millennia ago (Meltzer, 1991).

Clearly, a problem basic to this controversy was the inability to accurately assess the age of the American finds. Such chronological techniques as tree-ring dating and radiocarbon dating were not yet conceived. Furthermore, the study of stratigraphy, whereby successively deeper strata are recognized to increase in geologic age, was not yet fully applied in archeological excavations (Gifford and Rapp, 1985). But turn-of-the-century archeologists in America did understand the powerful argument for antiquity that their European colleagues had when they found human artifacts unquestionably associated with extinct forms of animals. Consequently, the American archeologists increasingly welcomed opportunities to uncover remains of Ice Age animals like those being reported in Europe. From 1900 to the early 1960s, when radiocarbon dating became perfected and accessible, finding unequivocal human artifacts associated with Ice Age forms of animals in undisturbed deposits was the principal means to establishing when people began occupying North America. Certainly, no animals are more representative of the Ice Age than mammoths and mastodonts. Through these six decades, Oklahoma's fossil elephant finds sporadically stimulated controversy and insight.

Afton Springs, Indian Territory

In the summer of 1901, the Smithsonian Institution was notified of chipped stone tools occurring with bones of mastodont and mammoth in a flowing spring in northeastern Oklahoma, near what is now the town of Afton, Delaware County (Fig. 2). The location was inspected initially by an assistant to the mammalogist-paleontologist for the U.S. National Museum of Natural History. There was no significant excavation, however, until late September 1901 when W. H. Holmes, head curator of the museum's Department of Anthropology, spent several days digging into the spring, with local help. The objective was to investigate the possible association of human artifacts with the bones of extinct animals (Holmes, 1903, p. 237). The work clearly was exasperating. Despite efforts to stave and divert the spring, its flow was voluminous enough to collapse profile walls and flood the excavation area several times. Eventually, however, the workmen prevailed. They dug to 13 ft in one spot, which allowed Holmes (1902, 1903) to make some cogent observations about the deposits, and about the fossils and artifacts recovered from them. Hundreds of purposefully flaked flint objects were recovered, along with teeth and bones of mammoth, mastodont, bison, elk, and horse (believed to be recent) (Holmes, 1903, p. 242–244). Because the artifacts were clustered around the spring's active vent, and because the fossil bones usually were broken and distributed deeper and more widely than the artifacts, Holmes (1903) concluded that the spring flow was mixing relatively late prehistoric artifacts with truly ancient animal bones. Moreover, Holmes believed that the artifacts had been tossed into the spring vent ritually.

The more than 800 artifacts recovered from the spring vent include many corner-notched spearpoints of a style, appropriately called Afton (Bell, 1958), now known to have been in use about 3,500 to 4,000 years ago. Many of the artifacts reportedly (Holmes, 1903, p. 244–246) are made from a bluish white microcrystalline flint, most likely from one of the exposures of the flint-bearing Keokuk Formation that occur in this area along the Grand River and its eastern tributaries (Banks, 1990; Huffman, 1958, p. 44–46).

Today, the Afton Springs fauna is recognized by paleontologists as a notable assemblage of aquatic, browsing, and grazing animals dating to the end of the last ice age (Kurten and Anderson, 1980, p. 75). This conclusion might date the assemblage at 12,000 to 14,000 years ago. Extinct forms of beaver, camel, horse, woodland musk-ox, stag moose, mastodont (*Mammut americanum*), and mammoth (*Mammuthus columbi* and *M. imperator*) are among the remains identified by Hay (1924, p. 253–255), who believed that this assemblage predated the last glacial period; it is possible that the collection actually represents a mixture of fossils of widely different ages. Given the few eastern Oklahoma locations known to yield Ice Age animals, the Afton Springs site merits reinvestigation using current techniques to date the bones and to study how they accumulated. However, based on what has been found at the site so far, there is little reason to believe that early people had anything to do with the animals, especially the mammoths and mastodonts, represented at Afton Springs.

Holloman Gravel Pit, Tillman County

That people were in North America near the end of the last ice age was firmly established in 1927 near the headwaters of the Cimarron River near Folsom in northeastern New Mexico. Paleontologist J. D. Figgins (of the Colorado Museum of Natural History) summoned archeologists to the site to view stone spearpoints lodged among the bones of a bison (*Bison antiquus*) known to have lived at the end of the last ice age. The Folsom discovery, and its impact on anthropological thinking about the long heritage of American Indians in North America, are well reported elsewhere (Cook, 1927; Clewlow, 1970; Figgins, 1927; Folsom, 1992; Meltzer, 1983, 1989, 1991; Wormington, 1957). What is not as well known is that Figgins's effort to find more evidence of early people in North America stirred up a little furor involving fossil elephants and other animals found in southwestern Oklahoma.

As Figgins was publicizing the Folsom find, he also had paleontological helpers visiting various Southern Plains locations, where other Pleistocene fossils might yield further traces of North America's earliest human inhabitants. One location of interest was a sand and gravel quarry in a high ridge just northwest of Frederick, in southwestern Oklahoma (Figgins, 1927) (Fig. 2). Quarry owner A. H. Holloman had reported finding stone artifacts, along with bones of extinct animals, including gomphotheres, mastodonts, and mammoths, from what appeared to be remnants of an early Pleistocene stream channel (Cook, 1928a,b; Hay, 1929; Hay and Cook, 1928, 1930). Even C. N. Gould, director of the Oklahoma Geological Survey, had visited the quarry and photographed a projectile point exposed, presumably in situ, in the lowest gravel deposit (Gould, 1929).

Controversy arose as scholars reviewed the reports and illustrations of the artifacts and fossils, which included several kinds of fossil horses and camels, as well as tapir, sloth, glyptodon, musk-ox, deer, and the proboscideans (Hay and Cook, 1930). This collection of animals appeared to be consistent with an early Pleistocene age (Cook, 1928b), but the artifacts, which included bifacially flaked knives and drills, as well as plant grinding implements, looked more advanced in technology than early Pleistocene implements known for Europe (Spier, 1928a,b). In other words, the artifacts appeared out of place given the general antiquity of the fossils. Geologist O. F. Evans inspected the site and concluded that the artifacts were relatively recent, whereas the bones, which commonly were broken and never part of articulated animals, comprised inclusions deposited by several streams of different ages (Evans, 1930a,b). While Cook (1931) took exception to these conclusions, geologist-paleontologist E. H. Sellards (1932) largely reaffirmed them (Branson, 1955). The Frederick controversy eventually waned in the 1930s as new, more convincing, finds of stone projectiles with mammoth remains were made and reported in Colorado, New Mexico, and Texas (Figgins, 1933; Howard, 1936; Sellards, 1938). Recently, paleontologist W. W. Dalquest (1977) reexamined the Holloman fossils and updated their classification and age assessment. The assemblage is considered representative of the Irvingtonian land mammal age, which would make it more than 1 million years old (Dalquest, 1977). Notably, the Holloman site is one of the few in North America to demonstrate the early coexistence of mammoth (*Mammuthus meridionalis*) with the early mastodont *Stegomastodon priestleyi*.

The Cooperton Mammoth, Kiowa County

Between 1930 and 1962, research on fossil elephants in Oklahoma was sporadic and not focused on resolving archeological or paleontological questions. Notes at the Oklahoma Museum of Natural History (Norman) indicate that paleontologist J. W. Stovall tried during this period to generate a statewide program of reporting and recording mammoth and mastodont finds, which met with mixed success. The museum's paleontological collection does contain one mammoth skeleton and parts of others that were collected, apparently for eventual exhibit. The skeleton, of

The Cooperton Mammoth

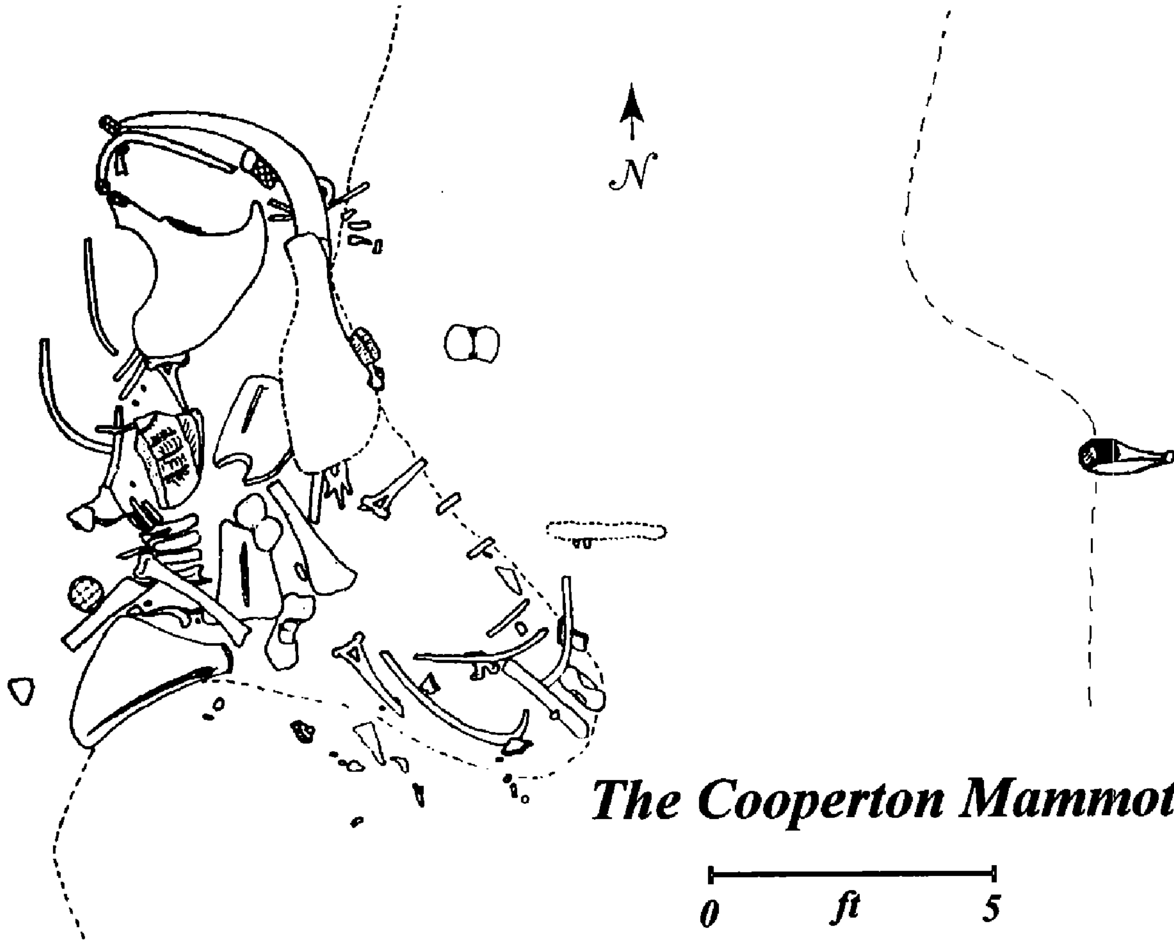

Figure 3. Plan view of disarticulated bones of the Cooperton mammoth (Kiowa County), uncovered by archeologists from the Museum of the Great Plains (Lawton). (Adapted from Anderson, 1975b, fig. 2.) See Figure 2 for locations of proboscidean finds in Oklahoma.

a *Mammuthus columbi*, comes from southwestern Jackson County, but there are few notes on its context or bone arrangement. During this entire period, but largely after World War II, isolated finds of tusks and/or mandibles, mostly from mammoths, occasionally were investigated and reported by both amateur and trained archeologists (Bell, 1962; Foster, 1961; Hall, 1952; Shaeffer, 1961). One of these finds was in Kiowa County. Unexpectedly, it developed into an intriguing project undertaken by the then just-acquired archeology staff at the newly completed Museum of the Great Plains in Lawton.

In 1961, heavy spring rains exposed large bones in the Cooperton Valley (Fig. 2) in the Wichita Mountains (Shaeffer, 1961). Staff from the Museum of the Great Plains inspected the location. The bones were recognized as the disarticulated skeleton of a mammoth (Fig. 3). In addition, a tool that looked like a chopper (chipped from a quartzite cobble) was found near the mammoth's head (Anderson, 1975a; Shaeffer, 1961). These were clues that the animal might have been killed and butchered by people, and the museum's archeologists decided to uncover the site and study it. They systematically excavated the location; exposed and recorded the bones and any likely cultural associations in situ; and had a geologist and a soils scientist study and document the geologic context (Albritton, 1975; Nichols, 1975).

Nearly half of the skeleton apparently had washed away; the uncovered remains represent about one-third of the heavier bones of a single *Mammuthus columbi* (Mehl, 1975). The bones were in a stratum of sandy alluvium, which was overlain by gravelly sand; the sand, in turn, was covered with a loamy soil that showed weak to moderate soil development (Albritton, 1975; Nichols, 1975). The bones were not in anatomical order, and their in-situ arrangement was interpreted to be a result of stacking, probably as the animal was butchered by humans (Mehl, 1975). The bones themselves seem to provide other clues to human activities. The left and right humeri have spiral, and other unusual, fractures thought to have been produced by battering while the bone was green (Bonfield, 1975). Potential tools for such work include several fist-sized cobbles (argued to be hammerstones) and a very large cobble (considered an "anvil"), found near a scapula and a radius (Anderson, 1975b). Because it came from the base of the overlying gravelly sand, the chopper-like tool found at the start of the field work could not be associated with the mammoth directly. A troubling aspect of this site was its lack of chipped stone spearpoints, knives, scrapers, or flakes from resharpening such tools. By the 1960s, such artifacts were commonly associated with other mammoth kills reported for the Southern Plains and the Southwest (Sellards, 1952; Wormington, 1957). Regardless of the absence of such obvious indications of human involvement, the Cooperton mammoth was considered an example of a mammoth used, perhaps scavenged, by people to obtain thick-walled bone needed for bone tools (Anderson, 1975a).

While the Cooperton mammoth offered some convincing clues that people had done things to the animal, the site's radiocarbon dates really raised eyebrows and suspicions. Three radiocarbon dates were obtained from teeth and bones of the animal: 17,575 ±550 years ago; 19,100 ±800 years ago; and 20,400 ±450 years ago (Anderson, 1975b, p. 156)! These dates are so much older than those being obtained for mammoths known to have been killed by humans in North America that most archeologists find it difficult to believe that the Cooperton site could be so old. Recent studies of bone chemistry do indicate that significant changes can take place in bones after they are buried; if certain changes occur, bones are not reliable materials for radiocarbon dating (Stafford and others, 1987; Taylor, 1994).

Little publicized, the Cooperton mammoth findings languished as more dramatic finds of late Pleistocene mammoths and mastodonts killed by people were found and reported for North America (Bonnichsen and Turnmire, 1991). In fact, even as the Cooperton analyses were beginning, the archeologists at the Museum of the Great Plains turned their attention to a new discovery in Caddo County.

The Domebo Mammoth Site, Caddo County

Winter runoff in 1961 also exposed bones of a mammoth in a deep arroyo that drains to the Washita River in southern Caddo County (Fig. 2). Having observed a tusk at the spot earlier, an amateur archeologist returned and saw that other bones had been uncovered. Staff at the Museum of the Great Plains were notified. The staff archeologist, eager to find a site with unequivocal evidence of the hunting of Ice Age animals by people, visited the bone deposit several times (Leonhardy, 1966, p. 1). On his second visit, he observed a broken spearpoint eroding from the black organic-rich deposit containing the bones. Thus began an investigation, which still is considered an exemplar of interdisciplinary research designed to document both the activities of prehistoric people and the environment in which they lived. A team composed of a geologist, a geomorphologist, a palynologist, and vertebrate and invertebrate paleontologists worked closely with the archeologist to assess the location's age, clues to its past environments, and the processes that created the sequence of soils and alluvial deposits evident in the arroyo's walls (Leonhardy, 1966).

Named after the Kiowa landowner, the Domebo (pronounced "DOME-bo" or "DUM-bo") site bears witness to a climate more moderate than today's, with its seasonal extremes, and to a deeply buried, 11,000-year-old marshy deposit, where Paleoindians (of late Pleistocene times) successfully killed and dismembered a single mammoth (Leonhardy, 1966). The beast probably was trapped in miry sediments that covered the bottom of an ancient arroyo. First identified as *Mammuthus imperator* (Mehl, 1966), this animal now is considered representative of the late Pleistocene species *M. columbi* (Graham, 1986). Two distinctively shaped spearpoints and a section of a third were found among the mammoth's bones (Fig. 4). In addition, two flake tools of the same exotic flint as the projectiles were found just downstream from the bones; they are believed to be tools used in butchering the animal (Leonhardy and Anderson, 1966). Notably, all of these artifacts are of a gray blue flint that has its bedrock source in Cretaceous limestone near Georgetown, Texas (Banks, 1990; Leonhardy and Anderson, 1966). Similar spearpoints of this, and other central-Texas, flint are recorded across Oklahoma and northwestern Texas; they provide a basis for believing that these mammoth-hunting people frequented central Texas as a staging area before their periodic hunting-gathering forays over the Southern Plains (Hofman and Wyckoff, 1991; Johnson, 1991; Meltzer, 1986).

Clovis Culture

The chipped stone tools found with the Domebo mammoth also link this site with others recorded across the United States and unglaciated parts of Canada. The common denominators in this link are the bifacially flaked, lanceolate spearpoints and the consistent ages for these locations. Usually 3–4 in. long, the spearpoints are distinguished by their form and by relatively wide scars from flakes that thinned (fluted) both faces of the stem. Because this style of projectile first was found in stratigraphic context with mammoth remains near the eastern New Mexico town of Clovis, the projectiles are called Clovis points; they and any associated tools of other kinds are referred to as the Clovis culture (Bonnichsen and Turnmire, 1991). Finds in Montana and Florida indicate that the well-fashioned stone tips were attached to 8–14-in. foreshafts (often made from mammoth or mastodont tusks); a foreshaft could be inserted into one end of a spear shaft or used as a handle, when the sharp-edged tip was needed as a knife (Bonnichsen and Turnmire, 1991). Other Clovis implements include scrapers and knives made from flakes of highest quality flint; natural hematite used for red paint; batonlike objects (function uncertain) made from bone or ivory; choppers made from thick bone or stone; and specially designed blocks of high-quality flint, from which ribbonlike long flakes were struck for use in various cutting, scraping, and piercing tasks (Stanford, 1991). Some of these artifacts, and especially the technologies for making them, have analogs in upper Paleolithic cultures known for central Russia and northeastern Asia (Haynes, 1982). Notably, radiocarbon dates for Clovis sites indicate that these people were here between 11,500 and 10,900 years ago (Bonnichsen and Turnmire, 1991; Ferring, 1994; Haynes, 1987; Stafford, 1994).

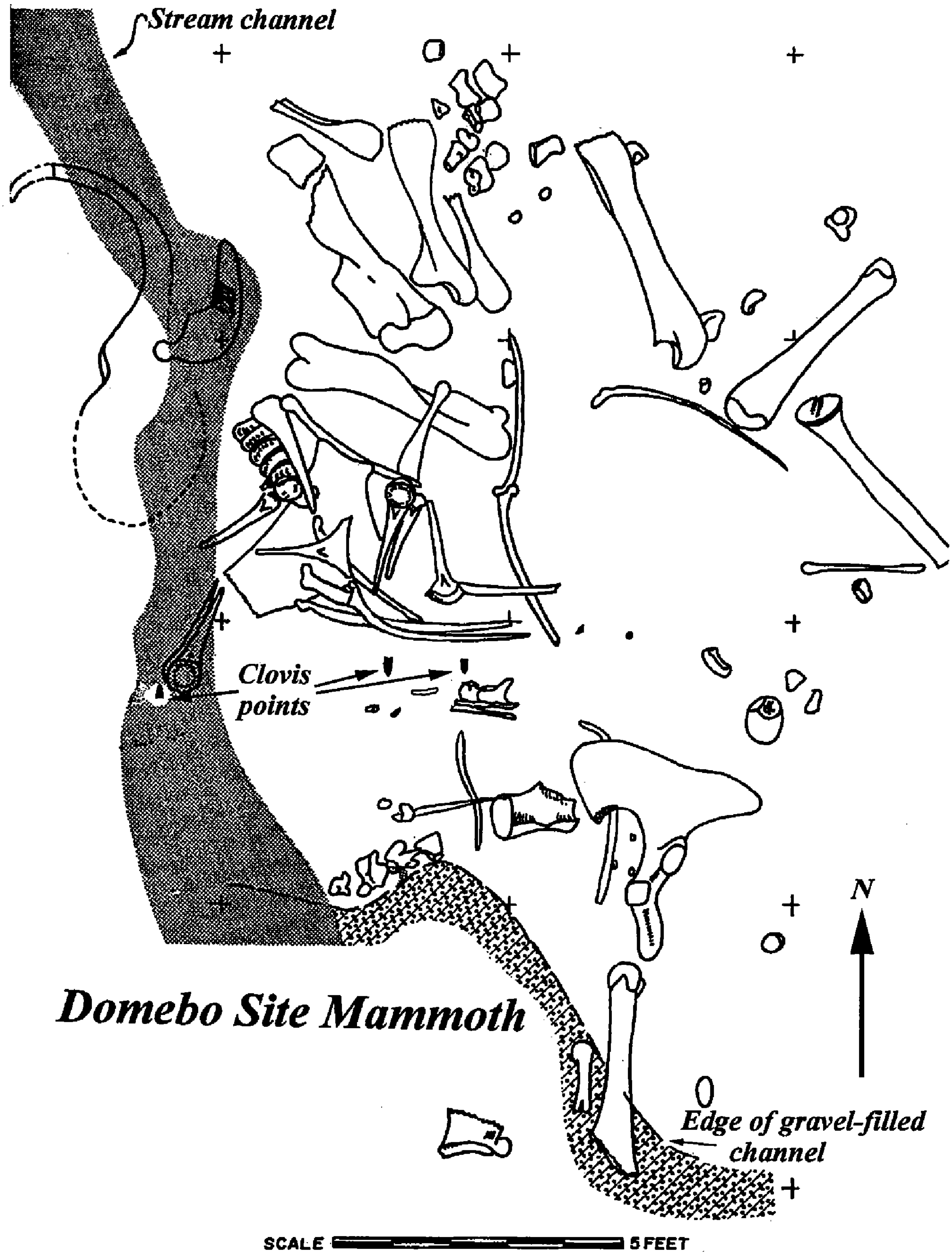

Figure 4. Plan view of disarticulated mammoth and associated human artifacts at the Domebo site (Caddo County). (Adapted from Leonhardy, 1966, fig. 14.) See Figure 2 for locations of proboscidean finds in Oklahoma.

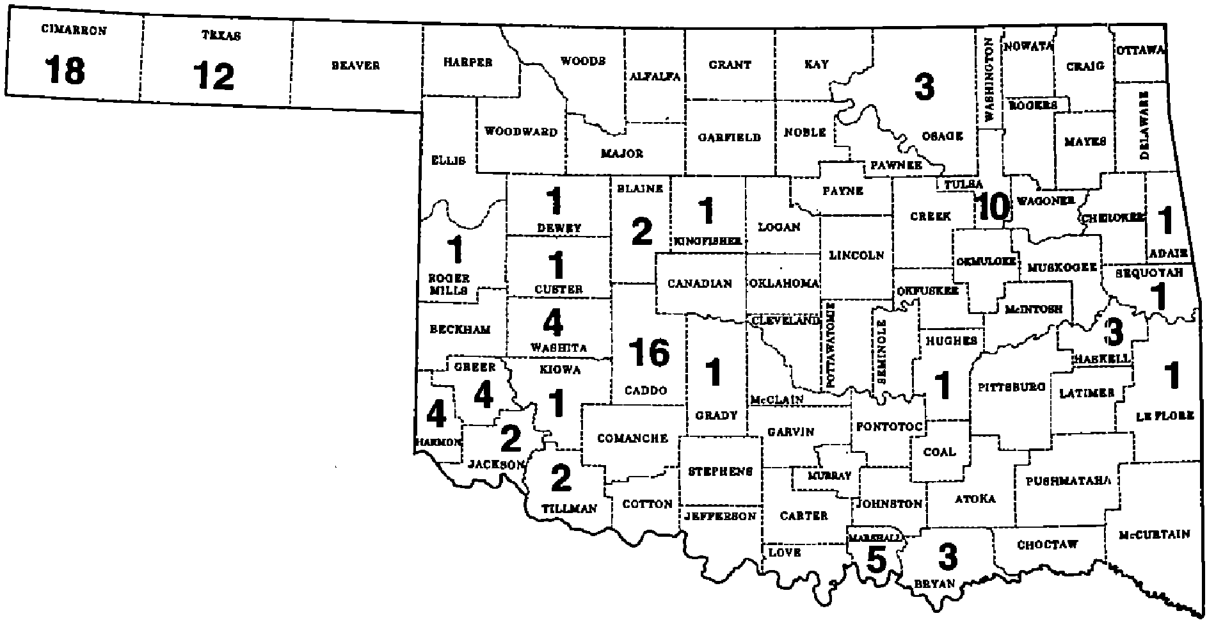

Figure 5. Distribution of Clovis projectile points recorded for Oklahoma counties as of 1996.

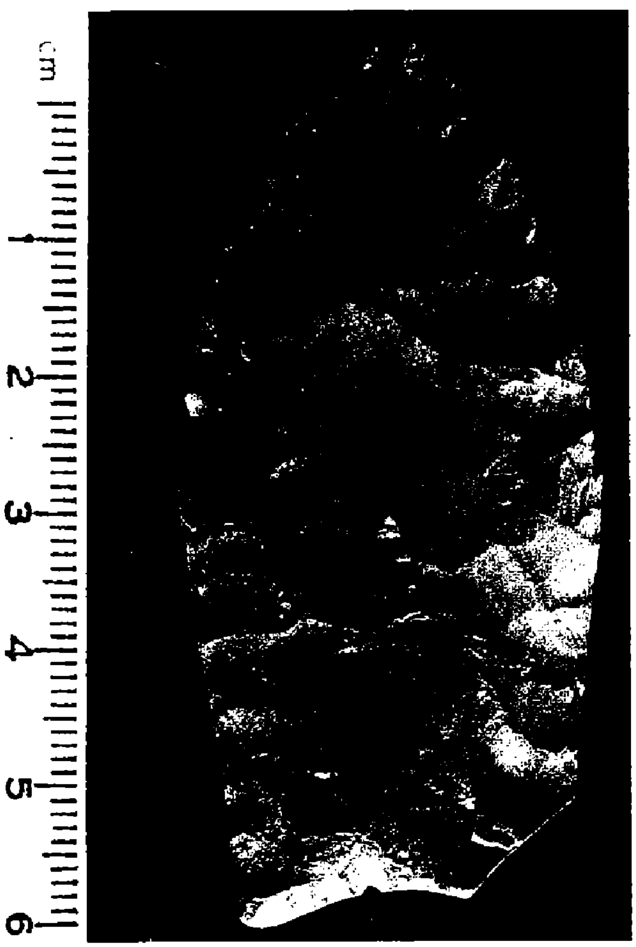

Figure 6. A Clovis spearpoint found in Hughes County; the material is a gray flint from central Texas. *(Photo courtesy of Gerald Gray.)*

During this relatively brief time span, people using the Clovis material culture were well dispersed over what is now the United States (Bonnichsen and Turnmire, 1991). A number of Clovis projectiles have been found on the surface in various Oklahoma settings (Hofman and Wyckoff, 1991) (Figs. 5, 6). We have no clear idea what the Clovis people looked like (the only burials known are cremations), and their mundane livelihood is only sketchily understood. They undoubtedly gathered some wild plant products for food, and they most likely trapped birds and small game to eat. Archeologists occasionally find clues that they killed bison and caribou, but Clovis people have gained renown for their prowess at hunting mammoths and mastodonts—and not just isolated, weakened individuals. At the Lehner site in southern Arizona, eight mammoths were taken in one hunting event (Haury and others, 1959), no mean trick for pedestrian hunters using spears!

Few North American mammoths or mastodonts have been found that are known to date more recently than 10,800 years ago (Agenbroad, 1984; Mead and Meltzer, 1984). This terminal date for the extinction of North American proboscideans closely coincides with ever-increasing evidence that Clovis descendants successfully occupied the countryside and underwent cultural changes as they adapted to emerging Holocene climatic and biotic changes (Anderson and Sassaman, 1996). For more than three decades, paleoecologist P. S. Martin (1967, 1974, 1984) has argued that the demise of North American proboscideans during the time when people spread over the continent was not merely a coincidence. As Clovis sites have been found, studied, and dated since the 1950s, most archeologists have come to the conclusion that Clovis people were the first humans to immigrate to North America, and that they did so soon after 12,000 years ago. Martin (1973, 1984) contends that North American mammoths and mastodonts had never been hunted by a predator as cunning and persevering as humans, and that overkill by bearers of the Clovis material culture caused the extinction of these animals.

For 23 years after the field work at the Domebo site, Oklahoma fossil elephants were investigated only sporadically, and never by interdisciplinary teams. Yet, some potentially interesting finds were explored briefly, thanks largely to the cooperation of interested landowners and ever-ready volunteers of the Oklahoma Anthropological Society. For example, the disarticulated, partial remains of a single mammoth (species uncertain) were uncovered under eolian sand on the uplands east of Mooreland (Woodward County) and were turned over to Northwestern State University (Alva) for exhibit purposes, when no clear-cut signs of human involvement were found (Kerr, 1964). Bones from this find, known as the Bartow mammoth, played a role in early efforts to study and improve reliable radiocarbon dating of Ice Age animals (Haynes and others, 1971). A date of 11,900 ±170 years ago was obtained on a rib from this animal (Haynes and others, 1971). Elsewhere, mammoth bones scattered by an ancient stream were uncovered in Major County (Lintz, 1980), and archeologists salvaged tusks, teeth, or other large bones exposed by farming, road work, or construction projects in Beaver, Caddo, Cotton, Grady, Garfield, Garvin, Kiowa, Oklahoma, and Washita Counties (Ferring and Hall, 1987; Lintz, 1980, table 1; McWilliams, 1962; Neel, 1985; Rohrbaugh, 1971, 1972; Slovacek and others, n.d.; Wyckoff, 1985). The site in Oklahoma County was the most extensively investigated of these finds, and it entailed the partial remains of a mammoth in stream sediments exposed by urban expansion in northwestern Oklahoma City (Neel, 1985). All clues indicate that this is a mammoth of the late Pleistocene, but there are no signs of human involvement and no firm age has been determined for it. Radiocarbon dates of 22,000–35,000 years ago were obtained from bones recovered in Caddo and Kiowa Counties (Lintz, 1980, table 1).

The Hajny Mammoth Site, Dewey County

In 1985, as part of a long-range plan to address gaps in our information about the State's prehistory, staff at the Oklahoma Archeological Survey began looking for locations where they could study Oklahoma's earliest human inhabitants, the effect of their arrival on the existing plants and animals, and the character of the State's ecology before, during, and after the last glacial period. Several reports of fossil elephant finds gave these researchers leads to places in eastern and western Oklahoma that might yield information. For example, amateur archeologists were reporting finds of mammoth and mastodont bones, as well as Paleoindian spearpoints, in the river channels below Keystone and Eufaula dams in eastern Oklahoma. Also, gravel quarrying along the Canadian River northwest of Oakwood, Dewey County, exposed mammoth bones high above the present river channel. Initial radiocarbon dates on mammoth bone and aquatic snails from this Dewey County discovery indicated a likely Clovis date, so Larry Neal and Don Wyckoff, of the Oklahoma Archaeological Survey, undertook its excavation.

Teeth and bones of a single mammoth were first discerned at this site in Dewey County, the Hajny (pronounced HAY-nee) site (Fig. 2), in 1983, while gravel was being quarried from alluvial deposits that are 120 ft above the Canadian River's present bed. The bones were observed in gleyed, snail-bearing spring sediments that lay below the quarried gravel lens and above underlying fluvial sands. All of these strata were 15–18 ft below the present surface of the ground. Years before, geologist R. O. Fay (1959) had studied the geomorphology of the area and recognized its complex past, which included mid-Pleistocene stream piracy as well as deposition of five terraces. Correlating the elevation of the Hajny gravel pit with the terrace sequence downstream that Fay (1959) described would place the fossils in alluvium that is more than 100,000 years old. Yet, a radiocarbon date for one of the mammoth bones only indicated an age of nearly 9,000 years ago, and snails from the spring sediments were dated to only 20,000 years ago (Wyckoff and others, 1992, p. 5). These findings suggested that the mammoth, itself, might be of late Pleistocene age, and archeologists decided to uncover the remains to see if people had been responsible for its demise. A detailed study of the site was compiled with the help of a soils geomorphologist, a vertebrate paleontologist, and two experts on snails (Wyckoff and others, 1992).

Between mid-October 1985 and May 1986, a metric grid was established over the spring deposit; several tons of gleyed, silty sediments were carefully removed by hand; the partial remains of two mammoths were uncovered in situ; several hundred feet of back-hoe trenches were dug, radiating out from the bone-bearing deposit (and their profiles were recorded); and four deep profiles were dug and recorded around the quarry pit's walls (Wyckoff and others, 1992). After only a few weeks of work, it was obvious that the bone deposit did not involve the actions of Paleoindians; instead, it was the result of terrace formation by the Canadian River. Nevertheless, the site provided an unparalleled opportunity to study a bone bed created by natural, rather than human, processes and to elucidate the chronology of the terrace formations along this part of the Canadian River. Therefore, the field work continued. The manual and back-hoe excavations revealed the presence of spring vents that came up through river-laid sands (Wyckoff and others, 1992). These vents had created springs that had flowed out over an ancient flood plain and attracted large box turtles, a form of water rat, and extinct forms of horse and mammoth. Two mammoths were found (Fig. 7). One was badly damaged by the quarrying equipment, and the other had been partially destroyed by gravel deposited in a channel cut by heavy runoff. Teeth of the mammoths have attributes of both *Mammuthus imperator* and *M. columbi*, and, for this reason, the site is believed to predate the last glacial period. The many snails recovered from the bone-bearing sediment, and from one other spring deposit with comparable strata, indicate that the springs were active seasonally during a time when the overall climate was slightly cooler than it is today.

Snails from the second spring deposit were radiocarbon dated, but the result (34,169 ±2,378 years ago) seemed unrealistic given the site's stratigraphic record

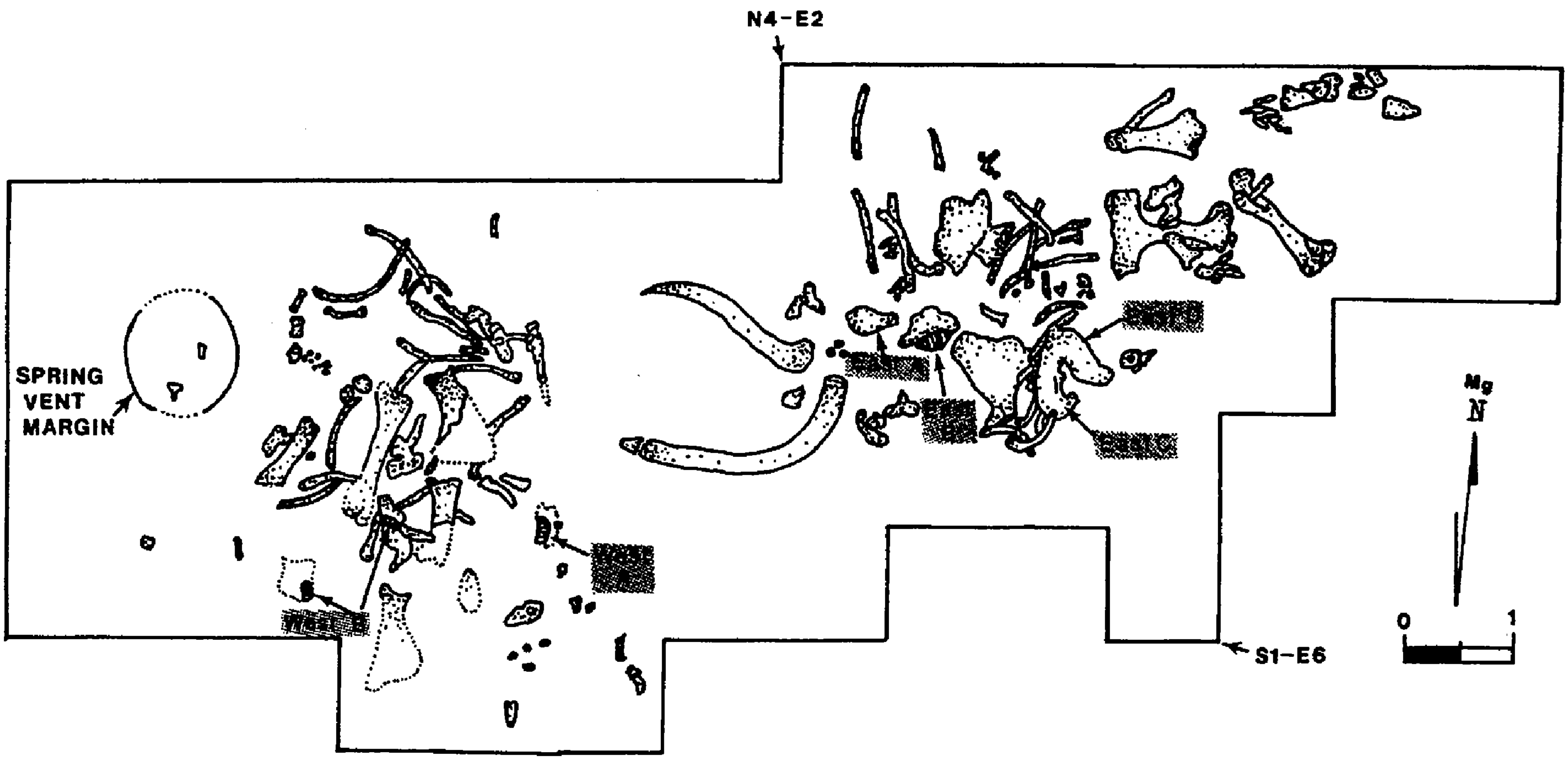

Figure 7. Plan view of the remains of two mammoths uncovered in 140,000–160,000-year-old alluvial deposits along the Canadian River at the Hajny site (Dewey County). (Adapted from Wyckoff and others, 1992, fig. 8-1.) See Figure 2 for locations of proboscidean finds in Oklahoma.

and its position relative to the river's present elevation. All alluvial studies of the Canadian River indicate that it was sand-choked and braided during the slow cutting of its valley (Brown, 1967; Dolliver, 1984; Fay, 1959). Consequently, it is difficult to believe that, in only 30,000 years, the river could have deposited 8–10 ft of alluvium over the Hajny fossil springs, and then cut its valley 120 ft below the springs. Because of long-recognized problems in accurately dating freshwater snail shells (Taylor, 1987, p. 52), several of the mammoth teeth were sent to a Southern Methodist University laboratory for dating by a uranium series technique. The results indicated a date of 143,000–166,000 years ago (Wyckoff and others, 1992, table 6-1). A span of more than 100,000 years for the processes of deposition and cutting seems much more in keeping with the amount of alluviation and incision along this part of the Canadian River.

The Burnham Site, Woods County

Although the Hajny site shed no light on the Pleistocene arrival of humans in North America, or on their hunting of Ice Age animals, its findings reaffirmed the importance of interdisciplinary studies for acquiring valuable information about biotic, environmental, and landscape conditions in the past. Moreover, a result of publicity about the Hajny site was leads to other locations with late Pleistocene animals. Tusks of unspeciated proboscideans were found at two such locations along the Canadian River at about the same elevation as the Hajny site, but farther west. One was a nicely preserved tusk found in gravel northwest of Camargo, Dewey County; the other was a huge, but severely broken and eroded, tusk found along the river southeast of Arnett, Ellis County. In the Salt Fork watershed of western Kay County, a brief study (Wyckoff, 1987) at what is known as the Tripp mammoth site (Fig. 2) revealed a single, disarticulated mammoth (*M. columbi*?) resting atop gleyed sediments some 10 ft below the present surface (Figs. 8, 9). A radiocarbon date for a bone from this animal indicates that it is more than 14,000 years old (Wyckoff, 1987). Some bones are missing (due to recent erosion), but those that remain are in very good condition. The Tripp mammoth merits further study, which has not been attempted because more excavation would encroach upon a road and nearby buildings. In 1992, a Cameron University archeology class, assisted by staff from the Oklahoma Archeological Survey, uncovered the tusk and a few other bones of a mammoth discovered on the grounds of that university, in Lawton. It was buried only a few feet below the surface of a terrace west of a tributary to Cache Creek. Much of this find is believed to be preserved, and it merits careful interdisciplinary study to document its taphonomy and age.

Of all the post-Hajny finds, the Burnham site (named after the landowner) in the Cimarron River watershed of western Woods County unexpectedly yielded the most provocative clues about the late Pleistocene in Oklahoma. In the late spring of 1986, as the Hajny field work wound down, construction of a small pond northwest of Freedom, Oklahoma, exposed several large bones in gleyed sediments containing many snail shells. These gray sediments had been 10–12 ft below the original surface before they were uncovered, as a bulldozer graded a nearly vertical bank to a much gentler slope. Besides uncovering a broken tusk and fragments of a mammoth tooth, the bulldozer had scraped across bones of extinct horse and the skull of a large-horned bison, one resembling those that lived before the last glaciation. The abundant snails and obvious late Pleistocene vertebrates made the Burnham site seem ideal for recovering clues to biota more than 21,000 years old, and the site

Figure 8. Initial uncovering of mammoth remains at the Tripp site (Kay County). The bones are at the upper boundary of a gleyed silt loam deposit that is more than 14,000 years old. See Figure 2 for locations of proboscidean finds in Oklahoma.

was tested in October 1986. This work entailed establishing a metric grid over the bison skull, manually excavating the sediment from around this skull, and washing all the removed dirt through window screen (2-mm mesh). The screenwashing was done in order to retrieve bones of very small animals, which provide better insight into prehistoric temperature and precipitation regimes than do large herbivores like mammoth and bison. The bison skull was recovered nearly intact and taken to a University of Kansas paleontologist (because none was available at the University of Oklahoma at that time). The skull was identified as a representative of *Bison alleni* (or *B. chaneyi*), a form antecedent to *B. antiquus*, which was prevalent during the last glacial period. In addition to the unusual bison skull, the screenwashed debris included bones from such small animals as turtles, salamanders, fish, pocket gophers, eastern wood rats, and prairie voles. The truly astounding discovery, however, was two small flakes from resharpening flint tools; both came from around, and in the same stratum as, the bison skull! A location being tested for clues to late Pleistocene biota and environments has produced what look like human artifacts and has thrust Oklahoma back into the controversial questions about the peopling of the Americas. If the Burnham findings are what they appear to be, they would indicate the presence of people in North America more than twice as long ago as indicated by Clovis artifacts, widely accepted as the earliest evidence for human beings on the continent.

To resolve questions about the Burnham site, more than three months of interdisciplinary field work were carried out there between 1986 and 1992. This work was supported by grants from the National Geographic Society and the National Science Foundation, financial gifts from several civic organizations and numerous

Figure 9. Disarticulated vertebrae parts of the Tripp mammoth (Kay County). Scale is in 5-cm increments. See Figure 2 for locations of proboscidean finds in Oklahoma.

private citizens, and the donation of hundreds of hours of labor by interested citizens. Tons of ancient sediment were carefully dug and methodically screenwashed; nearly 50 cores were drilled and recorded to depths approaching 30 ft below the present surface; several back-hoe trenches were dug and profiled, and their diverse strata radiocarbon dated; and nearly one-quarter mile of trenches were systematically scraped to depths approaching 18 ft below the present surface (Wyckoff and others, 1991, 1994). All of this work was undertaken to recover more artifacts, to document their stratigraphic distributions, and, hopefully, to firmly establish when and how they were incorporated into the sequence of soil and alluvial strata at the site (Wyckoff and others, 1991, 1994).

More artifacts were found: a flint cobble with two flakes struck from it; an edge fragment from a bifacially flaked tool; a broken flake that shows use as a scraper and a knife; and 48 flakes from resharpening stone tools. All were retrieved from a gray, snail-rich, loamy, fine sand that comprised remnants of the second lowest of four late Pleistocene ponds preserved stratigraphically at the site. Significantly, all of the artifacts were clustered around, or near, the skull and other assorted bones of the bison. Attempts to date these bones failed, but snails from this particular pond deposit were radiocarbon dated at 31,000 years ago and at nearly 36,000 years ago (Wyckoff and others, 1994, table 1). Charcoal flecks and fossil hackberry seeds have been radiocarbon dated to ~30,000 years ago. Most assuredly, when the Burnham site findings are published in several professional journals in 1997, Oklahoma will be back in the fray over the antiquity of humans in North America.

Current Research on Oklahoma Fossil Elephants

Bones of mammoths and mastodonts figure prominently in studies presently underway at the Tulsa Zoological Park; at the Oklahoma Archeological Survey and at the Oklahoma Museum of Natural History, both at the University of Oklahoma in Norman; and at the Department of Biology of Midwestern State University in Wichita Falls, Texas. The evolution of elephants comprises one of the interpretive topics at a new facility nearing completion at the Tulsa Zoological Park. For part of that exhibit, staff member Dr. Charles Rippy uncovered a mammoth found on a farm near Walters, Cotton County; this animal will be used to show relationships between living representatives of elephants and North America's only branch of the elephant family tree. Dr. Rippy also is working with one of the authors to compile and document Ice Age fossils and Paleoindian artifacts that are being found along the Arkansas River below Keystone Dam, in Tulsa County (Rippy and Wyckoff, 1994). Among the artifacts are some Clovis points (Fig. 10) and numerous teeth from mastodonts (Fig. 11), as well as from what appear to be different forms of mammoths. Whether or not the many recorded items are from a particular late Pleistocene hunting camp (not yet determined), at least they will help us better understand the ecological diversity that existed during the late Pleistocene around what is now Tulsa.

The Tulsa County compilation also provides a nice contrast to similar information from the Canadian River below Eufaula Dam, in Haskell County. Thanks to the diligence of a conscientious group of amateur archeologists in the Stigler area, hundreds of bones and chipped stone artifacts have been made available for study. W. W. Dalquest, paleontologist at Midwestern State University, has identified the bones of musk-ox, tapir, and many more teeth from mastodonts than from mammoths. Few Clovis spearpoints have been recorded here, but those that have been documented are of Ozark flint and are believed to indicate that bands of Clovis hunters frequented the area.

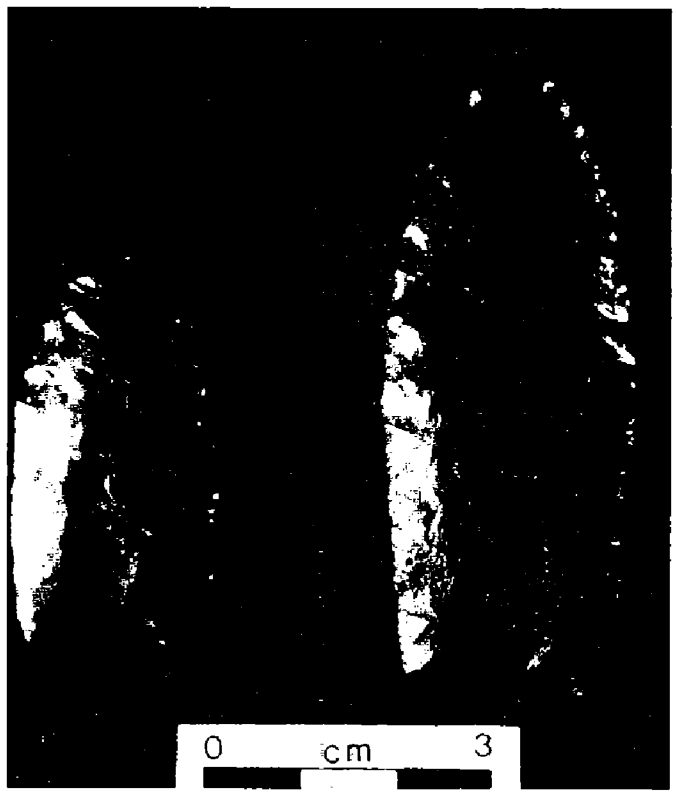

Figure 10. Two examples of Clovis spearpoints found along the Arkansas River below Keystone Dam (Tulsa County). The one on the left is made from Alibates agatized dolomite (from the Texas Panhandle), whereas the other is of fossiliferous chert from the Flint Hills of north-central Oklahoma. See Figure 2 for locations of proboscidean finds in Oklahoma.

In 1994, a notable mammoth find was made near Elmore City, in Garvin County (Neal, 1994). Portions of tusks, maxillae, ribs, and other bones of a single mammoth were exposed in a creek bank 27 ft below the surface of the ground (Fig. 12). Gravel and fluvial sands lay immediately over, and covered, the bones, but more than 20 ft of soil overlaid these alluvial deposits. Charcoal found below the skull yielded a radiocarbon date of 11,500 years ago (Neal, 1995). Although not found directly associated with the bones, a small, bifacially chipped tool was discovered in the gravel directly above the bones; it could represent an implement originally used on the animal but displaced by the heavy runoff that flushed gravel over the bones.

Finally, the 1995 discovery of a tusk, mammoth teeth fragments, and a few bones of other animals in a sand pit on the outskirts of Enid, Garfield County, is providing researchers from the Oklahoma Museum of Natural History a glimpse of the Ice Age in that part of the State, which was not available previously. Thus far, nothing recovered can be dated reliably, so the exact age of these remains is in question.

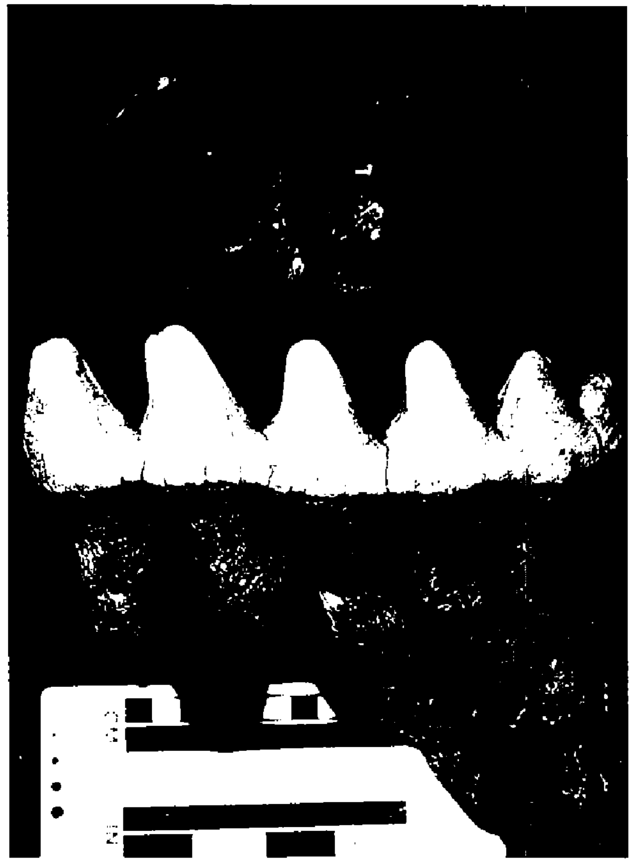

Figure 11. Examples of mastodont teeth found along the Arkansas River below Keystone Dam (Tulsa County). See Figure 2 for locations of proboscidean finds in Oklahoma.

Reports on the fossils and artifacts from Tulsa and Haskell Counties are being prepared for publication, and these monographs should be available by 1998. Meanwhile, there are leads to other mammoth and mastodont finds that merit investigation.

Summary

Almost 50 locations in Oklahoma have yielded traces of fossil proboscideans. Intensive studies at nearly a dozen of these places reveal that some form of these animals has inhabited the State from roughly 8 Ma to 11,000 years ago. Given proboscideans' long record of successful adaptation to varying ecological and environmental conditions in North America, their relatively recent extinction is perplexing. This extinction usually is attributed either to dramatic climatic change or to overhunting by North America's first humans. Attributing this extinction to the spread and hunting prowess of North America's first human inhabitants may have merit if people arrived here only 11,500 to 12,000 years ago. The Domebo site in Caddo County does represent a mammoth kill associated with people of that time. But clues at the Cooperton mammoth site in Kiowa County and at the recently studied Burnham site in Woods County indicate that the heritage of American Indians probably is much, much longer than most archeologists now believe. Confirmation of this new information will come, especially if bone-bearing deposits are carefully studied by teams of geologists, pedologists, paleontologists, archeologists, and other appropriate specialists.

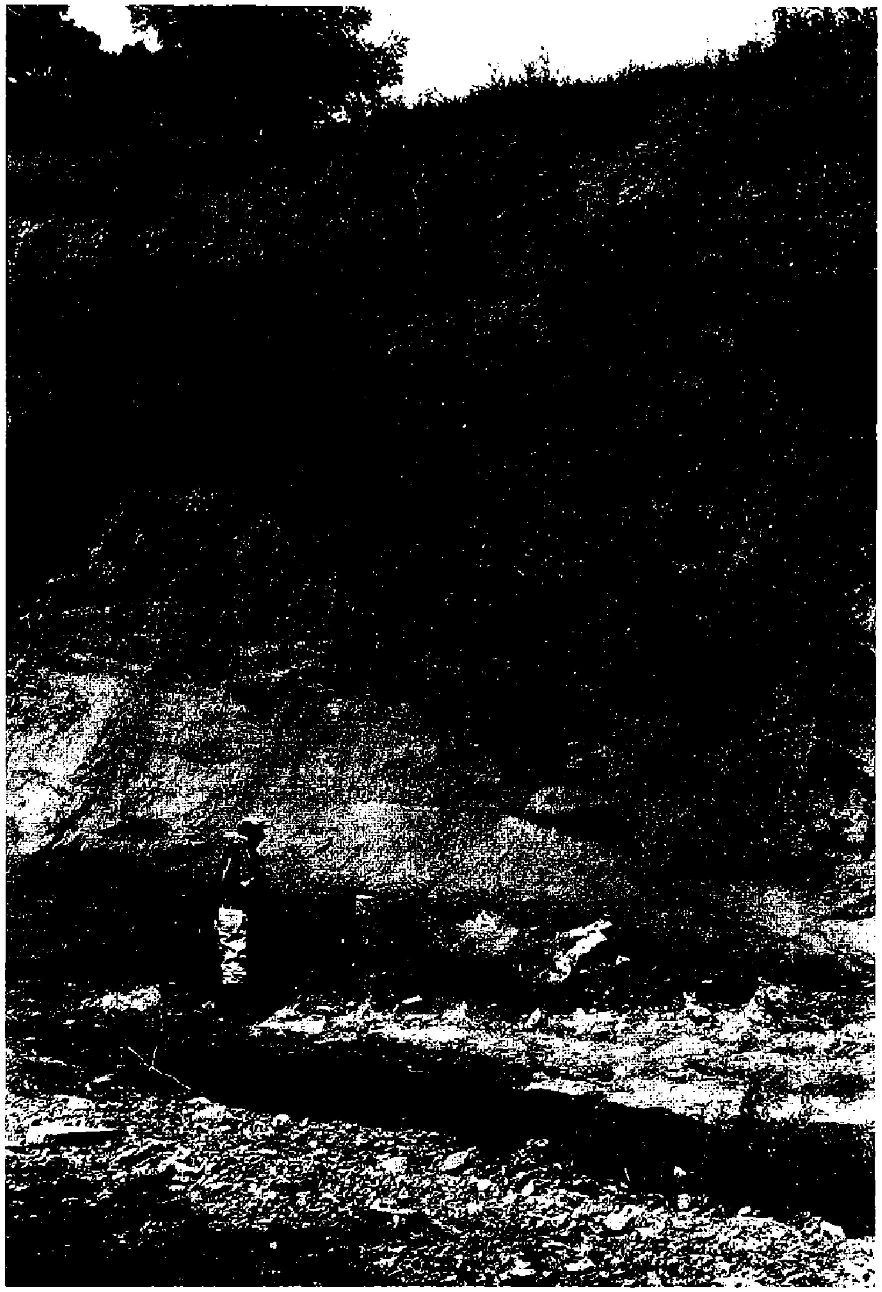

Figure 12. The 11,500+-year-old mammoth at the Hill site (Garvin County) and the overlying alluvial deposit and soil. See Figure 2 for locations of proboscidean finds in Oklahoma. *(Photo courtesy of Oklahoma Archeological Survey.)*

In addition to their potential relevancy to the question of when people first arrived in North America, proboscidean remains are valuable to the study of changes in the landscapes and environments of the late Miocene, the Pliocene, and the Pleistocene. Because of their size and density, teeth and bones of gomphotheres, mastodonts, and mammoths are better preserved than those of other mammals. The broad outline of proboscidean immigration to and evolution in North America is known. Thus, finds in Oklahoma are important for assessing and interpreting geologic deposits, as well as for addressing long-held questions about the origins and adaptations of particular species. Each Oklahoma find merits careful study by trained researchers.

Acknowledgments

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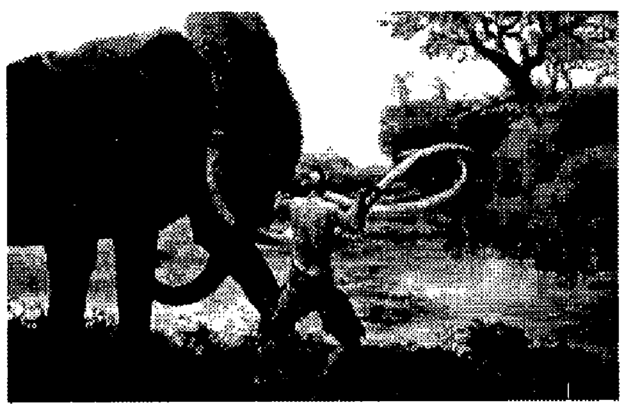
"Oklahoma's Ice Age" Geocalendars and Booklets Still Available



A great resource for anyone interested in Oklahoma's Pleistocene geology and the mammoth and human inhabitants during that time, this full-color, 20″ × 30″ OGS Geocalendar poster features a dramatic illustration by natural history artist Karen Carr as well as a removable 1997 calendar. A full-color 8-page booklet accompanies the poster or can be purchased separately. Written for a general audience by Nicholas J. Czaplewski and Don G. Wyckoff of the Oklahoma Museum of Natural History (authors of the preceding article), and Kenneth S. Johnson, associate director of the OGS, the booklet offers an in-depth look at mammoths and the Great Ice Age in Oklahoma. The booklet also lists Oklahoma sites with Ice Age fossils, artifacts, or geology.

The cost for the poster/calendar is now $2 (including booklet); the booklet alone is $1. Geocalendar 1997 can be purchased by mail from the Survey at 100 E. Boyd, Room N-131, Norman, OK 73069; phone (405) 325-3031 or (800) 330-3996, fax (405) 325-7069; for mail orders of the poster, add $2 to the cost for postage. All OGS publications can be purchased over the counter at the OGS Publication Sales Office, located at 1218-B W. Rock Creek Road, Norman; phone (405) 360-2886.

THE OGS NRIS FACILITY

Jane Weber[1]

In late 1994, the Oklahoma Geological Survey (OGS) was named the Regional Lead Organization for the Petroleum Technology Transfer Council's (PTTC) South Midcontinent region. One of the new responsibilities the OGS acquired at that time was to develop and maintain a computer facility where members of the petroleum industry would have access to relevant digital information and computer technology. Such a facility opened in June 1995 in the Energy Center on the campus of the University of Oklahoma. One year later, primarily due to parking problems at that site, the OGS moved the facility to its present location at 1218-B West Rock Creek Road on the north side of Norman (Fig. 1).

Exactly what is the facility? Well, what's in a name? The official name is the OGS NRIS Facility. However, the name over the door at the Rock Creek building is the Petroleum Technology Transfer Council Computer User Lab. Most OGS staff refer to the facility by yet another name, the Computer Lab. Each name highlights a slightly different aspect of the same facility. Describing the features suggested by each of the three names will provide a complete picture of the facility.

NRIS is the acronym for Natural Resources Information System, a collection of databases built from publicly available information on natural resources in the State of Oklahoma. Thus, the OGS NRIS Facility is the place where the public has access to that information. Currently, NRIS consists primarily of oil and gas data; individuals may navigate that database personally, or may request that Facility staff retrieve data for them, in digital or hard-copy format. The digitizing of information about Oklahoma coal, brine, and nonfuel minerals is in various stages of development. For example, by special request, coal and brine data now can be viewed, but tools to manipulate or retrieve specific information from those data sets have not yet been added to the system.

The second name for the facility, the Petroleum Technology Transfer Council Computer User Lab, describes the major function of the lab: the transfer of technology to oil and gas producers, via computerized data resources and equipment. The lab provides independent operators a single, centralized location where they can seek out well history information. Digitized data from more than 420,000 Oklahoma Corporation Commission completion reports (1002-A forms), as well as the monthly lease production totals reported to the Oklahoma Tax Commission since 1979, are available. Currently, data from Corporation Commission plugging reports (Form 1003) are being entered into NRIS and made available on a county basis, as each county's records are completed. The lab also offers, for use or purchase, a digital land grid covering the State of Oklahoma and provides the necessary software and hardware to produce maps using these data. The two most popular approaches for mapping are GeoGraphix and NRISMAPS, a customized version of ArcView that interfaces directly with NRIS data. More than two dozen additional primary software packages enable users to digitize and analyze logs; optimize pumping units; interpret 2D and 3D seismic reflection traces; simulate reservoirs; model or evaluate enhanced recovery techniques; or determine gas deliverability, among other applications. Several of these packages consist of a series of application modules or programs. Two good examples of this type are RockWare Utilities (45 geologic utilities

[1]Oklahoma Geological Survey.

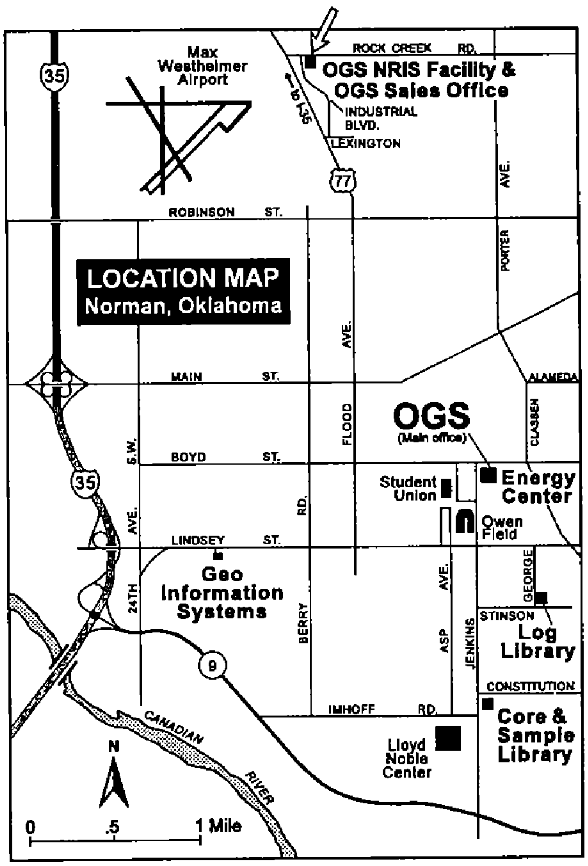


Figure 1. The building at 1218-B W. Rock Creek Road houses the OGS NRIS Facility, as well as the Oklahoma Commission on Marginally Producing Oil and Gas Wells and the OGS Publication Sales Office. There is abundant, free parking at the site. The OGS NRIS Facility is open *by appointment only*, Monday through Friday, 8:30 a.m.–4:30 p.m.

and calculations) and ToolKit (spreadsheet programs for 137 petroleum engineering calculations). This collection of donated software offers an interested operator a unique opportunity to inspect and test a particular program before deciding to buy it. (The programs produced by the Department of Energy are available as freeware.) While the term "one-stop shopping" comes to mind, it is probably too inclusive. Nevertheless, the array of petroleum-related applications made available to the industry through the PTTC lab is most impressive.

The Computer Lab, the name favored by OGS staff, emphasizes the concentration of hardware found at the facility, as well as its use as a classroom for training purposes. Through a grant from the Oklahoma Commission on Marginally Producing Oil and Gas Wells, the lab houses five 150-MHz Pentium computers, an E-size inkjet plotter, a desktop log scanner, and a black-and-white laser printer. It also has a zip drive to handle the transfer and storage of large files, such as map files. Classes to acquaint users with NRIS data, particularly as input data for producing maps (base, structure, contour), are scheduled several times a year. Training sessions to introduce other capabilities of the lab are announced from time to time.

Beyond its central focus of computer-oriented activities, the lab has another role to play. As one of the components of the South Midcontinent's Resource Center, it is the repository for technical reference material distributed by and through the PTTC. Among the collected items associated with the production of oil and gas are workbooks and videos dealing with such topics as blowout prevention, 3D seismic, and horizontal drilling. These items and other literature from various short courses and workshops are available for use within the facility.

Whatever you choose to call it, you now know what the OGS NRIS Facility has to offer. It is open *by appointment only* between the hours of 8:30 a.m. and 4:30 p.m., Monday through Friday. Nominal user charges are measured from computer "login" to computer "logout." To schedule an appointment, request data, obtain current information on fees or charges, inquire about technical consultation or mapping services, sign up for a class, or to learn more details about the facility, contact Jane Weber at 405-360-2886, 405-325-3031, or 800-330-3996. Further information can also be found on the OGS's web page at the following URL.

http://www.ou.edu/special/ogs-pttc/

OGS Spring Workshops Well Attended

Two successful workshops marked the month of March for the Oklahoma Geological Survey. Geologists and others who attended the fluvial-dominated deltaic (FDD) oil reservoirs workshop on the Red Fork play and "Marine Clastics in the Southern Midcontinent" heard papers presenting some of the latest findings on petroleum reservoirs in Oklahoma and the southern Midcontinent. They also had a chance to participate in the sometimes lively discussions that followed the presentations, ask questions, and share their ideas with others who would listen and give useful feedback.

The Red Fork workshop was presented March 5 in Norman and March 12 in Bartlesville; Marine Clastics met March 25–26 in Norman. The Red Fork play workshop, the sixth in a series on specific FDD plays, included new material and aerial photos that proved popular with audiences of 116 in Norman and 79 in Bartlesville. The Marine Clastics gathering provided the geological community with two days of papers and poster sessions, adding a great deal to what is known about this important class of petroleum-producing reservoirs. More than 210 people attended the meeting.

Rick Andrews was the primary presenter at the Red Fork meeting. "We completely reformatted the way we introduced FDD concepts for this workshop," he said. "We put more emphasis on the awareness of fluvial-bar morphologies and sedimentary structures such as you find in contemporaneous and ancient deposits. To do this, we included low-level air photos of present-day fluvial systems and related bar morphologies, and photos of trenches cut into channel bars to show bedding characteristics of point bars versus longitudinal bars. We also looked at slides of Red Fork outcrops showing reservoir geometry, and gave a brief conceptual summary using selected figures from previous FDD publications."

The workshop included three detailed field studies, two prepared by Andrews, a geologist with the University of Oklahoma's Geo Information Systems, and one by consulting geologist Kurt Rottmann of Oklahoma City. Rottmann's study of the Otoe City South field characterized a relatively tight Red Fork reservoir that was successfully waterflooded.

Andrews discussed the North Carmen field, which is in the early phases of waterflooding, and the Long Branch field, which produces from both fluvial and marine sandstone facies.

"The Red Fork oil pool in the Long Branch field is one of the most interesting field studies of the FDD series," Andrews said. "The oil pool occurs in two totally isolated compartments that are adjacent to one another. The depositional history involves a marine bar incised by a fluvial channel. The marine facies in the Long Branch produce black oil with an API gravity of 36°, but the fluvial facies (point bar) produces green 40° oil."

Marine Clastics workshop participants check out the poster presentations during a break.

Oklahoma Governor Frank Keating was the speaker at the Marine Clastics workshop banquet, held March 25 in Norman.

Oil samples were available to show the effectiveness of compartmentalization. Other exhibits included Red Fork cores and computer mapping demonstrations.

The Marine Clastics workshop—the 10th annual OGS spring workshop dealing with the search for, and production of, oil and gas resources in the southern Midcontinent—was attended by representatives from industry, academia, and government and featured a total of 20 oral presentations and 14 posters. The gathering was sponsored by the OGS and the Bartlesville Project Office of the U.S. Department of Energy. One of the highlights of the meeting was the banquet, where guests heard speaker Oklahoma Governor Frank Keating discuss Oklahoma's place in the world petroleum market and talk about legislative changes that could affect the industry.

Presentations at the workshop focused on the geology, deposition, diagenesis, and reservoir characteristics of marine-clastic rock units. Marine clastics include those units deposited in shallow or deep sea water: environments include beach, delta front, barrier island, offshore bar, continental shelf and slope, submarine fan, and transgressive sands. Such clastic rocks are major reservoirs that already have yielded large volumes of oil and gas, and they have great potential for yielding additional hydrocarbons by the use of improved exploration and development techniques, explained Ken Johnson, OGS associate director and meeting chair.

Papers and posters presented at the workshop will be submitted by authors for publication, and a proceedings volume will be issued by the OGS in late 1998. The Red Fork play workbook, OGS Special Publication 97-1, *Fluvial-Dominated Oil Reservoirs in Oklahoma: The Red Fork Play,* is available from the OGS for $6.

Next year's workshop title is "Pennsylvanian and Permian Geology and Petroleum in the Southern Midcontinent." Pennsylvanian and Permian rocks in the region include sandstones, limestones, and conglomerates that are major petroleum reservoirs. Most of the structural basins and uplifts in the region formed during the Pennsylvanian Period, which was a time of great tectonic activity.

Papers submitted for the meeting should be surface or subsurface studies dealing with the geologic setting, depositional environments, and structural and diagenetic history of these strata and/or reservoirs, as well as reservoir characterization, engineering factors that influence hydrocarbon accumulation or production, and specific field studies. The meeting will focus on the southern Midcontinent, including Oklahoma and contiguous parts of Kansas, Missouri, Arkansas, Texas, New Mexico, and Colorado.

For more information about submitting a tentative title for a presentation, contact Ken Johnson before September 1, 1997, at the OGS, 100 E. Boyd, Room N-131, Norman, OK 73019; phone (405) 325-3031 *or* (800) 330-3996; e-mail: ksjohnson@ou.edu.

—*Connie Smith*

AAPG MID-CONTINENT SECTION MEETING
Oklahoma City, Oklahoma ✷ September 14–16, 1997

The Oklahoma City Geological Society and the Geologists' Wives Association are the hosts for the 1997 AAPG Mid-Continent meeting. "New Technologies for an Old Frontier" was chosen as the theme to emphasize the geologist's continuing role in the Mid-continent's development. Although the basin is mature, recent new discoveries and continued development of older areas show that the Mid-Continent region is still a good place to drill for oil and gas.

Technical Program

An Overview of Exploration and Exploitation in the Mid-Continent
Remote Sensing Search and Prediction of Undeveloped Oil Production in the Panhandle Field, Texas
Geochemistry of Oils and Hydrocarbon Source Rocks, Forest City Basin, Northeastern Kansas and Adjacent Areas in Missouri, Iowa, and Nebraska
Surface Exploration in Mature Basins: Applications for Field Development and Production
Application of Dipmeter Data to Structurally Complex Areas in the Mid-Continent
Sequence Stratigraphy and Reservoir Evolution in the Hunton Group, Anadarko Basin
What's New in Oklahoma's Old Basement
Origin, Development and Distribution of "Plains-Type Folds" (Compactional Features) in the Cherokee Basin of the American Mid-Continent
Structural Inversion in Southern Oklahoma by Late Paleozoic Transpression, a Working Hypothesis
Examples of Scale-Independent Structural Models from the Arbuckle Mountains as Examples for Subsurface Interpretations
Multiple Stratigraphic Indicators of Major Strike-Slip along the Eola Fault, Subsurface Arbuckle Mountains, Oklahoma
Is the Washita Valley Fault a Strike-Slip Fault or a Thrust Fault, and Who Cares?
Current Issues in Oil and Gas Royalty Litigation
Gas Balancing
It's Time for a New Sheriff, or Why States Should Regulate Gas Gathering
Trends in Environmental Liability for the Oil and Gas Industry
Selected Recent Developments in Oil and Gas Law for Geologists, Engineers, and Geophysicists
Coal Geology of McIntosh and Muskogee Counties, Oklahoma
Oklahoma Coal Database
Kansas Coal Resources and Their Potential for Coalbed Methane
Coal-Bed Methane Resources and Reserves of Osage County, Oklahoma
Shallow Domestic Gas from Cherokee (Desmoinesian Series, Pennsylvanian System) Rocks in Bates County, Missouri
A Newly Recognized Upper Cherokee Channel Sand Complex Meanders through Southeast Kansas
Effects of Depth on Reservoir Characteristics and Production in Morrow and Springer Well Completions in the Anadarko Basin
Diagenetic Modification of Carbonates as a Result of Submarine Slumping, a Case History from the Jurassic Helmsdale Fault, Northern Scotland
Depositional and Diagenetic Environment of the Sonora Sands, Ozona Field, Crockett County, Texas

Depositional Systems and Sequence Stratigraphy of the Spiro Sandstone Interval, Arkoma Basin of Eastern Oklahoma

Characterization of Lower Permian, Cyclic Carbonate Reservoirs (Chase Group) in the Mid-Continent Based on Outcrop Model Analogs

Sequence Stratigraphy of the Jackfork Sandstone in the Ouachita Mountains and Applications for Petroleum Exploration

An Integrated Study of the Grayburg/San Andres Reservoir, Foster and South Cowden Fields, Ector County, Texas

The AVO Response of a Pennsylvanian-Age Channel Sandstone in the Arkoma Basin, Oklahoma

Donkey Creek North Minnelusa 3-D: Challenging Conventional Wisdom

Effects of Heterogeneity in the Red River Formation, Bainville North Field, Roosevelt County, Montana

Pressure Architecture of the Anadarko Basin: Implications for Exploration and Production

Fluid Inclusion Well Logs: Migration, Seals and Proximity to Pay

The Dickens Project—Advances in Surface Geochemical Technology

Short Courses

3-D Workstation Technical Training—What's Out There and What Are the Alternatives

A Practical Review, Guide and Status of 3-D Seismic for the Organization and Evaluation of Prospects

Field Trips

Desmoinesian Stratigraphy of the Arkoma Basin in the McAlester, Oklahoma, Area

Arbuckle Mountains Field Trip for Teachers

Perambulations in the Slick Hills

Oklahoma City '97

New Technologies For An Old Frontier

For further information about the meeting, contact the AAPG Convention Dept., P.O. Box 979, Tulsa, OK 74101; phone (918) 560-2619 or (918) 2660; fax (800) 281-2283 or (918) 560-2684. The preregistration deadline is *August 6, 1997.*

The Oklahoma Geological Survey thanks the Geological Society of America for permission to reprint the following abstracts of interest to Oklahoma geologists.

Most Primitive and Earliest Mammoths in North America

CARY T. MADDEN, Center for Mastodon and Elephant Research, P.O. Box 1197, El Prado, NM 87529

Mammoths are extinct elephants that belong to Genus *Mammuthus.* They had upper tusks that twisted and spiralled in the shape of a lyre, and great body height. Mammoths originated in Africa by early Pliocene, emigrated to Eurasia during middle Pliocene, and reached North America by latest Pliocene. *Mammuthus* was the only genus of elephants to migrate to America. At least two of its species migrated from Siberia to Alaska and Canada: *M. hayi* during latest Pliocene, and *M. mammonteus* or *"primigenius"* during latest Pleistocene. Most primitive and earliest mammoths in America were *M. hayi* and a new species from Colorado. Eurasian, late Pliocene to medial Pleistocene *M. valdarnensis or "meridionalis"* was never present in America.

Mammuthus hayi had primitive, small third molars; a primitive mandible; and large body size. Its last molars consisted of only 11 plates and were from 199 to 282 mm long. Its mandible had a long symphysis, high horizontal rami, and low coronoids. The paleozoogeographic distribution of *M. hayi* was Saskatchewan, California, New Mexico, Wyoming, Colorado, Nebraska, Texas and North Carolina. Its temporal range was latest Pliocene and earliest Pleistocene or latest Blancan and earliest Irvingtonian Ima (ca 1.7–1.4 Ma).

A new species of *Mammuthus* is from La Veta, Southern Colorado. Its morphology indicates that it was of later early Pleistocene age (ca 1.3–1.0 Ma). This *Mammuthus* differs from latest Blancan and earliest Irvingtonian *M. hayi* in evolving third molars with 14 plates, but retained small, low last molars and great body height. The La Veta mammoth was intermediate in morphology between latest Pliocene and earliest Pleistocene *M. hayi* and medial Pleistocene and earlier late Pleistocene or medial Irvingtonian to earliest Rancholabrean *M. imperator* or "Imperial Mammoths." Indeed, the Colorado species was the forerunner of all native, North American mammoths or species of *M.* (*Parelephas*).

Origin of endemic *M. (Parelephas)* took place in the Rocky Mountains during earlier Pleistocene times. *Mammuthus haroldcooki,* from Frederick, Oklahoma, is not an early, primitive mammoth, but is a valid species. It evolved relatively high third molars, a very short mandibular symphysis and relatively high horizontal rami.

Reprinted as published in the Geological Society of America *1995 Abstracts with Programs*, v. 27, no. 6, p. A-369.

Carboniferous Chaetetid Reef Mounds in a "Dirty" Environment

RONALD R. WEST and *KEITH B. MILLER,* Dept. of Geology, Kansas State University, Manhattan, KS 66506

Calcareous demosponge (chaetetid) reef mounds occur in Middle Carboniferous (Desmoinesian) rocks from northeastern Oklahoma into south central Iowa. Chaetetid reef mounds of different sizes and aerial extents are known from six of the eight recognized limestone units in the Upper Desmoinesian. These limestones are separated by

siliciclastic units (mudrocks, siltstones, sandstones, and shales) of different thicknesses; indeed the bulk of the Marmaton Group is siliciclastic. Commonly, reef mounds occur near the tops of the limestone units and appear to have been smothered by influxes of siliciclastics.

Structural features produced an irregular seafloor topography. Chaetetid reef mounds, in all six limestones studied to date, are associated with the "higher" palaeotopographic features. Demise of the reef mounds appears to have been assiciated with lowering of sea level as a result of climate, eustacy, some minor tectonic movement, or a combination of these factors. Subaerial exposure surfaces and evidence of rooting have been recognized at the top and upper parts of three of the six limestone units.

Within these reef mounds the growth form of the sponges varies from smooth columnar and ragged domical to tabular and cup-shaped. In some exposures smooth columns dominate. Growth forms appear to reflect relative sedimentation rates, episodicity of sedimentation, and water turbidity. Low turbidity and gradual sediment accumulation is reflected by smooth columnar and domical forms that appear to compete with phylloid algae for space—rocks containing smooth domical to columnar chaetetids or abundant phylloid algae, have essentially the same insoluble residue, around 5.0%. Moderate sedimentation rates are reflected by ragged domical forms, with the ragged margins of the growth form reflecting episodic sediment input. Episodes of high sediment influx and elevated turbidity are commonly associated with the establishment of encrusting organisms, such as auloporoid corals. High turbidity and frequent sediment influx is reflected by tabular forms in rocks with insoluble residues over 10%; in some cases over 50%. Highest sediment input is suggested by cup-shaped forms which grew along their upper margins producing new cups to keep ahead of rapidly accumulating sediment (Miller and West, in review).

The sequence of growth forms within a given limestone unit enables the changing turbidity of the environment to be inferred during initiation, growth, and demise of chaetetid reef mounds. Similarly, a comparison of growth forms between localities provides insights into regional patterns of sediment accumulation and transport.

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The Relationship Between Ecology and Taphonomy in the Fossil Record—An Example from the Wewoka Formation (Upper Pennsylvanian, Oklahoma)

THOMAS OLSZEWSKI, Dept. of Geosciences, Pennsylvania State University, University Park, PA 16802; and *RONALD R. WEST*, Dept. of Geology, Kansas State University, Manhattan, KS 66506

Subtle taphonomic signatures have been recognized in paleocommunity data from the Upper Pennsylvanian Wewoka Formation of Oklahoma. Each macrofossil species in each of seventeen fossil assemblages was evaluated using traditional taphonomic criteria to determine if it was autochthonous (a "screening" process). The criteria are based on the work of R. G. Johnson (1960), but have been reevaluated in the light of more recent actualistic work. Four variants of the data set—screened-numerical, unscreened-numerical, screened-binary, unscreened-binary—were then ordinated using non-metric multidimensional scaling and reciprocal averaging. Each form of data provides different information concerning the modification of a community's composition and relative abundances due to the effects of time and space averaging. In this case, two communities were present, distinct in both ecology and taphonomy. Autecological interpretations of the preserved species show that both fossil assemblages are dominated by epifauna and detritus feeders, although the stratigraphically lower fossil community

is richer in infauna and poorer in suspension feeders than the higher community. This bias is surprising considering that death assemblages are richer in suspension feeders and infauna than living assemblages from modern Texas bays (Staff et al., 1986).

Taphonomically, there is evidence that the lower community underwent more space averaging and less time averaging than the higher community. Since space averaging results from assemblage homogenization due to physical transport, and exposed epifauna are presumably more susceptible to transport processes than infauna, it might be expected that a community richer in epifauna would show a greater degree of space averaging. This is not the case in this particular example, which suggests that the modes of life in the living community do not significantly influence the ultimate taphonomic fate of the resulting fossil assemblages.

Reprinted as published in the Geological Society of America *1995 Abstracts with Programs*, v. 27, no. 6, p. A-114–A-115.

Astogeny and Substrate Preference of *Sutherlandia* (Anthozoa: Tabulata) from the Upper Desmoinesian Lost Branch Formation (Pennsylvanian), Northeastern Oklahoma

CURTIS J. FAULKNER, Dept. of Geosciences, Texas Tech University, Lubbock, TX 79409

Sutherlandia are small spherical to ellipsoidal, squamulate-bearing tabulate corals that occur in Desmoinesian and Missourian strata of eastern Oklahoma and Kansas. *Sutherlandia* collected from shale in the upper Lost Branch Formation in Oklahoma are encrusted on and around crinoid stems, bryozoans, productid spines, brachiopod shells and other bioclastic fragments. Coralla range in size from 0.5 mm to 13 mm diameter and contain up to 135+ number of corallites per corallum. Two hundred well-preserved specimens display the full range of astogeny from the earliest stages of corallum attachment to complete encrustation of the bioclastic fragments.

The faunal assemblage and depositional setting suggest *Sutherlandia* flourished in a low energy, mud substrate environment characterized by low sedimentation rates. All juveniles are attached to bioclastic fragments, which indicates that *Sutherlandia* required a hard surface for initial development. Juvenile *Sutherlandia* possessing only a few corallites show a preferred corallum orientation parallel to the long axis of the host bioclast, which suggests the host was in a vertical, or perhaps a living orientation during initial attachment. Some larger coralla are encrusted on the inside of brachiopod shells and over broken ends of bryozoan fragments, which indicates that bioclastic fragments were dead during final encrustation stages.

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Astogeny and Morphometric Analysis of Discoid *Palaeacis* (Anthozoa: Tabulata) from the Upper and Middle Pennsylvanian of Eastern Oklahoma and North-Central Texas

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Several authors have documented the astogeny and microstructure of *Palaeacis* for various wedge-shaped and irregular branching morphotypes. Unfortunately relatively little data exist for the discoid morphology. The lack of documentation is primarily due to the general lack of specimens. Nearly one hundred well-preserved specimens were recovered from three localities in Oklahoma and one locality in North-Central Texas.

These discoid coralla display the full range of corallum development ranging from early juvenile stages (one corallite) to mature stages (22 corallites). Growth of coralla in earlier stages of development tends to be relatively simple, with additional corallites secreted to margins of the corallum. Coralla consisting of more than eight corallites secrete additional ones to the outer margins, as well as encrusting and overlapping the medial corallites.

The differing arrangements of septal ridges, canals, stereoplasm within the calices, and the differing calices shapes suggest that the sample of *Palaeacis* collected may represent several different species. The shapes and arrangement of corallites within the discoid morphotypes of *Palaeacis* provide a good test subject for morphometric analysis. Morphometric analysis was applied to the sample set to test for growth patterns, the amount of variation among and between samples, and whether the sample set consists of several species.

Reprinted as published in the Geological Association of America *1996 Abstracts with Programs*, v. 28, no. 1, p. 13.

Morphometry of the Conodont Platform *Idiognathodus* and Its Use for Morrowan-Atokan (Pennsylvanian) Biostratigraphy

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The ubiquitous platform element *Idiognathodus* is an abundant, and usually predominant, component of Pennsylvanian conodont assemblages. Simple morphometric analysis, using 12 measured parameters on the oral surface, and the outline of the aboral surface, was performed on large numbers of individual elements taken from single samples representing single horizons of known age. As would be expected, parameters related to size, change predictably in these single populations, yet the other features of their oral surfaces exhibit a surprising range of variation, but little change associated with growth. For example, the number of corrugations of most specimens falls between 4 and 12, yet a specimen may have the same number of corrugations as another individual twice its size.

Differentiation of Morrowan versus Atokan populations of *Idiognathodus* from the southern midcontinent, based on this morphometric analysis, is equivocal and casts doubt on many of the form taxa proposed in the literature. Some general trends toward reduction in the number of corrugations, and reduction in the length of rostrum and the accessory lobes can be recognized, but they provide little basis for precise biostratigraphy. Based on multiple element reconstructions, *Idiognathodus* seems to be an excellent example of the stasis predicted by punctuated equilibria.

Reprinted as published in the Geological Society of America *1995 Abstracts with Programs*, v. 27, no. 6, p. A-243.

Lithostratigraphy and Conodont Biostratigraphy of the Devonian-Mississippian Boundary, Southern Ozark Region, Northwestern Arkansas and Northeastern Oklahoma

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University of Arkansas, Fayetteville, AR 72701

The Devonian-Mississippian boundary in the southern Ozark region is viewed generally as falling at the base of the St. Jo Limestone, where it is in contact with the underlying Chattanooga Shale. That boundary is marked by the development in the basal St.

Joe of a thin (usually <0.25 m) green, calcareous shale, occasionally associated with a thinner, white, orthoquartzitic sandstone. In sections where those lithologies mark the boundary, a significant unconformity is present. The oldest Kinderhookian conodont assemblage recovered from the basal St. Joe Limestone represents the *Gnathodus delicatus–Siphonodella cooperi cooperi* Conodont Biozone, that occurrence and other biostratigraphic evidence suggests that the Devonian-Mississippian hiatus spans the uppermost Upper Devonian and lower half of the Kinderhookian Series.

In southwestern Washington County, Arkansas, the contact of the Chattanooga Shale and St. Joe Limestone is characterized by interbedding of black shale, identical with the Chattanooga, and crinoidal packstones, identical with the St. Joe Limestone, through approximately 0.7 meters. No green shale occurs at the contact, and there is no physical evidence of an unconformity in those exposures. Nevertheless, conodonts recovered from the boundary interval indicate that a hiatus still exists, probably equivalent to that in sections where an obvious unconformity is developed. In the absence of biostratigraphic data, the Devonian-Mississippian/Chattanooga–St. Joe boundary in southwestern Washington County is drawn at the change in fissility that probably represents the Kinderhookian transgression.

Reprinted as published in the Geological Association of America *1996 Abstracts with Programs*, v. 28, no. 1, p. 22.

Recurrent Cephalopod Mass Mortality, Fayetteville Black Shale (Mississippian-Chesterian), Southern Ozark Region

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In its type area, the Fayetteville Shale comprises approximately 225 feet of transgressive and high stand, black concretionary shale of variable fissility that drowned an intertonguing carbonate shelf and deltaic complex and is succeeded by shelf carbonates during Chesterian deposition in the southern midcontinent. The section is unfossiliferous for the most part, but cephalopod assemblages, dominated by nautiloids, occur in abundance as isolated horizons separated by unproductive strata. The cephalopods are most commonly preserved as crushed specimens on bedding planes, but internal molds formed by siderite or marcasite-pyrite provide solid material.

These cephalopod assemblages reflect significantly different histories. The marcasite-pyrite intervals are confined to the lower Fayetteville Shale that represents maximum flooding during high stand. They are dominated by ammonoids that represent a size continuum from spat (ammonitellas) to fully mature individuals that were killed catastrophically, probably by sudden reduction of oxygen levels caused by coastal upwelling. In contrast, the sideritic horizons are dominated by nautiloids, and characterized by mostly mature individuals of similar size, and a marked absence of juvenile specimens. In the lower Fayetteville Shale, cephalopods occur to the virtual exclusion of other fossils, while in the upper Fayetteville, a benthic community of mostly gastropods, bivalves, and brachiopods is associated with some of the cephalopod assemblages. The episodic nature of these concretionary occurrences through the Fayetteville Shale, the abundance and similarity of sizes within individuals of a species, and the absence of juveniles supports the interpretation that the cephalopod assemblages reflect mass mortality as a consequence of reproduction (semelparity). Similar assemblages have been recognized elsewhere in Middle Carboniferous strata of the southern Ozark region.

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Possible Reproductive Mass Mortality and Pathologic Gigantism in Middle Carboniferous (Chesterian-Morrowan) Cephalopod Assemblages, Southern Midcontinent

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Cephalopod assemblages occurring through Middle Carboniferous (Chesterian-Morrowan) strata in the southern midcontinent (Arkansas, Oklahoma, Texas) reflect periodic mass mortality involving unusually large numbers of individuals. Occurrences are isolated both geographically and stratigraphically, and most represent high energy, near shore deposits, although some assemblages are preserved in deeper water concretionary shales. The individuals of any species are of strikingly similar size, appear to have been mature, and had ceased growth at the time of death. Juvenile specimens are notably absent in these assemblages and in the matrix preserving them. Death may have been the result of reproduction (semelparity) in a manner similar to that seen in some modern squids, perhaps as a result of breeding in shallow waters with temperatures above their normal tolerance.

Giant individuals (D > 4 times the standard deviation) that are conspecific with the "normal" size population are a rare component of many of these assemblages. These individuals reflect a pathologic condition that may be related to their inability to attain sexual maturity and thus, cease growth. Pathologic gigantism has been documented in prosobranch gastropods as a result of hormonal imbalance related to parasitic castration by larval trematode flatworms, although this condition has not been documented in living cephalopods. Nevertheless, it seems consistent with the occurrence of rare, abnormally large individuals within a population of conspecific forms of strikingly similar size that seem to have experienced reproductive mass mortality.

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Lower Silurian (Llandovery) Stromatoporoids from the Blackgum Formation of Eastern Oklahoma

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Stromatoporoids are a common component of the Lower Silurian (Llandovery) Blackgum Formation of eastern Oklahoma, a stratigraphic unit with few outcrops. Fourteen specimens were collected from the type locality, Blackgum Landing, on the southeastern shore of Lake Tenkiller, Cherokee County, Oklahoma. The Blackgum Formation is a limestone that is part of the upper Llandovery, representing either the upper part of the Aeronian Stage or the lower part of the Telychian Stage.

Diversity of the stromatoporoids is low, with only a few species in two genera, *Clathrodictyon* and *Ecclimadictyon*, present. Both genera are survivors of the end-Ordovician extinction event, and are the most typical Llandovery stromatoporoid genera worldwide. This low diversity is also found in upper Llandovery deposits of the Red Mountain Formation of Alabama and the Wallington Limestone Member of the Reynales Formation of New York, where once again *Clathrodictyon* and *Ecclimadictyon* are the only genera known. These low diversities are in sharp contrast to the high genus- and species-level stromatoporoid diversity displayed by the upper Llandovery LaPorte

City Formation of eastern Iowa, where there are about 10 species in at least seven genera currently under study. It is also apparent that the upper Llandovery Hendricks Member of the Burnt Bluff Formation of northern Michigan has a higher level of diversity than the faunas in Oklahoma, Alabama, and New York. In terms of Silurian paleogeography, the latter three areas were near the margin of Laurentia, whereas Iowa and Michigan were near the center of the craton.

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Lower Silurian (Llandovery) Stromatoporoids from the Hendricks Formation of Northern Michigan

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Stromatoporoids are a common component of the Lower Silurian (Llandovery) Hendricks Formation of northern Michigan. Over 50 specimens were collected from three localities in Mackinac and Schoolcraft Counties, Michigan. The Hendricks Formation is primarily a dolostone, with beds of limestone present locally. It is from the limestones that the stromatoporoids described here were collected. The Hendricks is part of the middle Llandovery Aeronian Stage.

Diversity of the Hendricks stromatoporoids is moderate for the Llandovery, with as many as seven species in seven genera present. Genera represented include *Plectostroma, Pachystroma, Clathrodictyon, Ecclimadictyon, Petridiostroma,* and possibly *Intexodictyon* and *Syringostromella.* This Michigan stromatoporoid fauna is more diverse at the generic level than other Aeronian faunas studied in the United States. Only *Clathrodictyon* and *Ecclimadictyon* have been found in the Aeronian of Alabama, Oklahoma, Missouri, Ohio, and New York. Less is known about diversity in the upper Llandovery Telychian Stage of the U.S.; however, there are three species in two genera in the Telychian of northeastern Alabama and about 16 species in eight genera in the Telychian of eastern Iowa. These diversity differences strongly suggest that localities that were nearer the center of Laurentia during the Llandovery provided environments more conducive to diversification than did localities closer to the margin of Laurentia.

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Paleoenvironmental Model for the Origin of Carboniferous–Lower Permian Dark Gray to Black Shales from the North American Midcontinent

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Upper Carboniferous and Lower Permian dark gray to black mudstones and shales are present in a number of stratigraphic intervals and represent at least four different paleoenvironments:

(1) Dark gray to black coaly shales with an absence of conodonts, ostracodes, and foraminiferans are interpreted to represent a coastal swamp setting with a rate of clastic influx too great to form well-developed coals.

(2) Dark gray to black mudstones to shales with abundant low diversity ostracode assemblage *(Geisina* biofacies), rare to absent conodonts, linguloid and orbiculoid brachiopods, pectinid, promytilid, and *Dunbarella* bivalves are interpreted to have formed in shallow marginal marine, possibly brackish to hypersaline lagoons.

(3) Dark gray to black, fissile, non-skeletal-phosphatic-rich radiolarian-bearing, shale with an abundant and diverse conodont assemblage *(Gondolella-Idioprioniodus* biofacies) are interpreted to represent core shales (marine condensed sections) that form in deep shelf oxygen-poor waters beneath a thermocline and influenced by cool nutrient-rich waters from upwelled waters from the deep basin to the southwest.

(4) Dark gray to black moderately fissile shale with abundant *Streptognathodus* conodonts, orbiculoid brachiopods, and abundant shark debris, but with an absence of non-skeletal phosphate are interpreted to represent classic core shales (marine condensed sections) deposited in deeper waters.

During the Upper Carboniferous–Lower Permian time span the deeper water black shales evolved from Type 3 to Type 4 due to a cessation of upwelling associated with the decreasing rate of basin subsidence coupled with the infilling of the Anadarko Basin. The lack of an open marine connection to cool nutrient-rich waters resulted in a progressive decrease in non-skeletal phosphates as well as ecologic exclusion of the *Gondolella-Neogondolella* conodont biofacies.

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Ammonoid Biostratigraphy Across the Missourian-Virgilian Boundary in the North American Midcontinent and North-Central Texas

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Ammonoid faunas from the Missourian-Virgilian boundary interval in Kansas and Oklahoma have been recovered (in ascending order) from the upper Lansing Group (Eudora Shale), basal Douglas Group (Weston Shale), middle Douglas Group (basal Robbins Shale), and the lower Shawnee Group (Heebner Shale). The Missourian-Virgilian boundary currently recognized by the Kansas Geological Survey is placed at the base of the Weston Shale. However, neither this level nor the original base of the Virgilian at the base of the slightly higher Tonganoxie Sandstone has been reported to correspond to any documented faunal change.

Our new work shows that neither the late Missourian Eudora Shale nor the current early Virgilian basal Weston Shale contains a diagnostic ammonoid fauna. By contrast, the higher, but still early Virgilian basal Robbins Shale contains a diverse ammonoid assemblage distinguished by the co-occurrence of the ancestral shumarditid *Pseudaktubites stainbrooki*, with the ancestral species of *Vidrioceras V. conlini*. The slightly younger Heebner Shale is marked by the appearance of *Vidrioceras uddeni, Uddenoceras oweni*, and *Svetlanoceras tenuosum.*

The basal Robbins Shale level is confidently correlated with North-Central Texas where the concurrent range of *Pseudaktubites stainbrooki*, and *Vidrioceras conlini* is within the Colony Creek Shale. The Heebner Shale equivalent in North-Central Texas is the Finis Shale which includes *Shumardites cuyleri*, in addition to *Vidrioceras uddeni, Svetlanoceras tenuosum* and *Uddenoceras oweni.* Significantly, the Heebner-Finis interval is the lowest level characterized by the joint occurrence of *Shumardites* and *Vidrioceras*, which characterizes the basal Gzhelian *Shumardites-Vidrioceras* Genozone in the former Soviet Union. Accordingly, both levels warrant consideration for further study as candidates for possible redefinition of the Missourian-Virgilian stage boundary based on ammonoids.

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Phosphatic Hardground Lag Deposits in Upper Carboniferous Cyclothems in Texas and Oklahoma

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Phosphate concretions are often abundant in certain dysoxic and anoxic sedimentary units of Pennsylvanian aged midcontinent North American cyclothems. Most phosphate concretions are platy to ellipsoidal in shape, have smooth outer surfaces, and often form around a discernible nucleus. Uncrushed nuclei and occasional slickensides suggest these concretions lithified prior to compaction of the host mud. At some localities, however, phosphate concretions are concentrated in a single horizon, and have surfaces corrugated by ridges, grooves, and pits. Commonly they are bored by unknown organisms and encrusted by foraminifera, brachiopeds, sponges, and other organisms, often displaying a well-defined succession of organismal encrustation.

Beds of these irregular, encrusted and pitted phosphate concretions are the product of winnowing, perhaps by storms, which concentrated the smooth, scattered, nodules into well-defined horizons. After exposure on the sea floor, such concretions were colonized by pioneer hardground invertebrate communities.

When present, phosphatic hardground lag deposits can provide information on sedimentation rates and water depths of the phosphate-bearing interval in individual cyclothems, where reworked phosphate lags may represent significant destruction of the sedimentological record.

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Early Carboniferous Paleoenvironmental Change: The Stable Carbon and Oxygen Isotope Records in Brachiopod Shells from North America

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Detailed carbon and oxygen isotope records were produced from early Carboniferous brachiopod shells in the mid-continent U.S. to determine paleoceanographic and global change in western Laurasia during the formation of Pangea. 234 thin sections were examined by petrographic and cathodoluminescence microscopy. 199 carbonate powders from 120 specimens were collected from well-preserved non-luminescent (NL) shell areas and from associated luminescent (L) matrices and/or cements (diagenetic indicator) for isotopic analyses.

$\delta^{13}C$ and $\delta^{18}O$ values for NL shell respectively range from 0.7 to 6.1‰ and –6.2 to 0.4‰. These values are higher than those of corresponding L fractions. Considering NL shell of all genera, $\delta^{13}C$ values increase 3.0‰, from middle Kinderhookean (2.4‰) to a late Kinderhookean maximum (5.4‰); decrease 1.9‰ from late Kinderhookean to late Osagean (3.5‰); decrease gradually and irregularly from late Osagean to late Chesterian (2.1‰) before increasing ~2‰ from late Chesterian to middle Morrowan (4.2‰). The $\delta^{18}O$ values increase ~3‰ from middle Kinderhookean (–3‰) to a late Osagean maximum (–0.4‰); decrease 1.7‰, from late Osagean to Meramecian (–2.1‰), then fluctuate between –3 and –1‰ from Meramecian to middle Morrowan. No correlation has been found between isotopic composition and depositional environment.

Within the limits of stratigraphic correlation, our NL $\delta^{13}C$ trend and values are similar to those of early Carboniferous mid-continent specimens (summarized in Brand, 1989: Palaeogeo., Palaeoclim., Palaeoecol. 75:311). However, our NL $\delta^{18}O$ trend differs from that of Brand (1989) and the values are 0.8 to 3.1‰ higher. The ~3‰ positive shifts in $\delta^{13}C$ and $\delta^{18}O$ may be due to: (1) changes in organic carbon reservoir size, (2) changes in paleoceanic circulation resulting from the formation of Pangea, and (3) the continental ice volume changes associated with temperature change.

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Pennsylvanian *Plocezyga* Microgastropod Biostratigraphy of the United States

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The microgastropod genus *Plocezyga*, because of its planktotrophic larval form, have been found to be useful for biostratigraphic zonations within the Pennsylvanian, Desmoinesian to Virgilian, strata of the United States. A biostratigraphic zonation of the Pennsylvanian of North-Central Texas was established using first occurrence species-level range zones of this genus. This zonation was initially used to correlate from North-Central Texas into the Appalachian Basin. Further work focused on the Desmoinesian-Missourian boundary of Oklahoma, and the Missourian-Virgilian boundary of Kansas. The Desmoinesian-Missourian boundary has been recognized based on the first occurrence of *Plocezyga (P.) costata.* The Desmoinesian strata below this boundary is recognized on the first occurrence of *Plocezyga (P.) robustus.* The Missourian-Virgilian boundary is not as well defined as the Desmoinesian-Missourian boundary. In Kansas, the first occurrence of *Plocezyga (P.) obscura* has been observed at or near the Missourian-Virgilian boundary, but in North-Central Texas this species first occurrence is found slightly above the Missourian-Virgilian boundary.

Recent work has focused on various Missourian and Virgilian units in the Illinois Basin and Desmoinesian units in Missouri. The Missourian and Virgilian units within the Illinois Basin have produced *Plocezyga* specimens which fit into the zonation. The Desmoinesian units from Missouri have also produced *Plocezyga* specimens which also fit the zonation. One of these units is near the Desmoinesian-Missourian boundary and appears to have *Plocezyga (P.) robustus,* the uppermost Desmoinesian microgastropod zone.

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The Oldtimers Were Right: New Data on the Relations Between the Type Cincinnatian and the Upper Ordovician in the Upper Mississippi Valley, Oklahoma, Texas, New Mexico, and the Western Interior

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Mainly based on distinctive shelly fossils, most authors prior to the late '70s considered the Maquoketa of the Upper Mississippi Valley to be of late Cincinnatian (Richmondian) age and to be coeval with the Fernvale of Tennessee-Arkansas, the Montoya of Texas–New Mexico, the Maravillas of W. Texas, the Hanson Creek and equivalent strata in the Great Basin, and the strata now known as the Welling in Oklahoma. Yet, during the last two decades it has been common practice to correlate the lower part of these units with the early Cincinnatian (Edenian), hence more than a stage lower than in the "classical" interpretation. New data from conodonts and graptolites supplemented by information from shelly fossils are in conflict with this recent correlation. That is, the base of the *A. ordovicicus* Conodont Zone, which in the Cincinnati region is in the upper *A. manitoulinensis* Graptolite Zone near the base of the lower-middle Richmondian Waynesville Formation, is in the Upper Mississippi Valley in the same graptolite zone near the base of the Maquoketa Shale. The same conodont horizon is present in the same graptolite zone just below the Welling of Oklahoma. Likewise, the characteristic *Hiscobeccus-Grewingkia* shelly fauna appears in the middle Richmondian in the Cincinnati region and in the middle Maquoketa (*D. complanatus* Graptolite Zone) in Iowa-Minnesota, as well as in the topmost Welling of Oklahoma and coeval strata in Texas and New Mexico. These regionally persistent relations between conodonts, graptolites, and shelly fossils appear to be present also in the Western Interior carbonate successions suggesting that the "classical" correlation was correct. This has major implications for the interpretation of Late Ordovician geologic history in much of central and western North America.

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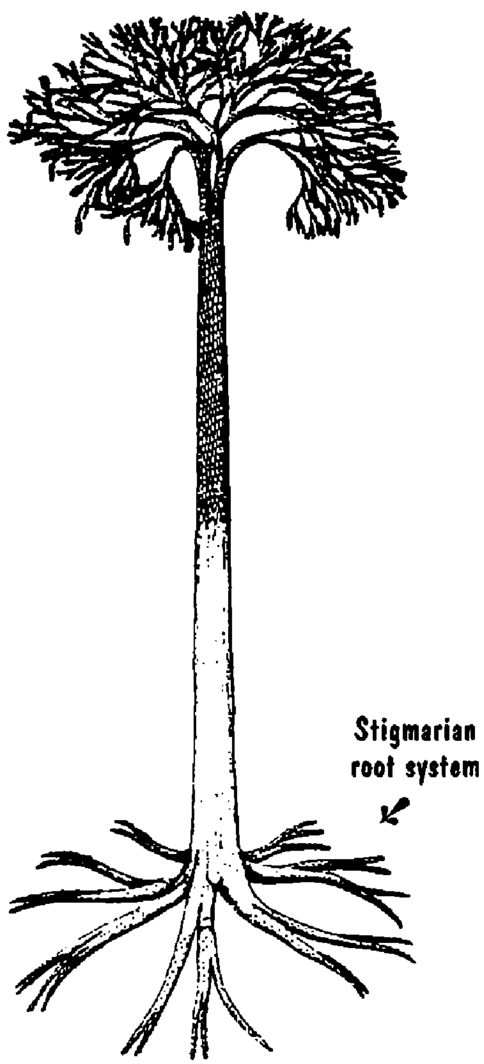
Stigmaria ficoides in Growth Position *(continued from p. 70)*

western part of the country, Marcou (1856) mentioned finding *Stigmaria* in the McAlester area. Stigmarian fossils are abundant in Oklahoma, and almost all collectors of rocks and fossils (particularly in the eastern part of the State) will have one or more *Stigmaria ficoides* specimens in their caches. Segments of *Stigmaria ficoides,* generally 4–12 in. long, are commonly found preserved as sandstone casts in the outcrop belts of Desmoinesian rocks.

Discovering *Stigmaria* in growth position is somewhat unusual. Most stigmarian fossil specimens are found as float in stream beds or on weathered outcrops. The position of the *Stigmaria* in the photo is deceiving; it gives the impression that the fossil grew vertically through the strata (much like a taproot). However, beds dip ~70° on the north flank of the tightly folded McAlester anticline where the photograph was taken, and the features that appear to be bedding planes are closely spaced joints. The *Stigmaria* can be viewed in its original growth position by turning the photograph clockwise 70°, to approximate the original position of the beds. (The geologic pick is 1.1 ft long.)



Reconstruction of *Lepidodendron* sp. (from Stewart, 1983, fig. 11.3, A).

The photograph was taken at an outcrop of the Savanna Formation located in a road cut along Oklahoma State Highway 31, ~5 mi northeast of McAlester, in Pittsburg County. A section measured at this outcrop will be one of 12 stops featuring the Krebs Group on a field trip to be conducted by the Oklahoma Geological Survey in conjunction with the AAPG Mid-Continent meeting in Oklahoma City, September 14–16, 1997 (see meeting announcement on page 106).

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