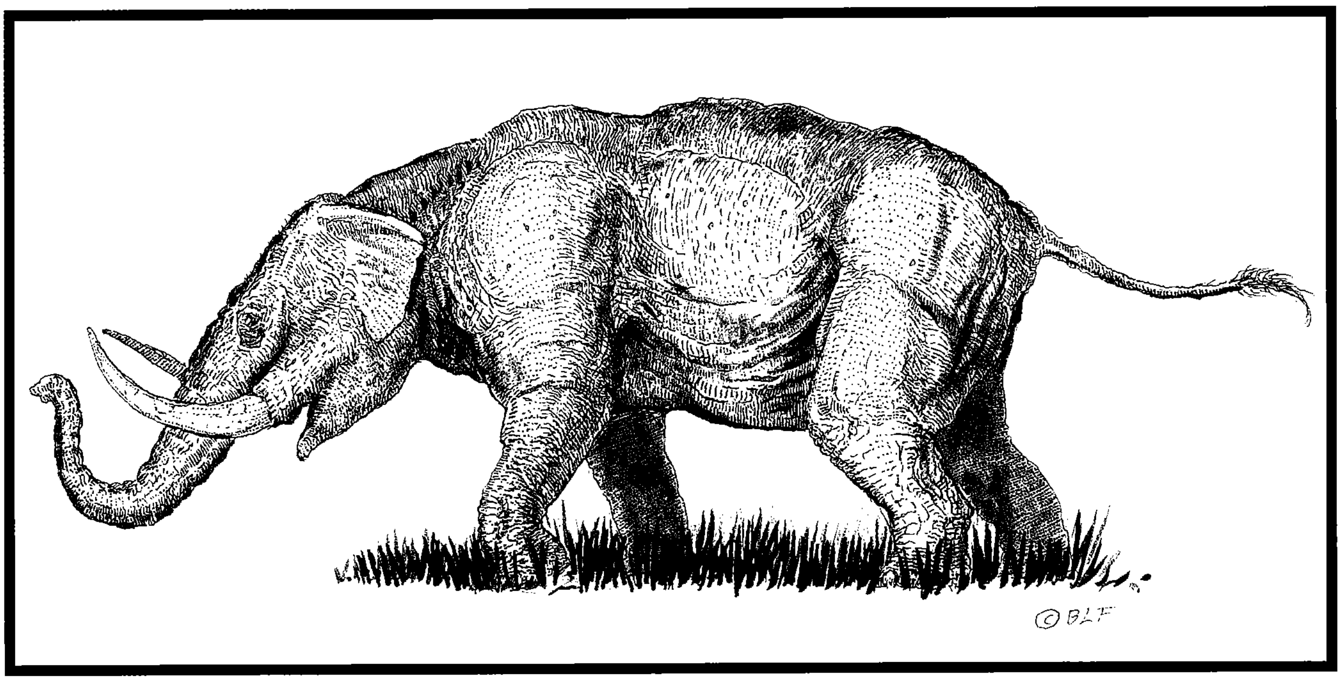
OKLAHOMA GEOLOGY

Oklahoma Geological Survey

Vol. 63, No. 3 Fall 2003



Featuring: The gomphothere *Stegomastodon*

Geonews roundup

on the cover

The gomphothere *Stegomastodon* in Oklahoma

In Oklahoma, remains of proboscideans are common in Pleistocene deposits (early Pleistocene, Irvingtonian land mammal age; late Pleistocene, Rancholabrean land mammal age), and they are found by amateur rock hunters as well as by professional archeologists and paleontologists. Most of these elephant remains belong to the families Mammutidae (mastodonts) and Elephantidae (mammoths). The cover illustration represents Gomphotheriidae: *Stegomastodon*, a third family of proboscidean that inhabited western Oklahoma during the Miocene to early Pleistocene. (In North America, the stegomastodonts occurred from the Blancan to the early Pleistocene; in South America, they survived until the late Pleistocene [Kurtén and Anderson, 1980].) Presently, only two records of *Stegomastodon* are reported for Oklahoma, and the localities occur within 100 km of each other in the southwestern part of the State. (See "The gomphothere *Stegomastodon* (Mammalia: Proboscidea) in the late Pliocene or early Pleistocene of Oklahoma," p. 104 of this issue.)

The stegomastodonts that inhabited Oklahoma, which stood a little over 2 m at the shoulder, were shorter and stockier than the Asiatic elephant. The stegomastodonts may have competed with the elephantids (*Mammuthus*) for the same grasslands habitat and been displaced by the more successful elephantids. Gomphotheriids are known from several early Blancan localities in nearby Kansas and Texas. No Blancan vertebrate faunas are known from Oklahoma and only three early Pleistocene faunas are known (Smith and Cifelli, 2000), which may explain, in part, so few records of gomphotheriids from the State.

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Smith, K. S.; and Cifelli, R. L., 2000, A synopsis of the Pleistocene vertebrates of Oklahoma: Oklahoma Geological Survey Bulletin 147, 36 p.

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Cover drawing by Brian Ford

OKLAHOMA GEOLOGY NOTES, ISSN 0030-1736, is published quarterly by the Oklahoma Geological Survey. It contains short technical articles, mineral-industry and petroleum news and statistics, abstracts, notices of new publications, and announcements of general pertinence to Oklahoma geology. Single copies, $1.50; yearly subscription, $6. Send subscription orders to the Survey at 100 E. Boyd, Room N-131, Norman, OK 73019.

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OKLAHOMA GEOLOGY

Vol. 63, No. 3 — Fall 2003

The gomphothere *Stegomastodon* (Mammalia: Proboscidea) in the late Pliocene or early Pleistocene of Oklahoma

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ABSTRACT.—Two partial lower third molars of the advanced gomphothere *Stegomastodon mirificus* are reported from a gravel pit in Beckham County, Oklahoma. Three other taxa of large vertebrates also occur in the deposit: an unidentified turtle, represented by a small shell fragment; a horse of the genus *Equus*, represented by tooth fragments; and a giant camelid, represented by a distal radius-ulna, a partial magnum, and a piece of a cheektooth. This assemblage was collected from a conglomerate containing clasts derived from the crystalline rocks of the Wichita Mountains; it was situated at the level of a low terrace of the North Fork of Red River. The presence of *S. mirificus*, Camelidae, and *Equus* indicates a late Pliocene (late Blancan) or early Pleistocene (early Irvingtonian) age for the deposit. In an early Irvingtonian local fauna from another Oklahoma locality, the Holloman gravel pit in Tillman County, three co-occurring genera of proboscideans appear to be present: *Stegomastodon*, *Cuvieronius*, and *Mammuthus*.

INTRODUCTION

Proboscideans, especially mammoths, are very common as fossils in the Pleistocene of North America. In the Pleistocene of the western part of the continent, however, proboscideans such as mastodons (Mammutidae) and gomphotheres (Gomphotheriidae: four-tuskers, shovel-tuskers, and relatives) are less common. Gomphotheres invaded North America from Asia in the late early Miocene (Lambert and Shoshani, 1998). They subsequently underwent a modest radiation and became widespread until disappearing before the end of the Pleistocene. One North American genus, *Stegomastodon*, is known only in the western half of the continent, where it has been reported from sites ranging in age from the late Miocene (late Hemphillian land mammal age) until the early Pleistocene (Irvingtonian land mammal age) (Kurtén and Anderson, 1980).

During the 1930s, two associated cheekteeth of *Stegomastodon* were collected and donated to the Oklahoma Museum of Natural History (OMNH). According to archival card catalogs dating from that time, the teeth were collected by H. D. Brown at a site in the NW¼NW¼ sec. 14, T. 8 N., R. 23 W., Beckham County, Oklahoma (Fig. 1). Despite their long presence in the OMNH collection, the *Stegomastodon* specimens have not been previously reported. In 1995, the authors and Donald E. Savage revisited this site, which is a small gravel pit surrounded by grazed pastures of mesquite-grassland. The authors visited it again in 2003. These visits resulted in discovery of fragmentary remains of a turtle and two other types of large mammals. Herein we document the presence of these vertebrates from a time interval that is very poorly represented in the fossil record of Oklahoma. The specimens are the first fossil vertebrates to be reported from Beckham County, Oklahoma.

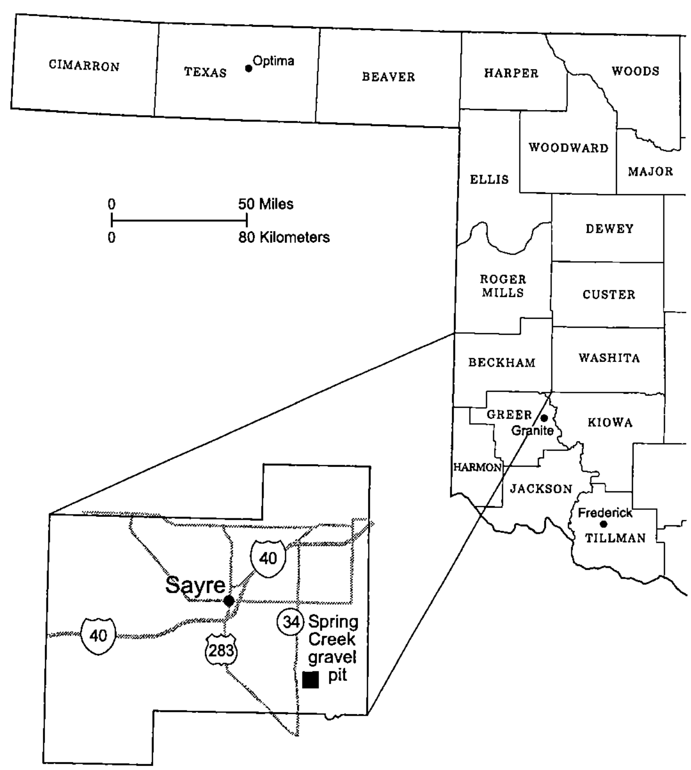

Figure 1. Map of Oklahoma showing the location of the Spring Creek gravel pit.

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SITE DESCRIPTION

The locality in which the fossils were discovered, herein called the Spring Creek gravel pit, is cataloged as OMNH vertebrate fossil locality V529. The site is ~16 km south of Sayre, Beckham County, Oklahoma. From the Spring Creek gravel pit, the gravel deposit extends to the west beneath a county road into the adjacent NE¼NE¼NE¼ sec. 15. It had been mined on both sides of the north-south county road, but the quarry was not active when visited in 1995 and 2003 (Fig. 2). The deposit lies at an elevation of ~560 m and is situated near a tributary to Spring Creek, ~3.5 km west of the North Fork of Red River. It is ~40 m above the present level of the river at its confluence with Spring Creek. The westernmost outliers of the Wichita Mountains are only 25–30 km to the southeast, near Granite, Oklahoma, and Quartz Mountain State Park (Figs. 1, 2A). These outliers consist of Cambrian granitic intrusions that metamorphosed sedimentary rocks that had been deposited earlier. Later, during the Pennsylvanian, the intrusions were uplifted as a part of the Amarillo-Wichita Uplift and subsequently exposed by erosion. They are reduced to present-day summits of 600–730 m; their bases are at about 450–500 m.

The Spring Creek gravel deposit consists of a poorly sorted, poorly lithified, matrix-supported, iron-rich conglomerate. Its matrix is made up of clay- to cobble-sized material, mostly coarse sand to pebbles. The gravel-, pebble-, and cobble-sized clasts vary from very angular to well rounded and consist mostly of quartz; there are also clasts consisting of granitic and extrusive volcanics, limestone, flint or jasper, petrified wood, goethite, and gneiss, which suggests a variety of source rocks of igneous, sedimentary, and metamorphic origins. The sand fraction is immature, containing more angular than rounded clasts. The conglomerate is poorly sorted and shows a low degree of cementation by an iron-rich source (Fig. 2C,D); it is weathering in place and some is easily crumbled by hand. There is no imbrication of clasts.

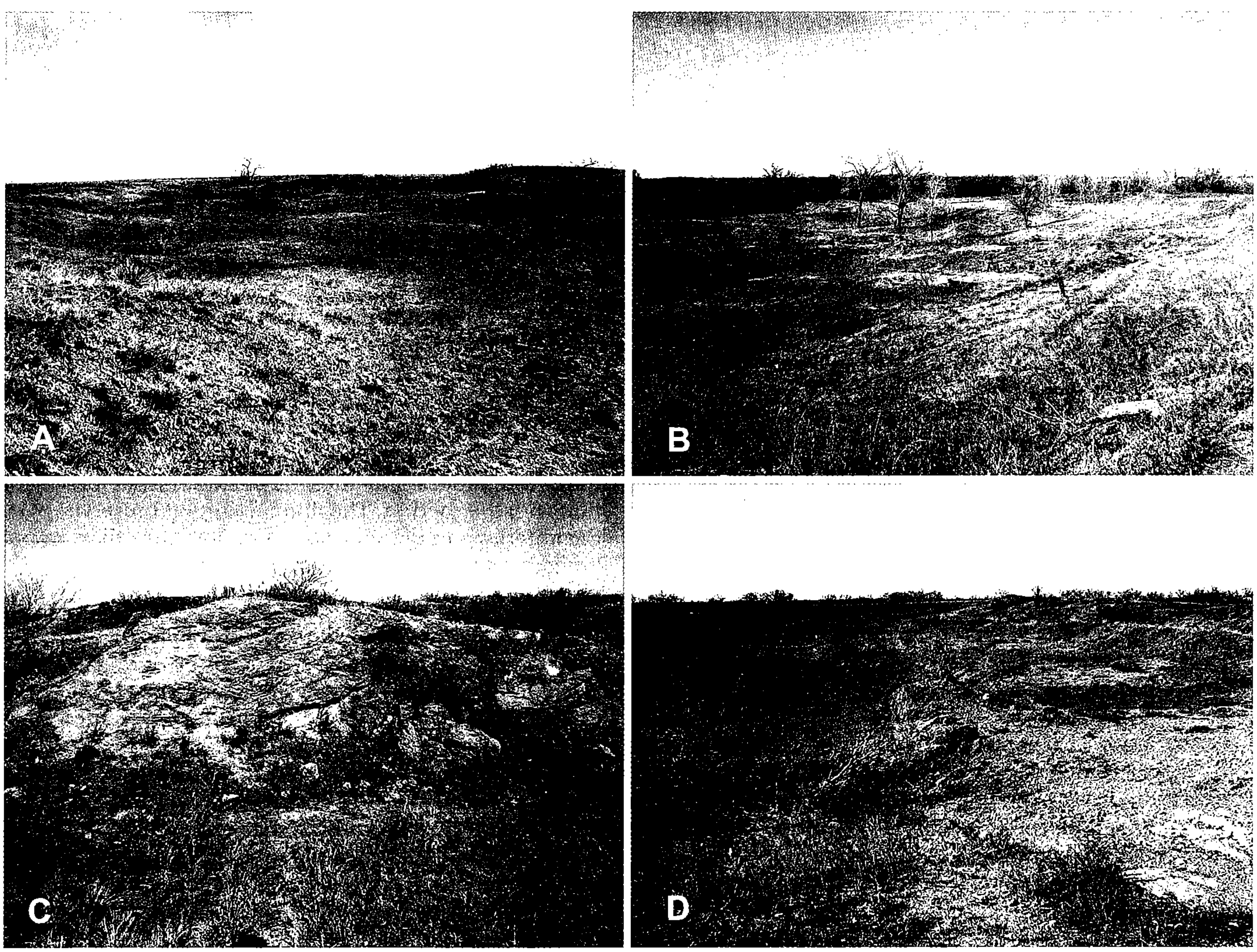

Figure 2. Photographs of the Spring Creek gravel pit. *A*—East half of quarry, east of county road; view is southeastward with Granite Mountain (600 m elevation; 25–30 km away) barely visible on the horizon to the right of center. *B*—View northwestward of western portion of quarry, partly overgrown with vegetation in 2003. *C*—Undisturbed mound (ca. 2 m high) within the quarry showing moderately cemented, cross-bedded conglomerate. *D*—The distal radius-ulna of a giant camel was found in 2003 on the ridge of weakly to moderately cemented conglomerate and sand running from the mound at left-center middle ground to center and right foreground.

The conglomerate represents a high-energy scour-and-fill environment close to the source of an exposed, intrusive basement rock highland that was shedding this material. Metamorphic rocks of the nearby Wichita Mountains surely served as the source of quartz and gneiss. The sources of extrusive volcanic clasts and of limestone and flint or jasper are less obvious. The fossil-bearing deposit originally must have come down from the highland as a slurry or mud flow, an episodic mass wasting from, or in, an upland situation that reworked the local Permian bedrock. The Permian red beds presently surrounding the area probably provided the source of iron in the cement.

Cannon (1967, 1968) mapped high, intermediate, and low terraces along the North Fork of Red River; very little of the high terrace remained. The Spring Creek gravel pit is in an area mapped by Cannon as a low terrace; however, the fossiliferous deposit is older than its position on the low terrace would suggest (early Pleistocene as indicated by the fossils described herein). The Spring Creek gravels may represent the same gravels that occupy cut-and-fill features in the Permian bedrock at the level of the high terrace noted by Cannon (1967, p. 13–14), who thought that these cut-and-fill features represented the mid-Pleistocene. The Spring Creek conglomerate probably lies directly on Permian red beds of the Blaine Formation, although this cannot be established because the base is covered; it likely represents a remnant of stream-laid deposits of an ancestral North Fork of Red River. In western Oklahoma, most Quaternary terrace deposits are on the north side of major rivers. They were left behind as the rivers cut laterally toward the south or southwest, following the slight dip of the Permian rock layers. Accordingly, in the Spring Creek area, high and intermediate terraces occur only on the north and east sides of the North Fork, on the opposite side from the Spring Creek gravel pit. On the south and west sides of the North Fork of Red River, only the low terrace is represented (Cannon, 1967). Cannon (1968) presented evidence for stream piracy of the North Fork between the deposition of the intermediate and low terraces.

A small deposit of volcanic ash occurs 11 km southeast of the Spring Creek gravel pit, also on the west side of the North Fork of Red River at ~530 m elevation. This area, too, was mapped by Cannon (1968) as the low terrace, which would indicate a relatively young age (late Pleistocene to Holocene). However, the ash was dated by fission track analysis to 0.58 ± 0.18 Ma (Ward and others, 1993; Ward and Carter, 1998, 1999), which indicates an early Pleistocene age.

The few available vertebrate fossils from the Spring Creek gravel pit are broken pieces of large mammal bones and teeth. Their fragmentary condition is not surprising in light of the coarseness of the gravels in which they were preserved. Although the faunule presently known is depauperate, it adds to the three previously known assemblages of early Pleistocene (Irvingtonian) age in Oklahoma (Smith and Cifelli, 2000). One of the taxa represented, the large proboscidean *Stegomastodon*, has only been reported previously from one locality in Oklahoma, the Holloman gravel pit in Tillman County (Dalquest, 1977). However, one of the Holloman specimens referred by Dalquest to *Stegomastodon* may belong to a different taxon (see below).

SYSTEMATIC PALEONTOLOGY

Class Reptilia
Order Testudines
Family, genus, and species indeterminate

Referred specimen: OMNH 72103, a small fragment of shell.

Discussion: This specimen is too small a piece of the shell to be identifiable, but it has the characteristic cross section of turtle shell bone on a broken edge (showing spongiform texture sandwiched by compact bone on either surface), as well as an unbroken edge bearing the small projections for a tight suture with another shell bone. It is the only nonmammalian member of the Spring Creek gravel pit faunule.

Class Mammalia
Order Perissodactyla
Family Equidae
Equus sp.

Referred specimens: OMNH 52579, three associated fragments of left lower cheekteeth (Fig. 3A); OMNH 72106, small fragment of an upper cheektooth; OMNH 72107, fifth lumbar vertebra; OMNH 52582, small portion of the left ilium.

Description: The cheekteeth fragments represent a large-bodied horse (Fig. 3A). The pieces are split and include only portions of the lingual side of the crowns: one piece includes a paralophid, metaconid, and metastylid; another, a paralophid and metaconid; the third, the metastylid and entoconid. No ectoflexids are preserved in any of the lowers. The metaconid, metastylids, and entoconids are elongated, as in *Equus* and unlike those in other late Miocene and Pliocene large-bodied horses such as *Dinohippus*, *Astrohippus*, and *Neohipparion*. One fragment preserves 49 mm of the original height of the crown. The fifth lumbar vertebra represents a large horse and consists of the complete centrum with small portions of the neural arch and right transverse process. The transverse process includes the posterior facet for articulation with the sacrum. The ilium fragment preserves part of the anterior rim of the acetabulum and the adjacent bone immediately anterior to the acetabulum; anteroventral to the acetabulum, there is a very shallow muscle scar pit.

Discussion: In North America, at least five species (and probably several more) of *Equus* occurred during the last 2.5 million years (Winans, 1989). The species can be difficult to distinguish even when complete skulls and mandibles are available; Winans (1989) distinguished species groups rather than assigning specimens to species, and most other recent authors have followed her lead. The tooth fragments from Spring Creek gravel pit are insufficient for a species identification, and even a generic identification is not absolutely certain. The ilium fragment also is too small to be diagnostic, but it is similar to the same region of the pelvis in comparative specimens of equids while differing from that area in camelids, bovids, and cervids. Except for historic reintroduction, the genus *Equus* had a temporal range in North America from the early Blancan (early Pliocene) until the late Rancholabrean (end of the Pleistocene) (MacFadden, 1998).

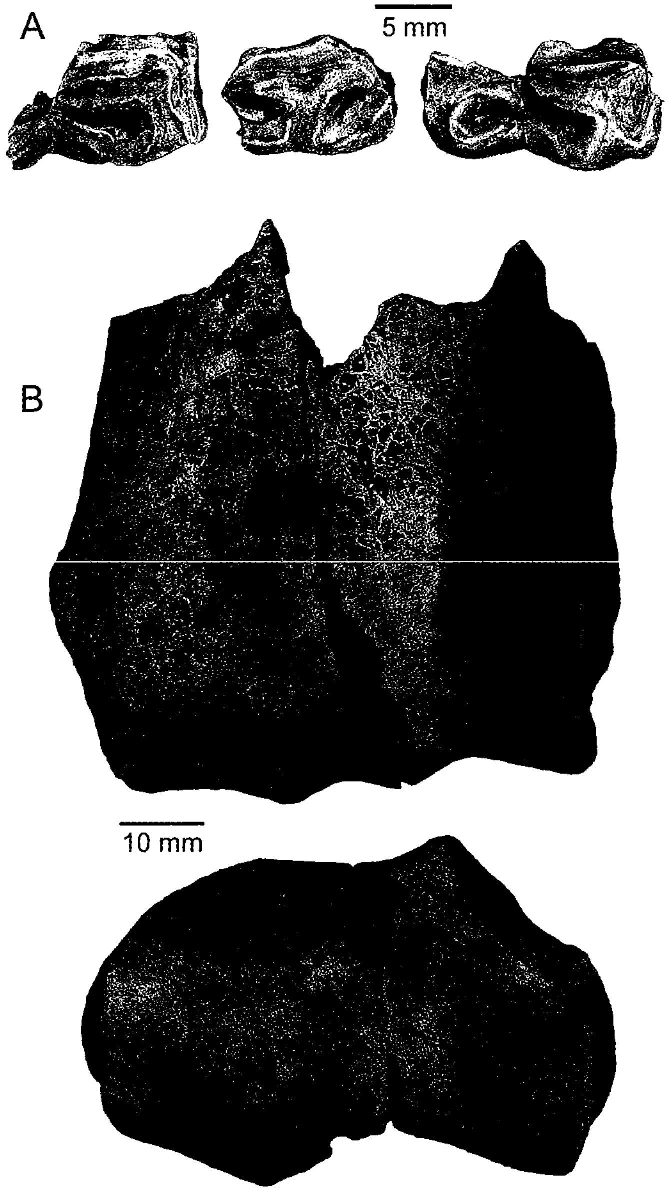

Figure 3. Horse and camel fossils from the Spring Creek gravel pit. *A—Equus* sp., associated fragments of 3 left lower cheekteeth (OMNH 52579) in occlusal view. *B*—Camelidae, distal fragment of radius-ulna (OMNH 72100) showing anterior surface (at top) and distal articular surface (at bottom).

Other genera of horses of Hemphillian age (*Neohipparion* and *Astrohippus*) are known from several gravel pits farther north in Ellis County, Oklahoma (Tedford and others, 1987). The Spring Creek horse does not appear to belong to these other genera.

Order Artiodactyla
Family Camelidae
Genus and species indeterminate

Referred specimens: OMNH 72100, distal end of left radius-ulna (Fig. 3B); OMNH 72105, left partial magnum; OMNH 52580, fragment of a cheektooth.

Description: OMNH 72100 includes the whole distal articular surface and a short distal section of the diaphysis of the radius-ulna (Figs. 3B). These elements are completely co-ossified and the epiphysis is also fully fused to the diaphysis (although the line of fusion at the epiphyseal plate is still visible as an interrupted line on the ulna). Two measurements of the incomplete radius-ulna are: greatest width at the distal end (GDW), 109.3 mm; greatest width of the distal articular surface (DAW), 91.4 mm. The magnum is missing a central portion and posterolateral projection. The thickness of the medial portion of the magnum (between the scaphoid facet and the metacarpal facet) is 21.5 mm. The tooth fragment includes the lingual enamel wall and adjacent dentine from a selene of a hypsodont cheektooth; ~35 mm of the height of the crown is preserved.

Discussion: Despite its incompleteness, the radius-ulna clearly represents a very large species of Camelidae. The Spring Creek gravel pit radius-ulna is in the size range of several genera of giant camels (*Gigantocamelus, Titanotylopus, Megatylopus, Megacamelus,* and *Blancocamelus* (Table 1) and much larger than the widespread late Pleistocene (Rancholabrean) species *Camelops hesternus* (Webb, 1965). Based on the paucity of available radii-ulnae for many late Cenozoic giant camelids and their measurements, the specimen cannot be identified to genus. In the preserved portion of the magnum, the overall size of the bone is similar to that of several specimens of *Megatylopus matthewi* from Optima, Oklahoma (late Hemphillian) (Fig. 1). However, proximodistal depth of the Spring Creek magnum (21.5 mm) is much thinner than the mean (24.9 mm) of six Optima *Megatylopus matthewi* specimens with which it was compared. The cheektooth fragment represents a large camelid, but it is too small a piece for precise identification.

Order Proboscidea
Family Gomphotheriidae
Stegomastodon Pohlig 1912
Stegomastodon mirificus (Leidy) 1858

Referred specimens: OMNH 4566, associated partial left and right m3s (lower third molars) (Fig. 4); OMNH 52581, small fragment of tusk. The m3s have previous catalog numbers on them (715, 28B-26-S8, and 28B-26-S9), which relate to old catalog cards that identify the collecting locality herein called the Spring Creek gravel pit.

Description: The m3s are both broken anteriorly and do not preserve the anterior root. They have concave wear surfaces. The amount of wear indicates that the teeth are from a mature individual (Savage, 1955); there is moderate wear on the preserved anterior portions but the posterior lophulids are only slightly worn. The teeth exhibit secondary trefoiling (accessory conulids wear to form compound or multiple spurs on the main lophids instead of the simple trefoils typical of other gomphotheres), ptychodonty (extreme plication of the enamel), choerodonty (the presence of numerous tubercles within the lophs), and an abundance of cementum. (For gomphothere cheektooth terminology, see Savage [1955] and Lambert and Shoshani [1998]). Due to breakage, it is not

TABLE 1.—MEASUREMENTS (IN MILLIMETERS) OF THE CAMELID DISTAL RADIUS-ULNA FROM THE SPRING CREEK GRAVEL PIT IN COMPARISON TO LARGE LATE CENOZOIC CAMELS FOR WHICH THE RADIUS-ULNA IS KNOWN

Species/specimen(s)	No. of specimens	GDW[a] Observed range	GDW[a] Mean	DAW[b] Observed range	DAW[b] Mean
OMNH 72100, Spring Creek gravel pit, Beckham County, Oklahoma	1	109.3	—	91.4	—
Gigantocamelus spatulus[c] Keefe Canyon, Meade County, Kansas	3	129.0–134.0	132.0	114.0–117.0	115.3
Holloman gravel pit[d] Tillman County, Oklahoma	1	106	—	—	—
Titanotylopus or *Gigantocamelus* sp.[e] Gilliland local fauna, Texas	1	118.0	—	113.0	—
Megatylopus gigas[f] Elmore County, Idaho	1	118.4	—	—	—
Megatylopus matthewi[g] Optima local fauna, Oklahoma	6	99.5–105.0	102.6	85.5–101.0	91.7
Megacamelus merriami[h] Keams Canyon, Arizona	5	104.0–126.2	113.9	—	—
Camelops hesternus[i] Rancho La Brea, California	16	79–93	87.3	—	—

[a]Greatest width of distal radius-ulna
[b]Greatest width of distal articular surface
[c]Hibbard and Riggs (1949, table 5)
[d]Meade (1953)
[e]Hibbard and Dalquest (1962)
[f]Thompson (2002)
[g]Unpublished OMNH specimens 15746–15749, 15751, and 15753 from Optima, Oklahoma
[h]Harrison (1985)
[i]Webb (1965)

possible to determine the exact number of lophids on the m3s from the Spring Creek gravel pit. The enamel is very complex, with compound trefoiling on labial as well as lingual cones (Fig. 4). The teeth have thick and abundant cementum, although it is partly broken away around the periphery of the crowns of both. The greatest transverse width of the preserved portion of the left m3 is 83 mm and of the right is 81 mm.

Discussion: *Stegomastodon* differs from other gomphotheres in having molar crowns with thick and abundant cementum (Shoshani, 1996; Lambert and Shoshani, 1998; Campbell and others, 2000), and the m3 in this genus bears at least five full-sized lophids and may also include additional reduced or incomplete lophids (lophulids). Thus, *Stegomastodon* m3s may have anywhere from five-and-one-half to seven-plus lophids (Savage, 1955). Recent authors recognize two species of *Stegomastodon*: *S. primitivus*, an early primitive form, and *S. mirificus*, a later advanced form. The two species differ in the presence of more cementum in *S. mirificus* than in *S. primitivus* (Savage, 1955; Lambert and Shoshani, 1998). The earlier form tends to have fewer lophids (usually five-plus) whereas the later form tends to have more lophids (six-plus to seven-plus) (Lambert and Shoshani, 1998). Complexity of the occlusal surface also increases through time; the enamel pattern is relatively simple (although more complex than in other North American genera of gomphotheriids) in the early (Hemphillian and early Blancan) form and becomes extreme in the later (Blancan and early Irvingtonian) species. Because both m3s from the Spring Creek gravel pit are broken, it is not possible to count the exact number of lophids in the specimens. However, the great complexity of the molar occlusal surface and the large amount of cementum indicate that the Spring Creek gomphothere is *S. mirificus*. The measurements are comparable to those of *Stegomastodon mirificus* from the late Blancan of Texas provided by Savage (1955). The tusk fragment consists of a very short segment <2 cm long with a few concentric layers of dentine. In cross sec-

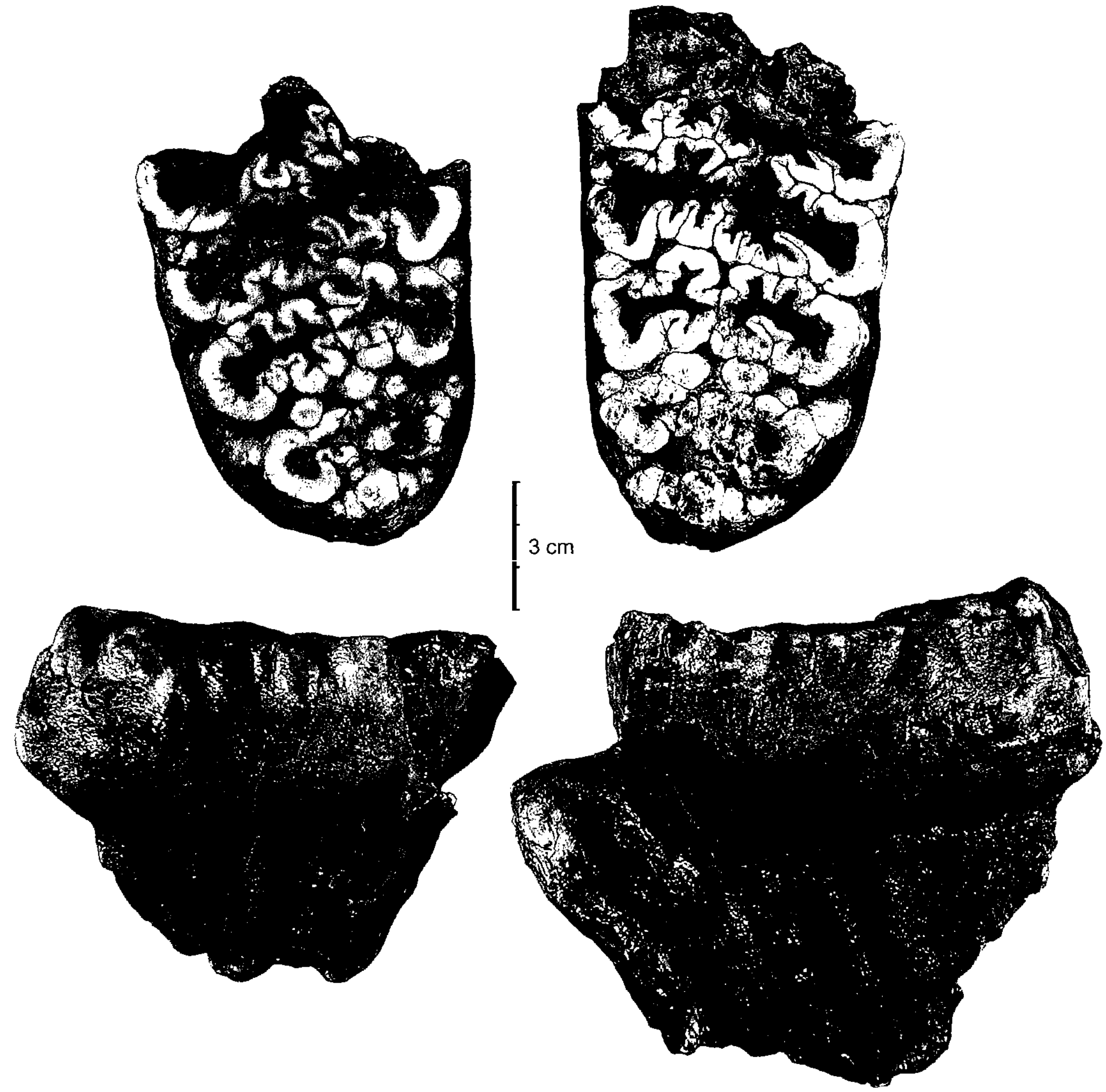

Figure 4. *Stegomastodon mirificus* from the Spring Creek gravel pit, associated partial left and right m3s (lower third molars) (OMNH 4566). *Top*—Occlusal view (some enamel appears darkened due to a coating of shellac, especially on the left m3). *Bottom*—Lingual views.

tion, the layers show the criss-crossing pattern of dentinal lines typical of proboscidean ivory. The fragment may also be referable to *S. mirificus*, although it was found about 70 years later than the molars and not in association with them.

AGE OF THE SPRING CREEK GRAVEL PIT

Tedford and others (1987) reported gravel pits of Hemphillian age (late Miocene) in northwestern Oklahoma containing two Miocene genera of horses *Neohipparion* and *Astrohippus*. These gravel pits differ from the Spring Creek gravel pit in that they are situated in the fill of channels cut into the Ogallala Formation instead of in a Quaternary river terrace. Miocene horses are absent from the Spring Creek gravel pit. Instead, the Pliocene to Pleistocene one-toed horse *Equus* is present. *Equus* has a temporal range in North America from the early Pliocene to the end of the Pleistocene (Blancan through Rancholabrean). The Spring Creek camelid could represent any of several genera of giant camels known from the late Miocene through Pleistocene of the western U.S.A. Therefore, it is of no help in precise age determination. *Stegomastodon* has a temporal range extending from the late Miocene (late Hemphillian) or early Pliocene (latest Hemphillian) to the early Pleistocene (early Irvingtonian) (Lambert and Shoshani, 1998). *Stegomastodon mirificus* occurs in the late part of this interval, being most common in the Pliocene (from the medial and late Blancan) but also extending into the early Irvingtonian. The *Stegomastodon* molars from the Spring Creek gravel pit are highly derived, as in the latest specimens of *S. mirificus* from the early Irvingtonian. The species *Stegomastodon mirificus* (and genus) became extinct in North America about 1.2 million years ago; its youngest known appearance is at Tule Canyon, Texas, where it is associated with a volcanic ash between 1.3 and 1.2 million years old (Izett, 1977; Tedford, 1981; Morgan and Lucas, 2003). The combination of *Stegomastodon mirificus* and *Equus* indicate an age between Pliocene (medial Blancan) and early Pleistocene (early Irvingtonian). The presence of *Stegomastodon* further indicates that the Spring Creek gravel pit assemblage can be no younger than 1.2 Ma. Only three localities definitely of Irvingtonian age have been reported previously in Oklahoma (Smith and Cifelli, 2000), and no definite Blancan vertebrate locality is presently known in the State, despite others in nearby Kansas and Texas.

OCCURRENCES OF *STEGOMASTODON* IN OKLAHOMA

Stegomastodon has been found in Oklahoma only in the Spring Creek gravel pit and in the Holloman gravel pit near Frederick, Tillman County (Fig. 1). The Holloman gravel pit is ~100 km southeast of Spring Creek gravel pit. The area in which it occurs was mapped and described by Cannon (1967) as an intermediate terrace of the North Fork of Red River. A diverse fauna of about 18 taxa of fossil vertebrates is known from the Holloman gravel pit (Dalquest, 1977), including the mammals ?*Megalonyx jeffersonii, Paramylodon harlani, Glyptotherium arizonae, Cynomys ludovicianus*, Felidae indet., *Platygonus* cf. *P. vetus, Gigantocamelus spatulus, Camelops* sp., *Hemiauchenia macrocephala, Odocoileus* sp., *Tapirus haysii*, several *Equus* spp., the elephantid *Mammuthus haroldcooki*, and one or two taxa of gomphotheres, as discussed below. The Holloman local fauna represents the early Irvingtonian land mammal age (Dalquest, 1977; Lundelius and others, 1987).

Two taxa of gomphotheres seem to be present in the Holloman local fauna (Hay and Cook, 1930). Presence of the genus *Stegomastodon* at Holloman was originally based on a small, worn molar fragment described and figured by Hay and Cook (1930, plate IV, fig. 2). The fragment was thought to represent the front of a left upper molar, possibly M2, including only the anterior cingulum and part of the first loph. Hay and Cook (1930) did not assign it to a species because of its incompleteness. A different fragment of a cheektooth from the Holloman gravel pit served as the holotype of *Gomphotherium priestleyi* Hay and Cook 1930. It consists of the slightly worn rear portion of a probable right m2 (lower second molar) with the posterior lophulid, the hindmost lophid, and half of the penultimate lophid (Hay and Cook, 1930, plate XII, figs. 2 and 3). This fragment has thicker enamel and a less complicated enamel pattern; in our opinion, it does not appear to belong to the same taxon as the *Stegomastodon* fragment mentioned above, as treated by Hay and Cook (1930). Meade (1953, p. 455) mentioned an additional specimen or specimens subsequently found at Holloman, including "several partial teeth and a nearly complete right and left jaw, possibly of the same individual but lacking the teeth." Meade (1953, p. 455) provided no details or description of his specimens, but referred them and all the previous Holloman gomphotheres to "*Stegomastodon* cf. *priestleyi*." Dalquest (1977) followed Meade in considering all the Holloman specimens to belong to one taxon without commenting on their morphology or on differences from the type specimen of *Gomphotherium priestleyi*, and he also referred them all to the genus *Stegomastodon* (as *Stegomastodon priestleyi*). Madden (1983) also considered all the Holloman gomphothere specimens together as belonging to one taxon. He noted that "the original record of Stegomastodon . . . recorded from the Holloman local fauna of Oklahoma by Hay and Cook (1930) is in error, for their material represents an advanced *Teleobunomastodon* ('*Cuvieronius*'... unpub. data) species. The Holloman *Teleobunomastodon* has *Stegomastodon*-like, double (but incomplete) trefoilids or tubercles on its lower second and third molars, the latter of which have only five ridges—unlike any species of *Stegomastodon* known . . ." (Madden, 1983, p. 275–276). We note that no other author has ever recognized the taxon *Teleobunomastodon* in North America, and Madden (1983) did not provide details nor justify his use of the name *Teleobunomastodon* for the Holloman *Cuvieronius* and *Stegomastodon* fragments.

In our opinion, the preserved crown morphology in the holotype fragment of *Gomphotherium priestleyi* differs from that of *Stegomastodon* (as originally recognized by Hay and Cook, 1930) and is consistent with that of *Cuvieronius*. Although we have not examined the holotype of *G. priestleyi*, the photographs in Hay and Cook (1930, plate XII, figs. 2 and 3) show that its crown morphology, which lacks highly crenulated enamel and multiple trefoils, is simpler than that of *Stegomastodon* molars. In their synopsis of North American proboscidean systematics, Lambert and Shoshani (1998, p. 612) remarked that "intraspecific variation in cheektooth morphology makes it extremely difficult to identify valid *Cuvieronius* species. Pending future clarification of this situation, it is best to refer *Cuvieronius* material to *Cuvieronius* sp." Accordingly, and especially given the presence in the Holloman local fauna of only one tooth fragment of uncertain locus, it seems prudent to us to consider the fragment originally named *Gomphotherium priestleyi* as *Cuvieronius* sp. indet. The other tooth fragment originally referred to *Stegomastodon* sp. indet. by Hay and Cook (1930) plus one of the partial teeth and mandible subsequently listed by Meade (1953) (both now in the Texas Memorial Museum, The University of Texas at Austin) do show the very complex enamel of *Stegomastodon*. These specimens probably represent *S. mirificus*, although confirmation in the way of additional, more complete specimens from Holloman would be welcome. Unfortunately, the most diagnostic feature separating teeth of *Cuvieronius* and *Stegomastodon* can only be observed in complete teeth: *Stegomastodon* has four lophs/lophids on M1/m1 and M2/m2 and six or more lophs/lophids on M3/m3, whereas *Cuvieronius* has a standard gomphothere configuration with three lophs/lophids on M1/m1 and M2/m2 and four lophs/lophids on M3/m3.

Given our re-identification of the type of *G. priestleyi* as *Cuvieronius* sp., the Holloman site in southwestern Oklahoma becomes one of few localities in which three proboscideans, *Stegomastodon, Cuvieronius*, and *Mammuthus* are found in association. The only other known localities where they co-occur are in the Gilliland local fauna, Seymour Formation, Texas (Hibbard and Dalquest 1966), and in gravel pits in the Camp Rice Formation near Las Cruces, New Mexico (Lucas and others, 2000). In each of these localities, the local fauna indicates an early Irvingtonian age. The faunas also probably reflect the former presence of similar environmental conditions in the region they share and/or continuous habitat suitable for these three genera of behemoths.

ACKNOWLEDGMENTS

Our thanks go especially to the landowners Dean and Joyce Damron for kindly granting permission to collect at the Spring Creek gravel pit and allowing the fossils to be placed in the OMNH. We are also grateful to the late Donald E. Savage for help in field work. William D. Peachey graciously provided the geological interpretation of the Spring Creek gravel pit conglomerate. Gary S. Morgan of the New Mexico Museum of Natural History provided ungulate specimens for comparison and helpful discussion about proboscideans. Pamela Owen provided information about Meade's (1953) specimens presently at The University of Texas at Austin. Richard L. Cifelli gave a thoughtful review of an earlier version of this manuscript.

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Oklahoma drilling permits at highest level in 15 years

TULSA—According to an Associated Press news story, producers taking advantage of higher oil and natural gas prices are drilling more new wells in Oklahoma than at any time in the last 15 years, energy regulators say.

The Oklahoma Corporation Commission said Thursday [Jan. 8, 2004] it issued 5,119 drilling permits to oil and gas producers last year, the most in a year since 1988.

"It's the best environment for our business in 20 years," said Mickey Thompson, president of the Oklahoma Independent Petroleum Association.

The number of permits is still well behind the state's record year, 1981, when regulators issued 22,685 permits as the oil boom peaked and oil prices were more than $30 a barrel.

Tight supplies and increased demand sent prices of gas and oil up in the last year, and they are expected to remain high for some time before softening, analysts say.

Oklahoma natural gas prices averaged $4.42 per thousand cubic feet in the first eight months of 2003, up from $2.65 during the same period in 2002, state figures show.

Gas closed at $7.09 per thousand cubic feet Thursday [Jan. 8, 2004] on the New York Mercantile Exchange.

Oklahoma oil averaged $30.43 per 42-gallon barrel during the first eight months of 2003, up from $18.21 during the same period in 2002, the state says.

Oklahoma City–based Chesapeake Energy Corp., the top producer of Oklahoma gas, was the most active driller in the state last year by a wide margin, spending more than $500 million on new drilling projects in state fields.

"We have expectations that prices are going to stay at historically higher levels," said Chesapeake spokesman Tom Price.

Oklahoma, the nation's third-largest gas producing state, has several trillion cubic feet of proven gas reserves, the U.S. Department of Energy says.

"A great deal of this state is unexplored at significant depths," Price said.

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For more information on oil and gas drilling activity in Oklahoma, visit the Oklahoma Corporation Commission's website at **http://www.occ.state.ok.us/**. Click on "Oil and Gas Information."

Another useful website is maintained by the U.S. Energy Information Administration at **http://eia.doe.gov/**. Click on "By Geography—States," then click on "OK," then click on "Petroleum—Overview."

Oil and gas prices climb as production drops

Some claim U.S. energy policy is limiting investments, output.

By Clayton Bellamy

TULSA—Along U.S. 75 between here and McAlester, a handful of rigs tower above the trees that line the highway, their fluorescent lights illuminating the white platforms where roughnecks labor day and night.

They're digging new oil and gas wells, mostly gas wells, as producers rush to capitalize on the high prices of both natural gas and crude oil. The rigs' continuous grinding is a welcome sound for those waiting on a revival of the state's second largest industry.

The number of rigs exploring for oil and gas in Oklahoma reached an 18-year high of 161 at the end of February, according to Baker Hughes Inc. The number rose throughout 2003 as gas prices topped $7 per thousand cubic feet and oil prices exceeded $30 per barrel.

Yet, oil and gas production in Oklahoma fell in the first 11 months of 2003 versus the same period in 2002 by 3 percent each, according to the latest Oklahoma Corporation Commission statistics.

"The last time energy prices were near these levels, Oklahoma had over 800 rigs actively exploring for oil and natural gas," said Denise Bode, commission chairman.

Many factors seen

Experts say there are almost as many factors in the production dip as there are rigs boring through the Oklahoma clay:

- A routine six-month lag between drilling permit application and oil and gas production.
- A national energy policy that the oil industry says has discouraged exploration, reduced the amount of drilling equipment available and scared off rig workers.
- The maturation of Oklahoma's long-tapped oil and gas fields.

"We're kind of seeing a combination of things," said Bruce Bell, chairman of the Mid-Continent Oil and Gas Association of Oklahoma. "We're seeing the reduction in prospects, the increase in the price of rigs and labor and overall loss in first year production in natural gas."

Producers frustrated

Oklahoma produced 1.41 trillion cubic feet of gas through November in 2003, when gas prices averaged $4.85 per thousand cubic feet. That's 40 billion cubic feet less than the first 11 months of 2002, when prices then were just $2.85 per thousand cubic feet.

Oil production fell to 59.2 million barrels at $29.9 per barrel through November in 2003, compared with 61 million barrels in the first 11 months of 2002, when the average crude price was $24.32.

It's not that producers don't want to produce. They filed 5,119 permit applications to drill new wells in 2003—more than they have since 1989, the commission reported.

The problem is that there are far fewer rigs available than there were before the 1980s oil bust. That means longer waits before proposed wells can be dug and higher costs when the equipment becomes available.

"There is a lot of wait on getting rigs right now, because we

Oil and gas prices *(continued)*

have increased our rig usage over the last year by 35 percent," said Bell, who stopped short of calling the lack of drills a "shortage."

The waits seem worse for smaller producers, the "checkbook drillers" who start new wells only when prices go up and who may only contract a rig to dig one or two wells at a time, officials said. These companies make up the majority of producers in Oklahoma.

"We can't respond to all the demand," said Larry Pinkston, president and chief operating officer for Unit Corp., a Tulsa-based driller that has 66 rigs in use in Oklahoma. "We just take care of the customers that we can."

Energy policy blamed

Bode sees a more corrosive cause for the small number of rigs. She and other Republican commissioners say the nation's energy policy creates too much price volatility and discourages domestic production.

These commissioners say producers are reluctant to spend money on increasing output when prices rise because they've seen them abruptly fall before, particularly in 2000 and 2001. In response to producers wariness, rig companies have cut back their inventories, and laid-off field hands have left the business for more steady employment, they say.

"It is the classic 'Catch 22' situation," commissioner Bob Anthony said. "Natural gas usage is increasing because it is offered as the clean-burning, environmentally friendly fuel. Yet, environmental concerns prohibit producers from drilling in many of the most promising areas."

Natural gas is known as having the most volatile price of any commodity. In 2003, gas prices ranged from $7.29 per thousand cubic feet in March to $4.12 per thousand feet in November.

Another factor at work is that Oklahoma's oil and gas reserves are aging: existing wells don't produce as much as they used to and what gas is left is deeper and harder and more expensive to find.

"That doesn't mean there's not plenty of oil and gas to recover here," said Mickey Thompson, president of the Oklahoma Independent Petroleum Association. "It's just so expensive that there are not many companies out there willing to take the risk."

The oil giants such as Exxon Mobil, ConocoPhillips Inc. and ChevronTexaco Corp. left Oklahoma long ago.

Mid-size Chesapeake Energy Corp. of Oklahoma City is the largest producer in the state. Its production rose by about 44 percent in 2003 over 2002, but that did little to stem the state's decline.

"We are in an era where you have to go deeper," said Tom Price, vice president and investor relations director for Chesapeake, which has 41 rigs drilling wells in Oklahoma. "It's going to be more expensive and the reserves are going to be smaller."

Bell says natural gas production peaked in 1998 nationally and has recently begun to fall, mirroring the cycle crude oil production went through after its domestic output peaked in 1970.

"We're drilling more holes and, in general, drilling deeper and more deeper holes just to maintain the same output of the last year," Bell said. "That's not a good sign long term in whether we'll be able to fill the natural gas needs."

Name change approved for stretch of North Canadian River

Senate Bill 1259 passed on 36-9 vote

By Sean Murphy

OKLAHOMA CITY—A decade ago, a stretch of the North Canadian River that meandered through Oklahoma City looked more like a vacant ditch than a river.

But with passage of a temporary 1-cent sales tax in 1993 to fund the Metropolitan Area Projects capital improvement program, $53.5 million was dedicated to transform the 7-mile stretch of river from Meridian to Eastern avenues.

Dams were contructed at Eastern, Western, and May avenues to raise the level of the river and the area is now bordered by landscaped trails.

On Monday, the Oklahoma Senate approved a measure to rename that stretch of the North Canadian River the Oklahoma River.

Senate Bill 1259, by Sen. Bernest Cain, D-Oklahoma City, passed on a 36-9 vote and directs the Oklahoma Centennial Commission to erect markers designating the name change.

The bill was originally brought to the floor last week but was laid over when concerns were raised about changing the name of the historic river.

On Monday [March 1, 2004], several members from the Oklahoma City area urged their colleagues to approve the name change as part of an economic development renovation that has taken place throughout downtown Oklahoma City.

"The folks in Oklahoma City want us to designate this as the Oklahoma River," said Sen. Mike Fair, R-Oklahoma City. "If you don't do it for those of us who live here, do it for those that have taxed themselves tens of millions of dollars to make that a beautiful area."

Although no one debated against the bill, nine members voted against it. They were Sens. Johnnie Crutchfield, D-Ardmore; Mike Johnson, R-Kingfisher; Owen Laughlin, R-Woodward; Richard Lerblance, D-McAlester; Robert Milacek, R-Enid; Mike Morgan, D-Stillwater; David Myers, R-Ponca City; Nancy Riley, R-Tulsa; and Frank Shurden, D-Henryetta.

The bill will now be considered in the House, where it is authored by Rep. Leonard Sullivan, R-Oklahoma City.

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For further information about geographic names in the United States, visit the U.S. Geological Survey's Geographic Names Information System at **http://geonames.usgs.gov/index.html**.

Tar Creek area may receive more money

Doctors have released some early results on studies involving lead and children.

By Sheila K. Stogsdill

MIAMI, OK—An appropriations bill that would fund $9.2 million for the Tar Creek area in northern Ottawa County is on its way to President Bush for his signature.

U.S. Sen. Jim Inhofe, R-Tulsa, announced Thursday [Jan. 22, 2004] the funding is included in the 2004 Omnibus Appropriations Bill. The funding brings total 2004 funding for Tar Creek to $16.7 million.

From the late 1880s to 1960, the Tar Creek area consisted of 300 miles of tunnels where lead was mined. After the mines closed in the 1960s, mining companies left behind countless environmental problems, including sinkholes, acid mine drainage and mountains of chat that are lead-poisoned.

Inhofe designated $2.2 million toward the Native Grassland Demonstration Project, $3 million to the University of Oklahoma Surface Water Treatment project and $4 million to the state Department of Environmental Quality for Neighborhood Restoration.

Inhofe also announced the first meeting of the principles to the Tar Creek Memorandum of Understanding, which took place Thursday in Tulsa. The group has adopted a unified cooperative approach to clean up the Tar Creek area.

"For too long, these federal agencies have had competing agendas that delayed progress at Tar Creek," Inhofe said in a prepared statement. "Now these agencies will be working together, cooperating and communicating, so as to expedite the cleanup of Tar Creek."

Friday [Jan. 23, 2004], preliminary results of a lead and manganese study on local pregnancies were reviewed.

The "Match," or Metals Assessment Targeting Community Health project, is a three-year study sponsored by Integris Baptist Medical Center, Harvard Medical School Metals Epidemiology Research Department and the L.E.A.D. Agency. The project is entering its second year.

Dr. Mark Osborn, a former member of the health committee for former Gov. Frank Keating's Task Force on Tar Creek and a member of the Tar Creek Basin Steering Committee, outlined the results from the first year.

Early results show mothers don't transfer lead to the child through the bloodstream, Osborn said. But a transfer exists through calcium from the mother's bones during the baby's development, he said.

UPDATE

Tar Creek appropriations

LATEST NEWS: A 2004 bill will include $9.2 million to clean the Tar Creek area.

BACKGROUND: The former lead-mining area has been plagued with sinkholes, acid mine drainage and lead-poisoned chat, leading to increased lead levels in the blood of those living in the area.

WHAT'S NEXT: The bill is to be signed by President Bush.

Tar Creek Superfund site

Henry unveils $5 million buyout plan

By Carmel Perez Snyder

Gov. Brad Henry rolled out a $5 million state plan Monday [Jan. 26, 2004] that would give families with young children—in the towns of Picher, Cardin and north Miami—the option of selling their homes in the Tar Creek Superfund site.

Henry said Oklahoma has a moral obligation to protect its most vulnerable citizens, and will ask the Legislature to set aside the money from the $117 million the state received last year from the federal budget legislation.

"After thoroughly reviewing the situation in Tar Creek and the many health studies related to the environmental hazards there, I'm convinced we have to do something to get as many children as possible out of harm's way," Henry said.

Plans for relocation

The voluntary plan would give families with children six years and younger the option of selling their property to the state for the average county market value for comparable properties.

UPDATE

Tar Creek

LATEST NEWS: A state plan presented to Gov. Brad Henry would give families with children ages 6 and under the option of selling their homes in the Tar Creek Superfund site.

BACKGROUND: Studies indicate exposure to lead—which is present in chat dust—during childhood can contribute to learning disabilities and health problems.

WHAT'S NEXT: Henry plans to present his plan to the Legislature when it convenes next month.

The plan also would help renters find and finance new rental property for 12 months. Landlords also would receive a 12-month stipend.

A special panel of local residents and other officials would be created to help oversee implementation of the relocations, Henry said.

Miles Tolbert, the state's secretary of the environment, said estimates indicate about 100 families could qualify for the voluntary relocation.

In addition to the assistance to families, the initiative would provide assistance to local government agencies, such as the school district and utility authority, to help minimize any fiscal impact from the relocation.

Children at risk

Officials in the affected area greeted Henry's plan with enthusiasm.

Tar Creek buyout plan *(continued)*

"The state of Oklahoma can be very proud of their governor today," said John Sparkman, executive director of the Picher Housing Authority and spokesman for Tar Creek Basin Steering Committee. "I think he's taken a step in the right direction and it's a step that needed to be taken."

Scientific studies indicate young children are particularly vulnerable to the effects of lead, which is present in chat dust. Lead exposure during childhood can contribute to learning disabilities and other health problems.

Health data indicate children in the Tar Creek area have higher blood lead levels than normal, something local school officials believe has caused a high incidence of learning disabilities among students in the Picher-Cardin district.

"This initiative is not a perfect or comprehensive solution, but it's a good-faith effort to address the immediate health problems of the most vulnerable residents," Henry said. "I envision it working in conjunction with ongoing federal efforts on Tar Creek."

U.S. Sen. Jim Inhofe, R-Okla., is pushing a $45 million federal cleanup plan that excludes buyouts.

A private plan

This past weekend, Inhofe announced a plan from the Cherokee Investment Partners of Raleigh, N.C., to buy out residences in the Tar Creek area.

State Sen. Rick Littlefield, D-Grove, said in a prepared statement from Inhofe's office that he supports the Cherokee Investment plan. Calls to his office and business were not returned Monday [Jan 26, 2004].

Henry said he supports the federal cleanup plan, but has concerns the private company would take advantage of the residents who are desperate to sell their property.

Area officials were critical of the private buyout plan.

"The plan that Senator Inhofe put together would give residents 10 cents on the dollar for their homes," Miami Mayor Harrell Post said. "People wouldn't even get market value, and they couldn't afford to relocate."

Sparkman said the governor's plan will give families an opportunity to improve the quality of life for their families.

"Governor Henry has taken time to come to Picher and meet with us," Sparkman said.

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For more information on Tar Creek, visit the Oklahoma Department of Environmental Quality's website at **http://www.deq.state.ok.us/**. Click on "Tar Creek Information."

Also, you may visit the U.S. Environmental Protection Agency's Superfund website at **http://www.epa.gov/superfund/sites**. Click on "Map of NPL Sites," then click on "Oklahoma." Scroll down to Ottawa County, and click on "Tar Creek (Ottawa County)."

State to check Picher park

By Sheila Stogsdill

PICHER—Despite a U.S. Army Corps of Engineers report showing a Picher city park may collapse into a mining cavern, Mayor Sam Freeman says the park will be fine for at least a couple of centuries.

State mining officials have been asked to assess the sinkhole dangers of a 106-foot-tall cavern beneath Picher Reunion Park, said Don Ziehl, a mining engineer with the U.S. Bureau of Land Management.

The cavern is about 150 feet below the park's surface and was created by lead and zinc mining, Ziehl said. The flooded void is about 100 feet to 150 feet in diameter, he said.

Picher Reunion Park is about two square blocks and each summer hosts about 3,000 people for the annual Miner's Reunion. The cavern in question is near a music stage and metal bleachers.

According to a 1997 report by the Tulsa District of the Corps of Engineers, a collapse of the void "was likely but no time frame for the collapse could be predicted."

The report prepared for the U.S. Environmental Protection Agency calls for a quarterly inspection of the park's surface area to detect early signs of collapse.

Freeman said he doesn't know if the environmental agency has conducted those inspections.

In 1997, the corps determined the land was safe enough for the environmental department to use its heavy equipment and do land remediation, he said.

The corps drilled four test holes on the weakest parts of the land, Freeman said. Three holes, each 100-feet deep, and one hole, 175-feet deep was drilled through solid rock, he said.

"They never hit a cavern of any kind," he said.

Freeman, who was instrumental in opening Reunion Park, said the area was fenced off by Eagle-Picher mining company, and sat dormant for 43 years before work began in 1997 to open a public park.

"It was an eyesore," Freeman said.

Reprinted with permission as published in *The Daily Oklahoman* February 25, 2004. Contributing: The Associated Press.

UPDATE

Possible sinkhole

LATEST NEWS: Picher's mayor says he doesn't believe a cavern beneath Picher Reunion Park is in danger of collapsing.

BACKGROUND: A 1997 report from the Tulsa District of the Corps of Engineers indicates a collapse is likely.

WHAT'S NEXT: State mining officials have been asked to assess the cavern's sinkhole dangers.

Superfund cleanup inching ahead

Only 3 of 13 sites cleared

By Michael Baker

Sherman Edwards often visits the abandoned Cyril refinery site where he toiled half his life installing and repairing asbestos.

Gone are the hustle and bustle of the business that employed at least three generations of people in this two-gas-station Caddo County community.

The Cyril refinery is one of 13 former industrial locations in Oklahoma to be labeled among the nation's most hazardous, or Superfund sites—a program with a history of strong emotion.and political battles.

Instead of dirtied men pumping Oklahoma's lifeblood, the rusted Cyril refinery has a scattering of workers in white body suits and respirators.

"I put all that asbestos on that they're taking off," the 87-year-old Edwards said. "I watch them tear it off. It's hard to watch happen."

In 1983, the U.S. Environmental Protection Agency added Oklahoma sites to its National Priorities List because of the public health and ecosystem threat.

Work at the sites has garnered mixed reviews locally, while funding battles waged in Washington.

About $450 million has been spent on Oklahoma Superfund sites, which include refineries, mines, military installations and junkyards, the EPA said.

The EPA Superfund program spent about $250 million. About $13 million came from Oklahoma as matching funds. Possible polluters have paid the rest, according to state and government agencies.

At its inception in 1980, Superfund was a polluter-pay tax principally on crude oil and chemical producers. The money was put in a trust fund and doled out for cleaning abandoned sites. In 1995, with Republicans newly in control of Congress and the Superfund seemingly overflowing, the tax was cut.

A new sense of urgency was added to the Superfund funding battles when the General Accounting Office recently said the trust fund is broke and taxpayer money from the general fund is making up the difference.

It costs between $1.3 billion and $1.7 billion yearly for Superfund operations. In the mid-1990s, the trust fund covered about 80 percent. Those reserves have dried up, but locations are continually added to the EPA's National Priorities List.

President Bush's 2005 budget proposes $1.4 billion in appropriations for Superfund—a $124 million, or 10-percent increase over last year.

It's not enough to cover the increasing costs, said Betsy Loyless with the League of Conservation Voters in Washington.

"If we wait on taxpayers' dollars, these sites will sit forever," Loyless said. "We have to fund the abandoned cleanup fund. The polluter-pay tax was the fairest and most equitable way to do that."

There's nothing fair about the tax, said Sen. James Inhofe, R-Tulsa.

(continued on p. 118)

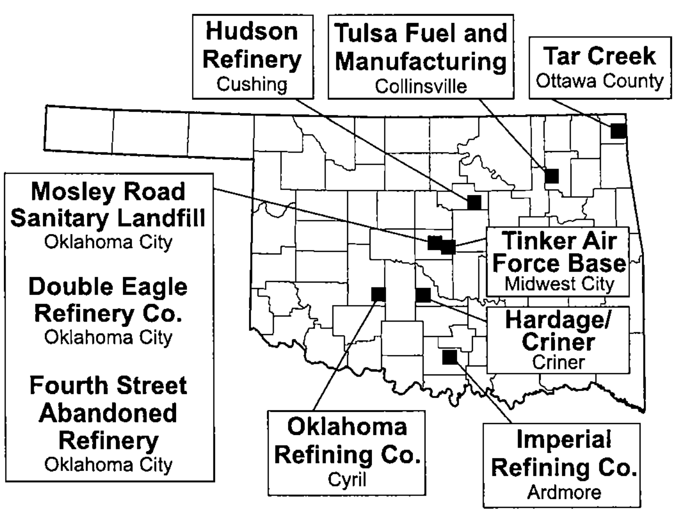
SUPERFUND SITES

Where are the sites?

Oklahoma is now home to 10 of the 1,240 sites listed on the EPA's National Priorities List [NPL] and therefore part of the Superfund program.

The Environmental Protection Agency defines Superfund sites as uncontrolled or abandoned places with hazardous waste possibly affecting local ecosystems or people.

As of December 2003, the EPA had spent $249.61 million to clean up the 13 sites that have made the National Priorities List. The state has spent $12.88 million in matching funds.



Compass Industries

- 60 acres in the Chandler Park area of Tulsa County.
- Landfill 1964–1970s.
- **Listed on NPL:** September 1984.
- **EPA spending:** $4.5 million.
- **State spending:** $0.
- **Contaminants:** Jet fuel, oily sludge, solvents, acids, caustics, bleaches and benzene.
- **Status:** Deleted from the NPL in July 2002.

Double Eagle Refinery Co.

- 12 acres southwest of Martin Luther King Avenue and NE 4.
- Operated 1929–1980.
- **Listed on NPL:** March 1989.
- **EPA spending:** $21.35 million.
- **State spending:** $1.71 million.
- **Contaminants:** Solvents, hydrocarbons, lead and arsenic.
- **Status:** Sludge removed. Area cov-

ered with clean soil and vegetation. Groundwater monitored.

Fourth Street Abandoned Refinery

- 42 acres northeast of Double Eagle.
- Operated 1940s–1970s.
- **Listed on NPL:** March 1989.
- **EPA spending:** $10.94 million.
- **State spending:** $528,000.
- **Contaminants:** Solidified waste oils containing lead and other metals.
- **Status:** Treated waste removed. Area covered with clean soil and vegetation. Groundwater being monitored.

Hardage/Criner

- 80 acres near Criner in McClain County.
- Industrial waste site from 1972 to 1980.
- **Listed on NPL:** September 1983.
- **EPA spending:** $29.17 million.
- **State spending:** $0.
- **Contaminants:** Pesticides, solvents, alcohols, arsenic, acids, oils, paint sluge, ink and heavy metals.
- **Status:** Groundwater being treated. Liquid pools incinerated. Currently covering the remaining waste.

Hudson Refinery

- 200 acres in Cushing, Payne County.
- Operated 1922–1982.
- **Listed on NPL:** July 1999.
- **EPA spending:** $18.2 million.
- **State spending:** $1.57 million.
- **Contaminants:** More than 70 hazardous chemicals potentially present.
- **Status:** Most refinery buildings removed. Need to determine soil, water contamination and propose remedy.

Imperial Refinery Co.

- 80 acres in east Ardmore.
- Operated 1917–1924.
- **Listed on NPL:** July 2000.
- **EPA spending:** $300,000.
- **State spending:** $0.
- **Contaminants:** Metals and refining wastes.
- **Status:** Currently under study.

Mosley Road Sanitary Landfill

- 72 acres off NE 36 at 3300 Mosley Road.
- For five months in 1976 the state authorized the acceptance of hazardous waste.
- **Listed on NPL:** February 1990.
- **EPA spending:** $1.14 million.
- **State spending:** $0.
- **Contaminants:** About 2 million gallons of hazardous waste were dumped into three unlined pits.
- **Status:** Landfill cover and gas management system near completion. Groundwater monitoring continues.

Oklahoma Refining Co.

- 160 acres in Cyril. Operated 1920–1984.
- **Listed for cleanup:** 1990.
- **EPA spending:** $29.1 million.
- **State spending:** $2.47 million.
- **Contaminants:** Arsenic, lead, cadmium, chromium and acids.
- **Status:** Soil, sediment and surface water cleaned. Removing old refinery buildings.

Sand Springs Petrochemical

- 225 acres at the Old Sinclair Refinery in Sand Springs.
- Operated 1900 to 1970s.
- **Listed on NPL:** June 1986.
- **EPA spending:** $6.32 million.
- **State spending:** $0.
- **Contaminants:** Petroleum and acid sludge waste.
- **Status:** Deleted from the NPL in March 2000.

Tar Creek

- 40 square miles in northeastern Ottawa County.
- Underground mining for lead and zinc from 1891 until the 1970s.
- **Listed on NPL:** September 1983.
- **EPA spending:** $123.73 million.
- **State spending:** $6.25 million.
- **Contaminants:** Lead, iron, sulfate, zinc and cadmium. Elevated blood/lead levels in children, which can cause learning disabilities and reduced growth.
- **Status:** More than 2,000 residential yards have been cleaned. Diversion diking done for Tar Creek. Yard cleanups will continue. Cleanup of nonresidential areas to begin. Community health education and blood lead screening.

Tenth Street Dump/Junkyard

- 3.5 acres in Oklahoma City at 3200 NE 10 Street.
- City operated landfill from 1950 to 1954. From 1959 to 1979 it was a privately owned salvage yard.
- **Listed on NPL:** July 1987.
- **EPA spending:** $3.11 million.
- **State spending:** $68,000.
- **Contaminants:** Polychlorinated Biphenyls (PCBs).
- **Status:** Deleted from the NPL in November 2000.

Tinker Air Force Base

- Building 3001 and Soldier Creek are primary sites on the 4,277-acre base south of Midwest City.
- On-site disposal of industrial wastes from 1942 to 1979.
- **Listed on NPL:** July 1987.
- **EPA spending:** $1.2 million.
- **State spending:** $0.
- **Contaminants:** Chromium and trichlorethylene.
- **Status:** Groundwater pumped and treated. Studying further possible contamination.

Tulsa Fuels & Manufacturing

- 50-acres zinc smelter and lead-roaster in Collinsville in northeast Oklahoma.
- Operated 1914–1925.
- **Listed on NPL:** January 1999.
- **EPA spending:** $550,000.
- **State spending:** $0.
- **Contaminants:** Lead and zinc.
- **Status:** Need to propose and complete remedy actions.

Superfund cleanup *(continued)*

The current system targets companies that pollute a specific site and has them pay, said Inhofe, who chairs the Senate Committee on Environment and Public Works.

"What I don't want to do is have a system where everybody pays regardless of whether they have polluted," he said.

Some of Oklahoma's newest sites—such as Ardmore's Imperial Refinery, which operated from 1917 to 1924, and Tulsa Fuel and Manufacturing in Collinsville, which ran from 1914 to 1925—"lack strong PRPs (potentially responsible parties)," said Hal Cantwell, who oversees Superfund sites for the state Environmental Quality Department.

Those two sites demonstrate an inherent problem with finding a responsible party: the company polluted decades ago and is possibly no longer in existence or in financial ruins, Cantwell said.

In Oklahoma, Cantwell said, while the process may slow somewhat without a reserve in the trust fund, work continues at such sites largely because the state is willing to provide matching funds.

Inhofe said he prefers to find a responsible party and have them pay for everything. But, Inhofe said, if a company no longer exists or cannot pay, he would rather cleanup money come from the general fund.

"I'd far prefer to do that than go after people who are innocent," Inhofe said.

At many sites such as Mosley Road Sanitary Landfill near Midwest City, which has been on the National Priorities List since 1990, companies are instrumental in the cleanup process. Waste Management Inc. inherited the liability to clean up the landfill when it bought the property in 1984 along with an adjacent landfill that is in use and not part of the Superfund site.

The work moves slowly, but people are satisfied enough with the progress that groups formed to monitor the situation have ceased to exist, said Helen Longwith, former president of the defunct North Canadian Preservation Association.

"It appears the remedies are working, but it's taken a long time," Longwith said. "It's just hard to keep people interested. Some have died; some of them moved."

In Oklahoma, the quickest a site has been added and then removed from the National Priorities List is 13 years.

Cleanups get mixed praise

Of the 13 Oklahoma sites that have been put on the National Priorities List, the EPA has removed three—Compass Industries in the Chandler Park area of Tulsa County, Sand Springs Petrochemical Complex and Tenth Street dump/junkyard in Oklahoma City.

Two more Oklahoma City locations soon may be removed from the list—Double Eagle Refinery and Fourth Street Abandoned Refinery, located across from each other on Martin Luther King Avenue south of Fourth Street.

Oklahoma City Councilwoman Willa Johnson, whose district includes Tenth Street, Fourth Street and Double Eagle, hopes the clean land will spur economic development.

Joe and Carolyn Cecil, who own a salvage yard next to the grassy plateau that used to be the Tenth Street dump, question the money spent and if the land will be useful.

The couple said the cleanup was successful in protecting their employees, who have fewer nosebleeds and headaches.

But Joe Cecil said he still gives his pets bottled water.

While mixed feelings are common, most recognize the need for change.

Hudson Refinery, intersected by State Highway 33, pumped petroleum from 1922 to 1982 and became a cornerstone of Cushing, which advertises itself to visitors as the "Pipelines Crossroads of the World."

The EPA has demolished most of the refinery structures.

While she is unsure what can be done with the land, Marcy Jones, 60, thinks neighbors' health was affected as the refinery sat abandoned.

"It needed to be cleaned up and probably still needs a lot of cleanup," said Jones, who owns a Cushing business with a view of the old Hudson Refinery land.

Costly cleanups

Tar Creek is the state's largest Superfund location, comprising 40 square miles of Ottawa County in northeastern Oklahoma. Cleanup is so complex the EPA designated it a "megasite."

Tar Creek has been on the EPA's list for more than two decades and received more than $123 million from Superfund. Next on the list is Hardage-Criner, an 80-acre landfill in rural McClain County, where the EPA has spent $29.17 million.

About 75 million tons of chat piles, or zinc and lead-laced mining waste, remain stacked in the Tar Creek area. Sludge ponds cover about 800 acres.

Children in the area have the state's highest blood-lead levels, which can cause brain damage, learning disabilities, stunted growth, kidney damage, high blood pressure and anemia.

Touring the site last year, hearing residents' complaints of shoddy work, Sen. Don Nickles, R-Ponca City, said Tar Creek is a prime example of government waste.

Gov. Brad Henry's $5 million buyout plan would give families with young children the option of selling their homes.

Inhofe proposed a buyout plan that would use a private firm to buy property in concert with a $45 million federal cleanup plan.

Efforts move slow because the EPA takes a limited approach, legislators drag their feet and government agencies don't work together, said Earl Hatley with the group Local Environmental Action Demanded.

"The problem is they all want to lead the parade," Hatley said. "We need them in the parade, but we need them all to march together."

Hatley also has served on the community advisory board for the Tinker Air Force Base Superfund site. He said Tinker is a much better example of how to clean up a Superfund site.

"It wasn't easy getting the attention of Tinker," he said. "But when we did, Tinker stepped up to that plate eagerly."

Cantwell said the hope is to get moving on the newest sites while continuing work on some of the older state sites.

"We're going to have a big pulse here shortly," he said.

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For more information on Superfund sites, visit the U.S. Environmental Protection Agency's Superfund website at **http://www.epa.gov/superfund/sites**. For information on Oklahoma's sites, click on "Map of NPL Sites," then click on "Oklahoma."

Marble City working on foundation for future

Town's residents try to recover from rocky years

MARBLE CITY—The marbled limestone bank building is about all that's left of Marble City's bustling past. Now, residents hope they can turn around the future by building on the city's rock solid history.

Built around a quarry more than 100 years ago, this community on the edge of the Cookson Hills has seen better days. Only about 250 people live here today, far fewer than in the city's boomtown days. There's one intersection, one store and four churches, a small town hall and a post office.

Only the bank still stands from the city's best days, shortly after the turn of the 20th century. Built in 1911, the Citizen's State Bank easily outlasted the quarry that provided the stone in its structure. The quarry closed a few years after the bank was built, but the towering walls still provide residents a hint of pride.

"I think it's wonderful," says Mildred Taylor, member of the Marble City Historical Society. "That was one of the brags, was that they had a marble bank."

A combination of community problems, economic pressures and bad luck decimated Marble City after about 1916, residents say. All they have now is history.

"We just want to preserve it," says Ellen McClendon, secretary-treasurer of the historical society. "Marble City just went bust pretty quick."

A few years ago, residents started to take that history and look to the future. They started, of course, with the bank building.

"It's the only building with any historical reference left in town," McClendon says. "It's the only thing that shows that Marble City was a thriving community."

"The stone from Marble City is between 410 and 430 million years old."

—Ed Reeves,
stone-cutter in Marble City

In 1997, the eastern Oklahoma town used grant money to repair a west wall that had collapsed. The bank now has new doors, new windows and a new second floor.

The next year, stone-cutter Ed Reeves reopened the old quarry, decades after the pit first closed. He invested over $100,000 in a diamond belt saw and spends weekends cutting chunks of limestone.

At one time, the quarry employed dozens, maybe hundreds, of people in the early 20th century and the compact stone was used all over the state.

"It's a good quality limestone, a high-density limestone," Reeves says. "It holds together well."

The quarry hasn't brought a glut of jobs, but it's a start. For now, Reeves needs only a few hands and his high-dollar saws, but he's hopeful that the marble's quality will eventualy make it a nationally known commodity.

"The stone from Marble City is between 410 and 430 million years old," Reeves says. "It's a very good stone. It was made at a time when the earth was very calm and in shallow seas."

Back downtown, the turnaround is starting, too. Last year, the city had its first big event in many years, a centennial celebration. But the historical society isn't waiting another 100 years for the next big event.

They've already planned a spring fling and another event in the fall. They're also selling photo albums to raise money for a new roof on the bank building.

"We want to save this town," McClendon says.

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Legislation introduced to protect playa lakes

Oklahoma Department of Wildlife Conservation

An important piece of conservation legislation to preserve playa lakes and recharge the Ogallala Aquifer was recently introduced to the floor of the U.S. Senate.

"The playa lakes are wetlands often overlooked, but invaluable to water quality, to recharging the Ogallala Aquifer and as sanctuary for wintering birds," said U.S. Senator Pat Roberts, R-Kan., who introduced the bill. "This bill works within legislation that is already proven to bring real conservation results in a sustainable way."

Playa lakes stretch from west Texas up through the panhandle and parts of Oklahoma, New Mexico, Kansas, Colorado, Nebraska, and Wyoming. Playas are the most common wetland in these areas, totaling approximately 60,000 in the seven states. They are shallow, clay-lined wetlands that average less than 30 acres and are not filled with water on a year-round basis. In many areas, the lakes have been used for grazing, irrigation and runoff. Some playas have also been filled in by sediment runoff from cropland.

According to Roberts, the bill protects these wetlands by amending the Farmable Wetlands Program under the Conservation Reserve Program to allow the enrollment of 40 contiguous acres instead of 10, and allow payment on 10 of the acres instead of five. These changes ensure that the majority of lakes and their buffer areas will be eligible for enrollment, and it also guarantees that playas will be considered eligible wetlands by the United States Department of Agriculture.

Permission courtesy *The Norman Transcript*, as published December 11, 2003.

For more information about playa lakes, visit the Playa Lakes Joint Venture website at **http://www.pljv.org/**.

Water rights spout debate

By Tom Lindley

SULPHUR—Cold and clear, artesian water has gushed skyward from a pipe in the ground in Flower Park for more than 80 years.

Whether it has served to heal the sick or carve out a lush piece of greenery on the banks of the prairie, the water that springs from the Arbuckle-Simpson Aquifer always has served a greater good.

East of Sulphur, rancher Bill Jacobs owns 12,000 acres of prime grazing land that spans the aquifer. He too thinks the water underneath his boots could serve a greater good.

But from the high ground near the center of his ranch, there is no place to put it to use for as far as the eye can see. With an average of 38 inches of rain a year, his pastures and ponds produce all the grass and water his cattle need.

There is a market far up the road for excess groundwater that Jacobs and others want to sell. Someone somewhere always needs water. In this case, the people of Yukon, Chickasha, Mustang and Piedmont have an agreement to build an 80-mile pipeline at a cost of about $100 million to meet their increasing needs and satisfy a federal mandate to reduce arsenic in the nation's water supply.

The proposed sale has sparked a controversy as prickly as any barbed wire ever strung across two knobby fence posts.

Who has a monopoly on the greater good?

It's now the question sparked by the state Legislature, which narrowly blocked the proposed water sale by calling for a comprehensive study to determine how the sale would affect streams and springs in the aquifer, whose depletion many environmentalists and wildlife advocates fear could tip the balance of nature.

The streams and springs that depend on the aquifer also have special historical significance to the Chickasaw Nation and are a vital source of water to numerous communities and to the Chickasaw National Recreation Area, where many springs have dried up over time.

Because of the sole-source aquifer's importance, the Oklahoma Academy, a policy group that researches key state issues, last month endorsed changing state law to further restrict the sale of water to municipalities not near the aquifer.

The state's moratorium on water sales outside the aquifer has produced lawsuits, threats and name-calling. Worst of all, it may be a sign of things to come as more Oklahomans covet their neighbor's water.

"Wherever it is you take it from, the people who have it feel like that water should stay where it is," state Environmental Secretary Miles Tolbert said. "When people see a valuable resource going away, they believe their natural environment has been eroded and that their chances of economic gain have been depleted."

Whether it's oil or gas, Oklahoma has a history of saying "come and get it." Water, however, is one natural resource that apparently isn't cut from the same pipeline.

Jacobs said he learned that the day he went to lunch in town with some friends, and while in the process of picking up the check, heard someone in the restaurant say: "Well, the grinch bought lunch."

Jacobs, who claims central Oklahoma cities would purchase only about one-tenth of the aquifer's annual recharge rate, said a "sky is falling campaign" launched by the opposition has led to many exaggerations about how much damage selling water to central Oklahoma would cause.

He said trouble of this sort was the last thing he expected to find when he left California 20 years ago and bought a famous ranch former Gov. Roy Turner built on limestone and Herefords.

"I wanted to get out of California because they were taking our property rights away from us," he said. "You couldn't build a barn without a permit."

Now, he's staring more regulation in the face.

"I don't expect people to worry about me, but I think they should be concerned that if this can happen to me, it can happen to them," Jacobs said, measuring his words. "This amounts to the taking of somebody's private property."

Sitting next to him were Carolyn and John Sparks who own 1,600 acres of land that has been in her family since the late 1800's. Although they aren't part of the water sale, they have been prevented from using their groundwater to irrigate pecan trees.

"We've been looking for a way to diversify our operation because it's getting harder to make a living ranching," Carolyn Sparks said. "Now the federal government is sending people in from Colorado to tell us how to water our trees."

Thousands of protests to the water sale have been filed with the Water Resources Board, which has initiated a joint multi-million dollar, five-year-plus maximum annual yield study to determine how much the aquifer would be harmed if more water were drawn from it.

Meanwhile, Yukon City Manager Jim Crosby is still looking for a more affordable and dependable source of water.

When he recently inquired about the possibility of buying water from Lake Eufaula, Crosby drew more opposition from area residents, who said the lake already is too low.

Yukon buys some of its water from Oklahoma City, but there are too many surcharges and stipulations in the agreement to satisfy Crosby.

Tolbert is among those who believe a way must be found for Oklahoma City and Canadian County to enter into an arrangement that will provide water at rates that will not be discriminatory.

Crosby and Jacobs are equally adamant the state was wrong to deny them access to excess water in the aquifer while allowing other cities to continue to use it.

"We're getting increasingly antsy, but the aquifer is the best and most viable answer to our problem," Crosby said.

Of no-nonsense German descent, Jacobs said he lives by a simple equation.

"I've learned you have to make the land come first, next come the cattle and then the men on the ranch," he said.

In its heyday, it took 40 cowboys to work the Turner Ranch. Today, Jacobs and his son get the job done with the help of one full-time hand.

"I'm not looking for enemies, but I will fight for my property rights," he said.

A water fight is surely what Oklahoma has got on its hands.

Reprinted with permission as published in *The Daily Oklahoman* February 29, 2004.

Water worries

Group aims to cut aquifer use

Those who want to sell water are attacking towns, landowners and government agencies.

By Jack Money

Yet another group is seeking to conserve the water of the Arbuckle-Simpson Aquifer in south-central Oklahoma.

The Arbuckle-Simpson Aquifer Protection Federation of Oklahoma Inc. is seeking to end many ongoing water uses within the aquifer.

Attorney James Barnett, who also represents landowners trying to sell aquifer water to several west-central Oklahoma communities, is representing the federation.

Barnett also is former director of the Oklahoma Water Resources Board. He's filed nine requests with the water board, asking the state agency to deny long-allowed uses of water from the Arbuckle-Simpson Aquifer.

More than half of the entities that Barnett's requests target have been involved in trying to stop his clients, plans to move aquifer water north and west to Canadian County.

Barnett's requests target:

■ **Davis**, which the federation claims transports water outside the aquifer's counties for public use—a practice it says is barred by state law until a detailed study of the underground aquifer can be completed. The federation wants the water board to deny Davis future permits and to force the town to plug wells that aren't permitted.

■ **Wapanucka Public Works Authority**, which the federation claims transports water outside the aquifer's counties for public use. The federation asks the water board to deny the authority's future permit.

■ **Murray County Rural Water District 1**, which the federation claims transports water outside the aquifer's counties for public use. The federation asks the water board to deny the district's future permits.

■ **Rubye and Harold Wingard**, whom the federation claims transport water outside the aquifer's counties for public use. The federation asks the water board to deny future permits.

■ **Johnston County Rural Water District 3**, which the federation claims transports water outside the aquifer's counties for public use. The federation asks the water board to deny future permits.

■ **Ada**, which the federation claims transports water outside the aquifer's counties for public use. The federation asks the water board to deny future permits.

■ **U.S. Fish and Wildlife Service**, which the federation claims uses more stream water than its permit authorizes. Fish and wildlife officials testified against Barnett-represented landowners who are seeking Arbuckle-Simpson water for agricultural purposes.

■ **National Park Service**. The federation claims the federal agency is using groundwater without permits or rights, and wants the water board to order the agency to plug all of its wells.

■ **Sulphur**, which the federation claims wastes water by allowing water to flow out of some well bores, and wants the wells plugged.

Barnett couldn't be reached for comment.

Brian Vance, the water board's spokesman, said staffers will investigate the issues raised.

"After we gather our facts, we will work with the targeted entities to get their sides of it. From there, the staff will make recommendations to the board about how to proceed," Vance said.

Reprinted with permission as published in *The Daily Oklahoman* January 20, 2004.

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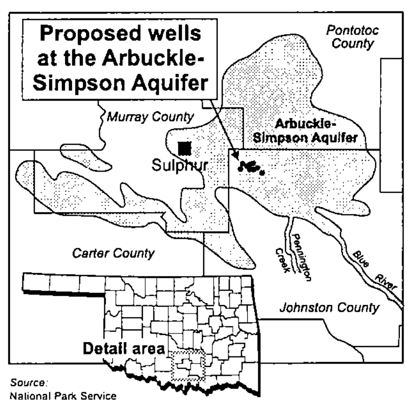
For more information on the Oklahoma Water Resources Board's Arbuckle-Simpson study, visit OWRB's website at **http://www.owrb.state.ok.us/index.php**. Click on "Arbuckle-Simpson Hydrology Study Page."

DID YOU KNOW ?



Source:
National Park Service
Water Resources Division

- The aquifer is in an area about 800 square miles in south-central Oklahoma.
- It is estimated to have 9 million acre-feet of freshwater in storage.
- The aquifer is as much as 9,000 feet thick.
- Recharge to the aquifer occurs from an estimated 4.7 inches of precipitation a year.

Source: U.S. Geological Survey

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Oklahoma abstracts

The Oklahoma Geological Survey thanks the American Association of Petroleum Geologists, Geological Society of America, and *Canadian Journal of Earth Sciences* for permission to reprint the following abstracts of interest to Oklahoma geologists.

Coalbed Methane: Economic Success in the Arkoma Basin, Oklahoma

BRIAN J. CARDOTT, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; and *MATTHEW A. BIDDICK*, Fractal Oil Company, 330 W. Gray, Suite 305, Norman, OK 73069

Economically successful coalbed-methane (CBM) wells depend on geology, engineering, and minimizing costs. Important geologic factors include coal thickness, rank, depth, gas content, structure, hydrology, and permeability, controlled by cleat spacing and mineralization. Middle Pennsylvanian (Desmoinesian) high volatile- to low volatile-bituminous coals in the Arkoma Basin are <10 ft thick with gas content values up to 560 cubic feet per ton. The optimal vertical depth range (based on an initial potential (IP) gas rate ≥50 Mcfd) is 598–4,397 ft.

There were 2,179 CBM completions (865 from the Arkoma Basin) in Oklahoma from 1988 through 2002. IP rates were from a trace to 2.3 MMcfd (average 128 Mcfd) from 726 wells in the Arkoma Basin. The greatest CBM potential was from 153 horizontal CBM wells in the Hartshorne coal with IP rates from 15 to 2,300 Mcfd (average 418 Mcfd). Of 222 wells having an IP ≥100 Mcfd, 125 are horizontal CBM wells with lateral lengths of 526 to 3,173 ft.

For vertical wells, profitability depends upon production rate, ultimate volume, competitive costs, a reliable, cost effective market for the gas, and low lease operating expenses often accomplished by economies of scale. The lease operating expenses per Mcf of gas produced are relatively high for CBM wells because of high water handling costs, compression fees, normal transportation and marketing fees, and relatively low production rates. CBM operators must expect large up-front expenditures.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 26.

Exploration Strategies for Coal Bed Methane in the Western Region of the Interior Coal Province

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The Pennsylvanian Age coals of the Western Region of the Interior Coal Province are being exploited as sources of gas in Oklahoma, Arkansas, Missouri and Kansas. The coals that have been the target of coal bed methane exploitation since the 1920s are found in the Cherokee and Marmaton Groups. The Western Region of the Interior Coal Province is composed of the Arkoma Basin, Cherokee Basin and Forest City Basin. The coals in the basin average less than two feet but are laterally consistent and are present throughout much of the basin. Over the past two years a number of test wells and pilot projects have been initiated that have helped define the play. New geologic data not directly related to the reservoir characteristics of the coals but related to the geologic and thermal history of the basin provide a more accurate definition of the area where the coals will probably be gas saturated and those areas where the coals are undersaturated. In addition, specific coals do not seem to be gas bearing whereas others consistently produce significant gas. By integrating various data sets an exploration strategy is provided for developing coal bed methane areas profitably in the Western Region of the Interior Coal Province.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 44.

Fracture Characterization of the Pennsylvanian Jackfork Group, Ouachita Mountains, Southeastern Oklahoma

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The Pennsylvanian Jackfork Group in southeastern Oklahoma contains approximately 1,500 meters of heavily-fractured clastic rocks identified as deepwater turbidite deposits. Although overall structural evolution is established, controls on fracture development in the Jackfork Group are still poorly understood. Recent hydrocarbon exploration in the Ouachita Mountains has demanded greater understanding of the structural complexity in the Jackfork Group and how it affects reservoir characteristics. Immediate application exists in southeastern Oklahoma, where the fractured Jackfork sandstones serve as a producing natural gas reservoir.

Fractured bedding surfaces at the Lynn Mountain and Rich Mountain synclines were analyzed to assess the relationship between stratigraphic and structural fracture controls. Linear scanlines were used to collect orientation and spacing data, and stratigraphic and mechanical bed thicknesses were recorded. Two dominant fracture sets were identified oriented orthogonal to one another and normal to bedding. The primary set is parallel to bedding strike at approximately 100°/60°N. The second set is parallel to bedding dip at 010°/89°W and generally terminates against the primary set. The alignment of both sets to bedding as opposed to the syncline axis suggests that fractures formed prior to folding. An approximately linear correlation exists between fracture spacing and bed thickness, meaning that thicker beds typically exhibit larger spacings. Primary set fractures closely correlate to bed thickness with a spacing to layer thickness ratios (S/T) ranging from 0.3 to 0.9. Secondary set fractures exhibit a weaker correlation to bed thickness, and S/T ranges from 0.5 to 4.3. We interpret that fractures in the primary set developed due to bed thickness, rock strength, and interaction with adjacent layers, until the fracture saturation limit (S/T»1) was achieved. Continued stress transfer between adjoining fractures controlled further fracture development,

possibly including the formation of secondary set fractures. In general, secondary set fractures do not saturate the rock mass, indicating subsequent fracture development under lithologic constraints and influenced by preexisting primary set fractures.

Reprinted as published in the Geological Society of America *2003 Abstracts with Programs*, v. 35, no. 6, p. 641.

Identification of Friable and Cemented Jackfork Sandstones in Southeastern Oklahoma

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A subsurface facies analysis of the Jackfork Group in southeastern Oklahoma reveals the presence of both friable and highly cemented sandstones which may have implications on production of gas in the area. The Pennsylvanian (Morrowan) Jackfork Group is a sequence of strata generally thought to be of deepwater origin, deposited in the Ouachita Basin. The purposes of this research are to (1) document the subsurface occurrence of friable and indurated sandstone and (2) place these sandstones into a sequence stratigraphic framework. The study incorporates data from 32 wells, although the type and completeness of data vary from well to well. Various facies are identified in each well in order to determine recurring patterns that indicate depositional environment. Faults are identified in the wells so that stratigraphic interpretation is not influenced by structural elements. Faults and fracture zones are recognized using cumulative dip and dip vector azimuth plots derived from dipmeter logs. Upon the identification of faults, a combination of conventional logs, dipmeter logs, and cuttings provide useful information for building facies classification schemes for this deepwater (turbidite) system. Certain characteristics can be determined using well logs, including lithology, hydrocarbon concentration and porosity. Cuttings allow an opportunity to calibrate well logs to actual lithologies and to help differentiate zones containing highly porous, possible gas-bearing sandstones from well-cemented sandstones (which may have fracture porosity and permeability). The relation between sandstone type and depositional sequence framework is discussed. Data was provided by Ward Petroleum of Enid, OK.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 32.

Origin and Distribution of Friable and Cemented Sandstones in Outcrops of the Pennsylvanian Jackfork Group, Southeast Oklahoma

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This paper presents the results of an outcrop study of the Pennsylvanian Jackfork Group in which the ultimate goal was to make connections between depositional and post-depositional geologic processes, their lithologic characteristics, sequences and reservoir quality characteristics. The importance of understanding these geologic controls on porosity and permeability is very critical for understanding and predicting the production performance of Jackfork reservoirs.

In certain outcrops in eastern Oklahoma, sandstones are predominantly quartz-cemented, subarkoses, which are sometimes fractured. However, extremely friable sandstones also occur stratigraphically adjacent to the quartz-cemented sandstones. The different sandstones are representative of differing porosity and submarine fan facies types. Four stratigraphic sections have been measured with corresponding outcrop gamma logs. The stratigraphy consists of possible third and fourth order depositional sequences and systems tract deposits, which aid in characterizing the distribution of facies in the sections.

Lithologically, the quartz-cemented sandstones are very fine to fine grained, moderately to well-sorted and planar-tabular bedded with characteristic deepwater sedimentary structures. By contrast, the friable sandstones are medium to fine grained, predominantly, poorly to moderately sorted, massive and amalgamated, frequently with undulatory bed boundaries. Petrographic and other studies of the sandstones show different diagenetic features of quartz overgrowth and pressure solution in the quartz-cemented sandstones and feldspar dissolution and clay content in the friable sandstones.

Though distinguishable in outcrop, results from the outcrop gamma log show that it is difficult to impossible to distinguish the zones containing matrix porosity from those containing fracture porosity on the basis of subsurface gamma ray logs.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 39–40.

Stratigraphy and Composition of Turbidite Deposits, Jackfork Group, Eastern Oklahoma

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This paper presents a subsurface study of the early Pennsylvanian (Morrowan) Jackfork Group turbidites in the Lynn Mountain Syncline—Potato Hills area of Eastern Oklahoma. Goals are to (1) determine the level of reliability that can be anticipated in well-to-well stratal correlations and to (2) establish criteria for developing a well-log based stratigraphic framework for sub-regional stratigraphic analysis. The structural complexity of the area and lateral variability in these turbidite facies make current correlations and interpretations of conventional subsurface data difficult.

Two gas-producing wells that penetrate the Jackfork are being studied in detail utilizing conventional logs, borehole image and dipmeter logs, and cuttings. These data provided a means to identify major faults through the Jackfork, and thus to subdivide the wells into discrete fault-bounded stratigraphic intervals. Sedimentary features that were not discernible on conventional well logs were identified from the borehole image logs and dipmeter patterns. These features provided a means of identifying stratigraphic turbidite elements. Also, complementary cutting thin section analysis permitted us to distinguish three sandstone types in the gas producing intervals: highly, quartz-cemented, friable and siderite-cemented sandstones. Bitumen is present in all sandstone types. Relations between stratigraphy and the sandstone types have been established. These results help to understand the factors that control the gas production in the area.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 42.

Spiro Equivalent Between the Windingstair and Ti Valley Faults: Implications for Correlation of the Atoka Formation in the Ouachita Fold-Thurst Belt

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Previously unreported occurrences of a skeletal-moldic sandstone, here regarded as the Spiro equivalent, have been discovered along OK-2 and OK-82 in Latimer County between the Windingstair and Ti Valley faults. Macroscopic petrology of these occurrences is identical to reported Spiro south of the Choctow fault on OK-82. This unique sandstone is considered a marker bed within the thick deepwater deposits of the Atoka Formation and Johns Valley Shale. Spiro equivalent occurs within lithology typical of the Johns Valley Shale in an outcrop south of Bengal on OK-82. This marker progressively rises stratigraphically within the Atoka Formation southward along OK-82 to the Windingstair Mountains. The Spiro also occurs in exposures of Atoka Formation along OK-2 where it is several tens of meters above the contact with the underlying Johns Valley Shale. Other authors have reported occurrence of a similar unique sandstone elsewhere. The clear implication resulting from the recognition of the Spiro equivalent is that the lithostratigraphic boundary between the Atoka Formation and Johns Valley Shale is not the same age everywhere within the Ouachita fold-thrust belt. In other words, the lithologies assigned to the Atoka and Johns Valley should be regarded as a facies change.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 36.

Cromwell Sandstone Core Studies and Prediction of Reservoir Trends, Haskell County, Oklahoma

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Reservoir quality in the gas-productive Morrowan Cromwell Sandstone is a challenge to correlate and map. This is mainly due to the low well log (GR and *f*Ö) contrast between reservoir and nonreservoir quality sandstones and a poorly understood depositional setting in previous studies. Facies architecture analysis using two cores and approximately 100 well logs covering four townships provide a means for better prediction of reservoir quality.

From detailed core studies, the Cromwell is regarded as having been deposited in a storm-dominated shelf setting. Physical and biogenic structures coupled with porosity determined from thin section analysis indicate that better quality reservoir rock is developed in the thickest part of sand-ridge deposits. These sandstones exhibit low-angle cross strata with superimposed ripple stratification, and are very well sorted with modal class of upper very fine sand with 10% clay matrix. Primary intergranular porosity is quartz overgrowth and carbonate cement reduced. Thin section porosity of 10% is combined primary porosity and carbonate cement dissolution enhanced secondary porosity.

Parasequence scale correlation and mapping is key to predicting sand-ridge trends. Locally, the informal Cromwell lithostratigraphic unit is made up of five retrogradational parasequence sets and includes two third-order sequence boundaries. Parasequence isopach maps delineate the geometry and trends of the sand ridges. Given the surrounding facies and retrogradational architecture, the best reservoir quality sandstones are located in the middle of the parasequence sets.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 41.

Deepwater Lower Atoka Sedimentology and Stratigraphy of Latimer County—New Findings and a Progress Report

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Deepwater lower Atoka road cut exposures are being studied along OK-2 and OK-82 between the Ti Valley and Winding Stair faults. Detailed measured sections, which include paleocurrent data analysis, have been completed in each area. Outcrop total and spectral GR profiles has been completed for OK-2 and is in progress for the OK-82 sections.

Work has focused on the Atoka within a few hundred meters above the contact with the underlying Johns Valley Shale because it was initially used as a stratigraphic reference. It is now possible to make detailed correlation using spectral GR and occurrence of a skeletal-moldic sandstone (Spiro equivalent) as a marker.

From detailed studies along OK-2, mudrocks dominate the section with interstratified sandstone beds rarely exceeding 0.5-m thick. Amalgamated Ta, Bouma successions with Ta present, and successions with Ta absent (Ta-e are rare) lithofacies associations and vertical bed-thickness trends indicate that most of the sandstones were deposited in fan lobes. Paleocurrent trends also serve to define specific lobes where sufficient data are present—general transport is westward. Mid-fan channel-levee deposits are also recognized. Exposures along OK-82 are clearly more proximal compared to those along OK-2 (~16 km. west of OK-82). Thick (2+ m) channel-levee deposits dominate the section. Paleocurrent indicators related to lithofacies indicate a general southward transport direction. A mud-dominated deepwater fan model is appropriate for the lower Atoka. It appears that smaller more locally derived fan deposits.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 36.

Structural Geology of the Spiro Sandstone Reservoirs along the Frontal Ouachitas–Arkoma Basin Transition Zone, Southeastern Oklahoma

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Three major gas fields of the Frontal Ouachitas–Arkoma Basin transition zone between Hartshorne and Wister Lake area are Hartshorne, Wilburton and Red Oak, producing mostly from the structural traps associated with the Lower Pennsylvanian Spiro sandstone reservoir. Since the mid-1990s, we have constructed over 20 balanced structural cross-sections along the transition zone. The cross-sections are based on the wire line logs of hundreds of wells, available 2-D reflection seismic profiles, and surface geologic maps.

The Wilburton Triangle zone (Cemen et al., 2000) is present between the Arkoma Basin and frontal Ouachitas fold-thrust belt in the Wilburton gas field area. The triangle zone is floored by the Lower Atokan Detachment (LAD) and flanked by the Choctaw fault to the south and the Carbon fault to the north. Below the triangle zone is a well-developed duplex structure, which was formed by hinterland dipping imbricate thrust faults splaying from a floor thrust and joining to the LAD in the Atoka Formation. The LAD continues northward and displaces the Red Oak sandstone before reaching a shallower depth and forming the Carbon fault as a north dipping backthrust below the San Bois syncline. To the east of the Wilburton field, the Carbon fault makes a lateral ramp to the east and becomes a blind backthrust. The Carbon fault loses its separation eastward in the subsurface and dies out in the Wister Lake area.

Almost all of the successful gas wells producing from the Spiro sandstone reservoir in the footwall of the Choctaw Detachment are drilled into the structurally higher parts of horses within the duplex structure where thrust faults may be serving as seals. This suggests that the Spiro reservoir was charged before the Pennsylvanian thrusting in the transition zone.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 27.

Structural Geometry and Evaluation of Thrust Faulting in the Damon and Wilburton Quadrangles in Latimer County, Southeastern Oklahoma

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The Arkoma Basin and the Ouachita Mountains of southeastern Oklahoma and western Arkansas were formed during the Late Paleozoic Ouachita Orogeny. In Oklahoma, the Choctaw fault forms the structural boundary between the frontal Ouachitas and the Arkoma Basin.

This study is aimed at determining the structural geometry of the Late Paleozoic thrust faults in the Damon, Wilburton, Eastern Gowen, and Higgins Quadrangles, Latimer County, southeastern Oklahoma. Eight balanced structural cross sections are under construction to delineate the structural geometry in the study area. Data from the surface geological maps by the Oklahoma Geological Survey, wire-line well logs, scout tickets, and seismic profiles, donated by Exxon and Amoco Corporations, were used to construct the cross sections.

The two main structural features of the study area are the south dipping Choctaw and the north dipping Carbon faults. The Carbon fault is a back thrust which forms the Wilburton Triangle with the south dipping Choctaw fault. Two cross sections already constructed, suggest that an antiformal stack, with two sets of horses, is present in the footwall of the Choctaw fault within the area of investigation. The Woodford detachment provided the floor thrust for the antiformal stack which makes a ramp over a normal fault, and becomes the Springer detachment. The lower Atoka Detachment forms the roof thrust of the antiformal stack. The surface trace of the Carbon fault ends north of the Wilburton gas field. Seismic data indicate that the Carbon fault becomes a blind thrust as it continues to define the northern flank of the triangle zone within the eastern part of the study area, probably through a lateral ramp along its fault surface. Additional cross sections will provide a better understanding of subsurface geomety in the Wilburton, Damon, Eastern Gowne, and Higgins Quadrangles.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 28.

Structural Geometry of Thrust Faulting in the Hartshorne Area of Frontal Ouachitas, Arkoma Basin, Oklahoma

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This study is concerned with the structural geometry of the Pennsylvanian thrusting within the Hartshorne SW quadrangle of the Frontal Ouachitas–Arkoma Basin transition zone in southeastern Oklahoma. The study area includes the Hartshorne gas field where gas production ranges from five bcf in 17 months (middle Atoka from Agnes #1 well) to numerous dry holes.

Five balanced structural cross-sections are being constructed to determine the geometry of the Late Paleozoic thrust system. Data from the surface geological maps by the Oklahoma Geological Survey, wire-line well logs, scout tickets, and seismic profiles, donated by Amoco and Exxon Corporations are used to construct the cross-sections. Upon their completion, the cross-sections will be restored to determine the amount of shortening induced by thrusting in the area.

The Hartshorne, Fanshawe, Red Oak, Panola, Brazil, and Spiro sandstones are identified as marker beds to construct the cross-sections. We considered the Spiro to include the Wapanucka limestone. Our preliminary interpretation of the available data suggests that a triangle zone exists between the Carbon Fault to the northwest and the Choctaw Fault to the southeast. The footwall of the Choctaw fault zone contains a duplex structure and associated horses above the Woodford and Springer detachments with the Lower Atokan Detachment as the roof thrust. The Gale-Buckeye thrust system is present in the footwall to the south of the duplex structure. The Gale-Buckeye system may contain a back thrust in the study area.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 32–33.

Structural Geometry of Thrust Faulting in the Potato Hills Area of the Ouachita Mountains, Southeastern Oklahoma

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This study is an attempt to reconcile the structural geometry of the Late Paleozoic thrusting in the Potato Hills area with the Frontal Ouachitas. Three balanced structural cross sections are being constructed to better understand the subsurface geometry of thrusting in the Potato Hills area. At least, one of these cross-sections will be extended northward to the Wilburton gas field area where previous workers have already established the structural geometry. Surface geology maps by the Oklahoma

Geological Survey, available well logs, and seismic data, and balancing software are being used to construct the cross sections.

The Potato Hills area of the Ouachita Mountains contains highly complex structural geometry due to several major thrust faults. The area contains three thrust faults exposed at the surface. These thrusts faults are South Potato Hills Thrust (SPHT), North Potato Hills Thrust (NPHT) and Cedar Creek Fault (CC). The units exposed at the surface ranges from the Middle Ordovician Womble Shale to the Mississippian Stanley Group. Recently, there has been substantial gas production from the Jackfork sandstone in the area.

In the subsurface, a major thrust fault separates Middle Ordovician rocks from the Lower Pennsylvanian rocks. The wells drilled in the area penetrated the Pennsylvanian Johns Valley Shale (Paj) below the Ordovician Womble Shale. This thrust is probably the Windingstair fault (WSF). Rock units above this fault are the Womble Shale (Ow), Bigfork Chert (Ob), Polk Creek–Missouri Mountain Shales (Op-Sm), Arkansas Novaculite (MDa) and Stanley Group (PMs).

Our preliminary interpretation suggests that the Windingstair fault is a major discontinuity within the Ouachita Mountains. Although the fault is a high angle fault at the surface, it gets almost horizontal at depth. We intend to delineate its structural relationship between the Woodford and Choctaw Detachments.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 36.

Paleooceanographic Aspects of the Early Chatfieldian (Upper Middle Ordovician) Positive $\delta^{13}C$ Excursion (GICE)

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The Guttenberg $\delta^{13}C$ excursion (GICE) has now been identified in sections worldwide including the Appalachian Basin (central Pennsylvania, New York, southwestern Virginia), the U.S. Midcontinent (Iowa, Wisconsin, Missouri), the Cincinnati Arch and Nashville Dome regions (north central Kentucky, Tennessee), the Arkoma Basin (Oklahoma), the Great Basin (Nevada), and Baltoscandia (Sweden, Estonia). There is a 2‰ offset in the peak GICE values from the Upper Mississippi Valley to the Appalachian Foreland Basin that reflects different temperature-salinity- defined water masses, or aquafacies, of Holmden and others (1998). The GICE in the Midcontinent aquafacies has beginning values ~–2‰ and peak values at +1.5‰, in the Southern and Taconic aquafacies the beginning values are ~0‰ and peak values are ~≥+3‰, and Baltioscandia values beginning values near 0‰ and peak values near ~+2‰, These isotopic differences reflect local environmental factors: riverine discharge (U.S. Midcontinent), upwelling (Oklahoma), and biological pumping of ^{12}C-enriched organic carbon (Virginia, Tennessee, Kentucky, Pensylvania). The causes of the GICE (e.g., enhanced organic matter burial in the Appalachian Basin) are still being assessed, but are related to the environmental changes also occurring during the late Middle Ordovician. These changes were previously interpreted as a response to the combined effects of the Taconic Orogeny and a eustatic sea-level rise (Holland and Patzkowsky, 1996), global cooling associated with the onset of glaciation (Pope and Read, 1997), and upwelling (Pope and Steffan, 2003).

The positive ($\delta^{13}C$) isotope excursion begins in the uppermost part of the Midcontinent *P. undatus* Conodont Zone, reaches its peak values in the *P. tenuis* Conodont Zone, and returns to pre-excursion values at and/or just before the *P. tenuis/ B. confluens* Conodont Zonal boundary. The GICE also lies within the North American *C. americanus* and/or *O. ruedemanni* Graptolite Zones. The GICE is geographically one of the most widely documented carbon isotope ($\delta^{13}C$) excursions in the Paleozoic, and apart from the end Ordovician positive excursion it is the most significant excursion documented in the Ordovician.

Reprinted as published in the Geological Society of America *2003 Abstracts with Programs*, v. 35, no. 6, p. 600.

Hydrology of the Western Arkoma Basin During the Ouachita Orogeny: Implications for Mississippi Valley–Type Ore Formation in the Tri-State Zn-Pb District

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The Zn-Pb ores of the Tri-State district of Oklahoma, Missouri, and Kansas represent one of the world's foremost examples of Mississippi Valley–type (MVT) mineralization. The ores are part of a family of MVT deposits located within the Ozark Plateau that appear to have been precipitated from a regional groundwater flow regime set in motion by uplift of the Arkoma foreland basin during the Pennsylvanian–Permian Ouachita orogeny. The present study seeks to characterize the flow regime in the western part of the Arkoma basin that was responsible for depositing the Tri-State ores. Construction of a flexurally compensated stratigraphic profile for Late Pennsylvanian to Early Permian time indicates that the ores formed at a depth of 2.5–3 km. Numerical modeling of basinal fluid flow and heat transport indicates that ore-forming temperatures were reached largely by conduction under the existing geothermal gradient, with additional heat supplied by advection from the deeper parts of the basin. The modeling predicts a decrease in temperature of approximately 10° C laterally across the district, which may have contributed to deposition of the ores by cooling. The modeling also shows Tri-State to have been a region of the basin where fluid velocities were maximized, which may have further contributed to the localization of mineralization in the district. The association of the Tri-State ores with a local pinchout or "window" in the underlying Ozark Confining Unit and with deep-seated faults and fractures has led to speculation by previous workers that a component of the mineralizing fluid ascended from deeper aquifers in the basin. The results of the present modeling confirm that faults and fractures in particular would have been effective in conducting fluid from depth to the ore-hosting formations in the district.

Reprinted as published in the Geological Society of America *2003 Abstracts with Programs*, v. 35, no. 6, p. 202–203.

Partitioning of Trace Elements in the Heavy Mineral Fraction of Ouachita Mountain Shales

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The whole-rock geochemistry of shales has been considered an average of continental crustal geochemistry since the time of Goldschmidt. It has largely been assumed that trace elements reside in the clay minerals that comprise the major component of shales. However, certain heavy minerals concentrate trace-elements to the degree that the overall whole-rock chemistry is influenced by minor variations in their accessory fraction. Samples were collected from nine formations within the Ouachita fold belt. These shales are of deep-water marine clastic origin, and range in age from late Cambrian through late Devonian. Aliquot-pairs consisting of a whole-rock split and a whole-rock split with heavy minerals removed (Li-metatungstate density separation process) were analyzed by XRF. Trace element analyses of Paleozoic deep-water shales from these nine formations indicate significant partitioning of Ti, Zr, Y, Ce, La and Th in the heavy mineral fraction. The aliquots with the heavy mineral fraction removed contain significantly reduced concentrations of these trace elements as compared to the whole-rock sample. A diverse suite of heavy minerals was identified, including zircon, monazite, rutile, tourmaline, and Fe-oxides, and are the most likely mineralogical sites for these elements. The partitioning of these elements and other lithophile trace elements in resistant heavy minerals has implications for interpreting provenance based upon whole-rock geochemistry of shales.

Reprinted as published in the Geological Society of America *2003 Abstracts with Programs*, v. 35, no. 6, p. 466.

Mineralogical Variations in Shales Due to Variable Thermal Maturity

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The sedimentary sequences in the Ouachita Mountains provide a natural laboratory to study diagenesis because of the increase in thermal maturity from Oklahoma through Arkansas. Although trends in clay-mineral diagenesis have been well documented, associated variations in the non-clay fractions are not well known. Sample sites were chosen based upon a previously published map of thermal maturity (Houseknecht and Matthews, 1985). Each sample site was separated into the component mineral fractions and analyzed using X-ray diffraction, Scanning Electron Microscopy, petrographic microscope, and X-ray fluorescence. Preliminary results show that illite crystalinity data from our samples differed from the previously published thermal maturity map. Based upon this new data and previous studies a new thermal maturity map was created. Quartz grains increase in polycrystallinity as maximum temperature increased. Whole rock chemistry, however, does not vary systematically with changes in thermal maturity. No correlation was determined to exist between illite crystalinity and total heavy mineral percentages or assemblages. The clay and quartz fraction in shale are dependant on diagenetic processes, while other mineral fractions are not. The low permeability of shale limits the diagenetic reactions.

Reprinted as published in the Geological Society of America *2004 Abstracts with Programs*, v. 36, no. 1, p. 5.

The Potato Hills Gas Field, Latimer and Pushmataha Counties, Oklahoma

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The Potato Hills have been the topic of debate since Miser, 1929, proposed that the surface structure exposes a fenster of older rocks viewed through a "window" in the low angle north-directed Potato Hills thrust fault (PHTF). Some recent workers observing small scale structures conclude that the Potato Hills result from either vertical uplift, stacking of thrust faults in a fan configuration or two periods of oppositely directed compression.

Shallow production at Potato Hills gas field was discovered by the Sinclair 1 Reneau in 1960, completed for 1.33 MMcfgd from Ordovician Bigfork Chert. However it wasn't until the completion of the GHK et al. #1-33 Ratcliff in September 1998 that a major gas accumulation was recognized. The Ratcliff well was completed for 35.77 MMcfgd from fractured Penn–Mississippian "Ratcliff Sandstone" (uppermost Jackfork Group sandstone). This paper presents new information developed during the GHK Corporation's development of the Potato Hills Gas Field.

The new data, though not completely definitive, suggest that Miser's interpretation is essentially correct although simplified. Observations have been made of (1) late Pennsylvanian folding of the PHTF and Windingstair thrust fault (WSTF) due to emplacement of an out-of-sequence fault carrying a large anticline on its hanging wall, (2) indications of a regional (?) unconformity near the top of the Jackfork, and (3) indications of early Mississippian tectonism, (i.e., a traveling normal fault affecting deformed Ordovician through Mississippian-aged rocks).

Because of ongoing exploration by GHK, this paper is restricted to depths about the Choctaw thrust fault; deep objectives in the Potato Hills are not discussed.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 29.

Comparison of Continental Paleo- and Neo-Rifts

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Southern Oklahoma Aulacogen (SOA) is one arm of a plume-generated set of 3 rifts which broke apart southern Laurentia in Late Proterozoic/Early Cambrian. The other 2 arms formed the Paleozoic southern boundary of Laurentia making the Ouachita reentrant and marking the boundary where the Precordillera of Argentina left Laurentia. How does this older rift compare with present rifts, such as the Rio Grande Rift (RGR)?

Direct signature of SOA is a strong positive gravity anomaly with extent 400 km by 50 km, essentially from Dallas WNW through southern Oklahoma to Amarillo. This contrasts sharply with most neo-rifts where widths range from 40–200 km but lengths are >1000 km. Most neo-rifts have substantial flank uplifts, commonly exposing basement and generating sediments in rift-related basins. SOA has no known flank uplifts or sediments. In fact "fill" in stretched upper crust is igneous: volcanic or shallow-seated intrusives. Gravity shows significant basic material entered the crust at middle/lower levels and at upper levels. The largest volume of acidic material is extrusive (~40,000 km^3 rhyolitic) with thin sheet-granite intrusives, all placed over gabbros. In contrast, Kenya Rift has 144,000 km^3 of extrusives. Basic units are alkalic-tholeiitic transitional; acidic units are A-type silicic. Estimated SOA extension is ~20 km; RGR is <24 km, but for a much longer and wider rift. RGR isotopic data indicate two mantle sources for magma. SOA isotopics indicate both acidic and basic are mantle-derived, with some acidics showing some crustal comtamination. Most neo-rifts have a life span of ~20 Ma, although some have longer pre-histories and several stages. SOA's life may have been as short as ~10 Ma (~540–530 Ma).

What does this say about the SOA? It must have been a very hot, well-elevated topographic bulge. Igneous rocks "filled" rift-spaces rather than sediments, indicating much new crust was formed. Magmatic feeder systems must have been concentrated and mostly linear. There were no "competing" or overlapping tectonic events as in the RGR. Perhaps SOA represents a transition between Precambrian rift characer and those of today.

Reprinted as published in the Geological Society of America *2003 Abstracts with Programs*, v. 35, no. 6, p. 557.

What's the Big Problem with the Wichitas?

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Anyone who has read the Rudnick and Fountain (1995) review of continental crustal structure, and has studied paleo-rifts, will be entranced with their Figure 2. Why? Because it shows clearly the problem of comparing neo-rifts with at least some paleo-rifts, especially the Cambrian Southern Oklahoma Aulacogen (SOA). That problem lies in the following: the M-discontinuity (crustal thickness) of neo-rifts, on average, is around 28 km, distinctly different from that of shield/platforms at 43 km—a difference of 15 km. The SOA M-discontinuity is now about 45 km (see Brewer, 1982; Suleiman, 1993), essentially the same as that of the surrounding shield/platform 1.4 Ga Laurentian crust. Our problem is how to change what should have been the crustal thickness in the Cambrian, if the SOA behaved as modern rifts seem to do, to that of its present status, that of a part of the North American platform.

Assuming that the SOA had a rift-type crust in the Cambrian, there are basically three different scenarios to "add" the required 15 km or so: basaltic underplating, transformation of eclogitic mantle to gabbroic crust, or deformation (squeezing) by some large factor. There are no significant heating events, later than Cambrian, in the geologic record of the upper crust in the southern Midcontinent. Thus, both underplating and transformation of eclogite to gabbro seem to be out. That leaves deformaion. For this we can appeal to the Pennsylvanian Ouachita collision which will require massive compression in a very specific part of the lower, ductile crust.

Ultimately we are left with 2 broad questions: did older rifts originate as present rifts do (as assumed above), and how to change rift crust into platform crust. These have to be questions of general significance since the geologic record clearly shows that bigger plates (e.g., Rodinia, Pangea, Gondwana, etc.) get broken up into smaller, or different plates, with time—and this happens by rifting. The consequences of adopting a compression scenario should be applicable to a wide variety of geologic settings both in time and space.

Reprinted as published in the Geological Society of America *2004 Abstracts with Programs*, v. 36, no. 1, p. 27.

Aspects of Mapping the Quanah Granite

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The Quanah Granite has been mapped at a scale of about 1:10,000 through an USGS EDMAP project, for presentation at 1:24,000. This was done to assist the Oklahoma Geological Survey in its preparation of the Lawton Sheet at the 1:100,000 series. The Oklahoma Geological Survey is working on the Statemap project which will end up mapping the entire State of Oklahoma. The map area is part of the Wichita Mountains of southwest Oklahoma and represents the exposed portion of the Cambrian Southern Oklahoma Aulacogen. Most of the outcrops are in the federal Wichita Mountains Wildlife Refuge and easily accessible.

Quanah Granite was one of the first granites recognized as a separate unit within what is now known as the Wichita Granite Group. This group was defined by Powell et al. (1980) and Myers et al. (1981), with modifications by Price (1998), and all the granites have a sheet form and are A-type. The Quanah is one of the youngest granites in the eastern Wichitas based on field relationships. It is distinctive in its relatively large grain size (~1 cm), compared to other Wichita granites, and it commonly carries riebeckitic amphibole and highly annitic biotite. There are internal fine-grained facies but these have not been mapped. Quanah contacts the Permian Post Oak Conglomerate (nonconformity), the older Glen Mountains Layered Complex, and the older Mount Scott Granite. The Mount Scott is distinctive in its micro-rapakivi texture.

This mapping project had both easy and difficult aspects. Contacts with anorthositic gabbro of the Glen Mountains Layered Complex are distinct. The Quanah contact with the Post Oak is normally clear except where recent erosion has left a thin veneer of Post Oak granite clasts on the substrate Quanah. However, the contact between the Quanah and the Mount Scott has been challenging for several reasons: (1) The Mount Scott fines and frequently loses its distinguishing grey ovoid feldspars toward the Quanah, and (2) the Quanah fines against the Mount Scott, while also including blocks of Mount Scott within its matrix. A zonal boundary rather than the traditional "line" boundary was determined to be the best method of dealing with these issues relating to this portion of the contact.

Reprinted as published in the Geological Society of America *2004 Abstracts with Programs*, v. 36, no. 1, p. 8–9.

An Alternative Interpretation of Linear Dipping Events on 2-D Seismic Data from the Wichita Mountains Frontal Zone

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Accurate geologic interpretations of seismic data are essential to successful oil and gas exploration. Computer simulations and analyses can be cost effective methods of validating an interpretation. A geological cross section incorporating all available well control provides the foundation for simulating seismic data. Geometric and kinematic constraints contribute to a viable cross section. A geological cross section paralleling SEI 5223 includes an overturned syncline, a reverse fault and an overturned anticline. Well control for this cross section includes Lone Star Producing Company's #1 Earnest Baden with a total depth of 30,050 feet and El Paso Natural Gas Company's #1 Alpha Jones, that drilled to 24,550 ft. A dip meter well log from the Alpha Jones provided critical structural information for the cross section.

The complex subsurface structure of the Wichita Mountains Frontal Zone in southwestern Oklahoma remains difficult to image clearly with seismic data. Seismic ray trace modeling can enhance the acquisition, processing and interpretation of seismic data. The complex structures on the cross section combine with large velocity contrasts between Permian sediments and Precambrian basement to give rise to complex seismic ray paths. High-amplitude linear dipping events visible on this 2D seismic line were initially thought to be steeply dipping faults. Analysis of synthetic ray paths clearly shows the reflections originate from a different structure. Synthetic seismic traces created from ray tracing results can be migrated and depth converted to give a more detailed picture of complex structures.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 29–30.

An Investigation of the Granites and Rhyolites of the Wichita Mountains Igneous Province, Southwestern Oklahoma, Using SEM-CL: Textural Features of Quartz Crystals Reflect Crystallization Histories

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When examined with scanned cathodoluminescence (SEM-CL), volcanic and plutonic quartz crystals display distinct characteristic textures not evident using other petrographic techniques. Examination of a suite of igneous rocks from the Wichita Mountains indicates that SEM-CL has the potential to be an effective method of revealing magma conditions during ascent and emplacement and, used in conjunction with other analytical techniques, provides the opportunity to better understand the nature and evolution of magmatic processes.

Plutonic quartz textures include: filled fractures and non-luminescent dark patches and CL streaks. Volcanic quartz displays distinct concentric oscillatory zoning. SEM-CL textures are interpreted to result from a range of sources including lattice defects, trace element impurities, fluid inclusions, stress fractures, and disruption of growth and diffusion rates during crystallization.

Quartz from the Carlton Rhyolite and Wichita Granites Wichita Mountains igneous province, southern Oklahoma) was studied in an attempt to relate textural features of quartz crystals to magmatic crystallization histories. Research indicates that initial eruption of large amounts of rhyolite above an older gabbroic complex created a crustal magma trap, allowing subsequent magma batches to pond and crystallize at depth, resulting in early fine-grained granites and later coarser-grained granites. SEM-CL textures of the three common igneous rock types (rhyolite, early and late granites) reflect their respective crystallization histories. Carlton Rhyolite quartz is commonly euhedral and displays oscillatory zoning, reflecting primary crystal growth in a compositionally variable melt prior to eruption. Quartz from fine-grained Mount Scott Granite displays embayed margins with margin-parallel zoning, possibly due to depressurization during ascent with continued crystallization upon emplacement. Quartz from coarse-grained Quanah Granite exhibits limited zoning and embayed margins, indicating higher H_2O content and emplacement at deeper crustal levels, both due to increased overburden.

SEM-CL provides previously unrecognized information of internal structures and features of quartz, and promises to be an essential tool in interpreting the evolution of magmatic processes.

Reprinted as published in the Geological Society of America *2003 Abstracts with Programs*, v. 35, no. 6, p. 326.

A New Microsaur (Tetrapoda: Lepospondyli) from the Lower Permian of Richards Spur (Fort Sill), Oklahoma

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Bolterpeton carrolli n.gen. n.sp. is described from the Lower Permian fissure-fill deposits of Richards Spur, Oklahoma. *Bolterpeton* is united with the gymnarthrid microsaur *Cardiocephalus* by having teeth compressed labiolingually, a narrow anterior process of the prearticular penetrating the splenial, and the arrangement of the contacts among the splenial, prearticular, and coronoids. It is united with both *Cardiocephalus* and *Euroyodus* by the size and distribution of the coronoid teeth and the presence of longitudinal striations of enamel on the lingual tooth surface. Unlike those two genera *Bolterpeton* has peg-like teeth, but it remains unknown whether this represents the primitive condition or a reversal of the massive conical teeth typical of gymnarthrids. *Bolterpeton* possesses a flat lamina that runs along the lingual surface of the tooth margin. Where two laminae meet at the point of the tooth a labiolingual ridge is formed, which is most pronounced at smaller sizes. Reexamination of *Cardiocephalus* shows it to have the same morphology on its "incisors." Previous authors have defined teeth bearing this ridge as "weakly bicuspid." If this ridge were homologous with the "strongly bicuspid" condition of lissamphibians, *Bolterpeton* would provide the first example of this tooth morphology in lepospondyls and would strengthen recent hypotheses suggesting lepospondyls gave rise to some, if not all, modern amphibians.

Reprinted as published in the *Canadian Journal of Earth Sciences*, v. 40, no. 4, April 2003, p. 499.

Wells Drilled to Basement in Oklahoma

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In the interest of preparing a basement structure map of Oklahoma, an effort to identify all wells drilled to basement was initiated early in 2002. Electronic databases (NRIS; Dwight's/PI) were the first level of investigation; they identified about 300 and 660 wells, respectively. Both databases are dependent on operator identification of basement penetration, and required a family of aliases; i.e., basement, granite, Wichita granite, Tishomingo granite, Precambrian, rhyolite, and Carlton rhyolite.

A check of the databases was made against one-another, and against documents of the Oklahoma Geological Survey revealed that the actual number of basement wells would be significantly greater than 700. Three published, and three unpublished reports of the Oklahoma Geological Survey, and one publication each of the AAPG and the Oklahoma City Geological Society have been the sources of about 700 additional wells in the compilation.

The compilation of all known (and probable) wells drilled to basement in Oklahoma is near completion as of this writing. That is, probable wells, because the basement top has not been identified in about 32% of the data compiled. They are classified as probable basement wells because the sources of information are reports by geologists who have had personal experience, knowledge, or access to company information to identify basement wells.

As the compilation approaches completion, approximately 1400 wells have been identified as having been drilled (or probably drilled) to basement in Oklahoma.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 26.

Two- and Three-Dimensional Mapping of Evaporite Karst in Western Oklahoma

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As part of the STATEMAP component of the USGS's National Cooperative Geologic Mapping Program, the Oklahoma Geological Survey has been undertaking a 2-part mapping program consisting of: (1) a series of 1:100,000-scale reconnaissance geologic maps of the entire State that will become the foundation for a new 1:500,000-scale geologic map of Oklahoma; and (2) detailed 1:24,000-scale geologic maps of metropolitan areas, which helps identify potential engineering and environmental hazards in rapidly growing urban areas. The 1:100,000-scale mapping performed in Western Oklahoma has helped delineate the extent of gypsum karst within the Blaine and Cloud Chief formations. The Nescatunga system, located within the Blaine Formation, in particular has a history of highway collapse hazards. Recent expansion of Highway 412 through Western Oklahoma has led to the detailed three-dimensional mapping of karst intersecting the highway Cavern morphology and distribution in Western Oklahoma evaporite karst systems were mapped using laser/global positioning systems. Digital mapping of cavern voids makes use of a reflectorless laser rangefinder with internal inclinometer linked to a digital compass and referenced to global positioning systems receivers positioned outside the cavern entrances. This is a standard surveying technique for use under bridges and beneath heavy tree canopies. A series of control stations are laser-located along a cavern traverse at approximately 20-meter intervals and marked by mounted reflectors. Fifty or so additional laser positions of cavern floors and walls are taken as offsets from each station. Positioning data is downloaded onto a laptop computer and visualized with GIS and CAD software, enabling a real-time geo-referenced image of cavern shape to be developed. Sub-decimeter scale accuracy is achieved and verified by reoccupation of stations and by positioning from two or more GPS locations at different entrances. The resulting digital 3-D map of a portion of each cavern system investigated is used in interpretation of the surface geophysical results, both in order to provide "ground truth" for the geophysical surveys and to refine the methods for use in cavern detection in surface-inaccessible sites. This system can be used to monitor the expansion to the karst systems by reoccupying the survey stations every year or two.

Reprinted as published in the Geological Society of America *2004 Abstracts with Programs*, v. 36, no. 1, p. 24.

3-D Exploitation of Oklahoma Anadarko Basin Gas Resources, Anadarko Basin, Western and Central Oklahoma

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During the past 5 years Chesapeake Energy has acquired over 3500 square miles of recent 3D data in Oklahoma, concentrated in the prolific gas producing area established within the Anadarko Basin. This basin is characterized by the structural and stratigraphic complexities associated with multiple episodes of extensional, thrust, and wrench tectonics. This complexity has provided the opportunity for 3D seismic to illuminate the potential for finding significant new gas reserves under and between the existing production. The 3D data is comprised of a series of large, overlapping, "regional" surveys that provide a unique geological context for prospect delineation. Chesapeake currently has over 30 rigs actively drilling for these reserves at depths up to 25,000 feet. Chesapeake's continued commitment to 3D in this area is reflected by a 2003 program that includes the acquisition of over 600 squares of new proprietary and spec data.

Slides will include examples of specific 3D strat and structural applications from several areas including: Cement, Chitwood, Watonga-Chickasha, and the Wichita Mtn. Front.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 38.

Structural Style of the Ardmore Basin

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The complex structural geology of the Ardmore Basin is considered by many workers to have formed because of large-scale sinistral strike-slip motion. A detailed re-interpretation of the data instead suggests that basement-involved contraction may be a better model. The newer hypothesis is based on a series of transverse, structurally balanced and palinspastically restored cross sections constructed across several of the significant geologic features in the basin. The cross sections were created and kinematically validated utilizing LithoTect structural modeling software and incorporate subsurface control provided by greater than forty-thousand oil and gas wells. The process of restoring the cross sections to a pre-deformed state suggests that flexural slip was the predominant folding mechanism. In addition, strain calculations ranging from 20–26% indicate deformation in a uniform NE–SW oriented horizontal stress field, inconsistent with wrench tectonics. At the largest scale, the structural style more closely resembles classic foreland basement-involved "compressive block uplifts" observed in the Laramide Rocky Mountains of North America. Like the Rocky Mountains, many of the mountain front areas across the Ardmore Basin have a significant component of "basement-overhang" that are documented by well penetrations and seismic. At the smaller scale, folds display a concentric to complex fold style with numerous volumetric crowd features and detachment surfaces. High-angle faults with either a vertical, reverse, normal, oblique-slip or strike-slip sense of motion are also noted in the basin, and may have resulted from re-activation of pre-existing zones of weakness in the basement during the Pennsylvanian.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 43–44.

Explore the Published Strike-Slip Faults

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Reverse faulting near the edge of a stratigraphic boundary can create a false image of a strike-slip fault. The Washita Valley fault might be an excellent example of such a fault. If, in fact, the Washita Valley fault is a reverse fault and not a strike-slip fault, then the Arbuckle Mountains may overlie some unexplored oil and gas prospects.

The Washita Valley fault is adjacent to two of the most prolific fields in southern Oklahoma: The Eola field and the Cumberland field. These two fields have each produced approximately 850,000 barrels of oil per well. The fields are approximately 70 miles apart, and may be indicative of a structural trend that has not yet been fully explored.

One way to determine the difference between a reverse fault and a strike-slip fault is to examine the direction of force that produced the fault. The force that creates a strike-slip fault is 90 degrees opposite in direction from a force that will create a reverse fault. A study of the Washita Valley fault strongly supports the reverse fault concept.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 45.

Characterization and Fracture Potential of the Viola Limestone, I-35 Road Cut, Carter County, Oklahoma

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The Viola Limestone is a rich oil producer in Oklahoma. Production is enhanced in fractured intervals, which tend to be cherty. An outcrop characterization study was conducted along the 730 foot thick I-35 road cut in Carter County, Oklahoma to document the relations among lithology and fracture potential, and to develop simple criteria for identifying fracture-rich zones from conventional gamma-ray logs.

The section was described and representative samples were collected for compositional analysis. An outcrop gamma ray log was obtained by measuring natural gamma radiation with a hand-held scintillometer at 2 ft. intervals throughout the stratigraphic section. Ten intervals—ranging from carbonate mudstone to grainstone with variable amounts of bedded and nodular chert—were defined on the basis of lithology. Chert content of the 10 intervals is variable, ranging from 0% to 21% of total interval thickness. Two of the intervals also contain karst horizons. Fracture frequency was measured on selected beds, and ranges from 0.2 fractures/inch in limestone beds to 3.8 fractures/inch in chert beds.

The 10 intervals are distinguishable by their outcrop gamma-ray log response, so that chert- and fracture-rich intervals can be distinguished from chert- and fracture-poor intervals. A subsurface gamma-ray log through the Viola Limestone in a nearby well revealed a similar pattern of relative variations in gamma-ray response. This calibration of outcrop gamma ray log to subsurface gamma ray log provides a means of predicting chert- and fracture-rich intervals in subsurface wells using a gamma-ray log. These results can improve the ability to recognize and map fracture-rich zones from conventional well logs, and thus, to better predict such trends in the subsurface for improved exploratory and development drilling.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 40–41.

Developing the Simon Creek Prospect in Carter County, Oklahoma

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The structural complexity of Southern Oklahoma creates a wealth of exploration opportunities. Enough wells have encountered thrust faults to indicate that there are significant sequences of potential reservoir rock that are virtually untested.

The existing bank of 2-D and 3-D seismic data can aid interpretations. In many instances, however, vertical beds and overturned folds cannot be imaged. The geologist must become comfortable with a structural style and then adhere to the predictability of projecting that style away from existing control. Dipmeter logs and the construction of true scale cross sections are essential.

The future of exploration in Southern Oklahoma will depend upon sound structural mapping and the availability of investment funds for high risk wildcatting. Each exploratory attempt must be integrated into the thinking for future exploration. The successful exploration effort will be a program, rather than a 1–2 prospect project.

Given the volume of oil and gas that has been produced, the volume of source rock, and the presence of high quality reservoir rocks, it should be safe to assume that many exciting discoveries are yet to be found.

The Ward Petroleum Nipp #1-21 is an example of the kinds of thinking, mapping, and selling that is required to explore for these structurally complex traps. Playing off the Joiner City and Southeast Joiner City fields south of the Criner Uplift in southern Carter County, the existing data was projected to predict the possibility of a large trap in the Arbuckle. Although the results were a dry hole, the idea was valid and the partners in the well were not negatively impacted concerning the future potential of the Southern Oklahoma basins.

Reprinted as published in the American Association of Petroleum Geologists *2003 Mid-Continent Section Meeting Official Program Book*, p. 31.

Trilobite Biostratigraphy of the Late Ordovician Viola Group in South-Central Oklahoma

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Trilobite faunas have been used for high-resolution biostratigraphy in the Cambrian and Early Ordovician but have been underutilized in younger strata. The diverse and abundant Late Ordovician (Mohawkian-Cincinnatian) trilobite fauna in the Viola Group of Oklahoma is used to construct high-resolution biozones that can be employed to evaluate and refine previous studies using graptolites and conodonts. Biostratigraphic data from this study are particularly important in lithofacies that do not preserve graptolites, such as those deposited in high-energy, shallow-water environments. Bioclastic sediment of the Viola Group was deposited along a depth gradient within and on the margins of the Southern Oklahoma aulacogen in south-central Oklahoma. Four lithofacies define a shallowing-upward sequence in the Viola Springs Formation as sediment filled the basin and these grade upward into shallow platform deposits of the Welling Formation. Sections along a transect from the depocenter of the aulacogen out onto the margins record varying thicknesses of each lithofacies. The base of the Viola Group is marked by deep-water deposits that formed following rapid subsidence of the aulacogen and preserves a low-diversity fauna limited to graptolites and such trilobites as *Cryptolithus, Isotelus* and *Anataphrus*. Near the margins of the aulacogen, sections shallow rapidly upward into coarse-grained facies interpreted to represent deposition in shallow subtidal and shoal environments. Graptolites are rare to absent, limiting their use as biostratigraphic tools, while the trilobite faunas, which include isotelines (*Isotelus, Anataphrus*), illaenines (*Thaleops, Bumastoides*), cheirurines (*Ceraurus, Ceraurinella*), pterygometopids (*Achatella, Calyptaulax*) and *Flexicalymene*, are abundant and diverse. The base of the Welling Formation is gradational at each section and is not isochronous across the basin. The Welling Formation consists of well-washed, coarse bioclastic pack-, grain- and rudstone that is rich in such trilobites as *Isotelus, Anataphrus, Ectenaspis* and *Calyptaulax* but nearly devoid of graptolites. This study demonstrates that trilobite biostratigraphy can be used to increase resolution in Late Ordovician deposits for which biostratigraphic data using graptolites and conodonts already exists.

Reprinted as published in the Geological Society of America *2003 Abstracts with Programs*, v. 35, no. 6, p. 159.

Strontium Isotope Stratigraphy of the Comanchean Series in North Texas and Southern Oklahoma

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Pioneering studies in north Texas and adjacent Oklahoma played an important role in the paleontologic and stratigraphic development of the Cretaceous in North America. We have used the results from 135 strontium isotope analyses from fossils and rocks collected from 43 sites to define the "middle" Cretaceous path of seawater $^{87}Sr/^{86}Sr$ during Comanchean time. The section represents an estimated duration of 19.3 m.y., from the late Aptian through late Cenomanian. The $^{87}Sr/^{86}Sr$ of seawater rises from 0.707318 ± 13 (errors given × 10^{-6} in the basal Glen Rose Formation to reach a peak value of 0.707522 ± 10 in the Walnut Clay, then gradually declines to 0.707468 ± 6 in the middle Grayson Marl. The upper Grayson Marl and lower Buda Limestone $^{87}Sr/^{86}Sr$ values decline to 0.707422 ± 9, then rise to near 0.707473 by the middle Buda Limestone. The $^{87}Sr/^{86}Sr$ mean of the basal Woodbine Formation, in the overlying Gulfian Series, is in agreement with the middle Buda value. Thirty of the analyzed samples yielded ratios higher than the mean determined for corresponding stratigraphic units. The $^{87}Sr/^{86}Sr$ ratios from whole-rock limestones and spar fillings of shells are inconsistent and more radiogenic than the best shell material. All but two samples yielding aberrant ratios could be identified by using appearance and trace element content. Isotopic results from oyster and pectin shells with low Mn and Fe concentrations are remarkably consistent. The agreement of results among samples collected from a stratigraphic interval at a single site with results from geographically removed sites in the same interval is strong evidence that these samples retain the original open-marine $^{87}Sr/^{86}Sr$ of Comanchean seawater. The seawater variation defined here shows fine structure not apparent in previous work. This definition can be used to better understand the complex relationship and timing between seawater $^{87}Sr/^{86}Sr$ variation, ocean anoxic events, mid-ocean-ridge production, and subsequent climate and ocean-productivity changes.

Reprinted as published in the Geological Society of America *Bulletin*, v. 115, no. 6, June 2003, p. 669.