OKLAHOMA GEOLOGY

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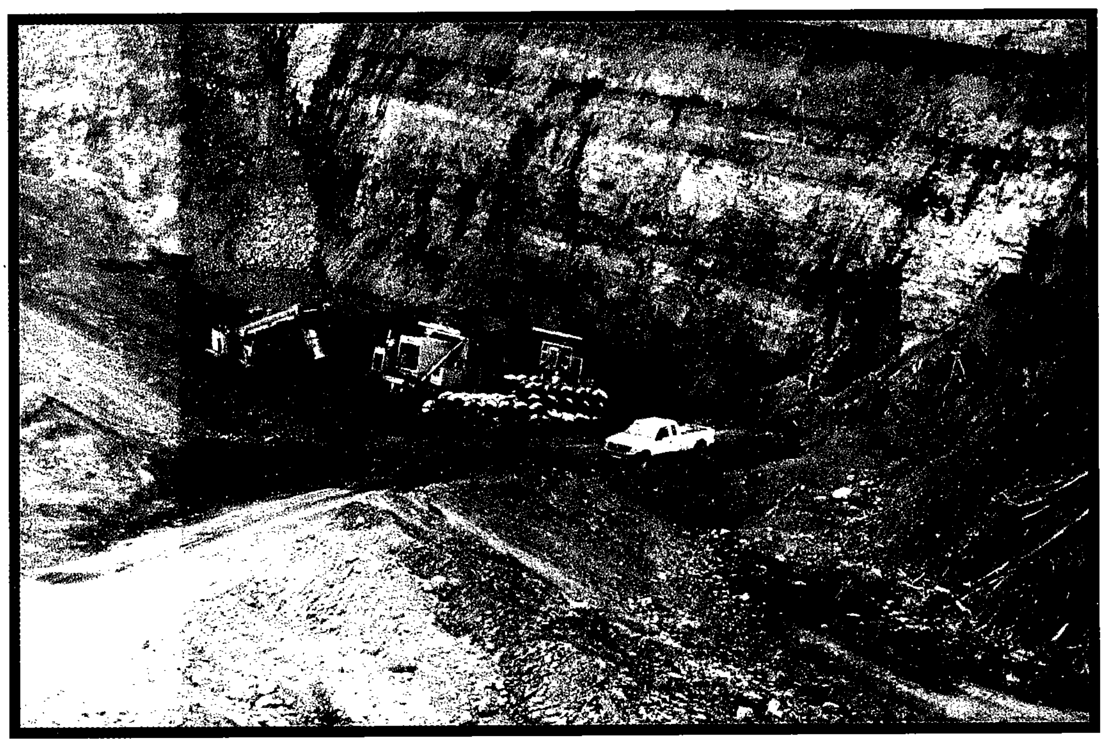

Featuring:
- *Miocene vertebrate fossil assemblage in Roger Mills County*
- *Abandoned Coal Mine Land Reclamation Program*

on the cover

Active Oklahoma coal mine, Le Flore County, Oklahoma

The cover photograph is a view looking northwest into an active pit of the Farrell-Cooper Mining Company Heavener East No. 2 coal mine. The coal mine, which is located on the south side of Poteau Mountain in east-central Le Flore County, Oklahoma (sec. 20, T. 5 N., R. 27 E.), was opened in April 1999. Year 2000 coal production from this mine was 372,234 short tons (~23% of Oklahoma coal production in 2000).

The mine incorporates both surface and underground mining techniques to mine the Lower Hartshorne coal (Hartshorne Formation; Desmoinesian; Middle Pennsylvanian). The Lower Hartshorne coal at this location is 5.9 ft thick, dips 15° (N. 30° W.), and is of medium-volatile bituminous rank. Gray shale in the Upper Hartshorne member of the Hartshorne Formation is above the Lower Hartshorne coal. The Upper Hartshorne coal, which is ~1.2 ft thick, lies ~62 ft above the Lower Hartshorne coal in the highwall.

The maximum depth to which the Lower Hartshorne coal can be profitably mined by surface methods is 120 ft. The pit is up to 250 ft wide. The more deeply buried coal is then mined by underground methods. Working right to left (as shown in the photograph), a 53-in.-diameter auger extracts coal to a distance of ~400 ft beyond the face of the highwall. Holes are drilled about 30 in. apart, and a space of 12 ft is left after every 12 holes to support the overburden. Approximately 46% of the in-situ coal is recovered using this method (Robert Cooper, personal communication, 2001).

The coal from the Heavener East No. 2 mine is shipped by truck to the Applied Energy Services Shady Point coal-fired cogeneration facility near Panama, Oklahoma (see Friedman, 1994). Commercial operation of the plant began on January 15, 1991. The nonutility electric power plant supplies electricity to Oklahoma Gas and Electric Company and food-grade carbon dioxide to food processing and dry ice companies. The plant has four coal-fired circulating-fluidized-bed steam boilers and two turbine generators rated at a net electrical output of 320 megawatts per hour (one megawatt is one million watts). Fluidized-bed combustion is an advanced technology for coal combustion that allows Oklahoma's high-sulfur coal to be burned with low emissions of sulfur dioxide and nitrogen oxide: calcium sulfate—a disposable, solid by-product of the coal combustion—is produced as sulfur dioxide from coal reacts with calcium carbonate from limestone (Tavoulareas, 1991). The Shady Point plant uses about 3,000 short tons of coal and 1,000 short tons of limestone per day.

Acknowledgments

The Oklahoma Geological Survey gratefully acknowledges Robert Cooper and Joe Benson of Farrell-Cooper Mining Company, and Craig Jackson and Harvey Geizer of Georges Colliers, Inc., for permission to visit the Heavener East No. 2 coal mine as stop 1 and the Pollyanna No. 6 coal mine (photo below) as stop 5 on the Oklahoma Coalbed Methane Field Trip on October 9, 2001.

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Friedman, S. A., 1994, Oklahoma's newest large electric power plant: Oklahoma Geology Notes, v. 54, p. 178, 220.

Tavoulareas, E. S., 1991, Fluidized-bed combustion technology, *in* Hollander, J. M. (ed.), Annual review of energy and the environment: Annual Reviews, Inc., Palo Alto, Energy and the Environment, v. 16, p. 25–57.

Brian J. Cardott

View looking southwest of recent reclamation in the Georges Colliers, Inc., Pollyanna No. 6 coal mine on the east side of Cavanal Mountain (sec. 22, T. 7 N., R. 27 E.) in north-central Le Flore County, Oklahoma. The medium-volatile bituminous Secor coal (Boggy Formation; Desmoinesian) was mined to a maximum depth of 85 ft from 1990 through 2000.

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OKLAHOMA GEOLOGY

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Wild Horse Creek #1: A Late Miocene (Clarendonian-Hemphillian) Vertebrate Fossil Assemblage in Roger Mills County, Oklahoma

Nicholas J. Czaplewski[1], *J. Peter Thurmond*[2], *and Don G. Wyckoff*[1]

Abstract.—Vertebrate fossils were collected from a locality near the eastern outcrop margin of the Tertiary Ogallala Formation in Roger Mills County, Oklahoma. The vertebrates include two tortoises: a large *Hesperotestudo* sp., and a smaller individual that could represent either *Gopherus* or *Hesperotestudo*; and several mammals, most of which are ungulates. The mammals are a bone-cracking canid (*Borophagus* sp.), a peccary (Tayassuidae gen. indet.), a camel (Camelidae gen. indet.), and several horses (*Cormohipparion occidentale, Hipparion tehonense*, and *Calippus martini*). Collectively, the mammals suggest either Clarendonian or early Hemphillian land-mammal age (or both) for the assemblage. This is consistent with other vertebrate faunas from the Ogallala Formation of the southern High Plains.

INTRODUCTION

In February 1983, the second author noticed bone fragments eroding from a road cut on the south side of State Highway 47, 8 km (5 mi) east of Roll, Roger Mills County, Oklahoma. The exposed bone was severely weathered. Excavation exposed a complete giant tortoise, well preserved. The specimen (Fig. 1) was photographed, measured, and reburied in anticipation of systematic collection. However, a few days later the tortoise was removed by fossil hunters, and damaged. Most of the specimen, rendered fragmentary and incomplete, has since been acquired by the Oklahoma Museum of Natural History (OMNH).

In 1984, Thurmond and Michael C. Moore visited the site and collected a smaller tortoise and fragmentary mammal fossils (including horse teeth). Most of these fossils came from the road cut, but surface prospecting revealed fossil fragments in erosional exposures about 150 m southwest of the tortoise locality. In 1991 and again in 1999, Czaplewski visited the sites and collected two carnivore teeth, remnants of a giant tortoise, and a toothless jaw fragment possibly from a peccary in the opposite (north) cutbank, and more horse teeth from a deep gully to the northwest. In 2000, Wyckoff and Thurmond returned and studied the sedimentary context.

We have named this vertebrate fossil locality Wild Horse Creek #1; it has also been designated OMNH vertebrate paleontological locality V697. The site is near the head of the south-flowing Wild Horse Creek, in the NW¼ sec. 15, T. 15 N., R. 23 W., Indian Base Line and Meridian. Wild Horse Creek #1 lies south of the crest of the drainage divide between the Canadian and Washita Rivers, about 670 m (2,200 ft) above sea level. The crest of this interfluve, known to archeologists as the Durham Divide (Thurmond and Wyckoff, 1999), slopes gently to the east at about 0.76 m per km (4 ft/mi). However, in the vicinity of the fossil locality, the Durham Divide is narrow and rugged, dissected by deep tributary canyons draining to the north and south (Fig. 2).

Figure 1. The first *Hesperotestudo* giant tortoise, OMNH 48724, discovered in 1983 at Wild Horse Creek #1. The carapace was 105 cm long, 70 cm wide, and 45 cm high. The 3-decimeter scale in the upper right background indicates magnetic north.

[1]Oklahoma Museum of Natural History, University of Oklahoma, Norman.

[2]Dempsey Divide Research Foundation, Inc., Cheyenne, Oklahoma.

Environs of the Wild Horse Creek #1 Paleontological Site

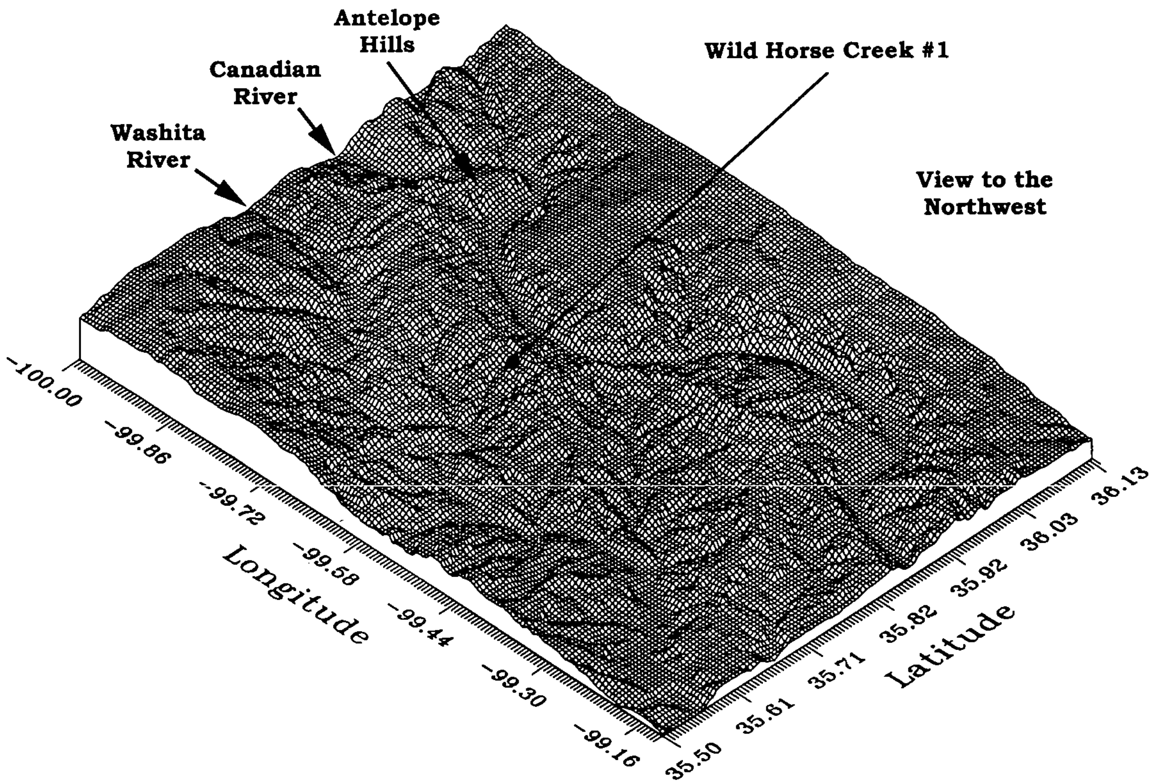

Figure 2. This orthographic map of the terrain surrounding Wild Horse Creek #1 encompasses most of Roger Mills, southern Ellis, and western Custer and Dewey Counties, Oklahoma. The great bends of the Canadian River are evident, and Foss Reservoir can be discerned in the southeast corner.

The crest of the Durham Divide near Wild Horse Creek #1 consists of an erosional remnant of the Ogallala Formation (late Miocene to early Pliocene), extending eastward as a long, narrow peninsula from the main body of the formation. The Ogallala Formation feathers out in this vicinity, and is underlain by Permian red-bed clastics of the Doxey Shale and the Cloud Chief Formation (Carr and Bergman, 1976). The full section of the Ogallala Formation is preserved in the Antelope Hills, 24 km (~15 mi) to the northwest. Kitts (1959, p. 10) characterized the Ogallala Formation in northern Roger Mills County as "fine- to medium-grained, well sorted quartz sands," seldom cemented by calcium carbonate. Other facies are noted, though, including rare clays and silts (Kitts, 1959). The Ogallala Formation is primarily alluvial, although significant eolian components are known (Kitts, 1959, 1965; Reeves and Reeves, 1996). Our conclusions and interpretation of the age and context of the Ogallala vertebrate fossils in this area are tentative.

The clastics of the Ogallala Formation around Wild Horse Creek #1, at the very base of the formation, appear to be a mix of Tertiary sand and river gravel transported from much farther west, and material reworked during the Miocene from the underlying Permian red gypsiferous sandstone and shale. Local Miocene deposits therefore range in color from white through light brown to red, depending on the depositional environment and the content of the reworked sediment. All the sediments at Wild Horse Creek #1 are reddish. Clasts containing fossil oyster shells (*Texagryphaea*) also occur in the Miocene unit, redeposited from the Kiowa Formation (Cretaceous), which is otherwise absent in the vicinity. To further complicate matters, reconnaissance of the surrounding area by the authors in 2000 revealed extensive fluvial cut-and-fill reworking of the Ogallala Formation outcrop edge in Late Pleistocene and Early Holocene times, probably in response to rapid and abrupt climate change (Thurmond and Wyckoff, 1998, 2001).

The road cut at Wild Horse Creek #1 exposes a broad, shallow depositional basin that in cross-section is some 120 m wide and more than 8 m deep. Much of the road-cut surface is masked by vegetation, but a schematic profile is shown in Figure 3, and the visible depositional units are described in Table 1. Both tortoises were about 3 m below the top of the road cut, lying on and partly embedded in the red silty clay of Unit 2; they had been buried by the cross-bedded sand of Unit 3. All the depositional units appear to be eolian. We interpret the context of the fauna here as an interfluvial upland basin, deflated and refilled by eolian processes in Miocene time.

SYSTEMATIC PALEONTOLOGY

Most of the vertebrate fossils—except the two tortoises—are fragmentary and poorly preserved, some are etched or weathered, and some are lightly concreted with carbonates (or with carbonate-cemented sand). Nevertheless, a small assemblage of vertebrates representing six or seven taxa are reported from Wild Horse Creek #1. Specimen numbers are those of the vertebrate paleontology collection at OMNH. All measurements are in millimeters unless otherwise noted. Measurements were made with dial calipers to the nearest 0.1 mm. The abbreviation "est." means estimated size of a broken specimen. For the mammals listed below, uppercase letters indicate upper teeth; lowercase, lower teeth.

Class Reptilia

Order Chelonia

Family Testudinidae

Hesperotestudo sp. indeterminate

Specimens: OMNH 48724, cranium, shell fragments, and limb elements of a giant tortoise (Fig. 1); OMNH 48734, costal osteoscute fragment.

Discussion: Although OMNH 48724 was virtually complete when discovered, it was severely fragmented by fossil hunters, and is now incomplete. Before breakage, the shell was 1,050 long, 700 wide, and 450 high; thickness of fragments varies from 6.2 to 12.9. Associated with the shell is a poorly preserved cranium, parts of pelvic and pectoral girdles, a complete right humerus, proximal half of a femur, fragments of other limb elements, three complete phalanges, and several osteoscutes from the armor on the legs. On the cranium, the distance from the anterior edge of the prefrontals to the approximate original extent of the occipital condyle (broken) is estimated at 145. Measurements of the humerus are greatest length: 278; greatest proximal width: 127; greatest distal width: 105 (est.). The isolated costal fragment (OMNH 48734) is 14.9 thick.

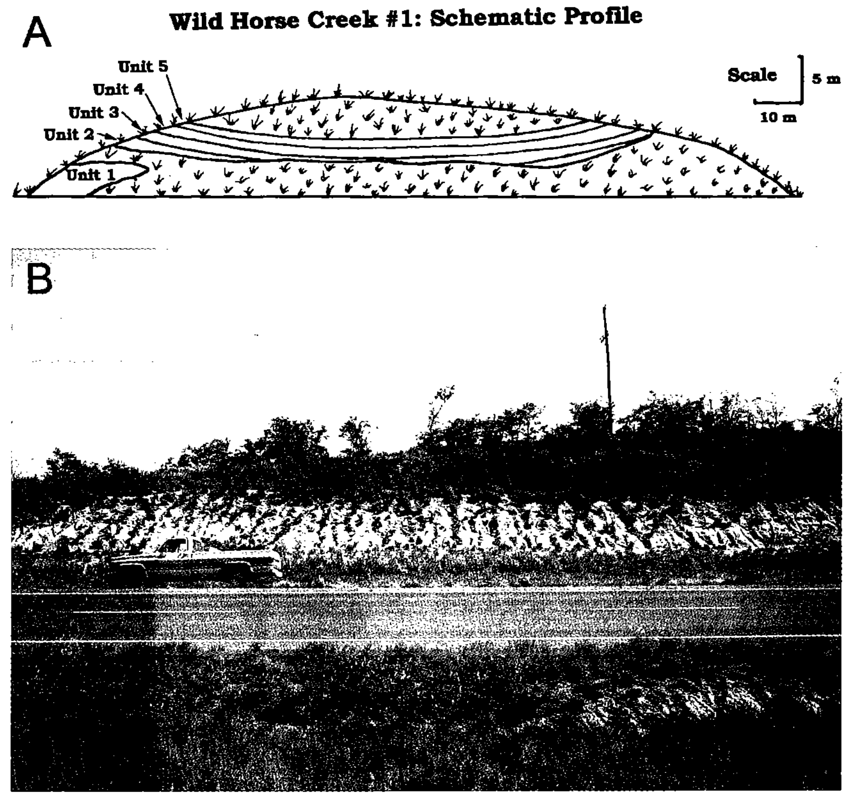

Figure 3. (A) Schematic drawing of the visible depositional units on the north side of State Highway 47 at Wild Horse Creek #1. The tortoises were found along the contact between Units 2 and 3 but in the south cutbank. The depositional units are discussed in the text. (B) Here is the same road cut (OMNH vertebrate paleontological locality V697). Photographed in August 1984 while the second tortoise was being excavated near the center of this view.

Gopherus sp. or *Hesperotestudo* sp.

Specimen: OMNH 48725, incomplete shell of a medium-sized tortoise (Fig. 4).

Discussion: This specimen was nearly complete when found, but is now well traveled, and has not traveled well. It was housed for several years at the Oklahoma Archeological Survey and then for several more at the Anadarko Basin Museum in Elk City. The specimen as accessioned by OMNH consists mostly of an internal mold of poorly consolidated fine red sand to which pieces of the carapace and most of the plastron adhere. In Neogene land tortoises of North America, shell thickness and surface features of the bony shell such as raised growth lines and shallowly incised scute sulci can of-

Figure 4. The second tortoise from Wild Horse Creek #1, OMNH 48725, collected in 1984. The tortoise was partly pedestaled by erosion of the road-cut face, but was clearly still in its original position of burial—inverted. The 3-decimeter scale indicates magnetic north.

TABLE 1. — State Highway 47 Road-Cut Profile, Wild Horse Creek #1

Unit 5 — Dry color: 2.5YR6/6, light red; moist color: 2.5YR5/6, red. Consistency: dry, soft; moist, very friable; wet, slightly sticky, nonplastic. Loamy fine sand, well-sorted, with no larger clasts. Faint eolian cross-bedding visible. HCl reaction: slightly effervescent. No visible carbonates. About 40 cm thick; this is the uppermost unmasked stratum.

Unit 4 — Dry color: 5YR6/6, reddish yellow; moist color: 5YR5/6, yellowish red. Consistency: dry, slightly hard; moist, very friable; wet, slightly sticky, slightly plastic. Fine sandy loam, well-sorted, with no larger clasts. Faint eolian cross-bedding visible. HCl reaction: violently effervescent. Moderately indurated by carbonates when dry. Many fine, hard carbonate nodules. About 60 cm thick; upper boundary abrupt and wavy.

Unit 3 — Dry color: 5YR7/4, pink; moist color: 5YR6/6, reddish yellow. Consistency: dry, very hard; moist, friable; wet, slightly sticky, nonplastic. Very fine sandy loam, well-sorted, with no larger clasts. Faint eolian cross-bedding visible. HCl reaction: violently effervescent. Strongly indurated by carbonates when dry. Many hard, fine carbonate nodules. About 1 m thick; upper boundary abrupt and smooth.

Unit 2 — Dry color: 5YR7/6, reddish yellow; moist color: 5YR5/6, yellowish red. Consistency: dry, very hard; moist, firm; wet, sticky, plastic. Silty clay, with no larger clasts. No pedogenic or sedimentary structure. HCl reaction: strongly effervescent. No visible carbonates. About 1 m thick; upper boundary abrupt and smooth.

Unit 1 — Dry color: 2.5YR6/6, light red; moist color: 2.5YR4/6 red. Consistency: dry, very hard; moist, friable; wet, nonsticky, nonplastic. Loamy fine sand, well-sorted, with no larger clasts. No pedogenic or sedimentary structure. HCl reaction: violently effervescent. Carbonate casts in krotovinae. Strongly indurated by carbonates when dry. Extends below base of road cut; more than 5 m thick. Upper boundary abrupt and smooth.

Recorded May 24, 2000.
Colors follow the Munsell Soil Color Charts (1994).
Descriptive terminology follows Soil Survey Division Staff (1993).

ten serve to differentiate giant tortoises, *Hesperotestudo* spp., from gopher tortoises, *Gopherus* spp. Unfortunately, much of the original surface of the remnants of carapace in the medium-sized tortoise from Wild Horse Creek #1 are concreted or were weathered after exposure by the highway road cut, so it is not possible to examine the sutural pattern of osteoscutes or the shape of the scute sulci. The plastron is complete except that the left bridge and epiplastron are missing. Anteroposterior length of the carapace of this specimen is about 330. Thickness of the shell ranges from about 5.6 to 8.7, as measured on fragments. Given the relatively thick shell, the specimen may represent a young *Hesperotestudo* or possibly a moderately large species of *Gopherus*.

Class Mammalia

Order and Family indeterminate

Specimen: OMNH 48726, right ulna.

Discussion: The specimen is a proximal fragment of the shaft, broken through the middle of the semilunar notch. Both the olecranon and the distal ends are missing. The ulna fragment is too small to belong to any of the identified members of the assemblage (see below). The bone indicates a mammal about the size of a pine marten (*Martes americana*) or a marmot (*Marmota* spp.). The specimen is too incomplete and non-diagnostic for precise identification.

Order Carnivora

Family Canidae

Borophagus sp.

Specimens: OMNH 14843, right M1 crown fragment including protocone, hypocone, protoconal basin, and lingual walls of the paracone and metacone. OMNH 14844, left I2.

Discussion: These two teeth were found together adjacent to the giant tortoise, and probably came from a single skull. The enamel on both is badly etched. The teeth represent a bone-cracking canid of the subfamily Borophaginae. Because they are so fragmentary, no useful measurements can be made (although the lingual anteroposterior length of the M1 is estimated at 13, and the I2 is 7.1 in anteroposterior length and 9.9 in transverse width). During the late Miocene-Pliocene in the Great Plains the jaws and teeth of common borophagine genera underwent an overall decrease in size. Species of *Epicyon*, of the late Barstovian–Clarendonian–early Hemphillian land-mammal ages, are large bone-eating dogs (Baskin, 1998). *Borophagus* species, represented by many North American species in the Clarendonian through Blancan land-mammal ages, are intermediate to small in size (Wang and others, 1999).

Direct comparisons of the Wild Horse Creek #1 specimens were made with specimens in the OMNH collection of *Epicyon* and *Borophagus*. A small sample of specimens of *Epicyon* is available in OMNH from the Arnett fauna of Oklahoma (also known as the Port of Entry fauna; Wang and others, 1999), and a large sample of *Borophagus secundus* (formerly known as *Osteoborus cyonoides*; Wang and others, 1999) from the Optima fauna of Oklahoma (also known as the Guymon fauna). The M1 fragment from Wild Horse Creek #1 is much smaller than M1s of *Epicyon haydeni* and *E. saevus* from Arnett, and the tooth is larger than the geologically youngest species of *Borophagus* (of Blancan age). This molar fragment is similar in general size and shape to *Borophagus* species of late Miocene age (Clarendonian and Hemphillian).

Wang and others (1999) recognized one species of *Borophagus* (*B. littoralis*) in the Clarendonian and six species in the Hemphillian of North America. The species exhibit a range of sizes with considerable inter- and intra-specific variation (Webb, 1969; Wang and others, 1999). Of the seven species, at least *B. hilli* and *B. secundus* are common bone-eating dogs in Hemphillian faunas of the Southern Plains. In addition to the size variability, morphological features of the

M1 (and other teeth) can vary greatly within a population of *B. secundus* (Webb, 1969; Wang and others, 1999) as evidenced by a large sample of the species from Coffee Ranch, Texas—the type Hemphill fauna. For those reasons it seems prudent to leave the Wild Horse Creek #1 borophagine unidentified until more and better specimens are available. Based on the present material, the size and morphology of the teeth are well within the range of variation exhibited by the *Borophagus* specimens from Optima, warranting a generic assignment to *Borophagus*.

Order Artiodactyla

Family Tayassuidae

Genus and species indeterminate

Specimen: OMNH 14845, a fragment of the lower jaw with the roots of p2-p3 and the broken bases of p4 and m1.

Discussion: This specimen was found in the road cut. Crowns of the teeth are gone but their remnants, the relative sizes of the tooth bases, and the deployment and shape of the roots closely match those of certain peccaries, especially *Prosthennops* and *Catagonus* specimens from elsewhere in the Southern Plains (Schultz, 1990a,b; Wright, 1989).

Family Camelidae

Genus and species indeterminate

Specimens: OMNH 48730, distal fragment of left humerus; OMNH 48733, right cuneiform; OMNH 48731, right pisiform; OMNH 48732, left unciform; OMNH 48728, distal fragment of the shaft of a metapodial; OMNH 48729, proximal fragment of a first phalanx; OMNH 48727, small fragment of a jaw bone with the partial wall of an alveolus for a high-crowned tooth.

Discussion: Preservation is similar among these bones (which might indicate they belong to a single skeleton) and differs from most of the other specimens in the Wild Horse Creek #1 assemblage. The metapodial fragment is a small piece of the shaft immediately proximal to the point of divergence of the distal ends. All the specimens indicate a camel of medium size. Greatest width of the distal articular surface of the humerus is 50.5. Width of the proximal end of the first phalanx is 29.1. The former measurement is smaller than for two specimens of *Hemiauchenia* cf. *blancoensis* reported by Morgan and others (1998). The latter measurement is similar to the same measurement in *Procamelus grandis* and is slightly larger than that of *Pliauchenia magnifontis* reported by Gregory (1942). It is also within the range of specimens of *Hemiauchenia* cf. *blancoensis* given by Morgan and others (1998). The specimens are much too small to represent a species of *Megacamelus* or *Megatylopus*. However, several other genera and species of medium-size camels occurred in the late Cenozoic of the Southern Plains (Harrison, 1979; Dalquest, 1980; Honey and others, 1998), with which it is not possible to make informative comparisons at present. More and better specimens, especially of the metapodials or jaws and teeth, are required for specific identification.

Order Perissodactyla

Family Equidae

Tribe Hipparionini

Cormohipparion occidentale

Specimens: OMNH 56877, associated left p3-m2 (Fig. 5A). OMNH 57309, left upper cheek tooth, probably P3 or P4 (Fig. 6A).

Discussion: The well-preserved series of lower cheek teeth represents a large, moderately hypsodont hipparionine horse. The protostylid (dental terminology from MacFadden, 1984a; Hulbert, 1988a,b) is moderately developed on p3-p4 and well developed on the molars. The ectoflexid is moderate in the premolars; in each of the molars it deeply penetrates the isthmus, to the extent that it forms a small convexity in the linguaflexid of the m1 and m2. The pli caballinid is moderately developed as a single loop in the premolars; it is barely noticeable in the molars. The metaconid and metastylid are about equal in size, are distinctly separated, and have rounded borders in all four teeth. The entoconid is large on p3-p4 with an anterolabial projection; the cusp is rounded in the molars. The entoconid is distinctly separated from the hypoconulid in p3-m2. Measurements of these teeth, made at the occlusal surface after the method of Hulbert (1988a,b), are anteroposterior length of p3: 25.3; p4: 24.8; m1: 22.5; m2: 24.1; anterior width of p3: 12.1; p4: 12.0; m1: 9.6; m2: 9.4; posterior width of p3: 13.2; p4: 12.5; m1: 8.5 (est.); m2: 8.7; metaconid-metastylid length of p3: 12.4; p4: 12.4; m1: 12.3; m2: 12.3; length of entoflexid of p3: 12.0; p4: 11.1; m1: 7.9; m2: 9.0.

The upper cheek tooth (OMNH 57309) is slightly damaged in the parastylar region. Its measurements: anteroposterior length 26.7; transverse width 27.1; protocone length 11.5; protocone width 4.5, crown height at mesostyle 41.5. It has a long, lenticular protocone, deep hypoconal groove, and a pli caballin with three loops. The prefossette is complexly folded posteriorly and there is a large, thick-enameled prefossette loop on the pli prefossette. The postfossette is somewhat unusual in being much simpler, with only a single fold anteriorly and one posteriorly. The mesostyle and metastyle are narrow. The tooth is referred to *C. occidentale* based on the shape of the protocone, presence of a pli caballin with multiple folds, and presence of a strong prefossette loop on the pli prefossette; its size agrees with the size of the lower cheek teeth mentioned above.

Hipparion tehonense

Specimen: OMNH 57308, associated left P3-P4 (Fig. 6B).

Discussion: These teeth were found lower in the local stratigraphic section than the other specimens included in this report. The teeth possess small, rounded oval protocones not connected to the protoselene, pli caballin with two loops, and a hypoconal groove. There is a prefossette loop with slightly thickened enamel on the pli prefossette. The parastylar and metastylar regions are damaged in the P3 and the mesostyle and metastyle are damaged on the P4. The parastyle is preserved in the P4 and is broad. Anteroposterior

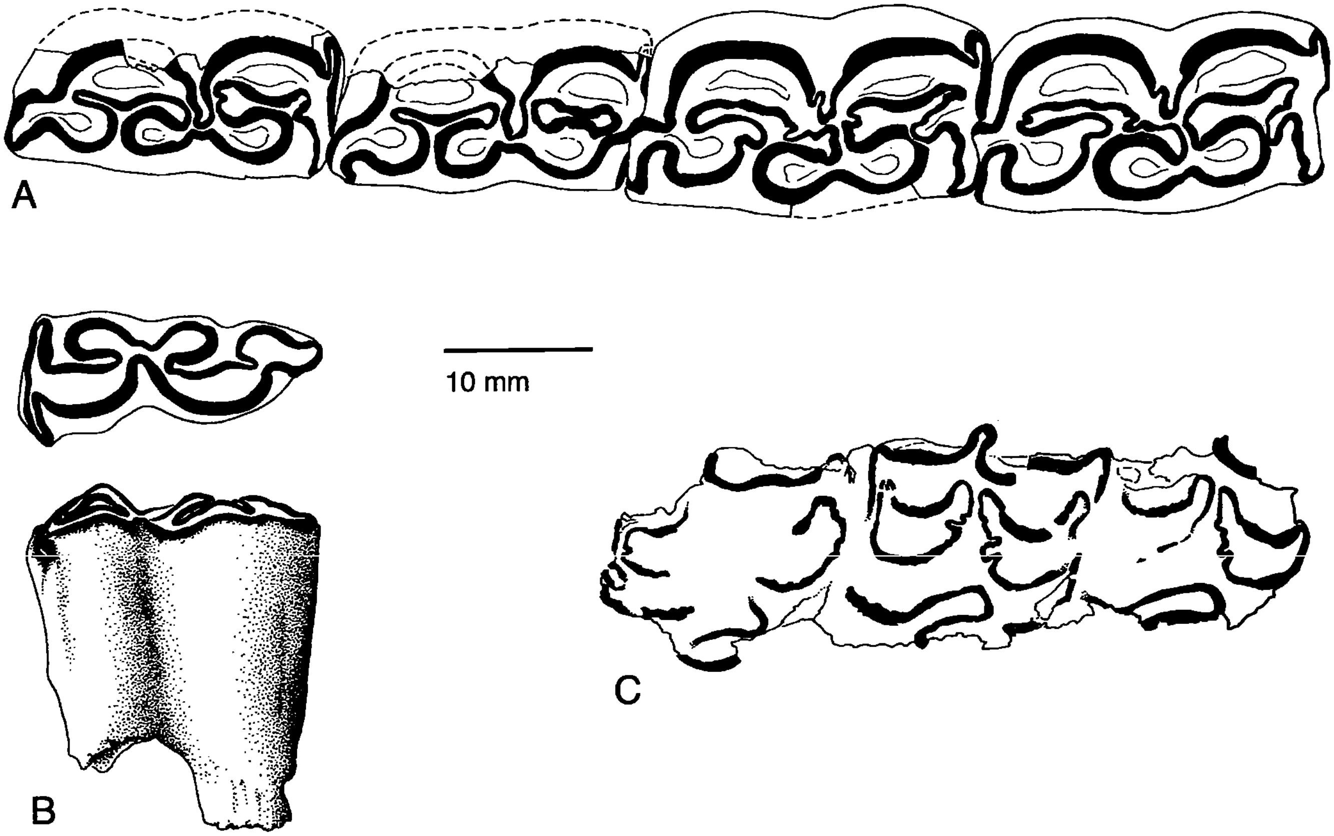

Figure 5. Miocene horse teeth from Wild Horse Creek #1. (A) *Cormohipparion occidentale*, left p3-m2 (OMNH 56877), occlusal patterns. (B) *Calippus martini*, left dp4 (OMNH 56878), in occlusal and labial views. (C) Equini, right M1-M3 (OMNH 48735), occlusal view.

length of P3: 21.9; P4: 20.2; transverse width of P3: 21.3 (est.); P4: 20.7; protocone length of P3: 7.2; P4: 6.4; protocone width of P3: 4.2; P4: 4.4; crown height at mesostyle of P3: 23.7 (est.); P4: 24.7. This specimen represents a species of horse smaller than *Cormohipparion occidentale.* It also differs distinctly from *C. occidentale* in the shape and size of the protocones. The features of its teeth are characteristic of hipparionine horses in North America (including *Hipparion, Neohipparion, Nannippus,* and *Cormohipparion*; Hulbert, 1987; MacFadden, 1984a). It is most similar in occlusal features to *Hipparion tehonense,* and we tentatively refer it to that species.

Tribe Equini

Calippus martini

Specimens: OMNH 56878, left dp4 (Fig. 5B); OMNH 56879, right dp4.

Discussion: These two deciduous teeth are from foals of a species of horse smaller than *Astrohippus ansae* as represented by deciduous teeth of that species from Optima, Oklahoma, in the OMNH collection. Identification, based only on two deciduous teeth, is tentative. The left dp4 from Wild Horse Creek #1 is moderately worn and its roots incomplete. It bears a very strong protostylid and deep ectoflexid. Anteroposterior length: 23.2; anterior width: 7.6; posterior width: 7.4. The right dp4 is unworn and the roots are not yet formed. This tooth measures 23.0 in anteroposterior length near the top of the crown (19.7 at the basal end); 6.8 in anterior width; and 6.9 in posterior width.

Equini, genus and species indeterminate

Specimen: OMNH 48735, associated series of three broken right maxillary molars (Fig. 5C).

Discussion: These poorly preserved teeth were found in the road cut along the highway. The teeth are rooted, hypsodont, and moderately curved (radius of curvature of the mesostyle on the M2 is about 70; Kelly, 1995). They are moderately worn. Crown height of the M2 at the mesostyle is 29.8; crown height of the M3 is 30.3. The occlusal surfaces are mostly covered with concretion which has been partly removed from the best-preserved tooth, the M2, in order to expose the enamel pattern. In each of the three teeth, the anterolingual part of the protocone is broken away at the occlusal surface. The remaining parts indicate that the protocones were moderately long and strongly connected with the protoloph. This is the characteristic pattern in upper molars of the tribe Equini and is unlike the Hipparionini (Webb and Hulbert, 1986; Hulbert, 1988a; MacFadden, 1992). Fossette plications are few and simple. There is no hypoconal groove in the M2 but in the M3 the hypoconal groove appears to have formed a fossette. A weak preprotoconal groove is preserved in the M2; the postprotoconal valley is moderately developed.

These teeth indicate a horse of medium to small size.

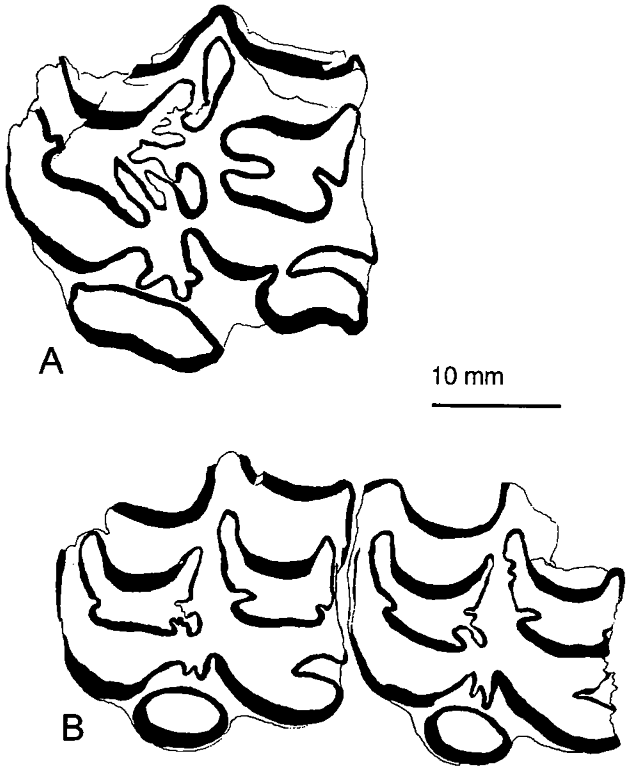

Figure 6. Miocene horse teeth from Wild Horse Creek #1. (A) *Cormohipparion occidentale*, left upper cheek tooth, probably P3 or P4 (OMNH 57309), occlusal view. (B) *Hipparion tehonense*, left P3-P4 (OMNH 57308), occlusal view.

Other measurements of the M2 are anteroposterior length: 17.7; transverse width: 17.5 (est.); protocone length: 7.1; protocone width: 4.3 (est.). For the M3, anteroposterior length: 17.1; transverse width: 16.6; protocone length: 7.0 (est.); protocone width: 3.0.

Among North American genera of Equini (MacFadden, 1992), the teeth are more hypsodont than in *Protohippus*. They are shorter in crown height at the mesostyle than in *Dinohippus*. They have less-developed postprotoconal valleys than *Hippidion* and *Onohippidium*. They are smaller and possess fewer enamel plications than *Dinohippus* and *Equus* (MacFadden, 1984b, 1986, 1992). In size and morphology, the teeth most closely resemble those of *Calippus* or perhaps *Pliohippus* or *Astrohippus*.

DISCUSSION

At a maximum, the Ogallala Formation includes vertebrate fossils ranging from middle Miocene to earliest Pliocene, spanning the Barstovian to Hemphillian land-mammal ages (Skinner and Johnson, 1984; Tedford and others, 1987). However, the older (Barstovian) fossils occur only in the northern High Plains—Nebraska (Reeves and Reeves, 1996). On the southern High Plains, the Barstovian land-mammal age is not represented, and Miocene vertebrate local faunas are all of Clarendonian and Hemphillian age, spanning about 7 million years—12 million to 4.5 million years ago. Few relevant studies have been made in the central High Plains of Kansas and Oklahoma, but Miocene vertebrate paleofaunas there also are representative of the Clarendonian and Hemphillian land-mammal ages.

Although the limited variety of fossil vertebrates precludes detailed interpretation, preliminary determination is possible of the relative age of the faunal assemblage of Wild Horse Creek #1 based primarily on the canid and the horses. Bone-cracking dogs of the genus *Borophagus* are common in local faunas of the Clarendonian, Hemphillian, and Blancan land-mammal ages (late Miocene and Pliocene) and are especially common in the Hemphillian (Tedford and others, 1987; Wang and others, 1999). The horse *Cormohipparion occidentale* was widespread in central and western North America from the late Barstovian through the early Hemphillian based on most records from the West Coast, the Great Basin, and the Great Plains. However, *C. occidentale* survived longer (until the late Blancan) in the Gulf Coast region (Hulbert, 1988a). *Cormohipparion* is particularly characteristic of the "Clarendonian chronofauna" of the Southern Plains, which encompasses Clarendonian and early Hemphillian land-mammal ages in this region (Tedford and others, 1987). The species *C. occidentale* occurs in the Gidley Horse Quarry of late Clarendonian age in Donley County, Texas. The second hipparionine horse, *Hipparion tehonense*, is common in Clarendonian and early Hemphillian faunas of the Great Plains (MacFadden, 1984a; Hulbert, 1993). It is possible that our specimen referred to *H. tehonense*—which occurred lower in the local stratigraphic section than the other fossils—indicates that the bottom of the local section represents the Clarendonian land-mammal age, whereas the top of the section could represent the Clarendonian or early Hemphillian. If the deciduous horse teeth are correctly identified as *Calippus martini*, they indicate a Clarendonian age. Fossils of *C. martini* are common in many of the classic localities around Clarendon, Texas—the type area for the Clarendonian land-mammal age (Schultz, 1990a).

The last fossil horse described here, a small species represented by poorly preserved upper molars, may also represent *Calippus*, but preservation is too poor to allow definite identification. Most other taxa in the reported assemblage are insufficiently identified to contribute to the age assignment, but they do not refute a Clarendonian-Hemphillian age for the assemblage. Additional fossils may help refine the age of the vertebrate assemblage. More important, further biostratigraphic and geological studies are necessary to explain the stratigraphic relationships of the Permian and Miocene deposits, particularly with respect to the reworking of Permian units during the Miocene, and the Miocene units in late Quaternary time.

Various geological and paleontological evidence from the southern High Plains indicate that, during deposition of Ogallala sediment, the climate changed from subhumid/subtropical at the beginning to semiarid/arid at the end (Reeves and Reeves, 1996). The giant tortoise *Hesperotestudo* is common in other local faunas of the Ogallala Formation, and allows a preliminary conclusion about paleoclimate: Giant tortoises are intolerant of prolonged freezing temperature and are unable to burrow, like smaller tortises, for protection. Thus they are restricted to tropical and subtropical climates (Hibbard, 1960; Cassiliano, 1997). Presence of large land tortoises at Wild Horse Creek #1 suggests a mild, nearly frost-free climate for western Oklahoma in late Miocene time.

ACKNOWLEDGMENTS

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Abandoned Coal Mine Land Reclamation Program of the Oklahoma Conservation Commission

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HISTORICAL BACKGROUND

Coal mining has been underway in eastern Oklahoma since 1872. Over the years, thousands of acres of mined land have been left unreclaimed in a 16-county area: more than 32,000 acres from surface mining and another 40,000 acres from underground mining (Fig. 1). Because early production in Oklahoma was almost entirely from underground mines, scarring of the landscape was not particularly obvious, except for scattered gob piles (mine refuse), shaft openings, and subsidence features. However, with the development of large power equipment, surface mining became increasingly important. In 1943, surface mining accounted for 50% of annual production; by 1967, it accounted for 99% or more. Today, more than 30 years later, surface mining continues to be the primary method of mining coal in Oklahoma. As a result, large areas with elongate ridges of spoils (overburden material), water-filled pits, and steep highwalls have been left after coal has been surfaced mined (Fig. 2). Unreclaimed areas are unsightly, unproductive, and, in many cases, dangerous. As of August 2001, 23 known deaths had occurred in Oklahoma at abandoned mine sites (Table 1).

For years, directors of conservation districts in eastern Oklahoma voiced their concern to local legislators about the mined areas and the need for reclamation legislation that would help restore them. However, no reclamation laws were passed in Oklahoma until the Open Cut Land Reclamation Act of 1968; it required leveling only the tops of spoil ridges to a width of 10 ft. In 1971, the State's reclamation requirements were strengthened by requiring "a rolling topography traversable by machines or equipment commonly used with the land after reclamation." Directors of conservation districts, as well as other groups and citizens in Oklahoma, believed that reclamation laws were still inadequate, and they turned to the U.S. Congress for assistance.

On August 3, 1977, President Jimmy Carter signed Public Law (PL) 95-87, known as the Surface Mining Control and Reclamation Act of 1977 (SMCRA). This federal legislation established a nationwide system for controlling the surface effects of active coal mining. The act also established a trust fund for the purpose of reclaiming orphan coal mine land that endangers public health and/or safety. Money for the Abandoned Mine Land (AML) Trust Fund is generated from a tax on active coal mining at the following rates: $0.35 per

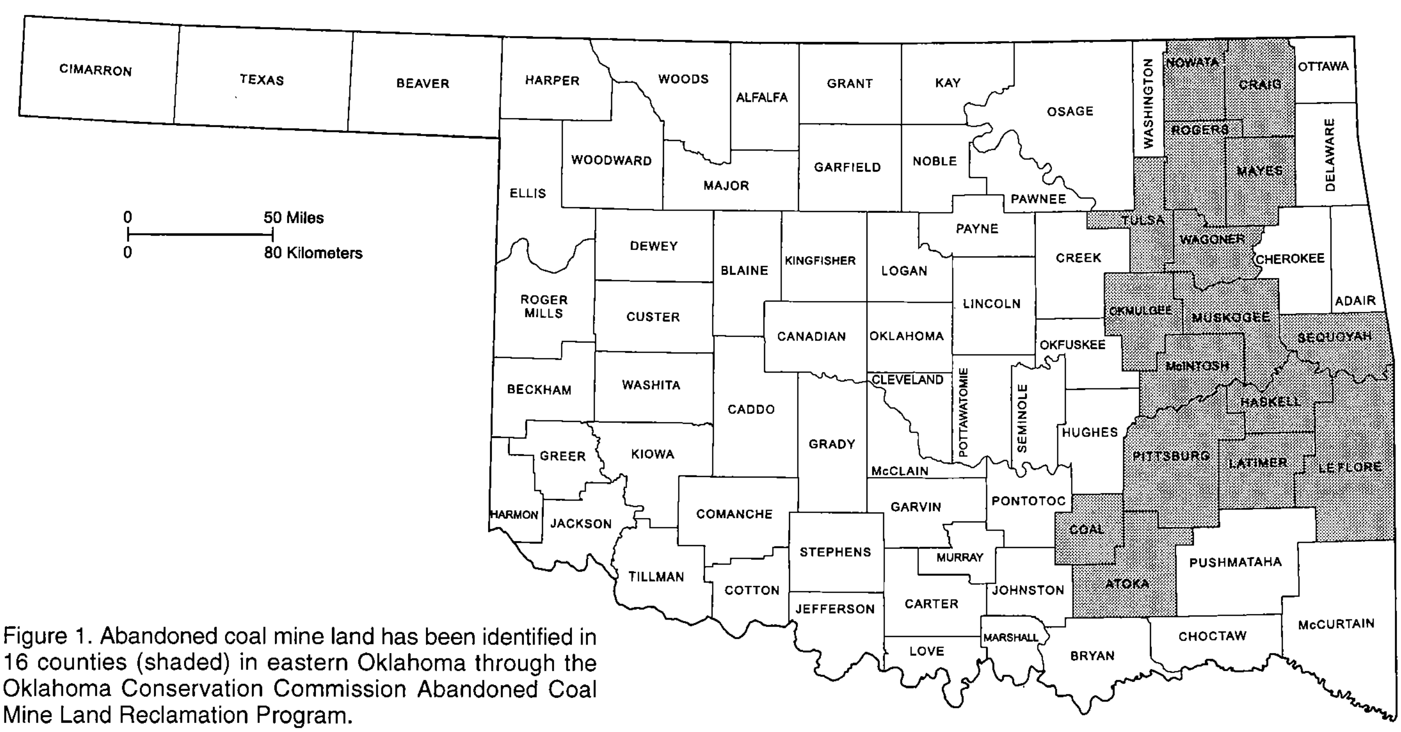

Figure 1. Abandoned coal mine land has been identified in 16 counties (shaded) in eastern Oklahoma through the Oklahoma Conservation Commission Abandoned Coal Mine Land Reclamation Program.

TABLE 1. — Known Deaths at Oklahoma AML Sites[a]

Year	Who	How	Where
1999	Female teenager	Drowned in strip pit	Next to Heavener city limits
1999	Male teenager	4-wheeler accident in spoil piles	Southeast of McCurtain
1997	Male teenager	Drowned in strip pit	Southwest of Sallisaw
1994	Female teenager	Drowned in strip pit	North of Kinta
1994	Male teenager	Drowned in strip pit	North of Claremore
1993	Male adult	Exposure among spoil piles	Near Chelsea
1992	Male teenager	Lack of oxygen in underground shaft	Northwest of Poteau[b]
1991	Male adult	Drowned in strip pit	East of Stigler[b]
1990	Female adult	Car into strip pit	Near Tulsa[b]
1989	2 Female children	Drowned in strip pit	Northeast Tulsa[b]
1988	Male teenager	Truck into strip pit	Northwest of Poteau[b]
1984	Male adult	Drowned in strip pit	West of Sallisaw[b]
1983	Male adult	Drowned in strip pit	Northeast of Poteau[b]
1983	Male adult	Fell from highwall into dry strip pit	West of Foyil[b]
1982	Male child	Drowned in strip pit	Northwest of Oologah[b]
1981 or 1982	Male child	Drowned in strip pit	Northwest of Foyil[b]
1980	Male child	Drowned in strip pit	Northwest of Foyil[b]
1979	Male adult	Drowned in strip pit	Northwest of Keota[b]
Mid 1970s	2 Adult newlyweds	Car into strip pit	West of Foyil[b]
Mid 1970s	Male adult	Drowned in strip pit	West of Foyil[b]
1972	Male adult	Drowned in strip pit	Southeast of Broken Arrow[b]

[a]23 known deaths as of August 2001.

[b]Site has been reclaimed.

Note: In May 1982, a bull elephant and four female elephants broke away from the circus in Sallisaw. The bull elephant was killed when he fell off a strip pit highwall and the other elephants fell on him.

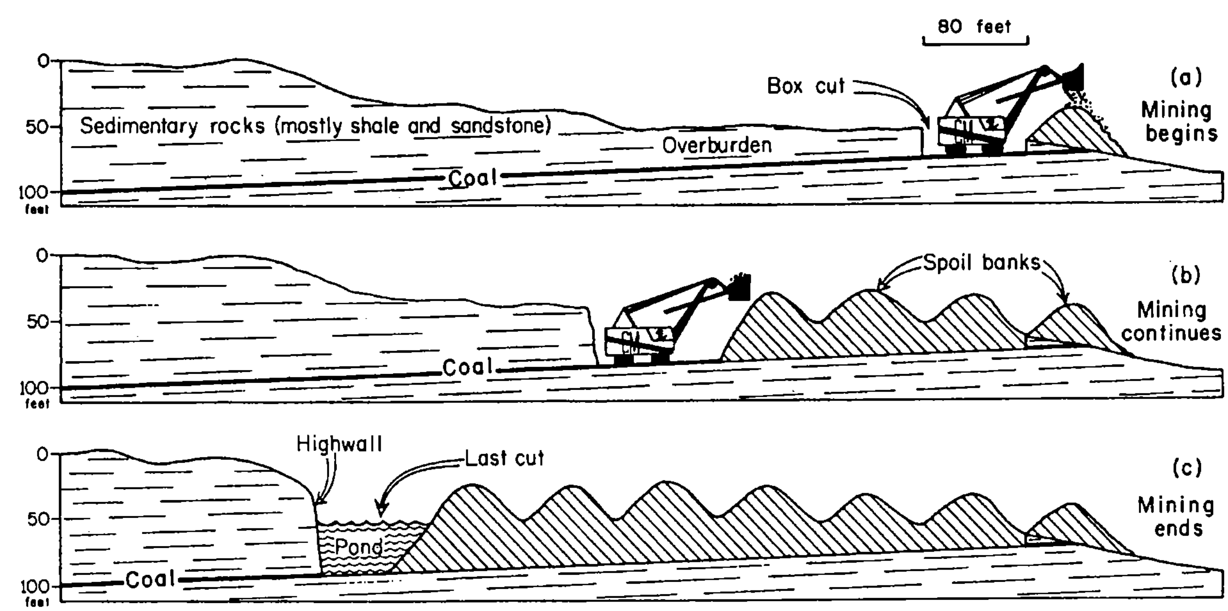

Figure 2. Schematic cross sections show the stages of surface mining for coal, as well as the highwall, water-filled pit, and spoil banks that need to be reclaimed when mining ends (from Johnson, 1974).

ton for surface-mined coal, $0.15 per ton for underground-mined coal, $0.10 per ton for lignite coal. By law, a state is to receive at least one-half of the fees collected in that state. The Office of Surface Mining Reclamation and Enforcement (OSM), within the U.S. Department of the Interior, is the federal agency responsible for allocating the reclamation fees in the AML Trust Fund. The tax on active coal mining is scheduled to end in 2004.

Because of their concern for the wise use and management of Oklahoma's natural resources, conservation districts had been monitoring the legislation leading to the passage of PL 95-87. Within months after its passage, Governor David Boren designated the Oklahoma Conservation Commission (OCC) as the State agency responsible for reclamation of abandoned coal mine land in Oklahoma.

On May 19, 1981, Governor George Nigh signed Oklahoma Senate Bill 217 implementing the AML Program in Oklahoma; the following spring, Cecil Andrus, Secretary of the U.S. Department of the Interior, approved the Oklahoma AML Reclamation Plan. Of 23 states with approved AML Programs, Oklahoma is the only one in which conservation districts are actively involved on a day-to-day basis with AML reclamation efforts.

The AML Program has inventoried hazardous abandoned mine sites in 16 counties in Oklahoma (Fig. 1). As of August 2001, the OCC had successfully completed 121 projects and had another six projects under construction, for a total of 3,438 reclaimed acres.

FUNDING FOR THE AML RECLAMATION PROGRAM

Funding Prior to 1982

Before Cecil Andrus, Secretary of the Interior, signed the Oklahoma AML Reclamation Plan in 1982, the AML Program received funding from the OSM through cooperative agreements. These agreements allowed the AML Program in Oklahoma to begin reclamation of AML problem areas before the State reclamation plan was approved.

Allocations from the AML Trust Fund

The first AML grants were approved by the OSM in 1982. For several years after that, states and tribes had to apply to the OSM annually for one-year administrative grants and three-year construction grants. Funding for the AML Program varied from year to year because states and tribes competed with each other for funding, which was based on the number of AML problem areas submitted to the OSM. Obviously, the states with more AML problems received most of the funds. The states and tribes continued to tell the OSM and the U.S. Congress that more stable funding was needed. Finally, in 1986, AML funding was allocated according to a formula that involved historic coal production in a state or tribal land, state share funds (from the tax on current coal mining), and the OSM's federal discretionary fund. This formula allowed states and tribes to know how much funding they would receive from year to year. In addition, both administrative and construction costs could be included under one grant.

In 1994, another positive change for states and tribes was simplification of the grant system. Originally, states and tribes had to submit a proposed project with detailed estimates of reclamation costs, letters of clearance, etc., before the grant could be approved. Under the simplified system, the grant proposal does not have to include a detailed cost breakdown for the project. The money is granted; then, when the state or tribe is ready for the construction dollars, the project is submitted to the OSM for a declaration of notice to proceed. With this system, there is no delay of funding.

Minimum Base Allocation Program

In FY 1988, the OSM established an annual minimum base allocation program. States with declining coal production, like Oklahoma, were given $1.5 million for construction and administration of their AML reclamation programs. The annual minimum base allocation fell to $1 million in FY 1989; it returned to $1.5 million for FYs 1990–91. Together with other members of the Mid-Continent Coal Coalition (Arkansas, Iowa, Kansas, Missouri, and Oklahoma), the OCC supported increasing the annual minimum base allocation to $2 million.

Under the budget reconciliation bill passed by the U.S. Congress in the fall of 1990, eligible states (such as Oklahoma) would receive not less than $2 million annually from the AML Trust Fund. This bill amended PL 95-87 by adding Section 402(g)(8). The new section states:

> Of the funds available for expenditure under this subsection in any fiscal year the Secretary shall allocate annually not less than $2 million for expenditure in each State, and for each Indian tribe, having an approved abandoned mine reclamation program pursuant to Section 405 and eligible lands and waters pursuant to Section 404 so long as an allocation of funds to such State or such tribe is necessary to achieve the priorities stated in paragraphs (1) and (2) of section 403(a).

For FYs 1992–94, the Oklahoma AML Program received the $2 million minimum annual allocation. However, the program received only $1.5 million in FYs 1995–2000 and only $1.6 million for FY 2001 (Fig. 3). The FY 2002 budget again proposes only $1.5 million. If the FY 2002 budget proposal is passed, Oklahoma will have lost $3.9 million in AML funds in the past eight years.

In Oklahoma, it would take more than $90 million to reclaim the high hazard sites (those most dangerous to the public) (Fig. 4). If funding in FY 2002 is again only $1.5 million, the ratio of total need to annual funding will be 60:1. Without increasing staff or overhead, Oklahoma's AML Program could utilize the full $2 million annual allocation specified in PL 95-87, Section 402(g)(8), as well as the annual $500,000 that the Rural Abandoned Mine Land Program received until 1995 (see section below on the Rural Abandoned Mine Land Program). Currently, AML projects budgeted at more than $3 million have been designed and are ready for construction as soon as funds are available. Thus, the $2 million minimum annual allocation is essential to Oklahoma's AML Program. Yet, the tax collected from active coal mine companies, which supports the AML Trust Fund, is scheduled to end in 2004. Currently, bills are being drafted for Congress to extend the tax for several more years. Extension of the tax is imperative!

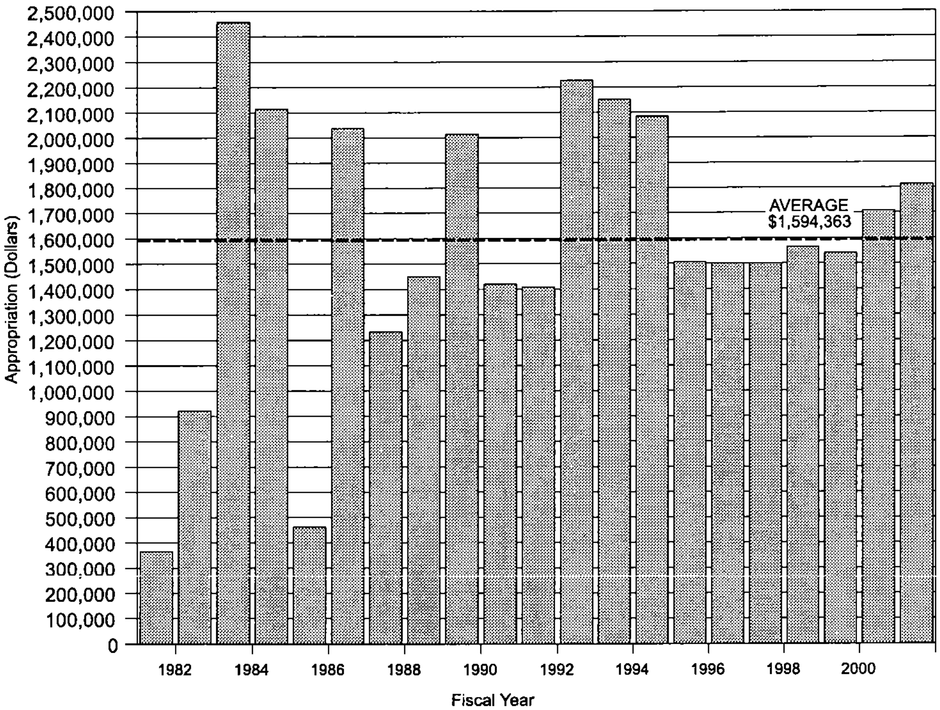

Figure 3. Annual congressional appropriations for Oklahoma reclamation grants. Note that appropriations for 1998–2001 include funding for the AML Emergency Program, for which the OCC assumed responsibility in 1998. Appropriations for 2000 and 2001 include funding for the Clean Streams Initiative.

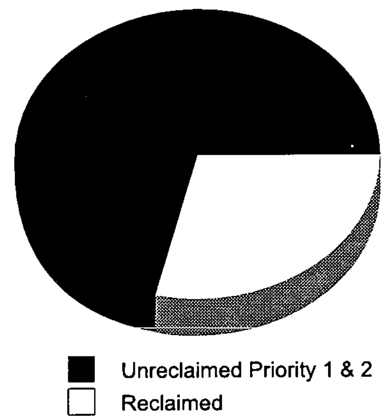

Figure 4. Unreclaimed abandoned coal mine land versus reclaimed land in Oklahoma as of August 2001. (Priority 1 and 2 projects are eligible for funding.)

Rural Abandoned Mine Land Program (RAMP)

In PL 95-87, the Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service, also has AML Trust Fund moneys set aside for reclamation purposes under the RAMP. Until FY 1996, expenditures for RAMP projects nationwide averaged approximately \$8–\$9 million per year. Oklahoma received about \$500,000 per year in RAMP funding. Congress has not appropriated any RAMP funds since FY 1995 because it said the states and the NRCS were duplicating reclamation efforts. Therefore, if shortfalls both in RAMP funds and in the minimum base allocation of AML funds are considered, Oklahoma will have lost \$6.9 million in reclamation dollars since 1995.

Unappropriated Money in the AML Trust Fund

At present, approximately \$270 million is collected annually from coal operators nationwide for the AML Trust Fund, but, for the past 23 years, Congress has appropriated only an average of about \$132.1 million per year in AML grants to states and tribes (Fig. 5). As of July 1, 2001, the balance of unappropriated money in the AML Trust Fund was more than \$1.6 billion. If this pattern continues, the amount of unappropriated money in the AML Trust Fund will continue to grow.

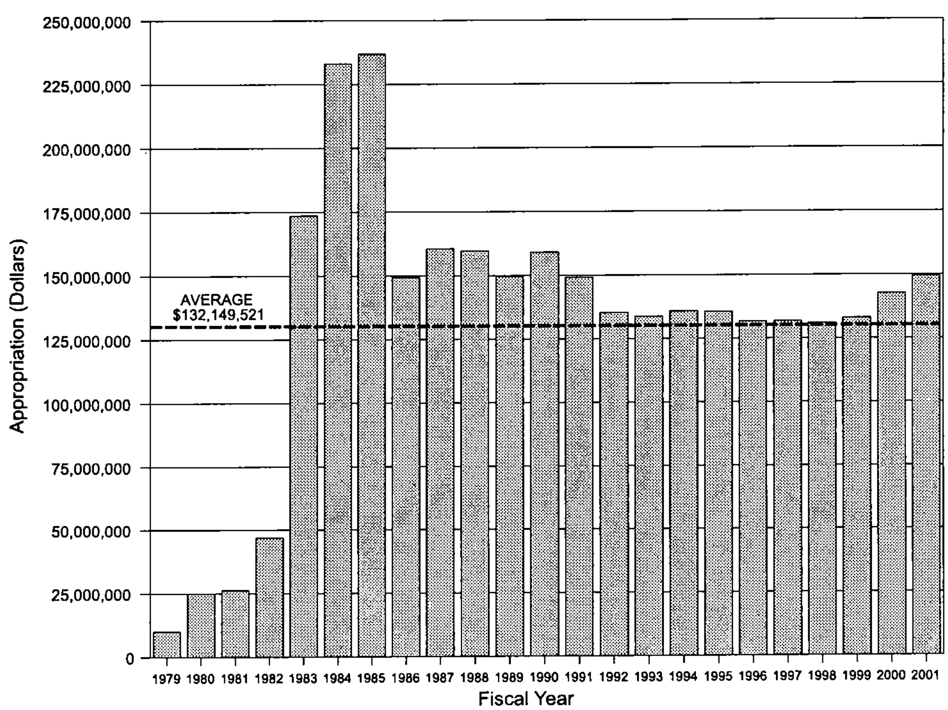

Figure 5. Annual congressional appropriations from the AML Trust Fund for state and tribe reclamation grants nationwide.

As a part of the Energy Policy Act of 1992, the AML Trust Fund began drawing interest. However, the interest is not added to funds for reclamation; instead, it goes to the United Mine Workers of America Combined Benefit Fund.

SELECTION OF PROJECTS IN THE AML RECLAMATION PROGRAM

Abandoned mine lands present public health, safety, and environmental problems. With assistance from the AML Program, conservation districts have gathered information and developed an inventory of hazardous sites in the 16 counties of the AML area (Fig. 1). Evaluations have been made of more than 30,000 acres, including surface-mined areas and areas with surface effects from underground mines. On U.S. Geological Survey (USGS) quadrangle maps, 261 problem areas have been identified; accompanying narratives describe the type and degree of each problem. Hazards range from dangerous highwalls and hazardous water bodies to open mine shafts, acid mine drainage, and dilapidated mine structures (Figs. 6–15). Numerous deaths and injuries have been associated with these problem areas (Table 1). Most deaths have been attributed to dangerous highwalls and associated hazardous water bodies. After the inventory was completed, most conservation districts ranked their AML problem areas according to the severity of hazard to the general public.

Annually, the AML staff selects project sites for future reclamation from the inventory and from sites identified by conservation districts and by the general public. To provide for more public input, four public regional meetings are held annually in the 16 counties with abandoned coal mine problem areas. Each regional meeting is held in conjunction with a meeting of the board of a local conservation district, and notices are published asking for public participation. Citizens may also submit AML problem sites to the AML Program in writing.

The AML staff reviews all problem sites identified by the conservation districts and the public. After each site is visited, a project selection matrix is used to rank the proposed

Figure 6. Dangerous highwall (Haskell County)—the vertical face remaining from the final cut of a surface mining operation. Highwalls in Oklahoma commonly are 20–90 ft in height. An associated pit may be either water-filled or dry. If a highwall is near a road or a populated area—as is the case in many instances—it constitutes a public safety hazard.

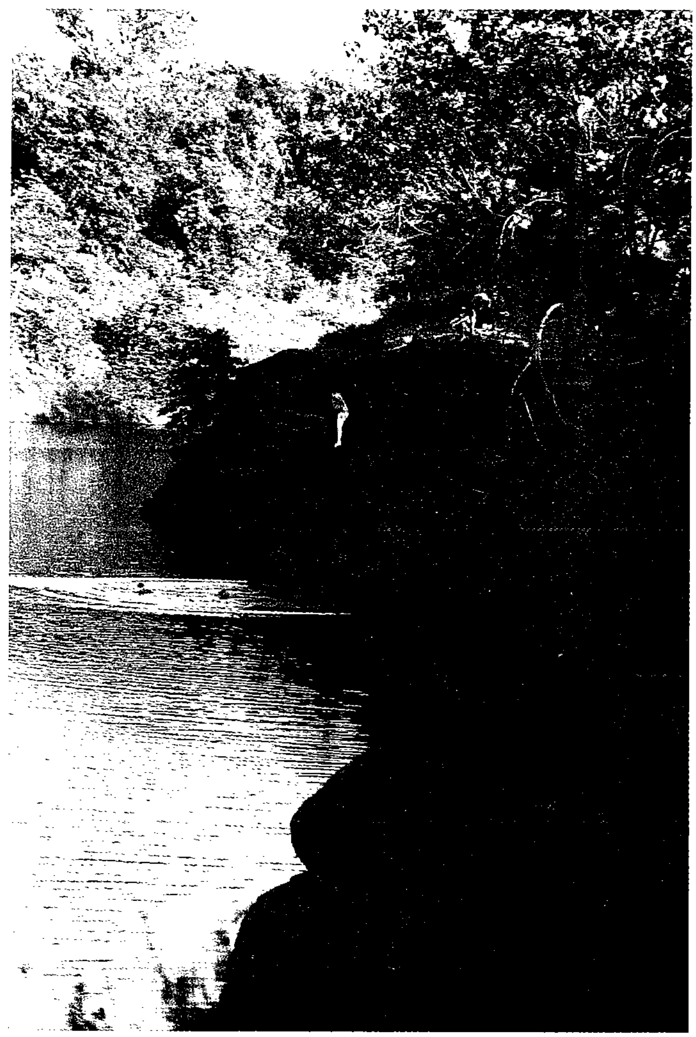

Figure 7. Hazardous water body (Sequoyah County)—any strip pit with impounded water, regardless of depth or surface area, that is considered an attractive nuisance and is located within close proximity to a populated area, public road, or other area of intense visitation. The hazard must be the result of some AML-related feature(s), such as hidden underwater ledges and steep or unstable banks. Hazardous water bodies are commonly associated with dangerous highwalls.

TABLE 2. — Steps in an AML Project

1. Problem identified
2. Site visit
3. Selection process
4. Landowner contacted
5. Right-of-entry for exploration
6. Survey and conceptual design
7. Right-of-entry for reclamation
8. Design—preliminary and final phases
9. Environmental assessment
10. Sent to Office of Surface Mining for approval and funding
11. Sent to Oklahoma Dept. of Central Services for bidding
12. Contractor accepted by AML program
13. Construction
14. Vegetation
15. Postconstruction monitoring

projects (Table 2). (Site visits are usually made between late fall and early spring, when there is minimal vegetative growth.) The AML staff then develops a list of potential projects for the near future, which is submitted to the State Reclamation Committee for comments and suggestions. (The State Reclamation Committee consists of the OCC; the Bureau of Land Management; the U.S. Army Corps of Engineers; the Department of Environmental Quality; the Natural Resources Conservation Service; the OSM; the Oklahoma Archeological Survey; the Oklahoma Association of Conservation Districts; the Oklahoma Biological Survey; the Oklahoma Department of Agriculture, Forestry Division; the Oklahoma Department of Mines; the Oklahoma Geological Survey; the Oklahoma Wildlife Federation; the Oklahoma Historical Society, State Historic Preservation Office; the USGS; and the Wildlife Conservation Department.)

Even after potential AML projects have been identified, there are many hurdles to overcome before reclamation funds can be received. A key element is making early contact with the land owner. After the site visit, the AML staff has a general concept about the kind and amount of reclamation that should take place. It is important to discuss the concept with the landowner at this early stage in a project. If such contact is not made, many staff hours and considerable money may be spent, only to learn later that a landowner is not in favor of reclamation. In these discussions, the landowner should be apprised of the three eligibility requirements for reclamation:

1. The land must have been mined before August 3, 1977, or after August 3, 1977, if there is no continuing responsibility for reclamation by the coal operator and little or no bond money is available from the State or federal government to accomplish the reclamation.

2. The land was left either unreclaimed or inadequately reclaimed.

3. The land is in a condition that endangers the health or safety of the public or the quality of the environment, or that prevents or damages the beneficial use of the land or water resources.

The AML Program may reclaim a site without a landowner's consent, but nonconsensual reclamation is used only in situations where the AML staff believes the potential danger to the public is very high. Of the 127 AML projects completed or under construction, nonconsensual reclamation has been used in only three cases.

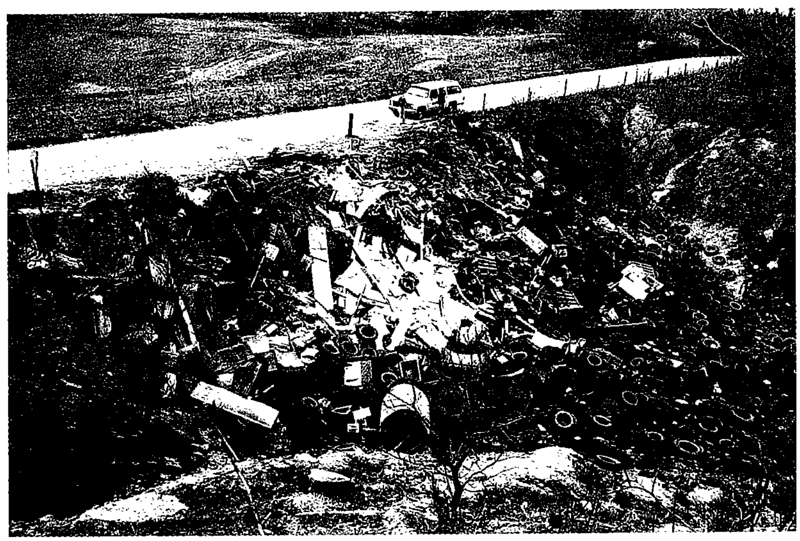

Figure 8. Industrial/residential waste (Rogers County)—unauthorized waste disposal (industrial or residential) at an AML site that poses a danger from unsanitary conditions or from the toxic emissions of burning refuse.

Figure 9 *(right)*. Hazardous equipment or facilities (Rogers County)—any dilapidated equipment or facilities at an AML site (old engines, mine cars, rails, mine entrance, and processing facilities) that are hazardous and located within close proximity to a populated area, public road, or other area of intense visitation.

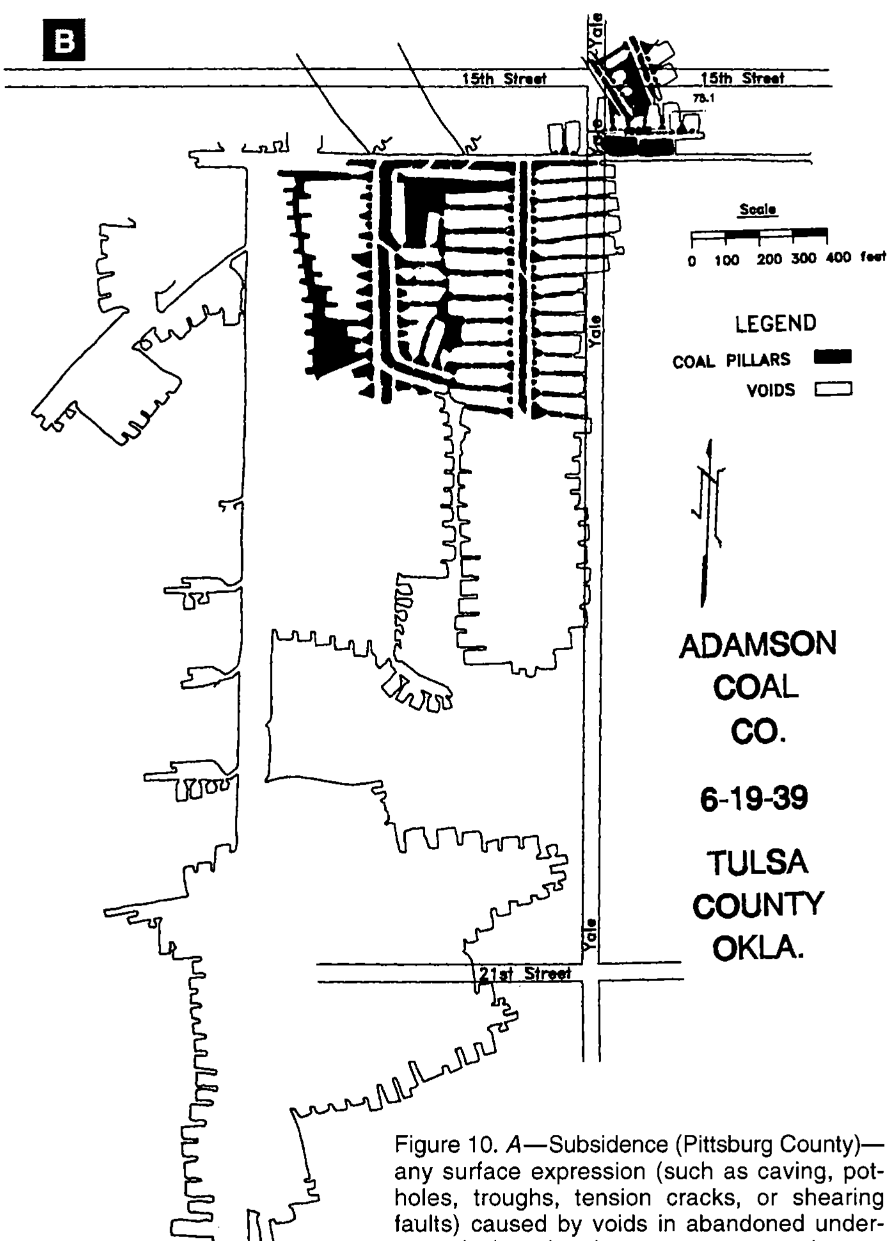

Figure 10. *A*—Subsidence (Pittsburg County)—any surface expression (such as caving, potholes, troughs, tension cracks, or shearing faults) caused by voids in abandoned underground mines that damages property and poses danger to the public. *B*—Example of underground mine workings (Tulsa County).

DESIGN OF PROJECTS IN THE AML RECLAMATION PROGRAM

The AML Program obtains a written right-of-entry from each landowner to do exploratory work (Table 2). Designs for AML projects are done by private firms and by AML staff. To date, all AML underground projects and most strip-pit projects have been designed in-house. When a project site is too heavily timbered or too dangerous to survey on the ground, the AML Program contracts for an aerial survey. Aerial data is then used to prepare the design.

An AML design is prepared in three phases: conceptual, preliminary, and final. The conceptual design is prepared after the site visit and shown to the landowner (Table 2). It may only be a rough, one-sheet plan view, showing the extent of the proposed reclamation. As mentioned in the previous section, landowner input is needed early in the design stage—before a lot of time and money is spent in preparing a detailed design. When the landowner and the AML staff agree on the conceptual design, the landowner signs a right-of-entry to permit the reclamation work. In the preliminary design phase, surveys are completed, grading plans are developed, and erosion control measures are designed. This phase requires more time than either of the other two design phases (conceptual and final) because of reviews, additions, deletions, and other input. In the final design phase, plans and specifications for all work items are completed and assembled in preparation for the bid process.

The design must take into account the hydrology of a site. During heavy rainfalls, most strip pits act as reservoirs. If—as most landowners wish—a pit is filled with the mining material left on site, its storage capacity for runoff water is eliminated. Therefore, it is critical to assess the amount of surface water that moves through a site. Sometimes a portion of the strip pit is left to act as the reservoir. In many cases in which the pit is filled in totally, channels are designed with appropriate grade stabilization in order to reduce the erosion and to slow the flow of water.

APPROVAL AND FUNDING OF PROJECTS IN THE AML RECLAMATION PROGRAM

According to the National Environmental Policy Act of 1969 (NEPA), when federal funds are involved in a project, a site-specific environmental assessment (EA) must be conducted. An EA examines whether or not project activity will have a significant impact on the physical, social, and/or economic environment. A broad range of environmental concerns are evaluated for each construction

Figure 11. Acid mine drainage (Latimer County)—water discharged from mining or mine-related operations that contains high levels of dissolved iron and aluminum sulfates in conjunction with pH values of <4.5 (acidic). It is produced when oxygen dissolved in water reacts with the pyritic (iron sulfide) materials found in association with most coal deposits. Acid mine drainage can degrade the water quality of streams, often to the point of eliminating all biological activity within a stream. Acid mine drainage also can degrade drinking water supplies. Iron and manganese, which may be associated with mine drainage, increase the cost of treating water for drinking.

Figure 12. Gob piles (Craig County)—refuse removed from an underground mine, including mine waste, rock, pyrites, slate, or other unmarketable materials that are separated during the cleaning process. Gob piles commonly are found at coal-processing facilities.

project. General categories of environmental concerns include public health and safety; cultural resources; wetlands; fish and wildlife; hydrology; transportation and utilities; vegetation; recreation; socioeconomic factors; land use; noise; air quality; geology/future mining/soils/topography; aesthetics.

Before the OSM will approve funding for a project, NEPA-driven clearances must be received from certain federal and State agencies. The U. S. Fish and Wildlife Service must certify that no threatened or endangered species of wildlife will be significantly impacted by a project's activity (Endangered Species Act of 1973). Currently, the only animal that has been of concern in Oklahoma is the American Burying Beetle. The area of particular interest has been in Haskell,

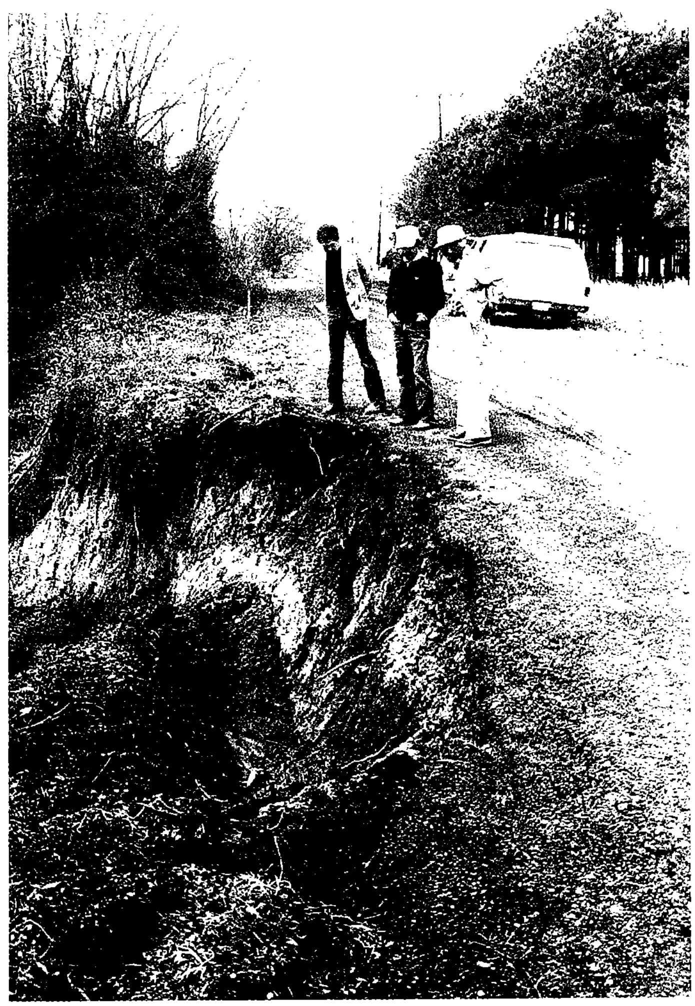

Figure 13. Clogged stream (Le Flore County)—the filling of a stream bed with silt and debris carried downstream from an AML site by surface runoff. The sediments block the stream and cause flooding of roads and/or residences, thus posing a danger to improved property and the public.

Figure 14. Portal (Le Flore County)—a surface entrance to a mine drift, tunnel, adit, or entry that is not sealed or barricaded. It poses a threat when it is located close to a populated area, public road, or other area of intense visitation.

Latimer, Le Flore, and Sequoyah Counties. So far, AML staff have conducted beetle surveys on two AML sites—one in Sequoyah County and one in Latimer County. Although other species of burying beetles were found, no American Burying Beetles were found on these sites. The AML Program has had to delay construction of one project in Haskell County so that the construction activity would not occur during the beetle season, May–September.

If a strip pit is water-filled and is larger than 0.5 acres, the AML staff must obtain a 404 Permit from the Corps of Engineers as mandated by the Clean Water Act. This permit allows fill material to be placed into U.S. waters, which include strip pits. Also, if the pit is not water-filled but contains vegetation characteristic of that found in wetlands, then a 404 Permit must be obtained. To date, the Corps has not denied a 404 Permit for any AML project; however, in some cases, the AML staff has had to mitigate the impact that the construction activity had on wetlands.

The National Historic Preservation Act of 1966 requires that the State Historic Preservation Office and the State Archeologist be consulted concerning any cultural resources. Historic features are sometimes associated with abandoned underground mines, most of which are more than 50 years old.

When all NEPA requirements are met and clearances have been received, the OSM issues the AML Program a notice to proceed with the construction project. This notice allows funds to be obtained for construction.

RECLAMATION OF PROJECT SITES IN THE AML PROGRAM

Construction

The AML Program works with the Construction and Properties Division of the Oklahoma Department of Central Services (DCS) to contract all AML construction. Copies of the project plans and specifications are given to the DCS, which sends them to all interested contractors (Table 2).

Figure 15. Vertical opening (Le Flore County)—[1] a vertical or steeply inclined mine shaft or opening that is not sealed or barricaded, or [2] a hazardous vertical opening to a mine caused by subsidence (see Fig. 10A). Such an opening is considered a threat to the public whether or not it is close to a populated area, a public road, or other area of intense visitation.

Bidding

The DCS sets the date for a prebid meeting, which is held at the project site in order to give contractors an opportunity to walk the site and to discuss the work to be performed with AML and/or DCS staff. (Attendance at all prebid meetings is mandatory for interested contractors.) At the prebid meeting, a DCS representative explains the DCS contracting requirement that three bonds be posted: statutory, performance, and defect. The statutory bond ensures that subcontractors and suppliers of equipment parts are paid. The performance bond ensures that the job is completed according to the plans and specifications. Both the statutory and performance bonds are released after all work has been completed and final inspection is held. The defect bond ensures that materials and workmanship are sound. The defect bond is released one year following acceptance (final inspection) of the job. Bond costs to the contractor commonly are about 3–5% of the bid price, and the amount of each bond equals the low bid accepted for the job. For example, if the low bid is $100,000, then the contractor has to post three bonds at $100,000 each.

During the prebid meeting, contractors are reminded that the contract specifies the number of calendar days to complete the work and that normal rain days have been included in this number. Contracts for AML projects average 6 to 7 months in length, and there are $300 per day liquidated damages for most projects that are not completed on time.

Each bid opening is conducted at the DCS office in Oklahoma City, and it usually occurs approximately two weeks after the prebid meeting. After the bid opening, the AML Program has 20 days to accept or reject the low bid. During this 20-day period, the AML staff reviews the equipment list provided by the low bidder, checks on references of past work (especially if the contractor has never performed AML work), and checks OSM's Applicant/Violator System (AVS). The AVS lists contractors who have outstanding violations in the active coal mining industry. If the low bidding contractor or subcontractor is on this list, then the low bid must be rejected. To date, the AML Program has never rejected a low bid on the basis of the AVS.

After the AML staff notifies the DSC in writing that the low bidder is accepted, the DCS prepares the contract and issues a work order. The contractor then has 10 days to begin the reclamation work. As soon as they receive a copy of the work order, the AML staff calls the contractor to set a date for the prework conference. During this meeting of the contractor and the AML staff (held on the project site), each contractual work item is discussed, and the contractor has the opportunity to ask questions concerning the job.

Inspection of Reclamation Work

When the actual reclamation work begins, an AML inspector provides on-site inspection of the work as it is taking place. The AML Program has eight temporary/part-time project inspectors. In the past, an inspector worked 40 hours per week while assigned to a reclamation project. However, budget cuts have forced the AML Program to reduce the work week to approximately 24 hours per week. Critical work—such as pouring concrete, installing pipe, and placing riprap—still require full-time inspection. Inspectors also use gas meters to check mine openings and subsidence areas for methane or for lack of oxygen, when these areas are being reclaimed. Such precautions are necessary to ensure safety.

The inspector calls the AML staff each Monday morning to provide an update of the work performed. When on-site, the inspector keeps a daily job diary of all work activities and submits a monthly written progress report to the AML Program. Photographs are taken before, during, and after construction to document the project work. These photos are invaluable for use in reports, news articles, slide presentations, or litigation. In order to provide information about the project, the inspector also attends monthly board meetings in the conservation district where the reclamation is being performed.

As a contractor nears the completion of the reclamation work, a final inspection date is set. At the final inspection, all work items are checked to see if they have been completed as called for in the plans and specifications. Those usually attending the final inspection are the contractor, the AML Project inspector, the AML Program engineer, and a representative from the DCS. Sometimes an OSM representative and someone from the local conservation district may attend. If all work items are completed, the final payment to the contractor can be made.

Vegetation

The primary contractor (dirt mover) is not responsible for providing vegetation on the completed AML project site. The AML staff relies heavily on local conservation districts to provide vegetation services because the number of private contractors in the vegetation business has dwindled since the mid-1980s.

Before any vegetation is planted, soil samples are taken and analyzed to assess the kind and amount of fertilizer to be applied and to check the pH. If the pH is low, lime will be incorporated into the fertilizer.

The type of permanent vegetation chosen for a reclaimed site depends on the time of year a project is completed. In the spring or early summer, the options are the native grasses or bermudagrass (Bermuda grass). During the fall and winter, cool season grasses—such as fescue, perennial ryegrass, and clover—can be used. Bermudagrass is not recommended for fall and winter planting because it takes too long to establish a full vegetative cover. In addition, bermudagrass requires much more maintenance (fertilizer, water, and other soil amendments), especially in the poor soils on most AML sites. During the winter, trees or shrubs—excellent wildlife habitat—may also be planted. However, as is the case with bermudagrass, poor soil conditions may limit the survival rate of trees and shrubs. The AML Program has planted trees and/or shrubs on several sites, particularly completed underground sites where the predominant cover is trees.

Another option for permanent vegetation is slab sod. It is sometimes used on steep slopes (where vegetative equipment cannot be used) or in low-flow drainage ditches to reduce erosion.

If an AML project is completed after the optimal time for planting permanent vegetation, a temporary cover will be used. Most AML sites lack organic matter and commonly

TABLE 3. — Summary of AML Emergency Projects in Oklahoma

Name	County	Completion date	Cost	USGS 7.5′ Quadrangle
1. Latimer County Road No. 1	Latimer	1/82	$ 29,746.93	Gowen
2. Walter Hogue Subsidence	Coal	12/84	70.00	Coalgate
3. Wilburton Subsidence (Vern Bullard)	Latimer	6/85	75.00	Wilburton
4. Eddie Watkins Subsidence No. 1	Coal	2/86	280.00	Coalgate
5. Eddie Watkins Subsidence No. 2	Coal	4/87	210.00	Coalgate
6. Latimer County Road No. 2	Latimer	4/87	43,886.33	Wilburton
7. Gowen Pit Subsidence	Latimer	4/87	11,425.90	Gowen
8. Waters Subsidence	Latimer	4/87	19,097.87	Wilburton
9. Coal County Courthouse Subsidence No. 1	Coal	7/88	347.00	Coalgate
10. Eddie Watkins Subsidence No. 3	Coal	7/88	240.00	Coalgate
11. Coalgate Tennis Court	Coal	9/88	13,724.75	Coalgate
12. Hartshorne High School	Pittsburg	10/88	16,729.75	Hartshorne
13. Center & Birch Street (Great Western Mine)	Latimer	3/89	17,796.00	Wilburton
14. Phillips Road	Coal	5/89	750.00	Coalgate
15. Haileyville School Subsidence No. 1	Pittsburg	8/89	2,255.70	Hartshorne
16. Coal County Courthouse Subsidence No. 2	Coal	3/90	700.00	Coalgate
17. Gayler Subsidence	Coal	3/90	609.95	Coalgate
18. Highway 31 Subsidence	Haskell	4/90	4,675.20	McCurtain
19. Panola Subsidence	Latimer	10/91	165.10	Panola
20. Highway 270 Subsidence (Harley Shelton)	Latimer	11/91	1,734.60	Wilburton
21. Haileyville School Subsidence No. 2	Pittsburg	12/91	532.01	Hartshorne
22. Wilkett Subsidence (SW 2nd Street)	Latimer	1/92	16,200.67	Wilburton
23. McCurtain Park Subsidence	Haskell	5/92	2,348.70	McCurtain
24. Grace Hood Subsidence	Latimer	8/92	1,945.10	Wilburton
25. Craig (Witteville Mine)	Le Flore	7/92	950.00	Poteau West
26. Hartshorne Hole (5th St. Subsidence)	Pittsburg	10/92	300.00	Hartshorne
27. Bonnie Cathey Subsidence	Latimer	11/92	1,028.90	Adamson
28. Haileyville School Subsidence No. 3 (Playground)	Pittsburg	12/92	827.01	Hartshorne
29. Wilburton (McCabe)	Latimer	1/93	386.81	Wilburton
30. Nancy Thurman Subsidence	Pittsburg	2/93	200.00	Hartshorne
31. Horine & 2nd Street (Haileyville No. 1)	Pittsburg	3/93	505.00	Hartshorne
32. Williams Meat Processing Co.	Pittsburg	6/93	575.00	Hartshorne
33. Dewar Subsidence	Okmulgee	5/93	946.25	Henryetta
34. Ken McDonald Subsidence	Pittsburg	5/93	575.00	Hartshorne
35. Alderson Shaft Subsidence (Ray Overton)	Pittsburg	12/93	18,410.92	Krebs
36. W. H. Webb Subsidence	Coal	1/94	299.20	Coalgate
37. Brenda Regan Subsidence	Latimer	5/94	700.00	Gowen
38. John McCabe	Latimer	6/94	382.00	Wilburton
39. Highway 31 Subsidence No. 2	Haskell	11/94	1,995.00	McCurtain
40. Highway 31 Subsidence No. 3	Haskell	11/94	862.20	McCurtain
41. Horine & 2nd Street (Haileyville No. 2)	Pittsburg	1/95	543.00	Hartshorne
42. Bill Smith Subsidence	Latimer	7/95	425.00	Wilburton
43. Otho Enis Subsidence	Latimer	10/95	590.00	Wilburton
44. Mildred Wilkett No. 2	Latimer	5/96	730.00	Wilburton
45. Lucy Watlington	Pittsburg	4/97	1,993.56	McAlester
46. Kenneth Lowe	Le Flore	10/97	11,113.55	Poteau West
		Subtotal	$229,884.96	
On February 17, 1998, the OCC AML Emergency Program took over responsibility for reclaiming emergency sites from the OSM.				
47. McAlester Prison Subsidence	Pittsburg	5/98	8,553.33	McAlester
48. Mule Creek Subsidence	Haskell	10/98	25,212.65	McCurtain
49. Bache Gob Fire	Pittsburg	9/98	1,972.74	Krebs
50. Haileyville School Subsidence No. 4	Pittsburg	5/99	8,942.92	Hartshorne
51. Mooney Subsidence	Latimer	6/99	28,648.15	Panola
52. Covey Subsidence	Pittsburg	6/99	4,494.41	McAlester
53. Enis	Latimer	7/99	6,811.17	Wilburton
54. Welch Subsidence	Pittsburg	9/99	4,361.88	Krebs
55. Haskell Land and Cattle Co. Subsidence	Pittsburg	11/99	9,905.45	Krebs
56. Hickerson Subsidence	Le Flore	4/00	13,761.98	Bokoshe
		Subtotal	$112,664.68	
		TOTAL	**$342,549.64**	

TABLE 4. — AML Civil Penalty Projects in Oklahoma

Project name	County	Acres reclaimed	Construction completion date	Cost of construction	USGS 7.5′ Quadrangle
J. C. Dixon	Okmulgee	40	9/14/89	$ 73,419.80	Okmulgee NE
Casselman Tipple	Okmulgee	15	6/1/90	16,475.00	Okmulgee NE
Rupert	Craig	132	6/27/90	89,315.50	Welch NW
Bill's Tipple (Fig. 16)	Craig	55	8/26/93	201,285.70	Okmulgee NE
Hefner	Craig	15	10/27/93	25,370.90	Estella
Cunningham	Okmulgee	18	3/28/96	53,052.97	Okmulgee S
	TOTAL	275			

consist of shaly soils. Temporary vegetation holds the soil in place until the permanent vegetation is planted, and the temporary covers can be excellent sources of organic matter as well.

The type of temporary vegetation planted depends on the season, as well as on the type of permanent vegetation chosen for the site. For example, if it were too late in the summer for a permanent planting of bermudagrass, millet could be planted as a temporary cover. Or, if construction on the site were not completed until the fall, winter wheat or ryegrass could be a temporary cover until the bermudagrass could be planted in the spring.

A site is hay mulched after the permanent vegetative cover is planted to prevent erosion and to hold soil moisture. A weed-free prairie hay or fescue hay is the preferred choice for mulch. The Rogers County Conservation District owns a hay mulcher and does the mulching on AML Program sites.

Maintenance and Monitoring

When landowners sign a right-of-entry for reclamation, they agree not to disturb or graze the permanent vegetation at a site for a minimum of two years from the time it is planted. If necessary, the AML Program—working with the local conservation district—applies fertilizer and controls weeds during this same period. If extreme weather conditions cause the vegetation to fail, the AML Program and the local conservation district will replant the permanent vegetation.

The AML staff monitors completed projects for several years. (A maximum number of years for monitoring

Figure 16. *A*—Bill's Tipple civil penalty project in Craig County before reclamation. *B*—Same site after reclamation, completed August 26, 1993.

has not been set.) The policy has been to correct sites where structural failures or excessive erosion occur. However, if erosion occurs because a landowner has allowed overgrazing of an AML site, the AML Program will not correct the problem.

OTHER TYPES OF PROJECTS

There are several funding sources for other AML projects. These projects also are funded from the AML Trust Fund, but they are not a part of Oklahoma's annual AML appropriation.

AML Emergency Projects

An AML emergency refers to a sudden danger or impairment that presents a high probability of substantial physical harm to the health, safety, or general welfare of people before the danger can be abated under normal procedures for program operation. The most common AML emergencies in Oklahoma are subsidence events, in which the surface of an abandoned underground coal mine collapses and leaves an open hole or a depression.

Prior to 1998, the OSM conducted all emergency work in Oklahoma. On February 17, 1998, the OSM gave the OCC authorization for the AML Emergency Program, and the OCC AML staff worked with the OSM to develop administrative procedures and guidelines. The position of OCC AML Emergency Coordinator was established. The coordinator is responsible for the initial investigation of a reported emergency, as well as for the reclamation work after an emergency is declared. The OSM still must approve a site as an emergency. Staff of the OSM and the AML Program can enter upon any land where an emergency has been declared in order to reclaim the site.

Annually, the OCC receives a one-year grant for emergency work from the OSM emergency account. Any funds not used at the end of the year are returned to OSM, and another grant is issued for the next year.

Fifty-six emergency projects have been completed in Oklahoma. Ten of the emergency sites have been reclaimed since the Oklahoma AML Emergency Program was authorized in 1998 (Table 3).

Civil Penalty Projects

Reclamation bonds are required by SMCRA (PL 95-87) for all permitted active surface coal mines. These bonds are intended to cover the cost of reclamation should the permitted coal company not be able to complete the required reclamation. However, during an interim of several years after SMCRA was passed in 1977, State agencies (such as the Oklahoma Department of Mines) were trying to enact new rules and regulations. During this period, several coal mining companies failed to reclaim sites or left them inadequately reclaimed.

Under Section 518 of SMCRA, the Secretary of the Interior can use money collected pursuant to the payment of civil penalties to reclaim sites left unreclaimed or inadequately reclaimed. These moneys are known as the civil penalty fund, which derives from fines paid by coal companies that violate SMCRA. In Oklahoma, there are more than 2,000 acres of civil penalty sites that need reclamation.

Through cooperative agreements with the OSM, states can apply for civil penalty moneys. Since 1988, the AML Program in Oklahoma has completed six civil penalty projects (Table 4). One such project was an abandoned coal-processing facility in Craig County, adjacent to State Highway 10 near Welch (Fig. 16). Many dilapidated structures and pieces of equipment at the site were safety hazards. In addition, the presence of ~15,000 yd^3 of acid-forming coal refuse on the surface was a public health hazard; it also posed a major threat to the underlying groundwater aquifer. Structures and equipment were salvaged or buried, and the coal refuse was buried with a minimum 2-ft clay cover. A total of 55 acres was reclaimed at a cost of $201,285.70.

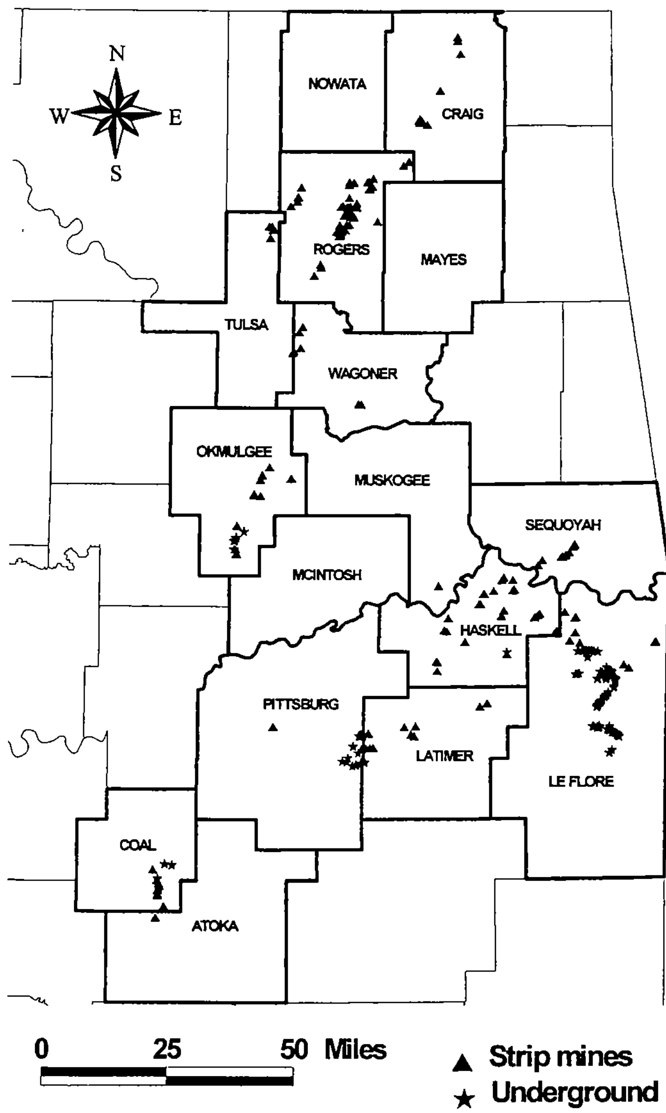

Figure 17. Reclaimed AML sites in Oklahoma. From Oklahoma Conservation Commission unpublished report, August 2001.

Clean Streams Initiative Projects

In FY 1997, Congress authorized funding for the Appalachian Clean Streams Initiative (CSI). The CSI is a government and public alliance, whose goal is to clean up streams and rivers polluted by acid and toxic drainage from abandoned coal mines. This initiative encourages increased information exchange, multi-agency coordination, and the formation of partnerships among government, citizens, and corporations to bring innovative solutions to this national problem. Over the past few years, funding has been expanded to states outside the Appalachian area.

Under the FY 2000 AML Simplified Grant, the OSM approved the first CSI grant to the OCC. The funds ($147,924.00) will be spent on a site in Latimer County known as the Red Oak Acid Mine Drainage project. The OSM issued the authorization for the project to proceed on June 26, 2001. The OCC has entered into an agreement with the University of Oklahoma for Dr. Robert Nairn (Assistant Professor, School of Civil Engineering and Environmental Science) to install a Mine Drainage Passive Treatment System (wetlands) and to provide postconstruction monitoring of the site.

The OSM approved a second CSI grant of $153,135 under the FY 2001 AML Simplified Grant.

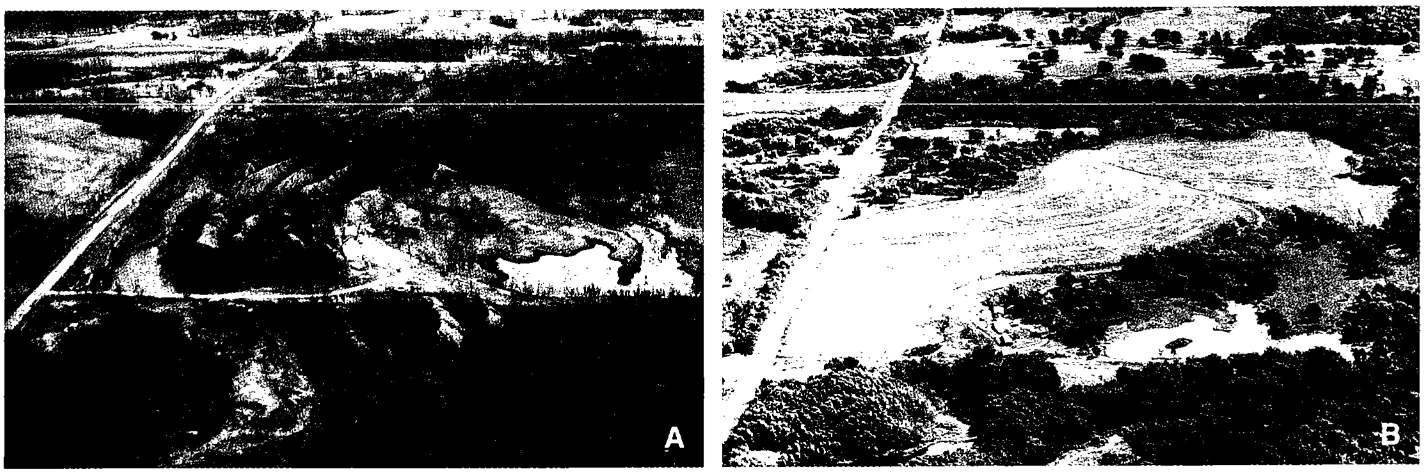

Figure 18. *A*—Lindsay-255 AML Project (Rogers County) before reclamation. This project is located near Claremore, close to the Oologah Reservoir. A 50-ft, final-cut highwall and pit paralleled the road to the reservoir. There was a strong potential for an accident because of considerable residential development in the area. *B*—Same site after reclamation. The pit was backfilled with the on-site spoil piles, eliminating 2,700 linear feet of highwall. A total of 37 acres was reclaimed at a cost of $227,114.00. The project was completed August 12, 1992.

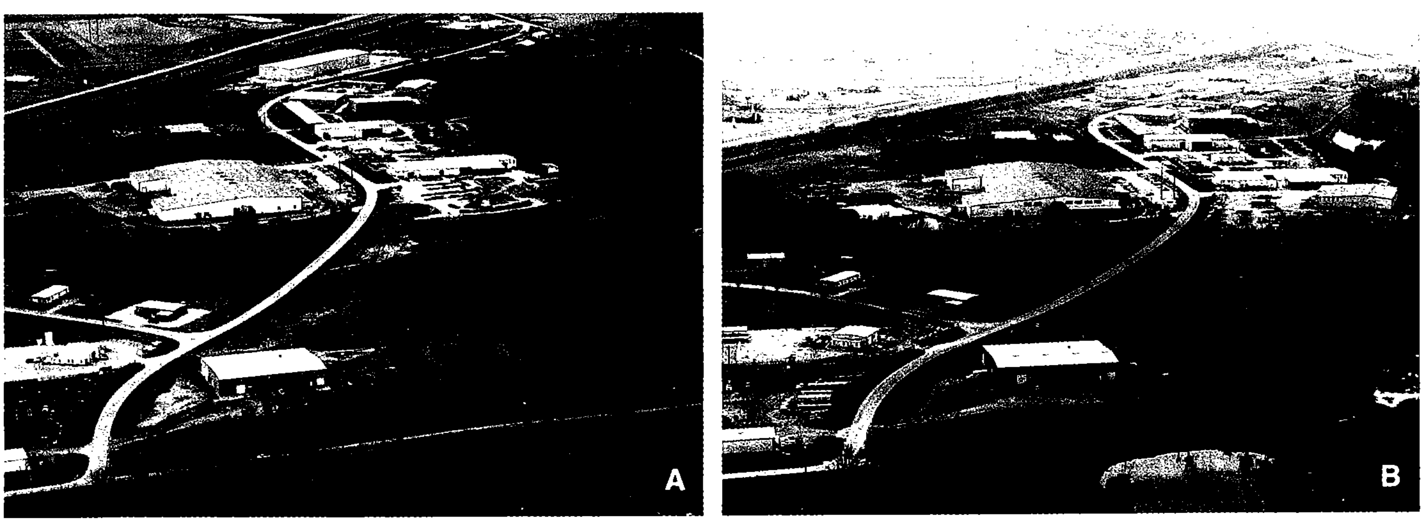

Figure 19. *A*—Industrial Park-208 AML Project (Rogers County) before reclamation. This project is located 3.5 mi southwest of Claremore in an industrial and residential development. The potential for a serious accident was very high because of the proximity of a well-traveled blacktop road and the absence of barriers between the old pits (with 8,820 linear feet of highwall) and residences in the area. *B*—Same site after reclamation. The pits were filled with on-site spoil piles (that had covered 19.4 acres). A total of 28 acres was reclaimed at a cost of $280,950.66. The project was completed March 2, 1994.

Special Projects

In 1988, the first reclamation project funded by OSM that involved a black college in research and demonstration was dedicated at Henryetta, Oklahoma. The U.S. Department of the Interior's Office of Historically Black College and University Programs was instrumental in obtaining the funding for this special project. The AML Program was responsible for the reclamation work on a hazardous water-filled strip pit, and Langston University conducted an experimental vegetation plot using various combinations of municipal sludge and fertilizers. The Okmulgee County Conservation District was the local sponsor.

Another project involved acid mine drainage from underground coal mines on U.S. Army Corps of Engineers' property on Lake Eufaula near Adamson in Pittsburg County. The Corps was concerned that acid water could ultimately reach the Pittsburg County Water Treatment Authority Plant just one-half mile from the acid seep. The Corps received money for a clean water program and provided the OCC with some of these funds. The AML Program worked with Dr. Mark Cox, University of Oklahoma Health Sciences Center, to install an anoxic drain to reduce the acidity of the water coming from the seep.

AML PROGRAM ACHIEVEMENTS

As of August 2001, Oklahoma's AML Program had completed 121 projects and had another six under construction, for a total of 3,438 acres reclaimed in 13 counties (Table 5; Fig. 17). The total acreage reclaimed includes hazardous water bodies, spoil piles, mine openings, subsidence sites, gob piles, dry pits, and mine waste. In the process of reclamation, 212,749 linear feet of highwall and 170 hazardous water bodies were eliminated; 132 subsidence sites were reclaimed; 18 structures were removed; and 286 mine openings were closed. Figures 18 and 19 show examples of AML Projects, before and after reclamation.

TABLE 5. — Oklahoma AML Program Achievements[a]

Number of authorized projects	127[b]
Projects completed	121
Projects under construction	6
Project pending	0
Total acres reclaimed	3,438.0
Hazardous water bodies	504.3
Spoil piles	2,758.8
Mine openings	60.6
Subsidence	13.2
Gob piles	31.0
Dry pits	62.0
Waste	8.1
Linear feet of highwall reclaimed	212,749
Hazardous water bodies reclaimed	170
Subsidence sites reclaimed	132
Structures removed	18
Mine openings closed	286

[a]As of August 2001.

[b]Authorized projects are those funded by an annual AML appropriation; they do not include other types of projects (i.e., emergencies, civil penalty, CSI, and special projects).

REFERENCE CITED

Johnson, K. S., 1974, Maps and description of disturbed and reclaimed surface-mined coal lands in eastern Oklahoma, showing acreage disturbed and reclaimed through June 1973: Oklahoma Geological Survey Geologic Map 17, scale 1:125,000.

Award Winning Partnership

In 1999, the Oklahoma Conservation Commission (OCC) and the Natural Resources Conservation Service (NRCS) teamed up to win the MidContinent Regional Award in the National Abandoned Mine Land Reclamation Awards Program. The awards program, which is sponsored annually by the Office of Surface Mining, honors states and tribes that have excelled in protecting the public from the hazards associated with abandoned mines.

The OCC and NRCS developed "The Oklahoma Partnership Approach to Reclamation of Abandoned Mine Land," which reclaimed 36 acres in Rogers County. The reclamation eliminated three dangerous highwalls, three hazardous water bodies, and a significant source of acid mine drainage into the Claremore municipal water supply. The partnership demonstrated that a very aggressive time schedule could be met by combining projects that were planned and designed by the two agencies into a single contract. Costs for administrative overhead, construction, and technical support were all reduced, and the project was completed two months ahead of schedule.

Left to right: Ron Clark, state conservationist, Oklahoma NRCS; Mike Thralls, executive director, OCC; Kathy Karpan, Office of Surface Mining.

Geological Society of America

South-Central Section Annual Meeting

April 11–12, 2002 ★ Alpine, Texas

The Department of Earth and Physical Sciences, Sul Ross State University, Alpine, Texas, will sponsor the 2002 annual meeting of the South-Central Section.

Located in the southern foothills of the Davis Mountains, the campus of Sul Ross State University is ideally situated for the meeting and celebrates the geology of Texas' only two National Parks.

Proterozoic metamorphic rocks that represent the Grenville orogeny in Trans-Pecos Texas are exposed in the Sierra Diablo and Van Horn Mountains, less than 100 miles to the northwest. Folded and thrusted marine strata ranging in age from Cambrian to Pennsylvanian that were deformed during the Ouachita-Marathon orogeny are well exposed in geologically classic areas like the Marathon basin, 30 miles to the east, and in the Solitario, 75 miles to the south. The world-famous Permian Reef forms several nearby mountain ranges, including the Guadalupe Mountains, 150 miles to the north, the Apache Mountains, 100 miles to the north, and the Glass Mountains, 30 miles to the east. Like much of central and west Texas, very thick sequences of Cretaceous limestone crop out throughout the Trans-Pecos area. In and near Big Bend National Park, 80 miles to the south, important fossil discoveries, including the pterosaur *Quetzalcoatlus* and the largest *Alamosaurus* ever found, have been excavated from these Cretaceous strata. Volcanic activity dominated the Trans-Pecos area in the mid-Tertiary, resulting in the creation of several large mountain ranges. These include the Davis Mountains, which represent the largest contiguous outcrop of alkalic rocks in the United States; the Chinati Mountains; the Bofecillos Mountains in Big Bend Ranch State Park; and the Chisos Mountains in Big Bend National Park, all within 100 miles of Alpine. The Trans-Pecos area is also situated in the easternmost part of the Basin and Range province in the United States.

One goal of this meeting is to focus on recent research in the National Parks and to discuss opportunities for acquisition of funding for continued work, including possibilities for revising the existing geologic maps of the parks.

The following agenda is planned:

Symposia

Geology of Big Bend National Park: What Have We Learned Since Maxwell and Others, 1967?
The Permian of the Southwest
Water Resource Frontiers
Long-Term Biogeochemical Responses to Global Change
Precambrian Geology of Southern Laurentia
Geoarchaeology

Short Course

Introduction to GIS/GPS for Geologic Field Studies

Field Trips

Middle Permian Stratotypes of the Guadalupe Mountains National Park *(premeeting)*
Geology of Big Bend National Park: What Have We Learned Since Maxwell and Others? *(postmeeting)*
Geology of Precambrian Rocks in the Van Horn Area *(postmeeting)*

For more information about the meeting:

Contact GSA, Meetings Dept., P.O. Box 1940, Boulder, CO 80301, (800) 472-1988 or (303) 447-2020; e-mail: meetings@geosociety.org; Web site: http://www.geosociety.org. Additional information or suggestions should be addressed to the General Chair, Kevin Urbanczyk, e-mail: kevinu@sulross.edu; (915) 837-8110.

Abstracts deadline: *January 5, 2002* ★ Preregistration deadline: *March 1, 2002*

notes on new publications

Ground-Water Quality, Levels, and Flow Direction Near Fort Cobb Reservoir, Caddo County, Oklahoma, 1998–2000

USGS Water-Resources Investigations Report 01-4076

Fort Cobb Reservoir in northwest Caddo County, Oklahoma, is managed by the Bureau of Reclamation for water supply, recreation, flood control, and wildlife. Excessive amounts of nitrogen in the watershed have the potential to cause long-term eutrophication of the reservoir and increase already elevated concentrations of nitrogen in the Rush Springs aquifer. The U.S. Geological Survey in cooperation with the Bureau of Reclamation studied ground water in the area surrounding a swine-feeding operation located <2 mi upgradient from Fort Cobb Reservoir in Caddo County, Oklahoma. Objectives of the study were to (1) determine if the operation was contributing nitrogen to the ground water and (2) measure changes in ground-water levels and determine the local ground-water flow direction in the area surrounding the swine-feeding operation. This 20-page report was written by C. J. Becker.

Order WRI 01-4076 from: U.S. Geological Survey, Water Resources Division, 202 N.W. 66th St., Bldg. 7, Oklahoma City, OK 73116; phone (405) 843-7570; fax 405-843-7712. A limited number of copies are available free of charge.

Flood Frequency Estimates and Documented and Potential Extreme Peak Discharges in Oklahoma

USGS Water-Resources Investigations Report 01-4152

Knowledge of the magnitude and frequency of floods is required for the safe and economical design of highway bridges, culverts, dams, levees, and other structures on or near streams. Flood plain management programs and flood insurance rates also are based on this information. In this 59-page report, flood frequency estimates for gaged streamflow sites were updated, documented extreme peak discharges for gaged and miscellaneous measurement sites were tabulated, and potential extreme peak discharges for Oklahoma streamflow sites were estimated.

Peak discharge and flood frequency for selected recurrence intervals from 2 to 500 years were estimated for 352 gaged streamflow sites. Data through 1999 water year were used from streamflow-gaging stations with at least 8 years of record within Oklahoma or ~25 km into the bordering states of Arkansas, Kansas, Missouri, New Mexico, and Texas.

Authors Robert L. Tortorelli and Lan P. McCabe developed potential extreme peak-discharge curves for streamflow sites in hydrologic regions of the State based on documented extreme peak discharges and the contributing drainage areas.

Order WRI 01-4152 from: U.S. Geological Survey, Water Resources Division, 202 N.W. 66th St., Bldg. 7, Oklahoma City, OK 73116; phone (405) 843-7570; fax 405-843-7712. A limited number of copies are available free of charge.

Water Flow in the High Plains Aquifer in Northwestern Oklahoma

USGS Fact Sheet 081-00

In this four-page USGS fact sheet, authors Richard R. Luckey, Noel I. Osborn, Mark F. Becker, and William J. Andrews summarize information contained in USGS Water-Resources Investigations Report 99-4104, "Hydrogeology, water use, and simulation of flow in the High Plains aquifer in northwestern Oklahoma, southeastern Colorado, southwestern Kansas, northwestern New Mexico, and northwestern Texas."

Order Fact Sheet 081-00 from: U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225; phone (303) 202-4700. Fact sheets are available at no cost.

U.S. Geological Survey Programs in Oklahoma

USGS Fact Sheet 036-96

This four-page fact sheet includes information on flooding, surface and ground water, mapping, cooperative programs, wildlife and aquatic resources, water contamination, and the National Oil and Gas Assessment Project.

Fact Sheet 036-96 is available only on the Web at http://water.usgs.gov/pubs/FS/FS-036-96/.

Oklahoma abstracts

The Oklahoma Geological Survey thanks the American Association of Petroleum Geologists and Geological Society of America for permission to reprint the following abstracts of interest to Oklahoma geologists.

Exceptional Preservation of Molluscs in the Buckhorn Lagerstätte (Late Carboniferous–Desmoinesian), Buckhorn Quarry, Southern Oklahoma

THOMAS E. YANCEY and *MICHAEL J. HEANEY, III*, Dept. of Geology, Texas A&M University, College Station, TX 77843; *ROYAL H. MAPES*, Dept. of Geological Sciences, Ohio University, Athens, OH 45701; and *ALEX NUTZEL*, Palaontologisches Institut, Erlangen, Germany

The early emplacement of asphalt into sand sediments at the Buckhorn asphalt quarry, Arbuckle Mountains of southern Oklahoma, produced seals protecting shell (and decay-resistant biomacromolecules) from alteration and protected minute shell features from dissolution and loss. The asphaltic matrix also inhibited the formation of mineralogic cement, so the removal of asphaltic matrix allows sediment to be disaggregated to a pre-burial "seafloor" condition. Sediments contain a diverse molluscan biota of cephalopods, gastropods, and bivalves in growth stages from larval to adult. In addition to providing growth series with larval and juvenile characters preserved and geochemical data on known taxa, the Buckhorn sediments contain a rich assemblage of minute molluscan taxa (especially gastropods) not normally seen in Paleozoic biotas, revealing the true diversity of molluscan biotas. This provides a control datum for biodiversity studies. Among bivalves, the pteriomorphians and praecardioids are the most important. Several taxa have major changes in growth form during ontogeny, including newly described praecardioids and taxa previously assigned to myalinids and to the genus *Chaenocardia*. The presence of praecardioids with ligament, prodissoconch, dentition, and full growth series preserved provides the best documentation of this obscure but diverse group of Paleozoic bivalves.

Pleiomorphians include several taxa that are difficult to assign to family and some with transition hinge types, suggesting the need for re-evaluation of phylogenetic relations and diagnoses of Paleozoic–Mesozoic families of this subclass.

Reprinted as published in the Geological Society of America *2000 Abstracts with Programs*, v. 32, no. 7, p. A-371.

Exceptional Preservation of Gastropods in the Buckhorn Lagerstätte (Late Carboniferous–Desmoinesian) Buckhorn Asphalt Quarry, Oklahoma

ALEX NUTZEL, Palaontologisches Institut, D-91054 Erlangen, Germany; *THOMAS E. YANCEY*, Dept. of Geology, Texas A&M University, College Station, TX 77843; and *ROYAL H. MAPES*, Dept. of Geological Sciences, Ohio University, Athens, OH 45701

The Buckhorn Asphalt deposit is a unique fossil lagerstätte that allows new insights into the evolutionary history of several molluscan groups. This deposit contains the best preserved Paleozoic gastropods known anywhere in the world. Due to oil/asphalt impregnation, it is one of the few Paleozoic gastropod faunas with aragonitic shell structures preserved. For many taxa, nacre, crossed lamellar structures, and prismatic calcitic outer layers are documented for the first time, e.g., the common archaeogastropod genus *Microdoma* has a thick nacreous inner layer and a thin calcitic outer layer. In addition, many gastropods have well-preserved larval shells that hold important information for larval ecology and systematics. Remarkably, certain Late Paleozoic slit-bearing genera, currently placed in the Murchisonioidea are not pleurotomarian archaeogastropods, but are caenogastropods. They have larval shells that are clearly of caenogastropod type. In contrast to most modern slit-bearing pleurotomarians, these murchisonioid genera lack nacre. Shell structure and larval shell morphology suggest that early caenogastropods were slit-bearing. The exceptional preservation of gastropods from the Buckhorn Asphalt increases the total number of known shell characters for many taxa, which contributes significantly to the phylogenetic analyses of Paleozoic gastropods.

Reprinted as published in the Geological Society of America *2000 Abstracts with Programs*, v. 32, no. 7, p. A-97.

Fossil Plants from the Buckhorn Lagerstätte (Late Carboniferous–Desmoinesian) in Southern Oklahoma

ROYAL H. MAPES, Dept. of Geological Sciences, Ohio University, Athens, OH 45701; *GENE MAPES*, Dept. of Environmental and Plant Biology, Ohio University, Athens, OH 45701; *THOMAS E. YANCEY*, Dept. of Geology, Texas A&M University, College Station, TX 77843; and *ZHAO HUA LIU*, Dept. of Environmental and Plant Biology, Ohio University, Athens, OH 45701

For almost 100 years, the Pennsylvanian age Buckhorn Asphalt Lagerstätte has been the focus of extensive research. The fauna is dominated by extraordinarily well-preserved mollusks that often retain unaltered shell material. Fossil plants are also present, but have received comparatively little study. The fossil plants that co-occur with the marine invertebrates are of two different ages. This suggests several taphonomic pathways influenced the plant/animal accumulations in the asphalt-impregnated sediments of the Buckhorn deposit. One set of plant specimens is confined to the interbedded chert pebble conglomerate lenses. These are wood fragments permineralized by silica. Although preservation of structural features is discontinuous and indistinct, scanning electron microscopy reveals some partial groupings of circular bordered pits on radial cell walls of tracheids. Such features are characteristic of the genus *Callixylon* which, in this region of southern Oklahoma, is only known to occur in Upper Devonian black shales.

The majority of the Buckhorn plants are of Carboniferous age. These Buckhorn plant remains are primarily decorticated and

coalified impressions of stems and petioles, so abraded that they lack diagnostic features. Some of the identifiable fragments include partial woody rounds and pithy centers of presumably cordaitean wood and striated calamitalean axes. In some intervals, there are reproductive remains including small platyspermic ovules, and numerous charcoal clasts up to 10 mm in diameter.

Conclusions drawn from the Buckhorn plant occurrences are: (1) The silicified *Callixylon* clasts indicate that Upper Devonian sediments were locally exposed during Middle–Late Pennsylvanian time, and the resistant silicified plant fragments were incorporated along with Ordovician chert clasts that form the main fabric of the Desmoinesian age conglomerate lenses. (2) The younger Virgilian age conglomerate that caps all the strata in the deposit lacks these diagnostic fossils. (3) The occurrence of large quantities of woody debris, seeds, and charcoal clasts suggests that a forested land source, subject to periodic forest fires, was located nearby during deposition and prior to asphaltization.

Reprinted as published in the Geological Society of America *2000 Abstracts with Programs*, v. 32, no. 7, p. A-15.

Subdividing the Lower Ibexian *Rossodus manitouensis* Conodont Zone Using *Leukorhinion* and Its Successor Taxa

OLIVER LEHNERT, Geological Institute, University of Erlangen, Schlossgarten 5, D-91054 Erlangen, Germany; *JOHN E. REPETSKI*, U.S. Geological Survey, 926A National Center, Reston, VA 20192; *JAMES F. MILLER*, Dept. of Geography, Geology, and Planning, Southwest Missouri State University, Springfield, MO 65804; *RAYMOND L. ETHINGTON* and *RUSSELL DRESBACH*, Dept. of Geological Sciences, University of Missouri, 101 Geosciences Bldg., Columbia, MO 65211

In many parts of the United States, in Canada, and Greenland, the lower Ibexian *Rossodus manitouensis* Conodont Zone represents an extremely thick carbonate succession. The observed evolutionary succession from species of *Leukorhinion* Landing 1996 through New genus A, to New genus B provides a tenable means of subdividing this extensive biozone.

The potential index species are present in most shallow-water areas across Laurentia (western Newfoundland, Greenland, the Appalachians, and the American Midcontinent). *Leukorhinion* is monospecific. In New genus A we distinguish two species: N. gen. A, n. sp. A (= type species) and N. gen. A, n. sp. B (= *Clavohamulus reniformis* Ji and Barnes 1994). New gen. B is monospecific, represented by N. gen. B, sp. A (= *Clavohamulus manitouensis* Seo and Ethington 1993).

The chronostratigraphic occurrence of members of this new conodont lineage provides an opportunity for a four-part subdivision of this extensive time interval. *Leukorhinion ambonodes* Landing 1996 is characteristic of the lower part of the *R. manitouensis* Zone, N. gen. A, n. sp. A of the lower middle part, N. gen. A, sp. B of the upper middle part, and N. gen. B, sp. A of the uppermost part of this zone. This well-defined new conodont lineage is restricted stratigraphically to the *Rossodus manitouensis* Zone and paleogeographically to Laurentia.

In the United States we document three locations where the evolutionary transitions between the taxa may be observed: the Lange Ranch section in central Texas (Tanyard Formation), sections of the McKenzie Hill Formation in the Arbuckle and Wichita Mountains, Oklahoma, and a section of the Chepultepec Formation at Avens Bridge, Virginia.

Reprinted as published in the Geological Society of America *2000 Abstracts with Programs*, v. 32, no. 7, p. A-457.

Taphonomy and Paleoecology of Ordovician Trilobite Clusters, Bromide Formation, South-Central Oklahoma

TALIA S. KARIM and *STEPHEN R. WESTROP*, Oklahoma Museum of Natural History and School of Geology and Geophysics, University of Oklahoma, Norman, OK 73072

The Poolville Member of the Bromide Formation of south-central Oklahoma shoals upward from subtidal to peritidal carbonate facies. The deepest subtidal facies includes horizons composed of numerous complete exoskeletons of a single species of isoteline trilobite. At least five of these horizons occur in a five-meter interval near the base of the member, with trilobite densities of up to 170 individuals per square meter. In some horizons, exoskeletons have librigenae and hypostomes in place and are therefore carcasses rather than molts. Facing directions of the exoskeletons are randomly oriented, and the majority of specimens are convex-up. Other horizons are composed of molts, as indicated by opening of the facial sutures and separation of the cranidium from the remainder of the exoskeleton. Cut slabs show that the trilobite horizons are overlain by up to 20 cm of lime mudstone that lacks skeletal debris but contains *Chondrites* burrows that increase in abundance upwards through the bed. This indicates that catastrophic mud-blanketing, probably during major storms, preserved the horizons. As such, the Ordovician clusters represent snapshots of trilobite behavior. As with younger clusters of phacopid trilobites described from the Devonian of New York State, they record behavioral aggregation of individuals for synchronous molting and, probably, reproduction. The occurrence of clustering in species from such phylogenetically distant clades as the Asaphina and Phacopida indicates that pre-molt aggregation is likely to have been a behavioral characteristic of trilobites in general.

Reprinted as published in the Geological Society of America *2000 Abstracts with Programs*, v. 32, no. 7, p. A-97.

Strontium Isotope Stratigraphy of the Comanchean Series in North Texas

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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 Period in North America. We have used 129 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 Ma, from late Aptian through middle Cenomanian; a time interval lacking paleomagnetic reversals for refined correlation. The $^{87}Sr/^{86}Sr$ of seawater rises from 0.707318 ± 13 in the basal Glen Rose Formation to reach a peak of 0.707522 ± 10 in the Walnut Clay, then slowly declines to 0.707468 ± 6 in the middle Grayson Marl. The upper Grayson Marl and lower Buda Limestone drop to 0.707421 ± 9 then rise to near 0.707473 in middle Buda time. The $^{87}Sr/^{86}Sr$ of the basal Woodbine Formation in the overlying Gulfian Series is within error of the middle Buda value. Thirty of the analyzed samples yielded ratios outside error of the mean determined for corresponding stratigraphic units. Whole rock limestones and spar fillings of shells were inconsistently more radiogenic than the best shell material and all but two aberrant samples could be identified using appearance and trace element content. Isotopic results from high quality shells with low Mn and Fe concentrations are remarkably consistent. The agreement of results from samples collected at a single site with results from geographically removed sites in the same formation interval is strong evidence that these samples retain the original open marine ratio of Comanchean seawater. The composite data set contributes to a sparsely studied and enigmatic portion of the Cretaceous $^{87}Sr/^{86}Sr$ seawater evolution curve. Although minor strontium isotope variation characterizes much of Comanchean deposition, refined correlation opportunities exist for the Glen Rose rise and upper Grayson–lower Buda fall in $^{87}Sr/^{86}Sr$.

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Middle Carboniferous Ammonoid Population Dynamics, Southern Midcontinent, United States

DANIEL A. STEPHEN, Dept. of Geology and Geophysics, Texas A&M University, College Station, TX 77843; *WALTER L. MANGER*, Dept. of Geosciences, University of Arkansas, Fayetteville, AR 72701; and *LISA K. MEEKS*, Dept. of Earth Sciences, Central Missouri State University, Warrensburg, MO 64093

Middle Carboniferous ammonoid occurrences in the southern midcontinent of North America (Arkansas, Oklahoma, Texas) reflect "hot spot" localities that are isolated both stratigraphically and geographically. These occurrences include a small number of taxa that seem to represent semelparous populations based on their similar conch size, assessed maturity, and abundance. Acceptance of these "hot spot" occurrences as semelparous mass mortality provides insight into other aspects of Middle Carboniferous population dynamics. Exceptionally large specimens of species represented in the populations are rare additions that reflect pathologic gigantism of individuals that did not reach sexual maturity, probably as a result of parasitic castration. Most, but not all, taxa occur as dimorphic pairs.

The conchs of these dimorphic pairs are represented by either a depressed cadicone form with widely spaced sutural elements or a compressed, narrowly umbilicate form with closely spaced sutural elements. Not uncommonly, ornament of depressed forms is coarse, while that of the compressed forms is fine. Ratio of compressed to depressed forms is highly variable among taxa, but compressed forms are typically the more abundant. Septal crowding and approximation have been regarded as traditional evidence for the attainment of sexual maturity in ammonoids. That does not seem to be the case in the Middle Carboniferous, where we have found no evidence, in some cases, of septal crowding in the depressed dimorph of a particular taxon in contrast to its common occurrence in the associated compressed form. These ammonoid taxa tend to be endemic in the southern midcontinent suggesting local reproductive populations. Our data suggest that the ammonoids may have inhabited deeper shelf environments as adults and then migrated into shallow water for reproduction and early growth stages. The dynamics of Middle Carboniferous ammonoid populations suggest a similarity to coleoids as a modern analogue.

Reprinted as published in the Geological Society of America *2000 Abstracts with Programs*, v. 32, no. 7, p. A-371.

Semelparous Cephalopod Assemblages Throughout the Geologic Record

BRANDY R. O'NEILL, MARY KATE WIMBERLY, and *WALTER L. MANGER*, Dept. of Geosciences, University of Arkansas, Fayetteville, AR 72701

Semelparity, or mass mortality associated with reproduction, is exhibited by a number of modern cephalopods, most notably species of Recent squids. This phenomenon has been documented in Middle Carboniferous ammonoid occurrences in the southern midcontinent, primarily Arkansas. There, ammonoid localities have been characterized as "hot spots" that are isolated both stratigraphically and geographically, and are separated by barren intervals. Fossiliferous horizons yield populations of multiple taxa represented by abundant individuals that are of similar size and level of maturity. These occurrences cannot be explained by mass mortality due to environmental catastrophe because ammonoid taxa are not represented by all growth stages and they lack an associated fauna that would have been affected by the "kill." While not all cephalopod occurrences can be explained by this phenomenon, our expanded investigations indicate that semelparity was common in nautiloids, ammonoids, and belemnoids throughout most of the geologic record. Studied nautiloid occurrences include those of *Isorthoceras* from the Upper Ordovician Maquoketa Shale, Iowa, *Aphelaeceras* from the Late Mississippian Fayetteville Shale, Arkansas, and *Hercoglossa* from the Paleocene Midway Formation, Arkansas. Additional investigations of ammonoid populations include *Muensteroceras* from the Early Mississippian of Indiana, and *Phaneroceras* from the Middle Pennsylvanian of Oklahoma. We have also examined occurrences of belemnoid rostra representing several horizons of *Pachyteuthis* from Utah. In all cases, these "hot spot" localities are represented by hundreds of individuals of a particular taxon that are of similar size and stage of maturity. These occurrences lack juveniles and associated fauna that usually suggest an environmental catastrophe.

Reprinted as published in the Geological Society of America *2001 Abstracts with Programs*, v. 33, no. 6, p. A-12.

Diversity of Paleozoic Non-Amniote Tetrapod Faunas

WILLIAM J. GARCIA, Dept. of Geology, University of Cincinnati, 500 Geology/Physics Building, Cincinnati, OH 45221

Peak diversities of non-amniote tetrapods occur during the later Pennsylvanian through the mid-Permian, spanning roughly 30 million years. Faunal assemblages for most of the Paleozoic are rare and are almost completely absent for roughly 30 million years from the end of the Devonian until the mid-

Mississippian. Most Paleozoic non-amniote faunas typically represent deposition in fresh- to brackish-water pond and swamp settings located in present-day North America and Europe. Faunal data from nine non-amniote faunas (Delta, Iowa; East Kirkton, Scotland; Joggins, Nova Scotia; Newsham, Northumberland; Nyrany, Czechoslovakia; Linton, Ohio; Waurika, Oklahoma; Geraldine, Texas; and Orlando, Oklahoma) were subjected to rareifaction, producing diversity curves with which comparisons of the various faunas were made. Mississippian faunas show lower diversity than either Pennsylvanian or Permian faunas, while diversity curves for Pennsylvanian faunas are much higher than either Mississippian or Permian faunas. The diversity peaks for the Pennsylvanian faunas, in particular Linton and Nyrany, coincide with family level diversity peaks for all three orders of lepospondyls. Examination of faunal lists for the nine localities show that Linton, Nyrany, and Joggins have greater numbers of lepospondyl taxa than any of the other faunas, while the number of taxa from other orders is roughly similar between localities. Faunal comparisons based upon the depositional environment of the localities indicate that diversity levels are not consistent through time. Lake faunas (Nyrany, Linton, Newsham, Waurika, Orlando, and Delta) show high levels of variation in diversity during the Paleozoic. In contrast, the curves for East Kirkton and Joggins, the two terrestrial deposits, show similar trajectories. The trajectory stability between terrestrial and fresh-water deposits are likely attributable to variation in depositional setting among the fresh-water faunas.

Reprinted as published in the Geological Society of America *2001 Abstracts with Programs*, v. 33, no. 6, p. A-388.

A Possible Connection of the Tethyan and Boreal Seas between the Albian Kiowa–Skull Creek Cycle and the Cenomanian Greenhorn Cycle

STAVENA L. AKINS, Dept. of Geosciences, Southeast Missouri State University, Cape Girardeau, MO 63701

This study tests the hypothesis that a previously unrecognized connection between the Tethyan and Boreal Seas at the early/late Cretaceous boundary existed. The traditional belief is that there were five third order transgressive/regressive cycles that dominated the western interior during the Cretaceous Period. A previously proposed hypothesis suggested a brief connection of the Western Interior Seaway during latest Albian–earliest Cenomanian, based on the introduction of Tethyan (*Metengonoceras*) ammonites mixing with Boreal endemic (*Neogastrophliets*) in the Boreal Mowry shale.

Evidence for the hypothesized connection would greatly help to illuminate the current complicated mid-Cretaceous biostratigraphic, lithostratgraphic, and sequence stratigraphic correlation between mid-Cretaceous rocks deposited in the Tethyan and Boreal realms. This study could also explain the unexpected marine faunal migrations addressed by other geologists.

Any connection between Mowry (Boreal) and the equivalent Tethyan marine strata in Texas must pass through the mid-Cretaceous strata of the southern high plains. This study examines mid-Cretaceous Muddy Sandstones and overlying Graneros Shale, in northeastern New Mexico, southeastern Colorado, extreme western Kansas, and the Oklahoma panhandle, for chemical evidence of marine influences. The approach to studying the target sample sites is detailed chemofacies analysis. Samples from various sites of the Muddy Strata will be collected and processed for Carbon and Sulfur. Carbon isotope data will be obtained by Mass Spectrometry. The influence of fresh versus marine water will be shown in the carbon content of the shaly strata samples of the target interval.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 85, p. 2046, November 2001.

Integrated Foraminiferal Assemblage, Nannofossil Assemblage and Planktonic Foraminiferal Porosity Paleoceanographic Interpretations, Western Interior Seaway, North America

CYNTHIA G. FISHER and *LAURIE A. MACK*, Dept. of Geology and Astronomy, West Chester University, 750 S. Church St., West Chester, PA 19383

We are testing the hypothesis that foraminiferal assemblages will be similar when located in the same "water mass," as defined by planktonic foraminiferal porosity; and progressively more different than assemblages found in progressively different "water masses." Correspondingly, calcareous nannofossil assemblages will vary in response to the "water mass"' in which they were living. We interpret relative water mass densities and ocean circulation of the Latest Cenomanian Western Interior Seaway based on porosity of the common, relatively shallow dwelling planktonic foraminifer *Hedbergella delrioensis*. Our interpretations of the Cretaceous paleoceanography are founded on modern planktonic foraminiferal ecology. Integral to this work are the previous studies which have shown that planktonic foraminiferal species construct more porous tests when living at lower latitudes in warmer and less saline waters and progressively less porous tests when living at higher latitudes in cooler and more saline waters.

Latest Cenomanian foraminiferal porosity indicates that a wide tongue of relatively lower density water spread up through the middle of the United States portion of the Western Interior Seaway. The tongue is wide in the south-southwest, narrowing and moving north through the central area of the seaway. Arranged concentrically around the tongue are outcroppings of progressively denser water (less porous foraminifers). Higher porosities in the four-corners localities may indicate downwelling. Planktonic foraminifer and calcareous nannofossil assemblages indicate that this was an area of increased fertility.

Reprinted as published in the Geological Society of America *2000 Abstracts with Programs*, v. 32, no. 7, p. A-143.

Human Occupations Across the Pleistocene–Holocene Transition on the Great Plains: Geomorphic and Regional Patterns

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A current synopsis of geomorphic evidence from selected Great Plains archaeological sites of Clovis, Folsom, and later Paleoindian ages is provided. Archaeological site occurrences and regional patterns of artifact finds are discussed by time period: pre-11,000, 11,000–10,000, and 10,000–8,500 radiocarbon yrs. BP, and by (geomorphic) depositional context: stream valleys, gullies, playas, and dunes. The number of recorded sites with detailed geomorphic and stratigraphic data is small, so existing patterns must be viewed with consideration of probable sampling bias. There are not enough sites within each time period to enable a statistically viable assessment of potential changes in land use patterns which may have resulted from environmental changes associated with the Pleistocene–Holocene transition. It is likely that there was recurrent use of upland playas (e.g., the Clovis-age Miami site), dunefields (e.g., the Folsom-age Shifting Sands site and the later Paleoindian Milnesand site), stream valleys (e.g., the Clovis-age Aubrey site, the Folsom-age Waugh site, and the later Paleoindian Plainview site), and gullies (e.g., the Folsom-age Cooper site and later Paleoindian Olsen-Chubbuck and Norton sites). The available evidence, however, provides important clues that aid in the interpretation of regional patterning in the archaeological record.

Within the Plains of Texas, Oklahoma, Kansas, eastern Colorado, Nebraska, and South Dakota, there are strong patterns in the distribution of diagnostic Paleoindian artifacts reflecting a combination of prehistoric population patterns, modern recording biases, and regional geomorphic processes. As examples, the documented occurrence of Clovis points diminishes dramatically from south to north in the Plains. This may reflect, in part, prehistoric population density or time-transgressive longevity of this technological tradition, as the oldest dated Clovis component is in the southern Plains. In contrast, the relatively low frequency of Folsom artifacts in western Kansas, compared to adjacent regions, may reflect a distinctive geomorphic history (erosion and/or deep burial) during or following the Pleistocene–Holocene transition.

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Paleosols Indicate Increasing C4 Plant Abundance and Temperature Across the Pleistocene–Holocene Boundary Throughout the Great Plains

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Modern ecological research in the North American Great Plains shows a strong positive relationship between C4 plant biomass production and temperature. Thus, stable C isotopes from paleosols can be used to estimate C4 abundance and temperatures in the past. Understanding climate change across the Pleistocene–Holocene boundary is important because of possible connections to changing Paleoindian cultures, megafauna extinctions, and the development of global circulation models. Stable C isotope values from alluvial paleosols are summarized in 1,000-year increments between 12,000 and 6,000 B.P. from Texas (29.5N) to North Dakota (46.5N) in an attempt to: (1) detect latitudinal trends in C4 abundance-temperature as compared to modern conditions, and (2) relate climate trends to Paleoindian chronologies. Results indicate C4 soil organic matter contributions ranged from 20 to 40% between 12 and 11 ka, considerably below modern levels. From 11 to 10 ka, C4 contributions to soil organic matter increased at all latitudes by 15 to 20% indicating rising temperatures. From 10 to 7 ka, C4 production and temperatures stabilized. By 7 to 6 ka, C4 production increased at all latitudes by another 10 to 15% indicating the onset of a second warming trend. Between 12 and 11 ka, the north-south C4 biomass-temperature gradient is suppressed in relation to modern conditions, perhaps in response to cold glacial meltwater in the Gulf of Mexico. The Younger Dryas is recorded as a period of gradual warming possibly because of diversion of glacial meltwater away from the Mississippi River and Gulf of Mexico. It is not until the middle Holocene that the C4 biomass-latitude curve begins to track the modern curve in both magnitude and gradient. Based on stable C isotopes from paleosols, the Clovis culture correlates with a relatively cool climate associated with reduced summer monsoon rains. The Folsom culture corresponds with a widespread warming episode probably associated with enhanced summer monsoon rains. For the remainder of the Paleoindian period, climatic conditions stabilized.

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An Update of Oklahoma Coalbed-Methane Activity

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About 1,200 wells have been drilled or recompleted specifically for coalbed methane (CBM) in Oklahoma from 1988 to April 1, 2001, according to the Coalbed-Methane Completions table in the Oklahoma Coal Database. About 60% of the wells were drilled on the northeast Oklahoma shelf, and about 40% were drilled in the Arkoma basin.

CBM completions on the shelf have been reported in 10 coal beds of Desmoinesian (Middle Pennsylvanian) age in 8 counties. Coal beds were perforated at depths-to-top of coal of 256–2,428 ft (78–740 m), averaging about 950 ft (290 m). Initial-potential CBM rates for wells on the shelf ranged from 0 to 260 thousand cubic feet of gas per day (MCFGPD), averaging 28 MCFGPD. Initial produced water on the shelf ranged from 0 to 1,201 barrels of water per day (BWPD; average of 61 BWPD).

CBM completions in the Arkoma basin have been reported in 5 Desmoinesian coal beds in 7 counties. The depths of these are 347–3,726 ft (106–1,136 m; average of about 1,425 ft [434 m]). Initial-potential CBM rates for wells in the basin ranged from a trace to 595 MCFGPD (average of 88 MCFGPD). Initial produced water in the basin ranged from 0 to 147 BWPD (average of 15 BWPD). To date, 5 operators have completed 49 horizontal CBM wells in the Arkoma basin.

Ninety operators have been involved in the CBM play in Oklahoma, which spans 89 gas fields. CBM continues to be an attractive play in Oklahoma.

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Surface to Subsurface Correlation of Methane-Producing Coals, Northeast Oklahoma Shelf Area

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Coalbed-methane production has been reported by operators from 10 named Pennsylvanian (Desmoinesian) coals in the northeast Oklahoma shelf area. They are (from oldest to youngest): the Riverton (McAlester Formation); Rowe, Drywood (Savanna Formation); Bluejacket (Boggy Formation); Weir-Pittsburg, Croweburg, Bevier, Iron Post, Mulky (Senora Formation); and Dawson (Holdenville Formation). Most of the production is from wells located in Nowata, Osage, Rogers, Tulsa, and Washington counties.

A subsurface stratigraphic framework, based primarily on gamma, density, and neutron well logs and core-hole logs, is established to assist operators in correctly identifying methane-producing coal beds. About 50 high-quality well logs (from the more than 200 examined) were used to construct five cross sections. Three east-west cross sections are oriented approximately parallel to present-day dip and extend about 60 miles west from the coal outcrop belt across Ts. 22, 25, and 28 N. Two north-south cross sections are oriented approximately parallel to present-day strike and extend about 50 miles from the Kansas-Oklahoma state line south to T. 20 N.

Persistent markers such as the Oologah Limestone (Big lime); the Fort Scott Limestone (Oswego lime); the Verdigris Limestone; the Tiawah Limestone (Pink lime); and others were used as reference strata to correlate the coal beds. A composite type log is designated for a site centrally located in the methane-producing shelf area. It shows the important marker beds (limestones, black shales, and persistent sandstones), as well as the stratigraphic positions of named coals.

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Cleats in Coals of Eastern Oklahoma

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Cleat orientation and frequency in coal beds are important because of their relationship to coalbed methane (CBM) production. Face cleat orientation (strike) is the primary factor determining fluid flow direction and thus permeability in bituminous coal beds.

The orientation of face and butt cleats, the dominant vertical fractures in Oklahoma Desmoinesian coals, were mapped at some 500 locations by Friedman (1971–95), Hemish (1978–98), and Iannacchione and Puglio (1979) in 27 bituminous coals in 17 eastern Oklahoma counties.

Face cleats strike north-northwestwards in most of the Oklahoma part of the Arkoma Basin and in the northeast Oklahoma shelf. This trend in both areas is normal to the axes of major anticlines, synclines, and faults in eastern Oklahoma. However, in 3 counties in the Basin the major structures trend northeastward, north-northeastward, or eastward, and face cleats are normal to these trends. Face-cleat frequency is a minimum of 2 per inch in the shelf and a maximum of 12 per inch in the Basin.

In parts of the Basin, lateral CBM wells appear to have yielded the greatest rate of production. Most of these wells have lateral trends almost normal to the average orientation of the face cleats. Vertical wells in the Basin appear to produce CBM at a greater rate than those in the shelf.

Therefore, knowledge of face cleat orientation and frequency in bituminous coal beds must be applied during drilling to maximize CBM production in Oklahoma and probably in other states.

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Heavy Metals in Fluvial Sediments of the Picher Mining Field, Northeast Oklahoma

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Heavy metals are present in fluvial sediments of the Picher Mining Field in northeast Oklahoma as a result of lead and zinc mining between 1904 and 1970. The underground mine workings began to fill with water when mining and dewatering ceased, and acid mine water began discharging into Tar Creek from boreholes and air shafts in 1979. The U.S. Geological Survey collected sediment samples in 1983–84 from Tar Creek and found concentrations of lead up to 6,800 ppm and of zinc up to 14,000 ppm. These metals and others pose serious health hazards for the local communities.

The purpose of our study was to determine if concentrations in Tar Creek have changed since the mid-1980s of lead, zinc, cadmium, copper, nickel, and iron. We collected stream sediments in the same locations as the earlier USGS study and used the same techniques for sampling and lab analyses to ensure comparable data. Concentrations remain at 109–862 ppm for lead and 3,500–17,000 for zinc. Heavy metal concentrations decreased in upstream sites because of drainage diversion projects constructed after 1984. Heavy metals increased in downstream sites for two possible reasons. Particle sizes may have decreased from 1983–84 to 2000 and smaller sizes generally adsorb higher concentrations. Alternatively, additional heavy metals could have been added to Tar Creek from the floodplain and tailings during large floods. Remediation efforts have met with limited success: clean-up is prohibitively expensive; residents in former mining communities may need to be relocated.

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Subcontinental Scale Fluid Transport of the Sulfide Component of Mississippi Valley-Type Ores

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The midcontinent of the U.S. hosts Zn-Pb mineralization in Paleozoic carbonate rocks. These "Mississippi Valley-Type" districts together contain hundreds of millions of tons of sulfide ore minerals and pyrite. Transport of the Zn, Pb, and other metals was by a hydrothermal flow system that extended hundreds of kilometers driven by late Paleozoic Ouachita tectonism. The source of sulfide in the ores is, however, problematic, as is the site of sulfide generation; both local (district scale) and distant sources have been proposed.

An isotopic and petrographic study on over 400 pyrite-bearing ore fluid aquifer samples was conducted to determine the origin of the sulfide sulfur. Samples were from 31 core holes within an area of 25,000 km^2. This "far-field" pyrite is a product of the passage of ore-forming fluids because: (1) the pyrite is intergrown with ore-stage vug-filling dolomite and (2) lead isotope compositions of trace lead in the epigenetic pyrite are similar to ores. The far-field sulfur isotopic data show a pronounced maximum in the range –0 to –6‰, which overlaps the values for ore sulfides of the geographically dispersed Tri-State, northern Arkansas, and central Missouri Districts. This isotopically light component occurs throughout the entire Ozark region in huge quantities. The enormous mass and isotopic homogeneity of this sulfide argue for formation from a gigantic source. The most likely candidate is thermal decomposition of sedimentary pyrite to form pyrrhotite + H_2S at T>300°C in clastic sediments of the adjacent Arkoma basin. There is a secondary maximum in the data in the range +6 to +18‰. This range overlaps the main stage ore sulfides of the Lead Belts of southeast Missouri. The isotopically heavy sulfide occurs over a large region but only in an aquifer that fed into the Lead Belts. This heavy sulfide formed by thermochemical reduction of sulfate migrating in this aquifer. The results of this study show that production of ore sulfide was by two distinct abiologic mechanisms and transport was by migrating hydrothermal fluids.

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Potential for Subsurface Contaminant Transport in Floodplains Adjacent to Municipal Landfills

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River and groundwater resources adjacent to landfills have the potential to become contaminated due to the high permeability of alluvium. Consequently, development of methods for evaluating plume movement away from landfills has application for remediation and land-use planning. On the basis of core and conductivity surveys, our analyses indicate that a contaminated point bar on the Canadian River adjacent to the Norman Landfill contains five zones or layers. The package of mud, sand and gravel is about 12 m thick though only the upper 3 m of the point bar appears to be active today. The base of the sediment package is in contact with Permian redbeds. This contact probably marks the base of an incised valley. Grain size in the amalgamated bars decreases upward at all scales from gravel at the base to very fine sand at the surface. Permeability estimates calculated from sediment texture suggest that the basal layer has the greatest permeability. Importantly, the basal gravel is not derived from local bedrock. This suggests the main permeability pathway in the alluvium is controlled by upstream sediment provenance sometime after formation of the incised valley. Considerations for classifying floodplain contamination risk adjacent to a landfill for a given climate include: (1) river type, (2) permeability of the underlying incised-valley fill surface, (3) depth of the incised surface, (4) depth of modern channel erosion, (5) grain size of provenance, (6) rate of meander migration, (7) frequency of avulsion, and (8) orientation of bars relative to position of the landfill.

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Gypsum Karst Leads to Abandonment of a Proposed Damsite in Oklahoma

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Recent engineering-geology assessment of a proposed damsite in an area of gypsum karst in southwestern Oklahoma has shown that the site is unsuitable and should be abandoned. The proposed Mangum damsite has been investigated and evaluated since 1937 as a potential site for a compacted, earth-fill dam, about 33 m high, that would provide for irrigation water, flood control, and recreation. Initial approval of the site was based only upon its favorable topography, because both proposed abutments are high and form a narrow water gap between them. This decision did not adequately consider the geology, foundation conditions, or water-impoundment capabilities of the site. Abutments would be in the Permian Blaine Formation, consisting here of 60 m of gypsum with thin interbeds of dolomite and shale. The Blaine Formation locally has abundant gypsum-karst features, such as caves, sinkholes, disappearing streams, and springs. Efforts since 1937 have focused on finding a suitable site within the flat-lying Blaine Formation where the karst problems would be minimal.

In 1999, a final assessment was made of the surface geology and the results of coring and pressure-testing of five boreholes (each 40–46 m deep) along the proposed dam alignment. The assessment showed: open cavities, clay-filled cavities, and other karst features are abundant in and near the abutments; and fluid losses (per 3-m interval) ranged from 60 to 250 L/min in most borehole pressure-tests, and in one borehole the losses were 1,600–5,300 L/min. Engineering measures needed to remediate karstic foundation conditions here would add greatly to the cost of construction, and still would not assure tightness of the reservoir or integrity of the dam. By recommending abandonment of the proposed site, and moving the investigation 11 km downstream to a site with thick shale abutments that are a greater distance apart, I believe a dam can be built at the new location without the potential problems of extensive leakage and possible failure of a dam built upon gypsum karst.

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Cave Development Rates of Gypsum Caves in Oklahoma: Preliminary Results

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Gypsum is about 10–20 times more soluble in pure water than limestone is in the presence of CO_2, resulting in extremely rapid cave development. In addition, several chemical and physical factors may enhance or renew gypsum dissolution. Quantitative estimates of the effect of these factors are sparse. The goal of this study is to determine the mechanisms and rates of gypsum cave development in Oklahoma, where gypsum occurs in 25% of the state. The proposed study will provide much needed information on gypsum karst of Oklahoma, with potential implications for gypsum karst elsewhere in the USA. The rapid cave development in gypsum rock poses many problems to the infrastructure and land use in areas where gypsum is found at the surface or in the subsurface; e.g., loss of farm or industrial equipment when the land surface gives way under its weight, loss of livestock that has fallen into sinkholes, collapse of sections of roads as a result of the retreat of cave entrances. Determining the rate of this development would greatly help urban planning and land use projects by supplying a better understanding of the risks of karst hazards in the areas involved. Gypsum karst, just like carbonate karst, is also very susceptible to environmental impact problems in general and water pollution in particular, due to rapid infiltration and limited filtration of pollutants in the relatively large solutional conduits. Research on cave development and karst hazards has been focused in carbonate rock mainly and less gypsum rock, undoubtably due to the fact that gypsum karst is much less common and accessible than carbonate karst. This study will attempt to identify and quantify the different dissolutional and mechanical cave development processes at work in gypsum caves in western Oklahoma, i.e., (1) dissolution by flowing and standing water; (2) effect of the presence of other salts on dissolution; (3) condensation corrosion: dissolution by aggressive condensation water in air-filled passages; (4) microbial activity: anaerobic reduction of sulphates in the presence of organic matter; (5) de-dolomitization of intercalated dolomite layers; (6) collapse. The study will involve digital mapping, cave microclimatological studies, water chemistry and condensation corrosion to determine erosion and dissolution rates.

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The State Parks: Invaluable Geological Showrooms and Classrooms

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There are no national parks or monuments in Oklahoma; however, like the national parks elsewhere, many of Oklahoma's state parks are natural showrooms and classrooms for geology. Indeed, many are state parks *because* of their spectacular geology. For example, Black Mesa, the highest point in Oklahoma, is a Tertiary basalt flow that caps Mesozoic dinosaur bone- and track-bearing strata. Alabaster Caverns is the only developed gypsum cave in North America. Hourglass selenite crystals can be collected in alluvial sand near Great Salt Plains. And the museum at Lake Murray displays the largest meteorite (Cretaceous) ever found in Oklahoma.

The Oklahoma Geological Survey (OGS) publishes several guidebooks and pamphlets for the public on the geology of some of the more popular state parks. Recently, the OGS published booklets on other popular "natural" areas including a large city/Corps of Army Engineers park (Arcadia Lake) in a suburb of Oklahoma City, a national wildlife refuge (Wichita Mountains), and reserves owned by The Nature Conservancy (e.g., Tallgrass Prairie). The format varies from professionally edited and formatted guidebooks to informal open-file reports. The audience for these reports is the casual visitor; teachers and students; and park professionals, volunteers, and docents. OGS staff frequently lead field trips for these groups. The publications and field trips are designed to describe the geology and stratigraphy of the park, explain fundamental geological principles in terms of what can be seen in the rocks, and point out the important role of geologists in today's society.

Writing for the public about the geology of one or several outcrops in a park or an entire park can be an excellent exercise for undergraduate and graduate students. With close early guidance, repeated reviewing and rewriting, and later editing, student "papers" can form the basis for a publishable guidebook.

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