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LAHOMA GEOLOGY

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On The Cover —

Oologah Lake Spillway Gates—Flood-Water Release of 1986

The cover photo shows the seven spillway gates at Oologah Lake, Rogers County, Oklahoma, with water being released at a rate of almost 50,000 ft^3 per second (400,000 gallons/second) during the flood of 1986. The turbulent water eroded the spillway channel down to the resistant Blackjack Creek Limestone Member of the Fort Scott Formation, and carved a gorge into underlying strata about 1 mi downstream, nearly to the channel's confluence with the Verdigris River. After the gates were closed and the channel drained, a stark, barren scene was revealed, devoid of vegetation. For contrast with the cover photo, see Figure 4, p. 92.

The denuded channel has changed little through time, and appears today much as it did more than a decade ago. For more information about this phenomenon, see the feature article beginning on p. 88.

LeRoy A. Hemish

Photo courtesy U.S. Army Corps of Engineers

OKLAHOMA GEOLOGICAL SURVEY

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OKLAHOMA GEOLOGY

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OKLAHOMA GEOLOGICAL SURVEY

The Channeled Scablands and Fort Scott Gorge, Northern Rogers County, Oklahoma

LeRoy A. Hemish[1]

Abstract

In October 1986, small-scale channeled scablands and a 25-ft-deep gorge were carved in the Fort Scott Formation (Pennsylvanian) when rapidly rising flood water was released from Oologah Lake's flood-control pool through the emergency spillway. All grassy vegetation, trees, soil, and non-resistant bedrock were swept away by the turbulent water, exposing the surface of the Blackjack Creek Limestone Member of the Fort Scott Formation. In the lower reaches of the 1.3-mi-long channel, rapids and a low waterfall formed as successive layers of the Blackjack Creek were plucked away, widening and extending back upstream a small gorge just above the confluence with the Verdigris River. Now, 13 years later, the erosional scar remains on the landscape—little changed.

Introduction

About 290 million years ago, during the Pennsylvanian Period, the area that is now the State of Oklahoma was situated less than 10° north of the equator (Heckel, 1980). During that period, alternating beds of fossiliferous marine limestone, black phosphatic marine shales, near-shore and terrestrial shale and sandstone, and widespread coal beds (originating in broad peat swamps) were deposited in northeastern Oklahoma (Heckel, 1994). Through time, these rock units were deeply buried, diagenetically altered, and pushed upward by tectonism associated with doming of the Ozarks. Erosion has exposed the rocks, which now dip gently to the northwest at about 35–50 ft/mi. In this report, these rocks are discussed in the section dealing with stratigraphy. Figure 1 shows the location of the study area, and Figure 2 shows the rock units in the stratigraphic column.

In geologically recent time, the advent of humans has led to alteration of the Earth's crust. Huge amounts of material have been excavated to build canals, to mine minerals and fossil fuels, and to construct tunnels; those are common engineering feats. Building dams across rivers for water storage has made life possible in arid regions. Other dams have been built to create lakes for flood control and for recreation, and to generate energy in hydroelectric plants. But nature still can make all human efforts seem puny, as when earthquakes, windstorms, fires, and floods unleash their awesome power. This story centers on one such natural event that affected northeastern Oklahoma a little more than a decade ago.

Geologic Setting

Rogers County is in northeastern Oklahoma, in an area known as the Claremore Cuesta Plains—a geomorphic province characterized by resistant Pennsylvanian sandstones and limestones that form gently northwest-dipping cuestas between broad shale plains (Curtis and Ham, 1972, p. 3). One of these cuestas (which are

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[1]Oklahoma Geological Survey.

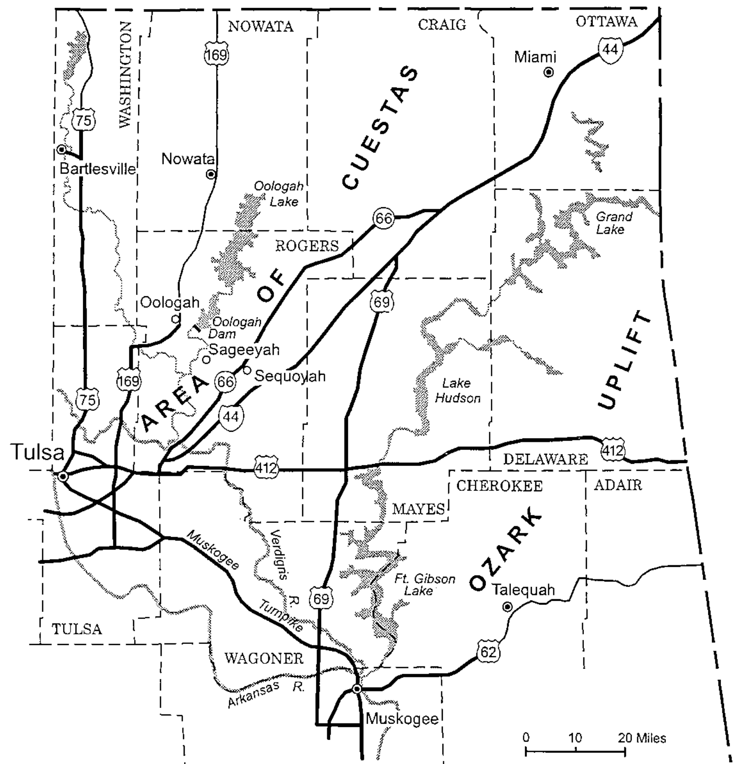

Figure 1. Geographic setting of the Oologah Lake area, northeastern Oklahoma. Excerpt modified from 1997–98 Oklahoma Official State Map showing the study area (ODOT, 1996).

marked by east-facing escarpments) is upheld by the resistant Oologah Formation. The plain just to the east of the Oologah escarpment is underlain by shale of the Labette Formation (Fig. 2; Appendix, measured section 1). The region is punctuated by isolated remnants of the Oologah escarpment called "mounds" (Fig. 3); their origin is similar to the origin of the buttes and mesas of arid regions. These mounds stand about 150 ft above the lowlands and in this region are capped by about 10–20 ft of limestone of the Oologah Formation. The underlying slopes consist of the nonresistant Labette Formation (Fig. 2; Appendix, measured section 1).

The mounds near the spillway and those in and around Oologah Lake probably originated when they were cut off from the Oologah escarpment by channels or tributary channels of the ancestral Verdigris River. Atop Lipe Mound (Fig. 3), water-worn chert pebbles show that the ancestral Verdigris flowed at much higher elevations than now.

The provenance of the chert pebbles is in Kansas; they are common constituents of terraces associated with the Verdigris River (L. A. Hemish and J. R. Chaplin, "Geology along the new PSO Railroad spur, northern Rogers County, Oklahoma," in preparation). In comparatively recent times the Verdigris has cut a gap through

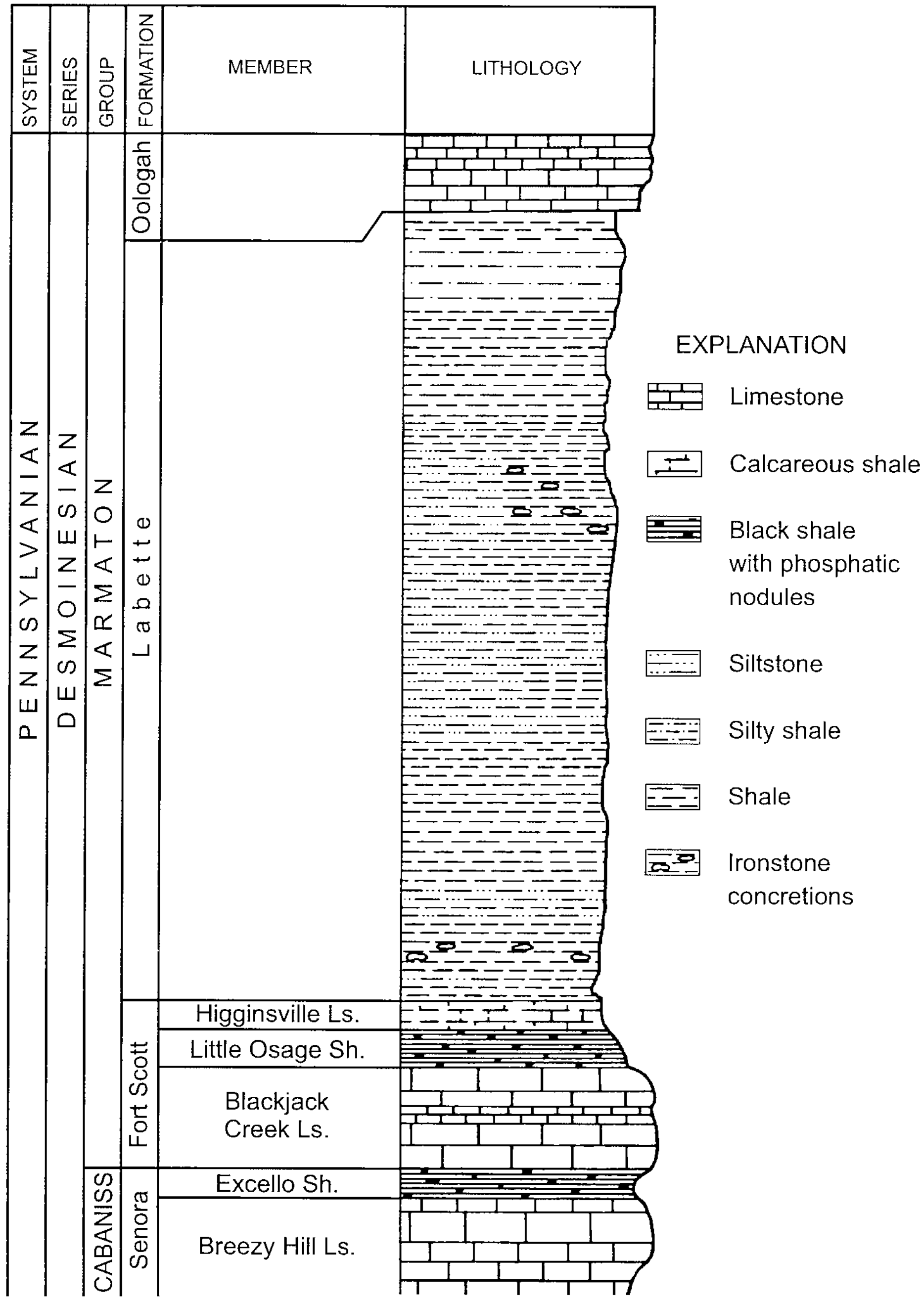

Figure 2. Stratigraphic column showing the rock units exposed in the study area. Thickness of units given in text and appendix.

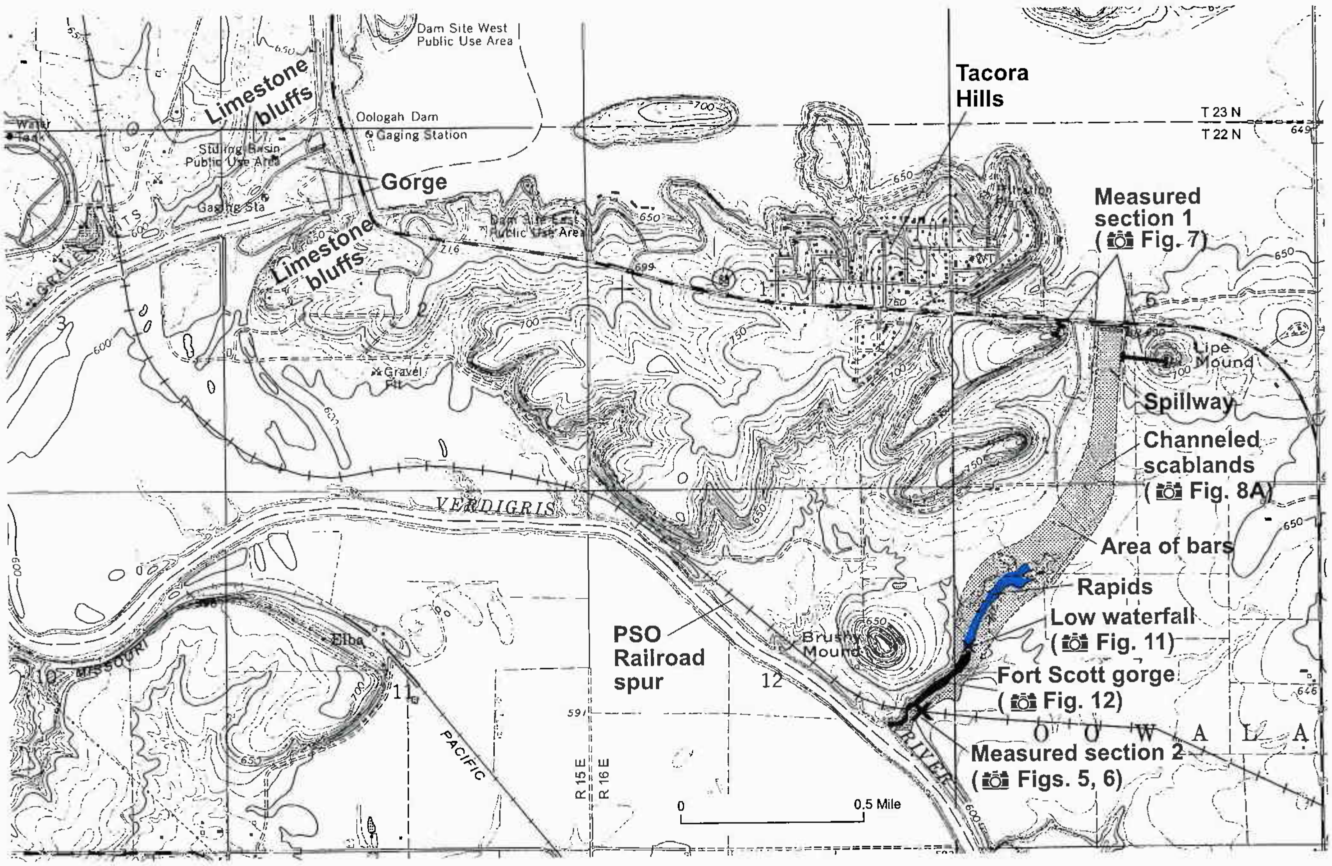

Figure 3. Part of the Oologah Quadrangle 7.5-minute-series map (modified from U.S. Geological Survey, 1970, photo revised 1980) showing the topography in the area of the Oologah Lake spillway, the location of the PSO Railroad spur, the location of measured sections 1 and 2 (Appendix), and the extent of the channeled scablands.

the Oologah Formation and then rapidly downcut through shale of the Labette Formation in the vicinity of the town of Oologah (Fig. 1), making a narrow gorge between limestone bluffs (Fig. 3). A similar breaching of the Oologah occurred 2 mi to the east, between Lipe Mound and the Tacora Hills area (Fig. 3), but the second gap probably was never occupied by the main channel of the Verdigris. In the 1940s, the gorge to the west and the low gap to the east were identified by the U.S. Army Corps of Engineers as ideal settings for a dam and an emergency spillway.

Oologah Dam and Lake

Oologah Lake was formed after the Corps of Engineers built Oologah Dam across the Verdigris River near the town of Oologah (Fig. 1). The dam is in northern Rogers County, about 90 river miles upstream from the confluence of the Verdigris and Arkansas Rivers (Fig. 1); it is about 25 mi northeast of Tulsa.

Although construction of the dam began in 1950, work stoppages during development stages delayed its completion until 1974. Overall, construction cost $46,600,000.

The dam was built primarily for flood control, but the lake also aids conservation. The conservation storage, which provides 553,400 acre-ft of water for municipal water supply, can yield 154 million gallons a day. Also, water is released to support navigation downstream on the Verdigris River. The lake traps sediment, too, and provides water for boating and other recreation.

The dam itself is 4,000 ft long and rises 137 ft above the stream bed. The gross length of the spillway (Fig. 4) is 328 ft. It has seven 40- × 21-ft floodgates. The top of the dam is 687 ft above mean sea level, and the top of the flood-control pool is at an elevation of 661 ft. (Statistics provided by the U.S. Army Corps of Engineers, Tulsa District.)

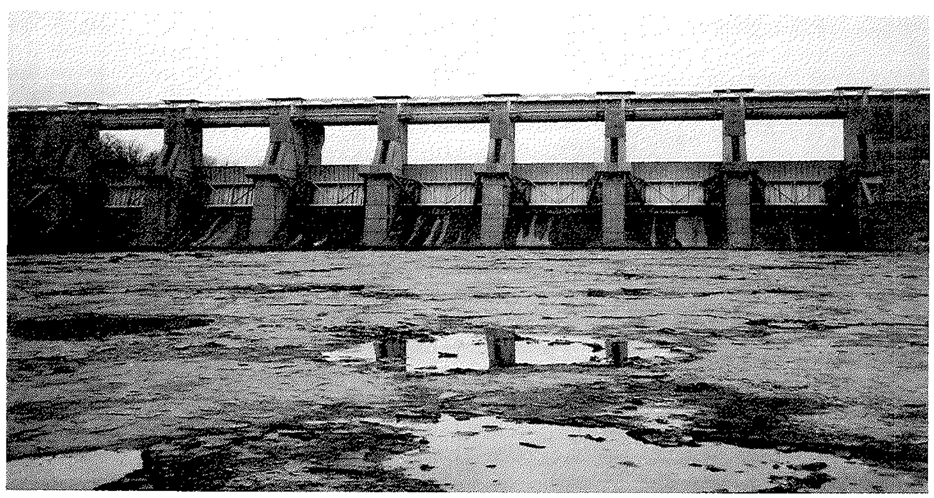

Figure 4. The Oologah Lake spillway showing the floodgates. S.H. 88 bridge crosses the structure (at top).

Stratigraphy

The oldest exposed bedrock in the study area is the Breezy Hill Limestone Member of the Senora Formation (Fig. 2). Only the upper 2 ft is exposed under the PSO Railroad bridge—near the confluence of the Verdigris River and the spillway channel (Fig. 5; Appendix, measured section 2).

The Excello Shale Member is the uppermost stratigraphic unit in the Senora Formation and the Cabaniss Group. It is well exposed under the PSO Railroad bridge, where it is 4.9 ft thick (Fig. 6) and consists of two beds: a black, brittle, platy, noncalcareous shale bed containing ovoid phosphatic nodules, 4.5 ft thick, overlain by a medium dark gray calcareous shale bed 0.4 ft thick (Appendix, measured section 2).

The Blackjack Creek Limestone is the basal member of the Fort Scott Formation of the Marmaton Group. It is exposed over a distance of ~1.3 mi from the spillway to just beyond the PSO Railroad bridge. Only a brief description of the unit is given in the Appendix (measured sections 1 and 2); however, the exposures are so good that ample material is available for studies of the stratigraphy, paleontology, and sedimentology of the Blackjack Creek. Any such work should start here.

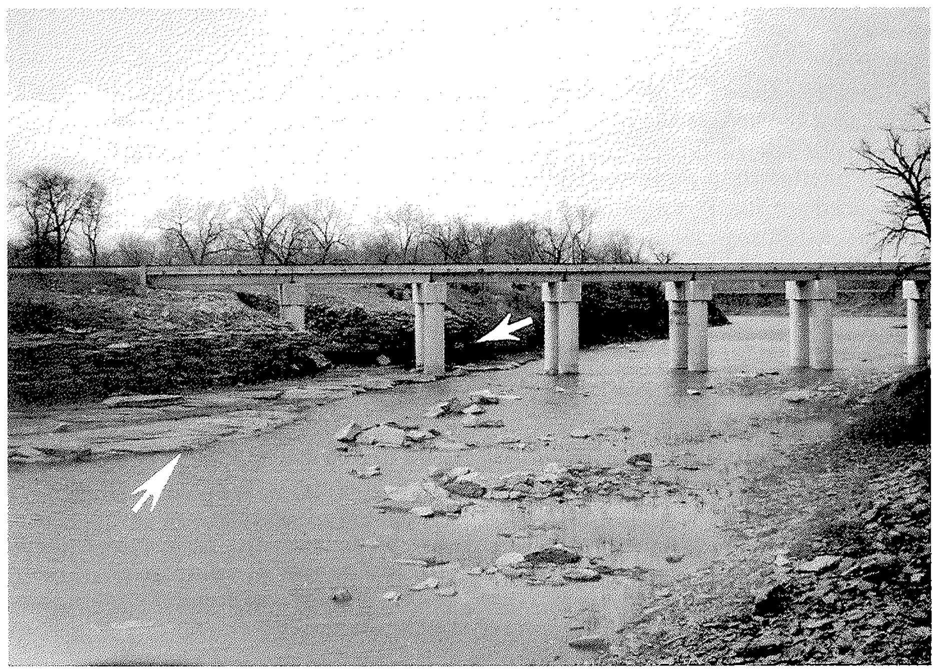

Figure 5. PSO Railroad bridge crossing the Oologah Lake spillway channel (looking south). The Breezy Hill Limestone is exposed at water's edge left (left arrow). The water here is at about the same level as the Verdigris River, and is continuously replenished by water escaping upstream through the spillway gates. The location of Figure 6 is shown by right arrow.

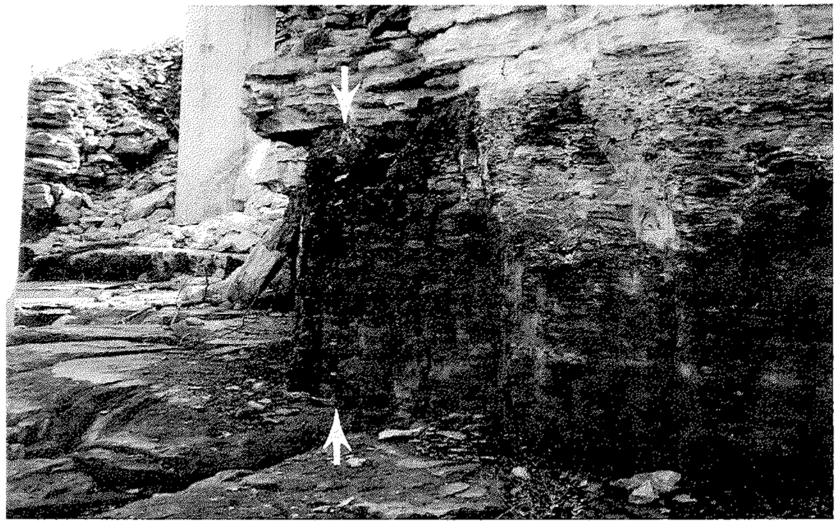

Figure 6. Excello Shale exposed under the PSO Railroad bridge. Its contact with the underlying Breezy Hill Limestone is marked by the hammer head (lower arrow). The top of the shale is marked by the base of the light-colored Blackjack Creek Limestone (upper arrow).

The Little Osage Shale Member of the Fort Scott Formation overlies the Blackjack Creek Limestone Member. It is well exposed at the edges of the spillway channel, just below the floodgates (Fig. 7), where it is 2.5 ft thick. The Little Osage is a black, brittle, platy shale containing spheroidal phosphatic nodules (Appendix, measured section 1), and looks much like the Excello Shale.

The Little Osage Shale is overlain by a 5-ft-thick grayish black calcareous shale containing medium gray, fossiliferous limestone nodules with irregular shapes resembling potatoes. This calcareous shale unit is placed in the Fort Scott Formation and correlated with the Higginsville Limestone Member (following Hemish, 1989, fig. 2). The Higginsville is a light gray to brown, thin-bedded, finely crystalline limestone from 0 to 40 ft thick in Craig County, just to the northeast (Branson and others, 1965).

The Labette Formation is 185 ft thick near the spillway. It is exposed on the slopes of Lipe Mound and also in the road cut south of S.H. 88 just west of the spillway, where it consists of a monotonous sequence of moderate yellowish brown, slightly silty shales containing reddish brown siltstone and ironstone stringers (Appendix, measured section 1).

Approximately 11–12 ft of limestone of the Oologah Formation is preserved as the cap rock of Lipe Mound. It is mostly medium gray to medium light gray, abundantly fossiliferous, wavy-bedded, fine-grained, dense limestone containing large chert pods (Appendix, measured section 1).

Although the limestone of the Oologah Formation did not directly control the landscape below its position atop Lipe Mound, it certainly is significant in the geologic and geomorphic history of the region. Without it, the chain of events recounted below would not have occurred.

Figure 7. Little Osage black shale at edge of spillway channel (arrow) just below the gate structure. The light-colored rock in the foreground is the top of the Blackjack Creek Limestone Member of the Fort Scott Formation. Here the fossiliferous, calcareous shale facies of the Higginsville Limestone Member is concealed by riprap, but it does crop out just above the Little Osage Shale Member farther south at the edge of the channel.

The Carving of the Scablands

The name "Channeled Scablands" was first used in the 1920s by geologist J Harlen Bretz of the University of Chicago, who proposed the idea that certain unusual erosional features in eastern Washington had resulted from a gigantic flood (U.S. Geological Survey, 1976, p. 3).

The flood occurred about 18,000–20,000 years ago when an ice dam was breached, and Glacial Lake Missoula, the largest lake in the Pacific Northwest during the Great Ice Age, drained catastrophically. Meltwater had been impounded in the lake as many as seven times before, but the last great flood modified or destroyed much of the evidence of the earlier floods. At its highest level, Glacial Lake Missoula covered about 3,000 square mi and contained perhaps half as much water as present-day Lake Michigan. Its depth at the ice dam was nearly 2,000 ft—more than twice the depth of Lake Superior (U.S. Geological Survey, 1976, p. 10–14).

Figure 8. A *(above)*—View of the channeled scablands (looking south) from the S.H. 88 bridge atop the spillway gates. The channel is ~150 yards wide. The flat surface partly covered by pools of water is the top of the Blackjack Creek Limestone. B *(opposite page)*—View of the channeled scablands of eastern Washington. Note similar appearance of the surface with that shown in A. Trees at extreme right-center (arrow) suggest the scale (U.S. Geological Survey, 1976, cover photo).

Water pouring out of Glacial Lake Missoula stripped soil away from the underlying lava flows, and moved material including boulders the size of automobiles. Turbulent currents scoured the rocks, plucked away bedrock, and deposited huge bars of gravel and debris. The water eroded deep gorges into the basalt, formed cataracts, extended the gorges back upstream, and left a jumble of irregular depressions on the denuded rock surface (U.S. Geological Survey, 1976, p. 16–17).

Comparing the "scablands" carved by the flood of 1986 below the Oologah Lake spillway with those carved by flood water released when the ice dam holding back Glacial Lake Missoula broke during the Great Ice Age seems almost nonsensical, but the processes were the same and the results are similar. By definition, scablands are essentially flat-lying surfaces (generally basaltic) with dry channels formed by catastrophic flood events. Similar features remain in both the eastern Washington scablands and also the spillway scablands in Oklahoma: (1) both formed on essentially flat-lying surfaces; (2) both were formed by flood events; (3) erosive forces of flood water stripped away preexisting nonresistant materials down to a resistant surface of hard rock; (4) large blocks of resistant rock were plucked out and carried downstream; (5) gravelly and bouldery debris bars formed where current velocity diminished; (6) cataracts and waterfalls formed where gra-

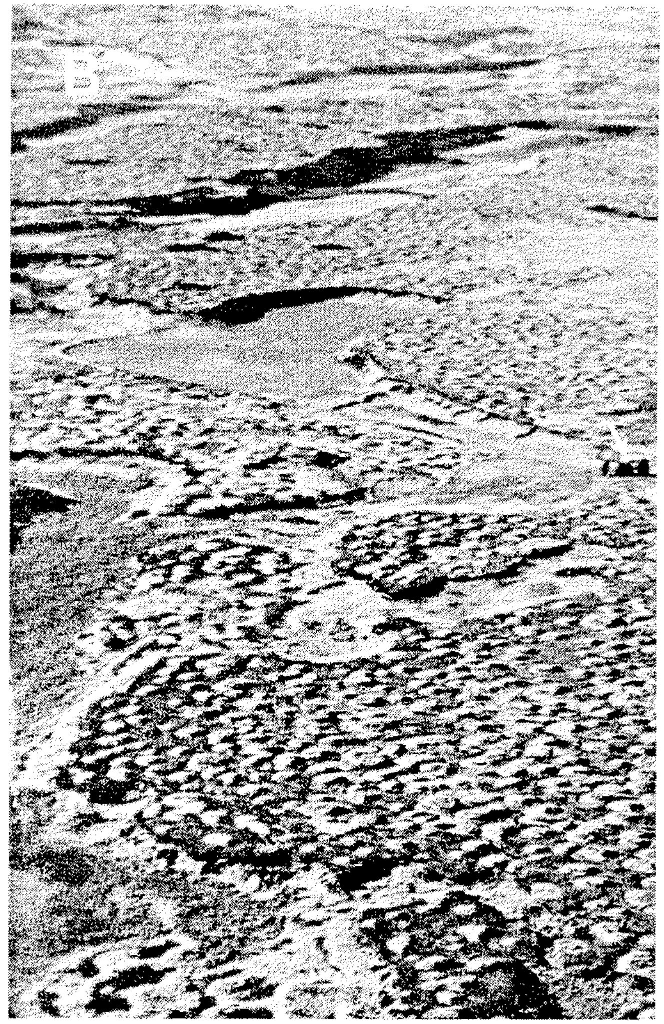

Figure 8 *(continued)*.

dients increased; (7) recessional gorges developed in both areas; and (8) both appear now as rough, barren wastelands with a jumble of depressions (Fig. 8A,B).

In Oklahoma, the spillway scablands (Fig. 9) cover only 9.5 acres, whereas the Washington scablands cover 15,000 mi^2 and document the greatest flood known. When Lake Missoula's ice dam broke, the maximum rate of flow was about 9.5 mi^3/hour—386 million ft^3/sec, or about 10 times the combined flow of all the rivers of the world (U.S. Geological Survey, 1976, p. 12). Flood water released from Oologah Lake in 1986 flowed at a maximum rate of 49,800 ft^3/sec (Paul Schockley, personal communication, 1999), not a small stream compared with the present-day Columbia River, whose average flow is 255,000 ft^3/sec (U.S. Geological Survey, 1976, p. 14).

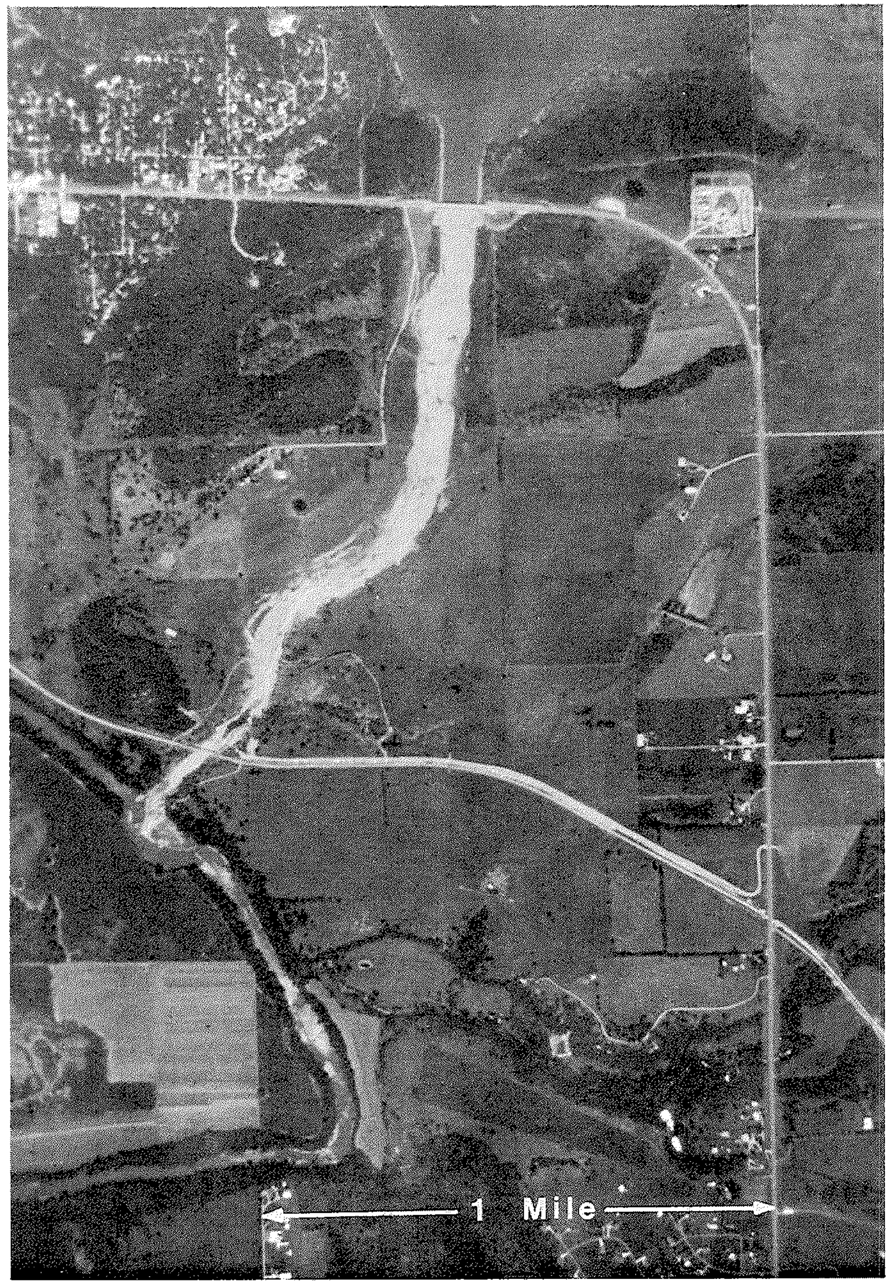

Figure 9. Aerial photograph from 1997 showing the spillway channeled scablands from the floodgates at Oologah Lake to the Verdigris River. Part of the PSO Railroad is visible where it crosses the Fort Scott gorge in the lower part of the photo. (Photo courtesy U.S. Department of Agriculture.)

Before the flood of 1986, the emergency spillway for Oologah Lake (whose dam was completed in 1974) had never been used, and below the floodgates the land was still covered by topsoil, grass, and trees.

In late September 1986, heavy rains began to fall in the upper drainage basin of the Verdigris River, in Kansas, north of the lake.

On September 27, the lake stood at its normal pool elevation of 638 ft above sea level. Six days later the Corps of Engineers began 24-hour emergency watch. On October 10, the lake level had risen almost 27 ft—to an elevation of 664.91 ft—and as the water approached the top of the spillway gates, it became apparent that the lake's capacity for storing the incoming water had been greatly reduced. Orders came from the Corps of Engineers in Tulsa to open all seven gates (Paul Schockley, personal communication, 1999).

The released water roared through the gates, producing violent currents (Fig. 10); water ripped away everything in its path, uprooting large trees and carrying them downstream. The turbulent currents moved boulders and slabs of rock 2–3 ft across and a few inches thick. Where the channel widens and bends to the southwest—about 0.75 mi below the floodgates—the currents apparently slowed and sediment was dropped and heaped together to form bars of chaotic debris. In places, large rock slabs were deposited in imbricate structures dipping upstream,

Figure 10. Turbulent water in the spillway channel below the floodgates, pouring from Oologah Lake during the flood of October 1986. (Photo courtesy U.S. Army Corps of Engineers.)

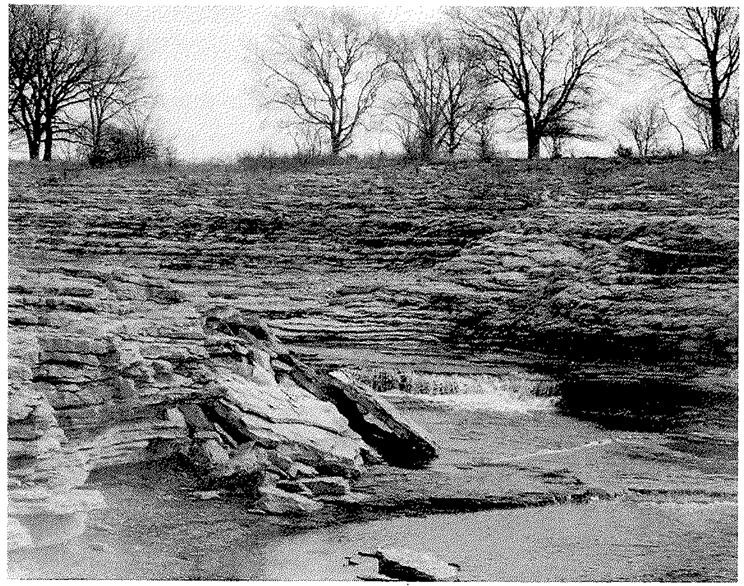

Figure 11. Narrowing of the gorge where the falls retreated upstream as water cut through the comparatively soft Excello Shale. The falls are ~4 ft high.

Figure 12. The Fort Scott gorge, looking northeast from just above the PSO Railroad bridge. A flank of Lipe Mound is visible at the extreme upper left of the photograph, behind the trees. The gorge is ~25 ft deep.

much as flat pebbles are arranged in a shingle-like pattern in stream beds. As the flow diminished, smaller particles ranging from clay to gravel were entrapped in debris bars; in the years since, growth of grass, weeds, and brush have done little to modify the starkness of the scene.

The fall from the floodgates to the normal level of the Verdigris River is ~60 ft. Most of the down-cutting occurred in the lower 0.6 mi of the channel. Toward the confluence with the Verdigris, the stream gradient steepened and the current again moved with greater swiftness. The speeding water carved first a series of steps into the Fort Scott Limestone, forming rapids (Fig. 3), then it created a low waterfall by undercutting into the Excello Shale (Fig. 11). The Fort Scott gorge (Fig. 12) was cut to a depth of about 25 ft from the base of the rapids to its confluence with the Verdigris, just beyond the PSO Railroad bridge (Figs. 3,5).

After 19 days of 24-hour watch, the emergency ended; the floodgates were closed on November 3. A hundred-year flood (Paul Schockley, personal communication, 1999) had left its mark, and as the water in the spillway drained away, the scablands were revealed for the first time.

The gorge in the lower part of the channel (Fig. 12) is now floored by the upper part of the resistant Breezy Hill Limestone Member of the Senora Formation. The upper part of the spillway channel is floored by the top of the Blackjack Creek Limestone Member of the Fort Scott Formation (Figs. 4,7,8A). As the photograph shows, the surface of the limestone is not flat but undulating, giving the channel its

Figure 13. "Pop up" feature (outlined) showing the results of freeze-thaw action within the Blackjack Creek Limestone Member. The outlined area is ~10 ft in diameter.

Figure 14. Crinoid column embedded in impure, silty, shaly limestone just below the contact between the Little Osage Shale and Blackjack Creek Limestone. The diameter of the column is about that of a dime (visible just to the right of center).

scabland appearance. This irregular surface did not result from scouring but from differential chemical and physical weathering at the base of the soil horizon, which was revealed when flood water removed the soil.

Although the limestone resists erosion, it is by no means immune. Figure 13 shows a "pop up" feature—a more or less circular structure ~10 ft in diameter; it has been fractured and uplifted by expansion of ice from water that had penetrated into the layered rock along bedding planes. Future releases of flood water will cause additional disruption of these broken slabs, and they will be transported downstream.

Since the 1986 catastrophe, flood water was released through the spillway in 1991 and again in 1994, but with little apparent modification of the landscape. The channel of scablands maintains an average width of about 150–200 yards.

Perhaps some people see the scablands as a wasteland, but the geologist sees them as a garden of Eden. One of the finest exposures of bedrock in the State is now available for research by stratigraphers, geomorphologists, paleontologists, and sedimentologists.

As noted in the measured sections (Appendix), the top layer of the Blackjack Creek Limestone contains abundant fossils—the most noteworthy being large crinoid columns, many an inch in diameter and some 3 ft long (Figs. 14,15). A search of the entire length of the channel might well reveal museum-quality specimens.

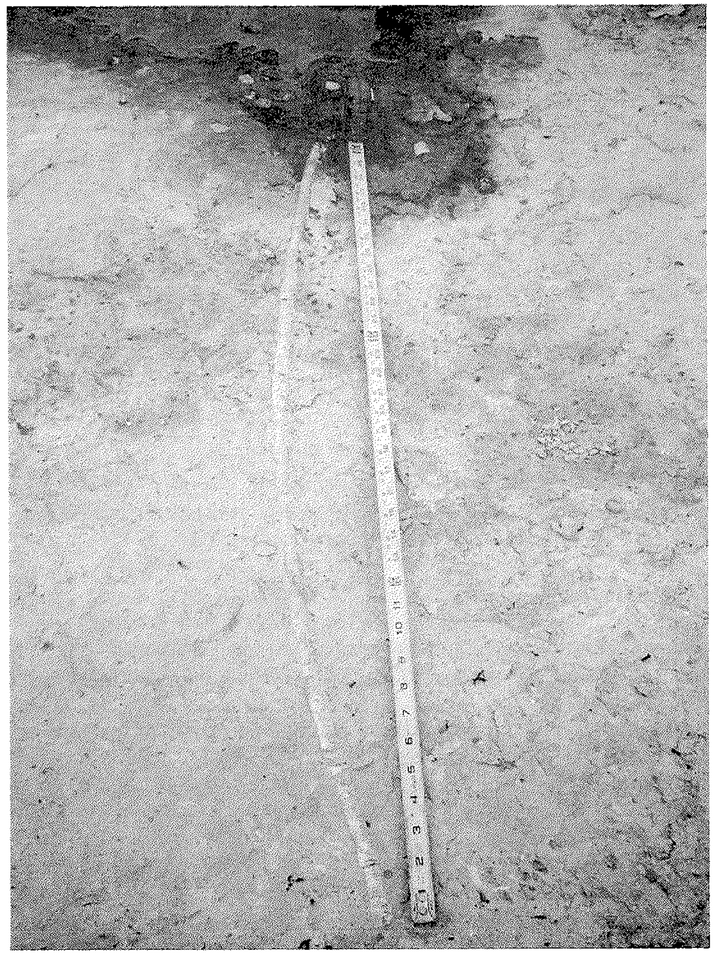

Figure 15. An intact, 3-ft-long crinoid column firmly embedded in the top of the Blackjack Creek Limestone. Note the preserved patch of muddy, dark limestone under the tape-measure case. This dark limestone bed (just below the Little Osage Shale) is the most prolific source of large crinoid columns.

Summary

Alteration of the landscape of a small part of northern Rogers County was greatly accelerated by a flood event in the fall of 1986. Formation of channeled scablands below the Oologah Lake spillway had little financial impact on the area—only some loss of pastureland in an acreage where the U.S. Army Corps of Engineers has an easement. The Oologah Dam and the floodgates withstood the battering of the water without structural damage—a testimonial to the design by the Corps of Engineers.

Other spillways have been eroded during major floods throughout the Midwest, and excellent exposures of bedrock have resulted. Most notable, perhaps, are the Wister Lake spillway in Oklahoma (Hemish, 1993, fig. 9), and the Milford Reservoir spillway and the Tuttle Creek Reservoir spillway in Kansas. Many others are in in Iowa, Nebraska, and Missouri.

Acknowledgments

Gratitude is expressed to Park Ranger Paul Schockley and all the personnel at the Oologah Resident Office of the U.S. Army Corps of Engineers, Tulsa District, for their cooperation in preparation of this article. Thanks also are given to Dolores Qualls of the U.S. Department of Agriculture, Rogers/Tulsa Counties, and her staff for their efforts in providing aerial photographs of the study area.

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APPENDIX—Measured Sections

Measured Section 1

Measured from the top of Lipe Mound down the west slope to the top of the eroded spillway channel and in south road cut at west end of S.H. 88 bridge over spillway, NW¼SE¼ and NE¼SW¼ sec. 6, T. 22 N., R. 16 E., Rogers County, by LeRoy A. Hemish. Rock-color terms are those shown on the rock-color chart (Rock-Color Chart Committee, 1991).

	Thickness (feet)
MARMATON GROUP	
Oolagah Formation	
6. Limestone, very pale orange (10YR8/2) to grayish orange (10YR7/4) to medium light gray (N6), fine-grained; thin, wavy-bedded; weathers hackly and nodular; fossiliferous; crinoids, brachiopods, and corals abundant; contact with underlying unit sharp	6.0
5. Limestone, medium gray (N5) to light brown (5YR6/4), fine-grained, dense, hard, abundantly fossiliferous; thick-bedded, vuggy; contains a discontinuous zone of light brown (5YR6/4) to dark yellowish orange (10YR6/6) chert pods, generally ~9 in. thick and 3.5 ft long in cross section; basal contact sharp	5.5
Labette Formation	
4. Shale, moderate yellowish brown (10YR5/4), slightly to highly silty; contains dusky red (5R3/4) to moderate reddish brown (10R4/6) ferruginous siltstone layers up to 2 in. thick, as well as ironstone concretions of the same color—both iron-rich units most abundant in lower 50 ft; some shale layers medium dark gray (N4) to olive gray (5Y4/1) and calcareous in fresh exposures	185.0
Fort Scott Formation	
Higginsville Limestone Member	
3. Shale, grayish black (N2), highly calcareous; includes abundant medium gray (N5), knobby, potato-shaped limestone nodules containing small brachiopods and other small fossil fragments; base sharp	5.0
Little Osage Shale Member	
2. Shale, black (N1), brittle, platy; stained dark reddish brown (10R3/4) on parting surfaces; contains abundant spheroidal black (N1) phosphatic nodules, generally <1 in. in diameter; base sharp	2.5
Blackjack Creek Limestone Member	
1. Limestone (top layer of Blackjack Creek Limestone), light brownish gray (5YR6/1), to dark gray (N3), flaky; contains abundant crinoid columns as much as 1 in. in diameter, with preserved columns up to 3 ft in length; underlain by a hard layer of grayish orange (10YR7/4) limestone, also containing well-preserved crinoid columns (top of eroded spillway channel)	0.3
Total thickness of section	204.3

Measured Section 2

Measured under the PSO Railroad bridge, SE¼NW¼NE¼SE¼ sec. 12, T. 22 N., R. 15 E., Rogers County, by LeRoy A. Hemish. Rock-color terms are those shown on the rock-color chart (Rock-Color Chart Committee, 1991).

	Thickness (feet)
MARMATON GROUP	
Fort Scott Formation	
Blackjack Creek Limestone Member	
4. Limestone, dark yellowish orange (10YR6/6) to grayish orange (10YR7/4) to light gray (N7), fine-grained, mostly medium- to thick-bedded, wavy-bedded in part, vuggy, includes algal-rich intervals; contains abundant invertebrate fossils such as brachiopods, bryozoans, fusulinids—and, most noteworthy, crinoid ossicles and columns, as much as 1 in. in diameter and 3 ft in length (best observed just below contact with overlying unit in upper part of spillway channel). Also contains 6–8-in.-diameter "mounds" on exposed surfaces of spillway channel (stromatolites?) that exhibit calcite-filled fractures and are generally preserved as septarians. Contact with underlying unit sharp and conformable; top weathered	~18.0
CABANISS GROUP	
Senora Formation	
Excello Shale Member	
3. Shale, medium gray (N5) to medium dark gray (N4) with dark yellowish orange (10YR6/6) weathered streaks, highly calcareous, soft and clayey in upper part	0.4
2. Shale, black (N1), with light brown (5YR5/6) and moderate yellowish orange (10YR6/6) staining on joint surfaces, brittle, platy, noncalcareous, well jointed; contains abundant spheroidal to ovoid phosphatic concretions from 0.5 to 2.0 in. in diameter that weather white (N9), and may contain identifiable fossil material such as shark's teeth in their centers; contact with underlying unit sharp	4.5
Breezy Hill Limestone Member	
1. Limestone, dark gray (N3), weathers light brown (5YR5/6) to moderate yellowish brown (10YR5/4), contains carbonaceous streaks; characterized by an abundance of broken fossil shell material and brachiopod valves occurring in clusters at top of unit; fine-grained, very thin to thin-bedded; contains parallel joints spaced from 2 to 6 in. apart; only about 2 ft exposed above water	2.0
Total thickness of section	24.9

UPCOMING *Meetings*

2D–3D Seismic: Effective Application Can Improve Your Bottom Line, Workshop, July 29, 1999, Oklahoma City, Oklahoma. Information: Michelle Summers, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031 or (800) 330-3996, fax 405-325-7069.

American Association of Petroleum Geologists International Conference and Exhibition, September 12–15, 1999, Birmingham, England. Information: AAPG Convention Dept., Box 979, Tulsa, OK 74101; (918) 560-2679, fax 918-560-2684.

Gulf Coast Association of Geological Societies/AAPG, Annual Section Meeting, September 15–17, 1999, Lafayette, Louisiana. Information: W. C. Terrell, 7 Eureka Plantation Road, Lafayette, LA 70508; (318) 233-1857; e-mail: dina411@aol.com.

Society for Organic Petrology, Annual Meeting, September 26–30, 1999, Salt Lake City, Utah. Information: Jeff Quick, Utah Geological Survey, 1594 W. North Temple, Suite 3110, Salt Lake City, UT 84114; (801) 537-3372, fax 801-537-3400; e-mail: nrugs.jquick@state.ut.us; World Wide Web: http://www.tsop.org.

Bartlesville Play Workshop, cosponsored by Oklahoma City Geological Society and Oklahoma Geological Survey, September 29, 1999, Oklahoma City, Oklahoma. Information: Carol Jones, OCGS, (405) 236-8086, ext. 11.

Society of Petroleum Engineers, Annual Meeting, October 3–6, 1999, Houston, Texas. Information: SPE, P.O. Box 833836, Richardson, TX 75083.

American Institute of Professional Geologists, Annual Meeting, October 5–8, 1999, Anchorage, Alaska. Information: AIPG, 7828 Vance Dr., Suite 103, Arvada, CO 80003; (303) 431-0831, fax 303-431-1332; e-mail: aipg@netcom.com.

Geological Society of America, Annual Meeting, October 25–28, 1999, Denver, Colorado. Information: Becky Martin, GSA Meetings Dept., Box 9140, Boulder, CO 80301; (303) 447-2020, ext. 164, fax 303-447-1133.

Soil Science Society of America, Annual Meeting, October 30–November 4, 1999, Salt Lake City, Utah. Information: SSSA, 677 S. Segoe Road, Madison, WI 53711; (608) 273-8090, fax 608-273-2021; e-mail: rbarnes@agronomy.org.

Society of Exploration Geophysicists, Annual Meeting, October 31–November 5, 1999, Houston, Texas. Information: Bob Lewis, (918) 497-5500, fax 918-497-5557.

National Science Teachers Association, Southern Area Convention, November 18–20, 1999, Tulsa, Oklahoma. Information: NSTA Conventions Office, 1840 Wilson Blvd., Arlington, VA 22201; (703) 312–9288.

Prue and Skinner Plays Workshop, cosponsored by Oklahoma City Geological Society and Oklahoma Geological Survey, December 6, 1999, Oklahoma City, Oklahoma. Information: Carol Jones, OCGS, (405) 236-8086, ext. 11.

Interstate Oil and Gas Compact Commission, Annual Meeting, December 12–14, 1999, New Orleans, Louisiana. Information: Interstate Oil and Gas Compact Commission, P.O. Box 53127, Oklahoma City, OK 75152; (405) 525-3556, fax 405-525-3592; e-mail: iogcc@iogcc.state.ok.us.

AAPG MID-CONTINENT SECTION MEETING
Wichita, Kansas August 29–31, 1999

The meeting is being held in conjuction with the annual meetings of the AAPG Midcontinent Section's Divisions of Professional Affairs and Energy Minerals, and the Kansas Independent Oil and Gas Association. The theme is "Geoscience for the 21st Century."

Technical Program

Occurrence and Development of Petroleum in Nebraska
The First Integrated Petroleum Production and Refining West of the Mississippi River
Kansas Oil and Gas Exploration, a Ten-Year History and Future Strategies
Detailed Reservoir Modeling on a Basinwide Scale and Implications on the Decision-Making Process
Upper Pennsylvanian and Lower Permian of Southeast New Mexico: Rejuvenation of Underdeveloped Fields Yields Major Reserves
Blind-Thrust Spiro Play—A Case History, Western Arkoma Basin, Oklahoma
Morrow Incised Paleovalley Production, Stateline Trend, Northern Anadarko Basin
South Eubank Field: Successful Development of Deeper Reservoirs Using 3-D Seismic
History and Development of the Stewart Field, Finney County, Kansas
Subtle and Not So Subtle Anticlinal Structures in the Salina Basin, North-Central Kansas
Petroleum Geology and Geochemistry of a Production Trend Along the McPherson Anticline in Central Kansas, with Implications for Long- and Short-Distance Oil Migration
Genetic Connections Between Ores, Hydrocarbon Deposits, Black Shales, and Migrating Basinal Brines
Relationships of MTV Mineralizations, Color-Altered Conodonts, Fluid Inclusions, J-Type Lead, and Migrating Oil-Field Type Basinal Brines with Unconformity-Bounded Stratigraphic Sequences
Pennsylvania History of the Chautauqua Arch, Oklahoma and Kansas
Significance of Accurate Carbonate Reservoir Definition and Delineation
The Strike-Slip, Compressional Thrust-Fold Nature of the Nemaha Ridge in Eastern Kansas and Oklahoma
Use of Gravity and Magnetics for Low-Cost Exploration and Development in Mature Areas such as Kansas
Regional Stratigraphic Analysis of a Pennsylvanian Carbonate Shelf and Shelf Margin
Compartmentalization of the Overpressured Interval in the Anadarko Basin
Reservoir Characterization of the Council Grove Group, Texas County, Oklahoma
Intravalley Cut-and-Fill Structures in Lower Cretaceous Fluvial Strata of Colorado and Kansas: A Cause for Compartmentalization in Fluvial Reservoirs
Computer Technology and the Petroleum Geologist, 1999
Changes in Patterns of Cyclicity of Upper Carboniferous Through Lower Permian (Virgilian-Sakmarian) Depositional Sequences in the North American Midcontinent
Evidence for Hierarchy of Stratigraphic Forcing in the Upper Carboniferous (Virgilian, Wabaunsee Group) in the Anadarko Basin

Seismic Sequence Stratigraphy of the Upper Morrow Formation: A Regional Study in the Western Anadarko Basin
Characterizing a Morrow Sandstone Reservoir Through Stratigraphic Interpretation of 3-D Seismic Data, Sorrento Field, Colorado
Subsurface Structure and Sequence Stratigraphy of the Western Margin of the Hugoton Embayment, Morton County, Kansas
Forward-Modeling of Log Responses from Rock Petrophysical Properties as an Aid in Reservoir Analysis
Resistivity Modeling and Neural Network Synthetics . . . Powerful New Exploration and Development Tools
The Prediction of Effective Porosity and Permeability in Mississippian Carbonates, Kansas
An Innovative Horizontal Drilling Program Opens a New Exploration Play in Admire (Permian) Reservoirs of the Northern Denver Basin, Nebraska
The State-of-the-Art of 3-D Seismic Technology: Integrated Multicomponent Characterization of Carbonate and Clastic Reservoirs
Small Closed Structural Lows: Unconventional Gas Exploration Targets in North Missouri
Oklahoma Coal-Bed Methane: From Mine Explosion to Gas Resource
Coal Geology and Underground-Mine Degasification Applied to Horizontal Drilling for Coal-Bed Methane
An Economic Evaluation of the Hartshorne Coalbed Methane Play in Oklahoma
Coal Resources and Coalbed Methane Potential in the Kansas Portion of the Forest City Basins
Evaporite Karst in the Southern Midcontinent
Compliance with Oil and Gas Environmental Regulations During Periods of Low Oil Prices
Halophyte Remediation of Brine Impacted Oil and Gas Sites in Kansas
ZOEI, a Computer Model to Calculate the Zone of Endangering Influence of Class II Injection
The Kansas Geological Survey's New Initiative in the Manhattan 1 × 2 Quadrangle, Northwest Kansas
The Big Basin Impact Craters of Western Kansas

Short Courses

3-D Seismic Short Course
Rocks in Your Head—Short Course for Teachers

Field Trip

The Chase Group in Southern Kansas Lithostratigraphy, Facies, and Sequence Stratigraphic Architecture

For further information about the meeting, contact Alan DeGood, American Energies Corporation, 155 N. Market, Suite 710, Wichita, KS 67202; (316) 263-5785; e-mail: degood@feist.com. *The preregistration deadline is August 13, 1999.*

Oklahoma ABSTRACTS

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

Aeolian Modification of Pleistocene Stream Terraces on the Cimarron River in Oklahoma

GREGORY F. SCOTT, USDA-NRCS, 4900 W. Oklahoma, Woodward, OK 73801

Whereas running water is the dominant agent of geomorphic change, during periods of aridity aeolian processes dominate. The resulting landforms reflect several cycles of fluvial dominance interspersed with periods of aeolian dominance during the Holocene. Wetlands on Pleistocene stream terraces in Oklahoma are often the result of aeolian deposition of sand dunes during arid periods in the Holocene.

Major rivers in Oklahoma, such as the Cimarron, South Canadian, and Salt Fork of the Arkansas, developed large stream terraces during high stream flows in the Pleistocene. A coarse dendritic drainage pattern developed on the terrace surface after emplacement. These rivers also carry large loads of sand. The bed load is available for transport by wind during dry periods. The sand is transported onto the stream terrace and impacts the previously developed dendritic drainage.

Research from several disciplines has established that the Holocene climate of the area has experienced several fluctuations. Warm, dry periods occurred about 1,200, 5,000, and 7,500 years BP. During these dry intervals, aeolian processes dominated the landscape and buried fluvial features developed during the preceding wet period. Up to five bands of sand dunes are emplaced parallel to the river. The dunes have different forms that reflect the availability of sand and degree of aridity during each period. The soils that developed on the aeolian surfaces reflect the age of the deposit in the development of the soil. The youngest soils have very weak horizonation, light colored surfaces, and abundant bases. The older soils are leached, and have argillic horizons and some mollic epipedons. These characteristics and buried organic layers provide the means to date the aeolian dominance of the fluvial system.

Reprinted as published in the Geological Society of America *1998 Abstracts with Programs*, v. 30, no. 3, p. 31.

Without Knowledge of Surficial Geomorphology—Geology, Remediation Models Are Calculated Guesses

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Surficial geologic materials, geomorphic features such as channels, swamps and dunes, and structural features such as fractures and folds are frequently masked by buildings, asphalt, concrete and landscaping in industrial developments. As contaminant investigations are most common in industrial areas, the changed geologic-

geomorphologic aspects can and do confuse the investigator. Test borings and monitor wells are located where they are accessible for drilling, close to suspected contaminant, and upgradient and downgradient from suspected contaminant. Based on data collected from the testing, a conceptual model is constructed. A contaminant plume is modelled to move from source to sink regardless of geologic conditions. In the rush to create a model, features controlling the shallow water are not considered or recognized and the resultant interpretation will be wrong.

A Tulsa example is used to demonstrate the influence of masked fluvial geomorphic features. Using monitor well data to create cross sections and direction of water flow, a source was incorrectly identified and an expensive remediation plan was designed which would have been ineffective. Excavation of soil under buildings revealed controlling buried channels which ultimately were perpendicular to the predicted plume. Detailed pre-development terrain analysis using old aerial photographs and topographic maps would have provided valuable data to the investigator before drilling test borings and monitor wells.

Reprinted as published in the Geological Society of America *1998 Abstracts with Programs*, v. 30, no. 3, p. 11.

Depositional Environments and Paleoclimatic Cyclicity within the Labette Shale, Eastern Oklahoma

TROY W. JOHNSON and *ALLEN W. ARCHER*, Dept. of Geology, Kansas State University, Manhattan, KS 66506

The Labette Shale (Marmaton Group, Desmoinesian Stage, Middle Pennsylvanian) is a thick predominately siliciclastic shale occurring in northeast Oklahoma, eastern Kansas, western Missouri, and southwest Iowa. The thickness of the Labette Shale ranges from approximately 12 m in southeast Kansas to 70 m in the subsurface of northeast Oklahoma. The Labette Shale consists of clay-rich shale, sandstone, minor amounts of limestone, and local occurrences of coal.

A surface exposure of the Labette Shale located in northeastern Oklahoma, contains many interesting depositional features, including cyclic patterns of laminae, a variety of sedimentary structures, and abundant trace fossils. The presence of these features provides an excellent opportunity to reconstruct the original depositional environment and to access short-term paleoclimatic fluctuations that were operative during sedimentation.

Exposures in the study area are primarily composed of very fine grained sandstone layers separated by thin, impersistent mud drapes. The sandstone itself is light to medium gray in color, well sorted and displays wavy and flaser bedding and herringbone cross stratification. The layers separate easily along the mud partings to reveal well preserved current ripples, current shadows, and various other sedimentary structures. Also preserved within the laminae are a variety of trace fossils, formed by epifaunal grazers and scavengers, resulting in few vertical burrows and little or no bioturbation within the sandstones.

The laminae periodicity recorded within the outcrop show a remarkable similarity to those of lunar orbital parameters. In addition, longer-term yearly periods suggest a moderate degree of seasonal flux from the fluvial regime. This evidence, when combined with the sedimentary structures and trace fossils, provides strong evidence of deposition within a fluvially modulated, tidally controlled environment.

Reprinted as published in the Geological Society of America *1998 Abstracts with Programs*, v. 30, no. 3, p. 8–9.

Glenn Pool Field, Oklahoma: A Case of Improved Production from a Mature Reservoir

DENNIS R. KERR, Dept. of Geosciences, University of Tulsa, Tulsa, OK 74104; *LIANGMIAO "SCOTT" YE*, ARCO EPT, 2300 W. Plano Parkway, Plano, TX 75075; *ASNUL BAHAR* and *B. MOHAN KELKAR*, Dept. of Petroleum Engineering, University of Tulsa, Tulsa, OK 74104; and *SCOTT L. MONTGOMERY*, Petroleum Consultant, 1511 18th Ave. E., Seattle, WA 96112

Glenn Pool oil field, discovered in 1905, is considered a mature field, and yet contains substantial amounts of potentially remaining recoverable reserves. Glenn Pool is a giant oil field that has produced over 330 MMbbl (million barrels) oil from the Pennsylvanian Bartlesville (Glenn) sandstone using primary and secondary methods, with limited tertiary recovery efforts. Despite a long history of production, some production tracts have recovered a total of only 21% of original oil in place, with many wells currently exhibiting water cuts of 99% or higher.

Results reported here are part of a reservoir characterization and management effort aimed at improving recovery in Glenn Pool field. This effort involves an industry-academic-government partnership included within the U.S. Department of Energy's Class I (fluvial-deltaic reservoir) initiative. Focus of the Glenn Pool Project has been on the Self unit, a 160 ac (64 ha) tract in the southeastern portion of the field. A combination of detailed geologic study, geostatistical modeling, and reservoir simulation has been employed to design and implement improved recovery strategies. A crucial result of this work has been a reinterpretation of Bartlesville depositional systems and facies architecture in northeastern Oklahoma. With only one-quarter of the total implementation plan in effect, oil production more than doubled, exceeding expectations. Water production, however, remains high. Additional management plans are under consideration.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 83, p. 1, January 1999.

Application of Borehole Imaging for Reconstruction of Meandering Fluvial Architecture: Examples from the Bartlesville Sandstone, Oklahoma

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Reconstruction of meandering fluvial architecture of the Bartlesville Sandstone (Middle Pennsylvanian age) was achieved through the analysis of borehole images. Three sites in northeastern Oklahoma were studied: Glenn Pool Field (Creek County), Amoco's Experimental Drilling Site (Rogers County), and an imaged well 850 feet behind a Bartlesville outcrop (Mayes County). Each site included a microresistivity log, conventional log suite, and whole core. The upper part of the Bartlesville Sandstone comprises meandering fluvial architectural elements including, but not limited to, multistory discrete genetic interval elements, and channel-fill and splay facies elements.

Channel-fill facies elements are reconstructed by comparing borehole image analysis to synthetic geometric model dip vector plots. Cases for different thalweg meandering histories are identified in the upper Bartlesville. Vertical trends in dip angle and ro-

tation indicate histories of thalweg translation (phase shift), expansion (amplitude increase), and migration of secondary nodes.

Crevasse splay facies elements were also reconstructed from borehole image analysis. Vertical dip azimuth rotation yields the position of a well relative to the crevasse break. Crevasse splay complexes, which are sourced from different crevasse breaks, can be reconstructed from detailed image analysis.

Reprinted as published in the American Association of Petroleum Geologists *1999 Annual Convention Official Program*, v. 8, p. A71–A72.

Thermal-Gas Repressurization of a Pennsylvanian Age Stream Channel Sandstone Reservoir in Osage County, Oklahoma

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THOMAS MEEKS, Wave Technology, Inc., Colton, CA; and
ANTHONY K. MILLER, U.S. Crude Ltd., Colton, CA

Landon Field is located in northern Osage County, Oklahoma. During September and October 1997 the operator conducted an 8 well cyclic steam pilot project to increase oil production to 10 barrels per day from less than 1 barrel per day and remediate paraffin precipitation. Cyclic steam operations successfully removed precipitated paraffin, allowing inflow of oil into the wellbore. Oil production increased to 12 barrels per well in the pilot project but quickly declined because of the lack of reservoir pressure to drive oil to producing wells. The operator, U.S. Crude Ltd., made the decision to design and constructed a thermal-gas (flue-gas) generator to repressurize the reservoir. The TM-98 Thermal-Gas generator was designed, constructed, and moved into Landon Field for a pilot test. After the first 5 days of thermal-gas injection by the TM-98 unit oil production in the pilot project increased more than 500 percent above the daily rate. The daily production rate was 5 barrels of oil per day total from 33 producing wells, the average production rate for more than 3 months prior to starting the test in September 1998. During the first 15 days of October 1998 more than 600 barrels of oil was produced and thermal-gas injection was started in 3 additional wells.

Reprinted as published in the American Association of Petroleum Geologists *Bulletin*, v. 83, p. 389, February 1999.

A High Resolution 3D Seismic Survey Using 55 × 55 Feet Bin Size in Osage County, OK, to Delineate Details of Structure, Stratigraphy and Subtle Lithologic Variations

B. SHARMA, *T. K. REEVES*, *W. I. JOHNSON*, *S. BANERJEE*, and *S. GEORGE*, BDM Petroleum Technologies, Bartlesville, OK; and *R. LINDSEY*, NPTO, Dept. of Energy, Tulsa, OK

A high resolution 3D seismic survey was recently concluded with carefully selected data acquisition parameters in a 16.75 sq mile area in Osage County, Oklahoma, to investigate the reserves growth potential of the platform deposits which have produced oil and gas from the area for over 100 years. The effectiveness of closer scanning of the subsurface with a smaller bin size was investigated by acquiring seismic data from 6 sq miles out of the total area with a bin size of 55 ft × 55 ft and the rest with the more conventional 110 ft × 110 ft bin configuration.

Data acquired with the two bin configurations in the same area indicate that due to averaging over a larger area, the small individual faults (throw around 30–40 ft) could not be resolved as effectively in the 110 ft bin data as in the 55 ft data. The higher frequency content in the 55 ft bin data (80–90 Hz from the deepest reflectors) have contributed to the sharpness of the fault plane images. This enables precise mapping of these faults in the entire sedimentary section down to the basement which occurs at a depth of around 4000 ft. The distribution of oil and gas production in Osage county indicates that some of the small faults mapped act as barriers to fluid migration.

Detailed correlation with wireline logs indicates that amplitude and wave shape variations of the reflected wavelet are mainly affected by changes in thickness, lithology, porosity and fluid saturations of the reservoir rocks. The shallow Pennsylvanian Layton gas sand (at a depth of around 1100 ft) gives a large negative reflection when the reservoir porosity and gas saturations are high in one part of the field but the amplitude diminishes as the reservoir becomes less porous due to an increase in the clay content and the gas saturation also decreases. A significant increase in clay content is indicated by a change in the reflected wave shape due to dampening of the pulse. Preliminary studies indicate that lithologic variations may be approximately quantified from the frequency content of the reflected pulse. The porosity development in thin, tight Arbuckle carbonates of Ordovician age is seen as a local zone of amplitude reduction in the high resolution seismic sections.

The superior imaging capabilities of seismic data acquired with 55 ft bin configuration has significantly improved our capabilities to conduct detailed investigation of structure, stratigraphy and fluid saturation distributions.

Reprinted as published in the American Association of Petroleum Geologists *1998 Annual Convention, Extended Abstracts*, v. 2, p. A592.

Reduction of Risk in Exploration and Prospect Generation through a Multidisciplinary Basin Analysis Program in the South-Central Mid-Continent

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Since the oil price decline in the 1980s, exploratory drilling and seismic field activity have decreased in the United States. To preserve the independent operator and service companies, the U.S. DOE is encouraging hydrocarbon exploration activities in unexplored and underexplored United States regions. Current research is focusing on the deep section in the South-Central Mid-Continent.

Early Mid-Continent Rift (MCR) studies suggested deep sediments in this region could contain substantial oil that had migrated from the rift to reservoirs in the Lower Paleozoic sediments. Subsequent work revealed that information on the organic content of the sediments along the southern portion of the rift system is sparse, and that organic contents of the few samples studied show steadily decreasing amounts of organic material in the rift progressing from Minnesota to Kansas.

In addition to disappointing organic content data, the MCR tectonic history was not favorable for releasing rift derived hydrocarbons into the Paleozoic section. Extensive seal breaking tectonic activity has not occurred in this area. Hydrocarbons generated from rift sediments may still be widely dispersed in small, "uncommercial" traps.

During early phases of the study, it was noted that deep drilling had discovered a string of Ordovician reservoirs along the east side of the Nemaha Uplift. Relatively few other wells in the region go this deep, so attention has been turned to this resource. The study focus shifted from concentrating on Precambrian basement sources, to possible local-sourcing for Ordovician oil, or for origins farther afield, to the southeast in the Ozark region.

Reprinted as published in the American Association of Petroleum Geologists *1998 Annual Convention, Extended Abstracts*, v. 2, p. A542.

Integrated Microbial and 3-D Seismic Survey: Hydrocarbon Microseepage in Osage County, Oklahoma

DANIEL C. HITZMAN, B. ROUNTREE, and *K. CUNNINGHAM,* Geo-Microbial Technologies, Inc., Ochelata, OK; *B. SHARMA* and *S. BANERJEE,* BDM Technologies, Bartlesville, OK

The U.S. Department of Energy's mandate to examine new cost effective exploration technologies has offered Oklahoma geochemical and seismic researchers the unique opportunity to combine their efforts and provide a detailed look at a new field prospect in Osage County, Oklahoma. In 1997, a high resolution 3-D seismic survey using 55 × 55 feet bin sites and a 440 foot-gridded microbial soil survey were completed over approximately 5.5 square miles. The detailed seismic and microbial results were compared and exploration targets identified.

The Microbial Oil Survey Technique (MOST), first developed by Phillips Petroleum Company, documents that hydrocarbon microseepage from oil and gas accumulations is common and widespread, is predominantly vertical (with obvious exceptions in some geologic settings), and is dynamic (responds quickly to changes in reservoir conditions). Patterns of microseepage over old fields can reflect reservoir heterogeneities and distinguish hydrocarbon-charged compartments from drained or uncharged compartments.

The Osage County microbial microseepage signatures are directly associated with a new Layton channel exploration target as defined by the high resolution seismic. An older Bartlesville sandstone reservoir within the survey area is likewise characterized by both exploration tools. Subsequent drilling results will be presented.

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Life Without Seismic: Old Field Exploration and Development Using Hydrocarbon Microseepage Signatures, Two Case Studies from Oklahoma

DANIEL C. HITZMAN, BROOKS ROUNTREE, and *DIETMAR SCHUMACHER,* Geo-Microbial Technologies, Inc., Ochelata, OK

Old oil and gas fields in the USA's Mid-Continent region offer multiple exploration and new development opportunities. Geophysical examinations are often not cost effective for these targets. Fortunately, less expensive hydrocarbon microseepage surveys can extensively examine old fields for areas of bypassed production and unproduced zones.

Detailed soil surveys document that hydrocarbon microseepage from oil and gas accumulations is common and widespread, is predominantly vertical (with obvious exceptions in some geologic settings), and is dynamic (responds quickly to changes in reservoir conditions). Patterns of microseepage over old fields can reflect reservoir heterogeneities and distinguish hydrocarbon-charged compartments from drained or uncharged compartments. Additionally, since hydrocarbon microseepage is dynamic, seepage patterns can change rapidly in response to production-induced changes.

Two Oklahoma waterflood oil fields, the SE Vassar Unit in Payne County and the Painter Ranch Field in Washington County, were first surveyed for detailed hydrocarbon microseepage signatures in 1995 and 1997, respectively. Patterns of by-passed production and alternate exploration targets were identified and case studies were presented to AAPG. The exact surveys were repeated in 1998. Comparative microseepage results, production histories, and geologic data will profile these two case studies.

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Reconstruction of Flood Sedimentation on Sequences and General Climatic Trends from the Southern Great Plains Region

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Paleofloods are direct, physical evidence of weather events that have occurred in the geologic past. They represent extreme hydrologic responses to past environmental conditions and are a key to predicting extreme hydrologic responses to potential future environmental changes. Paleogeomorphic hazards provide a physical link between longer-term meteorological conditions and are reflective of the climate during the Holocene.

The geomorphic effectiveness of paleofloods during the Middle to Late Holocene were used in the paleoflood reconstruction of the Black Bear Creek basin located in north-central Oklahoma. Holocene alluvial deposits were employed to interpret paleoflood events. One particular deposit along major tributaries, slackwater deposits, consists of fine-grained sediments that settle from suspension in low velocity areas during floods. Slackwater deposits provide an estimate of the minimum flood stage that emplaced them, and allow an estimation of discharge. Major paleoflood events occurred 3,590 ± 80 years B.P., and 1,150 ± 100 years B.P. The HEC-2 computer model was implemented to determine the paleodischarge that could emplace slackwater units at surveyed elevations.

Assessing the flood frequency distribution of rare floods in the south-central Great Plains will contribute to the knowledge of paleoclimate and landscape evolution. The southern Great Plains is a critical region for understanding the role of climate in hydrology, because it is a transitional hydroclimatic region between the Southwest and the Midwest. With a clear understanding of the generation of the paleofloods, analogies with present-day processes and links can be proposed.

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Depositional and Diagenetic History of the Mississippian Chat, North Central Oklahoma

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The Mississippian Chat, present at the unconformity between the Pennsylvanian and Mississippian, is a weathered and/or detrital interval of tripolitic chat or dense chert at the top of the Osagean.

The depositional environment of the Chat reflects uplift and both erosion and weathering-in-place of Osagean Mississippian cherty limestone. Fossiliferous clasts found in Chat cores were likely eroded in a high energy environment such as that found above wave base in Mississippian shallow seas. These clasts were transported by small scale debris flows into a lower energy environment and deposited in a lime mud matrix.

Examination of thin sections indicates late diagenesis partially replaced calcite shells and cement with silica subsequent to the debris flow. Well preserved original fossil structures suggest that "force of crystallization" was the method of molecule by molecule calcite replacement by silica. Dissolution of remaining calcitic fossils by intrusion of meteoric water created secondary porosity and a potential hydrocarbon reservoir.

The Chat appears on well logs as a low resistivity zone with low density and high porosity. Analysis of producing fields suggests production from structural highs, pinch-outs and diagenetically formed stratigraphic traps. Trend analysis suggests a relationship between positive structural residual values and Chat production. Seismic reflections resulting from the porosity contrast of the Chat with adjacent zones indicate the presence of the Chat.

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Rare Earth Element Systematics in Organic- and Phosphorus-Rich Pennsylvanian Shales: Implications for the Use of the Cerium Anomaly as a Paleoredox Indicator

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Of the rare earth elements (REE), only cerium exhibits intrinsic redox behavior in low-temperature marine systems. This gives rise to characteristic depletions or enrichments in Ce relative to neighboring elements in modern systems, which can be quantified using the Ce-anomaly. This parameter, as potentially recorded in apatite or whole-rock samples, has been utilized by some workers as a paleoredox indicator, while others have cautioned against such interpretations. In order to resolve these disparate observations, we have undertaken a high-resolution geochemical study of Pennsylvanian cyclothemic black shales, an ideal ancient analog for dynamic depositional redox. Using an integrated geochemical-sedimentological model, centimeter-scale vertical transitions between oxic and anoxic paleoenvironments (i.e., gray versus black shales) can be correlated across the Midcontinent.

Bulk samples from northern Oklahoma exhibit middle REE (MREE)depleted patterns, with occasional MREE-enriched patterns found in black shale samples enriched in authigenic phosphate (P_{inorg}) and proximal to the gray-black transition. This relationship suggests likely preferential mobilization of MREE into P_{inorg} during diagenesis. Gray shale samples from Iowa have patterns that are dominantly flat, while black samples, which are up to three times more enriched in organic C (C_{org}) than samples from Oklahoma, exhibit patterns with previously unreported enrichments in Sm. These enrichments appear to have resulted from enhanced scavenging of Sm by organic matter, with the magnitude of enrichment controlled by a balance between C_{org} and P_{inorg} concentrations. In no sample was there evidence for Ce enrichment or depletion as a function of varying redox conditions. These results highlight the caveats associated with the use of the Ce-anomaly as a redox indicator and may also provide evidence for the chemistry of Pennsylvanian seas.

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Stratigraphic and Petrophysical Characterization of the Pennsylvanian Cottage Grove Sandstone (Osage-Layton Sand), Chanute Formation: East Newkirk Field, Northern Oklahoma Platform

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A massive database from the Conoco 33-5 test well was used to integrate geological and petrophysical properties to characterize the Cottage Grove Sandstone (Osage-Layton Sand) of the Pennsylvanian (Missourian), Chanute Formation in northern Oklahoma.

The Cottage Grove Sandstone, of fluvial-deltaic origin in this geographic setting, consists of a heterogeneous, 121-ft thick sandstone-dominated succession. Subordinate lithologies consist of interlaminated and interbedded very fine-grained sandstone and black, fissile shale. Three distinctive lithofacies serve as reservoir and seals characterizing the Cottage Grove Sandstone and the overlying and underlying lithostratigraphic units: (1) a lower sandy, micaceous, calcareous siltstone and black fissile shale (offshore prodeltaic facies); (2) a middle very fine-grained sandstone succession deposited as part of a prograding delta front facies (distributary channel mouth bar); and, (3) a capping sequence of marine black, laminated "hot" shale deposited as a marine transgressive offshore facies (major flooding surface).

Compositionally, the sandstones vary from lithic subarkoses to subarkoses and feldspathic lithoarenites. The sandstones are dominantly very fine grained and moderately well sorted. Samples contain significantly more feldspar (5–17 percent) and rock fragments (1–19 percent) than do overlying and underlying formations.

Samples are quite variable in porosity ranging from 2 to 20 percent with an average of 16 percent. Porosity is dominantly a combination of primary intergranular and secondary grain-dissolution types. Permeabilities range from 0.007 to 97 md with an average of 15.3 md. Clay content, primarily illite and smectite, varies from 1 to 39 percent with an average of 18 percent, and is inversely correlated with grain size.

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Geochemistry of the Ozark Aquifer in Arkansas, Kansas, Missouri, and Oklahoma

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Geochemical reactions occurring in the ground water of the Ozark aquifer include carbonate dissolution, cation exchange, and sulfate reduction. The Ozark aquifer, located in parts of Arkansas, Kansas, Missouri, and Oklahoma, is composed primarily of carbonate rocks of Cambrian and Ordovician age. The aquifer is unconfined throughout most of its extent, but is confined by black shale of Devonian age in the southern and western parts of the study area. Regional ground-water flow in the confined aquifer is to the west and south. Ground-water samples were collected from 32 springs and 30 wells tapping the unconfined aquifer and from 20 wells tapping the confined aquifer. Temperature, dissolved oxygen, pH, and alkalinity of water were measured in the field. Thirteen samples from the confined aquifer were analyzed for sulfide in the field. Samples were analyzed in the laboratory for major ions, silica, and selected isotopes. Water type generally is calcium-magnesium bicarbonate, resulting from carbonate dis-

solution. Median bicarbonate concentration was significantly less in samples from the confined aquifer (3.4 milliequivalents per liter) than in samples from the unconfined aquifer (5.1 milliequivalents per liter). Sodium and chloride concentrations increase (to as much as 16 mllliequivalents per liter) toward the western and southern boundaries of the study area. Near the western boundary, sodium and chloride concentrations generally balance, indicating simple mixing of fresh water with saline, presumably connate, water. Near the southern boundary, sodium concentrations in samples were as much as four times greater than chloride concentrations, indicating cation exchange could be occurring in the aquifer. A decrease in calcium and magnesium concentrations accompanied the increase in sodium concentrations. Ground water in the confined aquifer generally was anoxic. Sulfide in samples from the confined aquifer, which ranged from 0.01 to 2.0 milligrams per liter, probably resulted from sulfate reduction. Mass-balance modeling indicated these reactions were plausible.

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Geohistory and Thermal Maturation in the Cherokee Basin (Mid-Continent, U.S.A.): Results from Modeling

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The Cherokee basin in southeastern Kansas contains a stratigraphic section consisting mostly of Permian-Pennsylvanian alternating clastics and thin carbonates overlying carbonates of Mississippian and Cambrian-Ordovician age on a Precambrian crystalline basement. Based on a conceptual model of events of deposition, nondeposition, and erosion, a burial history model for (1) noncompaction, and a series of models for (2) compaction are computed for a borehole location in the south-central part of the basin. The models are coupled with the calculation of nonsteady-state geothermal conditions. Maximum temperatures during basin evolution of about 70°C at the base of the organic rich Pennsylvanian are predicted by our models, assuming pure heat conduction and a heat flow from the basement of 60 mW/m^2. The maturation of organic matter as indicated by three different vitrinite reflectance (R_O) models is on the order of 0.3–0.5% R_O) for Pennsylvanian rocks and 0.6% R_O for the Devonian-Mississippian Chattanooga Shale. Vitrinite reflectance was measured on subsurface samples from three wells. The measured values correlate in the upper part of the sequence with modeled data, but diverge slightly in the Lower Pennsylvanian and Chattanooga Shale. The differences in maturation may be a result of differing local geological conditions within the basin. The relatively high R_O-depth gradient observed in one borehole may be explained by conditions in the Teeter oil field, which is a typical plains-type anticline that has been affected by fluid flow through vertical faults.

Higher R_O values correlate positively with the grade of sulfide mineralization in the sediment, which may be a hint of fluid impact. The high R_O values relative to the shallow depth of the Mississippian and the Chattanooga Shale in the Brown well are on the order of R_O values modeled for the same stratigraphic units at present-day greater depths and may reflect uplift of the Ozark dome, located farther east, affecting the eastern side of the Cherokee basin.

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Conceptual Models of the Habitat of the Southern and Ozark Cavefishes

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The range of the Ozark Cavefish (*Ambloysis rossae*) is limited to the Springfield Plateau of Missouri, Arkansas, and Oklahoma. Mitochondrial DNA analyses suggest that Ozark Cavefish subpopulations (individuals from separate caves) are genetically distinct. The species is known only from human-enterable caves and wells that are respectively developed in or penetrate Mississippian limestones (Burlington and Boone) underlain by the Northview Formation (an impermeable shale). The caves occupy small drainage basins with near-surface flowpaths that have been separated from each other by the downcutting of surface-water streams. Consequently, the cavefish appear to occur in relatively isolated basins, with population intermingling being minimal.

In contrast, Southern Cavefish (*Typhlichthys subterraneus*) occur in the Ozark Plateau aquifer, a large Cambrian-Ordovician aquifer of the Eminence and Potosi dolomites and limestones. Mitochondrial DNA analyses suggest that Southern Cavefish subpopulations may be less isolated. These fish inhabit large spring basins with flowpaths that penetrate to depth (tens of meters). The interconnectedness of the porosity of the laterally extensive Eminence and Potosi formations and the lack of significant downcutting by associated surface streams may allow Southern Cavefish to migrate and intermingle more readily.

We suggest that an understanding of the relative isolation of Ozark Cavefish subpopulations and continuity of Southern Cavefish populations needs to be predicated upon an understanding of the geology and hydrology of the Springfield and Ozark plateaus, respectively.

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