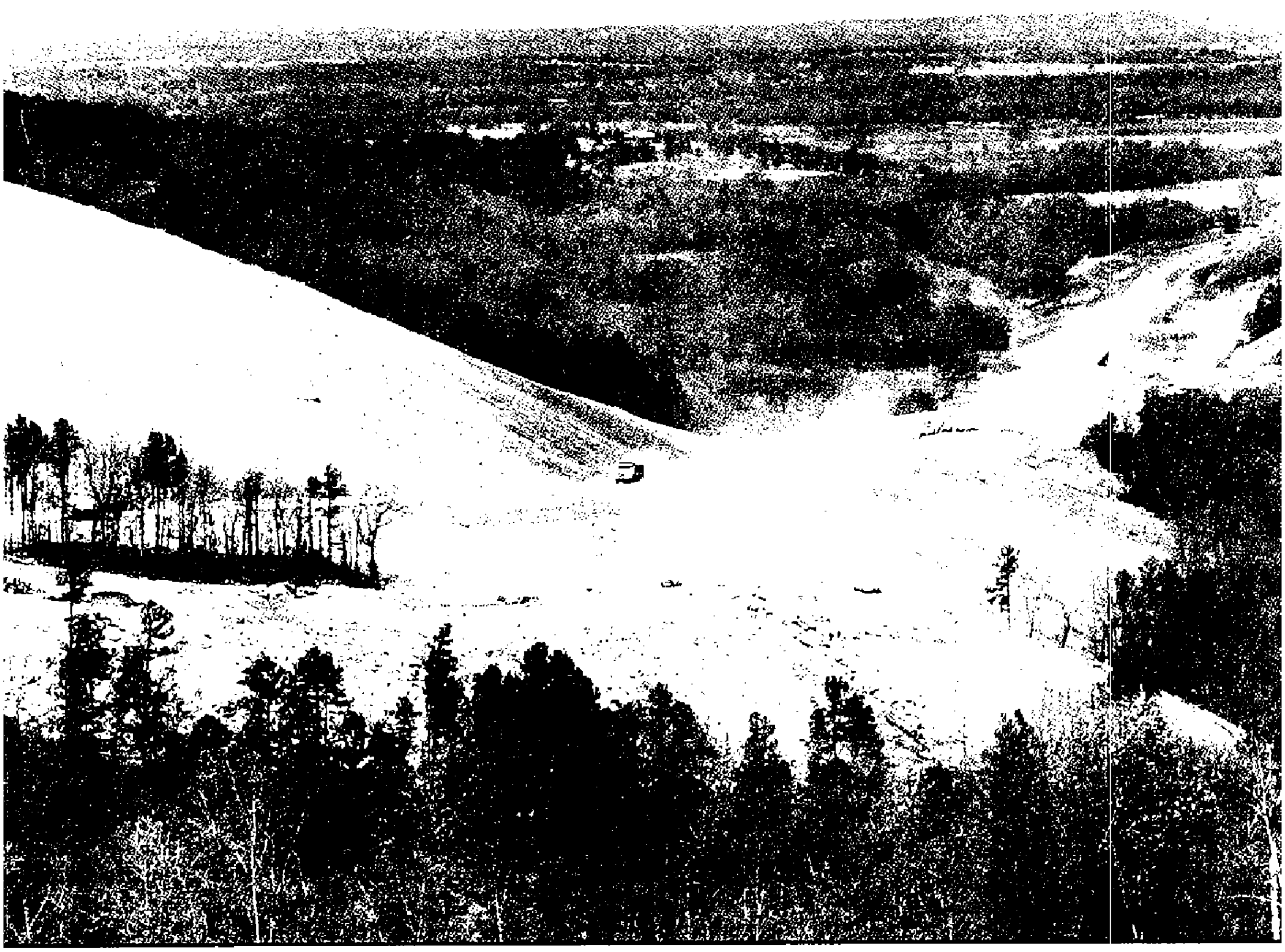
OKLAHOMA GEOLOGY



June 1998

Vol. 58, No. 3

On The Cover —

New Segment of Oklahoma State Highway 82 in the Sans Bois Mountains, Haskell County

Oklahoma's newest highway—a segment of State Highway 82—is an engineering marvel. It tames the rugged Sans Bois Mountains in such a way that the traveler is hardly aware of the precipitous bluffs, the deep canyons, and the mountain streams prone to flash flooding that challenged the planners, the surveyors, the drilling crews, and—most of all—the construction companies who forced the road through to completion. Millions of cubic yards of material had to be rearranged and stabilized against erosion. For it is indeed true that nature is constantly at work—breaking down rocks, wearing away mountains, and always moving materials downslope and into streams, where they continue their journey to the sea.

The north-looking, panoramic view on the cover shows the new road where it begins its ascent up the steep northern flank of the Sans Bois range. It is here that the highway traveler encounters the steepest grade (nearly 8%) as the road climbs, in a distance of ~1 mi, from 641 ft elevation (at the Eaton Creek crossing) to >1,300 ft at the crest of the high sandstone ridge that marks the north flank of the Sans Bois range. This stretch of highway was so difficult to build that it took almost three years to complete.

The view to the north from the ridge crest shows sandstone-capped ridges on the horizon, the flat plains underlain by shales of the McAlester Formation, Mountain Fork Creek, the new bridge over Eaton Creek, and the steep cut through the Bluejacket Sandstone escarpment. (These features are marked on inset photograph A).

South from the high sandstone ridge on the north flank of the mountains, the

(continued on p. 115)

OKLAHOMA GEOLOGICAL SURVEY

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OKLAHOMA GEOLOGY

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Engineering and Geologic Aspects of the New Segment of State Highway 82, Haskell and Latimer Counties, Oklahoma

LeRoy A. Hemish[1]

Abstract

A new 9.132-mi-long segment of Oklahoma State Highway 82 has been constructed across the Sans Bois Mountains, connecting the towns of Lequire and Red Oak. Construction was started in the late summer of 1994 and completed in the late spring of 1998. Most of the engineering problems encountered during construction were due to the rugged terrain, to the plastic properties of colluvial soils, and to ground-water seepage. The steepest grade on the new highway is ~8%.

Maximum relief along the new highway segment is ~800 ft, where the road crosses the axial trough of the Sans Bois syncline. The three bedrock units exposed in the area—the McAlester, the Savanna, and the Boggy Formations—are of Pennsylvanian (Desmoinesian) age. The units are predominantly shales interbedded with minor coals, but sandstone beds within the shales are sufficiently thick and well cemented to form prominent ridges. Heavily forested ridges and valleys, as well as spectacular sandstone bluffs, make the new segment of S.H. 82 one of Oklahoma's most scenic highways.

Introduction

The Oklahoma Department of Transportation (ODOT) has recently announced the upcoming completion of one of the State's newest stretches of highway. The new segment of State Highway 82 should be open for public use sometime during the summer of 1998. Although the length of the new road is only 9.132 mi (4.256 mi in Haskell County and 4.876 mi in Latimer County) (ODOT, 1993, 1995a,b), it is a vital link that connects the town of Lequire (and State Highway 31) on the north to the town of Red Oak (and U.S. Highway 270) on the south.

Although this segment of highway was first planned in the 1940s, actual construction was delayed until 1994, when the first phase of the project was started. Completion of the road means that S.H. 82 no longer has a missing link. The extended delays in joining the two existing segments of the southern part of S.H. 82 (Stigler to Lequire and Red Oak to Talihina) (Fig. 1) were due, mostly, to the rugged Sans Bois Mountains that stood in the way. The mountain barrier presented engineering and design problems thought by many too difficult and too costly to surmount. Larry Buie and Bill Sheets, geologists in the ODOT Research Division in the 1950s and 1960s, advised against attempting the highway construction. They predicted that the swelling properties of shales in the Savanna and Boggy Formations and the plastic nature of Recent clay-rich colluvial soils would cause massive slope failures along the route.

Plans to complete the highway across the mountains were revitalized in the early 1990s, largely through the efforts of State Senator Gene Stipe. Major factors in the decision to lay out a route across the Sans Bois were the needs of industry (coal and

[1] Oklahoma Geological Survey.

gas production are big business in the vicinity of Red Oak); the need for a truck route; and the need of local residents for access to the Native American Hospital in Talihina. Shopping, tourism, and recreation considerations also played a part. (A ski resort was planned in the area at one time. Construction of ski runs was actually started, but the project was abandoned for financial reasons.) Completion of S.H. 82 eliminates lengthy detours to cross the Sans Bois Mountains. In the past, motorists have had to travel from Lequire or Red Oak to State Highway 2 (~15 mi west) or to U.S. Highway 59 (~27 mi east), the only paved roads across the mountains (Fig. 1).

Engineering Aspects

Surveying for the new S.H. 82 alignment across the Sans Bois Mountains was begun in 1993 and completed in 1994. Actual construction was started in the late summer of 1994; Keck Construction Company was the prime contractor.

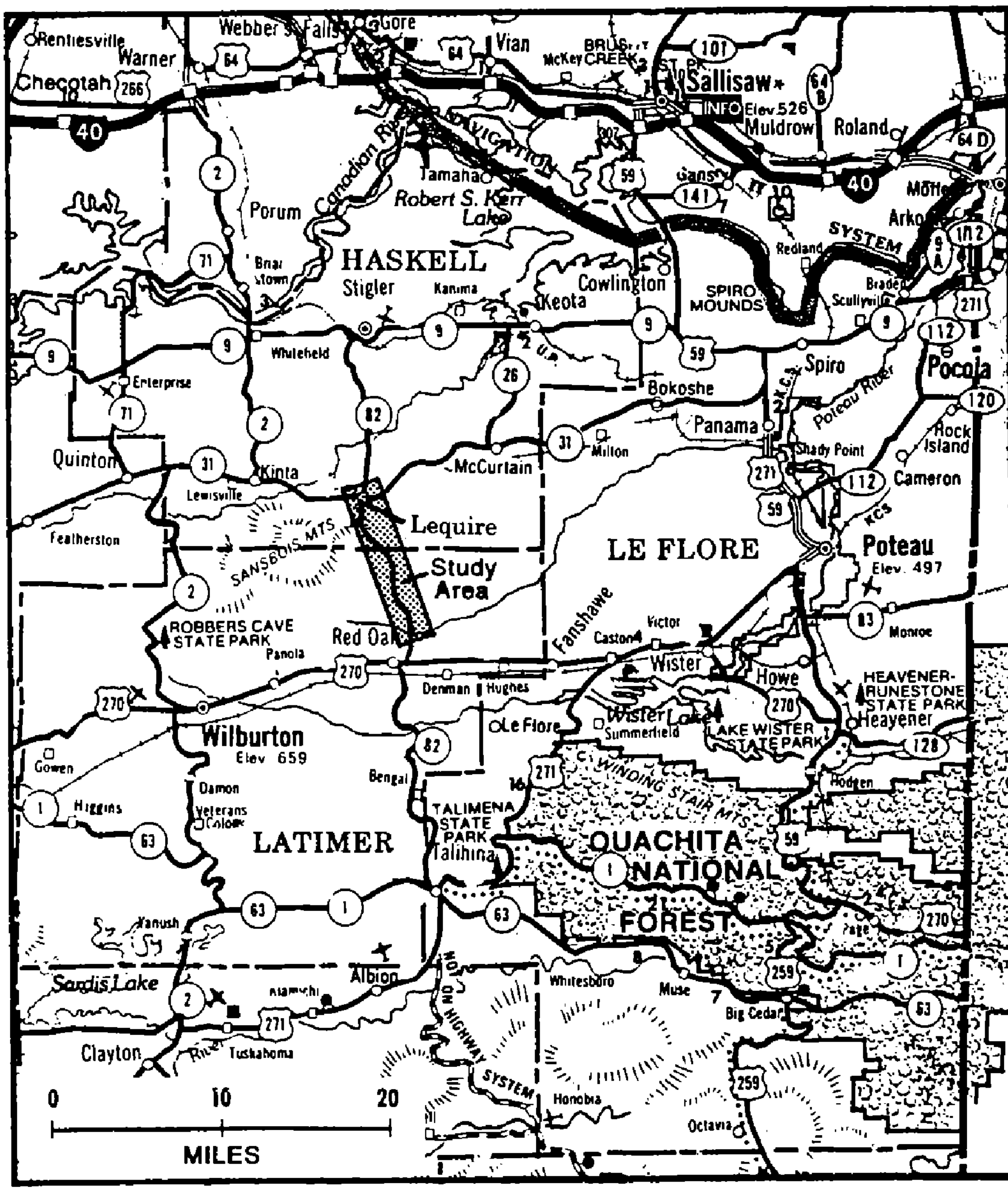


Figure 1. Excerpt from 1997–98 Oklahoma Official State Map showing the study area, the new segment of S.H. 82, and the previously existing highways (ODOT, 1996).

The construction was done in three phases (ODOT, 1993; 1996a,b). The first phase covered a distance of 1.2 mi in Haskell County (Fig. 2). It included one major bridge, across Andrew Creek (Fig. 3). Figure 4 shows construction in progress on a ridge of the Savanna Formation in the SW¼SW¼ sec. 8, T. 7 N., R. 21 E. This cut is one of the few places where excellent exposures of the geologic strata are preserved. Most of the exposures in other road cuts have been sloped and grassed over to prevent erosion.

The second phase of construction was started in April 1995 (Fig. 5); Sherwood Construction Company was the prime contractor. It covered a distance of 4.876 mi, all in Latimer County (ODOT, 1995a). The third phase of construction (Fig. 6), also done by the Sherwood Construction Company, was started in June 1995. It covered a distance of 3.056 mi, all but a small fraction of a mile in Haskell County (ODOT,

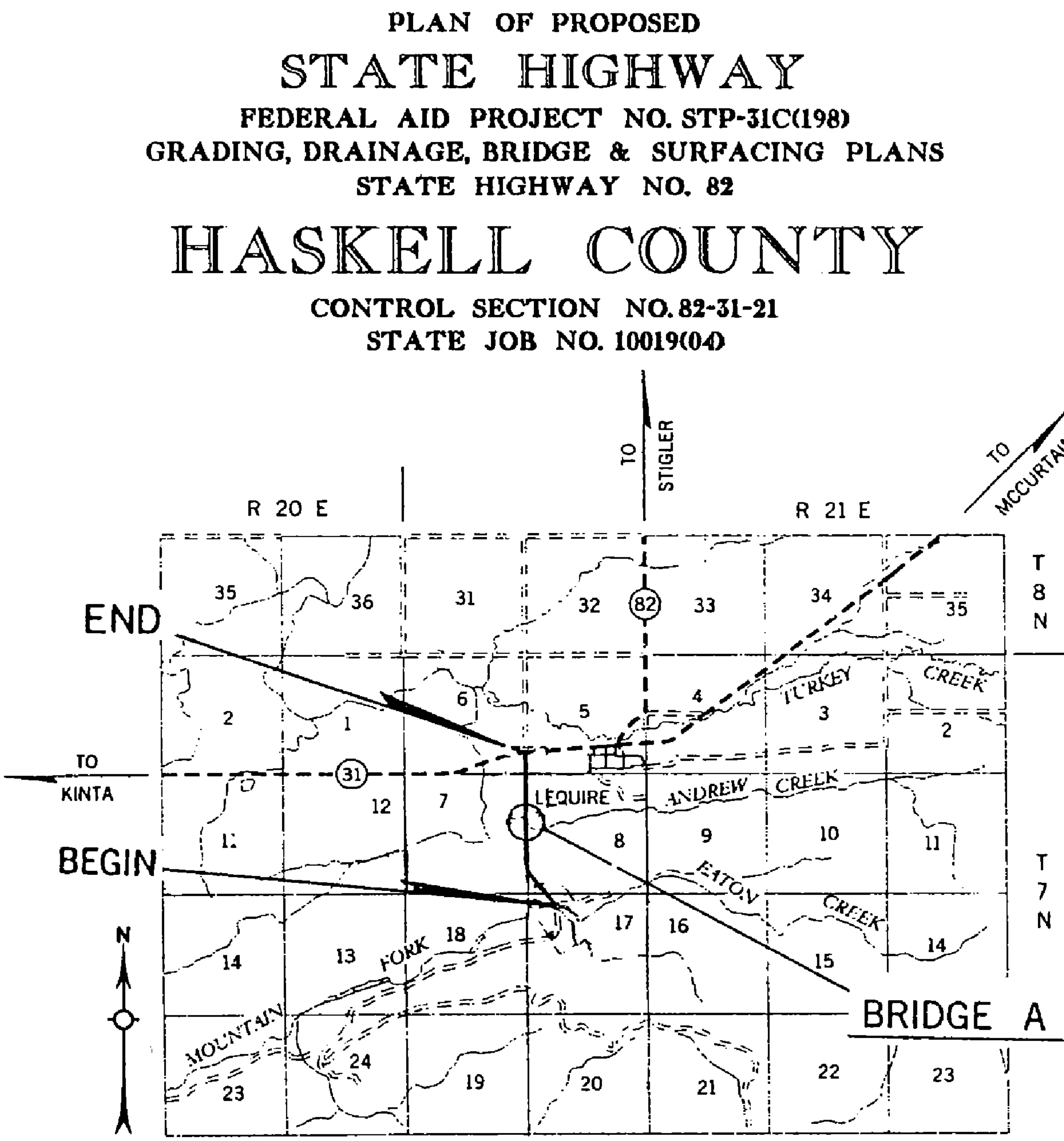


Figure 2. Modified excerpt from ODOT (1993) plans showing the location of the first phase of construction for the new segment of S.H. 82. Bridge A crosses Andrew Creek.

1995b). Construction of this third phase was the most difficult because it not only involved building a bridge across Eaton Creek (Fig. 6), but also required conquering the steep northern slope of the Sans Bois Mountains. Plans for a truck-escape lane on this slope had to be abandoned after partial completion because of problems with slope stability and with subsidence in fill material. This section of the highway, in secs. 16, 17, and 21, T. 7 N., R. 21 E., has a 7.76% grade, the steepest in the entire project.

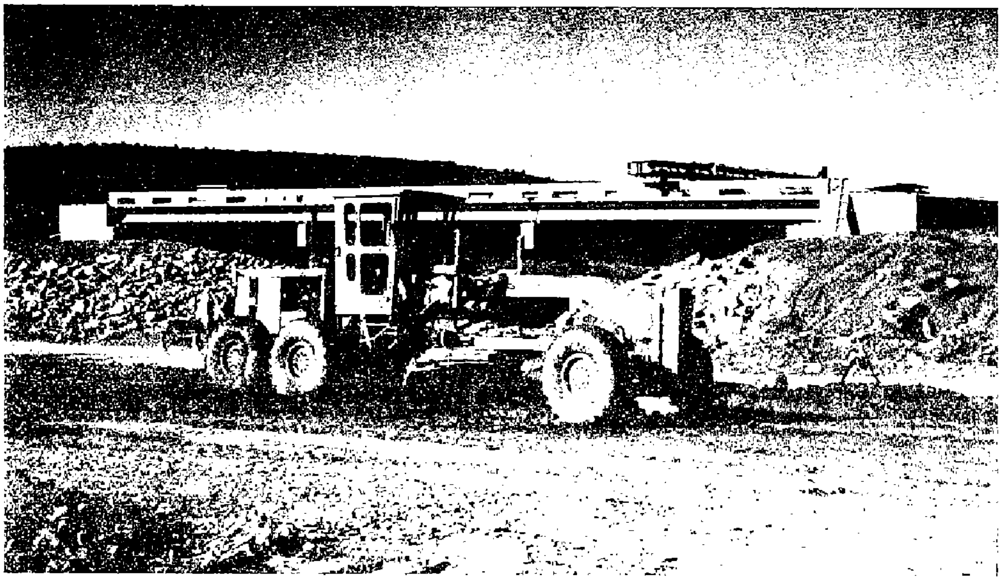


Figure 3. Photograph (taken October 12, 1994) of construction of the bridge over Andrew Creek (Bridge A in Fig. 2), just south of Lequire in Haskell County.

Figure 4. First phase of construction of the new segment of S.H. 82 in the SW¼SW¼ sec. 8, T. 7 N., R. 21 E., Haskell County, photographed October 12, 1994. View is to the south, toward the Sans Bois Mountains.

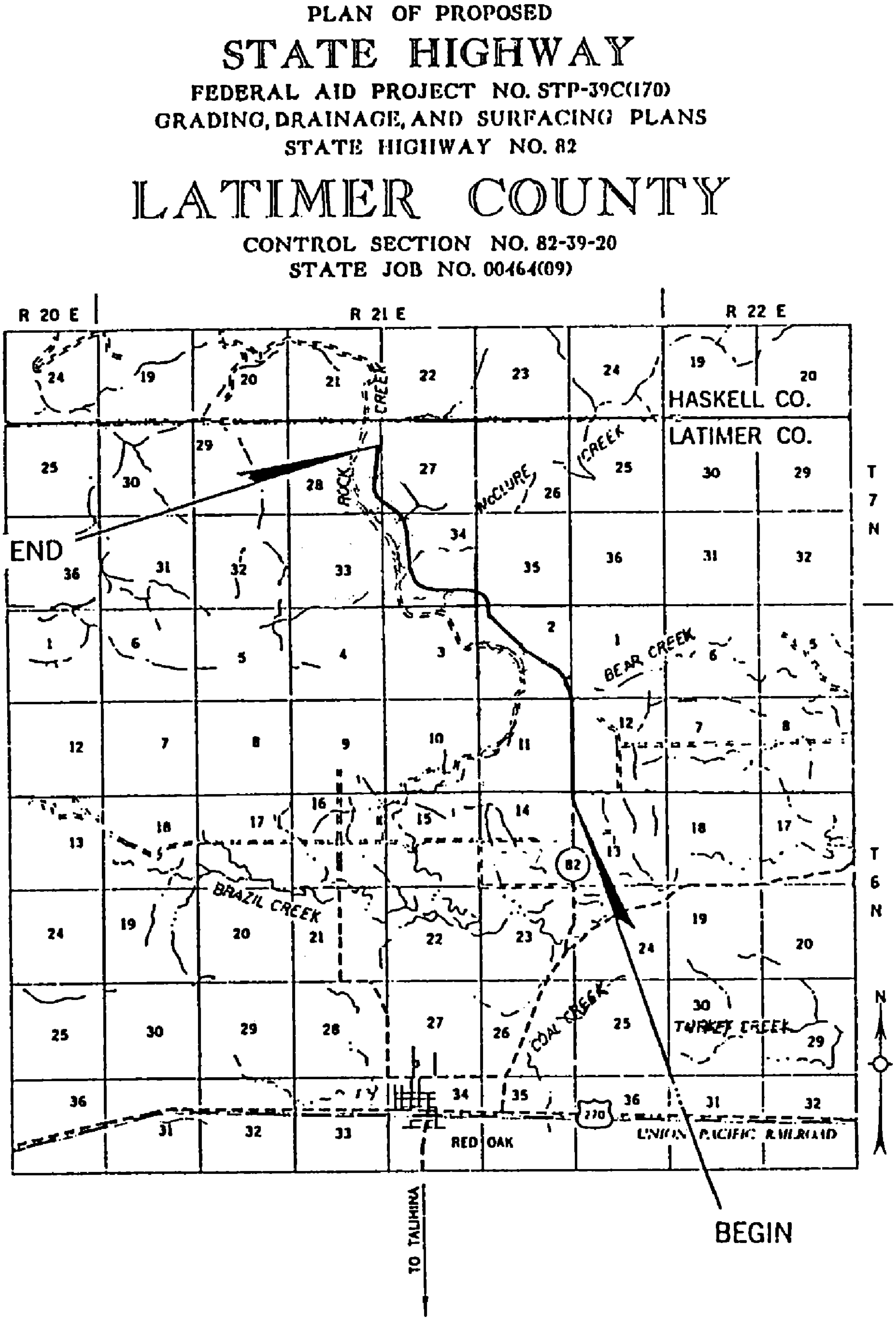


Figure 5. Modified excerpt from ODOT (1995a) plans showing the location of the second phase of construction for the new segment of S.H. 82.

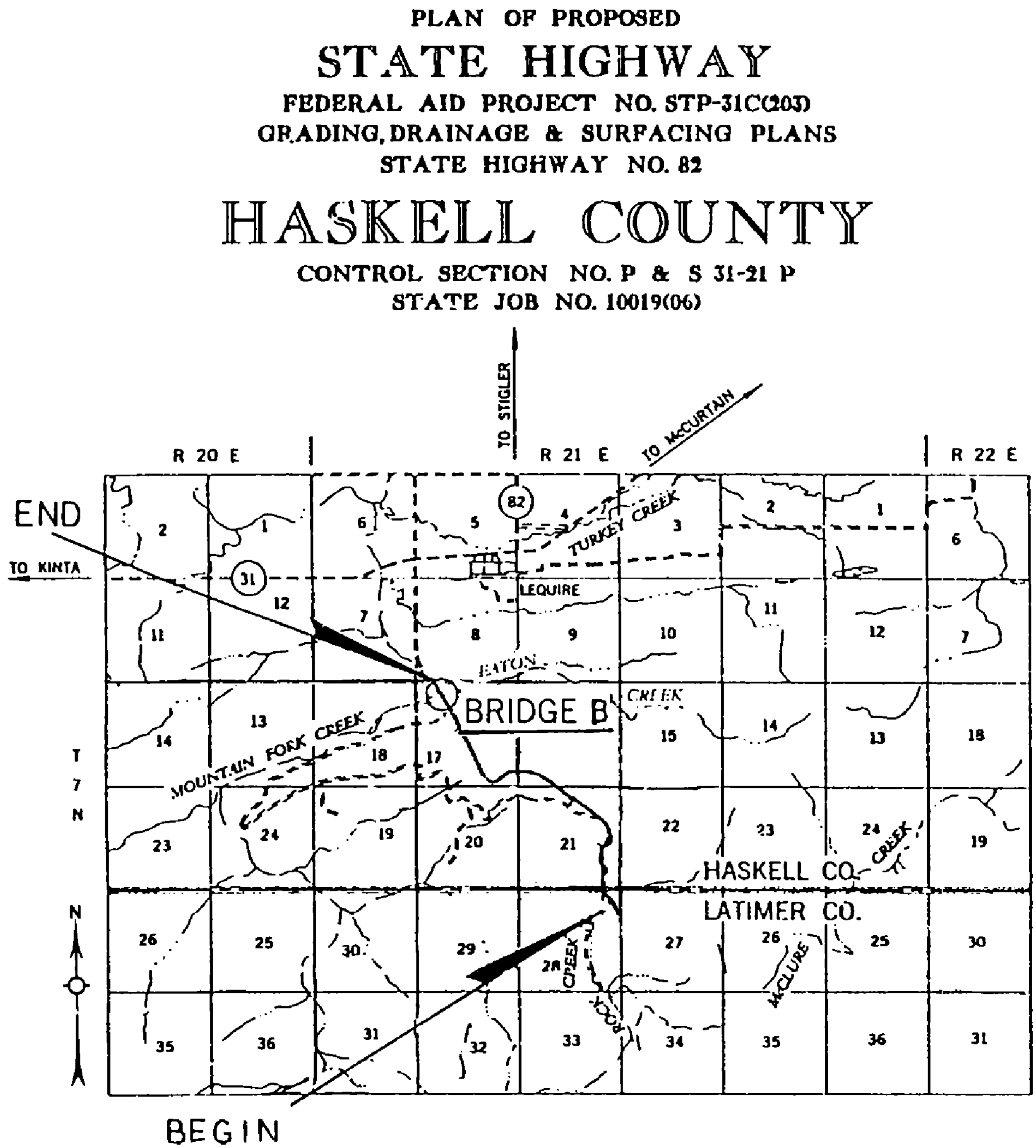


Figure 6. Modified excerpt from ODOT (1995b) plans showing the location of the third phase of construction for the new segment of S.H. 82. Bridge B crosses Eaton Creek.

The surface soils along this alignment are mapped by the Haskell County Soil Survey as the Enders-Hector complex and by the Latimer County Soil Survey as the Carnasaw-Clebit complex. Both soil complexes are similar but the Enders and Carnasaw are derived from shales, whereas the Hector and Clebit soils are formed from sandstones. The Enders and/or Carnasaw generally predominate. They can be characterized as stiff, moderate to high plasticity, blocky to fissured, structured residual clays with inclusions consisting of sandstone fragments, iron concretions, and joint fillings. The color varies from red to yellowish red, providing a distinct contrast to the underlying olive to olive brown shales. They can have a high shrink-swell potential, and occasionally are found to be moderately dispersive in the *in situ* and compacted states. Depths are on the order of 6.0 ft but are found on these projects up to 9.0 ft.

Colluvial soils formed from these four residual soils also are found in most mountain drainage ways along the highway alignment. They have a predominately clay matrix with significant amounts of boulders, cobbles, and sandstones. Six test pits dug by a large track hoe in these drainage ways in Haskell County indicate a deposition of colluvium ranging from 10 to 23 ft.

The deepest cut in the project is 105 ft on both sides of the roadway. At another place, 120 ft was cut on one side and 120 ft of fill was added to the other side. There is 180 ft of fill on one side of the highway in another area.

Major engineering problems were encountered during construction of the new segment of S.H. 82. The first major problem was slope instability. Four large slope failures occurred during construction, and at least six new ones have occurred since the slopes have grassed over (Fig. 7). Heavy rain and the swelling characteristics of the shales and plasticity of colluvial deposits caused the slumps. The second major problem, varying lithologies (well-cemented sandstones occur adjacent to soft shales), caused construction difficulties. In places, nearly vertical outcrops of 4–10-ft-thick sandstones were left overlying graded slopes of shale. Undercutting and slope instability could occur at or immediately below the contacts. The third major problem was with subsidence in areas of fill, particularly where large blocks of blasted sandstone were covered by finer grained material, because

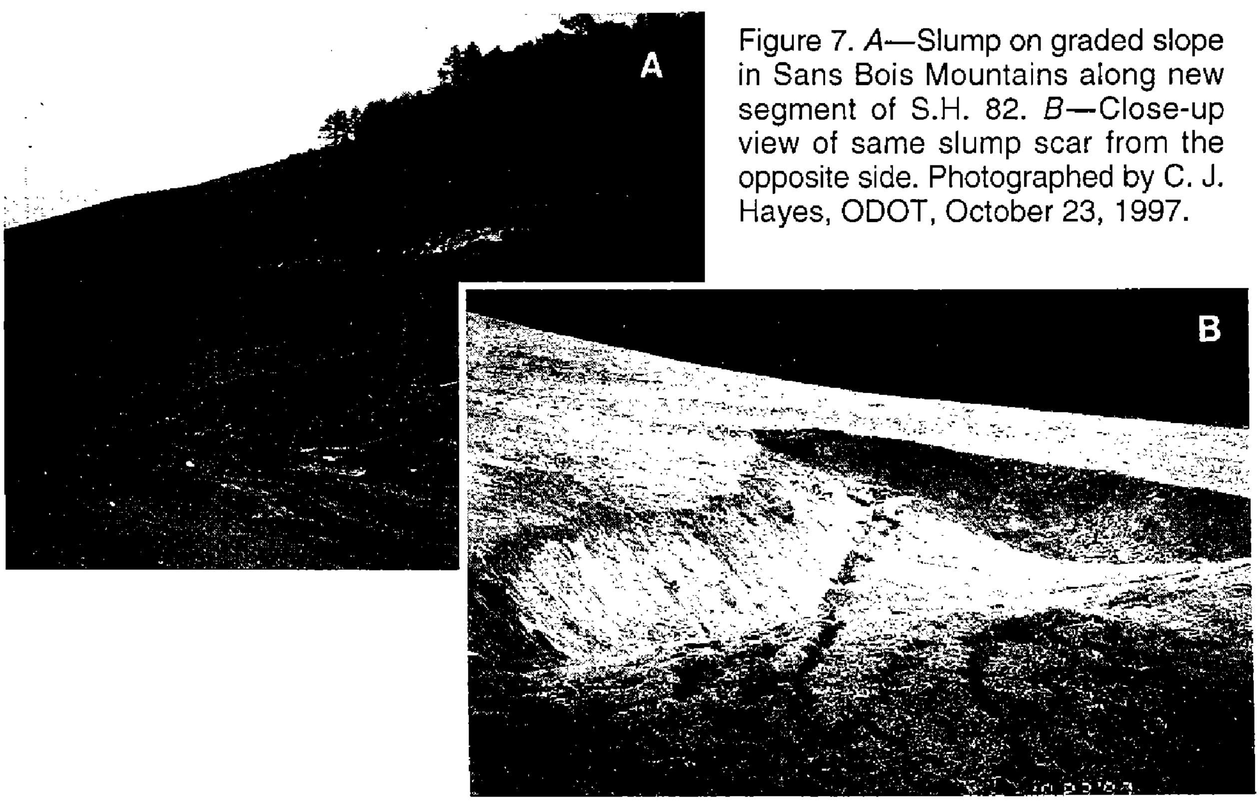


Figure 7. *A*—Slump on graded slope in Sans Bois Mountains along new segment of S.H. 82. *B*—Close-up view of same slump scar from the opposite side. Photographed by C. J. Hayes, ODOT, October 23, 1997.

voids could not be completely filled even during compaction stages of construction. In the future, further minor subsidence could occur in these areas. The fourth major problem was one of ground-water seepage, which can lead to slope failure in both cut and fill areas. Figure 8 shows how engineers combat the problem of ground-water seepage by installing underdrains at the base of embankment fills.

The new segment of highway has 8 in. of lime-treated subgrade, 6 in. of aggregate base, 4 in. of type A asphalt, and 2 in. of type B asphalt. Five hundred vehicles, 95 of them trucks, are expected to travel the road each day.

Geology

General

The scenery along the new segment of S.H. 82—ridges and valleys covered by pines and hardwoods, as well as spectacular views of clear mountain streams and precipitous sandstone bluffs—is largely due to the varying geology of the area. The geology along the route was mapped by the author in March 1994 (Fig. 9). The information was presented to ODOT prior to the start of road construction and made available to the public in 1996 in an Oklahoma Geological Survey open-file report (Hemish, 1996a). The geologic information and map reproduced in this article are from the open-file report. It should be noted, for those who may use the map to identify rock units along the highway, that contact lines shown on the map will be displaced downdip in deep road cuts through ridges.

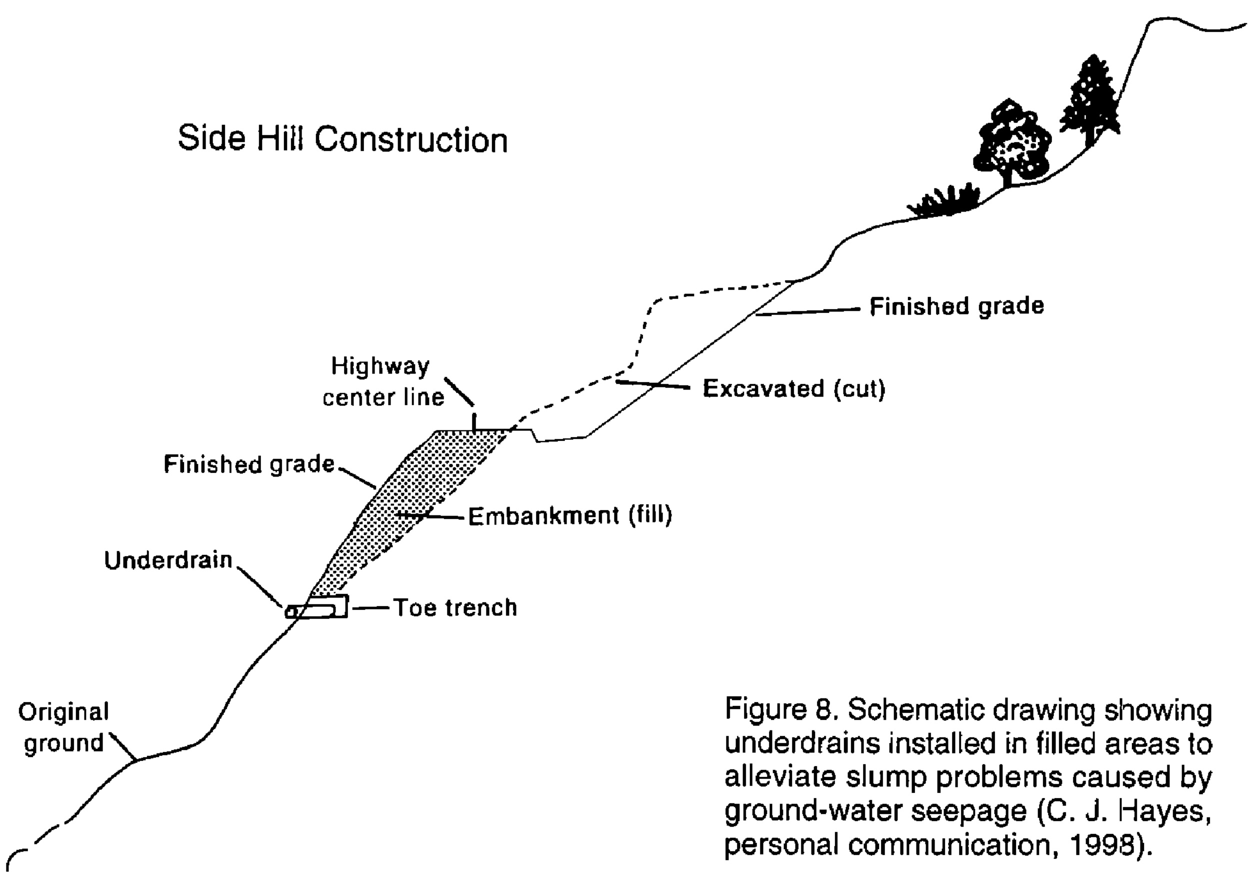


Figure 8. Schematic drawing showing underdrains installed in filled areas to alleviate slump problems caused by ground-water seepage (C. J. Hayes, personal communication, 1998).

A

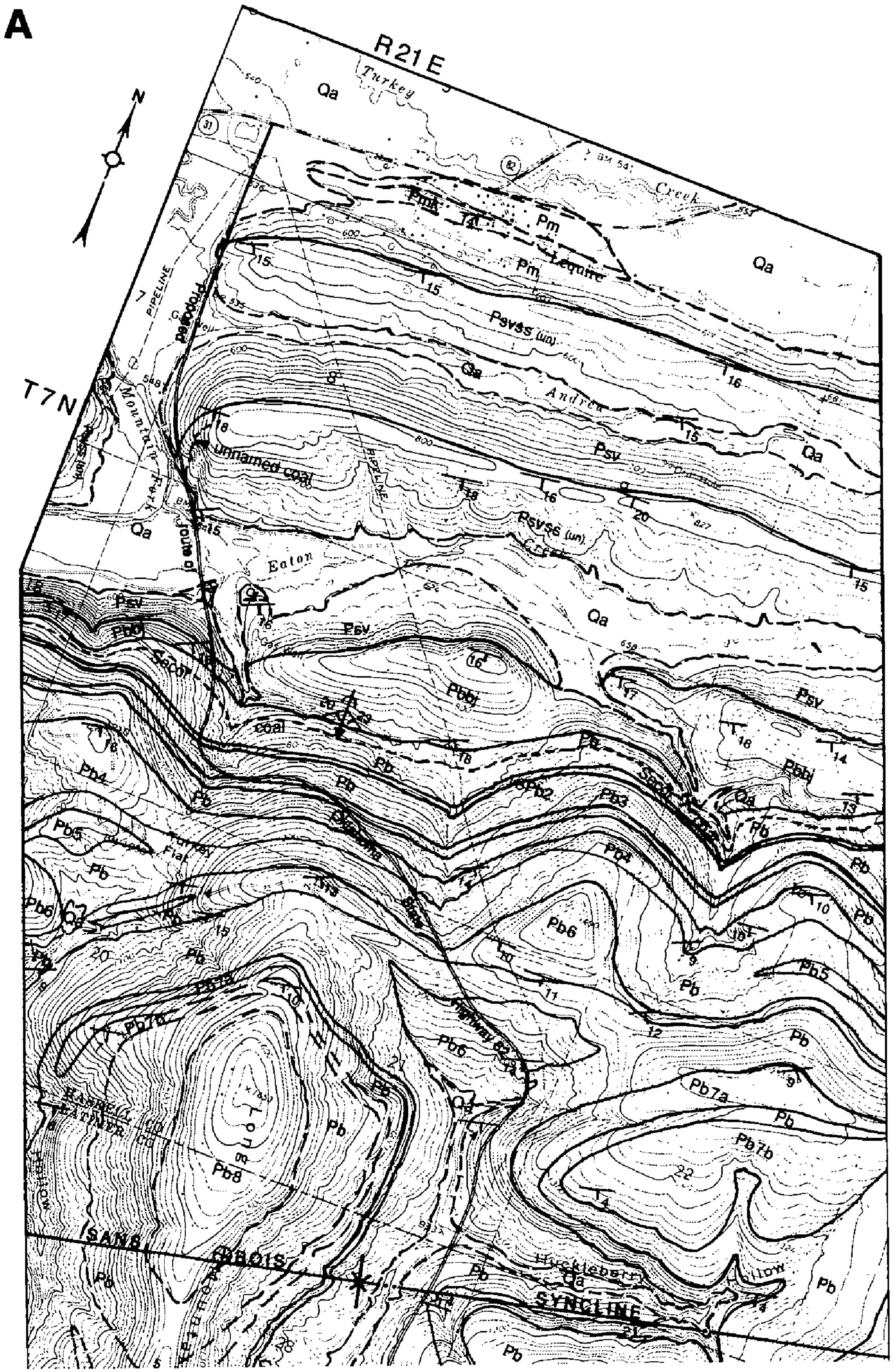
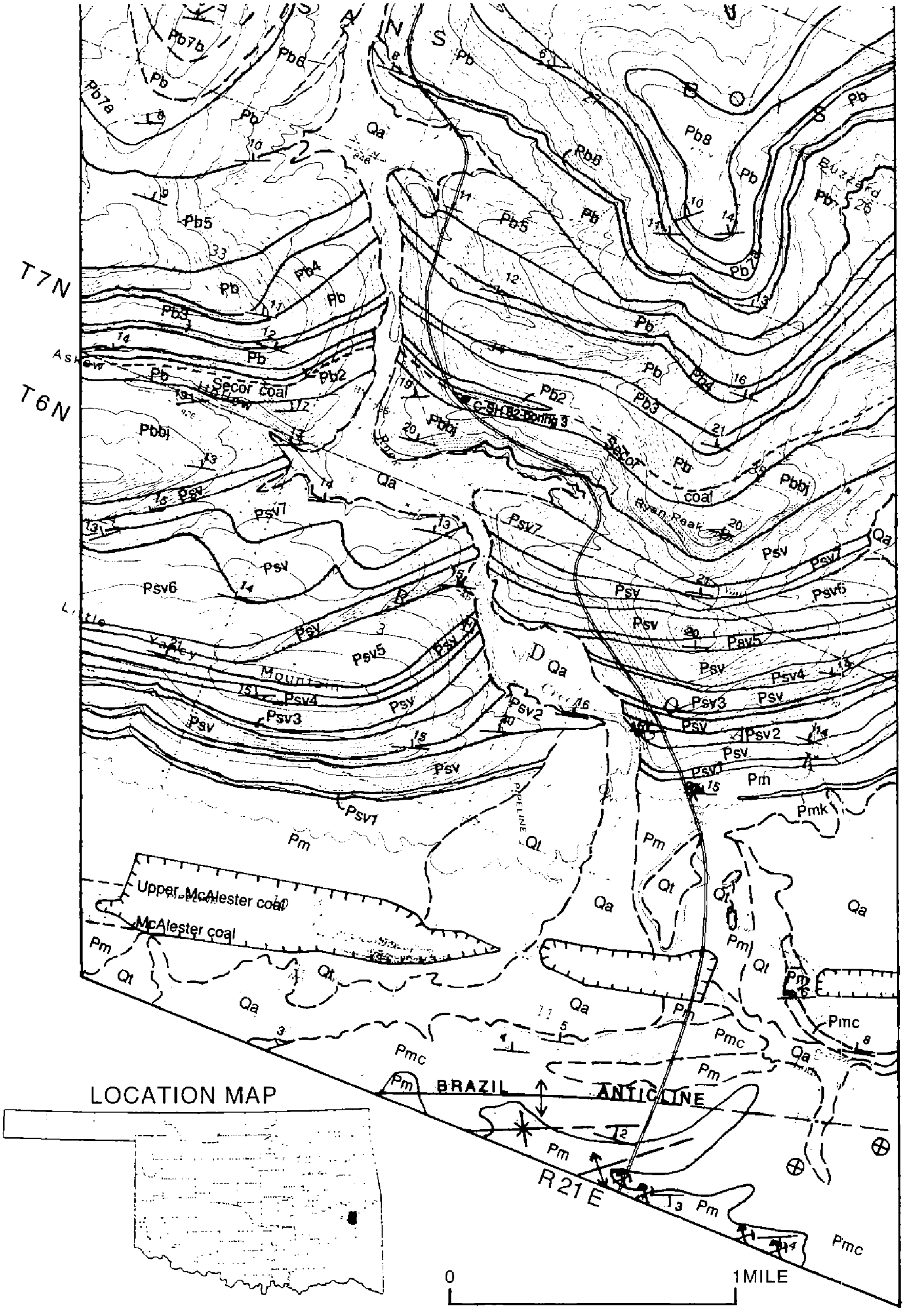


Figure 9A *(this page and facing page; see p. 106 for caption and explanation of symbols).*


T7N
T6N
R 21 E
Secor coal
Upper McAlester coal
McAlester coal
BRAZIL ANTICLINE
LOCATION MAP
0
1MILE

B

SYMBOLS APPEARING ON FIGURE 9A

CONTACT—Dashed where approximately located

COAL BOUNDARY—Approximate outcrop boundary of coal bed (named on map); triangle indicates exposure of coal

ANTICLINE—Showing crestline; dashed where approximately located; dotted where concealed

SYNCLINE—Showing troughline; dashed where approximately located; dotted where concealed

MINOR SYNCLINE—Showing plunge

ABANDONED SMALL COAL MINE

ABANDONED OR OPEN SHALE PIT

SURFACE COAL MINE—Abandoned or area reclaimed

STRIKE AND DIP OF BEDS

4 Strike and dip of beds, upright

Horizontal beds

CORRELATION OF MAP UNITS

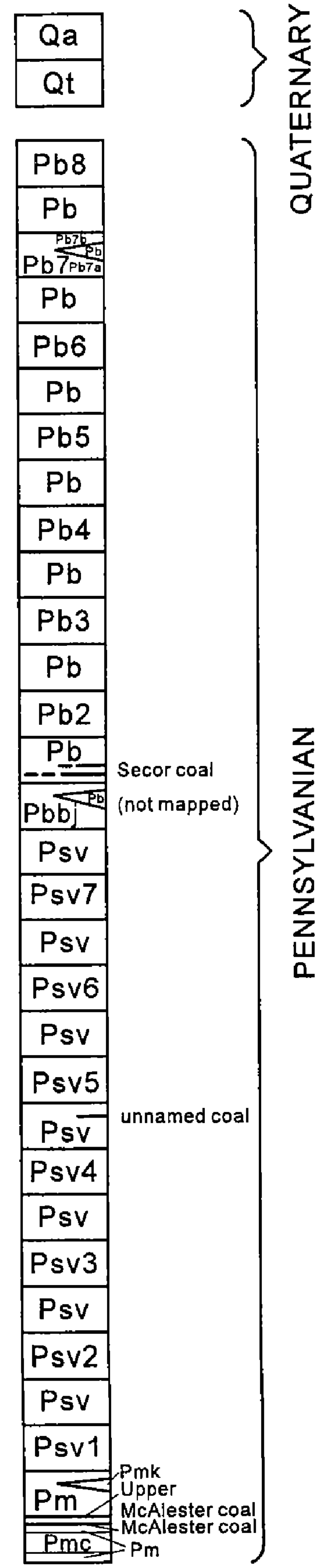


Figure 9. *A (p. 104–105)*—Geologic map of area along the route of the new segment of S.H. 82, prepared in 1994, prior to construction of the highway. *B (this page and facing page)*—Explanation of symbols and description of the stratigraphic units shown in A. (From Hemish, 1996a.)

	DESCRIPTION OF UNITS
Qa	ALLUVIUM (QUATERNARY)—Gravel, sand, silt, and clay on flood plains of present-day streams.
Qt	TERRACE DEPOSITS (QUATERNARY)—Subangular to subrounded cobbles, gravel, sand, and silt, forming a veneer, generally about 4–10 ft thick, on the surfaces of terraces that stand about 40–50 ft above the beds of present-day streams.
Pb	BOGGY FORMATION (PENNSYLVANIAN)—Predominantly sandy, silty, gray to olive-gray to grayish-black shales and siltstones (Pb) with scarp-forming sandstones. At base is the Bluejacket Sandstone Member (Pbbj), 150–200 ft thick. The Bluejacket Sandstone Member contains two major sandstone units separated by a gray to grayish-green silty shale unit that is ~100 ft thick in places. Both sandstone units contain shale beds. Numbered units (Pb2–Pb8) are mappable, scarp-forming, yellowish-brown, fine- to very fine grained sandstones, generally 10–45 ft thick. Pb7 is split into two mappable units (Pb7a and Pb7b) on the flanks of Long Mountain and in sec. 22, T. 7 N., R. 21 E. Some units (Pb2, Pb5, Pb6) appear to pinch out in places, or are too thin to be mapped continuously. The Secor coal bed and the overlying Secor Rider coal bed are known to be present in shale ~100 ft above the top of the Bluejacket Sandstone on the north flank of the Sans Bois Mountains, and may be present on the south flank also. Thin unmappable sandstone lenses are present in the shale units. Top of formation eroded. Thickness of remaining Boggy: 1,800–1,950 ft.
Psv	SAVANNA FORMATION (PENNSYLVANIAN)—Predominantly brown to olive-gray to dark-gray shales (Psv) with several mappable brown, very fine grained sandstone units (Psv1–Psv7). The sandstone units contain abundant sedimentary features such as soft-sediment deformation, sole marks, ripple marks, trace fossils, and fossil plants, particularly *Stigmaria*. The sandstones are variable in thickness, generally 5–25 ft, but locally may be much thicker. On the north flank of the Sans Bois Mountains the first two conspicuous ridges are formed by the upper and lower Savanna Sandstone zones (Psv ss [un]). The numbered sandstone units are not differentiated because they are unmappable separately. The lower sandstone zone probably comprises Psv1–Psv3, and the upper sandstone zone probably comprises Psv4–Psv7. The intervening shale zone contains a few thin sandstones, and both sandstone zones include some silty shale. A thin coal of no economic importance is present in the upper sandstone zone. The lower zone is 200–300 ft thick, the middle shale zone is 400–500 ft thick, and the upper sandstone zone is 150–300 ft thick. On the south flank of the Sans Bois Mountains the Savanna Formation is ~1,300 ft thick.
Pm	McALESTER FORMATION (PENNSYLVANIAN)—Predominantly dark-gray to black, blocky shales containing abundant ironstone concretions. Only the upper part is present in the map area. In the vicinity of Lodi, the Cameron Sandstone Member (Pmc) crops out. It is brown, very fine grained, thin-bedded, and about 10–40 ft thick. On the north side of the mountains, the youngest sandstone unit in the McAlester Formation, the Keota Sandstone Member, forms the low ridge in the town of Lequire. It is brown, very fine grained, thin-bedded, and shaly, and about 10–15 ft thick. Two coal beds, the McAlester and Upper McAlester beds, occur in the shale interval above the Cameron Sandstone on the south side of the mountains. They are ~2.0 ft and 1.7 ft thick, respectively, and have been mined extensively in the area.

The lowest elevation along the new highway is ~536 ft, at the northwestern corner of sec. 8, T. 7 N., R. 21 E., just west of the town of Lequire; the highest elevation is ~1,330 ft, at the crest of a ridge marking the top of the north flank of the Sans Bois Mountains. The road avoids crossing Mountain Fork Creek, a major north-flowing stream in the northwestern part of the map area. However, bridges had to be built over Andrew Creek and Eaton Creek, two west-flowing tributaries of Mountain Fork. Rock Creek is the major stream that flows southward from the high divide on the north flank of the mountains. It is deeply incised and cuts across northeast-southwest–trending ridges at nearly right angles. The highway alignment stays on the east side of Rock Creek along its course through the mountains. Only one bridge was constructed in this section of the road—a high span over an unnamed creek that flows west out of Huckleberry Hollow (Fig. 10). The road descends the more moderate slopes on the south flank of the Sans Bois and emerges onto relatively low-lying terrain just west of Lodi. (All features mentioned in this paragraph are shown in Fig. 9.)

Structural Geology

The Sans Bois syncline bisects the map area. Its axis trends northeast-southwest and crosses the boundary between Latimer and Haskell Counties ~0.5 mi east of S.H. 82 (Fig. 9A). Dip angles range from 0° to 2–4° along the synclinal axis and increase away from the axis, to a maximum of 21° (Fig. 9A). To the south, the Brazil anticline parallels the Sans Bois syncline. However, the surface expression of the Brazil anticline does not compare with the rugged topography formed by alternating intervals of sandstone and shale on the flanks of the Sans Bois syncline. Maximum relief in the map area is ~800 ft (from the channel of Rock Creek to the crest of Long Mountain—a highway distance of ~1 mi) (Fig. 9A).

Stratigraphy

The stratigraphic units present in the map area are shown and described in Figure 9B. The exposed bedrock units are Pennsylvanian (Desmoinesian) in age, and all of the three formations present are in the Krebs Group.

The McAlester Formation, the oldest formation present, is best exposed along the Brazil anticline near the southern edge of the map area (Fig. 9A), where the Cameron Sandstone Member is brought to the surface. Two commercial coal beds, the McAlester coal and the Upper McAlester coal, are present in the southern part of the map area. Both have been mined in recent times and the area reclaimed. The new highway crosses the east end of one of the reclaimed pits just northwest of Lodi (Fig. 9A). The Keota Sandstone Member crops out on both flanks of the Sans Bois syncline. The town of Lequire is built on a low ridge formed by this sandstone (Fig. 9A). The entire McAlester Formation does not crop out in the map area, but its total thickness is estimated to be 2,000–2,400 ft in the adjacent quadrangle to the south (Hemish and others, 1990).

In stratigraphic sequence, the Savanna Formation is the next higher formation. It is present in its entirety on both flanks of the Sans Bois syncline. On the south flank, however, the Savanna contains seven informally numbered, mappable, resistant, ridge-forming units separated by shales, while there are only two mappable

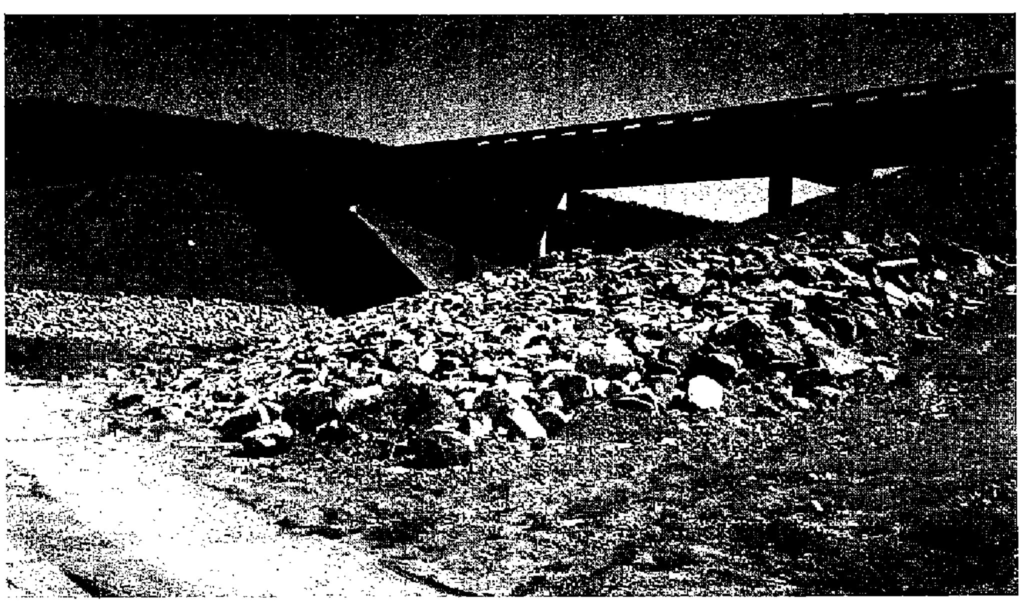


Figure 10. High bridge on S.H. 82 spanning an unnamed tributary of Rock Creek that flows out of Huckleberry Hollow (see Fig. 9A). Photographed April 2, 1998.

ridge-forming units on the north flank. A section of the entire Savanna Formation was measured by the author near the east edge of the map area, on the south flank of the syncline. The measured section (Lodi section) was designated a supplementary reference section for the Savanna Formation by Hemish (1996b). The Savanna is ~1,276 ft thick in the Lodi section, but it thins northward and its sandstone content decreases, as can be seen by lithologic differences on opposite flanks of the Sans Bois syncline (Oakes and Knechtel, 1948; Hemish, 1996b).

Exposures of the Savanna Formation along the new highway have been grassed over on the south flank of the syncline, but there are several good outcrops along Rock Creek (Fig. 11) that are accessible by the old county road. For detailed descriptions and photographs of the Savanna Formation, refer to the Lodi section (Hemish, 1996b).

A road cut across the nose of the Savanna ridge in the SW¼ of sec. 8, T. 7 N., R. 21 E. has exposed >100 ft of the middle part of the Savanna Formation. The cut was described by the author in October 1994 (Appendix), when construction of the highway was in progress. At that time, ~62 ft of section was exposed, including one 0.9-ft-thick coal bed. Since that time, the cut has been steepened and made deeper. Two other coal beds, ~0.4 ft thick, have been exposed near the base of the cut. Sandstone, siltstone, and shale beds containing an abundance of fossil plant material also are exposed. Figure 12 shows the uppermost coal bed when first observed in 1994. Figure 13A shows the cut as it appears now, and Fig. 13B shows the sandstone- and mud-filled, abandoned channel. My interpretation of the strata is that they were deposited in a delta-plain setting. Evidence includes the abundance of plant remains (in both the sandstones and shales); crevasse-splay deposits with soft-sediment deformation and *Calamites* in growth position (all leaning to the south); absence of any marine fossils; coal beds; paleosols; and the abandoned, mud-filled channel.

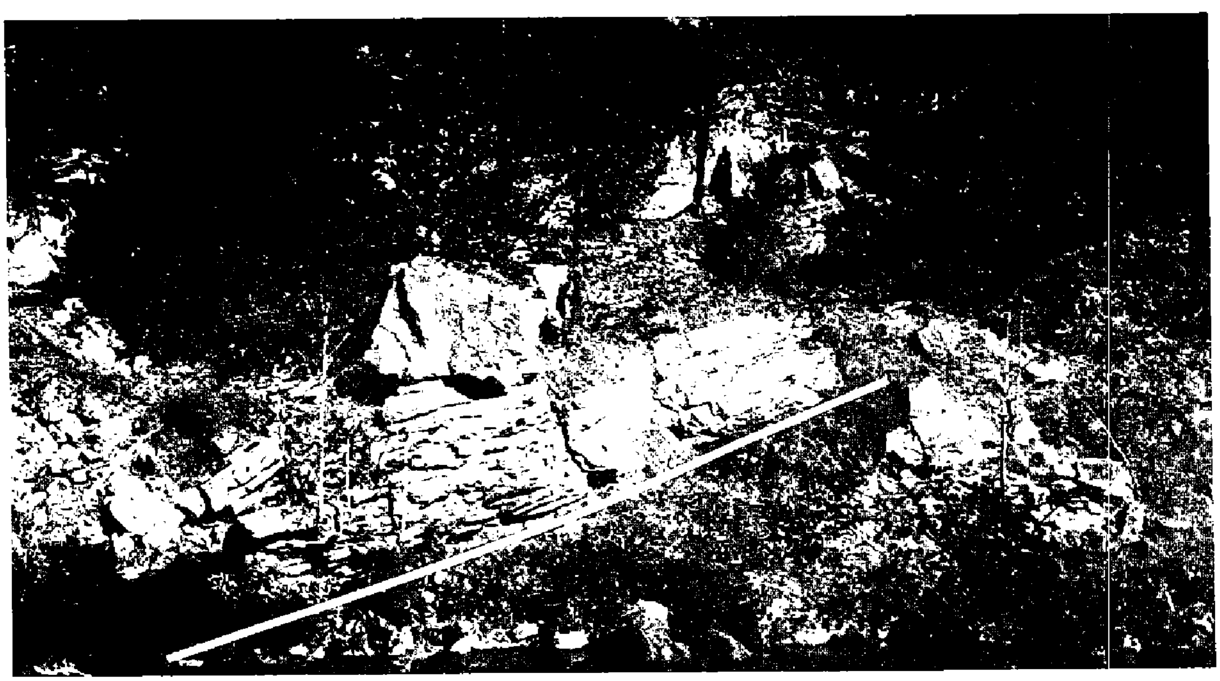


Figure 11. Basal sandstone unit of the Savanna Formation, shown in outcrop at the east edge of Rock Creek, SW¼NW¼NW¼SE¼ sec. 2, T. 6 N., R. 21 E., Latimer County. Contact with the underlying McAlester Formation is shown by white line (from Hemish, 1996b, fig. 5A).

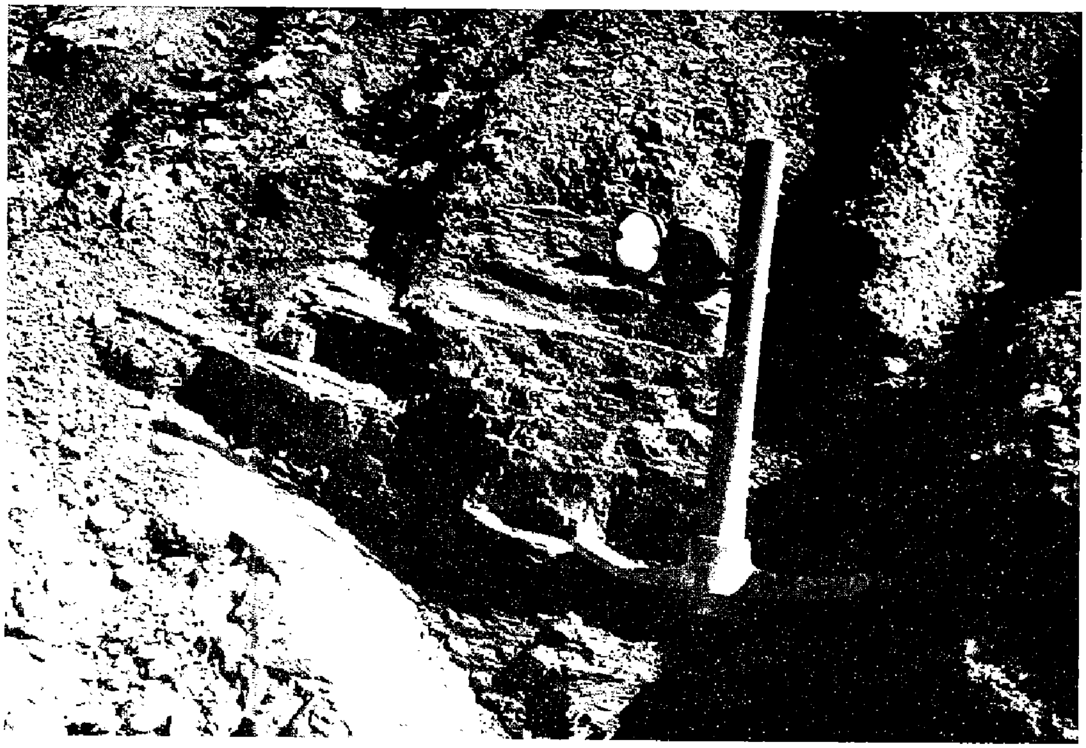


Figure 12. Eleven-inch-thick coal bed in the Savanna Formation exposed in a new road cut in the SW¼SW¼ sec. 8, T. 7 N., R. 21 E., Haskell County. The pick head is at the base of the coal and the Brunton compass is at the top. Beds strike N. 85° E. and dip SE. 18°. Photographed October 12, 1994.

Because of its steep slope, it is unlikely that this exposure of the Savanna Formation will grass over to any extent. It has field-trip-stop quality and certainly will be visited by many geologists in the future. Because of subsequent road-construction excavation, the exposure has changed since it was measured initially, and it should be remeasured at some future date.

The Boggy Formation is the youngest of the bedrock units present in the Sans Bois Mountains. It is exposed for a distance of ~5 mi along the highway, where the new segment winds through the mountains and crosses the axis of the Sans Bois syncline (Fig. 9A).

Like the Savanna Formation, the Boggy comprises a series of interbedded shales and sandstones; the shales predominate. The lowest sandstone unit is the Bluejacket Sandstone Member, which is >126 ft thick in the map area (Hemish, 1996b) and forms major ridges on both flanks of syncline (Fig. 14). Other ridge-forming sandstone units in the Boggy are informally named Pb2–Pb8 (Fig. 9A). The upper part of the Boggy Formation has been eroded, so its total thickness is unknown. The Secor and Secor Rider coal beds are present in the shale interval overlying the Bluejacket Sandstone (Hemish, 1996a), but they are not exposed and are not deemed economically important because of their thinness and their position in the mountainous terrain.

Quaternary deposits (consisting of boulders, gravel, sand, silt, and clay) are present in flood plains and terraces along all the major drainageways (Fig. 9A). Colluvial deposits are ubiquitous throughout the map area, but they were not identified nor mapped separately from their parent bedrock sources.

Figure 13. *A*—Final road cut through a ridge of the Savanna Formation showing interbedded shales, sandstones, and coals, SW¼SW¼ sec. 8, T. 7 N., R. 21 E., Haskell County. *B*—Incised sand- and mud-filled channel (shown by white line). Photographed April 2, 1998.

Summary

Oklahoma's newest highway, a segment of S.H. 82, crosses the Sans Bois Mountains between Red Oak on the south, and Lequire on the north. Most of the road is built on ridge and valley topography formed by differential erosion of sandstones and shales. Three Pennsylvanian-age formations crop out in the map area—the McAlester, the Savanna, and the Boggy Formations. Although several coal beds occur along the route of the highway, only the McAlester and Upper McAlester have commercial potential. Both have been strip mined where economically feasible.

Some slump problems have developed in the steep slopes of cuts along the new segment of S.H. 82, but the road bed itself is well built and, hopefully, will withstand the test of time. Opening of the road will provide another much-needed connection between two major east-west routes in Oklahoma—State Highway 9 and U.S. Highway 270.

Figure 14. Upper part of the Bluejacket Sandstone Member of the Boggy Formation exposed on Ryan Peak (see Fig. 9A) (from Hemish, 1996b, fig. 11B).

Acknowledgments

Gratitude is expressed to Curtis J. Hayes, geologist and research branch manager, ODOT, and Jim Nevels, soils and foundations engineer, ODOT, for their cooperation in preparation of this article. All of the information in the section on Engineering Aspects was provided by them, either through personal communication or through copies of the highway project plans.

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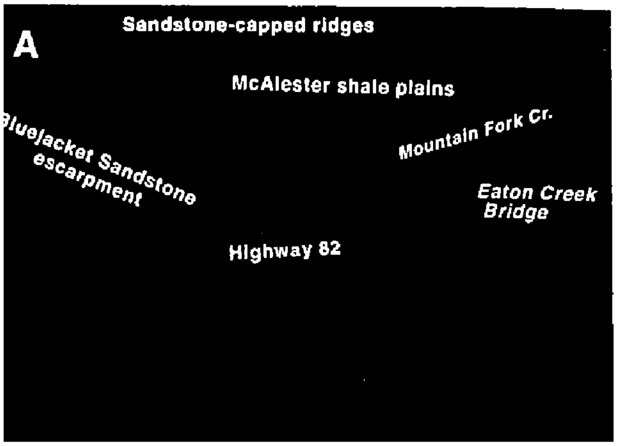
APPENDIX—Measured Section Ha-1-94-H (Lequire Section)

Measured in road cut east side of Oklahoma State Highway 82, NW½SW¼SW¼ sec. 8, T. 7 N., R. 21 E., Haskell County, Oklahoma, by LeRoy A. Hemish. Rock-color terms are those shown on the rock-color chart (Rock-color Chart Committee, 1991).

	Thickness (feet)
KREBS GROUP	
SAVANNA FORMATION	
18. Shale, grayish orange (10YR7/4) to moderate yellowish brown (10YR5/4), weathered, contains scattered dark yellowish orange (10YR6/6) and moderate reddish brown (10R4/6) clay-ironstone concretions about 1–2 in. in diameter, base gradational	11.0
17. Shale, olive gray (5Y4/1) to medium dark gray (N4), partly weathered; contains dark reddish brown (10R3/4) ironstone concretions as much as 3 in. long and 1 in. thick, base uneven and sharp	1.4
16. Sandstone, grayish orange (10YR7/4) to moderate yellowish brown (10YR5/4) with moderate brown (5YR4/4) staining, very fine grained, noncalcareous, occurs as a channel deposit ~50 ft wide, pinching out laterally in both directions; contains scour-and-fill features with shale interbeds; bedding has a lumpy, nodular appearance; basal contact sharp and erosional	1.5
15. Shale, light olive gray (5Y5/2), weathers light brown (5YR5/6) where sideritic; silty, base sharp	2.0
14. Sandstone, light olive gray (5Y5/2) to light brown (5YR5/6), very fine grained, silty, shaly, noncalcareous; contains low-angle cross-bedding, scour-and-fill features, abundant casts of plant material, and 1-in.-thick banded ironstone concretions; base gradational	5.2
13. Siltstone, pale yellowish brown (10YR6/2) with moderate brown (5YR4/4) staining, sandy; includes smutty, carbonized films of plant material just below contact with overlying unit; also includes light brown (5YR5/6) to moderate brown (5YR3/4) ironstone nodules 0.5–2 in. long and 0.5 in. thick, some of which reveal fossil ferns if split open; becomes increasingly shaly downward; contact gradational	6.4
12. Shale, medium dark gray (N4); includes abundant light brown (5YR5/6) and moderate brown (5YR4/4) ironstone stringers and nodules, some of which reveal fossil ferns if split open; base gradational	3.0
11. Shale, coaly, brownish-black (5YR2/1), contact gradational	0.1
10. Coal, black (N1), hard; cleats closely spaced, iron-stained calcite on cleat surfaces; base gradational (Rowe[?] coal)	0.9
9. Sandstone, grayish black (N2), interlaminated with coal; thickness variable due to billowy surface on underlying sandstone unit	0.3
8. Sandstone, medium gray (N5) with grayish orange (10YR7/4), light brown (5YR5/6), and pale yellowish brown (10YR6/2) staining, very fine	

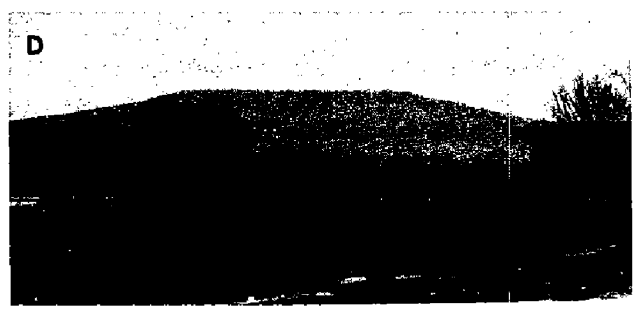
	grained, massive, blocky; contains black, carbonized plant fragments randomly oriented throughout, has a poddy appearance on the outcrop; base sharp	1.4
7.	Mudstone, medium light gray (N6), with minor grayish red (10R4/2) and grayish orange (10YR7/4) mottling, very silty, hard, blocky; contains root casts 0.6 ft long and 0.3 in. in diameter; base sharp	0.6
6.	Sandstone, light brown (5YR5/6) to dark yellowish orange (10YR6/6), very fine grained, silty, nodular; contains burrows and root casts; thickness variable laterally; base sharp in places, gradational in others	0.7
5.	Shale, medium light gray (N6) where weathered, medium dark gray (N4) where fresh; contains abundant irregularly shaped, grayish red (5R4/2), sandy, silty nodules and masses; base gradational	8.0
4.	Mudstone, grayish red (5R4/2) and medium gray (N5), mottled, silty, blocky (paleosol horizon[?])	0.9
3.	Shale, medium gray (N5) blocky, interbedded with medium light gray (N6) siltstone and very fine grained sandstone stringers and lenses; includes minor grayish red (5R4/2) staining; base sharp	3.9
2.	Sandstone, light gray (N7), very fine grained, hard, contains low angle cross-stratification, shaly in upper foot, trace fossils on sole, discontinuous, poddy	2.0
1.	Shale and mudstone, with interlayered siltstone stringers and lenses of very fine grained sandstone ~2 ft thick; variegated—medium gray (N5), grayish orange (10YR7/4), and grayish red (5R4/2); cross cut by oxidized veins and fractures; several horizons are nodular and contain slickensides; sandstones show cut-and-fill relationships and contain low-angle cross-stratification; overall appearance of the fresh exposure is one of a sequence of paleosols; base covered	20.0
	Total thickness of measured section	69.3

New Segment of Oklahoma State Highway 82 *(continued from p. 94)*



road snakes its way through verdant pine and hardwood forests, crossing canyons with quaint names like "Huckleberry Hollow" and providing views of Long Mountain (elevation 1,653 ft), Askew Hollow, Ryan Peak, and Little Yancy Mountain (see Fig. 9A, p. 104–105, this issue). On its course through the mountains, the road skirts boulder-strewn Rock Creek, the major south-flowing stream that cuts through the Sans Bois range. Along the way it is not unusual to drive through low-hanging clouds at higher elevations in the mountains (see inset photograph B, courtesy of C. J. Hayes).

From the high ridges on the south flank of the mountains, another breathtaking panorama unfolds. The low-lying valleys are again underlain by the McAlester Formation, but they are interrupted by high ridges of the sandstones and shales of the Savanna Formation just north of the town of Red Oak (hidden from view by Red Oak Mountain [inset photograph C]). Also in the panoramic view is Red Oak Peak (inset photograph D), just to the east of the gap used by the old Butterfield Stage route and now occupied by a previously built segment of S.H. 82.



In the distance, to the south, arise the seemingly endless ridges of the Ouachita Mountains. The new road descends into the McAlester Formation lowlands and links to the previously built segment of S.H. 82, which continues southward into the Ouachita Mountains and ends at the town of Talihina.

For more information on the new segment of S.H. 82, see the feature article in this issue, "Engineering and Geologic Aspects of the New Segment of Oklahoma State Highway 82, Haskell and Latimer Counties, Oklahoma," p. 96.

LeRoy A. Hemish

NEW OGS *Publications*

SPECIAL PUBLICATION 98-3. *Geological Considerations of Waterflooding*, by Kurt Rottmann and others. 171 pages. Price: $10.

This volume presents the material covered in two one-day workshops held by the Oklahoma Geological Survey in June 1998. Designed to acquaint geologists and engineers with the geological pitfalls that can jeopardize the potential success of a waterflood candidate, the workshops were geared toward regional producers, many of whom are on a limited budget and are producing oil from old fields in an era of depressed prices.

The publication deals with the primary phase of a waterflood project: the initial analysis up to the development of the reservoir model for the waterflood candidate. This is the geologically oriented phase of the waterflood project. The second phase, the development of the reservoir model to project abandonment, is engineering oriented and is not covered.

Topics addressed in the publication include:

- determining reservoir data;
- deciphering production data;
- determining and isopaching net pay;
- defining sand geometry and boundaries;
- implications of structure;
- understanding analogies;
- coring and core results;
- distinguishing natural and induced fractures;
- water-supply evaluation;
- permitting.

The publication, bound in a three-ring notebook, contains 172 figures and employs more than 40 case histories as examples.

Principal author Kurt Rottmann is a consultant geologist in Oklahoma City. He contributed to several of the OGS workshops on fluvial-dominated deltaic oil reservoirs. Other contributors to this volume are David R. Crutchfield, Oklahoma City; George Tew, Perry, Oklahoma; Dan Wilson, Golden Colorado; Mark Sutherland, Ada, Oklahoma, and Saleem Nizami, Oklahoma City.

LIST OF AVAILABLE OGS PUBLICATIONS, 1998/1999. 26-page catalog. Available free of charge.

OGS SP 98-3 can be purchased by mail from the Survey at 100 E. Boyd, Room N-131, Norman, OK 73019; fax 405-325-7069. To mail order, add 20% to the cost for postage, with a minimum of $1 per order.

All OGS publications can be purchased over the counter at the OGS Publication Sales Office, 1218-B W. Rock Creek Road, Norman; phone (405) 360-2886, fax 405-366-2882.

Spatial Variation in Hydraulic Conductivity Determined by Slug Tests in the Canadian River Alluvium Near the Norman Landfill, Norman, Oklahoma

Documented in this 28-page USGS water-resources investigations report by Martha A. Scholl and Scott Christenson are the results of tests used to measure hydraulic conductivity, a measure of how readily an aquifer can transmit water. The tests, known as "slug tests," were performed in small-diameter temporary wells near the City of Norman's closed landfill. Measured hydraulic conductivity in silt and sand ranged from 8.39×10^{-7} to 2.78×10^{-4} meters per second, with a median value of 6.6×10^{-5} meters per second. Measurements of hydraulic conductivity are needed to determine the velocity of ground-water flow and the rate of contaminant movement.

The City of Norman's closed landfill is a research site that the U.S. Geological Survey began to study in 1994 in collaboration with scientists at the University of Oklahoma, Oklahoma State University, and the Environmental Protection Agency.

Order WRI 97-4292 from: U.S. Geological Survey, Water Resources Division, 202 N.W. 66th St., Bldg. 7, Oklahoma City, OK 73116; phone (405) 843-7570. A limited number of copies are available free of charge.

Nitrate and Pesticides in Ground Water of the Ozark Plateaus Region in Arkansas, Kansas, Missouri, and Oklahoma

The results of a water-quality study of the Ozark Plateaus region are presented in this four-page U.S. Geological Survey fact sheet by James C. Adamski for the National Water-Quality Assessment Program. The study area is ~48,000 mi^2 and includes parts of Arkansas, Kansas, Missouri, and Oklahoma. Samples of ground water from springs and wells in the Springfield Plateau and Ozark aquifers were collected from 1993 through 1995 and analyzed for nitrite and pesticides. The results showed that the ground-water quality of these aquifers is susceptible to surface contamination and has been affected by elevated concentrations of nitrate and the occurrence of pesticides.

Order FS 182-96 from: U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225; phone (303) 202-4210. Fact sheets are free of charge.

Nutrients and Pesticides in Ground Water of the Ozark Plateaus in Arkansas, Kansas, Missouri, and Oklahoma

Prepared by J. C. Adamski for the National Water-Quality Assessment Program, this USGS open-file report contains 28 pages.

Order OF 96-4313 from: U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225; telephone (303) 202-4210. Cost is $9 for a paper copy or $4 for microfiche, plus $3.50 per order for handling.

Oklahoma Marginal Wells Commission Meeting, July 30, 1998, Oklahoma City, Oklahoma. Information: Marginal Wells Commission, 1218-B W. Rock Creek Road, Norman, OK 73069; (405) 366-8688 *or* (800) 390-0460, fax 405-366-2882.

National Speleological Society Convention, August 3–7, 1998, Sewanee, Tennessee. Information: William Shrewsbury, P.O. Box 4444, Chattanooga, TN 37406; (615) 886-3296; e-mail: 75254.1025@compuserve.com.

American Association of Drilling Engineers Industry Forum: Pressure Regimes in Sedimentary Basins and Their Prediction, September 2–4, 1998, Houston, Texas. Information: Alan R. Huffman, Conoco, Inc.; fax 580-767-6067; e-mail: alan.r.huffman@usa.conoco.com.

Highway Geology Symposium, September 10–14, 1998, Prescott, Arizona. Information: Nick M. Priznar, Arizona Dept. of Transportation, 1221 N. 21 Ave., Phoenix, AZ 85009; (602) 255-8089.

International Association of Hydrogeologists Congress, "Physical, Chemical, and Biological Aspects of Stream-Aquifer Interrelations," September 13–19, 1998, Las Vegas, Nevada. Information: John Van Brahana, U.S. Geological Survey, 114 Ozark Hall, University of Arkansas, Fayetteville, AR 72701; (501) 575-2570.

Interstate Oil and Gas Compact Commission, Fall Quarterly Meeting, September 17–18, 1998, Oklahoma City, Oklahoma. Information: IOCGG, P.O. Box 53127, Oklahoma City, OK 73152; (405) 525-3556, fax 405-525-3592; e-mail: iogcc@oklaosf.state.ok.us.

Society for Sedimentary Geology Research Conference, "Fluid Flow in Carbonates: Interdisciplinary Approaches," September 20–24, 1998, Green Lake, Wisconsin. Information: SEPM, 1731 E. 71st St., Tulsa, OK 74136; (918) 493-3361.

Society of Petroleum Engineers, Annual Conference, September 27–30, 1998, New Orleans, Louisiana. Information: Dan Lipsher, SPE, P.O. Box 833836, Richardson, TX 75083; (972) 952-9306; e-mail: dlipsher@spelink.spe.org.

American Institute of Hydrology and International Association of Hydrogeologists, Joint Conference, September 27–October 2, 1998, Las Vegas, Nevada. Information: AIH, 2499 Rice St., Suite 135, St. Paul, MN 55113; fax 612-484-8357; e-mail: AIHydro@aol.com.

Morrow Play Workshop to Be Held in September

The Oklahoma Geological Survey, in cooperation with the Oklahoma City Geological Society, will sponsor a half-day workshop, "Fluvial-Dominated Deltaic Oil Reservoirs in Oklahoma: The Morrow Play," on **September 10** from 1 p.m. to 5 p.m. It will be held at the Home Builders Association of Greater Oklahoma, 625 West Interstate 44 Service Road, Oklahoma City. OGS geologist Rick Andrews is the primary presenter. The cost is $30 for members of the OCGS, $35 for nonmembers. To register, please contact the OCGS reservation lines at (405) 236-8086 or (405) 235-3648, ext. 40. If you have questions regarding the workshop, call Carol Jones at (405) 236-8086, ext. 11.

Hartshorne Formation — Focus of Upcoming OGS Workshop and Field Trip

The Oklahoma Geological Survey will hold a one-day workshop on the natural gas and coalbed methane reservoirs of the Hartshorne Formation, and a two-day field trip to southeastern Oklahoma to view Hartshorne outcrops. The events are cosponsored by the Petroleum Technology Transfer Council.

The workshop, which runs from 9 a.m. to 4 p.m., will take place September 30 at the Francis Tuttle Vo-Tech in Oklahoma City, and again November 4 at the Indian Capitol Area Vo-Tech in Muskogee. OGS geologists Rick Andrews and Brian Cardott are the primary presenters.

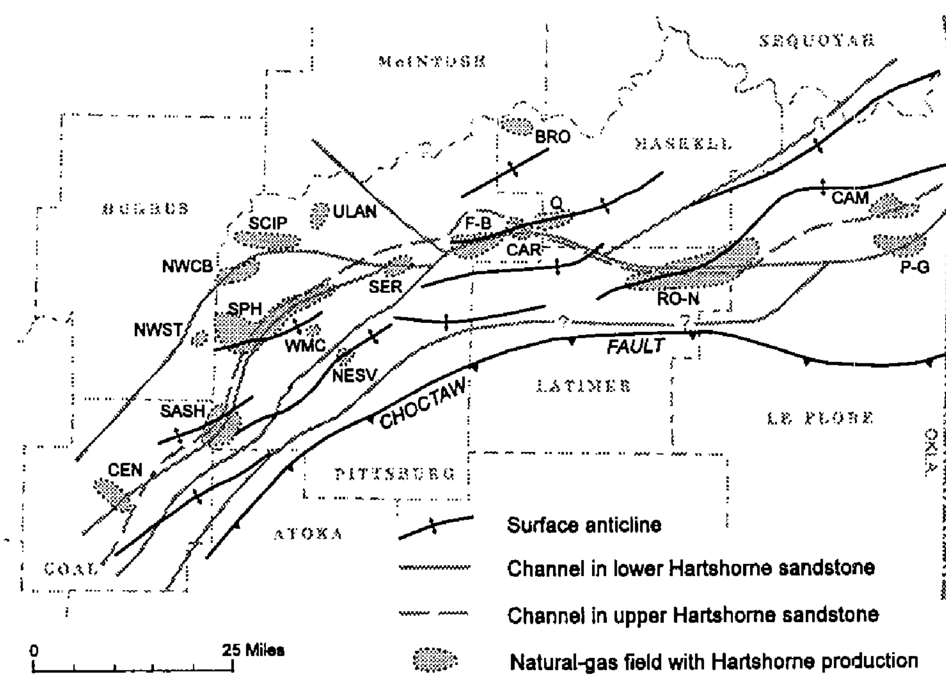
The two-day field trip, led by OGS geologist Neil Suneson, will be offered November 10–11 and November 12–13. The field trip begins and ends in McAlester.

The Hartshorne Formation is a prolific gas reservoir in the Arkoma basin of southeastern Oklahoma. Most wells are <4,000 ft deep and reserves are generally 250 MMcf to several Bcf. Production is largely attributed to sandstone reservoirs; coalbed methane has also been exploited recently. The workshop will examine the regional distribution of the Hartshorne Formation and provide detailed field studies of various sandstone and coal reservoirs.

The field trip will acquaint participants with a variety of sandstone and coal exposures illustrating floodplain, fluvial-dominated deltaic (FDD), and marine depositional facies. Surface exposures will be related to subsurface logs.

Costs to attend the workshop and field trip are yet to be determined. The cost for the workshop will include coffee, lunch, and a copy of the workshop publication. The cost for the field trip will include transportation, lunch, and a copy of the guidebook.

For more details, or for registration forms, contact Michelle Summers, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; phone (405) 325-3031 *or* (800) 330-3996; fax 405-325-7069. Updated information can be found on the OGS web site at the URL http://www.ou.edu/special/ogs-pttc/.



Generalized map of Hartshorne Formation workshop area.

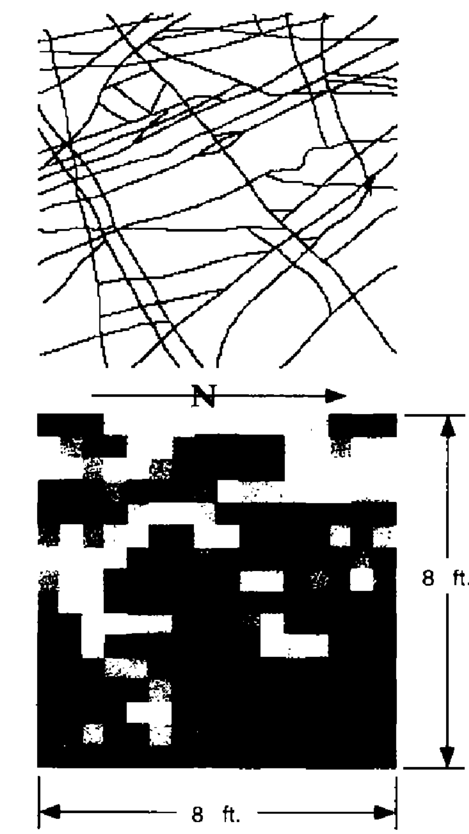
Oklahoma ABSTRACTS

The following abstracts were presented as part of the Geology Section program at the Oklahoma Academy of Science 86th annual technical meeting, University of Sciences and Arts of Oklahoma, Chickasha, November 7, 1997.

Estimation of Fracture Hydraulic Properties from an Infiltration Test

MICHAEL NICHOLL, School of Geology, Oklahoma State University, Stillwater, OK 74078

In 1994, a field infiltration experiment was performed in the Topopah Springs Unit at Yucca Mountain, Nevada (Nicholl and Glass, 1995). The infiltration test was designed to explore both three-dimensional geometry of the natural fracture network and small-scale flow processes within fractured rock such as gravity-driven fingering (e.g., Nicholl et al., 1994; Glass et. al., 1995). Local well water containing a visible tracer was ponded in a surface infiltration pit of approximately 5 feet in diameter. Flow rate was measured as a function of time during the ~40 minute duration of the test; a total of ~240 gallons of fluid were introduced to the initially dry fracture network. Because of the extremely low matrix permeability of this unsaturated, densely welded, fractured tuff unit, flow during the infiltration test was confined to the connected fracture network. Subsequent to the infiltration test, the rock mass was excavated in a series of 11 horizontal pavements at approximately 1.5 foot vertical intervals. At each vertical level, fractures and tracer distribution were mapped on an 8 × 8 foot region located directly below the infiltration pit.



Here we describe a means of using the map data collected by Nicholl and Glass (1995) to estimate the hydraulic properties of their fracture network. There are two basic approaches to describing flow through a fracture network: treat each fracture individually, or define an equivalent porous media. As a first step, we begin with the equivalent media approach and model the domain on a 3-dimensional rectangular grid; within each block of the grid, hydraulic properties (saturated hydraulic conductivity, porosity) are assumed to be homogenous and isotropic. We then assume that fracture density provides a first-order estimate of local hydraulic conductivity; e.g., permeability of each individual grid block will be proportional to the degree of fracturing within that block.

Fracture density is measured on scanned images of horizontal fracture trace maps collected during excavation of the field experiment. Each scanned image is processed to yield a binary array in which fractures are represented as a line of unit width and value one; unfractured regions are represented in the array by the number zero. The binary array is then subdivided into uniform grid blocks; the normalized sum of the binary array within each individual grid block gives the fracture density within that block. The accompanying figure shows an example of a digitized pavement map alongside its equivalent continuum representation for grid blocks that are 0.5 × 0.5 feet in area; bright shades represent high fracture density, while black indicates an unfractured region. Eleven of these equivalent pavements have been assembled to form a 3-dimensional equivalent continuum representation of the study area. The next step in this research is to simulate saturated flow through the system and calibrate fracture hydraulic aperture to the experimentally measured flow rate.

Selected References

Glass, R. J.; Nicholl, M. J.; and Tidwell, V. C., 1995, Challenging models for flow in unsaturated, fractured rock through exploration of small scale flow processes: Geophysical Research Letters, v. 22, p. 1457–1460.

Nicholl, M. J.; and Glass, R. J., 1994, Wetting phase permeability in a partially saturated horizontal fracture: Proceedings of the Fifth Annual International Conference on High Level Radioactive Waste Management, American Nuclear Society, Las Vegas, Nevada, May 22–26, 1994, p. 2007–2019.

Nicholl, M. J.; Glass, R. J.; and Wheatcraft, S. W., 1994, Gravity-driven infiltration instability in initially dry nonhorizontal fractures: Water Resources Research, v. 30, p. 2533–2546.

Trace Fossils as Indicators of Sedimentological Processes: Effects of Bioturbation on Sediment Properties

JAMES R. CHAPLIN, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019

Trace fossils are interfacial phenomena best suited to sequences with an interbedding of different grain sizes. Trace fossils often are superior to body fossils as indicators of depositional environments for the following reasons: (1) commonly restricted to narrow facies ranges, (2) often found in otherwise unfossiliferous rocks, (3) virtually always found in place, and (4) record ecological information of soft-bodied organisms. Common soft-bodied trace markers include annelids, coelenterates (sea anemones), and echinoderms. Common trace-makers with hard parts include pelecypods, gastropods, and arthropods.

Generally bioturbation increases seaward as: (1) water depth increases, (2) wave-tidal energy decreases, (3) mean sediment grain size decreases, (4) sedimentation rates decrease, and (5) physical and chemical parameters become more stable.

Horizontal traces produced by deposit feeders indicate a decrease in mean sediment grain size, increase in organic content of the sediment, and a lower energy regime. Vertical traces produced by suspension feeders indicate an increase in mean sediment grain size, decrease in organic content of the sediment, and relatively higher energy conditions.

The burrowing activities of organisms can alter the texture, composition, and stability of sediments. Sediment textures can be changed by: (1) mixing of different sedimentary layers, (2) sorting of sediments during ingestion, (3) breakdown of aggregates of sediment grains during digestion and excretion, and (4) burrow construction. Sediment composition can be changed with respect to: (1) total organic content, (2) trace element concentrations, and (3) redox potential. Sediment stability can be increased by the baffling effect of rigidly constructed dwelling tubes, or it can be decreased by organisms churning the sediment.

Bioturbation may be responsible for adding abundant clay-size material to the section. Organisms capture clays from bottom waters and, after passing the clays and attached morsels through their gut they add clay to the near-surface sediments in the form of fecal material or burrow linings. The mixing of mudstone and sandstone through bioturbation can affect permeability negatively and segment a hydrocarbon reservoir by creating barriers to cross-flow. In general, less complex and vertical traces enhance porosity. Locally, porosity may be restricted only to burrowed horizons.

Structural Geometry of Thrust Faulting in the Wister Lake Area of the Frontal Ouachitas, Arkoma Basin, SE Oklahoma

JEFF RONCK and *IBRAHIM CEMEN*, School of Geology, Oklahoma State University, Stillwater, OK 74078

The Ouachita Mountains and Arkoma basin are two related tectonic provinces formed during the Late Paleozoic Ouachita Orogeny. The Arkoma basin consists of gentle synclines and thrust-cored anticlines. The frontal Ouachitas are characterized by imbricate thrusts and complex fold geometries. The Choctaw fault serves as the leading edge thrust of the frontal belt.

This study analyzed the structural geometry of thrusting within the Blackjack Ridge and Leflore quadrangles. Five balanced structural cross-sections were constructed to depict the geometry of the Late Paleozoic thrust system. Data from the surface geological maps by the Oklahoma Geological Survey, wire-line well logs, scout tickets, and seismic profiles, from Enron, Amoco, and Exxon Corporations were used to construct the cross-sections. Upon their completion, the cross-sections were restored using the basal Atokan Spiro sandstone as the key-bed in order to determine the amount of shortening induced by thrusting in the area.

The hanging wall block of the Choctaw fault is dominated by south-dipping imbricate thrusts, which form a leading imbricate fan. Subsidiary faults flatten with depth and join the Choctaw Detachment at approximately –16,000 below sea level. The footwall block of the Choctaw fault hosts a variety of structures representing a transitional change into the more gentle deformation observed in the Arkoma Basin. It contains two detachment surfaces, a duplex structure and a well-developed triangle zone. Near the southern end of the study area, the deep Woodford Detachment ramps up to the stratigraphically higher Springer Detachment, which serves as the floor to the duplex. The Lower Atokan Detachment splays from the Springer Detachment forming both a roof to the duplex structure and a floor for the triangle zone. A north-dipping backthrust bounds the Cavanal Syncline to the south, and serves as the northern boundary to the triangle zone. Using the Spiro sandstone as a key-bed, restoration suggests shortening of approximately 42% in the study area.

Structural Geometry of Thrust Faulting in Red Oak and Talihina 7.5-Minute Quadrangles, Latimer and Le Flore Counties, Oklahoma

SYED MEHDI and *IBRAHIM CEMEN*, School of Geology, Oklahoma State University, Stillwater, OK 74078

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

Arkoma Basin. The frontal Ouachitas are characterized by imbricate thrusts and complex fold geometries. The Arkoma Basin contains gentle folds with minor faulting.

This study was concerned with the structural geometry of the Late Paleozoic thrust faults in Talihina and Red Oak quadrangles in Latimer and Le Flore Counties. Six balanced structural cross-sections were constructed to delineate the structural geometry in the study area. Data from the surface geological maps by the Oklahoma Geological Survey, wire-line well logs, scout tickets, and seismic profiles, donated by Exxon and Amoco Corporations, were used to construct the cross-sections.

The Pine Mountain, Ti Valley, and other thrust faults exposed at the hanging wall of the Choctaw fault are interpreted in the cross-sections as imbricate fans splaying from the Choctaw detachment surface. The structural cross-sections suggest the presence of a well-defined duplex structure containing at least two horse structures in the footwall of the Choctaw fault. The Springer Detachment is the floor thrust and the Lower Atokan Detachment is the roof thrust of the duplex structure. A well-defined triangle zone is also observed in the footwall of the Choctaw fault zone. It is bounded by the subsurface continuation of the Carbon fault on the north as a blind backthrust, and the Choctaw fault on the south. The triangle zone is floored by the Lower Atokan Detachment.

Collegiate Academy competition winners Valerie Green *(left)* and Kevin Ware *(right)*, students at the University of Oklahoma, display their awards for presenting the best paper in geology at the 86th Annual Meeting of the Oklahoma Academy of Science (OAS), November 7, 1997. The plaques were awarded by LeRoy A. Hemish *(center)* of the OGS, chairman of the OAS Geology Section. Student presentations were judged by Hemish and James R. Chaplin, also of the OGS. The abstract of the award-winning paper appears below.

Extraction of Iron/Sulfate Minerals for Bioremediation Assessment

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Iron and sulfate have a large potential for biological utilization which can be used to remediate organic contamination. The purpose of this research was to measure the ability of mild acid to extract iron or sulfur from synthetic iron and sulfur solids. Mild extractions have been used to estimate the amount of biologically available (III) and biogenically produced iron (II) used in subsurface microbial-organic interactions. Iron (II) is an indicator of recent microbial activity due to sulfate reduction processes (Lyon and Glass, 1997). Iron species extracted were ferrihydrite, goethite, hematite, and ferric monosulfide. Specific research objectives included: (a) determining the most favorable timespan and the most optimal extractant for testing (0.25 N hydroxylamine hydrochloride in 0.25 N hydrochloric acid or 0.5 N hydrochloric acid), (b) specifying the rate-determining characteristics, and (c) determining the effects of mineral type on extrac-

tion. Differing concentrations of iron species were used to determine if a direct relationship was present between the rate of extraction and the iron species concentration level, as seen in Figure 1. The more reactive species (ferrihydrite and ferric monosulfide) readily extracted in 24–48 hours, while more crystalline species (hematite and goethite) extracted poorly, as exhibited in Figure 2. The extractant choice did not affect the results significantly, so 0.5 N HCL (aq) was the preferred extractant. Concentration variance did not alter results. The more recalcitrant (crystalline) iron species comprise a majority of the background iron, so it appears that the 48-hour test in 0.5 N HCL (aq) will maximize the relative amount of reactive and biologically useful species extracted, while minimizing the extraction of background iron. Such information is helpful because natural sediments contain high concentrations of the previously listed iron mineral forms, and this data could be referenced in relation to an extraction of iron minerals in a particular sediment.

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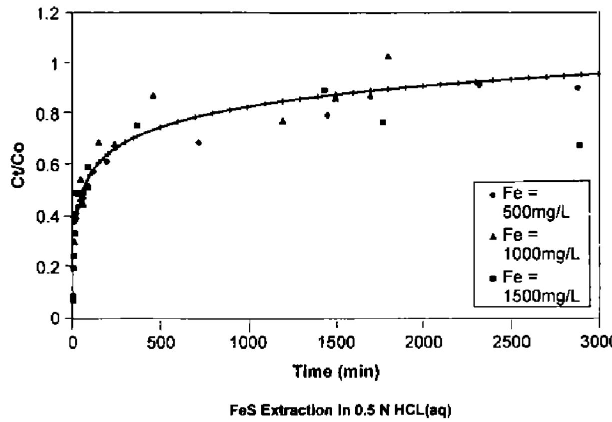

Figure 1. Illustration of iron extraction (over 48-hour time span).

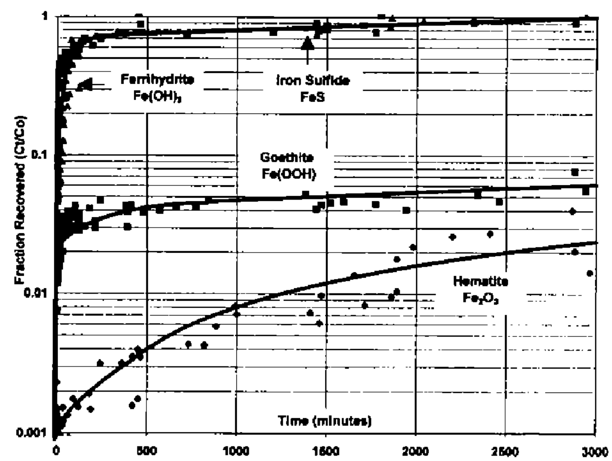

Figure 2. Illustration of extracted iron types over 48-hour time span.