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Featuring: *Geology of a proposed landfill site, Cherokee County*

on the cover

Cave in the Boone Formation, Cherokee County, Oklahoma

The cover photo shows a cave located on a bluff ~40 ft above Clear Creek in the SW¼NE¼ NW¼NE¼, sec. 14, T. 18 N., R. 20 E., Cherokee County. The mouth of the cave is ~2 ft high and ~3.5 ft wide. The total length of the cave is unknown. However, members of the Tulsa Regional Oklahoma Grotto (a group of spelunkers) inspected the tunnel for 18 ft back from its mouth until it turned and narrowed too much for further exploration. A flow of cool air detectable at its mouth suggests that the cave continues for a considerable distance beyond that point.

The cave has developed in the Boone Formation (Mississippian), which is comprised of interbedded limestone and chert. When caves first begin to form, dissolution of limestone occurs along joints, fractures, and bedding planes below the water table. The second stage of cave formation occurs if the water table drops below its original level; then, passageways are enlarged through erosion caused by fast-flowing subterranean streams and through cave-roof collapse (Chernicoff and Venkatakrishnan, 1995, p. 448–449).

Uplift of the Ozark plateau, and subsequent downcutting by Clear Creek, left the cave in its present position, with its mouth high above the stream valley. Erosion by ancient subterranean streams probably formed the first 18 ft of the cave, and dissolution enlargement of joints and fractures in the limestones of the Boone Formation could account for much of the unexplored part of the cave (see Fig. 7B, p. 83, this issue). It is likely that a network of cave chambers and connecting passageways are present in the unexplored part of the system.

Development of caves in the Boone Formation is common throughout the Ozark region of Oklahoma, Arkansas, and Missouri. McKnight and Fisher (1970, p. 81–82) discuss caves in the Boone, as well as other karst features that form in soluble limestone terrain. Further information about the Boone Formation is given in this issue's feature article, beginning on p. 76.

References Cited

Chernicoff, Stanley; and Venkatakrishnan, Ramesh, 1995, Geology—an introduction to physical geology: Worth Publishers, New York, 593 p.

McKnight, E. T.; and Fischer, R. P., 1970, Geology and ore deposits of the Picher field, Oklahoma and Kansas: U.S. Geological Survey Professional Paper 588, 165 p.

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OKLAHOMA GEOLOGY notes

Vol. 60, No. 4 **Winter 2000**

Geology in the Immediate Vicinity of a Proposed Landfill Site, Cherokee County, Oklahoma

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INTRODUCTION

In the early summer of 1999, Mr. Wesley Squyers of the Oklahoma Department of Environmental Quality (DEQ) asked the Oklahoma Geological Survey (OGS) to conduct a study and to report on the geology in the immediate vicinity of a proposed landfill site in the NW¼ sec. 7, T. 18 N., R. 21 E., in Cherokee County, ~2 mi southwest of the town of Peggs. The site had been proposed for a landfill by the property owners, Terry and Joyce Bailey.

The earliest records of site evaluation (under the name, "Hidden Valley Industries") indicate that drilling of 11 wells commenced on March 25, 1996. The drilling was completed by the end of the month. The contractor was Venture Drilling, and sample descriptions were done by Kurt G. Robinson, geologist.

Monitoring of ground-water elevations versus precipitation at nine monitoring wells and two piezometers commenced on April 1, 1996, and continued through December 1998. Cardinal Engineering, Inc., made the study and produced a ground-water-contour map showing ground-water elevations recorded during that time period. These records were provided to OGS by the DEQ for use in the geologic study.

The mission of the OGS is to provide an objective, unbiased report on the geology of the study area. It is not the role of the OGS to form any opinions or to make any decisions regarding the suitability or unsuitability of the property for use as a landfill site. During the investigation, a literature search was conducted, existing geologic maps were reviewed, and a two-day field reconnaissance of the area was carried out (August 23–24, 1999). The data from Cardinal Engineering, Inc., were evaluated and found to be useful for the study.

The location of a proposed landfill site in northeastern Oklahoma (NW¼ sec. 7, T. 18 N., R. 21 E., in Cherokee County, ~2 mi southwest of the town of Peggs) is within a geomorphic province of the southern Midcontinent known as the Ozark dome—also referred to as the Ozark uplift or Ozark plateau (Fig. 1). The plateau is deeply dissected and is formed in Mississippian limestones and chert.

The area studied by the Oklahoma Geological Survey is defined by a circle with its center in the middle of the proposed landfill site and a radius of ~2 mi (Fig. 2). The proposed landfill site is designed to use an unnamed hollow (referred to in this study as "Hidden Valley") adjacent to Clear Creek (Fig. 2). (A hollow is a low tract of land surrounded by hills or mountains; a small, sheltered valley in a rugged area [Jackson, 1997, p. 301]). The head of Hidden Valley is at an elevation of ~960 ft. It is near the crest of an elongate, dome-like hill that has its high point near the center of sec. 7 (Fig. 2). Field observations indicate that the hollow is an erosional feature that has been carved into the northwest flank of the dome-like hill down to the flood plain of Clear Creek. The elevation of Clear Creek at the mouth of the hollow is ~780 ft, so Hidden Valley descends ~180 ft in less than 0.5 mi. Runoff from heavy rainfall is funneled rapidly from the uplands into the valley and down to Clear Creek.

Clear Creek (so named on the Peggs 7.5-minute quadrangle) flows southwest into Ft. Gibson Lake (Fig. 1). Between the head of Clear Creek (Fig. 1), on the divide between Spring Creek and Clear Creek (~2 mi northeast of the study site) and a point ~2 mi below the site, the elevation decreases from ~900 ft to ~700 ft. The stream gradient, therefore, is ~50 ft/mi in this area.

A southern fork of Clear Creek (also known to the local people as "Clear Creek," and so labeled on the General Soil Map, Cherokee and Delaware Counties, Oklahoma [Cole, 1970]) extends southeastward from its juncture with Clear Creek in the NW¼ of sec. 13, T. 18 N., R. 20 E., and wraps around the elongated, dome-like hill previously mentioned (Fig. 2). Another valley, occupied by Little Clear Creek, is ~2 mi north of Clear Creek and is separated from the proposed landfill site by a NE–SW-trending divide. Little Clear Creek flows to the southwest for ~4 mi before it turns to the south; it joins Clear Creek ~4 mi downstream from the landfill site (Fig. 1).

Sec. 7, T. 18 N., R. 21 E., is moderately populated. Aerial photographs from the U.S. Department of Agriculture (unpublished, 1990) show 15 residences in the section, but a recent reconnaissance indicates that there are several new dwellings not shown on the 1990 photographs. Marty Hern estimated that there are now 32 occupied dwellings in sec. 7, and, although water is now available from the rural water distribution system, some of the residents still depend on private wells for human use as well as for livestock (Marty Hern, district conservationist, U.S. Department of Agriculture, Natural Resources Conservation Service, Tahlequah, Oklahoma, personal communication, 1999, 2000).

The main source of income in Cherokee County (and in the study area) is from the sale of livestock and livestock products. Small grains, corn, sorghum, and improved grasses are grown for livestock feed. Pasture grasses and native grasses in woodland are grazed by livestock. Woodland covers ~61% of Cherokee County (Cole, 1970, p. 1). U.S. Department of Agriculture aerial photographs (unpublished, 1990) indicate that the percentage of woodland in the study area is similar.

GEOLOGY

Stratigraphy

The area within a 2-mi radius of the proposed landfill site is underlain by only two mappable geologic units, the Mississippian Boone Formation and Quaternary alluvium and terrace deposits (undifferentiated) (Figs. 2, 3).

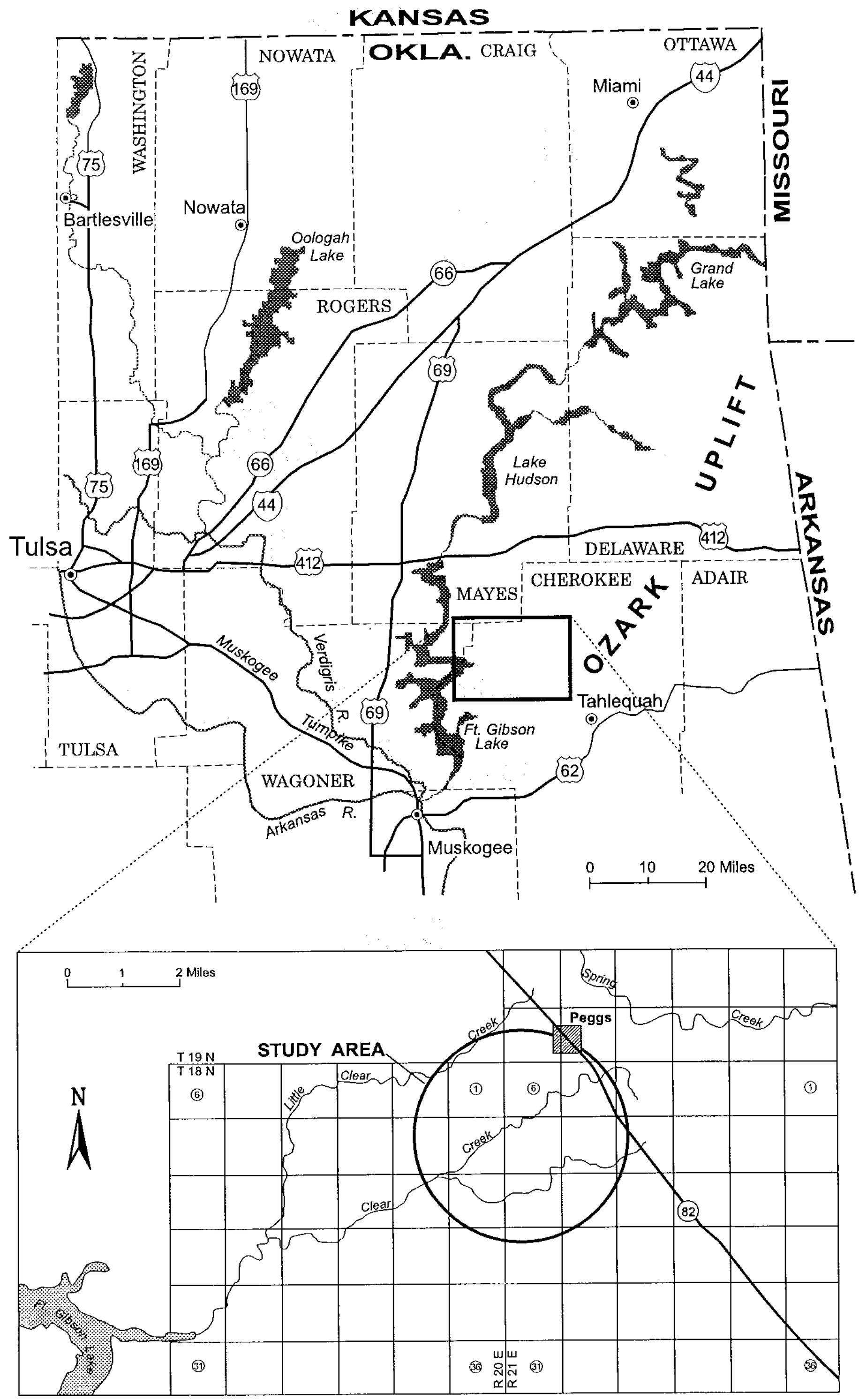


Figure 1. Geographic setting of the proposed landfill site in the Ozark uplift, Cherokee County, northeastern Oklahoma. The site is ~2 mi southwest of the town of Peggs (Fig. 2).

Boone Formation

The name "Boone" Formation, first published in 1891 (Simonds, 1891, p. 13), designated a heterogeneous unit of cherts and limestones that crop out widely in northern Arkansas. Subsequently, the name was extended to the Ozark region of Oklahoma to apply to equivalent strata (McKnight and Fischer, 1970, p. 19). In some locations, the Boone can be divided into several members, but the Boone Formation is not subdivided in this study.

In the study area, the Boone Formation disconformably overlies the Upper Devonian and Lower Mississippian Chattanooga Shale (Fig. 3). The Chattanooga is a widespread, black, fissile shale, commonly 30–70 ft thick. It does not crop out in the study area.

The Boone Formation is a blue gray to brown gray, crinoidal, finely crystalline, marine limestone with oolitic and glauconitic beds; it includes much bedded and nodular gray, blue, and tan chert. Chert generally comprises 10–30% of units described as cherty limestone (Johnson and others, 1989, p. 10). Drilling records from 14 test wells in the Hidden Valley area show that, of a combined total of 1,188 ft of bedrock penetrated, 63.5% of the Boone Formation is limestone and 36.5% is chert (K. G. Robinson, Hidden Valley Industries, unpublished data, 1996).

The top of the Boone is eroded in the study area and the remaining thickness there is not known. A test well in the SE¼SE¼NW¼ sec. 7, T. 18 N., R. 21 E., penetrated 169 ft of the Boone, but did not reach the base of the formation (K. G. Robinson, Hidden Valley Industries, unpublished data [no. 11 well log], 1996). The maximum recorded thickness for the Boone is ~400 ft, presumably in the Ozark uplift of Arkansas (Sutherland and Manger, 1979, p. 4). Huffman (1958, pl. II) records a maximum thickness of 300 ft for the Boone in the Ozark uplift of Oklahoma, which includes the study area.

Chert in structurally undisturbed strata in the study area is concordant with the bedding and has replaced limestone. This replacement of limestone by chert is thought to have taken place progressively during deposition of the Boone limestones. As volcanic ash that settled in sea water decomposed, it may have yielded soluble

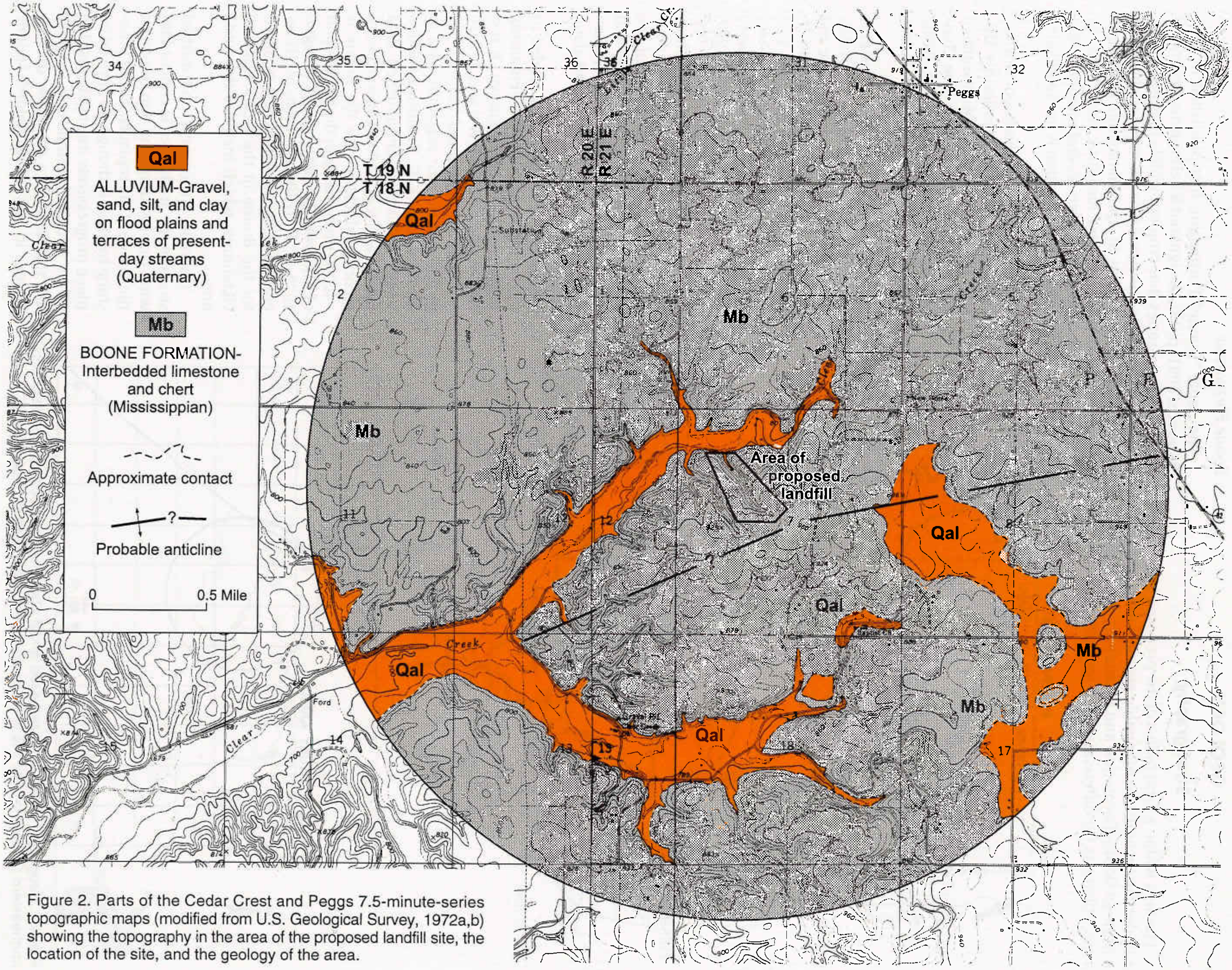


Figure 2. Parts of the Cedar Crest and Peggs 7.5-minute-series topographic maps (modified from U.S. Geological Survey, 1972a,b) showing the topography in the area of the proposed landfill site, the location of the site, and the geology of the area.

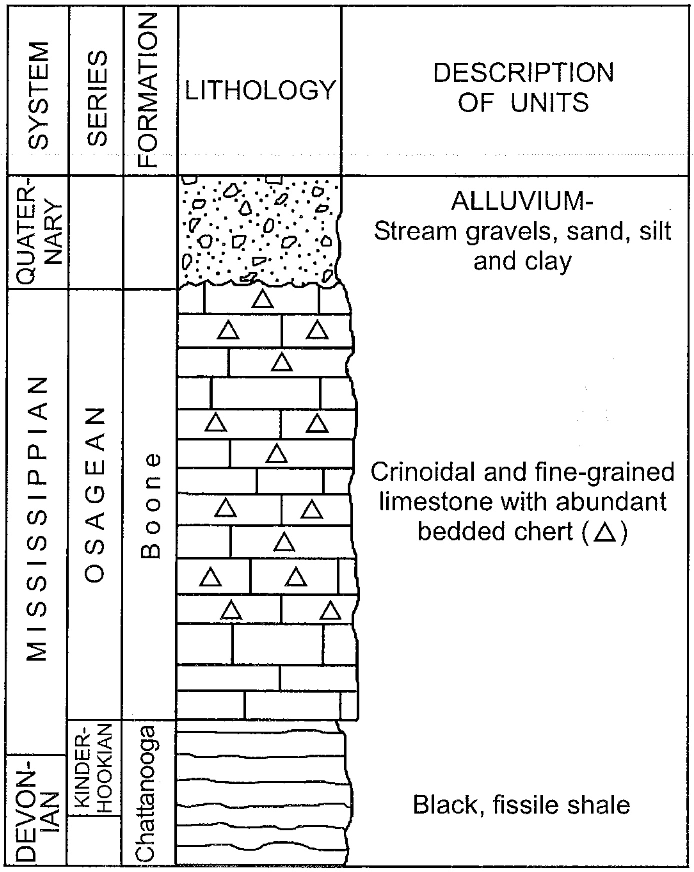


Figure 3. Generalized stratigraphic column showing pertinent rock units in the study area. Unit thicknesses are given in the text.

silica that then was available to replace susceptible limestone sediments on the sea floor (McKnight and Fischer, 1970, p. 3). According to Johnson and others (1989, p. 10), replacement of limestone by chert ranges from early diagenetic to postlithification, but the source of silica (hydrothermal waters, sponge spicules, volcanic ash, or other) is uncertain.

A little chert occurs as crosscutting veinlets (healed fractures in a limestone matrix). Dissolution of the limestone matrix results in a porous, honeycomb texture (Fig. 4). Some silica was dissolved from the cherty limestone by circulating ground waters and was then reprecipitated around preexisting chert masses (McKnight and Fischer, 1970, p. 10).

Quaternary Alluvium and Terrace Deposits

Quaternary alluvial and terrace deposits consist of clays, silts, and coarse cherty gravels. These units are composed of unconsolidated, clastic materials derived from the erosion of adjacent uplands. They are generally porous and permeable and have water tables relatively close to the surface. More details are given in the "Soils" section below.

Structure

Structural development in the study area is closely associated with the Ozark geanticline, which underwent several periods of uplift and subsidence during Paleozoic time. Major deformation took place in Pennsylvanian time during the last major uplift that formed the Ozarks (Huffman, 1958, p. 89). The study area lies on the southwestern end of the Ozark uplift. The regional dip is 25–50 ft per mile toward the northwest, but steeper dips occur locally. Neither Huffman (1958) nor Chenoweth (1983) mapped any folds or faults in the study area. No faults were observed by the author during this study, nor have any been mapped previously. Nevertheless, there may be small folds and/or faults that are undetectable at the surface, in part because bedrock is poorly exposed.

Places to get good readings on the attitude of bedding are rare, but the general dip of strata adjacent to Clear Creek appears to be to the northwest at about 3–7°. Five measurements of joints from the OGS study suggest general trends of N. 51° W. and N. 47° E. Air photos of sec. 7, T. 18 N., R. 21 E. (U.S. Department of Agriculture, unpublished, 1990) show a drainage pattern of N. 52° W. and N. 47° E., which coincides with measured joints in the study area.

Structural movements associated with the Ozark uplift fractured the rocks, mostly during the Late Pennsylvanian. Tectonic breccias of brittle chert formed during plastic deformation of incompetent associated limestones (McKnight and Fischer, 1970, p. 3). Exposures of chert in the Boone Formation observed by the author in and adjacent to Hidden Valley are characterized by curvilinear, closely spaced fracturing, which accounts for the abundance of residual chert clasts in soil profiles in the study area.

SOILS

Soils develop through time on bedrock (parent material) as the result of physical and chemical alterations (weathering). Because some geologic units are more resistant to weathering than others, different types of soil form on each unit. For example, a sandy, porous soil is derived from the breakdown of sandstone. Calcium carbonate in limestone dissolves readily in wet climates, and the insoluble residue

Figure 4. Honeycomb texture in residual chert boulder (visible at the left end of the rock). Such features contribute to the porosity of the chert. Geologic pick is ~1.1 ft long. (The location of the photograph is shown on Fig. 10.)

forms a more clayey soil. If a limestone contains abundant chert (which is composed of SiO_2 and is relatively stable at the earth's surface), the chert remains in the soil as residual clasts. The resultant soil is rocky and tends to be permeable. Alluvial soils reflect the materials derived from adjacent eroded uplands (Chernicoff and Venkatakrishnan, 1995, p. 127–143).

Classification

Soil scientists classify the soils that occur in a particular geographic area. In order to do so, they study each soil extensively, both in the field and in the laboratory. For example, they collect samples and test the physical properties of the soils. They also observe the steepness, length, and shape of slopes and the sizes and speeds of streams. They identify the kinds of native plants or crops a soil supports and the kinds of bedrock in the subsurface. They dig holes to expose soil profiles (sequences of natural layers, or horizons, in soils) that extend from the surface down into parent material that is largely unchanged by leaching or by the action of plant roots (Cole, 1970, p. 1). "Accurate soil classification influences decisions about the location of landfills, the design of buildings, and the ways we cultivate soils for food" (Chernicoff and Venkatakrishnan, 1995, p. 143–144).

Soils are classified according to nationwide, uniform procedures. Our current classification scheme names soils according to obvious physical characteristics. Classification terminology provides information about moisture content, mean annual air temperature, horizon development, soil chemistry, organic matter content, and even the origin and relative age of the soil (Chernicoff and Venkatakrishnan, 1995, p. 144).

The soil series and the soil phase are the categories of soil classification most often used. Soils that have profiles almost alike make up a soil series. Their major horizons are similar in thickness, arrangement, and other important characteristics. Each soil series is named for a town or other geographic feature near where a soil of the series was first mapped. For example, Baxter and Clarksville are the names of two soil series.

A soil series can be divided into phases based on differences in texture of the surface soil and in slope, stoniness, and some other characteristic that affects the use of soils by man. For example, Clarksville stony silt loam, 5–20% slopes, is one phase within the Clarksville Series (Cole, 1970, p. 1–2).

Soil scientists also map soil associations, that is, two or more distinguishable soils that occur together in a characteristic pattern in a given geographic area. A soil association normally consists of one or more major named soils and at least one minor named soil (Cole, 1970, p. 2). A map of soil associations provides a general picture of soils in an area and can be helpful in locating tracts of land suitable for certain kinds of use.

The General Soil Map for Cherokee and Delaware Counties (Cole, 1970) shows three soil associations in the study area. Sallisaw-Elsah-Staser soils are deep, gravelly or loamy soils on flood plains and benches. These soils occur on the flood plains and terraces of Clear Creek, of the south fork of Clear Creek, and of Little Clear Creek. Clarksville-Baxter-Locust soils are deep, stony and cherty, very gently sloping to steep soils on timbered uplands. These soils are present within and adjacent to the proposed landfill site. Baxter-Locust soils are deep, cherty, and loamy, nearly level to gently sloping soils on timbered uplands. These soils occur between drainages at higher elevations north and east of the proposed site.

Only five named soils occur in the immediate vicinity of the proposed landfill site (Cole, 1970, sheet 73):

1. The Sallisaw soils, which are nearly level to sloping, occur on benches along Clear Creek and along the south fork of Clear Creek. These soils have a surface layer of dark brown, gravelly silt loam and a subsoil of strong brown, gravelly silty clay loam (Cole, 1970, p. 2).
2. The Elsah soils, which are nearly level, occur on flood plains of Clear Creek and the south fork of Clear Creek and are flooded frequently. They have a surface layer of dark brown, very gravelly loam. The subsoil is dark grayish brown, very gravelly loam that is 60–90% gravel, by volume (Cole, 1970, p. 2).
3. The Staser soils, which are nearly level to very gently sloping, also occur on the flood plains of Clear Creek and the south fork of Clear Creek and are subject to occasional flooding. They have a surface layer of very dark, grayish brown, gravelly loam. The subsoil is a dark brown, gravelly loam that is 15–35% gravel, by volume (Cole, 1970, p. 3).
4. The Clarksville soils include the Clarksville silty loam (20–50% slopes), which occurs in hollows, and the Clarksville very cherty silt loam (1–8% slopes), which occurs in upland areas above the hollows. The Clarksville soils have a surface layer of dark grayish brown, stony silt loam and a subsoil of strong brown, very stony silty clay loam.
5. The Baxter soils (very gently to gently sloping) occur in upland areas north and east of the proposed landfill site. They have a dark grayish brown surface layer of cherty silt loam. The subsoil is yellowish red, cherty silty clay loam; the percentage of chert in the subsoil increases with increasing depth (Cole, 1970, p. 5).

The Locust soil does not occur in the immediate vicinity of the proposed landfill site.

Engineering Properties of Soils in the Study Area

Engineers are particularly interested in those soil properties that affect the construction and maintenance of manmade structures. Table 1, modified from tables 4 and 5 in Cole (1970), provides estimates of engineering properties of soils in the study area. Only those properties considered to be pertinent to this study—such as texture, permeability, and depth to bedrock—are included in the table.

The table is useful for evaluating the various soil series to determine their suitability or unsuitability in environmentally sensitive areas where excavations may be made. The properties listed are also useful for determining suitability of the soils for constructing embankments or for use as fill material. Permeability of the soils at the surface, as well as permeability at various depths, are the most critical properties to be considered in the construction and maintenance of manmade structures where water movement is a factor.

Formation of Soils in the Study Area

Five major factors affect the formation of a soil and determine its characteristics: (1) the physical and mineralogical

TABLE 1. — SELECTED ESTIMATED[a] ENGINEERING PROPERTIES AND ENGINEERING INTERPRETATIONS OF SOILS IN THE VICINITY OF THE PROPOSED LANDFILL (modified from Cole, 1970, tables 4,5)

Soil series	Depth to solid bedrock (inches)	Depth from surface of typical profile (inches)	USDA texture[b]	Permeability[c] (least permeable layer) (inches per hour)	Soil features affecting farm ponds: Impounding water in reservoir area	Soil features affecting farm ponds: Embankment
Baxter	>7	0–9	Silt loam or cherty silt loam	0.20–0.63	Chert beds locally below depth of 3 ft; may leak	Features favorable
		0–22	Silty clay loam to cherty silty clay loam			
		22–34	Cherty clay			
		34–60	Very cherty clay			
Clarksville	>72	0–10	Stony silt loam or very cherty silt loam	6.3–10.0	Chert beds below depth of 2 ft are permeable[d]	Material over chert beds limited
		10–40	Very stony silty clay loam			
		40–60	Mostly chert beds			
Elsah	>72	0–60	Very gravelly loam	6.3–20.0	Very permeable	Very permeable
Sallisaw	>72	0–18	Silt loam or gravelly silt loam	0.63–2.0	Permeable at lower depths[d]	Features favorable
		18–32	Silty clay loam to gravelly silty clay loam			
		32–63	Very gravelly silty clay loam			
Staser	>72	0–24	Silt loam or gravelly loam	2.0–6.3	Permeable at lower depths	Features favorable
		24–43	Silt loam or gravelly silt loam			
		43–60	Very gravelly loam			

[a]Estimates are based on field classification, the descriptions of the soils, data from laboratory tests of selected samples, test data from comparable soils in adjacent areas, and experience in working with the individual kind of soil in the survey area (Cole, 1970, p. 55).

[b]The U.S. Department of Agriculture defines texture as the proportion of sand, silt, and clay in soil material. The basic textural classes, in order of increasing proportion of fine particles, are sand, loamy sand, sandy loam, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sand clay, silty clay, and clay (Cole, 1970, p. 64, 74).

[c]Permeability relates only to movement of water downward through undisturbed and uncompacted soil. It does not include lateral seepage. The estimates are based on structure and porosity of the soil. Plowpans, surface crusts, and other properties resulting from use of the soils are not considered (Cole, 1970, p. 65).

[d]Detailed onsite investigation is essential because in many places substratum is too permeable to hold water.

composition of the parent material; (2) the climate under which the soil material has accumulated; (3) the plant and animal life in and on the soil; (4) the relief, or lay of the land; and (5) time.

Parent Material

Parent material is weathered, unconsolidated rock or mineral matter from which a soil develops. The two general kinds of parent material in the study area are residuum (unconsolidated, partly weathered mineral material that accumulates over disintegrating solid rock) and alluvium (soil material deposited on land by streams).

The Baxter and Clarksville soils developed from residuum derived from the cherts and limestones of the Mississippian Boone Formation. They have cherty to silty, clay-enriched horizons (Cole, 1970, p. 67). The Elsah, Sallisaw, and Staser soils developed from Quaternary-age, loamy alluvial deposits on flood plains and benches. See Table 1 for the engineering properties of these soils.

Climate

The climate of the study area is temperate and humid. The average annual rainfall of ~43 in. is generally well distributed throughout the year, but dry periods of 2–6 weeks occur during the summer. Intense rains commonly occur during spring and cause soil loss through erosion on most slopes (Cole, 1970, p. 67).

Temperature extremes range from >90°F to <0°F. Freezing and thawing have altered the rock structure, especially in the upper 2 ft of soils that have developed in cherty limestone material (Cole, 1970, p. 67).

Plant and Animal Life

Plants and animals are active in soil formation. Plants grow in weathered parent material and help break down rock structure. They contribute organic matter to soils and produce much of the O_2 and CO_2 involved in chemical weathering reactions. The kind and amount of vegetation in the study area regulate the thickness of the various soil horizons (Cole, 1970, p. 67). The kind of vegetation depends on the moisture supply and on the texture and acidity of the surface layer (Cole, 1970, p. 67).

Organisms, such as burrowing animals, ants, and earthworms, can affect the weathering rate of rocks and minerals by physically increasing their exposure to chemical weathering agents (Chernicoff and Venkatakrishnan, 1995, p. 134).

Relief

Relief influences soil development and horizon formation. Physical features of a landscape, such as hills and valleys and the steepness of slopes, influence the availability of water and other weathering factors, as well as the rate of soil accumulation. For example, steep slopes, such as those present in parts of the study area, allow rainfall to flow away swiftly; therefore, little or no soil develops there. Any soil that develops on steep slopes is removed almost as fast as it forms and is transported downhill to lowland valleys. In low-lying areas, or in nearly level upland areas, water accumulates and readily infiltrates the ground (Chernicoff and Venkatakrishnan, 1995, p. 140).

Time

There is a direct relationship between time and the effects of soil-forming factors. The longer a rock or sediment is exposed to weathering, the more it will decompose. The soils in the study area range from immature to old. Their age is indicated by their degree of development. Sallisaw, Staser, and Elsah soils are alluvial and immature. Clarksville and Baxter soils are old soils developed from cherty limestones. They have considerable chert in the upper horizons; lower horizons are deeply weathered (Cole, 1970, p. 68).

GROUND WATER

Ground water is water, beneath the land surface, that is contained in pore spaces within bedrock and regolith (the layer of fragmented, unconsolidated rock material that overlies bedrock and nearly everywhere forms the surface of the land) (Longwell and others, 1969, p. 234). Figure 5 shows the positions of the zone of saturation (the subsurface zone in which all openings are filled with water), the water table (the upper surface of the zone of saturation), and the zone of aeration (the zone in which open spaces in regolith or bedrock are normally filled mainly with air).

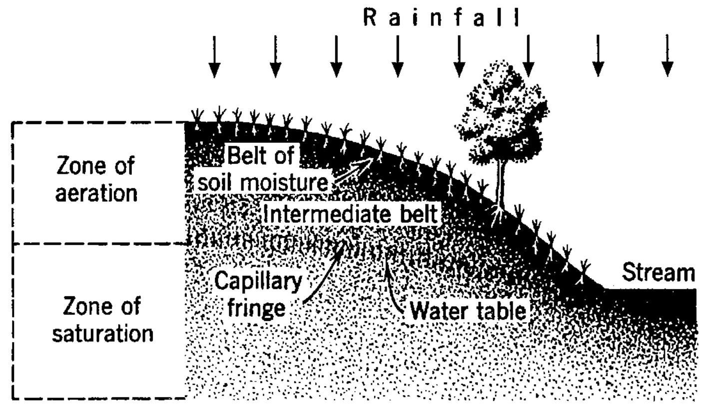


Figure 5. The positions of the zone of saturation, the water table, and the zone of aeration (which includes the belt of soil moisture, the intermediate belt, and the capillary fringe) (from Longwell and others, 1969, fig. 11-1). See the text for discussion.

Ground-Water Flow

Most of the ground water near the earth's surface flows. Responding to the force of gravity, the ground water tends to seek the lowest level. Water moves readily through porous material that has the capacity for transmitting fluids (permeability). Water from rain infiltrates the soil, then "drips" downward in the zone of aeration until it reaches the zone of saturation. In the zone of saturation, the flow of ground water is laminar. Laminar flow through interconnected spaces in saturated material is called percolation. Ground water percolates from areas with higher (relative) water tables to those with lower water tables (Fig. 6), and it can emerge as springs along streams.

Aquifers in the Study Area

"Aquifer" is the name that geologists and hydrologists give to a body of permeable rock or regolith through which ground water moves. Good aquifers, such as gravels, are those that have the most and largest interconnected spaces. In addition, bodies of rock or soil material that appear to be essentially impermeable in small hand samples may also be aquifers because they contain fissures, fractures, spaces between layers, and other openings (Fig. 7A,B). Dissolution along joints in rocks such as limestone can create openings that make the rock an aquifer. Fractures in chert can make the rock highly permeable and, hence, a good aquifer. Alluvial gravels consisting mainly of transported chert clasts commonly are good aquifers.

Marcher and Bingham (1971, sheet 2) show two units that are favorable for developing ground-water supplies within the area of the proposed landfill site: (1) Alluvium and terrace deposits and (2) the Keokuk and Reed Springs Formation and St. Joe Group (undifferentiated and collectively termed the Boone Formation in this report), also commonly called the "Boone chert." Both are shown as shallow aquifers.

According to Marcher and Bingham (1971, sheet 2), aquifers associated with minor streams can be "as much as 25 ft thick and consist of coarse sand and gravel. Where these deposits are 10 ft or more thick and are adjacent to perennial

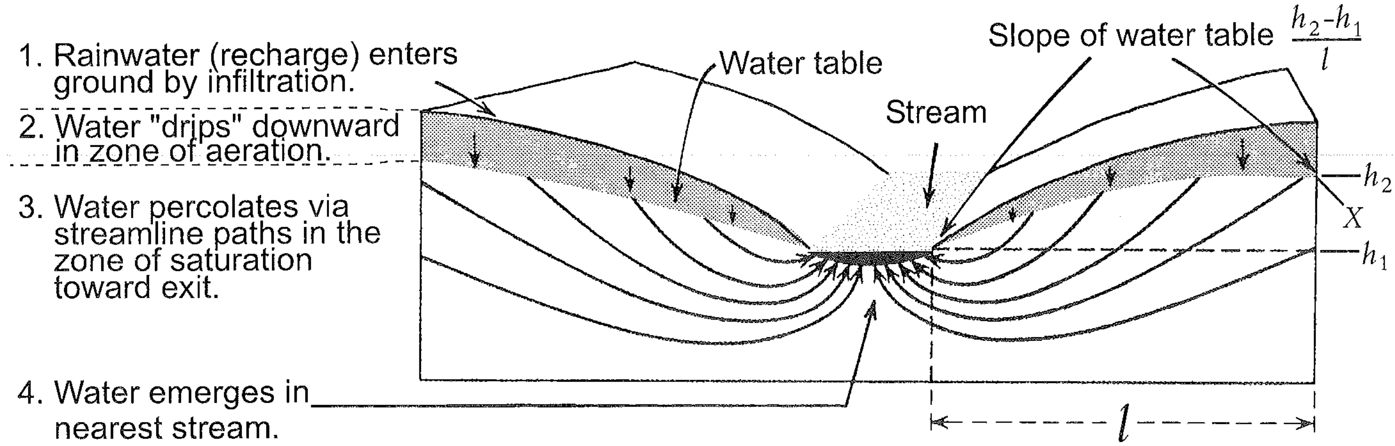


Figure 6. Movement of ground water in uniformly permeable material. The long curved arrows represent only a few of many possible subparallel paths. At any point, such as X, the slope of the water table is expressed by $\frac{h_2-h_1}{l}$ where $h_2 - h_1$ is the height of X above the point of emergence in the surface stream and l is the distance from X to the point of emergence (modified from Hubbert, 1940).

streams, yields of several hundred gallons per minute probably could be obtained from infiltration galleries."

The "Boone chert" consists of fractured massive chert with beds of cherty limestone and is a dependable source of water throughout most of its area of outcrop; it is the source of numerous springs (Marcher and Bingham, 1971, sheet 2). Measurements of one spring in the study area (NE¼ sec. 18., T. 18 N., R. 21 E.), show an estimated yield of 20 gal/min (yield data obtained in 1968) (Marcher and Bingham, 1971, sheet 2).

Marcher and Bingham (1971, sheet 3) show that the chemical quality of the water from the "Boone chert" in the study area is generally good: (1) Hardness is the most troublesome chemical characteristic; water is of the calcium-bicarbonate type. (2) Sulfate, chloride, and nitrate contents are generally low, and water-quality diagrams for ground water in the vicinity of the study area show total dissolved solids of 107 mg/L. There have been no analyses of the chemical quality of water from alluvial aquifers in the study area.

Karstification

Ground water creates caverns and sinkholes in carbonate rocks by dissolution and, in some regions, forms a peculiar topography called "karst topography." Dissolution by meteoric water (rain) is a postdepositional process in carbonates and occurs in the telogenetic zone—the near-surface zone that develops when long-buried carbonates are uncovered by erosion and subjected to porosity-forming processes (Choquette and Pray, 1970, p. 220) (Fig. 8).

Figure 9 illustrates telogenetic effects of weathering and erosional processes following uplift of formerly buried rocks. Note that dissolution enlargement of joints is greatest at depths of about 50–300 ft. Choquette and Pray (1970, p. 244) use the terms "cavern porosity" and "fracture-breccia porosity" to describe, respectively, openings of dissolution origin and those formed by postdepositional fracturing of sediment or rock.

Figure 10 shows karst features, the location of springs, and flow lines (probable directions of ground-water movement) in the study area.

GENERAL DISCUSSION AND SUMMARY

The previous part of this report has been devoted largely to a general overview of rock and soil types in the study area, as well as to an introduction to ground water, its movements, and its effect on certain rock types. How this information applies to the proposed landfill site follows.

The proposed Clear Creek landfill site is in an unnamed hollow in the NW¼ sec. 7, T. 18 N., R. 21 E., Cherokee County. Soils in the hollow are predominantly Clarksville silty loams. The Clarksville very cherty silt loam occurs in upland areas adjacent to the hollow. The Clarksville soils have a surface layer of dark grayish brown, stony silt loam and a subsoil of strong brown, very stony silty clay loam. The area surrounding the hollow is wooded, mostly by oak, but other hardwoods and brush are interspersed. Figure 11 is part of an aerial photograph showing the proposed landfill site.

The area within a 2-mi radius of the study site is underlain by only two mappable geologic units: Mississippian Boone Formation (interbedded limestone and chert) and Quaternary alluvium and terrace deposits (undifferentiated). Both units

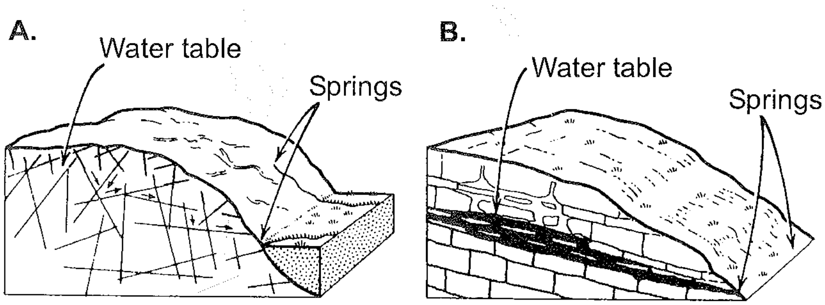


Figure 7. Common locations of aquifers and gravity springs, in (A) fractured rock, such as chert, and (B) cavernous rock, such as limestone (modified from Longwell and others, 1969, fig. 11-7).

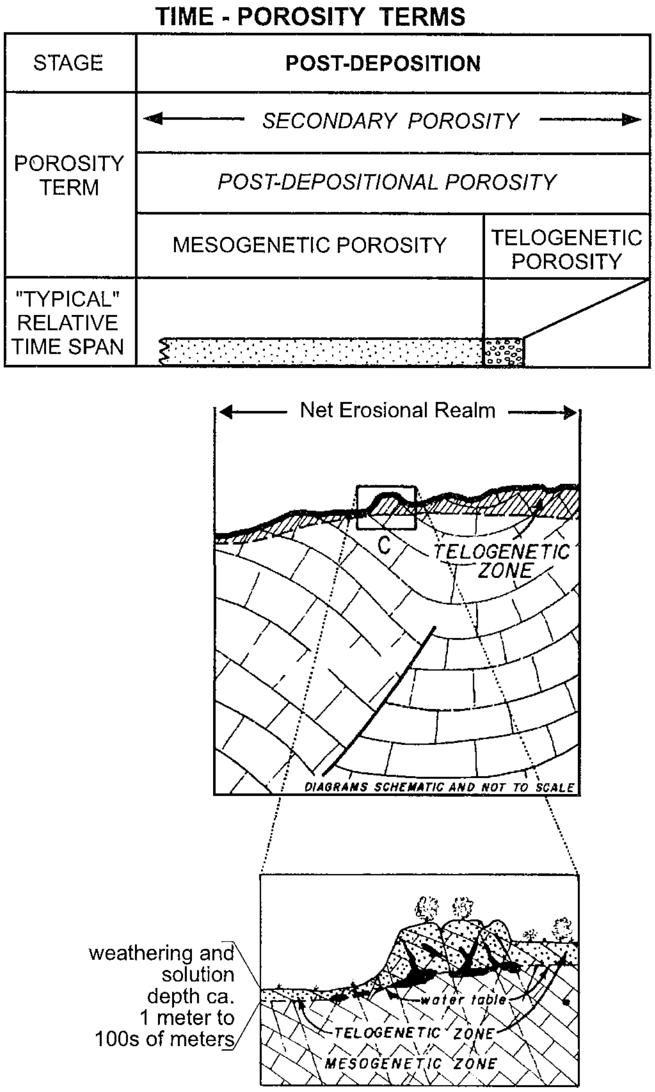


Figure 8. Time-porosity terms and zones in sedimentary carbonates where porosity is created and modified (modified from Choquette and Pray, 1970, fig. 1).

are shallow aquifers. Except for rare exposures in bluffs along hollows, or in bluffs along Clear Creek, unweathered (that is, unfragmented) Boone Formation is not observable. The soil and rubble that covers most of the Boone outcrop in the study area gives the impression that the Boone is 90% chert. Except for scattered ledges (Fig. 12) and outcrops in the bottom of drainages, the Boone in the study area occurs as residual concentrations of cobble-size, angular chert. However, drilling records show that, in the subsurface, the Boone actually consists of 63.5% limestone and only 36.5% chert (K. G. Robinson, Hidden Valley Industries, unpublished data, 1996). Alluvium in the area consists of transported material that is similar to the residuum from the Boone. It is of the Sallisaw-Elsah-Staser soil association and is commonly covered by grass.

The topographic expression of the elongate, dome-like hill that dominates sec. 7, T. 18 N., R. 21 E., as well as the drainage pattern of creeks surrounding it, strongly suggest that the hill is an anticline. Unfortunately, there are too few rock outcrops suitable for recording strikes and dips to confirm the impression.

The study area is within a moist region. In such areas, rainwater falling on high areas is added to the zone of saturation and flows, under the force of gravity along a pressure gradient, down into valleys until it emerges as a spring at a point where the pressure is least (Figs. 5–7). Such groundwater flow in the study area can be shown by superimposing flow lines on a topographic map (Fig. 10). The flow lines show ground-water movement from the high point (elevation ~960 ft near the crest of the dome-like hill) downward into low areas on all sides of the feature. Springs were observed in numerous places within the study area even though drought had prevailed for more than six weeks immediately preceding the study. Many springs emerge from the toes of alluvial fans at the feet of hollows, where the fans merge with the flood plain of Clear Creek (Fig. 13A,B). One spring was observed in the V-shaped floor of the proposed landfill site (Fig. 14).

The floor of the proposed landfill site has a thin accumulation of broken chert overlying rare exposures of bedrock in its upper and middle reaches. A widening of the hollow, which contains cherty alluvium ~10 ft thick, occurs in its lower part (K. G. Robinson, Hidden Valley Industries, unpublished data [no. 14 well log]). The steep walls of the hollow are tree covered and consist of soil, chert clasts that are angular and weathered, and rare ledges of cherty limestone (Fig. 15). Outcrops of noncherty limestone (even more rare) are present in the lower part of the hollow (Fig. 16). The upland areas also are covered by soil that contains numerous residual chert fragments. An uprooted tree shows soil characteristics in the 2 ft just below the surface in the upland area adjacent to Hidden Valley (Fig. 17). As the slope increases, just above the walls of the hollow, chert becomes so concentrated that the clasts nearly cover the ground (Fig. 18). The closely spaced fractures (0.5–3 in. apart) in the chert explain the abundance of chert clasts in the area. Where observed, the chert in outcrop is intensely fractured in all directions—often with a curvilinear pattern (Figs. 12, 15).

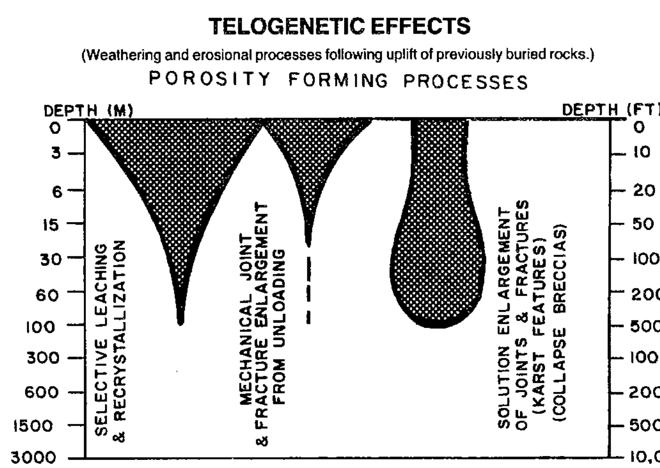


Figure 9. Telogenetic effects of major processes that form porosity during weathering and erosion. The width of field indicates the relative importance. The diagram is highly subjective (modified from Derby, 1983, fig. 8A).

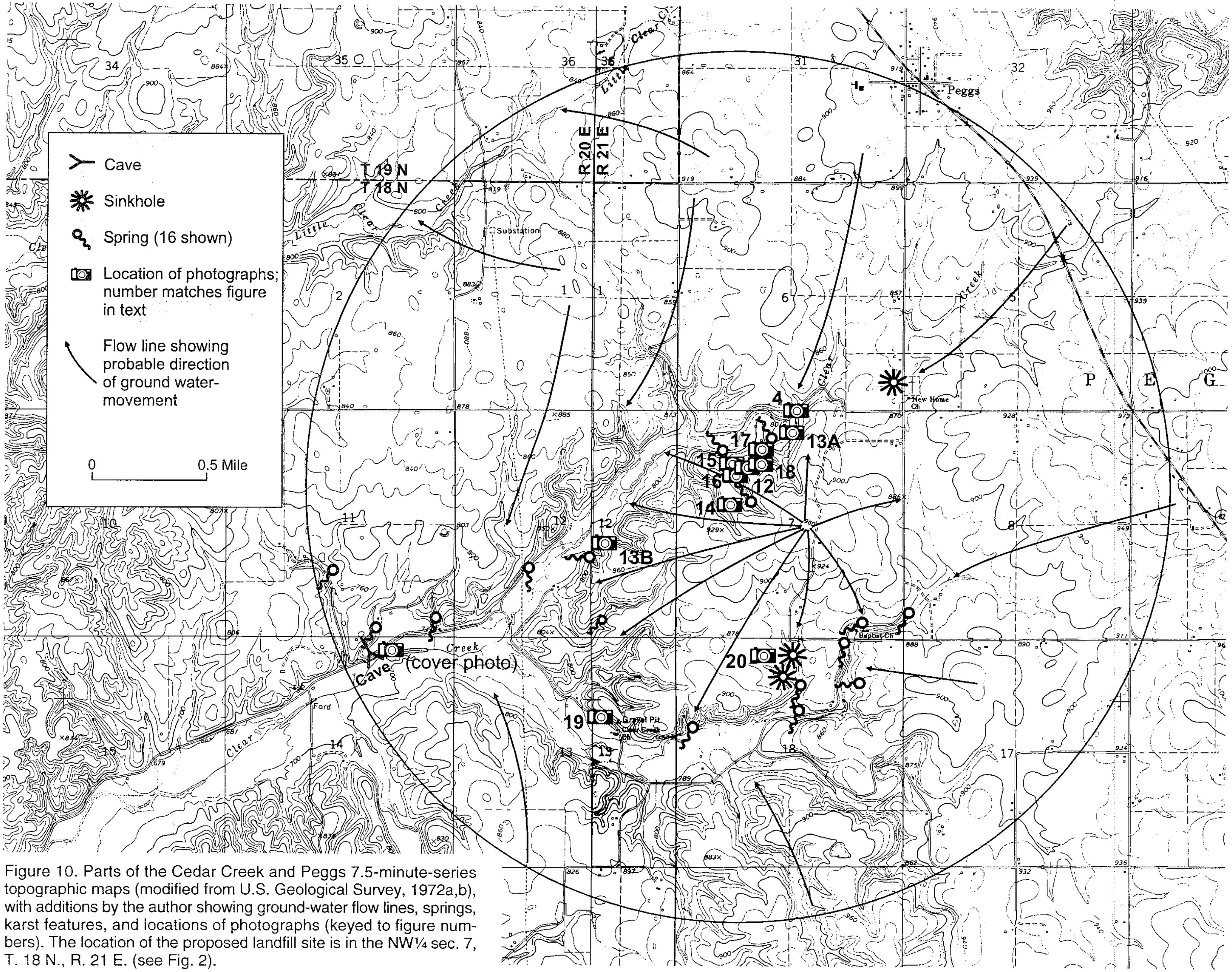


Figure 10. Parts of the Cedar Creek and Peggs 7.5-minute-series topographic maps (modified from U.S. Geological Survey, 1972a,b), with additions by the author showing ground-water flow lines, springs, karst features, and locations of photographs (keyed to figure numbers). The location of the proposed landfill site is in the NW¼ sec. 7, T. 18 N., R. 21 E. (see Fig. 2).

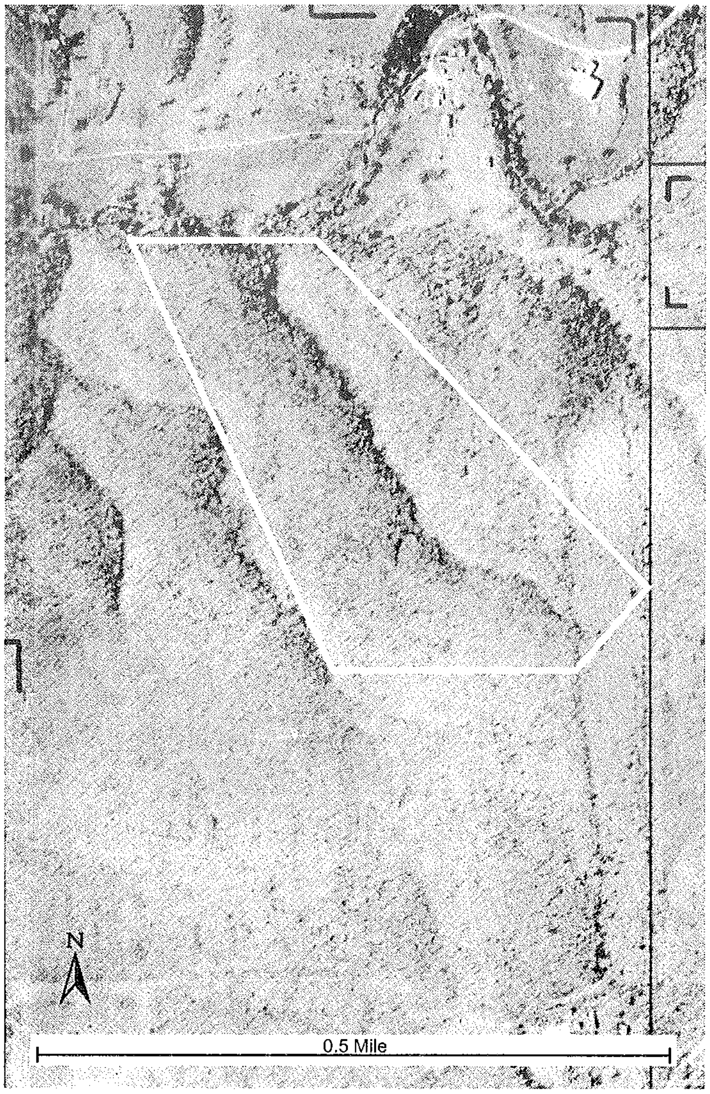


Figure 11. Excerpt from a 1990 aerial photograph showing the area of the proposed landfill site (outlined in white) in the NW¼ sec. 7, T. 18 N., R. 21 E., Cherokee County (photograph courtesy of U.S. Department of Agriculture).

Figure 13. *A*—Spring at the edge of Clear Creek. Water emerges (under fallen tree) from the toe of an alluvial fan at the mouth of an unnamed hollow. Note that upstream from the spring the chert-littered bed of Clear Creek (bottom middle of photograph) is dry. (The location of the photograph is shown on Fig. 10.) *B*—Man pointing to another spring, where the toe of an alluvial fan (at the mouth of a different unnamed hollow) merges with the flood plain of Clear Creek. Note the lush vegetation surrounding the spring. A perennial slough, 20–30 yds wide and ~250 yds long, extends downstream from the spring. (The location of the photograph is shown on Fig. 10.)

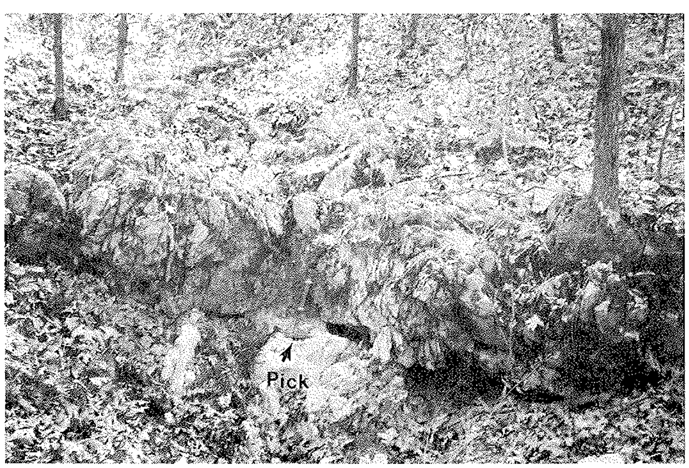


Figure 12. Ledge of fractured Boone chert in a gully joining Hidden Valley from the east. Geologic pick for scale. (The location of the photograph is shown on Fig. 10.)

Figure 14. Spring in the floor of Hidden Valley (at the end of the handle of the geologic pick). Note the lush vegetation below the spring. Geologic pick for scale. (The location of the photograph is shown on Fig. 10.)

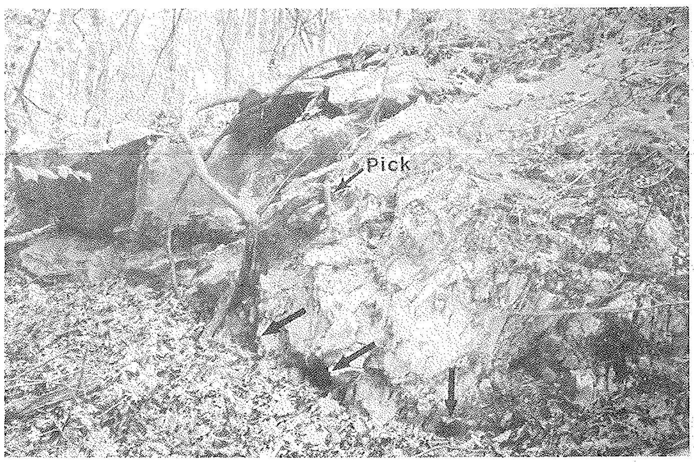


Figure 15. Ledge at the edge of Hidden Valley showing a jointed limestone facies of the Boone Formation in contact with a highly fractured chert mass (right side of photograph). The geologic pick in the center of the photograph marks the contact. Small tunnels (diameters, 4 in.), indicated by arrows, extend for an unknown distance into the chert mass. The tunnels probably were formed by piping as ground water moved through fractures in the chert. (The location of the photograph is shown on Fig. 10.)

Figure 16. Limestone ledge at the edge of Hidden Valley. The limestone is crinoidal and finely crystalline. The geologic pick rests on a bedding plane at the top of a joint surface. Bedding planes and joints contribute to permeability in the Boone Formation. (The location of the photograph is shown in Fig. 10.)

Depth of weathering is variable, depending on slope, but where the Boone chert is totally brecciated in a road cut just northwest of Clear Creek Church, at least 10 ft of weathered material can be observed (Fig. 19). No limestone is observable in the cut.

One cave (cover photograph; Fig. 10)—formed by mechanical piping and dissolution in fractured, interbedded limestone and chert—and three small, shallow sinkholes (Fig. 10; one shown in Fig. 20) were observed in the study area, which indicates that karstification has occurred and is still occurring in the area.

Figure 17. Soil trapped in the root ball of an uprooted tree in the highland area just east of Hidden Valley. Note the chert residuum present in the soil. (The location of the photograph is shown on Fig. 10.)

Figure 18. Concentration of chert residuum at the break in slope above the walls of the hollow, just east of Hidden Valley. (The location of the photograph is shown on Fig. 10.)

Figure 19. A 10-ft-thick horizon of moderate orange pink, silty clay and brecciated chert exposed in a road cut in a steep slope above the south fork of Clear Creek. The relationships of the materials in the exposure indicate that downslope creep is occurring. (The location of the photograph is shown on Fig. 10.)

Figure 20. Sinkhole in the Boone Formation. The sinkhole is ~3.5 ft in diameter and ~2.2 ft in depth. The pick head rests on the floor of the sinkhole. There is a second sinkhole of similar size ~50 yds to the northeast. (The location of the photograph is shown on Fig. 10.)

CONCLUSIONS

Although porosity percentage has not been determined, it is apparent that fracture and breccia porosity dominate the telogenetic (near-surface) zone and that high permeability is a property of the Boone Formation as well as of the gravelly Quaternary alluvial deposits in the study area. Thus, rain water readily infiltrates the soils and percolates downward into the aquifers, potentially carrying with it surface contaminants. Water that moves laterally through bedrock fractures emerges in the nearest stream, or as surface springs where it encounters the water table (Figs. 6, 7). Many of these springs are adjacent to the Clear Creek flood plain and discharge into Clear Creek. Runoff from heavy rainfall also moves downslope and into the Clear Creek drainage.

Apparently, consideration of Hidden Valley for use as a landfill site became a dead issue when Governor Frank Keating signed House Bill 2720 on May 15, 2000. The bill prohibits landfills above formations of fractured limestone and within 5 mi of drinking water intake sources.

REFERENCES CITED

Chenoweth, P. A. (ed.), 1983, Principal structural features of Oklahoma: PennWell Publishing Company, Tulsa, 1 sheet, scale 1 in.:~8 mi.

Chernicoff, Stanley; and Venkatakrishnan, Ramesh, 1995, Geology—an introduction to physical geology: Worth Publishers, New York, 593 p.

Choquette, P. W.; and Pray, L. C., 1970, Geologic nomenclature and classification of porosity in sedimentary carbonates: American Association of Petroleum Geologists Bulletin 54, p. 207–250.

Cole, E. L., 1970, Soil survey of Cherokee and Delaware Counties, Oklahoma: U.S. Department of Agriculture Soil Conservation Service in cooperation with the Oklahoma Agricultural Experiment Station, U.S. Government Printing Office, 74 p., 122 sheets, scale 1:20,000; General Soil Map (in pocket), scale 1:126,720.

Derby, J. R., 1984, Exploration for carbonate reservoirs, or "Just find a fat limestone with holes in it," *in* Hyne, N. J. (ed.), Limestones of the Mid-Continent: Tulsa Geological Society, p. 1–24.

Hubbert, M. K., 1940, The theory of ground-water motion: Journal of Geology, v. 48, p. 785–944.

Huffman, G. G., 1958, Geology of the flanks of the Ozark uplift, northeastern Oklahoma: Oklahoma Geological Survey Bulletin 77, 281 p., 6 pl.

Jackson, J. A. (ed.), 1997, Glossary of geology (4th edition): American Geological Institute, Alexandria, Virginia, 769 p.

Johnson, K. S.; Amsden, T. W.; Denison, R. E., Dutton, S. P.; Goldstein, A. G.; Rascoe, Bailey, Jr.; Sutherland, P. K.; and Thompson, D. M., 1989, Geology of the southern Midcontinent: Oklahoma Geological Survey Special Publication 89-2, 53 p.

Longwell, C. R.; Flint, R. F.; and Sanders, J. E., 1969, Physical geology: John Wiley and Sons, Inc., New York, 685 p.

Marcher, M. V.; and Bingham, R. H., 1971, Reconnaissance of the water resources of the Tulsa quadrangle, northeastern Oklahoma: Oklahoma Geological Survey Hydrologic Atlas 2, scale 1:250,000, 4 sheets.

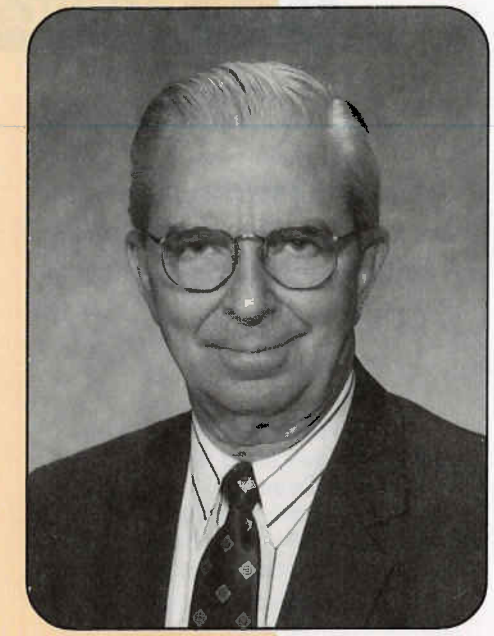
McKnight, E. T.; and Fischer, R. P., 1970, Geology and ore deposits of the Picher field, Oklahoma and Kansas: U.S. Geological Survey Professional Paper 588, 165 p.

Simonds, F. W., 1891, The geology of Washington County: Arkansas Geological Survey Annual Report for 1888, v. 4, 148 p.

Sutherland, P. K.; and Manger, W. L. (eds.), 1979, Mississippian-Pennsylvanian shelf-to-basin transition, Ozark and Ouachita regions, Oklahoma and Arkansas: Oklahoma Geological Survey Guidebook 19, 81 p.

U.S. Geological Survey, 1972a, Cedar Crest, Oklahoma, 7.5-minute-series topographic map: U.S. Geological Survey, 1 sheet, scale 1:24,000.

_______ 1972b, Peggs, Oklahoma, 7.5-minute-series topographic map: U.S. Geological Survey, 1 sheet, scale 1:24,000.



Charles J. Mankin

Mankin named new Energy Center director

Dr. Charles J. Mankin, director of the Oklahoma Geological Survey since 1967, has added an additional assignment to his activities at the University of Oklahoma. Mankin was named director of the Sarkeys Energy Center by the OU Board of Regents at their October meeting, and he officially assumed the office on November 1.

"Charles Mankin is nationally and internationally respected by both government and private sector leaders in the energy field," OU President David Boren said, noting Mankin's years of experience as an OU faculty member and OGS director. "Given his unparalleled knowledge of the entire history of the Sarkeys Energy Center and a clear understanding of its mission, Charles Mankin is the best possible person to provide leadership for the Energy Center as it moves to an even higher level of performance."

The mission of the Sarkeys Energy Center is to foster world-class interdisciplinary energy research and education and, through various means of technology transfer, strengthen and enhance regional economic growth as well as national energy and economic security. The Energy Center programs include six interdisciplinary institutes and a special institute that focuses on the Western Hemisphere. These institutes incorporate faculty from the colleges of Geosciences, Arts and Sciences, Law, Business, and Engineering to develop programs and technology that advance the energy industry in the State and throughout the world.

"The Sarkeys Energy Center was created to promote interaction among the University of Oklahoma, industry, and government to address issues relating to energy," Mankin says. "Institutes have been created in the Center to examine high priority areas of mutual interest. Our goal is to have the Center be the first point of contact for those seeking answers to energy issues."

new OGS publication

CIRCULAR 103

Marine Clastics in the Southern Midcontinent, 1997 Symposium

• *edited by* Kenneth S. Johnson
• 210 pages
• Paperbound, laminated cover
• $13

OGS Circular 103 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 $2 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; e-mail: ogssales@ou.edu.

Request the 2000–2001 OGS *List of Available Publications* for current listings and prices.

Contained in this volume are papers dealing with the search for, and production of, oil and gas resources from marine clastics of the southern Midcontinent. The research focuses on sandstones and other clastic rocks deposited in shallow- or deep-water marine environments. These clastics are major sources of oil and gas in the southern Midcontinent, and they have great potential for additional recovery using advanced technologies.

The 32 papers and abstracts in this book concentrate on geology, depositional settings, diagenetic history, reservoir sequence stratigraphy characterization, exploration, petroleum production, and enhanced oil recovery. The research originally was presented at a two-day workshop held in March 1997 in Norman, Oklahoma, cosponsored by the OGS and the National Petroleum Technology Office of the U.S. Department of Energy. The meeting drew more than 200 representatives from industry, government, and academia. In describing these marine clastics and their petroleum reservoirs, the researchers involved in this meeting increased our understanding of how the geologic history of an area can affect reservoir heterogeneity and the ability to efficiently recover hydrocarbons.

Among the reservoirs discussed are: Simpson Group, Jackfork Group, Morrow sands, Springer sands, Atoka Formation, Spiro sandstone, Bartlesville Sandstone, Red Fork Sandstone, and a number of other marine clastics reservoirs. As oil prices have increased recently, a greater interest in drilling in the State makes these papers a valuable resource for explorationists and operators in Oklahoma.

OU School of Geology names new director

Roger M. Slatt

Roger M. Slatt, formerly head of the Department of Geology and Geological Engineering at the Colorado School of Mines, has been selected to lead the University of Oklahoma School of Geology and Geophysics into its second hundred years.

After receiving his doctorate from the University of Alaska in 1970, Slatt taught geology for eight years at Memorial University of Newfoundland and Arizona State University. He spent the next 14 years in the petroleum industry, working for ARCO Research, ARCO International Oil and Gas Company, and Cities Service Research before joining the Colorado School of Mines in 1992. For the past five years, he also served as director of the Rocky Mountain Region Petroleum Technology Transfer Council.

Slatt has authored more than 90 academic papers and presentations on the subjects of petroleum geology, reservoir geology, seismic sequence stratigraphy, shallow marine and turbidite depositional systems, geology of shale, glacial and Pleistocene-Quaternary geology, and geochemical exploration.

A longstanding member of the American Association of Petroleum Geologists and the Society of Sedimentary Geology, Slatt was honored in 1996 with the AAPG's Distinguished Service Award.

OU's School of Geology and Geophysics has been a leader in the earth sciences since 1900, when Charles Gould founded the department of geology. As a result of the pioneering efforts of Gould and other faculty, OU gained recognition in the field of petroleum geology. Since that time, the school has graduated more than 5,000 practicing geologists and geophysicists, many of whom have become executives or research scientists in some of the industry's leading companies.

upcoming meetings

MARCH 2001

National Earth Science Teachers Association, annual meeting, March 22–25, 2001, St. Louis, Missouri. Information: NESTA, 2000 Florida Ave., N.W., Washington, DC 20009; (202) 462-6910, fax 202-328-0566; e-mail: fireton@kosmos.agu.org. Web site: http://www.

Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, March 26–31, 2001. Information: Buddy Poe, University of Missouri—Rolla, 103 ME Annex, Rolla, MO 65409; (573) 341-6061, fax 573-341-4992; e-mail: buddyp@umr.edu.

APRIL 2001

Offshore Technology Conference, April 30–May 3, 2001, Houston, Texas. Information: Society of Petroleum Engineers, P.O. Box 833836, Richardson, TX 75083; (972) 952-9393, fax (972) 952-9435. Web site: http://www.spe.org.

MAY 2001

Revisiting Old and Assessing New Petroleum Plays in the Southern Midcontinent, Oklahoma City, Oklahoma, May 8–9, 2001. Information: Brian Cardott, Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019; (405) 325-3031 or (800) 330-3996 ; fax 405-325-7069; e-mail: bcardott@ou.edu.

JUNE 2001

American Association of Petroleum Geologists, annual meeting, June 3–6, 2001, Denver, Colorado. Information: AAPG, 1444 S. Boulder Ave., Box 979, Tulsa, OK 74101; (800) 364-2274 or (918) 560-2679, fax 800-281-2283 or 918-560-2684. Web site: http://www.

Society for Sedimentary Geology National Convention, June 3–6, 2001, Denver, Colorado. Information: SEPM, 1731 E. 71st St., Tulsa, OK 74136; (918) 493-3361. Web site: http://www.sepm.org.

Springer Formation workshop and field trip set for April

The Oklahoma Geological Survey, in cooperation with the Petroleum Technology Transfer Council, will present a one-day workshop on the Springer gas play in western Oklahoma. The workshop will be held at the Moore-Norman Technology Center, 4701 12th Ave., NW, in Norman. Participants will have a choice of attending Wednesday, April 4, or Thursday, April 5.

A companion one-day field trip will run on Tuesday, April 10, and Wednesday, April 11, based out of Ardmore. The field trip is formatted to show surface to subsurface correlations in regard to reservoir quality, log characteristics, and interpretation of depositional environments. The field trip will be led by LeRoy Hemish, a retired OGS geologist, with assistance from Rick Andrews, principal presenter of the workshop.

The workshop is structured to assist in the regional understanding of the Springer, including discussion of stratigraphic nomenclature as used at the outcrop and projected throughout the Anadarko and Ardmore basins. The workshop and accompanying publication will review regional mapping of the various Springer sandstone zones (including the Cunningham, Britt, and Boatwright), in addition to the equivalent carbonate deposits in northwest Oklahoma and the Panhandle. Other regional work included in this study are shelf-to-basin cross sections, a map showing fields with production from the Springer, a Springer structure map, and a production allocation map based on current stratigraphic interpretations by Geological Data Services (data acquired from IHS Energy Group).

Additionally, the workshop includes three field studies that represent typical Springer gas reservoirs and their geology, depositional environment, production characteristics, and engineering parameters. Two of these studies pertain to the traditional marine sandstone reservoirs, while the third pertains to the Springer Britt and Boatwright carbonates that often are referred to as "Chester."

Guest speakers will provide information on the Springer regarding drilling and completion practices of Springer wells in the Anadarko basin. In addition, the speakers will participate in discussions of the hotly pursued Springer plays along the Mountain View fault, where it is overturned, and in the Cement area.

The companion field trip will present information on selected sandstone units in the Springer Formation, which straddles the Mississippian-Pennsylvanian boundary, and units in the lower Golf Course Formation (Morrow equivalent of the Pennsylvanian) in the Ardmore basin of south-central Oklahoma. The goal of the field trip is to help participants understand methods for making interpretations of depositional environments and facies changes that will help them successfully predict the potential of a reservoir rock.

The price for the workshop and field trip will be set at a later date; it will include the cost of the accompanying publications that contain the material presented.

For information, contact 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.

Geological Society of America

Rocky Mountain and South-Central Sections Annual Meeting

April 30–May 2, 2001 • Albuquerque, New Mexico

With scenery that is a veritable textbook of geology, New Mexico has from early days attracted pioneer earth scientists like Jules Marcou, J. S. Newberry, F. V. Hayden, Benjamin Silliman, Jr., J. W. Powell, G. K. Gilbert, Clarence Dutton, Waldemar Lindgren, N. L. Darton, Kirk Bryan, C. V. Theis, C. E. Jacob, and E. H. Colbert. Pre-Columbian Native Americans digging for turquoise and Spanish conquistadors seeking the gold of Cibola were forerunners of geologists who made New Mexico a leading producer of oil and gas, coal, uranium, copper, molybdenum, gold, silver, and potash.

The Albuquerque area lies near the intersection of five major geologic provinces. To the west and northwest is the Colorado Plateau and San Juan Basin region. To the north and northwest are Precambrian-cored foreland uplifts of the Nacimiento and southern Sangre de Cristo and Taos Ranges. Features related to the Cenozoic Rio Grande Rift continue southward from south-central Colorado through central New Mexico and merge with the Basin and Range province of southern New Mexico. To the east of the Sandia Mountains and behind Albuquerque lies the Great Plains province.

The Dept. of Earth and Planetary Sciences, University of New Mexico, Albuquerque, and the Dept. of Geology, Sul Ross State University, Alpine, Texas, will co-sponsor the 2001 annual meeting of the Rocky Mountain and South-Central Sections.

The following agenda is planned:

Symposia

Validating Models of Subsurface Flow and Transport
Ouachita-Marathon Tectonics: Current Research and Speculations—A Tribute to George Viele
Geologic Framework of the Middle Rio Grande Basin
Hydrogeology of the Middle Rio Grande Basin
Proterozoic Tectonics of the Southwestern U.S.
Geophysics of the Rio Grande Rift and Southern Rocky Mountains
Geoscience Education and Research in American Indian and Hispanic Communities
Development and Use of Web-Based Resources for College Instruction
Timing of Ancestral Rocky Mountain Orogeny
Meso- to Neoproterozoic of the Western U.S.: Record of Supercontinent Assembly and Breakup, and a Snowball Earth?

Theme Sessions

Undergraduate Research Poster Session
Climate Change, Hydrology, and Water Allocation in the Western U.S.
Forest Fire Impacts on Hydrochemistry and Hydrology

Partnering Short Course Program

GSA is introducing the new Partnering Short Course Program at this section meeting. This program offers short courses specifically designed to appeal to the members of both GSA and the partnering Associated Society. The first short course offered in the program is brought to you by GSA and SEPM (Society for Sedimentary Geology).

Paleosols for Sedimentologists

Field Trips

Volcanology and Hydrothermal Systems of Valles Caldera and the Jemez Mountains, *April 29*
Cenozoic Stratigraphy and Neogene Tectonic Evolution of the Middle Rio Grande Rift, *April 27–29*
Proterozoic Ductile Thrust Belt in the Manzano Mountains, *April 28–29*
NAGT Field Trip: Learning Geology in the Field—Old Mountain Belts to Young Volcanoes near Albuquerque, *April 28*
Tent Rocks, *April 29*

For more information about the meeting:

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Oklahoma abstracts

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

Compartmentalization of the Overpressured Interval in the Anadarko Basin

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Reservoir pressures within the lithologic column in the Anadarko basin are a tiered system. The overpressured zone called the Mega-Compartment Complex (MCC) is overlain and underlain by normally pressured intervals. Compartments are classified in three different groups or levels. The basinwide MCC is called a Level 1 compartment. Within the MCC, reservoirs that form fields or districts commonly have similar pressure values. These fields or districts are called Level 2 compartments. Detailed analyses of initial pressure, fluid types and decline curves indicate that Level 1 and 2 compartments contain many smaller and isolated (sealed) compartments called Level 3 type. The seals occur mainly in clay- or sand-rich rocks and commonly exhibit diagenetic banding patterns.

Banding patterns in clay-rich rocks appear to form independently of sedimentary textures or result from the enhancement or modification of sedimentary features. Diagenetic bands in sandstones typically consist of silica- and carbonate-cemented layers that are separated by clay-coated porous layers. Stylolites and other pressure-solution features such as penetrating grain boundaries suggest a mechanism for the source of silica cements. The integration of tectonic history, stratigraphic relationships, facies distribution, thermal history, and diagenetic patterns of seal zones suggests that seals and compartments evolved primarily during the Pennsylvanian orogenic episode. This occurred during the rapid subsidence phase of the orogeny over a period of approximately 30 million years.

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Thermal Structure of the Anadarko Basin

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The Anadarko basin of Oklahoma is a two-stage Paleozoic cratonic basin with as much as 12 km (7.5 mi) or more of sedimentary fill. We present a present-day thermal model of the basin based on lithologic analysis at 3-m (10-ft) intervals in 63 wells, heat flow measurements at seven sites, and in-situ thermal conductivity calibration of the sediment section at two sites. We do not use BHT bottom-hole temperature) information in the process, but we do, at the end of the process, compare the independently predicted temperatures to BHT information. The in-situ calibration of thermal conductivity was accomplished using detailed temperature logs and represents a new practical application for evaluating basin thermal characteristics. Shale exerts the most control on the temperature distribution because it is the most abundant lithology and has the lowest thermal conductivity. Shale comprises 47% by volume of rock in the basin and represents 75% of total thermal resistance, directly related to temperature gradient; therefore, shale dominates the thermal structure of the basin. Thus, the problems in sampling and in characterizing the in-situ thermal conductivity of shale from laboratory measurements represent a major limitation in basin thermal analysis; we use the in-situ calibration approach as a way to address the difficulty. The temperatures calculated do not mimic the structure of the sediments; i.e., the hottest area on a given age horizon in the lower Paleozoic is not in the most deeply buried part of the Anadarko basin. The combination of decreasing heat flow toward the Wichita Mountains and the facies changes in the Pennsylvanian units from marine shale (low thermal conductivity) in the basin to the granite wash (high thermal conductivity) toward the uplift results in the highest temperatures being displaced about 50 km (31 mi) northward into the basin. The pattern of vitrinite reflectance in the Woodford Shale is virtually identical to the present-day reconstructed temperature pattern; therefore, we conclude that the thermal pattern is and has been dominated by conductive heat transport.

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Patterns of Cenozoic Denudation on the Southern High Plains

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Spatial and temporal patterns of denudation on the southern High Plains of northeastern New Mexico, southeastern Colorado, the Texas panhandle, and western Oklahoma are constrained using apatite fission-track (AFT) thermochronology, heat flow, and sonic well-log velocity studies. AFT and modern temperature data are combined to estimate the timing and the magnitude of cooling due to denudation on the High Plains. AFT analysis of core samples from five deep oil wells in the area indicate that the base of the apatite partial annealing zone (PAZ) is preserved in the subsurface and it can be precisely located in two of the wells. The depth of the base of the PAZ below the ground surface and the amount of denudation recorded in the Logan and Payne wells are tabulated below:

<1,230 m	east-central New Mexico (1 Latigo Ranch C)	
~825 m	northeastern New Mexico (Logan)	~2–3 km
<1,800 m	Oklahoma panhandle (Stonebraker 1-AP)	
<3,390 m	Texas panhandle (Hobart Ranch 1-21)	
~3,074 m	Anadarko basin, Oklahoma (Payne 1)	~1–1.5 km

The AFT cooling age just beneath the break-in-slope on the age-depth plot is ~27 Ma in northeastern New Mexico and ~38 Ma in the Anadarko basin.

The interval transit time digitized from sonic logs can be used as an independent measure of the amount of denudation in an area. The interval transit time decreases with increasing burial depth according to a compaction curve that has to be calibrated for each unit examined. Rock units that are at a depth shallower than their maximum burial depth will have a lower-than-expected interval travel time. Approximately 50 sonic logs from SE Colorado and NE New Mexico have been digitized and estimates of the amount of erosion have been determined. The amount of erosion in southeastern Colorado predicted from this analysis ranges from ~3 km along the Sangre de Cristo Mountain front to 0.8 km near the Colorado-Kansas state line.

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Seismic Sequence Stratigraphy of the Upper Morrow Formation: A Regional Study in the Western Anadarko Basin

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The upper Morrow Formation in the western Anadarko Basin, northeastern Texas Panhandle, was studied using 360 km of seismic inversion data integrated with data from 80 wells. The goals were to use seismic data to interpret the lithologies, depositional environments, evolving paleogeography, and changing sea level represented by this stratigraphic interval.

Seismic interval velocity contouring, based upon wavelet character, and correlation with borehole data provided the basis for the interpretations. Characteristic seismic signatures of three lithologies, sandstone, shale, and clayey siltstone, were recognized.

Sandstone anomalies, concentrated at three seismic horizons, were mapped. The highest and lowest horizons are interpreted to represent deltaic distributary channel systems, whereas the middle horizon is interpreted to represent a meandering fluvial system. These seismic horizons are also interpreted to represent three minor progradational pulses of 4th- to 5th-order global stratigraphic cycles produced by repeated glaciation in the southern hemisphere, with possible tectonically generated pulses superimposed.

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Late Pennsylvanian and Early Permian Paleoenvironmental Reconstruction from the Stable Isotopic Composition of Paleosol Carbonate

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The oxygen isotopic composition of pedogenic carbonate forms in isotopic equilibrium with soil water, whose isotopic composition is correlated with meteoric water. Although the isotopic composition of soil water may be different from average local meteoric water for several reasons, the oxygen isotopic composition of paleopedogenic carbonate can be used in stratigraphic sequences to mark environmental change or to compare different localities. In addition, correlation of oxygen and carbon isotopic composition in paleosol carbonates can be used to delineate the environmental conditions of carbonate formation.

We will present isotopic data from dozens of Late Pennsylvanian and Early Permian localities found in Texas, Oklahoma, Colorado, Utah, Arizona, and New Mexico. With respect to the factors that control the oxygen isotopic composition of soil carbonate, some regions exhibit stratigraphic trends that are indicative of environmental change, whereas other regions appear to have remained relatively stable.

Furthermore, correlation of oxygen and carbon isotopic composition from these carbonates indicate that these paleosols developed under coastal, continental, and monsoonal environments.

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Using Strontium Isotopes to Determine the Age and Origin of Gypsum and Anhydrite Beds

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The variation of $^{87}Sr/^{86}Sr$ in seawater with time can be used to determine the age of calcium sulfate beds precipitated from brine derived from seawater. The determination of a marine origin can be established by the consistency of strontium isotope results from samples at different stratigraphic levels in a single gypsum/anhydrite bed collected at separated sites. The scatter of strontium isotope results in the gypsum/anhydrite samples examined here is interpreted to result from the contribution of meteoric strontium to the salina. Strontium isotope results from three evaporite settings, the Jurassic Todilto Formation from New Mexico, the Permian Blaine Formation from Blaine County, Oklahoma, and the Permian Salado Formation from New Mexico, are used to determine the age and origin of thc parent brine for these gypsum/anhydrite beds. The calcium sulfate beds from each of these formations precipitated from salinas that originated with a marine flooding but show, at different times and localities, volume dominance by meteoric water. The marine/meteoric mixing of ancient salinas can be modeled by using strontium concentrations and isotope ratios estimated from modern analogs. A limited comparison of strontium and sulfur isotopes shows that sulfur isotopes in the settings studied are less sensitive to meteoric influx.

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Petrophysical Reservoir Characterization in the Council Grove Group (Lower Permian) in the 21st Century: Panoma Field, Hugoton Embayment, Kansas

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Gas production from the Panoma Field within the Hugoton Embayment in southwest Kansas and northwest Oklahoma is from stacked reservoirs in the Council Grove Group (Lower Wolfcampanian) carbonates. The Panoma Field presently has over 2,500 producing wells and has produced over 2.5 trillion cubic feet of gas. The field underlies the giant Hugoton Gas

Field, which produces from the overlying Chase Group (Upper Wolfcampanian) cyclical carbonates.

The primary reservoir facies are gray bioclastic grainstone-packstone limestones that were deposited in a mosaic or series of bioclastic marine shoals. Intergranular, moldic and vuggy porosity varies up to 20% with 8 to 10% being considered the lower limit for economic production. Permeability is erratic, with 0.1 md considered to be the lower economic limit. The most effective ore type is intergranular. Producing grainstone-wackestone reservoirs are separated by thick (10 to 15 ft) red-brown to green-gray calcareous slightly argillaceous siltstones with low permeability and porosity. This siltstone is interpreted as a coastal plain to paleosol deposit.

Wireline analysis indicates that the water saturation is relatively high (50 to 70%), while the bulk volume water is intermediate (5 to 8%). The determination of effective porosity is critical to the reservoir characterization of the Council Grove. Laboratory NMR, wireline NMR data and capillary pressure data indicates that the effective porosity can be considerably less than the total NMR and core porosity primarily as a result of dolomitization of the micritic matrix, intraparticle and fine intercrystalline pores within a chert replacement, and microporosity.

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Revisiting Pennsylvanian Reservoir Architecture: Chitwood, Norge and NE Verden Fields, Caddo and Grady Counties, Oklahoma

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Pennsylvanian-aged, Mid-Continent reservoir sandstones have, historically, been interpreted to have originated in fluvial channel to fluvially dominated deltaic settings. In recent years, re-examination of cored intervals and outcrop analogs of many of these reservoir units has modified the original depositional models to include incised valley fills, tidally influenced estuarine to tide-dominated deltaic and shallow marine shoal settings. Incorporating these modified reservoir architectures into field development strategies has led to improved secondary recovery and maximized daily production volumes and ultimate cum.

In particular, the original geologic models for the 30-year-old Chitwood, Norge and Northeast Verden fields in Caddo and Grady counties, Oklahoma, have been substantially modified by re-examination of old field development cores and the recent acquisition of new cores and FMI datasets. Stacked, fluvial channels within the Huddleston Sandstone of Chitwood Field have been recognized as early transgressive valley fill with pronounced tidal channel/shoal reworking. Similarly, initial fluvial deltaic models in the Missourian Marchand Sandstone now reflect dramatic tidally influenced to tide-dominated shoal flow units. With no abrupt seaward shifting of facies present, a prograding highstand deltaic setting is envisioned for the Marchand Sandstone in Norge and NE Verden fields.

By revisiting such fundamental geologic information, producers can better understand reservoir architecture for optimal well placement and more efficient design of secondary recovery technologies. This is especially true where the geologic data is utilized in current, reservoir engineering flow models.

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Depositional History and Reservoir Characterization of the Northeast Hardesty Field, Texas County, Oklahoma

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The Northeast Hardesty Field in the Oklahoma Panhandle was developed in the early 1950s producing oil from the Morrow Formation. The lower part of the Morrow contains mixed clastic and carbonate shoreline sequences deposited during a marine transgression. The upper Morrow sandstones represent distributary channels on a prograding shoreline. The Morrow forms good hydrocarbon reservoirs, but vertical and lateral discontinuity, grain size variation, rapid facies changes and diagenesis make development challenging.

Upper Morrow production in Northeast Hardesty is from point bars and braid bars incised into the underlying sediments. The upper point bars show a fining upward pattern, small scale cross bedding, and wavy irregular ripple bedding. The mid point bars show larger scale festoon cross bedding. The lower point bars have coarse-grained channel lags and woody carbonaceous material.

The braid bars form stacked packages and show an overall upward coarsening pattern. The bars exhibit trough and planar cross stratification, small scale graded bedding and reactivation surfaces. Local scour surfaces, discontinuous lags and pebble sheets are common throughout.

Diagenesis has reduced the reservoir quality. Porosity and permeability have been decreased by cementation and compaction with clays clogging the pore throats and filling the pores themselves. Conversely, natural dissolution of chemically unstable detrital grains and authigenic cements has improved porosity and permeability in the reservoir.

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Hydrocarbons in the Ames Feature: The Oil Creek–Arbuckle (!) Petroleum System, Major County, Oklahoma

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A petroleum system includes a mature hydrocarbon source rock, genetically related oil and gas accumulations, and the geologic elements and processes responsible for the formation of the hydrocarbon deposits. This study defines the Oil Creek–Arbuckle (!) petroleum system located within the Ames feature, a Paleozoic structural depression believed to be an astrobleme. The effective source rock is the lower member of the Ordovician Oil Creek Shale, although some researchers suggest a biostratigraphic correlation of this facies with the McLish Shale (Repetski, 1995). The source interval is entirely contained within the depression, consisting of predominantly marine Type II, oil prone organic matter. Average total organic carbon (TOC) is 0.88%, but can locally exceed 2%. Optical and chemical methods indicate that the section has achieved a maturity level equivalent to 1.2%–1.3% vitrinite reflectance. Based on this information, Curtiss and Wavrek (1995) calculated pre-hydrocarbon generation TOC values of 2%–5% and hydrogen index (HI) between 400 and 600 for this interval.

Geochemical analyses indicate a correlation of this source rock to the oils reservoired in the underlying, highly fractured, Cambro-Ordovician Arbuckle Group. They are chemically distinct from the oils produced from shallower horizons, and consist of two genetically related types; one group of oils has an enhanced abundance of low molecular weight (LMW or lower than nC_{15}) compounds, most likely attributable to a higher thermal stress required for hydrocarbon generation and expulsion. A burial history reconstruction for the petroleum system indicates that the "critical moment," or time of peak hydrocarbon generation and expulsion, occurred at 225 Ma.

The generation accumulation efficiency (GAE) compares the amount of hydrocarbons generated by the source interval to the amount trapped in reservoirs. This petroleum system generated 145 MMBO (million barrels of oil), which contrasted with ultimate reserve estimates, establishes a GAE of 37%. The remaining 63% of the hydrocarbons generated were either lost (i.e., not trapped) or represent the potential for future discovery.

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Global Hydrocarbon Potential of Impact Structures

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Astroblemes, or ancient weathered impact craters, are reported to have produced hydrocarbons at Red Wing Creek Field, North Dakota; Viewfield Field, Saskatchewan; Avak Structure/Barrow Gas Field, Alaska; Calvin-28 and Mt. Pleasant Fields, Michigan; Ames Field, Oklahoma; and at Sheeba Crater, India. Throughtout the world numerous oil and gas fields produce from reservoirs and traps recognized as being of astrobleme origin, and it is probable that dozens more, if not hundreds, of already productive structures have yet to be recognized as having an astrobleme origin. Cumulative production from astroblemes is estimated to exceed 2.3 billion barrels of oil.

In order to explore for hydrocarbon-bearing astroblemes, one must first surrender the notion that meteorite impact events are random in space and time. A contrarian theory is presented which challenges this paradigm by illustrating several time-dependent, mappable crater trends on Earth, including the Pennsylvanian Meteorite Belt, and the Late Cretaceous Belt. This predictability is further related to crater belt forming events on other celestial bodies in the solar system as well as to the 1994 breakup of the Shoemaker-Levy 9 comet and subsequent impact belt which formed across the face of the planet Jupiter.

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