GEOLOGY OF A PROPOSED LANDFILL SITE, CHEROKEE COUNTY, OKLAHOMA

By
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Oklahoma Geological Survey

Open-File Report 5-99

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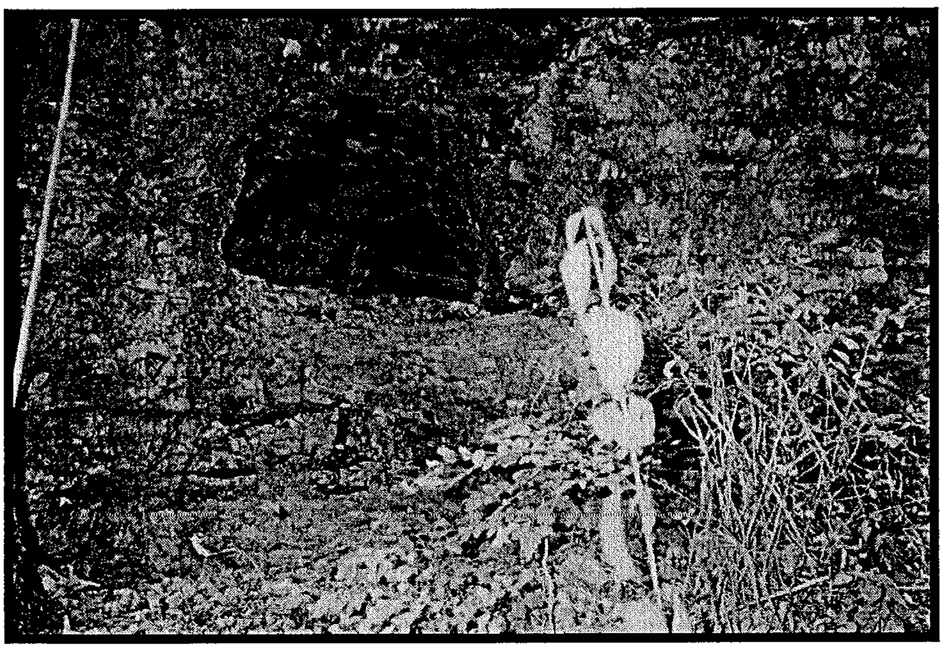

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On the Cover—

Cave in the Boone Formation, Cherokee County, Oklahoma

The cover photo shows a cave located on a bluff about 40 ft above Clear Creek in the SW ¼, NE ¼, NW ¼, NE ¼, 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 spelunker group) inspected the tunnel from its mouth back 18 feet until it turned and narrowed too much for further exploration. A cool airflow detectable at the mouth of the cave suggests that it continues for a considerable distance.

The visible part of the cave was formed by mechanical piping in highly fractured chert of the Boone Formation. The Boone comprises interbedded limestone and chert, so the possibility of dissolution enlargement of joints in limestone could account for the greater part of the unexplored part of the cave.

Development of caves in the Boone Formation is a common and widespread phenomenon 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 the following report.

OKLAHOMA GEOLOGICAL SURVEY
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Geology in the immediate vicinity of a proposed landfill site, Cherokee County, Oklahoma

INTRODUCTION

The primary considerations for evaluating a proposed landfill site are intimately related to the geology of the area. For example: What is the lay of the land? What are the rock types in the area? What are the properties of the rocks, such as solubility, presence of fractures, and fracture density? What are the types of soil developed on the rocks and the soil properties? What is the permeability of various horizons within the soil profile as well as within the hard bedrock? What are the effects of climatic conditions on the land, such as freeze-thaw periods, rainfall, and erosion resulting from flooding? What is the effect of ground water movement? Are aquifers present? Are streams and their flow a consideration? And last, what will be the effect of time on the site—particularly geologic time?

The proposed landfill site is located in northeast Oklahoma 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.

For purposes of this paper, the study area is defined by a circle with a radius of ~2 mi, with its center in the middle of the proposed landfill site (Fig. 2). The site is located in the NW ¼ sec. 7, T. 18 N., R. 21E., in Cherokee County, about two mi southwest of the town of Peggs. The proposed landfill is designed to utilize an unnamed hollow (in this report referred to as "Hidden Valley") adjacent to Clear Creek (Fig. 2). A hollow is defined as a low tract of land surrounded by hills or mountains; a small sheltered valley in a rugged area (Bates and Jackson, 1987). 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). 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.

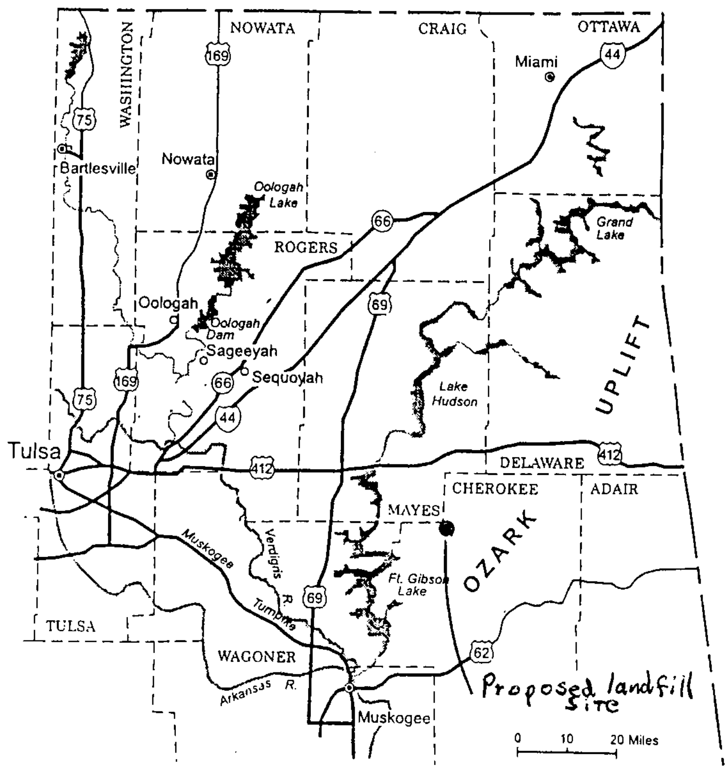


Figure 1. Geographic setting of the proposed landfill site, Cherokee County, northeastern Oklahoma.

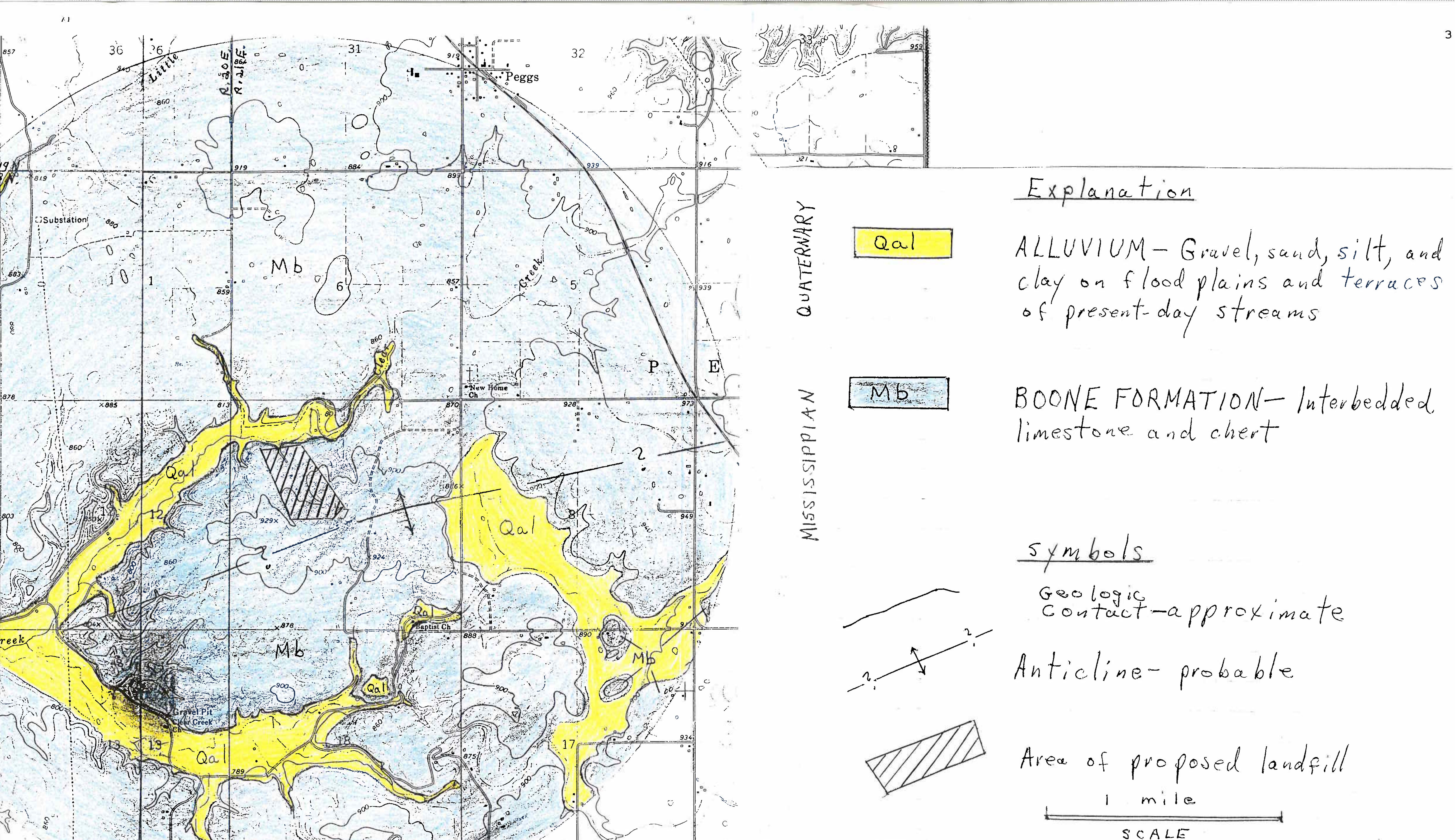
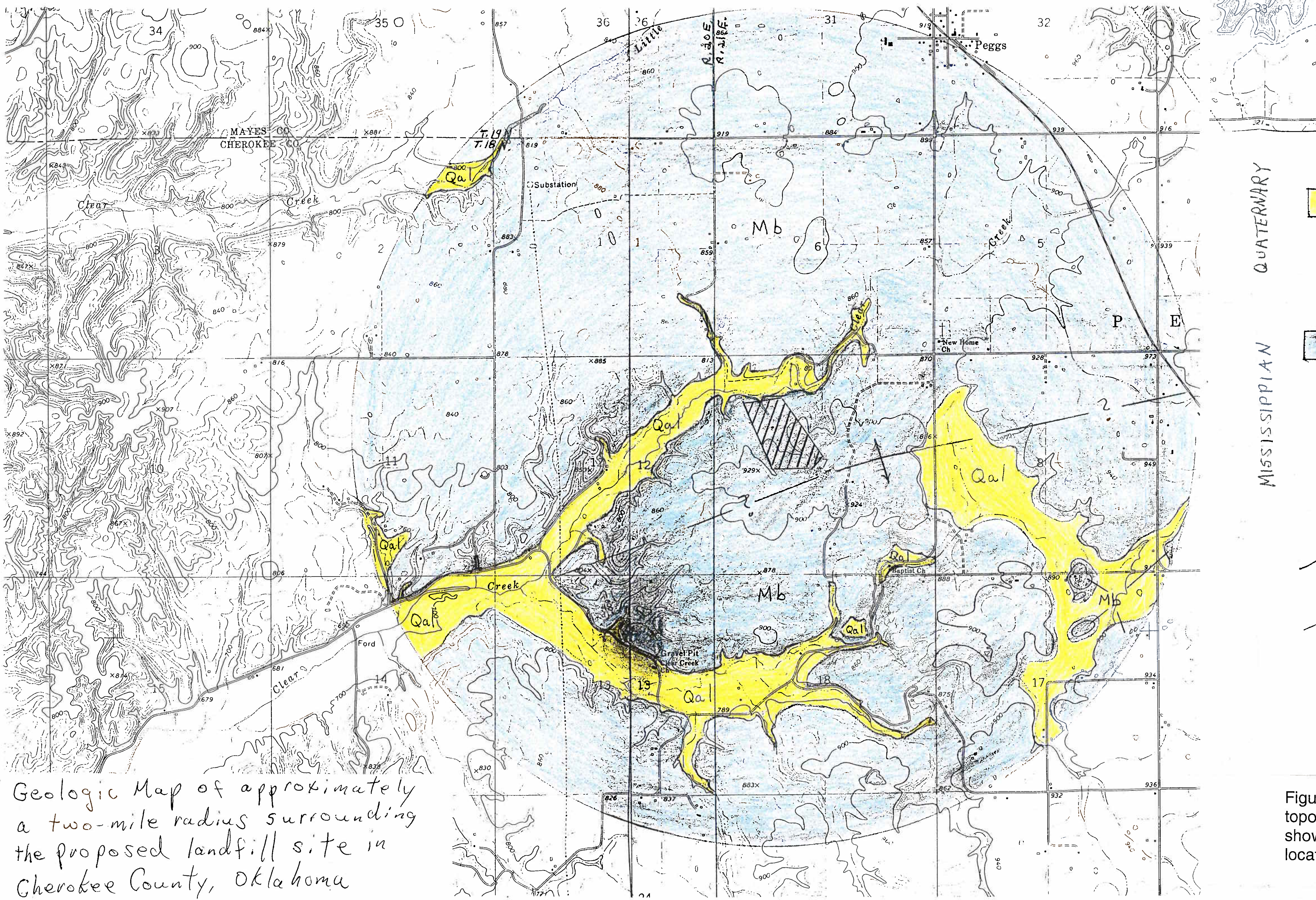


Figure 2. Parts of the Cedar Crest and Peggs 7.5-minute-series topographic maps (modified from U.S. Geological Survey, 1972) showing the topography in the area of the proposed landfill site, the location of the site, and the geology of the area.



Geologic Map of approximately a two-mile radius surrounding the proposed landfill site in Cherokee County, Oklahoma

Figure
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Clear Creek (so named on the Peggs 7.5-minute quadrangle) is a southwest-flowing stream that flows into Ft. Gibson Lake. Between its head, on the divide between Spring Creek and Clear Creek, about 2 mi from the study site, to a point about 2 mi below the site, Clear Creek descends from an elevation of ~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 labeled as such on the USDA General Soil Map, 1969) extends southeastward from its juncture with Clear Creek in the NW ¼ of sec. 13, T. 18 N., R. 20 E., and wraps around the elongated, dome-like feature previously mentioned (Fig. 2). Another valley, occupied by Little Clear Creek, is about 2 mi north of Clear Creek and is separated from the proposed landfill site by a NE-SW-trending divide. The creek flows to the southwest then turns south and joins Clear Creek ~ 4 mi downstream from the landfill site.

Sec. 7, T. 18 N., R. 21 E., is moderately populated. Aerial photographs from the U.S. Department of Agriculture (1990) show 15 residences in the section, but a recent reconnaissance indicates there are several new dwellings not shown on the photos. Marty Hern (personal communication, 1999) estimated that there are presently 32 occupied dwellings in sec. 7.

The main source of income in Cherokee County (and in the study area) is 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 occupies about 61 percent of Cherokee County (Cole, 1970, p.1). U. S. Department of Agriculture air photos (1990) indicate a similar percentage of woodland in the study area.

GEOLOGY

Stratigraphy

The area within a two-mile radius of the proposed landfill site is underlain by only two mappable geologic units: 1) Mississippian Boone Formation, and 2) Quaternary alluvium and terrace deposits (undifferentiated) (Figs. 2, 3).

The term "Boone" was first published in 1891 (Simonds, 1891, P. XIII) in reports of the Arkansas Geological Survey to designate a heterogeneous unit of cherts and limestones that crop out widely in

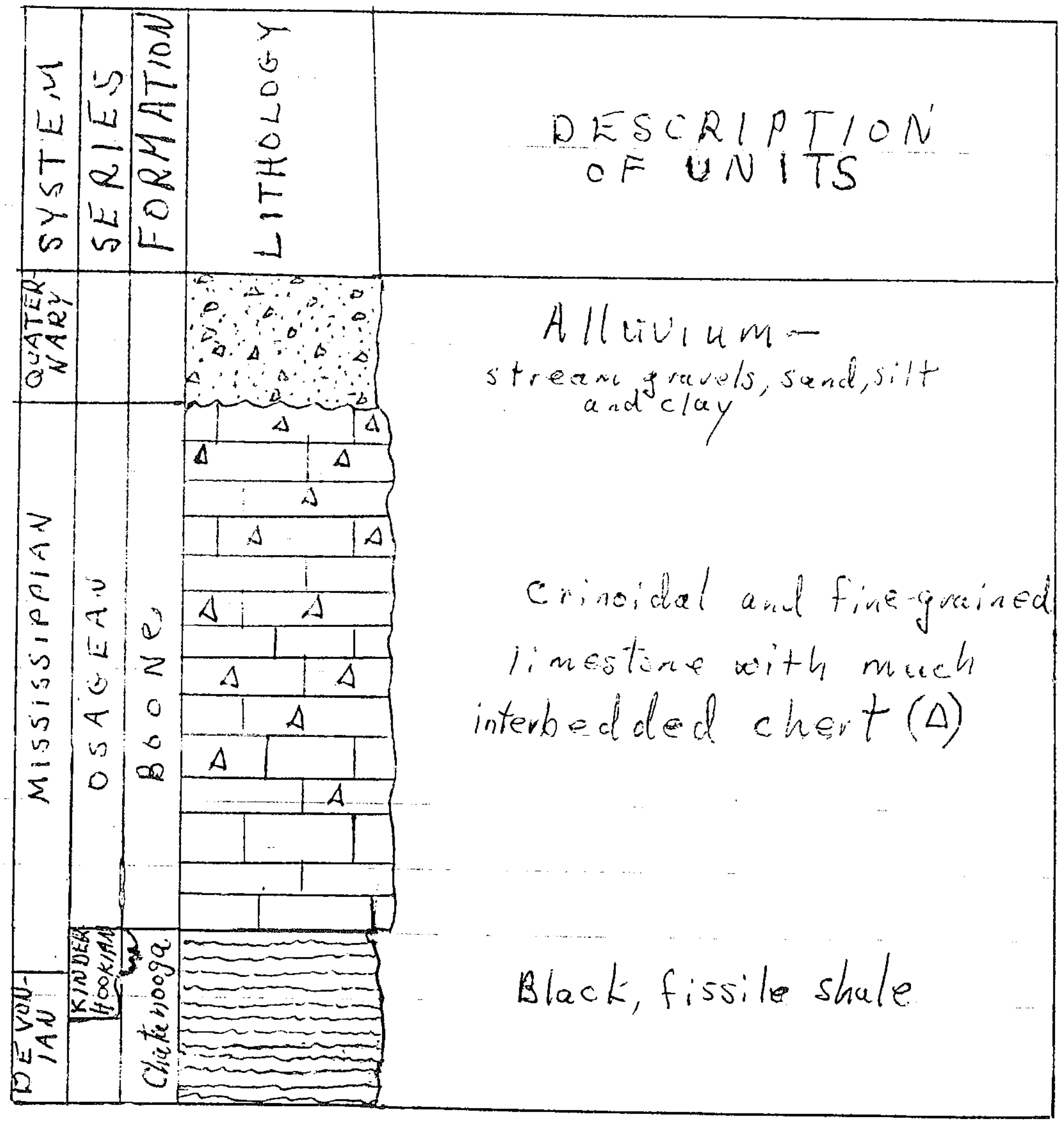


Figure 3. Stratigraphic column showing pertinent rock units in the study area. Thickness of units given in text.

northern Arkansas (McKnight and Fischer, 1970, p.19). The name was subsequently extended to the Ozark region of Oklahoma to apply to equivalent strata. The Boone can be divided into several members, depending on location, but for purposes of this report only the term "Boone Formation" is used.

The Boone Formation disconformably overlies the Upper Devonian and Lower Mississippian Chattanooga Shale in the study area (Fig. 3). The Chattanooga is a widespread, black, fissile shale, typically 30 to 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 to 30 percent 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 percent of the Boone Formation is limestone and 36.5 percent is chert (Robinson, 1996).

The top of the Boone is eroded in the study area and the remaining thickness is not known. However, the maximum recorded thickness for the Boone is about 400 ft (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. Within the study area, in the SE¼SE¼NW¼ sec. 7,T.18 N., R. 21 E., a test well penetrated 169 ft of the Boone, but did not reach the base of the formation. (Robinson, 1996, Log #11).

Chert in structurally undisturbed strata is concordant with the bedding and has replaced limestone. This replacement is believed to have taken place progressively during deposition of the Boone limestones, the silica being derived from sea water. Decomposition of volcanic ash that settled in sea water may have yielded soluble silica, which then was available for replacement of susceptible limestone sediments on the sea floor (McKnight and Fischer, 1970, p. 3). Johnson and others (1989, p. 10) state that replacement of limestone by chert ranges from early diagenetic to post lithification, but the source of silica (hydrothermal, sponge spicules, volcanic ash, or others) is uncertain.

A little chert occurs as crosscutting replacement veinlets and is of a second generation. Some silica was dissolved by circulating ground waters and was then reprecipitated around pre-existing chert masses (McKnight and Fischer, 1970, p. 10). The resulting "honeycomb" texture is shown in Figure 4.

Figure 4. "Honeycomb" texture in residual chert boulder (visible at left end of rock). Such features contribute to the porosity of the chert. Geologic pick is about 1.1 ft long, (for location, see camera symbol, Fig. 10)

Quaternary alluvial and terrace deposits consist of clays, silts, and coarse cherty gravels. More details are given in the "Soils" section of this report.

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 during Pennsylvanian time when the Ozarks became a positive structure (Huffman, 1958, p. 89). The study area lies on the southwest end of the Ozark Uplift. The regional dip is 25 to 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. However, small folds and/or faults may be present, but are undetectable at the surface, due in part to poor exposure of bedrock.

Fracturing of the rocks was produced by structural movements associated with the Ozark Uplift, mostly during the Late Pennsylvanian. Tectonic breccias of brittle chert formed during plastic deformation of incompetent associated limestones (McKnight and Fischer, 1970, p. 3). The Boone chert is characterized by curvilinear, close-spaced fracturing, which accounts for the abundance of residual chert clasts in soil profiles in the study area.

SOILS

Classification

Soil scientists determine the kinds of soils present within a county. They make their determinations by the following: sampling and testing the physical characteristics of the soil; observing steepness, length, and shape of slopes; the size and speed of streams; the kinds of native plants or crops; the kinds of bedrock, and many other facts about the soils. They dig holes to expose soil profiles. A profile is the sequence of natural layers, or horizons, in a soil; it extends from the surface down into the parent material that has not been changed much by leaching or by the action of plant roots (Cole, 1970, p. 1). Soils are classified according to set procedures using the study information.

The U.S. Department of Agriculture General Soil Map (1969) shows three associations of soil in the study area. 1) Sallisaw-Elsah-Staser: Deep, gravelly or loamy soils on flood plains and benches. These soils occur on the flood plains and terraces of Clear Creek ,the south fork of Clear Creek, and Little Clear Creek. 2) Clarksville-Baxter-Locust: 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. 3) Baxter-Locust: Deep, cherty, and loamy, nearly level to gently sloping soils on timbered uplands. These soils occur at higher elevations north and east of the site between drainages.

Soil associations are useful to people who want a general idea of soils in an area, or who want to know the location of tracts suitable for certain kinds of land use. A soil association is a landscape that has a distinctive proportional pattern of soils. It normally consists of one or more major named soils, and at least one minor named soil (Cole, 1970, p. 2).

Named soils in the immediate vicinity of the landfill site (Cole, 1970, sheet 73) are the following five soils: 1) The Sallisaw soils, which are nearly level to sloping and occur on benches along Clear Creek and 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, and are frequently flooded. They have a surface layer of dark brown, very gravelly loam. The subsoil is dark grayish-brown, very gravelly loam that is 60 to 90 percent gravel, by volume (Cole, 1970, p. 2). Elsah soils occur on the flood plains of Clear Creek and the south fork of Clear Creek. 3) The Staser soils, which are nearly level to very gently sloping, and occur on flood plains. These soils are subject to occasional flooding. They have a very dark, grayish-brown, gravelly loam surface layer. The subsoil is dark- brown gravelly loam that is 15 to 35 percent gravel, by volume (Cole, 1970, p. 3). Staser soils occur on the flood plains of Clear Creek and the south fork of Clear Creek. 4) The Clarksville soils, which include the Clarksville silty loam – 20 to 50 percent slopes (areas associated with hollows); and the Clarksville very cherty silt loam – 1 to 8 percent slopes (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, which are very gently to gently sloping have a cherty silt loam surface layer that is dark grayish-brown. The subsoil is yellowish-red, cherty silty clay loam that increases in chert with increasing depth (Cole, 1970, p. 5). Baxter soils are present in upland areas north and east of the landfill site.

Engineering properties

Table 1 is a modified excerpt compiled from Cole (1970, tbls. 4 and 5) that provides estimates of engineering properties of soils in the study area. Only those properties considered pertinent to the study, such as texture, permeability, and depth to bedrock, are listed in the table.

Formation of soils

TABLE 1. – Selected estimated engineering properties of soils in the vicinity of the proposed landfill (from Cole, 1970, Tables 4 and 5).

Soil Series	Depth to hard bedrock	Depth from surface of typical profile	USDA texture	Permeability (least permeable layer) *(Inches per hour)*	Soil Features affecting— Farm Ponds: Impounding Water in Reservoir Area	Soil Features affecting— Farm Ponds: Embankment
Baxter (BcB)	Inches	Inches			Chert beds locally below depth of 3 feet; may leak.	Features favorable.
	>7	0–9	Silt loam or cherty silt loan	0.20–0.63		
		9–22	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 feet are pervious.[1]	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 pervious	Very pervious
Sallisaw	>72	0–18	Silt loam or gravelly silt loam	0.63–2.0	Pervious at lower depths.[1]	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	Pervious at lower depths.	Features favorable.
		24–43	Silt loam or gravelly silt loam	----------		
		43–60	Very gravelly loam	----------		

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

Characteristics of soil are determined by: 1) the physical and mineralogical 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 is weathered, unconsolidated rock or mineral matter from which soils develop. The two general kinds of parent material in the study area are residuum and alluvium.

The Baxter and Clarksville soils developed from residual material derived from the cherts and limestones of the Mississippian Boone Formation. They have cherty to silty, clay-enriched horizons (Cole, 1970, p. 67). Table 1 lists the depth of these soils to hard bedrock, as well as their depth, thickness, and texture.

The Elsah, Sallisaw, and Staser soils developed from Quaternary-age loamy alluvial deposits on flood plains and benches. Table 1 lists their engineering properties.

Climate

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

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

GROUND WATER

Ground water is defined as the water, beneath the Earth's solid surface, contained in pore spaces within regolith and bedrock (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).

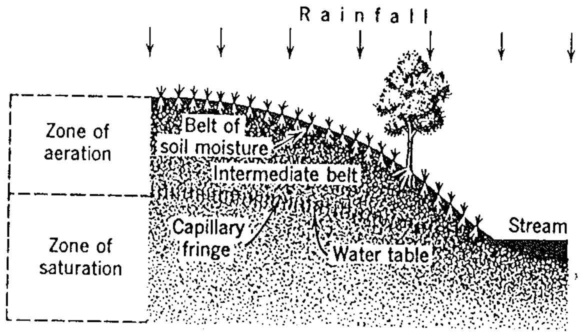


Figure 5. Positions of zone of saturation, water table, and zone of aeration (from Longwell and others, 1969, fig. 11-1).

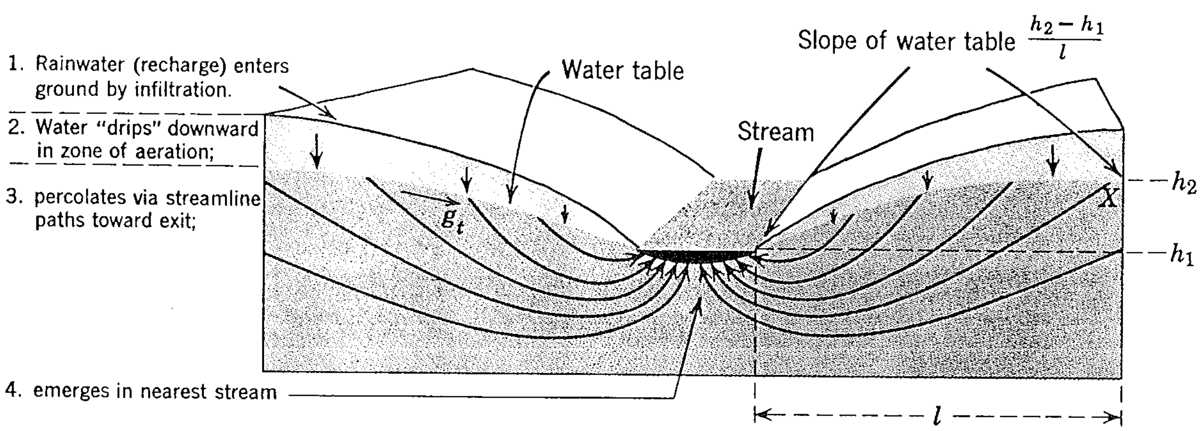


Figure 6. **Movement of ground water in uniformly permeable material. Long curved arrows represent only a few of many possible subparallel paths. At any point such as** x**, slope of water table is determined by**

$$\frac{h_2 - h_1}{l},$$

where $h_2 - h_1$ **is height of** x **above point of emergence in surface stream and** l **is distance from** x **to point of emergence** (from Hubbert, 1940).

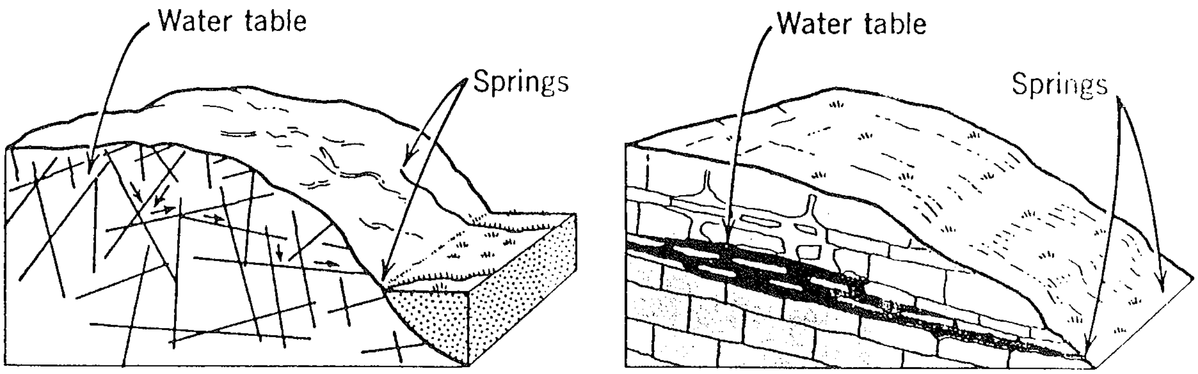
Most of the ground water near the Earth's surface moves. Responding to the force of gravity the water tends to seek its own level. Water moves readily through porous material that has the capacity for transmitting fluids (permeability). Water from rain infiltrates the soil, then "drips" downward in the 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. Water percolates from high-water-table areas to lower-water-table areas (Fig. 6), and can emerge as springs along streams.

Geologists and hydrologists refer to a body of permeable rock or regolith through which ground water moves as an aquifer. Good aquifers are the ones that have the most and largest interconnected spaces, such as gravels. However, other large bodies of rock or soil material that are essentially impermeable in small hand samples may contain fissures, fractures, spaces between layers, and other openings that also make them aquifers (Fig. 7 A,B). Solution 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 are generally good aquifers.

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

Derby (1984, fig. 8A) illustrates telogenetic effects resulting from weathering and erosional processes following uplift of previously buried rocks. Note that dissolution enlargement of joints is greatest at depths from 50 ft to about 300 ft (Fig. 9),. 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 post depositional fracturing of previously deposited sediment or rock.

Aquifers



A. In fractured rock such as chert

B. In cavernous rock such as limestone

Figure 7. Common locations of gravity springs (modified from Longwell and others, 1969, fig. 11-7).

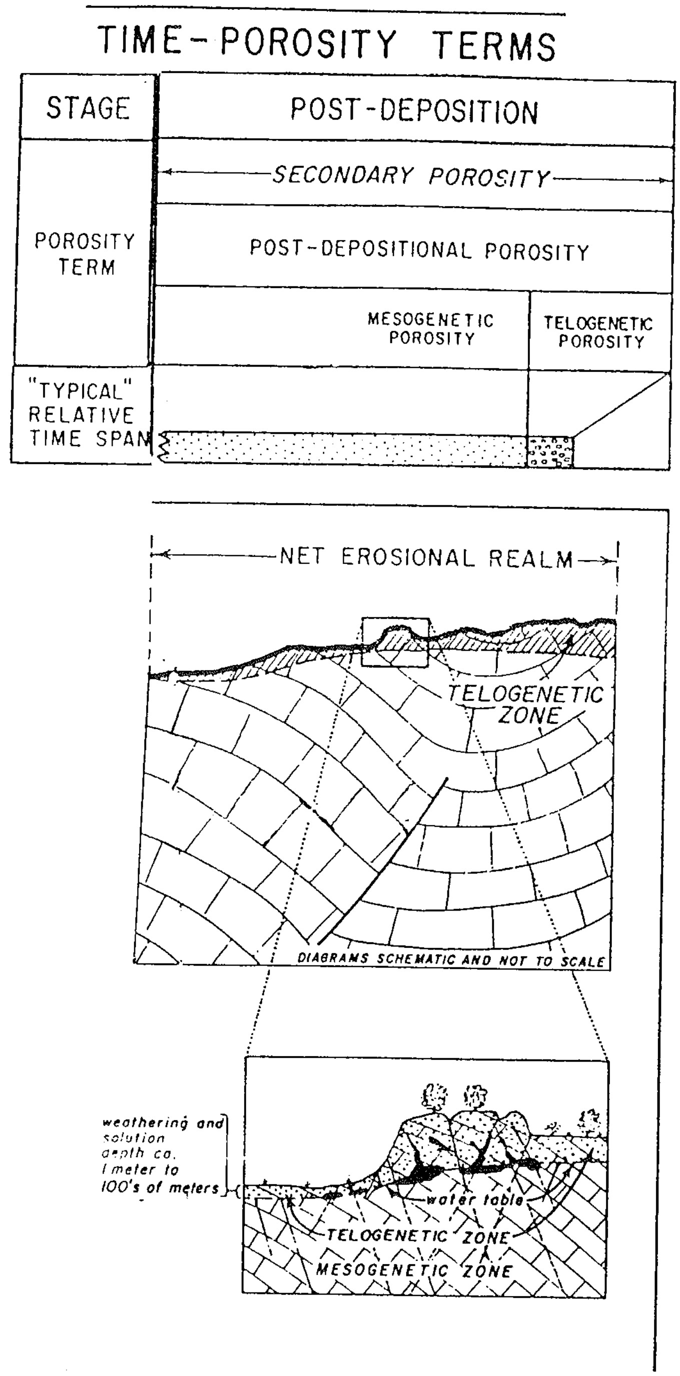


Figure 8. Time-porosity terms and zones of creation and modification of porosity in sedimentary carbonates (Modified from Choquette and Pray, 1970, fig. 1).

TELOGENETIC EFFECTS

(Weathering and erosional processes following uplift of previously buried rocks.)

POROSITY FORMING PROCESSES

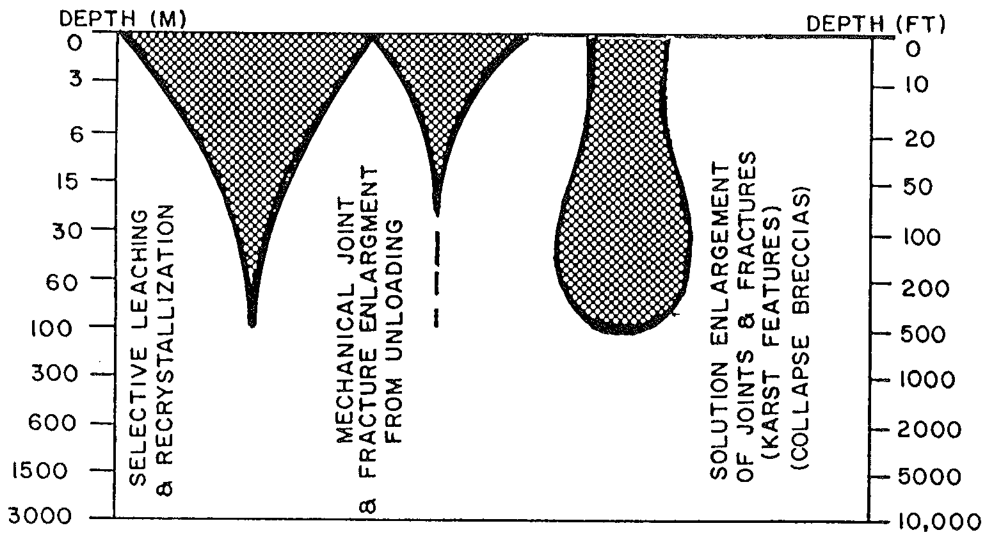


Figure 9. Telogenetic effects of major processes which form porosity during weathering and erosion. Width of field indicates relative importance. Highly subjective (from Derby, 1984, fig. 8A).

Marcher and Bingham (1971, sheet 2) show two areas within the area of the proposed landfill site as areas favorable for development of ground- water supplies. They are both listed as shallow aquifers. 1) Alluvium and terrace deposits--. Marcher and Binham (1971, sheet 2) say that 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 streams, yields of several hundred gallons per minute probably could be obtained from infiltration galleries." 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"-- Marcher and Bingham (1971, sheet 2) say that "the 'Boone Chert' consists of fractured massive chert with beds of cherty limestone....Throughout most of its area of outcrop the unit is a dependable source of water. The 'Boone Chert' is the source of numerous springs." Measurements of one spring in the study area (NE ¼ sec. 18. T., 18N., R. 21 E.), show an estimated yield of 20 gallons per minute (yield data obtained in 1968).

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. Hardness is the most troublesome chemical characteristic. Water is of the calcium-bicarbonate type. Sulfate, chloride, and nitrate contents are generally low. Water-quality diagrams in the vicinity of the study area show total dissolved solids of 107 milligrams per liter.

Specific information concerning chemical quality from alluvial aquifers in the study area was not given.

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

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.

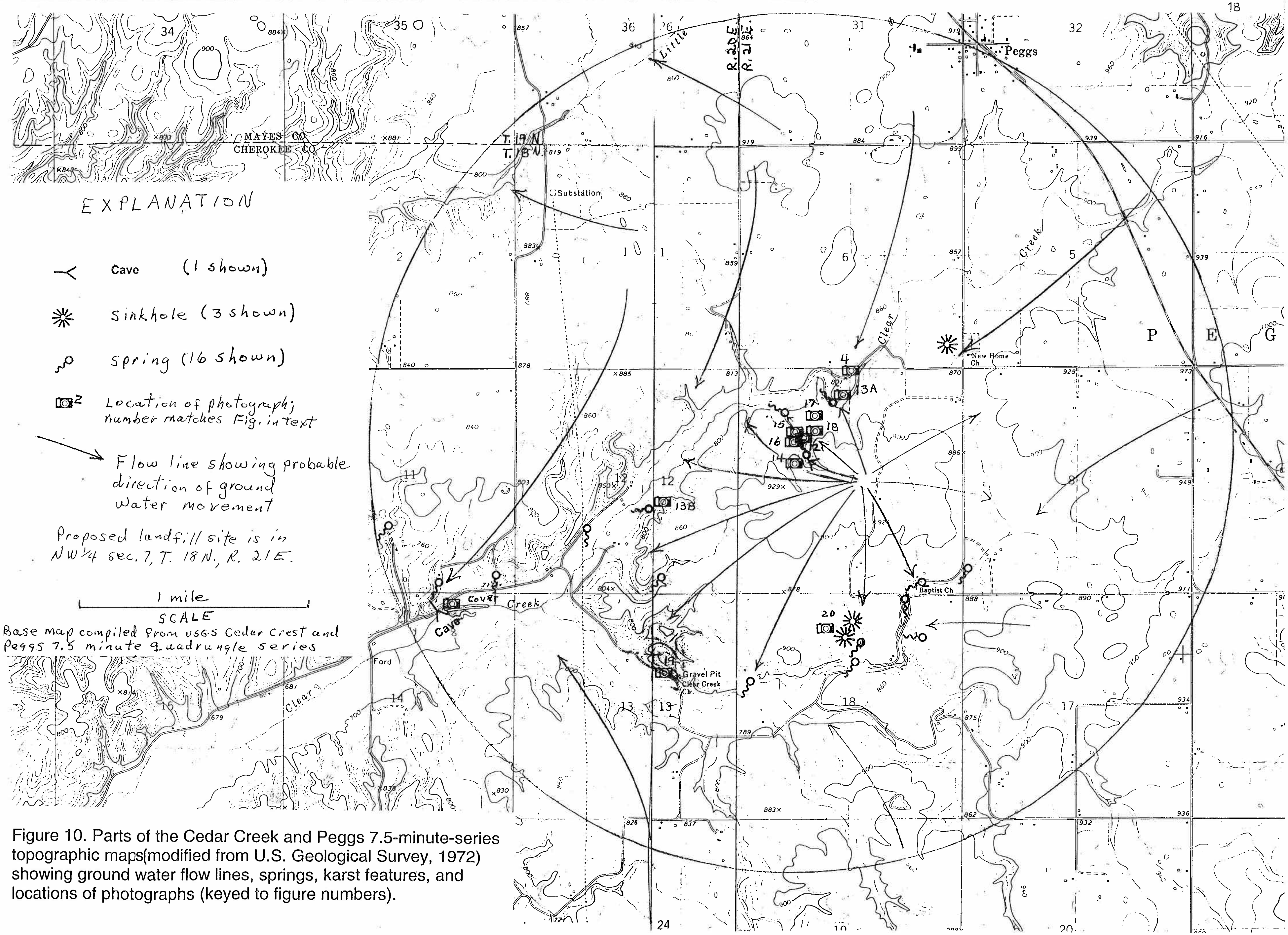


Figure 10. Parts of the Cedar Creek and Peggs 7.5-minute-series topographic maps(modified from U.S. Geological Survey, 1972) showing ground water flow lines, springs, karst features, and locations of photographs (keyed to figure numbers).

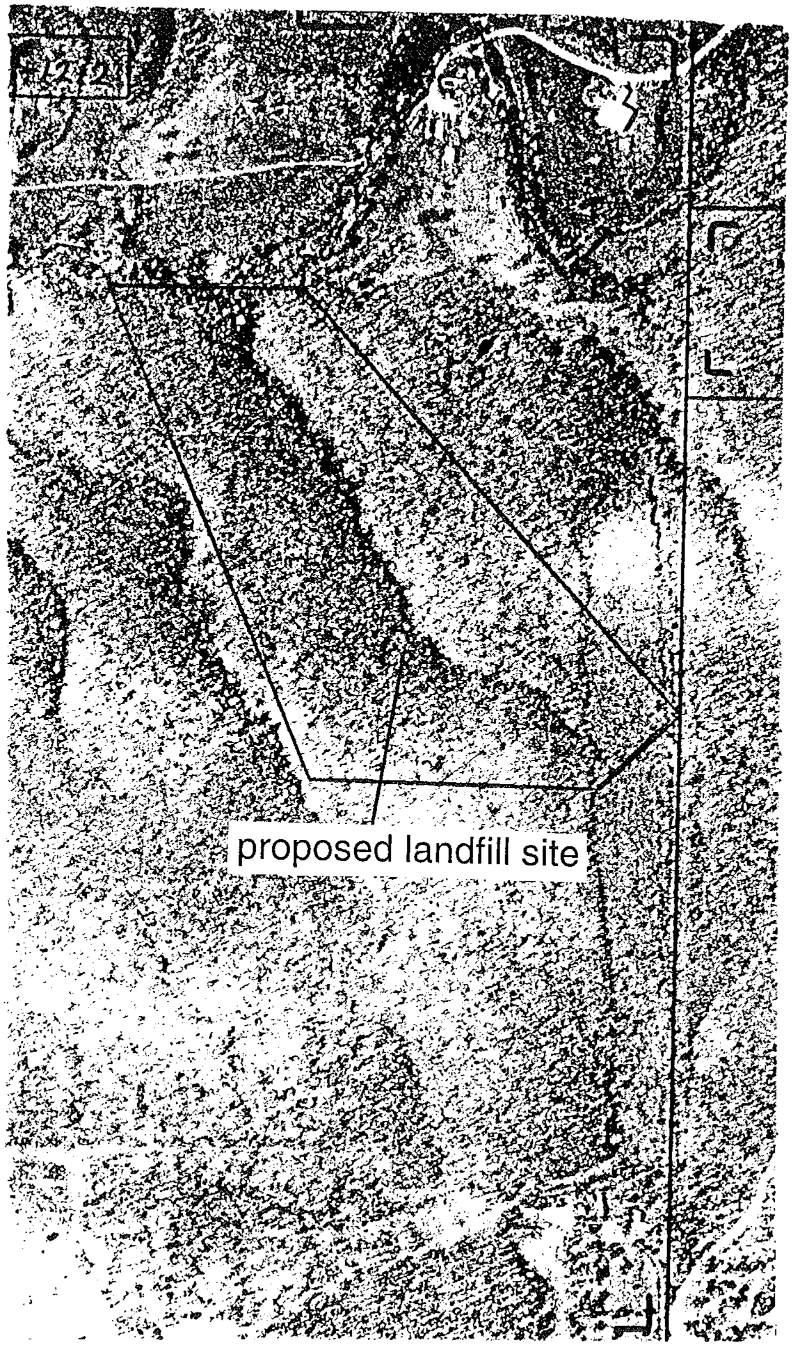


Figure 11. Excerpt from a 1990 aerial photograph showing the area of the proposed landfill site in the NW ¼ Sec. 7, T. 18 N., R. 21 E., Cherokee County. (Photo courtesy U.S. Department of Agriculture).

The proposed Clear Creek landfill site is in an unnamed hollow in the NW ¼ sec. 7, T. 18 N., R. 21 E. Soils in the hollow are predominantly Clarksville silty loams. The Clarksville very cherty silt loam occurs in upland areas adjacent to the hollow. The area surrounding the hollow is wooded--mostly oak, but other hardwoods and brush are interspersed. Figure 11 is part of an aerial photograph showing the study site.

The area within a two-mile 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 are shallow aquifers. Except for rare exposures in bluffs along hollows, or in bluffs along Clear Creek, unweathered, (*ie*, unfragmented), Boone Formation is not observable. One's impression of the Boone from examining soil and rubble that covers most of its outcrop in the study area, is that it is ~ 95 percent chert, which, except for scattered ledges (Fig.12) and outcrops in the bottom of drainages, occurs as residual concentrations of angular chert in the cobble-size range. However, drilling records show that in the subsurface, the Boone actually consists of 63.5 percent limestone, and only 36.5 percent chert (Robinson, 1996). Alluvium in the area consists of transported material similar to the residuum, generally covered by grass, and of the Sallisaw-Elsah-Staser soil association. (

No faults were observed during this study, nor have any been previously mapped. 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 NW at ~ 3-7°. Five measurements of joints suggest general trends of N 51° W and N 47° E. Air photos of sec. 7, T. 18 N., R.21 E., show a drainage pattern of N 52° W and N 47° E, which coincides with measured joints in the study area. Although rock outcrops suitable for recording strikes and dips were not adequate to confirm it, the topographic expression and the drainage pattern of creeks surrounding it strongly suggest that the elongate, dome-like hill dominating sec. 7 is an anticline.

Figure 12. Ledge of fractured Boone chert in a gully joining Hidden Valley from the east. Geologic pick for scale. (for location, see camera symbol, Fig. 10)

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, down into valleys along a pressure gradient until it emerges as a spring at a point where pressure is least. An example of this is shown by superimposing flow lines on a topographic map of the study area (Fig. 10). The flow lines show ground-water movement from the high point (elevation 960 ft) downward into low areas on all sides of the dome-like feature. Springs were observed in numerous places within the study area even though drought had prevailed for more than the previous six weeks. Many springs emerge from the toes of alluvial fans at the foot of hollows where the fans merge with the flood plain of Clear Creek (Fig. 13 A,B). One spring was observed in the V-shaped floor of the proposed landfill site (Fig. 14).

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 the chert-littered bed of Clear Creek (bottom middle of photograph) is dry upstream from the spring. (for location, see camera symbol, Fig. 10)

Figure 13. B--Man pointing to 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 yards wide and ~250 yards long, extends downstream from the spring. (for location, see camera symbol, Fig. 10).

Figure 14. Spring in the floor of Hidden Valley hollow (below geologic pick) Note the lush vegetation below the spring. (for location, see camera symbol, Fig. 10)

The floor of the 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 about 10 ft thick (Robinson 1996, Log #14), occurs in its lower part. The steep walls of the hollow are tree covered and consist of 1) soil, 2) weathered, angular chert clasts, and 3) rare ledges of cherty limestone (Fig. 15). Outcrops of pure limestone (even more rare) are present in the lower part of the hollow (Fig. 16). The upland areas are also soil covered, with numerous residual chert fragments. An uprooted tree shows soil characteristics in the two feet just below the surface in the upland area adjacent to Hidden Valley (Fig. 17). As the slope increases, just above the canyon walls, chert is concentrated to the extent that the clasts nearly cover the ground (Fig. 18). The closely spaced fractures (1/2-3 in. apart) in the chert explains 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).

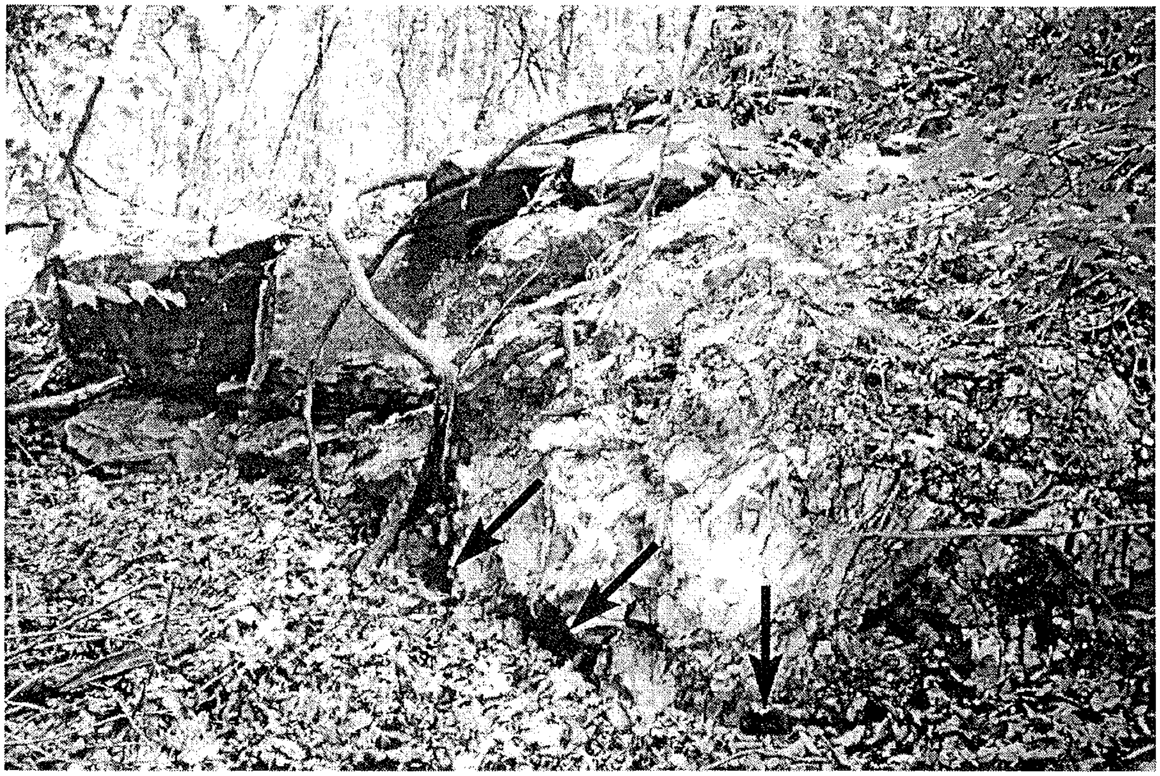
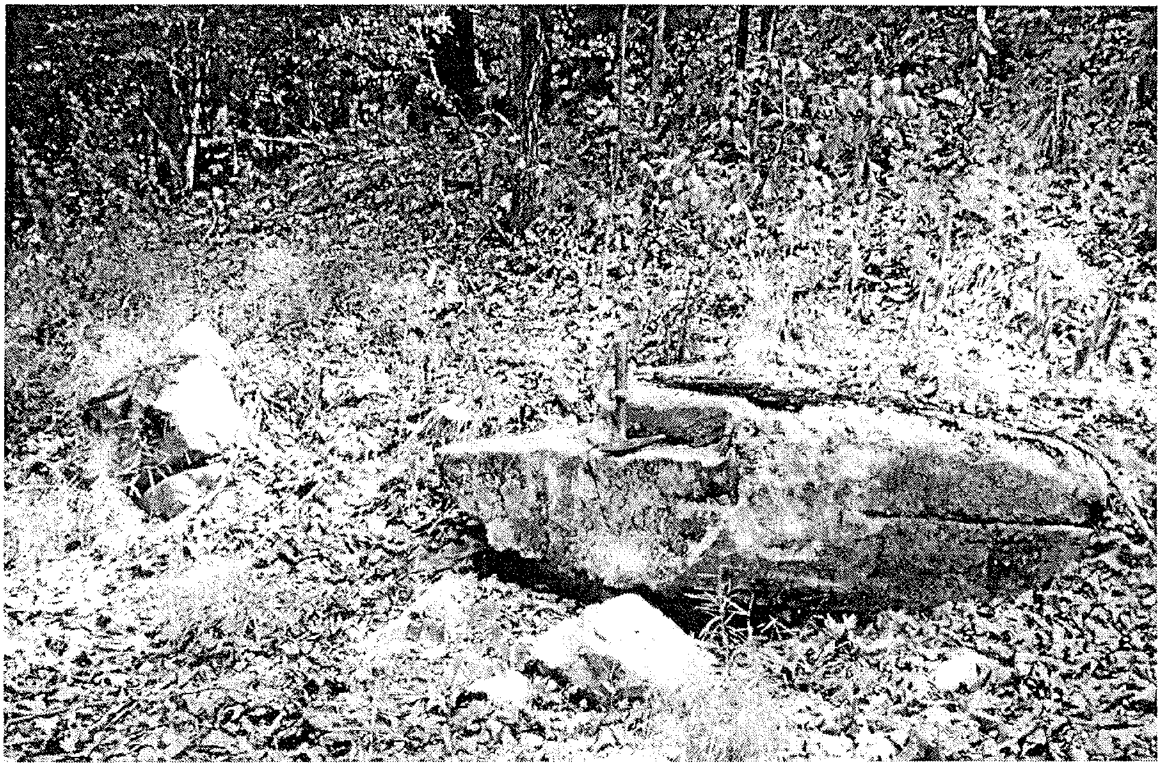


Figure 15. Ledge at the edge of Hidden Valley showing a jointed limestone facies of the Boone Formation in contact with a highly fractured chert mass (right side of photograph), Geologic pick in center of photograph marks the contact. Small (4 in. diameter) tunnels, indicated by arrows, extend back into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



.Figure 16. Limestone ledge at the edge of Hidden Valley. The limestone is crinoidal and finely crystalline. Geologic pick rests on a bedding plane at the top of a joint surface. Both features contribute to permeability in the Boone Formation. (for location, see camera symbol, Fig. 10)

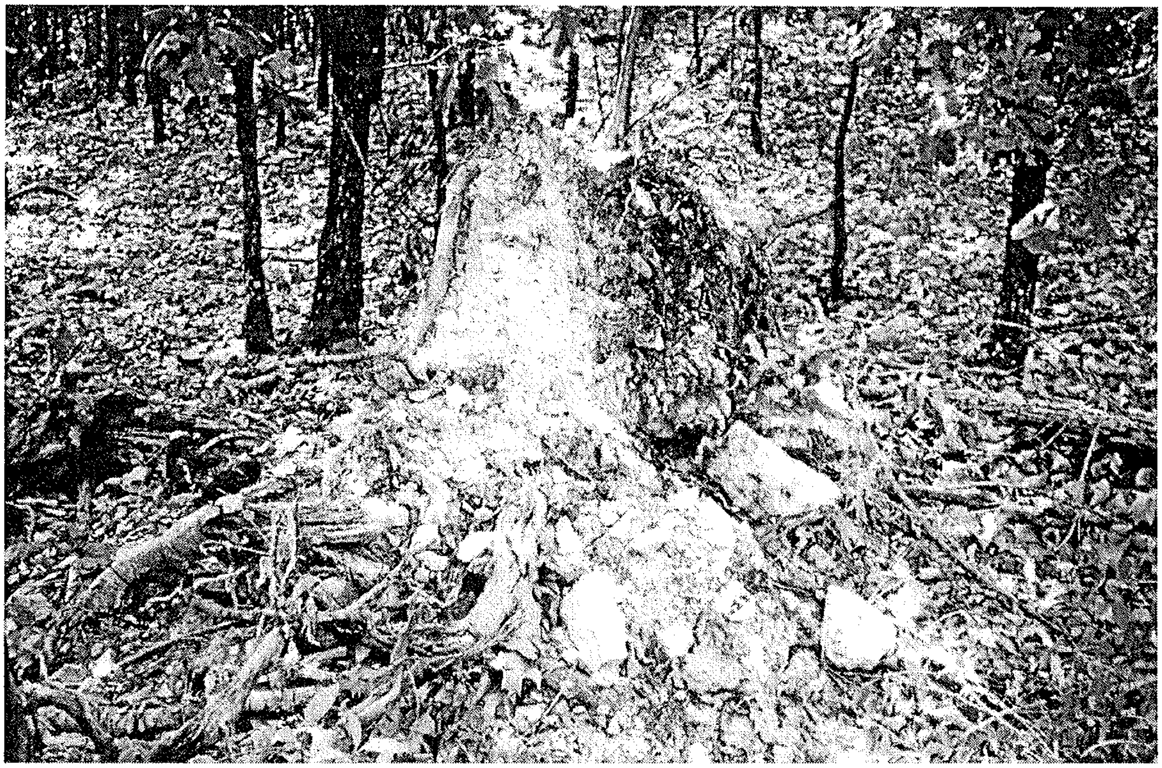


Figure 17. Soil trapped in the root ball of an uprooted tree in the highland area just east of Hidden Valley. Note the chert residuum present in the soil. (for location, see camera symbol, Fig. 10)

Figure 18. Concentration of chert residuum at the break in slope, just east of Hidden Valley (for location, see camera symbol, Fig. 10).

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

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. Downslope creep is indicated by the relationship of the material in the exposure. (for location, see camera symbol, Fig. 10)

One cave (cover photograph), formed by mechanical piping in fractured chert, and three small, shallow sinkholes (one shown in Fig. 20), were observed in the study area, indicating that karstification has occurred and is occurring in the area.

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 in the study area.

Figure 20. Sinkhole in the Boone Formation. The sink is ~3.5 ft in diameter and ~2.2 ft in depth. The pick head rests on the floor of the sink. A second sinkhole of similar size is present about 50 yards to the northeast. (for location, see camera symbol, Fig. 10)

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