



KENTUCKY GEOLOGICAL SURVEY
UNIVERSITY OF KENTUCKY, LEXINGTON

WALLACE W. HAGAN
Director and State Geologist

SERIES X
1968

*ENGINEERING GEOLOGY OF THE
CALVERT CITY QUADRANGLE,
LIVINGSTON AND MARSHALL
COUNTIES, KENTUCKY*

Warren I. Finch
U. S. Geological Survey

*Prepared by the United States Geological Survey
in cooperation with the Kentucky Geological Survey*



KENTUCKY GEOLOGICAL SURVEY
UNIVERSITY OF KENTUCKY, LEXINGTON

WALLACE W. HAGAN
Director and State Geologist

SERIES X
1968

*ENGINEERING GEOLOGY OF THE
CALVERT CITY QUADRANGLE,
LIVINGSTON AND MARSHALL
COUNTIES, KENTUCKY*

Warren I. Finch
U. S. Geological Survey

*Prepared by the United States Geological Survey
in cooperation with the Kentucky Geological Survey*

UNIVERSITY OF KENTUCKY

John W. Oswald, President
A. D. Albright, Executive Vice President
Lewis W. Cochran, Vice President for Research

KENTUCKY GEOLOGICAL SURVEY ADVISORY BOARD

Elmer C. Dyer, Chairman, Lexington
David W. Bayer, Wayland
Mart S. Bowne, Lexington
J. Edward Parker, Lexington
Ralph N. Thomas, Owensboro

KENTUCKY GEOLOGICAL SURVEY

Wallace W. Hagan, Director and State Geologist
Preston McGrain, Assistant State Geologist
Jo M. McGurk, Administrative Clerk
Susan W. Epperson, Secretary
Juanita G. Smith, Secretary

Areal Geology Section:

Martin C. Noger, Geologist and Head
William E. Jackson, Geologist
Avery E. Smith, Geologist
Gordon L. Carpenter, Jr., Geologic Assistant
Doris L. Oatts, Secretary

Coal Section:

Gilbert E. Smith, Geologist and Head

Industrial Minerals Section:

Preston McGrain, Assistant State Geologist and Head
Garland R. Dever, Jr., Geologist
Thelma C. Teater, Senior Laboratory Assistant
Lenora C. Stinnett, Laboratory Assistant

Oil and Gas Section:

Edward N. Wilson, Geologist and Head
Ellis C. Fernald, Geologist
Howard R. Schwalb, Geologist
Lorene Teater, Records Librarian
Daisy M. Crawford, Senior Laboratory Assistant

Publications Section:

William D. Rose, Geologist and Head, Editor
Roger B Potts, Chief Draftsman
John H. West, Draftsman
David M. Blair, Geologic Aide

Stratigraphy and Paleontology Section:

E. R. Branson, Geologist and Head

Water Section:

Harry M. Whitman, Geologist and Head

LETTER OF TRANSMITTAL

June 10, 1968

Dr. Lewis W. Cochran
Vice President for Research
University of Kentucky

Dear Dr. Cochran:

A thorough knowledge of the geologic materials of an area is desirable in planning and designing foundations for roads, buildings, and other structures.

This report, prepared as a part of the cooperative areal geologic mapping program of the United States Geological Survey and the Kentucky Geological Survey, should be most useful to industries, municipalities, and individuals concerned with the development of this important industrial region.

Sincerely,

Wallace W. Hagan

WALLACE W. HAGAN
Director and State Geologist
Kentucky Geological Survey

CONTENTS

	Page
Abstract	7
Introduction	8
General engineering properties and behavior of materials . . .	10
River levels and ground-water conditions	18
Earthquakes	19
Underground liquid-waste disposal	20
Construction materials	23
References cited	24
Appendix—selected bibliography of reports on underground waste disposal	26

ILLUSTRATIONS

	Page
Figure 1. Map of the southern part of the Calvert City quadrangle, showing drill holes	9
2. Map showing location of drill holes 20 through 51; lines A-A', B-B', C-C', D-D', and E-E'; and compaction samples	11
3. Logs of drill holes showing lithology and engineering classification of unconsolidated alluvial and lacustrine and fluviolacustrine materials	12
4. Consolidation test data for lacustrine and fluviolacustrine deposits	14
5. Consolidation test data for alluvium	14

TABLES

	Page
Table 1. Test data on loess, continental deposits, and McNairy Formation	15
2. Altitudes of upper surfaces of gravel of the continental deposits and of the basal gravel of alluvium in drill holes	16
3. Extreme river levels during 1945-1965 at gaging station 0.75 mile below Kentucky Dam	18

ENGINEERING GEOLOGY OF THE CALVERT CITY QUADRANGLE, LIVINGSTON AND MARSHALL COUNTIES, KENTUCKY

Warren I. Finch

ABSTRACT

The surface of much of the Calvert City quadrangle in Kentucky is developed on unconsolidated surficial deposits of silt, clay, sand, and gravel. A layer of silt and silty clay with a fairly uniform thickness of 8 to 10 feet is extensive. In the upland areas this layer is underlain by well-graded clayey gravel commonly 10-40 feet thick, whereas in the lowland areas it is underlain by a sequence of variable clayey and silty to clean sand layers commonly 30-50 feet thick. This sequence in turn lies on well-graded sandy gravel commonly about 50-70 feet thick. The surficial deposits in much of the area are underlain by poorly consolidated sand, clay, and gravel, which are much older than the surficial deposits and which have different engineering characteristics. In other areas, including the industrialized area north of Calvert City, the surficial deposits are underlain by very old hard chert and limestone.

Under proper conditions, surficial silt and silty clay have low shear strength and can safely support loads of 2,500 to 3,000 psf (pounds per square foot). They can be used for fills if slopes do not exceed 2 to 1 but are unsatisfactory for road subgrade and base. Gravel at or near the surface in the uplands has moderate to high shear strength and is excellent foundation material. The older sand and clay have variably low to moderate shear strength. Chert and limestone have great strength and serve as the foundation for Kentucky Dam. Solution cavities of considerable extent commonly occur in chert and limestone at the upper, eroded surface of the Fort Payne Formation beneath Cretaceous sand and clay and younger deposits; these cavities can cause engineering problems in the construction of foundations for major structures. Large caverns have been excavated in nonporous parts of this formation for use as storage of liquified industrial gases.

Tabulated data on water-level fluctuations of the Tennessee River from 1945 through 1965 show that the highest water level was about 342 feet above mean sea level and that the lowest water levels range from 2 to 3 feet below the pool stage of 302 feet. Water levels in the shallowest aquifer of the industrialized area range from 310 to 330 feet above mean sea level. Large quantities of ground water are available.

Calvert City is about 80 miles from New Madrid, Mo., the epicenter of one of the strongest earthquakes in the United States. Structures, particularly those founded on unconsolidated surficial silt and clay, should be designed according to available building codes pertaining to earthquake-resistant construction.

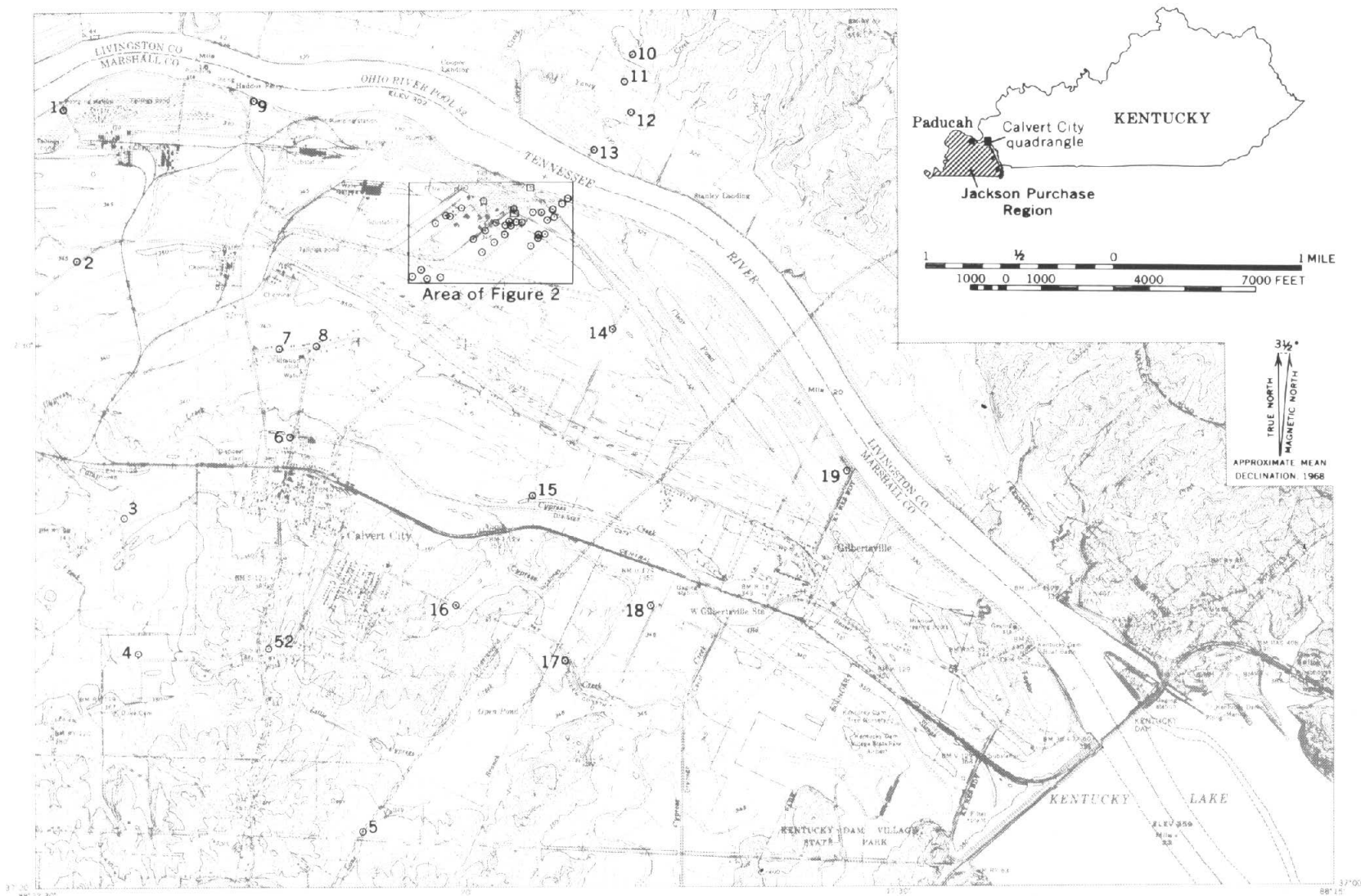
Few data are available to judge the feasibility of underground liquid-waste disposal in the Calvert City area. Circulation of ground water from surficial aquifers through cavities into Devonian and Mississippian formations rules out waste disposal in these formations. Older formations whose porosity may be sufficient for liquid-waste disposal are the St. Peter Sandstone and parts of the Knox Dolomite.

INTRODUCTION

Development of the large industrial complex north of Calvert City (Fig. 1) began during 1950, 5 years after the completion of Kentucky Dam. In 1966, nine major companies had industrial plants in the quadrangle, and several plants had either recently undergone or were planning expansion. Sites for future industrial growth in the quadrangle and the adjacent Little Cypress quadrangle have been outlined by the town of Calvert City and the Kentucky Department of Commerce (1962, map opposite p. 30, app. A).

A thorough knowledge of the engineering properties and behavior of the unconsolidated surficial deposits and of the poorly to well-consolidated sedimentary bedrock underlying the area is essential to insure the best land use and the best design of stable foundations for roads, buildings, and other structures. Many test data on these materials are available from private and public sources. Tests have been made on surficial materials about 20 miles to the west in Paducah East (Nichols, 1968) and Paducah West (Finch, 1968) quadrangles, and similar materials in the Calvert City quadrangle probably have similar engineering properties. In this report, the description of the engineering properties of the various materials provides a general assessment of their use as foundation materials and a guide in the planning of more detailed studies for specific road and building sites.

Much of the available test data was collected in connection with the geologic mapping of the Calvert City quadrangle in Marshall County. This short report was prepared, as part of the cooperative geologic mapping program of Kentucky by the Kentucky Geological Survey and the



Base by Tennessee Valley Authority
and U.S. Geological Survey, 1958

Figure 1. Map of the southern part of Calvert City quadrangle, Livingston and Marshall Counties, Ky., showing location of drill holes referred to in figures and text and the area of Figure 2.

U. S. Geological Survey, to relate the test data to the geologic map units. Although this report for the most part is complete within itself, parts of it will be more useful if direct reference is made to Geologic Quadrangle Map GQ-731 published by the U. S. Geological Survey (Amos and Finch, 1968), which describes the various geologic formations in greater detail and shows their horizontal and vertical distribution. A geologic section and contours drawn on the buried erosional surface cut on rocks of Cretaceous, Mississippian, and Devonian ages indicate the thickness of surficial materials and the depths to bedrock.

Test data presented herein are from unpublished engineering reports prepared by Dames and Moore for B. F. Goodrich Chemical Company and by Mitchell and Associates for the Calvert City Municipal Water and Sewer System. The data contained in these reports were synthesized to obtain only the information that has broad application. Additional data in reports prepared for other companies were made available, and though not included because they largely duplicate data presented here, they were useful in demonstrating that engineering characteristics of various materials are fairly uniform over large areas. The author is grateful to all companies and to the Municipal Government of Calvert City for their permission to publish this information and to auger test holes on company and municipal properties.

GENERAL ENGINEERING PROPERTIES AND BEHAVIOR OF MATERIALS

In the area of greatest industrial development, the surficial deposits generally consist of three parts (Figs. 2 and 3): (1) an upper layer, commonly 8 to 10 feet thick, of firm, unconsolidated cohesive clayey silt and silty clay (lacustrine and fluviolacustrine deposits on GQ-731), except on ridges marked by the 350-foot contour where it is partly or wholly composed of slightly to very sandy silt and silty sand; (2) a middle sequence, commonly 30 to 50 feet thick, of moderately dense, noncohesive silty sand, clayey sand, and clean sand (found only in the subsurface and probably part of lacustrine and fluviolacustrine deposits on GQ-731); and (3) a basal well-graded gravelly sand and sandy gravel (continental deposits on GQ-731), commonly 50 to 70 feet thick. In this area, these surficial deposits lie mostly on limestone and chert of Paleozoic age, as shown by drill-hole data on map GQ-731. Limestone and chert rubble, commonly about 5 feet thick but in places as much as 25 feet thick, was intersected in drill holes above altitudes shown on GQ-731 at the top of Paleozoic limestone and chert. Along the Tennessee and its

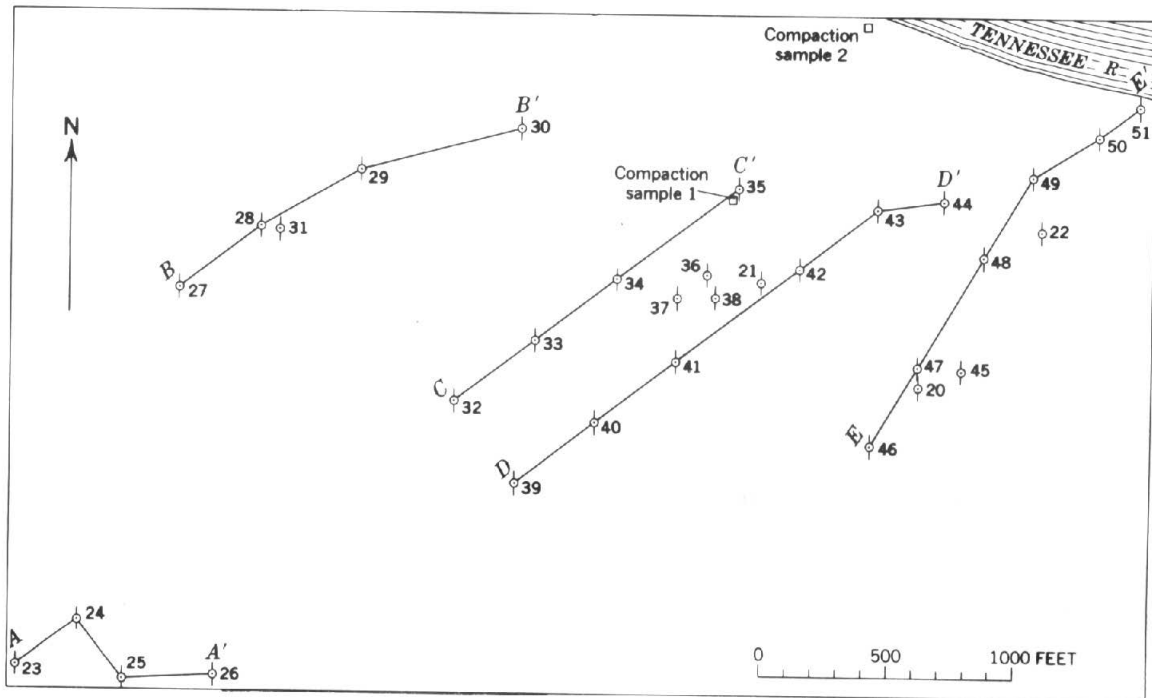
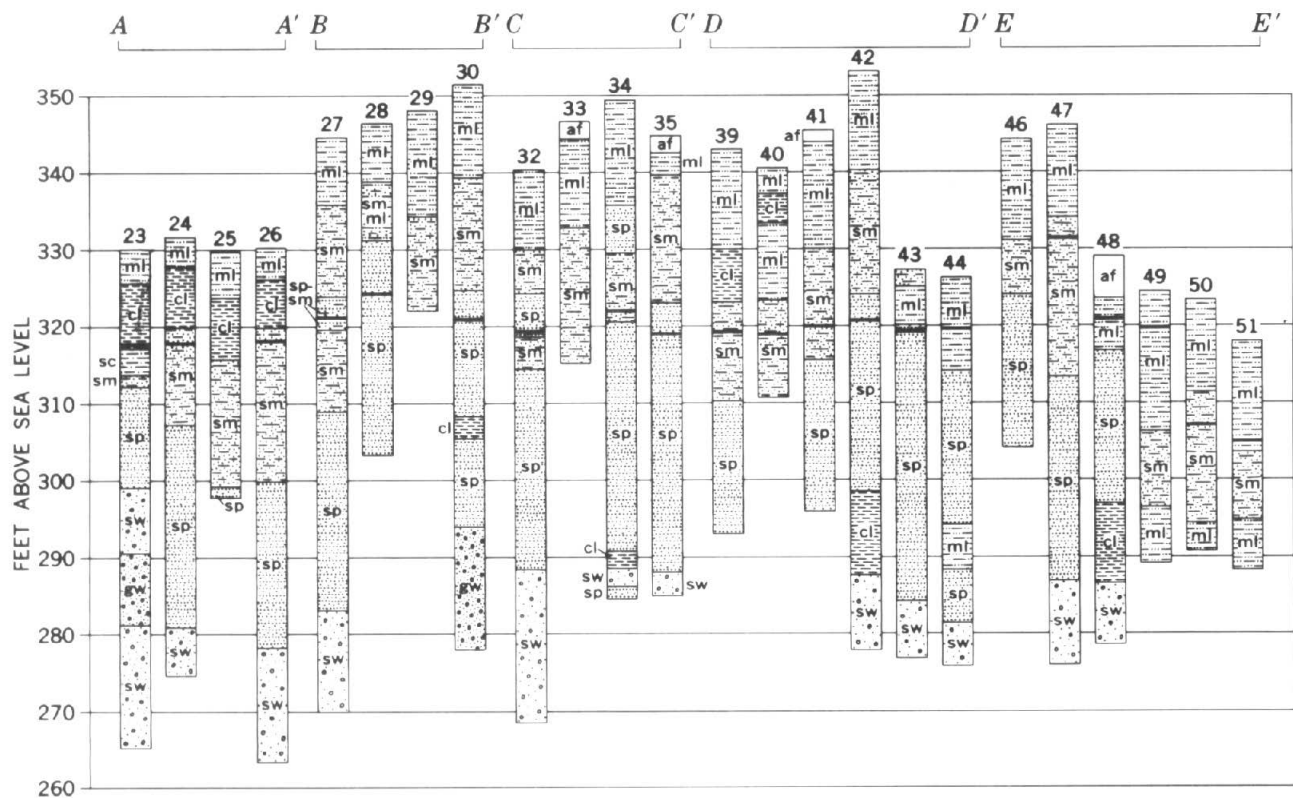


Figure 2. Map showing location of drill holes 20 through 51 and location of compaction samples in the B. F. Goodrich Chemical Company plant area. Logs of drill holes along lines A-A', B-B', D-D', and E-E' are shown in Figure 3. Location of this figure is shown on Figure 1.

tributaries are alluvial deposits (alluvium on GQ-731) consisting of a basal gravel and interlayered and intermixed silt, clay, and sand. In the uplands away from the main industrial area, firm, unconsolidated, cohesive clayey silt and silty clay (loess on GQ-731), commonly 5 to 10 feet thick, are underlain by well-graded clayey and sandy gravel (continental deposits) commonly 10 to 40 feet thick south of the Tennessee River; north of the river the gravel is commonly either thin or absent. The gravel deposits lie on an erosional surface cut on Cretaceous (McNairy and Tuscaloosa Formations) and older (St. Louis, Salem, Warsaw, and Fort Payne Formations) bedrock formations. The red contour lines on map GQ-731 can be used to determine approximately the depth to bedrock and the thickness of the surficial deposits (the difference in feet between the altitude of the land surface and that indicated by the red contour line).



The materials were classified by Dames and Moore by visual examination according to the Unified Soil Classification System (U.S. Federal Housing Admin. Architectural Standards Div., 1961, p. 45, 51). Fine-grained soils (median grain size less than 74 microns or No. 200 sieve size) with liquid limit less than 50 percent are classed as *ml* and *cl*; coarse-grained soils (median grain size greater than 74 microns) of more than half sand size with appreciable amount of fines are classed as *sm* and *sc*, and with little or no fines, as *sp*; and well-graded (poorly sorted in a geologic sense) sand and gravel mixtures with little or no fines are classed as *sw* (more than half of coarse fraction less than 4,760 microns or No. 4 sieve size) and as *gw* (more than half of coarse fraction greater than 4,760 microns)

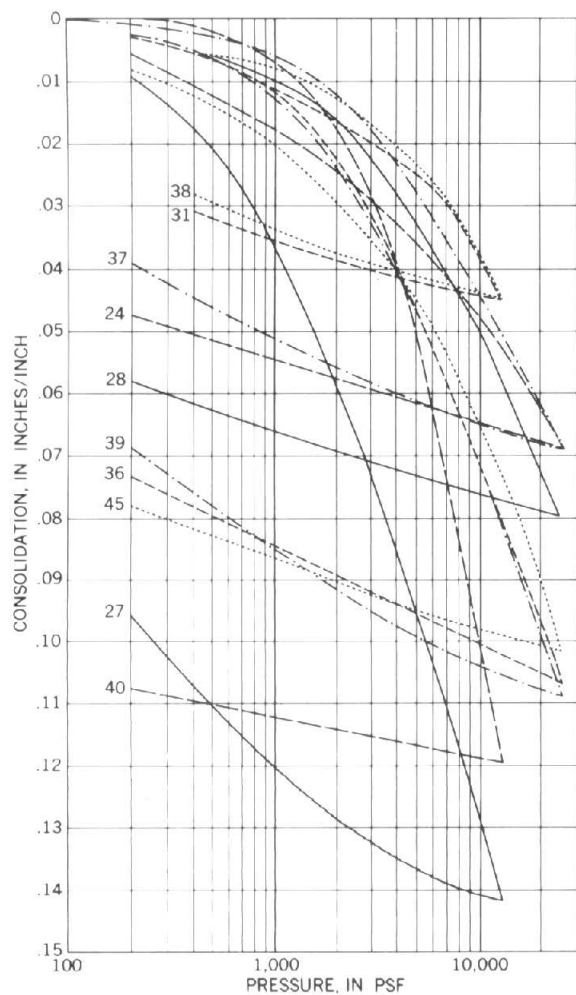


Figure 3. Logs of drill holes showing lithology and engineering classification of unconsolidated alluvial (GQ-731 map units Qal and QTc) and lacustrine and fluviolacustrine (GQ-731 map unit Qlf) materials. Locations of lines A-A', B-B', C-C', D-D', and E-E' are shown on Figure 2. Data adapted from unpublished foundation reports by Dames and Moore, consultants, Chicago, Ill., furnished through the courtesy of the B. F. Goodrich Chemical Company, Calvert City, Ky.

In general, the firm, cohesive clayey silt and silty clay in their natural state and under load at the surface may swell and compact differentially, particularly with changes in moisture content. These materials are characterized by slow to moderately slow percolation of surface and ground water. They are susceptible to rapid erosion unless protected and have moderate shear strength when dry; shear strength decreases rapidly as moisture content increases. The clay and silt compact well and have low compressibility and are thus suited for fill if slopes do not exceed 2 to 1 (horizontal to vertical) and if the materials are compacted to maximum density at optimum moisture content. They are not suited for road subgrade and base. Silty sand found on some ridges marked by the 350-foot contour commonly contains abundant mica and will not compact well. It is not suited for use as fill.

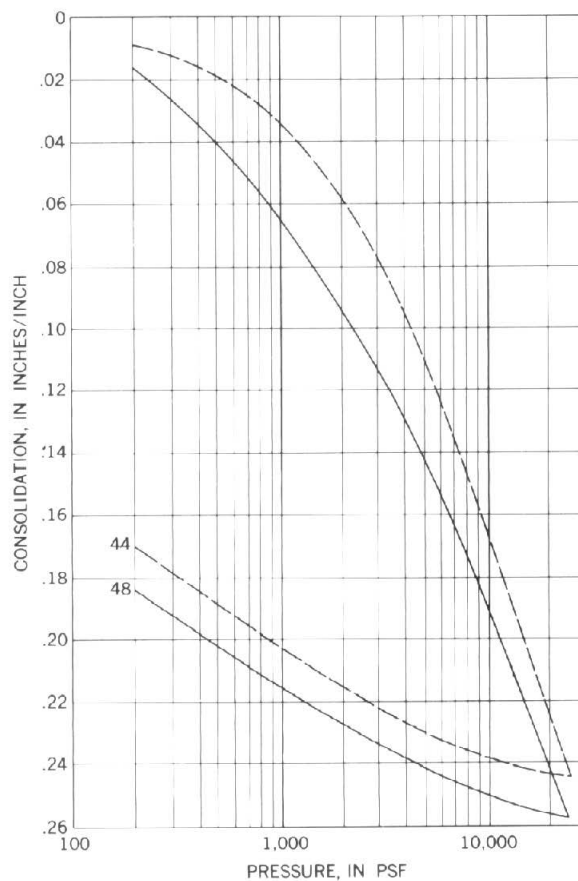
These generalities, which are based on tests of similar materials in the Paducah East (Nichols, 1968) and Paducah West (Finch, 1968) quadrangles, are supported by the engineering classification of surficial materials shown on Figure 3 and by various test data from the B. F. Goodrich Chemical Company plant area and the new Calvert City water-tower site (Table 1). Consolidation tests on lacustrine and fluviolacustrine silty and clayey materials in the Goodrich area (Fig. 2) indicate a consolidation of 3 to 11 percent of the thickness of the original sample after the release of pressure of 10,000 to 25,000 psf (pounds per square foot) (Fig. 4), and, similarly, on alluvial silty clay (alluvium on GQ-731) a consolidation of about 18 percent (Fig. 5). Results of numerous shear and compression tests in the B. F. Goodrich Chemical Company area indicate that lacustrine and fluviolacustrine clayey silt and silty clay can safely support loads of 2,500 to 3,000 psf and in places as much as 5,000 psf. Loessal clayey silt and silty clay would have similar load characteristics. A sample of lacustrine and fluviolacustrine clayey silt tested for fill showed an optimum moisture content of about 14.5 percent and a maximum dry density of 177 pounds per cubic foot (compaction sample 1, Fig. 2). Similarly, a sample of sand and gravel from alluvium showed an optimum moisture content of 10 percent and a maximum dry density of 125 pounds per cubic foot (compaction sample 2, Fig. 2).

Gravel of the continental deposits (Table 1) and of the Tuscaloosa Formation in areas of exposure probably has moderate to high shear strength and is excellent foundation material. The continental gravel beneath the lacustrine and fluviolacustrine deposits should be considered for pile and raft foundations, although depths to the gravel commonly would be 30 to 50 feet below the land surface, which ranges from about 340 to 350 feet above mean sea level (Table 2).



Drill hole	Altitude, feet	Description of material	Field moisture percent	Field dry density, lb/cu ft
27	311	Gray clay	31.5	92
28	339	Brown sandy silt	25.0	99
36	340	Brown silty sand	26.9	97
39	326	Gray clay	28.0	96
40	339	Mottled brown and gray silt	10.0	91
24	308	Brown fine to medium sand, micaceous	31.2	92
31	339	Brown clayey silt	24.1	100
37	335	Brown silty sand	24.1	99
38	345	Brown clayey silt	25.6	99
45	332	Brown silty sand with layers of gray silty clay, micaceous	29.0	94

Figure 4. Consolidation test data for lacustrine and fluviolacustrine deposits. (Data from Dames and Moore unpublished report, courtesy of B. F. Goodrich Chemical Company.)



Drill hole	Altitude, feet	Description of material	Field moisture percent	Field dry density, lb/cu ft
44	307	Layer of gray silty clay in brown fine to medium sand	40.5	80
48	305	do	47.0	74

Figure 5. Consolidation test data for alluvium. (Data from unpublished report by Dames and Moore, courtesy of B. F. Goodrich Chemical Company.)

Table 1. Test data on loess, continental deposits, and McNairy Formation. [Courtesy of Calvert City Municipal Water and Sewer System; adapted from report by Mitchell Testing Laboratory, Carbondale, Ill. Range in values from seven holes drilled around drill hole 52 for new water tower at south edge of Calvert City]

Geologic unit (see GQ-731); description of material	Depth (feet)	Penetration test ¹ (number blows per foot)	Unconfined compressive strength, tons		Moisture content (percent)
			Field, pocket penetrometer	Qu ²	
Loess: Brown stiff silty clay	2½	9-17	3.1-4.4	1.18-2.28	16.3-21.0
Continental deposits:					
Red to brown very stiff clayey and sandy gravel	7½	42-124	-	-	8.7-11.6
Do	10	58-84	-	-	9.2-15.7
Do	12½	76-132	-	-	7.9-13.1
McNairy Formation:					
Red, uniform, dense medium quartz sand	15	33-50	3.4 (one sample)	1.79 (one sample)	5.6-19.0
Gray, mottled red very stiff waxy clay	15-20	14-41	2.8-4.5	3.30-4.40	4.0-22.6

¹Used a standard split-barrel soil sampler, 140-pound weight, free fall of 30 inches.

²Qu, ultimate bearing capacity. Samples, trimmed to 1.4 inches in diameter and 2.8 inches long, were tested in a Rimac Spring tester. The sample fails either by shear (0% strain) or by bulging (20% strain). Dial readings are converted to the Qu values given.

Table 2. Altitudes of upper surfaces of gravel of the continental deposits and of the basal gravel of alluvium in drill holes.

Drill-hole number	Altitude of upper surface (in feet above mean sea level)	Drill-hole number	Altitude of upper surface (in feet above mean sea level)
1	280	17	286
2	284	18	286
3	274	19	299
4	330	23	299
5	335	24	281
6	311	26	277
7	291	30	294
8	285	32	288
9	306	34	288
10	340	35	288
11	310	42	288
12	311	43	284
13	298	44	281
14	295	47	287
15	286	48	286

Clay and sand of the McNairy Formation probably have low to moderate shear strength that varies greatly from place to place because of the lenticular nature of the clay in the dominantly sand sequence (Table 1).

Kentucky Dam is founded for the most part on limestone and chert of the Fort Payne Formation, whose average compressive strength was determined to be about 35,000± psi, " a very strong and substantial rock, " and on the Warsaw Limestone, whose average compressive strength was determined to be about 16,000 psi (Tennessee Valley Authority, 1949, p. 112). Likewise, limestone and chert of the other Paleozoic formations in the quadrangle would have great strength. Details of the engineering characteristics of the various geologic units in the dam area and of the construction of the dam are given by Rhoades (1940) and the Tennessee Valley Authority (1949).

Solution cavities are common in the Fort Payne Formation where it is overlain unconformably by Cretaceous and younger strata. The cavities were formed where limestone was dissolved by vadose water (above zone of saturation) and ground water, chiefly along nearly vertical joints and bedding planes. During the construction of Kentucky Dam, an unusually deep (about 200 feet from roof to base) and extensive cavity was discovered, which presented serious foundation problems (Moneymaker and Rhoades, 1945). This cavity as well as many smaller ones had to be thoroughly grouted where the cavernous rock could not be removed. During the course of auger drilling for subsurface data for map GQ-731, a cavity was intersected at a depth of about 97 feet in drill hole 19 north of Gilbertsville. Possibly another cavity was intersected in drill hole 16 southeast of Calvert City (Fig. 1).

Caverns for the storage of large quantities of liquified propane and other liquified gases were excavated by the B. F. Goodrich Chemical Company about 425 feet below ground surface in the Fort Payne Formation near drill holes 20, 21, and 22 (Fig. 2). The Fort Payne in this area is overlain by more than 100 feet of Warsaw Limestone (Amos and Finch, 1968, geologic section A-A') and was found to be entirely free of joints, solution cavities, and other features that might cause leakage (J. K. Koster, Plant Engineer, B. F. Goodrich Chemical Company, oral communication, 1966). This is rather remarkable, considering the proximity to faults and the prevalence of joints and solution cavities in the Fort Payne in outcrops and where it is covered unconformably by Cretaceous and younger strata. The relations shown in section A-A' on map GQ-731 suggest that the Fort Payne, where not faulted and where overlain by Warsaw Limestone, is not traversed by open joints and cavities. This relation suggests that search for new underground storage sites in the Fort Payne ought to be directed toward areas where a considerable thickness of Warsaw overlies the Fort Payne.

RIVER LEVELS AND GROUND-WATER CONDITIONS

Fluctuation in water levels of the Tennessee River is an important consideration in the construction of dock facilities and in the determination of areas affected by flooding. Table 3 shows the extreme water levels during the period 1945-1965 at the gaging station 0.75 mile below Kentucky Dam. The high-water level ranged from 322.46 feet above mean sea level on April 7, 1960, to 342.24 feet on February 13, 1950, and the low water level ranged from 298.43 feet on June 10, 1952, to 300.52 feet on June 14, 1953. High water occurred during the period January 1 to April 1 in 18 out of 21 years. The maximum recorded water level was 348.78 feet above mean sea level on February 2, 1937 (Hendricks, 1964, p. 261).

Table 3. Extreme river levels during the period 1945-1965 at the tailwater gaging station 0.75 mile below Kentucky Dam. [From records of the U. S. Geol. Survey, Louisville, Ky.]

Water year (Oct. 1 to Sept. 30)	Altitude (in feet above mean sea level) ¹	
	High-water level	Low-water level
1945	338.37	300.42
1946	337.55	299.98
1947	329.88	299.73
1948	338.76	298.44
1949	335.00	298.88
1950	342.24	299.95
1951	331.55	299.94
1952	332.38	298.43
1953	323.97	300.52
1954	326.85	299.56
1955	336.39	298.58
1956	331.76	299.60
1957	337.55	299.89
1958	329.38	299.90
1959	324.64	299.31
1960	322.46	299.69
1961	336.63	300.11
1962	339.21	299.29
1963	340.33	299.39
1964	335.58	300.35
1965	335.09	300.37

¹Altitude equals river gage reading river stage plus 286.35 feet.

The ground-water levels in the shallowest water-saturated formation are shown on the water-availability map by Morgan (1965) of the Calvert City and Little Cypress quadrangles, south of the Tennessee River. In the Calvert City industrial area, the shallowest aquifer is the middle sequence of sand in the surficial deposits. In this area the ground-water levels range from about 310 to 330 feet above sea level (Morgan, 1965) and at the Goodrich plant the ground-water level was about 320 feet at the time the test holes were drilled (Fig. 3). The upper surface of the water-saturated zone slopes about 5 to 10 feet per mile northward toward the Tennessee River. During flooding, the ground-water level rises and the slope of the surface flattens near the river and even may be reversed southward adjacent to the river.

Large quantities of ground water are available near the surface from sand and gravel in the surficial deposits and from the McNairy Formation, and are also available from deeper Devonian and Mississippian aquifers (Morgan, 1965).

EARTHQUAKES

The southern part of the quadrangle is at the extreme northeast part of the Mississippi embayment, which has had a long history of seismic activity. The New Madrid earthquake of 1811-1812 (Fuller, 1912), which toppled chimneys as far away as Cincinnati, Ohio, was centered about 80 miles southwest of Calvert City. This earthquake was one of the strongest on record in the United States. Since 1812, many minor earthquakes have been felt in the Jackson Purchase region (Finch, 1968). Earthquakes are caused by movement of rocks along faults; faults are numerous in the quadrangle, but evidence is lacking to indicate movement during geologically recent time. Collapse sinks near the south edge of the map, however, have formed recently along at least two faults; according to local residents, one formed in 1929. These collapse features were probably caused by solution of limestone along fault lines and did not give rise to earthquake shocks. Structures and roads built in the vicinity of faults, however, could fail if such a collapse should occur.

The firm, cohesive clayey silt and silty clay would have a viscous or viscoelastic response to earthquake shocks (classification of earthquake reactions after Schlicker and others, 1964) and would be susceptible to differential compaction and landslides under certain conditions and to ground motion from distant earthquakes such as at New Madrid. Noncohesive sand deposits which underlie silt and clay of the lacustrine and fluviolacustrine deposits would have a tendency for fluid response because they are generally water saturated (Fig. 3). Fluid response

generally causes total loss of strength of unconfined materials, but where the materials are confined, as in this case, the effects may be lessened, particularly on the overlying silt and clay. Sand and clay of the McNairy Formation, gravel, chert, and limestone generally should have an elastic reaction, constituting "good ground," but loose clean sand and gravel may have a tendency for fluid response if wet and for granular response if dry. Granular response causes densification and results in differential settlement. Earthquake-resistant construction should conform to available building codes, such as the Uniform Building Code (International Conference of Building Officials, 1964) and the National Building Code (National Board of Fire Underwriters, 1955, p. 265-268).

UNDERGROUND LIQUID-WASTE DISPOSAL

Waste disposal is a major problem in an industrial complex such as the one in the Calvert City area. The feasibility of underground liquid-waste disposal in this area has not been thoroughly investigated. Investigations to depths as great as 10,000 feet are needed to determine the maximum depth of occurrence of fresh ground water; the direction and velocity of fresh and saline ground-water movement; the thickness, porosity, permeability, and general character of the Paleozoic sedimentary formations underlying the surficial deposits; and the depth to and the porosity, permeability, and character of the Precambrian basement rocks underlying the sedimentary formations. From these data, the ability of a designated rock unit to accept, confine, transmit, or diffuse a specific chemical waste can be assessed. For guidance in such investigations, a selected bibliography of reports on underground waste disposal in other areas is included as an appendix to this report.

Underground liquid-waste disposal is not feasible in Devonian and Mississippian rocks underlying the area because the fresh ground-water supply, both deep and shallow, would be contaminated. Fresh water occurs below the Chattanooga Shale of Late Devonian age in the general area of Calvert City (Morgan, 1965). The water-bearing Paleozoic rocks are probably traversed by numerous fractures and many solution cavities, and ground water very likely moves freely between these rocks and the overlying surficial deposits, which for the most part are porous. A deep solution cavity at Kentucky Dam extended beneath surficial deposits to an altitude of about 75 feet above sea level (Moneymaker and Rhoades, 1945). The deepest well in the Calvert City quadrangle extends nearly to sea level. A sample of water from it contained 220 ppm (parts per million) dissolved solids, of which about 6 ppm were chloride anions (Morgan, 1965).

The fresh-saline water* interface in the quadrangle is shown by Hopkins (1966) to be 150 to 400 feet below mean sea level. This is as much as 400 feet below the deepest known fresh water in the quadrangle but is only a short distance below the deepest fresh water in the nearest control wells outside the quadrangle. The two nearest control wells shown by Hopkins are 7 miles south-southeast of Calvert City and 6 miles north-northwest. The dissolved solids in water from the two wells are 197 and 256 ppm, respectively, and the chloride contents are 4 and 11.5 ppm, respectively. According to the report by the Kentucky State Department of Health (written communication, 1964), the water sample from the well to the south-southeast came from a depth of 1,230 feet instead of the 820 feet shown by Hopkins. The drillers reported fractured Devonian limestone at the bottom of the hole. Electric resistivity and self-potential logs on this hole to a depth of 980 feet do not indicate a fresh-saline water interface, according to R. W. Davis (oral communication, 1967). These data indicate that the fresh-saline water interface in this hole is lower than 770 feet below mean sea level.

In the No. 1 Clark Heirs well in Ballard County, about 40 miles west of Calvert City, Walker (1956, p. 4) reports the recovery of fresh water on drill-stem tests at about 2,700 feet below mean sea level in the St. Peter Sandstone of Ordovician age. Hopkins does not show this well, possibly because the water was not analyzed, but he shows the fresh-saline water interface in the vicinity of the well to be only 850 feet below mean sea level. MacCary and Lambert (1962, p. 8) point out that the quality of water from Paleozoic bedrock in the Jackson Purchase region (Fig. 1) differs from that in the rest of Kentucky and that saline water in these rocks is rare, even at depths as great as 3,000 feet. These data indicate that in the Calvert City area, the fresh-saline water interface is probably lower than 800 feet below sea level and could be as low as 2,000 feet below sea level. More data are needed to adequately define the altitude of the fresh-saline water interface.

The feasibility of waste disposal in Lower Devonian and older formations beneath Calvert City can only be inferred from the character of these rocks in nearest outcrops and drill holes. These rocks do not crop out near Calvert City. Formations of Cambrian and Ordovician age and Precambrian granite crop out in the Ozark region of Missouri, and formations as old as Late Ordovician crop out along the Mississippi River in southern Illinois (Weller, 1940, p. 17-18, 61, 62-63). Howard R. Schwalb of the Kentucky Geological Survey (written communication, 1967)

* Fresh water is defined as water containing less than 1,000 ppm dissolved solids and saline water as water containing 1,000 ppm or more.

studied the geophysical logs and cores of the South Central Petroleum Company No. 1 Pearl J. Cherry well (Carter Coordinates 8-B-14) in Calverly County, about 30 miles south of Calvert City. According to Schwalb, rocks of Early Ordovician age, equivalent to the Gasconade Dolomite of Missouri, were intersected between depths of 5,400 and 5,610 feet. The well probably intersected a large cavernous zone below 2,988 feet because circulation was lost at this depth and was not restored during the remainder of drilling to the total depth of 5,610 feet. The nearest well that penetrates Cambrian formations is the M. D. Davis No. 1 (17-L-16), drilled to a depth of 8,821 feet in Crittenden County, about 30 miles north of Calvert City (McGuire and Howell, 1963, p. A-3). The Shell Oil Company information release (mimeographed report, undated) on this hole reported a small flow of fresh water at a depth of 1,805 feet from Devonian limestone and reported 40 barrels per hour of salty (54,000 ppm chlorides) sulfur water at 5,498 feet and 64 barrels per hour of salt (130,000 ppm chlorides) water at 7,978 feet from the Knox Dolomite of Late Cambrian and Early Ordovician age. Run number two of the electric log showed the fresh-saline water interface at depths of 4,300 to 4,500 feet. The only formations in the lower Paleozoic section that appear to have intergranular porosity sufficient for liquid-waste disposal are the St. Peter Sandstone and parts of the Knox Dolomite. Based on information from the No. 1 Clark Heirs well, the St. Peter may contain fresh water.

Only a few wells have been drilled to the Precambrian in Kentucky (McGuire and Howell, 1963, table 2-2, p. 2-4). None of these are close to Calvert City. In the Calvert City area the depths to Precambrian basement rocks, according to the basement map of North America (Am. Assoc. Petroleum Geologists and U. S. Geol. Survey, 1967), are on the order of 9,000 feet. H. R. Schwalb of the Kentucky Geological Survey (oral communication, 1968), however, concludes that the depths to Precambrian basement in the Jackson Purchase region probably exceed 10,000 feet and in the Calvert City area may be as much as 12,000 feet. He based his conclusions on extrapolations into Kentucky of data from two holes—the Gulf Oil Corporation No. 1 Spinks Clay (sec. 25, T. 2 S., R. 13 E.), Henry County, Tenn., and the Humble Oil and Refining Company No. 1 James Pickel (sec. 21, T. 13 S., R. 2 W.), Union County, Ill.—that bottomed in rocks of Cambrian age at depths of 10,748 feet and 8,400+ feet, respectively. These holes were drilled after the preparation of the basement map of North America.

Numerous faults traverse the Calvert City area, and fractured rock below the fresh-saline water interface may offer favorable sites for liquid-waste disposal. The possibility should be considered that discharge of liquid waste into a fault zone could activate movement along faults and consequently cause earthquakes. Recent earthquake activity

in the Denver, Colo., area has been attributed by Evans (1966a; 1966b) to disposal of liquid waste into fractured Precambrian gneiss at a depth of about 12,000 feet.

CONSTRUCTION MATERIALS

Abundant resources of limestone, gravel, and sand are available in the Calvert City area (Amos and Finch, 1968). Large amounts of limestone have been produced for concrete aggregate and riprap by the Reed Crushed Stone Company, Inc., 1.5 miles northeast of the locks of Kentucky Dam. Small amounts of rough building stone have been quarried from the Warsaw Limestone at several places near the center of the quadrangle.

Gravel used for road metal is obtained chiefly from the continental deposits; small amounts are obtained from narrow gravel ridges near the margins of the lacustrine and fluviolacustrine deposits and from the Tuscaloosa Formation. The locations of the pits are shown on GQ-731 (Amos and Finch, 1968). Gravel from pits in the Tuscaloosa near Gravel Switch, in the southeastern part of the quadrangle, has also been used for railroad ballast. Sand has been obtained for subfoundation fill from a pit in the McNairy Formation about 2 miles southeast of Calvert City.

REFERENCES CITED

- American Association of Petroleum Geologists and U. S. Geological Survey, 1967, Basement map of North America between latitudes 24° and 60°N: U. S. Geol. Survey, scale 1:5,000,000
- Amos, D. H., and Finch, W. I., 1968, Geologic map of the Calvert City quadrangle, Livingston and Marshall Counties, Kentucky: U. S. Geol. Survey Geol. Quad. Map GQ-731
- Calvert City and Kentucky Department of Commerce, 1962, Industrial resources, Calvert City, Kentucky: Frankfort, 44 p.
- Evans, D. M., 1966a, The Denver area earthquakes and the Rocky Mountain Arsenal disposal well: *Mountain Geologist*, v. 3, no. 1, p. 23-36
- 1966b, Man-made earthquakes in Denver: *Geotimes*, v. 10, no. 9, p. 11-18
- Finch, W. I., 1968, Engineering geology of the Kentucky parts of the Paducah West and Metropolis quadrangles: U. S. Geol. Survey Bull. 1258-B, in press
- Fuller, M. L., 1912, The New Madrid earthquake: U. S. Geol. Survey Bull. 494, 119 p.; reprinted, Cape Girardeau, Mo., Ramfre Press [1958]
- Hendricks, E. L., 1964, Compilation of records of surface waters of the United States, October 1950 to September 1960—Pt. 3-B, Cumberland and Tennessee River basins: U. S. Geol. Survey Water-Supply Paper 1726, 269 p.
- Hopkins, H. T., 1966, Fresh-saline water interface map of Kentucky: Kentucky Geol. Survey, ser. 10, scale 1:500,000
- International Conference of Building Officials, 1964, The uniform building code: Pasadena, Calif., v. 1, 503 p.
- MacCary, L. M., and Lambert, T. W., 1962, Reconnaissance of ground-water resources of the Jackson Purchase region, Kentucky: U. S. Geol. Survey Hydrol. Inv. Atlas HA-13, 9 p.
- McGuire, W. H., and Howell, Paul, 1963, Oil and gas possibilities of the Cambrian and lower Ordovician in Kentucky: Lexington, Spindletop Research Center, prepared for Kentucky Department of Commerce, 218 p.
- Moneymaker, B. C., and Rhoades, Roger, 1945, Deep solution channel in western Kentucky: *Geol. Soc. America Bull.*, v. 56, p. 39-44
- Morgan, J. H., 1965, Availability of ground water in the parts of the Little Cypress and Calvert City quadrangles in the Jackson Purchase region, Kentucky: U. S. Geol. Survey Hydrol. Inv. Atlas HA-155

- National Board of Fire Underwriters, 1955, The National Building Code: Chicago, 322 p.
- Nichols, T. C., Jr., 1968, Engineering geology of the Paducah East quadrangle, McCracken County, Kentucky: U. S. Geol. Survey Bull. 1258-A, in press
- Rhoades, R. F., 1940, Geology of the Kentucky project in Engineering geology of the Tennessee River system: Tennessee Valley Authority, Geol. Div. Tech. Mon. 47, p. 37-72
- Schlicker, H. G., Deacon, R. J., and Twelker, N. H., 1964, Earthquake geology of the Portland area, Oregon: Ore Bin, v. 26, no. 12, p. 209-230
- Tennessee Valley Authority, 1949, Geology and foundation treatment, Tennessee Valley Authority projects: Tennessee Valley Authority Tech. Rept. 22, 548 p.
- U. S. Federal Housing Administration, Architectural Standards Division, 1961, Engineering soil classification for residential developments: revised, Washington, D. C. (FHA No. 373), 168 p.
- Walker, F. H., 1956, Records of known wells in the Jackson Purchase region, Kentucky: Kentucky Geol. Survey, ser. 9, Inf. Circ. 8, 32 p.
- Weller, J. M., 1940, Geology and oil possibilities of extreme southern Illinois—Union, Johnson, Pope, Hardin, Alexander, Pulaski, and Massac Counties: Illinois Geol. Survey Rept. Inv. 71, 71 p.

APPENDIX

Selected Bibliography of Reports on Underground Waste Disposal

- Adinoff, J., 1955, Disposal of organic chemical wastes to underground formations in Ninth Indus. Waste Conf. Proc., May 10, 11, and 12, 1954: Purdue Univ. Eng. Dept. Ext., Ser. 87, p. 32-38
- Baker, J. A., Lang, S. M., and Thomas, M. P., 1965, Geology and hydrology of the Hartford Research Center, CANEL site, Middletown, Conn.: U. S. Geol. Survey Bull. 1133-G, 42 p.
- Beikman, H. M., 1962, Geology of the Powder River Basin, Wyoming and Montana, with reference to subsurface disposal of radioactive wastes: U. S. Geol. Survey open-file report, 85 p.*
- Birch, Francis, 1958, Thermal considerations in deep disposal of radioactive waste: Natl. Acad. Sci.—Natl. Research Council Pub. 588, 22 p.
- Colton, G. W., 1962, Geologic summary of the Appalachian basin, with reference to the subsurface disposal of radioactive waste solutions: U. S. Geol. Survey open-file report, 121 p.*
- de Laguna, Wallace, 1959, What is safe waste disposal?: Atomic Scientists Bull., v. 15, p. 34-43
- 1966, A hydrologic analysis of postulated liquid-waste releases, Brookhaven National Laboratory, Suffolk County, New York: U. S. Geol. Survey Bull. 1156-E, 51 p.
- de Witt, Wallace, Jr., 1961, Geology of the Michigan basin with reference to subsurface disposal of radioactive wastes: U. S. Geol. Survey TEI-771, 100 p.*
- Drescher, W. J., 1965, Hydrology of deep-well disposal of radioactive liquid wastes in Fluids in subsurface environments—a symposium: Am. Assoc. Petroleum Geologists Mem. 4, p. 399-406
- Hatch, L. P., Martin, J. J., and Ginell, W. S., 1954, Ultimate disposal of radioactive wastes: Brookhaven Natl. Lab., BNL-1781, 31 p.
- Hopkins, H. T., 1963, The effect of oilfield brines on the potable ground water in the Upper Big Pitman Creek basin, Kentucky: Kentucky Geol. Survey, ser. 10, Rept. Inv. 4, 36 p.
- Inoue, Yoritera, and Kaufman, W. J., 1962, Deep well injection of radioactive wastes: Health Physics Soc., Chicago, Seventh Ann. Mtg., 1962, 17 p. (preprint)
- Lansing, A. C., and Hewett, P. S., 1955, Disposal of phenolic wastes to underground formations in Ninth Indus. Waste Conf. Proc., May 10, 11, and 12, 1954: Purdue Univ. Eng. Dept. Ext., Ser. 87, p. 184-194

* Open-file reports may be consulted at one or more of the major U. S. Geological Survey depositories listed in U. S. Geological Survey Circular 518, and copies may be made upon request at the requester's expense.

- Leopold, L. B., and Tilson, Seymour, 1966, The water resource: *Internat. Sci. and Technology*, no. 55, p. 24-34
- Love, J. D., and Hoover, Linn, 1961, A summary of the geology of sedimentary basins of the United States, with reference to the disposal of radioactive wastes: *U. S. Geol. Survey TEI-768*, 89 p.*
- Lynn, R. D., and Arlin, Z. E., 1961, Deep well construction for the disposal of uranium mill tailing water by the Anaconda Co., at Grants, N. M.: *Mining Eng.*, v. 13, no. 11, p. 1254
- Manger, G. E., 1963, Porosity and bulk density of sedimentary rocks: *U. S. Geol. Survey Bull.* 1144-E, 55 p.
- Nace, R. L., 1960, Contributions of geology to the problems of radioactive waste disposal in *Disposal of radioactive wastes: Internat. Atomic Energy Agency, Vienna*, v. 2, p. 457-480
- 1961, Underground storage of radioactive wastes: *Interstate Oil Compact Comm. Bull.*, v. 3, no. 1, p. 20-34
- Palmquist, W. N., and Johnson, A. I., 1962, Vadose flow in layered and nonlayered materials: *U. S. Geol. Survey Prof. Paper* 450-C, p. C142-C143
- Pierce, W. G., and Rich, E. I., 1962, Summary of rock salt deposits in the United States as possible storage sites for radioactive waste materials: *U. S. Geol. Survey Bull.* 1148, 91 p.
- Repenning, C. A., 1959, Geologic summary of the San Juan Basin, New Mexico, with reference to disposal of liquid radioactive waste: *U. S. Geol. Survey TEI-603*, 57 p.*
- Roedder, Edwin, 1959, Problems in the disposal of acid aluminum nitrate high-level radioactive waste solutions by injection into deep-lying permeable formations: *U. S. Geol. Survey Prof. Paper* 1088, 65 p.
- Sandberg, C. A., 1962, Geology of the Williston basin, North Dakota, Montana, and South Dakota, with reference to subsurface disposal of radioactive wastes: *U. S. Geol. Survey open-file report*, 148 p.*
- Skibitzke, H. E., 1961, Temperature rise within radioactive liquid wastes injected into deep formations: *U. S. Geol. Survey Prof. Paper* 386-A, 8 p.
- Skibitzke, H. E., and Robinson, G. M., 1963, Dispersion in ground water flowing through heterogeneous materials: *U. S. Geol. Survey Prof. Paper* 386-B, 3 p.
- Stewart, J. W., 1964, Infiltration and permeability of weathered crystalline rocks, Georgia Nuclear Laboratory, Dawson County, Ga.: *U. S. Geol. Survey Bull.* 1133-D, 59 p.

* Open-file reports may be consulted at one or more of the major U. S. Geological Survey depositories listed in U. S. Geological Survey Circular 518, and copies may be made upon request at the requester's expense.

Stewart, J. W., Callahan, J. T., Carter, R. F., and others, 1964, Geologic and hydrologic investigation at the site of the Georgia Nuclear Laboratory, Dawson County, Ga.: U. S. Geol. Survey Bull. 1133-F, 90 p.

Theis, C. V., 1955, Geologic and hydrologic factors in ground disposal of waste in Sanitary Eng. Conf., Baltimore, 1954: U. S. Atomic Energy Comm. WASH-275, p. 261-283