GEOLOGIC EVALUATION OF SANITARY LANDFILL SITES IN TENNESSEE

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CONTENTS

Page

ILLUSTRATIONS

GEOLOGIC EVALUATION OF SANITARY LANDFILL SITES IN TENNESSEE

By

Robert A. Miller[1] and Stuart W. Maher[2]

ABSTRACT

The Tennessee Solid Waste Disposal Act of 1969 requires that all existing and proposed community disposal sites be evaluated by the Tennessee Department of Public Health. From a geologic standpoint, the following criteria must be met for a landfill site: maintenance of environmental quality, safety of operation, material suitability, site accessibility, and ease of day-to-day operation.

Various aspects of topography, geology and hydrology must be examined for each proposed site. These include relief, stability of earth materials, presence of karst features, and surface and subsurface hydrology. Data must also be obtained on the nature and depth of the regolith and on bedrock and rock-weathering features.

Few satisfactory landfill sites exist in the Unaka Mountains of East Tennessee because of high relief, steepness of topography, rapid runoff, thin soils, and potential mass movements. Rocks of the Valley and Ridge province are also restricted in their suitability for landfills, but various formations, particularly the thicker shale units, can be used. Acceptable sites on the Cumberland Plateau are scarce, and there, also, shale areas offer possibilities; coal strip mines also may provide acceptable sites.

In the Central Basin of Middle Tennessee, the most desirable landfill sites are in areas underlain by the Hermitage Formation, the Bigby limestone facies of the Bigby-Cannon Limestone, and extensive outliers of the Fort Payne Formation. Areas underlain by rocks of the Stones River Group are probably the poorest in the State for landfill use because of shallow soils, karst features, and irregular bedrock configuration. Cherty Mississippian rocks of the Highland Rim offer many potential sites, but karst features and ground-water conditions must be given special attention.

In West Tennessee many potential sites are present in Cretaceous and Tertiary sands and clays. Because some of the sands are important aquifers, special care must be taken to avoid ground-water contamination. Extremely shallow aquifers and flooding make all river-bottom areas, such as the Mississippi River valley, unacceptable for landfills.

INTRODUCTION

The sophisticated technological society of 20th century America has produced a high degree of affluence which, in combination with a rapidly increasing population, generates an enormous volume of waste. This volume of waste has become so large that it not only causes widespread offensive landscapes, but also even imperils our health. We simply must find solutions to the problems it creates; neither our physical health nor our sense of beauty can endure unless we do.

It is estimated that each American discards 6 to 8 pounds of solid waste per day. For our population of 200 million, this amounts to 600,000 to 800,000 tons of solids a day. Enormous amounts of industrial solid wastes are also produced daily. The disposal of this material is a major problem which is further complicated by the toxic nature of some of the wastes, the undesirable substances generated as it decays, the pathogens it contains, the vectors attracted to it, and the direct costs incurred in collecting, transporting, and disposing of it.

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That many of our methods of waste handling and disposal are unsatisfactory (i.e., open dumps, litter, auto graveyards, etc.) is obvious to anyone who travels a few miles along most highways, or along nearly any stream. Similarly, polluted springs and wells, odor, and smog resulting from existing disposal systems tells us that we are using undesirable and, indeed, unsafe means of waste handling. More intensive use by more people of an environment that is finite means, among other things, that "my freedom to pollute infringes my neighbor's rights to beauty and safety—my freedoms end where my neighbor's rights begin." This condition has led to governmental intervention in waste disposal operations.

The Tennessee Legislature passed the "Tennessee Solid Waste Disposal Act" (Tennessee Code Sects. 53-4301 through 53-4315) in May 1969. This law requires closing open dumps, prohibits unregulated burning that pollutes the air, and also prohibits placing waste into "The waters of the State except in a manner approved by the Department [of Public Health] and the Tennessee Stream Pollution Control Board." The effect of this law is to require disposal in a sanitary landfill that meets standards established by the Division of Environmental Sanitation and Solid Waste Management, Department of Public Health.

This report attempts to define the requirements of site location as related to geological factors, on the basis of research that has been done in Tennessee as well as some other states. The standards outlined herein are, therefore, not presented as final but are subject to modification by the findings of research programs which must be carried out in the future. These standards are designed to serve as a guide to aid sanitary engineers, sanitarians, and technologists in avoiding the geologic problems inherent in landfill site location.

Before outlining those environmental requirements of sanitary landfill sites that relate directly to geology we must define a sanitary landfill. For purposes of this report it is defined as a system of disposal of solid waste in the ground by spreading, compacting, and covering the waste with earthy materials on a daily basis so that no refuse is left exposed; and in a site that retains the waste so that it or its decomposition products do not pollute the surrounding rock, soil, water, and air (fig. 1).

From this definition certain basic requirements or criteria can be derived. A site must be able to accommodate a large volume of waste material without contaminating ground water or surface water. It must also have a practical usability—i.e., it must have an adequate thickness of residuum, the residuum must be workable (wet or dry) by machinery, and the topography of the site must allow ease of access, operation, and maintenance with a reasonable degree of safety. Operation of the site also should be as aesthetically compatible with the environs as possible. As little of the landscape as is practical should be disrupted, and previously disrupted land areas should be reclaimed wherever possible.

Numerous geologic criteria must be met to accommodate these requirements. These are presented in this report in the order in which one investigating a potential site would most likely consider such problems in an evaluation study. The surface configuration of the site is the first consideration. Next is an understanding of some of the general features of the "soil" that covers the site, such as its depth and composition. Then one must consider the rock that may outcrop in some places within the site, or that is known to underlie the soil, and further seek to understand the relationships of this soil to bedrock—how the rock weathers and the composition of the soil. Finally, special attention must be given to the movement of ground water—and potentially landfill leachate—through or across the soil and rock, and into aquifers or surface drainage.

The second part of the report describes the various physiographic subdivisions of the State and the rock units in each area. These rock units are evaluated according to the criteria outlined earlier in the report, and the favorable and unfavorable aspects of each are specified.

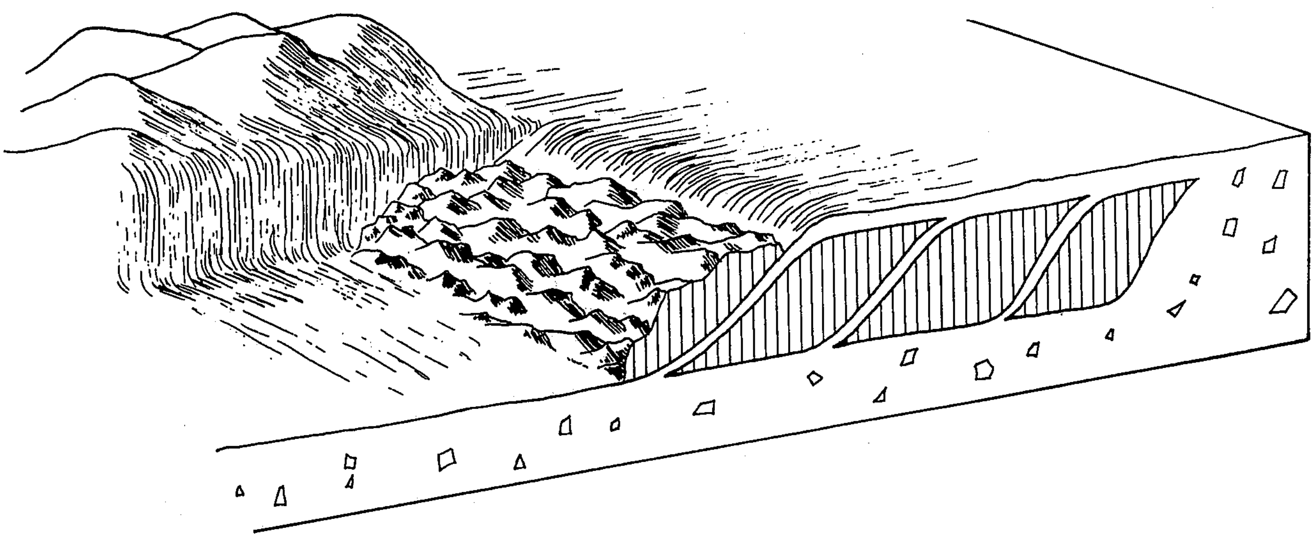

FIGURE 1.—Diagrammatic sketch showing the trench method of landfill operation. Each "cell" represents one day's collection of refuse, and is covered at the end of each day's operations.

ACKNOWLEDGEMENTS

This report was prepared under the direction of Robert E. Hershey, State Geologist. Field investigations and discussions with staff members of the Solid Waste Section, Division of Environmental Sanitation and Solid Waste Management, Tennessee Department of Public Health, under the supervision of David H. Booth, were most valuable in providing data for this report.

Some of the original field investigations were made by Charles M. Woodruff, Jr., who was employed by the Tennessee Division of Geology at that time, and the outline for this report is modified from a version he originally suggested.

Robert J. Floyd, Tennessee Division of Geology, Eugene D. Lockyear, Tennessee Department of Public Health, and C. W. Wilson, Jr., Vanderbilt University, reviewed the manuscript and provided helpful suggestions for improvements.

Photography is by George Hornal, Staff Photographer for the Department of Conservation.

GEOLOGIC CONSIDERATIONS, CRITERIA, AND PROCEDURES

Topography

GENERAL

Topography is the configuration of the earth's surface, including its relief, locations of bodies of water, roads, buildings, and other natural and cultural features. This definition has been modified from classical definitions to include the works of man as well as natural features. So defined, the topography is a prime factor in selection of landfill sites, for it includes such considerations as accessibility, drainage, location, and social factors.

Much topographic information is available in the form of topographic maps; that is, maps that identify, locate, and depict the features listed above, drawn to a scale, and using conventional symbols and colors to represent them. About 95 percent of Tennessee is covered by accurate and detailed topographic maps at a scale of 1 inch=2,000 feet. Properly used and studied, these maps often not only permit the elimination of certain areas for landfill sites, but also help to identify sites that merit further consideration.

Topography commonly reflects the character and geologic history of the rocks of a region. In fact, it is the result of the action of such geologic processes as mountain building, weathering and erosion, vulcanism, and other factors on earth materials. This principle is well illustrated in Tennessee by the various distinct topographic (or physiographic) regions of the State.

Rocks that resist weathering, especially chemical weathering, stand higher than the formations more readily attacked by weathering and erosion. Generally, sandstones, siliceous dolomites, cherts, and igneous rocks form ridges, whereas shales and limestones commonly form valleys. Extensively broken and cracked rocks, which allow access of water, weather and erode more readily than unfractured rocks. Regions that have stood above sea level for long periods of geologic time exhibit drainage patterns in which streams are flowing along lines of less resistant rocks. This is especially evident in much of East Tennessee.

RELIEF

An important element in topography is the *difference* in elevation between the high and low places in an area—the relief. Sites for landfills should be in areas of low relief, and steep slopes should be avoided even in areas of low relief. Areas with abrupt changes in relief and steep slopes are erosion-prone and make moving equipment difficult to operate. There is also a possibility of mass movement of materials down slope in such terrain.

Criteria and Procedures

(1) Areas of low to moderate relief
(2) Gentle to moderate slopes
(3) Uniform slopes

SLOPE STABILITY

Slope stability refers to the tendency of materials to remain at rest on a sloping surface. In areas where excavation, freeze and thaw cycles, saturation by rainfall, and other factors result in mass movements (also called gravity movements), stability is low. Also, in general, the steeper a slope, the less stable it is likely to be when subjected to these forces.

Gravity Movements

Several types of gravity movements must be considered in selecting landfill sites, such as slump (also called slope failure), debris flow, debris avalanches, and rock slides. In Tennessee, slump is the most common form of mass movement (figs. 2 and 3). It is characterized by the outward and downward movement of a curved wedge of semiconsolidated or unconsolidated material. Slump is common where weakly cohesive material is undercut at the base of a slope or escarpment, and therefore deep unconsolidated or weakly cemented materials should never be undercut on steep faces.

Study of the maps of an area with attention to arc-shaped scarps and hummocky terrain at the base of slopes is important; in the field small "slip" scarps, "rubbly" slopes, tilted trees, and related features are indicators of mass movements. Insights can also be gained by observing the stability in existing cuts, such as those made in highway construction. Areas having a high instability potential pose problems in operation because of slides and slope failure, and the possibility of risk to life and serious damage by large-scale failure of the slope.

Slopes most prone to failure are (a) deeply weathered, (b) steep, (c) mantled by saturated materials or materials capable of absorbing large amounts of water in wet seasons, (d) covered by unconsolidated

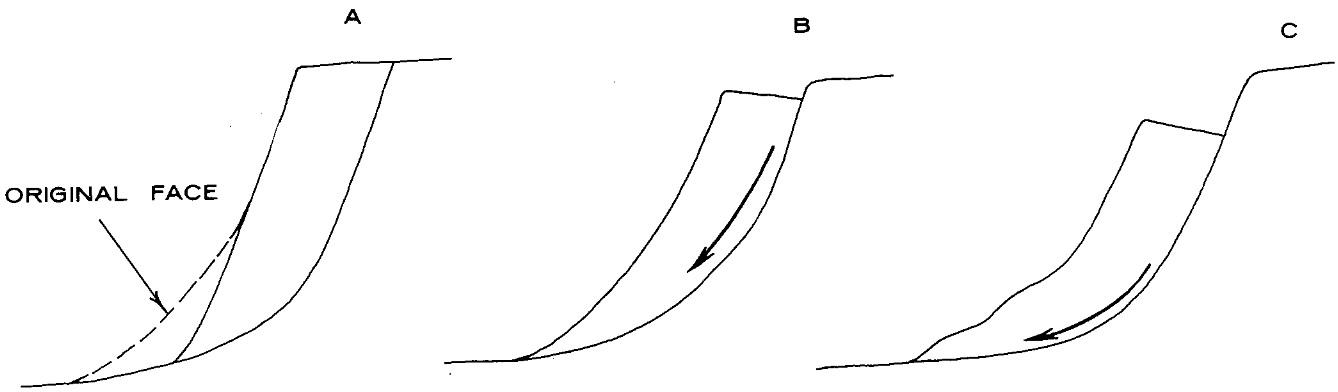

FIGURE 2.—Undercutting of semiconsolidated, jointed, or otherwise weakened or noncohesive material may result in the downward and outward movement of a slump block, such movement usually being very rapid. This type of mass movement is also called "slope failure."

FIGURE 3.—This photograph of slump development on Interstate 24 near Manchester, Tennessee, shows the typical curved "scarp" at the head of the slide. The water-saturated hummocky material at the toe of the slide shows evidence of debris flow, a slower movement which often follows slump. Such movements can be a nuisance or even hazardous in landfill excavation work.

random-sized materials (boulder-soil mixtures), (e) those showing evidences of previous mass movement, (f) slopes involving planes of fracture (joints, faults, etc.), (g) those with bedding planes that dip in the same direction as the slope (dip-slopes), (h) slopes underlain by weak material such as shale, and (i) slopes devoid of vegetation, especially well-rooted plants.

Criteria and Procedures

(1) Compare flood-plain width, valley profile, and channel characteristics with flood frequency and magnitude data. Do not locate landfills in areas having any flood history.
(2) Use bore hole investigations to locate the water table, gravel layers, and top of rock. Avoid levels subject to water table fluctuations or those that are permanently moist.
(3) Do not locate fills in or immediately above gravelly strata.

FLOOD PLAINS

Flood plains are the generally level "bottom lands" along streams, which are covered by water during floods. They are composed of unconsolidated clay, silt, sand, and gravels deposited by the stream. These areas are easily located on topographic maps by the wide spacing of contours and proximity to streams. Generally, the lands are cleared and used agriculturally.

The level surface, availability of cover material, and ease of excavation make flood plains seem attractive as landfill sites. However, other considerations suggest that these areas are generally poor. Frequent or even occasional flooding could completely wash away or severely damage a landfill, spreading waste material many miles downstream and allowing pollutants to enter the stream. In addition, flood plains commonly have a very shallow water table. Some are even swampy, indicating either a water table at ground level or the presence of a fragipan (a zone of impermeable material, such as a layer of hardened iron oxide or iron carbonate). This means that leachate[3] from the fill would have direct access to ground water. Also, there is the problem of the exchanging of water between the river and the zone of saturation (fig. 4). If ground water beneath the fill becomes polluted during low river water, the pollutants could move with the ground water into the stream. During high water, river water could move laterally into the flood-plain material and saturate the fill. Also, flood-plain alluvium is almost always wet and difficult to work (figs. 5 and 6).

Data on the frequency and level of floods are available from the U.S. Geological Survey, U.S. Army Corps of Engineers, and Tennessee Valley Authority. This information and its relationship to site elevation, valley profile and width, and channel characteristics should be utilized in evaluating sites on or near flood plains.

Criteria and Procedures

(1) Avoid areas of steep slope.
(2) Avoid areas showing evidence of previous slope failures and those with saturated unconsolidated residuum.
(3) Do not undercut fractured rock on steep slopes.
(4) Unconsolidated materials lying over weak shales on steep slopes are generally unstable.
(5) Avoid dip-slopes.

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[3] *Leachate is a solution emanating from solid waste and which contains dissolved and finely suspended solid matter and microbial waste products (modified from Brunner and Keller, 1971).*

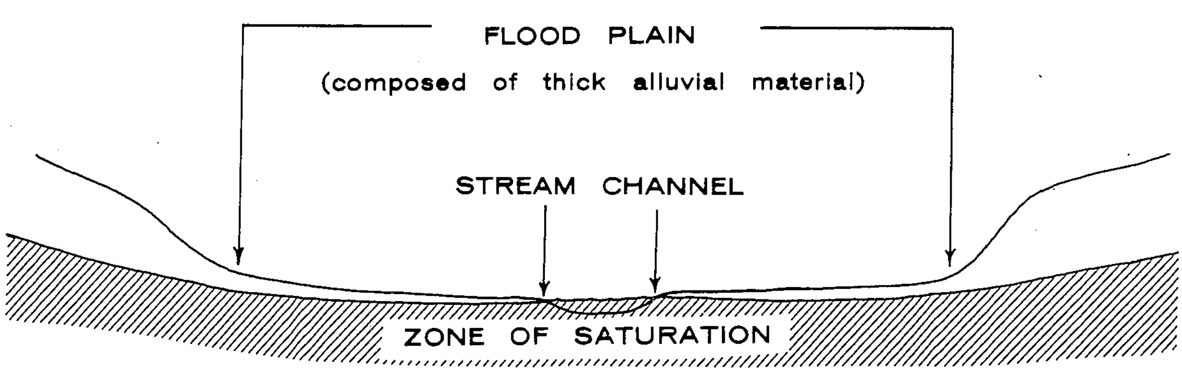

FIGURE 4.—In certain streams, typically those of West Tennessee, the flood plain is underlain by a very shallow water table which may intersect the stream, as shown in this illustration. Leachate reaching the zone of saturation can migrate easily into the stream, thus causing pollution of surface drainage as well as subsurface water.

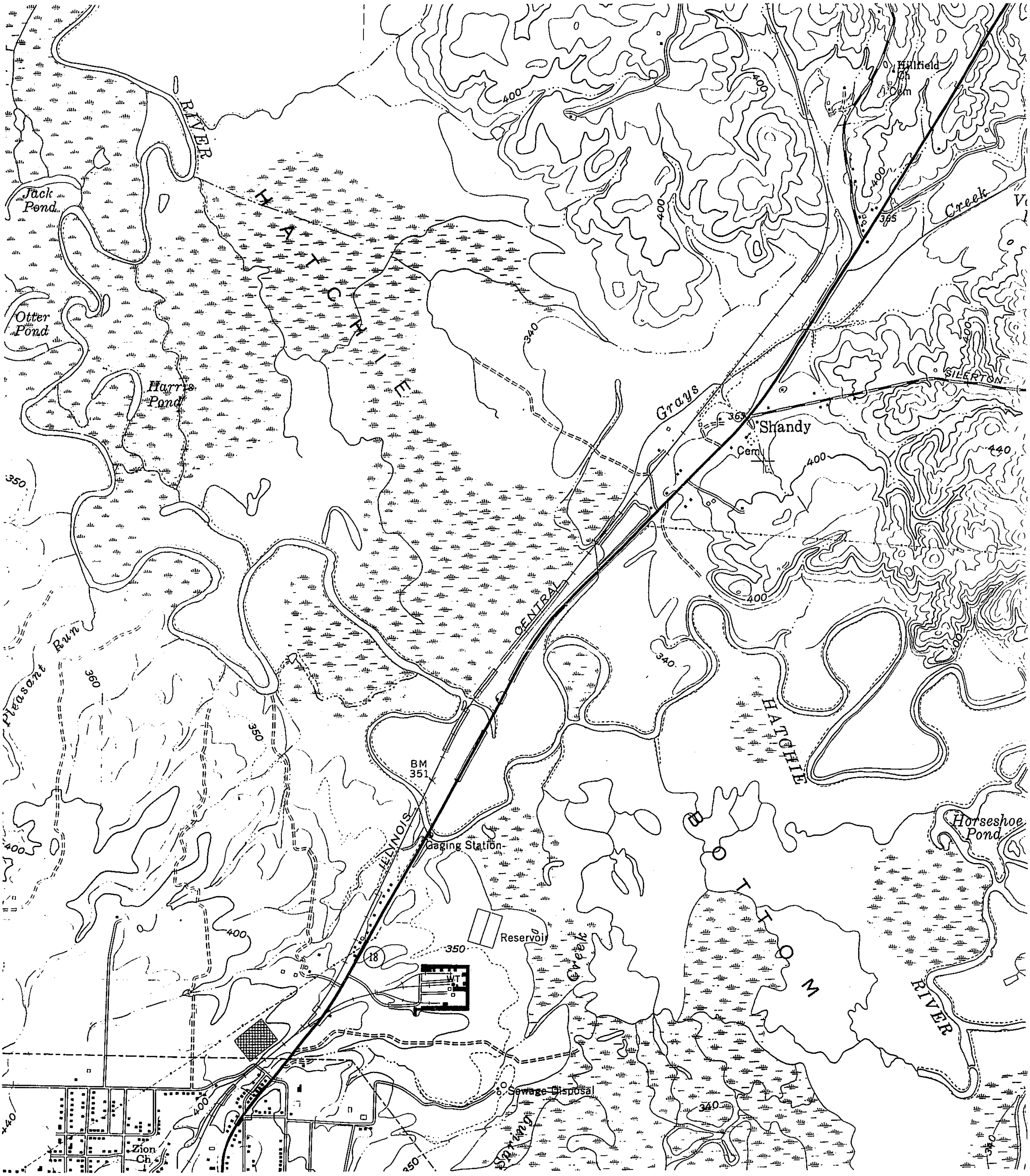

FIGURE 5.—This portion of the Bolivar East quadrangle illustrates the saturated nature of an extremely flat flood plain. The swamp areas are as much as 1¼ miles wide. West Tennessee streams characteristically have such flood plains.

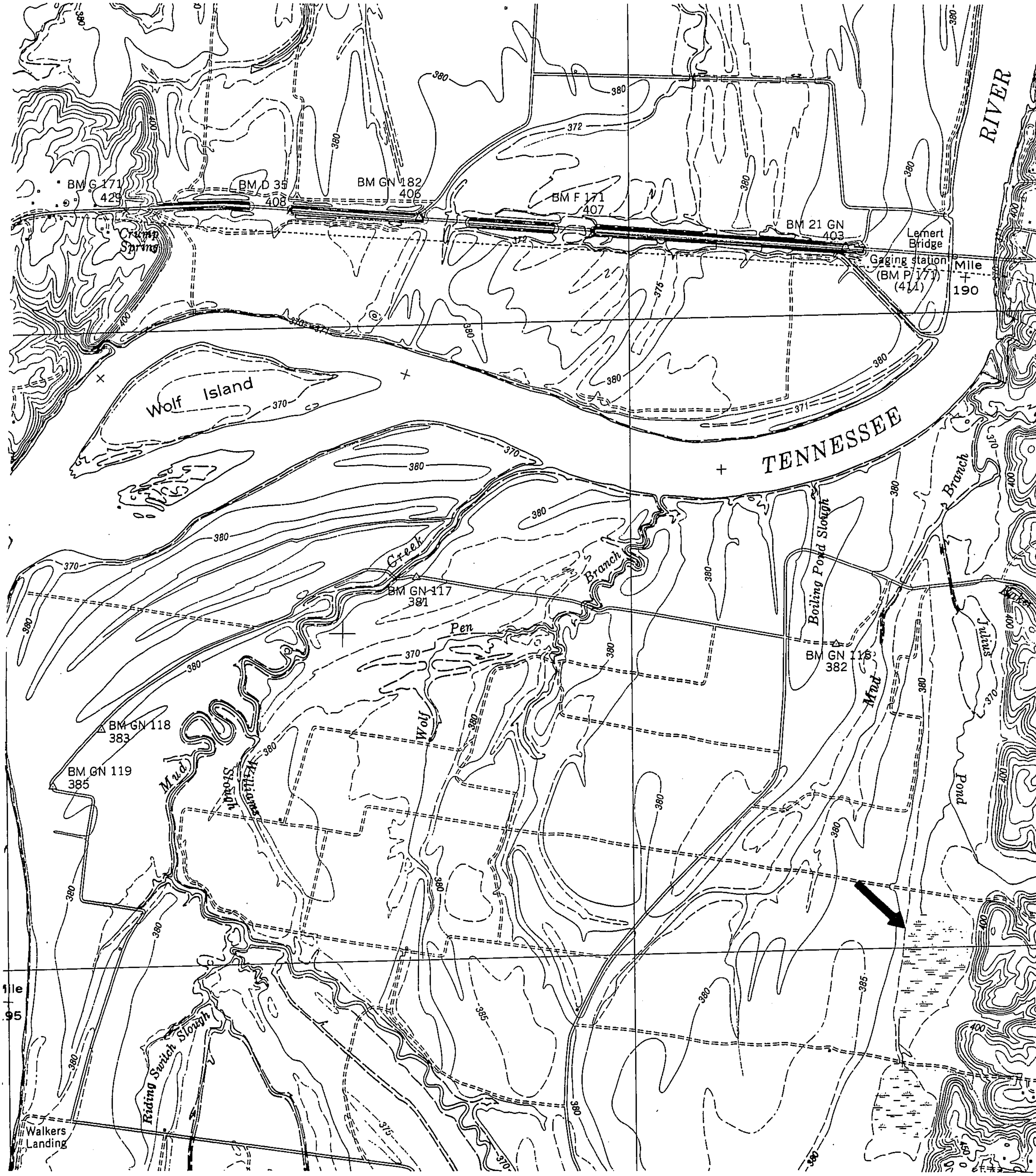

FIGURE 6.—Drainage developed on alluvial material may be complex, as illustrated by this portion of the Pittsburg Landing quadrangle. Note the "looped" patterns formed by the deposition of alluvium. Swampy areas in the nearly flat terrain are also present (shown by arrow).

KARST TERRAIN

This type of topography is characterized by sinkholes, caves, and similar solutional openings (fig. 7). Surface streams are few and typically flow into sinkholes to join the underground drainage system. The bedrock is characteristically limestone, dolomite, or marble. Such areas offer poor sites for landfills and should be avoided (fig. 8).

Drainage is accomplished by water entering sinks and fissures in the rock and flowing through solution openings, and then discharging from underground connections to surface streams or emerging as springs where topography intersects the water table. Sinkholes

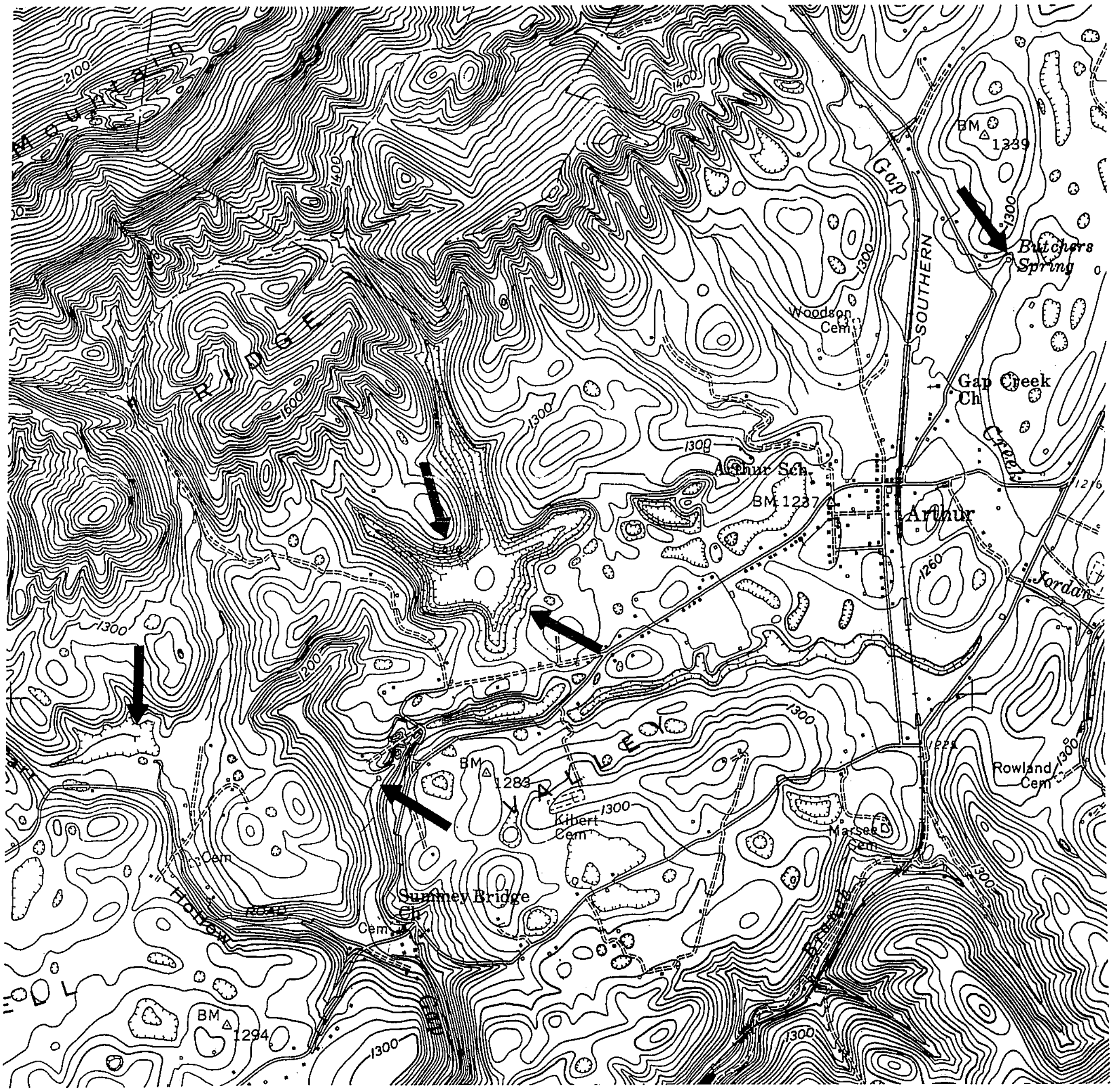

FIGURE 7.—This part of Powell Valley, Middlesboro South quadrangle, illustrates various karst features such as caves, springs, sinkholes, and disappearing streams (shown by arrows). This large system of caves and related features is developed in the Chickamauga Limestone.

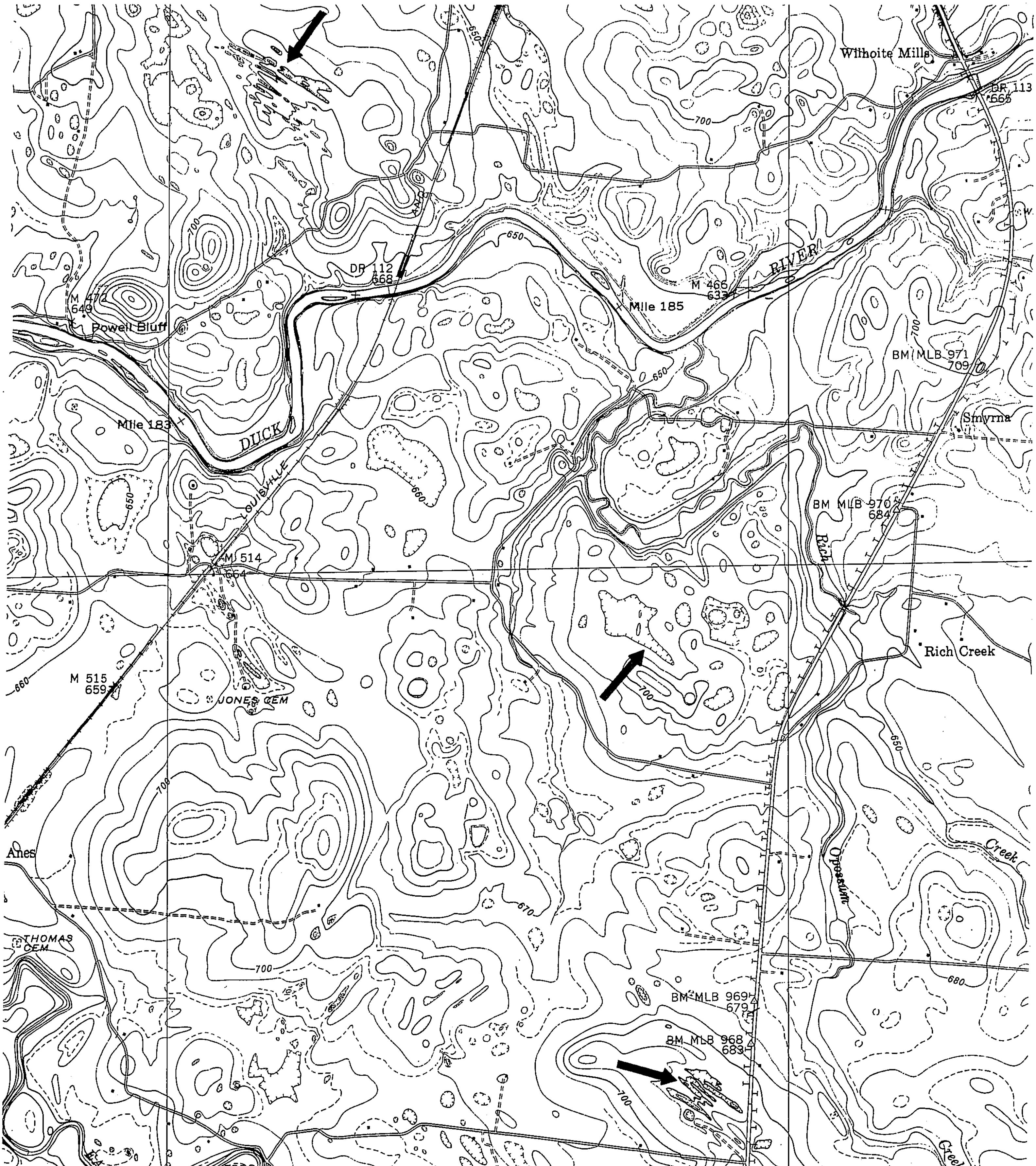

FIGURE 8.—Sinkholes, developed mostly in the Ridley Limestone, may have a linear pattern (shown by arrows), which is the result of joint control of solution in this area (Farmington quadrangle). Such sinkhole topography and subsurface drainage are typically developed in extensively jointed, relatively "pure" limestone.

deep enough to penetrate the water table contain ponds. In dry months the ponds may disappear as the water table drops, then fill again as the water table rises in the rainy season (fig. 9). Still other ponds form in "plugged" sinks and are subject to sudden loss of water. The open connections from surface to water table permit rapid introduction of undesirable materials into the water system with possible widespread effects.

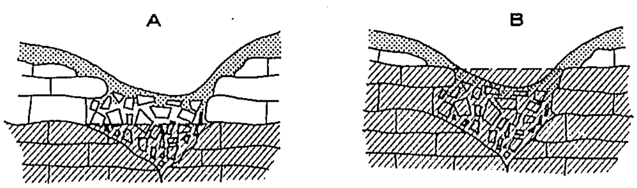

FIGURE 9.—During dry months, the water table may lie below the bottom of a sinkhole(A). In the rainy season the water table may rise to form a pond within the sink (B).

Areas of karst topography have notably irregular soil-rock interfaces. Thick soil overburden fills solutionally enlarged joints but thin soil covers the intervening rock "ribs." Sinks may or may not be filled with soil (depending upon basal openings). Active solution results in continued sink development and sometimes sudden collapse, which poses real dangers to the use of such areas (fig. 10).

Because the water table commonly conforms in a general way with the land surface configuration, drainage divides should be defined for they may control the direction leachate will migrate, perhaps into cavern systems and hence rapidly into the main zone of saturation.

Criteria and Procedures

(1) Karst areas should in general be ruled out as sites for landfills.
(2) Under *no circumstances* should refuse be placed in sinkholes or in close proximity to them.
(3) Use topographic maps to locate areas of sinks, caves, and water-filled sinks. The size, spacing, and number of such features should be noted, as they may imply the magnitude of underground openings.
(4) The water level in sinkholes may be an indicator of water table elevation.

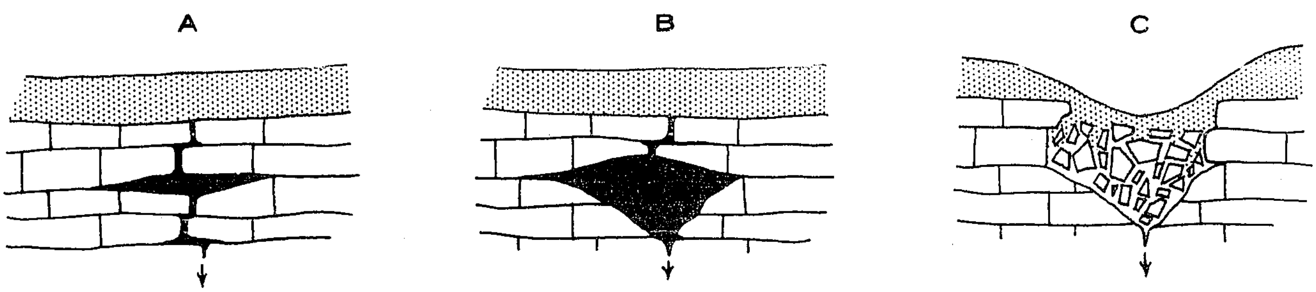

FIGURE 10.—Development of a sinkhole by solutional enlargement of joints and the eventual collapse of the "roof" of the cavern. An "incipient" sinkhole might collapse from the passage of trucks or other heavy machinery moving across it. Karst areas, regardless of the presence of sinkholes in the immediate site area, are underlain by caves and must be considered hazardous.

Regolith

GENERAL

The uppermost material encountered on the land surface in Tennessee is generally unconsolidated clay, silt, sand, broken rock fragments or various mixtures of these and other materials. This material includes the soil, subsoil, and (in engineering usage) materials that can be excavated without the use of explosives. For this unit the term regolith is used.

The suitability and mode of operation of a landfill site is dependent upon the properties of the regolith. The regolith in turn is strongly influenced by the source of its materials, the processes that have produced it, and its topographic configuration. Regolith materials consist essentially of rock-derived substances that have been affected and altered by such agents as weathering, erosion, mass movement, and plants and animals. Their origin may be the result of mechanical forces or chemical changes that affected the parental rocks, or the two in combination, or the material may be unconsolidated sediment that has been transported from a considerable distance. Perhaps the main point is that unconsolidated materials bear the imprint of their heritage and of their present environment, and understanding them involves knowledge of both factors.

Primary properties of the regolith as they bear on landfill site selection include thickness, geometry, composition (rock fragments, sand, gravel, etc.), permeability, resistance to slope failure, and workability. These and other aspects of earth materials are the province of soil scientists and engineers. Information is generally available from the agricultural departments of colleges, through the U. S. Department of Agriculture's Soil Conservation Service, and Forest Service (which has established guidelines for landfills in National Forests). The advice of these scientists and their reports should be used; their experience and knowledge is fundamental to sound landfill practice.

It is difficult to summarize briefly regolith conditions in Tennessee because geologic conditions are notably variable in different regions, and even in small areas where bedrock geology is complex. Somewhat more detailed observations are presented in the section on *Physiography and Geology*.

DEPTH TO ROCK

The depth to rock is variable over different bedrock types. It is also influenced by the rate of erosion, which in turn is controlled by climate. In general, regolith is thickest in regions of low relief, humid warm climates, geologically young and unconsolidated deposits, and regions of rock types subject to chemical decay. Thick mantle is also developed in the mountain regions of East Tennessee, where feldspar-rich crystalline bedrock is altered to clays by high rainfall and abundant humic acid. The residuum overlying the Knox Group is locally thick (but very irregularly so), owing to chemical weathering along fracture and bedding planes in the soluble carbonate formations. Very thick unconsolidated deposits underlie much of West Tennessee, as the rock units there are geologically young and have not been subjected to the process of lithification, or hardening into "bedrock." On the other hand, areas underlain by shales and sandstones, rocks that are chemically stable at the surface, generally develop relatively thin soils. It also appears that relatively pure homogeneous limestones, especially those that are thin-bedded and that have not been much deformed (as those underlying substantial parts of Middle Tennessee), decay slowly enough that soil formation and its removal by erosion are nearly balanced and thin overburden results.

Areas of steep slopes and high relief are easily denuded of soils by erosion, especially if the vegetation is disturbed. Therefore, steep slopes generally have a thin covering mantle and numerous bedrock outcrops. Where resistant rock ledges crop out up slope, boulders and other rock fragments litter the slopes below as talus and other colluvial masses. Obviously, such slopes are poor landfill sites.

Depth of the regolith can be *estimated* by examining man-made cuts, by observation of the number and spacing of bedrock outcrops and the nature of the bedrock, and by obtaining data from experienced builders and well drillers in the neighborhood. Data at a *particular* site can be obtained by auger drilling, by seismic study, or by using a portable resistivity unit. Auger borings are of limited value in rocky soils, because a sizeable rock fragment encountered will appear to be bedrock and thus indicate deceptively thin soil. Furthermore, where the rock-soil interface is highly irregular (as in areas underlain by massively bedded carbonate rocks), closely spaced holes must be bored to obtain reliable information. In contrast, seismic surveys can give continuous data over the area investigated and provide good detail in some cases. A portable resistivity unit indicates the presence of water in soils, and assists in determining depth to bedrock.

Criteria and Procedures

(1) Avoid extremely wet soils or soils where seepage is noted in bore holes or trenches.
(2) Avoid gravelly soils (they may provide water courses).
(3) Avoid placing bottom of disposal cuts on bedrock (bedrock surfaces may provide drainage planes).
(4) Consult Soil Conservation Service for drainage and compaction data on various soils.

Bedrock

GENERAL

Everywhere the land surface is underlain by rock masses—the bedrock. In some places the bedrock is covered by soil, rock fragments, and organic debris (residuum and colluvium); in others it is covered by unconsolidated sediment; and in still other places there is no cover and the bedrock is exposed.

Bedrock properties that influence landfill site selections result from the nature of the bedrock, the manner and depth to which it has weathered, and its ability to accept and transmit fluids. Here, as in preceding sections, some generalized remarks are offered and more detailed discussions are given in the section on *Physiography and Geology*.

Construction engineers distinguish rock from soil on the basis of techniques required to excavate the material. If drilling and blasting are required, the material is classified as "rock." If, on the other hand, the material can be removed by ripper or shovel, it is considered to be "soil." For landfill use, however, ease of "rock" or "soil" removal are less important than such factors as compactability, permeability, general workability, and consistency of composition.

Primary Properties of Bedrock

(1) Rock type—limestone, shale, sandstone, granite, etc. This influences weathering properties and chance of solutional openings.

(2) Bedding—very thick uniform beds, "flaggy" beds, etc. Bedding may influence geometry and depth of weathering.

(3) Open spaces—how porous and permeable is the bedrock? Primary openings (porosity) are largest in rocks consisting of uniform-size, uncemented or poorly cemented coarse-grained rounded particles and smallest in those consisting of mixed size, fine-grained angular particles. Permeability is the ability of a rock material to transmit fluid and is dependent, therefore, on interconnecting open spaces. Poorly cemented rock is more likely to be permeable than well-cemented rock (fig. 11).

Secondary Properties of Bedrock

(1) Joints—joints are cracks produced in rocks by stresses acting after the rock was formed, but little or no movement has occurred along joints. In

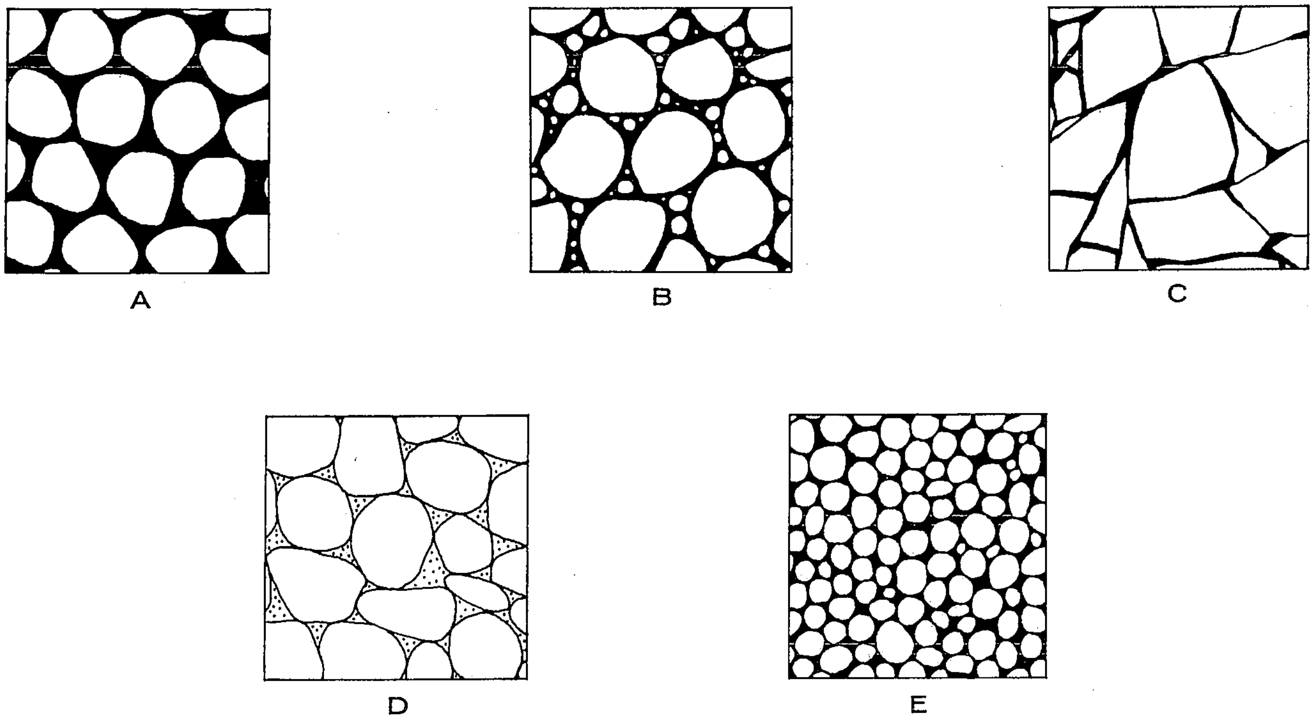

FIGURE 11.—Porosity is highest where particles are rounded, uncemented, and uniform in size (A); and is lowest where small particles fill the voids between large particles (B), or where angular fragments interlock (C).

Permeability is highest in uncemented material composed of large, rounded particles (A). The presence of cementing materials or clay particles (D) reduces open space (porosity) and also closes connections between voids, resulting in low permeability. Material composed of small particles (E) has low permeability because of the large amount of surface tension created by the greater surface area of the small particles, and because of the greater distance that fluids must move around the particles; although the permeability is low, the porosity is very high.

sedimentary rocks most joints are nearly perpendicular to the bedding. Joints open the rocks, and percolating solutions moving through them accelerate weathering (fig. 12). Joints also allow blocks of rock to move down slope under gravitational force.

(2) Faults—faults are planes of fracture along which movement has occurred in rock masses. These dislocations produce various effects, such as juxtaposing rocks normally separated by other rock units, and breaking and shattering rocks. Fault planes and broken rocks are places of weakness along which weathering may be more extensive than normal, and where open spaces may be developed. In areas of earthquakes, faults may be the loci of movement that causes heavy damage to structures on or near the fault line.

(3) Folds—rocks commonly are cast into "wrinkles" by earth-deforming forces. Originally horizontal strata are given the appearance of a wrinkled rug; the size of the "wrinkles" ranges from minute crinkles to structures many miles in extent. The effect of folding is to tilt the rocks, and to produce more or less fracturing, particularly along fold crests. This consequently results in variations in weathering, topographic slopes, and amenability to stability in cuts. Movement of ground water, and hence possibly landfill leachate, is anomalous in areas of such dipping rocks.

Rocks display other structural properties, both primary and secondary. Those described above are some of the ones most often encountered and most significant in engineering projects. Information about structural properties of rocks is given on geologic maps, which can be used to select areas having favorable landfill potential and to avoid problem areas. Areas where geologic mapping has not been done must, of course, be evaluated by field examination before even preliminary decisions are made concerning landfill site feasibility.

Criteria and Procedures

(1) Study the local stratigraphic section in an area before attempting to locate a landfill site. A geologic map is extremely helpful.
(2) Know the bedrock characteristics at a potential site and make observations in the field.
(3) Note all structural features, especially dip of bedding and the presence of fractures.

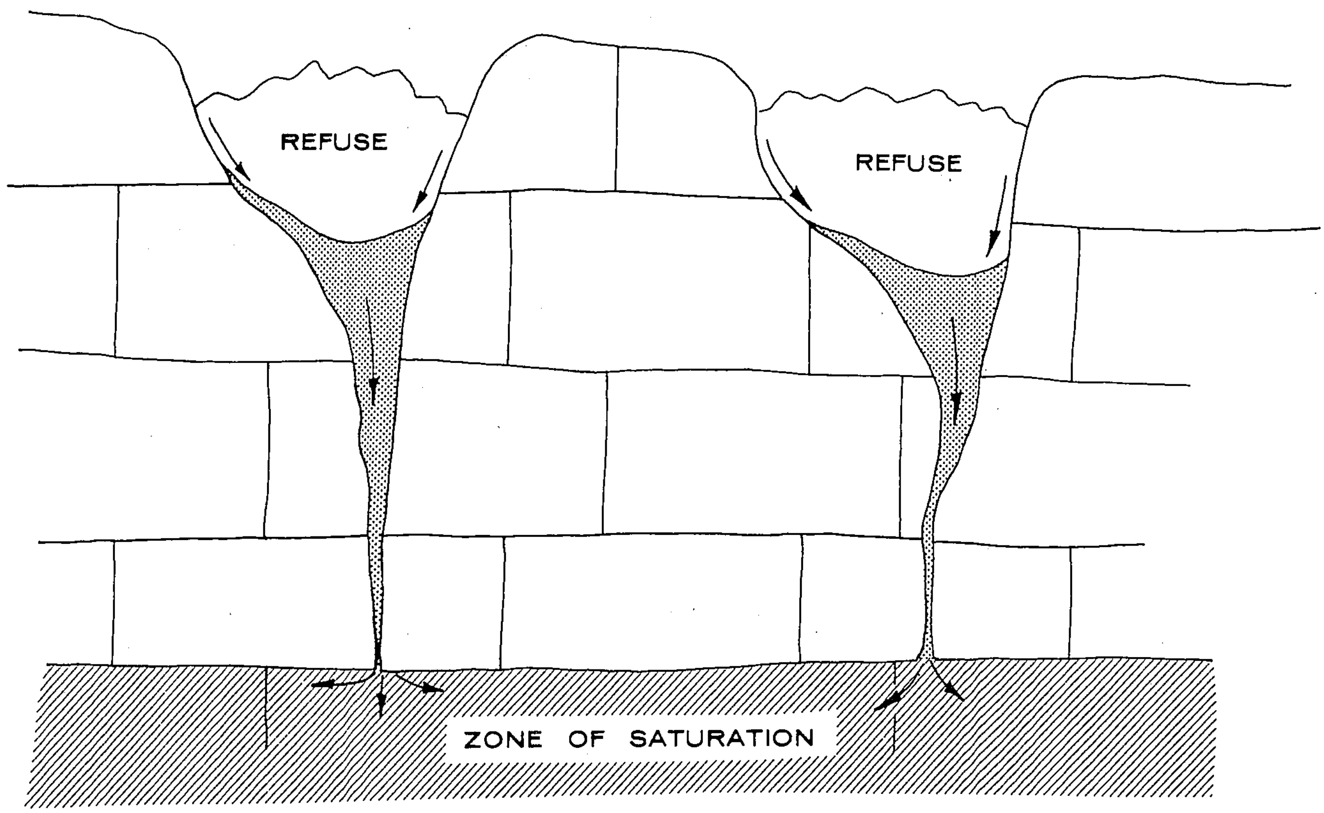

FIGURE 12.—Joints provide direct avenues of descent for leachate into the zone of saturation. They may actually tend to concentrate the leachate by "funneling" it into the narrow crevices at depth, thus decreasing the possibility for effective filtering.

Rock Weathering

GENERAL

Lower rock pressures, abundance of oxygen, activity of organisms, changes in temperature, presence of moisture, and freezing and thawing attack rocks and alter them to materials stable in a near-surface environment. These processes are collectively termed weathering. Two major processes of weathering are active—physical processes, which produce breaking and reduction of size of rock material (mechanical weathering or disintegration); and chemical processes, which alter the materials by changing their composition (decomposition). Thus, abrasion, frost-wedging, impacts against other rocks, and similar processes break large masses into smaller fragments by mechanical weathering; whereas, feldspars are altered to clays and soluble salts, and limestones are dissolved by natural acids, in chemical weathering.

The weathering features of a rock formation often will determine whether a potential landfill site is acceptable, regardless of other criteria. For example, if there is an inadequate thickness of residuum, or if the material is too clayey to be easily worked, it will be unacceptable. Therefore, it is most important to know the basic characteristics of the weathering products, geometry, and degree of weathering of a rock unit.

DEGREE

The type of rock, the dominant weathering process (mechanical or chemical), the length of time weathering has been in progress, presence of fractures, and climate all relate to the degree of weathering in an area. Long periods of rock decomposition may result in deep residuum, particularly if the underlying rock unit has a high percentage of insoluble constituents. Areas of such deep weathering, in general, are very desirable for landfills. Distintegration is more prominent in arid, semiarid, and cold areas.

In a temperate, moderately humid climate, such as that in Tennessee, the following typical soil profile will eventually develop after the onset of weathering (fig. 13). It consists of an upper zone (A-horizon) which contains humus, and which has been leached of soluble materials. For this reason, it is also called the "zone of leaching." Below this is the zone in which iron oxides and clay are accumulating, called the "zone of accumulation" (B -horizon). This grades into the lowest zone, consisting of less altered material (C-horizon), which grades downward into unaltered rock. As weathering progresses, each zone encroaches downward into the next, and thus the total profile becomes thicker with time. A soil with a fully developed profile is called a mature soil. Such soils may be 100 feet or more deep but are usually much thinner. Quite commonly, particularly in limestone areas, large blocks of essentialy unweathered rock remain in the C-horizon. These present a serious problem in operating a landfill. Again, the definition of "soil" becomes a problem. It should be pointed out that to the geologist soil and residuum are synonymous terms. To the pedologist or agronomist, soils are zones in which plant life grows.

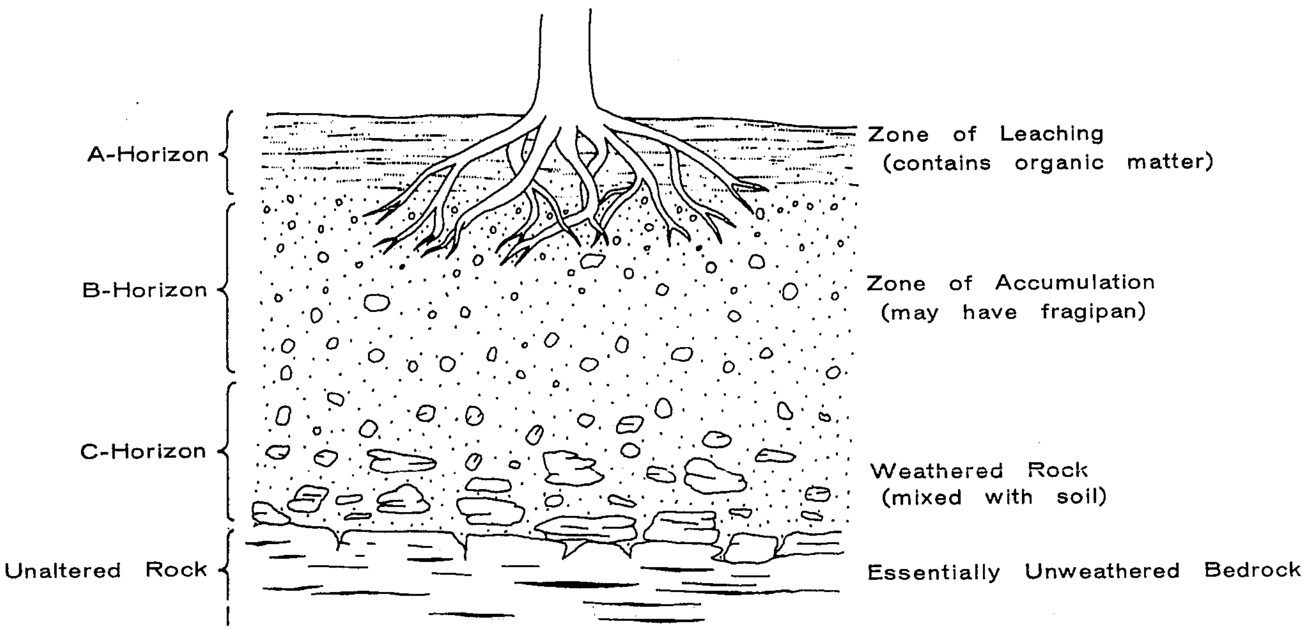

FIGURE 13.—Major soil horizons in a typical soil profile. Each grades into the other and, as weathering progresses, each encroaches downward into the underlying layer, thus causing the zones to become thicker with time.

GEOMETRY

The configuration of the bedrock-residuum interface is a very important consideration. Also important is the cause of a particular configuration. It is necessary to emphasize here that in many places there is no distinct break between residuum and bedrock. Therefore, the reference to the interface is to a zone in some cases rather than to a specific surface.

In flat-lying, nonjointed shales, sandstones and siltstones, a generally even to moderately irregular bedrock-residuum interface is developed. But in soluble rocks, which are subject to different weathering rates at various points, a very irregular interface may be present. This is particularly evident in jointed, massively bedded carbonate rocks, such as limestone and dolomite. Joints provide direct avenues of descent for ground water, and thus chemical weathering is more intense along them. Over a long period of time these joints may be greatly widened, and commonly to considerable depth. When adjacent joints are widened, the result may be deep troughs of residuum with intervening pinnacles of unweathered rock (fig. 14). This type of weathering is undesirable from the standpoint of landfill excavation and maintenance, particularly if the pinnacles are close to the surface. Joints also may allow quick access of pollutants into the zone of saturation.

A special situation, discussed previously, arises with material that is not primarily the result of weathering, but is unconsolidated or semiconsolidated sediment that has never been cemented. The sands, gravels, silts, and clays of West Tennessee are this type of material. The typical soil profiles are not as apparent. Fragipans (zones of impermeable material such as layers of hardened iron oxide and iron carbonate) may be present, however, and can present problems in excavation and in controlling ground-water and leachate movement. The stratigraphy of these sediments is important, for clay zones and consequent variations in permeability will affect ground-water movement.

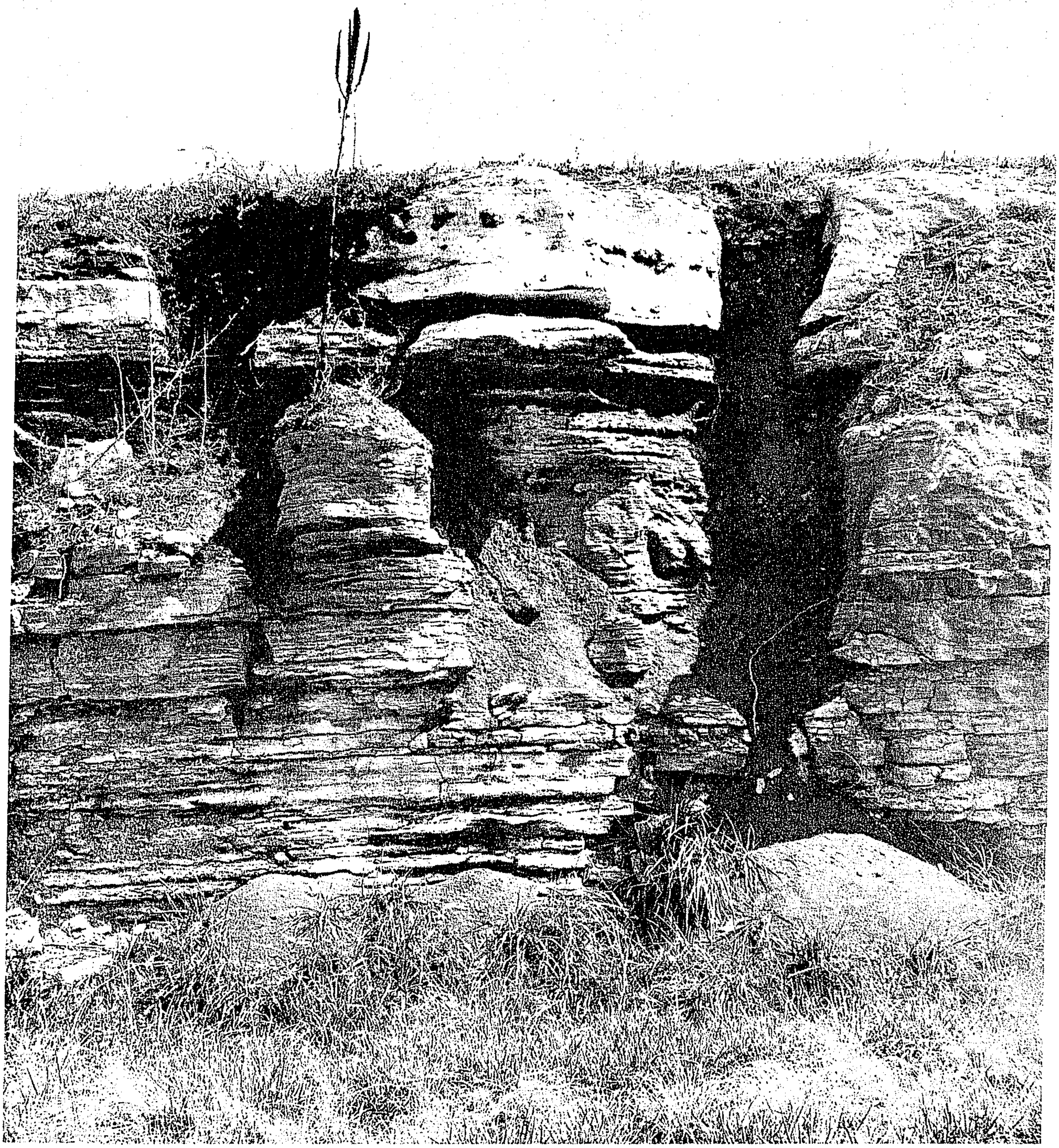

FIGURE 14.—Minute vertical fractures (joints) become widened by solutional removal of calcium carbonate in limestone, which produces soil-filled cutters and cavities as shown in the photograph. Ground water moves readily through these cutters and along bedding planes into the zone of saturation.

RESIDUUM COMPOSITION

One of the first observations to make is the general composition of the residuum, i.e., whether it is predominantly chert, clay, sand, or some other material. Specific composition of the zones within the soil profile should be determined. The average particle size, shape, range in particle size, and size group percentages also should be noted, for this will determine the porosity and permeability of the material. A moderate to high percentage of fine material, especially clay-sized particles (1/256 mm diameter or smaller), for example, will result in very low permeability and high cohesiveness.

The "ideal" material for landfills is difficult to define and may be in many, if not most, cases impossible to find. It should have low permeability, be compactable, contain no large blocks of "loose" rock, be homogeneous in composition, and be machine-workable whether wet or dry. Such material, therefore, would have to contain enough clay to be relatively low in permeability but not so much as to make the material impossible or even impractical to work in very wet weather.

A basic question yet to be answered is whether landfill leachate should be "contained" as totally as possible in a site, or allowed to filter at some slow rate, thereby allowing ion exchange,[4] complexing agents,[5] bacterial action, absorption[6] and adsorption[7] to remove the undesirable components. Indeed, it may be impossible to completely prevent any leachate percolation, even in very high clay soils. Also the possibility of "dammed-up" leachate in a clay body escaping by rupture of the enveloping material must be considered. When dry, a highly clayey soil will crack open. This will cause excess water to enter the fill and will allow vectors easier access to the refuse. Finally, as mentioned above, very clayey soils become almost impossible to work when extremely wet. In light of these considerations and the absence of contradictory data presented in research to date, it therefore seems that soils of moderately low permeability are a compromise answer to the type of soil most suitable for a landfill.

Criteria and Procedures

(1) Observe rock type, bedding characteristics, and the presence of joints.
(2) Avoid areas where an irregular residuum-bedrock interface is thought to be present, especially cutter-pinnacle development where pinnacles are shallow.
(3) Note particle size, shape, and relative percentages of various particle sizes in the residuum.
(4) Avoid residuum containing large blocks of rock.
(5) Avoid highly clayey soil for cover material.
(6) Avoid highly porous soils such as gravel or coarse sand containing little or no fine material.
(7) Select areas with deep, well-developed soils.
(8) Use seismic equipment or drill auger holes at selected points throughout the site to measure soil thickness accurately and to observe soil characteristics.

[4]Reversible exchange of ions contained in a crystal for different ions in solution without destruction of crystal structure or disturbance of electrical neutrality (A.G.I. Supp.).

[5]A substance that is an electron donor and that will combine with a metal ion to form a soluble complex ion (ASM Gloss.).

[6]Taking up, assimilation, or incorporation; as the absorption of gases in liquids . . . (A.G.I.) A taking in or reception by molecular or chemical action (Fay). The process by which a liquid is drawn into and tends to fill permeable pores in a porous solid body . . . (ASTM).

[7]A taking up by physical or chemical forces of the molecules of gases, of dissolved substances, or of liquids by the surfaces of solids or liquids with which they are in contact. (Webster 3d). Physical adhesion of molecules to the surfaces of solids without chemical reaction. (ASTM).

Hydrology

GENERAL

Perhaps the most important application of geology to landfill site location and operation is a knowledge of the hydrologic conditions in the site area and the effect that the introduction of waste material might have on underground and surface water. The key element in site location determination is avoidance of enviromental contamination. Therefore, it is of utmost importance that various major aspects of hydrology be examined in some detail.

SURFACE HYDROLOGY

This section deals with water in streams, lakes, ponds, swamps, and rill wash or slope wash. The most obvious consideration is the proximity of the site to bodies of surface water. Avoiding sites in flood plains was discussed in an earlier section. However, other aspects of location in close proximity to surface water must be considered.

One is the problem of slope wash or rill wash, the overland movement of precipitation runoff on hillsides and slopes in sheets or in small interconnected rivulets called rills. Whereas streams cause valley deepening, valley widening is primarily the result of slope wash, mass movements and tributary development. Such runoff is the main cause of erosion in a humid, temperate climate. Cover material will be washed off a landfill subjected to excessive slope-wash, and waste material will be washed away or carried out in solution. This is another reason to avoid steep slopes.

Even though the site has a moderate slope, and slope wash is kept to a minimum, some leachate may be carried out of the fill material and into surface drainage without seeping into the residuum if there is excessive rainfall, and if the site is too close to a stream or lake. It is therefore desirable to locate the fill a reasonable distance from bodies of surface water. With greater distance to travel, more overland flow will seep into the residuum.

Areas of gully development, generally seen at head of drainage, are to be avoided. The most severe erosion is likely to occur here.

Swamps or marshes are to be avoided at all times for landfill sites. They usually represent an intersection of the water table with the surface, and consequently a landfill in such a site will almost surely pollute the ground water and the surface water which might drain from the area. In many instances swamp land is also located in flood plains and therefore is commonly susceptible to flooding.

Landfill sites should also be located where runoff from adjacent land does not enter the fill. If other criteria have been met, but the site is in an area where runoff from adjacent land might enter the fill, the natural drainage should be diverted. The possible effects on natural drainage caused by alteration of existing topography by excavation also must be considered. The site should be surveyed and developed so as to avoid accidentally or carelessly altering drainage and creating areas of standing water or allowing water to enter the fill.

The drainage basin of a site area should be defined. This will help to determine if any streams, lakes, or ponds in the drainage basin are sources of water for human or agricultural use. Also, inasmuch as the configuration of the water table, and consequently the direction of ground-water movement, is basically conformable to topography, possible movement of contaminants in ground water can be better predicted if the drainage basin of the fill site is carefully delineated.

Criteria and Procedures

(1) Locate landfills a reasonable distance from bodies of surface water which might become polluted.
(2) Avoid steep slopes with high potential for slope and rill wash erosion.
(3) Never locate a landfill in a swamp or marsh.
(4) If possible, locate the fill so that the precipitation falling directly on the fill is the only source of water.
(5) Divert any adjacent surface drainage from the fill.
(6) Plan surface drainage carefully when altering existing topography.
(7) Define the drainage basin in which the site is located.

SUBSURFACE HYDROLOGY

Because waste in a landfill is being put underground, it is especially important to understand the nature of ground water, for its environment is most likely to be contaminated. In the United States 20 percent of the total water supply comes from ground water. To maintain its quality is imperative.

There are numerous aspects of ground-water geology, and each should be considered in landfill site location. Perhaps the first consideration should be depth to the water table. In general, the farther water must travel downward to the water table, the more natural "filtering" (hence "purification") it will receive. This does not mean, however, that certain types of contaminants cannot move long distances through the subsurface. The type of material it is moving through, the size of openings in the material, and the chemical-biological nature of the pollutant will all have an effect on the degree of filtering.

In its path downward to the water table, ground water moves through certain zones and subzones (fig. 15). Above the water table is the zone of aeration. This zone is further divided into an uppermost subzone of "soil moisture," which contains most plant roots and humus. Much of the water that enters this subzone is either used by plants (transpiration) or is evaporated. Some of it enters the next subzone, an intermediate zone of suspended water, which contains some water and some air. The surface tension here "suspends" the water and prevents gravity from moving the water farther downward. When a new supply of moisture from precipitation fills all open spaces, water will continue

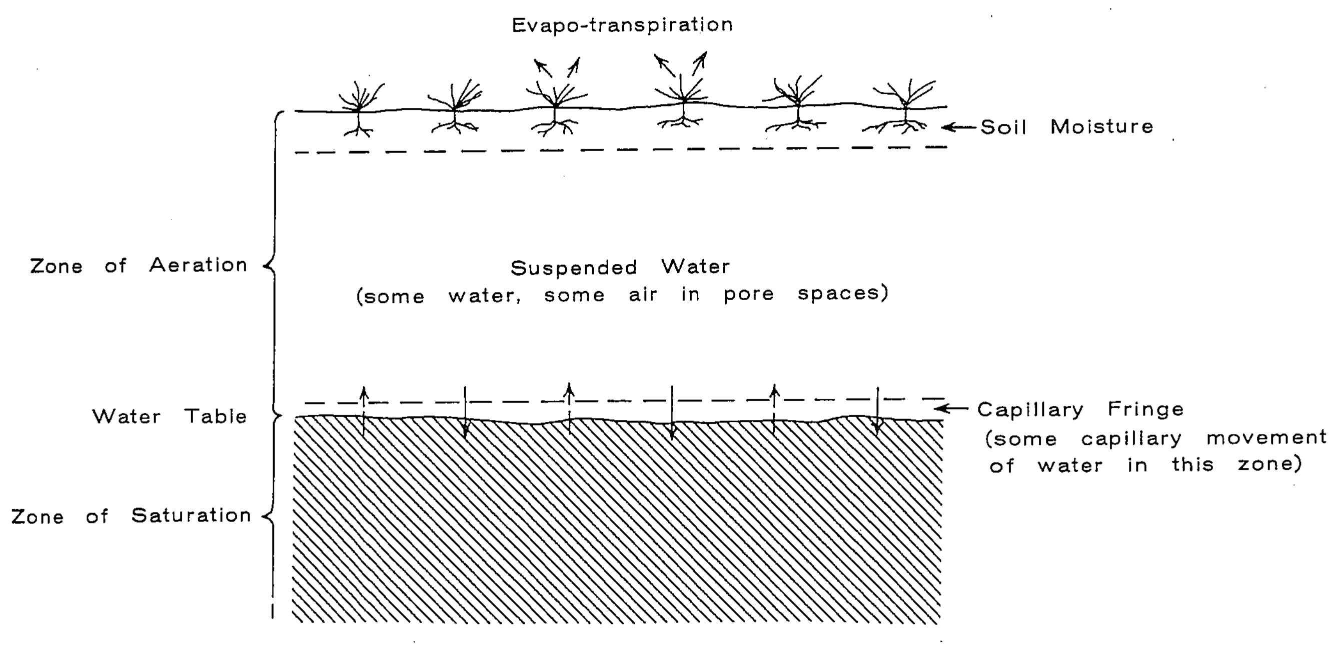

FIGURE 15.—Ground water, in its movement downward, passes through several zones and subzones. The uppermost part of the zone of aeration contains soil moisture, which may evaporate or be used by plants (transpiration). An intermediate zone contains water suspended by capillary tension. Adjacent to the water table (the surface between the zone of aeration and the zone of saturation) is the capillary fringe, where water may move between these zones by capillary action.

to move toward the water table. Below the intermediate zone is the capillary fringe. This subzone lies just above the water table, and moisture moves into and out of the water table by capillary action according to the balance of moisture supply, transpiration, and evaporation. The surface between the capillary fringe and the zone of saturation below is called the water table. Because spaces below the water table are filled with water, this zone is called the zone of saturation. The most efficient processes of leachate purification (e.g., ion exhange, complexing, aerobic bacterial actions, and absorption-adsorption) occur in the zone of aeration.

The depth to the water table is variable, and topography is a major controlling factor (fig. 16). It is deeper beneath hills and shallowest in valleys, although it conforms

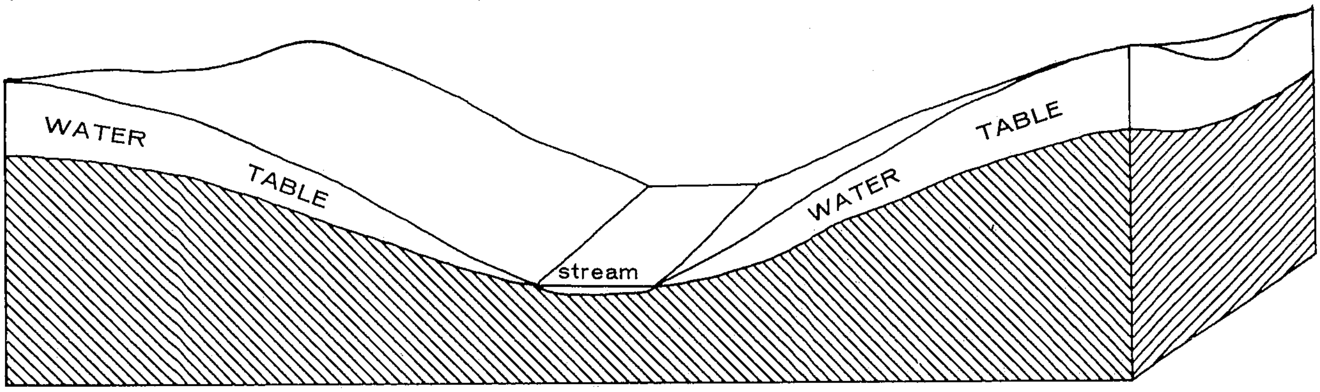

FIGURE 16.—In a typical permeable aquifer, or in level bedded rocks which contain adequately connected openings, the upper surface of the zone of saturation generally conforms to topography, as shown in this diagram. However, it is somewhat deeper beneath hills and shallower in valleys, perhaps even intersecting surface drainage in some cases.

in a general way with the topographic configuration. Topographic conformity is altered by factors such as dipping beds; water moving downward through dipping strata may travel along bedding planes to considerable depth. Differences in permeability of the rock material underlying an area also may cause water depth to vary. The water table will also fluctuate seasonally, according to the available moisture (this will be discussed in more detail further in this section).

The best aquifers, i.e., those which contain and transmit the largest volumes of ground water, are highly permeable materials such as unconsolidated gravels and coarse sands with low clay content. Limestones and dolomites may contain large volumes of ground water even though the rock material itself is impermeable. This is caused by the presence of solution-enlarged joint planes, bedding planes, fault planes, and other fractures, and the presence of caverns and smaller cavities. In such rocks, pollutants can move rapidly into and through the zone of saturation, and consequently much care must be taken in locating landfills in areas of carbonate rocks. In no case should waste material ever be put directly on such rocks, for pollutants then have immediate access to avenues of descent into the zone of saturation. A minimum of 5 feet of clayey residuum should always be left above bedrock.[8] If possible, considerably more should be left, especially where the residuum is more permeable. For example, 10 feet of undisturbed residuum should be left in outcrop areas of the Knox Group.

A special consideration in ground-water study is a perched water table (fig. 17). This situation occurs where a layer or zone of impermeable material, such as clay or shale, lies some distance above the main water table. Ground water, in its movement through the zone of aeration, encounters the impermeable material and cannot move any farther downward. It must then move laterally or "fill up" the zone above it, causing it to become saturated. This perched zone of saturation may be far above the main water table. In locating a landfill, therefore, it is most important to check for a potential perched water table, even if it is known that the main water table is at considerable depth.

The natural intersection of the water table with the surface may result in a spring. Therefore, all springs in

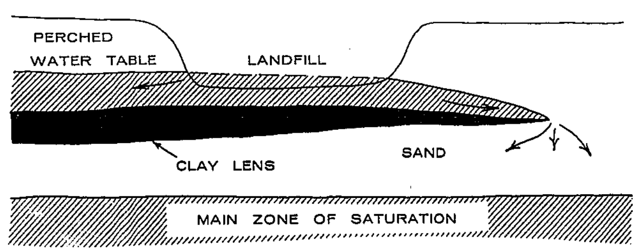

FIGURE 17.—The perched water table in the above illustration was created by a clay lens. Any impermeable zone (a shale, fragipan, etc.) can result in a similar condition. Such perched saturated zones make landfills difficult, if not impossible, to operate and create potential ground-water pollution problems by downward percolation into the main zone of saturation.

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[8]*According to Brunner and Keller (1971, p. 53 and 54):*

"When issuing permits or certificates, many States require that ground water and deposited solid wastes be 2 to 30 feet apart. Generally, a 5-foot separation [consisting of soil] will remove enough readily decomposed organics and coliform bacteria to make the liquid bacteriologically safe. On the other hand, mineral pollutants can travel long distances through soil or rock formations."

In most places in Tennessee the water table is considerably deeper than 5 feet, but downward-percolating water can move rapidly into the zone of saturation via solutionally-widened joints or other fractures once it reaches bedrock. Hence the 5 feet of clayey base residuum is a minimum precautionary measure for filtration of organics, and the potential removal of dissolved mineral matter by ion exchange and other processes.

the area of a landfill site should be located, as they offer monitoring sites to determine the presence of contaminants in the zone of saturation.

The zone of saturation is subject to seasonal and interim fluctuations. After periods of heavy precipitation the water table rises and, conversely, after dry periods it drops. Usually, there is not an immediate response in the water table to changes in the amount of precipitation because of recharge lag time. Inasmuch as the movement of ground water is usually very slow, considerably long periods of time (days to weeks) may elapse before the water table drops or rises in response to available precipitation. The length of time and degree of response will depend on the volume and duration of precipitation, depth to the water table, and the nature (permeability) of the overlying bedrock or residuum. It is important to know the maximum rise anticipated in the water table in an area. These factors must be considered in ground-water investigations in a site area.

Existing water wells in the immediate vicinity of a landfill should be scheduled for periodic monitoring to detect possible contamination. If no wells are present, a test well (or wells) should be drilled for the purpose of monitoring the quality of ground water. Also streams or rivers receiving runoff from the landfill or being fed by springs receiving water from the zone of saturation in the vicinity of the fill should also be analyzed periodically.

Criteria and Procedures

(1) Determine the depth to the water table.
(2) Check for potential perched water tables.
(3) Never place waste material directly on bedrock. No less than 5 feet of residuum should ever be left below the lowest waste material.
(4) Note the location of all springs in the landfill area.
(5) Define the recharge area (the area from which percolating water is gathered and enters an aquifer) of a landfill site.
(6) Monitor wells, springs, and surface water in the area of the landfill.

PHYSIOGRAPHY AND GEOLOGY

East Tennessee

GENERAL

Geologists divide East Tennessee into three major physiographic regions which contain parts or all of several geologic-physiographic subdivisions (figs. 18, 19, and 20). These subdivisions show significant variation in topography, rock character, mineral resources, soils, and patterns of human adaptation. That is, these geologic-physiographic subdivisions are real and affect man's activities to a notable extent.

The Unaka Mountains province is the easternmost physiographic region. The term Unaka Mountains is applied to that portion of the Appalachian Blue Ridge south of Virginia and essentially west of the crest of the mountains that separates east-sloping surfaces from those sloping west.

The Valley and Ridge province, or Valley of East Tennessee, extends from the western edge of the Unakas to the bold escarpment that rises to the top surface of the Cumberland Plateau. The Valley and Ridge province contains the principal cities and towns in East Tennessee. Rocks of the Unaka Mountains and Valley and Ridge provinces were formed in the Appalachian geosyncline structural province.

The Cumberland Plateau corresponds to the coal region of the State. It is a tableland broken by some mountainous topography in the north and by two linear valleys, Elk Valley in the north, and the much larger Sequatchie Valley in the south.

Overall the topographic and geologic "grain" of East Tennessee is elongated northeast-southwest in conformity with the trend of the Appalachian region. Thus, the rock formations, topography, soils, and rock structures are generally arranged in belted patterns trending about 30° east of north.

The rocks of the Unakas all show the effects of heat and pressure, i.e. they are metamorphosed, and the rocks of this and the adjacent Valley and Ridge have been considerably folded, faulted, and otherwise deformed by mountain-building processes in the geologic past. It is this history of deformation that causes the belted patterns of rock formations that are shown on geologic maps, and is also responsible for belts of the same formation appearing repetitively across the grain (northwest to southeast).

The entire region has a humid climate with long summers and relatively mild winters. The combination of abundant moisture and long periods of above-freezing temperatures leads to abundant plant growth and development of soils largely by chemical decay of the rocks. The fact that the region has stood well above sea level for a geologically long time has furthered the weathering effects and allowed development of many surface streams. It has also, particularly in the limestone areas, permitted development of caves, sinkholes, and related features. The cracks (joints) produced by folding and faulting and the planes separating beds of limestone served to guide the development of such openings.

The Valley and Ridge province is underlain by sedimentary rock strata now tilted and folded as described above. The chief rock types are magnesian limestones (dolomites), limestones, shales and smaller volumes of sandstone. Valleys are generally floored by shales and limy shales, or by limestones. The dolomites and sandstones form ridges.

The boundary between the Cumberland Plateau province and the Valley and Ridge province is the prominent east-facing Cumberland escarpment. The Plateau is underlain by sandstones, conglomeratic sandstones, and shales, with coal seams at various levels. In general the surface has less relief than the Valley or Unakas, but there are deep gorges (gulfs) and, particularly in the northern Plateau, prominent high ridges. The rock strata are much less disturbed than to the east, but folds and faults have developed in such areas as the Cumberland escarpment, Elk Valley from Caryville northwest toward Pioneer, along the Emory River, and in the vicinity of Sequatchie Valley.

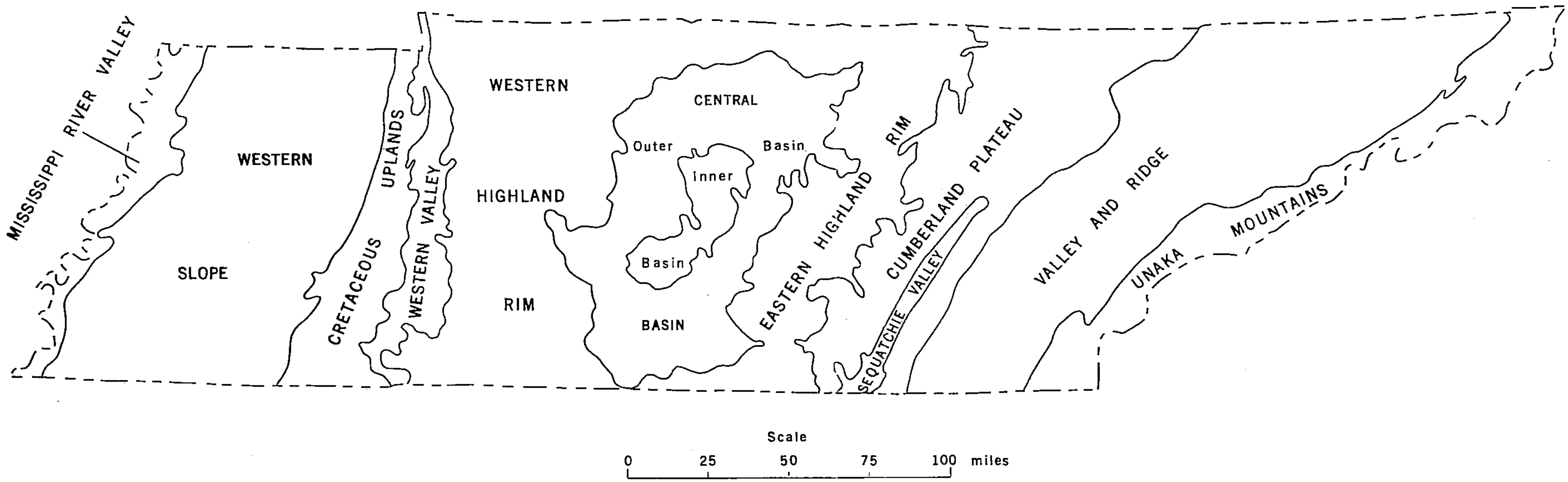


FIGURE 18.—Physiographic map of Tennessee.

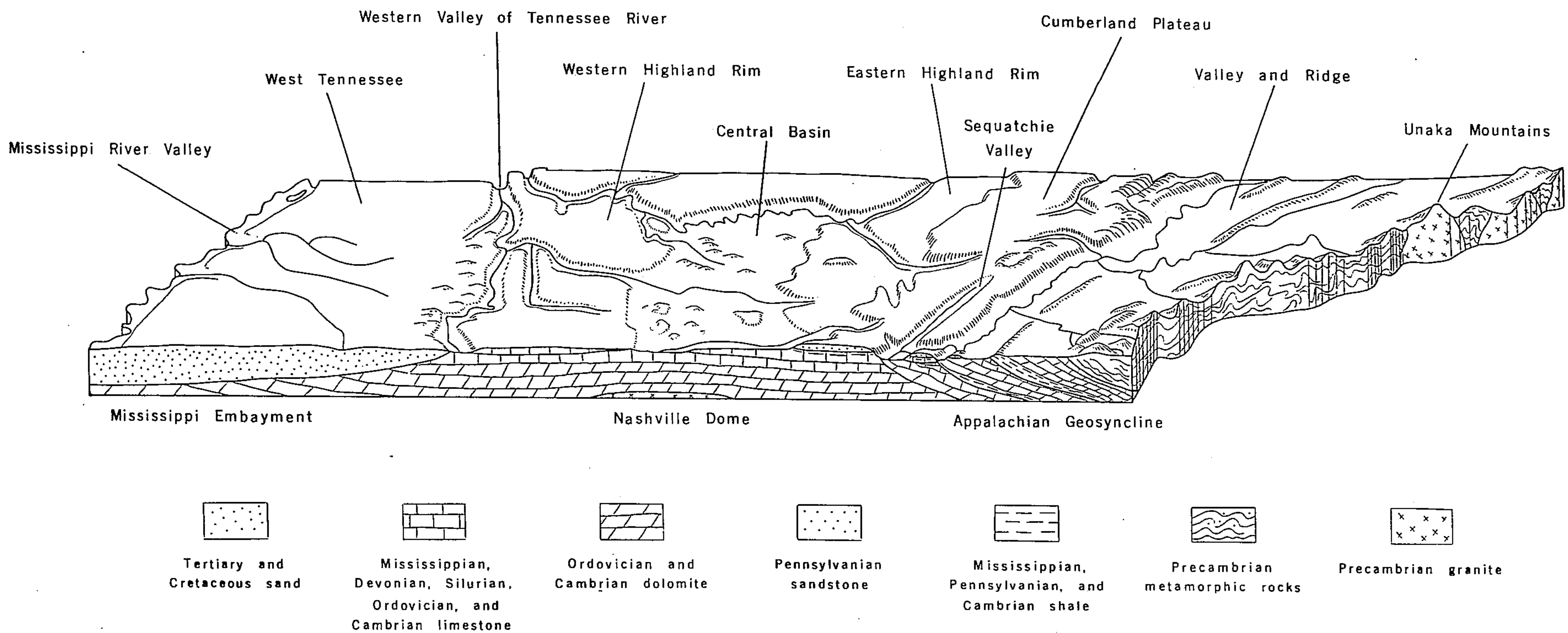
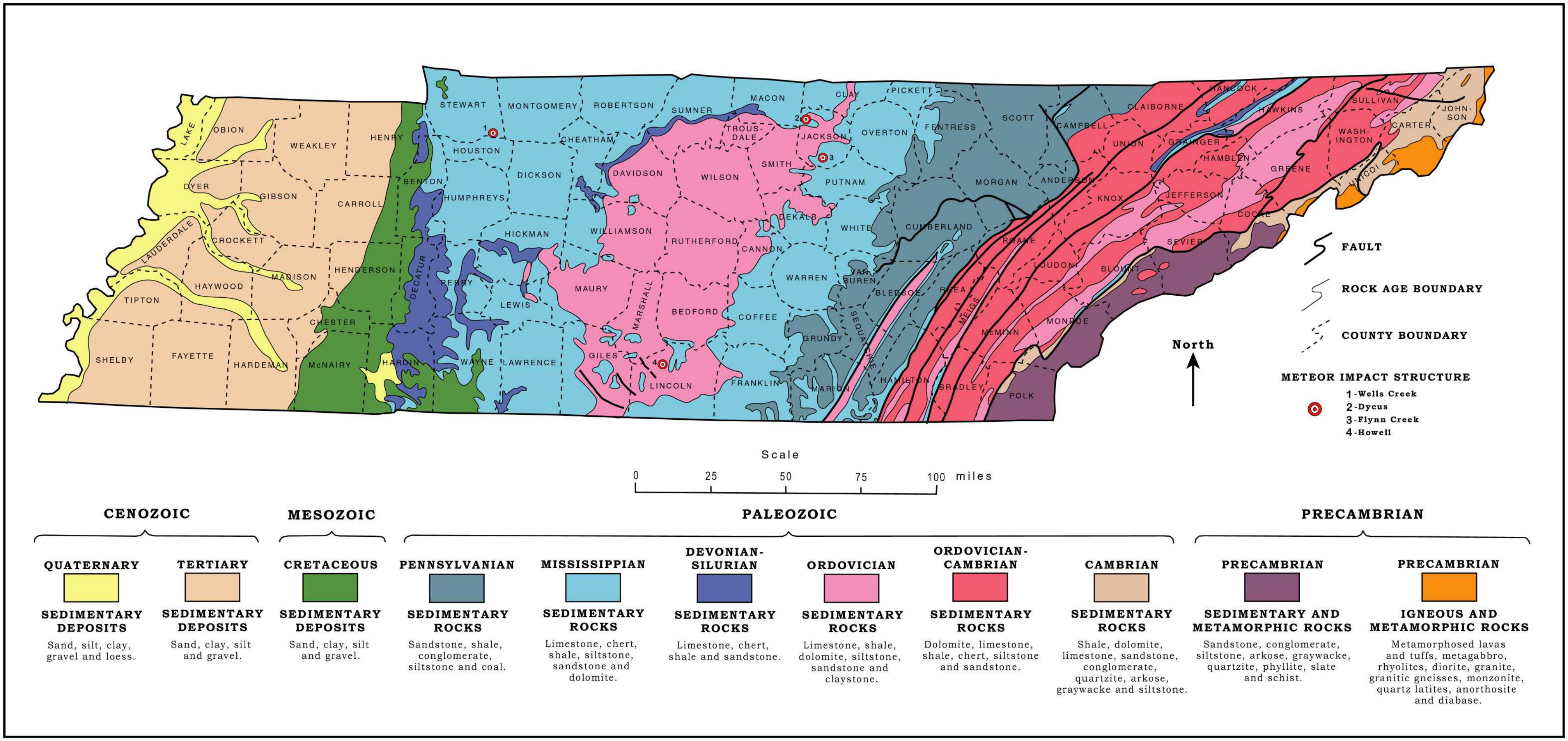


FIGURE 19.—Relief map of Tennessee showing the relationship of major geologic structures to physiographic units.

STATE OF TENNESSEE
DEPARTMENT OF CONSERVATION
DIVISION OF GEOLOGY
Robert E. Hershey
Director and State Geologist



GENERALIZED GEOLOGIC MAP OF TENNESSEE
1970
FIGURE 20.

UNAKA MOUNTAINS PROVINCE

The Unaka Mountains in Tennessee are defined herein as comprising the bold high topographic regions in the eastermost part of the State. They include the Great Smoky Mountains; Chilhowee, English, Bean, Starr, Meadow Creek, Holston, and Stone Mountains; and the coves (such as Cades, Wears, and Bumpass).

This is a region of rugged topography and swift-flowing streams, which is mostly forested or in laurel groves, broken by occassional natural clearings (balds) and mountain farms.

The region is geologically complex, but for landfill considerations can be divided into (1) areas underlain by crystalline (metamorphic and igneous) rocks in northeasternmost Tennessee, (2) areas underlain by metasedimentary slates and sandstones from approximately the Nolichucky River valley southwest to the Georgia line, (3) areas of the Chilhowee Group in the western foothills (e.g., Bean, Starr, Chilhowee, English, Meadow Creek, and Holston Mountains), and (4) limestone coves and valleys within the surrounding mountainous terrain.

Areas of Crystalline Rocks

Areas in East Tennessee underlain by crystalline rocks are limited to small portions of Johnson, Carter, Unicoi and Cocke Counties. On geologic maps this group of rocks consists of units variously termed "basement complex," "Cranberry," "Beech," "Max Patch," "Roan" (granites, gneisses), and "Bakersville Gabbro." Generally steep slopes, rapid surface drainage, and high rainfall and snowfall with resulting sheet erosion and downslope movement of weathered materials severely limit satisfactory landfill sites in these areas.

Sharp and numerous contrasts in rock types make for a wide variety of such subsurface conditions as thickness of soil and proportion of rock fragments and boulders in the soil profile. The granitoid rocks are weathered primarily by chemical decomposition of feldspars and iron-rich minerals to form clays and iron hydroxides, respectively. The quartz grains are resistant to decay and thus a more or less sandy, porous, and acid soil forms. In places the texture of the original rock is preserved as a spongy, soft, but coherent material, saprolite, which may be several tens of feet thick locally. More commonly hard rock is encountered within 5 feet of land surface. Because the soil-saprolite interval in these areas is rapid draining and easily eroded, satisfactory landfill sites in these circumstances are rare.

Areas of Metasedimentary Slates and Sandstones

A very thick sequence of altered shales, sandstones, and pebble conglomerates, termed the Ocoee Series, underlies significant portions of the easternmost tier of Tennessee counties, except for Johnson and Carter Counties. These rocks form the main mass of the Unakas in Unicoi County, the Bald Mountains of Greene and Cocke Counties, the Great Smoky Mountains proper of Cocke, Sevier, and Blount Counties, and the Unicoi Mountains in Monroe and Polk Counties.

The topography in these areas is similar to that in the crystalline rock region, and indeed might be described as even more rugged and steeper. Here, too, runoff is rapid and mass movement of weathered materials is common. Under these conditions soils are thin and commonly rocky. However, saprolite thicknesses exceeding 100 feet can be seen in some roadcuts; and in places the unconsolidated mantle above rock includes colluvium and alluvial materials on saprolite and/or bedrock. Depth to rock is generally less than 5 feet.

These conditions mean that satisfactory landfill sites in these areas are rare.

The Ocoee Series includes a large number of subdivisions, but their similarities in the context of landfill site selection permit treating them as a single unit. The subdivisions of the Ocoee Series are shown in the *Appendix*.

Areas of the Chilhowee Group

Rocks comprising the Chilhowee Group form the westernmost ranges (foothills) of the Unaka Mountains. Iron, Holston, Doe, Embreeville, English, Chilhowee, and Starr Mountains are underlain by this Group.

The Chilhowee Group is subdivided into the Unicoi, Hampton, Erwin, and Helenmode Formations, in ascending stratigraphic order. This rock nomenclature is applied from the Virginia line to the Pigeon River. From English Mountain southwestward the lithology of the sequence differs from the northeastern phase, and the formations, in ascending order, are the Cochran Formation, Nichols Shale, Nebo Sandstone, Murray Shale, Hesse Sandstone and Helenmode Formation.

The Unicoi and Cochran Formations are composed of thick conglomeratic sandstones with interbedded shales. These formations and the Nebo Sandstone underlie high ridges or mountains. The resistant sands or conglomerates in many places crop out on steep slopes or bluffs. The shale beds underlie valleys and lower slopes. In general, these rocks weather to thin soils and underlie steep ground. They offer few, if any, satisfactory sites for landfills, although they are rather impermeable and yield little water. The steepness of the topography and absence of suitable cover material are major drawbacks.

Limestone Coves and Valleys

A few areas of lower and more gentle topography are developed within the mountain areas. These places are termed "coves" or "valleys," e.g., Cades and Tuckaleechee Coves, and Wears Valley. They are generally free of rock outcrops and are underlain by limestones and dolomites of the Shady or Knox formations. The land surface in these coves and valleys is generally formed by transported clays, sands, and gravels washed down or carried by mass movements from the surrounding mountains; and these transported (alluvial and colluvial) materials may lie above clays (residuum) formed by weathering of the bedrock. By these processes locally thick unconsolidated mantle has accumulated.

These cove areas offer possible landfill sites, but thorough investigation and study prior to use is necessary to avoid water pollution and construction problems related to an irregular bedrock-residuum interface. Where stream-formed materials are abundant, coarse, rounded cobbles and pebbles are common, particularly in the lowest parts of the alluvial fills. Such zones are difficult to compact, are permeable, and are usually water-saturated. In many areas these zones are sources of domestic water supplies. In other places, especially areas of Shady Dolomite, deep plastic, yellow clayey residuum locally several tens of feet thick is developed above the gray limestone bedrock. The clay is plastic or "fat" and relatively impermeable, but it is cherty and easily worked. Such places offer good landfill sites provided a 5-foot thickness of clay is left undisturbed above the bedrock surface.

VALLEY AND RIDGE PROVINCE

Rome Formation

The Rome Formation is a sequence of interbedded sandstones, siltstones, and shales with minor dolomite zones. The rocks are characteristically variegated olive, maroon, and drab colors. The buff sandstone ledges form such ridges as Bays Mountains along the Knox-Sevier County line; Sharps and McAnnally Ridges in Knox County; Beaver Ridge, Pine Ridge, and Bluebird Ridge. Rome ridges are generally uncultivated, steep-sloped, pine-clad, and have a "comby" profile.

The Rome weathers to very shallow depths, and hard rock is generally only a few inches below the surface. The formation is a poor source of water, as it is relatively impermeable.

Potential landfill sites in Rome outcrop areas are available on a limited basis. The bedrock is impermeable and ground-water pollution is unlikely. However, lack of soil and generally steep slopes are unfavorable factors. Rome terrain abounds in narrow valleys that are tempting sites, but fills in these situations require diversion of natural surface drainage and hauling cover material from elsewhere.

Conasauga Group

The rock formations in the following discussion, beginning with the Pumpkin Valley Shale and ending with the Honaker Dolomite, belong to a larger geological unit, the Conasauga Group. The characteristics of Conasauga formations change from region to region, so that recognition of various units is not everywhere practicable. Therefore, geologic maps show various terminology for the formations of this group. In areas predominantly composed of shale the term "Conasauga Shale" or "Group" is used; in areas where carbonates are predominant, the term "Honaker Dolomite" is applied. In other areas terms such as "Rutledge-Rogersville-Maryville undivided" or "Upper Conasauga" may be used.

In applying landfill site criteria to units that are predominantly shale, the comments on the Nolichucky are apropos; whereas, in limestone or dolomite areas the discussion of the Maryville or Honaker can be used.

Pumpkin Valley Shale.—The Pumpkin Valley Shale lies along the southeastern edges of the Rome ridges in the Valley, and is similar in appearance to the Rome shales. The Pumpkin Valley lacks the sandstones of the Rome and therefore underlies less rugged terrain. The shales weather into chips to moderate depths (a few feet), usually form uncultivated acid soils, and are rather impermeable.

Pumpkin Valley Shale areas offer potential landfill sites, particularly where weathering permits excavating to sufficient depth by bladed or ripper equipment. The formation is tight and a poor source of water for wells or springs, so that ground-water pollution is not a serious hazard. Cover materials would have to be obtained elsewhere, but residual clays are commonly available nearby.

Rutledge Limestone.—The Rutledge Limestone is a blue-gray to dark-gray, thick-bedded limestone that weathers to a deep-red clayey soil. It has numerous joints that have been enlarged by solutional weathering. The rock-soil boundary is highly irregular, and depth to bedrock changes abruptly in a few feet laterally.

Because of their irregular soil-rock profiles and solutionally produced open spaces, Rutledge Limestone areas are not recommended as landfill sites. However, Rutledge soils may be useful as covering material for sites in the adjacent Pumpkin Valley Shale.

Rogersville Shale.—The Rogersville, which is typically a bright-green clay shale that weathers light-olive to buff, forms long narrow valleys. Rogersville soils are thin, filled with shale chips, and slightly acid. The narrow outcrop belts of Rogersville are often cultivated along with adjacent Rutledge and Maryville belts.

Landfill sites in the Rogersville are probably satisfactory. The shale is impermeable and is not a good source of well or spring water. Weathering is not deep, but in places earth-moving equipment can be used to excavate several feet below the surface. Suitable cover material may have to be hauled from adjacent limestone areas.

Maryville Limestone.—The Maryville is a gray to blue-gray, thick-bedded limestone whose weathered surfaces appear mottled. It closely resembles the older Rutledge Limestone but is separated from it by Rogersville Shale. The Maryville has numerous joints, which are locally solutionally enlarged, and it develops a dark-red clayey overburden. The soil-rock interface is generally irregular, and the depth to rock ranges from zero to several tens of feet. As the Maryville in some areas is deeply weathered to clay, in a few places it may underlie suitable sites for landfills. However, such sites are rare and would have to be located where the clayey overburden is thick enough to permit leaving not less than 5 feet of unexcavated clay below the base of the fill. This means careful and closely spaced augering or seismic profiling and control of excavation prior to and during use. The Maryville clayey soils are good sources of cover materials.

Nolichucky Shale.—The Nolichucky is a drab olive-yellow to yellow-brown, limy clay shale, with maroon-colored beds common near the base. The clay shale layers are interbedded with limestone beds that range in thickness from fractions of an inch to several inches. The carbonate content increases toward the top of the formation.

The Nolichucky underlies gently rolling to valley areas normally immediately northwest of Knox ridges. Many Nolichucky areas are cultivated.

The Nolichucky weathers to a thin clay soil containing shale chips and slivers, although it weathers more deeply than nonlimy shales, and in many places can be ripped to a depth of 10 feet or more by heavy earth-moving equipment.

Areas of Nolichucky Shale offer possible landfill sites. The dissolution of limestone interbeds renders the formation somewhat permeable, but it is not an important source of ground-water supplies. Sites considered should be tested to determine excavating difficulties—i.e., depth of weathering and rippability. The Nolichucky may have suitable cover materials, but probably in part the cover material must be obtained from clayey residuum overlying nearby limestones.

Maynardville Limestone.—The Maynardville is a blue to blue-gray, thick- to thin-bedded magnesian limestone. It generally forms the lower parts of the northwestern slopes of Knox ridges.

The Maynardville is similar to the overlying Knox and the lower Maryville Limestone in that it has a well-developed joint system, irregular rock-soil interface, and weathers to a clayey soil. Unlike the Knox soils, those of the Maynardville are not very cherty, and they are prevailingly orange, unlike the dark-red Maryville soils.

The "line" separating Maynardville and Knox is characterized by a moderate number of springs in East Tennessee; some have discharges of several hundred gallons per minute.

Maynardville areas are not likely to offer satisfactory landfill sites. Slope, relationship to water discharge, and thin soil cover over irregular rock surfaces are all negative considerations. However, Maynardville clayey residuum should provide useful cover material.

Honaker Dolomite.—The Honaker Dolomite is restricted to the region southeast of the Bays Mountains and northeast of the Cocke-Greene County line. The Honaker is a blue-gray to dark-gray magnesian limestone with some siliceous (cherty) beds locally developed. The formation generally weathers to a moderately thick yellow to orange soil with chert above the upper Honaker beds. Soil thicknesses generally are in the range of 3 to 10 feet. The clays are plastic and slow draining.

The Honaker is a source of water for wells and springs, some with relatively large yields. As the Honaker is a carbonate rock it is subject to solutional weathering, and its outcrop is marked in places by sinks.

These facts imply that Honaker outcrop areas are generally unfavorable for landfill sites. If sites containing several tens of feet of overburden, well removed from water sources and free of sinks can be found, and if at least 5 feet of compacted clay is left below the base of the fill, such sites may be used. The Honaker clayey residuum should be satisfactory for cover.

Knox Group

The Knox Group and its various subdivisions constitute the most extensively outcropping rocks in the Valley and Ridge province. The rocks of this Group underlie or crop out over about 40 percent of the area of the Valley.

The Knox is characteristically a gray to blue-gray, thin- to thick-bedded, siliceous magnesian limestone with interbeds of less magnesian limestone. The group aggregates some 3,000 to 3,500 feet of strata that weather to orange, orange-red, or yellow clayey soils commonly containing masses of chert (flint or silica). The more cherty portions of the Knox underlie broad, hardwood-covered or cultivated ridges. The tree cover in many places provides names for ridges—Blackoak Ridge, Chestnut Ridge, and Copper Ridge (copper beech) are examples.

Because of its wide areal extent and economic significance the Knox has been studied for many years, and has been subdivided into various formations. The most generally employed subdivision used on geologic maps is shown in the *Appendix.*

Aspects of the Knox significant to landfill site selection are its weathering features, the soil developed above it, and its role in the ground-water regime.

Knox outcrop areas are marked by broad ridge lines commonly with two subparallel higher lines of knobs separated by lower intervening valleys. The high ground is formed by the very siliceous Copper Ridge and Longview Formations that upon weathering produce a chert "paving" and retard erosion. The thickness of soils is thus greater as a rule on ridges underlain by Knox than over lower elevations similarly floored. Thickness of soil may be great as 100 feet or so, but owing to differential weathering abrupt and notable variations in depth to bedrock are common. Weathering is deepest along joints, in otherwise fractured rock, and in strata consisting of more "pure" limestone.

The Knox is subject to extensive weathering by solution, and in many outcrop areas karst phenomena are well developed. Such features as sinkholes, caverns and underground water courses are common. The lowermost and uppermost boundaries of the Knox in many places are zones of discharge for springs, some of large yield. The Knox outcrop appears to be the intake (recharge) area for these springs.

Knox residual soils are characteristically red to orange clay, locally sandy and generally cherty, belonging to the Dewey, Fullerton, and Clarksville soil systems. These soils have fair to moderately high permeability. The more cherty portions can be expected to resist compaction if the chert masses are large.

As landfill sites, Knox areas pose a variety of problems so that each individual site requires careful investigation and analysis. Water supplies that might contain leachate should be monitored during and after the filling of such sites to insure adequate protection of adjacent properties.

Ordovician Shales

Geologic maps of East Tennessee use various terminologies for a "wedge" of sedimentary rocks formed in the Ordovician Period. For the purposes of this report much of this nomenclatural problem can be avoided by classifying the rocks by lithology, as this property dominates their significance in landfill site evaluation.

Shales of Ordovician age included in this discussion are designated on geologic maps as Athens, Sevier, Ottosee, Martinsburg, and Reedsville Shales. Similar rock types appear on some maps as units of the Chickamauga Group. Shales thus designated may exhibit some differences one from another or within a given unit from place to place. However, all are thin-bedded to slabby, yellow-weathering strata. Where fresh the shales are blue-gray to gray-black (especially the Athens), and all are somewhat limy, particularly where fresh.

Shales on the eastern side of the Valley (essentially east of a line through Kingsport-Knoxville-Cleveland) in places contain thick lenses and beds of quartz sandstone and/or limy sandstone. The quartzose layers are tough and commonly form ridges or knobs in the shale outcrops. The limy sands (marbles) are particularly well developed in some areas mapped as "Ottosee Shale," e.g., east of Knoxville and near Mooresburg, Hawkins County. In general, the Sevier, Athens, and Ottosee Shales are limestone-bearing to some degree. The limestone commonly occurs as thin layers between more clay-rich beds; because weathering is more rapid along the limy beds, these shales may develop considerable permeability. This condition is particularly prominent near permanent water courses. DeBuchananne and Richardson (1956) report:

> Many wells in the Sevier shale located near streams or lakes yield more than 150 gpm [gallons per minute]. Water levels in wells on valley floors are usually less than 20 feet below the land surface * * *.

Depths of weathering in these shales range considerably from place to place, and in direct proportion to the lime content of the strata. The soil-rock profile is gradational from a chip-filled surface into hard rock, and owing to solutional removal of limestone presents a "saw-tooth"profile. In many areas the rippable materials do not extend more than 3 or 4 feet below the surface, but in other places this weathered zone may be as deep as 15 to 20 feet.

The Martinsburg and Reedsville Shales resemble those just described but are less limy, and crop out north and west of Knoxville on the lower slopes of Clinch, House, and Powell Mountains. These units thus are restricted to a relatively small area, commonly underlie steeper slopes, and are covered by very thin soils.

From the foregoing discussion it is apparent that Ordovician shales do not offer many sites suited to use as landfills. Particular care must be taken to ascertain the depth of weathering to prevent excessive excavation costs. Similarly, the depth to water and the proximity to surface discharge fed by water percolating through these shales is significant in pollution control. Any proposed site in these rocks should be drilled, nearby wells and springs should be located, and the absence of connections to nearby surface drainage should be assured. In general, sites meeting these criteria are sparse.

Ordovician Limestones and Marbles

Various terms are applied to limestones and marbles of Ordovician age (as explained in the section on shales) throughout the Valley and Ridge of East Tennessee. Names commonly used include Chickamauga (various subunits), Lenoir, Mosheim, Holston, Stones River Group, and Nashville Group. Again, the similarities of the rocks in landfill contexts are such that they can be discussed collectively.

Some of these limestones (as the Holston) are crystalline and rather pure; others are finer grained, less pure, generally blue-gray to gray; and others (Lenoir type) are "knotty," clayey, and impure.

These limestones weather chiefly by solutional attack; most are fractured and well-jointed; and most have highly irregular thicknesses of soil developed above them. The deepest weathering and thickest soil cover is generally found in areas of the Holston Marble, and the least soil cover is preserved over the Lenoir, Mosheim, and Chickamauga units on the northwestern side of the Valley.

Sites underlain by these limestones are generally unsatisfactory for landfills, either operationally (shallow soils, pinnacled surfaces) or because of pollution potential (such as fractures and sinks), or both. The Holston is characterized by karst features (sinks, caves, solutionally enlarged joints), and the rock-soil profile is practically everywhere irregular in the extreme. Sites in the Holston can be summarily dismissed.

Lenoir outcrop areas are characterized by outcropping limestone ledges with enlarged joints and bedding planes. Soils are typically less than a foot thick. Small sinks and caves are present in some areas. The Lenoir weathers to a yellow, rather plastic clayey soil of low permeability. In some places this overburden is thick enough (20 feet) to be used, provided that 5 to 10 feet of undisturbed soil is left below the lowest cut.

Areas commonly designated "Chickamauga Limestone" (various units) on the northwestern side of the Valley are similar to the Lenoir areas in that soil cover is nearly everywhere very thin. Because of solutional openings extremely thorough investigations of potential sites are recommended to avoid ground-water pollution. In general, areas of Chickamauga are unlikely to offer suitable landfill sites.

Areas designated as "Holston" are underlain by coarsely crystalline limestone ("marble") and lime-cemented gray to brown sandstone. Weathering produces a deep-red clayey soil that is sandy above the quartzose beds. The weathering profile is typically highly irregular and rock pinnacles are common. Places floored by the marble phase commonly are heavily karst (sink and "swallow" holes are numerous), and caves may exist. This, in conjunction with uneven top of rock, is a negative indicator. In no instance should Holston "marble" sites be used for landfills.

However, the upper sandy phase offers some possibilities for landfills. Shale seams in the weathered rock might serve to limit downward percolation. Again, the soil-rock boundary is generally irregular and may cause operating problems. Sites in this unit should be carefully investigated to determine the rock profile, permeability of the soil, and cut stability. (Note: this quartz sand interval is identical, or lithologically similar, to rock called "Holston," "Chapman Ridge," "Toqua," and "Tellico" on various maps).

Other Rock Formations

Bays Formation.—The Bays Formation is a prominent unit of shales, siltstones and sandstones that underlies generally hilly topography in the east half of the Valley (e.g., the Bays Mountains of Greene, Hawkins, Hamblen, Knox, Sevier, and Blount Counties). The Bays is characterized by dull-red siltstones that crop out in ledges. Other beds are olive shales and siltstones; quartzose, impure, whitish sandstones underlie prominent ridges.

The Bays is not deeply weathered, and the soil cover is generally thin and acid. The formation has low permeability and is not an important source of water.

The landfill aspects of Bays areas are analogous to the Rome. Thin soils, steep slopes, and lack of cover material limit first class sites; but the low permeability is favorable.

Moccasin Formation.—The Moccasin Formation is equivalent to the Bays but crops out in areas in the northwestern half of the Valley and Ridge province.

Red mudstones characterize the Moccasin, but it also contains silty yellow shale tongues and lentils of blue-gray limestone. The proportion of limestone increases northwestwardly; in the westernmost outcrop areas nearly all of the formation is limestone, which is generally shown on geologic maps as "Chickamauga Limestone." Major sinks are developed in this area. Both the red beds and limestones weather to flaggy pieces or ledges with thin soil cover and abundant outcrops. The yellow tongues weather to thin yellow soil with shale chips.

Ground water occurs in joints and fractures. In places small sinks are developed in the limestone. However, the Moccasin is not a particularly good aquifer.

Perhaps the most serious problem of Moccasin outcrop areas is the shallow soil and consequent lack of cover material. Excavations in the formation to depths greater than a foot or so will generally involve removal of rock. The limestones should be avoided owing to their soluble nature.

Juniata and Sequatchie Formations.—The Juniata and Sequatchie Formations are limited to a few areas of outcrop in East Tennessee. The two units are lateral equivalents, the term Juniata being applied to a red siltstone phase, e.g., on the higher slopes of Clinch Mountain; whereas, the Sequatchie crops out along the Cumberland Plateau escarpment and in Sequatchie Valley to the west. The Sequatchie is more calcareous than the Juniata, shows shades of pink, green, and blue, and is an argillaceous magnesian limestone.

Both of these units have shallow soils; the Juniata closely resembles the Bays. As pointed out, their outcrop areas are small and are commonly on the upper slopes of ridges. Neither is likely to afford good landfill sites.

Clinch Sandstone.—The Clinch Sandstone is restricted to a few long linear outcrop belts that coincide with such topographically high ridges as Clinch Mountain and Powell Mountain.

The Clinch is typically a white to iron-stained, well-cemented, quartzose sandstone. It crops out in steep terrain and forms extensive soil-free slopes.

The likelihood of a satisfactory landfill site in Clinch outcrop areas is small because of thin soil and steep slopes.

Rockwood Formation.—The Rockwood Formation is predominantly greenish to brownish, silty and sandy shale, with sandstone interbeds, and minor impure limestone. It is best known as an iron-bearing formation, and its outcrop is marked in many places by old iron workings. The Rockwood crops out primarily along the western side of the Valley and Ridge. It weathers to a thin shaly soil with the sandstones standing in higher relief. Where the sandstones are thick a fairly prominent ridge is formed.

The outcrop of the Rockwood may offer some landfill sites. In general, the Rockwood is a poor aquifer, has low permeability, and is rippable where sufficiently weathered. However, careful investigation is recommended prior to site selection to avoid sandstone ledges too tough to be ripped, limy zones, and steep slopes.

Chattanooga Shale.—The Chattanooga Shale is readily recognized by its gray-black color, altering on weathering to sulfur-stained creamed-coffee hues, its pyrite (fool's gold) content, and its weathering into paper-thin sheets. Areas of Chattanooga outcrop are commonly uncultivated or in submarginal use, as the soils are thin and strongly acid. Its outcrop in the Valley and Ridge is restricted to a few narrow belts along the northwestern foot of Chilhowee Mountain in Blount and Monroe Counties, southeast of Clinch Mountain from Grainger County to Virginia (Poor Valley), southeast of Powell Mountain in Claiborne and Hancock Counties, along the Cumberland Plateau-Lookout Mountain escarpment, and on Whiteoak Mountain in Bradley and Hamilton Counties.

Where fresh the Chattanooga is tough and resists breaking, but it has been deformed in the Valley and Ridge, and generally is pervasively weathered to slabby or chippy shale. It yields sulfurous and sulphate-bearing waters to wells and springs. The water flows along joints and fractures to points of discharge.

The Chattanooga is unlikely to offer attractive landfill sites. No suitable cover is available; many outcrops slope steeply or are on steep slopes; it is not easily excavated to sufficient depth for trenches; and its restricted outcrop further limits its significance.

Grainger Formation.—The Grainger Formation is limited in outcrop area to a few places. The easternmost exposures are in the Little Mountain area of Blount and Monroe Counties. The most extensive outcrops are on Poor

Valley Ridge in Grainger and Hawkins Counties and in the Short Mountain area of Hancock County.

The Grainger is a thick sequence (600 to 700 feet) of shales, siltstones, and sandstones with some conglomeratic beds. The formation is variegated in shades of drab to dark-green, dull-red, and rusty-yellow.

The Grainger is resistant to erosion and underlies ridges mantled by thin sandy soils or chip-filled shale soils. Well water supplies in the Grainger occur in joints and fractures, but it is not a particularly good aquifer.

Landfill sites in areas of Grainger outcrop do not pose serious ground-water pollution problems. However, the soil cover is thin, and in many places slopes are steep. Thus, the Grainger areas are not likely to offer good sites.

Fort Payne Formation.— The Fort Payne Formation crops out over limited areas of East Tennessee. It underlies a line of small ridges on the western side of the Valley in such synclines as East Fork Ridge, Ten Mile Ridge, and Whiteoak Mountain; and locally along and near the Cumberland Plateau escarpment.

The Fort Payne is very fine- to coarse-grained, medium- to thick-bedded, highly siliceous, gray limestone or dolomite. Wherever the formation crops out the original carbonate is replaced by silica so that the rock is a chert. Many specimens contain rounded moulds of leached fossils, and the stone resembles Swiss cheese.

The Fort Payne strongly resists erosion, and its outcrop commonly forms ridges paved by chert fragments in thin acid soils. Depth to rock is quite shallow in East Tennessee.

Thin soils, chert blocks, and tough abrasive bedrock make areas of Fort Payne poor for landfills in East Tennessee. The covering soils will not compact, and excavations can be made only with extreme difficulty.

Newman Formation or Group.—The term "Newman" is applied to a sequence of dominantly limestone strata that crops out in the Little Mountain, Clinch Mountain, Short Mountain-Newman Ridge synclines (i.e., the same areas as the Grainger), and in places along the Cumberland Plateau escarpment. In places the Newman has been subdivided into units with various names.

The Newman is gray, thick-bedded, somewhat magnesian limestone along the escarpment. In the more easterly exposures it is less pure; the limestones contain clay, some beds are shales, and some are quartz sandstones. The Newman is generally overlain by a thin clayey soil, in places cherty, and outcrops of bedrock are fairly common. The more limy beds are the sites of sinks and other solutional features. Obviously, such areas are poor landfill sites.

Generally, the Newman outcrop is unattractive for landfills. Thin soils, irregular pinnacled rock-soil interfaces, and possible solutional openings all are negative indicators.

Pennington Formation.—The Pennington Formation crops out in a few places in the Valley and Ridge. It is exposed in the Clinch Mountain syncline from the Virginia line southwestward to near State Highway 70, on Short Mountain and Indian Ridge in Hancock County, and along the Cumberland Plateau escarpment.

The Pennington along the escarpment is chiefly a red, green and drab shale with minor sandstone and limestone beds. Shales are common in the eastern exposures, but sandstone and limestone beds are more common and thicker. The shales are notably weak; slides in cuts in the Pennington are common. The clay shale portions of the formation are soft and can be removed rather easily. These strata are impermeable and transmit very little water.

The Pennington offers acceptable landfill sites where excavations can be made on nearly level or very gentle slopes. Its tendency to slide recommends that it not be disturbed on other than gentle slopes. Without addition of sand, or possibly lime, trafficability in Pennington outcrop areas could constitute problems in wet weather.

CUMBERLAND PLATEAU

The Cumberland Plateau coincides with the coal fields of Tennessee. The Plateau is separated from the Valley and Ridge to the east by a bold steep escarpment and from the Highland Rim to the west by a lower, much dissected escarpment. Particularly along the western margin deep valleys, locally called "gulfs," penetrate laterally for several miles into the Plateau. These gulfs are steep-sided and have high relief. South of Crab Orchard the Plateau is separated by Sequatchie Valley into an eastern segment (Walden Ridge) and a western segment (Cumberland Plateau).

The Plateau surface, from approximately the latitude of Crossville south (the gulfs and Sequatchie Valley excepted), is gently rolling and has low topographic relief, and in northern Cumberland, Scott, Morgan, and Campbell Counties possesses high enough relief to be termed mountainous.

The rocks comprising the Plateau region are an alternating sequence of clay shales, quartz-cemented sandstones and conglomeratic sandstones, with coal seams distributed through the rocks at various levels. In general the rocks are little deformed, but strong deformation has occurred along the margin of the Plateau for a mile or so west along and parallel to its eastern margin, and along the course of the Emory River in Morgan County. Another zone of deformation extends northwest from Lake City to the southwest end of Elk Valley (roughly the route of Interstate 75). Faulting is also prominent in an "s"-shaped pattern from the vicinity of Lantana northeastward through Crossville and then eastward toward the Emory River. These deformed areas are marked by inclined and disrupted strata and open fractures that extend to considerable depths. Water flows freely through and along these fracture systems. The Tennessee Division of Water Resources (1958) reports that water supplied by wells and springs in this region is controlled principally by fractures.

Soil cover on the Plateau is generally thin (maximum 6 feet, average 2 feet or less), acid, and very well drained. The bedrock shales and sandstones crop out widely and are rather impermeable. In most areas even shallow excavations involve removal of rock, much of which must be blasted. Thus much of the precipitation penetrates into the ground only to shallow depth and surface runoff is high. The generally shallow soils render much of the Plateau unfavorable for landfill sites. Unfortunately, the thickest soils have formed in areas of well-developed fracturing, and landfills in these places jeopardize the water supplies.

The rock sequence of the Plateau is divided into a number of geologic formations by major coal seams and prominent sandstones, siltstones, or conglomerate beds. For purposes of this discussion the significant differences are not assignment of the strata in the sequence so much as whether the rock is a shale or sandstone. For landfill purposes all Plateau shales are similar enough to be grouped, as is true of the sandstones. Areas underlain by shale can be excavated deeper by ripping than can sandstone areas, and movement of water in shales generally is slower and infiltration less than in sandstones. The interface between a sandstone and an underlying shale is commonly a zone of ground-water flow. Therefore, care should be taken not to introduce waste into pits intersecting such interfaces.

Many areas on the Plateau contain strip mines (coal), and using these excavations for landfills has commonly been recommended. Examination of the strip mines shows that only a few are actually suited to this use. Access to many mines is poor and would involve extensive rehabilitation of haul roads to provide all-weather access. Numerous other mines are long linear trenches (contour mines) developed on steep slopes. These are subject to erosion of the fill by surface drainage and to failure of the lower side of the fill. Other pits are catchments for water and cannot be worked because of water fill. Mines in areas of gentle slopes and places where area stripping, as opposed to contour stripping, has been done and where water has not ponded so deeply, offer the best sites for reclamation by landfill.

Suitable landfill sites in the Cumberland Plateau are scarce. Shale areas are more likely to offer sites than sandstone areas. Steep slopes are to be avoided altogether. Areas of coal stripping probably offer the best possibilities for landfill sites.

Middle Tennessee

GENERAL

Middle Tennessee is divided into two major physiographic units. These are the Central Basin and an upland area which encloses it, called the Highland Rim. The relatively pure limestones of the Basin are distinctly different from the more siliceous formations of the Rim.

The Central Basin is more distinctly a true basin-type physiographic feature in the northern and eastern parts, where a more prominent escarpment exists adjacent to it (the Highland Rim escarpment). To the south it is characterized by many outliers of Highland Rim cherty rocks, and to the west by lower elevations and a less distinct, more dissected escarpment.

The Highland Rim can be referred to by its Eastern and Western components. The Eastern Rim is, in general, less dissected but much more narrow than the Western Rim, and has definite flat, plateaulike features. The Western Rim is characterized by generally rolling topography but has locally flat areas. Several major streams cross the Highland Rim, and in places have developed moderately wide flood plains. The Western Valley of the Tennessee River marks the western boundary of the Highland Rim. It is bounded on the east by the western escarpment of the Cumberland Plateau.

The dominant structural feature in Middle Tennessee is the Nashville dome, a regional swell on the Cincinnati arch, the erosion of which has formed the Central Basin. The axis of the dome trends NE–SW, and in the south-central part of the basin the trend changes to west. The rocks in Middle Tennessee dip gently away from the axis of the dome.

As in East Tennessee a humid, temperate climate has caused extensive chemical weathering of the rocks, resulting in well-developed soil profiles, caves and sinkholes, joint-plane enlargement, and generally mature valley features, although some smaller streams on the Highland Rim retain some youthful characteristics. The deepest residuum is developed on the Highland Rim in Mississippian limestone and chert, which contain a high percentage of insoluble material. Ordovician limestones of the Basin, particularly rocks of the Stones River Group, have thinner soils and in some areas form extensive outcrops of rock. The formations of the Basin develop numerous types of soils and highly variable depths of residuum.

Most of the limestones in Middle Tennessee are sources of ground-water supplies. The water table is very shallow in some areas, and the water occupies joints, bedding planes, and other solutional openings. For these reasons, the locator of landfill sites in Middle Tennessee must consider the rapidity with which pollutants can enter shallow saturated zones via the solutional openings. These problems are inherent in virtually all the rock units in the Central Basin and the Highland Rim.

CENTRAL BASIN

The Central Basin can be subdivided into an Inner and Outer Basin on the basis of exposed rock units and distinct topographic features. The Inner Basin is underlain mostly by limestones of the Stones River Group. The topography is very gently rolling to nearly flat in some areas, with a few low hills. The Duck River and Stones River are the largest streams flowing across the area. The Outer Basin is underlain by younger Ordovician rocks which usually develop deeper residuum, for they contain higher percentages of insoluble material; outcrops of thin pre-Chattanooga Devonian and Silurian rocks are present along the western, northern, and southern periphery of the Basin. The Outer Basin has more distinctly rolling to hilly topography, with numerous high hills capped by the Fort Payne Formation. These higher hills are outliers of the Highland Rim rocks that once covered all of Middle Tennessee, and which have been almost completely eroded away to expose the older rocks. These outliers of Fort Payne are more numerous to the south, where the Basin is still in an intermediate stage of development.

The limits of the Central Basin might best be defined as the base of the Chattanooga Shale along its periphery. In most places this rock unit marks a distinct topographic break, the slope of the Rim being noticeably steeper above its base.

From the standpoint of potential landfill sites, the Central Basin can be classified into several geologic-topographic areas—(1) rocks of the Stones River Group, which are the predominant units of the Inner Basin, (2) the Nashville-Maysville Groups and younger rocks of the Outer Basin, and (3) hills and ridges capped by the Fort Payne Formation.

Inner Basin

Rutherford County comprises the largest part of the Inner Basin, with Murfreesboro essentially at its center. The Inner Basin is less distinct to the southwest, but does extend into Bedford and Marshall Counties. It also extends northward to include a part of Wilson County. Most of the rocks in this area are classified in the Stones River Group, but there are some outliers of younger Ordovician rocks, mostly Nashville Group. The formation that underlies the largest area of the Inner Basin is the Ridley Limestone, which forms nearly level areas referred to as "Ridley flats." Other formations with wide areal extent are the Lebanon, which forms low hills, and the Carters Limestone, which underlies slightly steeper hilly terrain.

Areas underlain by rocks of the Stones River Group are probably the poorest in the State for landfill use. Upon weathering they typically develop a thin, clayey residuum. The Lebanon Limestone forms the thinnest soils; some areas of several acres have almost no soil cover. The thickly bedded Ridley, which immediately underlies the Lebanon, may develop as much as 10 feet of residuum, but the residuum is highly irregular in thickness and may contain large pinnacles of unweathered rock. Joint widening is also common in the Ridley, and sinkholes are prevalent throughout its outcrop area. Karst features are present in other Stones River rocks, and the Inner Basin area is generally characterized by a notable lack of surface drainage.

The Pierce and Murfreesboro Limestones, which underlie the Ridley, are restricted in outcrop to the river valleys and smaller stream beds.

The youngest unit of the Stones River Group, the Carters Limestone, consists of a thick-bedded Lower Member and a thin-bedded Upper Member. The Carters also weathers differentially, with cutter-pinnacle development common, and its residuum is characterized by a high clay content. The major outcrop areas of the Carters are along the outer edge of the Inner Basin and in inliers throughout much of the Outer Basin.

The only units of the Stones River Group that form significant thicknesses of residuum are the Carters and Ridley Limestones. However, the bedrock surface configuration of these formations is highly irregular and unpredictable. In many places there is no soil preserved, and bare rock covers large areas. Even the minimum of 5 feet of underlying residuum suggested for a landfill base would be difficult to find over any sizable area. Also, when wet, these soils are difficult to work because of their clay content. In addition, the water table in the Inner Basin is quite shallow in much of the Ridley belt, in some places only 25 to 30 feet. With the high degree of joint-plane enlargement and cavern development, such thin residuum is inadequate to filter leachate which can quickly move to the zone of saturation.

These factors lead to the conclusion that all Stones River rock units should be avoided for sanitary landfill sites, except for the construction of "fills" above Stones River residuum by the use of cover material brought into the area. This is discussed under the section *Transportation of Cover Material.*

Outer Basin

This area is predominantly underlain by rocks of the Nashville Group, and, to a lesser extent, the Maysville Group. Above these in some areas are thin units of the Richmond Group (Upper Ordovician) and Silurian and Devonian rocks. These younger units are preserved mostly along the northern and western periphery of the Basin, in some outliers within the Basin, and in inliers on the Western Rim; in general, they are not acceptable for landfill sites.

The formations of the Nashville Group, from oldest to youngest, are the Hermitage Formation, the Bigby-Cannon Limestone, and the Catheys Formation. In general, the Hermitage and Bigby-Cannon Formations crop out in large rolling and hilly areas within the Basin, and the Catheys Formation is restricted to the peripheral areas and to the higher outliers and hillier sections within the Basin. The Leipers Formation (Maysville Group), which overlies the Catheys is lithologically similar to it, and for convenience will be considered with it in this discussion. The Leipers is even more restricted to the edges of the Basin than the Catheys.

The Hermitage Formation is moderately well suited for landfill use. The Laminated Argillaceous Member, which comprises the majority of the formation, characteristically weathers to moderately deep, sandy, silty, clayey residuum which is fairly permeable. Some of the problems associated with use of the Hermitage are (1) the prevalence of cavern development in the underlying Carters and the subsequent collapse of Hermitage into sinkholes, and (2) the presence of enlarged joints which may contain cavities.

The overlying Bigby-Cannon Limestone is subdivided into three facies. The predominant lithology on the east side of the Basin is the dense, dark, medium- to thick-bedded Cannon limestone facies, which weathers to a relatively thin, clayey residuum. Also present is the Dove-colored limestone facies, which is also dense but much lighter in color. Areas underlain by these members generally are unacceptable for landfill sites because of thin residuum. Farther west in the Basin the predominant lithology is the medium- to thick-bedded, crossbedded phosphatic Bigby limestone facies, which comprises the entire formation on the western periphery of the Basin, the lowermost and uppermost zone of the formation slightly farther toward the axis of the dome, and an even smaller percentage of the formation near the axis. It is mined for phosphate at several localities in the Central

Basin. The Bigby facies has some potential for landfill sites. Locally, it weathers very deeply, and the residuum is as much as 35 feet deep. In many places weathering has widened joint planes and also has extended them vertically down into the underlying Hermitage. Joint widening leaves intervening pinnacles of unweathered limestone in the residuum, and such a highly irregular bedrock surface makes landfill operations very difficult. The joints are also avenues of descent for large volumes of ground water, acting as "funnels" to carry leachate into the zone of saturation. Open cavities may also be present along these widened joints. Another problem with the Bigby residuum is that it is highly clayey and therefore difficult to work. Sinkholes are not as common in Bigby-Cannon areas as in Hermitage areas, but they should be avoided if present.

The Catheys and Leipers Formations in the east and south parts of the Basin and on hills within the Basin are mostly thin-bedded, silty, clayey limestones which weather to rubbly, clayey, thin residuum. Areas underlain by these rocks are not suitable for landfills. To the north, however, primarily in Sumner County, the Leipers Formation is phosphatic in part and is similar to the Bigby. Such areas, where the topography is relatively flat, offer possible sites for landfills, but they are quite limited and the same problems exist there as with the Bigby. Similar phosphatic zones are found in the Catheys and Leipers Formations to the west, but these areas are characterized by rather steep topography and generally thin residuum.

The Richmond (Ordovician), Silurian, and pre-Chattanooga Devonian formations are generally thin, have irregular thicknesses of residuum, are limited in outcrop area, and generally are restricted in outcrop area to steep slopes. They therefore have little potential for landfill sites.

Fort Payne Outliers

The siliceous Fort Payne rocks were once present over the entire Central Basin area, but erosional breaching along the axis of the Nashville dome and subsequent excavation by solution of the Ordovician limestones has resulted in a topographic basin with only higher hills still capped with remnants of the Fort Payne Formation. The segments of the once more extensive outcrop area are called outliers. The largest areas of Fort Payne are in the less eroded southern part of the Basin in Moore, Bedford, Marshall, Lincoln, and Giles Counties. Two other prominent areas of Fort Payne-capped hills are in Williamson and Davidson Counties in the west-central part of the Basin, each with an essentially NW-SE lineation. Numerous other outliers are present all along the periphery of the Basin, but the Fort Payne rock is preserved only on a few hills near its center. Because the rocks dip away from the center of the dome, the base of the Fort Payne is at lower elevations closer to the edge of the Basin.

The lower zones of the Fort Payne may offer acceptable sites for sanitary landfills. In most places the formation is weathered to a rubble of chert fragments and shaly flakes in a matrix of smaller siliceous fragments and clay. The chert becomes more blocky in the upper part of the formation. Permeability may range considerably, and may be high in some places. To the north and northwest the New Providence Shale is present at the base of the Fort Payne.

The Fort Payne in Middle Tennessee commonly weathers very deeply, and the resulting residuum in most places is thick enough for landfill excavation. Although beds of blocky chert may be encountered in excavation, they can be ripped and generally are separated by zones of smaller chert fragments or clayey material. In addition, some of the blocky chert can be broken or crushed. Most of the Fort Payne that is preserved on the outliers, though consisting of siltstone, silicastone, shale and cherty limestone where fresh, is weathered to such residuum as described above, and these bedrock characterisitics commonly are obliterated. The deepest weathering is on hilltops and ridgetops, the larger of which have moderately extensive rolling topography. Such areas may provide acceptable landfill sites.

There are several problems in the consideration of Fort Payne outliers for landfill sites. These hills are usually very steep and inaccessible, and moving trucks and equipment on them may be difficult. The steep sides of these hills are also subject to excessive erosion. Therefore excavations should be limited to the flatter areas on the hilltops or ridgecrests. Another problem is the material itself. The presence of large chert blocks may make covering and compaction more difficult. Zones of high permeability also must be avoided.

In general, the lower Fort Payne, particularly that facies known as "scraggy" chert, which consists of smaller sized fragments in a clayey base, provides good landfill cover material. Most of the better areas of this material are on the Highland Rim proper, especially the western Highland Rim, and not on outliers. However, the larger ridges and hills capped with "scraggy" chert offer possible sites to communities in the south-central part of the Central Basin, and sources of material that could be transported to sites lacking good cover.

HIGHLAND RIM

General

The Eastern and Western components of the Highland Rim can be further subdivided on the basis of the topographic expression of the dominant rock type and the stage of regional erosion.

The Eastern Rim is much narrower than the Western Rim, averaging approximately 25 miles wide. The regional dip away from the axis of the Nashville dome controls the distribution of rock units; successively younger units crop out to the southeast.

Adjacent to the eastern edge of the Basin is a generally flat, and in some places highly dissected, area of Fort Payne and Warsaw referred to as the Barrens. This area is characterized by a cover of deeply weathered siliceous residuum. Some St. Louis residuum is also present farther east. Unweathered Warsaw and St. Louis are present in the hillier, rolling areas closer to and along the west-facing escarpment of the Cumberland Plateau.

Overlying the St. Louis, and forming the base of the

Plateau slope, is the Monteagle Limestone, a much more "pure" limestone than the underlying Mississippian units and characterized by extensive cavern development. Along with the underlying St. Louis, it constitutes one of the classic karst areas in the United States. Higher on the escarpment are the Hartselle Formation (limestone, shale and sandstone), Bangor Limestone, and the Pennington Formation (shale, limestone, and dolomite).

The Western Rim can be divided into a northern area underlain mostly by Warsaw, St. Louis, and Ste. Genevieve cherty residuum and limestones; and a southern area dominated by cherty residuum of the Fort Payne, and lesser areas of Warsaw and possibly St. Louis. Also present over parts of the Western Rim, particularly in the south, are scattered patches of Tuscaloosa Gravel of Cretaceous age. In the southwest part of the Rim there are extensive areas of Tuscaloosa and younger Cretaceous unconsolidated sediments.

The Western Rim is, in general, characterized by a rolling to hilly topography dissected by many stream valleys. The general direction of stream flow is westward, possibly in response to the regional dip. In only a few places are there distinguishable remnants of a once-flat, plateaulike surface similar to that of the Barrens.

Eastern Highland Rim

The Barrens, the area with distinctly flat topography occupying the outer 10 miles of the Eastern Rim, is underlain chiefly by the Fort Payne Formation, and to the east by weathered Warsaw and St. Louis. This residuum is generally deep, as much as 50 feet or more, and natural exposures of unweathered rock are rare. Because of the flat terrain, deep residuum, and features of the material, this area offers numerous potential landfill sites. However, the presence of fragipans in the soil presents a special problem. They form impermeable zones in the upper part of the residuum and cause swampy areas to develop, especially where the terrain is very flat. After excavation, ground water will move laterally over the fragipan into the cut. Such zones containing fragipans, whether swampy or not, should be avoided generally, but they can be cut and the water diverted if the fill is properly designed. The advice of soil scientists is extremely important in these areas.

The Warsaw and St. Louis areas farther east also afford potential landfill sites, but they also present more problems. The Warsaw, like the upper Fort Payne, commonly weathers to blocky chert which can be difficult to work. Also the residuum is generally not as deep as that of the Fort Payne. Exposures of unweathered rock are more abundant, and shallow pinnacles may cause excavation problems. In the central part of the Rim, closer to the Plateau (Sparta-McMinnville area) cavern development and subsequent collapse has resulted in karst topography. Many of the sinkholes contain water, which may indicate a shallow water table. Such karst areas are to be avoided for landfill sites, for pollution of ground water is very likely, and the free movement of ground water through well-developed cavern systems can transport pollutants very quickly for considerable distances.

The Monteagle, Hartselle, Bangor, and Pennington Formations underlie generally poor areas for landfills. The Monteagle and Bangor have extensive cavern development. The Hartselle, although it forms flat areas (benches), has thin residuum. The Pennington is composed chiefly of clay shale (with some limy zones that in some places contain caverns), and it crops out on steep slopes. All of these units are generally confined in outcrop to the Cumberland Plateau escarpment or Plateau outliers. The main exception is the basal Monteagle, which crops out in some areas as flat or rolling lands at the base of the Plateau escarpment. Large springs are common in the lower Monteagle. Much of the outcrop area of Upper Mississippian rocks on the Plateau escarpment is covered by highly porous colluvium, mostly in the form of talus cones and irregular masses.

A special type of material which is found along the eastern part of the Rim in the Sparta-McMinnville area is stream terrace alluvium. This sandy, silty, clayey material is present as irregular, but in some places extensive, patches of soil high above the present channels of the Collins, Caney Fork, and Calfkiller Rivers. Areas of such deposits can be used for landfills except where karst features are developed.

Western Highland Rim

The northern area of the Western Highland Rim has a surface of cherty residuum derived from the deep, and often irregular, chemical weathering of the Warsaw, St. Louis, and Ste. Genevieve and, to a lesser extent, the Fort Payne Formation. Much of this area is suitable for landfills, but the area north of Springfield and Clarksville has many sinkholes and should be avoided.

In particular the Warsaw in the Western Highland Rim weathers irregularly, with cutter-pinnacle development common. It also produces blocky, massive chert upon weathering. The St. Louis and Ste. Genevieve, to the north of Springfield and Clarksville, and into Kentucky, form one of the classic karst regions of the world. Thousands of sinkholes are present, and much of the drainage is subsurface. Most of this entire region is unacceptable for landfill use.

From approximately the line of Interstate 40 southward, the Fort Payne Formation crops out over most of the Rim area. It is in this region that the "scraggy" chert facies is most typically developed, and the residuum should provide acceptable sites for landfills. Most commonly this material consists of small chert fragments (2 inches or less in diameter) in a matrix containing granule- and sand- to silt-sized chert fragments, shaly and siliceous flakes, and clay-size silica. Scraggy chert is generally moderately permeable but may be highly permeable where vertical joints are present in the residuum. As reported by Stearns and Wilson (1971), precipitation can move very rapidly down these joints (preserved in even the weathered material) and hence into a zone of saturation on the top of unweathered bedrock. Such shallow aquifers in Fort Payne residuum are commonly used on the Western Rim, where much of the water supply comes from "dug" wells. Extreme care should be taken, therefore, to determine the presence and number of such joints, and to ascertain the overall permeability of the material at the site under consideration. As mentioned previously, scraggy chert should provide good cover material, and might be transported an acceptable distance for use on a site where ground-water impairment is less likely. Fresh (unweathered) outcrops are rare on the upland areas, and the residuum in some places is as much as 100 feet thick. Some Warsaw and St. Louis residuum is present in the vicinity of Hohenwald and Lawrenceburg, where nearly flat remnants of an older plateau surface are preserved. These areas may provide acceptable landfill sites.

The valleys of several streams in the central and southern parts of the Western Highland Rim have been eroded into older rocks of Devonian, Silurian, and Ordovician age. In general, these areas are undesirable for landfills. One possible exception is the phosphatic Leipers Formation in the vicinity of Centerville, which in places weathers to a deep residuum that has been mined for phosphate. As is true of the Bigby limestone facies, the major problems are the very irregular bedrock surface configuration and the high clay content of the residuum. Most of these older rocks have a very restricted outcrop area, normally confined to narrow valley floors and walls, and generally weather irregularly because of their highly variable lithologies.

The youngest sediment within this area is alluvium. The most recently deposited alluvium is on the flood plains of almost all streams. Such areas must be avoided for landfills. Some older, and therefore higher, alluvial masses (terraces) are found along the valley slopes and on ridgetops in some areas. Because most of these deposits consist of gravel and sand, with some clay, they are commonly very porous and may be underlain by saturated zones. Only those terrace deposits high above the flood plain, on level to rolling terrain, and with a higher percentage of "fines" (which reduce permeability) should be considered for landfills. Even these must be carefully examined for underlying perched water tables.

West Tennessee

GENERAL

For purposes of this report, West Tennessee can be divided into three major physiographic units—the Western Valley of the Tennessee River, the Western Slope of the Coastal Plain, and the Mississippi River Valley.

The Western Valley includes the flood plain of the Tennessee River, its valley slopes, and the valleys of its smaller tributaries. The valley to the south is underlain mostly by Silurian and Devonian limestones, and to the north by siliceous Mississippian rocks.

The Western Slope consists of a somewhat hilly area to the east, adjacent to the Western Valley, composed primarily of Cretaceous sands; and a more rolling, gently westward-sloping area to the west, underlain by Tertiary sands but covered with a veneer of loess of Quaternary age. Numerous broad stream valleys cross this province. These streams originate in or adjacent to the upland Cretaceous area and flow westward into the Mississippi River.

The Western Slope of the Coastal Plain ends abruptly in most places on the west at a low bluff which marks the eastern limit of the Mississippi River Valley. This flood plain is extremely flat, and that part of it in Tennessee is as much as 14 miles wide. In addition to its flatness, it is characterized by numerous oxbows, meander scars, and swampy areas, typical of an old-age river valley. The material there is sand, silt, clay and gravel of fluvial origin.

Several major structural features are present in West Tennessee. A continuation of the Cincinnati arch extends through Clifton (the Clifton saddle), in the Western Valley. To the north is the southern extremity of the Illinois Basin, and to the south is the Warrior Basin. Overlapping these features is the Mississippi Embayment of the Gulf Coastal Plain, within which thick sections of Cretaceous and Tertiary sediments collected. The presence of these structures, along with several old buried erosional surfaces called unconformities, has resulted in a rather complex pattern of outcrop of Paleozoic rocks in the Western Valley.

The limy and cherty rocks of the Western Valley have developed soils typical of those in parts of the Central Basin and the Highland Rim. However, soils derived from the Cretaceous and Tertiary sands are distinctly different. The soils of the loess, the wind-derived silty sediment mentioned earlier, are also unique.

WESTERN VALLEY

Although the Western Valley is basically defined as the flood plain and valley of the Tennessee River, its east-west boundaries are indistinct, as the many small tributaries entering the river have highly dissected the valley wall slopes. If the east-west boundaries are considered to be the heads of the minor drainages entering the Tennessee River, the Western Valley is as much as 20 miles wide, and thus constitutes a large physiographic unit. It extends across the north-south dimension of the State, approximately 110 miles. The maximum width of the flood plain is 3½ miles, in Hardin County. The flood plain narrows considerably to the north, where it is completely covered by Kentucky Lake.

From the standpoint of landfill site evaluations, the Western Valley can be discussed in terms of (1) the flood-plain alluvium of the Tennessee River and its tributaries contained within the province, (2) areas of higher level fluvial deposits (old terrace material), (3) areas of pre-Chattanooga Paleozoic rocks, (4) areas of Mississippian rocks, and (5) outliers of Cretaceous deposits.

Flood-Plain Alluvium

The flood plain of the Tennessee River has a maximum width of about 3½ miles in Hardin County, but near the Hardin-Decatur County line it narrows considerably and has a fairly constant width of 1½ to 2 miles from there northward. These limits refer to the present (recent) flood plain and not to the higher level areas of alluvium (terraces). From the New Johnsonville area northward almost all of the flood plain is covered by Kentucky Lake. This lake extends to Pickwick Dam in southern Hardin County but covers little of the flood plain in the southern part of the valley.

The material that comprises the flood plain is sand, silt, clay, and gravel, probably as much as 50 feet thick. It is much thinner in the tributary valleys.

Although recent flooding on this part of the Tennessee River has been greatly reduced by upstream dams, there are still several reasons to avoid these zones for landfill sites. First is a commonly very shallow water table beneath and within the alluvium. Much of the bottom land is swampy, indicating saturated material and poor drainage. Any excavation is apt to encounter water-saturated material within a few feet of the surface. Also, as the flood plain is extremely flat, it is poorly drained and precipitation can easily saturate the material or pond in minor depressions, causing constant problems in excavation and operation. In some areas within such alluvial valleys fragipans have formed, which results in impaired movement of ground water, as well as problems in excavation. Finally, a high percentage of clay and silt in flood-plain alluvium would render the material very difficult to work. Flooding is a continuing possibility, especially in the small tributaries.

Higher Level Fluvial Deposits

Numerous extensive areas of older, higher level alluvial deposits are present along the Tennessee River, especially in Hardin, McNairy, and Decatur Counties. Some of these are more than 10 square miles in area, at elevations of more than 600 feet above sea level, or about 300 feet above the present river level. They overlie various types of terrain, including ridges and hilltops on the east, and broad, rolling to hilly, sloping areas on the west. Some cover very steep slopes. The thickness of these deposits ranges greatly but may be as much as 60 feet.

Terrace deposits are composed predominantly of chert gravel, with some quartzite pebbles, in a matrix of sand and silt, and some clay. In some places near the base this material is cemented into layers by iron oxide. A fine-grained silty material covers the gravel locally.

These terraces composed of older alluvium should, in general, be avoided for landfills for several reasons. First, most of them are highly permeable and contain a very small percentage of "fines." Percolating ground water will quickly carry leachate down and laterally through the material. Also, owing to this permeability, a zone of saturation may be present at the base, particularly if Paleozoic rocks with clayey residuum are present beneath it. Such aquifers may be an excellent source of ground water supply, if not contaminated. Finally, the thickness of these deposits is unpredictable, and the surface underlying them may be very irregular.

Pre-Chattanooga Paleozoic Rocks

From approximately the Camden area southward there are extensive areas of outcrop of Devonian, Silurian and, to a much lesser extent, Ordovician rocks. The largest such areas are in Perry, Wayne, Hardin, and Decatur Counties. North of Camden there are outcrops of Devonian and Silurian rocks in the lower valley of the Big Sandy River.

Although a variety of rock types are present in these units, limestone predominates. The oldest rocks exposed in the Western Valley are the Hermitage, Fernvale, and Mannie Formations of Ordovician age, which are generally confined in outcrop to the valley floors. In addition to forming generally shallow, clayey soils, their limited outcrop and location in flood-prone areas precludes their use for landfill sites.

Silurian rocks are widely exposed in the Western Valley. The Wayne Group is composed of limestone, some of which is argillaceous, limy shale, shale, and mudstone. The Brownsport Formation is limestone, some of which is cherty, and calcareous shale. The Decatur limestone is relatively "pure" but may contain some chert. In general, none of these units are good for sanitary landfills. In the instance of the shaly argillaceous units, a high clay content makes the residuum difficult to work. The limestones characteristically weather irregularly, develop pinnacles and generally form thin residuum. Where unusually deep weathering is evident, certain zones in the Silurian might be usable. But the combination of thick, uniform residuum of proper composition, with an acceptable topographic configuration, is difficult to find in the Western Valley.

The Devonian units of the Western Valley are limestone, calcareous shale, and chert. The Ross Formation consists of several lithologies. The Ross Limestone Member is cherty limestone which weathers to a porous, sandy, siliceous residue. The Birdsong Shale Member is mostly calcareous shale. The Rockhouse Limestone Member is relatively "pure" limestone, as is the Flat Gap Limestone, which overlies the Ross Formation. These units offer virtually no landfill site possibilities because of thin residuum and restricted outcrop area.

The Harriman-Camden Formations of Devonian age, which crop out most extensively in the central and northern areas of the Western Valley, are in most places completely weathered to chert in a clayey, tripolitic matrix. These units, lithologically identical, have weathered so deeply and intensively that the resulting residuum should be quite adequate in many areas for landfills. A possible problem is the permeability of the material in some zones, and the potential contamination of ground water. The chert itself is somewhat porous, and with the tripolitic material present, some filtering qualities are inherent in the residuum. Certainly the Harriman-Camden chert zones deserve more study as potential landfill site areas.

Mississippian Rocks

The Warsaw Limestone and the Fort Payne Formation are deeply weathered in the Western Valley area. Minor areas of St. Louis cherty residuum also are present. The resulting residuum is composed of chert in a siliceous, clayey matrix, with some tripolitic material in places; the chert is generally more blocky in the Warsaw areas and smaller in the Fort Payne areas. Some bedded chert is present, particularly where weathering has not been intense. Fresh (unweathered) outcrops of these formations are rare in this area.

The largest areas of outcrop of Mississippian rocks are in the north half of the Western Valley, where almost all of the valley slopes are Fort Payne, and some ridges and hills are capped by Warsaw Limestone. Numerous outliers of Fort Payne, some very large, are present in the south half of the Valley. Typically, these Mississippian rocks form rather steep topography in the Valley area, and this reduces considerably their potential for landfill sites. Where topography is acceptable, however, these rock units offer possible landfill sites.

Cretaceous Deposits

Outliers of Cretaceous age, composed of uncemented sand with some gravel, are present all along the western side of the Western Valley, and also on the eastern side in Hardin County. Much younger than the underlying rocks, these outliers rest on a major unconformity, or old erosional surface, and thus may overlie Paleozoic rocks of various ages. These Cretaceous units in this area range in age from Tuscaloosa to McNairy, but the predominant formation is the Coffee Sand.

These deposits consist of sand, some of which is glauconitic and micaceous, some clayey, and interbedded clay. The oldest of these units, the Tuscaloosa, consists primarily of chert gravel in a matrix of silt, sand, and clay. The most extensive areas of Tuscaloosa are in Hardin County.

Cretaceous deposits are probably well adapted for use as landfills. The material is easily excavated and workable, and in most places contains enough silt and clay to reduce permeability to a moderate level. The Tuscaloosa may prove to be too permeable, but some zones may contain enough "fines" to allow slow leachate percolation.

Topography is a possible limitation to the acceptability of certain Cretaceous areas, because the terrain of these outliers commonly is steep and gullied. Numerous gently rolling areas can be found, however, and where adequate thickness of sand exists and aquifers are sufficiently deep, they should make good landfill sites.

COASTAL PLAIN

The Coastal Plain has also been called the Plateau of West Tennessee, Gulf Coastal Plain, Mississippi Embayment, or simply West Tennessee.

Two subdivisions comprise the Coastal Plain in West Tennessee. One is a hilly zone of moderate elevation to the east and adjacent to the Western Valley, composed mostly of nonindurated Cretaceous sands. This area may be called the Cretaceous Uplands. It forms the divide between the Tennessee River and Mississippi River drainages. The streams that flow westward across the slope originate in these Uplands.

The other subdivision is the much more extensive, gently rolling (in places almost flat) area of lower elevation, further distinguished by several broad flood plains of the rivers flowing westward across it. This is the Western Slope, which hereafter will be called the Slope. It is bounded on the west by a typically distinct low bluff that marks the eastern limit of the Mississippi River flood plain.

Potential landfill sites in the Coastal Plain area can be discussed from the standpoint of these two subdivisions, and their alluvial valleys.

Cretaceous Uplands

This area is approximately 20 miles wide in southern McNairy County but narrows to about 7 miles in northern Henry County. The major drainage for the northern part of the area is the Big Sandy River, and for the southern part Beech River, White Oak Creek, and Cypress Creek. The highest elevations, slightly more than 700 feet, are in Natchez Trace State Park and Forest. However, the average elevation is about 500 feet.

The formations in the Uplands are the Coffee, Sardis, Demopolis, Coon Creek, McNairy, and Owl Creek. By far the most extensive in outcrop area is the McNairy, but the Coon Creek and Coffee also are exposed over a large area. The valley heads of eastward-flowing streams and their divide areas are mostly in Coon Creek, whereas westward-flowing streams head in the McNairy outcrop belt.

All of these formations, with the exception of the Demopolis, are predominantly quartz sand containing variable amounts of quartz pebbles and granules, glauconite, mica, and clay. The Demopolis is composed of marl (lime) and calcareous clay. The clay in these units is in the form of lenses, beds, blebs and small masses, as well as being disseminated in the sand as a matrix. Iron-cemented layers are also present in some of the sands. Permeability of the material depends on (1) the amount of clay and silt-sized particles present and intermixed with the sand, (2) presence or absence of clay beds or lenses, (3) extent of iron cementation and (4) angularity of the sand grains. In general these sands should be moderately permeable. With the exception of the iron-cemented zones, they are nonindurated and therefore easily excavated. They should also be easily workable when wet, with the exception of clay lenses or beds.

There is some moderately steep, gullied topography, but many flat to rolling areas are available. All flood plains in the area should be avoided for landfill sites for the reasons previously stated.

If care is taken to locate and avoid shallow aquifers, and if erosion-prone topography is avoided, finding adequate landfill sites in the Cretaceous Uplands should not be difficult.

The Slope

Although the eastern boundary (in general the contact between Cretaceous and Tertiary units) is somewhat arbitrary, the western boundary is distinct—the low bluffs of the Mississippi River Valley. This slope area comprises one of the largest physiographic units in the State. Its main features are the western bluffs, the wide alluvial valleys that cross it, and the slightly rolling surface elsewhere. The topography is slightly more rolling to hilly to the east, closer to the Cretaceous Uplands. This variation in topography corresponds to the contact (actually a zone) between thick loess (4 feet or greater) in the west and Tertiary sands and clays (covered by thin loess) in the east. Elevations range from an average of slightly less than 500 feet in the east to about 350 feet in the west. The major streams draining the area are the Hatchie, Wolf, Forked Deer, and Obion Rivers.

From the standpoint of landfill site evaluation, this subdivision can be discussed in terms of the Tertiary outcrop area with thin, discontinuous loess cover to the east, and the thick loess area to the west.

Tertiary Formations.—The area in which Tertiary sediments are exposed (or are covered by thin, discontinuous loess deposits) is extensive in southern Hardeman, eastern Fayette, and Madison Counties. This belt narrows to the north in Carroll and Henry Counties.

The sediments are the unconsolidated sands, some of which are clayey, and clays of the Clayton, Porters Creek, Wilcox, and Claiborne Formations, all of Tertiary age. Fluvial deposits of Pliocene and Pleistocene age composed of sand, silt, and clay, and loess of Pleistocene age overlie the above-mentioned units.

The Clayton is glauconitic sand with a limestone at the base in Hardeman County. The Porters Creek Clay is composed of blocky, massive clay that may contain some sand. The Claiborne and Wilcox Formations are irregularly bedded sands which contain clay as interstitial material, balls, pebbles, irregular masses, and lenses.

The sands, especially those with disseminated clay, should make acceptable landfill sites. Highly clayey zones, such as the Porters Creek, or layers and lenses of clay in the Wilcox or Claiborne, will present problems in excavation and in determining direction of leachate movement. Clays known to underlie a moderately thick section of sand will retard movement of leachate downward to the main water table, but perched water tables may also be present. Landfills located in material containing clays must therefore be carefully planned. The clay may be advantageous or detrimental depending on its form, extent, and position in the section. Disseminated clay in sand is the most desirable condition, since it limits permeability but still allows the material to be worked when wet. Bedded or massive clay, even if workable, shrinks upon drying. Large cracks may develop and allow access of vectors and water to the refuse.

As mentioned earlier, thin loess covers much of this Tertiary outcrop area. It is commonly 4 feet thick or less, and a fragipan may be present.

Sizeable areas of higher level fluvial deposits lie adjacent to the major drainages in this area. They are composed of unconsolidated quartz sand, fine- to very coarse-grained, which may contain some granules and pebbles; and silt, sandy in part. Clay is rare in these deposits, and therefore they have high permeability and should usually be avoided for landfill sites. The larger "terraces" of this material may contain perched aquifers, especially if clay beds or lenses directly underlie them. All recent alluvial material (in the flood plains) must also be avoided.

There is steep, irregular topography in gullies and small drainages, and on valley walls, especially to the east. Site erosion and difficulty in equipment movement can be expected in these areas. However, the numerous rolling to nearly flat areas offer many potential landfill sites.

Loess.—The area of West Tennessee covered by loess more than 4 feet in thickness is extensive. This semiconsolidated material, composed mostly of silt-sized angular fragments, was deposited by north winds during the Pleistocene Epoch (Ice Age). Some reworking of the loess by older, higher level stream systems has probably occurred since original deposition. Owing to the fineness, uniformity of fragment size, and angularity of the fragments, loess can maintain vertical slopes when eroded or excavated. It reaches a maximum thickness of 100 feet along the bluffs but averages about 50 feet throughout most of far West Tennessee.

Loess in this area forms several distinct soil types. As typified by those in Fayette County, such as the Calloway, Collins, Grenada, Lexington, Loring, and Memphis Series, they range considerably in permeability. The Calloway, for example, is developed from thick loess on level to gently sloping uplands, and is poorly drained. It also forms a fragipan 2 to 5 feet thick at some 20 inches of depth. The other soils series mentioned are moderately well drained, but the Grenada also forms a hardpan 1 to 5 feet thick at about 24 inches in depth. In addition to the variable permeability of the loess, the permeability of the immediately underlying material also must be considered. Gravels may underlie the loess, and they are highly permeable and may contain ground water. Thin loess overlying such gravels should be avoided. Assistance from soil scientists is always valuable, and is especially important when working with soils such as those mentioned here.

Although loess, because of its fine-grained character, can be difficult to work if saturated, it can be used for landfills if certain criteria are met. The location should be in thick loess, in moderately well-drained soils with no fragipans. In thinner loess, the underlying material should be of low to moderate permeability, and shallow aquifers must be avoided. Loess mixed with sand derived from older formations should make good landfill material.

MISSISSIPPI RIVER VALLEY

That part of the Mississippi River Valley that lies within Tennessee has a maximum width of 14 miles. It is bounded on the east by low bluffs (100 feet high), sometimes referred to as the Chickasaw Bluffs. It was formed by flooding of the Mississippi River and by the many lateral migrations of the river at least as far back as the Pleistocene Epoch. The valley has most of the classic features of an old age river—oxbow lakes, meander scars, backswamps, cutoffs, and natural levees.

The material comprising the valley bottom is sand, gravel, silt, and clay in variable proportions, all of fluvial origin. It is constantly being reworked by flooding and by river currents.

This material contains a very shallow aquifer, commonly 20 feet or less beneath the surface. In addition to the shallow saturated zones, the area is only a few feet above river level and is subject to frequent flooding. Consequently, no landfill should be located in the valley.

WATER-QUALITY MONITORING

As stated in the section on *Geologic Considerations, Criteria, and Procedures,* avoidance of underground or surface water contamination is of utmost importance. For this reason it is necessary to know the quality of water in the vicinity of the site *before* a landfill is started, for use as a standard, periodically during the fill operation, and after its completion.

The first step in setting up a program of periodic monitoring is to define the drainage area of the fill site and determine the probable direction of ground-water movement. All existing wells and springs in the site area should be located. A preliminary check can be made by using a topographic map and encircling houses in the vicinity. Also, sizeable springs are often shown on topographic maps. If no wells exist in the general vicinity of the site, a test monitoring well should be drilled. Such a well is preferable as it can be drilled in the optimum location and designed for the specific needs of the monitoring program. In certain situations, more than one well may be required.

Periodic analyses should also be made of surface water in the area.

TRANSPORTATION OF COVER MATERIAL

At some landfill sites, owing to very thin regolith or failure of the material to meet previously defined criteria, it may be necessary to bring in cover material. This may be economically preferable to transporting refuse long distances, since a single load of earth can be used to cover several loads of refuse. In addition, certain problems may be encountered in finding acceptable landfill locations across city or county boundaries.

In the event that transportation of cover material becomes necessary, several factors must be considered. First, is acceptable material available within a reasonable distance? This requires the use of geologic and soils maps and/or a field investigation to determine where such material can be found. Once a potential source has been located, the regolith should be tested for permeability and compactability, and it must be determined if sufficient tonnage is available.

Once it has been judged economically feasible to bring in cover material, the most desirable location for construction of the fill must be determined. Within the limits of the greatest practical distance the refuse can be hauled, the best topographic configuration should be sought. If the criteria discussed in other sections are met (such as avoidance of flood plains and karst features) the best terrain would be either a gentle head of drainage, which could be filled and properly contoured down valley, or a gently sloping flat area. The latter situation, and perhaps certain others, may require the construction of impermeable "berms" on the periphery of the fill. A base of 5 feet of low-permeability material should be present before the fill is used. This will require augering or seismic study to determine if the natural cover is adequate. If not, the base must be built up. Finally, the fill must be carefully designed to divert all outside drainage from entering the area.

It is possible in this type of fill construction to develop the optimum in site efficiency, not only from the standpoint of a design that is best integrated with the existing terrain, but also to channel and collect leachate for recycling or transferral to a treatment plant designed specifically for accepting such highly toxic wastes.

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APPENDIX
Composite Stratigraphic Section for Tennessee

WEST TENNESSEE

QUATERNARY SYSTEM	Alluvial Deposits Loess
QUAT. AND TER.	High-Level Alluvial Deposits
TERTIARY SYSTEM	Jackson (?) Formation Claiborne Formation Wilcox Formation Porters Creek Clay Clayton Formation
CRETACEOUS SYSTEM	Owl Creek Formation McNairy Sand Coon Creek Formation Demopolis Formation Sardis Formation Coffee Sand Eutaw Formation Tuscaloosa Formation
MISSISSIPPIAN SYSTEM	St. Louis Limestone Warsaw Limestone Ft. Payne Formation
MISS. AND DEV.	Chattanooga Shale
DEVONIAN SYSTEM	Pegram Formation Camden Formation Harriman Formation Flat Gap Limestone Ross Formation
SILURIAN SYSTEM	Decatur Limestone Brownsport Formation Dixon Formation Lego Limestone Waldron Shale Laurel Limestone Osgood Formation Brassfield Limestone
ORDOVICIAN SYSTEM	Mannie Shale Fernvale Limestone Hermitage Formation

MIDDLE TENNESSEE

QUATERNARY SYSTEM		Alluvial Deposits	
QUAT. AND TER.		High-Level Alluvial Deposits	
CRETACEOUS SYSTEM		Coffee Sand Eutaw Formation Tuscaloosa Formation	
PENNSYLVANIAN SYSTEM		Crab Orchard Mountains Group Gizzard Group	
MISSISSIPPIAN SYSTEM		Pennington Formation Bangor Limestone Hartselle Formation Monteagle Limestone—Ste. Genevieve Limestone St. Louis Limestone Warsaw Limestone Ft. Payne Formation	
MISS. AND DEV.		Chattanooga Shale	
DEVONIAN SYSTEM		Pegram Formation Camden Formation Harriman Formation Flat Gap Limestone Ross Formation	
SILURIAN SYSTEM		Decatur Limestone Brownsport Formation Dixon Formation Lego Limestone Waldron Shale Laurel Limestone Osgood Formation Brassfield Limestone	
ORDOVICIAN SYSTEM		Mannie Shale Fernvale Limestone Sequatchie Formation Arnheim Formation Leipers Formation Inman Formation	
	Nashville Group	Catheys Formation Bigby-Cannon Limestone Hermitage Formation	
	Stones River Group	Carters Limestone Lebanon Limestone Ridley Limestone Pierce Limestone Murfreesboro Limestone	
		Pond Spring Formation	Exposed only in Wells Creek and Flynn Creek structures
ORDOVICIAN AND CAMBRIAN		Knox Group	

EAST TENNESSEE

QUATERNARY SYSTEM		Alluvial Deposits	
PENNSYLVANIAN SYSTEM		Cross Mountain Formation Vowell Mountain Formation Redoak Mountain Formation Graves Gap Formation Indian Bluff Formation Slatestone Formation Crooked Fork Group Crab Orchard Mountains Group Gizzard Group	
MISSISSIPPIAN SYSTEM		Pennington Formation Newman Limestone—Greasy Cove Formation Ft. Payne Formation—Grainger Formation	
MISS. AND DEV.		Chattanooga Shale	
DEV. AND SIL.		Sneedville Limestone	
SILURIAN SYSTEM		Rockwood Formation Clinch Sandstone	
ORDOVICIAN SYSTEM	Chickamauga Group	Sequatchie Formation—Juniata Formation Reedsville Shale—Martinsburg Shale Moccasin Formation—Bays Formation	
		Ottosee Shale Holston Formation Lenoir Limestone—Athens Shale	Sevier Shale
	Knox Group	Mascot Dolomite Kingsport Formation Longview Dolomite Chepultepec Dolomite	Jonesboro Limestone
ORDOVICIAN / CAMBRIAN		Copper Ridge Dolomite—Conococheague Limestone	
CAMBRIAN SYSTEM	Conasauga Group	Maynardville Limestone Nolichucky Shale	
		Maryville Limestone Rogersville Shale Rutledge Limestone Pumpkin Valley Shale	Honaker Dolomite
		Rome Formation Shady Dolomite	
	Chilhowee Group	Helenmode Formation	
		Hesse Sandstone Murray Shale Nebo Sandstone	Erwin Formation
		Nichols Shale—Hampton Formation Cochran Formation—Unicoi Formation	
PRECAMBRIAN SYSTEM	Ocoee Series	Walden Creek Group Cades Sandstone—Rich Butt Sandstone Great Smoky Group Snowbird Group	
		Intrusives, volcanics, and plutonics (Mt. Rogers Group, Bakersville Gabbro, Beech Granite, Cranberry Granite, Roan Gneiss)	