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ABSTRACT

The purpose of this study was to determine whether or not septic tank drainfield failures in areas containing soils with a high biotite or chloritized vermiculite component could be the result of mineralogical changes that decrease the permeability of the soil at the drainfield interface.

Twenty-four drainfields in five Virginia counties were examined. Soil samples were taken at 16 sites and examined in the laboratory for chemical and mineralogical changes. In each instance, visible alterations were detected at the soil-drainfield interface, and all systems examined showed some chemical change. X-ray diffraction analysis revealed a mineralogical change in 12 sites, with six of these sites showing distinct mineralogical change. The change primarily consisted of the conversion of vermiculite chlorite intergrade into vermiculite and sometimes some montmorillonite, with some dissolution of kaolinite.

Soil samples from sites with a significant vermiculite chlorite intergrade content showed an increase in the sum of exchangeable bases at the soil-drainfield interface. This increase appeared to be linked to interlayer removal and vermiculite formation. The exchange complex of the soil at the drainfield interface was selective for calcium and sometimes magnesium and was not dominated with sodium, which was high in the effluent. Samples from some sites did show an increase in organic matter at the interface. However, the increase was not considered sufficient to cause a reduction of flow in the drainfield.

Field examinations of the soils revealed that the primary mode of effluent movement was channelized flow. At no site did the drainfield fail for purely mineralogical reasons. However, the changes detected could contribute to the eventual failure of the system by decreasing soil permeability, especially in soils with initial low permeability.

Key Words: Septic Tank Drainfield Failures, Mineralogical Changes, Soils, Groundwater, Water Pollution, Wastewater

INTRODUCTION

Septic tank percolation systems provide the only practical and economical method for domestic waste disposal whenever access to a public sewer system is unavailable. Surveys have indicated that 32 million people in the United States were served by septic tank systems in 1970 [Environmental Protection Agency, 1973a].

Most septic tank drainfield failures are the result of hydraulic overloading which causes septic tank effluent to break through the ground surface or to back up into the dwelling. Other less obvious failures are of the nutrient-biological type, which transmits nutrients, bacteria, or viruses to surface and ground water. Therefore, failure of a drainfield results in pollution of natural soils and ground and surface waters. In addition, failures create a health hazard and a nuisance because of the resulting odor and unsightly appearance.

Drainfields established in what appeared to be suitable, permeable soils have sometimes failed in four to eight years or even less time after installation. There are a number of variables that could contribute to this eventual failure, including:

1. Drainfield initially designed too small,

2. A substantial increase in water usage,

3. Clogging by bacterial mats and sludge,

4. Improper method of drainfield installation,

5. Unsuitable soil conditions or characteristics, and

6. Reduction in permeability of material surrounding the drainfield because of (a) dispersion and movement of existing clay as a result of its new environment, and (b) significant mineralogical alterations with formation of less permeable clay as an expression of its new environment.

Chemical and mineralogical interactions of septic drainfield effluent with the enclosing soil are assumed to occur at the effluent-soil interface. This interface is defined, for purposes of this report, as the zone directly in

contact with the effluent and which extends back into the soil as far as visible alteration of the soil color is observed.

I. Functional Septic Systems

The engineering designs [Olson et al., 1965], biological aspects (Winneberger et al., 1960], soil characteristics [Pettry et al., 1973; U.S. Department of Housing and Urban Development (HUD), 1967], and construction considerations [HUD, 1967] intended to minimize septic tank drainfield failure are well-documented and generally understood. Six basic criteria covering the design, installation, and operation of a functional septic tank and drainfield system have been proposed by the U.S. Department of Commerce in their *Manual of Septic-Tank Practice* [1967].

1. They will not contaminate any drinking water supply;

2. They will not give rise to . . . insects, rodents, . . . which may come into contact with food or drinking water;

3. They are not accessible to children;

4. They will not violate laws or regulations concerning water pollution or sewage disposal;

5. They will not pollute or contaminate public waters or streams, and;

6. They will not give rise to a nuisance odor or unsightly appearance.

II. Failed Septic Systems

Examination of two extensive bibliographic works on sewage, waste disposal, and pollution control reveal that the two most frequently cited factors for degrading septic field performance are sodium adsorption and biological alteration of the soil-drainfield interface [Ramsey, Wetherill, and Duffer, 1972; EPA, 1973b]. Failures seem to be more prevalent in recent years, possibly because of increased awareness of the problem or increased use of undesirable soil. However, little research has been directed toward the soil mineralogical components as contributing factors in septic tank system failures.

The potential of biologically induced mats to clog a system was noticed very early in work with septic fields. Increases in failure rate from overloading of the septic system were attributed to such household items as garbage disposals and washing machines [Winneberger et al., 1960]. Clogging was recognized to occur through physical, chemical, and biological means. Physical clogging resulted from the migration of fine particles to the soil-drainfield interface and was regarded to be irreversible. Chemical clogging was attributed to dispersion of soil aggregates because of sodium exchange. Biological clogging was regarded as being most important for general septic field failure. Paradoxically, a field allowed to drain and become dry would regenerate. The organic accumulation at the interface was believed to actually contribute to improved soil structure and increased infiltration rates.

Investigators also began to recognize that the infiltrative rate of a soil might not be the same as the percolative rate. The infiltrative rate was defined as the rate at which a liquid (sewage effluent) will pass through the soil-drainfield interface, and percolative rate was defined as the rate of movement of liquid through the soil once it has passed this interface [McGauhey and Winneberger, 1967]. In addition, complex causes of clogging related to failure were enumerated. Physical clogging was further related to: (1) compaction of soil by loading, even by the weight of the water itself, (2) smearing of soil surfaces by excavating equipment, (3) migration of fines during site preparation, (4) migration of fines resulting from rainfall on the exposed site, and (5) washdown of fines perched on larger particles. The chemical factors further enumerated for causing septic field clogging included deflocculation of clay material by sodium saturation and precipitation of ferrous sulfide under anaerobic conditions. Biological, non-uniform loading resulting in creep failure, poor construction practices, and oversize fill stone were other forms of failure mentioned. However, biological failure was still regarded as being most important for general septic field clogging and therefore, failure.

Three distinct phases of clogging have been recognized to occur in failed septic systems: phase I includes a slow reduction of infiltration under aerobic conditions, phase II produces a rapid decrease in infiltration rate under anaerobic conditions, and phase III includes a continuing gradual decline in infiltration rate under continuing anaerobic conditions [Thomas, Schwartz, and Bendixen, 1966]. Lysimeter studies showed the clogging to be a surface and near-surface phenomenon of the drainfield-soil interface and the clogged system to rejuvenate to a condition between

that of phase I and phase II quite rapidly when drained and aerated. Sulfide, phosphate, iron, and organic matter were shown to accumulate at the interface.

A slowly permeable silt loam soil, which typically created failed septic systems, was investigated by using artificial anaerobic and aerobic effluent and water with a simulated effluent salt content [Daniel and Bouma, 1974]. Significant differences in the reduction of flow rate by anaerobic and aerobic effluent were not noted. However, the reduction for effluent was greater than for the salt-containing water alone, and the salt-containing water did produce a decrease in flow rate with time.

III. Chemical Alterations

Studies of the effect of sewage effluent movement through columns of soil horizons from a loamy sand and a clay showed no restrictions on iron movement through the columns [DeJong, 1978]. Potassium and calcium were leached from the soil, while sodium and magnesium were increased on the exchange complex. There was a general increase in pH, but changes in Cation Exchange Capacity (CEC) were not obvious. The mineralogy of these soils was not noted, but the leaching of potassium and increase of magnesium seem to indicate an alteration of the exchange complex.

Although organic mats and ferrous sulfide have been implicated in clogging of septic fields, the potential of dissolved phosphates to cause clogging has not been widely recognized. Studies of ferrous iron systems used for the precipitation of excess effluent phosphate have shown that the precipitated vivianite [$Fe_3(PO_4)_2 \cdot 8H_2O$] is very fine-grained and could clog pores, thus reducing the rate of infiltration [Ghassemi and Recht, 1971]. Maximum precipitation of ferrous phosphate was shown to occur above pH 8, which can be encountered in septic tank effluent.

Analysis of septic tank sludge and municipal sludge indicates that a high iron and phosphorus content is often encountered [Brandes, 1978]. The phosphorus content of the effluent, sludge, and septage (the sludge fluid when removed from the solids) was high, but only depended on the total input of phosphate-containing substances and was not directly related to iron or aluminum content.

Soils treated with domestic wastewater containing phosphate show an

increase in both pH and CEC, with the effect more pronounced in the surface zone [Sawhney and Hill, 1975]. The effect of phosphorus on the CEC of tropical and some temperate soils is well-documented. Soils tend to adsorb phosphate until the adsorption capacity of the soil is reached and then the phosphates pass through the system unhindered as long as aerobic conditions are present [Sawhney, 1977]. No data on phosphate sorption under anaerobic conditions were presented. Phosphate from septic fields tends to move downward and laterally away from the field once buildup has taken place [Reneau and Pettry, 1976].

IV. Mineralogical Alterations

Drainfield failures resulting from a reduction in permeability of the material surrounding the drainfield can also be the result of mineralogical alterations. Ion exchange to create a monovalent system can effectively disperse the existing clay and result in reduced drainfield permeability from increased resistance to flow or reduced pore size [Winneberger et al., 1960; HUD, 1967]. However, structural alterations of a material with a high biotite or chloritized vermiculite component to produce montmorillonite or even vermiculite can also reduce drainfield permeability. This latter reaction is not documented in the septic tank drainfield environment.

Clay minerals are a very active and dynamic component of the mineral fraction of soil systems [Zelazny and Calhoun, 1971]. The dynamic alterations of clay minerals and their associated physical and chemical changes are well-documented [Millot, 1970]. The clay minerals of primary concern in this research are the well-known micas, biotite and muscovite, and chloritized vermiculite.

Chloritized vermiculite is defined as a 2:1-type non-expanding phyllosilicate which contains a significant hydroxide sheet consisting of aluminum or magnesium hydroxide in the interlayer position. It is characterized by a 14-angstrom (A) x-ray spacing when magnesium-saturated and glycerol-solvated. It neither moves entirely to 10A (as expected of true vermiculite) nor maintains its integrity at 14A (as would a true chlorite) upon potassium saturation and heating to 550°C [Zelazny and Carlisle, 1971]. The presence of the partial hydroxide sheet in the interlayer position renders these minerals relatively inert with a low CEC, specific surface area, and low shrink-swell characteristics [Lietzke and Mortland, 1973].

The weathering sequence of biotite or muscovite in an alkaline soil environment is:

biotite or muscovite → vermiculite → montmorillonite (1)

However, in an acid soil environment, a different weathering sequence is observed:

biotite or muscovite → vermiculite → choritized vermiculite (2)

Soils in which reaction 1 has occurred are generally not used for drainfields because of either wetness, high clay content, and very high plasticity or the presence of slow permeable subsoils. Soils in which reaction 2 has occurred are widespread in the southeastern United States and Virginia [Rich, 1968] and are used for septic tank drainfield establishment. Soil environmental conditions conducive to chloritized vermiculite formation [Rich, 1968] include: (1) moderately active weathering and leaching to remove calcium, potassium, and magnesium cations and to make aluminum cations available, (2) moderately acid soil pH (about 5.0), (3) low organic matter content, (4) frequent wetting and drying cycles, and (5) oxidizing conditions.

Reversing these soil environmental conditions produces a natural dechloritization reaction in the field that occurs very rapidly under laboratory conditions. This dechloritization reaction occurs as:

chloritized vermiculite → vermiculite + interstratified vermiculite and montmorillonite → montmorillonite (3)

Frink [1969] first showed that chloritized vermiculites from acid upland soils which eroded into a neutral to calcareous lake environment were dechloritized. Lietzke, Mortland, and Whiteside [1975] demonstrated that a similar reaction was occurring on a floodplain environment where vermiculite and interstratified vermiculite-montmorillonite were being formed.

It is generally recognized that in the presence of a septic tank drainfield, the original soil environment is altered by the following conditions: (1) an abundant amount of water; (2) an abundant amount of monovalent and divalent cations, especially sodium, ammonium, potassium, calcium, and magnesium; (3) an increase in the organic matter content; (4) a higher

pH; and (5) reducing conditions. Therefore, the altered conditions in a septic tank drainfield environment could change the soil weathering sequence such that montmorillonite and vermiculite could develop from biotite or muscovite and also from the dechloritization of chloritized vermiculite or chloritized montmorillonite. The formation of montmorillonite and even vermiculite should further reduce the permeability of the drainfield, and this reduced permeability would extenuate drainfield conditions to further catalyze the dechloritization reaction. The specific objective of this study was to test this hypothesis, specifically that septic tank drainfield failures in areas containing soils with a high biotite or chloritized vermiculite component could be the result of mineralogical alterations which decrease the permeability of the soil at the drainfield interface.

MATERIALS AND METHODS

I. Sample Sites

An extensive number of samples were taken from 16 septic tank drainfield sites *(Table 1)* in five counties in Virginia *(Figure 1).* Another eight sites were chosen for their geologic variety *(Figure 2)* and the interest and cooperation extended by local health department sanitarians. These sanitarians made the initial contact with the homeowners, obtained permission for site excavation, and aided in sample selection and collection.

The sites included locations in Loudoun County (LC) in the Northern Piedmont physiographic province with soils derived from greenstone schist, biotite schist, and granite gneiss. Sites in Fairfax (FC) and Prince William (PWC) counties from the Northern Piedmont and Coastal Plain physiographic provinces, respectively, had soil underlain by muscovite schist, granites, and Coastal Plain sediments. Chesterfield County (CC) sites, representing the Southern Piedmont and Coastal Plain physiographic provinces, were selected from soils derived from Coastal Plain sediment, granite gneiss, and biotite schist. Sample sites obtained from soils derived from limestone, shale, and sandstone were collected from Tazewell County (TC), representing the Appalachian physiographic province.

The septic tank drainfield systems examined included 20 standard drainfield systems, one standard drainfield system with an effluent pump, one standard bi-drainfield system in which effluent alternated yearly, and two seepage bed systems. These drainfield systems were installed three to 24 years ago, with the majority failing in four to eight years after construction.

II. Field Sampling Methods

Initial samples from failed drainfields were taken by digging a small pit into the trench and through the gravel layer to the in-place undisturbed soil below *(Figure 3).* A 15-cm diameter steel pipe was driven down through the loose gravel layer to prevent the hole from being filled with the surrounding gravel. Dirt and gravel were removed from the casing with a bucket auger *(Figure 3A).* Undisturbed soil cores were obtained by driving a tube sampler of 1.5-cm diameter into the soil beneath the trench. The model used for the initial sampling period was based on the assumption that a uniform flow of effluent occurred through the soil.

Samples were to be collected from the highly altered zone which had a gray-to-black color, the altered zone, and an unaltered sample taken from the same depth, but several feet away, generally between distribution lines *(Figure 4).*

Observations indicated that effluent was not moving uniformly through the soil, but in channelized flow patterns. Once this was realized, the sampling model evolved to one where a 3-cm tube sampler was driven down the trench side wall to the base of the gravel layer, then subsequently driven further into the soil. Samples were collected from the highly altered soil in the flow zone and the less altered adjacent soil. The purpose of sampling in this manner was to detect changes in clay mineralogy that were induced in the soil by the drainfield environment. Soil samples were taken from at least three locations in each drainfield:

1. The most visibly altered soil, which was dark gray to black and showed the most clay mineral alteration,

2. Another less visibly altered zone, and

3. The soil between two trenches or from an adjacent area at the same depth as the other two samples and having the same parent rock composition, which showed no evident alteration of clay minerals.

In this report, sample 1 (above) is referred to as *highly altered,* sample 2 as *altered,* and sample 3 as *unaltered.*

Sampling Model 1 *(Figure 4)* was abandoned because of the effort involved in digging through the gravel and then keeping loose gravel from filling the hole. Sampling Model 3 *(Figure 4)* was used most frequently since the 3-cm diameter coring tool could be pushed down in several areas adjacent to the trench to locate a channelized flow zone or to detect a more uniform wetting and alteration zone. Of the 24 drainfields examined, only two exhibited a "uniform" alteration zone on trench walls and bottoms. One drainfield was sampled from backhoe pits. The backhoe pits were located in a drainfield repair where the old failed system was being connected to a new system.

The drainfield-altered materials were placed in plastic sample jars and sealed to prevent oxidation. Other samples were placed in plastic sample

bags and sealed to prevent moisture loss. Not all sites were sampled extensively because of an inadequate interface or lack of visible alteration. However, some sites were sampled extensively, as indicated on the description sheets. Effluent and household water samples were also taken on the site except in urban areas where water data were available for an entire area.

III. Laboratory Analysis

The samples were stored in a moist condition and a subsample of each was dried at 110°C for use in laboratory analyses and clay separations. Because of the relative similarity within the various sampling sites, only one sample from the interface and one sample from the unaltered soil were subjected to the full set of laboratory tests. All other samples were examined by x-ray diffraction and chemical tests only.

Water-soluble and exchangeable calcium, magnesium, potassium, and sodium were extracted from soil samples with distilled water and 1.0 *N* ammonium chloride solutions, respectively, and analyzed using atomic absorption spectroscopy. The water-soluble cations are reported as parts per million (ppm) or μg/g of soil, while the exchangeable cations are reported as milliequivalents per 100 grams of soil (meq/100 g). Conductivity and pH were determined on separate 1:1 water-to-soil suspensions with the use of the appropriate electrodes and a Radiometer CDM3 conductivity meter and Radiometer PHM64 pH meter, respectively. Specific conductivity is reported as micro siemens per cm (μS/cm), which is equivalent to micro-mhos/cm.

The samples of household water and effluent were analyzed for calcium, magnesium, potassium, and sodium by atomic absorption spectroscopy and reported as parts per million (ppm) of liquid or μg/ml. These samples were also analyzed for electrical conductivity and pH as above.

Separate samples were used for particle-size distribution and organic matter analysis. Particle-size distribution was determined by the pipet method [Day, 1956] following soil dispersion with calgon. Organic matter analysis was measured by chromic acid oxidation with back titration of excess chromic acid by ferrous solution as indicated by orthophenanthroline-complex indicators [Walkley, 1947].

Quantitative clay mineralogical analyses were performed on the samples

collected by techniques incorporating x-ray diffraction and ion exchange analyses. Quantitative mineralogy was determined by the techniques of Alexiades and Jackson [1966] and Salyn and Drits [1972], with some modifications. Generally, mineralogical quantification was assumed to be proportional to x-ray diffraction peak area. A precision of ±10 percent is reported for natural samples [Gibbs, 1967; Johns, Grim, and Bradley, 1954; McNeal, 1968; Schultz, 1964], even for the most accurate techniques currently available [Schoen, Foord, and Wagner, 1972]. However, smaller differences may be detected, especially in systems with a similar matrix.

Inorganic clays were separated from the silt and sand fraction by the procedure of Jackson [1956] and Kittrick and Hope [1963]. The soils were washed with distilled water to remove all soluble salts and subsequently with ammonium chloride, which acted as both a cation extractant and pretreatment for the dispersal used in clay separation. No other pretreatments were used because the mineralogical changes being sought could be easily obliterated by the removal of organic matter, iron oxide, and amorphous material. The soil clay was separated by raising the pH to 10 with sodium bicarbonate water solution and repeatedly centrifuging and decanting the clay until only sand and silt remained in the sample bottle.

Sample preparation for x-ray analysis was conducted according to the procedure of Rich [1969]. Extreme sample curling and cracking was encountered, necessitating a slight modification of the procedure. Samples were treated with a solution of 0.8 *N* sodium silicate, which acts as a high-temperature cement during heat treatment of potassium-saturated slides. Subsamples were potassium-saturated and magnesium-saturated with glycerol solvation and subjected to incremental heat treatments for mineral identification. X-ray diffractograms were obtained using a Diano XRD-8300AD x-ray diffractometer equipped with a Cu-x-ray tube, graphite monochromator, PDP-8 computer and printout. The samples were scanned at 2° 2θ. Vermiculite-chlorite intergrade, vermiculite, montmorillonite, mica, kaolinite, feldspar, and quartz were estimated from the x-ray diffractogram peak areas.

Samples were prepared for scanning electron microscopy by sprinkling particles on a copper adhesive tape mounted on a sample stub and coated with gold and palladium under vacuum. The micrographs were taken using a model AMR 900 scanning electron microscope.

RESULTS AND DISCUSSION

I. Overview

Of the total 24 septic tank drainfield sites visited, 16 failed or unfailed systems were examined in detail *(Tables 1* and *2)*. Twelve of these systems showed measurable mineralogical change by x-ray diffraction analysis, with six systems showing a distinct alteration. All systems examined demonstrated some chemical change. The primary factor influencing the degree of mineralogical change appears to be the quantity and stability of vermiculite-chlorite intergrade mineral present in the clay fraction of the soil. Loss of aluminum interlayers from these minerals accounts for most of the observed mineralogical changes.

Vermiculite-chlorite intergrade or chloritized vermiculite is a 2:1-type silicate mineral which is intermediate in composition and structure between vermiculite (which contains no hydroxide interlayer) and chlorite (which contains a complete hydroxide interlayer). These hydroxide interlayers may be composed of aluminum or magnesium or some mixture of these elements. Vermiculite-chlorite intergrade minerals tend to form in acid, well-drained, high-alumina soils. These minerals are found in most Virginia soils. Chloritized vermiculite is distinguished from other clay minerals by a 14A x-ray peak when magnesium-saturated and a 12A peak when potassium-saturated which partially collapses toward 10A upon heating. The degree of collapse depends on the amount of interlayering; however, a collapse to about 11A is typical. Vermiculite-chlorite intergrade also has a lower CEC than high-grade vermiculite.

High-grade vermiculite is a 2:1 silicate mineral. It has a high CEC and is identified by a 14A peak when magnesium-saturated and a 10A peak when potassium-saturated. The collapse to 10A may not occur completely until a heat treatment of 300°C is reached.

Both muscovite and biotite are generally grouped as micas since it is difficult to separate them by simple mineralogical tests. Mica is a 2:1-type silicate mineral with a low CEC which is characterized by a 10A peak with both magnesium and potassium saturation, and remains at 10A with all heat treatments. Biotite schist tends to produce a vermiculitic soil on weathering and often contains mica-vermiculite regular interstratified minerals. These regular interstratifications are characterized by peaks at 24 and 12A (first- and second-order peaks) when magnesium-saturated,

and both collapse to 10A on potassium saturation.

The soils examined contained only a very small amount of montmorillonite, a 2:1-type silicate clay mineral which has a moderately high CEC and is the major contributor to the shrink-swell potential of soils. Once dispersed, montmorillonite tends to form a gel-like material which is very difficult to flocculate. Septic fields are generally not installed in soil systems with a high montmorillonite content unless the clay content of the soil is very low. Montmorillonite can form as an end product of the dechloritization or de-alumination of chlorite-vermiculite intergrade minerals under conditions of high pH and high magnesium ion concentrations. Montmorillonite has an 18A peak when magnesium-saturated and glycerol-solvated, and a 14A peak when potassium-saturated. On heating, it will collapse to about 10A.

Kaolinite is a 1:1-type silicate clay mineral with no shrink-swell character and very little CEC. It has a thermal decomposition between 300°C and 550°C. Kaolinite is usually identified by peaks at 7.2 and 3.5A, which remain unchanged in spacing through the 300°C heating treatments. These peaks are totally lost when the sample is heated to 550°C. Kaolinite is found in most Virginia soils, especially those of the Coastal Plain.

The oxides quartz and gibbsite and some feldspars are found in Virginia soils. Quartz is fairly common and determined by peaks at 4.21 and 3.34A. Gibbsite is usually found only in Coastal Plain soils in Virginia and has characteristic peaks at 4.83 and 4.34A. The plagioclase feldspars typically contain x-ray diffraction maxima at 6.3A with the feldspar group as a whole at 3.2A.

II. Site Specifics

The FC-1 site in Fairfax County illustrates the mineralogical changes that can occur in a 24-year-old drainfield *(Figure 5, Table 4).* The soil texture in the trench side wall is fine sandy loam to silt loam that had good initial permeability *(Table 3).* The drainfield trench bottom rests on or near the top of a Cr horizon that has very slow permeability. Effluent flow has been mostly lateral. The interface soil-clay mineralogy is essentially a vermiculite, kaolinite system, with lesser amounts of chloritized vermiculite *(Table 4).* The unaltered sample has about 12 percent chloritized vermiculite which has been completely converted to vermiculite at the drainfield interface *(Figures 6, 7,* and *8).* This change is also

reflected in the increase in Σ bases of the highly altered soil *(Table 4).* Notable about this and the other study sites is the fact that sodium does not dominate the exchange complex. The largest increases in exchange cations are for calcium and magnesium, which in this site, is selectively removed from the water entering this system. Organic mats or build-up of organic matter was also not evident, nor was the obnoxious odor associated with failed drainfields.

On the date of sampling, there was 2.5 to 5 cm of effluent in the trench bottom. We believe that even with significant changes in clay mineralogy, and the resultant decrease in permeability, the soil had sufficient initial permeability so that the drainfield continues to function even with a reduction in permeability. It may be that there is a critical threshold permeability, above which drainfields will continue to function with gradual reduced permeability, and below which they will fail.

The FC-3 site in Fairfax County *(Figure 9)* shows subtle mineralogical changes that can exist in a failed drainfield system that had been in operation for 24 years. At this site the initial soil was composed of a more highly weathered type of clay containing mostly vermiculite chlorite intergrade and kaolinite *(Table 5).* About 50 percent of the initial vermiculite chlorite intergrade had been converted to vermiculite in the highly altered soil *(Figures 10, 11,* and *12).* The Σ bases of the less altered soil was slightly increased over the Σ bases of the unaltered soil, but it should be observed that the total bases of this soil are fairly low initially *(Table 5).* Calcium and magnesium were not selectively removed from the water entering the septic field, but were enriched to a much smaller degree. Again it can be observed that organic matter accumulations could not be detected at the soil-drainfield interface.

The mode of effluent flow in this drainfield is lateral. The major difference between this site and FC-1 is the initial permeability. The drainfield trenches in this site have bottoms and side walls in a dense, slowly permeable fragipan horizon *(Table 5).* Effluent evidently ponded in the trench, rose to the top of the fragipan, and then flowed laterally downslope close to or at the surface. The only flow zones in the fragipan were in widely spaced old root channels, and around polygon edges. Even though the soil texture of this site is similar to FC-1, the initial slow permeability did not allow for much additional reduction without resulting in a failure.

The LC-3 site in Loudoun County *(Figure 13)* demonstrates a slight mineralogical alteration of vermiculite chlorite intergrade to vermiculite, and shows slight montmorillonite formation in the highly altered soil *(Figures 14, 15,* and *16).* These mineralogical changes are reflected by increased Σ bases in the highly altered soil with no significant increase in organic material *(Table 6).*

This drainfield did not fail as a result of mineralogical changes but from final landscaping that destroyed all but one line. However, this overloaded line produced the environment that resulted in mineralogical changes. The soils at this site are derived from greenstone and contain considerable epidote that could rapidly weather to montmorillonite. We suspect that this drainfield has not been in place long enough to produce much dechloritization. Furthermore, Fauquier soils normally have a higher pH and more bases so that a drainfield environment is only different for the additional water present.

Site LC-4 in Loudoun County *(Figure 17)* shows a very distinct alteration of vermiculite chlorite intergrade to vermiculite in addition to distinct montmorillonite formation *(Figures 18, 19,* and *20).* The age of this site was not apparent since numerous repairs had been made at this location. The soil is very impermeable and remains wet for long periods of time, which may account for the increased formation of montmorillonite detected under septic field conditions. All of the vermiculite chlorite intergrade minerals were converted to vermiculite in the highly altered soil environment. There is a large build-up of calcium on the exchange complex and a two-fold increase in the Σ bases in the highly altered soil *(Table 7).*

The soils at this drainfield site are interesting because they contain a natural component of sodium derived from the weathering of albite, a sodium-plagioclase. The other major mineral is biotite that weathers to vermiculite. The parent rocks contain very little potassium so that the vermiculite remains fairly stable except for chloritization as aluminum is released by the albite dissolution. Drainfields in these soils fail rapidly. The initial permeability is very marginal by health department standards, and most effluent movement is lateral, due to the presence of a Cr horizon immediately beneath or very close to the trench bottom. We suspect that the montmorillonite produced in the highly altered soils reduced the soil permeability to the point where the system and its many repairs failed.

Site PWC-1 in Prince William County *(Figure 21)* also shows an alteration of vermiculite chlorite intergrade to vermiculite. This mineralogical alteration consists mainly of increasing the ease of collapse of the mineral when potassium-saturated *(Figures 22, 23,* and *24).* Therefore, the altered mineral approached the 10A minimum at lower temperatures than the unaltered mineral, which is a result of the removal of weak or incomplete aluminum hydroxide interlayers. This is a common phenomenon for systems where there is insufficient interlayer material to prop open the structural sheets, but enough to reduce the degree of sheet collapse except at elevated temperatures. There was a slight increase in the Σ bases of the highly altered soils (as expected with loss of interlayer material) with the greatest increase coming from the less visible alteration zone *(Table 8).*

This particular drainfield had grossly failed. All of the soil between drain lines was saturated. Soil colors, texture, density, and lack of alteration indicate that the trench bottoms and side walls below the gravel never accepted any effluent. The effluent filled the trench, rose upward through the fill, and flowed laterally downslope in the loamy surface layer or above the surface in overland flow. Sample 1.3 (unaltered) was located upslope from the highest trench and should not have shown any large increase in sodium. It is possible that the ponded effluent could have been drawn by capillarity to a dry zone. It should also be pointed out that this site received no rainfall during the latter part of March and the month of April 1978, when the drainfield was sampled. It is possible that sodium-saturated effluent moved into the zone of sample 1.3, and subsequently to the surface and evaporated, leaving the highest concentration of sodium furthest away from the trench interface. The occurrence of highest sodium levels at a midpoint between trenches is noted in the discussion of other drainfields that were also sampled in April. We feel that this drainfield was installed in what was considered to be fractured shale rock—rock that can be removed by a backhoe, and when disturbed, appears friable and porous but is very dense and very slowly permeable when in place.

Site CC-5 in Chesterfield County *(Figure 25)* contains a distinct decrease in the quantity of vermiculite chlorite intergrade within the drainfield soil environment *(Figures 26, 27,* and *28).* The soil is mostly kaolinite and vermiculite chlorite intergrade but still has a substantial Σ bases, probably due to the vermiculite component observed in this soil. An increase in Σ bases for the highly altered soil occurs with calcium being

selectively removed from the water entering the septic field *(Table 9).* There is a very slight decrease in the amount of kaolinite in the highly altered sample observed by a decrease in the 7.2A peak intensity *(Figures 26* and *27).* It is possible that some kaolinite is being dissolved at the higher pH values observed in the drainfield environment. This system does contain appreciable exchangeable sodium, although the highly altered soil is lower than the unaltered soil. This distribution of sodium indicates that water is moving away from the drainfield trench. This drainfield was also sampled during a spring drought, so that sodium was concentrating away from the trench by water evaporation.

Site CC-6 in Chesterfield County *(Figure 29)* again shows an increase in the ease of collapsibility of the vermiculite chlorite interlayer mineral within the drainfield environment, but this effect is minimal *(Figures 30, 31,* and *32).* This was the only pumped drainfield system examined, and it had effluent with a much lower pH *(Table 10).* Minimal reducing conditions existed in the drainfield, presumably because of air admitted into the system during the pumping process. The vermiculite present in the soil must have some hydroxide layering since the Σ bases of this soil is very low *(Table 10).* No distinct difference in the Σ bases between the highly altered and the unaltered samples was observed. This particular drainfield shows no visible alteration of soil at the drainfield interface or in the flow zones. Flow zones were detected by their higher water content. This drainfield also exhibits a sodium concentration well away from the trench, indicating that effluent is moving out into the soil. We suspect that the minimal initial soil permeability *(Table 3)* was sufficiently reduced by mineralogical alterations to bring about failure in a relatively short time. There is absolutely no evidence of biological clogging in this system.

For site TC-2 in Tazewell County *(Figure 33),* the highly altered soil (as compared to the unaltered soil) shows an increased collapse of vermiculite chlorite intergrade to vermiculite when potassium-saturated *(Figures 34, 35,* and *36).* This condition indicates that an incomplete hydroxide interlayer has been partially or completely removed by the drainfield environment, which is verified by an increase in the Σ bases in the highly altered sample *(Table 11).* This seepage bed was installed in late winter in wet soils with the base of the bed entirely in and on a dense fragipan. Flow out of the bed was lateral and downslope onto the next lot. The seepage bed was under artesian pressure—each probe core removal created a spring. This drainfield failed because of the initial slow soil permeability

of the fragipan plus additional compaction when it was installed.

Site TC-3 in Tazewell County *(Figure 37)* demonstrates a slight decrease in vermiculite chlorite intergrade in the highly altered sample. The clay fraction contains significant feldspar *(Figures 38, 39,* and *40),* which is typical of soils derived from coal-bearing strata. This sample does demonstrate a significant buildup of organic matter in the highly altered position *(Table 12).* The Σ bases of both the highly altered and the unaltered soil is high, with the highly altered sample providing a slight increase in Σ bases. This particular system suffers from a wet weather malfunction. The seepage beds are located in a drainageway position that collects water from the highway and from higher areas of the watershed.

Site FC-4 in Fairfax County *(Figure 41)* shows no detectable decrease in vermiculite chlorite intergrade in the highly altered zone. The mineralogy is predominantly kaolinite with only minor amounts of vermiculite chlorite intergrade and vermiculite *(Figures 42, 43,* and *44).* The unaltered soil is very low in Σ bases and the less altered soil provides a dramatic increase in Σ bases *(Table 13).* At least part of the increase in bases for this soil may be due to pH-dependent changes. Since a change in CEC always accompanies removal of vermiculite chlorite intergrade interlayers, part of the Σ bases increase may be due to this removal, even though this condition was not detected by x-ray diffraction analysis.

This drainfield is located in a less-than-desirable concave landscape position where it receives house roof runoff water plus some additional water from higher slopes. This additional water contributes to a wet-weather malfunction. The malfunction condition probably can be alleviated by the installation of an interceptor drain above the seepage beds. However, the montmorillonite, either by swelling or by dispersing and moving to lower levels in the soil, could reduce the permeability to the point that the soil could not handle the sewage effluent. The initial perc-rate of 48 minutes/inch in the saprolite is probably now more than 60 minutes/inch. It may be that the 45 to 60 minutes/inch rate is critical for long-term drainfield functioning. Reductions in permeability by dispersion of clay particles and blockage of pores by other biological or mineralogical mechanisms will reduce the long-term perc-rate to a range of 90 to 120 minutes/inch, which, if the drainfield were large enough initially, should handle effluent disposal without malfunction or failure.

Site PWC-2 in Prince William County *(Figure 45)* shows only a slight de-

crease in vermiculite chlorite intergrade in the highly altered zone *(Figures 46, 47,* and *48).* This soil clay contains kaolinite with some vermiculite and vermiculite chlorite intergrade *(Table 14).* The Σ bases of the drainfield altered soil is very low but shows a sharp increase in comparison to the unaltered soil, which again may be due to a pH-dependent charge release from interlayer removal of vermiculite chlorite intergrade. However, the highly altered soil of this system does demonstrate a significant increase in exchangeable sodium.

This particular system failed for two major reasons: (1) the drainfield was not on grade, and (2) the trenches were placed in the highest clay content of the subsoil. Generally, the subsoil of Elioak soils has an estimated perc-rate of 90 to 120 minutes/inch. With changes in clay mineralogy, this perc-rate evidently decreased to the point where the drainfield failed.

Site CC-1 in Chesterfield County *(Figure 49)* shows no differences in mineralogy, detectable by x-ray diffraction, between the highly altered and the unaltered soil *(Figures 50, 51,* and *52).* The mineralogy is predominantly poorly crystalline kaolinite and vermiculite chlorite intergrade *(Table 15).* The Σ bases of the unaltered soil is very low. However, there is a distinct increase in the Σ bases in the highly altered zone.

This most evident cause of failure for this drainfield was the undersizing of the drainfield (in order to fit a very small lot). Furthermore, the drainfield was installed too deep in material of low permeability. Generally, Ruston soils are considered to have good drainfield potential, provided the installation is at the minimum allowable depth.

Sites CC-2 and CC-3 in Chesterfield County *(Figures 53* and *57)* show no change in vermiculite chlorite intergrade content in the highly altered soil *(Figures 54, 55, 56, 58, 59,* and *60).* However, there is a distinct reduction in the kaolinite content of the highly altered soil, which may be due to either dissolution or decrystallization. These processes could be responsible for the lack of interlayer removal since the aluminum removed from the kaolinite may have replaced or prevented that removal from the vermiculite chlorite intergrade. In addition, the soil from site CC-3 contains gibbsite, a crystalline aluminum oxide, which would also contribute to the soluble aluminum available in this system. Again there is an increase in the Σ bases in the less altered zone for both sites *(Tables 16* and *17).*

The soils on these two sites are extremely old and highly leached and should show maximum clay mineral stability. However, the formation of gibbsite indicates that clay minerals are being destroyed. It is interesting to note the destruction of kaolinite in a drainfield environment. The soils in both these drainfields have been considered to have fair-to-good potential, provided the installation is at a shallow depth (61-76 cm). Most soils classified as Typic and Aquic Paleudults have decreasing permeability with increasing depth. Either the perc-rate was underestimated (resulting in the undersizing of the drainfield) or there was sufficient clay disruption to form amorphous gels (reducing the soil permeability to a low level and causing wet weather malfunctions with effluent bleedout).

Site CC-4 in Chesterfield County *(Figure 61)* shows no changes in mineralogy detectable by x-ray diffraction, associated with the drainfield environment *(Figures 62, 63,* and *64).* This site is developed in a biotite gneiss and has the largest visible zone of reduced material of any drainfield interface examined *(Table 18).* The mineralogy is complicated by the presence of a mica-vermiculite, regular interstratified mineral with no vermiculite chlorite intergrade. There is a very slight increase in the Σ bases in the highly altered soil. Of all the drainfield sites examined, this one seemed to have the greatest potential for a true mineralogically induced failure, yet it offers almost no distinct mineralogical alteration. The relatively early weathering stage of the biotite gneiss and the high base status of the minerals (especially potassium) may contribute to the lack of detectable mineralogical alteration.

Site TC-1 in Tazewell County *(Figure 65)* also shows no detectable mineralogical change in the highly altered zone *(Figures 66, 67,* and *68).* A high vermiculite content, which is reflected by the relatively high Σ bases may be responsible for this condition in this soil *(Table 19).* There is a slight increase in the Σ bases of the highly altered soil and a substantial increase in organic matter detected. The soils in the drainfield are of colluvial origin and close to a drainageway and evidently fill with water seeping from higher areas in the watershed.

Examination by Scanning Electron Microscopy (SEM) of soils from highly altered and unaltered areas of site FC-1 in Fairfax County and site CC-4 in Chesterfield County did not reveal any visible changes in particle size or particle morphology *(Figures 69* and *70).* SEM analysis of clays is very difficult since most silicate clay particles are platy and seldom have crystal faces available for differentiation. A biotite flake from CC-4

in Chesterfield County was examined for edge and face alteration typical of vermiculite formations *(Figure 71)*. Other than some spalling off of clay-sized flakes, no distinct differences between flakes from the highly altered zone and the unaltered soil were observed. Examination of the biotite flakes using energy-dispersive x-ray analysis (EDAX) showed some structural titanium to be present. The spalling of small particles, which are then transported and re-deposited, may be a major cause of lowered permeability at the trench interface or flow zone interface with altered soil.

CONCLUSIONS

I. Field Observations

All failed septic tank drainfields had a pungent odor once a trench was opened and the gravel was exposed. The working drainfield, site FC-1, had a slight odor and site FC-2 had none. The gravel in failed drainfields, regardless of kind, had a thin black or dark gray coating, which was determined not to be organic, and presumed to be ferrous sulphate or manganese-iron hydroxides. Overworked and failed septic tank drainfield systems had the blackest-colored gravel and soil interface materials. Only in the failed system at site CC-6 was the gravel clean. In this system the effluent was pumped to the drainfield and may have been oxygenated sufficiently to keep gravel and interface soil material from greatly reducing and turning gray-to-black in color. The 24-year-old working drainfield FC-1 also had clean, uncoated gravel, but had soil interface alteration.

Most of the gravel in the failed drainfields had no noticeable organic slime coating or sludge coat. There was no observable blockage of trench side walls, bottoms, or channelized flow zones by organic matter, slime, or bacterial mats in failed drainfields.

It seems evident from field examinations that the primary mode of effluent movement is by channelized flow away from the trench in all the soils, whether in the Coastal Plain, Piedmont, or Appalachian physiographic provinces. However, biotite and muscovite mica schists exhibited a greater degree of a uniform wetting front than the other soil parent materials. Except for these mica schists materials, visual alterations of the soil in the drainfield environment occurred in channelized flow zones and only millimeter distances from the drainfield wall. Soil colors were bright and appeared unaltered at very short distances from the drainfield (unsaturated flow). At one site, however, effluent was observed to be flowing in a channel at a distance of 120 cm away from the distribution line. The movement of effluent in these flow patterns will require much more documentation and further examination.

Of the 24 drainfields that were sampled, in only two sites could the cause of failure or malfunction not be attributed to soil or installation problems. These were tentatively attributed to mineralogically induced failure.

II. Laboratory Analysis

Mineralogical alterations were detected by x-ray diffraction analysis and chemical techniques from soils in septic tank drainfield environments. These alterations included changes in mineral composition and structure, as well as chemical properties.

The mineral composition and structural alterations detected consist of (1) removal of vermiculite-chlorite intergrade interlayers, (2) dissolution or decrystallization of kaolinite, and (3) formation of montmorillonite. Exposure time to the effluent and the original soil mineralogy were the two most important factors affecting the degree of alteration. However, conditions found in slowly permeable soils also appear to enhance the rate of alteration.

The alterations consist of loss of aluminum and possibly iron from the system. It is surmised that aluminum loss may be due to increased solubility of the mineral components at higher pH values. Iron is more soluble under reducing conditions. Aluminum may be made soluble through the chelation character of soluble organic matter present in the effluent. It is also possible that aluminum and iron may be precipitated into new mineral forms of phosphates.

Chemical alterations consist mainly of an increase in the sum of exchangeable cations for the soils at the septic tank drainfield interface. Part of this increase could be due to pH-dependent charges; however, the measured effluent pH values did not increase to a sufficient degree to account for all the observed increase in charge. The most probable source of this increased Σ bases is the removal of hydroxy interlayers, which unblocked permanent exchange sites in the chlorite vermiculite intergrade minerals. It is also possible that an increase in organic matter content or phosphate adsorption could produce this observed increase in base retention. It is significant that the sodium saturation of the highly altered soil generally did not increase. It was below 15 percent, the level considered detrimental to soil physical conditions *(Table 2)*. In fact, most drainfield environment systems showed a decrease in the percentage of sodium adsorbed, with an increase in calcium and sometimes magnesium content. This is probably a result of valency effects.

The facts that sodium did not dominate the exchange complex and calcium was selectively removed at several sites indicate that the addition

of calcium salts to prevent possible clay dispersion in the drainfield environment may lead to similar mineralogical alterations of the soils. The use of limestone gravel or lime-containing gravel in drainfields may cause unwanted mineralogical changes. Further research is needed to determine if this practice should be avoided.

Some sites did show an increase in measured organic matter in the highly altered zone; however, the increase was not considered sufficient to cause a reduction of flow in the drainfield. Some of the increased organic matter was measured in fill material samples or samples taken when the mode of effluent flow was upward through the trench fill.

Our study shows that to reduce mineralogical alterations in soils with abundant chloritized vermiculite in the septic tank drainfield environment, it will be necessary to prevent interlayer removal and solubilization. The cause for these alterations could be any or all of the following: (1) increased pH, (2) increased reducing conditions, (3) increased soluble organic matter, and (4) increased phosphate concentration. Each of these conditions, as well as their interactions, will require further study. At no site could it be stated that the drainfield failed for purely mineralogical reasons. However, this research has demonstrated that mineralogical changes do exist that could contribute to drainfield failure. We recommend that soils dominated with a vermiculite chlorite intergrade mineralogy be classified and listed as potentially restrictive for septic field use, particularly in situations of minimal soil permeability, where mineralogical alterations could further reduce permeability.

LITERATURE CITED

Alexiades, C. A. and M. L. Jackson, 1966. "Quantitative Clay Mineralogical Analysis of Soils and Sediments." *Clays and Clay Minerals Proceedings* 14:35-52.

Brandes, M., 1978. "Accumulation Rate and Characteristics of Septic Tank Sludge and Septage." *Water Pollution Control Federation Journal* 50:936-43.

Daniel, T. C. and J. Bouma, 1974. "Column Studies of Soil Clogging in a Slowly Permeable Soil as a Function of Effluent Quality." *Journal of Environmental Quality* 4:321-26.

Day, P. R., 1956. "Report of the Committee on Physical Analysis, 1954-55." *Soil Science Society of America Proceedings* 20:167-69.

DeJong, E., 1978. "The Movement of Sewage Effluent Through Soil Columns: The Major Ions (Na, Ca, Mg, Cl, and SO_4)." *Journal of Environmental Quality* 7:133-36.

Frink, C. R., 1969. "Chemical and Mineralogical Characteristics of Eutrophic Lake Sediments." *Soil Science Society of America Proceedings* 33:369-72.

Ghassemi, M. and H. L. Recht, 1971. *Phosphate Precipitation with Ferrous Iron.* Office of Research and Monitoring, U.S. Environmental Protection Agency. Washington, D.C.: U.S. Government Printing Office.

Gibbs, R. I., 1967. "Quantitative X-Ray Diffraction Analysis Using Clay Mineral Standards Extracted from the Samples to be Analyzed." *Clay Minerals* 7:79-90.

Jackson, M. L., 1956. *Soil Chemical Analysis—Advanced Course.* Department of Soils, University of Wisconsin, Madison, Wisconsin.

Johns, W. D., R. E. Grim, and W. F. Bradley, 1954. "Quantitative Estimation of Clay Minerals by Diffraction Methods." *Journal of Sedimentary Petrology* 24:242-51.

Kittrick, J. A. and E. W. Hope, 1963. "A Procedure for the Particle-Size Separation of Soils for X-Ray Diffraction Analysis." *Soil Science* 96:319-25.

Lietzke, D. A. and M. M. Mortland, 1973. "The Dynamic Character of a Chloritized Vermiculitic Soil Clay." *Soil Science Society of America Proceedings* 37:651-56.

Lietzke, D. A., M. M. Mortland, and E. P. Whiteside, 1975. "Relationship of Geomorphology to the Origin and Distribution of a High Charge Vermiculitic Soil Clay." *Soil Science Society of America Proceedings* 39: 1169-77.

McGauhey, P. H. and J. H. Winneberger, 1967. *A Study of Methods of Preventing Failure of Septic-Tank Percolation Systems.* Federal Housing Administration, U.S. Department of Housing and Urban Development. Washington, D.C.: U.S. Government Printing Office.

McNeal, B. L., 1968. "Limitations of Quantitative Soil Clay Mineralogy." *Soil Science Society of America Proceedings* 32:119-21.

Millot, G., 1970. *Geology of Clays.* New York: Springer-Verlag.

Olson, G. W. et al., 1965. *Designs of Seepage Fields for Subsurface Sewage Disposal in Soils of Broome County, New York.* Agronomy Mimeo 65-20. Department of Agronomy, Cornell University, Ithaca, New York.

Pettry, D. E. et al., 1973. "Soil Pollution and Environmental Health." *Health Services Reports* 88:323-27.

Ramsey, R. H., C. R. Wetherill, and H. G. Duffer, 1972. *Soil Systems for Municipal Effluents and Selected References.* Environmental Protection Agency. Washington, D.C.: U.S. Government Printing Office.

Reneau, R. B., Jr., and D. E. Pettry, 1976. "Phosphorus Distribution from Septic Tank Effluent in Coastal Plain Soils." *Journal of Environmental Quality* 5:34-39.

Rich, C. I., 1968. "Hydroxy Interlayers in Expansible Layer Silicates." *Clays and Clay Minerals* 16:15-30.

——————, 1969. "Suction Apparatus for Mounting Clay Specimens on Ceramic Tile for X-Ray Diffraction." *Soil Science Society of America Proceedings* 33:815-16.

Salyn, A. L. and V. A. Drits, 1972. "On the Method of X-Ray Quantitative Phase Analysis of Clays." *Proceedings of the International Clay Conference, Madrid, Spain,* pp. 797-806.

Sawhney, B. L., 1977. "Predicting Phosphate Movement Through Soil Columns." *Journal of Environmental Quality* 6:86-89.

Sawhney, B. L. and D. E. Hill, 1975. "Phosphate Sorption Characteristics of Soils Treated with Domestic Waste Water." *Journal of Environmental Quality* 4:342-46.

Schoen, R., E. Foord, and D. Wagner, 1972. "Quantitative Analysis of Clays: Problems, Achievements and Outlook." *Proceedings of the International Clay Conference, Madrid, Spain,* pp. 787-96.

Schultz, L. C., 1964. *Quantitative Interpretation of Mineralogical Composition from X-Ray and Chemical Data for the Pierre Shale.* U.S. Geological Survey Professional Paper 391-C. Washington, D.C.

Thomas, R. E., W. A. Schwartz, and T. W. Bendixen, 1966. "Soil Chemical Changes and Infiltration Rate Reduction Under Sewage Spreading." *Soil Science Society of America Proceedings* 30:641-46.

U.S. Department of Commerce, National Mechanical Information Service, 1967. *Manual of Septic-Tank Practice.* Washington, D.C.: U.S. Government Printing Office.

U.S. Department of Housing and Urban Development, 1967. *Methods of Preventing Failure of Septic Tank Percolation Systems.* Washington, D.C.: U.S. Government Printing Office.

U.S. Environmental Protection Agency, 1973a. *Groundwater Pollution from Subsurface Excavations.* EPA Water Quality and Non-Point Source Control Division. Washington, D.C.: U.S. Government Printing Office.

U.S. Environmental Protection Agency, Office of Research and Monitoring, 1973b. *Research, Development, and Demonstration Grant, Contract, and In-House Reports.* Publications Branch (Water), Research Information Division. Washington, D.C.: U.S. Government Printing Office.

Walkley, A., 1947. "A Critical Examination of a Rapid Method for Determining Organic Carbon in Soils—Effect of Variations in Digestion Conditions and/or Inorganic Soil Constituents." *Soil Science* 63:251-64.

Winneberger, J. H. et al., 1960. *Biological Aspects of Failure of Septic-Tank Percolation Systems.* Sanitary Engineering Research Laboratory, College of Engineering and School of Public Health, University of California, Berkeley.

Zelazny, L. W. and F. G. Calhoun, 1971. "Mineralogy and Associated Properties of Tropical and Temperate Soils in the Western Hemisphere." *Soil and Crop Science Society of Florida Proceedings* 31:179-89.

Zelazny, L. W. and V. W. Carlisle, 1971. "Mineralogy of Florida Aeric Haplaquods." *Soil and Crop Science Society of Florida Proceedings* 31: 161-65.

FIGURES

FIGURE 1
Location of Counties and Physiographic Provinces for Sample Sites

County	Physiographic Province
1. Loudoun	Northern Piedmont greenstone schist, biotite schist, granite gneiss
2. Fairfax and 3. Prince William	Northern Piedmont and Coastal Plain muscovite schist, granites, coastal plain sediments
4. Chesterfield	Southern Piedmont and Coastal Plain coastal plain sediments, granite gneiss, biotite schist
5. Tazewell	Appalachian limestone, shale, sandstone

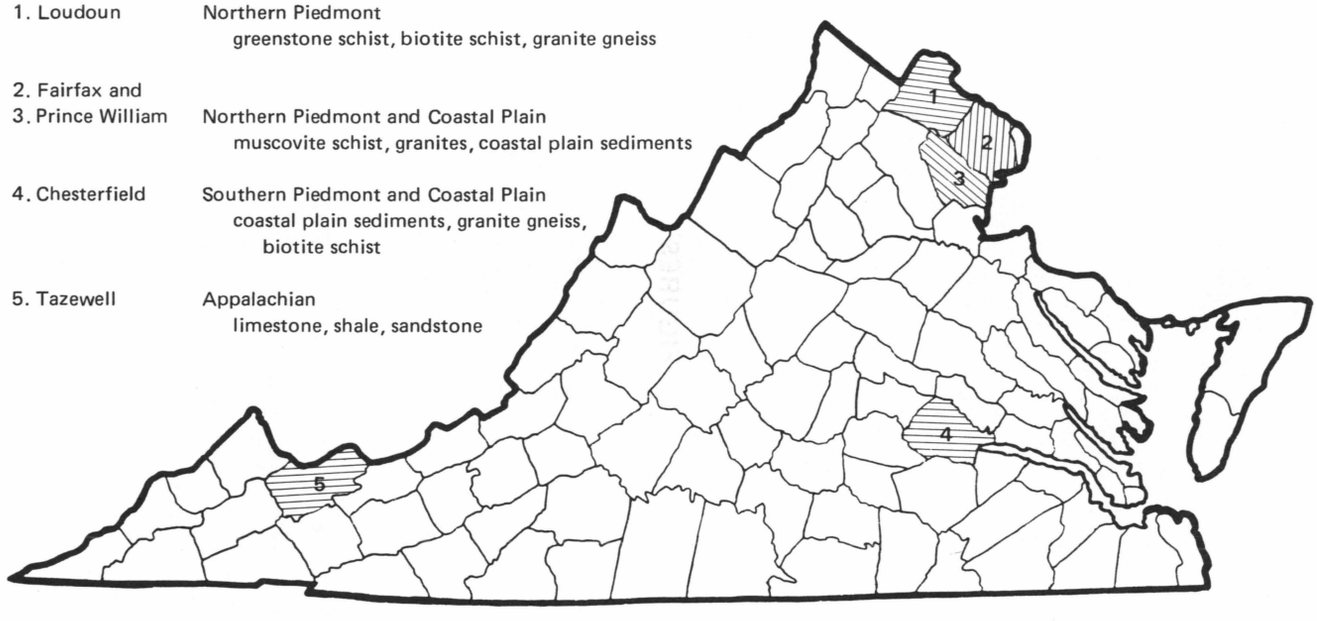


FIGURE 3
Technique Employed for Obtaining Drainfield Samples

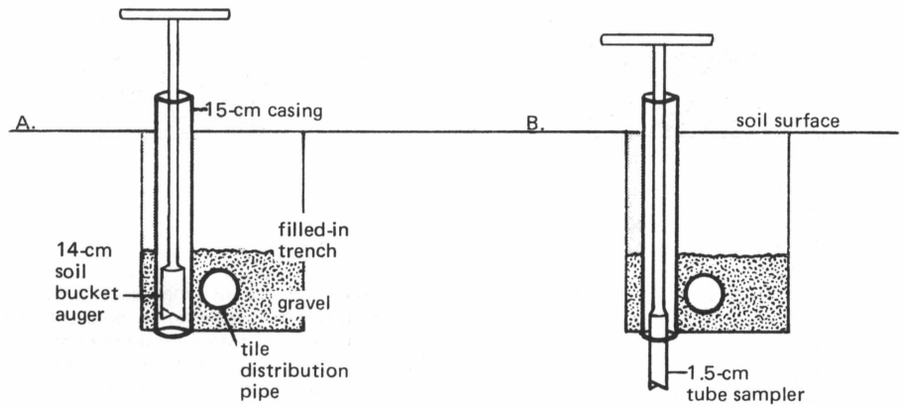
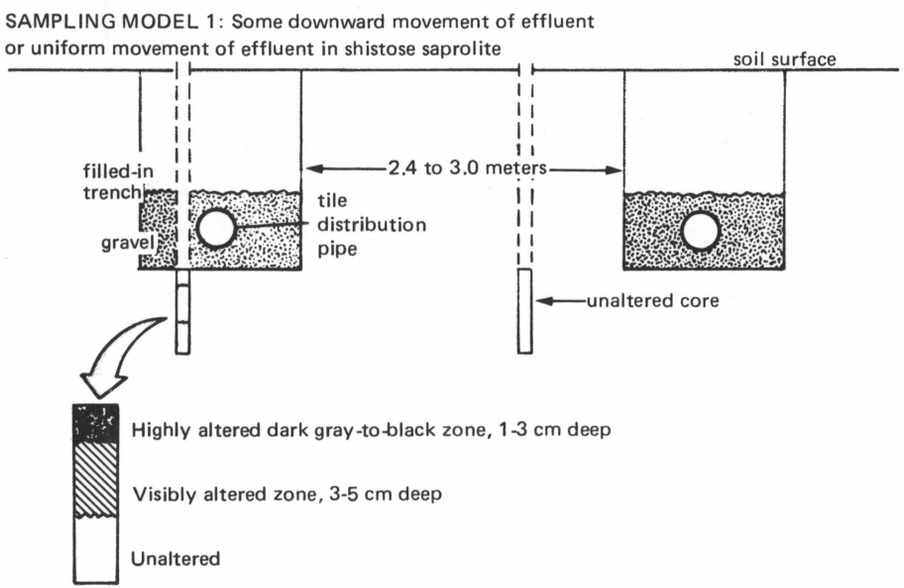


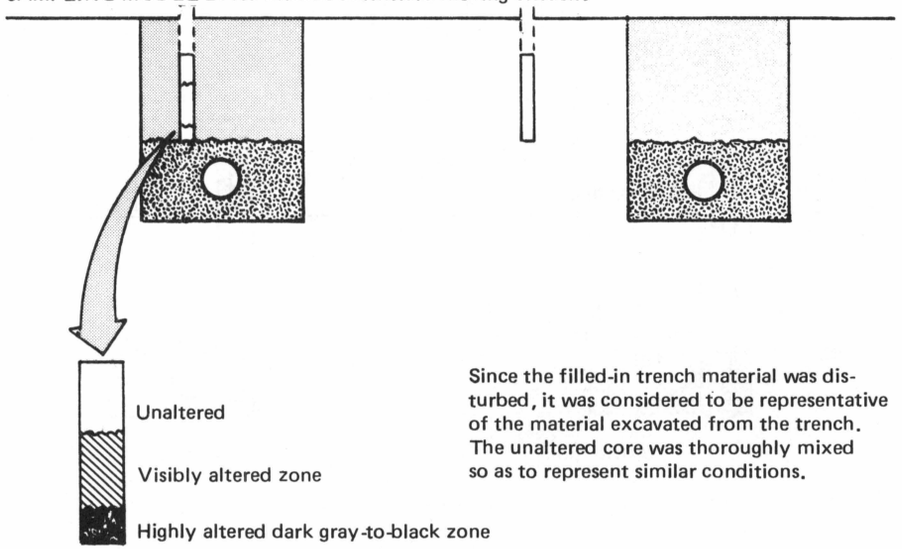
FIGURE 4
Models Employed for Sample Collections



(continued)

FIGURE 4 (continued)

SAMPLING MODEL 2: No evident downward moving effluent



Since the filled-in trench material was disturbed, it was considered to be representative of the material excavated from the trench. The unaltered core was thoroughly mixed so as to represent similar conditions.

SAMPLING MODEL 3: Channelized flow of effluent

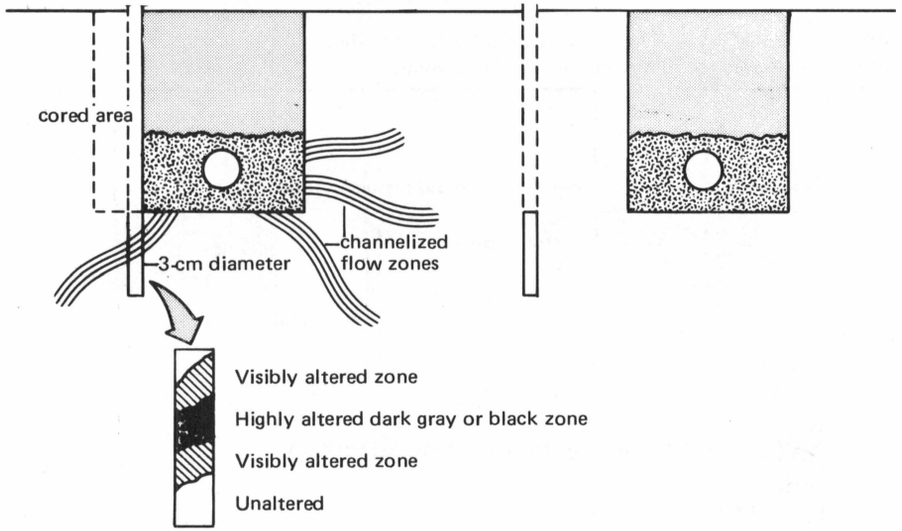
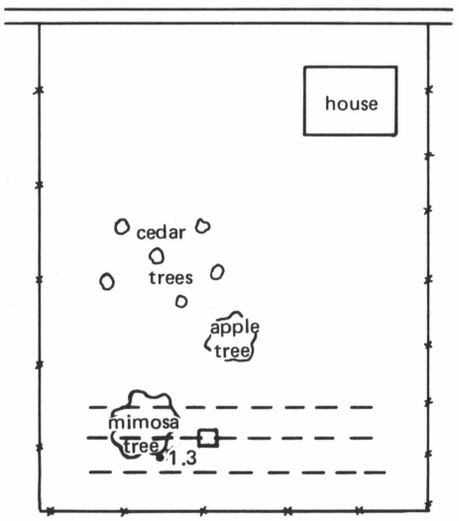


FIGURE 5
Location and Description for Site FC-1

Location: FC-1 (5 people)
Date Sampled: March 21, 1978
Sampled by: Pricci, Alexander, Barwood, Weber, Lietzke, Zelazny
Type of System: Standard drainfield installed February 1954
Soil: Bucks; Typic Hapludult; fine-loamy, mixed, mesic



Sample No.	Description
FC-1.1	0-10 cm below gravel—highly altered.
FC-1.2	10-20 cm below gravel—altered Cr horizon material.
FC-1.3	Unaltered sample at same depth as FC-1.1.
FC-1a	Effluent sample.
FC-1b	Drinking water sample.

Notes

1. This is a functioning drainfield.
2. It was difficult to locate any tile lines.
3. The trench sampled has effluent below the tile.
4. The trench bottom that was sampled was 10 cm above the top of the Cr horizon.
5. Most of the river-rounded quartz gravel were white and not black- or dark gray-coated as they were in failed drainfields.

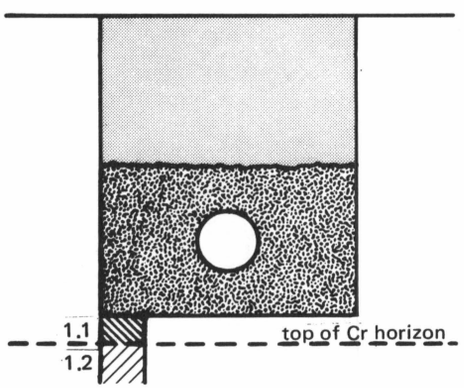


FIGURE 6
X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction at Room Temperature from Site FC-1

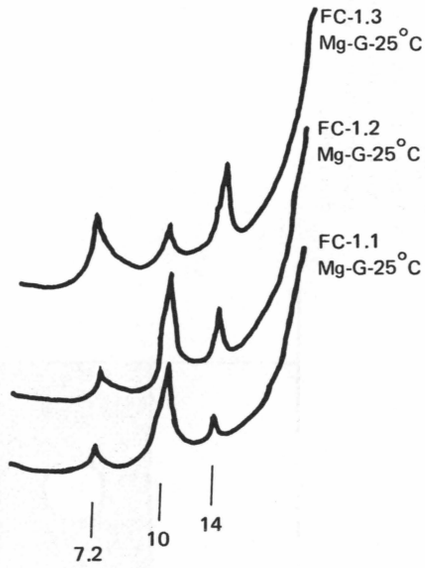


FIGURE 7
X-Ray Diffractograms of Potassium-Saturated Clay Fraction at Room Temperature from Site FC-1

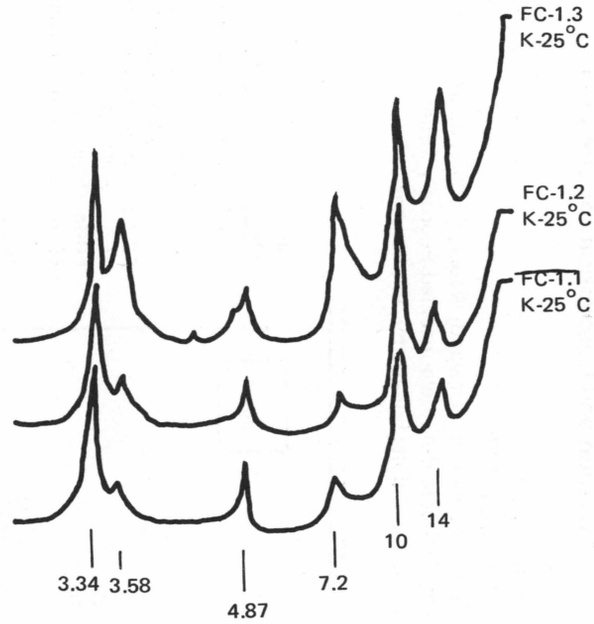


FIGURE 8

X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction Heated to 110°C (Mg-G 110°C); and Potassium-Saturated Clay Fraction Heated to 110°C (K-110°C), 300°C (K-300°C), and 550°C (K-550°C) for the Highly Altered Sample (FC-1.1) and the Unaltered Sample Midway Between Drainfield Lines (FC-1.3) from Site FC-1

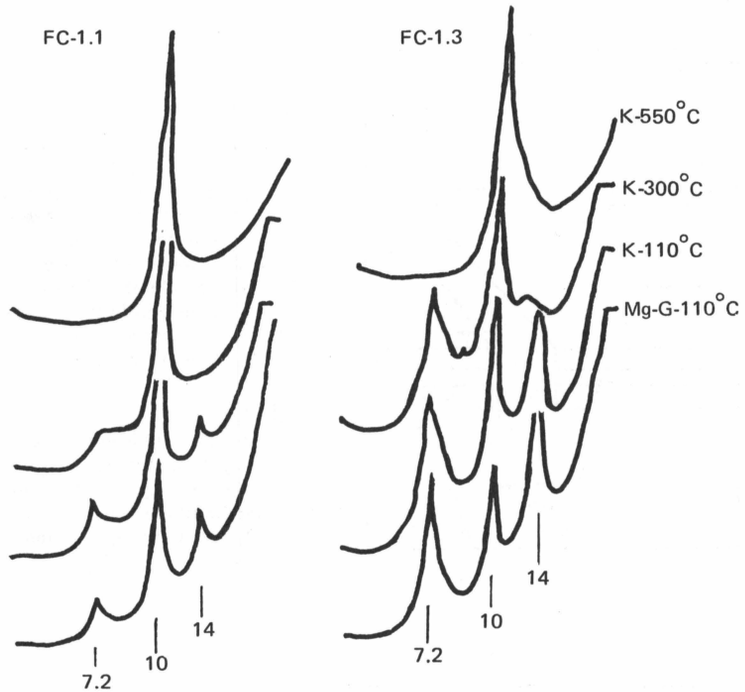
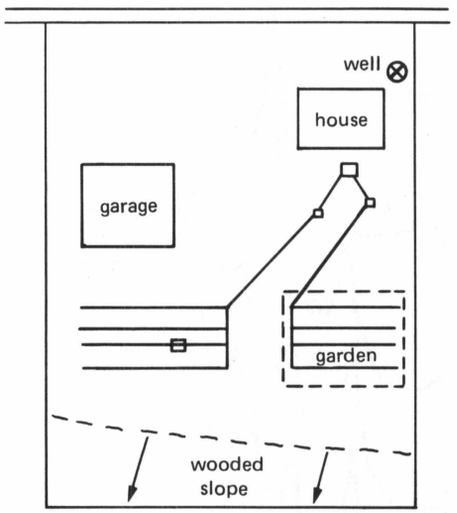


FIGURE 9
Location and Description for Site FC-3

Location: FC-3
Date Sampled: March 22, 1978
Sampled by: Pricci, Alexander, Weber, Barwood, Zelazny, Lietzke
Type of System: Standard drainfield, oldest part installed 25 years ago
Soil: Beltsville-Bourne; Typic Fragiudults; fine-loamy, siliceous, thermic; top of fragipan at 61-76 cm—fragipan continuous throughout the drainfield site



Sample No.	Description
FC-3.1	0-10-cm thickness—highly altered interface sample.
FC-3.2	10-20-cm sample away from interface—altered.
FC-3.3	Sample of unaltered fragipan.
FC-3.4	Sample of channelized flow zone within the fragipan—altered.
FC-3a	Effluent sample.
FC-3b	Well water sample.

Notes

1. The drainfield is in the fragipan, with effluent movement upward to the top of the fragipan, then laterally.
2. The drainfield site is nearly level—1-2 percent slope, thus, later flow is slow.

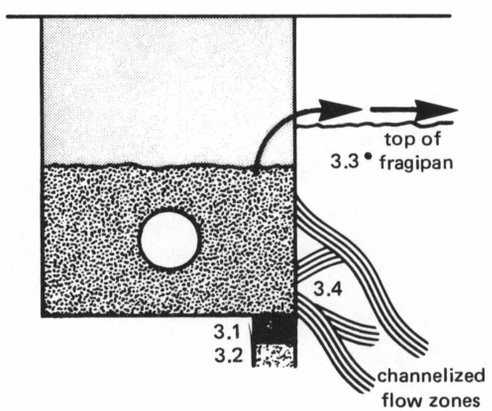


FIGURE 10
X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction at Room Temperature from Site FC-3

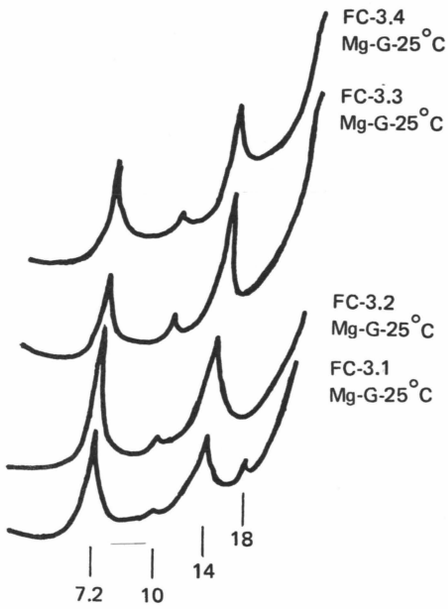


FIGURE 11
X-Ray Diffractograms of Potassium-Saturated Clay Fraction at Room Temperature from Site FC-3

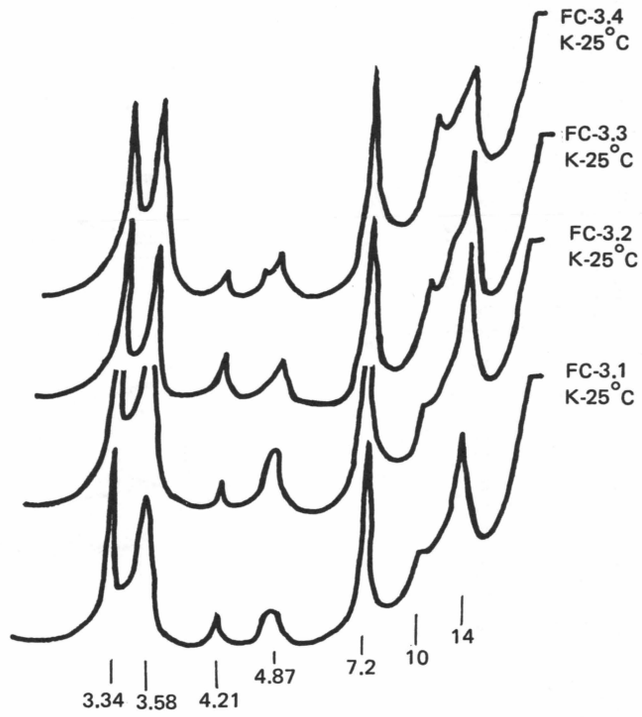


FIGURE 12

X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction Heated to 110°C (Mg-G 110°C); and Potassium-Saturated Clay Fraction Heated to 110°C (K-110°C), 300°C (K-300°C), and 550°C (K-550°C) for the Highly Altered Sample (FC-3.1) and the Unaltered Sample Midway Between Drainfield Lines (FC-3.3) from Site FC-3

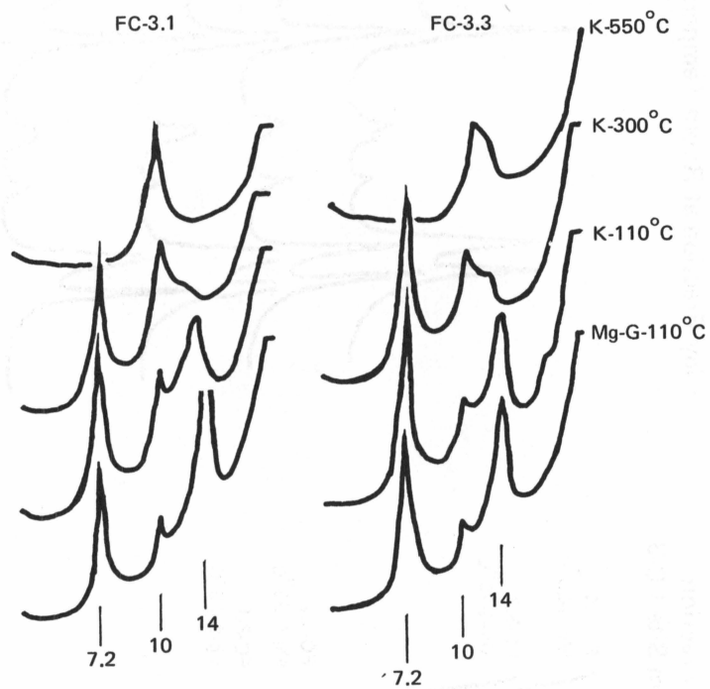
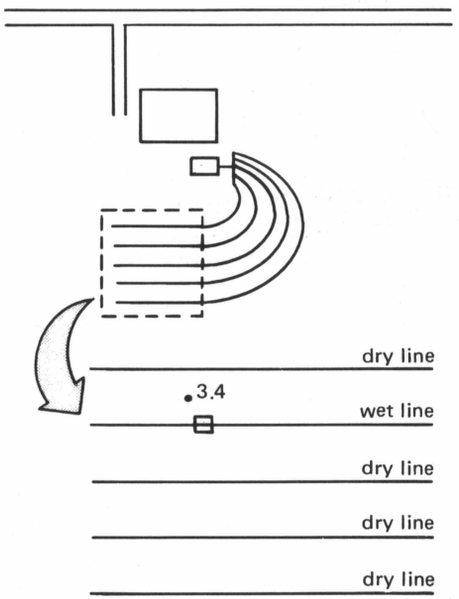


FIGURE 13
Location and Description for Site LC-3

Location: LC-3
Date Sampled: March 20, 1978
Sampled by: Zelazny, Barwood, Lietzke, Weber, Alexander
Type of System: Standard drainfield
Soil: Fauquier silt loam variant derived from greenstone schist; Ultic Hapludalf; fine mixed, mesic



Sample No.	Description
LC-3.1	0-2-cm depth below interface—highly altered.
LC-3.2	2-7-cm depth below interface—altered.
LC-3.3	7-12-cm depth below interface—less altered.
LC-3.4	60-80-cm depth composite sample, ½ distance between drainfield trenches—unaltered.
LC-3.5	Interface material of black and very dark gray soil—very highly altered.

Notes

Probable causes for failure:

1. Only one line was functioning.
2. Lines installed in B_2 horizon where observations were made.
3. Landscaping after installation broke tile in 4 of 5 lines so that only one line had effluent in it to the end (most probable cause of failure).

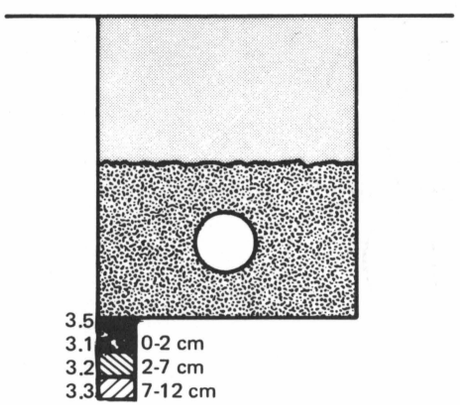


FIGURE 14
X-Ray Diffractograms of Magnesium-Saturated Glycerol-Solvated Clay Fraction at Room Temperature from Site LC-3

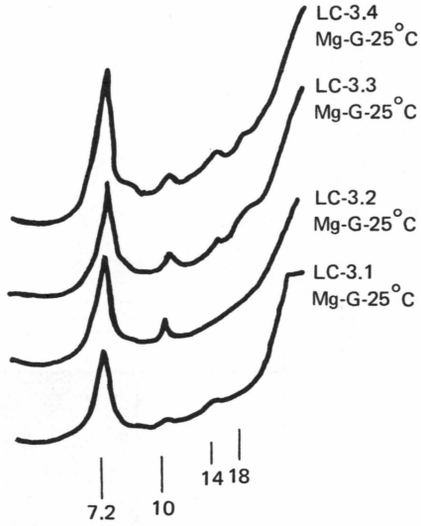


FIGURE 15
X-Ray Diffractograms of Potassium-Saturated Clay Fraction at Room Temperature from Site LC-3

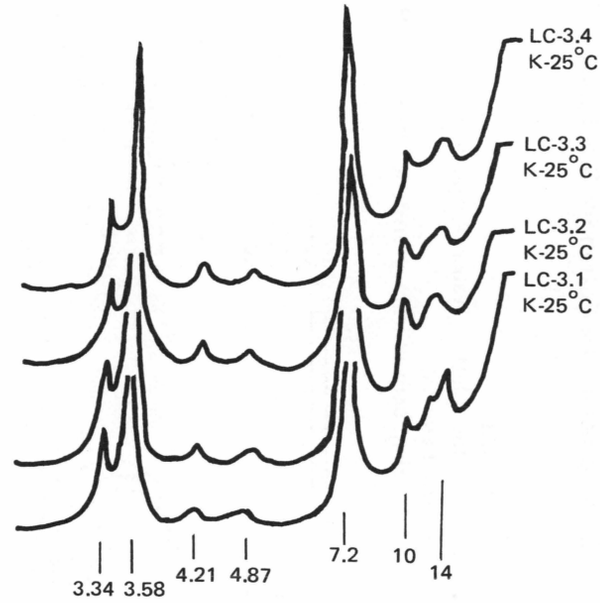


FIGURE 16

X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction Heated to 110°C (Mg-G 110°C); and Potassium-Saturated Clay Fraction Heated to 110°C (K-110°C), 300°C (K-300°C), and 550°C (K-550°C) for the Highly Altered Sample (LC-3.1) and the Unaltered Sample Midway Between Drainfield Lines (LC-3.4) from Site LC-3

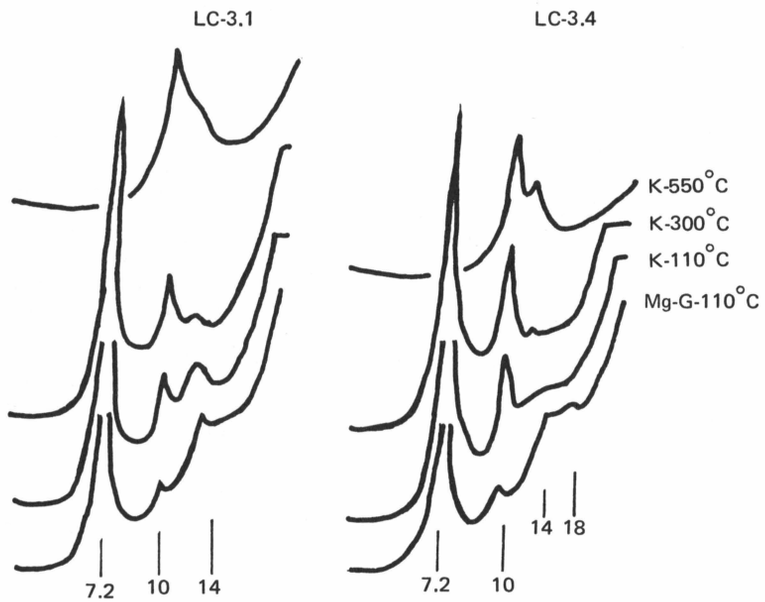
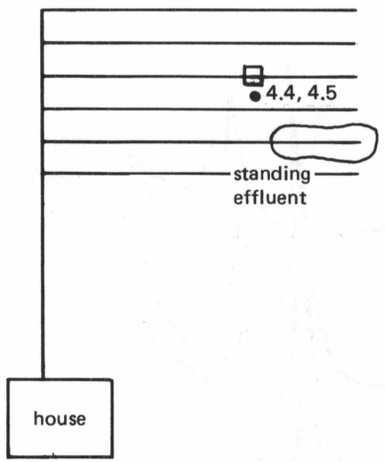


FIGURE 17
Location and Description for Site LC-4

Location: LC-4
Date Sampled: March 20, 1978
Sampled by: Zelazny, Barwood, Lietzke, Weber, Alexander
Type of System: Standard drainfield
Soil: Lehigh; deep clayey subsoil variant derived from pyroclastics of the Triassic basin. Aquic Hapludalf; fine, vermiculitic or mixed, mesic.



Sample No.	Description
LC-4.1	0-2 cm thick interface—highly altered.
LC-4.2	2-10 cm below interface—altered.
LC-4.3	10-20 cm below interface—Cr horizon just above paralithic contact—less altered.
LC-4.4	Sample at same depth as 4.1 but halfway between drainlines—unaltered.
LC-4.5	Sample at same depth as 4.3 but halfway between drainlines (same site as 4.4)—unaltered.
LC-4a	Effluent sample.

Notes

Probable cause for failure:
1. Impermeable subsoil and Cr horizon.
2. Wetness.

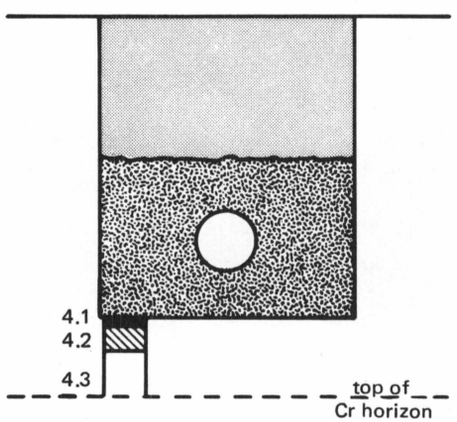


FIGURE 18

X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction at Room Temperature from Site LC-4

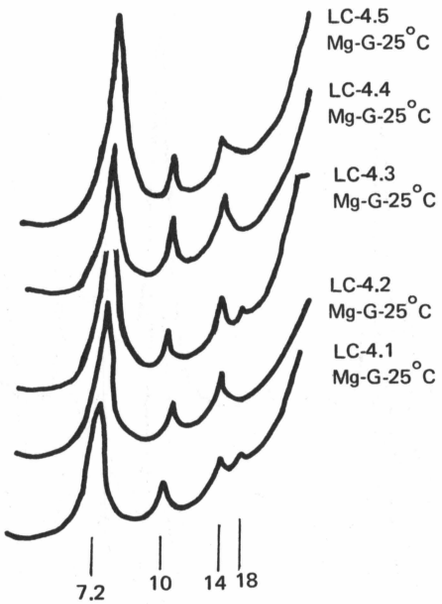


FIGURE 19

X-Ray Diffractograms of Potassium-Saturated Clay Fraction at Room Temperature from Site LC-4

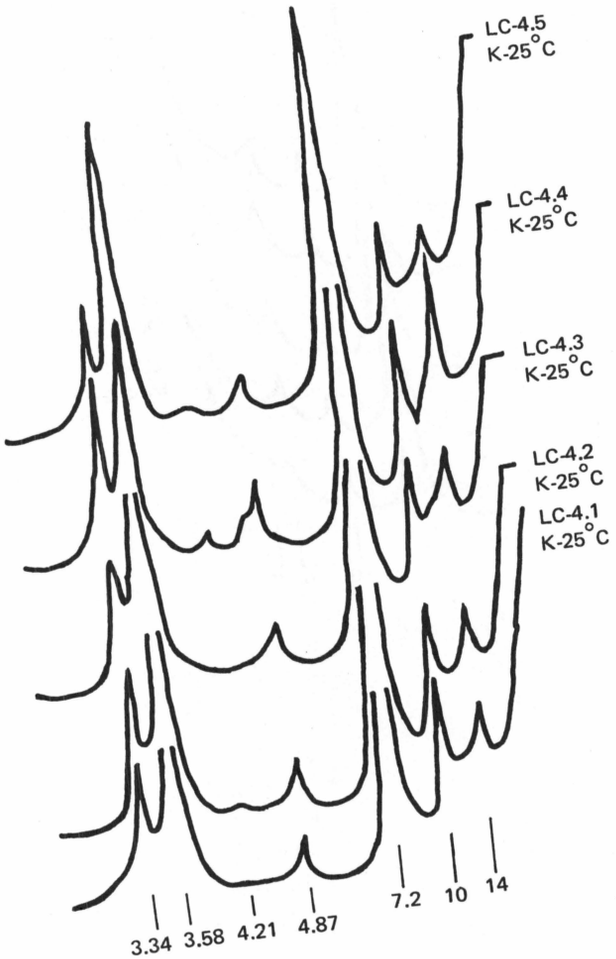


FIGURE 20

X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction Heated to 110°C (Mg-G 110°C); and Potassium-Saturated Clay Fraction Heated to 110°C (K-110°C), 300°C (K-300°C), and 550°C (K-550°C) for the Highly Altered Sample (LC-4.1) and the Unaltered Sample Midway Between Drainfield Lines (LC-4.4) from Site LC-4

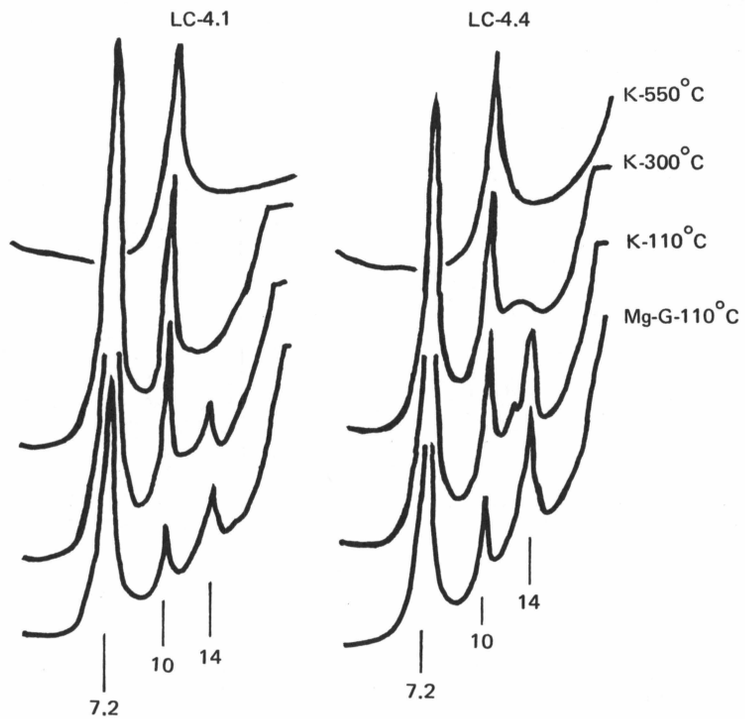
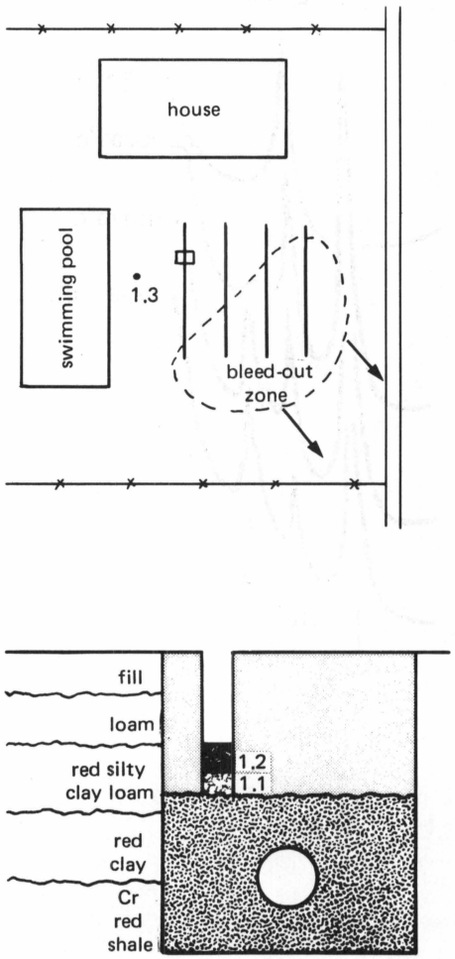


FIGURE 21
Location and Description for Site PWC-1

Location: PWC-1
Date Sampled: April 19, 1978
Sampled by: Kaster, Weber, Alexander, Lietzke
Drainfield Type: Standard drainfield
Soil: Reaville, clayey variant; Red Triassic shale parent material; Aquic Hapludalfs; fine, mixed, mesic



Sample No.	Description
PWC-1.1	Highly altered interface sample.
PWC-1.2	Altered sample.
PWC-1.3	Unaltered sample away from trench.

Notes

1. Effluent probably has never moved out of the trench bottom but has risen to the surface or new surface and flowed laterally.
2. Soil profile:

	0-13 cm fill.	
Ap	13-28 cm loam	10YR 4/4.
B1	28-38 cm loam	10YR 5/4.
B21t	38-56 cm silty clay loam 5YR 5/6 with red and 5YR 6/2 gray mottles at the base of the horizon. Gravel line at the base of the horizon.	
IIB22t	56-120 cm	5YR4/6 (no gray mottles except gray coatings in cracks); silty clay or clay texture.
IICr	Weathered red shale—very dense.	

FIGURE 22
X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction at Room Temperature from Site PWC-1

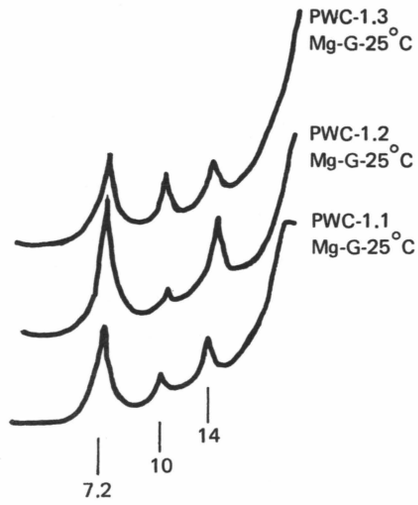


FIGURE 23
X-Ray Diffractograms of Potassium-Saturated Clay Fraction at Room Temperature from Site PWC-1

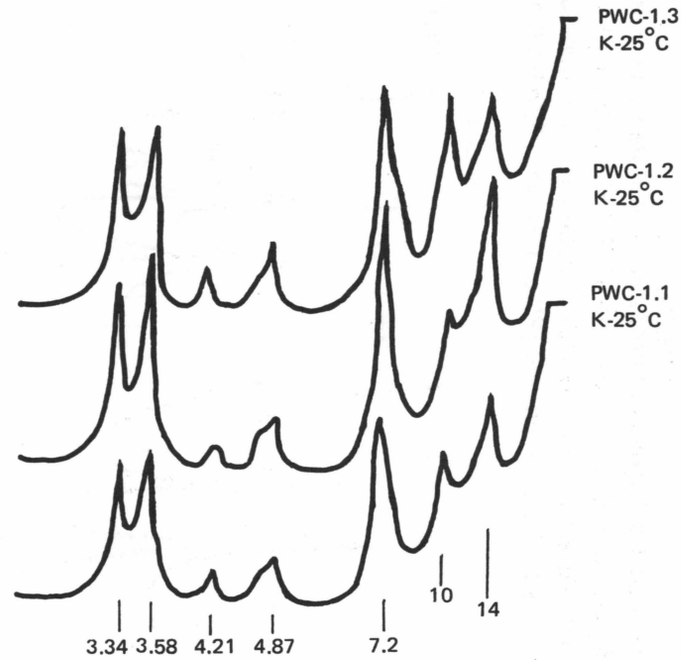


FIGURE 24

X-Ray Diffractograms of Potassium-Saturated Clay Fraction Heated to 110°C (K-110°C) and 300°C (K-300°C) for the Highly Altered Sample (PWC-1.1) and the Unaltered Sample Away from Drainfield (PWC-1.3) from Site PWC-1

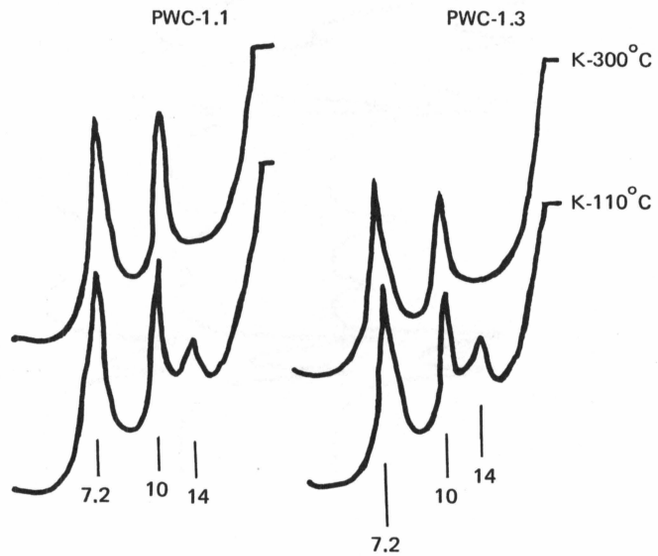
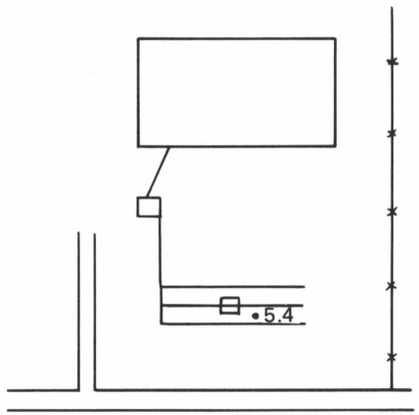


FIGURE 25
Location and Description for Site CC-5

Location: CC-5
Date Sampled: March 23, 1978
Sampled by: Clarke, Mendenhall, Barwood, Zelazny, Lietzke
Type of System: Standard drainfield
Soil: Wedowee; Typic Hapludults; clayey, kaolinitic, thermic



Sample No.	Description
CC-5.1	Channelized flow zone—highly altered.
CC-5.2	Altered zones next to channelized flow zone.
CC-5.3	Less altered soil material.
CC-5.4	Unaltered composite sample.
CC-5a	Effluent sample.
CC-5b	Water sample.

Notes

1. This is the first drainfield sampled in recognition of channelized flow.
2. Probable causes of malfunctioning:
   a. Concave landscape position,
   b. Drainfield too small for present number of people in the house.

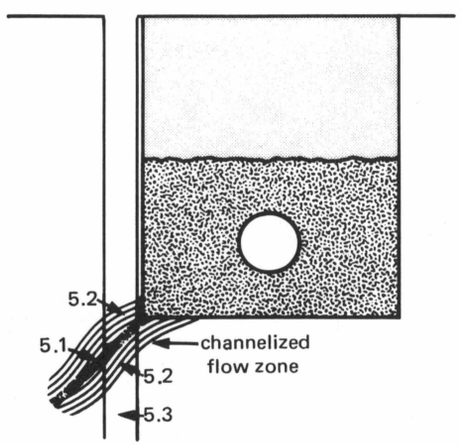


FIGURE 26

X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction at Room Temperature from Site CC-5

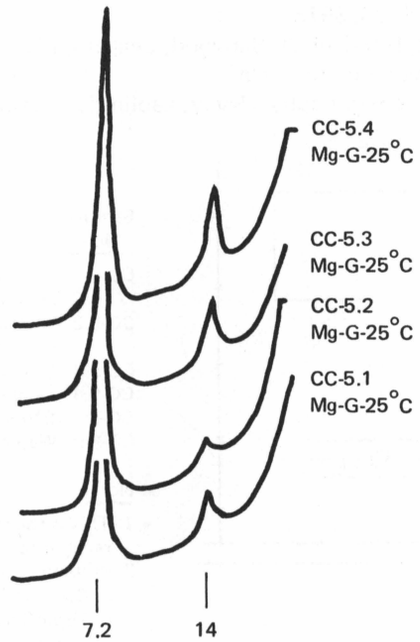


FIGURE 27

X-Ray Diffractograms of Potassium-Saturated Clay Fraction at Room Temperature from Site CC-5

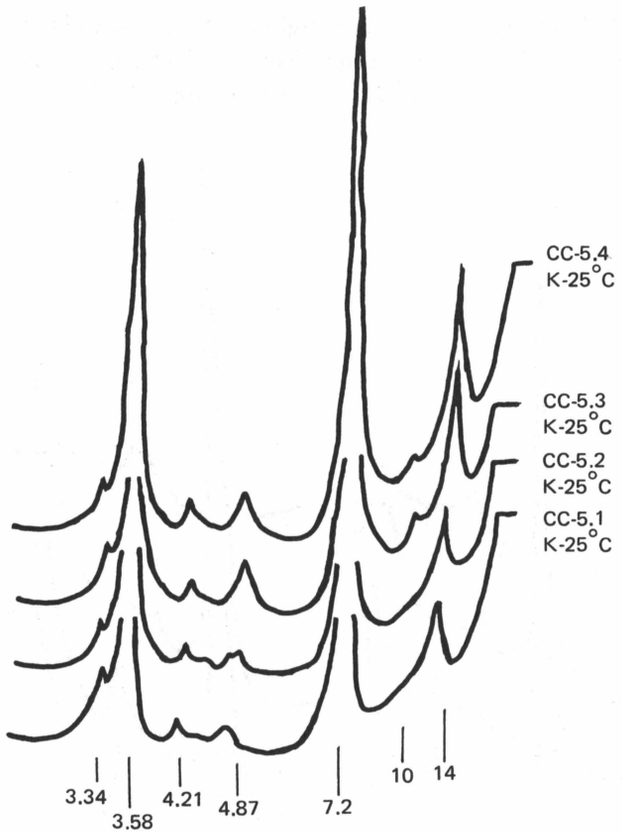


FIGURE 28

X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction Heated to 110°C (Mg-G 110°C); and Potassium-Saturated Clay Fraction Heated to 110°C (K-110°C), 300°C (K-300°C), and 550°C (K-550°C) for the Highly Altered Sample (CC-5.1) and the Unaltered Sample Midway Between Drainfield Lines (CC-5.4) from Site CC-5

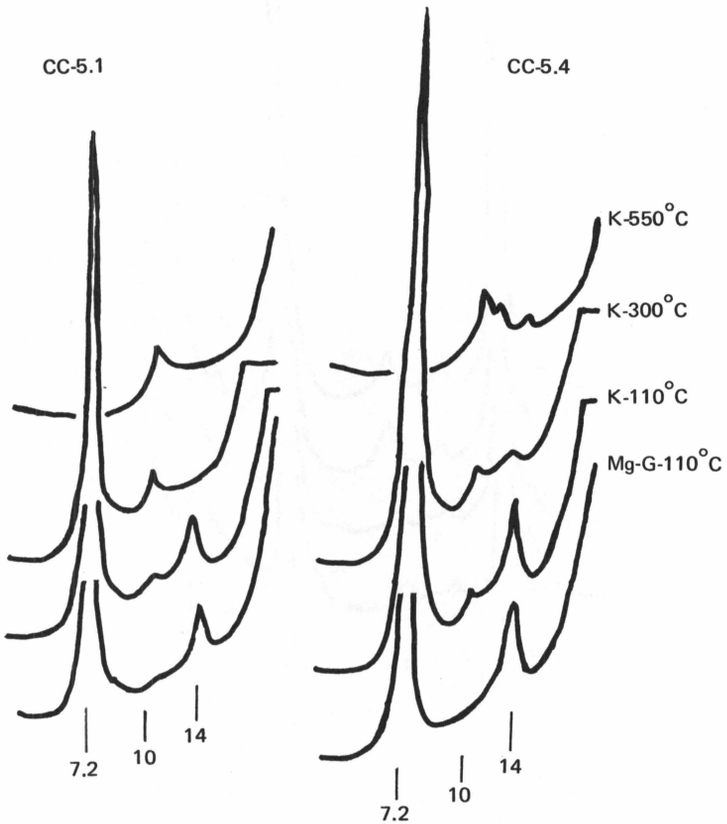
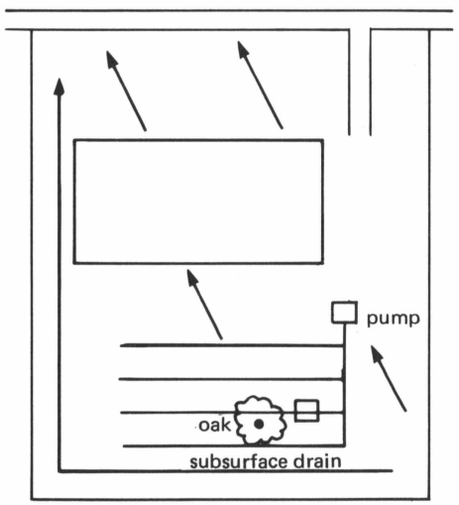


FIGURE 29
Location and Description for Site CC-6

Location: CC-6
Date Sampled: March 23, 1978
Sampled by: Clarke, Mendenhall, Barwood, Zelazny, Lietzke
Drainfield Type: Pumped system to standard drainfield
Soil: Masada; Typic Hapludult (or Typic Paleudult?); clayey, mixed, thermic



Sample No.	Description
CC-6.1	Saturated flow zone—not visibly altered.
CC-6.2	Non-saturated zone but very moist—not visibly altered.
CC-6.3	Deeper sample, moist—unaltered.
CC-6a	Effluent sample.
CC-6b	Water sample.

Notes

1. Very sticky clay in drainfield area of effluent movement.
2. No altered flow zones were observed in several probe observations due to oxygenated effluent.
3. Probable cause of failure:
   a. Slow permeability,
   b. Swelling clay formed.

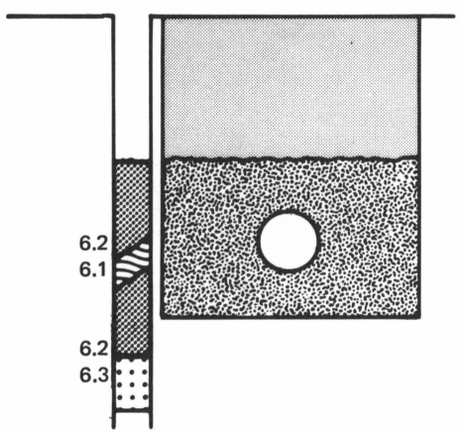


FIGURE 30

X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction at Room Temperature from Site CC-6

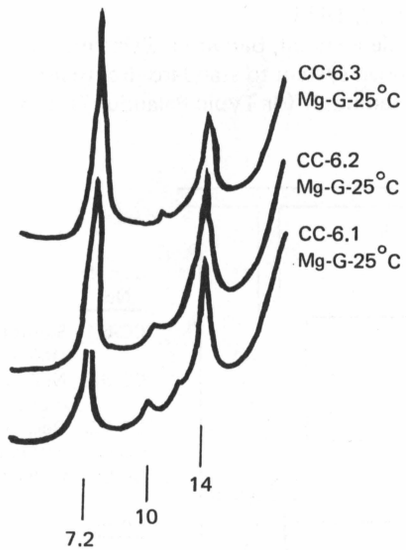


FIGURE 31

X-Ray Diffractograms of Potassium-Saturated Clay Fraction at Room Temperature from Site CC-6

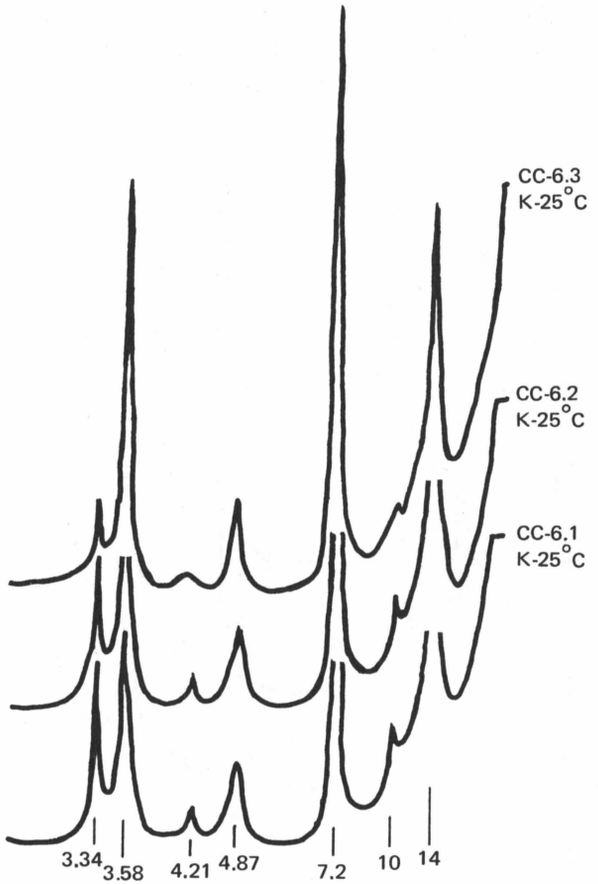


FIGURE 32

X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction Heated to 110°C (Mg-G 110°C); and Potassium-Saturated Clay Fraction Heated to 110°C (K-110°C), 300°C (K-300°C), and 550°C (K-550°C) for the Not Visibly Altered Sample (CC-6.1) and the Unaltered Sample Taken Below Other Samples (CC-6.3) from Site CC-6

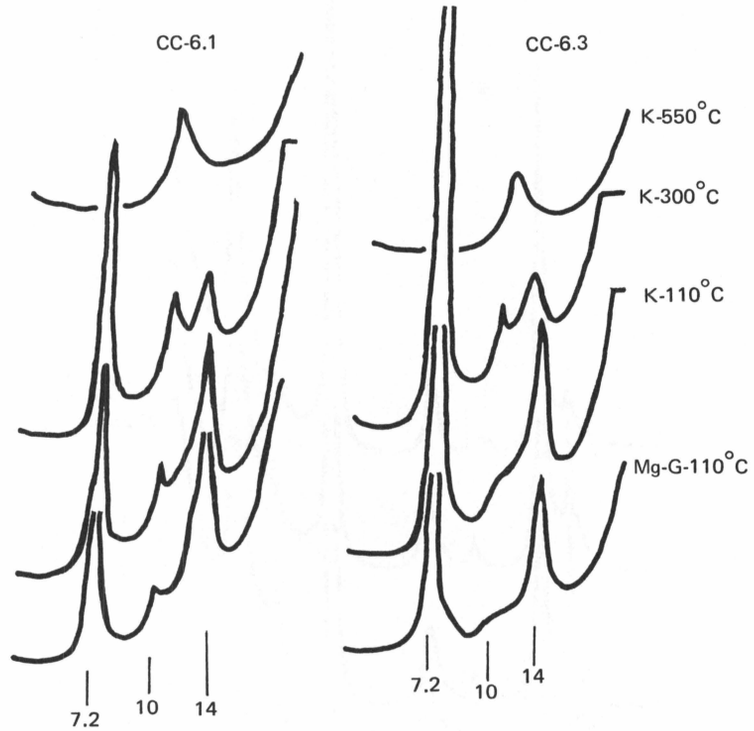
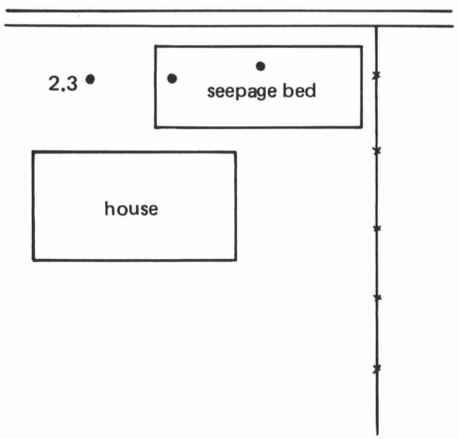


FIGURE 33
Location and Description for Site TC-2

Location: TC-2
Date Sampled: May 23, 1978
Sampled by: Nutter, Zelazny, Lietzke
Drainfield Type: Seepage bed installed February 1972
Soil: Locust; Glossic Fragiudults; fine-loamy or loamy-skeletal, siliceous mesic (collovial site low on slope)



Sample No.	Description
TC-2.1	Highly altered soil composite sample.
TC-2.2	Altered soil composite sample.
TC-2.3	Unaltered sample away from seepage bed.

Notes

1. Effluent under pressure in bed, had artesian flow after removing probe core.
2. Fragipan probably in sidewalls and seepage bed bottom.
3. Drainfield installed wet. Excavation filled with water before seepage bed was installed.

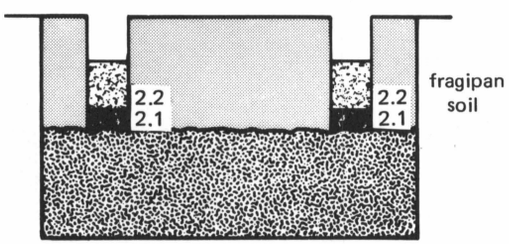


FIGURE 34
X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction at Room Temperature from Site TC-2

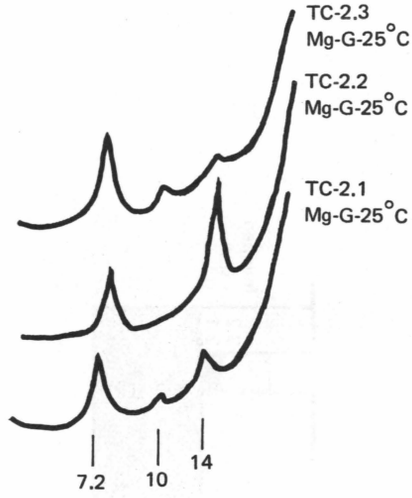


FIGURE 35
X-Ray Diffractograms of Potassium-Saturated Clay Fraction at Room Temperature from Site TC-2

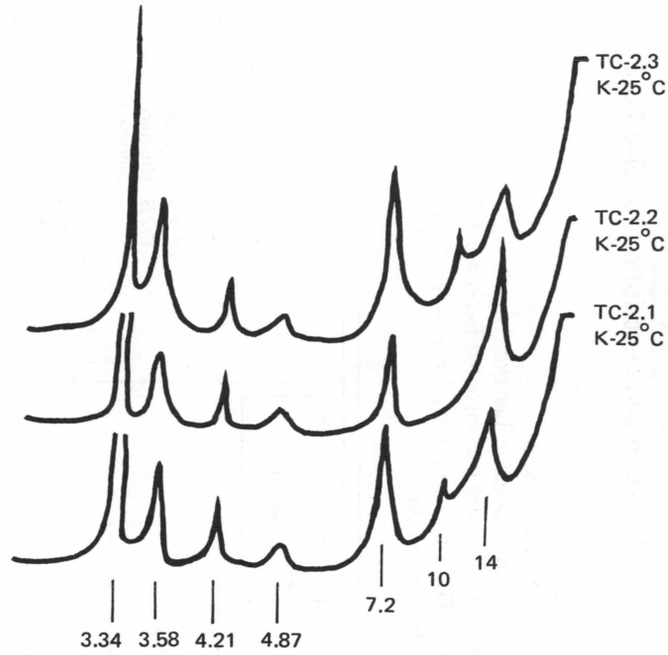


FIGURE 36

X-Ray Diffractograms of Potassium-Saturated Clay Fraction Heated to 110°C (K-110°C) and 300°C (K-300°C) for the Highly Altered Sample (TC-2.1) and the Unaltered Sample Away from Seepage Bed (TC-2.3) from Site TC-2

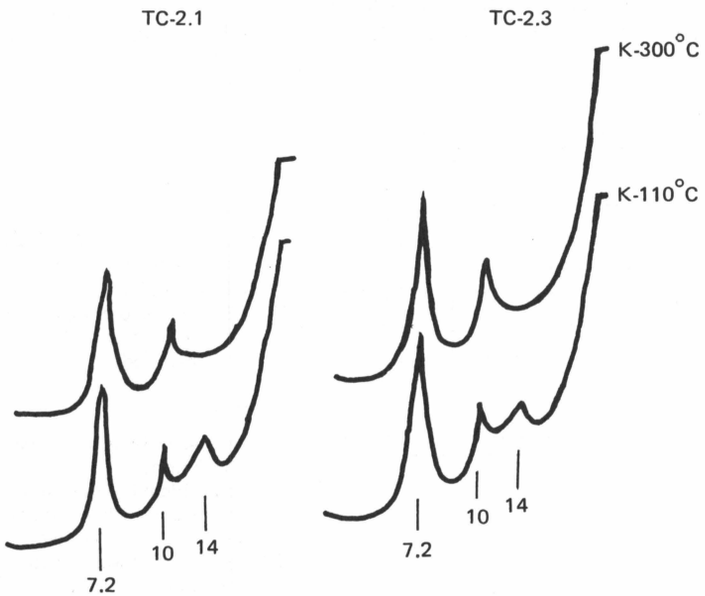
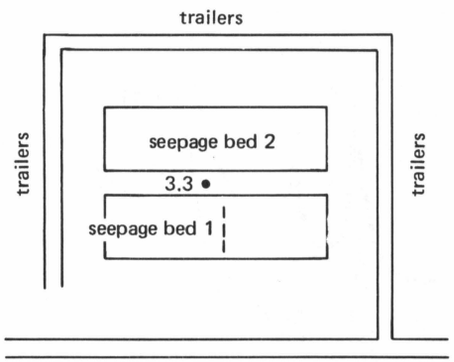
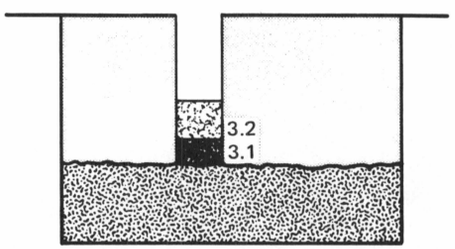


FIGURE 37
Location and Description for Site TC-3

Location: TC-3
Date Sampled: May 23, 1978
Sampled by: Zelazny, Nutter, Lietzke
Type of System: Seepage beds installed 1971
Soil: No known soil series; Typic or Aquic Hapludult; fine-loamy, derived from colluvium





Sample No.	Description
TC-3.1	Highly altered soil.
TC-3.2	Altered soil.
TC-3.3	Unaltered composite soil sample from 0-30-cm depth—unaltered.

Notes

1. The seepage beds have a wet weather malfunction.
2. One problem is water runoff from the highway and higher areas above. This water should be diverted.
3. Seepage bed 1 was wet to the surface when sampled. This seepage bed intercepts highway runoff.
4. Seepage bed 2 was not saturated to the surface.

FIGURE 38
X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction at Room Temperature from Site TC-3

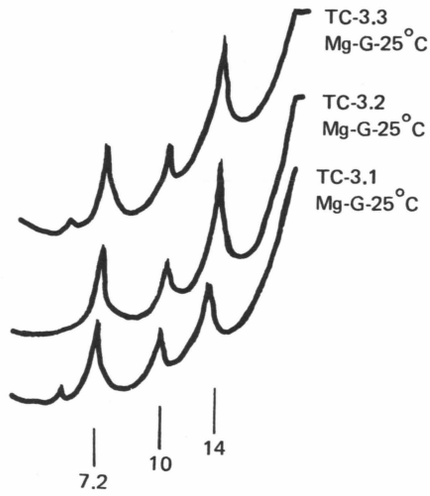


FIGURE 39
X-Ray Diffractograms of Potassium-Saturated Clay Fraction at Room Temperature from Site TC-3

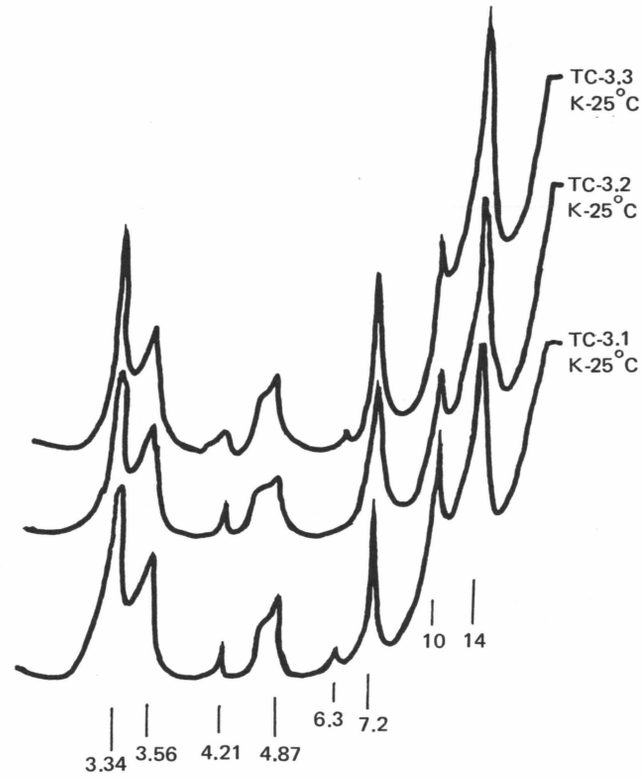


FIGURE 40

X-Ray Diffractograms of Potassium-Saturated Clay Fraction Heated to 110°C (K-110°C), and 300°C (K-300°C) for the Highly Altered Sample (TC-3.1) and the Unaltered Sample Midway Between Seepage Beds (TC-3.3) from Site TC-3

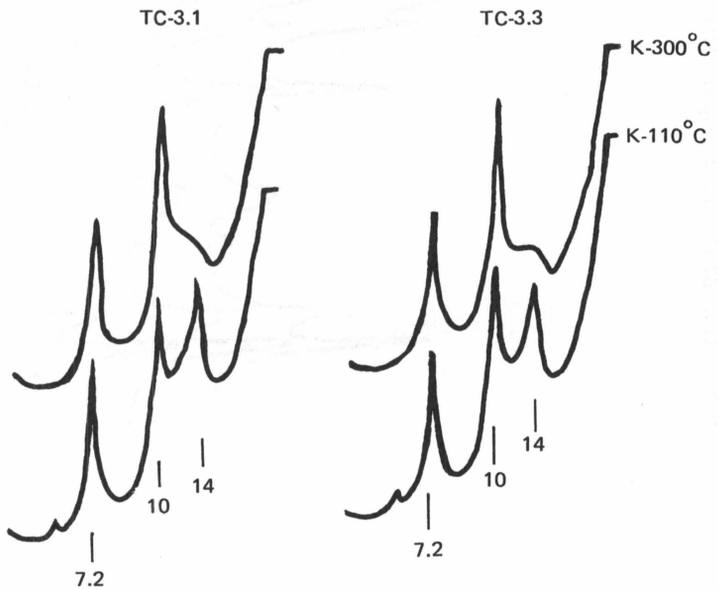
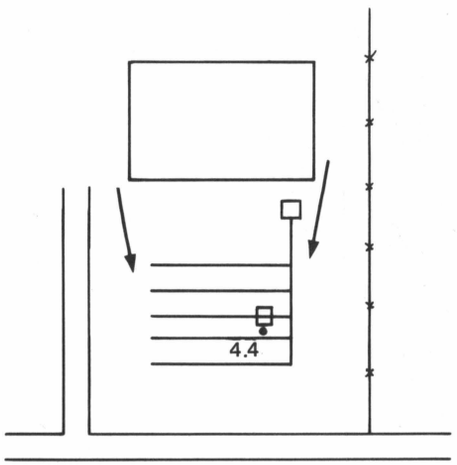


FIGURE 41
Location and Description for Site FC-4

Location: FC-4
Date Sampled: March 22, 1978
Sampled by: Pricci, Alexander, Weber, Barwood, Zelazny, Lietzke
Drainfield Type: Standard drainfield
Soil: Wedowee; Typic Hapludult; clayey, kaolinitic, thermic



Sample No.	Description
FC-4.1	Reduced, highly altered interface.
FC-4.2	Area around highly altered zone—altered.
FC-4.3	15-cm composite below sample 4.2—altered.
FC-4.4	Composite unaltered sample at same depth of samples 4.1, 4.2.

Notes

1. The drainfield was installed in saprolite.
2. The saprolite had a perc rate of 48 min/in.
3. Drainfield installed February 1960, was malfunctioning on sampling date.
4. Variable amounts of fill had been added to the surface.

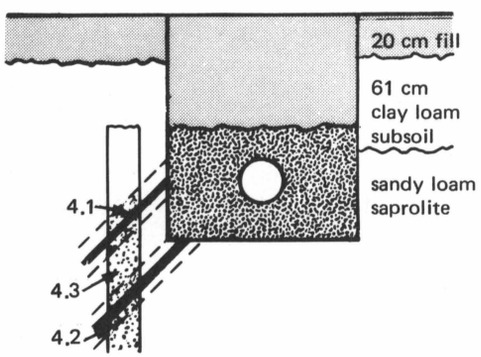


FIGURE 42

X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction at Room Temperature from Site FC-4

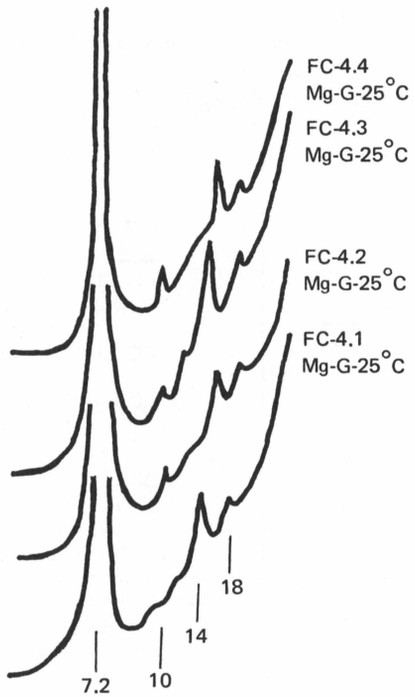


FIGURE 43

X-Ray Diffractograms of Potassium-Saturated Clay Fraction at Room Temperature from Site FC-4

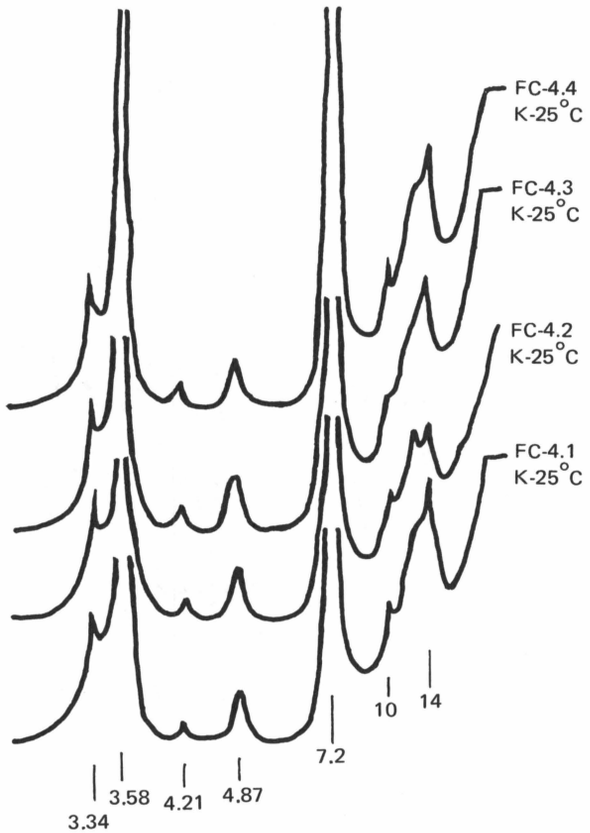


FIGURE 44

X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction Heated to 110°C (Mg-G 110°C); and Potassium-Saturated Clay Fraction Heated to 110°C (K-110°C), 300°C (K-300°C), and 550°C (K-550°C) for the Highly Altered Sample (FC-4.1) and the Unaltered Sample Midway Between Drainfield Lines (FC-4.4) from Site FC-4

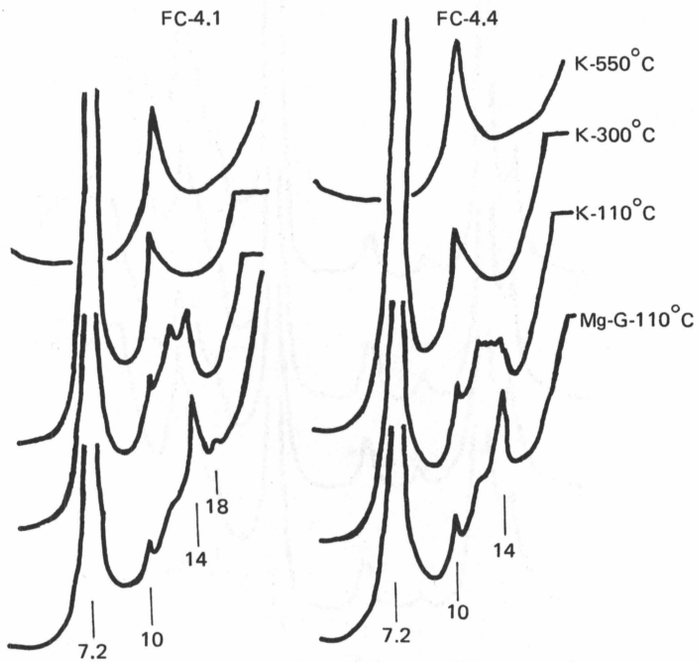
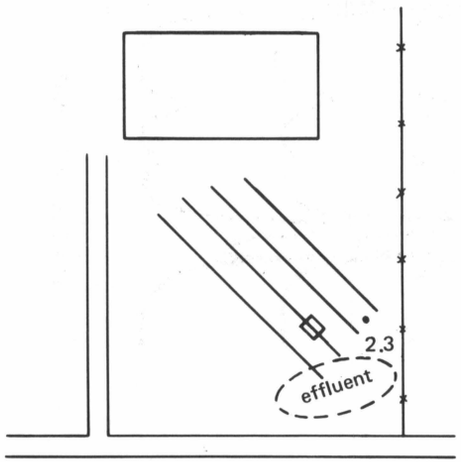


FIGURE 45
Location and Description for Site PWC-2

Location: PWC-2
Date Sampled: April 19, 1978
Sampled by: Alexander, Weber, Kaster, Lietzke
Drainfield Type: Standard drainfield
Soil: Elioak-Glenelg series; acid mica schist



Sample No.	Description
PWC-2.1	Highly altered, black soil material in channelized flow zones.
PWC-2.2	Gleyed zone above and below flow zone—altered
PWC-2.3	Unaltered soil material from the same depth as PWC-2.1 and 2.2

Notes

1. Drainfield installed in clay subsoil, not in the more permeable mica schist saprolite.
2. Drainfield was not installed on the contour.
3. Soil profile:

Ap	0-16 cm	7.5YR 5/6 loam.
B21t	16-30 cm	2.5YR 4/8 silty clay loam.
B22t	30-75 cm	2.5YR 4/8 silty clay; good structure; heavy, thick clay film.
B23	75-90 cm	2.5YR 4/8 silty clay loam.
C	90-115 cm	2.5 YR 4/6 saprolite crushed to loam, many mica flakes.

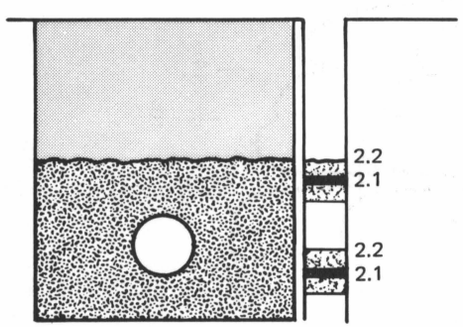


FIGURE 46

X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction at Room Temperature from Site PWC-2

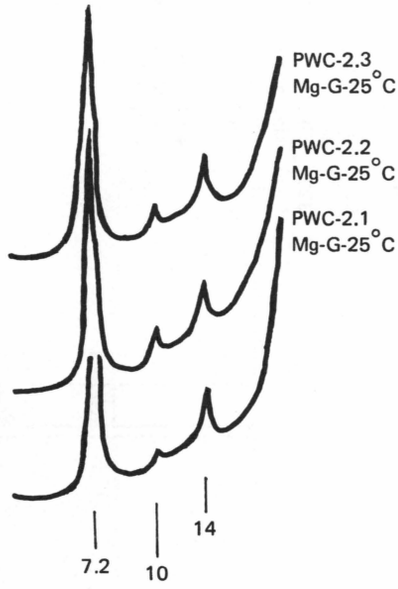


FIGURE 47

X-Ray Diffractograms of Potassium-Saturated Clay Fraction at Room Temperature from Site PWC-2

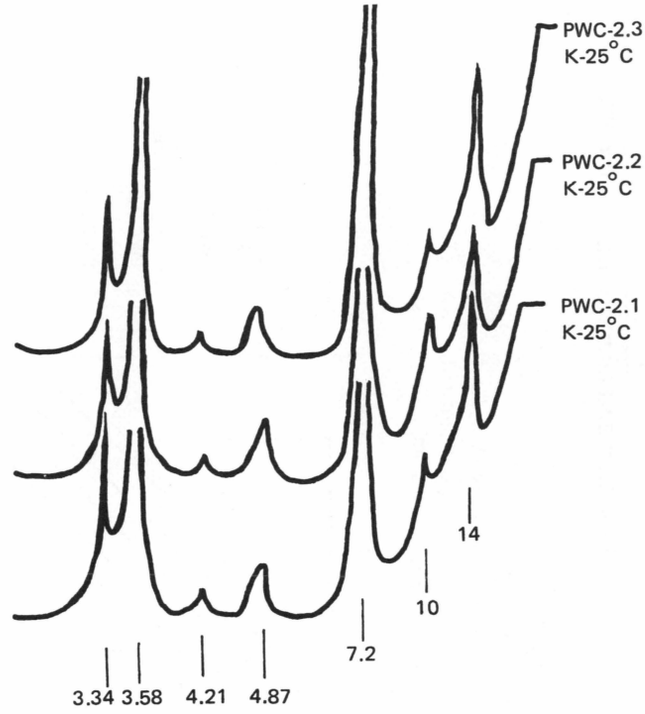


FIGURE 48

X-Ray Diffractograms of Potassium-Saturated Clay Fraction Heated to 110°C (K-110°C) and 300°C (K-300°C) for the Highly Altered Sample (PWC-2.1) and the Unaltered Sample Midway Between Drainfield Lines (PWC-2.3) from Site PWC-2

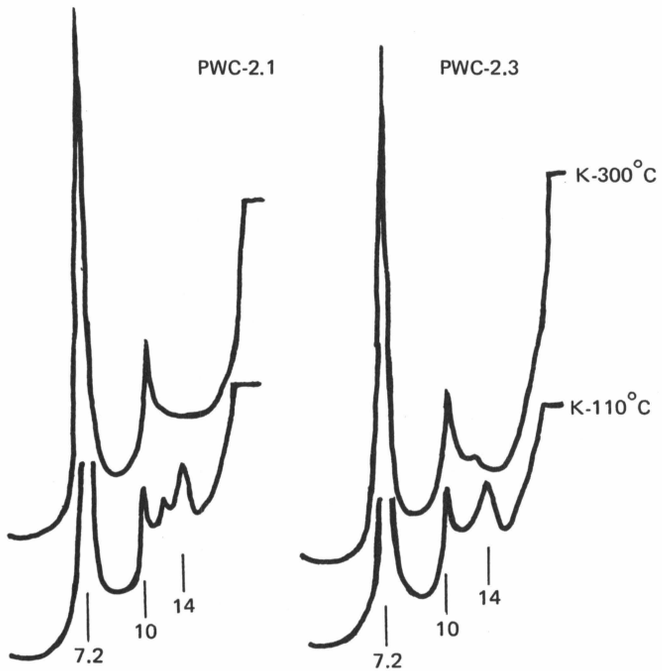
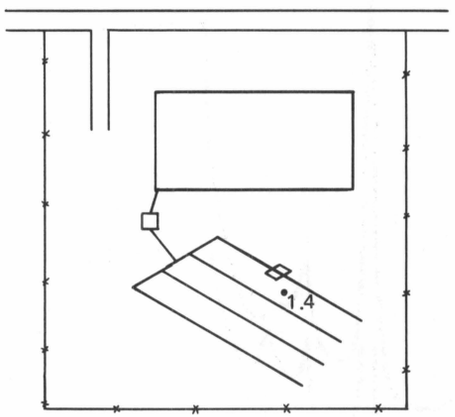


FIGURE 49
Location and Description for Site CC-1

Location: CC-1
Date Sampled: March 23, 1978
Sampled by: Clarke, Mendenhall, Barwood, Zelazny, Lietzke
Drainfield Type: Standard drainfield
Soil: Ruston series; clayey lower Bt horizon at 102-cm depth



Sample No.	Description
CC-1.1	2-cm thick highly altered interface material.
CC-1.2	2-10-cm thick less altered soil material than 1.1.
CC-1.3	10-20-cm thick less altered soil material than 1.2.
CC-1.4	90-100-cm depth. Unaltered composite sample at same depth as 1.1 to 1.3.
CC-1a	Effluent sample.
CC-1b	Water sample.

Notes

1. The drainfield had already been repaired by the installation of a deep seepage pit put through the lower clayey B into sandier C horizon materials.
2. Cause of malfunction was slowly permeable material at 1-meter depth; small drainfield size due to very small lot.

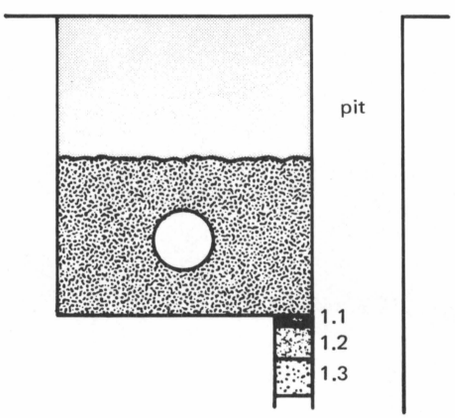


FIGURE 50
X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction at Room Temperature from Site CC-1

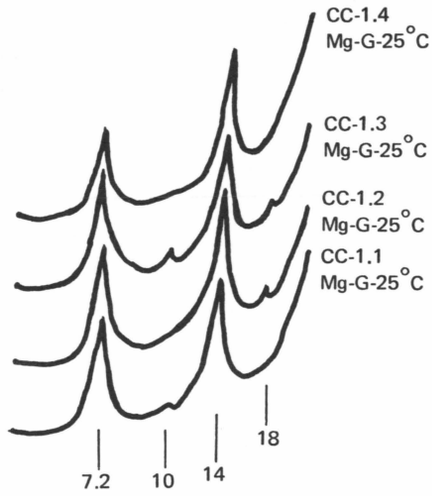


FIGURE 51
X-Ray Diffractograms of Potassium-Saturated Clay Fraction at Room Temperature from Site CC-1

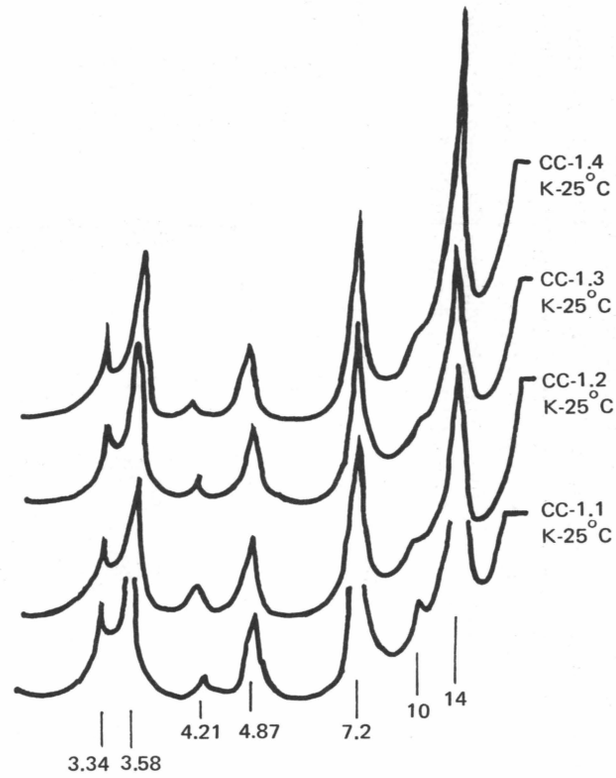


FIGURE 52

X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction Heated to 110°C (Mg-G 110°C); and Potassium-Saturated Clay Fraction Heated to 110°C (K-110°C), 300°C (K-300°C), and 550°C (K-550°C) for the Highly Altered Sample (CC-1.1) and the Unaltered Sample Midway Between Drainfield Lines (CC-1.4) from Site CC-1

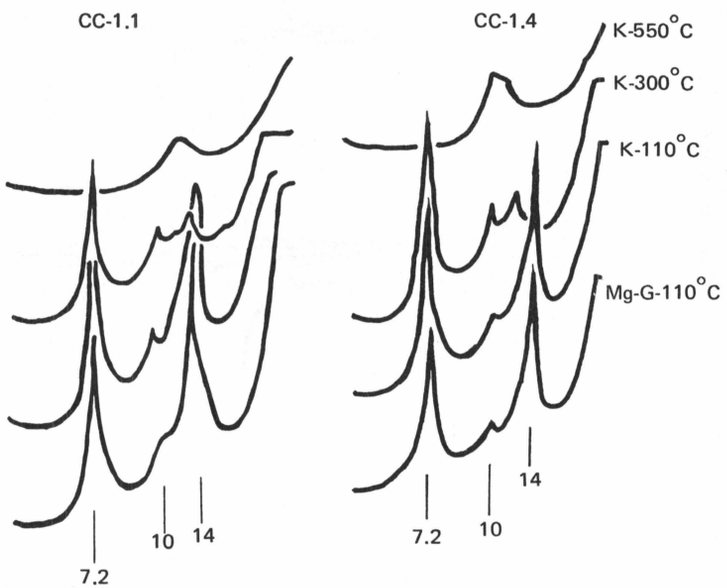
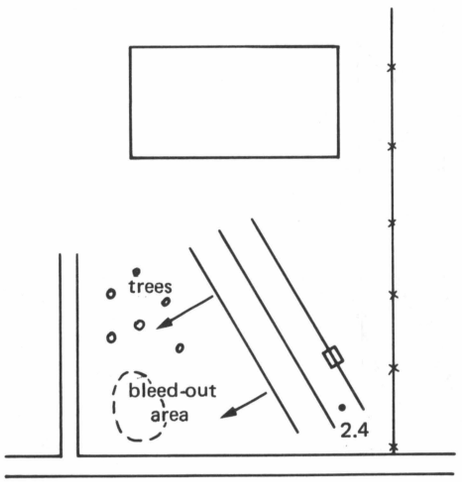
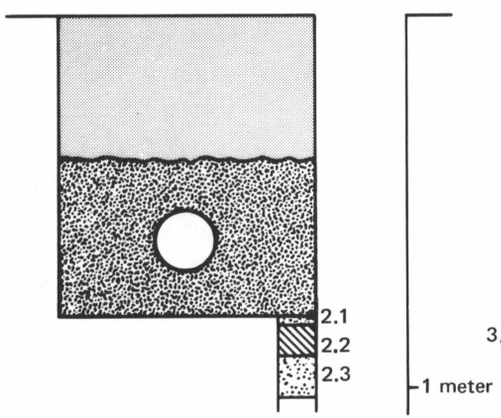


FIGURE 53
Location and Description for Site CC-2

Location: CC-2
Date Sampled: March 23, 1978
Sampled by: Clarke, Mendenhall, Barwood, Zelazny, Lietzke
Drainfield Type: Standard drainfield
Soil: Norfolk; Typic Paleudult; fine-loamy, siliceous, thermic





Sample No.	Description
CC-2.1	0.2-cm thick interface at base of gravel—highly altered.
CC-2.2	2-10-cm altered material below 2.1.
CC-2.3	10-20-cm zone beneath 2.2—altered.
CC-2.4	Unaltered composite sample at same depth as 2.1 to 2.2.
CC-2a	Effluent sample.
CC-2b	Water sample.

Notes

1. Effluent was rising in the soil and then flowing laterally beneath the surface the bleed-out zone.
2. Soil profile:
   0-20 cm fill.
   Ap 20-30 cm 10YR 4/3 sandy loam.
   Az 30-41 cm 2.5Y 6/2 loamy sand.
   A&B 41-56 cm A 5Y 6/3 loamy sand.
   B 10YR 6/6 sandy loam, 10-20 percent.
   B&A 56-91 cm Bz 10YR 5/6 sandy clay loam.
   A 10YR 6/4 sandy loam.
   IIB21t 91-112 cm 10YR 5/6 clay loam; few 2.5YR 4/6 mottles.
   IIB22t 112-127 cm 2.5YR 5/6; 7.5YR 5/6 sandy clay loam; 10YR 5/4; few 2.5Y 6/2 zones on ped edges.
   IIB23t 127-155 cm same colors but increasing amount of gray.
3. Probable cause of malfunction is slow permeable soil in trench bottoms.

FIGURE 54

X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction at Room Temperature from Site CC-2

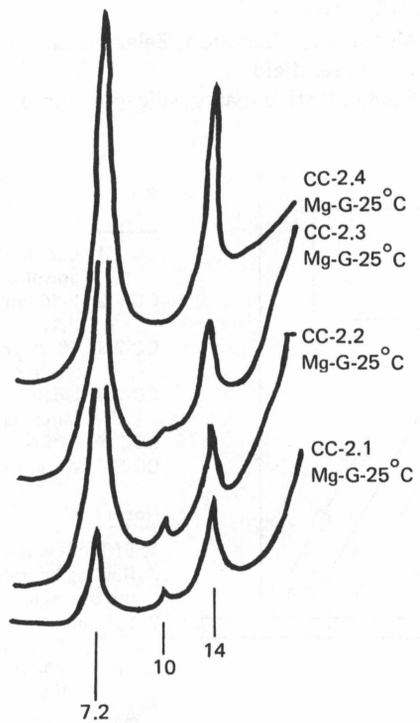


FIGURE 55

X-Ray Diffractograms of Potassium-Saturated Clay Fraction at Room Temperature from Site CC-2

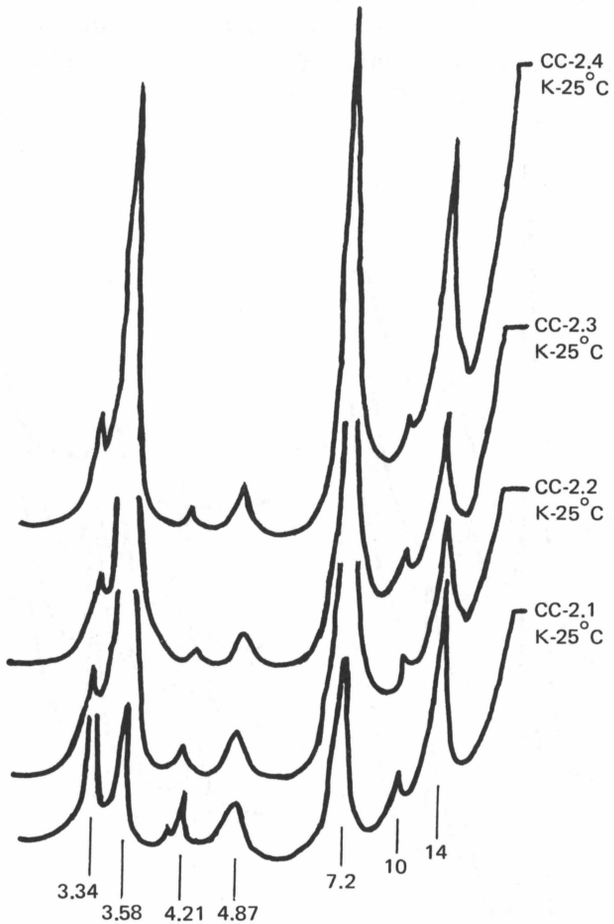


FIGURE 56

X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction Heated to 110°C (Mg-G 110°C); and Potassium-Saturated Clay Fraction Heated to 110°C (K-110°C), 300°C (K-300°C), and 550°C (K-550°C) for the Highly Altered Sample (CC-2.1) and the Unaltered Sample Midway Between Drainfield Lines (CC-2.4) from Site CC-2

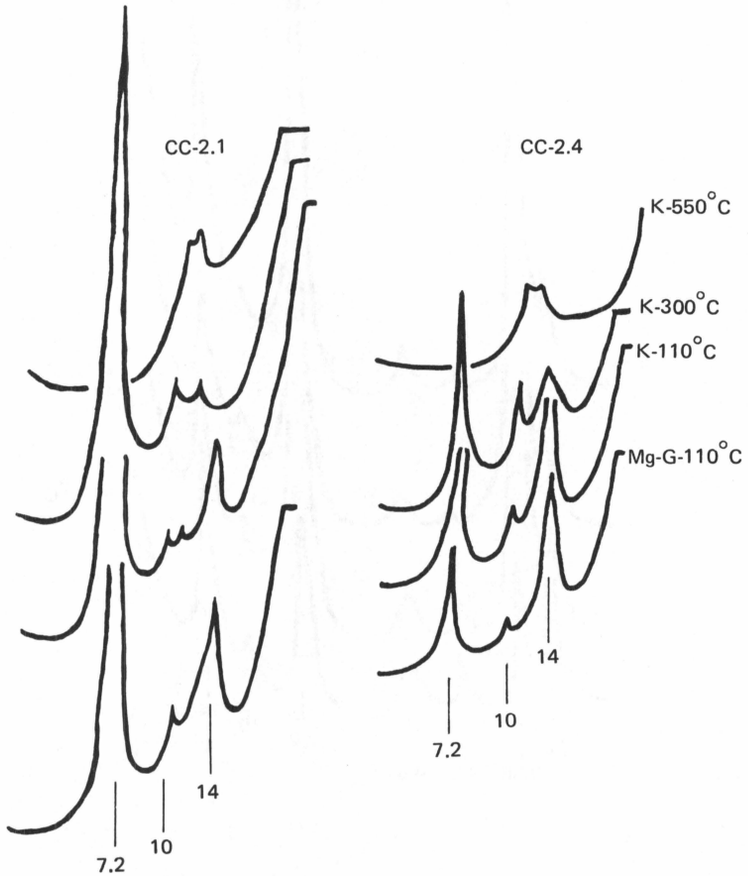
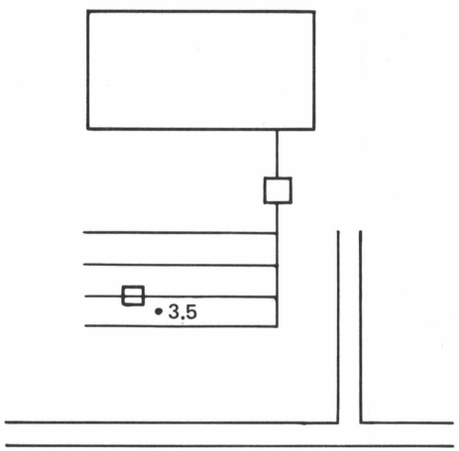
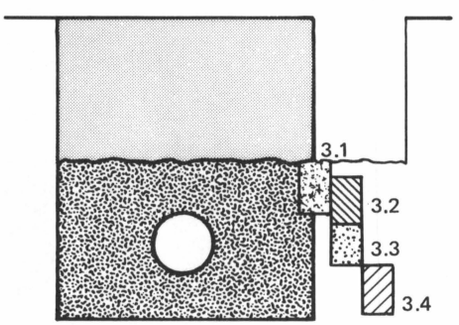


FIGURE 57
Location and Description for Site CC-3

Location: CC-3
Date Sampled: March 23, 1978
Sampled by: Clarke, Mendenhall, Barwood, Zelazny, Lietzke
Type of System: Standard drainfield
Soil: Goldsboro; Aquic Paleudults; fine-loamy, siliceous, thermic





Sample No.	Description
CC-3.1	0-2-cm thick interface at trench sidewall-gravel contact—highly altered.
CC-3.2	2-5-cm thick altered zone adjacent to the interface sample.
CC-3.3	5-10 cm away from interface and below—altered.
CC-3.4	10-15 cm away from interface and below—altered.
CC-3.5	Unaltered composite at the same depth of 3.1 to 3.3 but between 2 lines.
CC-3a	Effluent sample.

Notes

1. A gley zone 3 cm thick was above the gravel in the trench backfill material indicating the upward movement of effluent.
2. The sidewalls were saturated for a distance of 2.5 cm. Movement of effluent beyond this distance was channelized.
3. Probable cause of trouble is slow permeability of trench bottoms.

FIGURE 58

X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction at Room Temperature from Site CC-3

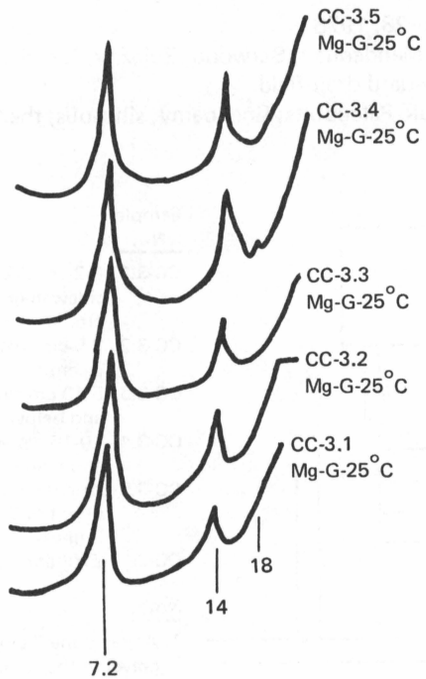


FIGURE 59

X-Ray Diffractograms of Potassium-Saturated Clay Fraction at Room Temperature from Site CC-3

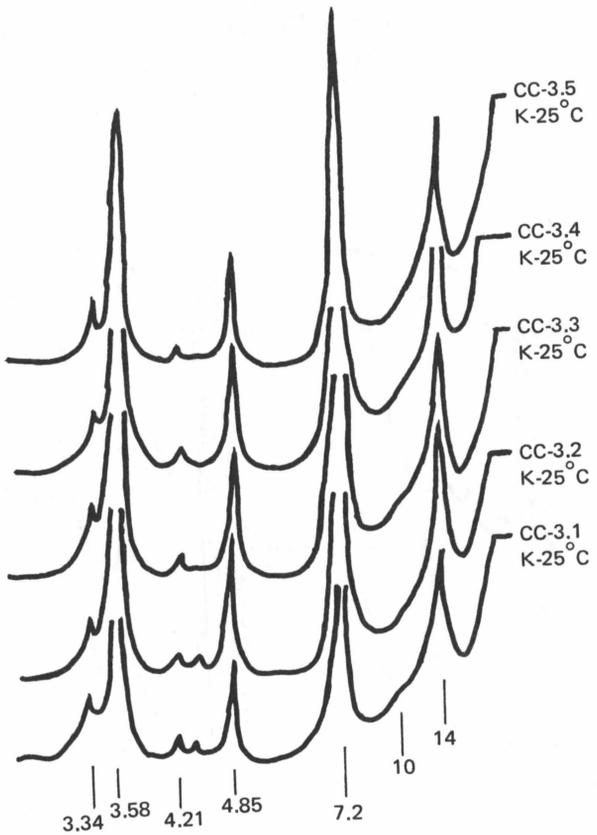


FIGURE 60

X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction Heated to 110°C (Mg-G 110°C); and Potassium-Saturated Clay Fraction Heated to 110°C (K-110°C), 300°C (K-300°C), and 550°C (K-550°C) for the Highly Altered Sample (CC-3.1) and the Unaltered Sample Midway Between Drainfield Lines (CC-3.5) from Site CC-3

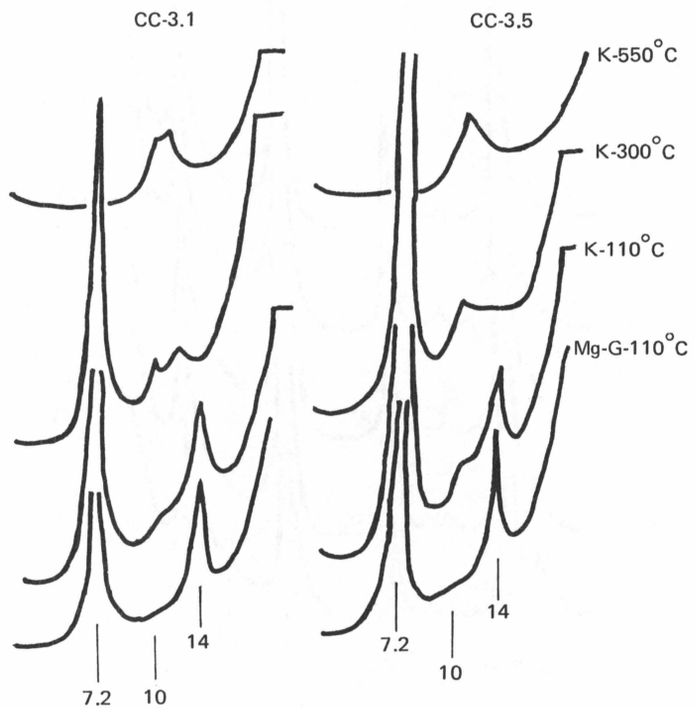
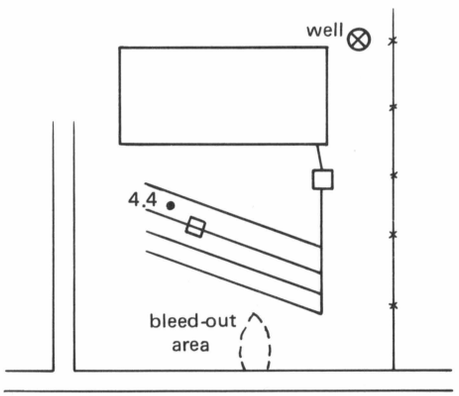
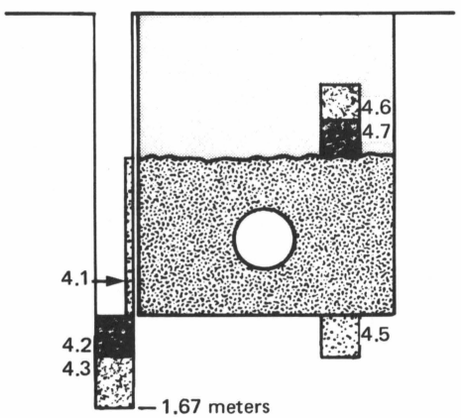


FIGURE 61
Location and Description for Site CC-4

Location: CC-4
Date Sampled: March 23, 1978
Sampled by: Clarke, Mendenhall, Barwood, Zelazny, Lietzke
Type of System: Standard drainfield
Soil: Grover variant; Utlic Hapludalfs; fine-loamy, micaceous, thermic, with biotite schist parent material



Sample No.	Description
CC-4.1	Sidewall interface composite 2 to 5 cm from trench wall—highly altered.
CC-4.2	Interface 5 cm thick—highly altered.
CC-4.3	Less altered 5-cm thick zone.
CC-4.4	Unaltered sample of C horizon.
CC-4.5	Interface at base of trench gravel—altered.
CC-4.6	Less altered 5-7-cm thick zone in trench fill.
CC-4.7	Interface—highly altered 2-5-cm thick zone in trench fill.
CC-4a	Effluent sample.
CC-4b	Water sample.



Notes

1. Soil profile:
   - Ap 0-10 cm 10YR 4/3 sandy loam.
   - B22t 10-53 cm 10YR 4/4 clay loam with many biotite flakes.
   - B3 53-93 cm 7.5YR 5/6 silty clay loam.
   - C 93-168 cm 10YR 5/6 silt loam to clay loam biotite schist saprolite.
2. The top 30-61 cm of subsoil in the drainfield had been removed during construction.
3. No strong visual evidence of channelized flow.
4. Drainfield mostly in parent material. Difficult to understand reason for failure.
5. Possible causes of failure:
   a. Colluvial landscape position.
   b. Roof water flowing across drainfield and being intercepted by the upper trench.
   c. Clay mineral diagenesis producing swelling clay or finer particles which reduced permeability.

FIGURE 61 (continued)

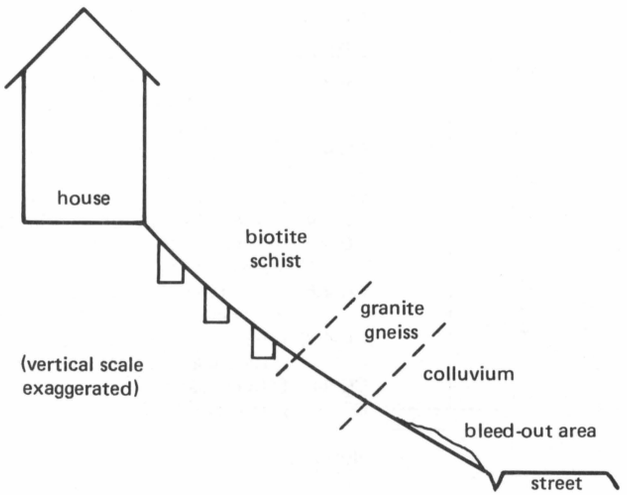


FIGURE 62

X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction at Room Temperature from Site CC-4

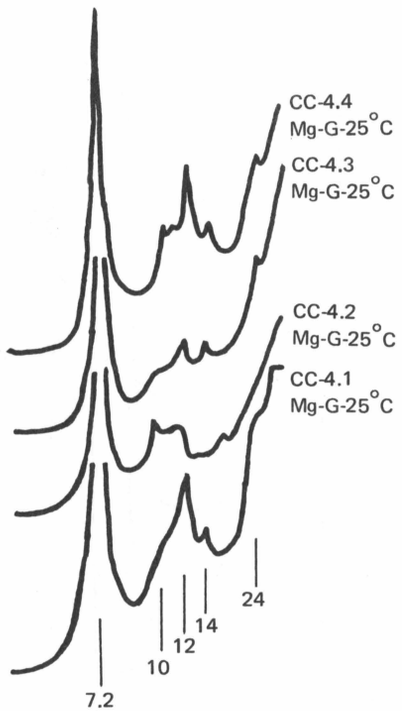


FIGURE 63

X-Ray Diffractograms of Potassium-Saturated Clay Fraction at Room Temperature from Site CC-4

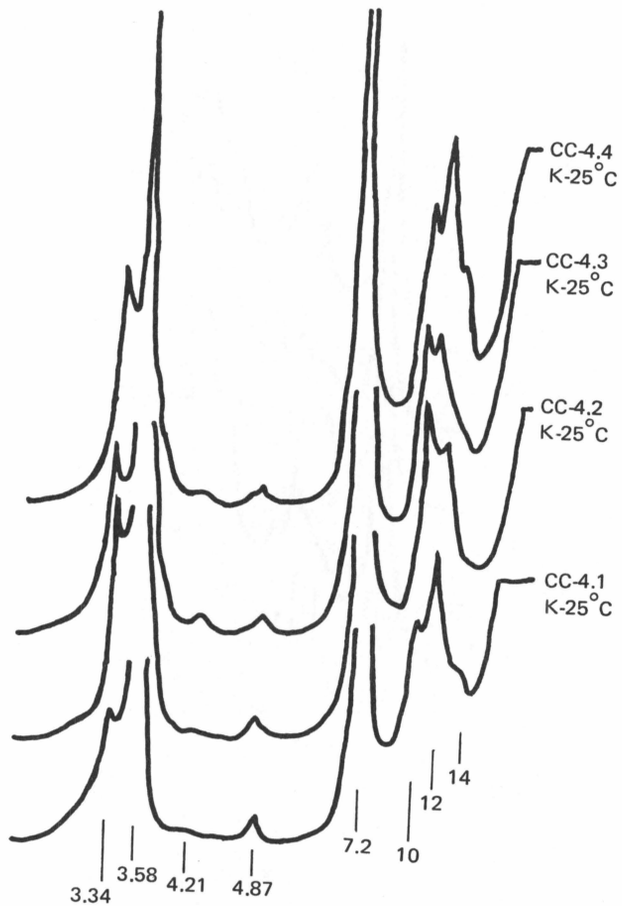


FIGURE 64

X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction Heated to 110°C (Mg-G 110°C); and Potassium-Saturated Clay Fraction Heated to 110°C (K-110°C), 300°C (K-300°C), and 550°C (K-550°C) for the Highly Altered Sample (CC-4.1) and the Unaltered Sample Midway Between Drainfield Lines (CC-4.4) from Site CC-4

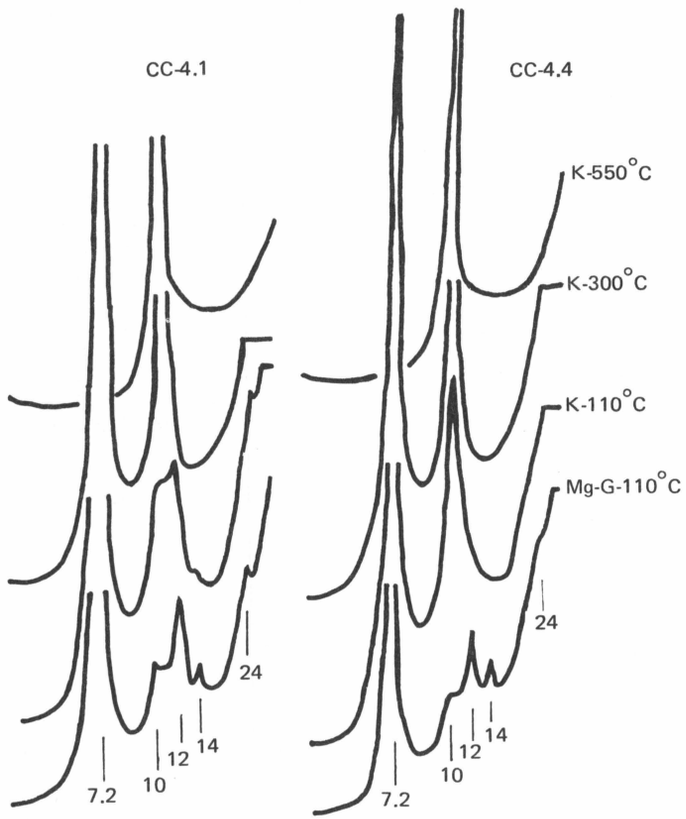
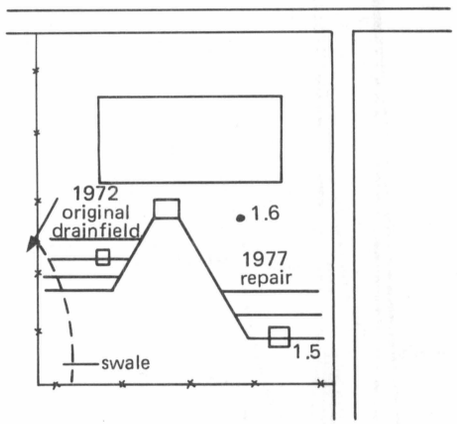


FIGURE 65
Location and Description for Site TC-1

Location: Site TC-1
Date Sampled: May 23, 1978
Sampled by: Nutter, Zelazny, Lietzke
Drainfield Type: Standard drainfield installed in 1972 in surface layer
Soil: No known soil series; Typic Hapludult; clayey, mixed, mesic (old colluvium)



Sample No.	Description
TC-1.1	Highly altered zone above gravel.
TC-1.2	Effluent-affected buried A horizon—altered.
TC-1.3	Effluent-affected subsoil—altered.
TC-1.4	Less affected subsoil—altered.
TC-1.5	Highly altered zone above gravel.
TC-1.6	Unaltered composite sample.

Notes

1. The original drainfield installed in 1972.
2. Repair made in 1977.
3. Repair failed in 1978. Seepage beds were being installed at time of sampling.
4. No water softener.

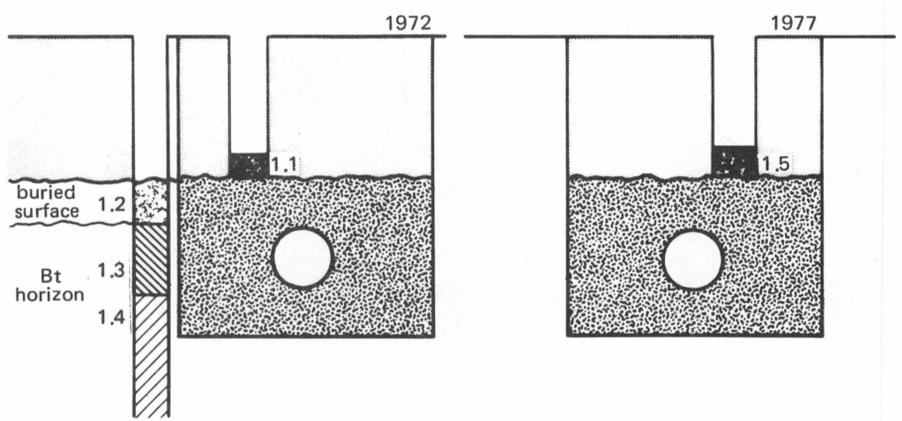


FIGURE 66

X-Ray Diffractograms of Magnesium-Saturated, Glycerol-Solvated Clay Fraction at Room Temperature from Site TC-1

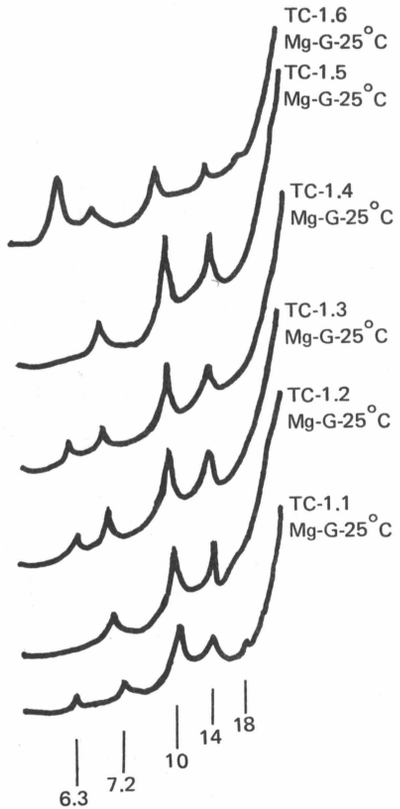


FIGURE 67

X-Ray Diffractograms of Potassium-Saturated Clay Fraction at Room Temperature from Site TC-1

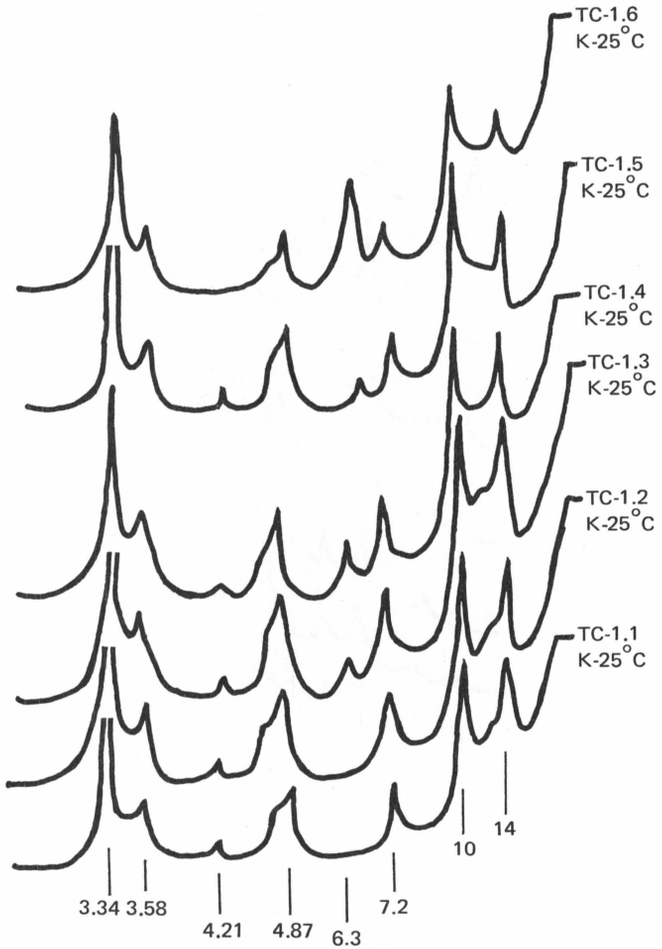


FIGURE 68

X-Ray Diffractograms of Potassium-Saturated Clay Fraction Heated to 110°C (K-110°C) and 300°C (K-300°C) for the Highly Altered Sample (TC-1.1) and the Unaltered Sample Midway Between Drainfield Lines (TC-1.6) from Site TC-1

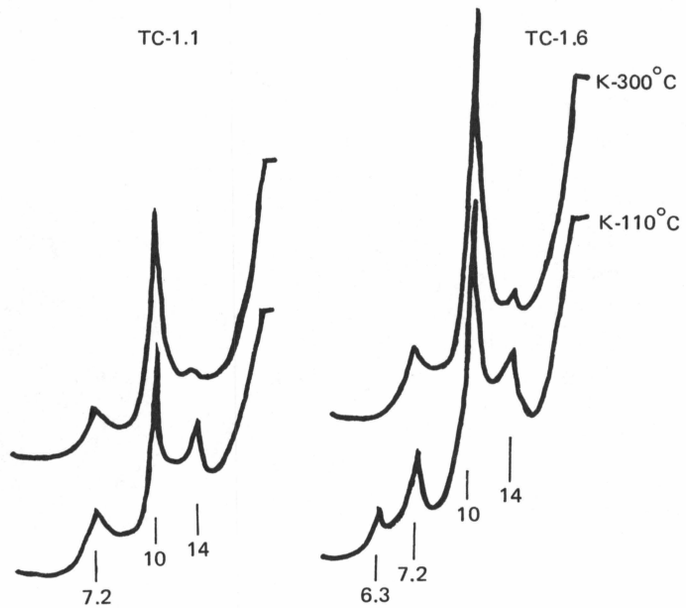


FIGURE 69

Particle Size and Morphology of Sample FC-1.1 (top) and Sample FC-1.3 (bottom) (x2000)

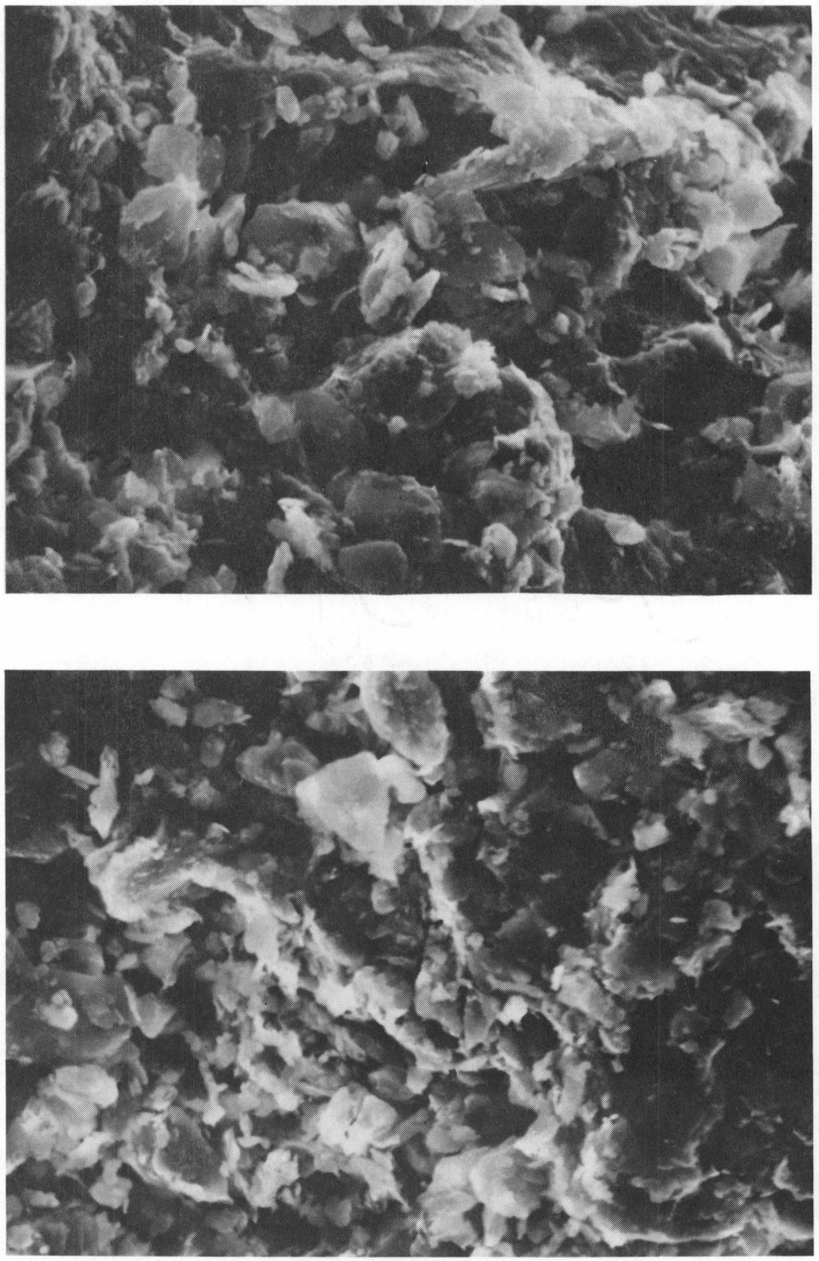


FIGURE 70
Orientation of Clay Particles in Sample CC-4.1 (top)
and Sample CC-4.3 (bottom) (x2000)

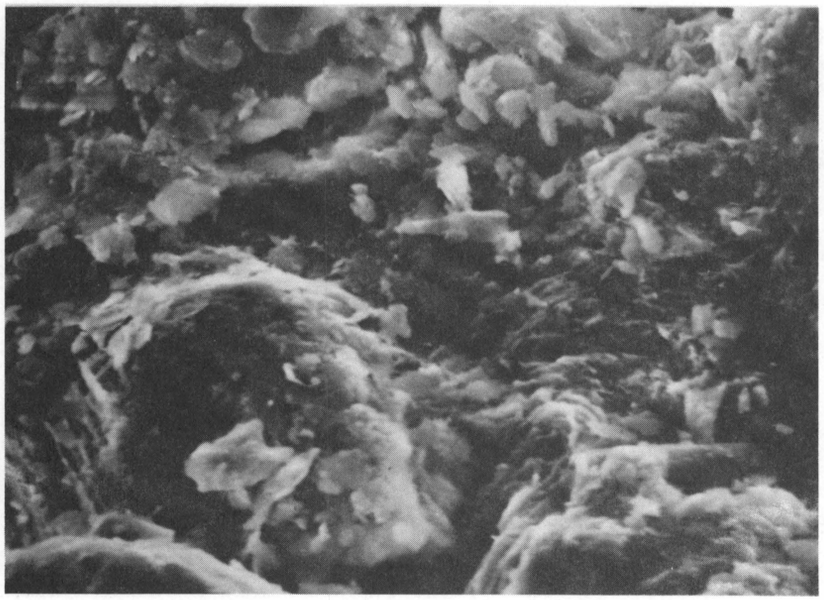
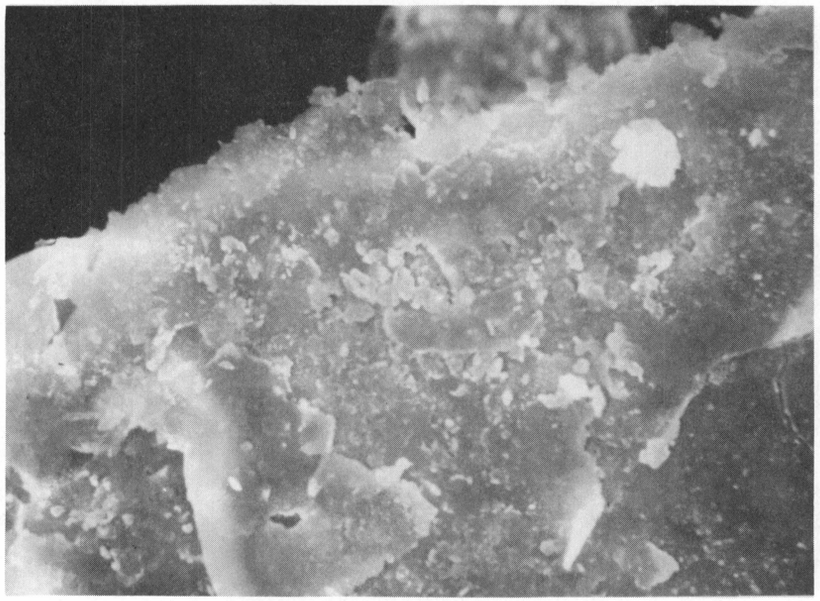


FIGURE 71

Large Biotite Flake Showing Edge and Face Alteration Taken from Sample CC-4.1 (top) and Sample CC-4.3 (bottom)(x2000)



TABLES

TABLE 1
Sample Site Number, Location, and Selected Characteristics

County	Sample Site	No. Soil Samples Collected	Effluent Samples Collected	Water Samples Collected	Type of System	Samples Examined in Lab
Fairfax	FC-1	3	Yes	Yes	Standard drainfield	Yes
Fairfax	FC-2	2	No	No	Standard bi-drainfield split alternate years	No
Fairfax	FC-3	4	Yes	Yes	Standard drainfield	Yes
Fairfax	FC-4	4	No	No	Standard drainfield	Yes
Fairfax	FC-5	0	No	No	Standard drainfield	No
Loudoun	LC-1	6	No	No	Standard drainfield	No
Loudoun	LC-2	5	No	No	Standard drainfield	No
Loudoun	LC-3	5	No	No	Standard drainfield	Yes
Loudoun	LC-4	5	Yes	No	Standard drainfield	Yes
Loudoun	LC-5	5	Yes	No	Standard drainfield	No
Loudoun	LC-6	5	No	No	Standard drainfield	No
Prince William	PWC-1	3	No	No	Standard drainfield	Yes
Prince William	PWC-2	3	No	No	Standard drainfield	Yes
Chesterfield	CC-1	4	Yes	Yes	Standard drainfield	Yes
Chesterfield	CC-2	4	Yes	Yes	Standard drainfield	Yes
Chesterfield	CC-3	5	Yes	No	Standard drainfield	Yes
Chesterfield	CC-4	7	Yes	Yes	Standard drainfield	Yes
Chesterfield	CC-5	4	Yes	Yes	Standard drainfield	Yes
Chesterfield	CC-6	3	Yes	Yes	Pumped to standard drainfield	Yes

(continued)

TABLE 1 (continued)

County	Sample Site	No. Soil Samples Collected	Effluent Samples Collected	Water Samples Collected	Type of System	Samples Examined in Lab
Chesterfield	CC-7	0	No	No	Standard drainfield	No
Tazewell	TC-1	6	No	No	Standard drainfield	Yes
Tazewell	TC-2	3	No	No	Seepage bed	Yes
Tazewell	TC-3	3	No	No	Seepage bed	Yes
Tazewell	TC-4	0	No	No	Standard drainfield	No

TABLE 2

Selected Characteristics of the Highly Altered Interface Sample and Unaltered Soil for Sites Examined

Sample Number	Sample Position	Organic Matter (%)	Water Extractable Ca (ppm)	Water Extractable Na (ppm)	Exchangeable Cation Na (meq/100 g)	Exchangeable Cation Σ Bases (meq/100 g)	Na Saturation (%)
FC-1	Highly Altered	0.3	190	146	0.13	5.97	2.18
	Unaltered	0.2	0	9	0.02	3.58	0.56
FC-3	Highly Altered	0.2	21	15	0.01	0.22	4.55
	Unaltered	0.1	6	4	0.00	0.33	0.00
LC-3	Highly Altered	0.2	9	50	0.20	12.43	1.61
	Unaltered	0.3	2	59	0.10	6.97	1.43
LC-4	Highly Altered	0.1	89	27	0.04	9.10	0.44
	Unaltered	0.1	4	6	0.03	3.09	0.97
PWC-1	Highly Altered	0.2	0	56	0.13	4.02	3.23
	Unaltered	0.5	0	72	0.12	3.67	3.27
CC-5	Highly Altered	0.2	6	99	0.35	4.47	7.83
	Unaltered	0.2	0.5	104	0.78	3.00	26.00
CC-6	Highly Altered	0.2	5	7	0.04	0.32	12.50
	Unaltered	0.1	0.5	28	0.08	0.43	18.60
TC-2	Highly Altered	0.9	75	43	0.03	3.95	0.76
	Unaltered	1.1	18	—	0.01	1.30	0.79
TC-3	Highly Altered	1.5*	97	27	0.02	6.57	0.30
	Unaltered	0.2	53	3	0.03	5.90	0.51

(continued)

TABLE 2 (continued)

Sample Number	Sample Position	Organic Matter (%)	Water Extractable Ca (ppm)	Water Extractable Na (ppm)	Exchangeable Cation Na (meq/100 g)	Exchangeable Cation Σ Bases (meq/100 g)	Na Saturation (%)
FC-4	Highly Altered	0.7	11	16	0.02	1.64	1.22
	Unaltered	0.1	0	5	0.01	0.57	1.75
PWC-2	Highly Altered	0.8	0	64	0.12	1.14	10.53
	Unaltered	0.1	0	23	0.02	0.53	3.77
CC-1	Highly Altered	0.2	36	29	0.03	3.00	1.00
	Unaltered	0.1	2	17	0.03	3.17	0.95
CC-2	Highly Altered	0.8	2	18	0.02	0.63	3.17
	Unaltered	0.1	0	10	0.02	0.70	2.81
CC-3	Highly Altered	0.1	0	21	0.05	0.51	9.80
	Unaltered	0.1	0.5	6	0.02	0.08	25.00
CC-4	Highly Altered	0.1	0.5	42	0.14	2.75	5.09
	Unaltered	0.1	0.5	23	0.06	1.55	3.87
TC-1	Highly Altered	1.6†	296	73	0.07	7.83	0.89
	Unaltered	0.8	3	78	0.18	5.78	3.11

*Fill material containing original surface layer soil with higher organic matter content.
†Flow zone in buried surface layer.

TABLE 3

Soil Series, Estimated Initial Soil Permeability, and Drainfield Characteristics for Sites Examined

Drainfield Number	Soil Series	Estimated Initial Permeability (in/hr)	Mineralogical Change Evident by X-Ray	Drainfield Still Functioning
FC-1	Bucks	2-6	strong	Yes
FC-3	Beltsville-Bourne	0.2-0.6	slight	No
LC-3	Fauquier, variant	1-2	slight	No—destroyed by landscaping and overloading of remaining line
LC-4	Lehigh, clayey variant	0.5-1	strong	No
PWC-1	Reaville, clayey variant	0.5-1	distinct	No
CC-5	Wedowee	1-2	distinct	No—overloaded by increased number of occupants in house
CC-6	Masada	1-1.5	distinct	No
TC-2	Locust	0.2-0.6	distinct	No
TC-3	Unknown	1-2	slight	No—wet weather malfunction
FC-4	Wedowee	1-2	no	No
PWC-2	Elioak-Glenelg	1-1.5	slight	No
CC-1	Ruston	1-1.5	no	Repaired
CC-2	Norfolk	1-1.5	slight	No—wet weather malfunction
CC-3	Goldsboro	1-1.5	slight	No—wet weather malfunction
CC-4	Grover, variant	1-1.5	no	No—wet weather malfunction
TC-1	Unknown	1-1.5	no	No—being repaired

TABLE 4

Selected Chemical, Physical, and Mineralogical Characteristics of Soil, Water, and Effluent from Site FC-1

Sample		Soil Characteristics			Water Extractable					Exchangeable Cations				
No.	Description	Organic Matter (%)	Texture	Water pH	Ca	Mg (ppm)	K	Na	Cond. (μS/cm)	Ca	Mg (meq/100 g)	K	Na	Σ Bases
1.1	HA*	0.3	–	5.45	190.0	55.0	8.2	146.0	420	4.30	1.15	0.39	0.13	5.97
1.2	A	–	–	5.70	4.0	2.9	54.0	108.4	108	7.78	1.69	0.85	0.26	10.58
1.3	U	0.2	sil†	5.00	0.0	0.0	12.2	9.2	25	2.05	1.28	0.24	0.02	3.58

Sample	Cond. (μS/cm)	pH	Ca	Mg (ppm)	K	Na
Water	379	8.57	16.90	0.85	0.82	11.8
Effluent	958	8.69	3.10	0.79	13.60	118.0

Mineralogy of >2μ Soil Fraction of FC-1.3

Kaolinite (66%)
Intergrade (12%)
Quartz (7%)
Vermiculite (5%)
Mica (5%)
Montmorillonite (5%)

*On this and following *tables,* HA = highly altered; A = altered; LA = less altered; U = unaltered.

†On this and following *tables,* sil = silt loam; l = loam; sicl = silty clay loam; sc = sandy clay; cl = clay loam; sl = sandy loam; scl = sandy clay loam.

TABLE 5

Selected Chemical, Physical, and Mineralogical Characteristics of Soil, Water, and Effluent from Site FC-3

Sample		Soil Characteristics			Water Extractable					Exchangeable Cations				
No.	Description	Organic Matter (%)	Texture	Water pH	Ca	Mg (ppm)	K	Na	Cond. (μS/cm)	Ca	Mg (meq/100 g)	K	Na	Σ Bases
3.1	HA	0.2	–	5.40	21.0	9.0	46.3	15.3	178	0.11	0.03	0.07	0.01	0.22
3.2	A	–	–	5.40	20.0	9.8	43.8	12.8	125	0.73	0.18	0.12	0.03	1.05
3.3	U	0.1	I	5.40	5.5	4.0	7.8	4.4	46	0.21	0.08	0.04	0.00	0.33
3.4	A	–	I	4.25	9.0	4.9	27.0	6.9	85	0.36	0.20	0.09	0.09	0.82

Sample	Ca	Mg	K	Na
		(ppm)		
Water	1.98	0.12	0.9	4.6
Effluent	3.10	0.30	71.0	63.0

Mineralogy of >2μ Soil Fraction of FC-3.3

Kaolinite (26%)
Intergrade (26%)
Mica (23%)
Montmorillonite (12%)
Quartz (8%)
Vermiculite (5%)

TABLE 6

Selected Chemical, Physical, and Mineralogical Characteristics of Soil from Site LC-3

Sample		Soil Characteristics			Water Extractable					Exchangeable Cations				
No.	Description	Organic Matter (%)	Texture	Water pH	Ca	Mg (ppm)	K	Na	Cond. (μS/cm)	Ca	Mg (meq/100 g)	K	Na	Σ Bases
3.1	HA	–	–	6.35	10.5	20.2	80.4	44.5	142	3.95	1.53	0.59	0.09	6.15
3.2	A	–	–	6.15	0.5	0.8	76.8	43.5	68	4.53	2.33	0.64	0.11	7.61
3.3	A	–	sicl	6.75	4.0	5.4	64.6	49.8	124	4.90	2.94	0.76	0.14	8.75
3.4	U	0.3	sicl	5.60	1.5	2.2	10.7	58.6	58	4.28	2.03	0.57	0.10	6.97
3.5	HA	0.2	sicl	6.45	9.0	15.7	99.0	50.2	211	6.40	5.53	0.30	0.20	12.43

Mineralogy of $>2\mu$ Soil Fraction of LC-3.4

Vermiculite (32%)
Kaolinite (27%)
Intergrade (21%)
Mica (20%)

TABLE 7

Selected Chemical, Physical, and Mineralogical Characteristics of Soil and Effluent from Site LC-4

Sample		Soil Characteristics			Water Extractable					Exchangeable Cations				
No.	Description	Organic Matter (%)	Texture	Water pH	Ca	Mg (ppm)	K	Na	Cond. (μS/cm)	Ca	Mg (meq/100 g)	K	Na	Σ Bases
4.1	HA	0.1	–	7.45	89.0	88.0	42.4	27.4	292	6.90	1.96	0.20	0.04	9.10
4.2	A	–	–	5.70	0.5	0.0	15.5	23.4	48	1.39	2.28	0.40	0.09	4.15
4.3	LA	–	sicl	5.30	0.0	0.0	8.1	21.3	24	0.48	3.15	0.30	0.10	4.03
4.4	U	0.1	sicl	5.40	4.5	2.0	5.5	5.6	23	2.45	0.49	0.12	0.03	3.09
4.5	U	–	sicl	5.65	0.0	0.0	9.1	2.7	10	0.07	2.28	0.36	0.04	2.75

Sample	Cond. (μS/cm)	pH	Ca	Mg (ppm)	K	Na
Effluent	241	7.46	3.74	0.39	9.9	19.3

Mineralogy of >2μ Soil Fraction of LC-4.4

Intergrade (45%)
Kaolinite (25%)
Quartz (20%)
Mica (5%)
Vermiculite (5%)

TABLE 8

Selected Chemical, Physical, and Mineralogical Characteristics of Soil from Site PWC-1

Sample		Soil Characteristics			Water Extractable					Exchangeable Cations				
No.	Description	Organic Matter (%)	Texture	Water pH	Ca	Mg (ppm)	K	Na	Cond. (μS/cm)	Ca	Mg (meq/100 g)	K	Na	Σ Bases
1.1	HA	0.2	–	6.05	0	5.7	23.5	56.5	100.3	2.88	0.70	0.31	0.13	4.02
1.2	A	–	–	6.75	0	2.0	5.6	33.5	33.6	5.85	0.35	0.13	0.07	6.40
1.3	U	0.5	–	5.85	0	1.9	21.6	72.0	99.8	2.75	0.50	0.30	0.12	3.67

Mineralogy of $>2\mu$ Soil Fraction of PWC-1.3

Vermiculite (38%)
Kaolinite (27%)
Quartz (20%)
Mica (15%)

TABLE 9

Selected Chemical, Physical, and Mineralogical Characteristics of Soil, Water, and Effluent from Site CC-5

Sample		Soil Characteristics			Water Extractable					Exchangeable Cations				
No.	Description	Organic Matter (%)	Texture	Water pH	Ca	Mg (ppm)	K	Na	Cond. (μS/cm)	Ca	Mg (meq/100 g)	K	Na	Σ Bases
5.1	HA	0.2	–	5.5	6.0	1.1	36.7	98.8	111.2	3.00	0.66	0.46	0.35	4.47
5.2	A	–	–	5.4	3.5	0.2	29.4	86.2	103.1	2.52	0.53	0.46	0.46	3.97
5.3	LA	–	–	5.4	4.0	1.3	19.7	107.4	85.1	3.38	0.25	0.67	0.67	4.75
5.4	U	0.2	–	5.9	0.5	0.0	10.0	103.5	70.9	0.81	1.08	0.78	0.78	3.00

Sample	Cond. (μS/cm)	pH	Ca	Mg (ppm)	K	Na
Water	–	–	3.61	–	–	3.89
Effluent	455	8.30	1.04	0.13	8.50	65.00

Mineralogy of >2μ Soil Fraction of CC-5.4

Kaolinite (56%)
Intergrade (22.8%)
Quartz (10%)
Vermiculite (10%)
Gibbsite (1.2%)

TABLE 10

Selected Chemical, Physical, and Mineralogical Characteristics of Soil, Water, and Effluent from Site CC-6

Sample		Soil Characteristics			Water Extractable					Exchangeable Cations				
No.	Description	Organic Matter (%)	Texture	Water pH	Ca	Mg (ppm)	K	Na	Cond. (μS/cm)	Ca	Mg (meq/100 g)	K	Na	Σ Bases
6.1	NVA*	0.2	–	4.95	5.0	4.4	13.9	6.6	39.5	0.08	0.13	0.07	0.04	0.32
6.2	NVA	–	–	4.55	5.0	5.9	14.8	8.0	50.5	0.07	0.23	0.09	0.04	0.43
6.3	U	0.1	sc	4.95	0.5	0.0	3.7	27.5	26.7	0.02	0.25	0.08	0.08	0.43

Sample	Cond. (μS/cm)	pH	Ca	Mg (ppm)	K	Na
Water	309	5.93	1.58	0.23	8.10	31.80
Effluent	237	5.49	0.89	0.30	1.75	29.50

Mineralogy of >2μ Soil Fraction of CC-6.3

Kaolinite (46%)
Intergrade (22%)
Quartz (10%)
Vermiculite (10%)
Mica (8%)
Gibbsite (4%)

*Not visibly altered.

TABLE 11

Selected Chemical, Physical, and Mineralogical Characteristics of Soil from Site TC-2

Sample		Soil Characteristics			Water Extractable					Exchangeable Cations				
No.	Description	Organic Matter (%)	Texture	Water pH	Ca	Mg (ppm)	K	Na	Cond. (μS/cm)	Ca	Mg (meq/100 g)	K	Na	Σ Bases
2.1	HA	0.9	l	7.35	75.4	9.1	16.2	42.7	164	3.50	0.31	0.11	0.03	3.95
2.2	A	–	–	7.00	18.1	3.6	2.9	21.2	57	3.80	0.34	0.08	0.03	4.25
2.3	U	1.1	sil	6.50	18.1	2.4	1.2	–	41	1.18	0.07	0.04	0.01	1.30

Mineralogy of $>2\mu$ Soil Fraction of TC-2.3

Quartz (40%)
Vermiculite (30%)
Mica (17%)
Kaolinite (13%)

TABLE 12

Selected Chemical, Physical, and Mineralogical Characteristics of Soil from Site TC-3

Sample		Soil Characteristics			Water Extractable					Exchangeable Cations				
No.	Description	Organic Matter (%)	Texture	Water pH	Ca	Mg (ppm)	K	Na	Cond. (μS/cm)	Ca	Mg (meq/100 g)	K	Na	Σ Bases
3.1	HA	1.5	cl	7.7	96.5	8.4	20.3	27.2	149	6.25	0.19	0.11	0.02	6.57
3.2	A	–	–	7.7	74.1	9.1	14.9	39.0	197	4.88	0.55	0.11	0.03	5.57
3.3	U	0.2	c	7.5	52.7	2.4	2.7	2.6	62	5.40	0.36	0.11	0.03	5.90

Mineralogy of $>2\mu$ Soil Fraction of TC-3.3

Vermiculite (33%)
Intergrade (32%)
Kaolinite (15%)
Quartz (15%)
Feldspar (5%)

TABLE 13
Selected Chemical, Physical, and Mineralogical Characteristics of Soil from Site FC-4

Sample		Soil Characteristics			Water Extractable					Exchangeable Cations				
No.	Description	Organic Matter (%)	Texture	Water pH	Ca	Mg (ppm)	K	Na	Cond. (μS/cm)	Ca	Mg (meq/100 g)	K	Na	Σ Bases
4.1	HA	0.7	sl	4.00	11.0	8.5	49.3	15.9	14.1	0.97	0.33	0.15	0.02	1.64
4.2	A	–	–	4.15	0.5	0.0	35.3	17.6	75.8	1.68	0.43	0.38	0.03	2.51
4.3	A	–	–	4.55	1.5	0.5	41.1	13.9	60.5	1.18	0.62	0.31	0.02	2.12
4.4	U	0.1	sl	4.70	0.0	0.1	18.1	5.4	21.6	0.02	0.43	0.12	0.01	0.57

Mineralogy of $>2\mu$ Soil Fraction of FC-4.4

Kaolinite (38%)
Intergrade (21.5%)
Vermiculite (20%)
Quartz (15%)
Montmorillonite (5%)
Gibbsite (0.5%)

TABLE 14

Selected Chemical, Physical, and Mineralogical Characteristics of Soil from Site PWC-2

Sample		Soil Characteristics			Water Extractable					Exchangeable Cations				
No.	Description	Organic Matter (%)	Texture	Water pH	Ca	Mg (ppm)	K	Na	Cond. (μS/cm)	Ca	Mg (meq/100 g)	K	Na	Σ Bases
2.1	HA	0.8	–	5.85	0	2.2	11.2	63.5	77.0	0.45	0.38	0.19	0.12	1.14
2.2	A	–	–	7.35	42.5	4.9	27.3	47.5	176.0	0.75	0.37	0.24	0.06	1.42
2.3	U	0.1	cl	6.50	0	4.9	11.0	23.5	34.5	0.02	0.32	0.17	0.02	0.53

Mineralogy of $>2\mu$ Soil Fraction of PWC-2.3

Kaolinite (32%)
Vermiculite (29%)
Intergrade (19%)
Quartz (12%)
Mica (8%)

TABLE 15

Selected Chemical, Physical, and Mineralogical Characteristics of Soil, Water, and Effluent from Site CC-1

Sample		Soil Characteristics			Water Extractable					Exchangeable Cations				
No.	Description	Organic Matter (%)	Texture	Water pH	Ca	Mg (ppm)	K	Na	Cond. (μS/cm)	Ca	Mg (meq/100 g)	K	Na	Σ Bases
1.1	HA	0.2	–	4.55	35.5	7.6	43.1	28.7	157	2.43	0.26	0.30	0.03	3.00
1.2	A	–	–	6.00	0.5	0.0	10.7	15.3	40	2.15	0.37	0.31	0.05	2.88
1.3	LA	–	–	6.00	0.5	0.0	13.9	11.1	18	0.06	0.33	0.20	0.03	0.62
1.4	U	0.1	–	5.00	2.5	3.7	17.8	17.3	46	1.33	1.48	0.33	0.03	3.17

Sample	Cond. (μS/cm)	pH	Ca	Mg (ppm)	K	Na
Water	126	7.30	15.10	2.52	2.89	7.86
Effluent	577	8.79	13.90	0.88	14.05	31.50

Mineralogy of >2μ Soil Fraction of CC-1.4

Intergrade (36.7%)
Kaolinite (26%)
Vermiculite (20%)
Quartz (8%)
Mica (5%)
Gibbsite (4.3%)

TABLE 16

Selected Chemical, Physical, and Mineralogical Characteristics of Soil, Water, and Effluent from Site CC-2

Sample		Soil Characteristics			Water Extractable					Exchangeable Cations				
No.	Description	Organic Matter (%)	Texture	Water pH	Ca	Mg (ppm)	K	Na	Cond. (μS/cm)	Ca	Mg (meq/100 g)	K	Na	Σ Bases
2.1	HA	0.8	–	6.45	2.0	0.6	20.1	17.5	45.1	0.46	0.09	0.06	0.02	0.63
2.2	A	–	–	6.50	0.0	0.0	8.4	27.5	37.7	1.15	0.36	0.28	0.12	1.90
2.3	A	–	–	6.60	0.0	0.0	2.6	27.8	18.2	0.63	0.40	0.30	0.03	1.35
2.4	U	0.1	scl	5.10	0.0	0.0	8.1	10.2	16.2	0.02	0.49	0.16	0.02	0.70

Sample	Cond. (μS/cm)	pH	Ca	Mg (ppm)	K	Na
Water	127	7.50	13.7	–	–	7.7
Effluent	463	8.60	1.7	0.22	14.20	26.5

Mineralogy of >2μ Soil Fraction of CC-2.4

Intergrade (39.2%)
Kaolinite (35%)
Quartz (10%)
Vermiculite (10%)
Mica (5%)
Gibbsite (0.8%)

TABLE 17

Selected Chemical, Physical, and Mineralogical Characteristics of Soil, Water, and Effluent from Site CC-3

Sample		Soil Characteristics			Water Extractable					Exchangeable Cations				
No.	Description	Organic Matter (%)	Texture	Water pH	Ca	Mg (ppm)	K	Na	Cond. (μS/cm)	Ca	Mg (meq/100 g)	K	Na	Σ Bases
3.1	HA	0.1	–	5.20	0.0	0.0	4.5	21.4	25.5	0.35	0.04	0.07	0.05	0.51
3.1a	A	–	–	5.70	0.5	0.0	6.2	27.8	22.6	0.30	0.08	0.13	0.07	0.58
3.2	A	–	–	6.25	0.0	0.0	1.7	27.5	17.8	0.44	0.05	0.11	0.20	0.80
3.3	A	–	scl	5.10	0.5	0.0	0.5	18.5	18.7	0.00	0.03	0.03	0.10	0.16
3.4	U	0.1	sl	5.00	0.5	0.0	1.3	5.5	11.4	0.00	0.03	0.03	0.02	0.08

Sample	Cond. (μS/cm)	pH	Ca	Mg (ppm)	K	Na
Water			private well—no analyses			
Effluent	8.87	8.37	0.94	0.68	9.9	47.5

Mineralogy of >2μ Soil Fraction of CC-3.4

Kaolinite (43%)
Intergrade (41.6%)
Quartz (8%)
Gibbsite (7.4%)

TABLE 18

Selected Chemical, Physical, and Mineralogical Characteristics of Soil, Water, and Effluent from Site CC-4

Sample		Soil Characteristics			Water Extractable					Exchangeable Cations				
No.	Description	Organic Matter (%)	Texture	Water pH	Ca	Mg (ppm)	K	Na	Cond. (μS/cm)	Ca	Mg (meq/100 g)	K	Na	Σ Bases
4.1	HA	0.1	–	5.05	0.5	0.0	13.6	42.1	39.2	0.70	1.71	0.20	0.14	2.75
4.2	HA	–	–	6.20	0.5	0.0	9.9	64.3	41.2	1.28	0.17	0.34	0.51	2.30
4.3	LA	–	sl	5.00	20.0	10.7	21.1	13.1	50.6	0.38	1.36	0.35	0.06	2.15
4.4	U	0.1	scl	5.70	0.5	0.0	11.6	23.2	22.6	0.13	1.21	0.15	0.06	1.55
4.5	A	–	–	5.10	0.5	0.0	27.2	80.1	97.2	1.22	0.61	0.32	0.38	2.53
4.6	LA	–	–	5.85	1.5	5.0	13.5	10.4	27.5	0.85	1.03	0.26	0.04	2.18
4.7	HA	–	–	5.70	4.5	8.5	28.9	30.3	55.2	0.79	0.57	0.28	0.06	1.70

Sample	Cond. (μS/cm)	pH	Ca	Mg (ppm)	K	Na
Water	–	–	3.61	–	–	3.89
Effluent	428	8.57	1.24	0.42	7.4	48.00

Mineralogy of >2μ Soil Fraction of CC-4.4

Kaolinite (41%)
Interstratified (27%)
Vermiculite (17%)
Mica (15%)

TABLE 19

Selected Chemical, Physical, and Mineralogical Characteristics of Soil from Site TC-1

Sample		Soil Characteristics			Water Extractable					Exchangeable Cations				
No.	Description	Organic Matter (%)	Texture	Water pH	Ca	Mg	K (ppm)	Na	Cond. (μS/cm)	Ca	Mg	K (meq/100 g)	Na	Σ Bases
1.1	HA	1.6	sil	5.50	296.5	20.5	44.4	73.0	471	7.30	0.25	0.21	0.07	7.83
1.2	A	—	—	7.95	42.3	10.6	116.5	199.5	323	4.90	0.44	0.26	0.10	5.70
1.3	A	—	sil	7.50	12.0	4.6	44.2	80.0	98	5.40	0.58	0.18	0.12	6.28
1.4	A	—	—	7.40	5.9	19.5	24.0	47.5	80	8.00	0.98	0.63	0.13	9.74
1.5	HA	—	sil	7.70	79.2	9.1	46.9	19.7	173	6.80	0.32	0.10	0.02	7.24
1.6	U	0.8	l	7.30	3.3	2.8	24.0	78.0	60	4.85	0.57	0.18	0.18	5.78

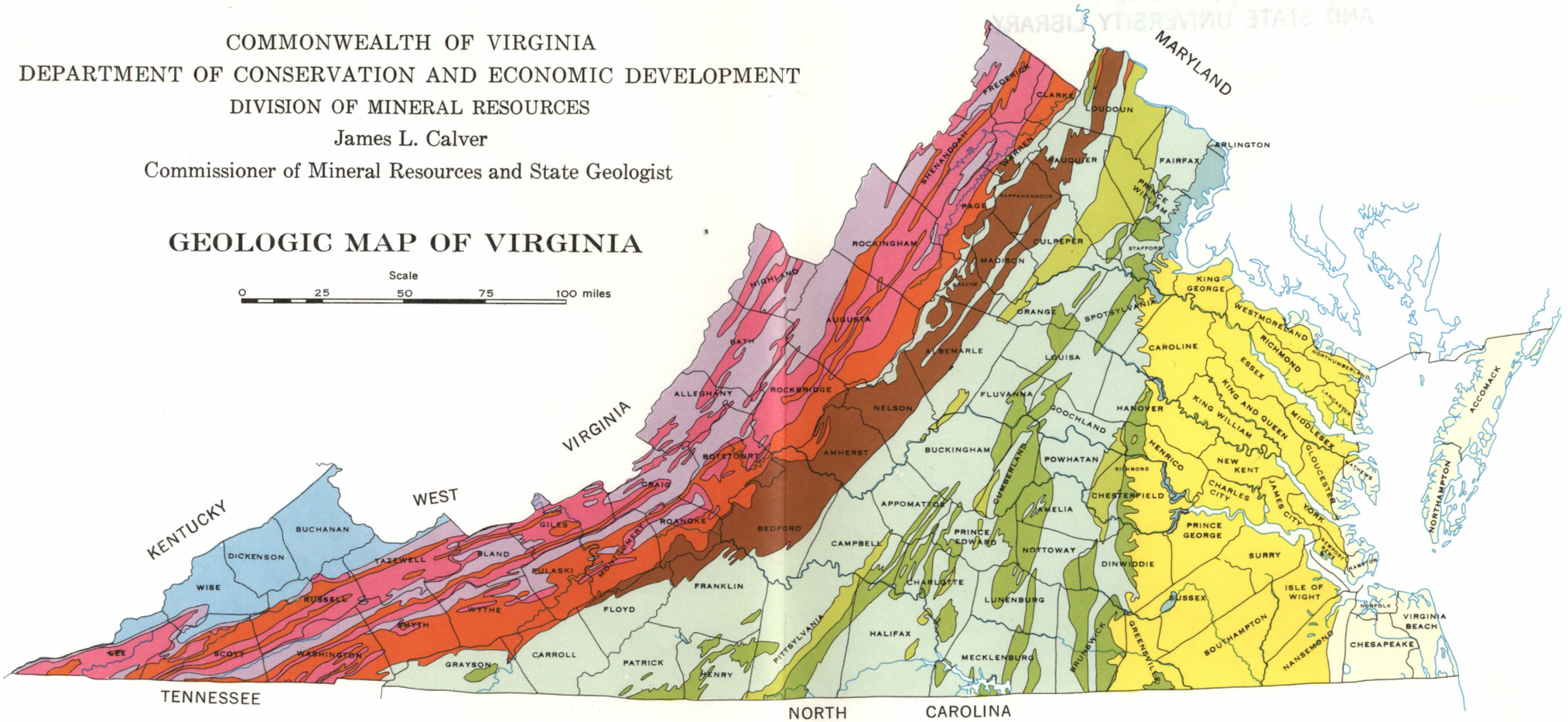
Mineralogy of $>2\mu$ Soil Fraction of TC 1.6

Vermiculite (34%)
Kaolinite (22%)
Intergrade (20%)
Mica (19%)
Quartz (5%)

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES
James L. Calver
Commissioner of Mineral Resources and State Geologist

GEOLOGIC MAP OF VIRGINIA

Scale
0 25 50 75 100 miles



CENOZOIC

QUATERNARY
(0-1 million years) Sand and gravel.
Sand and gravel.

TERTIARY
(1-70 million years) Loose or partly indurated sand, clay, marl, and diatomaceous earth.
Sand, clay, marl, and diatomaceous earth.

MESOZOIC

CRETACEOUS
(70-135 million years) Partly indurated sand, clay, and sandstone.
Sand and clay.

TRIASSIC
(180-225 million years) Red and gray shales and sandstones intruded by diabase; some thin coal layers.
Crushed stone, shale, and lightweight aggregate.

PALEOZOIC

PENNSYLVANIAN
(270-310 million years) Sandstone, shale, and coal.
Sand, coal, coke, lightweight aggregate, and natural gas.

MISSISSIPPIAN-DEVONIAN
(310-400 million years) Sandstone, shale, limestone, gypsum, and coal.
Coal, coke, silica sand, gypsum, shale, cement, salt brine, and natural gas.

SILURIAN-ORDOVICIAN
(400-500 million years) Limestone, dolomite, shale, and sandstone.
Lime, crushed stone, cement, shale, and petroleum.

CAMBRIAN
(500-600 million years) Dolomite, limestone, shale, and sandstone.
Crushed stone, sand, zinc, lead, and shale.

PRECAMBRIAN

VIRGINIA BLUE RIDGE COMPLEX
(Older than 600 million years) Granite and gneiss.
Crushed stone

ROCKS OF UNCERTAIN AGE

GRANITE and GNEISS
Granite, granodiorite, augen-gneiss, granite gneiss.
Crushed stone

METAMORPHIC ROCKS and IGNEOUS INTRUSIVES
Schist, slate, phyllite, quartzite, marble, metamorphosed arkose and conglomerate; greenstone, diorite, and gabbro.
Crushed stone, soapstone, anorthosite, slate, dimension stone, kyanite, feldspar, aplite, and titanium minerals.

Williams & Heintz Map Corporation, Washington 27, D.C.

The Virginia Water Resources Research Center is a federal-state partnership agency attempting to find solutions to the state's water resources problems through careful research and analysis. Established at Virginia Polytechnic Institute and State University under provisions of the Water Research and Development Act of 1978 (P.L. 95-467), the Center serves five primary functions:

- It studies the state's water and related land-use problems, including their ecological, political, economic, institutional, legal, and social implications.
- It sponsors and administers research investigations of these problems.
- It collects and disseminates information about water resources and water resources research.
- It provides training opportunities in research for future water scientists enrolled at the state's colleges and universities.
- It provides other public services to the state in a wide variety of forms.

More information on programs and activities may be obtained by contacting the Center at the address below.

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