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University Park PA 16802

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Comparison of Some Properties of Minesoils and Contiguous Natural Soils

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COMPARISON OF SOME PROPERTIES OF MINESOILS AND CONTIGUOUS NATURAL SOILS

by

Tom A. Pedersen, Andrew S. Rogowski, and Roger Pennock, Jr.
U.S. Department of Agriculture, Science and Education
Administration, Federal Research
Northeast Watershed Research Center
University Park, Pennsylvania 16802

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Project Officer

Clinton W. Hall
Office of Energy, Minerals and Industry
Washington, D. C. 20250

Office of Research and Development
U.S. Environmental Protection Agency
Washington, D. C. 20250

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FOREWORD

The Federal Water Pollution Control Act Amendments of 1972, in part, stress the control of nonpoint source pollution. Sections 102 (C-1), 208 (b-2,F) and 304(e) authorize basin scale development of water quality control plans and provide for area-wide waste treatment management. The act and the amendments include, when warranted, waters from agriculturally and silviculturally related nonpoint sources, and requires the issuance of guidelines for both identifying and evaluating the nature and extent of nonpoint source pollutants and the methods to control these sources. Research program at the Northeast Watershed Research Center contributes to the aforementioned goals. The major objectives of the Center are to:

- study the major hydrologic and water-quality associated problems of the Northeastern U.S. and
- develop hydrologic and water quality simulation capability useful for land-use planning. Initial emphasis is on the hydrologically most severe land uses of the Northeast.

Within the context of the Center's objectives, stripmining for coal ranks as a major and hydrologically severe land use. In addition, once the site is reclaimed and the conditions of the mining permit are met, stripmined areas revert legally from point to nonpoint sources. As a result, the hydrologic, physical, and chemical behavior of the reclaimed land needs to be understood directly and in terms of control practices before the goals of Sections 102, 208 and 304 can be fully met.

The following report considers an important component of the reclaimed strip-mined area--the minesoil. The chemical, physical, and morphological properties of minesoil control oxygen and water movement to the underlying spoil, the amount of available water retained for supporting a protective or productive vegetative cover, and the erosivity of the material. The pertinent minesoil properties need to be identified and compared with the properties of the original undisturbed soil before the hydrologic and chemical impact of stripmining and reclamation practices can be predicted adequately. The following report takes a major step in this direction by comparing minesoils with contiguous natural soils to establish the effects of mining and reclamation procedures.

Signed: Harry B Pionke

Harry B. Pionke
Director
Northeast Watershed
Research Center

ABSTRACT

Investigations were conducted to evaluate soil changes due to surface coal mining and reclamation operations in Clearfield County, Pennsylvania. Objectives included comparison of minesoils with contiguous natural soils to establish what effect mining and reclamation procedures have on the properties of minesoils.

Four minesoil pits located within the disturbed area and four natural soil pits located in adjacent undisturbed areas were described and sampled. Three of the natural soils were classified as Typic Dystrochrepts and one was an Aquic Fragiudult. The minesoils were classified as Udorthents.

Bulk densities were determined at 10 randomly located sites. Microlysimeters were subsequently installed at these sites and used to determine saturated hydraulic conductivities and evapotranspiration.

Pedogenetic development in the minesoils was minimal and the most prominent feature of the minesoils was their high degree of coarseness and their high rock fragment content. Roots tended to concentrate along soil-coarse fragment interfaces. Few roots penetrated the massive minesoil material in the C horizons.

In general, the chemical constituents of the minesoils resembled the natural soils. However, the weathering of the natural soils has leached bases from them and significantly more extractable aluminum was found in these soils than in minesoils. Organic carbon and nitrogen determination was affected by the high content of carboniferous shale and coal fragments in the minesoils. The clay minerals present in the minesoils had not been weathered as much as those in the natural soils. The mineralogy suggests that these minesoils and the natural soils were derived from the same materials.

Results showed that minesoils contained 75% coarse fragments (by weight) as compared with 50% for contiguous natural soils. Minesoils also contained significantly less sand and clay than natural soils. The minesoils studied had lower specific surface than natural soils due to their lower organic matter and vermiculite contents. Average bulk density of the minesoil surface was 1.70 g/cm^3 vs 1.26 g/cm^3 for adjacent soils.

The natural soils retained an average of 14.3% (by weight), whereas the minesoils retained an average of 10.3% available water. The range of water retained between -0.3 and -15 bar matric potential of the minesoil ranged from 5.5 to 16.7% as compared with 7.1 to 39.2% in the natural soils. "In situ" determinations of field-capacity yielded values between 6 and 12% (by weight), whereas microlysimeters retained from 12 to 19% after 2 days of drainage.

Microlysimeter data indicated that evapotranspiration of minesoils could be approximated by A-pan results.

Single ring infiltrometer studies indicated that infiltration rate of the minesoil ranged from 0.5 to 34.3 cm/hr.

Extreme variation existed in saturated hydraulic conductivity values obtained using microlysimeters. Use of a small plot to determine unsaturated hydraulic conductivity of the minesoil indicated that infiltrating water followed voids present in the minesoil.

This report was submitted in partial fulfillment of EPA-IAG-D5-E763 by the Northeast Watershed Research Center, U.S. Department of Agriculture, Science and Education Administration, Federal Research, under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from September 1, 1975 to August 31, 1977, and work was completed as of November 30, 1977.

CONCLUSIONS

Soil changes due to surface coal mining and reclamation operations in Clearfield County, Pennsylvania were evaluated. Morphological, chemical, physical and hydraulic properties of minesoils were compared to those of contiguous natural soils.

Studies showed that pedogenetic development in the minesoils was minimal and the most prominent feature was their high degree of coarseness and their high rock-fragment content. Clay mineralogy data suggested that these minesoils and natural soils were derived from the same materials.

Minesoils contained more rock fragments (by weight) and less sand and clay than did adjacent natural soils. The natural soils had higher specific surface than the minesoils studied due to their higher organic matter and vermiculite contents. The minesoils were denser than the natural soils due to their higher coarse fragment content and lack of structural development.

Results showed that natural soils retained more water at equal matric potentials than did minesoils. Infiltration rate of minesoils was highly variable as was saturated hydraulic conductivity determined using microlysimeters. Use of a small plot to determine unsaturated hydraulic conductivity indicated that water flow followed voids present in the minesoil.

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SECTION 1

INTRODUCTION AND EXPERIMENTAL SITE

INTRODUCTION

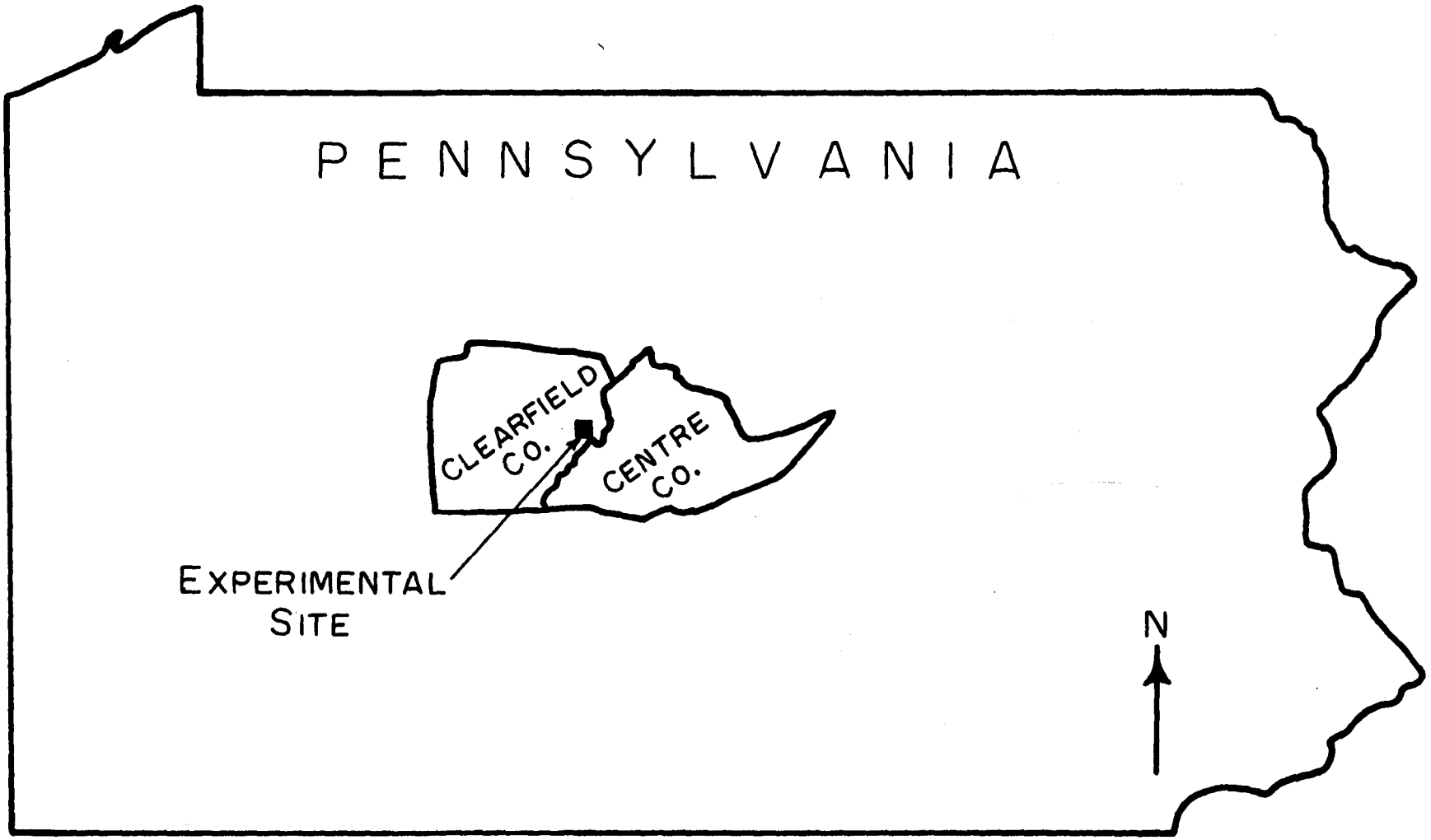
Increased occurrence of surface coal mining to provide for energy needs has spurred renewed concern about its environmental effects. Employment of modern reclamation techniques (Grim and Hill, 1974) may minimize pollution potentials of reclaimed areas. However, acid mine drainage, erosion, and increased sediment loads are among the problems that will most likely continue to be associated with stripmined land (Van Voast, 1974) in the future.

Stabilization of spoil banks through rapid vegetation is very important. Properties of minesoils determine, to a large extent, if rapid revegetation is possible. This study was initiated to establish what effect surface mining and reclamation operations have on the properties of minesoils. Our objective was to determine the morphological, chemical, and physical characteristics of minesoils as compared with contiguous natural soils, both in situ and in the laboratory.

EXPERIMENTAL SITE

The experimental site consists of a recently reclaimed 4-ha bituminous coal stripmine adjacent to undisturbed land. The site is located about 1.2 km northeast of Kylertown in Clearfield County, Pennsylvania (Figure 1). The site lies within the Pittsburgh Plateau section of the Appalachian Plateau Province. The geologic system is Pennsylvanian, characterized by cyclic sequences of sandstone, shale, coal, and clay. The area is underlain by flat-lying to gently folded sedimentary rocks (Glass, 1972) consisting of reddish, yellowish and brownish clay shale and yellowish brown sandstone, shale and siltstone. The coal

Figure 1. Location of experimental site.



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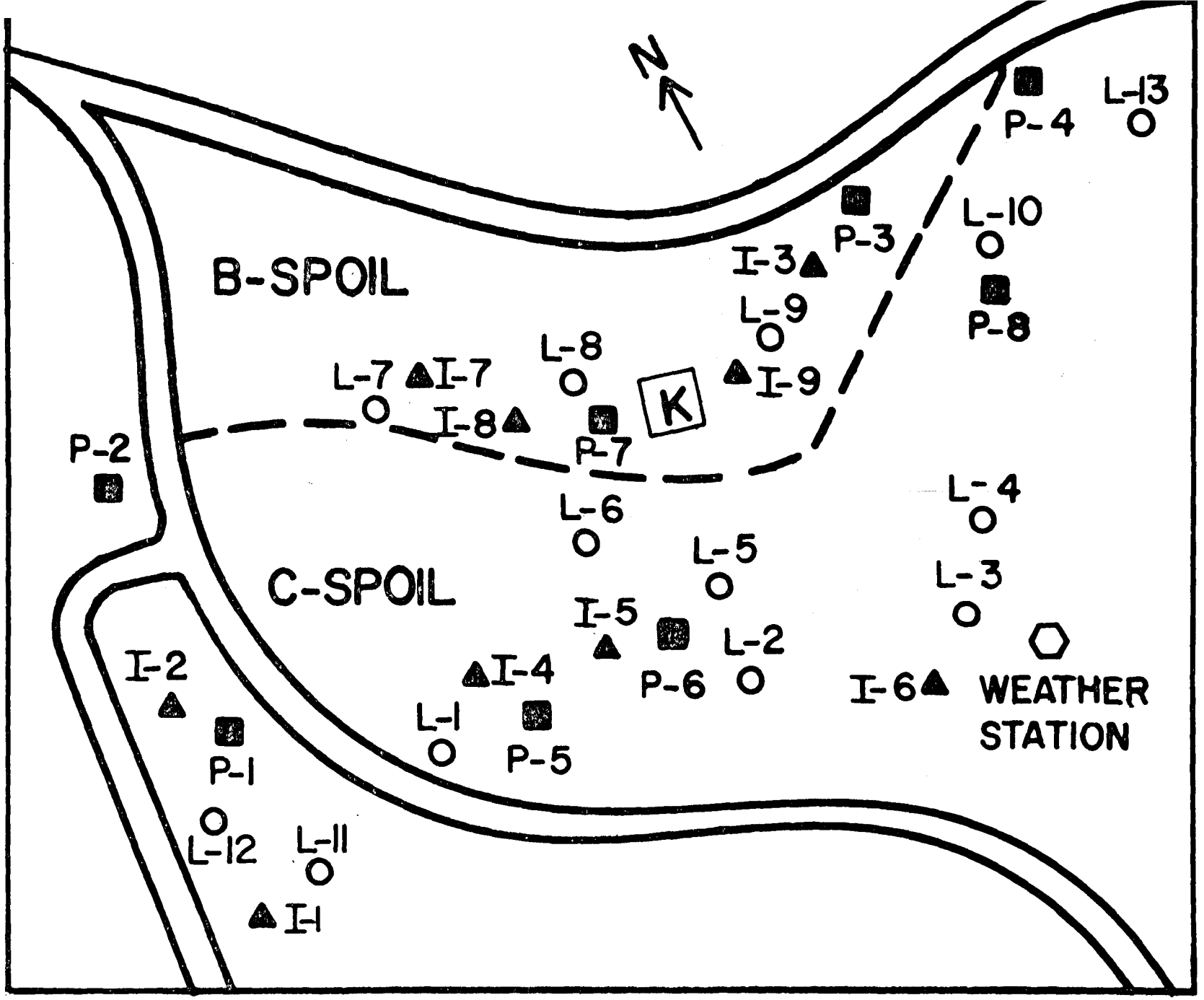
seams include the middle and lower Kittanning seams (C & B) of the Allegheny group. Silt shale, thin bedded sandstone, siltstone and clay shale underlie the middle Kittanning C-seam under which the lower Kittanning B-seam is found. The general topography of the area is broad with slightly rounded divides, which are separated by narrow V-shaped valleys (Glass, 1972). Mean elevation of the site is about 450 m with a northern to northeastern aspect.

Before stripmining, the vegetation of the area was hardwood forest in which oak and hemlock predominated. Grasses and legumes have become established on the site after reclamation.

Continuous meterological data was obtained from instruments located at the site (Figure 2) from May 24, 1976 through May 24, 1977 (Appendix F). Precipitation was measured by a universal recording raingauge. A U.S. Weather Bureau Class A evaporation pan was used to monitor evaporation. Maximum-minimum thermometers and a hygrothermograph were also located at the site. A pyreheliometer was used to record solar radiation.

The climate of the study site is humid. The average annual precipitation is 107 cm with an average 150 days without frost.

Figure 2. Schematic diagram of study area and location of experimental sites. P-1 through P-8 are soil pits, L-1 through L-13 are lysimeter sites, I-1 through I-9 are infiltration sites, and K is the unsaturated hydraulic conductivity plot.


N
B-SPOIL
C-SPOIL
K
P-1
P-2
P-3
P-4
P-5
P-6
P-7
P-8
I-1
I-2
I-3
I-4
I-5
I-6
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L-1
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L-13
WEATHER STATION

SECTION 2

MORPHOLOGICAL AND CHEMICAL CHARACTERISTICS

INTRODUCTION

Surface mining for coal inevitably disturbs the soil and rock strata, which overlie the coal. The soils present before stripmining in many cases were moderately well to well-developed and reflected properties associated with the components of the soil-forming factors. Many areas that have been stripmined were previously forested, like our site. The soils associated with these areas are generally not suited for agricultural production. These forest soils usually have some characteristic that limits their agricultural use. In some cases, slopes or stoniness are excessive and in others the depth to a limiting layer, like bedrock or a fragipan, is shallow, making agricultural use impractical.

Soil reconstruction aims to duplicate soils that existed before mining (McCormack, 1974) and when possible to eliminate any limiting factor.

Rapid establishment of vegetation on these disturbed areas is essential to initiate soil development has to control erosion and to stabilize minesoil.

Jones et al. (1975) stated that the amount of organic matter added during the initial stages of soil development has the greatest affect on profile differentiation.

Sobek et al. (1976) showed that minesoils are young pedogenically and reflect the properties of their parent material more closely than mature undisturbed soils. Grube et al. (1974) showed that the unweathered sedimentary rocks exposed from mining contain a wealth of primary minerals. Values of extractable P, K, Ca, and Mg in incremental depth samples of overburden showed that concentrations of these

cations are likely to be higher in pulverized unweathered rock than in old soils and weathered rocks. However, Barnhisel and Massey (1969) reported that levels of Ca, K, and P were low in Kentucky spoil materials. They also reported that Mg levels were sufficient for plant growth, but an imbalance in the Ca/Mg ratio was evident.

Sobek et al. (1976) stated that the primary properties of overburden materials are pH and relative proportions of acids and bases. Massey and Barnhisel (1972) reported that the most difficult chemical problem in minesoils is their acid condition. These acid conditions arise if iron sulfide (pyrite), present in the material are oxidized, yielding sulfuric acid and metal sulfates (Massey and Barnhisel, 1972). Most of this acidity is attributed to H^+ resulting from oxidation of sulfide minerals and not from Al^{+3} (Barnhisel and Massey, 1969).

In Pennsylvania, soils that have formed from sandstones tend to be coarse-textured, highly pervious, and lower in base status and plant nutrients than soils derived from shale (Sobek et al., 1976). Sobek et al. (1976) also showed that sandstone overburden contained moderate amounts of pyrite, whereas shales generally were finer in texture and contained higher amounts of carbonates.

Upon oxidation of the metal sulfides present in the material, some Cu, Zn, and Ni could be solubilized and remain in solution if pH remained sufficiently low (Massey and Barnhisel, 1972). These elements could be present in minesoil at levels that are toxic to plants. Barnhisel and Massey (1969) found high levels of Fe, Mn, Cu, Ni, Mg, Al, and SO_4 in acid-forming spoils in Kentucky.

Due to free salts in minesoils, no clear relationship exists between the amount of cations extracted and CEC. No clear relationship exists among mineralogy and amount of cations extracted or CEC either (Barnhisel and Massey, 1969). Barnhisel and Massey (1969) also reported that high amounts of mica could supply part of the K, and that clay minerals serve as a "buffer" by reacting with acids produced by oxidation of sulfides.

MATERIALS AND METHODS

Profile Descriptions and Field Sampling

Eight pits, labeled P1-P8 in Figure 2, were located in and around this recently stripmined and reclaimed area. Four pits about 2 m deep, 3 m long, and 1.5 m wide were excavated around the periphery of the mined land in the material representative of soils originally present in the disturbed area. Detailed morphological descriptions of the profiles (Appendix A) were made according to the Soil Survey Manual (Soil Survey Staff, 1951) and the soils were subsequently classified according to Soil Taxonomy (Soil Survey Staff, 1975). Soil pH was determined in the field on moist samples using indicator dyes (Soil Survey Staff, 1951).

Three to five soil clods were removed from each horizon, when possible, and coated with saran solution in the field. In addition to clods, bulk samples of about 5000 cm^3 were collected from each horizon.

Within the mined and reclaimed area four pits were located at random. These profiles were also sampled and described morphologically. Bulk samples from each horizon were sieved in the field and material less than 1.9 cm was retained for analysis. When possible, clods were also collected. From each of the eight profiles, composite samples combining material from all horizons were obtained (25-35 kg). The bulk samples and clods were submitted for analysis to The Pennsylvania State University Soil Characterization Laboratory.

Laboratory Characterization

Bulk soil samples collected in the field were allowed to air dry. The samples were sieved to separate coarse fragments from the fine earth (<2 mm). The fine earth and coarse fragments were weighed and stored in cardboard containers for subsequent analyses. Percent moisture (Ciolkosz and Pletcher, 1974) was determined on all air-dried samples and used later to convert all laboratory data to an oven-dry basis. All characterization data reported are on an oven-dry, <2-mm basis.

Soil pH was determined in the laboratory with a pH meter and glass electrode on a soil:solution suspension (1:1 by weight) with distilled water, 1N KCl and 0.01M $CaCl_2$.

The Ca, Mg, K and Na were extracted with 1N NH_4OAc solution at pH 7 (Peech et al., 1947). Levels of Ca and Mg were determined by atomic absorption spectrophotometry, and K and Na contents were determined by flame emission spectrophotometry (Perkin-Elmer Corporation, 1968). Exchangeable acidity was determined by titration of $BaCl_2$- triethanolamine soil extract of pH 8.1 (Mehlich, 1948). The Aluminon method (Yuan, 1959) was used to determine Al, which was extracted with a 1N KCl solution. Free Fe_2O_3 extracted with $Na_2S_2O_4$—$Na_3C_6H_5O_7 \cdot 2H_2O$ was analyzed colorimetrically. Organic C was determined by the ignition method in a Fischer induction furnace (Young and Lindbeck, 1964) and, subsequently, by the Walkley-Black method (Richards, 1965).

The Pennsylvania State University Soil Testing Laboratory determined total N by the Kjeldahl method (Jackson, 1958).

Samples from each horizon were prepared for X-ray diffraction analysis (copper radiation) by removing free iron oxides and organic matter (Anderson, 1963). Clay material (<2 μm) was removed by centrifugation and two subsamples obtained. One subsample was saturated with Mg and the other with K. X-ray diffraction patterns were run on the Mg-saturated slides at room temperature (25°C) and again after solvation with ethylene glycol at 80°C. Patterns were also obtained from the K-saturated slides at room temperature (25°C), after 2 hours of heat treatment at 300°C, and again after 2 hours of heat treatment at 500°C. X-ray diffraction traces were analyzed for relative peak height. Clay mineralogy data are presented to the nearest 5% of the clay minerals present in the <2 μm soil material.

The Pennsylvania State University Mineral Constitution Laboratory determined the types and amounts of S present in selected horizons of the minesoils and natural soils. The horizons selected for analysis were representative of surface

or subsurface horizons for each pit. Horizons to be subsampled were compared as to Munsell color, pH, CEC, and percent base saturation.

Pyritic sulfur was determined either by atomic absorption spectroscopy of Fe when small amounts of S were present, or by Eschka method D271-70 (ASTM, 1971). Sulfate sulfur was obtained by ASTM D2492-68 (ASTM, 1971) method as adapted by The Mineral Constitution Laboratory. Quantitative spectrometric and semiquantitative spectrographic analyses of these samples were also obtained.

Statistical Analysis

Statistical analyses of chemical data were made using an experimental design with nested classification. Natural soils were compared with minesoils with four replications within each soil type (with three missing values). Soil depths within each pit were compared as follows:

(1) A1 and A2 horizons in natural soils were compared with surface horizons in minesoils.

(2) The first B horizons encountered in the natural soils were compared with the C1 horizons in the minesoil.

(3) B22, B23 (Pits 1, 2, and 4) and Bx1t through Bx3t (Pit 3) horizons in soils were compared with the C2 and C3 horizons of the minesoil.

(4) C horizons of natural soils were compared with C4 and C5 horizons of minesoils. (No horizons from Pits 3, 4, and 6 were compared at this depth.)

Fixed effects included soil types and depths. Replications within soil types are random effects.

Statistical calculations were made using library programs provided by the Computation Center of The Pennsylvania State University. The RUMMAGE program was used to obtain analysis of variance and the FOLUP program was utilized for mean separation using Tukey's WSD criterion. Square root transformations were used to insure that the experimental errors had common variances.

Chemical factors analyzed included Ca, Mg, Na, K, total bases, percentage base saturation, H, CEC, Al, percentage Fe_2O_3, and percentage of N.

RESULTS AND DISCUSSION

Soil and Minesoil Morphology

Field Morphology--

The undisturbed Hazleton and Dekalb soils, at Pits 1 and 2, were located in an area that had a natural forest vegetation, while the trees on the Cookport and Hazleton soils, at Pits 3 and 4, had been removed. The pedogenetic features common in well-developed soils were expressed in the soils at these four locations. Soils at Pits 5 through 8 were located within the area, which has been stripmined and reclaimed, and exhibited characteristics of minimal pedogenetic development.

Structural development and horizon differentiation (Appendix A) are evident in the Hazleton silt loam taxadjunct soil (Pit 1). The very dark grayish brown (10YR 3/2) color of the A1 horizon due to the influence of the solum ranges from brown (10YR 5/4) to dark brown (7.5YR 5/8). The reddish yellow (7.5YR 6/6) color of the C horizon is lithochromic. Clay films in the B22t and B3t horizons indicated pedogenetic development; however, the amount of clay accumulated does not make either of these horizons as argillic. The texture of the soil ranges from silt loam to loam and reaction (pH) of the solum ranges from 4.8 to 5.6.

The Dekalb silt loam, taxadjunct soil (Pit 2) resembles the Hazleton soil (Pit 1), except in depth to bedrock. The Hazleton soil is deep (>75 cm to bedrock), whereas the Dekalb is moderately deep (50-75 cm to bedrock). Except for depth, the morphologies of the two profiles (Pits 1 and 2) were virtually identical.

The A1 horizon of the Cookport channery loam, taxadjunct (Pit 3) was compacted depositional material. This material seemed to have been eroded from the upper areas of the stripmine. The very firm thick platy structure of this horizon was an evidence of compaction. This soil (Pit 3) was also the only one described with a fragipan. Clay films were evident in the Bx1t through the Bx4t horizon and the

Bx1t horizon had enough illuvial clay to qualify as an argillic horizon. Mottles in the Bx2t through the Bx4t horizons indicated the impeded drainage of this pedon. The fragipan extended from 66 cm to the bottom of the pit at 167 cm.

The Hazleton channery silt loam, taxadjunct (Pit 4) also had a surface horizon which has been subjected to erosion as a result of stripmining and reclamation of adjacent areas. Beneath this horizon, the soil appeared undisturbed.

The Hazleton channery silt loam, taxadjunct (Pit 4) soil resembled the soil encountered in Pit 1; the difference was the higher percentage of channers in the particle-size-control section. In this profile, a weathered coal seam (coal blossom) was found at a depth of 94 cm (IIC1) overlying mottled underclay (IIIC2).

The surface horizon of minesoil in Pit 5 had moderate medium platy structure parting to weak very fine subangular blocky structure, indicating that some soil-forming processes had already taken place. The abrupt color change from the Ap to the C1 horizon indicated the topsoiled nature of this profile. The C horizons were all structureless with textures ranging from loam to loamy sand. The moist consistence ranged from friable to firm and wet consistence ranged from slightly sticky, slightly plastic to nonsticky, nonplastic.

The Ap horizon of the minesoil in Pit 6 had granular and weakly developed subangular blocky structure. The vegetation had exerted its effect enhancing this development. The transitional (AC) horizon had subangular blocky structure grading to structureless, massive soil material. The C horizon (as in Pit 5) exhibited no structural development. The C3 horizon was composed entirely of rock fragments with about 15 to 20% void space.

The surface horizons, Ap1 and Ap2, in Pit 7 had a weakly developed fine subangular blocky structure grading to massive material at about 30 cm. This minesoil did not have an abrupt color change from the A to C horizon because no topsoil was spread over this area of the site. The color of Ap horizons in this profile seemed to be influenced largely by the shale fragments present. The C horizons of this profile all had structureless, massive soil. In the C3

horizon of this profile, no fine material was present. The horizon was composed mainly of rock fragments with 20% void space.

The Ap horizon in the Pit 8 minesoil had developed a weak fine granular and a weak very fine subangular blocky structure. The subsurface horizons of this minesoil were all structureless and massive. The texture ranged from loam to loamy sand. Bands of different colored materials were present in the C4 and C5 horizons, and the C5 horizon (145 cm) was composed primarily of rock fragments.

Pedogenetic development was minimal in the minesoils studied. The greatest amount of development had taken place in the surface horizons. The C horizons in all cases were structureless and massive with wavy horizon boundaries. An extremely large portion of the soil consisted of coarse fragments. The minesoils described herein contained an average of 67% coarse fragments by volume. In contrast, the average coarse fragment content of 14 West Virginia minesoils, described by Sobek et al. (1976), was only 24% by volume.

The continuity of larger pores in natural soils with well-developed structure is well documented (Crompton, 1967). These cavities drain quickly after rain and provide essential aeration channels for root respiration and growth. Many fine capillaries are also present which retain water for plant utilization. Minesoils studied lacked structural development. The larger pores, created in part by the large volume of coarse fragments, generally were not as effective in their water-holding capacity, and lack of fine capillaries inhibited water utilization by plants. The most prominant characteristics of minesoils seemed to be extremely high rock fragment content and lack of pedogenetic development.

Soil Classification--

Field morphology (Appendix A) and laboratory characterization data (Appendix B) were used in the classification of the eight pedons (Pits 1-8).

The soil in Pit 1 was classified as a coarse-loamy, mixed, mesic Typic Dystrochrepts. This pedon falls slightly outside the range of characteristics of the Hazleton series (Typic Dystrochrepts; loamy-skeletal, mixed, mesic) and

is a taxadjunct to that series. The pedon contained less than 35% rock fragments by volume in the particle-size-control section (25-100 cm) and, therefore, did not fit the modal concept of the Hazleton series.

Hazleton soils have developed from weathered gray and brown acid sandstone. The soils are generally found on nearly level to very steep uplands and ridges. Modal Hazleton soils, in general, have a thin organic (02) horizon overlying a dark gray sandy loam mineral (A1) horizon. The subsoil ranges from dark reddish brown through dark brown sandy loam and channery sandy loam. The C horizon is a reddish yellow very channery sandy loam. Solum thickness ranges from 65 to 130 cm and depth to bedrock ranges from 100 to 180 cm or more. Usually, there are from 5 to 70% angular sandstone fragments in the solum and from 35 to 80% in the C horizon. Reaction is strongly acid to extremely acid where unlimed. The most abundant clay minerals are kaolinite, illite, and vermiculite. The soil is typically well drained with rapid permeability.

The soil in Pit 2 was classified as a coarse-loamy, mixed, mesic, Typic Dystrochrepts. This pedon falls slightly outside the range of characteristics of the Dekalb series (Typic Dystrochrepts; loamy-skeletal, mixed, mesic) and is a taxadjunct to that series. It contained less than 35% rock fragments by volume in the particle size control section (25-100 cm) and, therefore, did not fit the modal concept of the Dekalb. The pedon was well drained and moderately deep. In general, Dekalb soils have formed in material weathered mainly from sandstone on gently sloping to very steep uplands and ridges.

The modal Dekalb soil, in wooded areas, has a surface layer of very dark gray channery sandy loam over light yellowish brown channery sandy loam. The subsoil, typically, is yellowish brown channery sandy loam and the substratum is dark brown very flaggy loam. Depth to bedrock ranges from 50 to 100 cm. Flat sandstone fragments increase with depth ranging from 10 to 60% in the B horizons and from 50 to 90% in the C horizons. The reaction of the soil is extremely to strongly acid when unlimed. Common clay minerals are predominantly illite, kaolinite, and

vermiculite. The soil typically is well drained with moderately rapid (6.3-12.5 cm/hr) through rapid (12.5-25 cm/hr) permeability.

The soil in Pit 3 was classified as a coarse-loamy, mixed, mesic Aquic Fragiudult. This pedon falls slightly outside the range of characteristics of the Cookport series (Aquic Fragiudults; fine-loamy, mixed, mesic) and is a taxadjunct to that series. The fine-earth fraction of this pedon contains less than 18% clay in the particle-size-control section (25-100 cm) and, therefore, does not fit the modal concept of the Cookport series. This pedon was moderately well drained.

Cookport soils have formed in materials weathered from acidic sandstone and siltstone. They are found on nearly level to strongly sloping broad ridge tops of the Allegheny Plateau. The modal Cookport soil has a very dark grayish brown and brown loam upper horizon and a yellowish brown, friable fine gravelly clay loam subsoil, which is mottled below about 40 cm.

A firm, brittle fragipan is usually encountered at a depth of 50 to 95 cm. The substratum is grayish brown very channery sandy loam and is underlain by sandstone bedrock below 100 cm. The surface layer and upper part of the subsoil is moderately permeable, and the lower part of the subsoil has a slow (0.13-0.5 cm/hr) to very slow (<0.13 cm/hr) permeability.

The soil in Pit 4 was classified as a coarse-loamy, mixed, mesic Typic Dystrochrept. The pedon falls slightly outside the range of characteristics of the Hazleton series (Typic Dystrochrepts; loamy-skeletal, mixed, mesic) and is a taxadjunct to that series. This pedon contains less than 35% rock fragments by volume in the particle-size-control section (25-100 cm) and, therefore, does not fit the modal concept of the Hazleton series.

General properties and occurrence of the Hazleton series was described in detail for Pit 1.

The soils in Pits 5-8 were classified as loamy-skeletal, mixed, mesic members of the Udorthent group. The minesoils (Pits 5-8) were classified as

Entisols because of their lack of horizon differentiation. The epipedons of the minesoils were the only horizons to exhibit any pedogenetic development. Pits 5, 6, and 8 were located in C-Spoil material and Pit 7 was located in B-Spoil material (Figure 2). The color changes from the A to C horizons in minesoils of Pits 5, 6, and 8 were due to the "topsoiling" practice. The "topsoil" stockpiled before stripping is now required to be spread over the spoil material after stripmining. Operators, in general, consider any material above unconsolidated bedrock as topsoil. The "topsoil" that was placed on the spoil at this experimental site was a mixture of all the loose surface material pushed aside before the actual stripping.

Ciolkosz et al. (1977) sampled and characterized 25 minesoil pedons in Pennsylvania. They found most of these minesoils to have pH values of 4 to 5. The texture of these samples was usually sandy loam to loam. The Research Committee on Coal Mine Spoil Revegetation in Pennsylvania (1971) also found that minesoil developed from Lower Kittanning and Middle Kittanning spoil in Pennsylvania generally had loam texture.

Rock fragment content of the 25 minesoils analyzed by Ciolkosz et al. (1977) ranged between 50 and 90% (by volume), while the fine earth content of Lower and Middle Kittanning minesoils was found to be 30 and 25% (by weight), respectively (Research Committee on Coal Mine Spoil Revegetation in Pennsylvania, 1971).

Root Distribution--

Root penetration in natural soils (Pits 1-4) was controlled by either bedrock or a limiting zone. Direct comparison of root distributions in Hazleton and Dekalb soils (Pits 1 and 2) with the minesoils (Pits 5-8) cannot be made since the forest vegetation of Pits 1 and 2 is not comparable to the grass and legume vegetation in Pits 5 through 8. However, vegetation in Pits 3 and 4 is comparable to that on minesoils, and a comparison of root distribution can be made. Detailed root-distribution descriptions are given in Appendix A.

Few roots (<1,000/m^2) penetrated into the upper part of the fragipan in the Cookport taxadjunct (Pit 3) profile. There were many roots (≥10,000/m^2) to a depth of 43 cm, below which they decreased in number and size until they reached the fragipan at 66 cm. Below this, the root number decreased significantly with only a few fine (1-2 mm diam.) roots penetrating the fragipan. The roots seemed to grow laterally along the upper boundary of the fragipan and those that penetrated the fragipan were located along prism walls.

Many roots were present in the A1 horizon of the Hazleton taxadjunct profile in Pit 4. Most of them were present in the A2 horizon (8-20 cm) and few were present below this horizon. No roots penetrated the IIIC2 horizon at 125 cm.

Many very fine (≤1 mm diam.) grass roots were present in the Ap horizon (0-20 cm) in Pit 5. These roots tended to grow parallel to the soil surface on plates and on ped faces and through some plates to 3 cm. Common (1,000-10,000/m^2) very fine fibrous roots were present to 20 cm. These roots were usually flattened on coarse fragments. In the C1 horizon (20-36 cm), few very fine roots were present on the coarse fragments. No roots were observed below 36 cm.

In Pit 6 many very fine fibrous grass roots were present on and through weakly developed granules of the A1 horizon to a depth of 12 cm. Many very fine roots were found between structural units on, around, and below coarse fragments in the AC (13-28 cm) horizon to 20 cm. Common very fine roots were observed in and around pockets associated with coarse fragments in the AC horizon. Few roots penetrated the massive material at 28 cm, and no roots were present below 41 cm.

Many very fine roots were observed in the Ap1 (0-10 cm) horizon in Pit 7. The roots were predominantly found flattened on sandstone fragments. Taproots seemed contorted and one taproot extended to only 13 cm. Common very fine roots were observed flattened between ped faces and in pores. Roots were fewer on shale than on sandstone fragments in the Ap2 (10-31 cm). One very fine root extended to 33 cm on ped faces and on surfaces of coarse fragments. No roots were observed below the Ap2 horizon.

Many very fine to fine fibrous roots were evenly distributed throughout the AC horizon (0-18 cm) in Pit 8. Many fine to medium (2-5 mm diam.) taproots extended to 3 cm in this horizon. Nodules and lesions were observed on these taproots. Few very fine roots penetrated the C1 horizon (18-36 cm) to 20 cm. Taproots within the C1 horizon became increasingly branched and followed ped faces and voids associated with coarse fragments. Few very fine roots extended to a depth of 124 cm.

Roots seldom penetrated the massive C horizons of the minesoils. The roots within the minesoils were located predominantly on coarse fragments. These roots were associated with the cracks and fissures in the soil material near the coarse fragments. Although deeper profiles for root proliferation do exist in minesoils, the structureless nature of the subsoil limits root extension.

Roots also will not penetrate horizons, which do not supply adequate moisture. The large pores associated with horizons composed entirely or predominantly of rock fragments drain rapidly leaving little available water for roots. These horizons are effective barriers to root extension as well.

Laboratory Analyses

Chemical Characterization Data--

Complete chemical characterization data for the natural soils and minesoils are given in Appendix B. Cation exchange capacity, percent base saturation, pH and total acidity are also depicted on Figures 3 and 4. The cation exchange capacity ranged from 8.5 to 61.2 meq/100 g in the natural soils and from 7.3 to 22.4 meq/100 g in the minesoils.

The IIC1 horizon of Pit 4 represented a seam of decomposing coal. The high absorptive capacity of carbonaceous matter (Rankama and Sahama, 1950) accounts for the high CEC value of this horizon. The high CEC's of the A1 horizons of Pits 1 and 2 are attributed to the high organic matter content of these horizons--6.3 and 3.6% organic carbon (Ignition), respectively. Most of these exchange sites are likely to be occupied by H^+ and Al^{+3} ions.

Figure 3. Cation exchange capacity, base saturation, pH and total acidity for the natural soils.

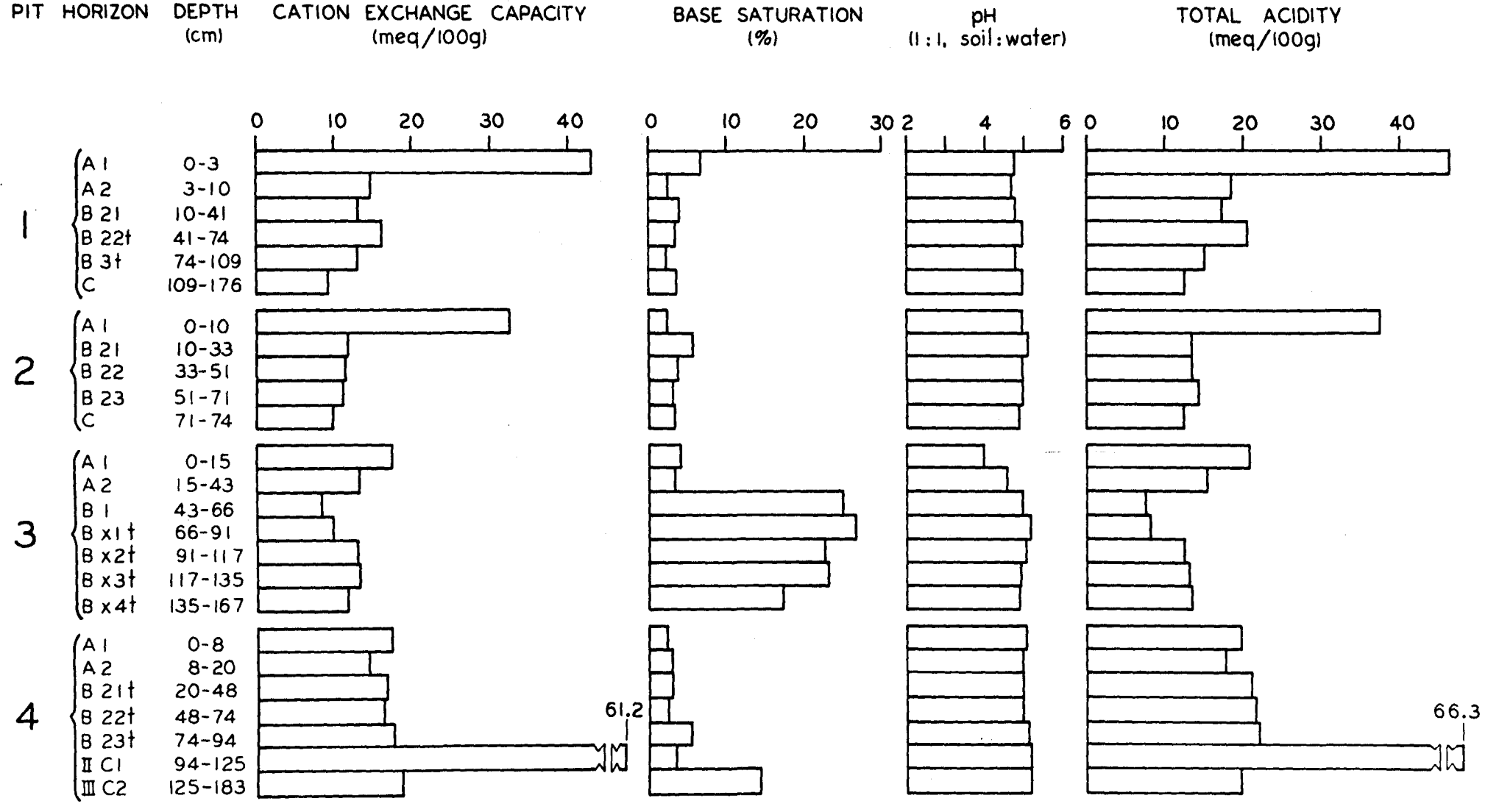
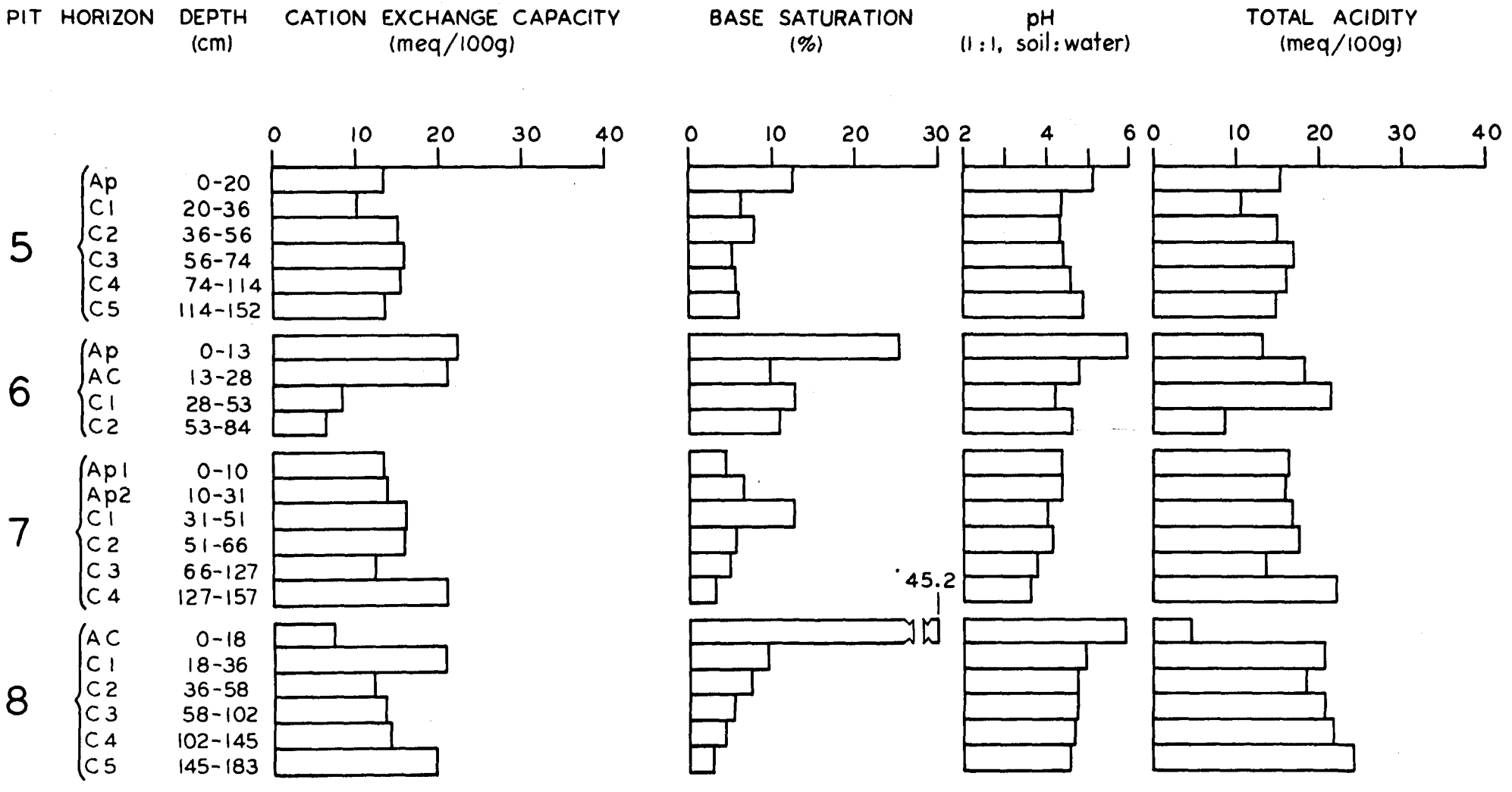

PIT
HORIZON
DEPTH (cm)
CATION EXCHANGE CAPACITY (meq/100g)
BASE SATURATION (%)
pH (1:1, soil:water)
TOTAL ACIDITY (meq/100g)
0 10 20 30 40
0 10 20 30
2 4 6
0 10 20 30 40
1
A 1 0-3
A 2 3-10
B 21 10-41
B 22t 41-74
B 3t 74-109
C 109-176
2
A 1 0-10
B 21 10-33
B 22 33-51
B 23 51-71
C 71-74
3
A 1 0-15
A 2 15-43
B 1 43-66
B x1 t 66-91
B x2t 91-117
B x3t 117-135
B x4t 135-167
4
A 1 0-8
A 2 8-20
B 21t 20-48
B 22t 48-74
B 23t 74-94
II C1 94-125
III C2 125-183
61.2
66.3

Figure 4. Cation exchange capacity, base saturation, pH and total acidity for the minesoils.


PIT
HORIZON
DEPTH (cm)
CATION EXCHANGE CAPACITY (meq/100g)
BASE SATURATION (%)
pH (1:1, soil:water)
TOTAL ACIDITY (meq/100g)
0 10 20 30 40
0 10 20 30
2 4 6
0 10 20 30 40
5
Ap 0-20
C1 20-36
C2 36-56
C3 56-74
C4 74-114
C5 114-152
6
Ap 0-13
AC 13-28
C1 28-53
C2 53-84
7
Ap1 0-10
Ap2 10-31
C1 31-51
C2 51-66
C3 66-127
C4 127-157
45.2
8
AC 0-18
C1 18-36
C2 36-58
C3 58-102
C4 102-145
C5 145-183

The average CEC in the minesoils (17 meq/100 g) was higher than in the natural soils (14 meq/100 g). The differences, however, were not significant at the 5% level. Because of inconsistencies with depth, a significant (soil x depth) interaction was found. The relative CEC values were not equal over depth.

Smith et al. (1971) found lower cation exchange capacities and total bases for Fe ore spoil than for the upper layer (3 cm) of natural Gilpin and Dekalb soils. Below this depth the exchange capacities, bases and base saturation for natural soil horizons were lower than that for corresponding spoil.

The percentage base saturation for the AC horizon of Pit 8 and the Ap horizon of Pit 6 showed the effect of liming. In general, the percentage base saturation was higher in the minesoils; Pit 7 was an exception. Pit 7 is composed primarily of shaly materials, which could account for this discrepency. The lower base saturation of the natural soils was due to leaching which has taken place over time. The fragipan horizons of Pit 3 have a higher base saturation than overlying horizons because these horizons do not transmit much water and, therefore, are not as extensively leached as the overlying horizons. Some of the bases measured in the minesoil could also have been due to free salts, like gypsum.

The amount of Ca (Appendix B) present in the natural soils ranged from 0 to 1.9 meq/100 g and from 0 to 5.1 meq/100 g in the minesoils. The high values of 5.1 and 2.4 meq/100 g for surface horizons of Pits 6 and 8, respectively, are due to effects of liming. In general, the amount of Ca decreased with depth, except where fragipans or lithologic discontinuities were present. No significant difference between minesoils and natural soils in respect to Ca existed.

Extractable Mg ranged from 0.1 to 2.2 meq/100 g in natural soils and from 0.4 to 1.5 in minesoils. Magnesium behaved similarly to Ca in its distribution throughout the soils, but slightly more Mg was present in the minesoils.

The surface horizons of natural soils contained slightly more K than did the corresponding horizons of the minesoils.

Grube et al. (1974) reported that high levels of plant available Ca, Mg, and K are found in young minesoils as compared with old natural soil. In this study, no significant differences between the minesoils and natural soils existed for these three elements and in general; the natural soils tended to have slightly higher levels of these elements. These results can also be contrasted with the results of Smith et al. (1971), who found that fresh spoil derived from non-calcareous acid shales and fine grained sandstones retained slightly more basic cations (Ca, Mg, K) than did the natural soils.

The average amount of extractable Na present in both minesoils and natural soils was 0.06 meq/100 g with very little variation between horizons, sites, or soils. Excess amounts of Na tend to disperse clays, but quantities sufficient to adversely affect the soils and minesoils were not present in any of the horizons.

The pH values of the natural soils (Pits 1-4) were generally lower and total acidity generally higher due to leaching of bases in these soils over time. The high total acidities of the A1 horizons of Pits 1 and 2 are attributed to the high organic matter content of these horizons and the effect of an acid leaf

litter overlying these mineral horizons. The large difference in total acidity for the AC horizon of Pit 8 is again due to the liming of the minesoil.

The pedogenetically younger minesoils have not been exposed to the leaching that the mature natural soils have. The relatively equal pH values throughout the natural soils indicated that these soils are in equilibrium with their environment.

The low pH values of Pit 7 can be attributed to its high S content (Table 1). The oxidation of sulfides to sulfates has contributed to the acidity. The oxidation reaction which liberates H_2SO_4 is as follows:

$$4\ FeS_2 + 15\ O_2 + 2\ H_2O = 2\ Fe_2(SO_4)_3 + 2\ H_2SO_4.$$

This oxidation reaction produces $Fe_2(SO_4)_3$, which is characterized by a yellow color (Black, 1968). These yellow colors were observed at the site on shale fragments, and on the minesoil surface.

The range of SO_4 found in the minesoils was 0.01 to 0.16%, and total S content in the natural soils was not high enough to warrant further analyses. In comparison, Jackson (1964) reported that the total SO_4 content of humid temperate soils ranged from 0.01 to 0.15%. The minesoils would be expected to retain more SO_4 because of their lower pH's. High levels of Fe (Chao et al., 1963) and the presence of kaolinite clay (Russell, 1961) also enhance SO_4 retention.

The amount of S present in the minesoils ranged from 0.03 to 0.38%. Total S of some eastern Kentucky acid-forming coal spoil materials ranged from 0.11 to 3.86% (Barnhisel et al., 1969). The amount of S present in the minesoils of this study was comparatively low, however, the S present in the minesoils is in an environment optimum for acid production. The rainwater, which percolates through the soil, could be expected to solubilize much of the S present. The S is not concentrated in a localized seam, as it would be in coal, but is distributed throughout the minesoil and spoil. The amount of S, therefore, distributed throughout this material with depth might contribute significantly

TABLE 1. TOTAL SULFUR, SULFATE SULFUR, PYRITIC SULFUR AND ORGANIC SULFUR OF SELECTED HORIZONS

Site	Depth	Horizon	Form of S			
			Total S	Sulfate-S	Pyritic-S	Organic-S
	cm			%		
P-1	3-10	A2	0.03	-*	-	-
	41-74	B22t	0.03	-	-	-
P-2	0-10	A1	0.04	-	-	-
	33-51	B22	0.03	-	-	-
P-3	15-43	A2	0.04	-	-	-
	43-66	B1	0.03	-	-	-
	117-135	Bx3t	0.04	-	-	-
P-4	8-20	A2	0.03	-	-	-
	48-74	B22t	0.03	-	-	-
	94-125	IIC1	0.19	0.01	0.03	0.15
P-5	0-10	Ap	0.03			
	74-114	C4	0.13	0.05	0.07	0.01
P-6	0-13	Ap	0.03			
	58-84	C2	0.13	0.05	0.08	0.00
P-7	10-31	Ap2	0.10	0.05	0.02	0.03
	51-66	C2	0.38	0.16	0.07	0.15
P-8	0-18	AC	0.04			
	58-102	C3	0.08	0.04	0.04	0.00

*Total S <0.05%, no further analysis.

to acid production. However, Sobek et al. (1976) reported that total S only accurately quantifies the materials' potential acidity when all the S is present in the pyritic form.

Barnhisel and Massey (1969) reported that most of the acidity present in the minesoils was from the H^+ resulting from the oxidation of sulfide minerals. In the minesoils (Pits 6, 7, and 8), the amount of H increased with depth, whereas the concentration of H decreased with increasing depth in the natural soils.

Pit 5, however, showed no clear trend with depth. The shaly material at this site probably supplied enough S throughout to offset any leaching effects.

In old Fe ore spoil, Smith et al. (1971) found no significant pH differences with depth. They found the pH range resembled that in the natural Dekalb soils. They concluded that long-time soil forming processes, in their region, did not change soil horizon pH appreciably when the soil material initially was within the acid range.

The natural soils contained significantly more extractable Al than the minesoils (Appendix B). The higher levels of extractable Al present in the natural soils were due to their more mature state. The leaching of these soils has lead to weathering of clays, release of Al, and removal of bases. Toxic levels of Al, however, did not exist in any horizon.

Iron oxide redistribution in soils is associated with weathering. Increasing concentration of Fe_2O_3 is an indication of increasing weathering (Buol et al., 1973).

The natural soils had greater percentage of Fe_2O_3 in general; however, Pit 7 contained an appreciable quantity of the oxide. This was probably related to the weathering of the FeS_2 present.

Iron oxides tend to render a reddish yellow color to the soil. They also promote aggregate stability. Over time the Fe weathering in the minesoils might be of benefit in this respect.

Spectrometric and Spectrographic Analyses

Quantitative spectrometric analyses (Table 2) revealed that very little difference existed between soil and minesoil composition.

The higher SiO_2 contents of the natural soils were due to their higher concentration of quartz. Since these soils are derived from sandstone, these results were expected, whereas the minesoils which are developing from a mixture of soil, sandstone, and shale have lower contents of quartz.

TABLE 2. QUANTITATIVE SPECTROMETRIC ANALYSIS OF SELECTED HORIZONS

Site	Depth	Horizon	Component Oxides										
			Ash	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	MgO	CaO	MnO	Na_2O	K_2O	Total
	cm		%										
P-1	3-10	A2	94.03	79.0	12.0	0.92	4.75	0.78	0.11	0.061	0.33	1.96	99.9
	41-74	B22t	94.81	76.5	13.8	0.89	5.75	0.61	0.14	0.076	0.27	2.24	100.3
P-2	0-10	A1	90.05	84.0	9.0	0.80	2.92	0.76	0.12	0.039	0.29	1.43	99.4
	33-51	B22	96.12	86.0	8.7	0.74	2.71	0.39	0.12	0.039	0.24	1.46	100.4
P-3	15-43	A2	95.22	84.0	9.3	0.79	2.65	0.39	0.09	0.039	0.25	1.63	99.1
	43-66	B1	96.47	83.0	10.0	0.79	3.30	0.49	0.17	0.049	0.28	1.85	99.9
	117-135	Bx3t	95.76	81.5	12.1	0.79	4.58	0.75	0.17	0.075	0.47	2.25	102.7
P-4	8-20	A2	94.35	78.5	14.1	1.04	4.55	0.69	0.11	0.069	0.37	2.35	101.8
	48-74	B22t	94.10	74.0	15.8	1.02	5.95	0.91	0.08	0.046	0.40	2.67	100.9
	94-125	IIC1	70.12	71.0	18.9	1.19	5.30	0.68	0.32	0.067	0.03	3.10	100.9
P-5	0-10	Ap	95.43	82.0	12.6	0.87	4.22	0.53	0.18	0.046	0.26	2.09	102.8
	74-114	C4	94.27	90.5	11.7	0.63	5.62	0.49	0.11	0.058	0.12	2.23	101.5
P-6	0-13	Ap	95.03	82.0	11.2	0.82	3.93	0.48	0.40	0.074	0.24	1.87	101.0
	53-84	C2	94.07	79.0	12.6	0.69	6.80	0.54	0.15	0.055	0.12	2.39	102.4
P-7	10-31	Ap2	92.96	78.5	13.3	0.77	5.23	0.51	0.09	0.088	0.14	2.40	101.0
	51-66	C2	77.09	73.0	15.5	0.92	8.75	0.72	0.19	0.074	0.19	2.66	102.0
P-8	0-18	AC	95.54	86.0	8.3	0.64	3.85	0.37	0.27	0.064	0.20	1.37	101.1
	58-102	C3	91.80	77.5	14.2	0.91	6.55	0.69	0.10	0.102	0.30	2.53	102.9

The Fe_2O_3 content of soils, generally, ranges from 1 to 6% (Jackson, 1968). Data obtained for the natural soils fall within this range but the minesoils subsurface horizons approach the upper end of this range or exceed it. These higher values are due to the dissolution of FeS_2 and redistribution of this compound in the soil, as previously discussed.

According to Jackson (1968), CaO and MgO contents of natural soils, are generally less than 1%. Values obtained from minesoils and natural soils agreed with this value, however, we noted no distinct trend in distribution of these compounds.

The K_2O content of the minesoils was slightly higher than that of corresponding natural soil horizons. The K_2O content of soils ranges from 0.05 to 3.5% according to Jackson (1968). The greater proportion of K_2O in the minesoils is possibly due to the weathering of illite which liberates K.

All other elements analyzed for spectrometrically fell into expected ranges for natural soils.

Little, if any difference, was observed between trace elements of minesoils and natural soils (Table 3), when semiquantitative spectrographic analysis was performed.

The amount of Cu present in the minesoils, composed dominantly of shale coarse fragments (Pits 7 and 8), was slightly higher than that in natural soils. The Cu content of the soils and minesoils, however, fell within the range of Cu found in natural soils (Baker and Chesin, 1975).

The amount of Co present in the Ap2 of Pit 7 and C3 of Pit 8 exceeded the 1 to 40 ppm range reported by Baker and Chesin (1975). This higher amount of Co could be attributed to the shaly nature of these profiles, which generally contain more Co than sandstone materials.

The amounts of Ba, Cr, V, Be, and Ni found in the minesoils and soils fell within ranges established by Baker and Chesin (1975) for natural soils.

TABLE 3. SEMIQUANTITATIVE SPECTROGRAPHIC ANALYSIS OF SELECTED HORIZONS

Site	Depth	Horizon	Element*													
			Ba	Be	Ce	Co	Cr	Cu	Ga	La	Ni	Sc	Sr	V	Y	Zr
	cm		ppm													
P-1	3-10	A2	350	<3	120	<20	74	23	23	40	25	12.0	41	96	31	420
	41-74	B22t	380	<3	<100	<20	100	31	25	32	32	15.0	47	100	33	390
P-2	0-10	A1	390	<3	<100	<20	74	16	15	23	<25	6.6	35	66	33	440
	33-51	B22	310	<3	<100	<20	56	16	18	30	<25	8.0	30	62	26	290
P-3	15-43	A2	380	<3	<100	<20	70	15	19	30	26	8.4	50	72	26	340
	43-66	B1	320	<3	<100	<20	66	18	18	31	<25	10.0	43	74	36	340
	117-135	Bx3t	350	<3	<100	<20	84	24	21	38	31	12.0	50	100	29	340
P-4	8-20	A2	410	<3	<100	<20	100	20	25	48	25	12.0	64	110	35	340
	48-74	B22t	430	<3	<100	<20	100	32	28	52	33	17.0	86	130	40	410
	94-125	IIC1	300	4	120	39	120	54	39	60	74	25.0	160	150	60	330
P-5	0-10	Ap	340	<3	100	<20	76	22	22	43	<25	13.0	42	110	32	340
	74-114	C4	300	<3	<100	<20	80	26	23	34	44	13.0	46	100	22	250
P-6	0-13	Ap	340	<3	120	<20	86	21	23	50	<25	12.0	45	100	33	490
	53-84	C2	270	<3	<100	<20	60	30	22	43	27	13.0	45	100	35	310
P-7	10-31	Ap2	390	<3	<100	50	96	35	26	43	27	14.0	64	110	30	240
	51-66	C2	440	<3	110	<20	110	50	26	44	40	18.0	120	120	37	370
P-8	0-18	AC	290	<3	<100	<20	50	12	16	29	<25	5.4	41	120	30	380
	58-102	C3	430	<3	<100	43	100	50	29	40	46	16.0	80	120	39	310

*Not detected in all samples: Ag, Bi, Ge, Mo, Nb, Pb, Sn, Yb.

Clay Mineralogy

Clay mineralogical data for the natural soils and minesoils are presented in Appendix B.

Vermiculite and kaolinite were the dominant clay minerals in the natural soils (Pits 1-4), while illite and kaolinite were dominant in the minesoils (Pits 5-8).

In Pennsylvania soils, the dominant clay-weathering transformation is the conversion of illite to vermiculite or to vermiculite-chlorite intergrades (Ciolkosz et al., 1975).

The illite of the natural soils has been weathered to vermiculite. Over time the amount of vermiculite in the minesoils will most likely increase at the expense of illite. The high proportions of illite in the minesoils, however, could be expected to supply part of the K needed for plant growth (Barnhisel, 1969). Kaolinite, the most resistant of common clays, occurs when leaching is extensive. This explained the high proportion of kaolinite found in the highly weathered natural soil.

Barnhisel (1969) reported that the clay minerals serve as "buffers" by reacting with acids produced by the oxidation of sulfides.

The large amount of montmorillonite in Pit 3 can be attributed to the impeded drainage of this profile. The fragipan effectively slows down the rate of weathering of this mineral within this horizon. The fact that montmorillonite is present in Pit 4 is possibly due to this soil's topographic position. The montmorillonite in the minesoils will probably be weathered from the soil over time because this mineral is unstable in leaching environments.

The clay minerals present in the IIC1 and IIIC2 horizons of Pit 4 agreed with generalizations proposed by Grim (1953). Bituminous coal is usually high in kaolinite, whereas kaolinite and illite are associated with underclay.

Smith et al. (1971) found no great differences between clay mineralogy of natural soils and minesoils. They also found similarities between young minesoil

and contiguous natural (Gilpin) subsoil, which they claimed indicates that the mineralogy of the minesoils may be inherited from disintegration of parent rock.

From mineralogical data obtained, minesoils seem to be similar to the contiguous natural soils. The minesoils, however, have not been exposed to the weathering processes that natural soils have encountered.

Sand grain mineralogy of the minesoils might give a better idea of what minerals will be present in the future and better predict soil development.

Organic Carbon and Organic Nitrogen

Organic C data are presented in Appendices B and C, and organic N data are presented in Appendix B.

As indicated in the Materials and Methods section, two methods were used to determine the amount of organic C present in the soil. The values obtained by the ignition method seemed high in some instances, and we questioned the validity of this procedure for these materials since carboniferous shale and coal fragments in the samples could account for the high organic C contents obtained.

Organic matter has a marked effect on minesoil development. Organic matter acts as a cementing agent which aids in the formation of aggregates. Jones et al. (1975) reported that newly reclaimed minesoils generally contain less than 0.3% organic matter. Caspall (1975) found that 30- and 76-year-old minesoils, which were improperly managed, also had low organic matter contents.

In general, organic C content decreased with depth in the natural soils and increased with depth in the minesoils. The highest amounts of organic C were found in the IIC1 horizon of Pit 4, followed by the A1 horizons of Pits 1 and 2. The IIC1 horizon (Pit 4) was a partially decomposed coal seam. The horizons above (B23t) and below (IIIC2) this seam also had high organic C values. The A1 horizons (Pits 1 and 2) seem to have accumulated organic matter over time from the forest vegetation at these locations and the darker colors of these surface horizons were due in part to their organic matter contents. The soil at Pit 7 had very high organic C content. This soil is composed mainly of material

derived from carboniferous shale and the high C values could possibly be due to this material.

The Walkley-Black method seemed to agree in general with the ignition method values for the surface horizons of the natural soils, but gave lower values for subsurface horizons. The values obtained by the Walkley-Black method for the minesoils did not agree with those determined by ignition. The values obtained by ignition were 1/3 to 6 times higher than those obtained by the Walkley-Black method; however, this relationship was not constant and the AC horizon of Pit 8 had higher organic C when determined by Walkley-Black method.

Apparently the organic C in minesoils cannot be accurately determined by either of these methods when shale and coal fragments are present. Alternate methods should be sought, which could give more reliable determinations.

The organic N of the natural soils decreased with depth, whereas in minesoils it increased with depth. Carbon to nitrogen (C/N) ratios are presented in Tables 4 and 5 for natural soils and minesoils, respectively. The C/N ratios for the natural soils were higher than expected and generally became smaller with depth. The organic-N values (Appendix B) fell within the range of those expected for natural soils (Black, 1968); however, the organic C values were suspect. Values obtained for organic C (Appendices B and C) were high.

The C/N ratios for Pit 4 are inconsistent with those obtained for the other three natural soils. The coal blossom (IIC1) and underclay (IIIC2) had high organic C content and resulting high C/N ratios as expected.

The C/N ratios obtained for the minesoils were very eratic. In general, the minesoils higher in shaly material and darker in color had higher organic C values and higher C/N ratios than could be attributed to organic matter alone.

TABLE 4. CARBON/NITROGEN RATIOS FOR NATURAL SOILS

Pit	Depth	Horizon	Method	
			Ignition	Walkley-Black
	cm			
1	0-3	A1	18.1	20.2
	3-10	A2	33.3	15.0
	10-41	B21	10.5	
	41-74	B22t	8.7	
	74-109	B3t	2.1	
	109-176	C	3.5	
2	0-10	A1	21.4	18.0
	10-33	B21	15.1	
	33-51	B22	14.3	
	51-71	B23	10.5	
	71-74	C	5.9	
3	0-15	A1	12.4	14.4
	15-43	A2	26.7	15.4
	43-66	B1	7.7	
	66-91	Bx1t	10.9	
	91-117	Bx2t	6.9	
	117-135	Bx3t	12.6	
	135-167	Bx4t	9.5	
4	0-8	A1	61.9	34.5
	8-20	A2	14.7	
	20-48	B21t	26.2	
	48-74	B22t	7.2	11.8
	74-94	B23t	26.5	
	94-125	IIC1	36.3	
	125-183	IIIC2	34.4	27.5

TABLE 5. CARBON/NITROGEN RATIOS FOR MINESOILS

Pit	Depth	Horizon	Method	
			Ignition	Walkley-Black
	cm			
5	0-20	Ap	10.5	4.9
	20-36	C1	26.6	8.3
	36-56	C2	27.1	7.5
	56-74	C3	38.2	11.5
	74-114	C4	28.5	11.2
	114-152	C5	27.5	9.3
6	0-13	Ap	13.5	12.6
	13-28	AC	37.5	20.3
	28-53	C1	27.8	13.9
	53-84	C2	36.5	17.0
7	0-10	Ap1	39.7	18.4
	10-31	Ap2	42.2	00.6
	31-51	C1	37.2	11.7
	51-66	C2	40.0	8.2
	66-127	C3	34.6	4.7
	127-157	C4	70.0	4.1
8	0-18	AC	13.8	18.7
	18-36	C1	7.6	16.7
	36-58	C2	25.5	11.4
	58-102	C3	36.8	14.7
	102-145	C4	29.7	15.0
	145-183	C5	24.5	21.3

SUMMARY

A study was conducted to determine soil changes that have occurred as a result of coal stripmining and reclamation procedures. Soil and minesoil morphology and root distributions were described in the field. Samples were obtained from each horizon and soil chemical tests were performed. Pedogenetic development in the minesoils was minimal and the most prominent feature of the minesoils was their high degree of coarseness and their high rock fragment content. Roots tended to concentrate along soil-coarse fragment interfaces. Few roots penetrated the massive minesoil material in the C horizons.

In general, the chemical constituents of the minesoils resembled those of natural soils. However, the weathering of the natural soils has leached bases from them and significantly more extractable Al was found in these soils than in minesoils.

Organic C and N determination were affected by the high content of carboniferous shale and coal fragments in the minesoils.

The clay minerals present in the minesoils have not been weathered as much as the clay minerals in the natural soils. The mineralogy suggested that these minesoils and the natural soils were derived from the same materials.

SECTION 3

PHYSICAL CHARACTERISTICS

INTRODUCTION

Typically, minesoils are low in organic matter and high in coarse fragments, with little or no natural structure. Their surface horizons contain the greatest amounts of fine soil material, less than 2 mm in diameter. Large boulders and fragmented rock pieces are common. During the mining operation, overburden rock is shattered by blasting, and as a result many "fines" essentially consisted of pulverized unweathered rock materials.

This chapter deals with the effects of surface stripmining and reclamation operations on some physical and hydrologic properties of minesoil. The objectives of this study were to determine the moisture characteristics, particle-size distributions, and specific surface of minesoils as compared with contiguous natural soil; to establish the range and variation in bulk density of the minesoil; to determine the hydraulic conductivity of the material; and to ascertain evapotranspiration from the minesoil.

Bulk densities of minesoils are usually greater than those of undisturbed soils because of their compacted state, immature pedogenetic nature and higher coarse fragment content. Natural soils tend to be more porous with an intricately developed system of cracks and fissures. Although, in general, the total porosity is lower, pores in minesoils are typically larger.

Physical and morphological properties of both natural soils and minesoils influence water retention and movement within a profile. Soil-water retention depends mainly on the amount of the "soil" fraction (<2 mm) and soil structure.

The degree of tension with which the water is held determines its availability to plants. The specific retention decreases with an increase in particle size (Farmer and Richardson, 1976), resulting from a decrease in surface area and an increase in pore size; however, it does not seem to be changed significantly by the shape or type of fragments, nor by the time allowed for drainage (ElBoushi, 1966).

It is difficult to obtain undisturbed samples for determination of hydraulic properties of minesoils because of the large percentage of coarse fragments and weak structural development of these materials. Sieved samples, although not necessarily representative of the natural minesoil, give a useful estimate of hydraulic properties, like moisture characteristic and hydraulic conductivity, particularly when corrected for coarse-fragments content.

Shaykewich (1970) showed that sample disturbance lowered the limit of available water and that disturbed samples differed in water retention more frequently at the lower tensions. Moisture tension data for natural soils indicated that moisture content at -15 bars of sieved sample and loose aggregate samples was highly correlated, and moisture content at -0.3 bar of natural clods and loose aggregate samples was also highly correlated (Holtan et al., 1968). Unger (1975) found that at -0.3 bar, cores retained more water than sieved samples when water content was below 11% and the opposite was true at higher moisture contents. Unger (1975) also found that throughout the encountered water-content range, cores contained about 1% more water than sieved soils at -15 bar. Young and Dixon (1966) have shown that sieved samples have higher gravimetric water contents due to an increase in total pore space and an increase in the number of pores that hold water at -0.3 bar. Bruce (1972) concluded that sieving of coarse-textured, organic-matter-deficient materials does not significantly modify their water retention properties. In general, research results (Bruce, 1972; Unger, 1975) indicated that if natural soil structure is present, any type of sample disturbance will disrupt it, modifying pore-size distribution and pore volume. However, in soils with little or no structured development,

like minesoils, this effect should either be minor or absent. Because of the minesoils' coarser texture, greater rock fragment content and associated larger pores, storage of plant available water is reduced. However, Plass and Vogel (1973) reported that under normal conditions minesoils can supply ample water to plants.

Rates of infiltration and hydraulic conductivity usually increase as the soil becomes coarser textured. The coarser texture, however, restricts unsaturated moisture movement within the profile due to a decrease in area for flow and increase in tortuosity (Mehuys et al., 1975). Minesoils may occupy up to 25% greater volume than the natural material (Van Voast, 1974), with the subsurface containing large channels which allow rapid drainage. Therefore, values for water movement into and through minesoils are highly variable. Coleman's (1951) results showed that infiltration on minesoils had a lag period after which it increased significantly. In contrast, adjoining natural soil generally had lower infiltration rates which leveled off or decreased with time. In related studies, ElBoushi (1966) has shown that water infiltrating through loose granular material (similar to subsurface horizons of many minesoils) tends to concentrate into discrete paths. Similar flow due to wetting front instability has been discussed by Hill and Parlange (1972), and more recently by Raats (1973) and Philip (1975).

MATERIALS AND METHODS

Laboratory Analyses

Bulk samples from individual horizons were analyzed for particle-size distribution by the pipette method (Kilmer and Alexander, 1949), and sand-size particles were sieved to obtain required separates. To obtain an overall average of the particle-size-distribution, composite samples, obtained from each soil pit, were sieved and weighed.

The Soil Characterization Laboratory determined the bulk densities, 1/3 and 15 atmo water retention (Brasher et al., 1966), and coefficient of linear extensibilities (Grossman et al., 1968) as outlined by Ciolkosz and Pletcher (1974).

Soil moisture characteristics of sieved (<2 mm) materials from each horizon of the soils and minesoils were obtained experimentally by desorption (Richards, 1965). Triplicate samples were run emphasizing the low tension end of the curve. Subsequently, these values were corrected for coarse fragments by multiplying the value obtained by the percentage of material <2 mm and adding a correction factor which was multiplied by the percentage of material >2 mm. Correction factors were obtained by determining the amount of water retained by the coarse fragments. The correction factor for sandstone fragments was 0.0282 and for shale fragments it was 0.0687.

Percentage of organic matter (OM) was estimated by multiplying the percentage C, determined by the Walkley-Black or the ignition method by a factor of 2.5. This value, along with -15 bar water content (W) of the matrix soil, was used to estimate specific surface of the mineral fraction (SS) (in square meters per gram of soil) using a recently proposed equation of Young and Onstad (1976):

$$SS = -2.36 + 7.96\ (W) - 4.49\ (OM).$$

Field Studies

Bulk densities were determined at 10 sites randomly located within the reclaimed area (L-1 to L-10; Figure 2), and three sites located in adjacent natural soils (L-11 to L-13; Figure 2). Five replicate readings around each site were made with a gamma density probe (Blake, 1965; Troxler, 1970) at the 15 and 30 cm depths. Bulk density was also determined gravimetrically using a modified excavation technique (Bertram, 1973). At each of the 10 sites a steel ring 90 cm in diameter was placed on the spoil surface and loose stones and excessive vegetation were removed. A pliable rubber liner was then fitted inside the steel ring and the volume of water needed to fill the ring was determined. The minesoil within the ring was then removed to about the 45 cm depth and weighed. Small grab subsamples were taken to determine gravimetric water content. The rubber liner was then replaced in the excavation and water added to the same level as before. From volume differences and soil weight,

corrected for water content, dry bulk density was determined. Soil clods were obtained when possible to make an additional check on the bulk density at these sites.

Some of the excavated minesoil at each site was repacked by hand into small plastic microlysimeters (20 cm ID x 30 cm) (Rogowski and Jacoby, 1977), to approximate field wet bulk density. The microlysimeters were seeded with ryegrass (Lolium perenne L.) and set on collecting pans in the excavations. Acrylic liners were placed around each microlysimeter and the minesoil returned to its original level. Vegetation was reestablished at each site and an evapotranspiration (ET) study initiated. The amount of water seeping through the minesoil and the weight of each cylinder was recorded twice weekly. Rainfall, evaporation, maximum-minimum temperatures and solar radiation data were also monitored during this time. Following the ET study, bulk densities of the minesoil in each microlysimeter were determined by oven drying.

Field capacity estimates were also made. When saturated from below, tops of the microlysimeters were covered with plastic film to prevent evaporative loss and the weight after 2 days of drainage was obtained. Concurrently, field capacity was studied on the experimental site. Two days after a 3 cm rain, which effectively saturated the minesoil, gravimetric samples were obtained from the surface and subsurface of minesoils in close proximity to each of the 10 microlysimeter sites within the reclaimed area. Water content was determined on the dried and weighed samples and apparent field capacity was calculated.

Before and after the evapotranspiration study, saturated hydraulic conductivities were measured in the 10 microlysimeters. The microlysimeters used for ET study were saturated from below by raising the water level to expel any trapped air and ensure total saturation. Hydraulic conductivities were run under a low head (Klute, 1973).

Infiltration values were computed using steel cylinder infiltrometer data following Coleman (1951) at nine sites (I-1 - I-9; Figure 2). Three sites each were located within the B-spoil, C-spoil, and the natural soil, respectively. Soil was excavated from the circumference of the ring to a depth of 10 to 15 cm and the infiltrometer installed. Bentonite clay was used to form an impervious

barrier to lateral flow from the bottom of the cylinder. Clay was also used to decrease the seepage down the side of the cylinder. Coleman's (1951) procedure for determining infiltration was followed with some slight modifications. The cylinder was 50.8 cm in diameter and about 20 cm in height. Five liters of water were added to the cylinder and allowed to infiltrate. This amount was equivalent to an application of 2.5 cm of water.

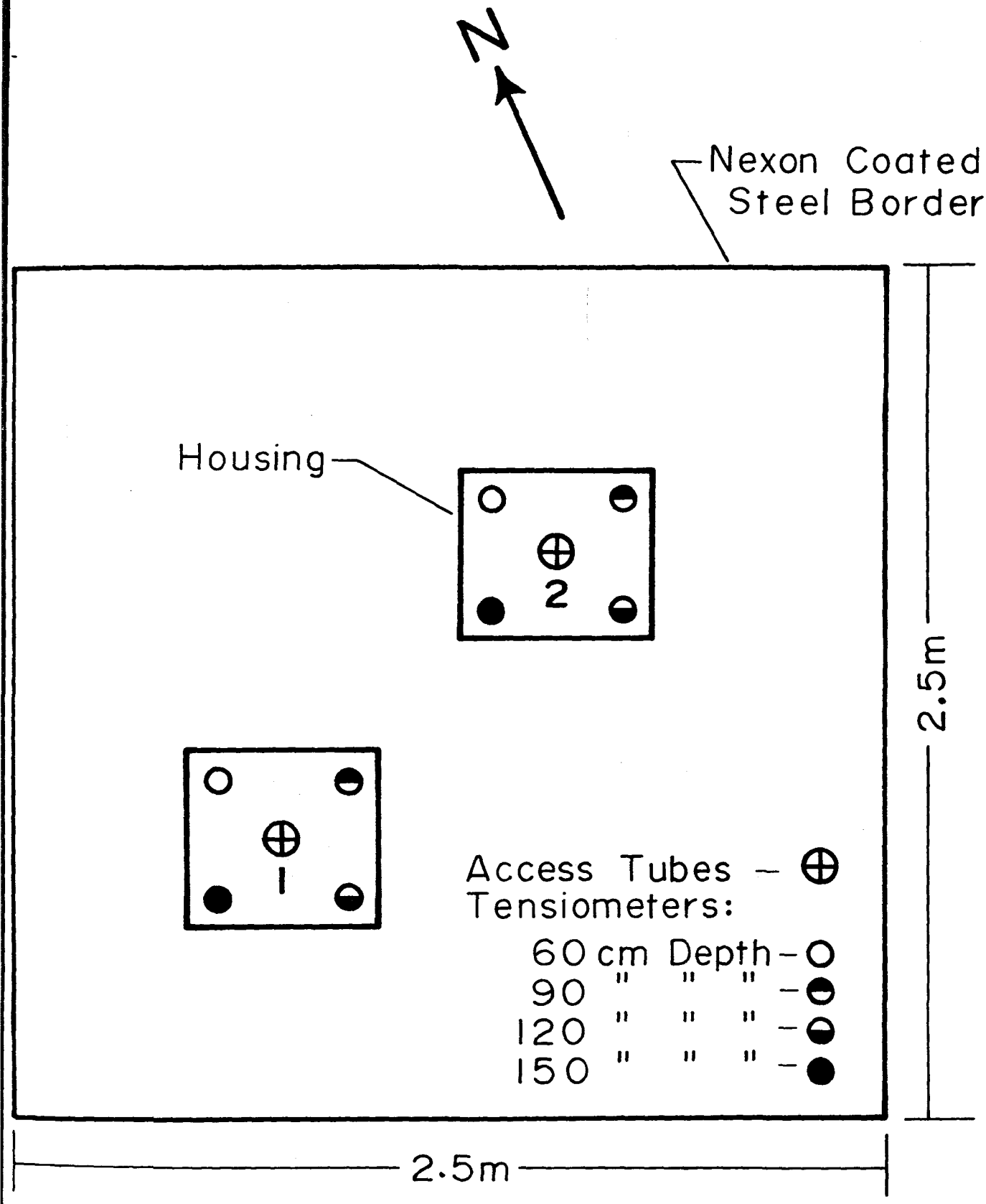
"In situ" determination of water-holding capacity and unsaturated conductivity was attempted on the minesoil using a modification of a procedure outlined in Nielsen et al. (1964), Davidson et al. (1966), Cassell and Sweeney (1974), and Cassell (1974). The experimental plot is denoted by K on Figure 2. The modification included trenching to the 1-m depth, using a metal perimeter coated with a corrosion-resistant paint, backfilling in place and predrilling holes for the access tubes and tensiometers. Subsequently, the space around the tensiometers was packed with a slurry of fine minesoil (<2 mm). Because of safety considerations and remoteness of the site, gage-type tensiometers, rather than mercury tensiometers, were used. Duplicate tensiometers and two neutron access tubes were placed at 60, 90, 120 and 150 cm below the minesoil surface within the plot. Figure 5 is a schematic diagram of the plot. The plot was irrigated several times before the run to insure stability of the repacked material. Moisture and density determinations were made using nuclear methods before the initial run.

Water was then applied to the plot (890 liters) and when one-half the surface area of the plot remained ponded, the initial readings time zero were taken. The surface was then covered with black polyethelene to prevent evaporative loss and tensiometer readings and moisture determinations, by nuclear methods, were made periodically during the drainage period.

Statistical Analyses

Physical data were analyzed using a nested classification analysis of variance. Natural soils were compared with minesoils with four replications within each soil type as described previously in Section 2.

Figure 5. Schematic representation of unsaturated hydraulic conductivity plot.


N
Nexon Coated
Steel Border
Housing
2
1
2.5m
Access Tubes –
Tensiometers:
60 cm Depth –
90 " " " –
120 " " " –
150 " " " –
2.5m

Fixed effects include soil types and depths. Replications within soil types are random effects.

Statistical calculations were made using library programs provied by the Computation Center of The Pennsylvania State University. The RUMMAGE program was used to obtain analysis of variance and the FOLUP program was utilized for mean separation using Tukey's WSD criterion. Square root transformations were used to insure that the experimental errors had common variances.

The MINITAB II program was used to run unpaired t-tests on means.

Physical factors analyzed included percent sand, silt, and clay in <2-mm material and percent sand, silt, clay, and various rock fragment fractions of the total material.

The means and standard deviations for other physical parameters were also obtained.

RESULTS AND DISCUSSION

Physical Properties

Particle Size--

Particle-size-distribution data for the natural soils and minesoils are reported in Appendix B. Summation percentages for 2- to 254-mm material are presented in Appendix D. Summation percentages, for 0.15- to 102-mm material, of the composite samples (Table 6) indicated the general difference between natural soils (Pits 1-4) and minesoils (Pits 5-8). About 50% (by weight) of the natural soil consisted of soil-size material, in contrast to the minesoil where only 25% of the material was made up of soil-size material.

The composite sample of the natural soil contained significantly more material between 0.15 to 0.30 mm in diameter than the minesoils. The other size fractions of the composite samples were not significantly different from each other.

In Figure 6 summation curves of selected composite samples are presented. The curves for Pits 5, 6, and 8 approximated each other. Pit 7, composed largely of shaly material, was coarser. The summation curve for Pit 2 approached that of the

TABLE 6. COMPOSITE SAMPLE-SIZE DISTRIBUTION

Fraction	Pit							
	P-1	P-2	P-3	P-4	P-5	P-6	P-7	P-8
mm	% finer by weight							
0.15	4.1	10.0	7.1	3.5	1.7	1.3	0.1	2.6
0.30	15.5	18.0	22.7	18.7	7.3	5.9	2.6	8.6
0.60	38.7	29.8	35.5	32.6	17.6	16.9	5.9	18.6
1.18	45.8	36.3	41.9	43.9	22.7	22.7	8.6	22.8
2.36	52.5	40.6	47.3	56.6	28.0	29.3	12.8	27.8
4.75	58.8	43.8	54.0	72.0	33.1	36.1	17.0	34.1
9.50	63.6	47.6	61.7	86.7	36.8	42.0	21.2	41.1
19.1	69.0	54.2	69.7	93.7	41.8	49.9	25.2	49.6
25.4	73.2	58.0	75.2	95.9	44.2	55.8	25.4	54.1
50.8	82.3	74.2	86.1	97.2	52.5	66.3	30.7	69.2
76.2	91.9	82.8	98.1	97.6	67.7	78.4	43.0	88.0
101.6	99.8	93.1	99.9	100	80.7	100.2	57.8	100.1

minesoils at the coarser end of the curve. Pit 4, however, differed from the others in having most of its material less than 2 mm in size. Figures 7 through 12 show the sand, silt, clay, and coarse fragment (>2 mm-25 cm diam.) distribution with depth for selected soil and minesoil profiles.

The distribution with depth of sand, silt, and clay in Pits 1 and 2 (Figures 7 and 8) agreed with each other. These two soils, which are derived from the same material, would be expected to be similar. The distributions for Pits 3 and 4 (Figures 9 and 10) also seemed to agree, but Pit 4 had considerably less sand than Pit 3. The percentage of 2-mm material for Pit 5 (Figure 11) indicated that the Ap horizon in the minesoil had weathered or was finer because of its topsoiled nature. The sand content increased sharply in the C1 horizon and the silt and clay fractions decreased. The increase in percent of rock fragments (>2 mm diam.) in the C1 horizon indicated that the Ap horizon had been topsoiled. The distribution of materials in Pit 6 resembled that of Pit 5.

Figure 6. Particle size summation curves for composite samples.

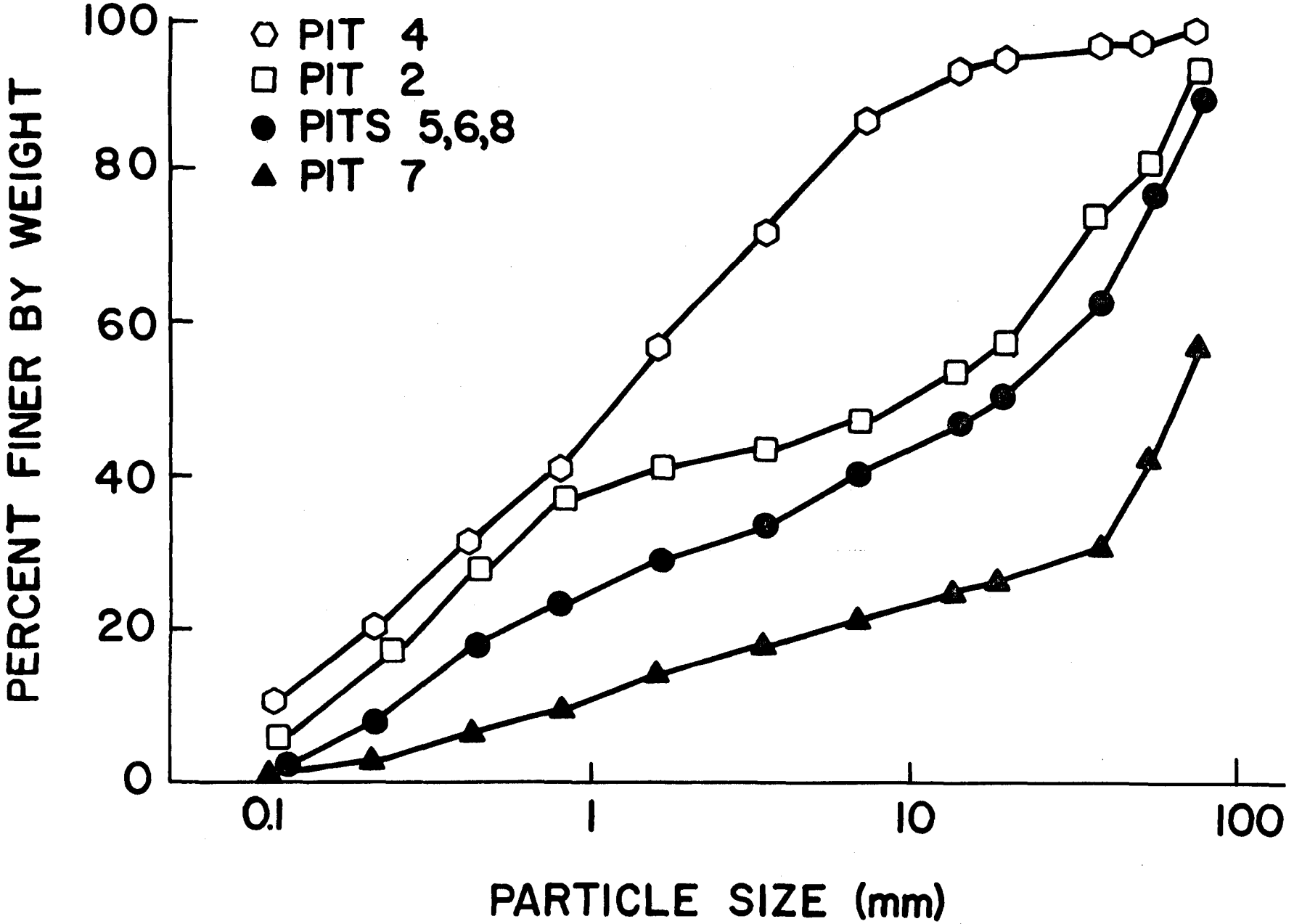

PIT 4
PIT 2
PITS 5,6,8
PIT 7
PERCENT FINER BY WEIGHT
100
80
60
40
20
0
0.1
1
10
100
PARTICLE SIZE (mm)

Figure 7. Sand, silt, clay and coarse fragment distribution with depth for Pit 1.

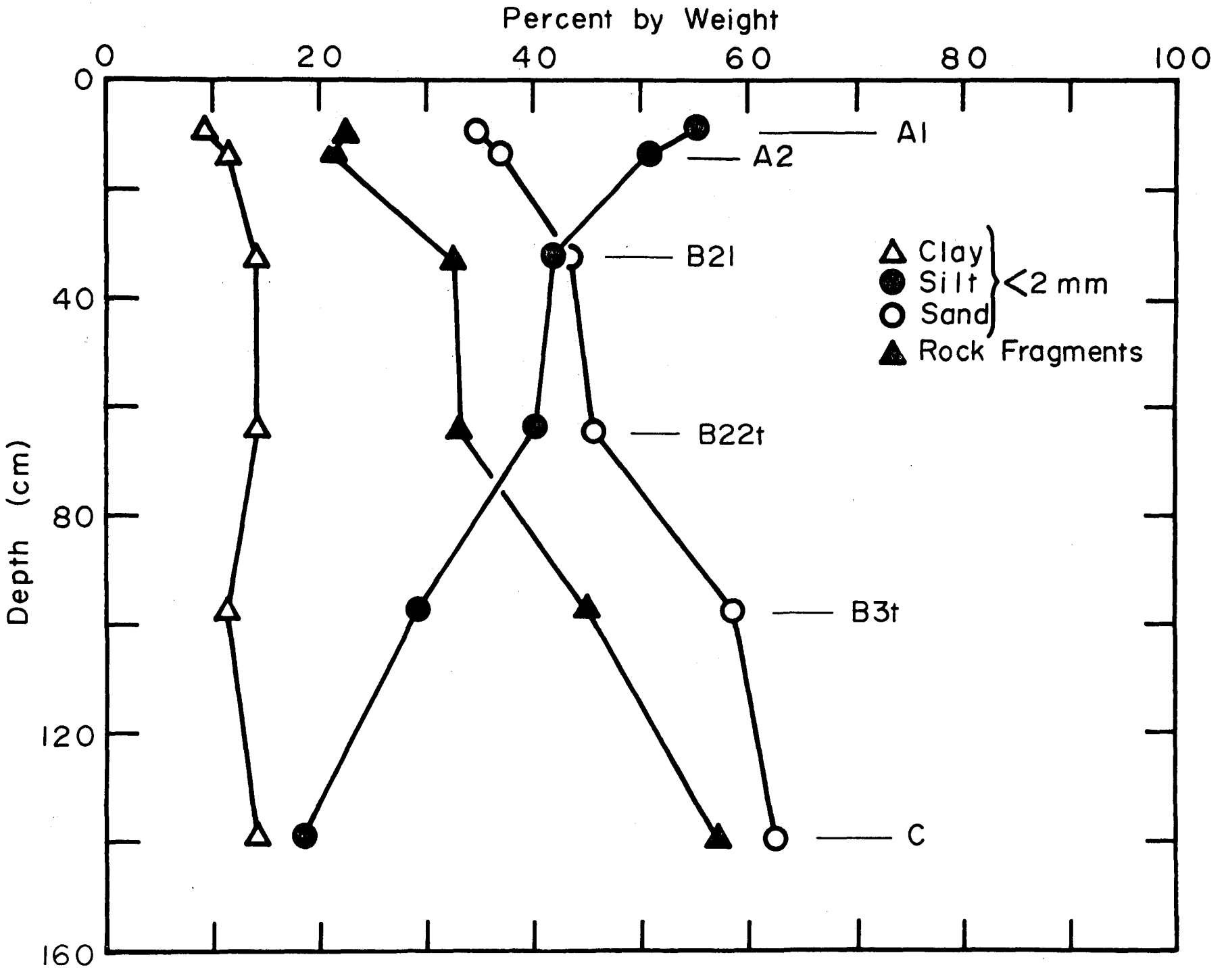

Percent by Weight
0
20
40
60
80
100
Depth (cm)
0
40
80
120
160
A1
A2
B21
B22t
B3t
C
Clay
Silt
Sand
<2 mm
Rock Fragments

Figure 8. Sand, silt, clay and coarse fragment distribution with depth for Pit 2.

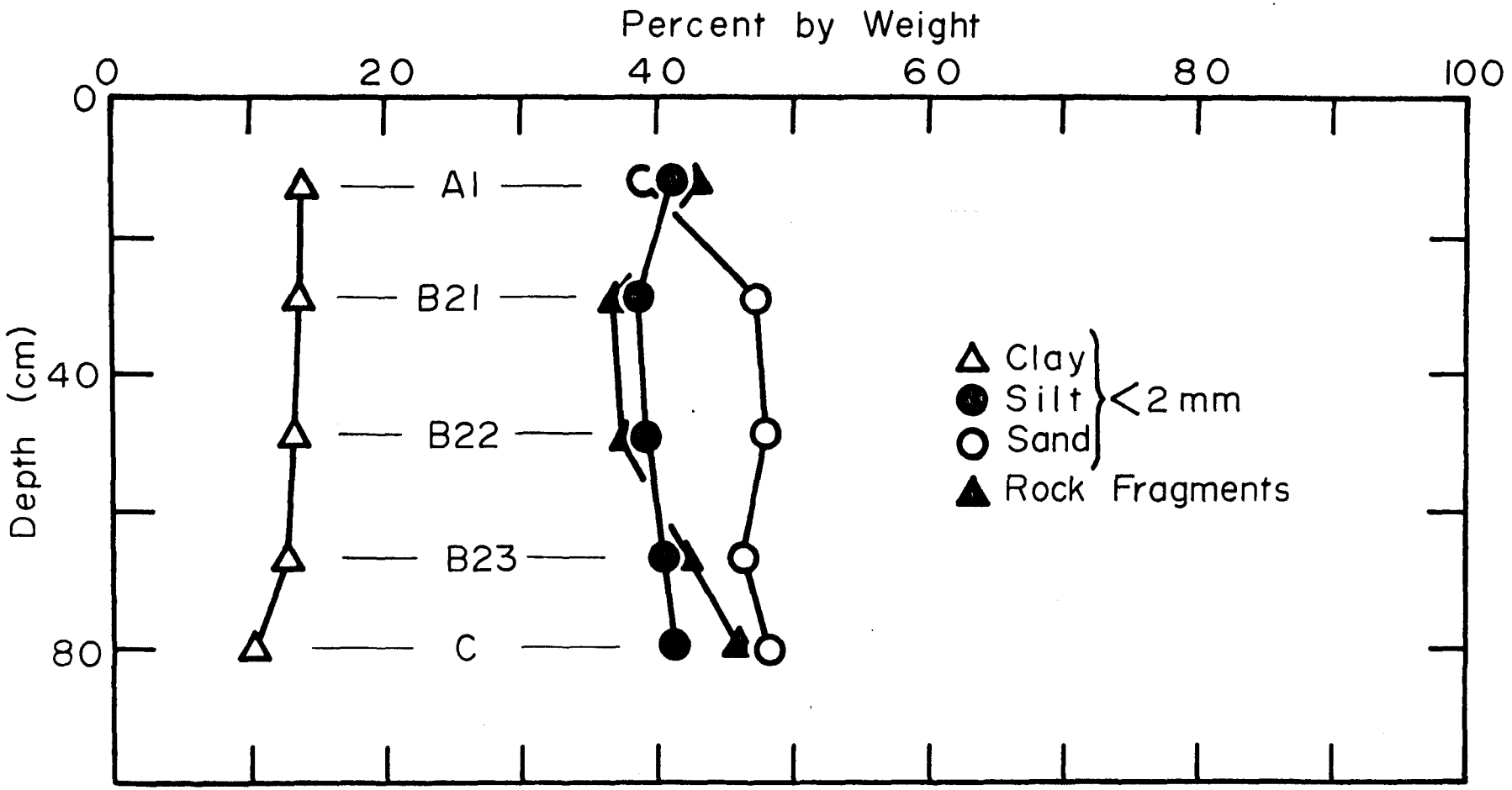

Percent by Weight
0
20
40
60
80
100
Depth (cm)
0
40
80
A1
B21
B22
B23
C
Clay
Silt
Sand
<2 mm
Rock Fragments

Figure 9. Sand, silt, clay and coarse fragment distribution with depth for Pit 3.

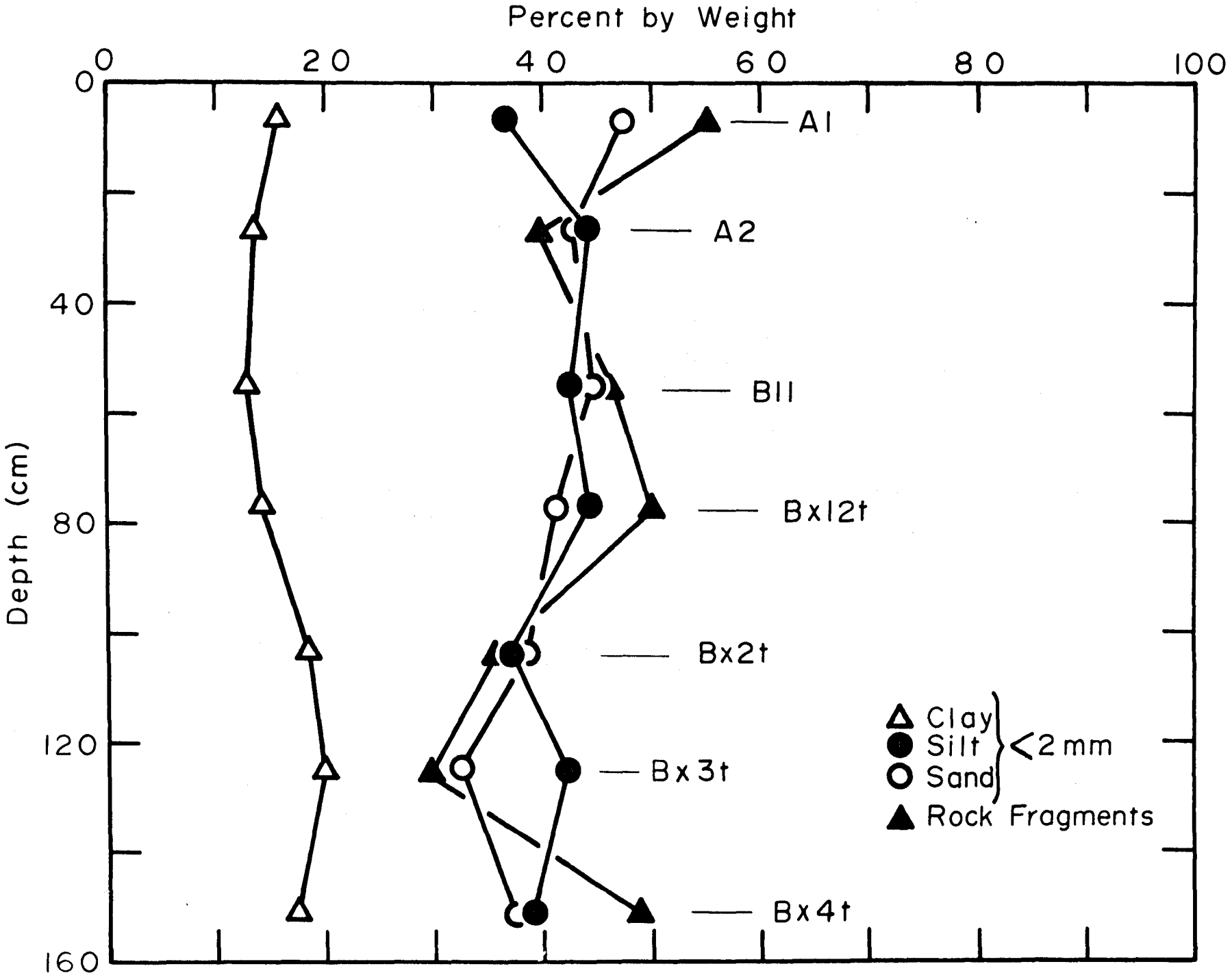

Percent by Weight
0
20
40
60
80
100
Depth (cm)
0
40
80
120
160
A1
A2
B11
Bx12t
Bx2t
Bx3t
Bx4t
Clay
Silt
Sand
<2 mm
Rock Fragments

Figure 10. Sand, silt, clay and coarse fragment distribution with depth for Pit 4.

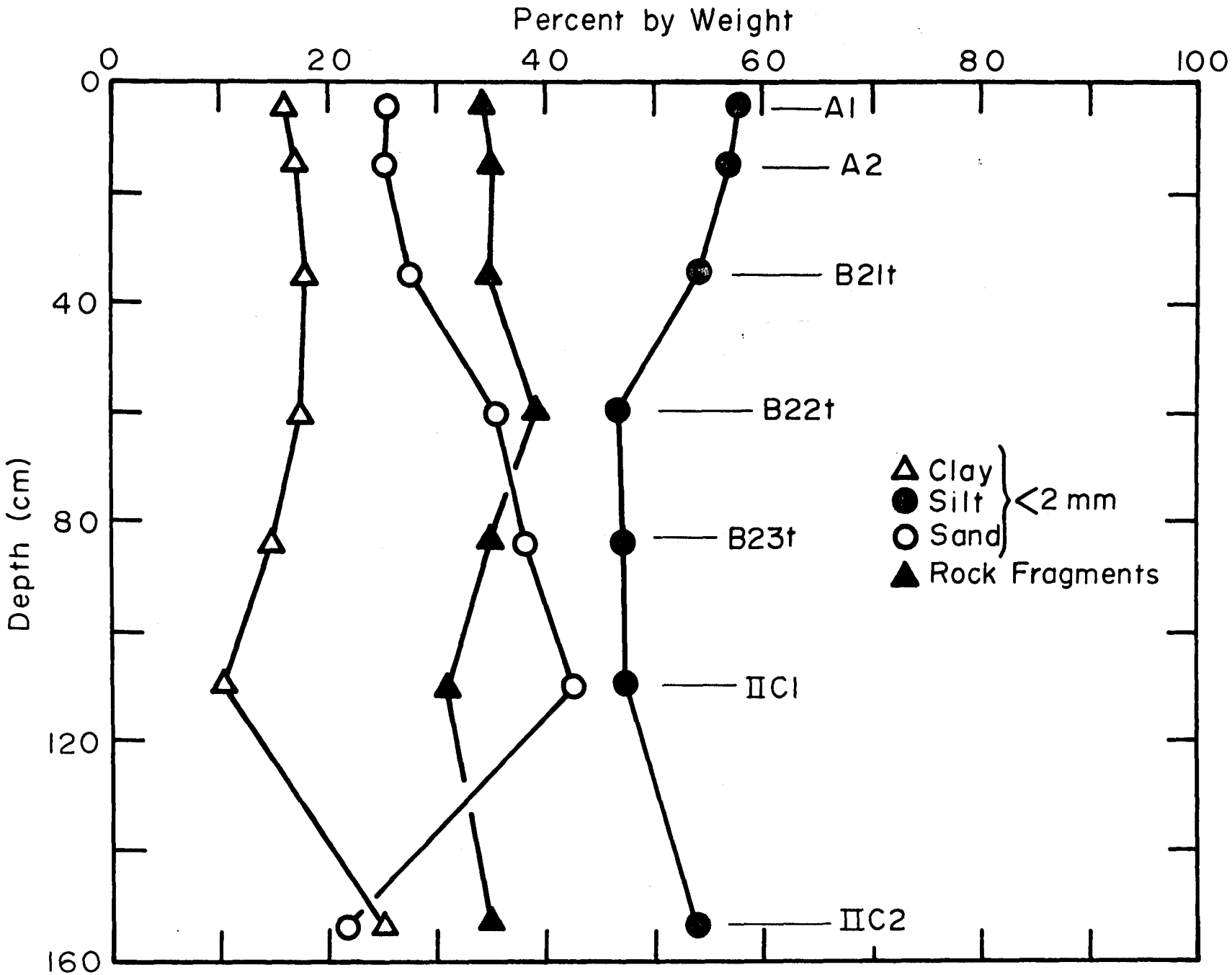
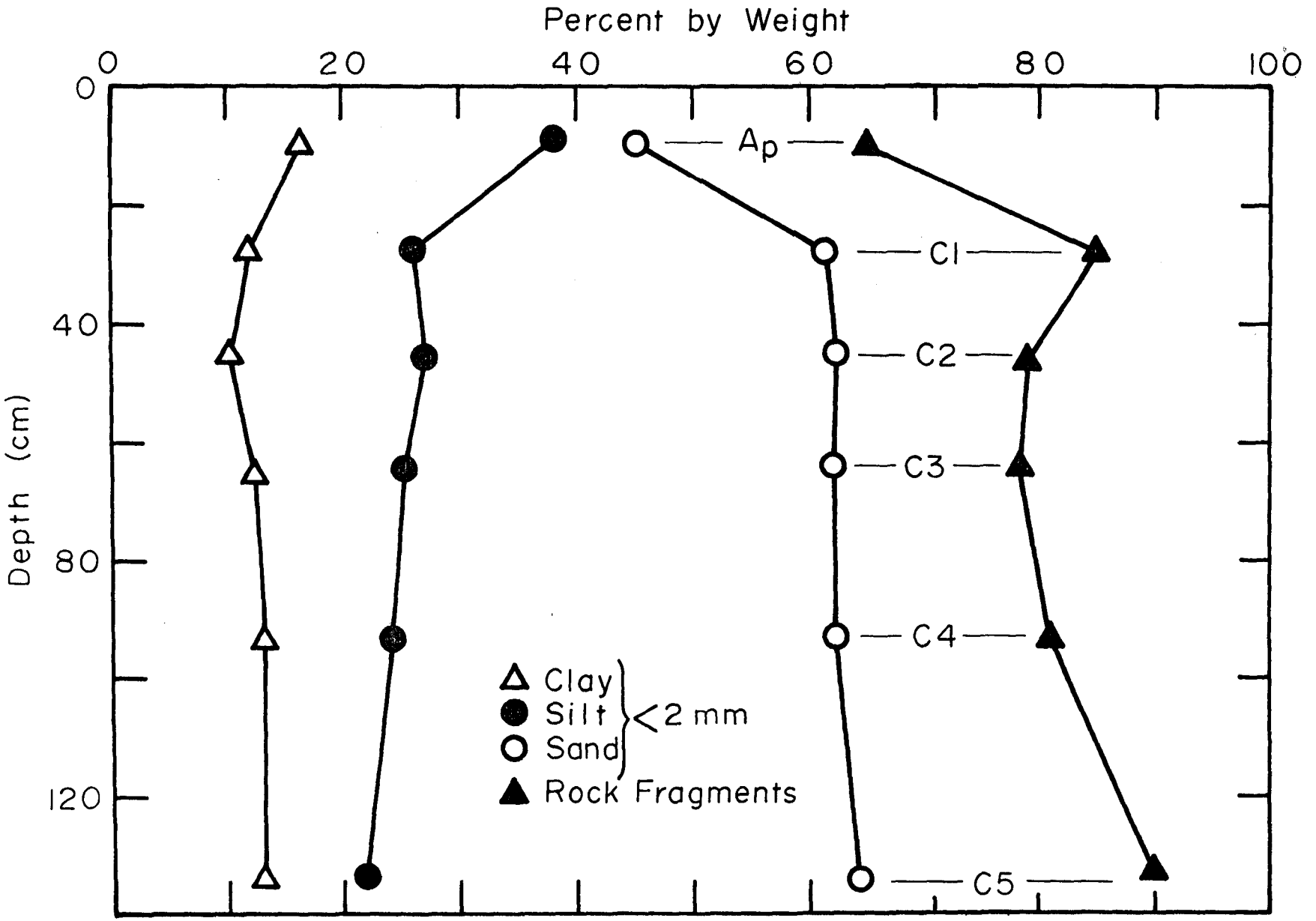

Percent by Weight
0
20
40
60
80
100
Depth (cm)
0
40
80
120
160
A1
A2
B21t
B22t
B23t
IIC1
IIC2
Clay
Silt
Sand
<2 mm
Rock Fragments

Figure 11. Sand, silt, clay and coarse fragment distribution with depth for Pit 5.


Percent by Weight
0
20
40
60
80
100
Depth (cm)
0
40
80
120
Ap
C1
C2
C3
C4
C5
Clay
Silt
Sand
<2 mm
Rock Fragments

A slight increase in sand content was apparent in the C2 horizon at Pit 7 (Figure 12). The sand, silt, and clay content in the Ap1 and Ap2 were virtually the same. The C1 horizon had less clay and more silt than the overlying horizons. The rock fragment content of the Ap2 was much less than that of the Ap1 horizon. This could indicate that fines have been eroded from the surface horizon. The rock fragment content again increased in the C1 and was eratic below 40 cm. The distribution of fines in Pit 8 was consistent with depth, and no changes were apparent either in the fines or in the rock fragment content with depth.

In general, the minesoils were dominated by sand in their fine earth fraction. The distribution of rock fragments in the minesoils was eratic and generally greater than 60%, whereas the rock fragment content of the natural soils was generally less than 50%.

In general, the minesoils had considerably less silt and more sand in their fine earth fraction, than did the natural soils.

Figure 13 shows depth distributions of percent clay (<2 μm). Clay content of the natural soils ranged from 9.6 to 24.9% and for the minesoils it ranged from 8.8 to 17.5%. The decrease in clay at about 110 cm for Pit 4 was associated with the coal blossom (IIC1). The clay content of the fine earth did not vary significantly from horizon to horizon nor from pit to pit.

The percent coarse fragments in the natural soils and minesoils is shown in Figure 14. The data showed that most materials in minesoils (by weight) were coarse fragments.

Surface horizons of the natural soils contained an average of 8.3% clay, 33.3% silt, and 19.7% sand. The remaining 38.7% was made up of material >2 mm. The surface horizons of the minesoils contained an average of 4.1% clay, 11% silt, 13% sand, and 71.9% consisted of material >2 mm.

The surface horizons of minesoils contained a greater percentage of fine soil material (<2 mm) than any underlying horizon. The amount of fine material would increase as weathering continued if removal of fines by erosion was not greater

Figure 12. Sand, silt, clay and coarse fragment distribution with depth for Pit 7.

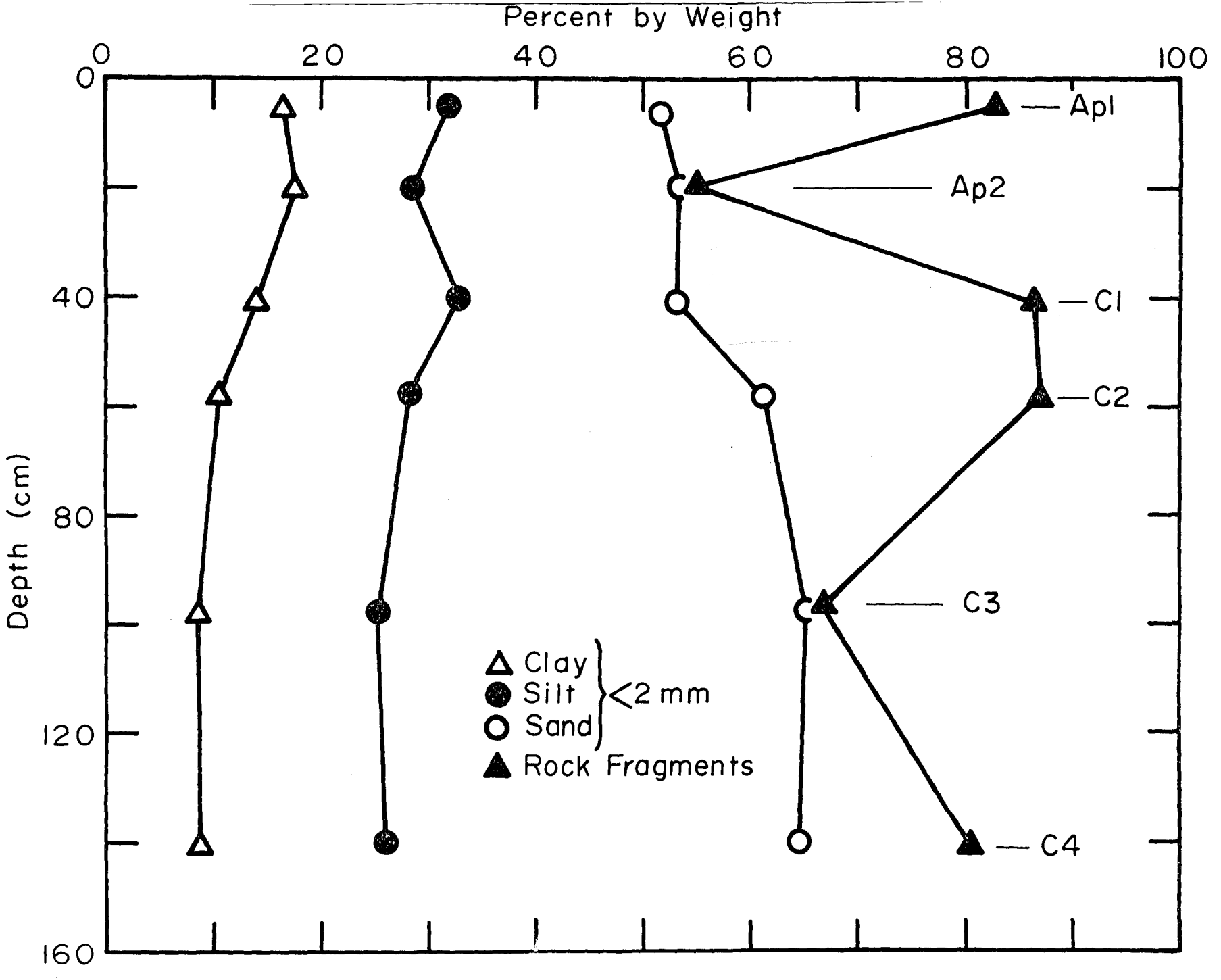

Percent by Weight
0
20
40
60
80
100
Depth (cm)
0
40
80
120
160
Ap1
Ap2
C1
C2
C3
C4
Clay
Silt
Sand
<2 mm
Rock Fragments

Figure 13. Clay (<2 μm) distribution with depth for Pits 1 through 8.

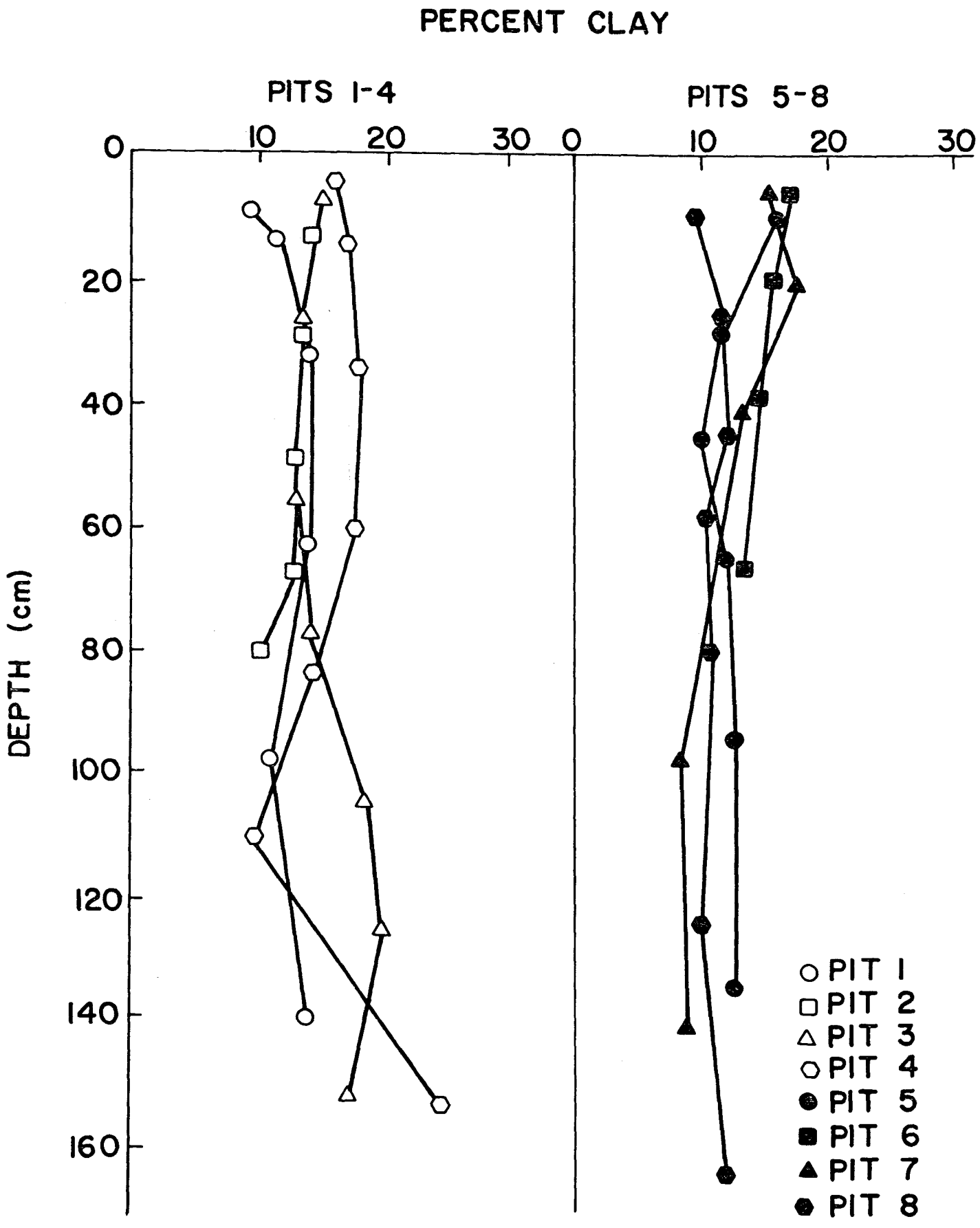
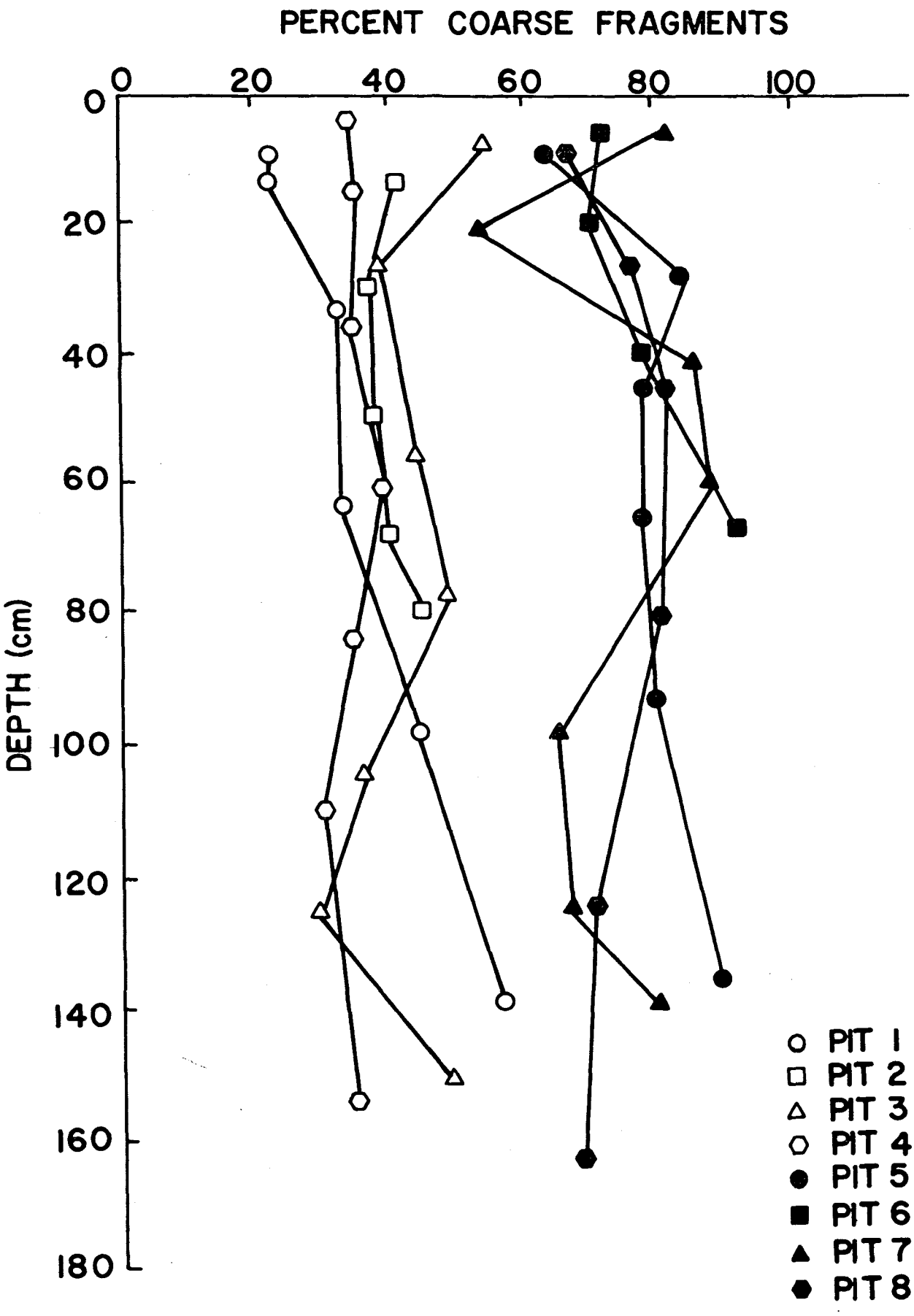

PERCENT CLAY
PITS 1-4
PITS 5-8
0
10
20
30
0
10
20
30
DEPTH (cm)
20
40
60
80
100
120
140
160
PIT 1
PIT 2
PIT 3
PIT 4
PIT 5
PIT 6
PIT 7
PIT 8

Figure 14. Coarse fragment (>2 mm) distribution with depth for Pits 1 through 8.


PERCENT COARSE FRAGMENTS
0
20
40
60
80
100
DEPTH (cm)
0
20
40
60
80
100
120
140
160
180
PIT 1
PIT 2
PIT 3
PIT 4
PIT 5
PIT 6
PIT 7
PIT 8

than their genesis. Plass and Vogel (1973) reported that the percentage of soil material (<2 mm) of natural soils in areas adjacent to minesoils ranged between 35 and 95%, whereas minesoils contained from 17 to 64% of fine material.

The minesoil contained significantly more material between 19 and 254 mm than did the natural soil. Minesoils typically were high in coarse fragment content. The high percentage of coarse material was due to the mixing of consolidated materials with the subsoil in spoil piles. The coarse fragments in the minesoils were distributed throughout the profile, possibly causing a proliferation of irregularly sized and spaced pores. These larger pores would be expected to drain faster by gravity. Coarse fragments have less surface area than equal volumes of finer material, thus reducing the surface area for adsorption of water.

Coarse-fragment data of several researchers (Smith et al., 1971; Plass and Vogel, 1973; Coleman, 1951) showed that coarse fragment content (by weight) can range from about 40 to 70%. Plass and Vogel (1973) found that for 39 West Virginian minesoils, 63% (by weight) of the minesoil was greater than 2 mm. Smith et al. (1971) studied about 100-years-old minesoil derived from Fe ore surface mining in West Virginia. The methods used to extract this ore resembled strip-mining techniques currently in use. Higher proportions of coarse fragments were found in minesoils derived from fine-grained sandstone and silty brown shales, possibly due to the increased resistance to weathering of the material, as compared with minesoils derived from dark gray and brown shales.

The soil-size material (<2 mm) of the minesoils was predominantly sand-sized, whereas silt-size-material predominated in all but Pit 3 of the natural soils.

The silt present in the natural soils was significantly greater than that in the minesoils, and the minesoils contained significantly more sand than the natural soils.

There was a highly significant difference between the minesoil and natural soil with respect to clay and sand content of the total material; the minesoil containing generally less clay and more sand.

Specific Surface--

The amount of surface area in soils is determined largely by the amounts and type of colloidal material (<2 μm) present. Of the common clay minerals, montmorillonite has the greatest specific surface per unit weight, followed by vermiculite, illite, and kaolinite (Baver et al., 1972). The specific surface areas of the natural soils and minesoils studied are presented in Tables 7 and 8, respectively. Organic C values, determined both by ignition and the Walkley-Black methods, were used to calculate specific surface of the mineral fraction.

Horizons in which montmorillonitic clays were detected (Appendix B) had high specific surface. The B21 and B22t horizons of Pit 1, and the Bx2t and Bx3t horizons of Pit 3 had higher specific surface than all other subsoil horizons. These higher values were attributed to the presence of montmorillonite. The Ap horizon of Pit 5 had a greater specific surface than any underlying horizon in this pedon also due to the presence of montmorillonite.

In general, those horizons which had greater quantities of vermiculite than illite had higher specific surfaces. The specific surface values of the minesoils were slightly less than those of the natural soils. This was probably due to their higher kaolinite and illite contents.

Bulk Density and Porosity--

Bulk density values of 10 minesoil sites are illustrated in Figure 15. Bulk densities were determined by three methods. A Troxler gamma moisture/density probe gave lower bulk density values than the other two methods at most sites (L-1, 2, 3, 4, 6, 9 and 10). However, at L-5, results for gamma probe were higher than either of the other methods, while at L-7 and L-8 gamma-probe-density values were higher than the excavation technique but lower than microlysimeter values. The steep slopes at sites L-9 and 10 made excavation difficult and measurements questionable. We found greater differences in bulk densities measurements between the methods when a larger percentage of the rock fragments was made up of shale. Average values of bulk density obtained by various methods are listed in

TABLE 7. CALCULATED VALUES OF SPECIFIC SURFACE AREA FOR PITS 1 THROUGH 4

Pit	Depth	Horizon	Specific Surface	
			Ignition	Walkley-Black
	cm		m^2/g	
1	0-3	A1	72.21	64.26
	3-10	A2	34.86	48.02
	10-41	B21	63.77	
	41-74	B22t	69.03	
	74-109	B3t	45.23	
	109-176	C	39.93	
2	0-10	A1	34.47	40.95
	10-33	B21	40.79	
	33-51	B22	56.33	
	51-71	B23	60.08	
	71-74	C	49.06	
3	0-15	A1	68.74	66.05
	15-43	A2	32.24	39.46
	43-66	B1	49.11	
	66-91	Bx1t	53.69	
	91-117	Bx2t	65.92	
	117-135	Bx3t	65.86	
	135-167	Bx4t	51.58	
4	0-8	A1	-	36.03
	8-20	A2	43.82	45.82
	20-48	B21t	59.05	48.39
	48-74	B22t	65.15	
	74-94	B23t	43.18	
	94-125	IIC1	35.03	
	125-183	IIIC2	39.79	

TABLE 8. CALCULATED VALUES OF SPECIFIC SURFACE AREA FOR PITS 5 THROUGH 8

Pit	Depth	Horizon	Specific Surface	
			Ignition	Walkley-Black
	cm		m^2/g	
5	0-20	Ap	50.49	52.83
	20-36	C1	24.29	38.26
	36-56	C2	25.91	38.07
	56-74	C3	30.06	44.74
	74-114	C4	36.09	46.39
	114-152	C5	30.06	40.67
6	0-13	Ap	49.30	49.87
	13-28	AC	29.73	39.02
	28-53	C1	26.51	35.72
	53-84	C2	29.01	34.71
7	0-10	Ap1	1.28	27.59
	10-31	Ap2	31.46	45.72
	31-51	C1	-	26.03
	51-66	C2	-	28.52
	66-127	C3	-	18.78
	127-157	C4	-	17.67
8	0-18	AC	33.04	30.31
	18-36	C1	43.83	36.64
	36-58	C2	19.86	37.54
	58-102	C3	21.11	39.71
	102-145	C4	22.18	38.81
	145-183	C5	34.78	38.72

Figure 15. Dry bulk densities of minesoil determined by various methods.

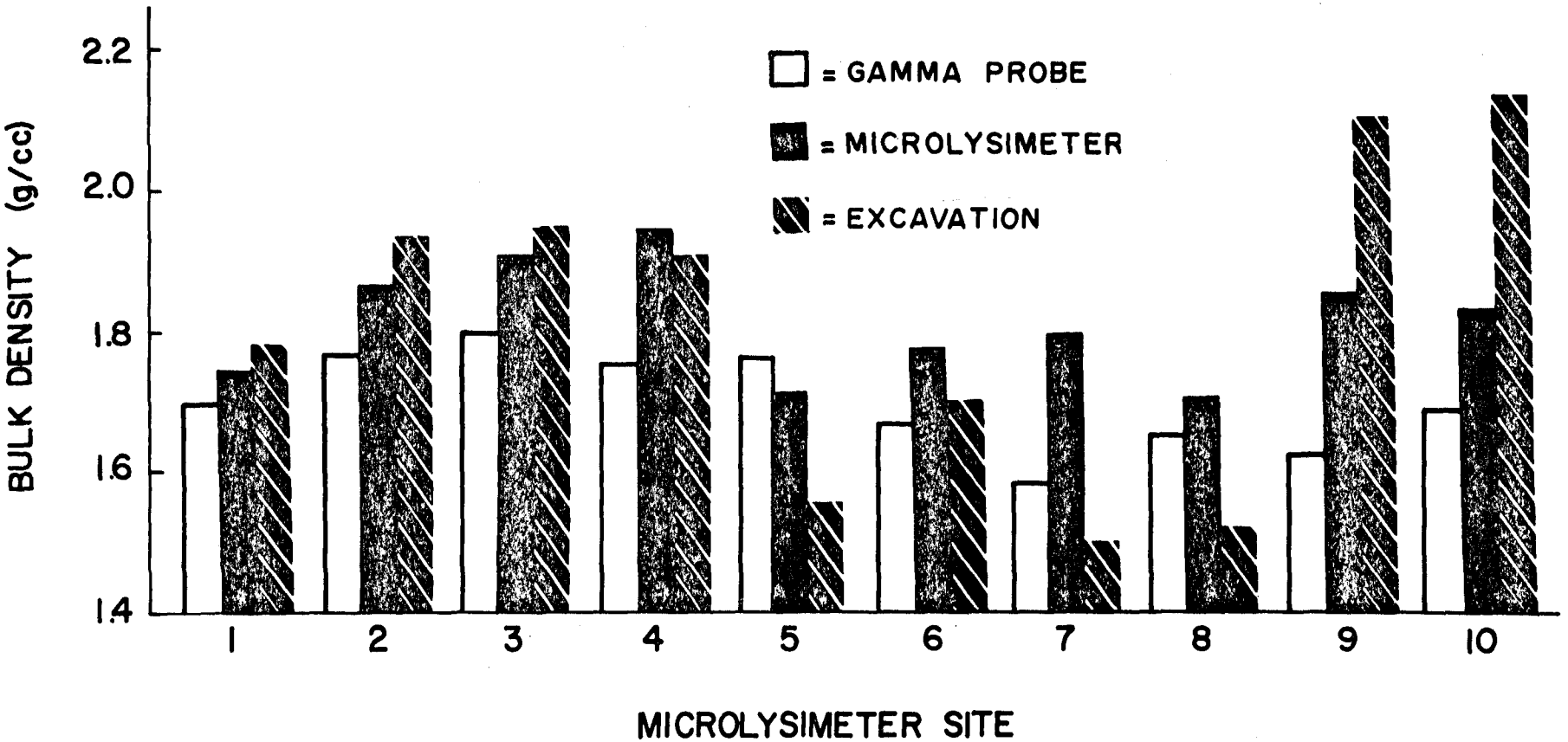

= GAMMA PROBE
= MICROLYSIMETER
= EXCAVATION
BULK DENSITY (g/cc)
2.2
2.0
1.8
1.6
1.4
1
2
3
4
5
6
7
8
9
10
MICROLYSIMETER SITE

Table 9. The bulk density values obtained with the gamma probe, excavation, lysimeter and clod methods were not significantly different from each other at the 0.05% level.

TABLE 9. BULK DENSITY STANDARD DEVIATION, AND COEFFICIENT OF VARIATION OF MINESOILS DETERMINED BY VARIOUS METHODS

Method	Mean	SD	CV%
	g/cm^3		
Excavation	1.81	0.24	13
Gamma Probe	1.70	0.19	11
Lysimeters	1.81	0.08	5
Clods	1.78	0.12	7

The average value obtained by the excavation method agreed with density of the material handpacked into the lysimeters. These lysimeters were exposed to environmental conditions after packing, after which their oven-dry densities were determined. The density of these lysimeters remained essentially unchanged after the exposure. Bulk-density determinations at three sites (L-11, L-12 and L-13) in undisturbed soil are presented in Table 10. The excavation method was not used at site L-13 because the soil material exhibited properties (i.e., platy structure, shale fragments) which indicated that it was disturbed. The A horizons at site L-11 had been eroded and the density values obtained here were probably representative of the natural soil B horizon. At site L-12 the natural soil litter layer was removed before density determinations. Excavation was difficult in this wooded area because of the many large roots present in the soil and voids in the soil material were created when roots were removed. These voids, as well as the roots, tended to lower the bulk density value of the soil determined by excavation.

Clod data (Appendix B) showed that bulk densities of the natural soils increased with depth. Bulk density of surface horizons of the natural soils (Pits 1 and 2) ranged from 0.88 to 1.39 g/cm^3. Very few clods were obtained for determination of surface bulk density in the minesoils. Bulk densities of clods

obtained at the lysimeter sites are presented in Table 11. The average density of the surface minesoils obtained at the lysimeter sites was 1.78 g/cm^3, whereas the density of the surface clods obtained at Pits 5 and 7 averaged 2.20 g/cm^3.

TABLE 10. BULK DENSITIES OF NATURAL SOILS

Site	Method	
	Gamma Probe	Excavation
	g/cm^3	
L-11	1.75	1.99
L-12	1.26	1.52
L-13	1.79	-

TABLE 11. BULK DENSITIES OF MINESOILS DETERMINED BY THE CLOD METHOD

Site	Bulk Density Values	
	Uncorrected	Corrected
	g/cm^3	
L-1	1.78	1.42
	1.71	1.65
	1.60	1.58
L-4	1.83	1.63
L-5	1.71	1.66
	1.89	1.65
	1.72	1.57
L-6	1.65	1.52
	1.86	1.75
	1.73	1.51
L-7	1.68	1.61
	1.69	1.63
	1.72	1.63
L-8	1.40	1.39
	1.56	1.51
	1.43	1.37
L-9	1.97	1.80
	1.69	1.60
	1.80	1.75

The excavation technique had the highest coefficient of variation, whereas the lysimeters had the lowest. The mean bulk density value of the sites did not vary significantly from one another. The gamma probe gave reasonable results, which were comparatively easy to obtain. This method was acceptable when total density was desired, however, when values corrected for coarse fragments were desired, additional samples were needed.

Bulk densities reported by Smith et al. (1971) for minesoil ranged from 1.41 to 1.52 g/cm^3, whereas those for natural soils ranged from 0.90 to 1.13 g/cm^3. The corrected values obtained from the surface minesoils in this study ranged from 1.39 to 1.85 g/cm^3. The surface soils of Pits 1 through 4 had average bulk densities of 1.02, 1.08, 1.63, and 1.40, respectively.

The higher bulk densities in the minesoils were attributed in part to the higher coarse fragment content of these materials. The minesoils were also coarser textured (loam to sandy loam) than the natural soils (silt loam to loam). The coarser-textured materials tended to pack closer increasing the bulk density. Higher bulk densities could also be attributed to the compacted state of this material. The effect of organic matter on decreasing bulk density in the natural soil is usually correlated with structural development.

Calculated porosities for B-spoil and C-spoil surface minesoil were 39 and 34%, respectively, whereas the surface soils of Pits 1 and 2 had an average of 65% pore space. Smith et al. (1971) found minesoils had from 40 to 47% pore space as compared with 57 to 66% for associated soils.

Coarse-textured soils with little organic matter usually have porosities between 30 and 40% (Nielsen et al., 1964). Natural soils are porous due to their intricately developed system of cracks and fissures. Pores in minesoils are generally larger but fewer.

The degree of soil structural development decreased as profile depth of the minesoil increased. The subsurface horizons were usually characterized as structureless and massive. Because of structural deterioration related to

mining processes, minesoils tended to be denser and less porous than naturally occurring soils.

Freeze, thaw, root action, and organic matter accumulation normally would be expected to decrease the bulk density and increase the porosity of the minesoil with time.

Soil Water

Moisture Characteristics--

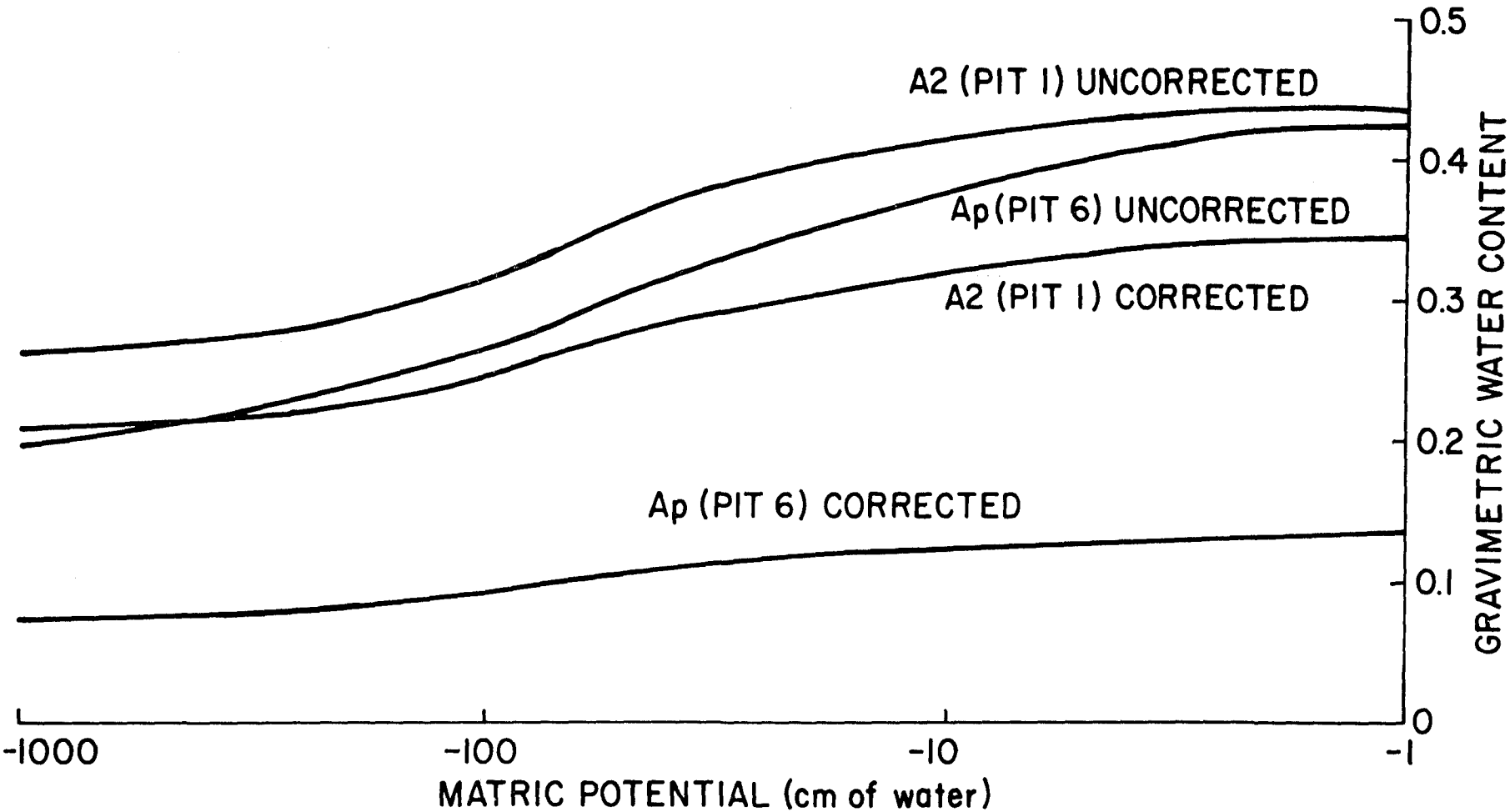
Detailed moisture characteristics of soils and minesoils studied are tabulated in Appendix E.

The average amount of water retained (uncorrected) at any matric potential by the A or B horizons of the natural soils was greater than that retained by the A horizons of the minesoils. The fragipan horizon at Pit 3 also was more effective in retaining water than the minesoils. At equal matric potential, the amount of water retained by the C horizons of the natural soils resembled that retained by the C horizons of the minesoils.

The minesoils generally had loam A horizons and sandy loam C horizons, whereas the natural soils had silt loam to loam A horizons and loam to fine sandy loam C horizons. The textural differences and organic matter deficiencies of the minesoils accounted for their lower water-holding capacities. When corrected for coarse fragments, the minesoils retained substantially less water than comparable natural soil horizons.

Moisture characteristics for the A2 and Ap horizons of Pit 1 and Pit 6, respectively, are presented in Figure 16. These horizons were found at about the same depth and both had silt loam textures. When corrected for coarse fragments, the curve of the A2 horizon (Pit 1) was not displaced as much as that of the Ap (Pit 6) horizon. The Ap horizon, corrected for coarse fragments, retained much less water at comparable matric potential than the A2 horizon. At higher water contents, the water retained by both horizons approximated each other.

Figure 16. Moisture characteristics for A2 horizon, Pit 1, and Ap horizon, Pit 6.


A2 (PIT 1) UNCORRECTED
Ap(PIT 6) UNCORRECTED
A2 (PIT 1) CORRECTED
Ap (PIT 6) CORRECTED
0.5
0.4
0.3
0.2
0.1
0
GRAVIMETRIC WATER CONTENT
-1000
-100
-10
-1
MATRIC POTENTIAL (cm of water)

less water at comparable matric potential than the A2 horizon. At higher water contents, the water retained by both horizons approximated each other.

Figure 17 shows the moisture characteristics of the B22 (Pit 2) and C2 (Pit 8) horizons. Both of these horizons were found at about the same depths and both had loam textures. The uncorrected curves of the soils and minesoils did not differ from one another appreciably. However, corrected curves showed the effect of coarse fragments on moisture retention.

Water Retention

The percentage of water retained (by weight) at -15 bar matric potential of the natural soils and minesoils corrected for coarse fragments are tabulated in Tables 12 and 13, respectively. The surface horizons of the natural soils retained more water at this matric potential than any subsoil horizons, except the IIC1 horizon of Pit 4. This horizon, being composed largely of organic material, was able to retain more water than other horizons within this pedon. The surface horizons of minesoils did not retain significantly more water at -15 bar than their subsurface horizons.

Tables 14 and 15 give values of water retained between -0.3 and -15 bar matric potential, for natural soils and minesoils, respectively. The amounts of water retained in both natural soils and minesoils generally decreased with increasing depth of the pedons. The surface horizons of the natural soils were able to retain more water due to their organic matter content and structural development. The natural soils retained an average of 14.3% (0.143 g of water/g of soil), whereas the minesoil retained only 10.3%. This difference is even more pronounced when moisture characteristics are corrected for coarse fragments. The water content in the separate horizons of the minesoil ranged from 5.5 to 16.7% as compared with 7.1 to 39.2% in the natural soils. The minesoil located within the B-spoil (Pit 7) had the lowest water content.

Plass and Vogel (1973) reported that minesoils were able to supply ample water to plants under normal environmental conditions. However, under stress conditions the amount of water available to plants in minesoils could be critically low due

Figure 17. Moisture characteristics for B22 horizon, Pit 2, and C2 horizon, Pit 8.

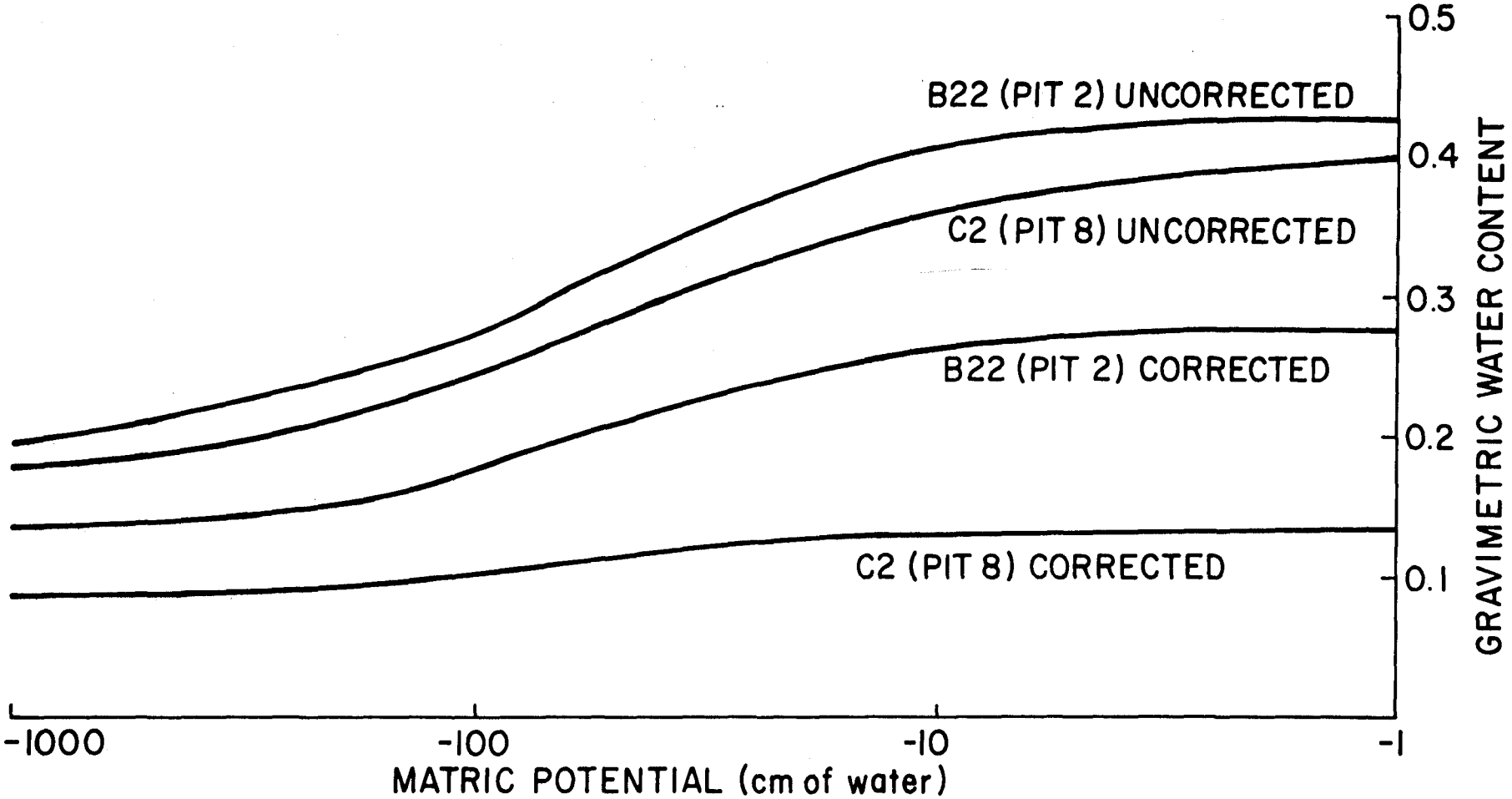

B22 (PIT 2) UNCORRECTED
C2 (PIT 8) UNCORRECTED
B22 (PIT 2) CORRECTED
C2 (PIT 8) CORRECTED
0.5
0.4
0.3
0.2
0.1
GRAVIMETRIC WATER CONTENT
-1000
-100
-10
-1
MATRIC POTENTIAL (cm of water)

TABLE 12. GRAVIMETRIC WATER CONTENT AT -15 BAR MATRIC POTENTIAL FOR NATURAL SOILS

Site	Depth	Horizon	Mean	SD*	CV†
	cm		g/g		%
P-1	0-3	A1	0.1821	0.0104	5.73
	3-10	A2	0.0768	0.0003	0.42
	10-41	B21	0.0890	0.0028	3.14
	41-74	B22t	0.0942	0.0042	4.46
	74-109	B3t	0.0612	0.0004	0.71
	109-176	C	0.0544	0.0019	3.40
P-2	0-19	A1	0.0976	0.0048	4.92
	10-33	B21	0.0621	0.0007	1.11
	33-51	B22	0.0798	0.0010	1.24
	51-71	B23	0.0815	0.0002	0.19
	71-74	C	0.0670	0.0021	3.08
P-3	0-15	A1	0.1109	0.0037	3.31
	15-43	A2	0.0649	0.0001	0.15
	43-66	B1	0.0679	0.0015	2.14
	66-91	Bx1t	0.0738	0.0009	1.16
	91-117	Bx2t	0.0886	0.0023	2.64
	117-135	Bx3t	0.0905	0.0008	0.89
	135-167+	Bx4t	0.0727	0.0001	0.19
P-4	0-8	A1	0.0728	0.0009	1.23
	8-20	A2	0.0700	0.0012	1.68
	20-48	B21t	0.0866	0.0025	2.87
	48-74	B22t	0.0896	0.0042	4.67
	74-94	B23t	0.0785	0.0009	1.08
	94-125	IIC1	0.1365	0.0015	1.06
	125-183+	IIIC2	0.0812	0.0008	0.92

*Standard deviation.

†Coefficient of variation.

TABLE 13. GRAVIMETRIC WATER CONTENT AT -15 BAR MATRIC POTENTIAL FOR MINESOILS

Site	Depth	Horizon	Mean	SD*	CV†
	cm		g/g		%
P-5	0-20	Ap	0.0719	0.0012	1.67
	20-36	C1	0.0590	0.0019	3.30
	36-56	C2	0.0592	0.0016	2.75
	56-74	C3	0.0671	0.0013	1.86
	74-114	C4	0.0696	0.0017	2.39
	114-152	C5	0.0609	0.0014	2.24
P-6	0-13	Ap	0.0759	0.0009	1.14
	13-28	AC	0.0657	0.0009	1.33
	28-53	C1	0.0594	0.0040	6.74
	53-84	C2	0.0528	0.0006	1.04
P-7	0-10	Ap1	0.0662	0.0020	3.00
	10-31	Ap2	0.0776	0.0011	1.38
	31-51	C1	0.0661	0.0008	1.21
	51-66	C2	0.0721	0.0015	2.02
	66-127	C3	0.0645	0.0013	1.96
	127-154	C4	0.0620	0.0005	0.74
P-8	0-18	AC	0.0542	0.0007	1.20
	18-36	C1	0.0655	0.0005	0.81
	36-58	C2	0.0681	0.0009	1.25
	58-102	C3	0.0684	0.0001	1.50
	102-145	C4	0.0731	0.0006	0.82
	145-183	C5	0.0853	0.0009	1.02

*Standard deviation.

†Coefficient of variation.

TABLE 14. WATER RETAINED BETWEEN -0.3 AND -15 BAR MATRIC POTENTIAL FOR PITS 1 THROUGH 4

Site	Depth	Horizon	Water Retained
	cm		g/g
P-1	0-3	A1	0.3918
	3-10	A2	0.2020
	10-41	B21	0.1136
	41-74	B22t	0.1214
	74-109	B3t	-
	109-176	C	-
P-2	0-10	A1	-
	10-33	B21	-
	33-51	B22	0.1302
	51-71	B23	0.0856
	71-74	C	0.1259
P-3	0-15	A1	0.0804
	15-43	A2	0.1931
	43-66	B1	0.1410
	66-91	Bx1t	0.1338
	91-117	Bx2t	0.1468
	117-135	Bx3t	0.0936
	135-167+	Bx4t	0.0709
P-4	0-8	A1	0.1525
	8-20	A2	0.1240
	20-48	B21t	0.1478
	48-74	B22t	0.1420
	74-94	B23t	0.1323
	94-125	IIC1	0.1673
	125-183+	IIIC2	0.1100

TABLE 15. WATER RETAINED BETWEEN -0.3 AND -15 BAR MATRIC POTENTIAL FOR PITS 5 THROUGH 8

Site	Depth	Horizon	Water Retained
	cm		g/g
P-5	0-20	Ap	0.1078
	20-36	C1	0.0862
	36-56	C2	0.0804
	56-74	C3	0.1013
	74-114	C4	0.0989
	114-152	C5	0.0973
P-6	0-13	Ap	0.1396
	13-28	AC	0.0975
	28-53	C1	0.0696
	53-84	C2	0.0605
P-7	0-10	Ap1	0.0999
	10-31	Ap2	0.0996
	31-51	C1	0.1108
	51-66	C2	0.0928
	66-127	C3	0.0660
	127-154	C4	0.0550
P-8	0-18	AC	0.1667
	18-36	C1	0.0957
	36-58	C2	0.1246
	58-102	C3	0.1394
	102-145	C4	0.1175
	145-183	C5	0.1668

to the larger pores, coarser texture, and greater percentage of rock fragments in the minesoils.

Field Soil Water--

Gravimetric and volumetric water contents of the lysimeters at saturation and "field capacity" are shown in Table 16. The amount of water retained by the minesoils 2 days after 3 cm of rain along with water retained by clods at -1/3 bar matric potential are shown in Table 17. The clods retained less water than the gravimetric sample at "field capacity" in all cases. However, water retention of sieved samples from the surface horizons of the minesoils, corrected for coarse fragments, at -0.3 bar, agreed with values obtained from the gravimetric samples. The average corrected values for the surface horizons retention for Pits 5 through 8 (Appendix E) was 9.1% as compared with 8.3% retained by gravimetric samples.

The field capacity of the minesoils (determined gravimetrically) did not agree closely with values obtained from the lysimeters. "In situ" determinations yielded between 6 and 12% (by weight) of water retention, whereas the minesoils in the microlysimeters retained from 12 to 19% of water after 2 days of drainage.

Particle-size-distribution data for the lysimeters are presented in Table 18. Lysimeters, which contained greater amounts of material >76 mm had lower field capacity values. Thus, L-8, which had the greatest amount of material >76 mm retained the least amount of water at "field capacity."

Evapotranspiration--

Meteorological data collected during the evapotranspiration study are presented in Appendix F. Evapotranspiration losses (ET), determined by a model (Ritchie, 1972), A-pan data, and lysimeter data are presented in Table 19.

Lysimeter 4 had an average ET of 0.22 cm/day for the period of October 19 through November 2. During this same period, the model gave a value of 0.15 cm/day and the A-pan a value of 0.23 cm/day.

TABLE 16. GRAVIMETRIC (G) AND VOLUMETRIC (V) WATER CONTENTS OF LYSIMETERS AT SATURATION AND "FIELD CAPACITY"

Site	Saturated		"Field Capacity"	
	G*	V†	G	V
	g/g	cm^3/cm^3	g/g	cm^3/cm^3
L-1	0.213	0.367	0.185	0.318
L-2	0.258	0.502	0.187	0.364
L-3	0.193	0.365	0.155	0.294
L-4	0.158	0.324	0.120	0.246
L-5	0.234	0.352	0.176	0.264
L-6	0.218	0.353	0.150	0.241
L-7	0.198	0.279	0.173	0.245
L-8	0.218	0.331	0.129	0.195
L-9	0.232	0.484	0.123	0.256
L-10	0.222	0.489	0.147	0.323

*G is water content by weight.

†V is water content by volume.

TABLE 17. GRAVIMETRIC (G) AND VOLUMETRIC (V) WATER CONTENT AT "FIELD CAPACITY"

Site	Gravimetric Samples*		Clods -1/3 Bar
	G	V	V
	g/g	cm^3/cm^3	
L-1	0.106	0.180	0.143
L-2	0.088	0.155	-
L-3	0.082	0.150	-
L-4	0.082	0.159	0.106
L-5	0.091	0.161	0.109
L-6	0.092	0.177	0.116
L-7	0.105	0.125	0.114
L-8	0.079	0.103	0.078
L-9	0.062	0.130	0.085
L-10	0.121	0.128	-

*Gravimetric samples obtained 2 days after 3 cm rain.

TABLE 18. PARTICLE SIZE DISTRIBUTION OF LYSIMETERS BY WEIGHT

Site	Particle Size >76 mm	76-19 mm	<19 mm
	%		
L-1	4.95	7.03	88.02
L-2	3.89	22.17	73.94
L-3	6.71	23.75	69.54
L-4	0	18.45	81.55
L-5	0	10.87	89.13
L-6	8.05	16.11	75.84
L-7	0	13.02	86.98
L-8	15.25	20.70	64.05
L-9	7.20	16.42	76.38
L-10	0	25.97	74.03

Figure 18 presents the cumulative evapotranspiration during the study period measured by lysimeters and A-pan evaporation. The evapotranspiration from both the B and C spoil minesoil by the lysimeters was approximated by A-pan evaporation.

Because of the large amount of rainfall over the study period, many seepage values obtained were inaccurate. Seepage in excess of the amount of rainfall indicated that water collected in the pans and bags due to either interflow, runoff, or both. Temperatures also fell below freezing during the study period having an adverse effect on the evapotranspiration estimates.

Soil-Water Movement

Infiltration--

Infiltration data (Table 20) indicated the extreme heterogeneous behavior of the minesoil. In Figure 19, cumulative infiltration was plotted against elapsed time. The infiltration rates on the shaly B-spoil (I-7, I-8, K-Plot) and those on the C-spoil (I-4, I-6) were lower on the average than on natural soil (I-1, I-2).

The surface horizons of the soil at infiltration site I-1 had been eroded. The infiltration rates probably represented natural subsoil (B horizons).

TABLE 19. EVAPOTRANSPIRATIONAL LOSS ESTIMATED BY VARIOUS METHODS

Mo/Day	Model	A-Pan	Lysimeter 1	2	3	4	5	6	7	8	9	10
	cm											
9/28	.49	.62									.1	
10/1	.24	.46	.8	.3	.3	5.4	.3		.2	.2	.2	
10/5	.68	.61				2.2	.6				.6	
10/8	.26	.50				2.1					.1	
10/12	.50	.76		1.4		2.3	.5				2.3	
10/15	.53	.44		.7	.8	1.2	.8		.5	.7	.7	.6
10/19	.58	.89		.4	.4	.7	.3	.2	.2	.2	.5	.2
10/22	.29	.85				.7					.2	
10/26	.26	.33				.6					.6	
10/29	.47	.52		4.3	.6	.5	.5	.5		.4	.3	.6
11/2	.41	.35			.2	.3	.4	.4			.2	
Total	4.71	6.33									5.8	

Figure 18. Cumulative evapotranspiration (ET) from lysimeters, and evaporation from A-pan during study.

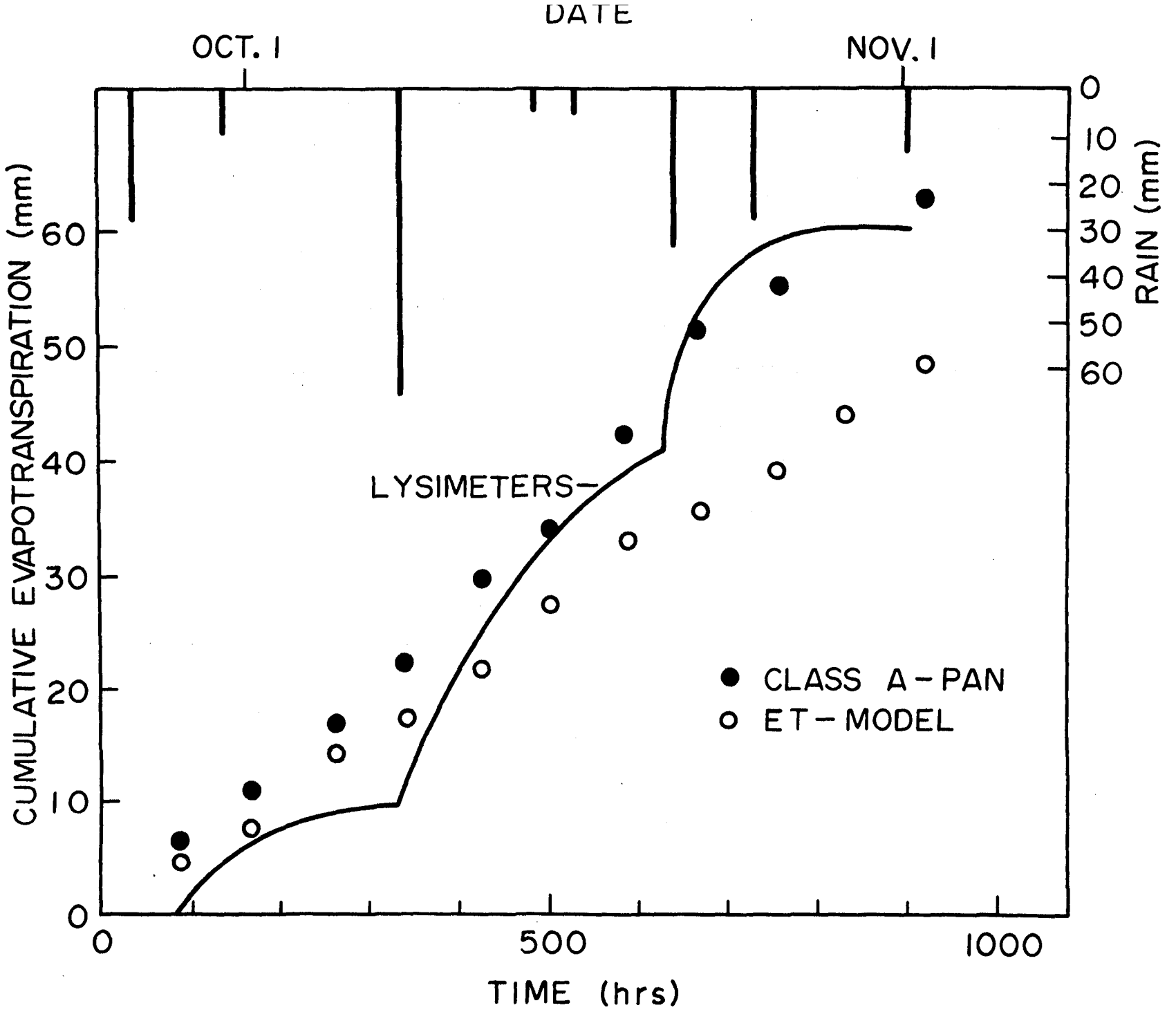

DATE
OCT. 1
NOV. 1
CUMULATIVE EVAPOTRANSPIRATION (mm)
RAIN (mm)
LYSIMETERS
CLASS A-PAN
ET-MODEL
TIME (hrs)
0
10
20
30
40
50
60
500
1000

Figure 19. Infiltration on minesoil using single ring infiltrometer (I), and infiltration on the unsaturated hydraulic conductivity plot (K-Plot).

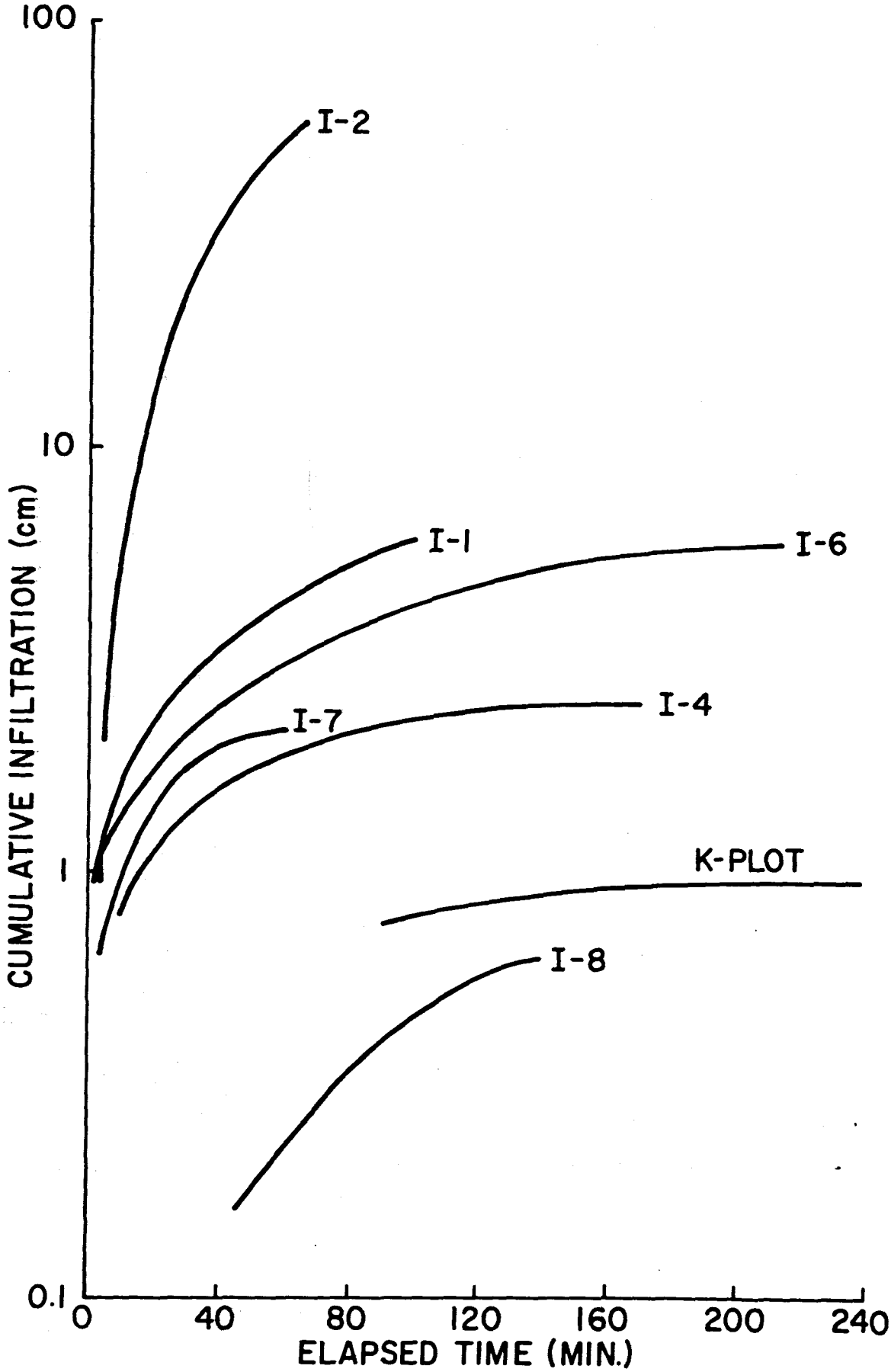

100
10
1
0.1
CUMULATIVE INFILTRATION (cm)
I-2
I-1
I-6
I-4
I-7
K-PLOT
I-8
0
40
80
120
160
200
240
ELAPSED TIME (MIN.)

TABLE 20. INFILTRATION RATES ON MINESOILS AND NATURAL SOILS

Site	Material	Infiltration Rate	
		Initial	Final
		cm/hr	
I-1	Soil	14.01	2.67
I-2	Soil	60.30	28.22
I-4	C-spoil	1.91	0.32
I-6	C-spoil	28.57	0.48
I-7	B-spoil	9.52	0.32
I-8	B-spoil	0.48	0.48
K-Plot	B-spoil	0.75	0.11

At site I-2, the organic litter layer was removed before installation of the infiltrometer.

The B-spoil minesoil at I-8 and K-Plot sites had lower initial infiltration rates than the I-4 and I-6 C-spoil because of compaction and packing of these shaly materials, which have broken down more easily than the sandstone material of the C-spoil. The higher infiltration amounts on the I-6, C-spoil could be related to better structural development and vegetative cover. Infiltration curves for sites I-4, I-6, and I-7 showed the characteristic decrease in infiltration rate with time, as contrasted with Coleman's (1951) findings that infiltration rates on minesoils had a lag period, after which they increased significantly. The increasing infiltration rates, reported by Coleman (1951), could possibly have been due to washing of fines from the surface horizons. Coleman (1951) studied spoil that had not been topsoiled and found higher infiltration rates on shaly materials (>240 cm/hr) than on adjacent natural soils (<70 cm/hr). Verma and Thames (1975) reported lower final infiltration rates on minesoils as compared with natural soils. They found the average final infiltration rate on the minesoil was 0.4 cm/hr as compared with 14.7 cm/hr on the natural soils. Jones et al. (1975) found infiltration rates on minesoils ranging from 0.08 to 0.74 cm/hr using a double-ring

infiltrometer. Final infiltration rate on Kylertown minesoils was 0.40 cm/hr, which agreed with values reported previously (Jones et al., 1975; Verma and Thames, 1975), and final infiltration on contiguous natural soils was 15.4 cm/hr. Smith et al. (1971) noted significantly higher infiltration rates for soils as compared with associated minesoils. Rates of infiltration also tended to decrease with increasing percentage soil-size material on minesoils (Coleman, 1951). The dense compact nature of the surface horizon of minesoils also contributed to lower infiltration rates.

Infiltration on the K-Plot was extremely slow and decreased with time from 0.75 cm/hr after 1.5 hr to less than 0.11 cm/hr after 60 hours. Because water was added to the plot at a slow rate, the initial infiltration reading was taken after the maximum rate had passed.

Saturated Hydraulic Conductivity--

Saturated hydraulic conductivity values of the 10 lysimeters are presented in Table 21. The conductivities were measured before (I) and after (II) 4 months of field exposure. Extreme variability in conductivity existed between the lysimeters. The very high values obtained for the second run (L-6, L-8) were due to initial washing out of fine material from the lysimeters. The conductivities generally were less after being exposed to the elements and ranged from 0.4 to >300 cm/hr.

Use of these lysimeters as an estimate of saturated hydraulic conductivities did not prove successful. Problems associated with flow along the walls of the container as well as voids created by packing were evident.

Unsaturated Hydraulic Conductivity--

Tensiometer readings taken during water addition are presented in Table 22. From these data, no indication of a uniform wetting front advance was apparent. The matric potential of the minesoils over time indicated a general drying trend.

TABLE 21. SATURATED HYDRAULIC CONDUCTIVITIES (K), SAMPLING VARIABILITY (S), AND RELATIVE MEASURE OF VARIABILITY (S/K), BEFORE (I) AND AFTER (II) 4 MONTHS OF EXPOSURE

Site	I			II		
	K	S	log S/log K	K	S	log S/log K
	cm/hr		%		cm/hr	%
L-1	3.0	2.0	63	0.3	1.5	>100
L-2	17.5	2.1	26	2.0	1.1	14
L-3	7.0	1.8	30	2.8	1.1	9
L-4	12.5	1.9	25	2.2	1.0	3
L-5	743.4	1.3	4	150.5	2.2	16
L-6	170.8	1.2	4	-	-	-
L-7	148.2	1.8	12	304.4	1.0	2
L-8	297.3	1.4	6	1930.5	1.0	<1
L-9	123.2	2.0	14	14.2	1.2	7
L-10	47.3	2.3	22	15.3	1.2	8

TABLE 22. TENSIOMETER READINGS ON MINESOIL DURING UNSATURATED HYDRAULIC CONDUCTIVITY STUDY

Depth	Time (Hours)					
	0	20	48	115	138	168
cm	m bars					
60	50*	50	60	70	70	80
	50†	40	50	70	50	70
90	90	80	90	100	100	80
	90	80	90	100	90	100
120	100	90	100	100	110	110
	110	110	110	120	120	120
150	150	120	140	140	140	160
	120	140	120	120	120	140

*Values for Box 1.

†Values for Box 2.

Tensiometer readings taken during the course of water addition and drainage indicated no clear wetting front or an insensitivity of the tensiometers to the water movement through the material. The water movement was extremely slow and the volumetric water content indicated that the minesoil was drying after initial time. The readings at the 90-cm depth for both Box 1 and 2 behaved similarly. However, at the 60-, 120-, and 180-cm depth, variations existed.

The volumetric water content at time zero and after 138 hours (Figure 20) also indicated that the minesoil has dried over this period. The general drying trends for both Box 1 and 2 approximated each other.

Neutron depth probe standardization data (Table 23) indicated varying water contents with depths. These variations could be attributed to pockets of fine material interspersed within the coarse material.

The tensiometers utilized in this study were gauge-type and, possibly, were not sensitive enough to record matric potential changes as water moved past them. Poor tensiometer, ceramic cup/minesoil contact could contribute to problems. However, these results could also support the idea of channelized flow within the minesoil.

The dense surface layer of the K-Plot accounted for the extremely slow infiltration on this material. However, beneath this layer coarse fragments and void space predominates. Coarse-textured horizons, underlying finer textured ones, will not conduct significant amounts of water until many of the pores in the upper horizon are saturated and a pressure-head develops (Miller, 1973). ElBoushi (1966) has shown that water infiltrating through loose granular material (similar to subsurface horizons of many minesoils) tends to concentrate in small parts of the total area into discrete paths. This leads to a decrease in percentage of surface wetted by percolating waters.

Figure 20. Volumetric water content within the unsaturated hydraulic conductivity plot.

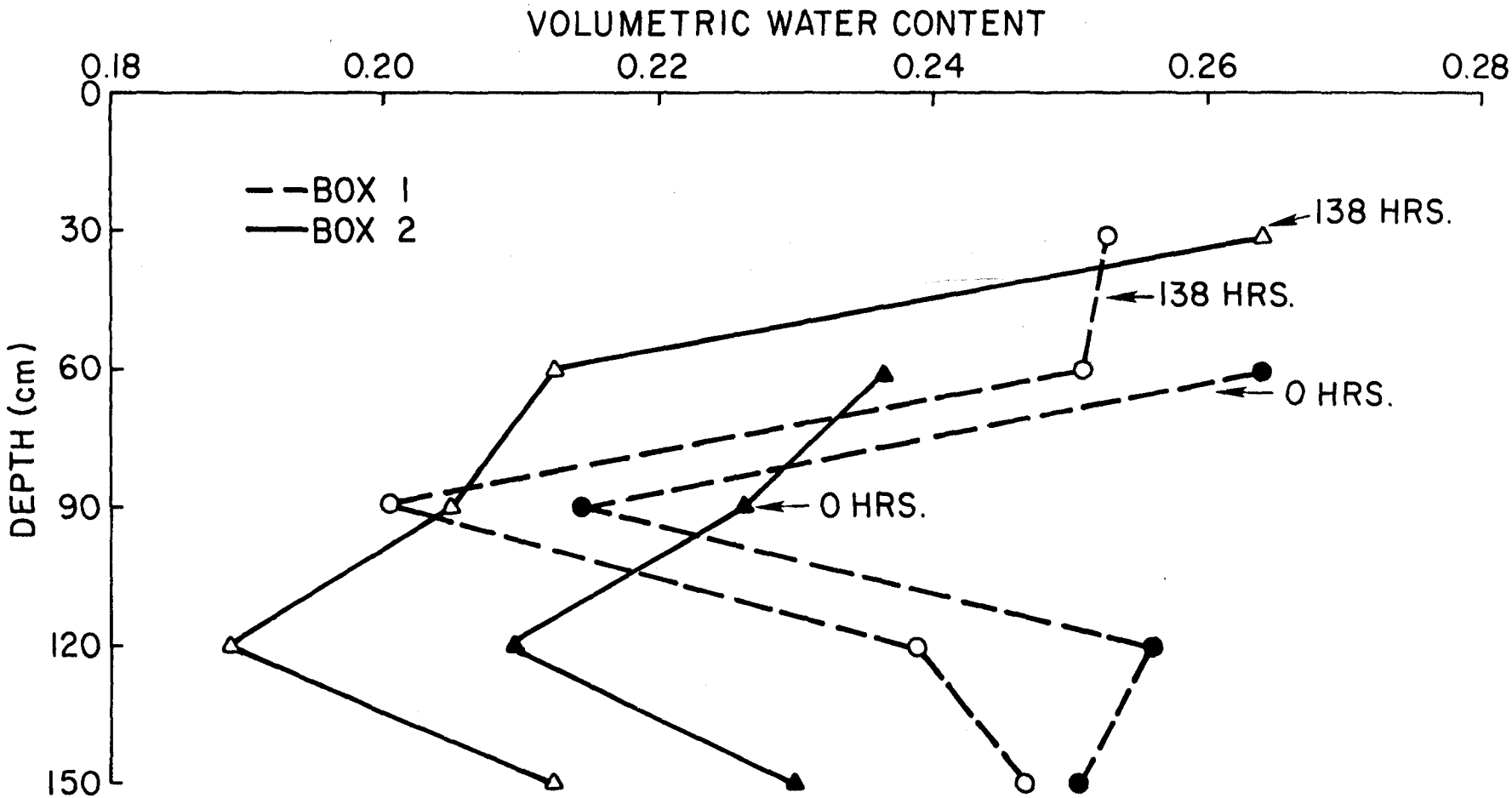

VOLUMETRIC WATER CONTENT
0.18
0.20
0.22
0.24
0.26
0.28
DEPTH (cm)
0
30
60
90
120
150
BOX 1
BOX 2
138 HRS.
138 HRS.
0 HRS.
0 HRS.

TABLE 23. GAMMA AND NEUTRON DEPTH PROBE STANDARDIZATION OF K-PLOT. BULK DENSITY (BD) AND VOLUMETRIC WATER CONTENT (V)

Depth	(BD) 1	(BD) 2	(V) 1	(V) 2
cm	g/cm^3		cm^3/cm^3	
15	1.82	1.74	0.2800	0.2974
20	1.82	1.76	0.2777	0.2999
25	1.82	1.75	0.2755	0.2935
31	1.82	1.79	0.2718	0.2846
36	1.83	1.80	0.2620	0.2813
41	1.80	1.79	0.2546	0.2647
46	1.77	1.80	0.2514	0.2473
51	1.75	1.77	0.2469	0.2367
56	1.75	1.71	0.2491	0.2241
61	1.74	1.68	0.2529	0.2178
66	1.72	1.62	0.2565	0.2213
71	1.72	1.56	0.2586	0.2327
76	1.68	1.57	0.2516	0.2404
81	1.67	1.57	0.2321	0.2367
86	1.70	1.59	0.2221	0.2355
91	1.70	1.64	0.2116	0.2300
97	1.72	1.67	0.2092	0.2245
102	1.71	1.72	0.2103	0.2183
107	1.66	1.72	0.2158	0.2056
112	1.63	1.72	0.2246	0.1887
117	1.61	1.69	0.2340	0.1814
122	1.59	1.61	0.2404	0.1847
127	1.60	1.60	0.2474	0.1993
132	1.58	1.61	0.2541	0.2123
137	1.61	1.60	0.2583	0.2206
142	1.63	1.59	0.2564	0.2216
147	1.65	1.57	0.2501	0.2235

SUMMARY

Comparison of physical and hydraulic properties of minesoils with contiguous natural soils indicated that surface mining and reclamation operations have had a significant effect on the particle-size distribution. The minesoils studied had a greater percentage of rock fragments but less sand and clay than natural soils due to lower organic matter and vermiculite contents. Average bulk densities of the minesoils were greater than that of adjacent soils.

The average amount of water retained by the A and B horizons of the natural soils at any matric potential was greater than that retained by the A horizons of the minesoils. The natural soils also retained more water between -1/3 and -15 bars than did the minesoils. Evapotranspiration from the minesoil was approximated by A-pan results.

Single-ring-infiltrometer data and saturated hydraulic conductivity values of minesoils varied considerably. Use of a small plot to determine unsaturated hydraulic conductivity indicated that water flow followed voids present in the minesoil.

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APPENDIX A

PROFILE DESCRIPTIONS FOR SOILS AND MINESOILS

Soil and Minesoil Profile Descriptions

Soil pits 1 through 8 were located within a 4 ha site. Pits 1 through 4 were located in undisturbed soils and pits 5 through 8 were located in minesoils. The site is located 1.2 km northeast of Kylertown in Clearfield County, Pennsylvania. The area is in the Pittsburgh Plateau section of the Appalachian Plateaus Province; the geologic system is Pennsylvanian. Sedimentary bedrock is horizontal to gently folded. Coal seams in the immediate vicinity are the Middle and Lower Kittanning (C & B) of the Allegheny group. The mean elevation is 450 m and the climate is humid temperate. All colors were described moist.

Hazleton Silt Loam, Taxadjunct, Pit 1

This pedon is classified as a member of the coarse-loamy, mixed, mesic Family of Typic Dystrochrepts, it is well drained and has developed in gray acid sandstone residuum. Site characteristics include: oak and hemlock native vegetation, no erosion, moderate to moderately rapid permeability, north 30 degrees east aspect and a 6% slope. This pedon was described by J. Hallowich, R. Pennock, Jr., and T. Pedersen on May 4, 1976.

O1--8-3 cm, Deciduous leaf litter mainly from oaks.

O2--3-0 cm, Black (5YR 2.5/1) decomposed and partially decomposed oak leaf litter.

A1--0-3 cm, Very dark grayish brown (10YR 3/2) silt loam; moderate very fine granular structure; friable, nonsticky, nonplastic; very strongly acid (pH 4.8); clear wavy boundary.

A2--3-10 cm, Yellowish brown (10YR 5/4) silt loam to loam; weak medium platy structure parting to moderate fine and medium subangular blocky; friable, nonsticky, nonplastic; many medium and fine roots; medium acid (pH 5.6); clear smooth boundary.

B21--10-41 cm, Yellowish brown (10YR 5/4) loam; weak medium platy structure parting to moderate fine and medium subangular blocky; friable, nonsticky, slightly plastic; many fine roots; 7% sandstone fragments; strongly acid (pH 5.4); gradual smooth boundary.

B22t--41-74 cm, Brown (7.5YR 5/4 and 7.5YR 4/4) channery loam; weak coarse subangular blocky structure, friable, nonsticky, nonplastic; few thin clay films; some bridging of sand grains; abundant fine roots; 15% sandstone fragments; strongly acid (pH 5.4); clear wavy boundary.

B3t--74-109 cm, Strong brown (7.5YR 5/8) and brown (7.5YR 4/4) channery silt loam and light yellowish brown (10YR 6/4) weathered sandstone; weak coarse subangular blocky structure; firm, nonsticky, nonplastic; few roots below 74 cm; few thin patches in pores and bridging sand grains; 40% sandstone fragments; strongly acid (pH 5.2); gradual wavy boundary.

C--109-176 cm, Reddish yellow (7.5YR 6/6) very channery silt loam, loamy sand around rock fragments; weak medium subangular blocky structure and single grained around rock fragments; firm, nonsticky, nonplastic; 80% sandstone fragments; strongly acid (pH 5.2); gradual wavy boundary.

R--176-203 cm, Pale red (2.5YR 6/2) bedded sandstone.

Dekalb Silt Loam, Taxadjunct, Pit 2

This pedon is a member of the coarse-loamy, mixed, mesic Family of Typic Dystrochrepts, it is well drained and has developed in gray acid sandstone residuum. Site characteristics include: oak and hemlock native vegetation, no erosion, moderate permeability, a north 30 degrees east aspect and a 6% slope. This pedon was described by J. Hallowich, R. Pennock, Jr., and T. Pedersen on May 4, 1976.

01--8-5 cm, Deciduous leaf litter mainly from oaks.

02--5-0 cm, Black (5YR 2.5/1) decomposed and partially decomposed oak leaf litter.

A1--0-10 cm, Very dark gray brown (10YR 3/2) silt loam; moderate fine granular structure; friable, nonsticky, nonplastic; 5% sandstone fragments; very strongly acid (pH 4.8); clear smooth boundary.

B21--10-33 cm, Yellowish brown (10YR 5/6) loam; weak, fine and moderate subangular blocky structure; friable, nonsticky, nonplastic; 7% sandstone fragments; strongly acid (pH 5.4); gradual wavy boundary.

B22--33-51 cm, Yellowish brown (10YR 5/6) channery loam; moderate medium subangular blocky structure; friable, nonsticky, nonplastic; 15% sandstone fragments; strongly acid (pH 5.2); gradual wavy boundary.

B23--51-71 cm, Strong brown (7.5YR 5/6) channery loam; moderate medium subangular blocky structure; friable, nonsticky, nonplastic; 40% sandstone fragments; very strongly acid (pH 5.0); clear wavy boundary.

C--71-74 cm, Reddish yellow (7.5YR 6/6) very channery loam; structureless massive; firm to friable, nonsticky, nonplastic; 60% sandstone fragments; very strongly acid (pH 4.8); clear wavy boundary.

R--74-122+ cm, Pale red (2.5YR 6/2) bedded sandstone.

Cookport Channery Loam, Taxadjunct, Pit 3

This pedon is classified as a member of the coarse-loamy, mixed, mesic Family of Aquic Fragiudult; it is moderately well drained and has developed in sandstone residuum. Site characteristics include: white pine and black cherry vegetation, slow permeability, north 5 degrees east aspect and a 14% slope. This pedon was described by J. Hallowich, A. Topolanchik, R. Pennock, Jr., and T. Pedersen on May 6, 1976.

A1--0-15 cm, Overburden material (not described). Soil very firm with thick platy structure due to heavy machine activity; very strongly acid (pH 4.6); diffuse irregular boundary.

A2--15-43 cm, Light yellowish brown (10YR 6/4) channery loam; weak fine and medium angular blocky structure; friable, nonsticky, nonplastic; abundant roots to 43 cm; 20% rock fragments; very strongly acid (pH 4.8); gradual wavy boundary.

B1--43-66 cm, Yellowish brown (10YR 5/6) channery loam; moderate medium angular blocky; friable, slightly sticky, slightly plastic; 25% rock fragments; strongly acid (pH 5.2); clear wavy boundary.

Bx1t--69-91 cm, Dark brown (7.5YR 4/4) channery loam; weak very coarse prismatic structure parting to fine angular blocky; firm, slightly sticky, plastic; few thin discontinuous clay films in pores and on ped faces, common fine Mn concretions; few roots below 66 cm; 20% rock fragments; very strongly acid (pH 4.8); gradual wavy boundary.

Bx2t--91-117 cm, Brown (7.5YR 4/4) clay loam; few fine distinct light brownish gray (10YR 6/2) mottles; weak very coarse prismatic structure, parting to weak medium subangular blocky; firm, slightly sticky, slightly plastic; few thin discontinuous clay films in pores and on ped faces; 15% rock fragments; very strongly acid (pH 5.0); gradual wavy boundary.

Bx3t--117-135 cm, Yellowish brown (10YR 5/4) silt loam; many medium distinct strong brown (7.5YR 5/6) and light brownish gray (10YR 6/2) mottles; weak very coarse prismatic structure parting to weak coarse subangular blocky; firm, sticky, plastic; few thin discontinuous clay films in pores and on ped faces; 10% rock fragments; very strongly acid (pH 5.0); clear wavy boundary.

Bx4t--135-167+ cm, Dark brown (10YR 3/3) very channery loam; few medium distinct light brownish gray (10YR 6/2) mottles; weak very coarse prismatic structure parting to weak coarse subangular blocky; very firm, nonsticky, slightly plastic; few thick clay films discontinuous in pores and on ped faces; prism face light brownish gray (10YR 6/2) matrix strong brown (7.5YR 5/6); 70% rock fragments; very strongly acid (pH 5.0).

Hazleton Channery Silt Loam, Taxadjunct, Pit 4

This pedon is classified as a member of the coarse-loamy, mixed, mesic Family of Typic Dystrochrepts, it is moderately well drained and has developed in sandstone residuum. Site characteristics include: white pine and black cherry natural vegetation, moderate permeability, north 5 degrees east aspect and a 12% slope. This profile was described by J. Hallowich, A. Topolanchik, R. Pennock, Jr., and T. Pedersen on May 6, 1976.

A1--0-8 cm, Dark gray brown (10YR 4/2) channery silt loam; moderate very thin platy structure parting to weak very fine granular; friable, slightly sticky, plastic; many roots; 15% rock fragments; strongly acid (pH 5.2); clear wavy boundary.

A2--8-20 cm, Yellowish brown (10YR 5/4) channery silt loam; moderate very thin and thin platy structure parting to weak very fine and fine subangular blocky; friable, sticky, plastic; abundant roots; 15% rock fragments; very strongly acid (pH 5.0); clear wavy boundary.

B21t--20-48 cm, Yellowish brown (10YR 5/8) channery silt loam; weak fine and medium subangular blocky structure; friable, sticky, plastic; few thin clay films in

pores; few roots; 15% rock fragments; very strongly acid (pH 4.8); gradual irregular boundary.

B22t--48-74 cm, Dark yellowish brown (10YR 4/4) channery silt loam; few fine faint mottles; moderate fine subangular blocky structure; firm, slightly sticky, slightly plastic; thin discontinuous clay films in pores and on ped faces; few fine and medium Mn concretions; few roots; 15% rock fragments; very strongly acid (pH 4.8); gradual irregular boundary.

B23t--74-94 cm, Yellowish brown (10YR 5/8) channery silt loam; moderate fine subangular blocky structure; friable, slightly sticky, slightly plastic; thin discontinuous (thick in places) clay films in pores and on ped faces and on coarse fragments; few roots; 15% rock fragments; very strongly acid (pH 4.8); abrupt wavy boundary.

IIC1--94-125 cm, Black (N 2/0) very channery silt loam; weathered coal; structureless, massive, friable, nonsticky, nonplastic; few roots; 75% rock fragments; abrupt irregular boundary.

IIIC2--125-183+ cm, Light gray (10YR 6/1) and light yellowish brown (10YR 6/4) very channery silt loam varigated with strong brown (7.5YR 5/8); structureless, massive; very friable, nonsticky, nonplastic; 90% rock fragments; very strongly acid (pH 4.8).

Minesoil Very Channery Loam, Pit 5

This pedon is classified as a loamy-skeletal, mixed, mesic member of the Udorthent great group and is well drained. Site characteristics include: grass and legume vegetation, slight erosion, moderate permeability, northeast aspect and a 5% slope. This pedon was described by E. J. Ciolkosz and T. Pedersen on June 9, 1976.

Ap--0-20 cm, Yellowish brown (10YR 5/6) very channery loam and dark yellowish brown (10YR 4/4) very channery loam; moderate medium platy parting to weak very fine subangular blocky structure and weak fine subangular blocky structure; friable to firm, slightly sticky, slightly plastic; many very fine grass roots

predominantly parallel to plates on ped faces and through some plates to 3 cm, common, very fine fibrous roots flattened along coarse fragments to 20 cm; 55% rock fragments; strongly acid (pH 5.2); abrupt wavy boundary.

C1--20-36 cm, Dark brown (10YR 3/3) very channery sandy loam; structureless, massive; friable, slightly sticky, nonplastic; few very fine roots on surface of coarse fragments; 65% rock fragments; very strongly acid (pH 5.0); gradual wavy boundary.

C2--36-56 cm, Dark brown (10YR 3/3) very channery sandy loam, structureless, massive, friable, slightly sticky, nonplastic; no roots; 65% rock fragments; very strongly acid (pH 4.8); diffuse smooth boundary.

C3--56-74 cm, Dark brown (10YR 3/3) very channery sandy loam; structureless, massive; firm, slightly sticky, nonplastic; 65% rock fragments; strongly acid (pH 5.2); clear wavy boundary.

C4--74-114 cm, Yellowish brown (10YR 5/4) very channery sandy loam; structureless, massive; firm, slightly sticky, nonplastic; 65% rock fragments; strongly acid (pH 5.2); gradual wavy boundary.

C5--114-152 cm, Dark brown (10YR 4/3) very channery loamy sand; structureless, massive; friable, nonsticky, nonplastic; 75% rock fragments; strongly acid (pH 5.4).

Minesoil Very Channery Loam, Pit 6

This pedon is classified as a loamy-skeletal, mixed, mesic member of the Udorthent great group and is well drained. Site characteristics include: grass and legume vegetation, slight erosion, moderate permeability, northeast aspect and an 11% slope. This pedon was described by E. J. Ciolkosz and T. Pedersen on June 9, 1976.

Ap--0-13 cm, Yellowish brown (10YR 5/4) very channery silt loam; moderate fine granular and weak very fine subangular blocky; friable, slightly sticky, slightly plastic; many very fine fibrous grass roots, on and through weakly developed granules, roots decreased in number below 12 cm; 55% rock fragments; medium acid (pH 6.0); abrupt wavy boundary.

AC--13-28 cm, Dark brown (10YR 4/3) very channery sandy loam; weak very fine subangular blocky to structureless, massive; friable to firm, slightly sticky, slightly plastic; many very fine roots flattened between structural units, roots concentrated on, around, and below coarse fragments to 20 cm; common very fine roots in and around pockets associated with coarse fragments, few roots penetrating massive material to 25 cm; 55% rock fragments; strongly acid (pH 5.2); gradual wavy boundary.

C1--28-53 cm, Dark yellowish brown (10YR 4/4) very channery sandy loam; structureless, massive; firm, slightly sticky, slightly plastic; few very fine roots to 41 cm, no roots below 41 cm; 55% rock fragments; very strongly acid (pH 5.0); clear wavy boundary.

C2--53-84 cm, Brown (7.5YR 5/4) very channery loamy sand; structureless, massive; friable, nonsticky, nonplastic; 85% rock fragments; very strongly acid (pH 4.8); gradual irregular boundary.

C3--84-152 cm, 100% rock fragment, about 15-20% void space.

Minesoil Very Shaly Loam, Pit 7

This pedon is classified as a loamy-skeletal, mixed, mesic member of the Udorthent great group and is well drained. Site characteristics include: grass vegetation, moderate erosion, moderate permeability, northeast aspect and a 9% slope. This pedon was described by E. J. Ciolkosz and T. Pedersen on June 9, 1976.

Ap1--0-10 cm, Dark brown (7.5YR 3/2) very shaly loam; weak fine subangular blocky; friable, slightly sticky, slightly plastic; many very fine grass and clover roots, roots flattened on sandstone fragments; 55% rock fragments; very strongly acid (pH 4.6); abrupt broken boundary.

Ap2--10-31 cm, Dark brown (10YR 4/3) very shaly sandy loam; weak fine subangular blocky to structureless, massive; friable to firm, slightly sticky, slightly plastic; one fine tap root extending to 13 cm, common very fine roots flattened between ped faces and in pores, few roots on shale fragments to

13 cm, few very fine roots, one very fine root extending to 33 cm on ped faces and surfaces of coarse fragments; 55% rock fragments; extremely acid (pH 4.4); abrupt broken boundary.

C1--31-51 cm, Grayish dark brown (10YR 4/2) very shaly sandy loam; structureless, massive; firm, slightly sticky, nonplastic; no roots; 55% rock fragments; extremely acid (pH 4.2); gradual wavy boundary.

C2--51-66 cm, Very dark grayish brown (10YR 3/2) very shaly loamy sand; structureless, massive; friable; nonsticky, nonplastic; 70% rock fragment 5% voids; extremely acid (pH 4.4); clear wavy boundary

C3--66-127 cm, 100% rock fragment, 20% void space; few Fe_2O_3 coatings, few gypsum crystals, clear wavy boundary.

C4--127-152 cm, Very dark gray (10YR 3/1) very shaly loamy sand and black (N 2/0) loamy sand coal bands; structureless, massive; friable, nonsticky, nonplastic; 65% rock fragments; extremely acid (pH 4.0).

Minesoil Very Shaly Sandy Loam, Pit 8

This pedon is classified as a loamy-skeletal, mixed, mesic member of the Udorthent great group and is well drained. Site characteristics include: grass and legume vegetation, slight erosion, moderate permeability, northeast aspect and a 16% slope. This pedon was described by E. J. Ciolkosz and T. Pedersen on June 9, 1976.

AC--0-18 cm, Yellowish brown (10YR 5/4) very shaly sandy loam; weak fine granular and weak very fine subangular blocky; friable, slightly sticky, slightly plastic; many very fine to fine fibrous roots, and fine to medium tap roots extending to 3 cm, common very fine to fine roots evenly distributed to 18 cm, nodules and lesions on roots; 50% rock fragments; medium acid (pH 5.6); abrupt smooth boundary.

C1--18-36 cm, Dark brown (10YR 4/3) very shaly sandy loam; structureless, massive; friable to firm, slightly sticky, nonplastic; few very fine roots to 20 cm,

tap roots becoming increasingly branched following ped faces and voids associated with coarse fragments; 65% rock fragments, very strongly acid (pH 5.0); gradual wavy boundary.

C2--36-58 cm, Dark brown (10YR 3/3) very shaly sandy loam; structureless, massive; firm slightly sticky, nonplastic; no roots; 65% rock fragments; very strongly acid (pH 4.8); gradual wavy boundary.

C3--58-102 cm, Dark grayish brown (10YR 4/2) very shaly sandy loam; structureless, massive; firm, slightly sticky, nonplastic; 65% rock fragments; extremely acid (pH 4.4); gradual wavy boundary.

C4--102-145 cm, Very dark grayish brown (10YR 3/2) with bands of dark yellowish brown (10YR 4/4) very shaly loam; structureless, massive; firm, slightly sticky, slightly plastic; some very fine roots at 124 cm; 65% rock fragments; very strongly acid (pH 4.6); clear irregular boundary.

C5--145-183+ cm, Dark grayish brown (10YR 4/2) with bands of dark yellowish brown (10YR 4/4) very shaly loamy sand; structureless, massive; firm, nonsticky, nonplastic; 90% rock fragments; 5% fines; strongly acid (pH 5.2).

APPENDIX B

LABORATORY CHARACTERIZATION DATA FOR PEDONS DESCRIBED IN APPENDIX A

TABLE B-1. PHYSICAL CHARACTERIZATION DATA FOR PIT 1

No.	Depth cm	Horizon	Coarse Fragment Distribution (mm) (%) >76	76-19	19-4.7	4.7-2.0	Total Wt.	Total Vol.	Textural Class Lab	Textural Class Field	Total Bulk Density (g/cm^3)
1	0-3	A1		10.6	4.1	8.5	23.2	17.3	SIL	SIL	0.88
2	3-10	A2		5.6	6.5	11.0	23.1	12.6	SIL	SIL	1.39
3	10-41	B21		11.5	8.8	11.9	32.2	13.6	L	L	1.78
4	41-74	B22t		7.3	10.9	15.8	33.9	14.4	L	L	1.92
5	74-109	B3t		25.0	9.3	10.0	14.3	16.9	FSL	SIL	2.07
6	109-176	C		29.5	22.7	5.2	57.4	23.8	FSL	SIL	

No.	Particle Size Distribution (mm) (% <2mm) Sand 2.0-1.0	Sand 1.0-0.5	Sand 0.5-0.25	Sand 0.25-0.10	Sand 0.10-0.07	Sand 0.07-0.05	Silt 0.02-0.002	Silt 0.005-0.002	Sand 2.0-0.05	Silt 0.05-0.002	Clay < 0.002
1	7.3	5.0	6.7	9.7	3.1	2.9	36.3	9.5	34.8	55.6	9.6
2	9.4	4.6	7.9	10.2	2.8	2.4	33.2	9.8	37.3	51.1	11.6
3	11.5	5.5	10.0	11.2	2.8	2.8	24.4	8.0	43.9	42.0	14.1
4	11.5	7.3	11.0	10.8	2.6	2.4	25.2	7.0	45.6	40.3	14.1
5	1.1	2.9	23.7	22.0	6.3	2.6	19.4	6.3	58.7	29.7	11.7
6	2.3	3.6	23.3	27.1	3.3	2.9	15.9	7.1	62.5	23.4	14.1

No.	Bulk Density (g/cm^3) 1/3 Atm Moisture Entire Clod	1/3 Atm Moisture <2mm in Clods	Dry <2mm in Clods	Dry >2mm in Clods	COLE <2mm	Moisture (%) Retained at 1/3 Atm Entire Clod	1/3 Atm <2mm in Clods	15 Atm <2mm Sieved	1/3 to 15 Atm Wt. (%)	1/3 to 15 Atm cm/cm of Soil
1	0.83	0.82	1.02	1.32	0.027	26.1	24.8	18.4	5.6	0.046
2	1.38	1.31	1.32	1.84		20.6	22.2	5.6	12.7	0.177
3	1.69	1.59	1.66	2.36	0.015	15.6	19.0	7.2	7.8	0.155
4	1.84	1.70	1.73	2.62	0.017	13.1	16.8	7.1	6.4	0.123
5	1.95	1.87	2.02	2.41	0.025	10.6	12.9	4.9	4.5	0.093
6								4.8		

TABLE B-2. CHEMICAL AND MINERALOGICAL CHARACTERIZATION DATA FOR PIT 1

No.	Depth cm	Horizon	Extractable Cations (Meq/100 g <2 mm material) Ca	Mg	Na	K	Total Bases	H	CEC (SUM)	Al	Base Sat. (%)	Ca/Mg
1	0-3	A1	1.9	0.7	0.08	0.18	3.0	40.1	43.1	6.22	6.9	2.7
2	3-10	A2	0	0.2	0.06	0.08	0.3	14.7	15.0	4.17	2.3	0
3	10-41	B21	0	0.4	0.06	0.07	0.5	12.7	13.2	4.95	3.2	0
4	41-74	B22t	0	0.4	0.06	0.07	0.6	15.6	16.2	5.09	3.5	0
5	74-109	B3t	0	0.1	0.06	0.06	0.3	12.7	13.0	3.61	2.0	0
6	109-176	C	0	0.2	0.06	0.10	0.3	8.9	9.2	3.82	3.5	0

No.	pH Water	pH 1N KCl	pH 0.01M $CaCl_2$	Organic Matter C(%)	Organic Matter N(%)	Fe_2O_3 (%)	Clay Minerals (%) of (<0.002 mm material) Mont	Verm	Ill	Kaol	Int	Qtz
1	4.8	3.7	4.2	6.27	0.346	3.3		45	15	40		tr
2	4.7	3.9	4.3	2.13	0.064	2.8		40	20	35		5
3	4.8	4.0	4.4	.42	0.040	3.1	15	30	25	35		5
4	5.0	4.0	4.4	.32	0.037	3.2	15	20	30	35		tr
5	4.8	4.0	4.3	.10	0.048	2.6	5	15	35	45		
6	5.0	4.0	4.3	.09	0.026	2.2						

TABLE B-3. PHYSICAL CHARACTERIZATION DATA FOR PIT 2

No.	Depth cm	Horizon	Coarse Fragment Distribution (mm) (%) >76	76-19	19-4.7	4.7-2.0	Total Wt.	Total Vol.	Lab	Textural Class Field	Total Bulk Density (g/cm^3)
1	0-10	A1		22.4	16.8	2.5	41.7	41.7	L	SIL	0.99
2	10-33	B21	5.6	12.4	12.8	6.9	37.7	16.9	L	L	1.78
3	33-51	B22	4.8	15.2	12.5	5.8	38.3	16.7	L	CNL	1.88
4	51-71	B23		21.5	12.0	7.0	40.5	17.7	L	CNL	1.89
5	71-74	C		27.7	11.8	6.3	45.8		L	VCNL	

No.	Particle Size Distribution (mm) (% <2 mm) Sand 2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.10	0.10-0.07	0.07-0.05	Silt 0.02-0.002	0.005-0.002	Sand 2.0-0.05	Silt 0.05-0.002	Clay < 0.002
1	2.0	3.2	17.9	7.9	6.2	1.8	34.4	10.8	39.1	46.7	14.1
2	3.8	3.6	20.4	14.6	2.6	2.2	27.7	6.9	47.3	38.8	13.8
3	4.0	4.8	20.9	13.7	2.5	2.0	29.0	7.2	47.9	39.0	13.1
4	3.4	4.7	19.8	6.7	9.4	2.3	26.3	8.0	46.2	40.9	12.9
5	2.4	4.1	20.8	14.2	3.8	3.1	26.9	8.2	48.4	41.4	10.2

No.	Bulk Density (g/cm^3) 1/3 Atm Moisture Entire Clod	1/3 Atm Moisture <2mm in Clods	Dry <2mm in Clods	Dry >2mm in Clods	COLE <2mm	Moisture (%) Retained at 1/3 Atm Entire Clod	1/3 Atm <2mm in Clods	15 Atm <2mm Sieved	1/3 to 15 Atm Wt. (%)	1/3 to 15 Atm cm/cm of Soil
1	1.00	1.00	1.08	1.00	0.021	19.4	15.4	9.5	3.4	0.035
2	1.71	1.58	1.55	2.23	0.004	13.1	17.4	5.1	7.7	0.137
3	1.79	1.69	1.67	2.29	0.013	13.3	16.8	4.9	7.4	0.138
4	1.81	1.67	1.64	2.38	0.005	11.8	16.5	5.5	6.6	0.124
5								4.2		

TABLE B-4. CHEMICAL AND MINERALOGICAL CHARACTERIZATION DATA FOR PIT 2

No.	Depth cm	Horizon	Extractable Cations (Meq/100 g <2 mm material) Ca	Mg	Na	K	Total Bases	H	CEC (SUM)	Al	Base Sat. (%)	Ca/Mg
1	0-10	A1	0	0.4	0.07	0.14	0.7	31.5	32.2	6.22	2.1	0
2	10-33	B21	0	0.5	0.07	0.07	0.7	11.0	11.7	2.76	5.7	0
3	33-51	B22	0	0.3	0.06	0.08	0.4	11.0	11.4	2.76	3.8	0
4	51-71	B23	0	0.2	0.07	0.06	0.4	11.0	11.4	3.54	3.2	0
5	71-74	C	0	0.2	0.07	0.05	0.4	9.5	9.9	2.97	3.6	0

No.	pH Water	pH 1N KCl	pH 0.01M $CaCl_2$	Organic Matter C(%)	Organic Matter N(%)	Fe_2O_3 (%)	Clay Minerals (%) of (<0.002 mm material) Mont	Verm	Ill	Kaol	Int	Qtz
1	5.0	3.6	4.0	3.64	0.170	2.4	tr	50	20	30		tr
2	5.1	4.1	4.5	.56	0.037	2.1		55	15	30		tr
3	5.0	4.0	4.5	.43	0.030	1.9		55	15	25		5
4	5.0	4.0	4.5	.22	0.021	1.8	tr	50	20	30		tr
5	4.9	4.0	4.4	.17	0.029	1.9	tr	35	30	35		tr

TABLE B-5. PHYSICAL CHARACTERIZATION DATA FOR PIT 3

No.	Depth cm	Horizon	Coarse Fragment Distribution (mm) (%) >76	76-19	19-4.7	4.7-2.0	Total Wt.	Total Vol.	Lab	Textural Class Field	Total Bulk Density (g/cm^3)
1	0-15	A1		17.0	25.0	13.7	55.7	25.2	L		1.84
2	15-43	A2		13.8	14.9	9.8	38.5	13.1	L	CNL	1.95
3	43-66	B1		28.0	8.2	8.4	44.7	26.1	L	CNL	1.93
4	66-91	Bx1t		21.5	18.2	10.0	49.6	26.8	L	CNL	2.13
5	91-117	Bx2t		12.3	11.9	12.3	36.5	20.4	L	CNL	1.90
6	117-135	Bx3t		7.5	8.0	13.5	29.0	16.9	L	SIL	1.85
7	135-167+	Bx4t		16.4	24.1	9.0	49.5	26.5	L	VCNL	2.22

No.	Particle Size Distribution (mm) (% <2 mm) Sand 2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.10	0.10-0.07	0.07-0.05	Silt 0.02-0.002	0.005-0.002	Sand 2.0-0.05	Silt 0.05-0.002	Clay < 0.002
1	11.3	7.8	10.8	5.7	8.0	3.5	25.9	7.9	47.1	37.5	15.4
2	3.6	3.7	16.0	13.5	3.0	2.9	30.6	9.2	42.7	44.0	13.3
3	2.9	4.4	15.9	15.5	3.1	3.2	27.4	7.3	45.1	42.2	12.7
4	4.0	4.5	14.9	12.0	3.3	2.7	27.2	6.8	41.4	44.3	14.3
5	4.6	4.6	13.3	11.3	2.3	2.1	28.4	6.3	38.4	43.4	18.2
6	3.1	3.9	12.0	5.5	6.2	2.0	32.7	7.5	32.6	47.4	20.0
7	4.9	5.4	12.4	10.4	2.4	2.6	29.7	7.9	38.2	44.4	17.6

No.	Bulk Density (g/cm^3) 1/3 Atm Moisture Entire Clod	<2mm in Clods	Dry <2mm in Clods	>2mm in Clods	COLE <2mm	Moisture (%) Retained at 1/3 Atm Entire Clod	<2mm in Clods	15 Atm <2mm Sieved	1/3 to 15 Atm Wt. (%)	cm/cm of Soil
1	1.76	1.52	1.63	2.21	0.024	10.8	18.7	6.3	5.4	0.101
2	1.79	1.63	1.72	2.93	0.018	13.0	17.8	5.1	7.8	0.148
3	1.91	1.66	1.71	2.44	0.010	10.8	18.4	5.0	7.4	0.140
4	2.08	1.89	1.85	2.43	0.008	10.2	16.2	6.5	4.9	0.104
5	1.82	1.69	1.79	2.47	0.012	13.7	17.7	7.9	6.2	0.118
6	1.76	1.68	1.72	2.44	0.019	15.8	18.5	8.6	7.1	0.130
7	2.18	2.10	1.87	2.38	.021	9.9	15.3			0.114

TABLE B-6. CHEMICAL AND MINERALOGICAL CHARACTERIZATION DATA FOR PIT 3

No.	Depth cm	Horizon	Extractable Cations (Meq/100 g <2 mm material) Ca	Mg	Na	K	Total Bases	H	CEC (SUM)	Al	Base Sat. (%)	Ca/Mg
1	0-15	A1	0	0.6	0.06	0.06	0.7	16.5	17.2	4.17	4.1	0
2	15-43	A2	0	0.3	0.06	0.06	0.4	12.7	13.1	2.76	3.2	0
3	43-66	B1	0.7	1.3	0.06	0.08	2.1	6.4	8.5	.99	25.0	0.5
4	66-91	Bx1t	1.1	1.3	0.06	0.10	2.6	7.2	9.8	1.06	26.8	0.8
5	91-117	Bx2t	1.6	1.1	0.07	0.14	3.0	10.1	13.1	2.62	22.8	1.5
6	117-135	Bx3t	1.5	1.3	0.07	0.14	3.0	10.1	13.1	2.97	22.9	1.2
7	135-167+	Bx4t	0.6	1.2	0.06	0.10	2.0	9.8	11.8	3.54	17.0	0.5

No.	pH Water	pH 1N KCl	pH 0.01M $CaCl_2$	Organic Matter C(%)	Organic Matter N(%)	Fe_2O_3 (%)	Clay Minerals (%) of (<0.002 mm material) Mont	Verm	Ill	Kaol	Int	Qtz
1	4.0	3.4	3.8	1.53	0.123	4.1	10	15	35	40		tr
2	4.6	3.8	4.3	1.52	0.057	2.2	10	20	25	45		tr
3	5.0	4.0	4.7	.23	0.030	2.7	10	20	30	40		tr
4	5.2	4.1	4.8	.24	0.022	3.0	10	15	30	45		tr
5	5.1	4.0	4.6	.20	0.029	3.3	15	15	35	35		tr
6	4.9	4.0	4.6	.34	0.027	3.7	20	15	30	35		tr
7	4.9	4.1	4.6	.35	0.037	4.5	15	15	30	40		tr

TABLE B-7. PHYSICAL CHARACTERIZATION DATA FOR PIT 4

No.	Depth cm	Horizon	Coarse Fragment Distribution (mm) (%) >76	76-19	19-4.7	4.7-2.0	Total Wt.	Total Vol.	Lab	Textural Class Field	Total Bulk Density (g/cm^3)
1	0-8	A1		2.2	12.6	19.2	34.1	15.4	SIL	CNSIL	1.57
2	8-20	A2		2.4	11.7	21.4	35.5	15.3	SIL	CNSIL	1.82
3	20-48	B21t		1.0	10.9	22.2	34.2	13.9	SIL	CNSIL	1.85
4	48-74	B22t		2.7	12.2	23.8	38.8	15.9	L	CNSIL	1.86
5	74-94	B23t		0.5	10.6	23.4	34.5	14.1	L	VCNSIL	1.81
6	94-125	IIC1		4.5	14.8	11.9	31.2	13.7	SIL	VCNSIL	1.45
7	125-183+	IIIC2			15.3	19.8	35.1	14.0		VCNSIL	2.01

No.	Particle Size Distribution (mm) (% <2 mm) Sand 2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.10	0.10-0.07	0.07-0.05	Silt 0.02-0.002	0.005-0.002	Sand 2.0-0.05	Silt 0.05-0.002	Clay < 0.002
1	5.9	4.1	7.3	3.4	3.0	2.1	41.6	11.6	25.7	58.0	16.3
2	5.0	4.7	6.8	4.6	1.9	2.6	41.7	11.7	25.6	57.1	17.3
3	7.3	5.3	6.8	4.7	1.7	1.9	35.9	10.9	27.8	54.3	17.9
4	8.0	8.8	8.2	5.7	2.3	2.5	31.1	7.1	35.4	46.7	17.8
5	9.7	8.9	8.8	0.7	7.2	2.8	28.8	5.4	38.0	47.2	14.8
6	4.8	7.0	9.9	11.5	5.1	4.2	29.2	8.6	42.5	47.4	10.1
7	6.0	6.2	3.5	2.2	1.0	2.6	21.0	14.5	21.4	53.7	24.9

No.	Bulk Density (g/cm^3) 1/3 Atm Moisture Entire Clod	1/3 Atm Moisture <2mm in Clods	Dry <2mm in Clods	Dry >2mm in Clods	COLE <2mm	Moisture (%) Retained at 1/3 Atm Entire Clod	1/3 Atm <2mm in Clods	15 Atm <2mm Sieved	1/3 to 15 Atm Wt. (%)	1/3 to 15 Atm cm/cm of Soil
1	1.54	1.36	1.40	2.22	0.010	17.1	24.5	7.1	11.4	0.177
2	1.71	1.62	1.67	2.32	0.009	15.4	18.4	6.6	7.7	0.138
3	1.74	1.64	1.71	2.45	0.013	16.2	19.6	7.3	8.1	0.150
4	1.76	1.62	1.68	2.43	0.012	14.3	18.8	8.1	6.6	0.122
5	1.69	1.59	1.67	2.44	0.017	15.7	19.0	6.9	7.9	0.143
6	1.41	1.25	1.39	2.28	0.038	21.5	29.1	12.3	11.6	0.168
7	1.84	1.82	1.98	2.51	.029	16.1	16.8	7.1	6.3	0.128

TABLE B-8. CHEMICAL AND MINERALOGICAL CHARACTERIZATION DATA FOR PIT 4

No.	Depth cm	Horizon	Extractable Cations (Meq/100 g <2 mm material) Ca	Mg	Na	K	Total Bases	H	CEC (SUM)	Al	Base Sat. (%)	Ca/Mg
1	0-8	A1	0	0.2	0.06	0.11	0.4	16.7	17.1	2.97	2.3	0
2	8-20	A2	0	0.3	0.06	0.07	0.4	13.9	14.3	3.82	2.7	0
3	20-48	B21t	0	0.3	0.06	0.07	0.5	16.2	16.7	4.95	2.8	0
4	48-74	B22t	0	0.3	0.06	0.05	0.4	15.9	16.3	5.94	2.4	0
5	74-94	B23t	0	0.8	0.06	0.07	0.9	16.5	17.4	5.38	5.3	0
6	94-125	IIC1	0.8	1.1	0.07	0.05	2.0	59.2	61.2	7.07	3.3	0.7
7	125-183+	IIIC2	0.4	2.2	0.06	0.07	2.7	16.2	18.9	3.54	14.2	0.2

No.	pH Water	pH 1N KCl	pH 0.01M $CaCl_2$	Organic Matter C(%)	Organic Matter N(%)	Fe_2O_3 (%)	Clay Minerals (%) of (<0.002 mm material) Mont	Verm	Ill	Kaol	Int	Qtz
1	5.1	4.0	4.5	6.25	0.101	3.0	15	25	20	40		tr
2	5.0	3.9	4.5	.85	0.058	3.3	15	25	20	40		tr
3	5.0	3.9	4.4	0.67	0.058	3.4	10	25	25	40		tr
4	5.0	4.0	4.4	0.34	0.047	3.8	10	20	30	40		
5	5.1	4.0	4.5	1.51	0.057	4.0	10	10	40	40		
6	5.1	3.8	4.4	12.59	0.347	1.7	5	5	40	50		
7	5.2	3.9	4.5	2.03	0.059	4.0	5		40	55		

TABLE B-9. PHYSICAL CHARACTERIZATION DATA FOR PIT 5

No.	Depth cm	Horizon	Coarse Fragment Distribution (mm) (%) >76	76-19	19-4.7	4.7-2.0	Total Wt.	Total Vol.	Lab	Textural Class Field	Total Bulk Density (g/cm^3)
1	0-20	Ap	33.3	11.5	10.9	8.7	64.4	25.7	L	VCNL	2.19
2	20-36	C1	43.9	25.9	10.2	4.6	84.6		SL	VCNSL	
3	36-56	C2	19.3	36.9	17.0	6.5	79.7		SL	VCNSL	
4	56-74	C3	32.2	30.2	13.3	3.7	79.4		SL	VCNSL	
5	74-114	C4	29.5	37.7	9.9	3.3	80.4		SL	VCNSL	
6	114-152	C5	32.2	46.8	8.1	2.9	90.0		SL	VCNLS	

No.	Particle Size Distribution (mm) (% <2 mm) Sand 2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.10	0.10-0.07	0.07-0.05	Silt 0.02-0.002	0.005-0.002	Sand 2.0-0.05	Silt 0.05-0.002	Clay < 0.002
1	4.0	4.9	11.1	14.9	6.7	3.8	25.4	7.0	45.5	38.3	16.3
2	8.1	8.3	22.8	15.1	3.8	3.3	16.4	5.3	61.4	26.6	12.0
3	8.2	9.0	23.8	11.3	6.9	3.1	15.3	5.4	62.3	27.2	10.5
4	9.0	8.3	22.7	14.0	4.5	3.7	14.7	4.8	62.1	25.4	12.4
5	8.3	7.7	23.5	15.6	3.4	3.8	15.6	4.4	62.3	24.3	13.3
6	8.6	7.5	25.2	15.8	4.4	3.0	13.9	4.8	64.6	22.2	13.2

No.	Bulk Density (g/cm^3) 1/3 Atm Moisture Entire Clod	<2mm in Clods	Dry <2mm in Clods	>2mm in Clods	COLE <2mm	Moisture (%) Retained at 1/3 Atm Entire Clod	<2mm in Clods	15 Atm <2mm Sieved	1/3 to 15 Atm Wt. (%)	cm/cm of Soil
1	1.91	1.79	1.85	2.51	0.013	11.5	14.8	6.4	3.0	0.066

TABLE B-10. CHEMICAL AND MINERALOGICAL CHARACTERIZATION DATA FOR PIT 5

No.	Depth cm	Horizon	Extractable Cations (Meq/100 g <2 mm material) Ca	Mg	Na	K	Total Bases	H	CEC (SUM)	Al	Base Sat. (%)	Ca/Mg
1	0-20	Ap	1.4	0.2	0.06	0.07	1.7	11.8	13.5	3.54	12.8	7.0
2	20-36	C1	0	0.5	0.06	0.07	0.6	9.8	10.4	1.41	6.0	0
3	36-56	C2	0.1	0.9	0.06	0.09	1.1	14.0	15.1	.99	7.5	0.1
4	56-74	C3	0	0.7	0.07	0.08	0.8	14.9	15.7	1.34	5.4	0
5	74-114	C4	0	0.7	0.07	0.09	0.9	14.6	15.5	1.27	5.6	0
6	114-152	C5	0	0.7	0.06	0.07	0.8	13.0	13.8	.71	5.8	0

No.	pH Water	pH 1N KCl	pH 0.01M $CaCl_2$	Organic Matter C(%)	Organic Matter N(%)	Fe_2O_3 (%)	Clay Minerals (%) of (<0.002 mm material) Mont	Verm	Ill	Kaol	Int	Qtz
1	5.1	4.2	4.6	.39	0.037	1.7	10	15	35	40		tr
2	4.4	3.7	4.1	1.81	0.068	1.9		10	45	40		5
3	4.3	3.7	4.2	1.68	0.062	2.1		10	40	45		5
4	4.4	3.8	4.2	1.87	0.049	1.8	5	10	45	40		tr
5	4.6	3.9	4.3	1.51	0.053	1.8	5	5	40	45		5
6	4.9	4.1	4.7	1.43	0.052	1.8	5	5	45	40		5

TABLE B-11. PHYSICAL CHARACTERIZATION DATA FOR PIT 6

No.	Depth cm	Horizon	Coarse Fragment Distribution (mm) (%) >76	76-19	19-4.7	4.7-2.0	Total Wt.	Total Vol.	Lab	Textural Class Field	Total Bulk Density (g/cm^3)
1	0-13	Ap	52.1	10.2	8.7	2.3	73.3		L	VCNSIL	*
2	13-28	AC	7.0	36.6	19.8	7.7	71.1		SL	VCNSL	
3	28-53	C1	21.7	37.5	16.7	3.5	79.3		SL	VCNSL	
4	53-84	C2	52.3	32.0	7.0	1.5	92.8			VCNLS	

No.	Particle Size Distribution (mm) (% <2 mm) Sand 2.0-1.0	Sand 1.0-0.5	Sand 0.5-0.25	Sand 0.25-0.10	Sand 0.10-0.07	Sand 0.07-0.05	Silt 0.02-0.002	Silt 0.005-0.002	Sand 2.0-0.05	Silt 0.05-0.002	Clay < 0.002
1	4.6	4.9	11.9	15.2	7.0	4.0	24.3	7.8	47.6	35.7	16.7
2	6.8	7.6	18.5	13.0	3.5	3.6	18.9	4.9	53.0	31.0	16.0
3	8.5	8.5	22.2	8.3	7.8	3.5	15.8	4.8	58.8	26.1	15.2
4	12.5	10.1	24.2	10.1	6.5	3.2	12.6	4.5	66.5	20.3	13.2

*No clods were obtained from this profile.

TABLE B-12. CHEMICAL AND MINERALOGICAL CHARACTERIZATION DATA FOR PIT 6

No.	Depth cm	Horizon	Extractable Cations (Meq/100 g <2 mm material) Ca	Mg	Na	K	Total Bases	H	CEC (SUM)	Al	Base Sat. (%)	Ca/Mg
1	0-13	Ap	5.1	0.4	0.07	0.08	5.6	16.8	13.8	0.14	25.1	12.7
2	13-28	AC	0.8	1.0	0.07	0.10	2.0	19.2	22.4	1.70	9.4	0.8
3	28-53	C1	0.2	0.7	0.06	0.07	1.1	7.5	21.2	2.62	12.4	0.3
4	53-84	C2	0	0.6	0.08	0.06	0.7	5.9	8.6	1.34	1.34	0

No.	pH Water	pH 1N KCl	pH 0.01M $CaCl_2$	Organic Matter C(%)	Organic Matter N(%)	Fe_2O_3 (%)	Clay Minerals (%) of (<0.002 mm material) Mont	Verm	Ill	Kaol	Int	Qtz
1	5.9	5.0	5.7	0.78	0.058	1.2	10	15	30	40	tr	5
2	4.8	4.1	4.7	1.80	0.048	1.7		10	40	45		5
3	4.2	3.7	4.0	1.64	0.059	1.6	tr	5	50	45		tr
4	4.6	3.9	4.4	0.95	0.026	2.2		10	40	50		

TABLE B-13. PHYSICAL CHARACTERIZATION DATA FOR PIT 7

No.	Depth cm	Horizon	Coarse Fragment Distribution (mm) (%) >76	76-19	19-4.7	4.7-2.0	Total Wt.	Total Vol.	Lab	Textural Class Field	Total Bulk Density (g/cm^3)
1	0-10	Ap1	21.3	47.0	9.3	4.6	82.2	33.97	L	VSHL	2.21
2	10-31	Ap2	9.0	19.6	16.5	9.0	54.1		SL	VSHSL	
3	31-51	C1	36.7	30.0	14.4	5.3	86.4		SL	VSHSL	
4	51-66	C2	25.5	45.0	14.2	4.2	88.9		COSL	VSHLS	
5	66-127	C3		17.7	40.7	7.6	66.0		COSL		
6	127-154	C4		45.6	24.8	10.5	80.9		COSL	VSHLS	

No.	Particle Size Distribution (mm) (% <2 mm) Sand 2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.10	0.10-0.07	0.07-0.05	Silt 0.02-0.002	0.005-0.002	Sand 2.0-0.05	Silt 0.05-0.002	Clay < 0.002
1	9.8	7.5	14.3	9.4	6.3	4.4	20.3	7.5	51.7	31.9	16.4
2	6.6	6.5	19.9	13.5	3.8	3.3	19.2	7.0	53.6	28.9	17.5
3	13.3	10.3	12.7	9.8	3.6	3.8	19.7	7.0	53.5	32.7	13.8
4	18.1	11.6	13.7	8.9	5.6	3.6	17.3	6.0	61.4	28.1	10.5
5	18.9	14.7	14.5	10.2	4.2	3.2	15.3	5.5	65.7	25.5	8.8
6	22.1	19.7	12.5	6.8	1.9	1.5	16.8	6.1	64.6	26.1	9.3

No.	Bulk Density (g/cm^3) 1/3 Atm Moisture Entire Clod	<2mm in Clods	Dry <2mm in Clods	>2mm in Clods	COLE <2mm	Moisture (%) Retained at 1/3 Atm Entire Clod	<2mm in Clods	15 Atm <2mm Sieved	1/3 to 15 Atm Wt. (%)	cm/cm of Soil
1	1.81	1.6	1.67	2.42	0.015	10.8	16.5	6.6	1.8	0.039

TABLE B-14. CHEMICAL AND MINERALOGICAL CHARACTERIZATION DATA FOR PIT 7

No.	Depth cm	Horizon	Extractable Cations (Meq/100 g <2 mm material) Ca	Mg	Na	K	Total Bases	H	CEC (SUM)	Al	Base Sat. (%)	Ca/Mg
1	0-10	Ap1	0	0.5	0.06	0.07	0.6	12.7	13.3	3.61	4.4	0
2	10-31	Ap2	0	0.8	0.06	0.06	0.9	12.7	13.6	3.11	6.7	0
3	31-51	C1	0	1.5	0.05	0.05	2.0	14.3	16.3	2.62	12.4	0.3
4	51-66	C2	0.4	0.8	0.06	0.04	0.9	15.2	16.1	2.76	5.3	0
5	66-127	C3	0	0.5	0.05	0.02	0.6	11.8	12.4	2.12	4.9	0
6	127-154	C4	0	0.6	0.05	0.02	0.6	20.5	21.1	1.84	3.1	0

No.	pH Water	pH 1N KCl	pH 0.01M $CaCl_2$	Organic Matter C(%)	Organic Matter N(%)	Fe_2O_3 (%)	Clay Minerals (%) of (<0.002 mm material) Mont	Verm	Ill	Kaol	Int	Qtz
1	4.4	3.7	4.2	4.37	0.110	2.3	tr	10	40	50		tr
2	4.4	3.9	4.3	2.49	0.059	2.2	5	10	40	45		tr
3	4.0	3.5	3.9	6.88	0.185	2.3	tr	5	45	45		5
4	4.1	3.5	3.9	11.40	0.285	1.9	5	5	40	45		5
5	3.8	3.3	3.6	19.90	0.576	2.4	5	10	40	40		5
6	3.6	3.1	3.5	22.83	0.644	3.1	5	5	40	40		10

TABLE B-15. PHYSICAL CHARACTERIZATION DATA FOR PIT 8

No.	Depth cm	Horizon	Coarse Fragment Distribution (mm) (%) >76	76-19	19-4.7	4.7-2.0	Total Wt.	Total Vol.	Lab	Textural Class Field	Total Bulk Density (g/cm^3)
1	0-18	AC	26.7	23.7	13.3	4.1	67.8		SL	VSHSL	*
2	18-36	C1	44.3	12.2	14.7	5.3	76.5		SL	VSHSL	
3	36-58	C2	41.6	20.0	15.4	4.0	81.0		L	VSHSL	
4	58-102	C3	31.7	25.4	18.2	6.0	81.4		L	VSHSL	
5	102-145	C4	14.2	29.7	22.1	5.6	71.6		L	VSHL	
6	145-183	C5	22.0	22.0	21.0	4.8	69.9		L	VSHLS	

No.	Particle Size Distribution (mm) (% <2 mm) Sand 2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.10	0.10-0.07	0.07-0.05	Silt 0.02-0.002	0.005-0.002	Sand 2.0-0.05	Silt 0.05-0.002	Clay < 0.002
1	4.0	5.3	21.5	17.5	4.4	2.3	22.8	7.3	55.1	35.1	9.8
2	9.7	8.1	16.3	8.5	8.3	3.7	21.3	7.2	54.8	33.1	12.1
3	8.8	7.5	14.8	9.2	6.8	3.5	23.7	6.0	50.6	37.1	12.3
4	10.6	8.7	12.8	5.9	8.2	3.7	24.7	7.6	50.0	38.9	11.1
5	9.3	7.8	13.4	10.9	3.5	3.0	27.0	8.7	48.0	41.7	10.3
6	5.9	5.1	11.8	11.8	2.9	3.6	31.1	8.7	41.1	46.5	12.4

*No clods were obtained from this profile.

TABLE B-16. CHEMICAL AND MINERALOGICAL CHARACTERIZATION DATA FOR PIT 8

No.	Depth cm	Horizon	Extractable Cations (Meq/100 g <2 mm material) Ca	Mg	Na	K	Total Bases	H	CEC (SUM)	Al	Base Sat. (%)	Ca/Mg
1	0-18	AC	2.4	0.7	0.07	0.07	3.3	4.0	7.3	.14	45.2	3.4
2	18-36	C1	1.0	0.8	0.07	0.08	2.0	18.8	20.8	1.91	9.4	1.3
3	36-58	C2	0.2	0.6	0.07	0.08	0.9	11.2	12.1	2.62	7.4	0.3
4	58-102	C3	0.1	0.5	0.06	0.07	0.7	13.0	13.7	2.76	5.2	0.2
5	102-145	C4	0	0.5	0.06	0.07	0.6	13.3	13.9	3.61	4.5	0
6	145-183	C5	0	0.5	0.07	0.09	0.6	19.2	19.8	5.09	3.2	0

No.	pH Water	pH 1N KCl	pH 0.01M $CaCl_2$	Organic Matter C(%)	Organic Matter N(%)	Fe_2O_3 (%)	Clay Minerals (%) of (<0.002 mm material) Mont	Verm	Ill	Kaol	Int	Qtz
1	5.9	5.0	5.8	0.69	0.050	1.2	5	30	20	35		10
2	5.0	4.2	4.8	0.53	0.070	1.6	5	10	45	40		
3	4.8	4.1	4.6	2.85	0.112	1.8	10	15	35	40		tr
4	4.8	4.0	4.6	2.76	0.075	1.8	5	15	35	40		5
5	4.7	4.0	4.5	3.00	0.101	1.8	5	20	35	35		5
6	4.6	4.0	4.4	2.74	0.112	1.9	10	15	30	40		5

APPENDIX C

ORGANIC CARBON (WALKLEY-BLACK) VALUES FOR SELECTED HORIZONS

TABLE C-1. ORGANIC CARBON OF SELECTED HORIZONS DETERMINED BY THE WALKLEY-BLACK METHOD

Pit	Depth	Horizon	Organic Carbon
	cm		%
1	0-3	A1	6.978
	3-10	A2	0.958
2	0-10	A1	3.063
3	0-15	A1	1.770
	15-43	A2	0.877
4	0-8	A1	1.742
	74-94	B23t	0.672
	125-183	IIIC2	1.620
5	0-20	Ap	0.182
	20-36	C1	0.565
	36-56	C2	0.596
	56-74	C3	0.562
	74-114	C4	0.593
	114-152	C5	0.485
6	0-13	Ap	0.729
	13-28	AC	0.973
	28-53	C1	0.820
	53-84	C2	0.442
7	0-10	Ap1	2.026
	10-31	Ap2	1.214
	31-51	C1	2.158
	51-66	C2	2.326
	66-127	C3	2.691
	127-157	C4	2.612
8	0-18	AC	0.933
	18-36	C1	1.170
	36-58	C2	1.276
	58-102	C3	1.103
	102-145	C4	1.516
	145-183	C5	2.389

APPENDIX D

SIZE DISTRIBUTION DATA FOR PEDONS DESCRIBED IN APPENDIX A

TABLE D-1. PARTICLE SIZE DISTRIBUTION FOR PIT 1

Fraction	Horizon					
	A1	A2	B21	B22t	B3t	C
mm	% finer by weight					
0.002	7.37	8.92	9.56	9.32	6.52	6.01
0.005	14.67	16.46	17.56	16.32	12.82	13.11
0.02	35.25	34.45	28.68	28.35	20.12	16.86
0.05	50.07	48.22	38.04	35.96	23.06	15.98
0.07	52.30	50.07	39.94	37.55	24.51	17.22
0.10	54.68	52.22	41.84	39.27	28.02	18.63
0.25	62.13	60.06	49.43	46.41	40.27	30.18
0.50	67.28	66.14	56.21	53.68	53.47	40.11
1.0	71.12	69.68	59.94	58.51	55.09	41.64
2.0	76.80	76.90	67.80	66.10	55.70	42.60
4.7	85.30	87.90	79.70	81.90	65.70	47.80
19	89.40	94.40	88.50	92.80	75.00	70.50
76	100	100	100	100	100	100
254						
> 254						

TABLE D-2. PARTICLE SIZE DISTRIBUTION FOR PIT 2

Fraction	Horizon				
	A1	B21	B22	B23	C
mm	% finer by weight				
0.002	8.22	8.60	8.08	7.68	5.53
0.005	14.52	12.90	12.52	12.44	8.53
0.02	28.28	25.86	25.97	23.33	18.63
0.05	35.45	32.77	32.14	32.02	27.97
0.07	36.50	34.14	33.37	33.39	29.65
0.10	40.11	35.76	34.91	38.98	31.71
0.25	44.72	44.86	43.36	42.97	39.41
0.50	55.16	57.57	56.26	54.75	50.68
1.0	57.03	59.81	59.22	57.55	52.90
2.0	58.30	62.30	61.70	59.50	54.20
4.7	60.80	69.20	67.50	66.50	60.50
19	77.60	82.00	82.00	78.50	72.30
76	100	94.40	95.20	100	100
254		100	100		
>254					

TABLE D-3. PARTICLE SIZE DISTRIBUTION FOR PIT 3

Fraction	Horizon						
	A1	A2	B1	Bx1t	Bx2t	Bx3t	Bx4t
mm	% finer by weight						
0.002	6.82	8.18	7.02	7.21	11.56	14.20	8.89
0.005	10.32	13.84	11.06	10.64	15.56	19.53	12.88
0.02	18.29	27.00	22.18	20.92	29.59	37.42	23.89
0.05	23.43	35.24	30.36	28.48	39.12	47.85	31.31
0.07	27.20	37.02	32.13	29.84	40.45	49.27	32.62
0.10	30.74	38.87	33.84	31.50	41.91	53.67	33.83
0.25	33.27	47.17	42.41	37.55	49.09	57.58	39.08
0.50	38.05	57.01	51.20	45.06	57.54	66.10	45.34
1.0	41.51	59.29	53.63	47.33	60.46	68.87	48.07
2.0	44.30	61.50	55.30	50.40	63.50	71.00	50.50
4.7	38.00	71.30	63.70	60.40	75.80	84.50	59.50
19	83.00	86.20	71.90	78.60	87.70	92.50	83.60
76	100	100	99.9	100.1	100	100	100
254			100				
> 254							

TABLE D-4. PARTICLE SIZE DISTRIBUTION FOR PIT 4

Fraction	Horizon						
	A1	A2	B21t	B22t	B23t	IIC1	IIIC2
mm	% finer by weight						
0.002	10.74	11.16	11.78	10.89	9.69	6.95	16.16
0.005	18.09	18.71	18.95	15.24	13.23	12.87	25.57
0.02	37.86	38.06	35.40	29.93	28.56	27.04	29.79
0.05	48.96	47.99	47.51	39.47	40.61	39.56	51.01
0.07	50.34	49.67	48.76	41.00	42.44	42.44	52.70
0.10	52.32	50.89	49.88	42.41	47.16	45.96	53.35
0.25	54.56	53.86	52.97	45.90	47.62	53.87	54.77
0.50	59.37	58.25	57.45	50.92	48.27	60.68	57.08
1.0	62.07	61.28	60.93	56.30	54.10	65.50	61.07
2.0	65.90	64.50	65.80	61.20	65.50	68.80	64.90
4.7	85.10	85.90	88.00	85.00	88.90	80.70	84.70
19	97.70	97.60	98.90	97.20	99.50	95.50	100
76	99.90	100	99.90	99.90	100	100	
254							
> 254							

TABLE D-5. PARTICLE SIZE DISTRIBUTION FOR PIT 5

Fraction	Horizon					
	Ap	C1	C2	C3	C4	C5
mm	% finer by weight					
0.002	5.80	1.85	2.13	2.55	2.61	1.32
0.005	7.15	2.36	2.76	3.31	3.36	1.62
0.02	13.70	4.07	4.77	5.35	5.56	2.53
0.05	19.43	5.95	7.65	7.78	7.37	3.54
0.07	20.78	6.46	8.28	8.54	8.14	3.84
0.10	23.17	7.04	9.68	9.47	8.78	4.28
0.25	28.47	9.37	11.97	12.35	11.84	5.86
0.50	32.42	12.88	16.81	17.03	16.44	8.38
1.0	34.17	14.16	18.63	18.74	17.95	9.13
2.0	35.60	15.40	20.30	20.60	19.60	10.00
4.7	44.30	20.00	26.80	24.30	22.90	12.90
19	55.20	30.20	43.80	37.60	32.80	21.00
76	66.70	56.10	80.70	67.80	70.50	67.80
254	100	100	83.44	73.20	100	100
> 254			16.56	26.8		

TABLE D-6. PARTICLE SIZE DISTRIBUTION FOR PIT 6

Fraction	Horizon			
	Ap	AC	C1	C2
mm	% finer by weight			
0.002	4.46	4.62	3.15	0.95
0.005	5.53	5.66	3.87	1.18
0.02	9.94	4.34	6.15	1.76
0.05	13.99	13.59	8.55	2.41
0.07	15.06	14.62	9.28	2.64
0.10	16.92	15.63	10.89	3.11
0.25	20.99	19.39	12.61	3.84
0.50	24.16	24.74	17.20	5.58
1.0	25.47	26.93	18.96	6.31
2.0	26.70	28.90	20.70	7.20
4.7	29.00	36.60	24.20	8.70
19	37.70	56.40	40.90	15.70
76	47.90	93.00	78.40	47.70
254	100	100	100.1	59.82
>254				40.18

TABLE D-7. PARTICLE SIZE DISTRIBUTION FOR PIT 7

Fraction	Horizon					
	Ap1	Ap2	C1	C2	C3	C4
mm	% finer by weight					
0.002	2.92	8.03	1.88	1.17	2.99	1.78
0.005	3.70	9.54	2.40	1.57	4.08	2.07
0.02	5.98	15.14	4.13	2.82	7.41	4.11
0.05	8.60	21.30	6.33	4.29	11.66	6.65
0.07	9.38	22.81	6.85	4.69	12.75	6.94
0.10	10.50	24.56	7.34	5.31	14.18	7.30
0.25	12.17	30.76	8.65	6.30	17.64	8.60
0.50	14.72	39.89	10.38	7.82	22.57	10.99
1.0	16.06	42.87	11.78	9.11	27.57	14.75
2.0	17.80	45.90	13.60	11.10	34.00	19.10
4.7	22.40	54.90	18.90	15.30	41.60	29.60
19	31.70	71.40	33.30	29.50	82.30	54.40
76	78.70	91.00	63.30	74.50	100	100
254	100	91.78	73.11	76.36		
>254		8.22	26.89	23.64		

TABLE D-8. PARTICLE SIZE DISTRIBUTION FOR PIT 8

Fraction	Horizon					
	AC	C1	C2	C3	C4	C5
mm	% finer by weight					
0.002	3.16	2.84	2.34	2.07	2.93	3.73
0.005	3.90	3.71	3.01	2.76	3.78	4.81
0.02	8.89	7.02	6.37	5.94	8.98	11.55
0.05	14.46	10.62	9.39	9.31	14.77	17.73
0.07	15.20	11.49	10.06	10.00	15.62	18.81
0.10	16.62	13.44	11.35	11.52	16.62	19.69
0.25	22.25	15.44	13.10	12.62	19.71	23.24
0.50	29.18	19.27	15.91	15.00	23.52	26.79
1.0	30.88	21.17	17.33	16.62	25.73	28.33
2.0	32.20	23.50	19.00	18.60	28.40	30.10
4.7	36.30	28.80	23.00	24.60	34.00	34.90
19	46.90	43.50	33.40	42.80	56.10	55.90
76	73.30	55.70	58.40	68.20	85.80	77.90
254	100	100	100	99.90	100	99.90
>254						

APPENDIX E

MOISTURE CHARACTERISTICS FOR PEDONS DESCRIBED IN APPENDIX A

TABLE E-1. MOISTURE CHARACTERISTICS FOR PIT 1

Depth	Horizon	Matric Potential (cm of water)										
		0	-10	-20	-40	-60	-80	-100	-150	-240	-330	-1000
cm		g/g										
0-3	A1	.9315*	.8581	.8551	.8275	.7833	.7450	.6585	.6266	.6050	.5739	.5180
		.7218†	.6655	.6632	.6420	.6080	.5786	.5122	.4877	.4711	.4472	.4043
3-10	A2	.4372	.4017	.3808	.3699	.3495	.3322	.3031	.2963	.2884	.2788	.2607
		.3427	.3154	.2993	.2909	.2752	.2619	.2395	.2343	.2282	.2208	.2069
10-41	B21	.3839	.3512	.3168	.2685	.2387	.2279	.2241	.2086	.2071	.2026	.1977
		.2694	.2472	.2239	.1911	.1709	.1636	.1610	.1505	.1495	.1465	.1431
41-74	B22t	.3604	.3220	.3179	.2980	.2713	.2542	.2349	.2294	-	.2156	.2153
		.2478	.2224	.2197	.2065	.1889	.1776	.1648	.1612	-	.1521	.1519
74-109	B23t	.3582	.3297	.3048	.2780	.2651	.2458	.2250	.2180	.2107		
		.2120	.1961	.1822	.1673	.1601	.1494	.1378	.1339	.1248		
109-176	C	.3531	.3230	.3006	.2830	.2695	.2483	.2222	.2115	.1959		
		.1666	.1537	.1442	.1367	.1310	.1219	.1108	.1062	.0996		

*Uncorrected.

†Corrected for coarse fragments.

TABLE E-2. MOISTURE CHARACTERISTICS FOR PIT 2

Depth	Horizon	Matric Potential (cm of water)										
		0	-10	-20	-40	-60	-80	-100	-150	-240	-330	-1000
cm		g/g										
0-10	A1	.7963*	.7506	.6808	.6071	.5713	.5255	.4594	.4426	.4265		
		.4760†	.4493	.4087	.3657	.3448	.3181	.2796	.2698	.2604		
10-33	B21	.4400	.4118	.3691	.3280	.2998	.2709	.2565	.2478	.2377		
		.2847	.2671	.2405	.2149	.1973	.1793	.1703	.1649	.1586		
33-51	B22	.4232	.4097	.3794	.3334	.3062	.2887	.2659	.2476	.2398	.2100	.1982
		.2717	.2633	.2446	.2163	.1995	.1887	.1746	.1633	.1585	.1401	.1328
51-71	B23	.3899	.3701	.3442	.2982	.2743	.2585	.2498	.2249	.2111	.1671	.1481
		.2433	.2316	.2161	.1888	.1746	.1652	.1600	.1452	.1370	.1108	.0995
71-74	C	.3354	.3297	.3113	.2902	.2744	.2629	.2457	.2323	.2194	.1929	.1817
		.1946	.1915	.1816	.1701	.1616	.1553	.1460	.1388	.1318	.1174	.1113

*Uncorrected.

†Corrected for coarse fragments.

TABLE E-3. MOISTURE CHARACTERISTICS FOR PIT 3

Depth	Horizon	0	-10	-20	-40	-60	-80	-100	-150	-240	-330	-1000
cm		g/g										
0-15	A1	.3595*	.3465	.3186	.2845	.2659	.2535	.2416	.2290	.2199	.1913	.1797
		.1749†	.1691	.1568	.1417	.1334	.1280	.1227	.1171	.1131	.1004	.0953
15-43	A2	.4623	.4164	.3854	.3460	.3288	.3092	.2982	.2850	.2740	.2580	.2497
		.2952	.2669	.2479	.2236	.2131	.2010	.1942	.1861	.1794	.1695	.1644
43-66	B1	.3965	.3449	.3239	.2943	.2763	.2608	.2477	.2225	.2225	.2089	.1939
		.2318	.2033	.1917	.1753	.1653	.1568	.1495	.1430	.1356	.1281	.1198
66-91	Bx1t	.3994	.3540	.3326	.3019	.2777	.2629	.2538	.2384	.2220	.2076	.1974
		.2152	.1924	.1816	.1661	.1539	.1465	.1419	.1341	.1258	.1186	.1134
91-117	Bx2t	.4133	.3794	.3569	.3207	.2978	.2801	.2707	.2576	.2460	.2354	.2229
		.2769	.2512	.2369	.2139	.1994	.1881	.1821	.1738	.1665	.1597	.1518
117-135	Bx3t	.4023	.3785	.3611	.3144	.2965	.2789	.2654	.2524	.2290	.1841	.1764
		.2938	.2769	.2645	.2314	.2187	.2062	.1966	.1874	.1707	.1389	.1334
135-167+	Bx4t	.3436	.3131	.2999	.2582	.2402	.2259	.2201	.2113	.1834	.1436	.1285
		.1875	.1721	.1654	.1443	.1353	.1280	.1251	.1207	.1066	.0856	.0788

*Uncorrected.

†Corrected for coarse fragments.

TABLE E-4. MOISTURE CHARACTERISTICS FOR PIT 4

Depth	Horizon	Matric Potential (cm of water)										
		0	-10	-20	-40	-60	-80	-100	-150	-240	-330	-1000
cm		g/g										
0-8	A1	.4715*	.4246	.3834	.3197	.2969	.2838	.2777	.2703	.2480	.2253	.2153
		.3203†	.2894	.2622	.2202	.2052	.1966	.1926	.1877	.1730	.1580	.1514
8-20	A2	.3554	.3263	.3073	.2733	.2573	.2494	.2445	.2376	.2277	.1940	.1887
		.2392	.2204	.2082	.1862	.1759	.1708	.1677	.1632	.1568	.1351	.1317
20-48	B21t	.4184	.3790	.3577	.3098	.2925	.2780	.2735	.2669	.2457	.2344	.2301
		.2849	.2589	.2449	.2134	.2020	.1925	.1895	.1852	.1712	.1638	.1610
48-74	B22t	.4089	.3721	.3469	.2997	.2840	.2819	.2645	.2603	.2384	.2316	.2205
		.2611	.2386	.2232	.1943	.1847	.1833	.1727	.1702	.1568	.1526	.1458
74-94	B23t	.3992	.3533	.3297	.2927	.2789	.2642	.2549	.2502	.2244	.2108	.1997
		.2711	.2411	.2256	.2014	.1923	.1827	.1766	.1735	.1593	.1477	.1405
94-125	IIC1	.4753	.4229	.4125	.3826	.3625	.3471	.3376	.3342	.3118	.3038	.2901
		.3358	.2997	.2926	.2720	.2582	.2476	.2410	.2387	.2233	.2178	.2083
125-183+	IIIC2	.3797	.3204	.3037	.2736	.2602	.2511	.2431	.2255	.2135	.1912	.1826
		.2563	.2178	.2070	.1874	.1787	.1728	.1676	.1562	.1484	.1339	.1284

*Uncorrected

†Corrected for coarse fragments.

TABLE E-5. MOISTURE CHARACTERISTICS FOR PIT 5

Depth	Horizon	0	-10	-20	-40	-60	-80	-100	-150	-240	-330	-1000
cm		g/g										
0-20	Ap	.4205*	.3494	.3337	.2975	.2766	.2650	.2569	.2265	.2122	.1797	.1667
		.1678†	.1425	.1369	.1241	.1166	.1125	.1096	.0988	.0937	.0821	.0775
20-36	C1	.3271	.2856	.2727	.2337	.2208	.2128	.2098	.1890	.1715	.1452	.1370
		.0734	.0678	.0658	.0598	.0579	.0566	.0562	.0530	.0503	.0462	.0449
36-56	C2	.3267	.2786	.2650	.2249	.2158	.2017	.1989	.1799	.1686	.1396	.1338
		.0888	.0790	.0762	.0681	.0663	.0634	.0628	.0590	.0567	.0508	.0496
56-74	C3	.3483	.2828	.2696	.2289	.2141	-	.1999	.1792	.1772	.1684	.1621
		.0931	.0798	.0771	.0688	.0658	-	.0629	.0593	.0589	.0570	.0557
74-114	C4	.3588	.3009	.2848	.2395	.2189	-	.2017	.1823	.1790	.1685	.1634
		.0966	.0846	.0813	.0720	.0677	-	.0642	.0602	.0595	.0574	.0563
114-152	C5	.3308	.2771	.2636	.2231	.2098	-	.1934	.1783	.1724	.1582	.1510
		.0584	.0531	.0517	.0477	.0463	-	.0447	.0432	.0426	.0412	.0405

*Uncorrected.

†Corrected for coarse fragments.

TABLE E-6. MOISTURE CHARACTERISTICS FOR PIT 6

Depth	Horizon	Matric Potential (cm of water)										
		0	-10	-20	-40	-60	-80	-100	-150	-240	-330	-1000
cm		g/g										
0-13	Ap	.4250*	.3777	.3577	.3115	.2892	-	.2687	.2331	.2273	.2155	.1956
		.1341†	.1215	.1162	.1038	.0979	-	.0924	.0829	.0813	.0782	.0729
13-28	AC	.3457	.2900	.2716	.2343	.2081	.1983	.1930	.1816	.1678	.1632	.1524
		.1200	.1039	.0985	.0878	.0802	.0774	.0758	.0725	.0685	.0672	.0641
28-53	C1	.3409	.2852	.2801	.2564	.2193	.2084	.1999	.1780	.1483	.1290	.1207
		.0929	.0814	.0803	.0754	.0677	.0647	.0637	.0592	.0530	.0491	.0473
53-84	C2	.2921	.2270	.2255	.1930	.1690	.1492	.1426	.1312	.1201	.1133	.1017
		.0472	.0425	.0424	.0400	.0383	.0369	.0364	.0356	.0348	.0343	.0335

*Uncorrected.

†Corrected for coarse fragments.

TABLE E-7. MOISTURE CHARACTERISTICS FOR PIT 7

Depth	Horizon	Matric Potential (cm of water)										
		0	-10	-20	-40	-60	-80	-100	-150	-240	-330	-1000
cm		g/g										
0-10	Ap1	.3087*	.2668	.2568	.2328	.2007	.1930	.1876	.1786	.1677	.1661	.1544
		.1114†	.1039	.1022	.0979	.0922	.0908	.0898	.0882	.0863	.0860	.0839
10-31	Ap2	.3309	.2954	.2779	.2498	.2134	.2005	.1946	.1900	.1815	.1772	.1641
		.1890	.1727	.1647	.1518	.1351	.1292	.1265	.1244	.1205	.1185	.1125
31-51	C1	.3815	.3092	.2972	.2525	.2244	.2084	.1999	.1865	.1749	.1769	.1615
		.1112	.1014	.0998	.0937	.0899	.0877	.0865	.0847	.0831	.0834	.0813
51-66	C2	.3680	.3034	.2970	.2509	.2156	.1924	.1875	.1774	.1587	.1573	.1440
		.1019	.0947	.0940	.0889	.0850	.0824	.0819	.0807	.0787	.0785	.0770
66-127	C3	.3574	.2905	.2724	.2162	.1794	.1679	.1610	.1466	.1365	.1305	.1241
		.1668	.1440	.1379	.1188	.1062	.1023	.1023	.0951	.0917	.0896	.0874
127-154	C4	.4057	.3066	.2764	.2314	.2073	.1920	.1770	.1559	.1361	.1170	.1071
		.1331	.1142	.1084	.0998	.0952	.0923	.0894	.0850	.0816	.0779	.0761

*Uncorrected.

†Corrected for coarse fragments.

TABLE E-8. MOISTURE CHARACTERISTICS FOR PIT 8

Depth	Horizon	Matric Potential (cm of water)										
		0	-10	-20	-40	-60	-80	-100	-150	-240	-330	-1000
cm		g/g										
0-18	AC	.4277*	.3954	.3523	.3102	.2921	.2757	.2559	.2403	.2313	.2209	.2053
		.1843†	.1739	.1600	.1465	.1406	.1354	.1290	.1240	.1211	.1177	.1127
18-36	C1	.3912	.3558	.3261	.2899	.2676	.2515	.2349	.2085	.1993	.1612	.1538
		.1445	.1362	.1292	.1207	.1155	.1117	.1078	.1016	.0994	.0900	.0887
36-58	C2	.3969	.3621	.3276	.2890	.2708	.2592	.2386	.2192	.2025	.1927	.1771
		.1310	.1244	.1179	.1105	.1071	.1048	.1009	.0973	.0941	.0922	.0892
58-102	C3	.3779	.3503	.3206	.2835	.2692	.2569	.2421	.2278	.2212	.2078	.1876
		.1262	.1211	.1155	.1086	.1060	.1037	.1009	.0983	.0970	.0946	.0908
102-145	C4	.3054	.2953	.2775	.2507	.2352	.2240	.2123	.2003	.1963	.1906	.1833
		.1359	.1331	.1280	.1204	.1160	.1128	.1094	.1061	.1050	.1033	.1013
145-183	C5	.4418	.3943	.3556	.3398	.3022	.2843	.2704	.2607	.2561	.2521	.2450
		.1810	.1667	.1550	.1503	.1390	.1336	.1293	.1265	.1251	.1239	.1217

*Uncorrected.

†Corrected for coarse fragments.

APPENDIX F

METEOROLOGICAL DATA

TABLE F-1. METEOROLOGICAL DATA

DATE			TIME OF OBS	AIR TEMP °C			HYGROTHERMOGRAPH				A PAN				ONE METER WIND	PPT
				MAX	MIN	OBS	TA °C	RH	MAX TA °C	MIN TA °C	WATER TEMP °C			EVAP		
MO	DAY	YR	EST					%			MAX	MIN	OBS	LITERS	KM/HR	CM
5	24	76	9:10	26.7	1.1	13.3	13.9	54	25.6	2.2	35	-0.6	12.2			0
6	1	76	13:00	23.9	0.6	17.8	17.2	100	22.8	4.4	26.7	4.4	15.6	21.0	3.48	1.27
6	3	76	12:00	18.3	5.6	20.0	17.8	48	21.1	6.7	24.4	7.8	18.9		12.24	0
6	4	76	10:30	21.7	5.6	17.2	20.0	42	23.3	6.1	26.7	5.0	14.4		3.54	0
6	7	76	10:30	23.9	6.7	20.6	18.3	88	26.7	11.7	27.8	7.8	-	17.4	4.24	0
6	9	76	12:00	29.4	10.6	26.7	26.7	46	28.3	12.2	31.7	10.6	26.7		4.84	0
6	14	76	9:00	30.0	10.0	21.7	22.8	100	26.1	13.3	31.1	10.6	21.7	48.8	7.78	0
6	18	76	9:30	30.6	11.7	21.1	21.1	81	26.7	11.7	31.1	13.9	19.4		6.61	0
6	21	76	8:20	27.8	14.4	19.4	20.6	100	25.0	15.0	29.4	16.1	17.8	-85.6	6.70	3.81
6	23	76	9:15	27.2	17.2	24.4	23.9	72	27.8	17.2	30.0	17.2	23.9		4.71	0
6	24	76	10:20	28.3	16.1	26.1	25.6	58	26.1	16.1	32.2	17.2	26.7		3.96	0.51
6	26	76	13:10	27.2	15.0	26.7	26.7	41	27.2	15.0	32.8	14.4	32.2		6.70	0
6	28	76	9:30	30.6	14.4	29.4	25.6	60	30.6	16.1	32.8	13.9	23.3	0	4.44	0.38
6	30	76	8:55	29.4	15.6	18.3	19.4	100	30.6	16.7	32.2	15.6	17.2		4.60	0.89

TABLE F-1 (continued)

DATE			TIME OF OBS	AIR TEMP °C			HYGROTHERMOGRAPH				A PAN				ONE METER WIND	PPT
				MAX	MIN	OBS	TA °C	RH	MAX TA °C	MIN TA °C	WATER TEMP °C			EVAP		
MO	DAY	YR	EST					%			MAX	MIN	OBS	LITERS	KM/HR	CM
7	1	76	7:05	23.9	14.4	15.6	16.7	88	18.9	13.3	23.9	12.8	13.3		6.53	0
7	2	76	9:35	20.0	11.1	19.4	19.4	64	13.3	11.7	20.6	10.6	18.9	8.0	7.65	0
7	6	76	9:25	32.8	11.1	23.3	23.9	60	31.1	11.7	26.1	10.6	25.0	15.5	3.71	0
7	7	76	8:20	27.2	15.6	17.2	16.7	100	26.7	16.1	30.6	16.1	16.7	-14.2	3.43	2.16
7	9	76	8:50	23.3	10.6	16.7	16.1	93	23.3	13.3	30.0	14.4	16.1	- 1.0	4.01	0.13
7	12	76	8:45	28.3	9.4	17.2	17.2	73	19.4	14.4	30.6	12.8	16.7	- 6.0	4.85	0
7	13	76	8:20	20.0	2.8	16.7	16.7	67	21.1	12.2	17.2	11.7	14.4		11.02	0
7	14	76	8:30	21.7	11.7	16.7	16.7	76	21.1	12.2	21.1	11.7	15.6	6.8	9.28	1.52
7	16	76	8:55	28.9	14.4	20.6	20.0	90	25.6	16.1	30.0	14.4	23.3		4.27	0.13
7	19	76	9.10	26.1	9.4	22.2	21.7	59	26.7	12.2	27.8	10.0	18.9	- 4.7	5.86	0
7	20	76	9:05	27.8	12.2	23.9	23.3	64	27.8	13.3	31.1	13.9	21.1		2.49	0
7	26	76	8:20	27.8	6.1	18.9	18.3	58	26.7	7.8	29.4	11.7	16.7	19.0	6.34	0
7	30	76	11:00	29.4	12.2	23.9	22.2	86	25.0	17.8	32.2	12.8	22.2		3.89	0.13
8	2	76	13:10	25.6	6.7	21.7	22.2	40	23.3	7.8	26.7	7.2	25.6	19.0	4.16	0
8	6	76	13:30	26.7	6.1	21.7	21.7	92	23.3	18.3	29.4	5.6	23.3	16.0	3.63	0.13
8	18	76	10:25	29.4	8.9	21.1	21.1	50	25.6	10.0	30.6	9.4	19.4	-27.0	3.78	0
8	26	76	10:30	30.0	8.3	27.2	27.2	70	28.9	13.3	33.3	10.6	26.7	20.0	3.21	0

(continued)

TABLE F-1 (continued)

DATE			TIME OF OBS	AIR TEMP °C			HYGROTHERMOGRAPH				A PAN				ONE METER WIND	PPT
				MAX	MIN	OBS	TA °C	RH	MAX TA °C	MIN TA °C	WATER TEMP °C			EVAP		
MO	DAY	YR	EST					%			MAX	MIN	OBS	LITERS	KM/HR	CM
9	2	76	9:40	29.4	3.3	14.4	14.4	93	24.4	14.4	31.1	4.4	15.0	22.5	4.64	1.14
9	7	76	8:50	25.6	2.8	16.1	16.1	60	26.7	14.4	26.7	4.4	12.8	22.3	5.21	0
9	14	76	8:40	29.4	5.0	16.1	16.1	90	28.9	9.4	30.0	4.4	13.9	19.5	4.93	1.27
9	21	76	12:45	28.3	8.9	16.7	16.7	43	28.9	9.4	28.9	9.4	18.3	34.0	4.52	4.45
9	24	76	14:00	23.3	-	15.6	16.1	39	17.2	4.4	21.7	1.1	21.7	8.7	6.36	0
9	28	76	8:50	13.9	-11.1	10.6	1.1	84	19.4	5.6	21.7	1.7	10.0	-25.3	3.26	2.79
10	1	76	10:30	17.2	1.7	11.1	11.7	100	17.8	3.9	18.9	2.8	10.6	3.8	3.70	0.13
10	5	76	8:50	21.7	3.3	10.6	11.1	94	22.2	5.0	22.2	6.1	10.0	- 1.9	2.73	0.95
10	8	76	10:05	20.6	8.9	11.1	11.7	100	16.7	10.0	21.7	8.9	10.6	- 9.0	5.95	1.27
10	12	76	8:45	12.8	- 3.9	4.4	3.9	90	15.6	1.7	14.4	-1.1	1.7	-52.6	5.91	5.27
10	15	76	10:30	20.6	2.2	19.4	19.4	37	20.0	3.9	17.2	1.7	12.8	2.9	7.92	0.32
10	19	76	9:00	22.2	- 6.1	1.1	1.1	61	22.2	- 3.9	21.7	-0.6	0	5.9	6.39	0.38
10	22	76	10:00	7.8	1.1	1.1	2.2	75	8.3	0.6	6.1	-0.6	0.6	-27.2	9.83	3.18
10	26	76	9:20	11.7	- 6.1	1.7	2.2	64	12.2	- 1.7	10.6	-0.6	1.7	-29.7	7.32	2.87
10	29	76	10:00	5.0	- 9.4	4.4	5.0	54	11.1	- 7.8	6.1	-2.2	-0.6	6.1	7.44	0

(continued)

TABLE F-1 (continued)

DATE			TIME OF OBS	AIR TEMP °C			HYGROTHERMOGRAPH				A PAN				ONE METER WIND	PPT
				MAX	MIN	OBS	TA °C	RH	MAX TA °C	MIN TA °C	WATER TEMP °C			EVAP		
MO	DAY	YR	EST					%			MAX	MIN	OBS	LITERS	KM/HR	CM
11	2	76	12:30	10.6	- 5.6	7.8	5.0	51	10.6	- 3.9	6.7	-0.6	5.0	-10.2	7.65	1.22
11	9	76	9:35	11.1	-11.1	- 3.3	- 2.8	71	11.1	- 8.9					7.42	0.23
11	15	76	12:25	5.6	- 6.7	1.7	2.2	56	6.1	- 4.4					7.57	0.25
11	22	76	9:50	11.7	-10.6	- 3.9	- 3.3	81	11.7	- 6.1					7.80	0.13
11	29	76	9:45	15.6	- 7.8	- 4.4	- 4.4	88	15.6	- 5.0					8.63	1.24
12	6	76	10:10	-	-	-	-	-	1.1	-15.6					8.35	0.38
12	13	76	11:00	10.0	-25.6	- 9.4	-10.0	100	10.0	-12.8					10.07	2.92
12	20	76	10:35	11.1	-15.0	12.8	9.4	92	21.1	-14.4					7.07	0.13
12	27	76	14:40	8.9	-16.7	- 9.4	10.0	60	10.0	-13.9					9.96	0.76
1	3	77	10:45	10.0	-22.8	- 7.8	- 7.8	98	- 2.2	-20.0					8.87	1.24
1	21	77	9:00	- 1.7	-29.4	-10.0	- 8.9	93	- 1.7	-17.8					-	1.35
1	28	77	12:00	-	-	-	-11.1	94	- 1.7	-23.3					12.83	-
2	2	77	12:30	0	-26.1	- 6.1	- 5.6	72	1.1	-22.2					5.25	0.13
2	9	77	10:45	0.6	-21.1	- 6.1	- 3.3	52	0.6	-18.9					10.73	0.76
2	16	77	12:05	5.0	-15.0	- 9.4	- 9.4	54	10.0	-12.8					9.65	1.19
2	23	77	10:00	12.8	-19.4	12.8	10.0	51	10.0	-19.4					7.99	0.41

(continued)

TABLE F-1 (continued)

DATE			TIME OF OBS	AIR TEMP °C			HYGROTHERMOGRAPH				A PAN				ONE METER WIND	PPT
				MAX	MIN	OBS	TA °C	RH	MAX TA °C	MIN TA °C	WATER TEMP °C			EVAP		
MO	DAY	YR	EST					%			MAX	MIN	OBS	LITERS	KM/HR	CM
3	1	77	12:00	16.1	- 6.1	0	0	69	16.1	- 4.4					11.50	1.91
3	9	77	9:20	11.7	-19.4	11.7	11.1	46	11.1	- 7.8					8.50	3.81
3	16	77	10:50	20.0	- 2.2	6.7	6.7	58	19.4	0					7.71	2.79
3	23	77	10:35	10.0	- 6.1	2.2	2.2	38	10.0	- 3.3					11.88	3.48
3	30	77	11:40	25.6	-10.0	25.6	25.6	42	-	- 9.4					10.96	1.91
4	6	77	9:45	26.7	- 3.3	- 0.6	0	84	26.7	- 2.2					12.58	7.37
4	13	77	10:35	27.2	-10.6	23.9	23.9	43	27.2	- 8.9					9.32	0
4	20	77	9:55	26.7	- 2.2	15.6	15.6	54	26.7	- 0.6				27.0	6.08	0.20
4	27	77	12:50	26.7	- 0.6	15.0	15.6	36	26.7	1.1				6.8	6.60	1.65
5	5	77	15:35	24.4	- 4.4	22.2	22.2	75	24.4	- 2.8				13.0	6.81	1.84
5	11	77	11:00	26.7	- 3.9	15.6	16.7	44	26.7	1.7	26.1	- 1.1	16.7	22.0	11.06	0.25
5	18	77	10:15	30.0	0	25.6	26.1	58	30.0	1.1	-	-	-	-	6.94	0
5	24	77	10:35	30.0	9.4	25.6	26.1	62	30.6	12.2	30.6	12.2	24.4	24.0	4.49	0.57

(continued)

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

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4. TITLE AND SUBTITLE Comparison of some properties of minesoils and contiguous natural soils		5. REPORT DATE August 1978 issuing date
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15. SUPPLEMENTARY NOTES
This project is part of the EPA-planned and coordinated Federal Interagency Energy/Environment R&D Program.

16. ABSTRACT

Four minesoil pits located within the disturbed area and four natural soil pits located in adjacent undisturbed areas were described and sampled. Bulk densities were determined at ten randomly located sites. Microlysimeters were subsequently installed at these sites and used to determine saturated hydraulic conductivities and evapotranspiration.

The most prominent feature of the minesoils was their high degree of coarseness and their high rock fragment content. Roots tended to concentrate along soil-coarse fragment interfaces. Few roots penetrated the massive minesoil material in the C horizons.

The weathering of the natural soils has leached bases from them and significantly more extractable aluminum was found in these soils than in minesoils. Organic carbon and nitrogen determinations were affected by the high content of carboniferous shale and coal fragments in the minesoils. The clay minerals present in the minesoils had not been weathered as much as the clay minerals in the natural soils.

Average bulk density of the minesoil surface was 1.70 g/cc contrasted with 1.26 g/cc for adjacent soils.

17. (Circle One or More) KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS			b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Ecology Environments Earth Atmosphere Environmental Engineering Geography Other:	Hydrology Limnology Biochemistry Earth Hydrosphere Combustion Refining	Energy Conversion Physical Chemistry Materials Handling Inorganic Chemistry Organic Chemistry Chemical Engineering	Energy Production Energy Extraction Fuel Gas Cleaning Direct Combustion Synthetic Fuels Nuclear Thermal Improved Efficiency Advanced Systems Other	Impacts & Effects Transport Processes Ecological Effects Health Effects Integrated Assessment Energy Supply Extraction Processing Conversion Utilization Fuel Coal Oil Shale Nuclear Geothermal Solar Waste as Fuel Hydroelectric Multi-Fuel Performance	8H 48A 48E 48F

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