SOIL GENESIS ON RELATIVELY YOUNG SURFACE MINED LANDS IN SOUTHERN WEST VIRGINIA

by

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DEDICATORY

To my parents

Sometimes those to whom we owe the most,
we are able to repay the least.

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INTRODUCTION

Before the beginning of the 20th century the total land area disturbed by surface mining was quite small. Land was plentiful, and little attention was given to reclamation. As this century unfolded, technologic advancements facilitated the removal of thicker overburden and extraction of lower grade minerals. The economic advantages of blasting improved methods of materials handling and increases in size of equipment, as well as a constantly increasing demand for coal, caused surface mining to increase and expand to areas of more valuable land (Doyle, 1976).

Surface mining offers several advantages over conventional methods of underground mining. The output per man-day is more than three times as great, operating costs are 35 to 40% lower, and coal recovery efficiency is nearly twice as great in a surface mining operation. Perhaps the greatest advantage lies in the increased personal safety offered a surface miner (Bennett et al., 1976).

In the Appalachian region, land is being disturbed by surface coal mining at the rate of about 12,546 hectares per year (Curtis, 1971). By 1976, more than 385,274 hectares had been disturbed by surface mining in Appalachia (Armiger et al., 1976).

The state of West Virginia has long felt the effects of surface mining. The only state lying entirely within Appalachia, the most productive coal region in the world, West Virginia has produced more coal (over 8 billion tons) than any other state (WVSMRA, 1977). West Virginia produces approximately 101.7 million tons annually, with 20 million tons produced by surface mining methods. Thirty-four of the state's 55 counties presently contain some type of surface mining (W.Va. Coal Assoc., 1977). An early 1970 survey (Hodel, 1972) of each of these 34 counties reported that an average of 11% of their acreage had been disturbed to some degree by these operations.

Although only 30% of West Virginia's total acreage is farm land, the value per acre of this land is the second highest in the nation (USDA, 1977). Table 1 lists land acreage by use in West Virginia. More than 94,000 hectares of land, an amount equal to about 5% of the total farm acreage, have been reclaimed within the state since 1961 (Table 2). With proper reclamation, this land could be placed into intensive useage, such as agricultural production, within a certain time period.

Description of Study Area

Over 3/4 of West Virginia consists of the Pennsylvanian geologic system (280-310 million years old). All of West Virginia's 117 coal beds were formed during this period. Of these, 61 are considered mineable ($\geq$ 3 feet thick, although thinner beds have recently been mined) and constitute a 75.5 billion ton coal reserve. Another 41 billion tons occur in thinner and less pure beds. The coal areas of West Virginia cover 4,475,658.2 hectares, but the total mineable acreage of all seams extends over 9,719,016.2 hectares because many of the seams overlap in their parallel bedding. Of the State's 55 counties, 44 contain mineable coal and 37 have produced or currently are producing coal.

Table 1. West Virginia land uses (1974).

Land Use	Hectares (x1000)
Crop land	316
Pasture only	306
Idle	33
Grassland pasture	291
Forest	4,907
Special use areas	240
Other land	142
TOTAL	6,235*

*Area considered "farmland" - 1,881,855 hectares

Table 2. Hectares reclaimed in West Virginia (1961-1978).*

Year	Hectares Reclaimed
1961	335
1962	1,243
1963	1,228
1964	1,216
1965	2,159
1966	2,694
1967	2,956
1968	8,061
1969	6,927
1970	5,360
1971	8,243
1972	11,061
1973	10,252
1974	8,344
1975	6,289
1976	7,262
1977	6,425
1978	4,807
	TOTAL 94,882

*Obtained from Benjamin C. Greene, President, West Virginia Surface Mining and Reclamation Association. Personal communication, February 23,1979.

The state has a calculated capacity to produce over 200 million tons annually (Price et al., 1938).

The Pottsville Series of the Pennsylvanian system occurs in nearly 70% of the state. Over 60% of the coal mined in West Virginia comes from beds in the Pottsville Series. Its thickness ranges from 200 feet (61 m) in the northern panhandle to 3850 ft. (1173 m) in the southern counties, an expansion of nearly 20 times in crossing the state. In northern West Virginia, the Pottsville Series has not been subdivided, due to thinness, but in the southern counties it has been subdivided into three groups: the Kanawha, New River and Pocahontas Formations (Price et al., 1938).

All mine soil samples used in this study were collected in the New River Formation, within or along the borders of Raleigh County in south-central West Virginia. The New River Formation contains massive conglomeratic sandstones, sandy shales, fire clays, thin limestones, lenticular iron ores, and 10 mineable coal beds. Lying within the Allegheny Plateau physiographic region, this area is generally rough and mountainous. As an old dissected plateau region, it contains some rather broad flats at elevations of 2,000-2,500 ft. (610-762 m) and narrow valleys with steep side walls. The deepest geologic erosion is along the narrow, gorgelike valley of the New River, about 1,300-1,700 ft. (396-518 m) deep and about 1 mile wide (Gorman and Espy, 1975).

The humid, continental climate of this area is characterized by sharp temperature contrasts, both seasonal and diurnal. The mean daily maximum temperature is 64° F (18° C), and a mean daily minimum is 39° F (4° C). Cold waves occur two or three times annually, but seldom last longer than a few days. Below-zero temperatures, as well as temperatures in the 70's (° F) have been recorded in December, January and February. The annual frost-free growing season averages 141 days. Mean annual precipitation is 45 in. (115 cm) while snowfall ranges from 30-40 in. (76-102 cm), with the greatest amounts occurring in the eastern portions of the county. Snowfall totals for the season of 60 in. (152 cm) are not uncommon on the highest ridges (Gorman and Espy, 1975).

Some phase of either the Dekalb, Gilpin or Muskingum series make up nearly 80% of the soils of Raleigh County (Table 3). In 1964, 736 farms with an average size of 83 ac. (32.68 ha) comprised 15.8% of the acreage in Raleigh County, approximately equal to the land not included in the Dekalb, Gilpin and Muskingum series (Gorman and Espy, 1975).

The Dekalb series has a channery to very channery subsoil, with slopes ranging from 3 to 70%, but most are greater than 40% (Table 3). Very stony units make up more than half the acreage. The Dekalb soils are generally well-drained, moderately deep, have low to moderate available moisture, rapid permeability and low natural fertility. slope and stoniness are the major factors limiting its use (Gorman and Espy, 1975).

Slopes of the Gilpin series range from 3 to 65%. The Gilpin series usually has a channery subsoil with moderate available moisture,

Table 3. The most extensive soils of Raleigh County, West Virginia, and the proportion of those soils occurring on very steep slopes (from Gorman and Espy, 1975).

Soil series		Percentage of Raleigh Co. land area	Percentage of series occurring on slopes > 40%
Dekalb		21.3	10.0
Gilpin		17.7	8.4
Muskingum		40.2	34.5
	TOTAL	79.2	52.9

permeability and natural fertility. This soil is deep, well-drained and strongly sloping for the most part.

Steep slopes also dominate the Muskingum series (Table 3). The most extensive slope class is the very steep (>40%), although slopes range from 10 to 75%. Two-thirds of this series has been mapped as being very stony, with channery subsoils. Available moisture is high, while natural fertility and permeability are moderate. The series is usually moderately deep and well-drained (Gorman and Espy, 1975).

Surface mining can be considered an interim land use. It removes acreage from its current use for a relatively short period of time, and then returns it in an altered state. In areas such as West Virginia where level or gently rolling land is highly valued, an effort should be made to use surface mined areas. However, even with the most modern equipment and techniques, most surface mined areas cannot be made to equal or surpass immediately the productivity of the original land. Many products of surface mining are corrected or significantly improved only with the passage of time. In the Appalachian region, 100 to 1000 years may be necessary for the economic returns of current pre-mining land use to offset the cost of reclamation (Wahlquist, 1976). Theoretically, this time could be substantially shortened by substituting some land use with higher economic return, such as farm land. However, agricultural production on surface mined sites may be highly dependent upon soil conditions found at the mined site.

These soil conditions can be expected to be far from optimum immediately after mining in most cases, but after a period of exposure to the soil forming factors, these conditions would be expected to improve.

The objectives of the study were:

1) To describe and measure differences in morphological, physical and chemical properties of mine soils of various ages from the New River Formation of the Pennsylvanian system in southern West Virginia.

2) To evaluate differences in soil properties as a function of age of mine soils formed on spoils of this geologic formation.

LITERATURE REVIEW

The initial concern of reclamation research, and the continuing concern of most reclamation research, has centered on the revegetation of disturbed areas. Consequently, the techniques for revegetating spoils are fairly adequate (Lowry and Finney, 1962). The weathering of mine soils, and the study of mine soil pedogenesis in a somewhat controlled situation, has been studied only briefly.

In 1860, E. W. Hilgard, in his Report on the Geology and Agriculture of the State of Mississippi, introduced to this country the concept that different kinds of soils are products of climate and vegetation acting upon the rock materials produced by weathering (Kellogg, 1957). Jenny (1941) gave us the classic equation of soil formation:

$$S \text{ or } s = f\ (cl, o, r, p, t, \ldots).$$

In this equation, soil (S) or any soil property (s) is considered to be a function of the combined influence of climate (cl), organisms or biota (o), topography or relief (r), the soil parent material (p), time (t), and any other unspecified factors of local importance.

In Jenny's equation, if all the factors are permitted to vary, it is impossible to sort out the effect of each factor, and the equation cannot be solved. In an effort to overcome this difficulty, Jenny solved the equation by permitting one factor to vary while the others are held constant. In doing so, he established the following functions:

$$S = f\ (\underline{cl}, o, r, p, t, \ldots) \text{ climofunction}$$

$$S = f\ (\underline{o}, cl, r, o, t, \ldots) \text{ biofunction}$$

S = f (r,cl,o,p,t, . . .) topofunction

S = f (p,cl,o,r,t, . . .) lithofunction

S = f (t,cl,o,r,p, . . .) chronofunction

To solve each function, the first factor listed (underlined) is permitted to vary while the others remain constant (Birkeland, 1974).

Many critics of Jenny have searched for easier solutions, but the theoretical basis for Jenny's functional approach has in no way been successfully challenged (Yaalon, 1975). Runge (1973) felt soil formation could be adequately described by three factors: leaching, organic matter production, and time. Rode (1961) added three more soil forming factors to Jenny's original five: the economic activity of man, the earth's gravity, and the ground, soil and surface waters. Man was also recognized as a factor in soil formation by Bidwell and Hole (1965). Yaalon and Yaron (1966) described man-induced processes and changes in the soil profile with the term "metapedogenesis."

We must distinguish between factors of soil formation and processes of soil formation. Soil processes actually produce the soil, while soil forming factors define the state of the soil system (Birkeland, 1974). No matter what factors are considered, soil forming processes progress in indistinct stages which are difficult to separate (Simonson, 1957).

The two major processes of soil formation are parent material accumulation and differentiation of horizons in the profile (Simonson, 1957). Weathering of the initial materials precedes soil formation in hard rocks and accompanies it in soft rocks and soil materials. It is a continuing reaction during soil development, to the point where no more reactants are available. Weathering proceeds both below the solum and within the solum itself (Buol et al., 1973). Solid rocks weather relatively slowly under the influence of climate. Heating and cooling, freezing and thawing, wetting and drying all tend to weaken rock structure. Mineral reactions with water and air induce stresses and strains which further weaken the rock structure. The final effect of physical weathering is to break the rock into small pieces, often into constituent mineral grains. The loose, weathered rock material may then become soil parent material (Simonson, 1957).

Horizons are formed in soil profiles because of gains, losses and alterations. As plants and soil organisms become established, their residual material and by-products become incorporated into the soil. The addition and decay of organic matter gradually changes the character and appearance of the soil's surface layer. As this layer begins to differ from the underlying layers in several respects, it becomes an A horizon, the first stage in the differentiation of horizons. By the time rock has weathered enough to form a regolith, horizon differentiation also will have begun. Soil profiles with A and C horizons, both of which may be thin, can therefore be found in all but the very youngest of weathering materials. With the passing of time, a faint A horizon slowly becomes thicker and more distinct, growing at the expense of the C horizon (Simonson, 1957).

The rate of soil horizon formation is related to pedogenetic days per year, much in the manner that plant growth is related to growing days per year. The rate of soil formation and the number of pedogenesis days will vary across geographic boundaries. In many areas, the rate may be quite rapid. In North Dakota, for example, 15 cm of an A1 horizon were observed to have developed over a 50-year period (Buol et al., 1973).

The B horizon begins to develop after the A has become distinct, although in some cases A and B horizons may be formed together. Buol et al. (1973) cite numerous examples of the considerable periods of time required to weather materials and differentiate horizons. However, the ratio of the age of these materials versus their rate of formation (years:soil depth [cm]) is the best in the incipient stages of development.

As Jenny (1941) hypothesized, one can keep all other factors of soil formation constant and let time be the only variable of soil development. This is the independent variable method of study of soil genesis (Buol et al., 1973). One objection to this method of studying soil development is the implied assumption that the soil in question is monogenetic, or that it has developed under constantly uniform conditions since its inception. This is true for very young soils, and generally true for soils no older than the last ice age (Barshad, 1964).

Jenny (1941) discussed the relevance of time as a factor of soil formation in the following manner:

> The estimation of relative age or degree of maturity of soils is universally based on horizon differentiation. In practice, it is generally maintained that the larger the number of horizons and the greater their thickness and intensity, the more mature is the soil. However, it should be kept in mind that no one has ever witnessed the formation of a mature soil. In other words, our ideas about soil genesis as revealed by profile cri-

> teria are inferences. They are theories, not facts . . . it is evident that the issues center around the factor time in soil formation.

Dickeson and Crocker (1953/54) stated there are two phases of soil development operating effectively over time: 1) the introduction and survival of organisms, giving upper layers dominated by organic matter and lower layers carrying the traits of the parent material, and 2) the later evolution of the profile due to weathering and eluviation of sesquioxides.

A sequence of related soils that differ in certain properties, primarily as a result of time as a soil forming factor, is termed a chronosequence (Soil Science Society of America, 1973). The observed differences among soils of different ages forming a sequence are considered to be the result of the lapse of the different time intervals since the initiation of soil formation. In a chronosequence, the scope of any soil property is functionally related to time if the other soil forming factors are constant or vary insignificantly (Stevens and Walker, 1970).

Chesworth (1973) feels that time is the only factor of soil formation, as it is the only independent factor. Time eventually nullifies even the parent material effect.

Stevens and Walker (1970) believe all sequence studies have failed in one way or another to "control" the soil forming factors other than time. Also, the sequence studies are not widely applicable, as they occur in different regions with features peculiar to each individual sequence. However, even with these differences, Stevens and Walker feel the similarities outnumber the differences in observed properties.

Nearly all sequence studies based on time, point out rapid initial changes due mainly to organic matter production. This causes several properties of the soil profile to become depth-dependent. These initial changes are directly and completely correlated with the advent, growth and distribution of various vegetation associations. Eventually, morphological changes due to eluviation and illuviation come to dominate pedogenesis, followed by changes in physical composition and further evolution of the profile.

Surface mine spoil material can be considered as soil parent material, just beginning the normal processes of soil formation. Organic matter and organisms are noticeably absent, as is soil structure (Bennett et al., 1976)

Chronosequences have rarely been studied on surface mine spoils, although they offer excellent opportunities to do so, since in most cases they are easily dated. Anderson (1977) studied spoils in a semi-arid climate ranging from 28 to 40 years of age. He noted soluable components leaching out quite rapidly, and his analysis of fractional composition and spectral properties of humic acids indicated that the humus of soils 28 years old was similar to that of the normal regional soils. A study of the effect of time on 19 separate mine soils in Ohio (Lowry and Finney, 1962) employing the use of lysimeters was initiated January 1, 1959. However, results of this study to date are sketchy at best. One study was conducted recently in West Virginia (Delp, 1975), but deals primarily with classification, and does not relate observed characteristics to age of the spoil material. A recent Pennsylvania study (Pederson, 1977) compares a recently mined area to contiguous natural soils. One particular West Virginia study (Sencindiver, 1977) deals primarily with mine soil classification, despite its title (Classification and Genesis of Mine Soils), but has had a great impact in this area and is gaining in acceptance and use. Some studies have recently been concerned with predicting the characteristics of the resulting mine soils by analysis of the overburden prior to mining (Krause, 1973; Smith et al., 1974; Smith et al., 1976). Haynes and Klimstra (1975) investigated soil factors on surface mined areas and related them to both age of the soil and vegetation density. Perhaps the report which most closely resembles this study was the investigation of 85 to 103 year old soils derived from iron ore soils in northern West Virginia (Smith et al., 1971). Although the parent material of these iron ore soils was fairly different from that of the mine soils observed in this study, some results were fairly similar, and are noted as such throughout this thesis.

Theories of Aggregate Formation

Structure can be viewed as the arrangement of primary particles (sand, silt and clay) into compound particles or clusters (aggregates or peds) that are separated from adjoining clusters and have properties unlike an equal mass of unaggregated primary soil particles (Taylor and Ashcroft, 1972). The genesis of soil structure is complicated and obscure. The nature and origin of the parent material is important, as well as physical and biological processes of soil formation, particularly those resulting in the synthesis of clay and humus. Climate is also a prime consideration, as is the downward migration of clay, iron oxides and calcium and magnesium carbonates, as well as organic matter accumulation and the processes by which it decays.

Genesis is influenced by wetting and drying, freezing and thawing, the physical activity of roots and soil animals, the decay of organic matter and of the slime from microorganisms and other life forms, the modifying effects of adsorbed cations and soil tillage. In general, any activity that will develop lines of weakness, shift the particles back and forth, and force contacts that otherwise might not occur, encourages aggregation (Brady, 1974). All of these factors either directly or indirectly influence the amount and activity of soil organic matter or the clay colloids, and dependent upon the climate, influence aggregate formation.

Clay behavior is quite complex and it enters into many reactions that might tend to bind aggregates. These reactions are associated with the amount and distribution of charge on the clay particles. Sands and silts, which dilute the effect of clay, have a low specific surface so that the binding action becomes negligible. Suspensions of lyophobic colloids are never stable in a thermodynamic sense. Their large surface area represents a large amount of free energy which can be at a minimum only when the particles have been united into one large crystal or mass. This tendency to reduce the interfacial area, generally regarded as a London - van der Waals force, is a contributing force causing particles to flocculate (Taylor and Ashcroft, 1972).

In 1934, the cation-dipole linkage theory, as put forth by Russell (Taylor and Ashcroft, 1972), speculated on the exact nature of aggregate formation as influenced by the colloidal fraction of the soil. Each clay particle in suspension, according to Russell's theory, carries an electric charge that contributes to the electric conductivity of the suspension. The charged particle is surrounded by an electric double layer of cations. Soils that possess a favorable electric double layer environment will, when left alone, tend to regenerate aggregates. Polar molecules of the liquid surrounding the clay particles tend to be oriented along the lines of force radiating from each ion and from each free charge on the clay particle. As the water is removed, the thickness of the envelope is reduced, and each ion then shares its envelope with two clay particles which are then held together by this attraction. In theory, any colloid that possesses the right kind of characteristics would be effective in aggregate formation (Taylor and Ashcroft, 1972).

To effectively influence aggregate formation, organic matter must be active; that is, in the form of living organisms. Microorganisms are especially beneficial, although living roots of higher plans, particularly grasses, may have a desirable influence. A sod crop of grass frequently produces large numbers of fine fibrous roots (profile descriptions, Appendix I) that die each year and are continuously decomposing. In this manner the organic matter is thoroughly dispersed throughout the soil to a depth where it might be most effective (Taylor and Ashcroft, 1972). However, much of the desirable influence of roots is caused by the microorganisms that are associated with them.

Rhizobia, routinely used as a plant inoculant in reclamation, are symbiotic, in that they convert atmospheric nitrogen to combined forms only in association with the roots of plants of the family Leguminosae (Janick, 1972). The bacteria supply the plants with utilizable nitrogen, while the plants supply the bacteria with an adequate energy supply of carbohydrates (Tortora et al., 1970). The Rhizobia attach to the roots of legumes, enter a single-celled root hair where they rapidly proliferate, growing toward the base of the root hair and piercing the cortex of the root. As a result of this penetration, marked cell proliferation takes place, and a nodule, which is a mass of root tissues containing millions of bacteria, is formed (Tisdale and Nelson, 1975).

Mechanisms of Soil Acidity

The aluminosilicate clay minerals which are major sources of soil acidity are the 1:1 and 2:1 layer clays, typified by kaolinite and montmorillonite. These clays cause the soil to behave like a buffered weak acid, resisting sharp changes in pH, due to the exchange and hydrolysis of aluminum ions (Coleman and Thomas, 1967). In acid clays or soils, these adsorbed aluminum ions maintain an equilibrium with aluminum ions in the soil solution. Their hydrolysis gives rise to hydrogen ions in solution as indicated in the following equation.

$$Al^{3+} + H_2O \rightarrow AlOH^{2-} + H^+.$$

The addition of a small amount of a base will neutralize these hydrogen ions and precipitate the aluminum as $Al(OH)_3$. However, the equilibrium of the systems will be maintained by the movement of adsorbed aluminum ions into the soil solution. These aluminum ions then hydrolyze, producing more hydrogen ions, and the pH tends to remain as it were before the addition of the base. As more bases are added, more of the adsorbed aluminum will be replaced and ultimately neutralized on the soil colloid by the cations of the added base, thereby effecting a gradual pH change (Tisdale and Nelson, 1975).

Additions of acidic components to the soil will have the opposite effect on pH, as the added H^+ ions neutralize OH^- ions. Any $Al(OH)_3$ in the soil will dissolve, enter into solution and gradually replace basic cations held on the soil clay, causing a continual but slow decrease in the soil pH (Tisdale and Nelson, 1975).

Hydrous oxides of iron and aluminum also contribute to the weak-acid character of soils. Their presence, either as interlayers or surface coatings, causes an interaction with layer silicates (Coleman and Thomas, 1967). The hydrous oxides' interaction is pH dependent upon charge.

Clays contain charges originating from lattice substitution of lower valence cations for higher valence cations, and from dissociation of hydrogen ions from hydroxyl groups or from structural water. These charges can be separated into two categories. The first, or permanent charge, is responsible for the electrostatic bonding of aluminum and other ions, and results largely from isomorphous substitution.

The second, or pH-dependent charge, is responsible for the covalent bonding of hydrogen and other ions. It originates from structural OH^- groups at the corners and edges of clay lattices, which may dissociate hydrogen ions in a slightly acid to alkaline environment. At these higher pH values, amorphous iron and aluminum hydroxy compounds, which are coating the aluminosilicate clays, may hydrolyze and unblock exchange sites on the minerals (Tisdale and Nelson, 1975). The hydrous oxide coatings, along with organic matter, account for most of the charge and buffer capacity developed between pH 5.5 and 8 (Coleman and Thomas, 1967).

Aluminum ions which are displaced from clay minerals by basic cations hydrolyze in the soil solution. These may be readsorbed by the clay minerals, resulting in further hydrolysis. The resulting hydrogen ions react with and dissolve or decompose soil minerals (Tisdale and Nelson, 1975).

Acidity as determined by the $BaCl_2$-TEA method (Peech, 1965) is not an indication of exchangeable acidity, but rather that acidity which is titratable (neutralized) at a pH of 8.2. The exchange acidity of a sample, which results from the replacement of hydrogen and aluminum ions and from dissociation of acidic groups, is neutralized by the free triethanolamine, a weak base which is fairly well buffered at pH 8.2. The barium, which is at relatively high concentrations, not only replaces exchangeable aluminum ions on clays, hydrous oxides and organic matter, but also increases hydrolysis of the adsorbed aluminum ions and the dissociation of the acidic groups on the exchange sites, both of which are affected by the pH of the system which, in turn, is dependent upon the salt concentration of the extracting solution (Peech, 1965).

Therefore, titratable acidity at pH 8.2 is an overestimation, and is actually the pH dependent charge reflecting the covalently bonded hydrogen released from the functional groups on organic matter and edge groups, and not bound by permanent charge on aluminosilicate clays (Tisdale and Nelson, 1975). A soil at pH 5 or 5.5 may have very little exchange acidity, but may have large amounts of titratable ($BaCl_2$-TEA) acidity (Coleman and Thomas, 1967).

Water Infiltration

Infiltration, or the process by which water enters the soil, is one of the primary factors affecting the surface runoff from soil. Most soils have maximum and minimum infiltration rates. For any given rainfall, the value will be highest at the beginning and then will gradually decrease to a somewhat stable minimum. For water storage and erosion control, the infiltration capacity of the soil ideally should equal the rainfall intensity. However, this is practically impossible to obtain (Jones et al., 1975).

Farmer and Richardson (1976), in studying mine soils of southeastern Montana, found that mine soils from 1 to 24 months of age decreased their average infiltration rates about 10 times with increasing age, although this could not be correlated with any other measured properties and may well be the result of initial settling of the unconsolidated spoil material.

One recent study (Rogowski and Jacoby, 1977a) has shown that topsoiled sites contribute more sediment to infiltrating water than non-topsoiled sites. Also, in the same study, oxygen concentrations in the soil recovered much faster following wetting on mine soils that were not topsoiled. In both types of mine soils, infiltrating water was observed moving downward very rapidly through a system of macropores such as that created in coarse textured and stony mine soils (Rogowski and Jacoby, 1977b).

METHODS OF STUDY

Sampling Scheme

The sampling scheme was designed to allow sampling of mine soils (within the New River Formation) which had been produced from three different parent materials; either sandstone, shale or an approximately equal mixture of the two. By selecting sites that had been reclaimed for 2, 5, and 10 years, my objective was to study pedogenesis occurring on similar materials of differing ages (Table 4).

Sites of the correct ages to fit the sampling scheme were selected from records made available by the West Virginia Department of Natural Resources, Reclamation Division. Specifically, the ages were determined as closely as possible from files containing the date at which mining was completed, or at which revegetation procedures had begun. Although the time required to process these files may have caused some variation in reported dates, the error could not be more than a few months at most. Also, some mines may operate for a period of time under a permit for a particular area, extending the mining operation sequentially through the area with time. Hence, one side of a contour mining operation may be a year or more older than the opposite end of the same operation. This variable was removed when records or on-site observation indicated sequential discrepency, but the sequence of mining was oftentimes difficult to determine, particularly for some of the older areas. Most of the 10 year old sites were so small, however, that the mining was probably completed within a few months' time.

Table 4. Parent material, age and replications used in this study.

Parent Material	Age (yrs.)	Replications
Predominately sandstone	2	3
	5	3
	10	3
1/2 sandstone - 1/2 shale	2	3
	5	3
	10	3
Predominately shale	2	3
	5	3
	10	3
"Topsoiled" sites	-	3
Natural soil series		
Dekalb	-	1
Gilpin	-	1
Muskingum	-	1

In either case, I do not feel this short amount of time affects the results significantly.

After locating potential sites to fit the age requirements, each site was visited and further classified by the predominant overburden (parent material) in the exposed highwall. Coal seams were found to be overlain by either sandstone, siltstone or shale. No attempt was made to distinguish between siltstones and shales. The purpose of identifying the overburden type was to compare the properties of soils forming from course textured materials (sandstone) against soils forming from fine textured materials (siltstone or shale). Therefore, sites described as shale overburden may be composed of either shale or siltstone. "Mixed" overburden denotes sites having approximately equal volumes of sandstone and shale in the highwall. Parent material types could not be determined for the three topsoiled sites, as all three were mountain top removal operations with no adjacent highwall for analysis. Three replicates (separate mine sites) were sampled for each parent material type within each age group.

Field Methods

At each site, fresh rock samples were collected from the highwall for further study. A shrubbery spade, commonly known as a "sharpshooter," was used to collect the soil samples. The sola of mine soils are usually quite shallow, so a spade proved satisfactory for extracting the samples. A plug of soil, approximately 15 cm in diameter, was cut from the solum to a depth where relatively unweathered rock material prevented further penetration. The plug samples were easy to extract, and horizons could be observed in a relatively undisturbed state.

The profiles were described using standard Soil Survey nomenclature (Soil Survey Staff, 1975). Colors for moist soil samples were determined using Munsell soil color chips (Munsell Color Co., Inc., 1954). Other properties described in the field included textural class; structure; consistence; moisture content; compaction in place; the percentage, size and type of coarse fragments; root size, distribution and growth habit; and any inclusions of soil, coal or slag materials. The area was described in terms of its vegetatative cover, landscape position, slope and aspect, surrounding micro-relief and distance from highwall. Full descriptions for each sampling site are given in Appendix I.

Undisturbed soil cores (3 in., 7.62 cm in diameter) for determining hydraulic conductivity were obtained at each site using a Coile soil core sampler (Coile, 1936). To substantiate the results obtained by this method, hydraulic conductivity was determined _in situ_ at selected sites by a double ring infiltrometer, using a slight variation of the method described by Musgrave (1935). In this method, the outer ring is installed to check lateral seepage. The drop in water applied to the middle ring is measured directly by a stationary metric ruler.

After the morphological characteristics of each plug were described, the plug was separated into its respective horizons, with each placed in separate containers for transport to the laboratory.

Laboratory Methods

Each sample, after air-drying, was passed through a 10-mesh (2 mm) sieve and the retained material was washed with a 5% solution of sodium hexametaphosphate to disperse aggregates and material adhering to the coarse fragments.

The pH of each sample was determined in a 1:1 soil:water paste by a standard pH meter and electrode. Titratable acidity was extracted with barium chloride-triethanolamine and titrated with HCl, as described by Peech (1965).

Aluminum was also determined by the titration method of Yuan (1959), and bases (Mg, Ca and K) were extracted (Jackson, 1958) for determination with a Perkin-Elmer 306 atomic absorption spectrophotometer. The cation exchange capacity was calculated by summation of the exchangeable cations plus titratable acidity.

The Yoder sieving machine (Yoder, 1936) was used to determine the percentage of water stable aggregates present in each sample by a method described by Kemper (1965).

Moisture retention values were determined for each sample at five different tension levels (0.06, 0.1, 0.33, 1.0 and 15.0 atm). Soil bulk density cores, 2 in. (5.08 cm) in diameter and 1 in. (2.54 cm) high, were covered at one end with double layer cheesecloth and filled with the air-dry, <2 mm soil material. Duplicates were made for each sample. These samples were then placed on porous ceramic plates and allowed to saturate with water, following the procedure described by Richards (1965). Although the procedure normally requires undisturbed cores for low-tension desorption, we felt that undisturbed cores could not be obtained from mine soils with their significant component of course fragments. These samples were alternately saturated and desorbed through all five tensions (0.06 - 15.0 atm).

Along with the selected hydraulic conductivity values determined in the field with the double ring infiltrometer, conductivity on a 3 in. (7.62 cm) saturated soil core was also determined in the laboratory by the constant head method (Klute, 1965). The rate (K) was determined using the equation given by Klute:

$$K = (Q/At)\ (L/\Delta H)$$

where Q equals the volume of water passing through the sample per unit time, A is cross sectional area of the sample, t is the time unit, L is the length of the sample, and ΔH is the drop in hydraulic head, measured as the distance from the top of the standing water (constant head) to the bottom of the soil core. A 3 in. (7.62 cm) head of water was kept constant on each sample, thus making ΔH equal 6 in. (15.24 cm). Using the length (L) of the sample 3 in. (7.62 cm), the equation can be simplified to:

$$K = [(Q/A) \times .5].$$

Clay mineralogy was determined for six separate A horizons, and proved so similar no further mineralogical analyses were made. The samples were prepared for x-ray diffraction by removing any carbonates (Kunze, 1965), free iron oxides (Mehra and Jackson, 1960) and organic matter (Kunze, 1965). The sample was then fractionated into its sand, silt and clay components (Jackson et al., 1950; Day, 1965) and the clay was retained and flocculated (Kunze, 1965). The clay was kept in solution and deposited on ceramic tiles by a suction apparatus (Rich, 1969). Tiles were prepared under potassium saturation, and also under magnesium saturation solvated with glycerol. Since different cations may retain different amounts of water of hydration, clay samples prepared for diffraction analysis must be saturated with one cation and made homoionic. This ensures that expansion from hydration will be uniform for all crystals of a species. Magnesium saturation allows relatively uniform interlayer adsorption of water by expandable layer silicates. Potassium saturation specifically restricts interlayer adsorption of water by vermiculite. These two methods then can be used in conjunction for species identification (Whittig, 1965).

The similarity in basal spacing of Mg-saturated vermiculite and montmorillonite species necessitates further differentiation to distinguish between the two groups of minerals. The ability of montmorillonitic clays to adsorb double sheets of glycerol molecules between adjacent layers and to yield a basal spacing of approximately 17.7 Angstroms is used to differentiate the two groups. Solvation of vermiculite with glycerol does not substantially change its interlayer expansion (Whittig, 1965).

The clay-coated tiles were analyzed with a Diano XRD-8300AD system (Appendix III). Each was analyzed at room temperature (25°C) and also after heating to 110°C. The K-saturated tiles were subsequently heated to 300°C and then to 550°C for further analysis (Whittig, 1965).

Distinction of kaolinite from other minerals was made by a differential thermal analysis (MacKenzie, 1957) using a DuPont 990 Thermal Analyzer with a gold reference (Appendix IV).

Mineralogy was also examined by use of commercially prepared thin sections of representative rocks most commonly encountered during sampling.

Statistical Methods

The assembled data was analyzed by Duncan's Multiple Range procedure (Barr et al., 1976) for significant differences (.05 level) among results obtained for each age group (2, 5 and 10 years, topsoiled sites and natural soils) and each parent material (sandstone, shale, mixed, topsoiled sites and natural soils). Interactions between age and parent material were also calculated with the same general linear model of the statistical analysis system, SAS-76 (Barr et al., 1976). This computer model compares the means of the various age and parent material classes. All A horizons were compared separately, as were all subsurface horizons, except the small number of C horizons, which were also compared separately. A distinction was made for the A horizons, since this is where the most intense weathering is presumed to have taken place, and for the C horizons so that their depths of occurrence could be compared.

RESULTS AND DISCUSSION

Morphological Characteristics

The first noticed and most striking differences of the mine soil profiles were the differences in depth of the sola and the increased horizonation evident in the 10 year old profiles. Generalized soil profiles for the individual age classes are listed in Appendix II.

The solum thickness (depth to C horizon) of the 10 year old mine soils was significantly different from the 2 and 5 year old mine soils, and was slightly greater than that of the topsoiled sites. None of the mine soil sola were as thick as the sola of the natural soils of the region (Table 5). The 2 year old mine soils had an average solum thickness greater than the 5 year old mine soils. This difference, although not significant, may be due to recent regrading and reclamation techniques which emphasize conservation of soil materials for revegetation. No one type of parent material appeared to be weathering into a deep solum more rapidly than any other type.

Not only were the 10 year old sola thicker, they were also more differentiated into horizons (Appendix II). The 2 year old sites consisted generally of heterogeneous soil material, lacking horizonation. Three of the 2 year old sites contained subsurface horizons described as AC horizons. The parent material of two of these sites was shale, and the third was sandstone. Topsoiled sites were similarly horizonated.

The majority of 5 year old sites did contain a B horizon within their profile, with an average thickness of 5.8 cm. These horizons

Table 5. Average thickness of A horizons, subsurface horizons and sola of different age mine soils, topsoiled sites and natural soils.

Soils	Average thickness (cm) A horizon	Subsurface horizon	Solum
Mine soils			
2 years	6.3a*	8.3a	10.6**ab
5 years	2.7b	5.8a	8.6a
10 years	3.5ab	7.7a	14.6b
Topsoiled sites	11.5c	-	11.6b
Natural soils	14.0c	21.3b	70.7c

*Values in the same column followed by the same letter are not significantly different at the 5% level.

**The sum of the average A horizon and subsurface horizon thickness do not necessarily equal the solum thickness value, due to the occurrance of more than one subsurface horizon (above a C horizon) in many soils.

usually contained less visible organic matter (such as roots) than the overlying A horizon, but did show evidence of alteration in the form of a slight color difference or a different structural aggregate shape as compared to the A horizon. These differences are not as pronounced in the average soil profile for 5 year old sites (Appendix II) as in comparing the A and B horizons of individual 5 year old profiles (Appendix I).

The 10 year old profiles all contained B horizon, and on the average were nearly 2 cm thicker than the B horizons of the 5 year old profiles (7.7 cm vs. 5.8 cm). The 10 year old B horizons also exhibited more pronounced structural and color variations in comparison to both the overlying 10 year old A horizon and the 5 year old B horizons. The B horizons were developed strongly enough in three of the profiles (10-C, 10-E and 10-J) to be described as B21 and B22 horizons. All three represent different material types. Eight of the 10 year old profiles included a surface organic horizon of approximately 2 cm thickness.

The three regional soil series sampled were highly developed in comparison to the mine soils. With an average solum thickness of 70.7 cm (Table 5), the sola of these soils was horizonated with relatively thick Ap, B1, B2t or B21 and B22 and C horizons. The surface of these three series had at one time been disturbed, which accounts for the absence of an O horizon and the presence of an Ap horizon. Many of the morphological properties of these profiles appear depth-dependent, in that the surface horizons significantly vary from the underlying horizons in properties such as texture, color, structure and consistence.

In comparing the thickness of the A horizons, the 2 year old mine soils proved to be significantly thicker than either the 5 or 10 year old A horizon (Table 5). However, this anomoly is due to the way in which the A horizon is described. In the average 2 year old profile, the A horizon was 6.3 cm thick, with the A horizon being defined on these sites as the undifferentiated surface soil layer containing organic matter accumulation, and is overlying a C horizon. However, in the 5 year old profiles, the A horizon (ave. 2.7 cm thick) is beginning to show signs of elluviation, such as a color difference, and is no longer just an organic matter-bearing surface horizon. There is a slight increase in the average thickness of the 10 year old A horizons (3.5 cm) as compared to those of the 5 year old sites. The average thickness of the A horizons of the topsoiled sites (11.5 cm) is significantly greater than those of the 2, 5, and 10 year old mine soils (Table 5), but is defined in a manner similar to that of the 2 year old mine soils. All three topsoiled sites sampled were 2 years old or less, as this is a relatively new mining technique. Thus, the topsoiled profiles have their main profile characteristics determined somewhat by their relatively young state of development. Again, the natural soils of the region surpassed the mine soils, having an average A horizon thickness of 14 cm, resulting from their mature stage of development.

Likewise, the average thickness of subsurface horizons was greater in the natural soils (Table 5) than the mine soils. The mine soils were not significantly different from each other in terms of subsurface horizon thickness, although the average thickness of the AC horizons observed in three of the 2 year old mine soils was slightly greater than that of either the 5 or 10 year old mine soils. Since these three 2 year old mine soils had very thin A horizons, the remainder of their solum was described as AC horizon. More differentiation has occurred in the 5 and 10 year old mine soils, and although the sola thickness has increased somewhat with age, the differentiation of the subsoil into horizons has resulted in more horizons, although thinner, being found in 5 and 10 year old mine soils than in the 2 year old mine soils.

Color differences were related with significance in the A horizons to the age of mine soils (Figure 1), and to both the age and parent material of subsurface horizons (Figures 2 and 3).

The Munsell hue of the A horizons differed significantly with the age of the profile, with the 10 year old sites being somewhat darker or redder than the 2 or 5 year old mine soils, whose A horizon hues were about the same. These average hues were still significantly different when the topsoiled sites and the natural soils were considered in the statistical analysis. The topsoiled and natural soils both had an average hue of 10 YR in their A horizons. This is not surprising, as the topsoiled materials have the natural soils as their source.

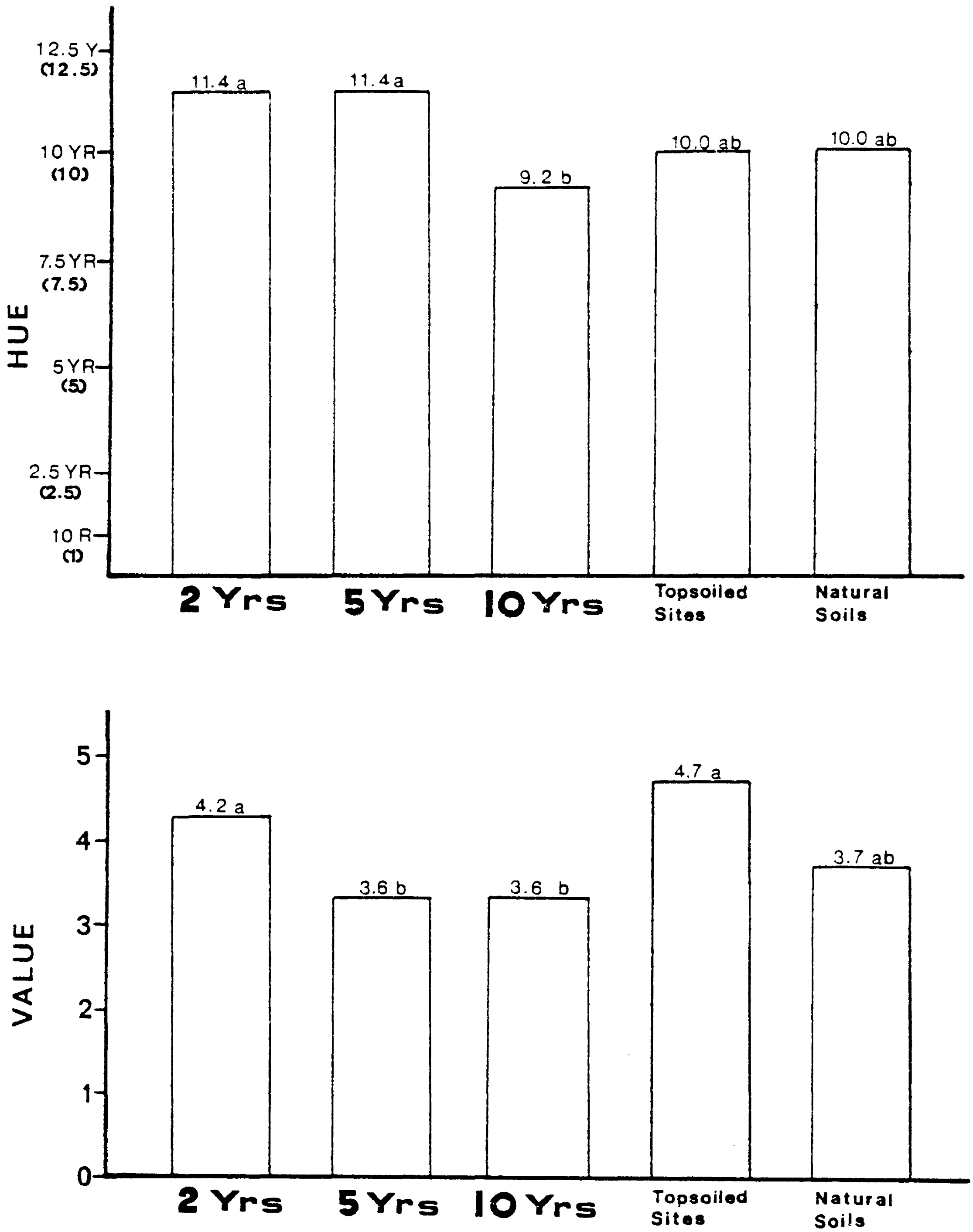

Figure 1. Munsell hue and value of A horizons of different age mine soils, topsoiled sites and natural soils. (Numbers followed by the same letter are not significantly different at the 5% level.)

The 10 year old sites, along with having a somewhat darker or more reddish hue, had thin organic horizons at their surface as discussed previously. The presence of organic matter on the surfaces may account for the significant hue difference in A1 horizons of 10 year old mine soils, as organic matter is becoming incorporated within the upper horizon, resulting in darker color.

Age was again a significant factor in determining the Munsell color value of the mine soil A horizons (Figure 1). The 2 year old soils had an average value significantly higher than those of either the 5 or 10 year old soils. The 2 year old soils had an average value somewhat higher than 4, while the 5 and 10 year old soils had average values slightly above 3.5. The A horizon color value of the natural soils averaged only slightly higher than that of the 5 and 10 year old soils. However, unlike the hue, the value of the topsoiled sites was significantly higher than that of the natural soils (above 4.5). The mixing of subsoil materials with the surface layer during the salvage and regrading of these topsoil materials would account for this, along with the relatively young state of development of the topsoiled sites (2 years or less).

The Munsell color hue of the subsurface horizons of the mine soils was significantly darker in soils of shale parent material (Figure 2). The hue of the natural soils varied significantly from the mine soil formed on sandstone and mixed parent material, but did not differ significantly from the hues of the other mine soils as a function of age.

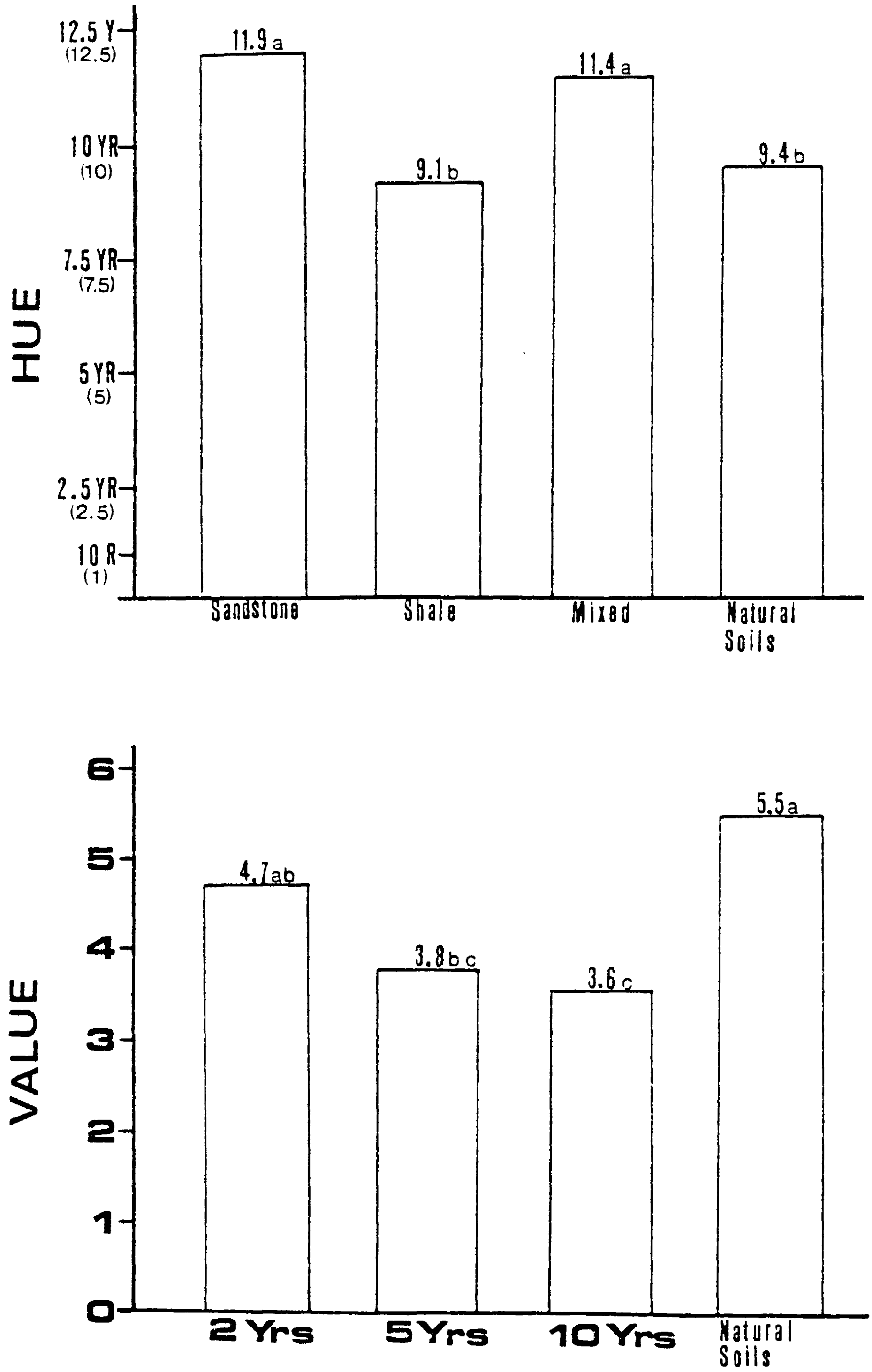

Figure 2. Munsell hue and value of subsurface horizons of different parent materials and different ages of mine soils and natural soils. (Numbers followed by the same letter are not significantly different at the 5% level.)

The Munsell value of the subsurface horizons of natural soils differed significantly from the 5 and 10 year old mine soils, which varied significantly from that of the 2 year old soils. The value of the natural soils (Figure 2) averaged 5.5 in the subsurface horizons. The mine soils do show a decreasing value trend with age. The topsoiled sites are absent from all subsurface comparison of properties since only one topsoiled site contained a horizon other than an A or C horizon.

The chroma of the subsurface horizons of the mine soils did change significantly with age (Figure 3). The 10 year old soils were significantly darker than either the 2 or 5 year old mine soils. The natural soils of the region had an average subsurface chroma of nearly 6, significantly higher than any of the mine soils. This may be similar to the darker hue of the A horizons of the 10 year old mine soils, apparently resulting from organic matter addition, as evidenced by an O1 horizon forming on the 10 year old surfaces. The chroma of the 10 year old subsurface horizons is fairly dark when compared to the significantly lighter subsurface horizons of the natural soils.

As Birkeland (1974) suggests, gains exceeded losses early in the stages of soil formation. Organic matter gradually accumulates, and the A and O horizons thicken. With time, a steady-state condition is reached, and the gains equal the losses. Apparently, then, 10 years is far too short a time for the soil to reach a steady-state condition. The natural soils of the region appear to have either reached this steady-state condition, or perhaps have gone beyond to a point where losses exceed gains.

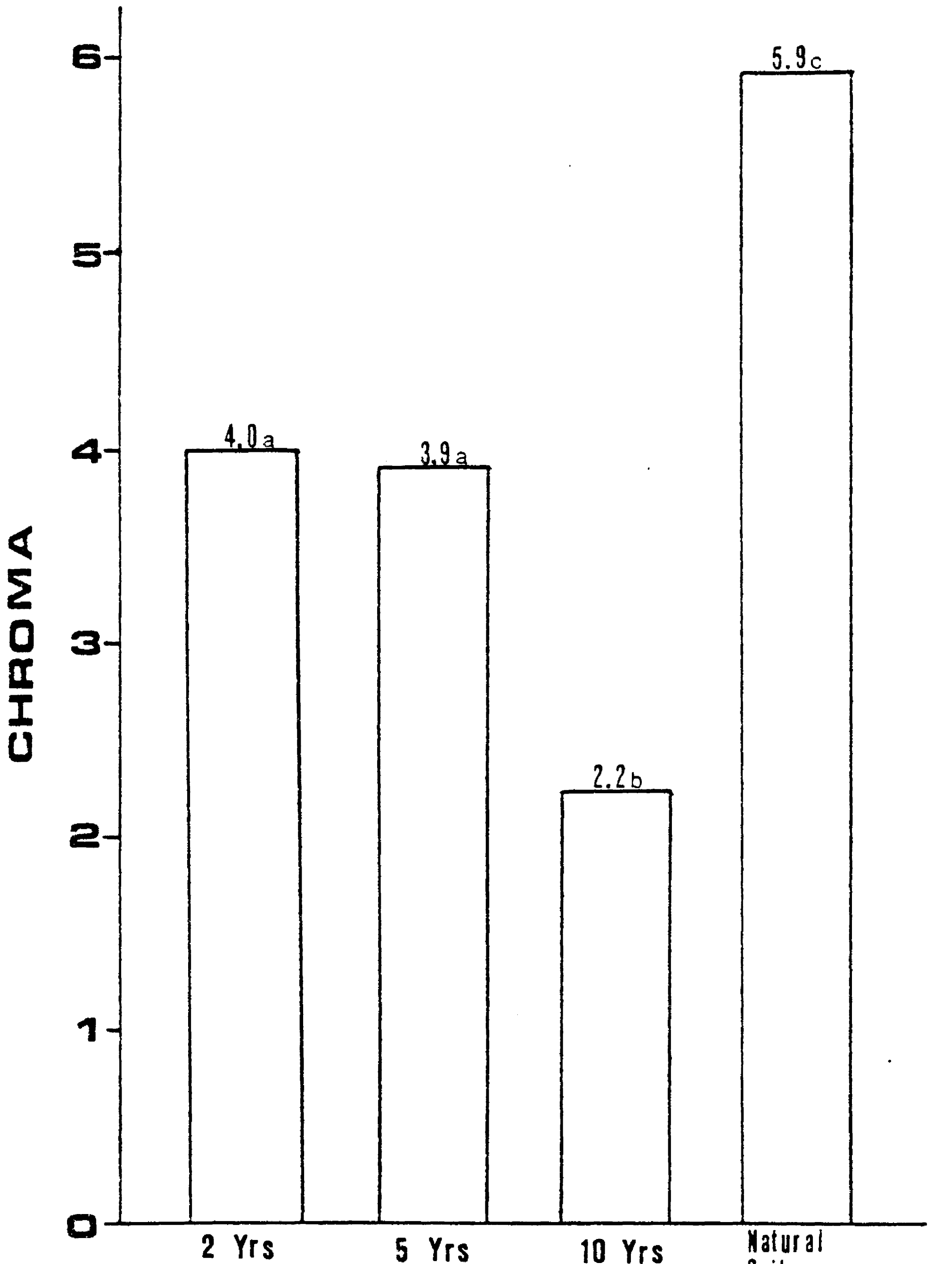

Figure 3. Munsell chroma of subsurface horizons of different age mine soils and natural soils. (Numbers followed by the same letter are not significantly different at the 5% level.)

An interaction between the age and parent material of each mine soil appears as significant in determining the chroma of the subsurface horizons when the natural soils are included in the statistical analysis (Figure 4). The 2 year old mine soils are not included as they generally lacked subsurface horizons. In general, the mine soils are lower in chroma than the natural soils, while the 10 year old soils are somewhat lower than the 5 year old soils. These dark gray shaley parent materials give rise to soils with lower chromas, with the 10 year old subsoils appearing extreme in that regard. The variation in trends of the 5 and 10 year old subsoils may result from a difference in the proportions of sandstone and shales among the various mixed sites.

Mottles appeared more frequently in 10 year old mine soils (Table 6). The unusually high value and chroma suggest that all mottles result from rock weathering rather than impeded drainage. Not only is the incidence of mottles more frequent in 10 year old mine soils, but the average color of these mottles is more yellow (higher in hue) than the average 5 year old mottle. The greater incidence and higher hue of the 10 year old mottles indicates increased weathering of the component rock structure. Two year old sites and topsoiled sites showed a low incidence of mottling, as did the natural soils.

In reviewing the average soil profiles for each age group of the mine soils (Appendix II), the structure apparently improves slightly with age. The 2 year old sites and the topsoiled sites had weak, very fine to fine crumb structure, and were very friable. The 5 year old sites had the same type structure and consistence in their A horizons

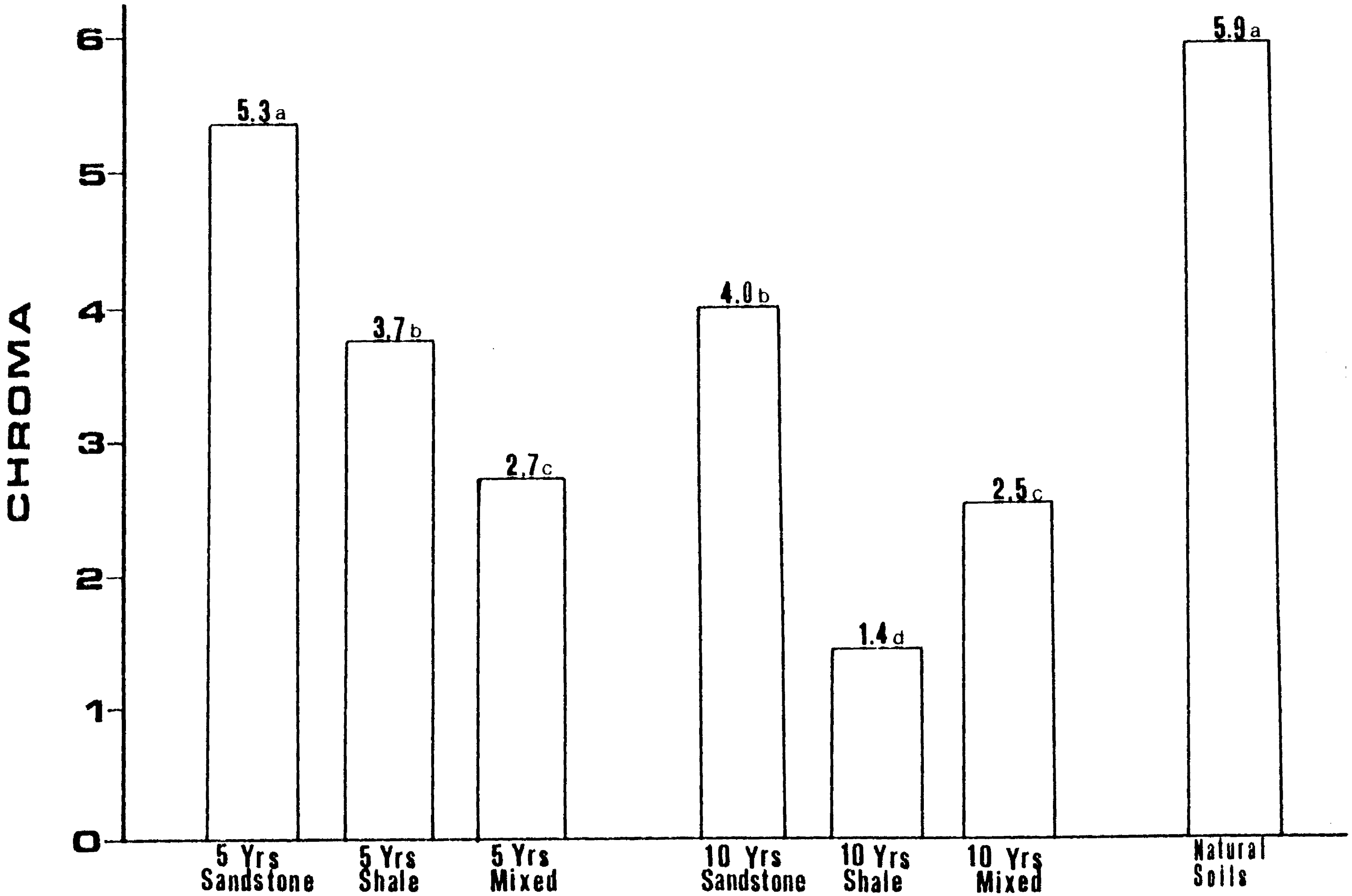

Figure 4. Interaction of age and parent material in determining Munsell chroma of mine soil subsurface horizons. (Numbers followed by the same letter are not significantly different at the 5% levels.

Table 6. Matrix and mottle color and other mottling characteristics as a function of soil age and parent material.

Sample	Horizon	Parent Material	Mottle Colors	Prominance	Matrix
10-A	B2	mixed	7.5 YR 5/8	C2D	10 YR 5/4
10-B	A	shale	7.5 YR 6/8	F2D	2.5 Y 3/2
10-B	B	shale	7.5 YR 6/8	C3D	2.5 Y 4/2
10-B	BC	shale	2.5 Y 5/6	F2D	10 YR 3/2
10-B	BC	shale	10 R 4/8	F2D	10 YR 3/2
10-C	A	mixed	7.5 YR 6/8	F3P	10 YR 3/2
10-C	B21	mixed	7.5 YR 6/8	F2D	10 YR 3/2
10-D	C	sandstone	7.5 YR 5/8	M3P	10 YR 5/2
10-E	A	sandstone	7.5 YR 6/8	F2P	5 YR 4/3
10-E	B21	sandstone	2.5 Y 6/2	M3P	2.5 Y 4/2
10-E	C	sandstone	7.5 YR 6/8	M3P	10 YR 4/3
10 year old average-			7.5 YR 5.5/7.3		10 YR 3.7/2.4
5-D	A	shale	2.5 YR 4/8	F2P	10 YR 4/4
5-D	A	shale	5 Y 4/1	F2P	10 YR 4/4
5-D	AC	shale	2.5 YR 4/8	F2P	10 YR 4/4
5-D	AC	shale	5 Y 4/1	F2P	10 YR 4/4
5-H	B	mixed	5 YR 5/8	F2P	10 YR 4/4
5 year old average -			2.5 YR - 5 YR 4.2/5.2		10 YR 4/4
2-C	A	sandstone	10 YR 7/8	F2D	10 YR 5/8
2-F	A	shale	7.5 YR 6/8	C3D	2.5 Y 4/4
2-F	A	shale	10 YR 3/3	F2P	2.5 Y 4/4
2 year old average			7.5 YR - 10 YR 5.3/6.3		10 YR - 2.5 Y 4.3/5.3
T-3	A	"topsoil"	7.5 YR 5/8	F2D	10 YR 4/4
Muskingum	Ap	natural soil	7.5 YR 5/4	F2F	10 YR 4/3
Dekalb	B22t	natural soil	5 YR 5/6	C2D	10 YR 6/5
Natural soils average			5 YR - 7.5 YR 5/5		10 YR 5/4

(weak to moderate, very fine crumb), and weak, very fine to fine crumb structures in their subsurface horizons. The consistence of these 5 year old aggregates was very friable.

In the 10 year old sites, the A horizons usually contained moderate, very fine to fine subangular blocky structure (very friable), and the B horizon contained weak to moderate fine crumb or subangular blocky structure, and were friable.

The mine soils lacked the structural development of the natural soils. Smith et al. (1971) observed this on iron ore tailings 85 to 103 years old in northern West Virginia, and felt it was due to the lesser amounts of organic matter and biological activity found in the mine soils.

The composite profile of the three natural soil series (Appendix II) indicates structure becomes more pronounced with depth. The Ap horizon had weak, fine granular structure (friable), and the B1 horizons had moderate, fine to medium subangular blocky structure. Deeper into the profile, the B2t or B21t and B22t horizons contained strong, medium, subangular blocky peds (firm), while the C horizons characteristically contained moderate, coarse angular or subangular blocky structure (firm). This agrees with the generalization of Brady (1974), that two or more types of structure often occurs in the same solum in humid, temperate regions. A granular aggregation in the surface horizon with a blocky, subangular blocky or platy structure in the subsoil is usual, although granular subhorizons are not uncommon.

Factors of aggregate formation can be grouped according to their influence on one of the following environmental factors of aggregate formation: 1) the amount and activity of the organic matter, 2) the relative amounts and activity of the soil colloids, and 3) the kind of exchangeable ions connected with the soil colloids (Taylor and Ashcroft, 1972). The longer these factors have been in effect, the more pronounced their effect will be, as evidenced by the generally stronger structure observed in the 10 year old mine soils and the natural soils.

As previously stated, the majority of aggregates observed in the 10 year old mine soils were subangular blocky. Bacteria produce small, compact and angular aggregates, with smooth edges and surfaces, or aggregates which fit the description of those observed in the 10 year old mine soils. However, in order of the greatest number of aggregates produced, fungi > antinomycetes > bacteria (Taylor and Ashcroft, 1972), although bacteria are much more abundant in most humid region soils (Waksman and Starkey, 1931). These 10 year old structural aggregates may very well be the result of root penetration and annual die-back from the sod grasses found on all the mine sites sampled, as well as from the microbes associated with these roots. One particular group of bacteria, the Rhizobia, are commonly introduced to surface-mined sites as part of the revegetation process.

Inclusions of coal, other soils and pyritic materials associated with the coal seam ("slag" materials) were visually estimated where encountered (profile descriptions, Appendix I). Coal fragment commonly occurred in all minerals studied. "Slag" materials occurred less frequently, and soil inclusions were rarely noted, although soil inclusions were quite common in the topsoiled sites, as would be expected. Such inclusions, especially coal, were also noted in mine soils studied by Barnhisel and Massey (1969) and by Sencindiver (1977).

Particle Size Analysis

Nearly all significant variances in texture of the mine soils could be attributed to the parent material. Five different size fractions of sand, three of silt and a clay value were determined in an attempt to relate particle size distribution to the age of the soil and the parent material. The 2, 5 and 10 year old mine sites did not vary significantly for any of the particle size fractions. The mean values for the coarse silt fraction (0.05-0.02 mm) of all three mine soil age groups did vary significantly from the mean coarse silt percentage for the natural soils and for the topsoiled sites (Figure 5). With a coarse silt content of 24.2% as opposed to 16.3% for topsoiled sites, the natural soils had slightly more of this fraction in their A horizons. Although the natural soils are the source for the topsoil materials, the mixing of lower horizons in the processes of salvaging and regrading probably account for this slight difference.

In the subsurface horizons, very fine sand (0.10-0.05 mm) was significantly greater in the 2-year old mine soils than in either the 5 or 10 year old soils (Figure 6). However, only three of the 2-year old mine soils contained a subsurface horizon, so less data determines the mean. The natural soil series, with more than one subsurface horizon each, do not vary significantly from the mine soils. Topsoiled

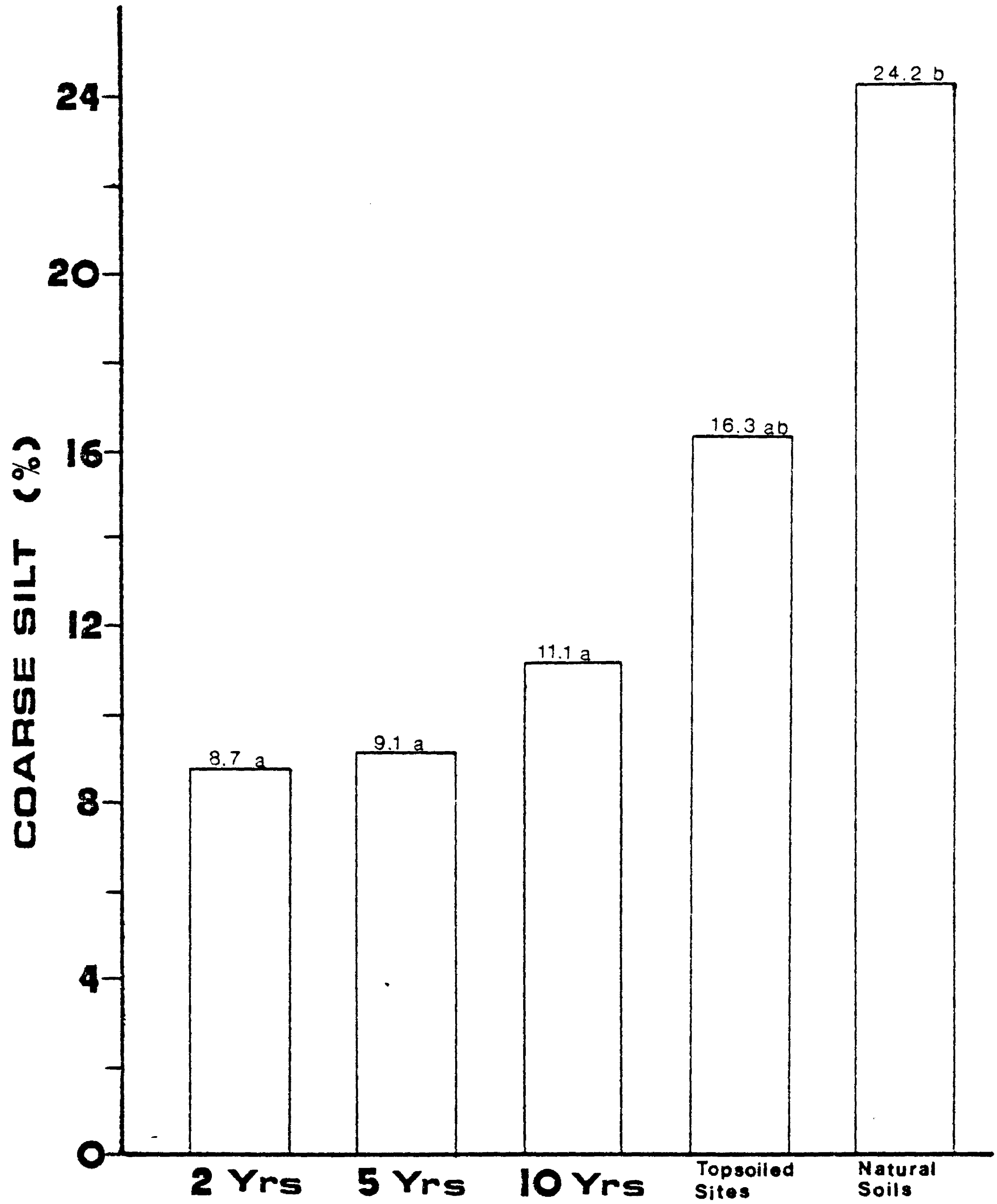

Figure 5. Coarse silt (0.05-0.02 mm) fraction of different age mine soils, topsoiled sites and natural soils. (Numbers followed by the same letter are not significantly different at the 5% level.)

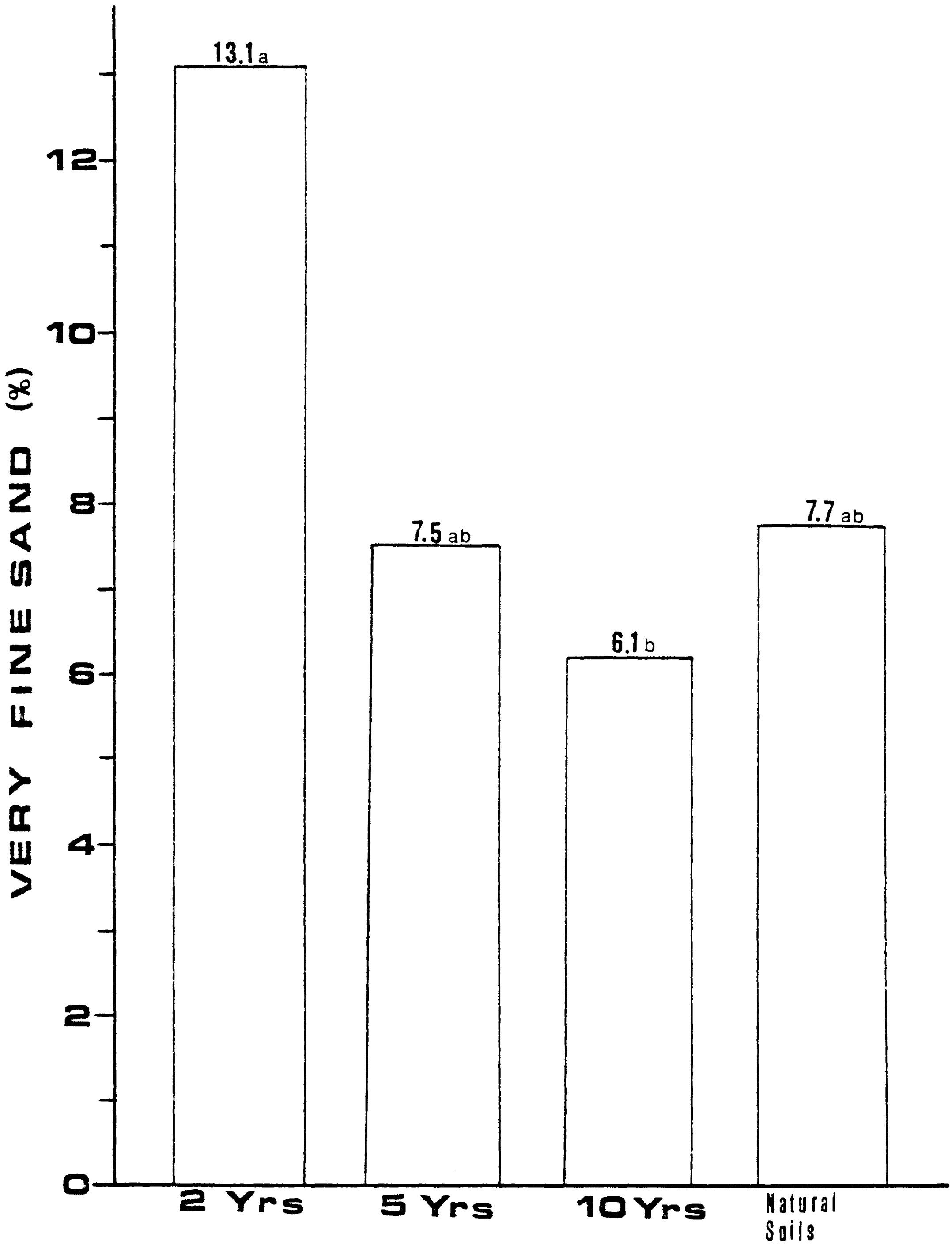

Figure 6. Very fine sand (0.10-0.05 mm) fraction of different age mine soils' and natural soils' subsurface horizons. (Numbers followed by the same letter are not significantly different at the 5% level.)

sites are not considered, as only one topsoiled site contained a subsurface horizon other than a C horizon.

We should expect to find a higher percentage of certain sand fractions in these young mine soils. Most of the material in the 2-year old mine soils comes from the overburden and is relatively unweathered. Weathering reduces this material to silt and clay size, which explains why this fraction is fairly constant in the 5 and 10 year old mine soils, and also why the A horizons may differ. The A horizons should occupy the zone of most intense weathering since they are exposed to the atmosphere and contain more roots and other living organisms. By appearing significantly different in the A horizons, and not differing significantly with age in the subsurface horizons, these sedimentary rock fragments appear to have been easily weathered down to silt and clay in the A horizons after only 2 years.

Several particle size fractions varied with parent material. Usually the soils were influenced by the grain size of the parent rock, with soils from sandstone containing more sand while soils from shale were higher in silt and clay.

Table 7 illustrates that soils from sandstone were highest in medium and fine sand (0.5-0.25 mm and 0.25-0.10 mm respectively) in their A horizons while soils from shale were lowest in these fractions. The natural soils and the topsoiled sites, were lower than mine soils in medium and fine sand, apparently due to the greater age and more prolonged weathering these soil materials have undergone. Soils resulting from mixed parent material reflect the influence of this mix-

Table 7. Medium sand (0.5-0.25 mm), fine sand (0.25-0.10 mm), fine silt (0.005-0.002 mm) and clay (<0.002 mm) fractions in A horizons of mine soils weathering from sandstone, shale and mixed parent material, and in topsoiled sites and natural soils.

Soils	Medium sand	Fine sand	Fine silt	Clay
	%			
Mine soil parent material				
Sandstone	15.5a*	22.2a	6.4a	13.7a
Shale	6.2b	7.9b	11.5b	23.3b
Mixed	9.0ab	11.4b	12.1b	21.3b
Topsoiled sites	2.3b	5.5b	12.4b	24.2b
Natural soils	1.5b	7.6b	9.3ab	21.1b

*Values in the same column followed by the same letter are not significantly different at the 5% level.

ing with medium and fine sand values falling between mine soils from sandstone and shale.

Fine silt (0.005-0.002 mm) and clay (<0.002 mm) of the A horizons are also shown in Table 7. Mine soils weathering from sandstone were significantly lower than other soils in both fine silt and clay. Mine soils weathering from shale or mixed overburden, the topsoiled sites and natural soils were not significantly different from each other. The natural soils were lower in both fine silt and clay than the topsoiled sites although not significantly. This probably reflects the influence of the finer textured subsoil materials salvaged along with the topsoil prior to mining and subsequently used for topsoiling.

Similar parent material influences on the subsurface horizons can be observed for the fine sand (0.25-0.10 mm) and fine silt (0.005-0.002 mm) fractions (Table 8). Although the mine soils from sandstone were highest in fine sand, soils weathering from mixed overburden were much higher in fine silt than the other soils. Soils from sandstone contained significantly less clay (<0.002 mm) than the other soils (Table 8). The natural soils contained somewhat more clay in subsurface horizons, indicating the effect of illuviation of fine materials with time.

The natural soils were also significantly lower in coarse sand (1.0-0.5 mm) in the subsurface horizons than the 5 and 10 year old mine soils (Table 9). Again this may be attributed to a longer period of exposure to the soil forming factors. Table 9 also shows that the 5 year old sites are slightly higher in coarse sand content than the

Table 8. Fine sand (0.25-0.10 mm), fine silt (0.005-0.002 mm) and clay (<0.002 mm) fractions in subsurface horizons of mine soils weathering from sandstone, shale and mixed parent material and in natural soils.

Soils	Fine Sand	Fine silt	Clay
		%	
Mine soils			
Sandstone	18.9a*	9.7a	15.3a
Shale	7.4b	11.8a	23.2ab
Mixed	9.4b	18.8b	26.5b
Natural soils	6.3b	10.8a	27.8b

*Values in the same column followed by the same letter are not significantly different at the 5% level.

Table 9. Coarse sand (1.0-0.5 mm) and medium sand (0.5-0.25 mm) fractions in subsurface horizons of different age mine soils and and in natural soils.

Soils	Coarse sand	Medium sand
	%	
Mine soils		
2 years	3.6ab*	8.2ab
5 years	5.8b	11.1b
10 years	4.3b	5.6a
Natural soils	1.7a	1.4a

*Values in the same column followed by the same letter are not significantly different at the 5% level.

2 and 10 year sites. A similar trend can be seen for the medium sand (0.5-0.25 mm) fraction. Apparently rock fragments, weakened and fractured by the mining and reclamation processes, are easily weathered into sand-size particles after a period of about 5 years in the soil environment. We would expect these coarse fragments to continue to weather at a decreasing rate producing more coarse sand in the 10 year old mine soils. Were this true, a decrease in coarse fragments after 5 years would be expected.

Although coarse fragments will be discussed in more detail in a later section, the 5 year old sites were slightly higher in subsurface horizon coarse fragments than either the 2 or 10 year old sites, although barely lacking statistical significance. Therefore, the coarseness and skeletal nature generally observed in the 5 year old mine soils may not be due to increased disintegration of coarse fragments. The higher rock content may be due to differences in mining and regrading methods in the past 5 years. The current emphasis is on salvaging geologic strata which appear most suited for plant growth media. While topsoiling has been required for the past 2 years by new federal legislation (U.S. Congress, 95th, 1977), and West virginia has been emphasizing this for several years, soils of the Appalachian region are often thin and rocky, making topsoiling undesirable or uneconomical. Five year old mine soils do not reflect the benefits of regrading the mined area with selected geologic strata or topsoiling materials.

In the subsurface horizons, the natural soils were significantly higher in coarse silt (0.05-0.02 mm) than the mine soils (Table 10).

Table 10. Coarse silt (0.05-0.02 mm) fraction in subsurface horizons of mine soils of different ages and parent material and in natural soils.

Soils	Coarse silt (%)
Mine soils (age)	
2 years	9.7a*
5 years	10.0a
10 years	7.3a
Mine soils (parent material)	
Sandstone	9.6ab
Shale	10.4ab
Mixed	6.0a
Natural soils	16.9c

*Values within the same parameter (age or parent material) followed by the same letter are not significantly different at the 5% level.

The mine soils did not vary significantly in coarse silt, either with age or parent material. Again, the natural soils reflect the influence of a longer period of development.

In all other particle size fractions, the mine soils did not vary significantly with age or parent material, or from the topsoiled sites or the natural soils. A lack of significant difference in the various properties indicates these soils, in this respect, are no worse or no better than the natural soils found in the sampling region. The slight changes in sand, silt and clay content with age are summarized in Table 11 showing total sand content decreasing with age, while silt and clay increase somewhat.

The flow and storage of water, air movement, and nutrient supplying ability of the soil are determined by the size and arrangement of the soil particles (Russell, 1957). Of the 62 mine soil horizons sampled, 60 were some type of loam (Table 12). In a recent study of mine soils in Illinois, which also were weathering from Pennsylvanian strata, Haynes and Klimstra (1975) found 95% of the soils sampled were silt loam, sandy loam and loam. Another mine soil study in southern West Virginia (Bennett et al., 1976) found the texture of about two-thirds of the spoil materials to be finer than sandy loam.

Increased time of weathering should result in greater differences in particle size distribution of the mine soils. Smith et al. (1971), in studying soils formed from 19th century iron ore spoils, found textures similar to those found in this study. A study of deglaciated areas up to 85 years of age (Stevens and Walker, 1970), indicated that

Table 11. Particle size and texture as influenced by increased time of weathering.

	A horizons %				Subsurface horizons %			
	Sand	Silt	Clay	Texture	Sand	Silt	Clay	Texture
Mine soils								
2 years	45.7a*	35.9a	18.4a	loam	45.7b	37.2ab	17.0a	loam
5 years	41.1a	39.3a	19.7a	loam	39.6b	40.1b	20.7a	loam
10 years	38.3a	41.4a	20.2a	loam	30.6ab	42.8b	23.7a	loam
Topsoiled sites	23.8b	52.0b	24.2a	silt loam	21.6a	52.8c	26.0b	silt loam
Natural soils	19.5b	59.4b	21.1a	silt loam	18.3a	53.9c	27.8b	silty clay loam

*Values in the same column followed by the same letter are not significantly different at the 5% level.

Table 12. A textural classification of mine soils by parent material and horizon.

Sandstone Parent Material

Site	Horizon	Texture
2-A	A	sandy loam
2-C	A	sandy loam
2-E	A	sandy loam
	AC	loam
5-A	A	loam
	B	loam
	C	loam
5-C	A	sandy loam
	AC	sandy loam
5-E	A	sandy loam
	B	sandy loam
10-D	A	sandy loam
	B2	loam
	C	silt loam
10-E	A	silt loam
	B21	silt loam
	B22	silt loam
	C	silt loam
10-F	A	sandy loam
	B2	sandy loam
	C	sandy loam

Shale Parent Material

Site	Horizon	Texture
2-F	A	loam
2-G	A	loam
	IIC	clay loam
2-H	A	loam
5-D	A	loam
5-F	A	sandy clay loam
	AC	clay loam
5-G	A	loam
	B	silt loam
10-B	A	clay loam
	B	clay loam
	BC	clay loam
10-H	A	loam
	B	loam
10-J	A	silt loam
	B21	silt loam
	B22	silt loam

Table 12. A textural classification of mine soils by parent material and horizon. (cont.)

Mixed Parent Material

Site	Horizon	Texture
2-B	A	sandy loam
	AC	loam
2-D	A	loam
	AC	loam
2-J	A	loam
5-B	A	loam
	B	loam
5-H	A	loam
	B	loam
5-J	A	silt loam
	B	silty clay loam
10-A	A	loam
	B2	loam
10-C	A	loam
	B21	silty clay loam
	B22	silty clay
	C	silty clay
10-G	A	loam
	B	loam

Topsoiled Sites

Site	Horizon	Texture
T-1	A	silt loam
	AC	silt loam
T-2	A	silt loam
T-3	A	loam

Natural Soils

Series	Horizon	Texture
Muskingum	Ap	silt loam
	B1	silt loam
	B2t	silty clay loam
	C	silt loam
Gilpin	Ap	loam
	B1	silt loam
	B21t	silty clay loam
	B22t	silty clay loam
	C	silty clay loam

Table 12. A textural classification of mine soils by parent material and horizon. (cont.)

Series	Horizon	Texture
Dekalb	Ap	silt loam
	B1	loam
	B21	loam
	B22t	clay loam
	C	silty clay loam

coarse sand was nearly halved as age increased from 5 to 85 years, fine sand was increased from 29 to 51%, silt increased from 6 to 11%, but clay did not change. A 10 year time period on the sedimentary Pennsylvanian-age material of this study apparently is not long enough to cause significant textural classification changes in these mine soils.

Chemical Properties

Chemical analyses were conducted in these soils primarily for the purpose of soil characterization and classification. In nearly all chemical characteristics important to plant growth, the mine soils were superior or equal to the natural soils of the regions. Among the mine soils, the 5 year old soils were chemically superior for plant growth. Chemical data for the A horizons is summarized in Table 13, and for the subsurface horizons, Table 14.

The pH is highest in the 5 year old soils in both the surface (A) and the subsurface (B) horizons (Tables 13 and 14), but only significantly higher in the A horizons (Table 13). Among the A horizons, the natural soils and 2-year old mine soils had the lowest pH (4.6).

Smith et al. (1971) observed Appalachian mine spoil pH values stabilizing after 4 years, indicative of the time they believed necessary for the spoil-soil transition to occur. Plass and Vogel (1973) studied regraded mine sites which were 6 months or less in age and found the average pH values to be above 5.0. Another study on eastern Kentucky mine soils of the Pennsylvanian system (Cummins et al., 1965) found the soils to be medium to extremely acid. Vimmerstedt (1970) developed a spoil classification system based on pH which allows pre-

Table 13. Mean chemical characteristics of the A horizons as related to age and parent material.

Age of mine soils (years)	pH	Ca	Mg	K	Titratable Acidity*	Titratable Al*	CEC	% Base Saturation
		meq/100 g soil						
2	4.6a**	1.5a	1.5bc	0.2a	7.1c	2.3b	10.3b	31.1b
5	5.4b	3.2b	2.7a	0.2a	6.7c	0.5c	12.8ab	47.7a
10	4.9ab	2.2ab	1.7b	0.2a	11.3ab	2.0b	15.4a	26.6b
Parent materials								
Sandstone	4.9a	2.3ab	1.7ab	0.2a	7.4c	1.3b	11.6ab	36.2b
Shale	4.8a	2.2ab	1.8ab	0.2a	10.4b	2.3ab	14.6a	28.8b
Mixed	5.2b	2.5b	2.4a	0.3b	7.3c	1.1b	12.5ab	41.6a
Topsoiled sites	4.7a	1.7a	0.9bc	0.2a	9.2bc	2.7ab	12.0ab	23.3bc
Natural soils	4.6a	0.5a	0.2c	0.2a	14.5a	4.0a	15.4ab	5.8c

* at pH 8.2

** values in the same column followed by the same letter are not significantly different at the 5% level.

Table 14. Mean chemical characteristics of the subsurface horizons as related to age and parent material.

Age of mine soils (years)	pH	Ca	Mg	K	Titratable Acidity*	Titratable Al*	CEC	% Base Saturation
	meq/100g soil							
2	4.8ab**	1.3ab	1.2ab	0.2ab	6.6ab	1.9bc	9.3b	29.0a
5	5.3a	2.3a	2.4a	0.3a	6.6ab	0.3c	11.6b	43.1b
10	5.0ab	2.2a	1.7a	0.2ab	10.9a	2.6b	15.0a	27.3a
Parent materials								
Sandstone	5.1ab	2.0a	1.7a	0.1b	8.1ab	1.5b	11.9b	31.9a
Shale	5.1ab	2.8a	2.1a	0.1b	11.1a	2.0b	16.1a	31.0a
Mixed	5.0ab	1.6ab	1.9a	0.3a	7.4b	2.1b	11.2b	33.9a
Natural soils	4.8b	0.3b	0.1b	0.1b	9.9a	5.0a	10.4b	4.8c

* at pH 8.2

** values in the same column followed by the same letter are not significantly different at the 5% level.

diction of the amounts and kinds of chemicals released during weathering of several types of spoils. Toxic materials with a pH of less than 4.0 initially produce 25 times as much soluble chemicals, 40 times as much sulfate and 300 times as much manganese as calcareous spoils having a pH above 7.0 or acid spoils with a pH of 4 to 7.0.

Calcium and magnesium in the A horizons of the 5 year old soils, along with pH, were higher than that of the other mine soils, and much higher than that of the natural soils (Table 13). The topsoiled sites had intermediate pH, Ca and Mg values. This reflects the mixing of less weathered subsoil materials with highly weathered horizons near or at the surface of these natural soils which were salvaged for post-mining regrading, along with mixing of fractured overburden rock.

Although pH did not vary significantly in subsurface horizons, calcium and magnesium again were higher (but not significantly) in the 5 year old mine soils, and extremely low in the natural soils (Table 14). Topsoiled sites were not included in this comparison as they generally lacked subsurface horizons.

Titratable acidity and aluminum were highest in natural soils and lowest in the 5 year old mine soils. Of the many factors responsible for soil acidity, those most important in mine soils are aluminosilicate clays, hydrous oxides of iron and aluminum, exchangeable aluminum and organic matter (Tisdale and Nelson, 1975). Organic matter would probably be a major factor only in the older mine soils.

Soil organic matter contains reactive components capable of bonding hydrogen ions. As such, these components cause organic matter to behave as weak acids, and the covalently bound hydrogen will dissociate (Tisdale and Nelson, 1975). Organic matter determinations on the mine soils were not reliable, because of the fine coal or other associated carboniferous rock fragments commonly found in these soils. These carbon-bearing rocks gave inflated values to soils analyzed by the Walkley-Black (1934) method. Experiments to quantify plant organic matter, while not including carboniferous materials, failed for various reasons. These experiments included organic matter ignition by direct heat and organic matter digestion by hydrogen peroxide. Perhaps the only possible method of determining plant organic matter in soils containing coal fragments would be to separate the soil particles from the coal particles by specific gravity techniques, a time-consuming project.

Titratable acidity of the A horizons was lowest in the 5 year old mine soils and highest in the natural soils (Table 13). The soils from shale contained significantly higher titratable acidity than soils of sandstone or mixed parent material (Table 13). The subsurface horizons were not as acid as the A horizons, and the 2 and 5 year old mine soils were similar in their relatively low titratable acidity (Table 14). The 10 year old mine soils were somewhat higher (but not significantly) than the natural soils in titratable acidity.

The same trend exists for aluminum as with acidity in the mine soils (Tables 13 and 14), and because of similar methodology, we can make assumptions similar to those for determining titratable acidity (Yuan, 1959). The 5 year old mine soils contained significantly less aluminum than the other mine soils, while the natural soils contained the most aluminum by far. A similar trend was observed for titratable acidity, and, as with acidity, the topsoiled sites are intermediate in exchangeable aluminum, reflecting the effects of mixing weathered and unweathered material. Both procedures tend to overestimate the measured component due to the high extraction pH (8.2). Nevertheless, measured acidity and aluminum are quite low in the 5 year old soils and fairly high in the natural soils. Either no true difference in acidity and aluminum exists between these soils, or else pH-dependent charge varies in these soils. The latter seems more probable.

The 2 year old soils, containing many fresh, highly fractured rock fragments, would release hydroxyls under a high pH extraction. The 5 year old soils apparently have weathered and leached enough to be nearly devoid of hydrous oxides, which would contribute to the titratable acidity and aluminum at pH 8.2. The 10 year old soils have weathered still further until some hydrous oxide coatings have developed, and perhaps more importantly, appear to contain significant quantities of organic matter which will contribute to the observed trends. The natural soils, due to their advanced stage of pedogenesis, should contain many more hydrous oxide coatings and more organic matter which would increase pH-dependent charge and the titratable acidity and aluminum.

Mine soils from shale contained significantly higher titratable aluminum than soils from sandstone or mixed parent material (Table 13 and 14). Because of their finer texture, soils from shale would offer more exchange sites for pH-dependent charges to be bound. The same trend was noted earlier for titratable acidity. In the subsurface horizons (Figure 7), significant interactions between parent material and age were observed for the mine soils. While the 10 year old mine soils were generally more acid than the 5 year old soils, the 10 year old soils from shale contained even more titratable acidity than the natural soils, indicating the bulk of the exchange sites in the natural soils' A horizons may be due to organic matter. An increase in the amount of titratable acidity in the 10 year old subsurface horizons indicates the presence of more exchange sites, presumably in the form of clay. The 10 year old soils from sandstone and shale contain more titratable acidity than those 5 year old mine soils from the same parent material. Soils from mixed parent material do not follow this trend of increasing acidity with age. We should emphasize that "mixed" is a relative term, with the possibility that the proportion of shale to sandstone may have been somewhat greater in the 5 year old soils than in the 10 year old soils. This would provide more exchange sites (clay) for the 5 year old mine soils.

Potassium in the mine soils did not vary significantly with age, but varied with parent material type, both in the A horizons (Table 13) and the subsurface horizons (Table 14). However, the soils from mixed parent material contain significantly higher amounts of potassium. Feldspars and micas, which are abundant in these soils, are the major mineral sources of potassium in most soils (Brady, 1974). Thin sections of the sandstones contained several large mica flakes, while the

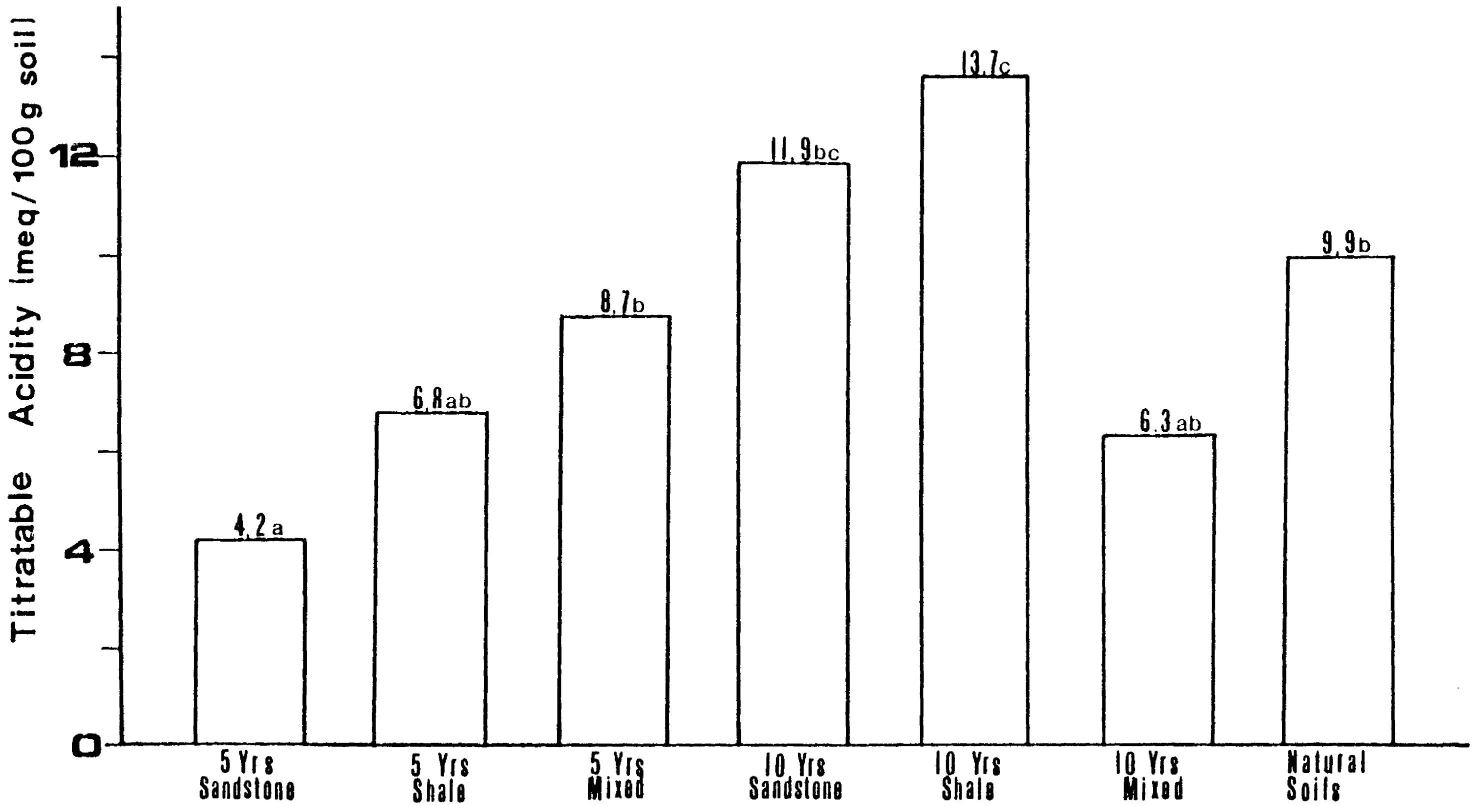

Figure 7. Interaction of age and parent material in determining titratable aluminum in subsurface horizons of mine soils and natural soils. (Numbers followed by the same letter are not significantly different at the 5% level.)

shales contained many small mica rods. Both contained appreciable amounts of feldspars, and were often cemented with iron containing serecite particles. Apparently, facies rich in mica and orthoclase feldspar were encountered more frequently in the mixed parent material sites.

The natural soils were fairly low in A-horizon K, but were not significantly different from soils formed on sandstone and shale in subsurface horizon K. In the A horizons, again the topsoiled sites are intermediate, between the natural soils and the mine soils.

Base saturation of the natural soils was quite low (Tables 13 and 14), and was significantly higher in the 5 year old mine soils than the other mine soils. This trend is in agreement with those noted previously for pH, calcium, magnesium, and opposite to the trend of titratable acidity and aluminum. In general, the 5 year old mine soils appear to be more fertile than either the 2 or 10 year old mine soils. A large fraction of the coarse fragments and soil-size material produced mechanically during the mining process appear to be weathering significantly up to 5 years after mining. The release of $CaCO_3$ and $MgCO_3$ buffers the soil, dominates available exchange complexes with bases and raises the pH. Then, apparently between the 5 and 10 year time period, the weathering rate decreases as the supply of these highly fractured, easily weathered rock and soil sized fragments decreases. Within this five-year time period, more organic matter is added to the soil, thereby providing another source of hydronium ions, rapidly depleting the easily available bases, whether by vegetative uptake or by leaching. One study (Smith et al., 1971) found older mine soils (85 to 103 years of age) were lower in base saturation than the surrounding natural soils.

The cation exchange capacity of the A horizons of the mine soils increased with age; with the 10 year old mine soils having nearly the same capacity as the natural soils of the region (Table 13). This increase with age was also true for the subsurface horizons, however, the CEC of the natural soils was well below that of the 10 year old subsurface horizons (Table 14). Apparently, organic matter and clay synthesis and translocation are helping to increase the CEC of the mine soils, while organic matter is maintaining it in the A horizons of the natuaral soils. Older mine soils have been observed (Smith et al., 1971) with lower CEC's than the natural soils of the same region.

Mine soils from shale parent material have significantly higher CEC than soils from other parent material, due to the somewhat higher concentration of clay particles (Tables 13 and 14). A significant interaction between parent material and age was observed in the CEC's of the subsurface horizons (Figure 8). The 10 year old soils are higher than the 5 year old soils (only shale parent material had developed subsurface horizons in the 2 year old mine soils), and the CEC of the soils from shale is slightly higher than soils from sandstone. Again, following observations of titratable acidity, soils from mixed parent material do not follow the trend. Apparently, this reflects the nature of the "mixed" parent material, with 5 year old mine soils containing slightly more shale than the 10 year old mine soils derived from mixed parent material, thus providing more exchange sites.

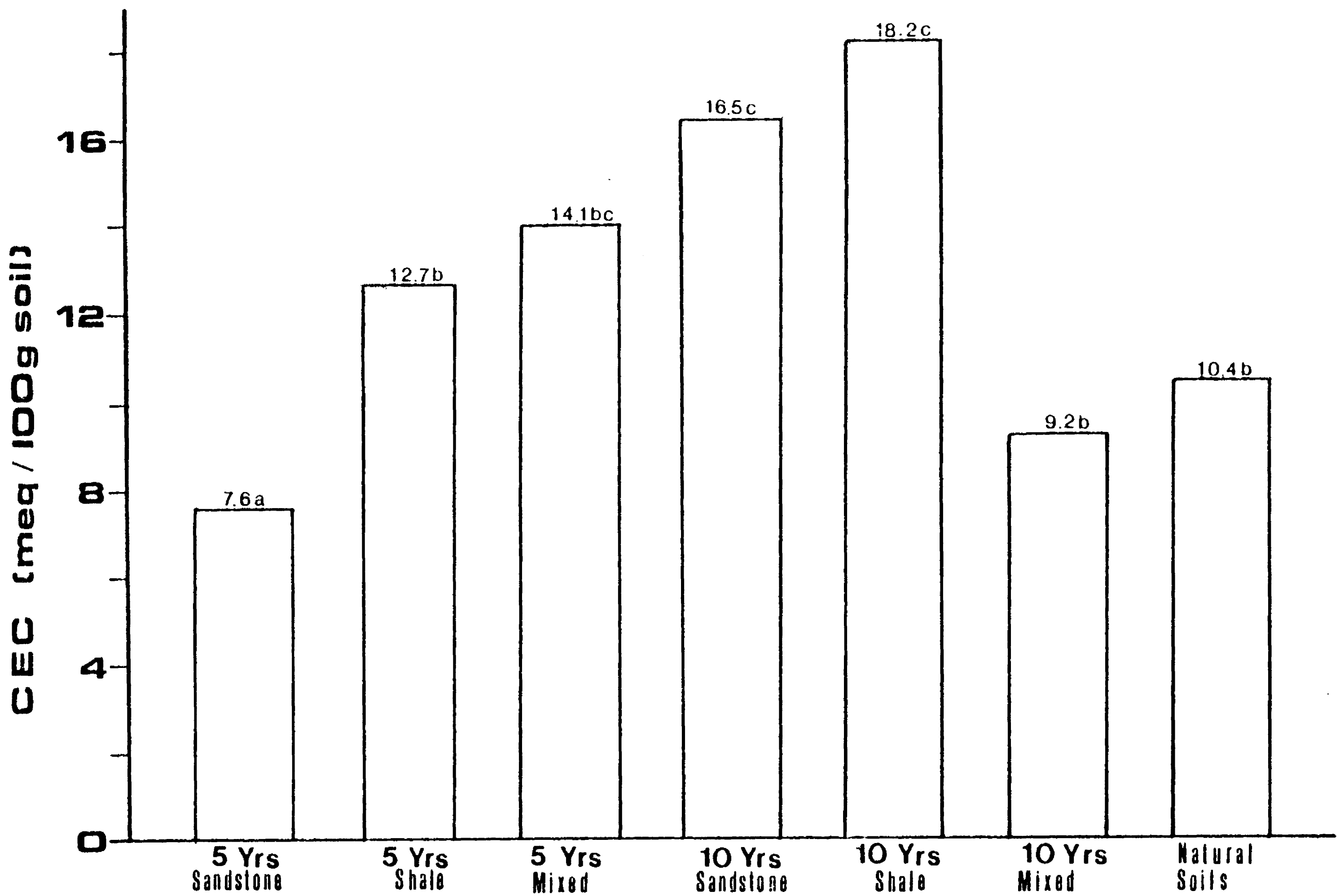

Figure 8. Interaction of age and parent material in subsurface horizons in determining cation exchange capacity of mine soils and in natural soils. (Numbers followed by the same letter are not significantly different at the 5% level.)

Thin Section Analysis

Several sandstone and shale samples obtained from exposed highwalls and some large coarse fragments and bedrock samples from the natural soils were selected for thin section analysis. Thin sections were prepared by a commercial laboratory. Analysis of these thin sections through a polarizing microscope revealed similar mineralogy among the samples.

Figure 9 is a photograph of a representative sandstone from the New River formation viewed under crossed nicols. They are composed primarily of quartz, and also contain lesser amounts of feldspar, muscovite and biotite. The sandstones are cemented by both silica and a hematite-bearing clay (Fig. 10).

The shale differed from the sandstones principally in being finer grained (Fig. 11). Here quartz is abundant, along several small rod-shaped mica flakes (muscovite and biotite). This particular rock in Figure 11 would perhaps be more correctly termed an argillaceous siltstone. It contains very fine silt and is cemented by a ferruginous clay matrix (Fig. 12).

While the rock fragments from the Dekalb, Gilpin and Muskingum series were similar to those rocks from the mine soil sites, the thin section from the R horizon of the Muskingum soil provides an interesting demonstration of the importance of time as a soil forming factor. The yellow-orange area in the center of Figure 13 is a gelatinous flow of clay lining a small crevice in this rock. Flow

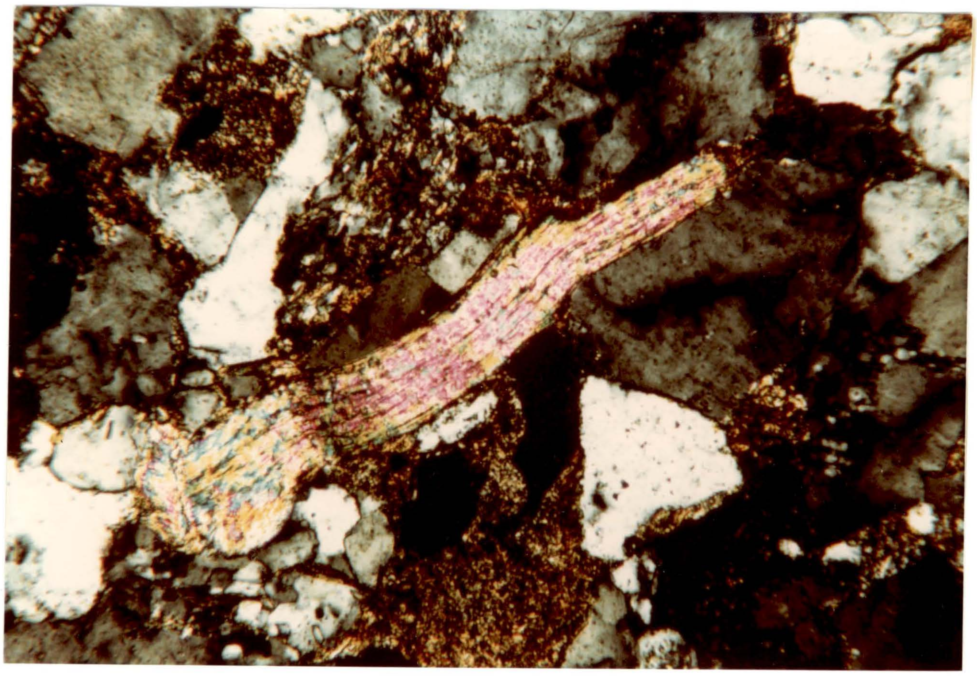

Figure 9. Thin section of a New River Formation sandstone viewed through crossed nicols. These sandstones contain biotite (thin tabular pleochioic crystals near the center of the photograph), feldspar (colorless to cloudy) crystals with weak birefringence), some small rock fragments (generally dark colored or non-illuminescent) and large quantities of quartz, which appears clear to gray to black, due to its birefringence properties (parallel or symmetrical extinction). Silica and clay predominate the cementing matrix.

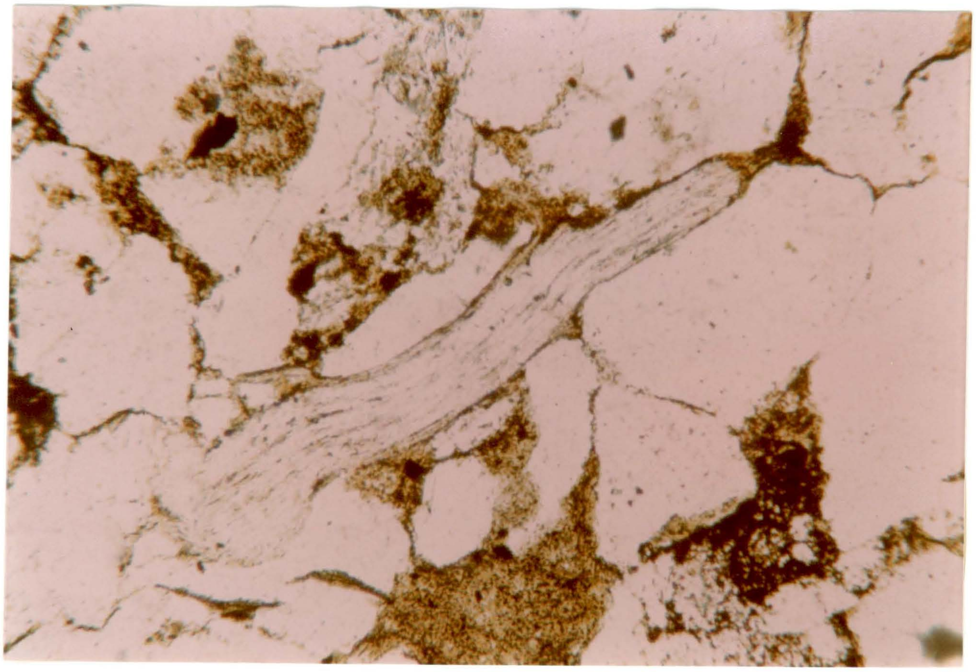

Figure 10. The same sandstone thin section as in Figure 9 as viewed through natural light. Hematite concentrations and stainings appear as dark brown and reddish brown.

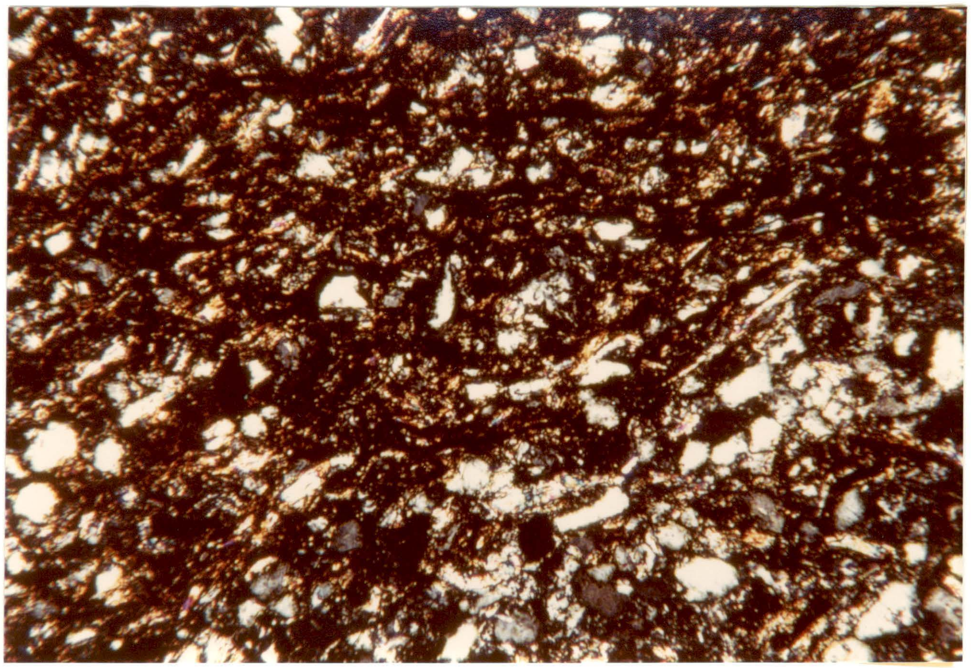

Figure 11. Thin section of an argillaceous siltstone of the New River Formation viewed through crossed nicols. Some very small mica flakes are visable as the only distinguishable mineral crystals. These siltstones are composed of very fine silt and a ferruginous clay matrix.

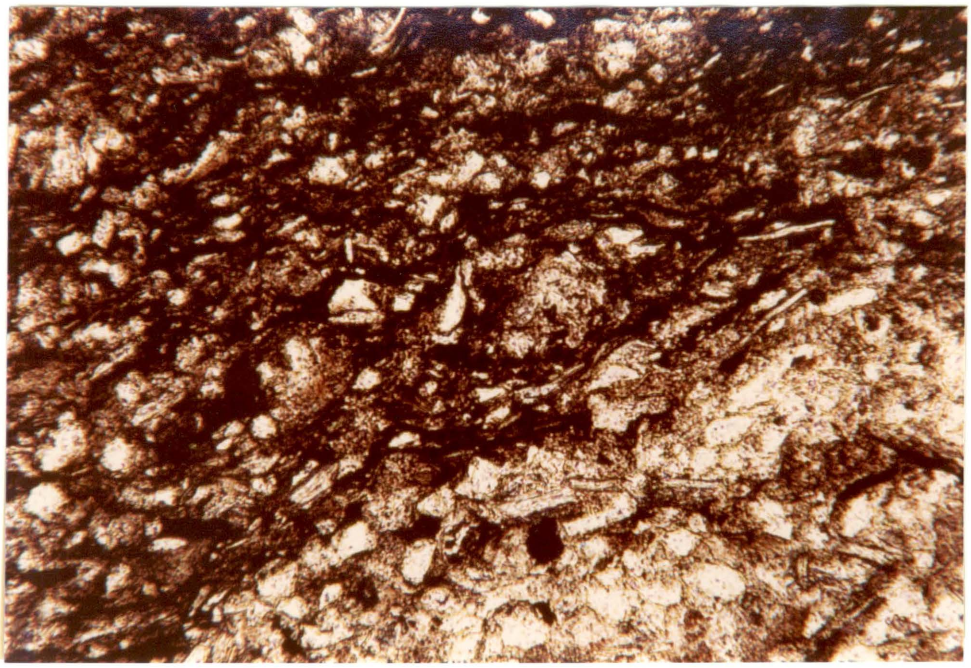

Figure 12. The same argillaceous siltstone thin section as in Figure 11 as viewed through natural light, evidencing the high concentrations of finely dispersed ferruginous clay (dark brown).

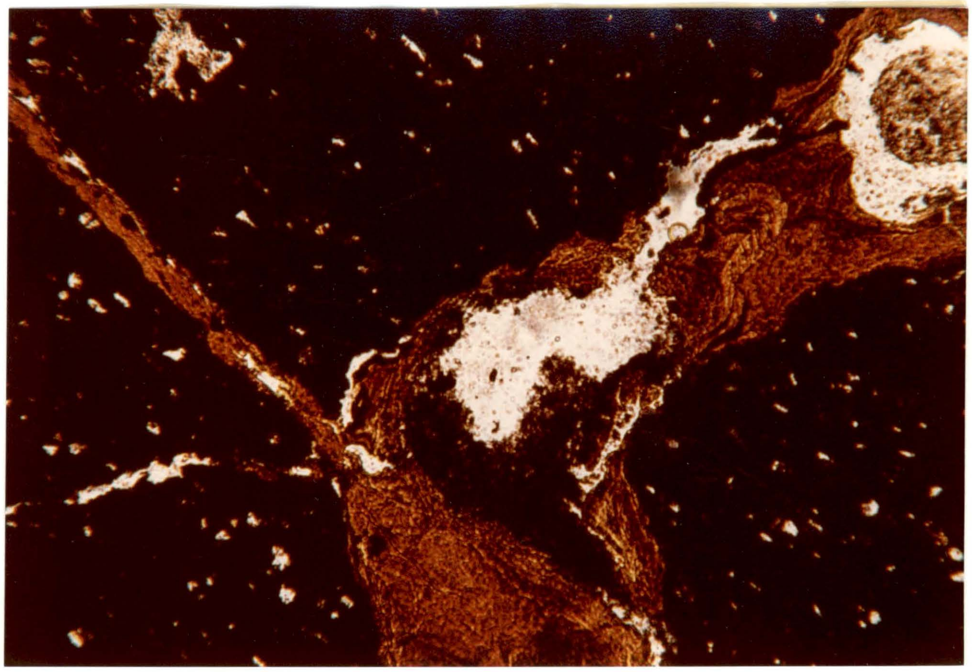

Figure 13. Thin section of shale fragment from R horizon (66-87+ cm) of Muskingum soil series viewed through crossed nicols. A yellow-orange gelatinous flow of clay is visible in the photograph. The flow is due to water dissolution of ferruginous clay minerals along the rock fissure and subsequent formation of hydrated iron silicates. These silicates dehydrate forming crysalline goethite and quartz, visible as bright reddish-brown areas between the rock matrix and the yellow-orange clay flow.

lines are visible in this material, caused by water dissolving clay from the rock and forming hydrated iron silicates. As this material ages and dehydrates, it evolves into bright, reddish-brown crystalline goethite. The downward flow of water has proceeded at this depth (66 - 86^{+} cm) long enough for such flows and crystals to form. No such phenomenon were observed in the rock fragments from mine soils.

X-Ray Diffraction Analysis

X-ray diffraction analysis was employed to determine the clay minerals present in 2, 5 and 10 year old mine soils from sandstone and shale.

The clay fractions were dominated by mica, vermiculite, kaolinite and montmorillonite. Lesser amounts of quartz were found in certain samples (Appendix III). The area an x-ray peak occupies, or its intensity, is generally thought to represent the quantitative amount of that clay species present. There are other principal factors affecting intensity, such as particle size, crystal perfection, chemical composition, variations in sample packing, crystal orientation, and presence of amorphous substances. If it were possible to hold each of these variables constant, or if one were able to evaluate properly the influence of these variables, a precise quantitative estimation of species would be possible. Unfortunately, these factors cannot be controlled in most cases (Whittig, 1965).

The kaolinite in each sample was determined by the method of Sampath and Zelazny (1977) using differential thermal analysis patterns (Appendix IV). However, for most other clay-mineral groups, only the relative amounts of each can be determined in a particular sample. By use of the direct comparison method, one compared the theoretical intensity ratio of the x-ray peaks from clay minerals with the theoretical relative amount of the clays in the sample (Schoen et al., 1972). For this study, a direct comparison method was used, in that relative peak intensities were compared to each other. This method assumes that only clay minerals are present and that the system contains no amorphous material. It also assumes that intensity is solely dependent on quantity present. By such assumptions, the clay species quantification for each sample was determined (Table 15).

Random silt powder mounts for each sample (Appendix III) were dominated by quartz, a mineral found only in minor amounts in the clay fractions of certain samples. Mica and kaolinite were also present, and the diffraction patterns show several orders of peaks for each of the three minerals. Because of the large number of secondary peaks, we did not attempt quantification of the silt fractions.

Barnhisel and Massey (1969) in studying spoils on seven mined sites in eastern Kentucky on the Breathitt formation of the Pennsylvanian system, which is synonymous to the Kanawha and New River formations in West Virginia, also found the clay mineral fraction of their samples to be mixtures of mica, kaolinite and quartz.

The mica, vermiculite and quartz in the clay fractions most likely weathered from the parent material, since these three minerals appeared frequently in the thin sections. Quartz is weathering to clay

Table 15. Clay mineral distribution by x-ray diffraction of mine soils from sandstone and shale spoils.

Shale Parent Material

2 year old soil (2-A)		5 year old soil (5-F)		10 year old soil (10-B)	
mica	50%	mica	50%	mica	55%
kaolinite	20%	vermiculite	35%	vermiculite	30%
vermiculite	20%	kaolinite	15%	kaolinite	10%
montmorillonite	10%	montmorillonite	10%	montmorillonite	5%

Sandstone Parent Material

2 year old soil (2-G)		5 year old soil (5-A)		10 year old soil (10-F)	
mica	40%	mica	40%	mica	40%
kaolinite	25%	vermiculite	35%	vermiculite	30%
vermiculite	20%	kaolinite	20%	kaolinite	25%
montmorillonite	10%	montmorillonite	10%	montmorillonite	5%
quartz	5%			quartz	<5%

size more slowly than the vermiculite, and considerably slower than the mica. Some synthesis of vermiculite may be occurring since Table 15 indicates vermiculite is increasing slightly with age; however, this is for one sample only of each age group within the two parent material types. Nevertheless, conditions exist in these mine soils for vermiculite synthesis because it is formed under conditions of moderate hydrogen ion concentrations permitting potassium and magnesium removal from interlayer positions of the initial materials. The initial materials must also contain mica and silica in relatively large amounts (Buol et al., 1973), which has been demonstrated for these mine soils by petrographic analysis and x-ray diffraction. In addition to the previous constraints, aluminum in solution must be low, or it will be precipitated into interlayers to form 2:1 and 2:2 integrades (Buol et al., 1973). No intergrades were detected by x-ray diffraction and aluminum in the mine soils is low, as was discussed in a prior section.

The conditions required for optimum synthesis of the kaolin group do not exist in all the mine soils studied, which may explain why kaolinite varied in the 6 samples studied. Normally, kaolinite is synthesized under approximately equal concentrations of silica and aluminum, with a high hydrogen ion concentration and essentially no magnesium and other bases. Kaolinite synthesis is aided by the presence of layer silicates which act as patterns for its 1:1 sheet structure (Buol et al., 1973).

Where rainfall is moderate, precipitation removes most of the metallic cations but few of the hydrogen ions from the soil. The soil pH then becomes low enough to render both aluminum oxides and silicates relatively insoluble. This soil combination of hydrogen, aluminum oxides and silica results in the formation of the kaolin group of clay minerals (Keller, 1957). These conditions do exist on most of the mine soils studied, but not always to the degree necessary for optimum genesis of kaolin.

Mine soils receive hydrogen ions from several sources, including living plants. Rapidly growing reclamation species create acid soil conditions which increases the weathering rate. The same plants extract calcium, magnesium, potassium and other bases while releasing hydrogen.

Another source of hydrogen ions may be the sulfide minerals commonly found in mine soils, including coal fragments, and particularly pyrites associated with the coal seam. Pyrite is oxidized by oxygen or ferric iron to produce ferrous sulfate and sulfuric acid, as shown in the following equations (Hill, 1971).

$$\underset{\text{(Pyrite)}}{2FeS_2} + 2H_2O + 7O_2 \longrightarrow \underset{\text{(Ferrous Iron)}}{2FeSO_4} + \underset{\text{(Sulfuric Acid)}}{2H_2SO_4}$$

$$\underset{\text{(Pryite)}}{FeS_2} + \underset{\text{(Ferric Iron)}}{14Fe^{3+}} + 8H_2O \longrightarrow \underset{\text{(Ferrous Iron)}}{15Fe^{2+}} + \underset{\text{(Sulfate)}}{2SO_4{}^{2-}} + \underset{\text{(Acid)}}{16H^+}$$

These reactions, resulting in hydrogen and strong mineral acids oxidized from pyrite and other sulfide minerals, can effectively implement hydrolysis (Keller, 1957).

Montmorillonite or other minerals of the smectite group appear in limited amounts in the x-ray diffraction patterns (Appendix III), particularly in the potassium saturated samples as part of the peak near 14 Å, which is primarily due to vermiculite. In the magnesium saturated-glycerol solvated samples, montmorillonite appears as a very small peak or shoulder on the diffraction pattern around 17-18 Å. The 2:1 smectites adsorb double sheets of glycerol molecules between adjacent layers to yield a basal spacing of 17-18 Å. Solvation of vermiculite with glycerol does not materially change its interlayer expansion (Whittig, 1965).

The formation of smectites requires a high ionic concentration of silica and magnesium or iron, conditions which would be met in the decomposing silicate minerals of these mine soils. A high silica concentration is maintained by slow movement or stagnation of soil water (Buol et al., 1973). The infiltration rates for most of the mine soils were fairly high (as will be discussed in another section), a condition tending to cause instability in montmorillonite. However, this same rapid infiltration should hasten weathering of coarse fragments and provide more silicates to the soil. The presence of montmorillonite in these samples indicates weathering is taking place, but its limited quantity indicates the silica content is either near equilibrium with the weathering and leaching processes, or excessive leaching (and possibly a high hydrogen ion content) is causing instability in these synthesized smectites (Buol et al., 1973).

Physical Properties

Coarse Fragments

Coarse fragments did not vary significantly among the mine soil A horizons as a function of age (Table 16). Surprisingly, the coarse fragments percentage in the A horizons of the natural soils did not vary significantly from that of the mine soils. Although the natural soils were significantly less rocky than mine soils, they were still quite rocky in their surface horizons. When these natural soils are stockpiled for topsoiling, these coarse fragments are mixed with underlying horizons, giving topsoiled sites slightly fewer coarse fragments than mine soil A horizons. The natural soils contained significantly fewer coarse fragments in their subsurface horizons than the mine soils, probably due to the length of time these soils have been forming in place.

Most previous studies on mine soils of the Pennsylvanian system have reported finding a greater percentage of coarse fragments. Cummins et al. (1965), after passing their samples through a 1-inch screen, determined that 60% of the material passed a 10 mesh (2 mm) screen. Plass and Vogel (1973) reported finding soil-size material

Table 16. Mean coarse fragments of mine soils and natural soils.

Soil	Coarse fragments (%) A horizons	Coarse fragments (%) Subsurface horizons
Mine soils (years)		
2	28.0a*	25.2ab
5	35.2a	43.5a
10	36.6a	28.4ab
Topsoiled Sites	21.6a	53.6a**
Natural Soils	25.6a	14.1b

*Values in the same column followed by the same letter are not significantly different at the 5% level.

**One observation only.

made up only 37% of the samples in their study of mine soils of the Pennsylvanian system. Coarse fragments on century old disturbed sites in northern West Virginia were more numerous and were less weathered than those found in natural soils (Smith et al., 1971).

Smith et al. (1976) felt coarse fragments, especially those deep in the profile, could be beneficial rather than harmful. According to this study, subsoil suitability for plant roots, aeration and available water retention are likely to be improved rather than harmed by some coarse fragments. They felt that coarse fragments, as stable, angular rocks, formed the best basal contact with bedrock or old soil.

Water-Stable Aggregates

A significant increase with age in the percentage of water-stable aggregates was observed in the A horizons of the mine soils (Fig. 14). Although the increase is significant, the mine soils are considerably lower than the 43.3% of water-stable aggregates observed in the A horizons of the natural soils. Most of these aggregates apparently are either destroyed or mixed throughout the salvaged material that is later regraded on topsoiled mine sites, since the topsoiled sites had a fairly low percentage of water-stable aggregates in their A horizons.

Generally, any action that will develop lines of weakness, shift the particles back and forth and force contacts that otherwise might not occur, encourages aggregation (Brady, 1974). Genesis of structure

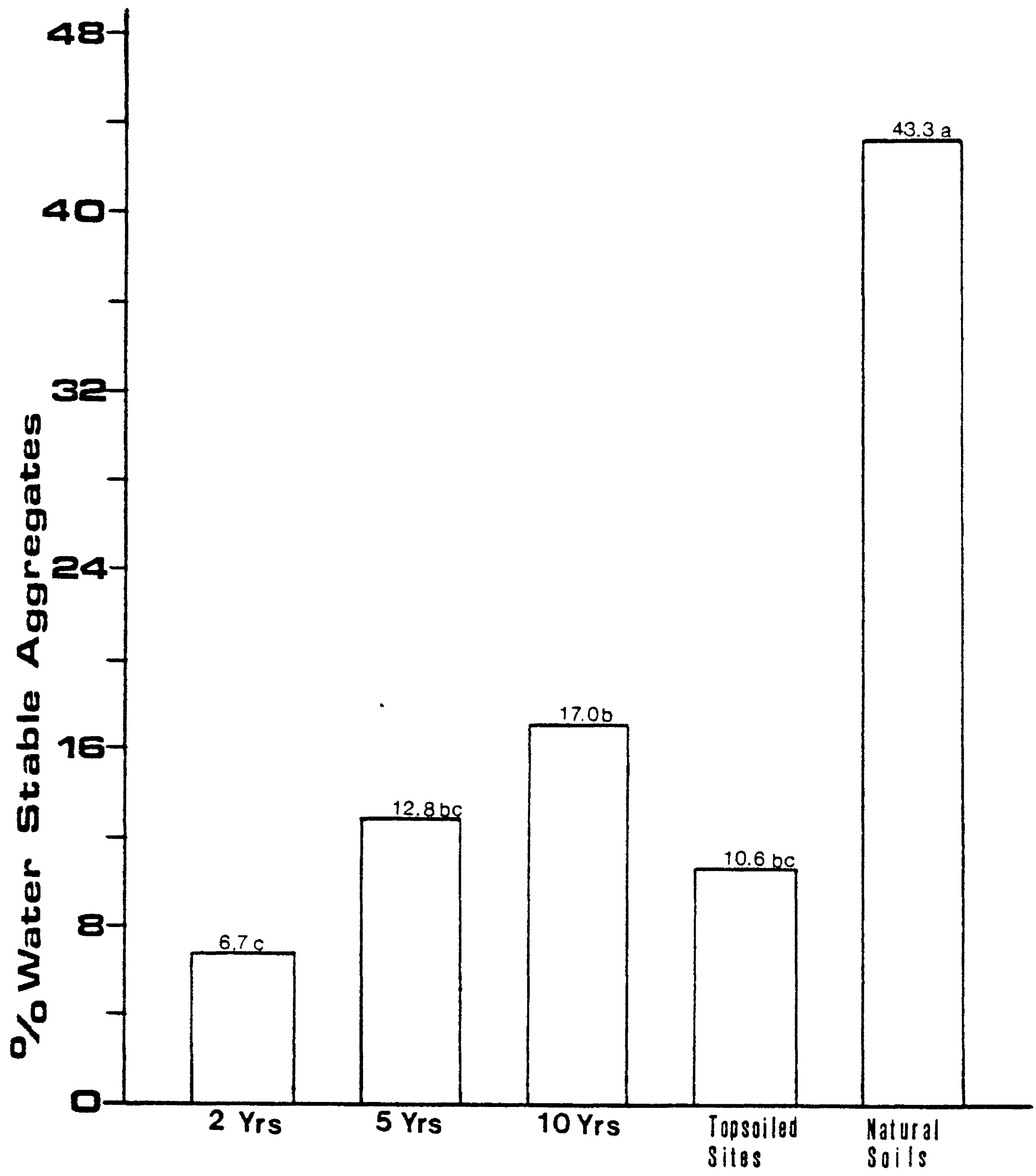

Figure 14. Percentage of water stable aggregates in A horizons of different age mine soils, topsoiled sites and natural soils. (Numbers followed by the same letter are not significantly different at the 5% level.)

generally is dependent on some physical action, while stability is dependent on introduction of some cementing agent or bonding by chemical or organic means. Presumably because of the decreased physical activity of roots in subsurface horizons and the absence of humic compounds for stability, the subsurface horizons of the mine soils did not vary significantly among themselves or with the natural soils in water-soluble aggregates.

Wilson (1957) investigated aggregate genesis and stability on five 10 year old mine soils and two century-old iron ore tailings and found the effect of vegetative cover on the aggregate stability of these soils to follow in this sequence:

nonvegetated < pine < locust < forage grasses and legumes

Sencindiver (1977) does not feel that observed horizons and soil structure in mine soils are pedogenic in the classic sense, but rather are formed by mining and reclamation equipment during the moving and spreading of overburden materials. But even this infers that the aggregates were created by some physical activity which caused planes of contact to form between the particles. The significant increase in their stability with increasing age, as observed in this study, can only be attributed to the increasing effect of factors of aggregate stability with the passage of time.

Perhaps the aggregates to which Sencindier (1977) refers are those which apparently are formed directly from fresh rock material that has become highly fractured during the mining process. In this study, several samples, especially those from shale overburdens, contained coarse fragments which were easily dissolved when washed in a 5% Calgon solution. During analysis for water-stable aggregates (Kemper, 1965), the procedure calls for dispersion of the aggregates by use of Calgon and a rubber-tipped glass rod. At this point in the process, many sharp, angular, very coarse sand fragments could be dispersed with only moderate prodding from the dispersing rod. We then had to decide whether these fractured rock materials, although dispersed with relative ease, should be considered soil aggregates.

This phenomena was also observed by co-workers in another study on mine soils of the Pennsylvanian system.[1] In their study, an experiment was designed to develop a procedure for determining water-stable aggregates in fresh spoil material. Separate samples were dispersed in pH 10 water only, and placed on a reciprocating shaker for periods of 10 seconds, 15 minutes, 30 minutes, 1, 2, 4, 8 and 16 hours. After dispersion by shaking for these time increments, the sand was fractionated according to standard particle size analysis technique (Day, 1965). Four rock types commonly found in the Pennsylvanian system in southwestern Virginia were initially used in the experiment. The results of the sand fractionation after shaking are shown in Appendix V. Both the total sand fraction and the sum of the very coarse,

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[1] Everett, Charles J. and D. F. Amos. 1979. Unpublished data. VPI & SU.

coarse and medium sand fractions are shown. The sum of the three coarsest sand fractions is given because these fractions represent the physical size limit of material which would remain on a 60 mesh (0.25 mm) sieve after dispersion of aggregates by the standard method of analysis (Kemper, 1965). This figure is then subtracted from the amount of material on the sieve immediately after wet sieving and prior to aggregate dispersion.

The graphs of the data show that increased periods of shaking cause substantial decreases in the sand fractions of the samples. This effect is most pronounced for the siltstones. However, both the siltstone and sandstone samples show significant decreases in sand content through 4 hours of shaking, which indicates that more sand-sized materials are dispersed with increased periods of shaking. Beyond 4 hours, slight decreases in sand content occur. The 4 hour shaking, therefore, was considered the amount of time necessary for the dispersion of aggregated materials by this method.

To compare the methods used in this study with the pH 10 water method, two samples were selected having coarse fragments which readily dissolved in a 5% Calgon solution. The B22t horizon of the Gilpin series contained only 0.4% coarse fragments stable through the Calgon dispersion technique while the C horizon of a 10 year old sample (10-C) contained 0.68% Calgon stable coarse fragments. In addition, sample 10-C had an exceptionally high percentage (54.9) of water stable aggregates in the C horizon, many of which apparently were easily dispersed, very coarse or coarse sand grains. These two samples represented extremes in coarse fragment content and in the amount of pedogenesis that has taken place.

The results of shaking these two samples for different periods of time in pH 10 water are also shown in Appendix V. Sample 10-C (C horizon) had a rapid decrease in the total and > 60 mesh sand fractions through 2 hours shaking time. The Gilpin B22t horizon experienced some decrease through the 2 hour time period, but the effect is not as pronounced as that of the mine soil sample. Since we are considering the material that would be retained on a 60 mesh (0.25 mm) sieve, it is possible to relate this data to aggregate stability.

The 10 second shaking time is analogous to the wet sieving procedure involving the Yoder sieving machine (Yoder, 1936), which is performed prior to aggregate dispersion in the standard method of determining aggregate stability (Kemper, 1965). Both 10 seconds shaking in pH 10 water and wet sieving accomplish only the separation or removal of unaggregated fine and very fine sand, silt and clay from the remainder of the sample. The result of this step in each procedure is used as a reference, as the washed sample now contains sand > 0.25 mm and aggregates. In standard procedure (Kemper, 1965) the aggregate and sand were weighed, then the aggregates dispersed, and the remaining sand is weighed and subtracted from the original aggregate and sand weight to give the percentage of water-stable aggregates.

In the previously cited VPI & SU experiment,[2] the results of the shaking procedure are plotted, and the flex point of the graph reveals the time after which a decrease in the coarser sand fractions is minimal. Any further decrease after this time would presumably be due to erosive and abrasive forces encountered during prolonged shaking.

In the original experiment, 4 hours appeared to be the desired amount of time, while in this study, the 10 year old mine soil C horizon and the Gilpin B22t horizon (Appendix V) appear to have dispersed adequately after 2 hours, although the 4 hour analysis is not significantly different. By subtracting the total amount of very coarse, coarse and medium sand in the samples after either 2 or 4 hours from that amount contained in the samples after 10 seconds, an approximation of the per cent of water-stable aggregates can be obtained (Table 17). The point where the graphed points become nearly level represents a well-dispersed sample (Appendix V). The 10-second sample still contains intact aggregates. The difference between the two represents the percentage water-stable aggregates. The values obtained from the pH 10 water method closely agree with those obtained by Kemper's (1965) method. Since the two methods vary in harshness of dispersion, the sand-sized fractured rock in the mine soils apparently behave as structural aggregates. For this dispersion to

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[2] *Op. cit.*

Table 17. Variation in very coarse, coarse and medium sand fractions as a function of shaking time in pH 10 water, and relation to % water-stable aggregates measured by standard Calgon dispersion.

Shaking Time in pH 10 Water	Sand Fraction (%) VCOS	CS	MS	Σ	>60 mesh sample-Σsand
	10-C C horizon				
10 seconds	15.47	45.50	0.0	60.97	-----
15 minutes	2.63	9.40	13.75	25.78	35.19
2 hours	0.81	1.11	1.62	3.54	57.43
4 hours	0.60	1.45	1.70	3.75	57.22
	Gilpin B22t horizon				
10 seconds	0.41	1.62	2.54	4.57	-----
15 minutes	0.20	0.61	1.02	1.83	2.74
2 hours	0.41	0.51	0.71	1.63	2.94
4 hours	0.41	0.51	0.61	1.53	3.04

Water-stable aggregates by Calgon dispersion (Kemper, 1965)

Soil Sample	% Water-stable aggregates
10-C C horizon	54.93
Gilpin B22t	4.44

occur, the individual fragments must have been fractured, with pore space probably occurring along fracture planes, the resultant smaller components remain relatively stable, resulting in the gentler slopes of the dispersion line after either 2 or 4 hours of shaking (Appendix V). Since the aggregate stability of the 10 year old (10-C) C horizon was much higher than most other samples (including the natural soils), we may assume the presence of easily dispersed rock fragments.

Sobeck et al. (1978) describe a similar procedure to identify materials that will disintegrate quickly when exposed to surface weathering. Smith et al. (1974) shook samples for 16 hours to identify strongly cemented rock types suitable for lining drainageways, and also developed a gentle dispersion procedure, known as Sieve Analysis after Intermediate Disaggregation (SAID), to distinguish coarse rock fragments from soil fines. Both procedures use a 5% Calgon solution for dispersion.

Moisture Holding Capacity

The moisture holding capacity of the mine soils generally increased with age, although this trend was not always significant. These mine soils had not yet developed the moisture retention capacity of the natural soils, as measured at 0.06 and 0.1 atmosphere tension (Table 18). The mine soils do not vary significantly, while the topsoiled sites, with values between mine soils and natural soils, again reflect the mixing effect of stockpiling and regrading.

Table 18. Moisture holding capacity at 0.06 and 0.1 atmosphere of A horizons of different age mine soils, topsoiled sites and natural soils.

Soils	Atmospheres	
	0.06	0.1
	--% moisture--	
Mine soils		
2 years	21.5b*	19.5b
5 years	19.4b	18.3b
10 years	20.9b	19.6b
Topsoiled sites	23.9ab	22.1ab
Natural soils	29.5a	27.9a

*Values in the same column followed by the same letter are not significantly different at the 5% level.

At 15 atmosphere tension, the A horizon of mine soils generally retained more moisture than the A horizons of natural soils from similar parent material (Table 19). The shale and mixed parent material type soils are significantly higher in moisture content than the sandstone soils, due to their higher content of fine particles. Possibly because of their inclusion of B horizon material in the surface layer, the topsoiled A horizon contained the greatest amount of moisture observed at 15 atmospheres.

Although the natural soils contained a relatively low amount of moisture in their A horizons at 15 atmospheres (Table 19), they contain more moisture at lower tension levels in their subsurface horizons than the mine soils (Table 20). This significant difference is due to the long period of illuviation in these subsurface horizons, thereby increasing their water holding capacity. Among the mine soils, the 10 year old sites indicate some illuviation has occurred in this time period, as they contain somewhat more clay and have better structure than the other mine soil subsurface horizons.

The total amount of available water, if defined as that amount of water held between 0.1 and 15 atmospheres (Brady, 1974), proved to be higher for the natural soils due to their finer texture and superior structure (Table 21).

Table 19. Percent moisture held at 15 atmospheres in A horizons and subsurface horizons of mine soils weathering from different parent materials, topsoiled sites and natural soils.

Soils	Percent moisture (15 ATM)	
	A horizons	Subsurface horizons
	% moisture	
Mine soils (parent material)		
Sandstone	8.2b*	9.3a
Shale	12.5a	11.8a
Mixed	11.6a	13.2a
Topsoiled sites	13.3a	-----
Natural soils	10.0ab	11.9a

*Values in the same column followed by the same letter are not significantly different at the 5% level.

Table 20. Percent moisture held in subsurface horizons of different age mine soils and natural soils at 0.06, 0.1, 0.33 and 1.0 atmosphere.

Soils	Atmosphere			
	0.06	0.1	0.33	1.0
	% moisture			
Mine soils				
2 years	20.7ab*	18.9ab	15.1b	12.5b
5 years	18.5b	17.5b	15.4b	13.5b
10 years	21.6ab	19.8b	17.1b	15.2ab
Natural soils	24.9a	23.3a	19.9a	17.2a

*Values in the same column followed by the same letter are not significantly different at the 5% level.

Table 21. Reserve of plant available water (cm/horizon and cm/solum) as influenced by age and thickness of soil material.

Mine soils	A horizons	Subsurface horizons	Solum*
(years)	cm/horizon		cm/ solum
2	0.51a**	0.64a	0.79a
5	0.24a	0.43a	0.70a
10	0.29a	0.53a	1.10a
Topsoiled sites	1.01abc	----	1.01a
Natural soils	2.50c	2.43b	10.98b

*Mean values for sola are not equal to the sum of the means for A horizons and subsurface horizon. Solum values were calculated by obtaining an average value for each solum, which then were averaged for each age group.

**Values in the same column followed by the same letter are not significantly different at the 5% level.

Infiltration and Permeability

The hydraulic conductivity values were perhaps the most difficult to obtain, and varied most widely among the characteristics measured. This resulted largely from the compact coarse fragment content of most of these soils, which made core sampling difficult if not impossible.

Initially, core samples were obtained with a 6 in. (15 cm) diameter sampler, but this sampler proved too difficult to use at many sites, and appeared to cause serious shattering of the core, because of the hammering required to drive the sampler into the ground. Switching to a 3 in. (7.5 cm) core sampler helped this problem somewhat.

The infiltration results obtained from 3 in. (7.5 cm) cores by the constant head method (Klute, 1965) are given in Table 22. The range of hydraulic conductivities by age was wide, but the mean conductivity generally increased with age. The 2 and 5 year old soils belong in the moderate class of hydraulic conductivity, while the 10 year old soils belong in the moderately rapid class (Klute, 1965). The surface horizons of the natural soils were rocky enough to prevent core sampling, however, the Muskingum and Dekalb series are estimated to have moderate to moderately rapid hydraulic conductivity, and the Gilpin is estimated to have moderately slow to moderate infiltration in the area sampled (Gorman and Espy, 1975).

While soil texture does influence the rate of hydraulic conductivity, the two most commonly observed soil textures developed

Table 22. Infiltration and permeability of 2, 5 and 10 year old mine soils as measured by alternate method.

Mine soil age (yrs)	Infiltration	Permeability
	cm/hr	
2	2.3a*	1.2a
5	4.5ab	2.4a
10	7.0b	7.0b

*Values in the same column followed by the same letter are not significantly different at the 5% level.

increased conductivity with age (Fig. 15). The somewhat coarser sandy loam soils had higher values than the loam soils in all three age groups, but both improved over the 10 year period.

Since the hydraulic conductivity of 3 in. (7.5 cm) cores was quite variable among age groups, we attempted to verify the results in situ by measuring permeability (Musgrove, 1935) with double ring infiltrometers. Four replicate tests per site were made on 2, 5 and 10 year old soils from mixed parent material. As with the cores, the infiltrometers indicated that water movement was improving with mine soil age (Table 22).

The values observed in this study for infiltration and permeability are higher than on-site conditions (such as surface cresting) suggest they would be. The installation of double ring or removal of 3 inch (7.5 cm) cores may cause some soil shattering and the artificial creation of fissures.

Ollier (1975) felt that a system of fissures and cracks allowed leaching to operate from the beginning on mine soils. Such leaching caused soil formation to be rapid at first, then gradually slow down. In such materials, periods in tens or hundreds of years are sufficient for a distinct soil to develop (Ollier, 1975). The findings in our study are in basic agreement with this concept.

Classification of Mine Soils

Classification systems for soils forming on mine spoils have been primarily aimed at determining the properties of the surface material

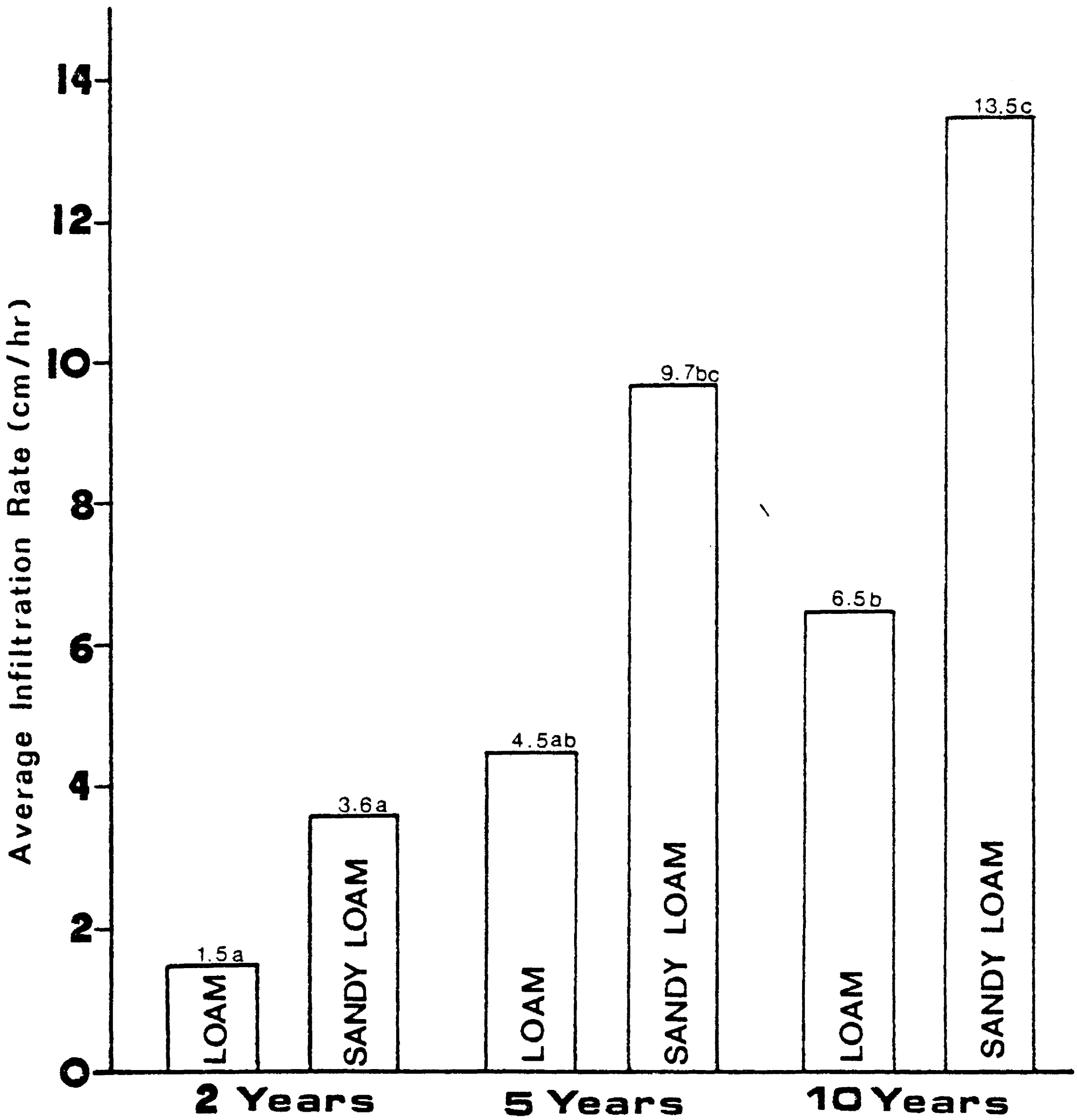

Figure 15. Infiltration as a function of age and texture of soils. (Numbers followed by the same letter are not significantly different at the 5% level.)

for plant growth, such as soil reaction (pH), texture, stoniness and slope (Sencindiner, 1977). Such a system is shown in Table 23 (Doyle, 1976). Surface mined areas are not mapped or interpreted in soil surveys other than as mine spoil. Since differences in mine soils do exist and continue to diverge as the soil ages, these soils need to be classified precisely according to their distinguishing properties, particularly those properties which may influence management (Sencindiner, 1977).

Mine soils are indeed soils, and should be classified as such. Soil Taxonomy (Soil Survey Staff, 1975) defines soil as "the collection of natural bodies on the earth's surface, in places modified or even made by man of earthy materials, containing living matter and supporting or capable of supporting plants out-of-doors." Mine soils certainly fit this definition, as they are man-made, or at least are highly modified by man. Granted, many mine soils are nothing more than highly fractured rock, but would still be considered soil by Jenny's (1941) definition, which states that rock as soil parent material "is merely the state of the soil system at the soil-formation time zero. As soon as rock, consolidated or unconsolidated, is brought into a new environment and is acted upon by water, temperature and organisms, it ceases to be parent material and becomes soil." A study in southwestern Virginia[3]

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[3] Howard, J. L. and D. F. Amos. 1979. Unpublished data. VPI & SU.

Table 23. Stoniness class, criteria and tillage potential of mine soils (from Doyle, 1976).

Stoniness class	Criteria	Tillage potential
Nonstony	< 0.01% stones and boulders	Can be tilled
Stony	0.01%-15% stones and boulders	Tillage limited
Very stony	15-50% stones and boulders	Treat by hand
Extremely stony	> 50% stones and boulders	Cannot use equipment

found that 35 to 45% of overburden materials were soil-sized immediately after blasting from the highwall.

The classification of mine soils according to Soil Taxonomy (Soil Survey Staff, 1975) raises some interesting points concerning soil genesis and the classification system itself.

As discussed previously, the sampling procedure allowed for extraction of a sample of the solum from the surface to a depth where an impenetrable mass of coarse fragments was encountered, or a lithic or paralithic contact. This was usually considered to be the C horizon, as material above this layer appeared to be weathering in place, or at least had been segregated into separate horizons by the soil forming processes. Often, due to the high volume of coarse fragments in the C horizon, it was difficult to determine where the boundary between the C horizons and the underlying rock occurred.

This may be due to the regrading process. Coarse materials including large rocks are dumped back into the mined area first, and are then covered with finer materials. More recently, the concept of removing and storing the original soil material (topsoiling), has received acceptance and is now part of Federal reclamation legislation. This layer of fine earth which is regraded over the mined site obviously has a determinable depth. However, the underlying unconsolidated rock material may be several meters deep, depending upon the size of the mining operation.

This underlying boundary with large, unconsolidated rock material is probably more correctly termed as lithic contact, as it is continuous under each mine soil, but may be underlain by materials soft enough (< 3 Moh's scale) to make it a paralithic contact. In other words, the materials below the lithic or paralithic contact and their resistance to digging with a spade depends on the rock type and its degree of weathering. This layer, when first encountered, was described as the C horizon, with only its upper boundary depth and its components noted. Four of the 10 year old profiles (10-C-F) had C horizons which had weathered enough to be distinguishable from underlying rock and were sampled separately.

All mine soils sampled were quite shallow to rock material. Despite their shallowness, evidence of pedogenesis could be observed in the horizons above the rock. Color and textural differences and the formation of diagnostic horizons were evident in these profiles, especially at the 10 year old sites. Although soil genesis was evident and horizons were readily apparent, the 5 and 10 year old sites do not readily fit into the current classification system, with their subsequent taxonomic labels not being truly descriptive of the soil properties actually found in those pedons. The primary shortcoming is that Soil Taxonomy (Soil Survey Staff, 1975) does not consider the possibility that soils shallower than 25 cm may have diagnostic horizons or other evidence of pedogenesis. It classifies all soils with lithic or paralithic contacts shallower than 25 cm as Orthents (Entisols on recent erosional surfaces). The taxonomic classifications of the mine soils according to the criteria established by Soil Taxonomy, except for the requirement that the lithic or paralithic contact be greater than 25 cm below the soil surface are given in Table 24. Without waiving this depth requirement, all mine soil profiles observed in this study (except 10-J) would be classified as Lithic Udorthents, indicating there is virtually no difference in their soil properties, when in reality there are appreciable differences among age groups.

All topsoiled and two year old sites were classified as Lithic Udorthents, ignoring the 25 cm depth requirement, because of their lack of profile development. Not enough time had elapsed on these sites for much more than the formation of a thin surface horizon to occur, showing the effects of vegetation and some eluviation in most instances. All of these profiles were acid and had mixed mineralogy. The family particle size class was either loamy-skeletal, coarse-loamy or fine-loamy, depending on the volume of coarse fragments present.

Of the 5 year old sites, the three profiles weathering from predominantly shale parent material (profiles 5-D, 5-F and 5-G) were classified as Lithic Udorthents, again because they lacked evidence of much alteration in the subsurface horizon. Profiles 5-D and 5-F were described as containing AC subsurface horizons, while 5-G was described with a B horizon because it has somewhat stronger structure although laboratory analysis indicated that it contained less clay than the overlying A horizon. All other 5 year old sites were classified (waiving the 25 cm depth requirement) as Inceptisols, because they show signs of alteration in their subsurface horizons.

Table 24. Classification of mine soils by the criteria given in Soil Taxonomy (25 cm minimum depth to lithic or paralithic contact waived).

Topsoiled sites

T-1	loamy-skeletal, mixed (acid), mesic Lithic Udorthent
T-2	fine-loamy, mixed (acid), mesic Lithic Udorthent
T-3	fine-loamy, mixed (acid), mesic Lithic Udorthent

Two Year Old Sites

Profile	Parent Material	Classification
2-A	sandstone	coarse-loamy, mixed (acid), mesic Lithic Udorthent
2-B	mixed	coarse-loamy, mixed (acid), mesic Lithic Udorthent
2-C	sandstone	coarse-loamy, mixed (acid), mesic Lithic Udorthent
2-D	mixed	loamy-skeletal, mixed (acid), mesic Lithic Udorthent
2-E	sandstone	coarse-loamy, mixed (acid), mesic Lithic Udorthent
2-F	shale	fine-loamy, mixed (acid), mesic Lithic Udorthent
2-G	shale	loamy-skeletal, mixed (acid), mesic Lithic Udorthent
2-H	shale	fine-loamy, mixed (acid), mesic Lithic Udorthent
2-J	mixed	fine-loamy, mixed (acid), mesic Lithic Udorthent

Five Year Old Sites

Profile	Parent Material	Classification
5-A	sandstone	loamy-skeletal, mixed, mesic Lithic Dystrochrept
5-B	mixed	loamy-skeletal, mixed, mesic Lithic Dystrochrept
5-C	sandstone	loamy-skeletal, mixed, mesic Lithic Eutrochrept
5-D	shale	loamy-skeletal, mixed (acid), mesic Lithic Udorthent
5-E	sandstone	coarse-loamy, mixed, mesic Lithic Dystrochrept
5-F	shale	loamy-skeletal, mixed (nonacid), mesic Lithic Udorthent
5-G	shale	loamy-skeletal, mixed (acid), mesic Lithic Udorthent
5-H	mixed	loamy-skeletal, mixed, mesic Lithic Dystrochrept
5-J	mixed	loamy-skeletal, mixed, mesic Lithic Dystrochrept

Table 24. Classification of mine soils by the criteria given in Soil Taxonomy (25 cm minimum depth to lithic or paralithic contact waived).

Ten Year Old Sites

Profile	Parent Material	Classification
10-A	mixed	loamy-skeletal, mixed, mesic Lithic Dystrochrept
10-B	shale	loamy-skeletal, mixed, mesic Lithic Dystrochrept
10-C	mixed	fine, mixed, mesic Lithic Dystrochrept
10-D	sandstone	loamy-skeletal, mixed, mesic Lithic Dystrochrept
10-E	sandstone	fine-loamy, mixed, mesic Lithic Dystrochrept
10-F	sandstone	loamy-skeletal, mixed, mesic Lithic Dystrochrept
10-G	mixed	loamy-skeletal, mixed, mesic Lithic Dutrochrept
10-H	shale	loamy-skeletal, mixed, mesic Lithic Eutrochrept
10-J	shale	coarse-loamy, mixed, mesic Lithic Dystrochrept

Contiguous Soils

Dekalb series	loamy-skeletal, mixed, mesic Typic Dystrochrept
Gilpin series	fine-loamy, mixed, mesic Typic Hapludult
Muskingum series	fine-loamy, mixed, mesic Typic Dystrochrept

Except for the thickness requirement, these subsurface horizons meet the criteria for cambic horizons.

It is as if soil genesis were taking place on a smaller scale than previously observed. Of the 5 year old Inceptisols, all but one can be classified as Lithic Dystrochrepts, due to their low base status. Most fit the concept of a typical Dystrochrept, with an ochric epipedon over a cambic horizon (Soil Survey Staff, 1975). The only other 5 year old soil (5-C) is classified as a Lithic Eutrochrept, (again waiving the depth requirement). In the definition of Eutrochrepts, Soil Taxonomy (Soil Survey Staff, 1975) states that these soils must either have carbonates in the cambic horizon or in the C horizon, or must have a base saturation that is $\geq$ 60% in some subhorizon that lies between depths of 25 and 75 cm below the soil surface. Pedon 5-C has a base status of nearly 76% in its AC horizon, but is just 15 cm deep.

Perhaps the justification for setting a 25 cm depth requirement is to assure this is a subsurface horizon, so that soils with a high base status in their subsurface horizons are classified differently than soils with a high base status in their surface horizons. A high base status in the subsurface horizons would be more dependent on parent material, especially in young soils, whereas a high base status in the surface horizon would more closely reflect the recycling of bases by vegetation as influenced by climate. In this general principle concerning base-rich subhorizons, profile 5-C meets the requirements for a Eutrochrept, but dces not quite reach the arbitrary depth limit imposed by the classification system.

The 10 year old pedons had deeper solum development and exhibited, in general, greater evidence of weathering. These sites again are difficult to classify because of their inability to meet arbitrary depth requirements, despite the amount of pedogenetic characteristics they exhibit. By waiving the 25 cm depth requirement, all 10 year old sites were classified as Inceptisols, specifically Ochrepts. As with the majority of 5 year old sites, the majority (7) of the 10 year old sites were classified as Dystrochrepts, due to their low base status. The 2 remaining 10 year old pedons were classified as Eutrochrepts; 10-G, because of its high base status and 10-H, because of its reaction with a 10% HCl solution (Soil Survey Staff, 1975). Chemical analysis has shown these sites are relatively high in Ca and Mg. Pedons 10-C and 10-D have properties which closely resemble those of umbric epipedons, but were not classified as such due to their relative thinness.

Mine soils studied in northern West Virginia (Grube et al., 1972) were classified as either Dystrochreprts or Udults, although no mention is made of the age of these soils. Another study classified mine soils on recently disturbed Pennsylvanian strata as Udorthents (Pederson, 1977).

Three of the 10 year old pedons showed enough increase in clay in their subsurface horizons to classify these horizons as argillic, but two of these pedons (10-C and 10-D) had clay increasing continuously with depth through the pedon, indicating the clay is a product of the weathering of the parent material. However, profile 10-E has its highest concentration of clay in the B21 horizon, and the concentration of clay is greater than 1.2 times that of the overlying A horizon, thus qualifying the horizon as an argillic. Argillic horizons also must have some indication of illuviated clay, usually in the form of clay skins on ped surfaces. Since this degree of weathering was not anticipated on soils of this young age, no intact peds were saved for fabric analysis by thin section. The probability of one 10 year old pedon in nine having an increase in clay in the subsurface horizon should be good, so it may in fact, be the result of random sampling. The probability would be even greater if the parent material were shale, or perhaps mixed. In that case some of the clay might be attributed to the breakdown of sand-sized soil fragments by shaking in a Calgon solution. This pedon (10 E), however, has formed from sandstone.

If indeed the clay could be shown to be illuvial, and an argillic horizon determined to exist, the pedon would be classified as an Alfisol (Hapludalf). In the strict criteria of Soil Taxonomy (Soil Survey Staff, 1975), all evidence seems to indicate that this horizon is not an argillic horizon. Soil Taxonomy (Soil Survey Staff, 1975) concludes that a few thousand years are required for the formation of an argillic horizon, due to the lack of evidence of illuviation on young landscapes. It goes on to say that illuvial clay is usually only a small part of the total amount of clay, that the majority of clay in an argillic horizon has either been formed within the horizon, or has been inherited from the parent material. As noted in the discussion of particle size analysis, there is an indication of illuviation in many of the minerals in that the clay content of 10 year old subsurface horizons was slightly higher than that found in the 2 and 5 year old mine soils. Therefore, illuviation and the formation of an argillic horizon may, in fact, be taking place in this pedon at a much faster rate than previously thought possible.

If the clay in the B21 horizon of profile 10-E is illuvial, the horizon will not meet the arbitrary thickness requirement stated in Soil Taxonomy (Soil Survey Staff, 1975). The thickness of an argillic horizon by the definition should be at least 1/10 that of the overlying horizons or, if the overlying horizons are "very thin," the argillic horizon should be at least 7.5 cm thick in order to indicate significant illuviation. The horizon in question is 4.5 cm thick.

All 10 year old pedons had mixed mineralogy. The particle size class was either loamy-skeletal, coarse-loamy or fine-loamy. One exception to this was pedon 10-C, which made the fine particle size class. This pedon had a concentration of coarse fragments high enough to classify as either coarse-loamy or loamy-skeletal, but the coarse fragments, many of which were argillacious shale, dissolved readily in the Calgon solution used in normal laboratory routine to cleanse coarse fragments and remove aggregates. This dissolution of coarse fragments was observed in other samples of shale and mixed parent material, but not to the extent observed in pedon 10-C.

The 5 and 10 year old minerals classified by waiving the 25 cm depth requirement compare favorably to the classification of the Muskingum and the Dekalb series, both of which are Typic Dystrochrepts. Twelve of the eighteen 5 and 10 year old pedons are Lithic Dystrochrepts. The particle size classes are similar, because the natural soil series were also fairly high in their coarse fragments. The Gilpin series was classified as a Typic Hapludult, and was the most strongly developed soil observed in this study.

Sencindiner (1977) proposed a new classification system specifically for mine soils which is aimed at giving a more definitive meaning to taxonomic labels for disturbed soils. Sencindiner also observed the unique properties of these soils, such as coal fragments, a variety of rock types, disordered arrangement of coarse fragments, artifacts and highly variable mottling. His objective was to use these unique properties as a basis for descriptive classification of disturbed soils, particularly mine soils. The five existing suborders of Entisols (which is the order Sencindiver feels all mine soils should occupy) do not accommodate mine soils, and he proposes a new suborder, Spolents, which he defines as "soils that include recently deposited earthy materials resulting from surface mining or other earthmoving operations, or deposits of solid wastes accumulated in connection with some phase of mining or other industrial activity, or deposits from such activities as sanitary landfills" (Sencindiver, 1977).

There is a need for such a classification system. It would permit a more descriptive classification of mine soils, and would reflect the factors that will affect management. However, this classification should not be restricted to only the Entisol order. We believe that our study shows not all mine soils are lacking in pedogenetic development. A more definitive classification of mine soils is needed in the more specific taxa in categories no higher than the subgroup level. Sencindiver (1977) makes very useful suggestions for mine soil subgroups, which are distinguished mainly on the basis of coarse fragment lithology. Since mine soils are created from fractured rock, the coarse fragments automatically play a major role in determining genetic processes as well as governing requirements for future use and management. For example, one such proposed subgroup has the modifier "carbolithic," which include those mine soils containing greater than 50% coarse fragments having a Munsell soil color value $\leq$ 3 for the streak or powder. This would include items commonly found in mine soils, such as coal and carbon-rich shales. Carbon-rich mine soils would then immediately be identifiable by the use of the term "carbolithic."

Again, we must emphasize that these subgroup modifiers should not be restricted to Entisols (specifically Spolents). Many of the properties they describe could persist for many years in the process of pedogenesis. Mine soils in their initial state of development will obviously be classified as Entisols, but they cannot be expected to remain in that order for long periods, as pedogenesis should quite rapidly modify these soils. These descriptive modifiers need to be used at a level where they can apply to mine soils in their initial state, as Entisols, and also as they progress with age to Inceptisols and on to more highly developed orders.

Sencindiver (1977) has not addressed the likelihood of shallow soils having pedogenetic horizons. His control section for mine soils which have not bee topsoiled is between 25 cm and 100 cm from the immediate surface. The horizons observed in our study were mostly shallower than 25 cm. Sencindiver (1977) feels that young mine soils (5-10 years old) are essentially lacking in pedogenic horizons. He states that all horizons observed near the surface were formed through deposition during the spoil regrading process. He notes few surface horizons formed by chemical and physical weathering, but these surface horizons were ignored and not included in the proposed classification. Sencindiver feels the surface of mine soils is too easily altered by many through agricultural practices, and, in fact, could be changed every year.

Through observation, we found the surface horizon of the mine soils to be changing with increasing age, thereby indicating some change probably occurring on an annual basis. All sites sampled were under some type of permanent vegetation, and although agricultural practices could produce alterations, the observed alterations were due to climate and vegetation acting on parent material over different periods of time. Topography was not a major consideration, as all samples were collected from fairly level bench areas.

Sencindiver (1977) chose to number his observed horizons instead of assigning names (A, B or C) as he felt these layers were not the result of pedogenesis, except for the surface layer. Assuming that the horizons Sencindiver (1977) numbered "1" are surface horizons, we used the additional data supplied in his thesis' appendix listing the age of the sites in a correlation procedure involving SAS-76 (Barr et al., 1976). This indicated a correlation between age of the sites and the reported depth of the number "1" horizons that was significant at the .05 level of significance with a correlation coefficient of 0.71.

Sencindiver (1977) even proposes changes in the definitions of several suborders of Entisols in order to exclude mine soils and to assure their placement in Spolents. A less radical approach may be the waiving of certain depth and thickness requirements to permit mine soils to be classified according to Soil Taxonomy (Soil Survey Staff, 1975), along with the subgroup terminology proposed by Sencindiver (1977).

Obviously, problems exist in classifying mine soils, evey by Soil Taxonomy (Soil Survey Staff, 1975), which looks for properties that are genetically significant. One can discover which properties are genetically significant in all soils only when on has first classified the soil. It may not be possible to perfect a classification system for soils or other natural objects, as they lack definitive classes or models of comparison, or finite standard deviations (Webster, 1968).

SUMMARY AND CONCLUSIONS

The Appalachian region, the world's leading producer of coal, is dominated by steep, mountainous terrain. Its soils are generally thin and rocky, and its most fertile land, the floodplains, are hazardous because of frequent and severe flooding and are utilizable only seasonably. Most of the land is unmanaged forest or woodlots.

In our study, 2, 5 and 10 year old mine soils forming from 3 different types of parent material (sandstone, shale or mixed) of the New River formation of the Pennsylvanian system in southern W. Va. were sampled to determine if pedogenesis could be observed to a significant degree in a 10 year period. Mine sites which had been topsoiled and 3 soil series which comprise most of the immediate study region were also sampled for comparison.

The properties of any ecosystem are a function of three factors. First, the basis of comparison can begin with the assemblage of properties at Time Zero. For the mine soils, this would be the production of highly fractured parent material and the creation of new landforms, often having gentler relief than the natural terrain. Second, the external flux potentials, such as climate and biotic factors, make their mark upon the assembled properties. All mine soils sampled were under fairly similar vegetation, consisting of a permanent sod cover and occasionally including a few small trees (locust or pine) or shrubs (autumn olive). The study area is characterized by a humid, continental climate with sharp seasonal and diurnal temperature fluxuations. Third, the effects of this flux on the initial materials will depend on the age of the ecosystem. Time is an anomolous factor, having no influence in itself, but governing the influence of the other factors on the soil until an apparent dynamic steady state is achieved (Stevens and Walker, 1970).

Although no dynamic steady state has been achieved, 10 years is an adequate period of time to observe many pedogenetic changes in these mine soils. Within a 10 year period, substantial horizonation develops in the mine soils, and age causes these horizons to thicken. The 10 year old sites were not as well developed as the natural soils in the region, which might be expected because of their extreme youth.

The 10 year old mine soils exhibited several properties which indicated an increase in organic matter over the 2 and 5 year old mine soils. Organic matter determinations were unreliable due to the presence of coal in other carbon-rich rock fragments. Properties which suggest an organic matter increase in the 10 year old mine soils included generally darker or redder hues in their A horizons, an increase in the average percentage of water-stable aggregates, and more titratable acidity and aluminum. These properties were even more pronounced in the natural soils. The values for titratable acidity and aluminum, due to the methods used, may indicate the presence of more pH dependent charge, including that attributable to organic matter.

The mine soils were lower in titratable acidity and aluminum than the natural soils, and had higher values for pH, calcium, magnesium and base saturation. Cation exchange capacity for A horizons was nearly equal, although it was higher in the subsurface horizons of the mine soils than the natural soils. Among the mine soils, the 5 year old soils were most fertile, while the 2 and 10 year old mine soils were approximately equal in fertility.

Potassium content of the mine soils was somewhat higher than that of the natural soils, but did not vary significantly with age of the mine soils. Potassium content was significantly higher in the mixed parent material, although this apparent anomoly may be due to K-rich facies being encountered more often in the 5 year old sampling areas.

Coarse fragment content was not significantly different among the mine soils, and surprisingly, the A horizons of the mine soils were not significantly different from the coarse fragment content of the A horizons of the natural soils.

Mottles occurred more frequently in the 10 year old mine soils than in either the 2 or 5 year old mine soils or the natural soils. Their high values and chromas indicate these mottles are not the result of impeded drainage, but rather the result of weathered rock fragments.

Structure within the pedons increased with age somewhat, but was superior in the natural soils and was dependent upon depth in these older soils. The percentage of water stable aggregates increased significantly with age in the mine soils, but these values were far below those observed in the A horizons of the natural soils.

Infiltration and moisture holding capacity of the mine soils improved with age, perhaps due to the presence of more organic matter. The moisture held by the mine soils at the permanent wilting point (15 ATM) was dependent upon parent material, being highest in the soils from clay-bearing shale and mixed parent material.

No mineralogical changes were observed in the 10 year old mine soils, although proper conditions exist in some of the mine soils for genesis of kaolins and smectites. Certain species of each of these were found in samples from each age and parent material group.

All three topsoiled sites studied were 2 years or less in age, and their sola thickness, horizonation and structure resembled those of the 2 year old non-topsoiled sites. However, having been derived from the natural soils of the region, many of the properties of the topsoiled sites are intermediate between the natural soils and the mine soils as a group. This is due to the mixing of relatively unweathered subsoil material and saprolite with the weathered surface horizons of the natural soils during stockpiling and post-mining regrading and reclamation. These properties include soil color, certain particle size fractions and most chemical properties.

Textural classification did not vary with age as much as with parent material type. Sandstones gave rise to sandy loam soils, and shales generally produced clay and silt loam soils. Slight increases in clay were observed with age in the subsurface horizons, along with slight decreases in sand and silt, indicating some weathering and illuviation have taken place. Most mine soil horizons of all 3 age groups could be classified as loams. Topsoiled sites and the A horizons of the natural soils were generally silt loams, while the subsurface horizons of the natural soils showing substantial illuviation were silty clay loams.

Taxonomic classification of the mine soils proved difficult, whether by standard USDA nomenclature (Soil Survey Staff, 1975) or by classification systems designed specifically for mine soils (Sencindiver, 1977). Classification by Soil Taxonomy resulted in all mine soils being classified as Entisols, unless arbitrary depth requirements imposed by this system are waived. With this exemption, the mine soils progressed with age from Entisols to Inceptisols.

As a result of this study, we feel the following conclusions are evident:

1) Pedogenetic processes can be observed within a 10 year period.

2) Mine soils up to at least 10 years of age are more fertile in terms of those elements measured than naturally occurring soils of this study area.

3) Five year old mine soils are more fertile than either 2 or 10 year old mine soils, apparently due to the weathering of and release of bases of highly fractured rock, which is depleted by the time the soil is 10 years old.

4) Pedogenetic development with time results in increases in percentage water-stable aggregates, infiltration and moisture holding capacity.

5) The coarse fragment content of the mine soils' A horizons was not significantly different than that of the natural soils' A horizons. Coarse fragments were few in the B horizons of the natural soils.

6) Ten years is not long enough to cause substantial changes in the textural classification of these soils, although slight increases in clay were observed with age in the subsurface horizons.

Surface mining is an interim land use which leaves the land in a highly altered state. Most surface mined land in Appalachia is returned to its pre-mining land use, the economic returns of which will require 100 to 1000 years to offset the initial costs of reclamation (Wahlquist, 1976). Identification of key pedogenetic factors on these lands will aid in predicting the type of soil that will be found on these areas in the future and identify alternative land uses that will provide greater economic returns.

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APPENDIX I

Profile Descriptions

Site: 2-A
Date sampled: 8/30/78
Rock type: Tan, fine-grained, micaceous sandstone
Location: Garden Grounds, W. Va., Prince quadrangle; 37°52'29"-81°06'55"
Described by: Sweeney

Pedon

A 0-7 cm; brown-dark brown (10YR 4/3)[1] sandy loam; structureless, single-grained; loose; 33.9%[2] sandstone fragments, 2-40 mm; 5%[3] coal fragments; common fibrous roots; moist;[4] clear, wavy boundary.

C 7^{+} cm; very hard tan and gray sandstone.

NOTES:

Position: Bench Distance from highwall: 6 meters
Vegetation: Fescue (moderate), ryegrass (sparse)
Slope: 2% east; nearly level; a few nearby wet spots
Company and permit: Fayette Coal and Land Co.; 186-76
Date mining completed: September, 1977

Rock type determined from immediately adjacent site, as highwall has been regraded to approximate original contour on this site.

[1] All colors in this and the following descriptions are for moist soils.

[2] Coarse fragment percentages are by weight.

[3] Coal and slag were estimated visually.

[4] Expression of field moisture status at the time of description.

Site: 2-B
Date sampled: 9/7/78
Rock type: Light brown-light gray, blocky structure, sandstone; light gray argillaceous shale, weathering to light orange-brown (ferruginous)
Location: Basin, W. Va.; Odd quadrangle; 37°31'-81°14'
Described by: Sweeney

Pedon

A 0-1 cm; olive brown (2.5 Y 4/4) sandy loam; structureless, single grained; loose; 19.2% sandstone and shale fragments, 2-8 mm; common fine roots; moist; abrupt, smooth boundary.

AC 1-15 cm; yellowish brown (10 YR 5/6) loam; structureless, massive; loose; 23.9% sandstone and shale fragments, 2-50 mm; 10% coal fragments; common fibrous roots; moist to dry; abrupt, irregular boundary.

C 15^{+} cm; hard, light brown sandstone fragments, and dark gray, easily carved shale.

NOTES:

Position: Bench Distance from highwall: 12 meters
Vegetation: Fescue (moderate), ryegrass (moderate)
Slope 1%; level
Company and permit: Hawley Coal Mining Corp., 222-72
Date mining completed: August, 1977

Site: 2-C
Date sampled: 9/8/78
Rock type: Buff, fine grained, blocky structure sandstone
Location: Lanark, W. Va.; Beckley quadrangle; 37°49'42"-81°09'46"
Described by: Sweeney

Pedon

A 0-14 cm; yellowish brown (10 YR 5/8), mottled with yellow (10 YR 7/8, f2d) sandy loam; weak, very fine crumb structure; 15.8% sandstone fragments, 2-30 mm; common fibrous roots; moist; abrupt, wavy boundary.

C 14^+ cm; moderately weathered yellowish orange sandstone fragments

NOTES:

Position: Bench Distance from highwall: 25 meters
Vegetation: Fescue (heavy), red clover (heavy)
Slope: 1%; level
Company and permit: Laco, Inc.; 48-77
Date mining completed: September, 1977

Site: 2-D
Date sampled: 9/6/78
Rock type: Tan, micaceous, pillow structure sandstone, and thin bedded, argillaceous shale, light brown with dark streaks.
Location: Slab Fork, W. Va.; Lester quadrangle; 37°40'34"-81°19'16"
Described by: Sweeney

Pedon

A 0-7.5 cm; olive brown (2.5 Y 4/4) loam; moderate very fine crumb structure; very friable; 42.7% sandstone and shale fragments, 2-30 mm; common roots to 4 mm diameter; moist; abrupt, smooth boundary.

AC 7.5-13 cm; light olive brown (2.5 Y 5/4) loam; weak very fine granular structure; very friable; 32.6% sandstone and shale fragments, 2-25 mm; few roots; moist, abrupt, irregular boundary.

C 13^+ cm; easily carved dark gray shale, and hard, orangish-brown sandstone.

NOTES:

Position: Bench Distance from highwall: 30 meters
Vegetation: Serricea (moderate), fescue (moderate)
Slope: 6% northeast; gently sloping
Company and permit: Anderson and Anderson Contractors, Inc.; 13-75
Date mining completed: October, 1976

Average soil pH before mining - 5.0

Site: 2-E
Date sampled: 9/7/78
Rock type: Buff, thin bedded and light gray, blocky structure sandstone
Location: Basin, W. Va.; Odd quadrangle; 37°30'-81°15'
Described by: Sweeney

Pedon

A 0-15 cm; olive brown (2.5 Y 4/4) sandy loam; weak very fine crumb structure; 6% sandstone fragments, 2-10 mm; common fine roots; moist; abrupt, smooth boundary.

AC 1.5-7 cm; dark grayish brown (2.5 Y 4/2) loam; structureless, massive; loose; 19.1% sandstone gragments, 2-45 mm; few fine roots; moist; abrupt, smooth boundary.

C 7^{+} cm; hard, light brown sandstone fragments.

NOTES:

Position: Bench Distance from highwall: 25 meters
Vegetation: Serricea (moderate) Slope: 12% south, moderately sloping
Company and permit: Hawley Coal Mining Corp.; 93-72
Date mining completed: August, 1977

Two large, excellent stands of corn occupy a section of this site.

Site: 2-F
Date sampled: 10/17/78
Rock type: Light gray; argillaceous shale; minor amounts of sandstone
Location: Eccles, W. Va.; Eccles quadrangle; 37°45'21"-81°17'00"
Described by: Sweeney

Pedon

A 0-10 cm; olive brown (2.5 Y 4/4) mottled with reddish yellow (7.5 YR 6/8, c3d) and dark brown (10 YR 3/3, f2p) loam; structureless, single grained; 26.3% sandstone and shale fragments, 2-30 mm; 20% coal fragments; 5% "slag" material; few fibrous roots; moist; abrupt, smooth boundary.

C 10^{+} cm; hard light gray shale and hard brown sandstone

NOTES:

Position: Bench Distance from highwall: 10 meters
Vegetation: Fescue (sparse), bluegrass (sparse), white pine (sparse)
Slope: 15% west; moderately sloping
Company and permit: Tamroy Mining Co.; 195-74
Date mining completed: February, 1976

Rock type determined from coarse fragments; slope due to regrading highwall to approximate original contour.

Site: 2-G
Date sampled: 8/31/78
Rock Type: Dark gray argillaceous shale, weathering to brown
Location: Whitby, W. Va.; Crab Orchard quadrangle; 37°40'20"-81°08'38"
Described by: Sweeney

Pedon

A 0-4.5 cm; brown-dark brown (10 YR 4/3) loam; weak very fine crumb; slightly sticky, slightly plastic; 44.7% shale fragments, 2-20 mm; 10% coal fragments; common roots; wet; abrupt, smooth boundary.

IIC 4.5-8 cm; strong brown (7.5 YR 5/6) clay loam; structureless, massive; slightly sticky, slightly plastic; 29.8% shale fragments, 2-30 mm; 10% coal fragments; common fine roots; wet; abrupt, wavy boundary.

IIIC 8^+ cm; dark gray shale fragments, weathering to tan and brown.

NOTES:

Position: Bench Distance from highwall: 10 meters
Vegetation: Fescue (moderate) Slope: 1%; level
Company and permit: Sterling Smokeless Coal Co.; 83-73
Date mining completed: December, 1976

Site: 2-H
Date sampled: 9/1/78
Rock type: Thin, irregularly bedded light gray shale, weathering to brown
Location: Odd, W. Va.; Odd quadrangle; 37°35'-81°15'
Described by: Sweeney

Pedon

A 0-10 cm; yellowish brown (10 YR 5/6) loam; weak very fine crumb structure; very friable; 31.6% shale fragments, 2-20 mm; common fibrous roots; moist; gradual, irregular boundary.

C 10^+ cm; easily carved dark gray shale.

NOTES:

Position: Bench Distance from highwall: 6 meters
Vegetation: Fescue (moderate) Slope: 9% north, gently sloping
Company and permit: Sterling Smokeless Coal Co., 5-73
Date mining completed: Information not readily available
Micro-terrain very rugged; many small mounds, 8-12 cm high.

Site: 2-J
Date sampled: 8/31/78
Rock type: Tan, micaceous blocky sandstone and dark gray to black, thin bedded, easily parted shale.
Location: Whitby, W. Va.; Crab Orchard quadrangle; 37° 37'51"-81° 11'03"
Described by: Sweeney

Pedon

A 0-11 cm; dark grayish brown (2.5 Y 4/2) loam; weak very fine granular structure; very friable; 31.4% sandstone and shale fragments, 2-60 mm; 2% coal fragments; common fibrous roots; moist; abrupt, smooth boundary.

C 11^+ cm; hard, fragmented sandstone and shale.

NOTES:

Position: Bench Distance from highwall: 15 meters
Vegetation: Fescue (moderate)
Slope: 2% east; slightly sloping
Company and permit: Sterling Smokeless Coal Co.; 118-76
Date mining completed: Information not readily available

<u>Site</u>: 5-A
<u>Date sampled</u>: 8/9/78
<u>Rock type</u>: Buff, fine-grained massive sandstone
<u>Location:</u> Slab Ford, W. Va.; Lester quadrangle; 37°41'-81°20'
<u>Described by</u>: Sweeney

Pedon

A 0-4 cm; dark yellowish brown (10 YR 4/4) loam; weak fine crumb structure; very friable; 36.8% sandstone fragments, 2-15 mm; many fine roots; moist; abrupt, wavy boundary.

B 4-10.5 cm; yellowish brown (10 YR 5/8) loam; weak fine crumb structure; very friable; 43.5% sandstone fragments, 5-20 mm; many fine roots; moist; abrupt, smooth boundary.

C 10.5^{+} cm; yellowish brown (10 YR 5/6) loam; moderate fine crumb structure; very friable; 46.3% sandstone fragments, 5-40 mm; common fibrous roots; moist.

NOTES:

Position: Bench Distance from highwall: 12 meters
Vegetation: Serricea (heavy), black locust (moderate)
Slope: 1%; level; a few wet spots nearby
Company and permit: Anderson and Anderson Contractors, Inc; 20-71
Date mining completed: November, 1972

Site: 5-B
Date sampled: 8/9/78
Rock type: Light brown pillow structure sandstone and thin layered ferruginous shale with travertine coating.
Location: Princewick, W. Va.; Lester quadrangle; 37°40'-81°16'
Described by: Sweeney

Pedon

A 0-2 cm; very dark gray (5 Y 3/1) loam; weak very fine granular structure; very friable; 25.6% sandstone and shale fragments, 2-10 mm; many fine roots; moist; abrupt, wavy boundary.

B 2-8 cm; very dark brown (2.5 Y 3/2) loam; weak very fine granular structure; very friable; 44% sandstone and shale fragments, 5-30 mm; common fine roots; moist; abrupt, smooth boundary.

C 8^{+} cm; hard, yellowish sandstone and tan, easily carved shale.

NOTES:

Position: Bench Distance from highwall: 6 meters
Vegetation: Serricea (heavy), black locust (sparse)
Slope: 1%, level
Company and permit: Oscar Vecellio, Inc.; 361-70
Date mining completed: August, 1971

Adjacent to site 5-C.

Site: 5-C
Date sampled: 8/9/78
Rock type: Grayish brown, pillow structure sandstone, and tan to brown, thin bedded sandstone
Location: Princewick, W. Va.; Lester quadrangle; 37°40'-81°15'45"
Described by: Sweeney

Pedon

A 0-1.5 cm; very dark grayish brown (10 YR 3/2) sandy loam; moderate fine angular blocky structure; very friable; 26.5% sandstone fragments, 2-8 mm; many fine roots; moist; abrupt, smooth boundary.

AC 1.5 - 8 cm; dark yellowish brown (10 YR 4/4) sandy loam; weak very fine crumb structure; very friable; 51.6% sandstone fragments, 5-30 mm; common fine roots; moist, clear, irregular boundary.

C 8^{+} cm; very hard sandstone fragments

NOTES:

Position: Bench Distance from highwall: 25 meters
Vegetation: Serricea (moderate)
Slope: 8% north, gently sloping
Company and permit: Oscar Vecellio, Inc.; 2-72
Date mining completed: October, 1972
Adjacent to site 5-B.

Site: 5-D
Date sampled: 9/1/78
Rock type: Light gray, evenly bedded shale, weathering to light brown and red
Location: Slab Fork, W. Va.; Lester quadrangle; 37°40'20"-81°18'41"
Described by: Sweeney

Pedon

A 0-6 cm; dark yellowish brown (10 YR 4/4), mottled with red (2.5 YR 4/8, f2p) and dark gray (5 Y 4/1 f2p) loam; moderate fine crumb structure; very friable; 36.5% shale fragments, 2-60 mm; 15% coal fragments; common fibrous roots; moist; abrupt, smooth boundary.

AC 6-15 cm; dark yellowish brown (10 YR 4/4), mottled with red (2.5 YR 4/8, f2p) and dark gray (5 Y 4/1, f2p) loam; structureless, massive; loose; 32.3% shale fragments, 2-45 mm; 10% coal fragments; few fibrous roots; moist; abrupt, wavy boundary.

C 15^+ cm; hard, dark gray shale; a few sandstone fragments.

NOTES:

Position: Bench Distance from highwall: 30 meters
Vegetation: Fescue (moderate), serricea (sparse)
Slope: 3% west; gently sloping
Company and permit: Anderson and Anderson Contractors, Inc. 228-73
Date mining completed: September, 1974

Site: 5-E
Date sampled: 8/16/78
Rock type: Thin bedded light brown sandstone, and light gray to tan, massive sandstone; small tongue of dark gray shale
Location: Corinne, W. Va.; Rhodell quadrangle; 37°34'-81°21'
Described by: Sweeney

Pedon

01 1-0 cm; light brown leaves and straw

A 0-2 cm; olive brown (2.5 Y 4/4) sandy loam; weak very fine crumb structure; very friable; 25.8% sandstone fragments, 2-5 mm; many fine roots; moist; abrupt, wavy boundary.

B 2-6 cm; dark yellowish brown (10 YR 4/4) sandy loam; weak very fine crumb structure; very friable; 29.2% sandstone fragments, 2-25 mm; many fine roots; moist; abrupt, wavy boundary.

C 6^+ cm; light yellow to orange sandstone; a small amount of weathered light brown shale.

NOTES:

Position: Bench Distance from highwall: 12 meters
Vegetation: Orchardgrass (heavy)
Slope: 3% west; gently sloping
Company and permit: Perry and Hylton, Inc.; 155-70
Date mining completed: July, 1971
Several paved streets, eight houses and airplane landing strip now occupy this site.

Site: 5-F
Date sampled: 8/17/78
Rock type: Tan to dark brown ferruginous, argillaceous shale; bedding is thin, tilted and in some places discontinuous
Location: Whitby, W. Va.; Crab Orchard quadrangle; 37°40'-81°10'
Described by: Sweeney

Pedon

A 0-2 cm; olive brown (2.5 Y 4/4) sandy clay loam; moderate fine subangular blocky structure; very friable; 40.2% shale fragments, 2-10 mm; common fibrous roots; moist; clear, smooth boundary.

AC 2-6 cm; dark yellowish brown (10 YR 4/4) clay loam; weak fine subangular blocky structure; very friable; 49.9% shale fragments, 2-25 mm; common fibrous roots; moist to dry; clear, smooth boundary.

C 6^{+} cm; dark gray to brown hard shale fragments.

NOTES:

Position: Bench Distance from highwall: 50 meters
Vegetation: Serricea (heavy); black locust (sparse)
Slope: 15% southeast; moderately sloping
Company and permit: Sterling Smokeless Coal Co.; 329-71
Date mining completed: November, 1973
Slope due to highwall reduction.

Site: 5-G
Date sampled: 8/17/78
Rock type: Dark gray to brown ferruginous, argillaceous, thin bedded shale
Location: Fireco, W. Va.; Crab Orchard quadrangle; 37°40'-81°10'
Described by: Sweeney

Pedon

A 0-2 cm; dark yellowish brown (10 YR 4/4) loam, moderate very fine crumb structure; very friable; 16.6% shale fragments, 2-12 mm; many fibrous roots; moist; clear, wavy boundary.

B 2-7 cm; dark brown (10 YR 3/3) silt loam; moderate very fine crumb structure; very friable; 45.1% shale fragments, 2-20 mm; common fibrous roots; moist; gradual, smooth boundary.

C 7^+ cm; dark gray, easily carved shale, weathering to reddish brown.

NOTES:

Position: Bench Distance from highwall: 30 meters
Vegetation: Serricea (heavy), black locust (sparse), white pine (sparse)
Slope: 12% north, gently sloping
Company and permit: Sterling Smokeless Coal Co.; 359-70 (converted to 1971 law)
Date mining completed: Information not readily available
Slope on this site due to highwall reduction.

Site: 5-H
Date sampled: 8/10/78
Rock type: Massive, tan sandstone and thin bedded, gray argillaceous shale
Location: Josephine, W. Va.; Odd quadrangle; 37°36'46"-81°14'28"
Described by: Sweeney

Pedon

O1 1-0 cm; brown leaves and straw

A 0-2.5 cm; very dark grayish brown (10 YR 3/2) loam; weak very fine crumb structure; very friable; 49.3% sandstone and shale fragments, 2-12 mm; many roots to 25 mm diameter; moist; abrupt, smooth boundary.

B 2.5 - 8.5 cm; dark yellowish brown (10 YR 4/4) loam; weak very fine crumb structure; very friable; 48.9% sandstone and shale fragments, 2-25 mm; common roots 10 mm diameter; clear, irregular boundary.

C 8.5^+ cm; large fragments of hard sandstone and gray shale.

NOTES:

Position: Bench Distance from highwall: 4 meters
Vegetation: Serricea (heavy), black locust (moderate)
Slope: 1%; level
Company and permit: Sterling Smokeless Coal Co.; 204-73
Date mining completed: August, 1974

Site: 5-J
Date sampled: 8/17/78
Rock type: Massive tan sandstone and light gray argillaceous shale
Location: Pluto, W. Va.; Shady Spring quadrangle; 37°45'-81°05'
Described by: Sweeney

Pedon

A 0-2.5 cm; very dark grayish brown (2.5 Y 3/2) silt loam; moderate medium angular blocky structure; friable; 59.8% sandstone and shale fragments, 2-8 mm; many fibrous roots; moist; abrupt, smooth boundary.

B 2.5-8 cm; very dark grayish brown (2.5 Y 3/2) silty clay loam; weak fine subangular blocky structure; very friable, 46.9% sandstone and shale fragments, 2-40 mm; common fibrous roots; moist to dry; clear, wavy boundary.

C 8^+ cm; hard, orangish brown sandstone and hard, black to gray shale.

NOTES:

Position: Bench Distance from highwall: 7 meters
Vegetation: Serricea (heavy), fescue (moderate), black locust (sparse)
Slope: 3% north; gently sloping
Company and permit: White Ridge Coal Co.; 318-71
Date mining completed: November, 1974

Site: 10-A
Date sampled: 8/8/78
Rock type: Ferruginous, easily parted, brown sublithic and gray sandstone, and black to gray argillaceous shale, easily parted.
Location: White Oak Mountain, W. Va.; Hinton quadrangle; 37°40'-81°00'
Described by: Sweeney

Pedon

O1 2-0 cm; brown leaves and straw

A 0-3 cm; yellowish brown (lo YR 5/4) loam; moderate fine angular blocky structure; very friable; 37.7% sandstone and shale fragments, 2-5 mm; common roots to 5 mm diameter; moist; abrupt, smooth boundary.

B2 3-18 cm; yellowish brown (10 YR 5/4), mottled with strong brown (7.5 YR 5/8, c2d) loam; moderate fine crumb structure; very friable; 47.4% sandstone and shale fragments, 2-30 mm; few fine roots; moist; abrupt, smooth boundary.

C 18^+ cm; hard brown sandstone and gray shale fragments.

NOTES:

Position: Bench Distance from highwall: 60 meters
Vegetation: Serricea (moderate) Slope: 5% west; gently sloping
Company and permit: Raleigh Empire Coal Corp.; 304-68
Date mining completed: August, 1970
Adjacent area being lightly grazed; also near vegetable garden study (USDA-SEA).

Site: 10-B
Date sampled: 8/8/78
Rock type: Dark gray to black ferruginous, massive sandy shale; fissile where weathered.
Location: White Oak Mountain, West Virginia; Hinton quadrangle; 37°40'-81°02'
Described by: Sweeney

Pedon

01 1-0 cm; dark brown leaves and straw

A 0-3 cm; very dark grayish brown (2.5 Y 3/2) mottled with reddish yellow (7.5 YR 6/8, f2d) clay loam; moderate medium subangular blocky structure; very friable; 38.4% shale fragments, 2-8 mm; many fine roots; moist; abrupt, smooth boundary.

B 3-11 cm; dark grayish brown (2.5 Y 4/2) mottled with reddish yellow (7.5 YR 6/8), c3d) clay loam; moderate fine subangular blocky structure; very friable; 30.5% shale fragments, 2-8 mm; 15% coal fragments; common fine roots; moist; abrupt, smooth boundary.

BC 11-16 cm; very dark grayish brown (10 YR 3/2), mottled with light olive brown (2.5 Y 5/6, f2d) and red (10 R 4/8, f2d) clay loam; weak very fine crumb structure; friable; 33% shale fragments, 5-15 mm; few fine roots; moist; abrupt, wavy boundary.

C 16^{+} cm; yellow to gray shale, easily carved

NOTES:

Position: Bench Distance from highwall: 8 meters
Vegetation: Fescue (heavy), serricea (heavy), autumn olive (moderate), white pine (sparse)
Slope: 1%; nearly level
Company and permit: Raleigh Empire Coal Corp.; 99-69
Date mining completed: October, 1970

Site: 10-C
Date sampled: 7/19/78
Rock type: Light brown massive sandstone and gray, argillaceous, easily carved shale
Location: Odd, W. Va.; Odd quadrangle; 37°35'-81°10'
Described by: Sweeney, Kirks

Pedon

01 4-0 cm; brown leaves and straw

A 0-4 cm; very dark grayish brown (10 YR 3/2) mottled with reddish yellow (7.5 YR 6/8, f3p) loam; medium very find crumb; very friable; 6.8%* sandstone and shale fragments, 2-5 mm; 10% coal fragments; 5% "slag" material; common fine roots; moist; abrupt; smooth boundary.

B21 4-6.5 cm; very dark grayish brown (10 YR 3/2) mottled with reddish yellow (7.5 YR 6/8, f2d) silty clay loam; moderate fine subangular blocky structure; friable; 0.18%* sandstone and shale fragments, 2-5 mm; 20% coal fragments; 10% "slag" material; few fibrous roots; moist; abrupt, smooth boundary.

B22 6.5-11 cm; dark gray (5 Y 4/1) silty clay; moderate fine subangular blocky structure; friable; 0.38%* sandstone and shale fragments, 2-8 mm; 20% coal fragments; 10% "slag" material; few fibrous roots; moist; abrupt, wavy boundary.

C 11^{+} cm; black (5 Y 2.5/2) silty clay; moderate medium angular blocky structure; firm; 0.68%* sandstone and shale fragments, mixed, 5-15 mm; 5% coal fragments; very few fibrous roots; moist.

NOTES:

Position: Bench Distance from highwall: 12 meters
Vegetation: Serricea (heavy), white pine (sparse)
Slope: 2% south; nearly level
Company and permit: Sterling Smokeless Coal Co.; 86-67
Date mining completed: February, 1968

* A larger volume of coarse fragments were observed in the field, but most broke down easily in Calgon solution.

Site: 10-D
Date sampled: 7/19/78
Rock type: Light brown, block structure, ferruginous sandstone
Location: Odd, W. Va.; Odd quadrangle; 37°34'-81°14'
Described by: Sweeney, Kirks

Pedon

01 3-0 cm; tan to strong brown leaves and straw

A 0-4.5 cm; very dark gray (10 YR 3/1) sandy loam; moderate fine subangular blocky structure; very friable; 46.4% sandstone fragments, 2-10 mm; 5% coal fragments; 5% "slag" material; many roots to 7 mm diameter; moist; abrupt, smooth boundary.

B2 4.5-11 cm; dark olive gray (5 Y 3/2) loam; weak fine subangular blocky structure; very friable; 30.1% sandstone fragments, 2-20 mm; 5% coal fragments; 25% "slag" material (banded); common roots to 7 mm diameter; moist; abrupt, wavy boundary.

C 11^{+} cm; grayish brown (10 YR 5/2) mottled with strong brown (7.5 YR 5/8, m3p) silt loam; structureless, massive; firm; 17.6% sandstone fragments, 10-20 mm; few fine roots; moist; abrupt, wavy boundary.

NOTES:

Position: Bench Distance from highwall: 4 meters
Vegetation: Serricea (heavy) Slope: 3% south; nearly level
Company and permit: Sterling Smokeless Coal Co.; 51-68
Date mining completed: Information not readily available

Site: 10-E
Date sampled: 7/18/78
Rock type: Massive light brown ferruginous sandstone
Location: Amigo, W. Va.; Rhodell quadrangle; 37°35'-81°19'
Described by: Sweeney, Kirks

Pedon

A 0-6 cm; reddish brown (5 YR 4/3) mottled with reddish yellow (7.5 YR 6/8, f2p) silt loam; moderate very fine crumb structure; friable; 8.4% sandstone fragments, 205 mm; common fibrous roots; moist; gradual, wavy boundary.

B21 6-10.5 cm; dark grayish brown (2.5 Y 4/2) mottled with light brownish gray (2.5 Y 6/2, m3p) silt loam; weak very fine crumb structure; very friable; 10.1% sandstone fragments, 2-10 mm; 5% coal fragments; common fibrous roots; moist, gradual, wavy boundary.

B22 10.5-14 cm; very dark grayish brown (2.5 Y 3/2) silt loam; weak very fine crumb structure; very friable; 25.9% sandstone fragments, 2-15 mm; 10% coal fragments; few fibrous roots; moist; gradual, wavy boundary.

C 14^{+} cm; dark brown-brown (10 YR 4/3) mottled with reddish yellow (7.5 YR 6/8, m3p) silt loam; weak very fine granular structure; very friable; 14.9% sandstone fragments, 10-35 mm; few fibrous roots; moist.

NOTES:

Position: Bench Distance from highwall: 5 meters
Vegetation: Serricea (heavy), black locust (moderate)
Slope: 2%, nearly level, some standing water nearer to highwall
Company and permit: Amigo Smokeless Coal Co.; 94-67
Date mining completed: February, 1969
1970 - average soil pH - 5.0

Site: 10-F
Date sampled: 7/18/78
Rock type: Tan to strong brown (ferruginous) massive sandstone
Location: Stephenson, W. Va.; Rhodell quadrangle; 37° 55'-81° 20'
Described by: Sweeney, Kirk

Pedon

01	2.5-0 cm; strong brown leaves and straw
A	0-3 cm; yellowish brown (10 YR 5/6) sandy loam; moderate fine crumb structure; very friable; 68% sandstone fragments, 1-5 mm; many fine roots; moist; abrupt, smooth boundary.
B2	3-7 cm; light olive brown (2.5 Y 5/6) sandy loam; moderate fine subangular blocky structure; very friable; 36.2% sandstone fragments, 5-7 mm; 5% "slag" material; common fibrous roots; moist; clear, smooth boundary.
C	7.5-10$^+$ cm; brownish yellow (10 YR 6/8) sandy loam; weak medium subangular blocky structure; very friable; 50% sandstone fragments, 8-20 mm; common fibrous roots; moist.

NOTES:

Position: Bench Distance from highwall: 30 meters
Vegetation: Serricea (moderate), black locust (moderate)
Slope: 2% east, nearly level
Company and permit: Amigo Smokeless Coal Co.; 30-69
Date mining completed: May, 1970

Site: 10-G
Date sampled: 9/18/78
Rock type: Tan blocky structure sandstone, and light gray argillaceous shale
Location: Abraham, W. Va.; Layland quadrangle; 37°50'-81°00'
Described by: Sweeney, Emerson

Pedon

01 1-0 cm; brown leaves and straw

A 0-2.5 cm; very dark grayish brown (10 YR 3/2) loam; moderate medium subangular blocky structure; very friable; 50% sandstone and shale fragments, 2-40 mm; 5% coal fragments; common fine roots; moist; abrupt, smooth boundary.

B 2.5-8 cm; dark brown (10 YR 3/3) loam; moderate fine crumb structure; very friable; 54.3% sandstone and shale coarse fragments, 2-30 mm; common fine roots; moist; abrupt, wavy boundary.

C 8^{+} cm; hard fragmented dark gray shale and moderately weathered yellowish orange sandstone.

NOTES:

Position: Bench Distance from highwall: 8 meters
Vegetation: Serricea (moderate), black locust (sparse), autumn olive (sparse), white pine (sparse) Slope: 1%, level
Company and permit: Royal Sparks Mining Co.; 152-68
Date mining completed: Information not readily available

Site: 10-H
Date sampled: 6/26/78
Rock type: Calcareous block shale, travertine coated outcrops, with interbedded black, ferruginous, carbonaceous shale
Location: Hotchkiss, W. Va.; Lester quadrangle; 37°40'-81°22'
Described by: Sweeney, Amos, Howard

Pedon

O1 2-0 cm; brown leaves and straw

A 0-3 cm; very dark grayish brown (10 YR 3/2) loam; moderate very fine-fine granular structure; very friable; 48.9% shale fragments, 2-10 mm; 2% soil inclusion (strong brown); many fibrous roots; moist; abrupt, smooth boundary.

B 3-23 cm; very dark gray-black (10 YR 2/5/1) loam; moderate very fine-fine subangular blocky structure; friable; 53.4% shale fragments, 5-20 mm; 2% soil inclusion (strong brown); common fibrous roots; moist; abrupt, wavy boundary.

C 23-43$^+$ cm; easily carved ferruginous gray shale.

NOTES:

Position: Bench Distance from highwall: 16 meters
Vegetation: Serricea (moderate), black locust (moderate), weeping lovegrass (sparse)
Slope: 3% east, gently sloping
Company and permit: Sterling Smokeless Coal Co.; 60-68
Date mining completed: September, 1968

Site: 10-J
Date sampled: 6/26/78
Rock type: Buff, argillaceous shale; moderately indurated; minor sandstone tongue
Location: Odd, W. Va.; Amigo-Rhodell quadrangles; 37°36'-81°18'
Described by: Sweeney, Amos, Howard

Pedon

01 2.5-0 cm; brown leaves and straw

A 0-2.5 cm; very dark gray (5 YR 3/1) silt loam; weak very fine granular structure; very friable; 15.7% shale fragments, 2-10 mm; common fine roots; moist; abrupt, smooth boundary.

B21 2.5-13.5 cm; black (5 YR 2.5/1) silt loam; moderate-strong fine-medium subangular blocky-angular blocky structure; hard, 16.9% shale fragments, 2-18 mm; 15% soil inclusion (light yellowish brown); common fine roots; dry; abrupt, smooth boundary.

B22 13.5-21 cm; dark gray (5 YR 4/1) silt loam; moderate-strong fine-medium subangular blocky structure; firm; 22% shale fragments, 2-18 mm; 15% soil inclusion (light yellowish brown); common fine roots; abrupt, wavy boundary.

C $21-30^{+}$ cm; mixed shale, sandstone and heterogenous soil material.

NOTES:

Position: Bench Distance from highwall: 15 meters
Vegetation: Serricea (moderate), black locust (moderate)
Slope: 2% east, nearly level
Company and permit: Vecellio and Grogan, Inc.; 10-68
Date mining completed: December, 1970

Site: T-1 (Topsoiled)
Date sampled: 10/3/78
Location: Sullivan, W. Va.; Crab Orchard quadrangle; 37°43'55"-81°12'39"
Described by: Sweeney

Pedon

A 0-3 cm; yellowish brown (10 YR 5/6) silt loam; weak fine crumb; very friable; 20% sandstone and shale fragments, 2-18 mm; common fibrous roots; moist; abrupt, smooth boundary.

AC 3-11 cm; brownish yellow (10 YR 6/8) silt loam; strong medium subangular blocky structure; very friable; 53.6% sandstone and shale fragments, 2-100 mm; 15% soil inclusion (strong brown); common fibrous roots; moist to dry; abrupt, wavy boundary.

C 11^+ cm; saprolitic shale and sandstone; easily carved; large volume of coarse fragments.

NOTES:

Position: Upper terrace of mountain top removal
Vegetation: Bluegrass (heavy), clover (heavy), serricea (sparse)
Slope: 2% west; nearly level
Company and permit: Piney Creek Coal Co.; 238-74
Date mining completed: Still in progress on a section of this permit.

Site: T-2 (Topsoiled)
Date sampled: 10/3/78
Location: Sullivan, W. Va.; Crab Orchard quadrangle; 37°44'-81°12'
Described by: Sweeney

Pedon

A 0-18 cm; yellowish brown (10 YR 5/4) silt loam; structureless, single grained; loose; 28.9% sandstone and shale fragments, 2-50 mm; 15% soil inclusion (yellowish brown, silty clay); few roots; dry; abrupt, irregular boundary.

C 18^+ cm; hard sandstone and shale fragments.

NOTES:

Position: Upper terrace of mountain top removal
Vegetation: Fescue (sparse); clover (sparse); recently seeded
Slope: 1%; level
Company and permit: Piney Creek Coal Co.; 170-76
Date mining completed: May, 1978

Site: T-3 (Topsoiled)
Date sampled: 10/5/78
Location: Coal City, W. Va.; Coal City quadrangle; 37°42'08"-81°13'38"
Described by: Sweeney

Pedon

A 0-5.5 cm; dark yellowish brown (10 YR 4/4) mottled with strong brown (7.5 YR 5/8, f2d) loam; moderate fine crumb structure; very friable; 16% sandstone fragments, 2-15 mm; 15% coal fragments; 5% "slag" material; common fibrous roots; moist, abrupt, wavy boundary.

C 5.5^{+} cm; hard brown sandstone fragments.

NOTES:

Position: Upper terrace of mountain top removal
Vegetation: Bluegrass (moderate)
Slope: 3% south, nearly level
Company and permit: Sterling Smokeless Coal Co.; 92-75
Date mining completed: August, 1976

Currently the location of new Independence High School

Mapping unit DsF   Dekalb Series

Date sampled: 10/31/78
Rock type: Sandstone and shale parent material
Location: Crab Orchard, W. Va.; along haulroad to Piney Creek Coal Co. permit 238-74
Described by: Sweeney, Amos

Pedon

Ap   0-12 cm; dark grayish brown (10 YR 4/2) silt loam; weak very fine granular; very friable; 48.2% sandstone fragments, 5 mm - 25 cm; few fine roots; abrupt, smooth boundary.

B1   12-37 cm; brownish yellow (10 YR 6/6) loam; weak very fine - fine subangular blocky; firm; 24.5% sandstone fragments, 5-30 mm; few fine roots; clear, smooth boundary.

B21 37-66 cm; brownish yellow (10 YR 6/6) loam; moderate fine-medium subangular blocky; friable-firm; 11.2% sandstone fragments, 5-30 mm; thin discontinuous clay skins; few fine roots; gradual, smooth boundary.

B22t 66-86 cm; light yellowish brown-brownish yellow (10 YR 6/5) clay loam; moderate fine-medium subangular blocky structure; firm; 18% sandstone fragments, 5-30 mm; thin discontinuous clay skins; few fine roots; clear, smooth boundary.

C   86-109 cm; yellowish brown (10 YR 5/4) silty clay loam; 31% weathered reddish brown very fine sandstone fragments and shale; frequently finely banded with brown and red.

R $109\text{-}120^{+}$ cm; slightly weathered fragments of very fine sandstone and shale; weak red and brown; many internal manganese stainings and segregations.

NOTES:

Position: Side slope; 45 meters relief
Vegetation: Second growth oak
Slope: 36% west; steeply sloping

Mapping unit MkE Muskingum Series

Date sampled: 10/31/78
Location: Sophia, W. Va.; at intersection of Route 16 and 54
Rock type: Shale parent material
Described by: Sweeney, Amos

Pedon

Ap 0-12 cm; brown-dark brown (10 YR 4/3) mottled with strong brown (7.5 YR 5/4, f2f) silt loam; weak fine-medium granular and subangular blocky structure; friable; 25.3% shale fragments, 2-10 mm; a few small coal fragments to 5 mm diameter; common fine roots; abrupt, smooth boundary.

B1 12-21 cm; strong brown (7.5 YR 5/6) silt loam; moderate fine-medium subangular blocky structure; friable; 24% shale fragments, 2-50 mm; common fine roots to 10 mm diameter; clear, smooth boundary.

B2t 21-51 cm; strong brown (7.5 YR 5/6) silty clay loam; strong fine to coarse subangular blocky structure; firm; 31.8% shale fragments, 2-30 mm; common fine roots; clear, smooth boundary.

C 51-66 cm; varigated with reddish yellow-strong brown (7.5 YR 5.6/6) and light brown-reddish yellow (7.5 YR 6/5) silt loam; weak course blocky weathered shale fragments containing vesicular pores; 5% shale fragments, 2-40 mm; abrupt, smooth boundary.

R $66\text{-}87^{+}$ cm; slightly to moderately weathered shale; pale brown to brown.

NOTES:

Position: End of narrow ridge; 50 meters relief
Vegetation: Second growth oak and pine
Slope: 33%, southeast; steeply sloping

Mapping unit GiC   Gilpin Series

Date sampled: 10/31/78
Rock type: Shale parent material
Location: Sullivan, W. Va.; adjacent to surface mine permit 238-74, Piney Creek Coal Co.; area to be stripped
Described by: Sweeney, Amos

Pedon

Ap   0-18 cm; dark brown (10 YR 3/3) loam; moderate fine-very fine granular structure; friable; 3.2% sandstone and shale fragments, 3-25 mm; common fine roots to 30 mm diameter; abrupt, smooth boundary.

B1   18-35 cm; yellowish brown (10 YR 5/6) silt loam; moderate fine-medium subangular blocky structure; friable to firm; 2.3% shale fragments, 2-15 mm; few fine roots to 5 mm diameter; clear, smooth boundary.

B21t   35-58 cm; yellowish brown (10 YR 5/6) silty clay loam; strong fine to coarse subangular blocky structure; firm; 1% shale fragments, 1-50 mm; thin discontinuous clay skins, few fine roots; clear, smooth boundary.

B22t   58-75 cm; brownish yellow (10 YR 6/6) silty clay loam; strong medium coarse subangular blocky and angular blocky structure; very friable; 0.4% shale fragments, 2-50 mm; thin discontinuous clay skins; few fine roots; abrupt, smooth boundary.

C   75-82 cm; brownish yellow (10 YR 6/6) silty clay loam; moderate coarse subangular blocky structure; firm; 5% shale fragments, 2-5 mm; few fine roots running laterally along surface of R horizon; abrupt, smooth boundary

R   82-100^{+} cm; predominately weak red weatherd shale

NOTES:

Position: Along broad ridge; 100 meters relief
Vegetation: Second growth oak and pine
Slope: 4% west; gently sloping

APPENDIX II

Generalized Soil Profiles

AVERAGE SOIL PROFILE

2 Year Old Sites
(9 samples)

Horizon	Thickness	Color	Texture	Structure	Consistence	Coarse Fragments
	(cm)					(%)
A	6.3	10YR-2.5Y 4.2/4.2	loam	weak, very fine crumb	very friable	28.0
C	Below 6.3 cm; a heterogenous mix of partially weathered and unweathered rock, of various sizes and shape.					

AVERAGE SOIL PROFILE

5 Year Old Sites
(9 samples)

Horizon	Thickness (cm)	Color	Texture	Structure	Consistence	Coarse Fragments (%)
A	2.7	10YR-2.5Y 3.5/3	loam	weak-moderate, very fine crumb	very friable	35.2
B	5.8	10YR-2.5Y 3.8/3	loam	weak, very fine-fine crumb	very friable	43.5
C	Below 8.5 cm; a heterogenous mix of partially weathered and unweathered rock, of various sizes and shapes.					

AVERAGE SOIL PROFILE

10 Year Old Sites
(9 samples)

Horizon	Thickness (cm)	Color	Texture	Structure	Consistence	Coarse Fragments (%)
01	2					
A	3.5	7.5YR-10YR 3.5/2.5	loam	weak, very fine-fine subangular blocky	very friable	36.6
B2	7.7	10YR-2.5Y 3.6/2.2	silt loam	weak-moderate, fine crumb-subangular blocky	very friable	28.4
C	Below 11.2 cm; a heterogenous mix of partially weathered and unweathered rock, of various sizes and shapes.					

AVERAGE SOIL PROFILE

Topsoiled Sites
(3 samples)

Horizon	Thickness (cm)	Color	Texture	Structure	Consistence	Coarse Fragments (%)
A	11.5	10YR 4.7/4.7	silt loam	weak, fine crumb	very friable	21.6
C	Below 11.5 cm; a heterogenous mix of partially weathered and unweathered rock, of various sizes and shapes.					

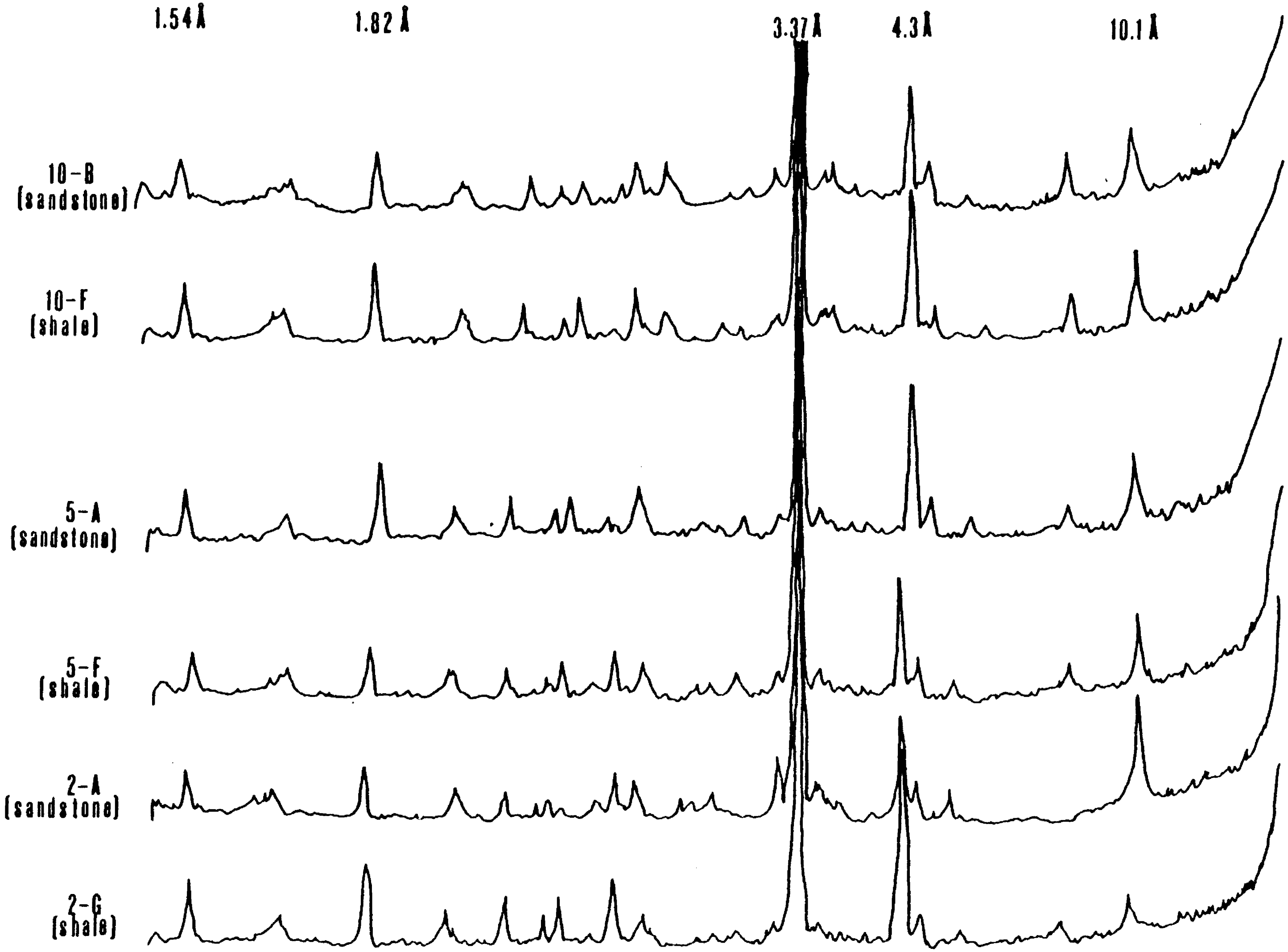
AVERAGE SOIL PROFILE

Natural Contiguous Soil Series
(Dekalb, Muskingum, Gilpin)

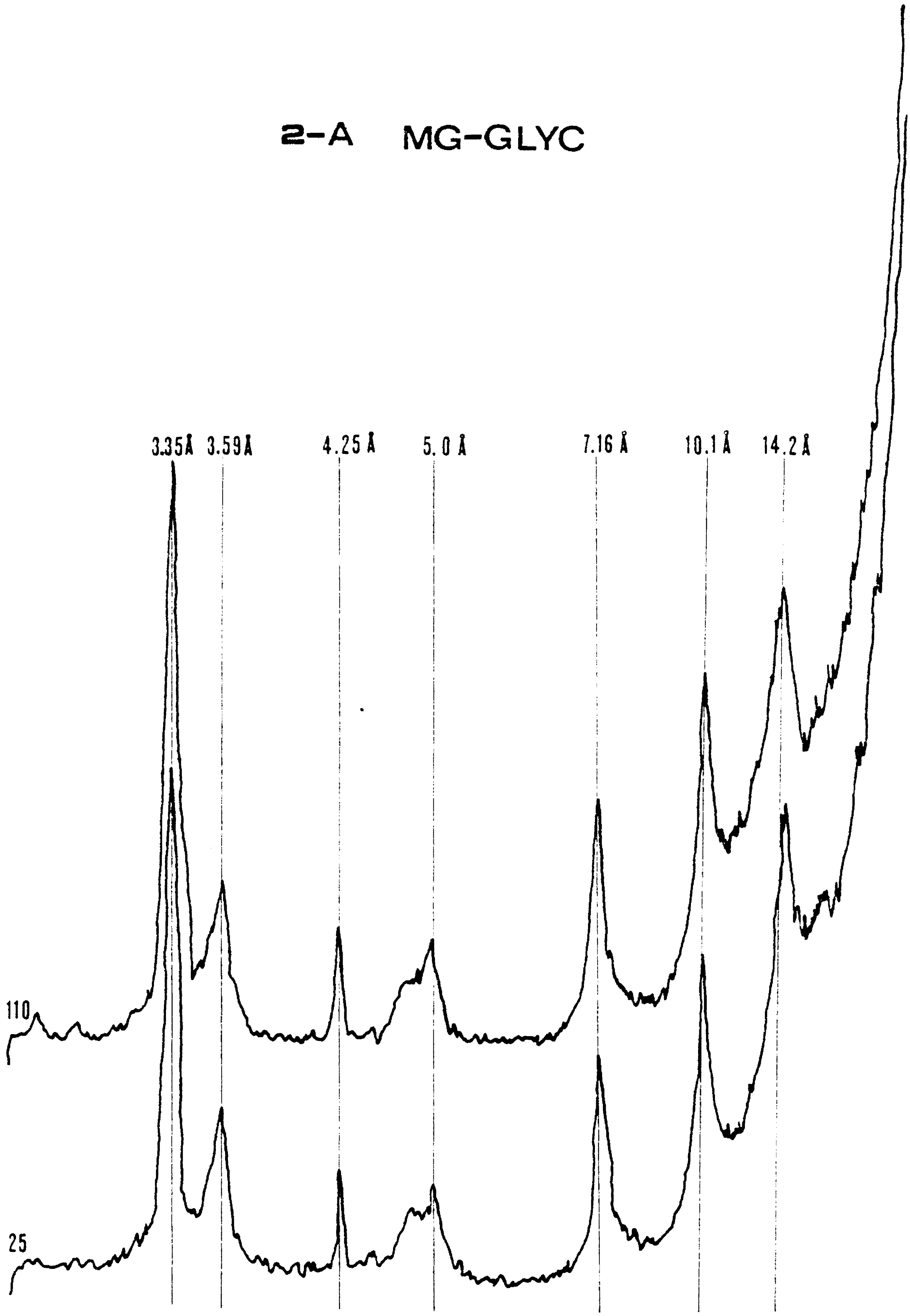
Horizon	Thickness (cm)	Color	Texture	Structure	Consistence	Coarse Fragments (%)
Ap	14.0	10YR 3.7/2.7	silt loam	weak, fine granular	friable	25.6
B1	17.0	7.5YR-10YR 5.3/6	silt loam	moderate, fine-medium subangular blocky	friable	16.9
B2t (or B21&B22)	39.7	7.5YR-10YR 5.6/6	clay loam-silty clay loam	strong, medium sub-angular blocky	firm	12.4
C	15.0	7.5YR-10YR 5.5/5	silty clay loam	moderate, coarse angular-sub-angular blocky	firm	13.6
R	Below 85.7 cm; saprolitic rock structure.					

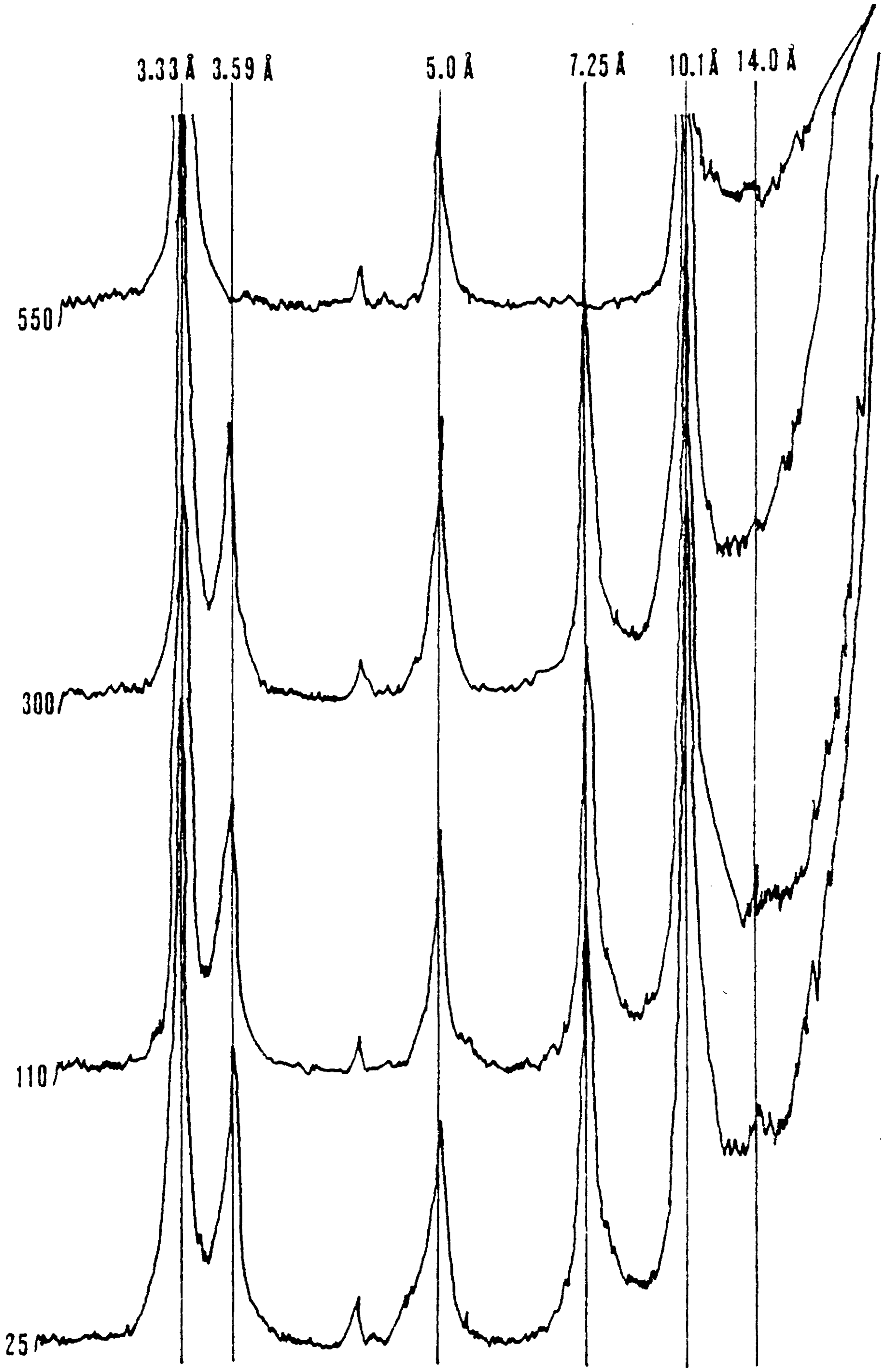
APPENDIX III

X-Ray Diffraction Patterns

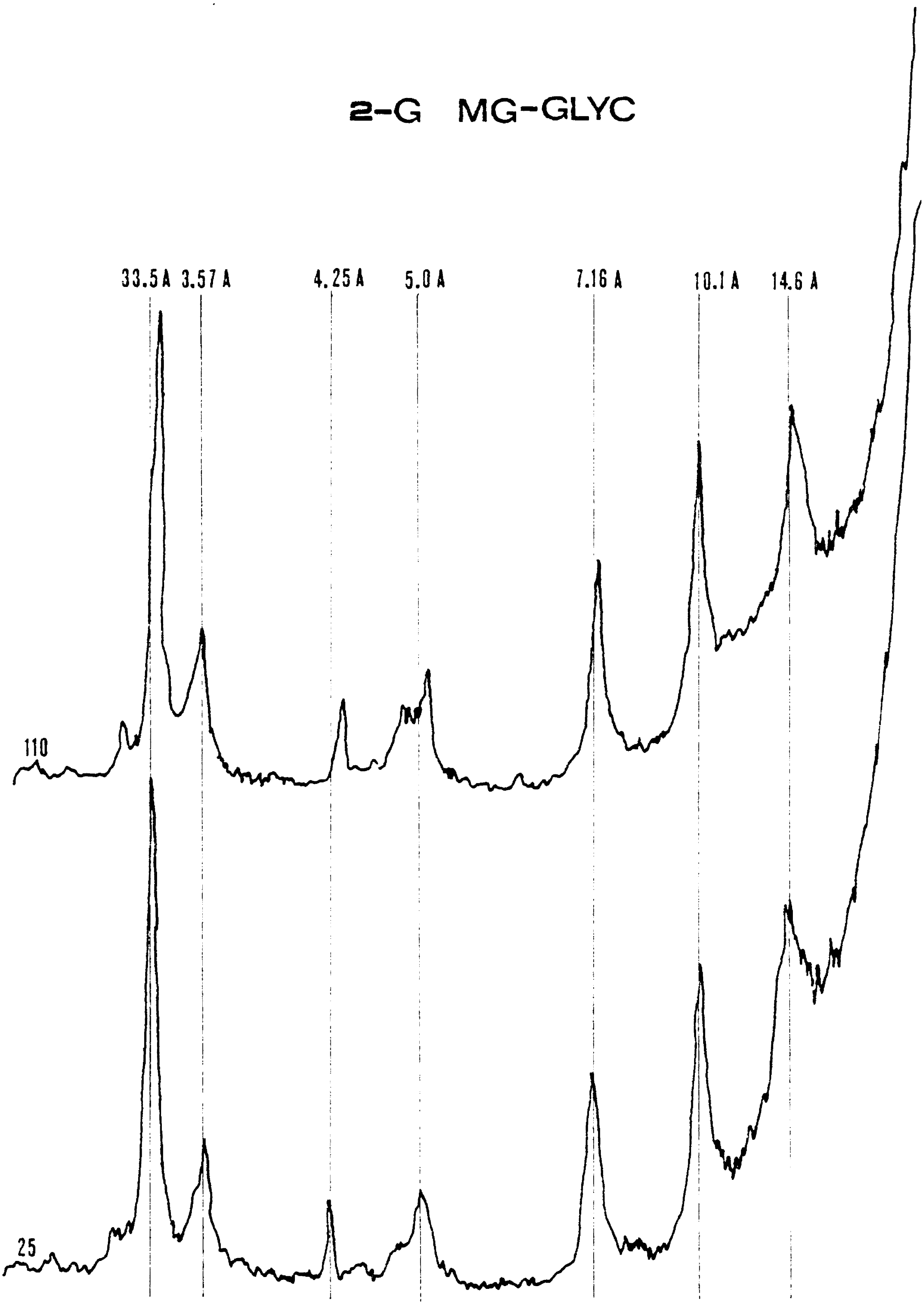


SILT POWDER MOUNTS

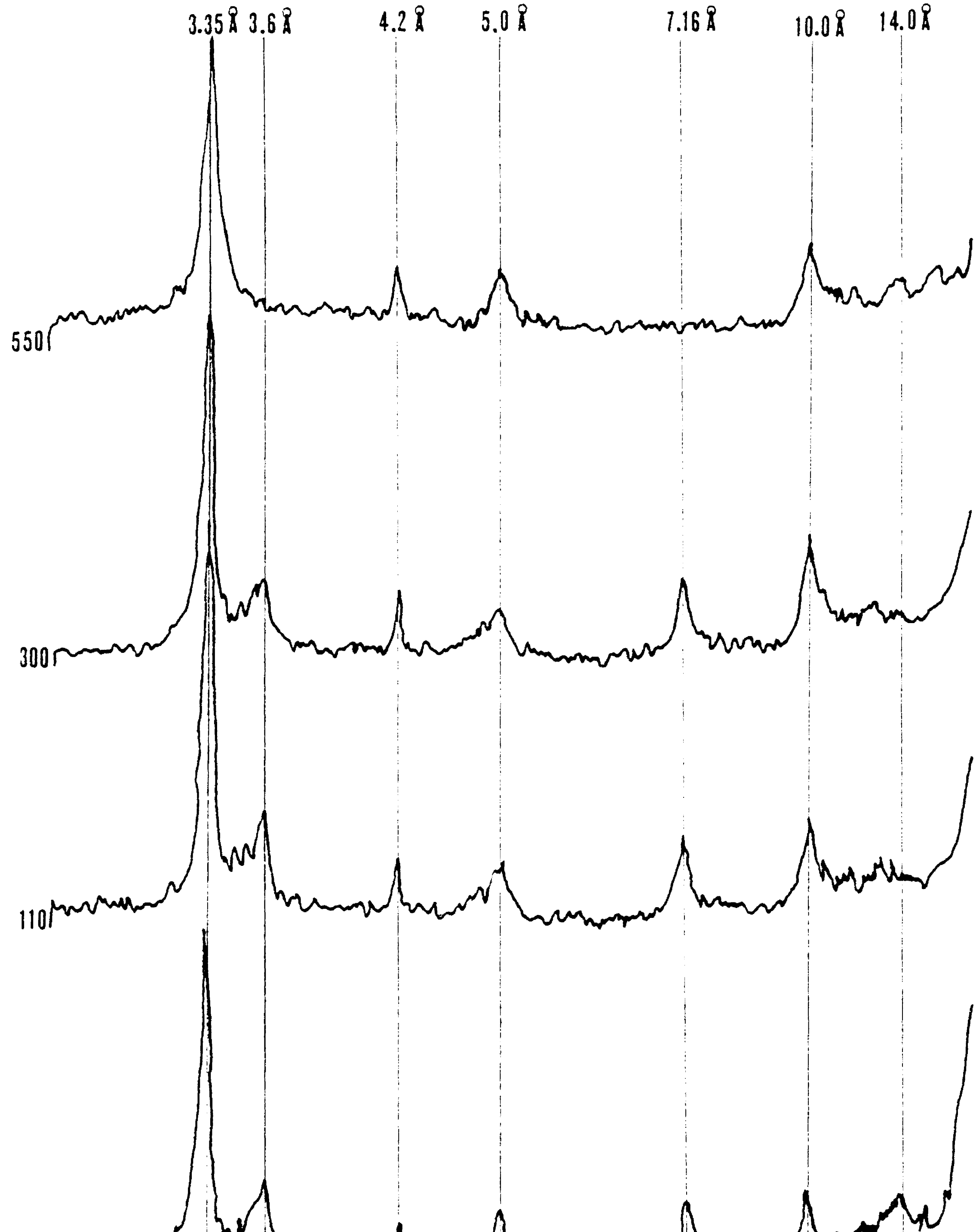

2-A MG-GLYC
3.35Å
3.59Å
4.25 Å
5.0 Å
7.16 Å
10.1 Å
14.2 Å
110
25

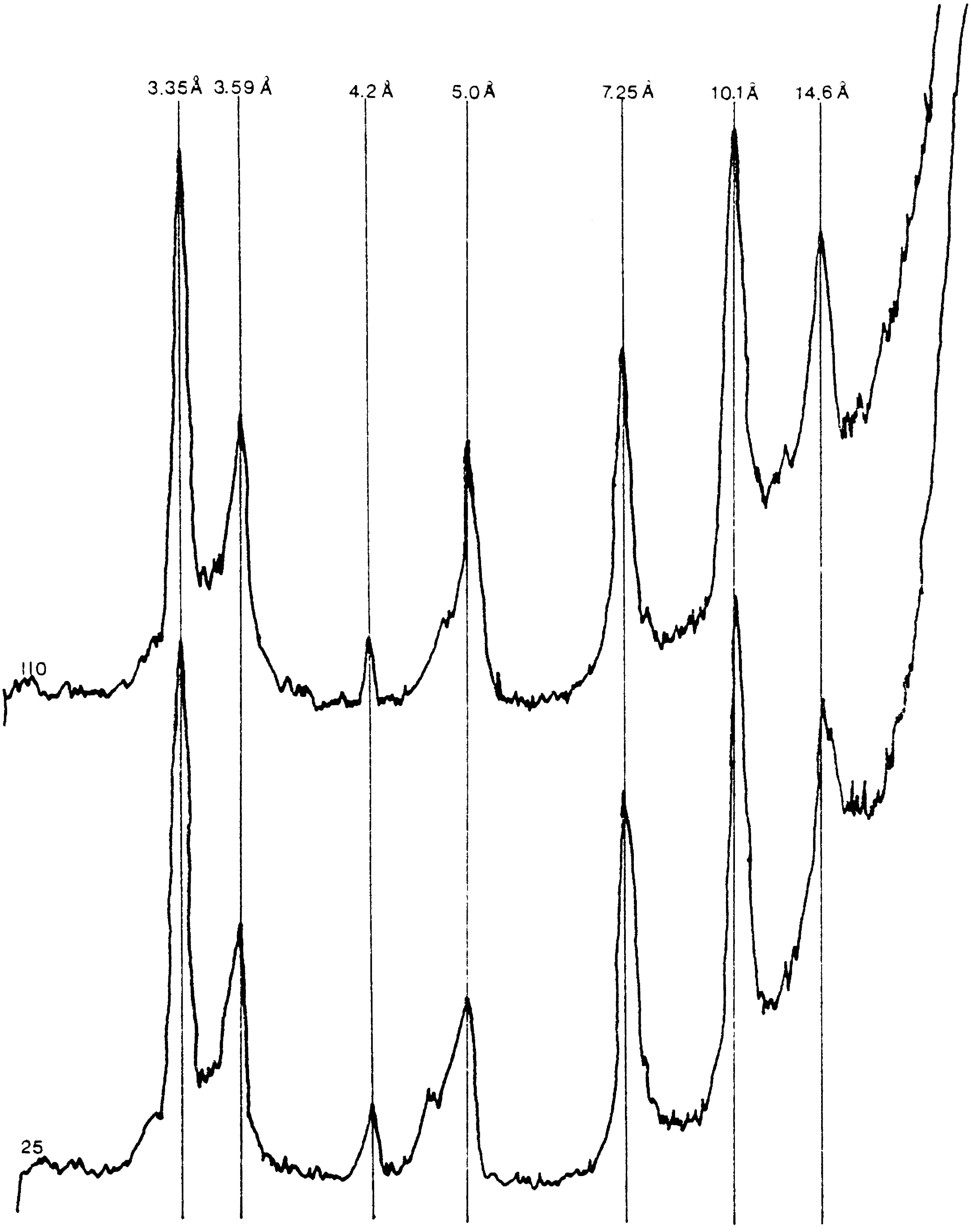


2-A K-SATURATION

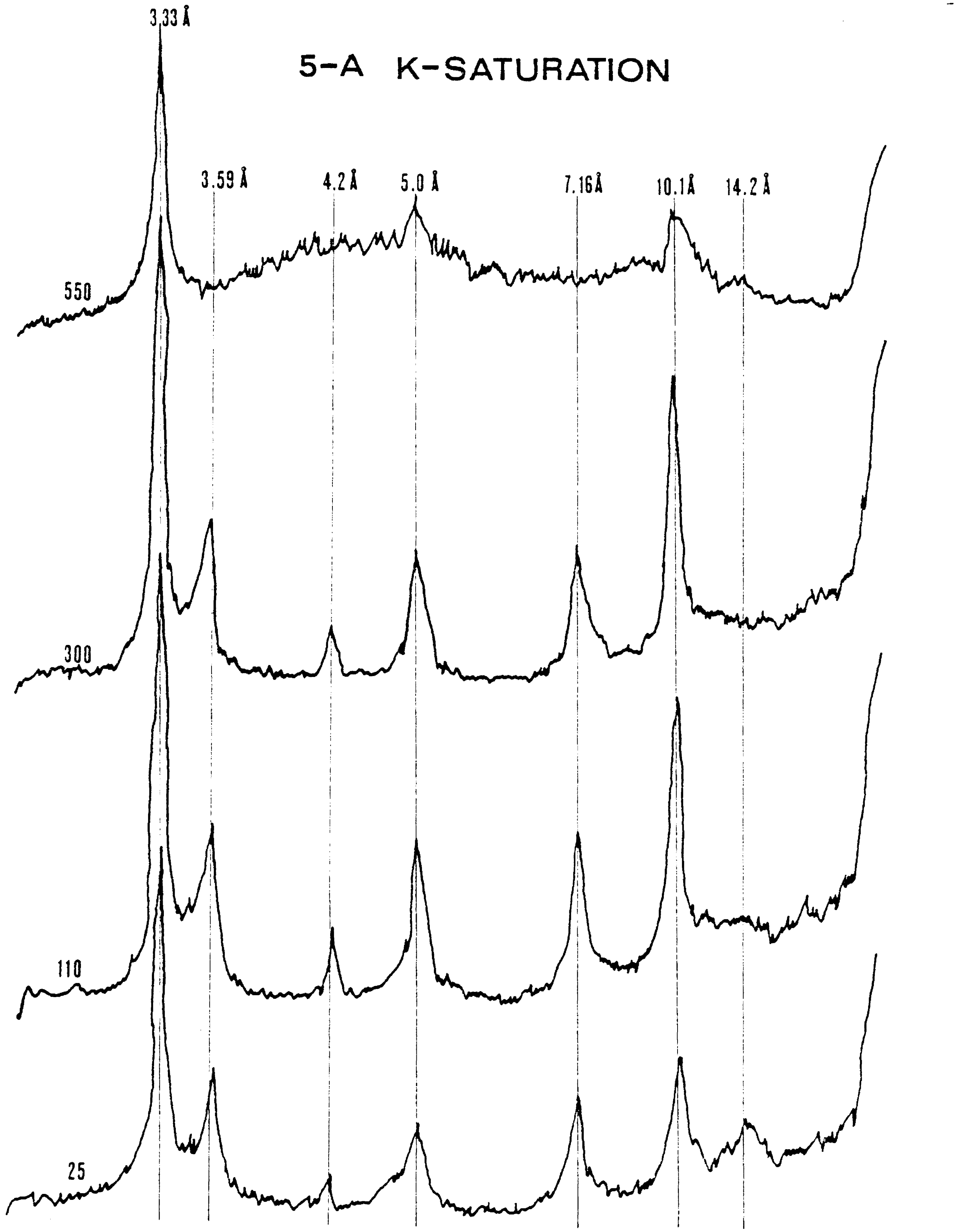

2-G MG-GLYC
33.5 A
3.57 A
4.25 A
5.0 A
7.16 A
10.1 A
14.6 A
110
25

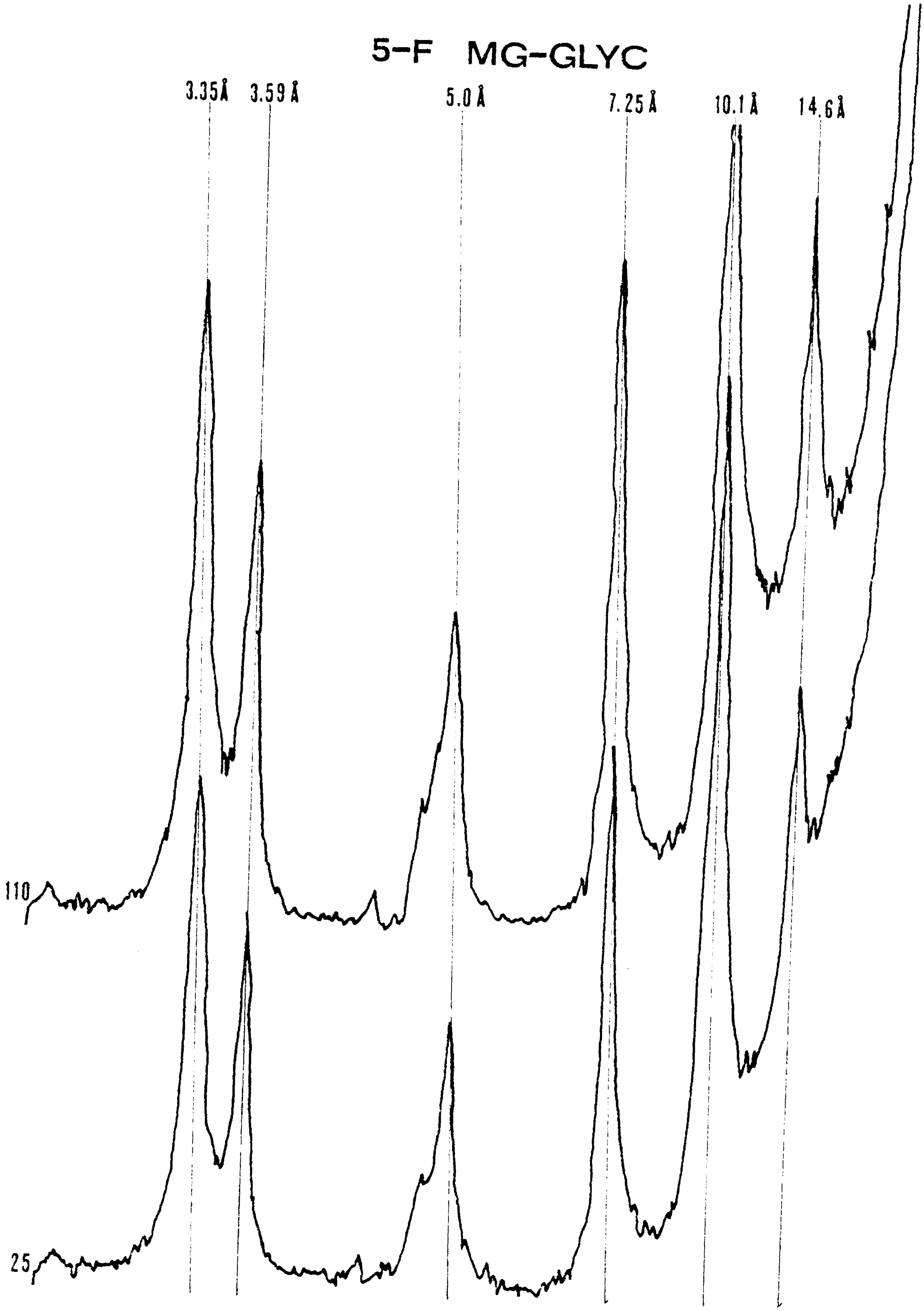
2-G K-SATURATION

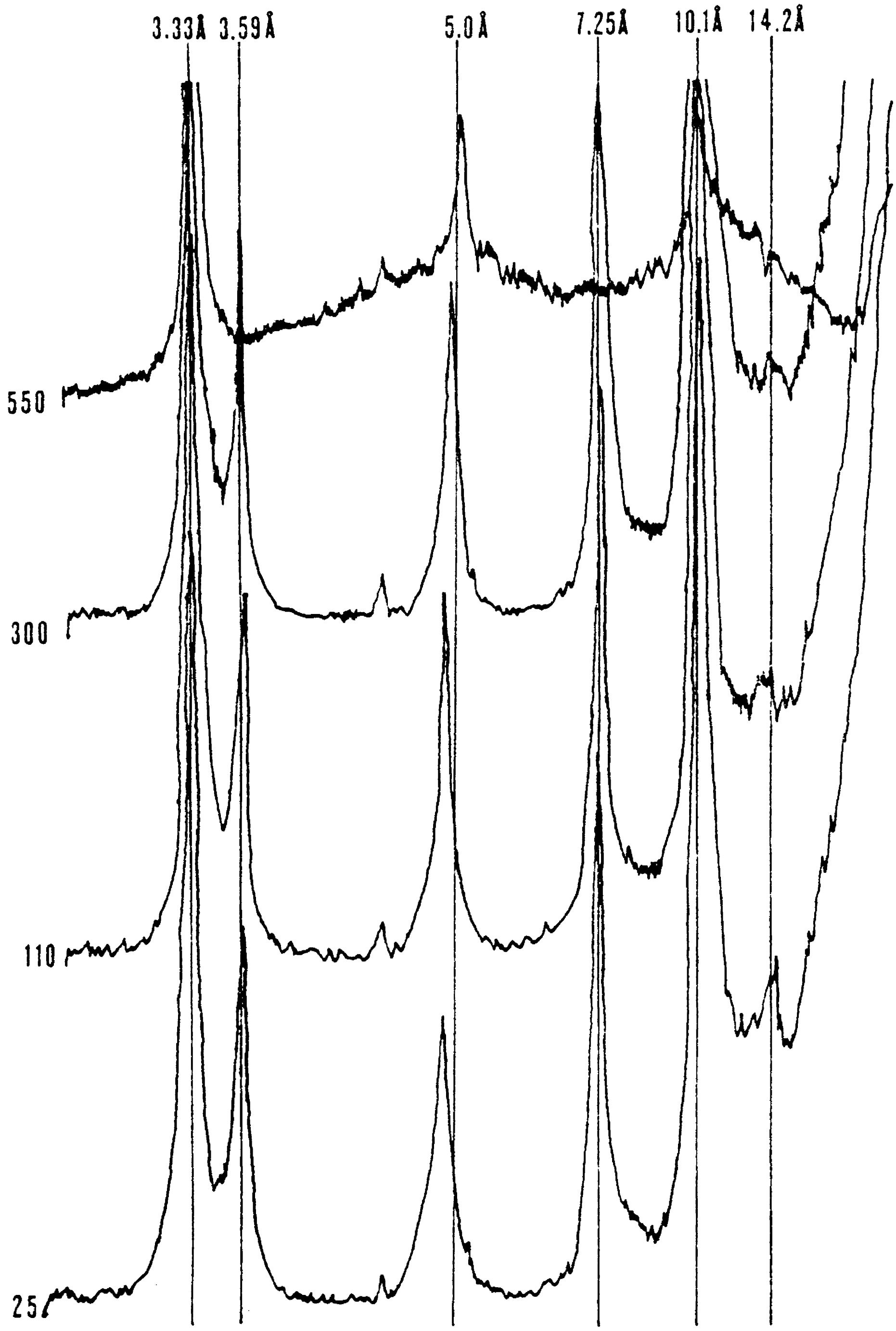




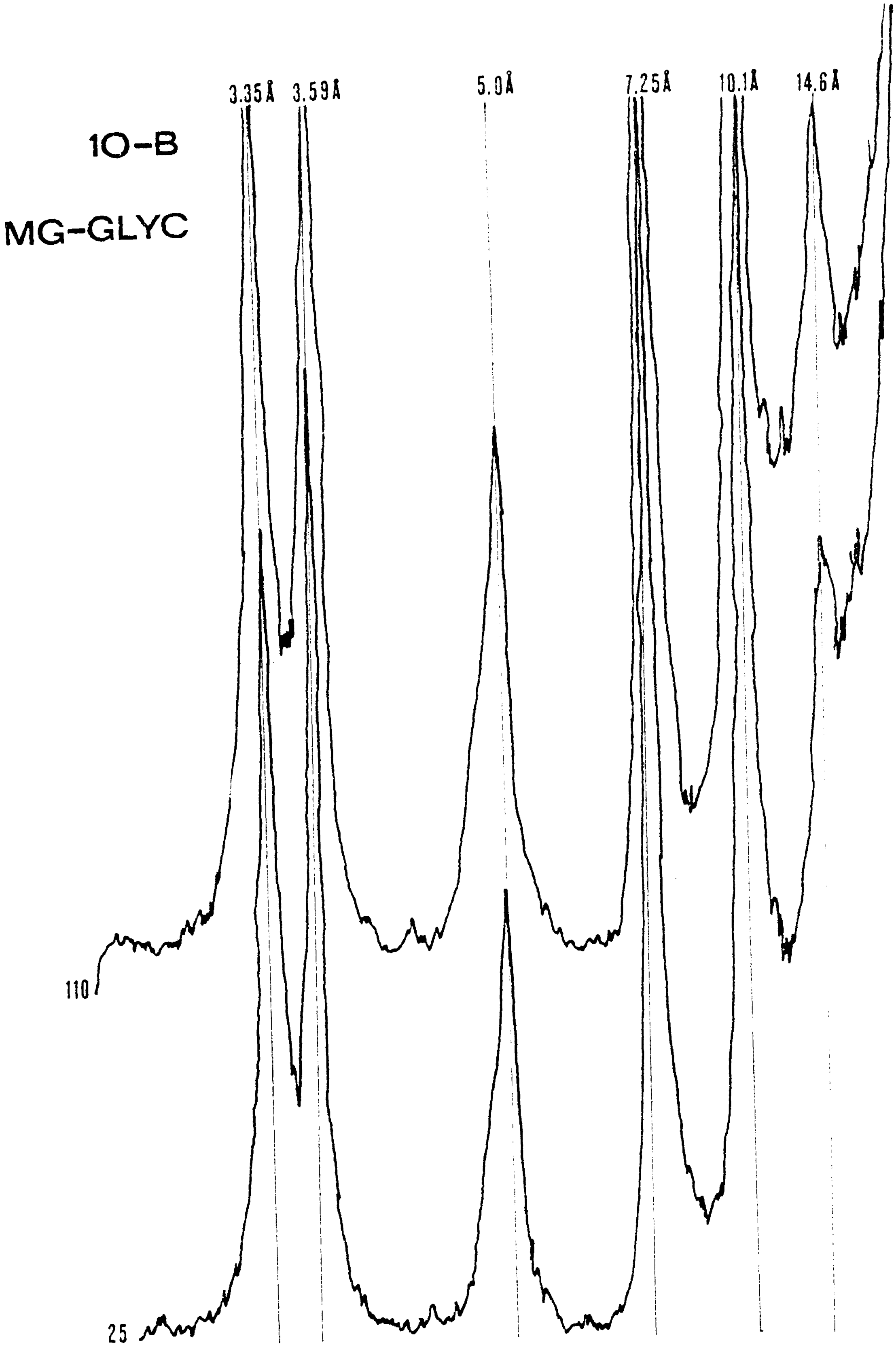
5-A MG-GLYC


3.33 Å
5-A K-SATURATION
3.59 Å
4.2 Å
5.0 Å
7.16Å
10.1Å
14.2 Å
550
300
110
25

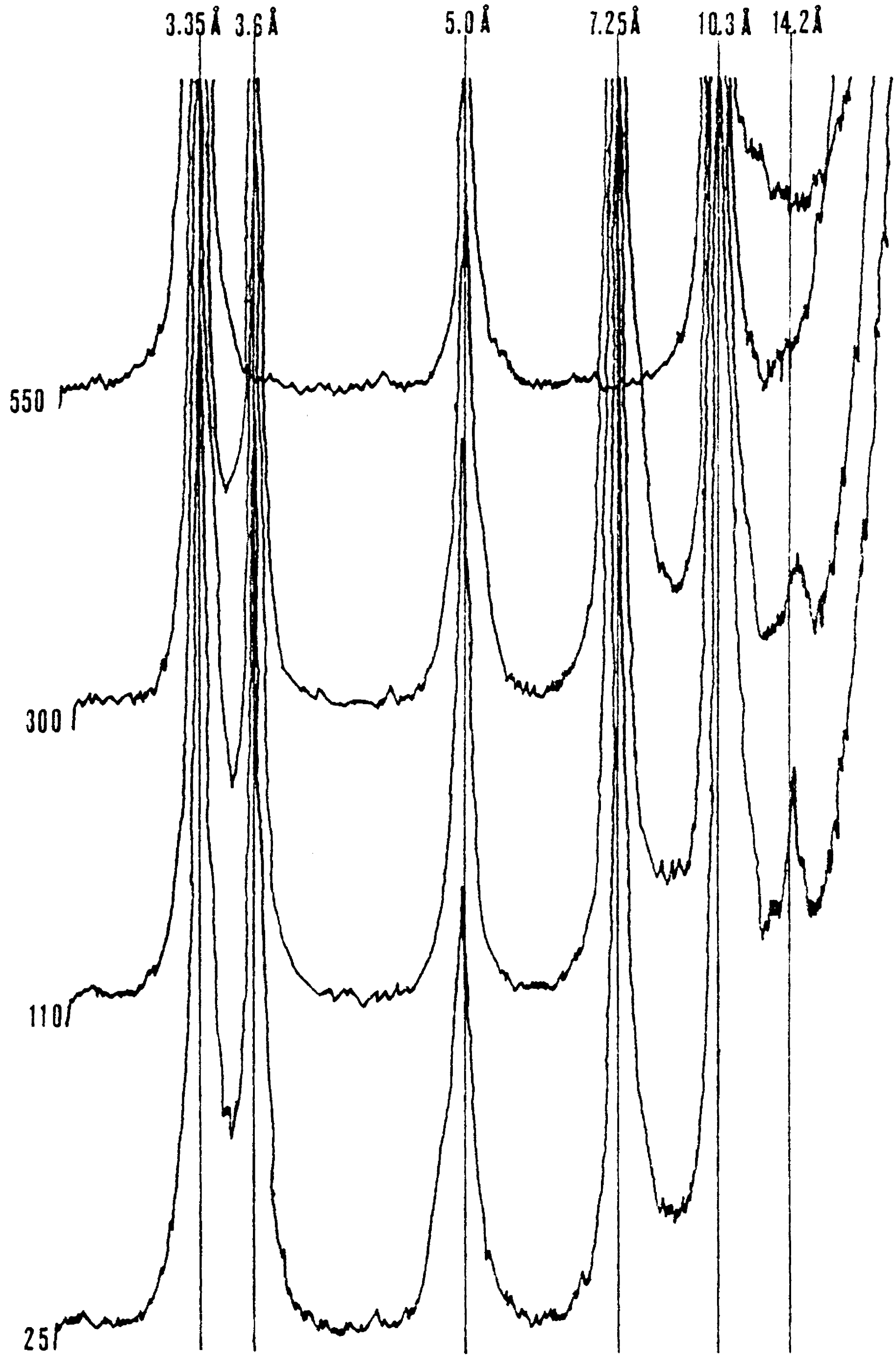

5-F MG-GLYC
3.35Å
3.59Å
5.0Å
7.25Å
10.1Å
14.6Å
110
25



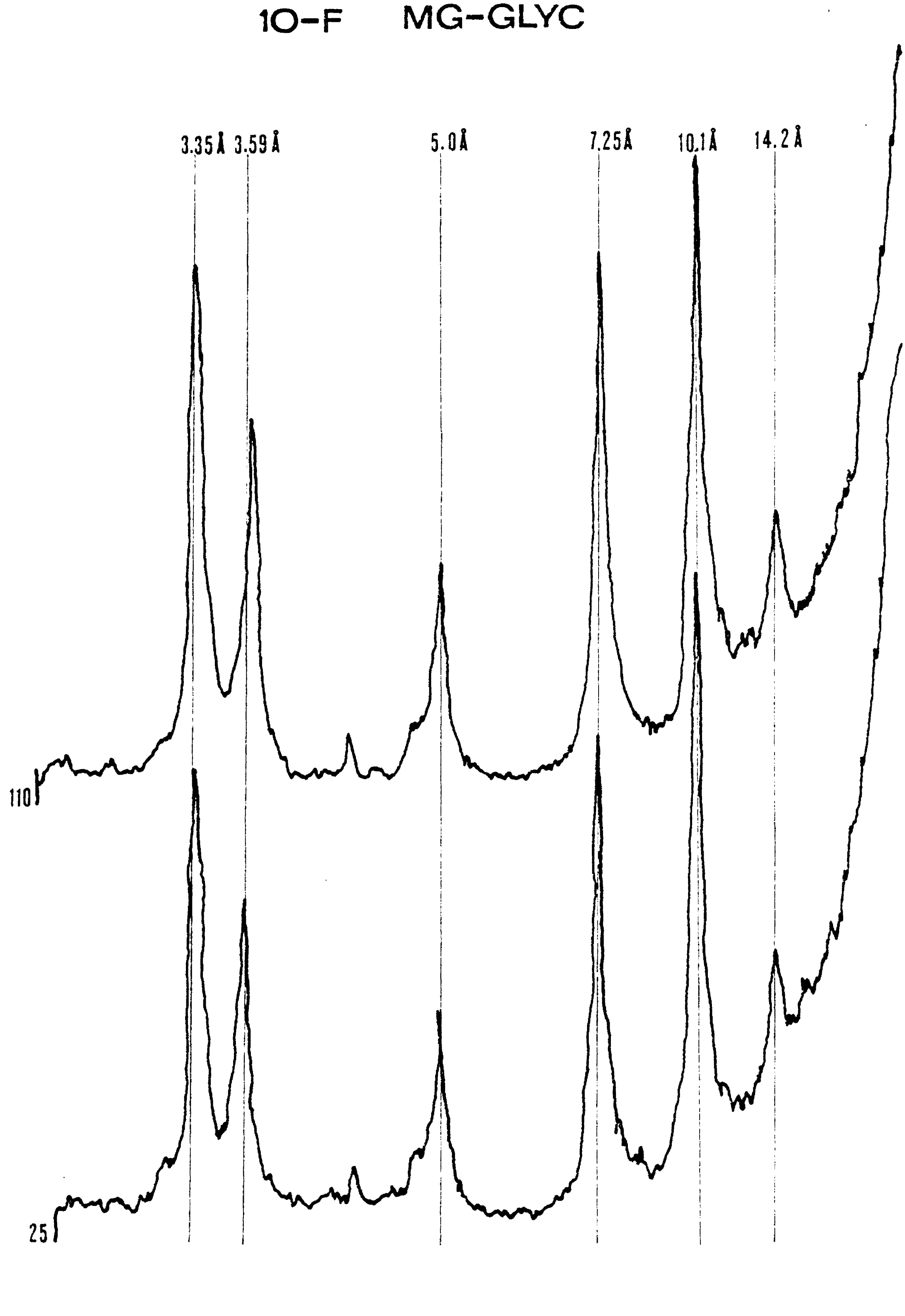
5-F K-SATURATION

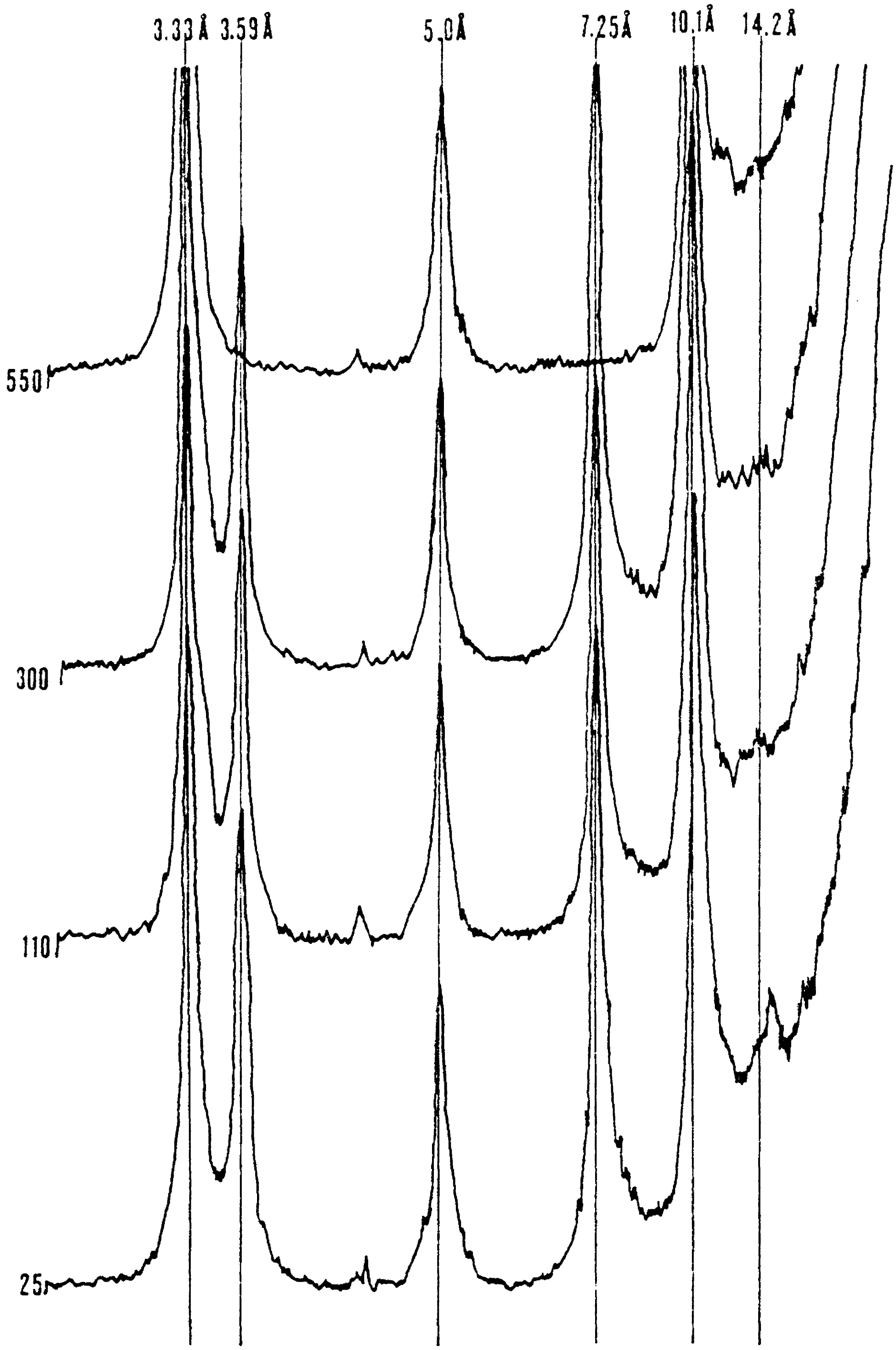


3.35Å
3.59Å
5.0Å
7.25Å
10.1Å
14.6Å
10-B
MG-GLYC
110
25



10–B K–SATURATION


10-F MG-GLYC
3.35Å
3.59Å
5.0Å
7.25Å
10.1Å
14.2Å
110
25

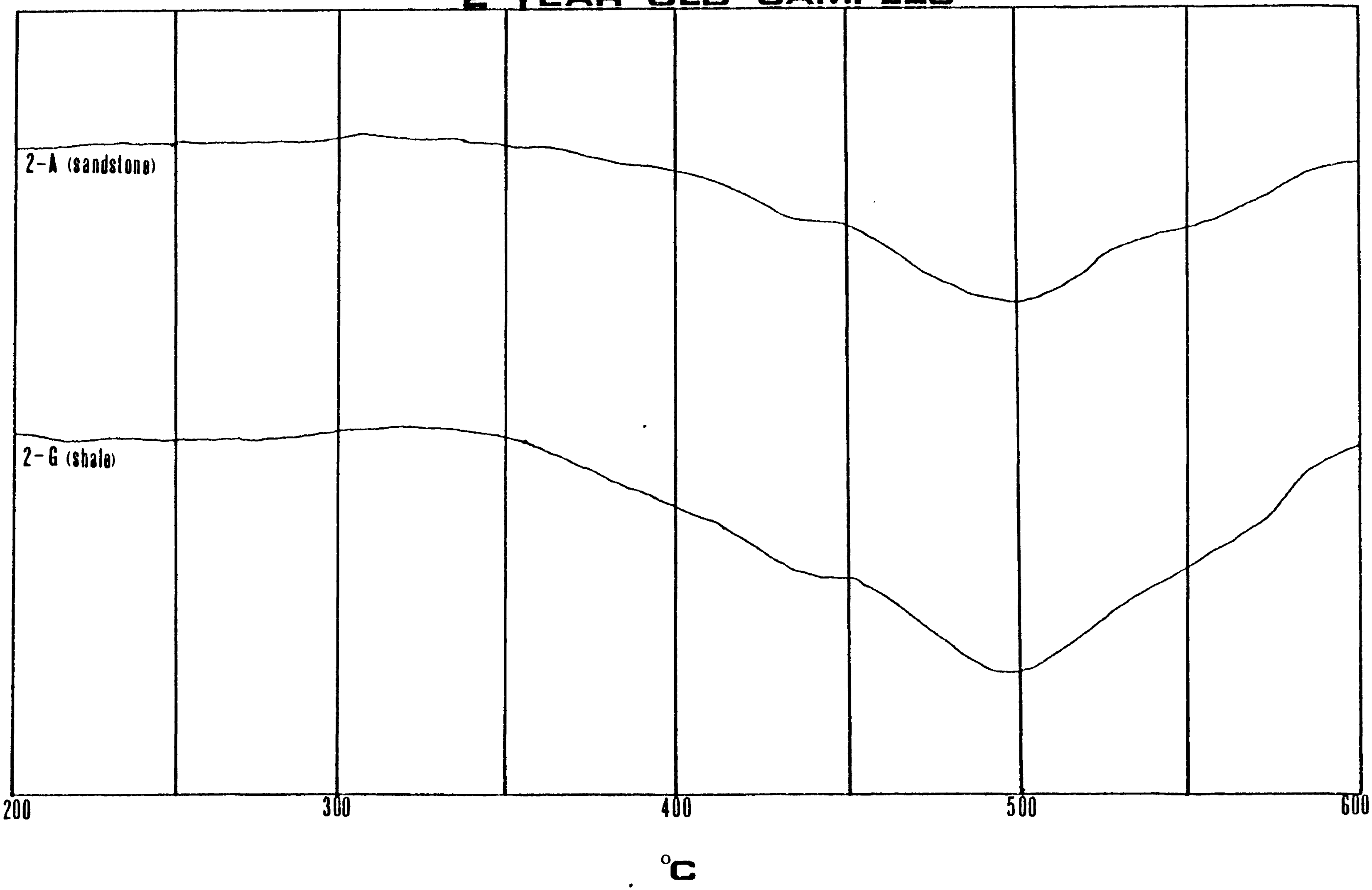


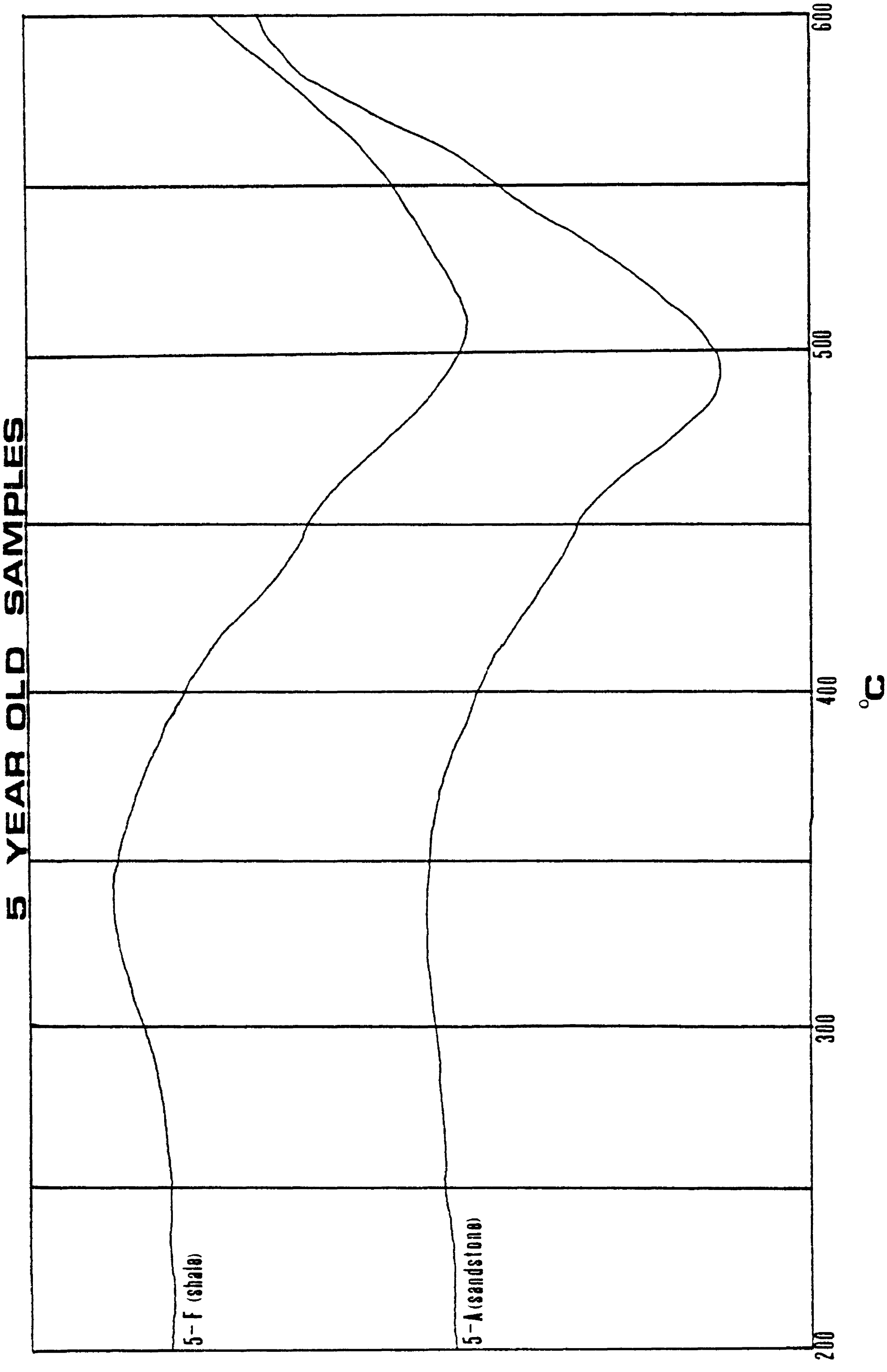
10-F K-SATURATION

APPENDIX IV

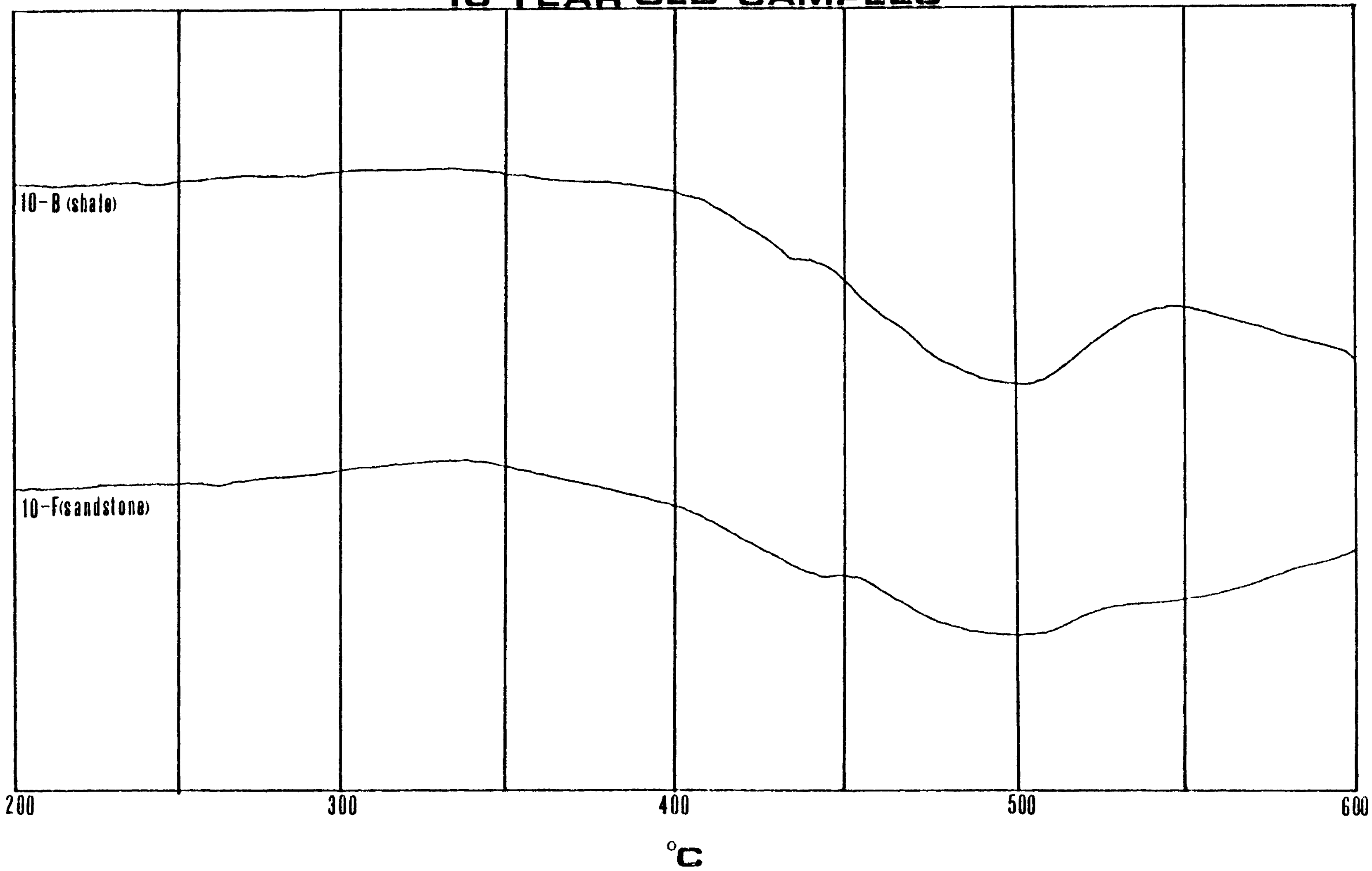
Differential Thermal Analyses

2 YEAR OLD SAMPLES



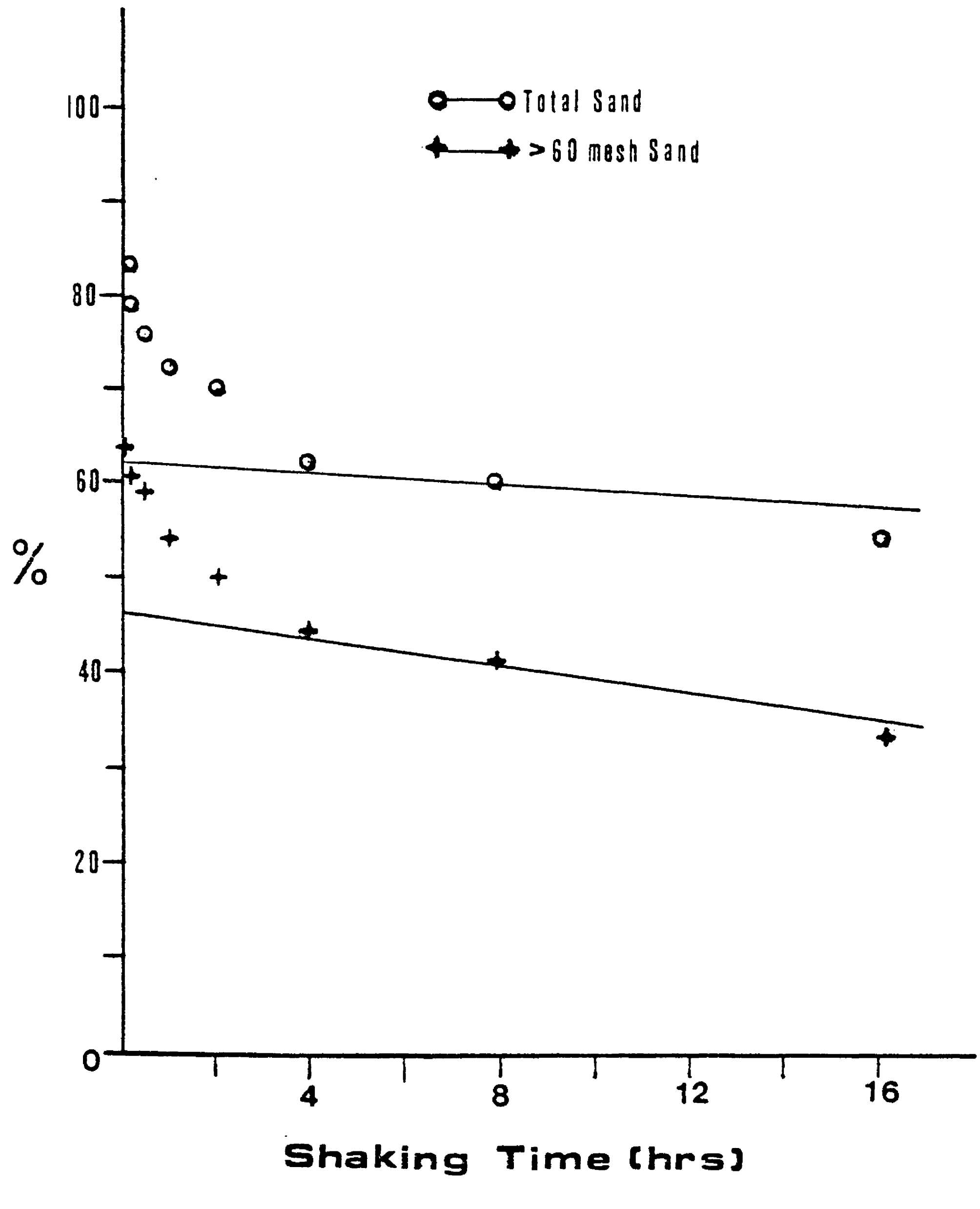

5 YEAR OLD SAMPLES
°C
200
300
400
500
600
5- F (shale)
5-A(sandstone)

10 YEAR OLD SAMPLES

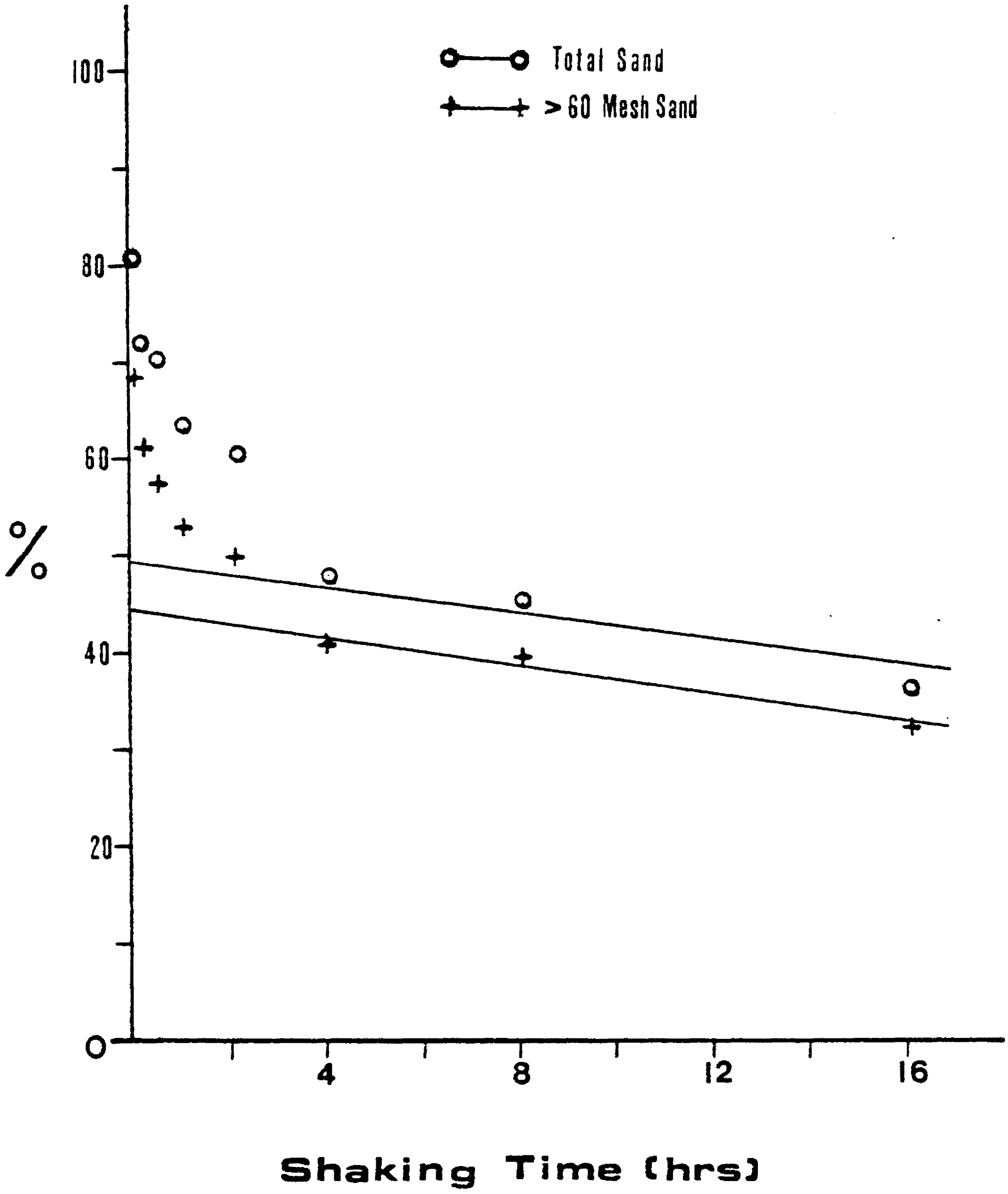


APPENDIX V

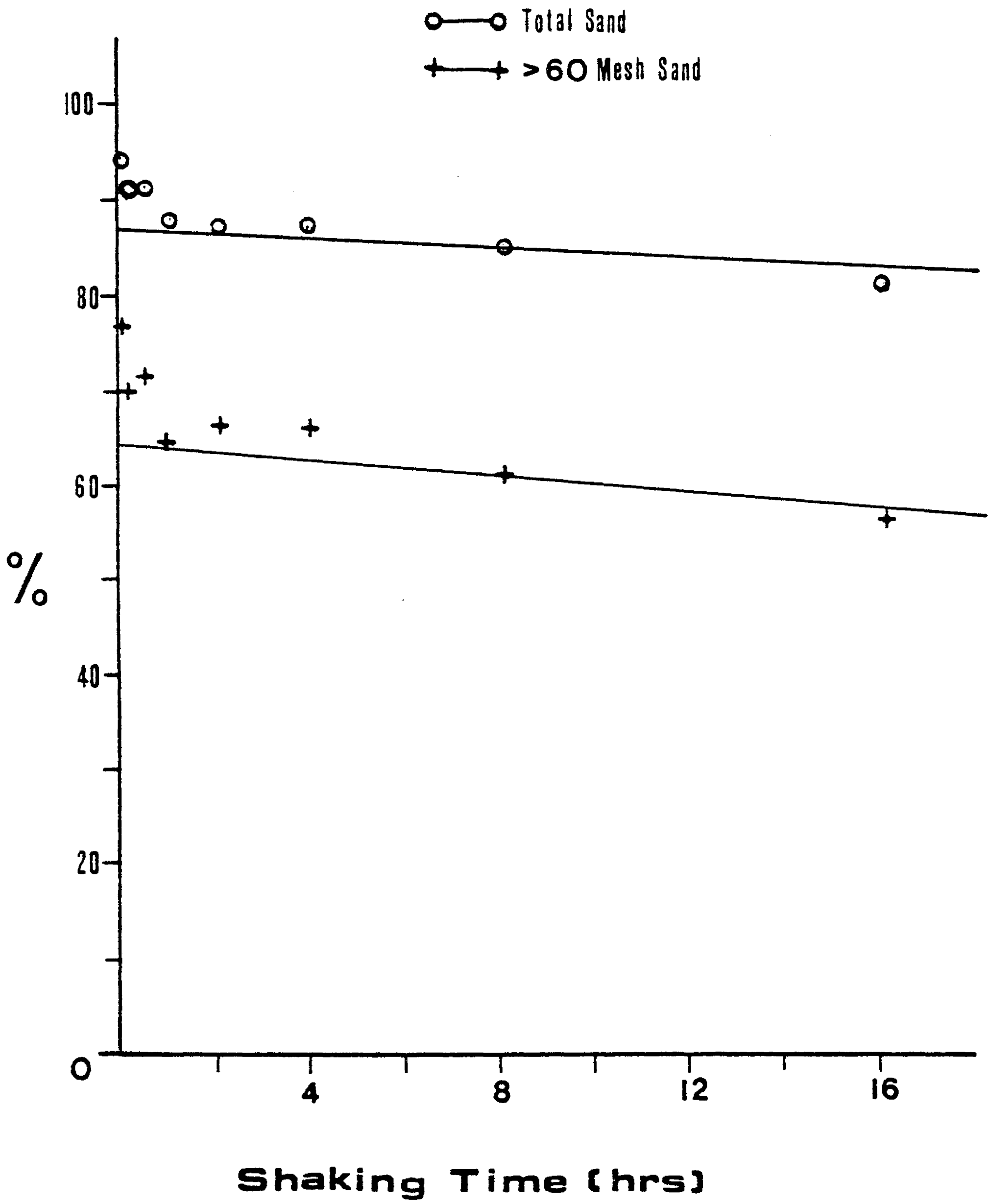
Total Sand And > 60 Mesh Sand As Determined
By Shaking For Different Periods Of Time In pH 10 Water



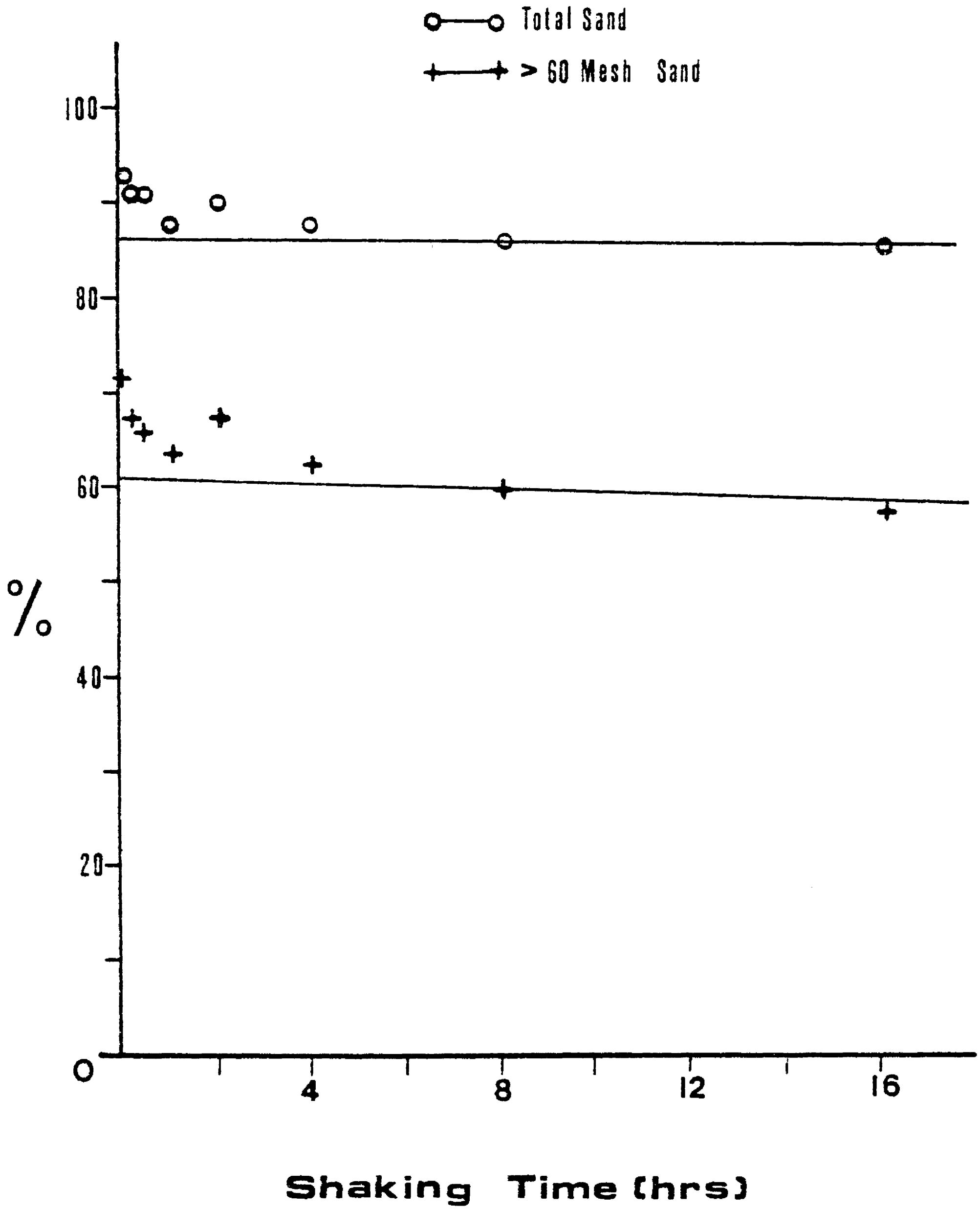
V-A. Total sand and >60 mesh sand of Pennsylvanian age brown siltstone sample after dispersion in pH 10 Water for various lengths of time.



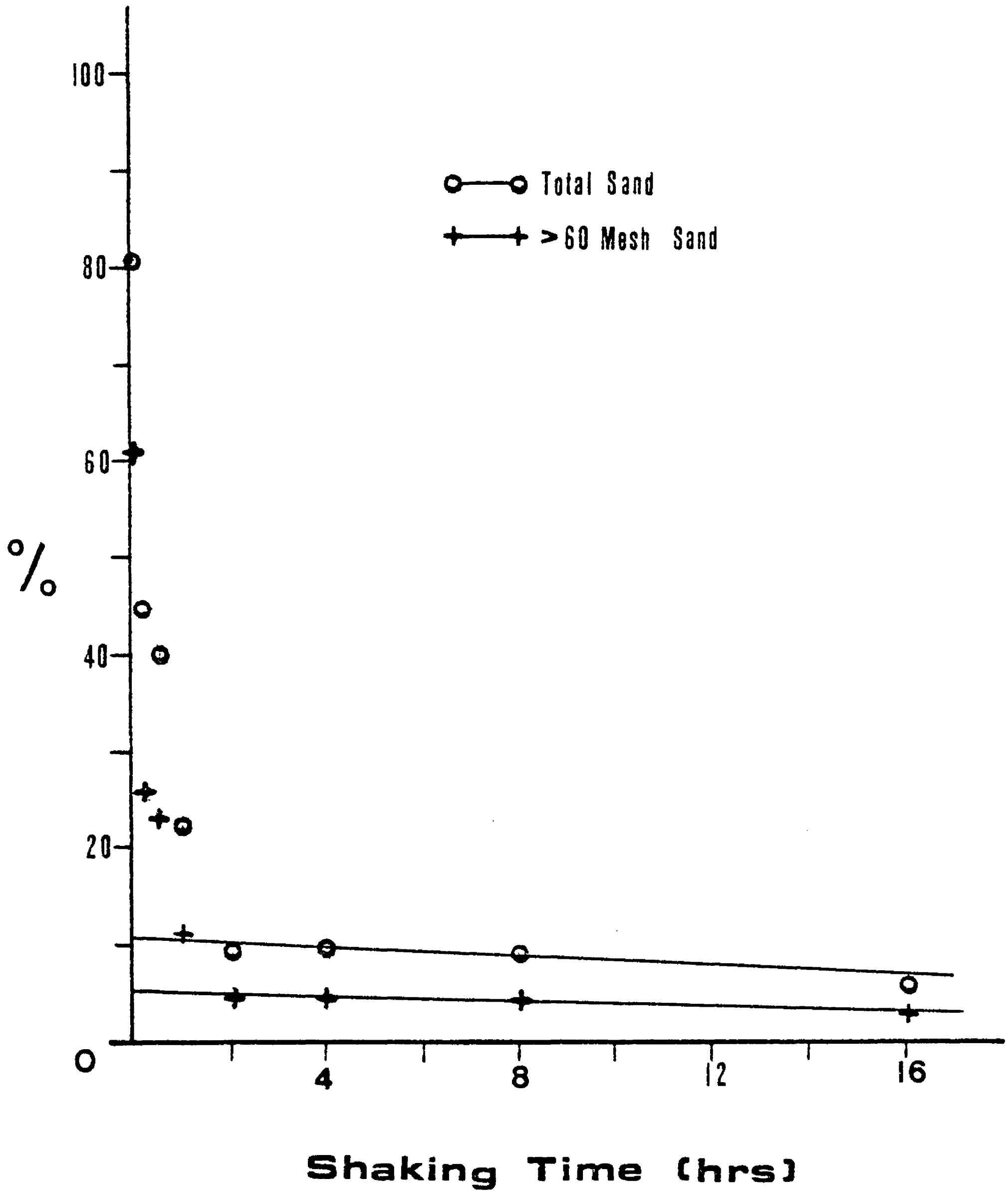
V-B. Total sand and >60 mesh sand of Pennsylvanian age gray siltstone sample after dispersion in pH 10 water for various lengths of time.



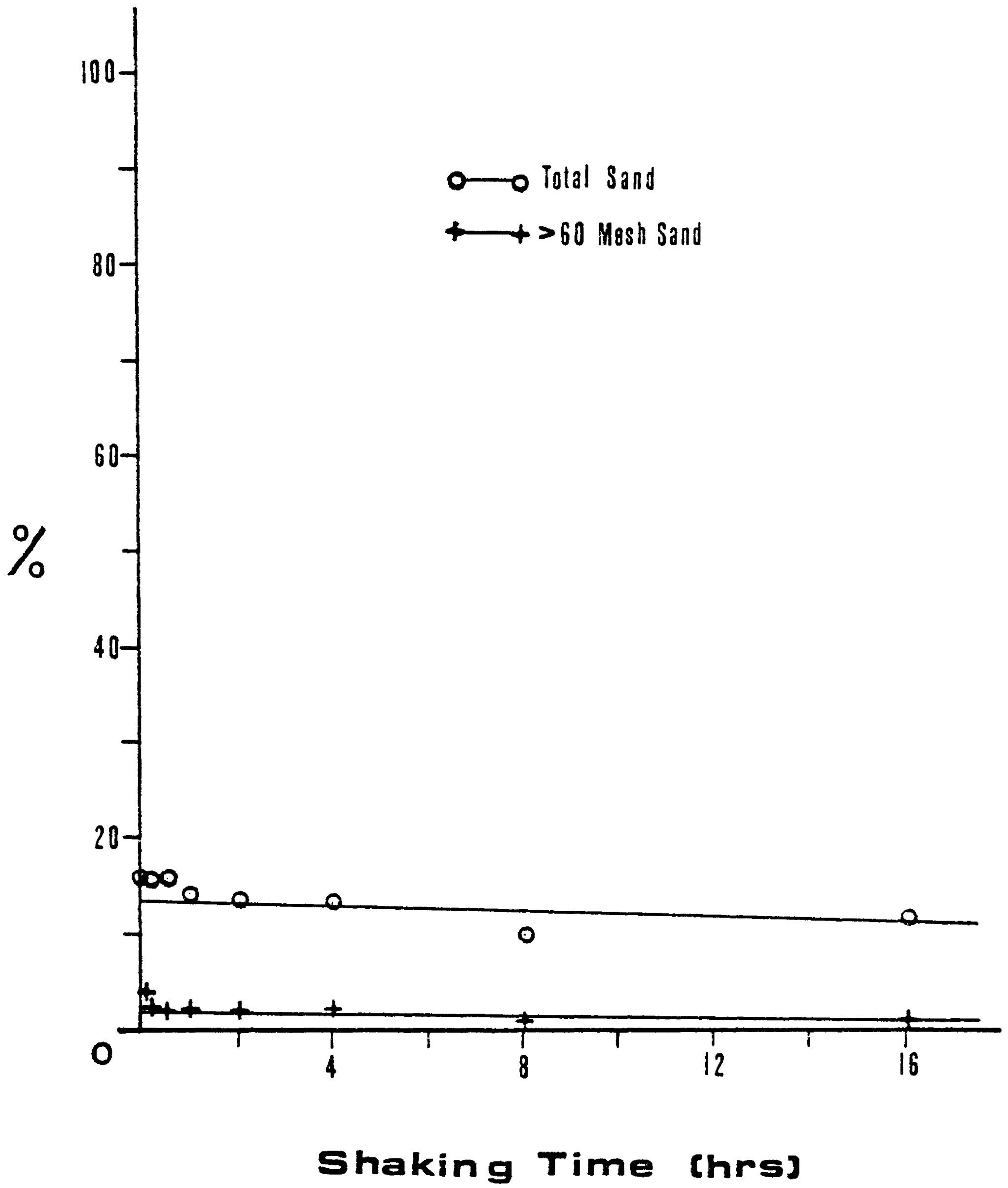
V-C. Total sand and >60 mesh sand of a Pennsylvanian age brown sandstone sample after dispersion in pH 10 water for various lengths of time.



V-D. Total sand and >60 mesh sand of a Pennsylvanian age gray sandstone sample after dispersion in pH 10 water for various lengths of time.



V-E. Total sand and >60 mesh sand of a 10 year old mine soil (10-C) C horizon after dispersion of pH 10 water for various lengths of time.



V-F. Total sand and >60 mesh sand of Gilpin B22t horizon after dispersion in pH 10 water for various lengths of time.

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SOIL GENESIS ON RELATIVELY YOUNG SURFACE MINED LANDS
IN SOUTHERN WEST VIRGINIA

by

Larry Ross Sweeney

(ABSTRACT)

In this study I observed, described and measured differences in morphological, physical and chemical properties as a function of age on mine soils formed from overburden from the New River formation of the Pennsylvanian system in southern West Virginia. Within each group, we sampled nine separate sites and further catagorized each to one of three predominant overburden types as observed in the exposed highwall (either predominantely sandstone or shale or an approximately even mixture of the two). Three "topsoiled" sites were sampled for comparative purposes, along with three contiguous soil series commonly found in the region.

The most striking differences attributable to age were depth of profile development and horizonation. Aggregate stability, hydraulic conductivity and soil color also showed significant variance with age.

The mine soils were generally more fertile in those elements analyzed than the natural soils, and the A horizons of mine soils and the natural soils contained approximately the same amounts of coarse fragments. Among the mine soils, the 5 year old soils were more fertile than the 2 or 10 year old soils.

Ten years was not enough time to cause significant differences in textural classification of these soils. Texture was reflective of the parent material.