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EPA-600/7-79-253
December 1979

Research and Development

Soil Development and Nitrates in Minesoil

Interagency Energy/Environment R&D Program Report

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EPA-600/7-79-253
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SOIL DEVELOPMENT AND NITRATES IN MINESOIL

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This work was designed to measure the effect of soil forming processes on mine spoil material of known age and to determine the amount of nitrate in different age minesoils. The results of this work should be of interest to the soil scientist and reclamation specialist involved in the reclamation of land disturbed by coal mining. For further information contact the authors or the Extraction Technology Branch of the Resource Extraction and Handling Division.

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ABSTRACT

Samples of minesoils from 16- and 40-year-old mine spoil piles were analyzed in the laboratory for various chemical and physical properties to ascertain to what extent the materials have been influenced by pedogenic processes during their relatively brief time of exposure. Nitrate levels in the minesoils were also measured to determine if a potential hazard exists. Results of the study indicated that both the 16- and 40-year-old materials showed signs of incipient soil development. The data also showed that nitrate levels in the minesoils are higher than in adjacent undisturbed native soils. In general however, the levels in the minesoil still are within the range normally expected for arable soils. It also appears that the nitrate level in the minesoil decreases with time of exposure.

This report was submitted in fulfillment of Contract No. 684-15-35 by the University of Wyoming under the sponsorship of the U. S. Environmental Protection Agency. This report covers the period August 7, 1976 to September 30, 1978.

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ACKNOWLEDGMENT

We wish to thank the Rosebud Coal Sales Company for allowing the study to be conducted on their property. And special thanks to Mr. Dave Evans, reclamation officer, Rosebud Coal Sales Company for his assistance in selecting sites for the study. Thanks also go to Dr. Gerald Schuman and Mr. Frank Rauzi, U.S.D.A.-S.E.A., and Dr. Steve Williams, University of Wyoming, for their expert advice during the study.

INTRODUCTION

Federal legislation enacted in 1977 as well as previous Wyoming laws have resulted in mandatory reclamation of areas disturbed by mining. Many spoil piles resulting from early mining done prior to the establishement of such laws were left abandoned. These undisturbed so-called, "orphan spoils" provide excellent conditions for pedogenic studies on materials of datable age. Spoil may be defined as a mixture of overburden and discarded coal.

It is generally recognized that soil development under natural conditions is a slow process requiring from several hundred to many thousands of years. A study of minesoils should allow one to determine the changes that occur in the profile during the early stages of soil development.

The objectives of this study were to determine:

1) If measurable changes have occurred in the profile of minesoils during their relatively brief time of exposure to pedogenic processes.

2) The nitrate content of different age minesoils and to compare with the amount contained in adjacent native soils.

CONCLUSIONS

1. The overburden material at the Hanna site differed considerably from that at the Elmo site in texture, pH and $CaCO_3$ content. Since the Hanna Geological formation is so variable with respect to thickness and composition of individual strata from one location to another, the spoil piles from this formation are a hodgepodge of sandstone, shales, and mixtures of both with no predictable sequence of horizonation.

2. Evidence of soil development:

   a. K enrichment has occurred in the surface 5 cm of both the 16- and 40-year-old minesoils. The enrichment is thought to result from biocycling of K.

   b. Some downward movement of soluble salts has occurred in the sandy loam textured Hanna minesoil as indicated by an increase in electrical conductivity (Ec) to a depth of 30 to 45 cm (12 to 18 inches).

   c. Soluble Ca and Mg salts are primarily responsible for the increase in Ec with the highest concentration of soluble Ca and Mg occurring near the base of the root zone at a depth of 30 to 45 cm.

3. There is no evidence of translocation of clay in the minesoils after 16 or 40 years of exposure.

4. There is no evidence of $CaCO_3$ movement in the minesoils.

5. The slightly acid pH thoughout the profile of the Elmo minesoil reflects the presence of acid forming pyritic minerals in the overburden and the absence of $CaCO_3$ to neutralize the acidity.

6. The slightly alkaline reaction of the Hanna minesoil results from the $CaCO_3$ present in the overburden and its neutralizing effect on the potential acidity.

7. The Hanna and Elmo minesoils and the Elmo native soil all contain more oxidizable carbon than is normal for soils of arid climates. Very fine coal dust dispersed throughout the minesoils and native soil mask the organic matter which is contributed by active biotic forces that is normally considered to be the true soil organic matter.

8. Nitrates are not a potential pollutant. The minesoils studied contained more nitrates than nearby native soil, however, the amounts were not excessive being near the upper end of the range of nitrates found in arable soils. The level of nitrates in the minesoils did decrease with age of the minesoil.

9. Sodium presents no hazard in the minesoils studied as reflected by the low sodium absorption ratios which ranged from 0.19 to 2.01, well below the levels of 12 to 15 which indicate potential management problems.

RECOMMENDATIONS

1. The sparseness of vegetation and the near absence of soil development on abandoned minesoils at Elmo and Hanna, Wyoming indicate a need for proper land preparation and topsoiling of disturbed lands in future mining operations before revegetating. Topsoiling is necessary even though the normal diagnostic tests may show overburden materials to be very similar chemically and in some respects physically, to the topsoil. It must be recognized that topsoil differs from overburden in many ways that normal diagnostic tests do not evaluate--to mention a few: first, the tests do not evaluate the biotic regime of the topsoil which has a very dynamic effect on plant growth; second, topsoil is a source of native seeds which can aid in the revegetation process; and third, topsoil will normally have well developed stable aggregation which can greatly improve plant air-water relationships over that found in poorly aggregated overburden materials.

2. There is no technical need for reworking of old abandoned "Orphan Spoils" if tests show the surface 50 cm contain no toxic materials, natural revegetation is occurring and erosion is not a significant factor. However, from a standpoint of aesthetics, many of the old abandoned spoils should be reshaped, topsoiled, and revegetated in order to blend in with the natural landscape.

3. Abandoned "Orphan Spoils" on which natural revegetation is not occurring because of unfavorable chemical or physical conditions should be reshaped to blend with the natural topography, topsoiled to a depth of at least 30 to 45 cm, and seeded to appropriate vegetation.

4. It is recommended that a method be developed to determine what fraction of the easily oxidizable carbon results from fine coal dust and what fraction results from true soil organic matter as the term normally implies. Such a method would greatly aid in studies like this, where the amount of biotic activity that has occurred in the soil is being inferred from the amount of organic matter that has accumulated in the soil profile.

REVIEW OF LITERATURE

When considering the topic of soil, as in other scientific disciplines, a working definition of the subject must be stated and agreed upon. The utility of such a definition will vary with its intended use as in the disciplines of pedology and edaphology. Brady (1974) states, "Edaphology is the study of the soil from the standpoint of higher plants. It considers the various properties of soil as they relate to plant production." Another edaphological definition states "soil is the natural medium for the growth of land plants, whether or not it has 'developed' soil horizons," (Soil Survey Staff, 1962). Although these definitions satisfy the needs of the edaphologists, they do not meet the requirements of pedologists. Buol, et al. (1973) speaking as a pedologist, takes exception to soils merely being a medium for plant growth stating that, "such a definition is unsatisfactory in that it is dependent upon something besides soil." He further defines soil as, "a natural body of mineral and organic matter which changes or has changed in response to climate and organisms The change is called soil genesis." Thus, the pedologist is concerned with the evolution of a natural body through chemical and biological pedogenic processes which results in a decrease in entropy of the system as represented by soil profile development.

The Environmental Protection Agency's (EPA) definition of soil has, to a certain extent, incorporated both the edaphologist's and pedologist's points of view. The agency defines soil as "the unconsolidated mineral and organic matter on the immediate surface of the earth that serves as a natural medium for the growth of land plants" (EPA, 1976). This definition, though more edaphologic in nature, does incorporate elements of the pedologic concept of soil, i.e., "unconsolidated mineral and organic matter." However, it ignores the genetic nature of soil, again relegating it to a medium for plant growth. For the purposes of this inquiry, soil will be considered as "a natural body consisting of layers or horizons of mineral and/or organic constituents of variable thicknesses, which differ from the parent material in their morphological, physical, chemical and mineralogical properties and their biological characteristics" (Birkeland, 1974).

SOIL GENESIS, A MODEL

The tendency of soils to develop in different ways, from similar if not comparable origins, is attributable to five independent variables known as "soil forming factors" (Jenny, 1941). Jenny expressed his five soil forming factors in the empirical relationship, s = f (cl, o, r, p, t), where "s" is the soil system (dependent), cl = climate, o = organisms, r = topography, p = parent material and t = time. From this relationship, Jenny indicates that "for a given combination of cl, o, r, p and t, the state of the soil system is fixed; only one type of soil exists under these conditions." The possible combinations from this relationship lead other researchers to isolate two dominate processes of pedogenesis: first, the decay of organic residues with subsequent formation of the soil organic constituent, namely humus; and second, the decomposition (mechanical and chemical) of mineral compounds from parent rocks, with the creation of new complexes (Glinka, 1963). The logical consequence of these two processes is that soil should be composed of two solid constituents, mineral and organic, with the greatest volume being normally occupied by the mineral fraction as liberated by weathering (Gerasimov and Glazovskaya, 1965).

WEATHERING

Weathering is defined as the disintegration and decomposition of the primary minerals, (Rode, 1961). The relative rate at which this occurs has been related to the stability of a mineral at the earth's surface (Fridland, 1967). Mineral stability appears to be directly correlated to "the progressive increase in the sharing of oxygens between adjacent silica tetrahedra" (Birkeland, 1974), while inversely related to the temperature at which the mineral formed.

In examining weathering processes, recognition of both the physical and chemical aspects is important. However, Reiche (1962) has pointed out that "the essentially physical weathering processes are of secondary importance." Of the five processes which fall into this category, (unloading, thermal expansion and contraction, crystal growth, colloid plucking, organic activity), only two, crystal growth and unloading, are especially significant. While physical weathering may not command the recognition that chemical weathering holds, it initiates an increase in available surface area of geologic materials and is therefore a prerequisite for chemical weathering (Rode, 1962). Hunt (1972) states, "the processes that cause weathering, whether mechanical, chemical or biological, depend on the entrance of water into joints or partings in the rock or into the pore spaces between mineral grains." Although water as a mechanism for all weathering may be debated, it is the foundation upon which chemical weathering proceeds. Reiche (1962) states, "Under these circumstances, hydration is a surface adsorption, and calls into play hydrolosis. It is the forerunner of all the more profound chemical alterations."

PRECIPITATION

Ideas as to the effect of precipitation on the development of soils are not new. Joffe (1936) states, "Water plays as important a role in the soil as blood does in the animal organism. Its movement through the parent material determines the features of the soil profile." Water can then be considered a factor in the rate and depth of profile development. However, under conditions of similar climate (precipitation inclusive), where organisms, topography and time are constant, parent material will ultimately determine the direction of soil development.

SPOIL AND PARENT MATERIAL

Spoil, by nature, is a heterogenous mixture of geologic material, the properties of which are determined by the proportions of various types of sedimentary rocks they contain. Grube et al. (1974), suggest that "rock type distinctions can help indicate future soil particle sizes, rates of soil development, and contribution of minerals to soil chemical properties." However, application of Grube's suggestion is rather difficult because, as Schroer (1976) has shown, the chemical and physical properties of overburden vary vertically, horizontally and between sites on the same or similar strata. Smith, Tryon and Tyner (1971), in comparing 70 to 130-year-old iron ore mine spoils to natural soils of the Morgantown, West Virginia area, concluded, "Natural soil proved superior to the old spoils in bulk densities (lower), porosity (higher), soil structure development, infiltration, nitrogen or organic matter especially near the surface, surface texture (more loamy), and smoother land surface"; while spoils were superior in "depth for plant rooting, total available water holding capacity, and certain plant nutrients." However, both materials were similar in mineralogy and pH. Sobek and Smith (1971), in examining the properties of selected barren coal mine spoils over one coal seam in West Virginia, showed mean pH values ranged from 2.8 to 5.0. Smith et al. (1974) attributed such acidic values to the oxidation of pyrite and marcasite and suggested that the presence of inherent free carbonates or the artificial maintenance of pH values of above 5.5 would either neutralize sulfuric acid formed by oxidation of pyritic sulfur, or would inhibit microbial oxidation of pyrite.

SPOIL AS SOIL

The classification of minesoils, until recently, was not considered practical. Smith et al. (1975)1/ states, "Prior to the development of the new comprehensive soil classification system by the National Cooperative Soil Survey, mine spoil was not considered to be soil." Delp (1978) states, "In the proposed system, minesoils would be classified at the order level as Entisols. Pedogenic horizons were either weak or absent in nearly all the profiles studied." Classification on the series level is highly complex because of the extreme variability in composition of parent materials (spoil) and the lack of knowledge concerning dominant genetic processes.

MINESOILS

Grube et al. (1974) states that, "an apparent deficiency of minesoils as compared to undisturbed soils, is the absence of near surface organic matter." Smith et al. (1974) notes, "Even in minesoils as old as 70 to 100 years, no recognizable illuvial clay skins have been observed." Smith, Tryon and Tyner (1971), in a study of West Virginia iron ore spoils, concluded, "Apparently, leaching, organic litter deposition on the surface, and other soil forming processes, have failed to differentiate pH horizons clearly during 70 to more than 100 years." The general conclusions are that soil forming processes, though operative, have not yet developed discernible characteristics of horizonation.

1/ A proposed revision of Modern Soil Taxonomy by Dr. Richard M. Smith, John C. Sencindiver, Charles H. Delp, and Keith O. Schmude, submitted to John Rourke, Chairman, Northeast Soil Taxonomy Committee in a letter dated November 25, 1975 from Keith O. Schmude, State Soil Scientist, Soil Conservation Service, P.O. Box 865, Morgantown, West Virginia, 26505.

DESCRIPTION OF THE AREA

LOCATION

The towns of Hanna and Elmo, Wyoming, found in T22N, R81W- 6P.M. served as a focal point around which two study areas were established. The first area was at Rosebud pits number 1 and 2, located 1.6 km west of the town of Hanna. The second area was north of the old mining town of Elmo, which lies just east of the Hanna city limits.

GEOGRAPHY

The Hanna Basin is approximately 65.6 km long, trending east to west and 41.0 km wide. It is a small intermountain basin located in south central Wyoming; delineated on the north by the Shirley, Seminoe, Freezeout and Ferris Mountains, to the south by the Snowy Range, and to the west by the Rawlins Hills. The primary drainage in the region is the north flowing North Platte River and its tributaries.

GEOLOGY

The Hanna Basin is a structural trough formed by downwarping during the Laramide orogeny, seventy million years ago. In planar view, it occupies 2,690 km^2. Though small as an intermountain basin, it is unusually deep. Sediments here lie on a crystalline basement and are estimated at between 9,231 and 10,850 m thick, with 5,580 to 6,200 m of this containing Tertiary and Cretaceous coal bearing rocks (Glass, 1972).

SOILS

Soils of the area are developing in residuum from interbedded sandstone and clay shales, with the principle associations being Ustic and Typic Torriorthents, as represented by the Blazon, Delphil and Garsid series (Young and Singleton, 1977).

CLIMATE

The Hanna Basin is an area of low precipitation, representative of many of the mining areas of the arid West. The annual precipitation is less than 24 cm, of which about half is in the form of snow. However, the effective precipitation of this region is notably less as a result of snow sublimation and high evaporation losses due to wind. The average January and July temperatures are approximately -6 and 21°C respectively, with a frost-free period of about 108 days from May 30 to September 15.

METHODS OF STUDY

SITE SELECTION

Reconnaissance activities began in early June 1977 for specific sampling sites. With the cooperation of Mr. Dave Evans, Reclamation Engineer, Rosebud Coal Sales Company, sites for sampling were selected. The University of Wyoming Agricultural Experiment Station, Laramie, Wyoming, entered into an agreement with the above company, effective 27 June 1977, which allowed the University to conduct research.

Two primary areas for sampling were established. The first area was at Rosebud pits numbers 1 and 2, located approximately 1.6 km west of the town of Hanna. The second area was north of the old mining town of Elmo, which lies several kilometers east of Hanna. These two sites were chosen since they, along with the present mining site, established a chronology for the study of soil development. From these locations spoil materials of the following ages were available: a) recent spoil from near an active dragline 0.8 km north of the old Elmo site proper; b) 16-year-old spoil from Rosebud pits numbers 1 and 2; c) 40-year-old spoil at the Elmo site proper; and, d) native undisturbed soil 0.8 km west of the Elmo site.

Further reconnaissance was conducted at the old townsite of Carbon in an effort to locate old underground mineworks and hopefully locate areas which would yield overburden material left undisturbed since the early 1900's. Several old sites were located, however, the spoil from underground mining in most all instances, was covered by a layer of slack coal and coal dust several decimeters thick. Samples of such material would not reflect the activity of soil forming processes normally associated with overburden materials.

FIELD METHODS

Sample Selection

The primary emphasis in sample selection was on sampling for pedogenic analysis. Samples for nitrate analysis were also collected.

Sampling for Pedogenic Processes

The technique of sample selection for pedogenic analysis was established by observing the relative stabilities of materials on the spoil piles. As would be expected, areas in which the native vegetation had become re-established were in a close proximity to undisturbed native range (Figure 1). Such areas were suitable for sampling since they had experienced relatively long term stability. The method of sampling on spoil materials was random with the top 15 cm of the material sampled at 2.5 cm increments and then at 15 cm increments to 60 cm where possible. However, native soils were sampled to the greatest depth obtainable (Table 1). This technique was used on the Rosebud and Elmo sites, as well as the native soils near Elmo.

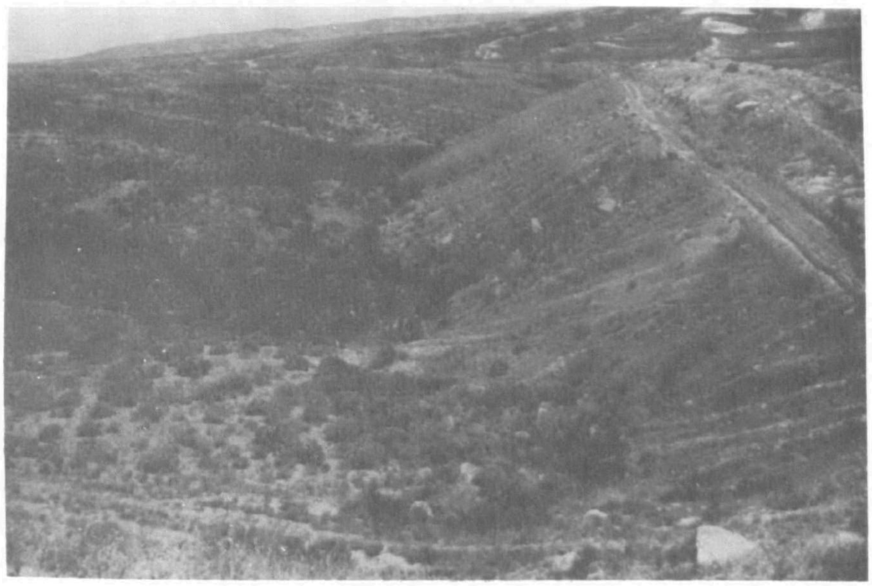

Figure 1. This picture shows an area in the vicinity of Hanna pits 1 and 2. On the right hand side can be seen undisturbed native range in contrast to sparsely vegetated minesoil on the left.

TABLE 1. MAXIMUM DEPTHS TO WHICH MATERIALS WERE SAMPLED

Sample Designation	Maximum Depth (cm)
Hanna Minesoils	
A	60
B	45
C	45
D	45
E	60
Elmo Minesoils	
I	45
II	45
III	30
IV	30
V	45
VI	30
VII	15
Elmo Native Soils	
I	80
II	80
III	80
IV	80

Samples for Nitrate Determination

This phase of sampling was conducted in response to concerns voiced over possible nitrate contamination from paleocene shales, exposed during the strip mining process.

Since most of the overburden spoil piles in the Hanna mining district are a mixture of sandstone and shale, it was necessary to seek out areas composed primarily of shales for sampling. In the areas chosen, core samples were collected in 16 cm increments to a depth of 120 cm, where possible. The samples were placed in plastic bags and refrigerated with dry ice during transport. The dry ice was to keep microoorganism activity at a minimum. The samples were then placed in an oven and dried for 48 hours at 110°C. Following drying, the samples were ground and screened through a 2 mm sieve. Duplicate samples were then analyzed for nitrate, using the procedure outlined in Øien and Olsen (1969).

LABORATORY ANALYSIS

Samples collected for pedogenic study were analyzed for texture; pHp; total soluble salts; soluble cations (Na^+, Ca^{++}, Mg^{++}, K^+); total Al_2O_3; total Na^+, Ca^{++}, Mg^{++}, K^+; organic carbon; and $CaCO_3$ equivalent.

Soil Texture

Soil texture is the size of individual soil particles; while the proportion of sand, silt and clay size fractions comprise the textural class. Both chemical and physical properties of the soil material are influenced by texture. The soil texture was determined in duplicate on materials samples from Elmo pits I-IV, Hanna A-D, and the Elmo native soil III. The method of particle size analysis was done according to Bouyoucos (1936).

Soil pHp

The pH or the logarithm of the reciprocal of the hydrogen ion concentration in gram equivalents per liter of solution, is an index of the acidic or basic nature of the soil. The pH of a soil paste (pHp) was determined with a glass electrode pH meter as outlined in USDA Handbook No. 60 (U.S. Department of Agriculture, 1954).

Total Soluble Salts

Soil pastes from the pHp determination were placed in a high pressure filter press and the soil solutions extracted. Salinity was determined by measuring millimhos conductance per cm with a Standard Wheatstone Bridge (U.S. Department of Agriculture, 1954). Since the osmotic pressure of soil solutions increases directly with the amount of salts present, it can be expressed as a function of electrical conductivity. This determination gives a good index as to the suitability of soils for plant growth.

Soluble Cations of Na^+, Ca^{++}, Mg^{++} and K^+

A measurement of the soluble cations gives an indication of the composition of the salts which are present. The method used is according to USDA Handbook No. 60, U.S. Department of Agriculture, (1954). Concentrations of soluble cations were determined with an atomic absorption spectrophotometer.

Total Al_2O_3

Analysis of total Al content may be utilized in characterizing the parent material from which a soil formed and therefore, can be used as an index of weathering. The percentage of Al_2O_3 was determined by Wyoming Analytical Laboratories of Laramie with the boron hydrate fusion method outlined in the ASTM Annual (1978).

Total Na^+, Ca^{++}, Mg^{++} and K^+

A comparison of the total amount of these bases contained in the parent rock with those contained in the weathered spoil can be used as an indicator of the impact weathering has had on the spoil materials. Total analysis was accomplished by the perchloric digestion method outlined by Pratt (1965). Concentrations of the ions were determined with an atomic absorption spectrophotometer.

Organic Carbon/Organic Matter

The presence of organic matter in a soil often can be used as an expression of soil development. Although it is usually present in relatively small amounts, it has a profound influence on the chemical, physical and biological properties of soil. The organic carbon was determined by the wet digestion method outlined in USDA Handbook No. 60 (U.S. Department of Agriculture, 1954), from which the percent organic matter was calculated.

$CaCO_3$ Equivalent

Calcium Carbonate ($CaCO_3$) is one of several alkaline-earth carbonates which exert an influence on the physical and chemical properties of soil. $CaCO_3$ was determined by the rapid titration method after Piper (1950).

RESULTS AND DISCUSSION

GENERAL

The intent of this study was to examine "Orphan Spoils" of different age to determine if any soil characteristics could be measured that might indicate whether some degree of transition from raw spoil to a developed soil has occurred with time. Orphan spoil piles that were 16 and 40 years old were chosen for the study. Both piles were chosen from the same general area in the Hanna Basin area of Wyoming in order to have as uniform conditions as possible between the two sites. However, as the study progressed, it became evident that differences existed between the spoil material in the 16-year old Hanna site and the 40 year old Elmo site. The primary differences were in texture, pH, and percentage $CaCO_3$ equivalent (Table 2). Even sampling pits within each site showed a great deal of variation in material with depth due to the heterogeniety of the overburden material of which the spoil piles were built. The overburden is material from the Hanna Geological Formation which consists of interbedded sandstones and clay shales of varying thickness and composition. Thus, one area of a spoil pile may have a very different sequence and thickness of geologic material in its profile than another area only a few feet away. In view of the inherent differences between the two sites, each site should be evaluated as independent unrelated sites.

It should also be remembered that this study is located in an area that receives approximately 23 cm (9 inches) of moisture annually. At least half of this precipitation comes in the winter in the form of snow. Most of the snow sublimates except in localized areas where vegetative barriers have caused some drifting. The rains come in the form of infrequent light showers or as short torrential downpours. With the light rains little moisture enters the soil because of evaporation and with the downpours much is lost as runoff. Also this area is subjected to strong and persistent winds which greatly increase the evapo-transpiration rate. Thus, the amount of water entering the soil yearly is at most not over 10 cm (4 inches) and this is spread over the entire year. As previously stated, exceptions may occur in localized areas where snow is trapped and slow melting occurs. The maximum depth of the root zone in the lighter textured sandy loam minesoil varied between 30 and 45 cm (12 to 18 inches) which indicates moisture does reach that depth. It is not likely that moisture reaches that depth every year due to the highly variable pattern of the precipitation from year to year.

PARTICLE SIZE

Results of textural analysis of minesoils from four 40-year-old spoil piles, four 16-year-old piles and from a native soil, all from an area near Elmo and Hanna, Wyoming are shown in Table 3.

TABLE 2. LABORATORY DATA OF THE UNWEATHERED OVERBURDEN MATERIAL FROM HANNA AND ELMO SPOIL PILES AND FROM THE ELMO NATIVE SOIL PARENT MATERIAL

Data		ELMO SPOIL	HANNA SPOIL	ELMO NATIVE SOIL
Textural class		Loam	Sandy loam	Loam
pH		5.8	7.2	7.6
$CaCO_3$ equivalent, percent		0.0	2.0	4.0
Electrical conductivity mmhos/cm		3.1	4.1	1.6
Organic matter, percent		5.5	3.9	4.7
Soluble cations:				
Calcium	meq/100g	1.16	1.13	0.23
Magnesium	" "	1.30	1.26	0.15
Sodium	" "	0.06	0.04	0.01
Potassium	" "	0.03	0.01	0.01
Total cations:				
Calcium	meq/100g	70.4	50.1	104.4
Magnesium	" "	76.2	39.9	50.2
Sodium	" "	238.8	167.3	198.1
Potassium	" "	46.3	36.8	40.9
Total Al_2O_3, percent		14.3	7.8	9.6

The undisturbed soil referred to as Elmo Native Soil III, was sampled at seven depths, the maximum being at 80 cm. Four of the samples (57%) consisted of loams while three of the samples (43%) were sandy loams. The amount of clay in the various samples ranged from 14.3 to 18.8%, the sand 46.6 to 58.0% and the silt 25.5 to 37.0%. The arithmetic mean texture was obtained over the various profile depths (Table 3), and was calculated to be a loam.

The four 40-year-old minesoils from the Elmo area, designated as Elmo I through Elmo IV, consisted of 29 observations with maximum depths ranging from 30 to 45 cm. These 29 samples consisted of one textural class (Table 3), that of a loam. The particle size analysis of the samples indicated clay ranged from 18.1 to 24.9, sand 41.3 to 50.6% and silt from 30.8 to 35.7%.

The 16-year-old minesoils in the Hanna area, designated as Hanna A through Hanna D, are represented by 32 samples with maximum depth ranging from 45 to 60 cm. Particle size data for the samples are shown in Table 3. One textural class was representative of all samples, that of a sandy loam. The particle size analysis indicated clay ranged from 11.0 to 15.3%, sand 65.0 to 70.8% and silt 16.9 to 21.7%.

An Analysis of Variance using the percent clay as the dependent variable and depth of each sampling site from 0-15 cm as the independent variable was conducted on the Hanna and Elmo minesoils (Table 4). Differences in clay content were not found to be significant with depth for the Hanna minesoil, however at the same confidence level, the Elmo minesoil showed a slight increase in clay with depth. The absence of clay staining or clay films suggests the clay differences occurred during placement of the spoil and not as a result of illuviation. Also the lower amount of clay in the surface 2½ cm may be the result of wind removal of the finer material.

TABLE 3. PERCENTAGE OF SAND, SILT AND CLAY AT VARIOUS DEPTHS IN THE PROFILE OF SEVERAL MINESOILS FROM "ORPHAN SPOIL PILES" AND A NATURAL SOIL IN THE AREAS OF HANNA AND ELMO, WYOMING

	Depth (cm)	No. samples	*% Sand	*% Silt	*% Clay	Textural class
Elmo	2.5	4	49.3	32.6	18.1	L
Minesoils	5.0	4	46.6	32.3	22.1	L
I-IV	7.5	4	45.2	35.4	19.4	L
(40-yr-old)	10.0	4	42.5	34.6	22.9	L
	12.5	4	41.3	35.7	23.0	L
	15.0	4	42.3	32.8	24.9	L
	30.0	3	43.8	33.2	23.0	L
	45.0	2	50.6	30.8	18.6	L
Elmo	2.5	1	51.3	34.4	14.3	L
(Native)	5.0	1	51.3	34.4	14.3	L
Soil	7.5	1	55.6	33.1	11.3	SL
III	10.0	1	58.0	25.5	16.5	SL
	12.5	1	50.0	31.2	18.8	L
	15.0	1	57.1	28.9	14.0	SL
	80.0	1	46.6	37.0	16.4	L
Hanna	2.5	4	70.8	18.2	11.0	SL
Minesoils	5.0	4	70.1	16.9	13.0	SL
A-D	7.5	4	68.5	18.0	13.5	SL
(16-yr-old)	10.0	4	68.6	19.1	12.3	SL
	12.5	4	67.8	19.4	12.8	SL
	15.0	4	67.0	19.7	13.3	SL
	30.0	4	65.0	19.7	15.3	SL
	45.0	3	66.0	21.7	12.3	SL
	60.0	1	-	-	-	-

*An average percentage over the number of samples for each depth.

pH SATURATED PASTE

A total of 87 pH determinations were made on field samples from three locations. The data in Table 5 show that the 16-year-old Hanna minesoil is slightly alkaline while the 40-year-old Elmo minesoil is slightly acid. These are inherent differences as shown from the overburden analysis in Table 2. It is very probable that both the Hanna and Elmo overburden contain some acid forming pyritic material, however, the Hanna overburden also contains calcium and magnesium carbonates (Table 13) which no doubt have neutralized the acidity and caused the Hanna minesoil to have a slightly alkaline reaction.

TABLE 4. ANALYSIS OF VARIANCE TABLES OF CLAY CONTENT FOR THE HANNA AND ELMO MINESOILS FROM A RANDOMIZED COMPLETE BLOCK DESIGN

Variation	DF	SS	MS	F
		Elmo Minesoil		
Sites	3	576.56	192.19	20.92
Depth	5	128.17	25.63	2.79†
Error	15	137.79	9.19	
Total	23	842.52		
		Hanna Minesoil		
Sites	3	31.29	10.43	4.43
Depth	5	16.17	3.23	1.37NS
Error	15	35.35	2.36	
Total	23	82.81		

† Significant at .10 level
NS Not significant at .10 level

TABLE 5. DIFFERENCES IN pH BETWEEN THE HANNA AND ELMO MINESOILS

Depth (cm)	Mean
HANNA	
2.5	7.75
5.0	7.79
7.5	7.71
10.0	7.66
12.5	7.64
15.0	7.54
30.0	7.44
45.0	7.13
ELMO	
2.5	6.49
5.0	6.51
7.5	6.48
10.0	6.56
12.5	6.55
15.0	6.31
30.0	6.00
45.0	5.77

TOTAL SOLUBLE SALTS AND SOLUBLE NA^{+}, CA^{++}, MG^{++} AND K^{+}

Electrical conductivity (Ec), was determined for each natural and minesoil sample obtained. An Analysis of Variance was utilized to decide if significant increases or decreases in electrical conductivity had occurred with depth in the 16- and 40-year-old minesoils (Table 6). The results indicate that a significant increase in (Ec) has occurred with depth, in the Hanna, but not the 40-year-old Elmo minesoil. To differentiate this apparent increase, Duncan's test was applied (Table 7).

TABLE 6. ANALYSIS OF VARIANCE TABLES OF ELECTRICAL CONDUCTIVITY FOR THE HANNA AND ELMO MINESOILS FROM A RANDOMIZED COMPLETE BLOCK DESIGN

Variation	DF	SS	MS	F
		Elmo Minesoil		
Sites	5	53.297	10.659	9.402
Depth	6	3.596	0.599	0.528NS
Error	30	34.012	1.134	
Total	41	90.905		
		Hanna Minesoil		
Sites	4	49.445	12.361	6.599
Depth	7	70.818	10.117	5.401**
Error	28	52.451	1.873	
Total	39	172.714		

NS Not significant at .10 level
** Significant at the .01 level

Electrical conductivity in the Hanna minesoil was found to increase significantly at the 45 cm level, indicating that conductivity was directly related to depth. After examining the data for soluble cations, this increase in electrical conductivity was suspected to be due to the migration of Ca^{++} and Mg^{++} with depth. The 16-year-old Hanna spoil was found to have a significant increase of both cations at the 45 cm depth suggesting that this depth was a zone of illuviation for Ca^{++} and Mg^{++} (Tables 8 and 9). Since it appeared that increases in Ca^{++} and Mg^{++} might be responsible for increases in electrical conductivity, a multiple regression analysis was used to construct the model ($y = .374 + .029X_1 + .069X_2$) in which electrical conductivity was the dependent variable (Y), while Ca^{++} and Mg^{++} were independent variables (X_2 and X_1 respectively (Table 10). Several things should be noted: First, the model accounted for 97% of the variation in the data. This suggests that the soluble Ca^{++} and Mg^{++} contribute more to increases in electrical conductivity than do Na^+ or K^+. Second, the ratio of partial correlation coefficients indicates that Ca^{++} contributes 1.6 times as much to the model as does Mg^{++}. The results of these tests, in conjunction with field observations for maximum rooting depth (~45 cm), indicate highest Ca^{++} and Mg^{++} concentration are occurring at or near the base of the root zone.

The seemingly anomalous situation in which salts have been leached to a lower horizon in the younger minesoil but not in the older minesoil can probably be explained by differences in texture and permeability. The younger minesoil is a sandy loam containing from 11 to 15.3% clay and is more permeable to water than the older minesoil which is a loam containing from 18.1 to 24.9% clay. Thus, the limited moisture entering these minesoils would be more effective in leaching in the lighter textured soil.

TABLE 7. DIFFERENCES IN (EC) WITH DEPTH FOR THE HANNA AND ELMO MINESOILS AS TESTED WITH DUNCAN'S NEW MULTIPLE RANGE TEST: WITH EQUAL REPLICATIONS

Depth (cm)		Mean (Ec) mmhos/cm
	HANNA	
2.5		1.59^{b**}
5.0		1.43^{b}
7.5		1.19^{b}
10.0		1.66^{b}
12.5		1.49^{b}
15.0		1.11^{b}
30.0		3.61^{ab}
45.0		5.07^{a}
	ELMO	
2.5		2.61^{a}
5.0		2.34^{a}
7.5		2.26^{a}
10.0		1.99^{a}
12.5		1.77^{a}
15.0		2.05^{a}
30.0		2.72^{a}
45.0		2.93^{a}

**Means with same letter do not differ significantly at the .01 level

TABLE 8. ANALYSIS OF VARIANCE TABLES FOR Ca^{++} AND Mg^{++} FOR THE 16-YEAR-OLD HANNA MINESOILS FROM A RANDOMIZED COMPLETE BLOCK DESIGN

Variation	DF	SS	MS	F
	Hanna Minesoil Testing the Significance of Ca^{++}			
Sites	4	3929.141	982.285	10.082**
Depth	7	5506.180	786.597	8.074**
Error	28	2727.934	97.426	
Total	39	12163.255		
	Hanna Minesoil Testing the Significance of Mg^{++}			
Sites	4	5726.063	1431.516	3.125
Depth	7	12368.105	1766.872	3.857**
Error	28	12827.738	458.133	
Total	39	30921.906		

** Significant at the .01 level

TABLE 9. DIFFERENCES IN TWO DIVALENT CATIONS WITH DEPTH, FOR THE HANNA MINESOILS AS TESTED WITH DUNCAN'S NEW MULTIPLE RANGE TEST: WITH EQUAL REPLICATIONS

Depth (cm)	Mean meq/1
Ca^{++}	
2.5	10.00 b**
5.0	9.11 b
7.5	10.46 b
10.0	15.52 b
12.5	10.61 b
15.0	12.88 b
30.0	28.02 ab
45.0	44.74 a
Mg^{++}	
2.5	7.97 b**
5.0	6.43 b
7.5	7.08 b
10.0	12.72 ab
12.5	7.82 b
15.0	9.17 b
30.0	46.84 ab
45.0	50.88 a

** Means with the same letter do not differ significantly at the .01 level

TABLE 10. MULTIPLE REGRESSION ANALYSIS OF THE 16-YEAR-OLD HANNA MINESOIL FOR ELECTRICAL CONDUCTIVITY, AS EXPLAINED BY Ca^{++} AND Mg^{++}

Regression Coefficient for Mg (X_1)	$B_1 = .029$
Regression Coefficient for Ca (X_2)	$B_2 = .069$
Constant	$B_0 = .374$
Model	$Y = .374 + .029X_1 + .069X_2$
Partial Regression Coefficient Mg	$B_1' = .380$
Partial Regression Coefficient Ca	$B_2' = .606$
Ratio B_2'/B_1'	1.59
Coefficient of Determination	$r^2 = .972$
Multiple Correlation Coefficient	$r = .986$

SOLUBLE K^+ AND BIOCYCLING

Schafer et al. (1978), has recently indicated that biocycling of K^+ is occurring in minesoils. To determine if significant increases in K^+ were occurring in the surface of the Hanna and Elmo minesoils, an Analysis of Variance was again utilized (Table 11). In both the 16- and 40-year-old minesoils, K^+ significantly decreased with depth. To isolate at what depth K^+ was significantly higher, Duncan's test was applied (Table 12). K^+ was

TABLE 11. ANALYSIS OF VARIANCE TABLES OF THE K^+ CONTENT FOR THE HANNA AND ELMO MINESOILS FROM A RANDOMIZED COMPLETE BLOCK DESIGN

Variation	DF	SS	MS	F
		Elmo Minesoil		
Sites	3	7.053	2.351	18.050
Depth	5	3.574	0.715	5.487**
Error	15	1.954	0.130	
Total	23	12.581		
		Hanna Minesoil		
Sites	3	0.835	0.278	0.629
Depth	5	13.121	2.624	5.930**
Error	15	6.637	0.442	
Total	23	20.593		

** Significant at .01 level

TABLE 12. DIFFERENCES IN (K^+) WITH DEPTH FOR THE ELMO AND HANNA MINESOILS AS TESTED WITH DUNCAN'S NEW MULTIPLE RANGE TEST: WITH EQUAL REPLICATIONS

Depth (cm)		Mean (K^+) meq/l
	Elmo K^+	
2.5		2.02 a **
5.0		1.41 ab
7.5		1.19 b
10.0		0.94 b
12.5		0.94 b
15.0		0.96 b
	Hanna K^+	
2.5		2.66 a **
5.0		1.61 ab
7.5		0.95 b
10.0		0.86 b
12.5		0.62 b
15.0		0.52 b

** Means with same letter do not differ significantly at the .01 level significantly higher in both minesoils for the top 2.5 cm. These did not differ significantly from the 5-cm depth; however, all other depths were significantly lower in K^+, in comparison to the 2.5-cm level. Thus, it appears that K^+ enrichment is occurring at the surface of both minesoils.

TOTAL Al_2O_3 AND TOTAL Na^+, Ca^{++}, Mg^{++}, K^+

In this analysis, four Elmo minesoils, two Hanna minesoils, and the Elmo Native Soil III were examined. The percentage of each constituent was then changed to molecular values (App. Ia and Ib) by dividing percentage data by the molecular weights, in a method outlined by Jenny (1941). Jenny states that "stoichiometric relationships are more clearly brought out by molecular data than by weight figures." Using Jenny's method, an index of relative weathering rates was established utilizing ba_1 and beta values (App. Ic). A beta value of unity indicates that no loss of the monovalent cations of Na^+ and K^+ has occurred with respect to aluminum. These values were not interpretated since: 1) surface materials could not be positively identified as having originated from materials below; and 2) to obtain meaningful beta values, parent material should be in a relatively less decomposed state, which was not the case in samples obtained.

ORGANIC CARBON

Both the Hanna and Elmo minesoils were found to be higher in organic carbon than the Elmo Native Soil III (App. IIa and IIb), with the Elmo minesoils having highest organic carbon content of the three. Although several values in the data would indicate an increase of organic carbon in the surface layers of minesoils, no overall trends were apparent when the data were considered as a whole. However, the native soils does have a layer of enrichment at the surface which decreased with depth, then increased again to a maximum content at 80 cm. During field examination, minesoils were noted to be mixed with very fine coal dust which conceivably has confounded the presence of organic matter accumulation at the surface. Flecks of coal carbon in the native soil at 80 cm could also account for the increase in carbon at that depth.

$CaCO_3$ EQUIVALENT

Elmo minesoils were, in every case, devoid of $CaCO_3$. The Elmo Native Soil III was found to contain 4% $CaCO_3$ at 80.0 cm, but 0% $CaCO_3$ from 0-15 cm depth (Table 13). The lack of carbonates in the native soil is most likely due to the effects of leaching, as well as organic acids acting over a long span of time. The increase at 80 cm suggests a zone of $CaCO_3$ accumulation generally found in semiarid climates. Many old Aridisols contain illuvial horizons that have developed under much wetter climatic regimes than have occurred in recent geologic time. However, the difference in $CaCO_3$ between the Hanna and Elmo minesoils is due to the variation of $CaCO_3$ in the overburden material (Table 2).

TABLE 13. $CaCO_3$ EQUIVALENT PERCENTAGE FOR THE HANNA AND ELMO MINESOILS AND THE ELMO NATIVE SOIL

Depth (cm)	Mean % $CaCO_3$
Hanna Minesoil	
2.5	1.06
5.0	1.13
7.5	1.13
10.0	1.50
12.5	1.19
15.0	1.06
30.0	1.38
45.0	2.00
60.0	2.38
Elmo Minesoil	
2.5	0
5.0	0
7.5	0
10.0	0
12.5	0
15.0	0
30.0	0
45.0	0
Elmo Native Soil	
2.5	0
5.0	0
7.5	0
10.0	0
12.5	0
15.0	0
80.0	4.0

NITRATES

To determine if shales weathering in 16- and 40-year-old minesoils contained an excess of No_3-N, a standard for arable dryland soils of 2 - 60 ppm Russell (1973) was used as a comparison (Table 14). All samples except those of Hanna Pit 1-B, fell within acceptable limits. However, the nitrate values in Pit 1-B were very high, averaging 263 ppm. The actual influence of the extreme values found here is of questionable importance, as the total volume of material represented is unknown. Generally, it can be concluded that: 1) nitrates are decreasing in both quantity and variability between samples with increasing age; and 2) though minesoils are higher in No_3-N than in native soils, they appear to fall within acceptable limits as established for arable soils.

TABLE 14. A COMPARISON OF NO_3-N IN THE HANNA 16-YEAR-OLD MINESOIL, ELMO 40-YEAR-OLD MINESOIL AND ELMO NATIVE SOIL III

Area	No. Samples	*NO_3-N (ppm)	sd
Elmo minesoil	17	27.05	17.87
Hanna minesoil	33	33.67	27.79
Elmo Native Soil-III	25	5.43	1.32
Hanna Pit 1-B	8	263.60	99.38

* The mean value for the total NO_3-N ppm in an area over the number of samples

SODIUM

Sodium absorption ratios (SAR) were calculated from data contained in appendices IVa and IVb pertaining to soluble Ca, Mg, and Na. SAR values are used to point out problem soils with respect to sodium. Soil materials being considered for "topsoiling" in disturbed areas are rated good with respect to sodium content if the SAR values are 6.0 or less. Those materials with SAR values of 15.0 or higher are considered unfavorable for "topsoil" use because of potential management problems. As can be noted in Table 15 the SAR values of the Hanna and Elmo minesoils are very favorable ranging from 0.19 to 2.01. Thus, no sodium problem exists in the minesoils studies.

OTHER DATA

Saturation percentages of all samples are contained in Appendix IIIa and IIIb. Soluble cations expressed in both milliequivalents per liter and milliequivalents per 100 grams are shown in Appendix IVa and IVb.

TABLE 15. SODIUM ABSORPTION RATIOS FOR THE HANNA AND ELMO MINESOILS

Depth	Mean Value
Hanna	
2.5	1.82
5.0	2.01
7.5	0.86
10.0	0.78
12.5	0.90
15.0	0.67
30.0	0.34
45.0	0.19
Elmo	
2.5	0.69
5.0	0.61
7.5	0.57
10.0	0.38
12.5	0.38
15.0	0.35
30.0	0.26
45.0	0.30

SUMMARY

The objectives of this study were to determine:

1) If measurable changes have occurred in the profile of minesoils during their brief time of exposure to pedogenic processes.

2) The nitrate content of different age minesoils and native soil.

Minesoils from two areas were studied. Sixteen-year-old minesoils were obtained from Rosebud Mine Pits 1 and 2, while 40-year-old minesoils and native soils were collected north of Elmo, Wyoming. Both sites are in the same area of the Hanna mining district in Wyoming.

The samples were subjected to a chemical assay of 14 separate determinations and textural analysis. This data was then evaluated where possible using Analysis of Variance and Duncan's New Multiple Range Test.

In general very little evidence was detected to show that measurable soil development has occurred. Two factors showing evidence of change in the raw spoil was movement of soluble salts in the profile and the accumulation of K in the upper 5 cm of the profile probably due to biocycling.

Nitrates and sodium were found not to be a problem in the minesoils investigated.

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APPENDIX Ia. MOLECULAR VALUES[1/] FOR
Al_2O_3 OF THE HANNA AND ELMO MINESOILS AND ELMO NATIVE SOIL

Area	Depth (cm)	Molecular Value Al_2O_3*
Elmo I	0-5	.150
	5-10	.155
	10-15	.150
	PM	.138
Elmo II	0-5	.136
	5-10	.143
	10-15	.150
	PM	.135
Elmo III	0-5	.124
	5-10	.130
	10-15	.141
	PM	.149
Elmo IV	0-5	.122
	5-10	.122
	10-15	.128
	PM	.137
Elmo Native Soil III	0-5	.099
	5-10	.103
	10-15	.119
	PM	.094
Hanna-A	0-5	.076
	5-10	.087
	10-15	.083
	PM	.077
Hanna-B	0-5	.060
	5-10	.073
	10-15	.077
	PM	.075

* Average of two laboratory determinations.
1/ Molecular value equals percentage divided by molecular wt, i.e. moles Al_2O_3/100g soil material.

APPENDIX Ib. MOLECULAR VALUES[1/] FOR
CaO, MgO, Na_2O and K_2O OF THE HANNA AND ELMO MINESOIL AND ELMO NATIVE SOIL

	Depth (cm)	Molecular Value for Total*			
		CaO	MgO	Na_2O	K_2O
Elmo I	0-5	.010	.026	.112	.022
	5-10	.013	.026	.097	.024
	10-15	.013	.027	.074	.026
	PM	.078	.073	.175	.026
Elmo II	0-5	.075	.087	.201	.028
	5-10	.011	.026	.091	.023
	10-15	.013	.024	.090	.023
	PM	.022	.030	.103	.022
Elmo III	0-5	.012	.028	.104	.023
	5-10	.018	.031	.089	.025
	10-15	.014	.030	.086	.024
	PM	.025	.025	.103	.021
Elmo IV	0-5	.016	.022	.062	.020
	5-10	.020	.028	.073	.023
	10-15	.021	.027	.085	.023
	PM	.015	.026	.097	.023
Elmo Native Soil II	0-5	.018	.025	.069	.022
	5-10	.016	.023	.090	.021
	10-15	.019	.029	.090	.022
	PM	.052	.025	.099	.020
Hanna-A	0-5	.037	.022	.105	.019
	5-10	.031	.022	.086	.020
	10-15	.029	.024	.089	.020
	PM	.022	.019	.085	.017
Hanna-B	0-5	.018	.015	.063	.018
	5-10	.019	.016	.072	.019
	10-15	.019	.018	.081	.021
	PM	.028	.021	.082	.020

* An average of two laboratory determinations.

1/ Molecular value equals percentage divided by molecular weight, i.e. moles/100g soil material.

APPENDIX Ic. ba_1 VALUES AND BETA VALUES[1/] FOR THE HANNA AND ELMO MINESOILS AND ELMO NATIVE SOIL

	Depth (cm)	ba_1	Beta
Elmo I	0-5	0.893	0.613
	5-10	0.781	0.536
	10-15	0.667	0.458
	PM	1.457	---
Elmo II	0-5	1.684	1.819
	5-10	0.797	0.861
	10-15	0.753	0.813
	PM	0.926	---
Elmo III	0-5	1.024	1.231
	5-10	0.877	1.054
	10-15	0.780	0.938
	PM	0.832	---
Elmo IV	0-5	0.672	0.767
	5-10	0.787	0.898
	10-15	0.844	0.963
	PM	0.876	---
Elmo Native Soil III	0-5	0.919	0.726
	5-10	1.078	0.852
	10-15	0.941	0.743
	PM	1.266	---
Hanna-A	0-5	1.632	1.232
	5-10	1.218	0.919
	10-15	1.313	0.991
	PM	1.325	---
Hanna-B	0-5	1.350	0.993
	5-10	1.247	0.917
	10-15	1.325	0.974
	PM	1.360	---

1/ Jenny 1941. $ba_1 \text{ value} = \frac{Na_2O + K_2O}{Al_2O_3}$. All expressed as molecular values.

$\beta \text{ value} = \frac{ba_1 \text{ weathered layer}}{ba_1 \text{ parent material}}$

APPENDIX IIa. HANNA MINESOIL, ORGANIC MATTER AND ORGANIC CARBON

Hanna Spoil	Depth (cm)	% Organic Matter*	% Organic Carbon*
A_1	2.5	3.19	1.85
A_2	5.0	3.16	1.83
A_3	7.5	5.30	3.07
A_4	10.0	5.55	3.22
A_5	12.5	5.55	3.22
A_6	15.0	5.86	3.40
A_{12}	30.0	5.90	3.42
A_{18}	45.0	4.64	2.69
A_{24}	60.0	3.34	1.94
B_1	2.5	3.24	1.88
B_2	5.0	3.99	2.32
B_3	7.5	3.87	2.25
B_4	10.0	3.53	2.05
B_5	12.5	4.15	2.40
B_6	15.0	4.23	2.45
B_{12}	30.0	6.32	3.67
B_{18}	45.0	4.49	2.60
C_1	2.5	6.00	3.48
C_2	5.0	5.34	3.09
C_3	7.5	6.07	3.52
C_4	10.0	5.93	3.44
C_5	12.5	5.28	3.06
C_6	15.0	4.83	2.80
C_{12}	30.0	4.59	2.66
C_{18}	45.0	4.84	2.81
D_1	2.5	7.18	4.16
D_2	5.0	4.61	2.67
D_3	7.5	3.53	2.05
D_4	10.0	3.24	1.88
D_5	12.5	2.76	1.60
D_6	15.0	2.68	1.55
D_{12}	30.0	3.21	1.86
D_{18}	45.0	3.00	1.74

* An average of two laboratory determinations.

APPENDIX IIb. ELMO MINESOIL, ORGANIC MATTER AND ORGANIC CARBON

Elmo Spoil	Depth (cm)	% Organic Matter*	% Organic Carbon*
I_1	2.5	5.35	3.11
I_2	5.0	5.04	2.93
I_3	7.5	5.15	2.99
I_4	10.0	4.71	2.74
I_5	12.5	4.59	2.66
I_6	15.0	4.62	2.68
I_{12}	30.0	4.67	2.71
I_{18}	45.0	5.43	3.14
II_1	2.5	6.66	3.86
II_2	5.0	6.23	3.61
II_3	7.5	5.92	3.43
II_4	10.0	5.80	3.36
II_5	12.5	5.24	3.04
II_6	15.0	5.58	3.23
II_{12}	30.0	5.70	3.30
II_{18}	45.0	5.79	3.36
III_1	2.5	6.40	3.71
III_2	5.0	6.38	3.70
III_3	7.5	6.30	3.65
III_4	10.0	6.49	3.76
III_5	12.5	6.05	3.51
III_6	15.0	5.58	3.23
III_{12}	30.0	4.90	2.84
IV_1	2.5	6.51	3.77
IV_2	5.0	6.66	3.86
IV_3	7.5	6.35	3.68
IV_4	10.0	6.35	3.68
IV_5	12.5	6.45	3.74
IV_6	15.0	5.96	3.45
IV_{12}	30.0	5.82	3.38
Elmo III Native Soil, Organic Matter and Organic Carbon			
III1	2.5	4.19	2.43
III2	5.0	2.29	1.19
III3	7.5	1.72	1.00
III4	10.0	1.48	0.86
III5	12.5	2.25	1.31
III6	15.0	3.07	1.78
PM=80		4.67	2.71

* An average of two laboratory determinations.

APPENDIX IIIa. MOISTURE SATURATION PERCENTAGES FOR ELMO MINESOIL SAMPLES

#	Can wt Gr	Can + 25g Paste Gr	Can + 25g Ovendried	Δ Gr	Δ x 100 Gr	(Can + od) - (Can) Gr	Sat %
I_1	22.38	47.38	39.86	7.52	752	17.48	43.02
I_2	22.54	47.54	40.03	7.51	751	17.49	42.94
I_3	22.74	47.74	39.27	8.47	847	16.53	51.24
I_4	22.97	47.97	39.18	7.79	779	16.21	48.06
I_5	22.00	47.00	39.63	7.37	737	17.63	41.80
I_6	22.58	47.58	40.28	7.30	730	17.70	41.24
I_{12}	22.78	47.78	39.97	7.81	781	17.19	45.43
I_{18}	21.72	46.72	38.56	8.16	816	16.84	48.46
II_1	21.68	46.68	38.35	8.33	833	16.67	49.97
II_2	22.23	47.23	40.05	7.18	718	17.82	49.29
II_3	22.32	47.32	40.35	6.97	697	18.03	38.66
II_4	22.61	47.61	39.62	7.99	799	17.01	46.97
II_5	22.49	47.49	39.53	7.96	796	17.04	46.71
II_6	22.49	47.49	40.27	7.22	722	17.78	40.61
II_{12}	21.35	47.35	39.70	7.65	765	17.35	44.09
II_{18}	21.67	46.67	38.92	7.75	775	17.25	44.93
III_1	22.57	47.57	40.20	7.37	737	17.63	41.80
III_2	22.87	47.87	40.12	7.75	775	17.25	44.93
III_3	22.53	47.53	38.31	9.22	922	15.78	58.43
III_4	22.72	47.72	38.83	8.89	889	16.11	55.18
III_5	22.26	47.26	39.09	8.17	817	16.83	48.54
III_6	22.85	47.85	38.73	9.12	912	15.88	57.43
III_{12}	22.50	47.50	39.21	8.29	829	16.71	49.61
IV_1	22.20	47.20	38.80	8.40	840	16.60	50.60
IV_2	22.50	47.50	39.29	8.21	821	16.79	48.90
IV_3	22.42	47.42	39.12	8.30	830	16.70	49.70
IV_4	21.78	46.78	38.00	8.78	878	16.22	54.13
IV_5	22.02	47.02	38.24	8.78	878	16.22	54.13
IV_6	22.10	47.10	37.51	9.59	959	15.41	62.23
IV_{12}	22.58	47.58	39.27	8.31	831	16.69	49.79

#	Can wt Gr	Can + 25g Paste Gr	Can + 25g Ovendried	Δ Gr	Δ x 100 Gr	(Can + od) - (Can) Gr	Sat %
V_1	22.51	47.51	39.45	8.06	806	16.94	47.58
V_2	22.57	47.57	39.81	7.76	776	17.24	45.01
V_3	22.44	47.44	39.15	8.29	829	16.71	49.61
V_4	22.68	47.68	39.90	7.78	778	17.22	45.18
V_5	21.84	46.84	38.95	7.89	789	17.11	46.11
V_6	22.75	47.75	39.52	8.23	823	16.77	49.08
V_{12}	22.55	47.55	39.89	7.66	766	17.34	44.18
V_{18}	22.04	47.04	38.69	8.35	835	16.65	50.15
VI_1	22.28	47.38	39.93	7.45	745	17.55	42.45
VI_2	22.86	47.86	40.63	7.23	723	17.77	40.69
VI_3	22.20	47.20	39.76	7.44	744	17.56	42.37
VI_4	22.25	47.25	39.39	7.86	786	17.14	45.86
VI_5	22.22	47.22	39.44	7.78	778	17.22	45.18
VI_6	22.45	47.45	39.87	7.58	758	17.42	43.51
VI_{12}	22.56	47.56	39.44	8.12	812	16.88	48.10
VII_1	21.82	46.82	38.55	8.27	827	16.73	49.43
VII_2	22.35	47.35	39.63	7.72	772	17.28	44.68
VII_3	21.83	46.83	39.24	7.59	759	17.41	43.60
VII_4	22.83	47.83	39.75	8.08	808	16.92	47.75
VII_5	22.65	47.65	40.13	7.52	752	17.48	43.02
VII_6	22.55	47.55	30.18	7.37	737	17.63	41.80

APPENDIX IIIb. MOISTURE SATURATION PERCENTAGES FOR HANNA MINESOIL SAMPLES

#	Can wt	Can + 25g Paste	Can + 25g Ovendried	Δ	Δ x 100	(Can + oil) - (can)	Sat %
A_1	21.82	46.82	41.29	5.53	553	19.47	28.40
A_2	22.54	47.54	42.00	5.54	554	19.46	28.47
A_3	22.79	47.79	41.41	6.38	638	18.62	34.26
A_4	22.05	47.05	41.13	5.92	592	19.08	31.03
A_5	22.03	47.03	40.85	6.18	618	18.82	32.84
A_6	22.61	47.61	41.20	6.41	641	18.59	34.48
A_{12}	22.84	47.84	41.82	6.02	602	18.98	31.72
A_{18}	22.47	47.47	41.78	5.69	569	19.31	29.47
A_{24}	23.06	48.06	42.66	5.40	540	19.60	27.55
B_1	21.67	46.67	41.04	5.66	566	19.34	29.27
B_2	22.26	47.26	41.27	5.99	599	19.01	31.51
B_3	22.37	47.37	41.64	5.73	573	19.27	29.74
B_4	22.64	47.64	41.96	5.68	568	19.32	29.40
B_5	22.54	47.54	41.60	5.94	594	19.06	31.16
B_6	22.52	47.52	41.93	5.59	559	19.41	28.80
B_{12}	22.39	47.39	31.13	6.26	626	18.74	33.40
B_{18}	21.70	46.70	40.83	5.87	587	19.13	30.68
C_1	22.54	47.54	41.45	6.09	609	18.91	32.31
C_2	22.83	47.83	41.72	6.11	611	18.89	32.25
C_3	22.52	47.52	41.71	5.81	581	19.19	30.28
C_4	22.71	47.71	41.59	6.12	612	18.88	32.42
C_5	22.25	47.25	41.83	5.42	542	19.58	27.68
C_6	22.69	47.69	41.90	5.79	579	19.21	30.14
C_{12}	22.50	47.50	41.75	5.75	575	19.25	28.87
C_{18}	23.00	48.00	42.71	5.29	529	19.71	26.84
D_1	22.20	47.20	40.48	6.72	672	18.28	36.76
D_2	22.48	47.48	41.15	6.33	633	18.67	33.90
D_3	22.43	47.43	41.03	6.40	640	18.60	34.41
D_4	21.78	46.78	39.88	6.90	690	18.10	38.12
D_5	22.08	47.08	41.15	5.93	593	19.07	31.10
D_6	22.13	47.13	40.47	6.66	666	18.34	36.31
D_{12}	22.59	47.59	41.47	6.12	612	18.88	32.42
D_{18}	22.51	47.51	41.35	6.16	616	18.84	32.70
E_1	21.50	46.50	41.39	5.11	511	19.89	25.69
E_2	22.46	47.46	41.11	6.35	635	18.65	34.05
E_3	22.52	47.52	40.93	6.59	659	18.41	35.80
E_4	22.00	47.00	40.15	6.85	685	18.15	37.74
E_5	22.09	47.09	40.26	6.83	683	18.17	37.59
E_6	22.47	47.47	39.85	7.62	762	17.38	43.84
E_{12}	22.42	47.42	40.56	6.86	686	18.14	37.82
E_{18}	22.64	47.64	40.93	6.71	671	18.29	36.69
E_{24}	22.04	47.04	41.32	5.72	572	19.28	29.67

APPENDIX IVa. SOLUBLE CATIONS IN ELMO MINESOIL SAMPLES

#	Na Meq/L	Na Meq/100g	Ca Meq/L	Ca Meq/100g	Mg Meq/L	Mg Meq/100g	K- Meq/L	K- Meq/100g
I_1	1.17	.05	6.19	.27	5.21	.22	1.27	.05
I_2	1.12	.05	5.00	.21	4.04	.17	.96	.04
I_3	.43	.02	3.11	.16	3.00	.15	.77	.04
I_4	.54	.03	4.86	.23	3.81	.20	.65	.03
I_5	.64	.03	5.51	.23	4.17	.17	.47	.02
I_6	1.30	.05	11.65	.48	9.10	.38	.83	.03
I_{12}	1.08	.04	26.91	1.11	34.92	1.43	.56	.02
I_{18}	1.16	.06	27.09	1.31	30.15	1.46	.63	.03
II_1	2.88	.14	12.65	.63	11.04	.55	2.78	.14
II_2	1.54	.06	5.63	.23	5.10	.21	1.10	.05
II_3	1.49	.06	3.60	.14	2.85	.11	.78	.03
II_4	1.04	.05	5.10	.24	3.87	.18	.66	.03
II_5	1.01	.05	5.99	.23	3.40	.16	.49	.02
II_6	1.25	.05	20.00	.81	7.10	.29	.62	.03
II_{12}	1.79	.08	31.34	1.38	34.04	1.50	.81	.04
II_{18}	2.20	.10	26.36	1.18	37.92	1.70	.89	.04
III_1	1.74	.07	14.05	.59	12.60	.53	1.16	.05
III_2	1.01	.05	8.73	.39	8.71	.39	1.08	.05
III_3	.62	.04	5.09	.30	5.08	.30	.76	.04
III_4	.54	.03	5.34	.29	6.52	.36	.78	.04
III_5	.87	.04	6.16	.30	6.40	.31	.99	.05
III_6	.42	.02	3.85	.22	4.50	.26	.68	.04
III_{12}	.64	.03	25.33	1.25	23.71	1.18	.38	.02
IV_1	4.78	.24	25.81	1.31	28.46	1.44	2.87	.15
IV_2	4.95	.24	27.00	1.32	35.12	1.72	2.48	.12
IV_3	5.27	.26	31.32	1.55	38.75	1.93	2.46	.12
IV_4	2.95	.16	25.44	1.38	31.21	1.69	1.67	.09
IV_5	2.41	.13	25.11	1.36	28.94	1.57	1.82	.10
IV_6	2.12	.13	23.79	1.48	27.75	1.73	1.72	.11
IV_{12}	.97	.05	17.60	.88	20.13	1.00	.46	.02

APPENDIX IVb. SOLUBLE CATIONS IN HANNA MINESOIL SAMPLES

#	Na Meq/L	Na Meq/100g	Ca Meq/L	Ca Meq/100g	Mg Meq/L	Mg Meq/100g	K- Meq/L	K- Meq/100g
A_1	14.52	.41	4.55	.13	4.21	.12	2.67	.08
A_2	8.36	.24	4.60	.13	3.50	.10	1.58	.05
A_3	7.72	.26	5.45	.19	3.52	.12	.94	.03
A_4	8.47	.26	9.56	.30	6.40	.20	.86	.03
A_5	7.39	.24	8.33	.27	7.58	.25	.74	.02
A_6	5.54	.19	10.54	.36	9.29	.32	.41	.01
A_{12}	1.53	.05	31.71	1.01	136.75	4.34	.48	.02
A_{18}	2.07	.06	62.99	1.86	100.83	2.97	.52	.02
A_{24}	1.67	.05	57.30	1.58	84.25	2.32	.55	.02
B_1	.39	.01	6.45	.19	3.44	.10	.96	.03
B_2	1.29	.04	5.53	.17	4.06	.13	.94	.03
B_3	.37	.01	5.11	.15	2.23	.07	.92	.03
B_4	.45	.01	4.58	.14	1.88	.06	.95	.03
B_5	.57	.02	5.43	.17	2.00	.06	.86	.03
B_6	.40	.01	6.26	.18	2.35	.07	.76	.02
B_{12}	2.45	.08	27.41	.92	18.42	.62	1.01	.03
B_{18}	.92	.03	19.73	.61	13.00	.40	.62	.02
C_1	9.93	.32	31.50	1.02	26.94	.87	4.35	.14
C_2	4.33	.14	25.73	.83	19.06	.62	1.61	.05
C_3	2.82	.09	32.20	.98	24.29	.74	.50	.02
C_4	4.10	.13	44.45	1.44	45.33	1.47	.82	.03
C_5	2.07	.06	30.96	.86	24.60	.68	.32	.01
C_6	2.39	.07	30.93	.93	24.73	.75	.66	.02
C_{12}	1.40	.04	34.86	1.01	28.60	.83	.32	.01
C_{18}	1.15	.03	48.70	1.31	54.42	1.46	.29	.01
D_1	.64	.02	5.00	.18	3.37	.12	2.65	.10
D_2	.70	.02	4.08	.14	2.40	.08	2.31	.08
D_3	.93	.03	3.50	.12	2.15	.07	1.43	.05
D_4	.77	.03	3.58	.14	1.85	.07	.81	.03
D_5	1.42	.04	3.73	.12	2.15	.07	.55	.02
D_6	2.09	.08	3.91	.14	2.13	.08	.23	.01
D_{12}	4.62	.15	5.61	.18	3.90	.13	.24	.01
D_{18}	1.80	.06	20.51	.67	30.40	.99	.22	.01
E_1	1.90	.05	2.50	.06	1.90	.05	1.70	.04
E_2	1.36	.05	5.63	.19	3.13	.11	.65	.02
E_3	1.03	.04	6.04	.12	3.23	.12	.29	.01
E_4	.87	.03	15.44	.58	8.12	.31	.20	.01
E_5	2.29	.09	4.59	.17	2.75	.10	1.40	.05
E_6	.77	.03	12.75	.56	7.35	.32	.13	.01
E_{12}	.46	.02	40.50	1.53	46.56	1.76	.20	.01
E_{18}	.70	.03	71.76	2.63	55.77	2.05	.24	.01
E_{24}	.97	.03	50.69	1.50	48.60	1.44	.30	.01

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

1. REPORT NO. EPA-600/7-79-253	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE SOIL DEVELOPMENT AND NITRATES IN MINESOIL		5. REPORT DATE December 1979 issuing date
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) P. C. Singleton, D. A. Barker		8. PERFORMING ORGANIZATION REPORT NO. CR-8
9. PERFORMING ORGANIZATION NAME AND ADDRESS Wyoming Argricultural Experiment Station, University of Wyoming, P. O. Box 3354 -University Station, Laramie, Wyoming 82071		10. PROGRAM ELEMENT NO. INE 623
		11. CONTRACT/GRANT NO. 684-15-35, EPA-IAG D6-E762
12. SPONSORING AGENCY NAME AND ADDRESS Industrial Environmental Research Lab. - Cinn, OH, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final Aug. 1976 to Sept 1978
		14. SPONSORING AGENCY CODE EPA/600/12

15. SUPPLEMENTARY NOTES This project is part of the EPA planned and coordinated Federal Interagency Energy/Environment R & D Program in Cooperation with USDA, SEA-CR.

16. ABSTRACT

Samples of minesoils from 16- and 40-year-old mine spoil piles were analyzed in the laboratory for various chemical and physical properties to ascertain to what extent the material have been influenced by pedogenic processes during their relatively brief time of exposure. Nitrate levels in the minesoils were also measured to determine if a potential hazard exists. Results of the study indicated that both the 16- and 40-year-old materials showed signs of incipient soil development. The data also showed that nitrate levels in the minesoils are higher than in adjacent undisturbed native soils. In general however, the levels in the minesoil still are within the range normally expected for arable soils. It also appears that the nitrate level in the minesoil decreases with time of exposure.

This report was submitted in fulfillment of Contract No. 684-15-35 by the University of Wyoming under the sponsorship of the U. S. Environmental Protection Agency. This report covers the period August 7, 1976 to September 30. 1978.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Soils	Pedogenic processes	13B
Coal	Wyoming	
Coal Mines	Overburden	
Spoil	Hanna Basin	
Nitrate	S.A.R.	

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 52
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

U S GOVERNMENT PRINTING OFFICE 1980-657-146/5524