



Minesoil resources in the Northern Great Plains: characterization, evaluation and potential
by William Morgan Schafer

A thesis submitted in partial fulfillment of the requirements for the degree of DOCTOR OF
PHILOSOPHY in Soil Science

Montana State University

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Abstract:

Coal extraction, which is increasing in the Northern Great Plains region, drastically alters the physical and biological nature of a region. In order to evaluate the impacts of mining upon soil resources, the potential of soils before mining must be compared to the potential of minesoils created during the reclamation process.

This study was aimed at evaluating minesoils in the Northern Great Plains constructed after passage of recent reclamation laws (1973-present). The patterns of variability in minesoils was compared to that in natural soils to see how minesoils could best be mapped. Thirteen new soil series were drafted to map nearly 2,200 acres of mined land. Several specific and unique management problems were found in minesoils. The Soil Taxonomy was not able to adequately classify minesoils so soil phases were liberally employed. Regional trends in both spoil and topsoil quality were identified and were related to Paleocene depositional environments, and to differences in soil development. Two systems of interpreting the uses or potentials of soils were applied to minesoils. These systems included the Land Capability Classification system and the Soil Potential Index system. The youngest minesoils studied had Soil Potential Index and Land Capability Classification ratings consistently better than older minesoils indicating that recent reclamation standards have led to improving minesoil quality.

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by

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of the requirements for the degree

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ABSTRACT

Coal extraction, which is increasing in the Northern Great Plains region, drastically alters the physical and biological nature of a region. In order to evaluate the impacts of mining upon soil resources, the potential of soils before mining must be compared to the potential of minesoils created during the reclamation process.

This study was aimed at evaluating minesoils in the Northern Great Plains constructed after passage of recent reclamation laws (1973-present). The patterns of variability in minesoils was compared to that in natural soils to see how minesoils could best be mapped. Thirteen new soil series were drafted to map nearly 2,200 acres of mined land. Several specific and unique management problems were found in minesoils. The Soil Taxonomy was not able to adequately classify minesoils so soil phases were liberally employed. Regional trends in both spoil and topsoil quality were identified and were related to Paleocene depositional environments, and to differences in soil development. Two systems of interpreting the uses or potentials of soils were applied to minesoils. These systems included the Land Capability Classification system and the Soil Potential Index system. The youngest minesoils studied had Soil Potential Index and Land Capability Classification ratings consistently better than older minesoils indicating that recent reclamation standards have led to improving minesoil quality.

CHAPTER I

INTRODUCTION

Strippable coal deposits underlay 2.6 million acres of land in the Northern Great Plains. If energy demands grow as expected, approximately 100,000 acres will be mined in this region by the year 2000. Loss of productivity from this land area would have a small impact on region-wide agricultural production (NGPRP, 1975), however, impacts on local economy and on long-term productivity would be more significant. This loss of productivity coupled with public environmental concern makes rehabilitation of mined land a key issue in energy resource development.

The coal extraction process drastically alters the physical and biological nature (ecosystem) of a mine area. Rehabilitation of mined land is impossible without an understanding of geologic, hydrologic, biologic, and edaphic processes operating in unmined landscapes. In addition, the characteristics of mine spoil must be well understood. Rehabilitation procedures are also dependent on the intended post mining use of mined land. Dominant land uses in the Northern Great Plains include 1) pasture and rangeland (69%), 2) dryland agriculture (25%), 3) forest and woodland (4%), 4) urban (1%), and 5) irrigated cropland (1%) (NGPRP, 1975). The potential

may exist, through mining, of creating land resources designed to satisfy local needs such as stock-water impoundments, irrigated agriculture, quality pastureland, or urban development. Before these goals can be achieved, however, more knowledge about pre- and post-mine landscapes are needed.

A typical unmined landscape in the Northern Great Plains consists of 20 to 150 feet of weakly cemented sandstone, siltstone, and shale in varying amounts overlying a thick coal seam; a moderately developed soil immediately below the land surface formed during a 10,000 year period; and a plant community which has developed in response to the climate, soil, and grazing history at that location. After mining, this same area will consist of a rolling topography of fractured rock mixed from all segments of the overburden without vegetation or established stream channels. Material salvaged from soil horizons before mining is respread to speed soil development. The mined landscape has been permanently altered. Successful rehabilitation of this land depends on our ability to understand differences between mined and unmined land and to isolate problems associated with mined area.

In response to the need to better understand soils on mined land, a study was initiated at Montana State University to inventory and evaluate minesoil resources in the Northern Great Plains. Soil resource inventories of mined land should be an effective management

tool which in addition should provide a means of evaluating the success of various reclamation techniques (Murray, 1978). Soils on mined land need to be mapped, described, and characterized to provide such an inventory. Before maps of minesoils can be prepared, the spatial variability of minesoils must be studied.

To accomplish these diverse goals, program objectives were outlined as follows (Figure 1). A study of spatial variability of minesoils was selected as the first phase of the project. The second phase included soil mapping at individual mines and characterization of each of the soils mapped. In the third phase, the suitability or agricultural potential of minesoils was evaluated. Finally, a statistical test of the accuracy of soil maps in predicting analytical properties was conducted.

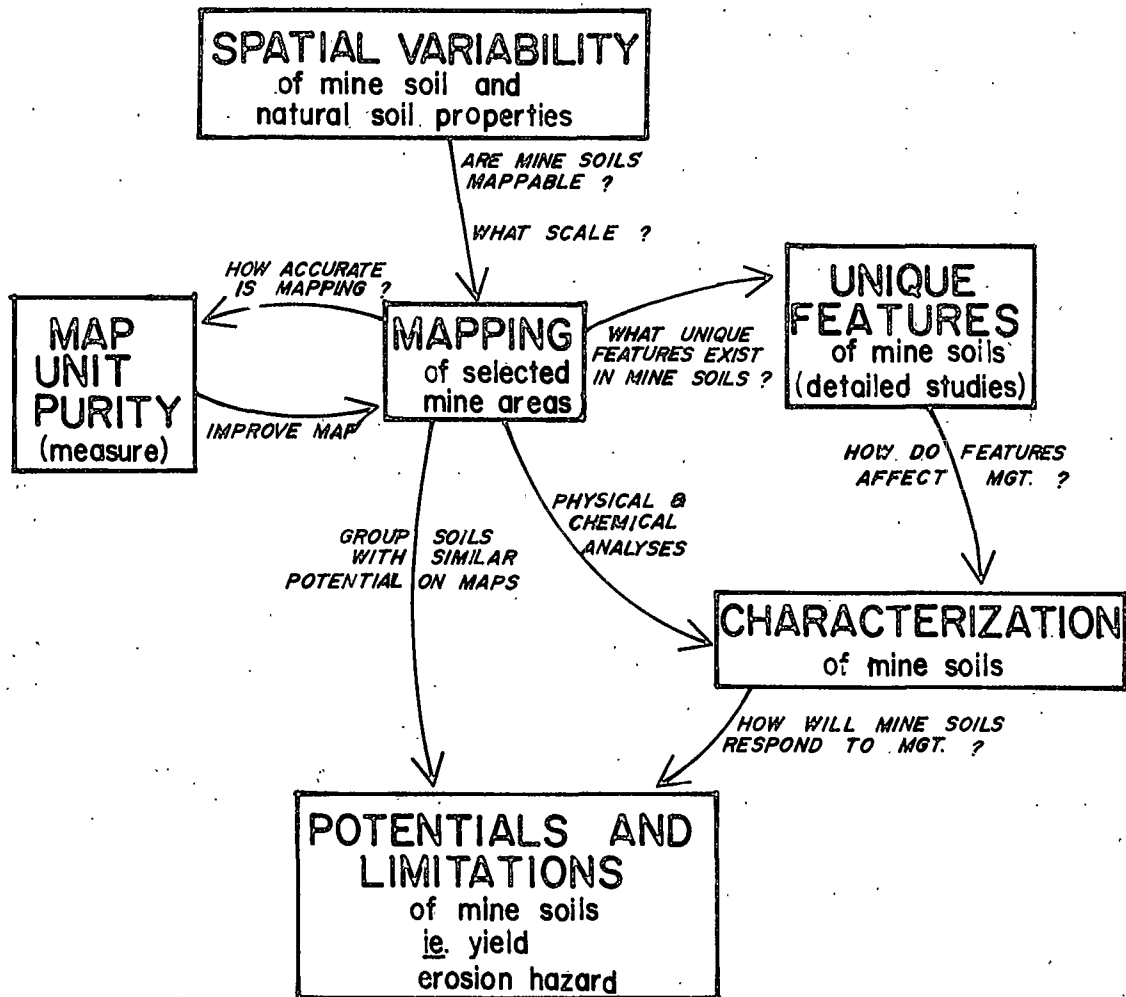


Figure 1. Organization and flow chart on study on minesoil resources in the Northern Great Plains.

CHAPTER 2

LITERATURE REVIEW

Effects of Mining on Soils

Coal mining in the Northern Great Plains has increased dramatically in the last decade in response to growing needs for energy. The extensive coal reserves in this region, obtainable by stripmining methods, in addition to the low sulfur content makes Western coal particularly marketable (Table 1, Averitt, 1975).

Stripmining for coal results in the complete destruction of the original soil and landscape. Dynamic balances achieved and maintained over thousands of years are similarly lost (Curry, 1975). However, mining does not necessarily cause a complete loss of the productive capacity upon which man relies. The primary effect of mining on soil resources is the conversion of natural soils with a given potential to minesoils with their own potential. The potential of natural soils and minesoils depends on differing factors which will be discussed.

The conversion of natural soils to minesoils is occurring at the rate of 2,000 to 4,000 acres per year in the Northern Great Plains region. By the year 2000, nearly 100,000 acres of land in this region will have been disturbed by stripmining (NGPRP, 1975; NAS,

Table 1. Coal reserves in the Northern Great Plains (Averitt, 1975)

State	Total Reserves	Stripmine Reserves
-----billion tons-----		
Montana	472	42.6
North Dakota	531	16.0
Wyoming	936	23.7

1974)(Table 2). In cases where deep, fertile, medium-textured, level, sub-irrigated soils are mined, soil potential or productivity will often decrease (OSM, 1979). However, where natural soils have developed slowly from rock and have been removed by erosion nearly as quickly, then soil potential may increase after mining (Smith and others, 1971). Most often in a surface mining operation a combination of both of these situations will take place (Schafer, and others, 1979).

To assess the impacts of mining on soil resources one must compare the natural soils of an area before mining to those created by man after mining. Both natural soils and minesoils vary tremendously from place to place. The value of soil to man is often measured by the yield of plants that soil can sustain. It has often been assumed that minesoils cannot sustain productivity as high as

Table 2. Acreage of surface-mined land in the Northern Great Plains under three development forecasts (from Packer, 1974).

Development forecast	Year	Campbell Co.	Big Horn Co.	Rosebud Co.	Mercer- Oliver Co.	Other Co.	(NGP) Total
Base	1980	56	96	1,605	2,599	0	4,356
	1985	2,036	1,276	4,900	5,999	900	15,111
	2000	7,977	4,816	14,785	16,199	3,840	47,617
Probable	1985	2,341	1,533	4,900	5,199	900	15,673
	2000	12,287	9,018	22,690	26,804	18,330	89,129
Extensive	1985	2,341	1,993	6,295	13,069	8,870	32,568
	2000	25,890	13,528	43,975	54,584	57,110	195,087

the best natural soils in an area (OSM, 1979; Nielsen, 1979). Therefore, laws have been written to either protect the most productive soils from mining or require stringent reclamation that insure equal or greater productivity after mining (OSM, 1979; SMCRA, 1977). In other areas, natural soils are not highly productive due to steep slopes, shallow bedrock, or some other limiting factor. Mining may increase productivity in these areas.

The characteristics of any particular soil depends on its genetic history. Soils change through time due to constructive and destructive physical, chemical, and biological forces. Climate, parent material, organisms, relief, and time interact to form soil development processes which modify soil materials over time (Jenny, 1941 Birkeland, 1974). These processes cause organic matter to accumulate and reach an equilibrium. They cause carbonate, gypsum, and soluble salts to become redistributed to different soil depths, and they cause clay minerals to move or form in place (Hole and Nielsen, 1970). In addition primary minerals like feldspars, pyroxenes, amphiboles, and micas break down under the intense weathering conditions common in soil (Jackson and Sherman, 1953). Depending on a soils' landscape position, soil may be removed from or added to the solum causing rejuvenation of the soil development cycle at one location and formation of overthickened horizons at others (Huggett, 1975). In short, natural soils result from the complex interaction of many inter-

related factors acting over thousands of years. Soils at any particular stage of development can be valuable to man because of an appropriate combination of factors. Hall (1979) pointed out that moderately young soils are often the most productive because organic enrichment has had time to occur but excessive leaching or formation of detrimental horizons has not yet happened.

Minesoils are unlike natural soils in that they were formed by man (Smith and Sobek, 1978). They are youthful soils and so have not had the benefit of short-term soil development which can increase soil productivity (Dickson and Crocker, 1953a, 1953b, 1954). Geochemical processes which operated in natural soils are disrupted in minesoils and are reset to a new starting point. Curry (1975) discussed several possible limitations of minesoils due to changes in biogeochemical cycles. These limitations included alteration of soil development patterns, surface salt accumulation, open nutrient cycles and changes in ecological succession.

Plant performance on minesoils has often been encouraging in the Northern Great Plains for introduced grasses (Sindelar and Plantenburg, 1978), native grasses and shrubs (DePuit, and others, 1978), and in North Dakota for cereal grains (Bauer and others, 1978). Reconstruction of productive minesoils by placement of suitable soil media near the surface has, therefore, been demonstrated.

Chemical and physical changes that may occur in young minesoils through time is also a concern. Anderson (1977) investigated changes in glacial till minespoil in Saskatchewan ranging from 28 to 40 years in age. Soluble salts had been leached to below 50 cm and large amounts of carbon and nitrogen had accumulated. These are all regarded as beneficial processes. Humus in the 28-year-old minesoil was very similar to that found in natural soils. Schafer and others (1979) found that many properties of minesoils changed by soil development processes to become similar to natural soils in less than 50 years. It was projected that other soil properties would require thousands of years to achieve levels found in unmined soils. Still other properties of minesoils would always remain different, it was concluded. Although minesoils were different than natural soils, Schafer and others (1979) concluded minesoils properly constructed with high quality cover-soil could be as productive or even more productive than unmined soils. To put the impact of mining on soils into perspective, the potential of natural soils and minesoils must be compared, and efforts must be made to create the best possible minesoils for a given use.

Soil Restoration

Many philosophies about reclamation have existed during the history of mining. Early in the century the thought that resources

were limitless pervaded (Udall, 1963). As a result, no reclamation was practiced. As an awareness grew of the cumulative environmental effects of mining, attempts at reclamation increased. Early reclamation merely involved flattening the crests of spoilbanks and scattering some readily-available seed. Current reclamation technologies are an involved system aimed at preserving groundwater flow and quality, at maintaining ecosystem diversity and stability, and at creating stable landforms with continuity to the region as a whole (Dollhopf and others, 1978; Hodder, 1978).

Soil restoration has been approached in many different ways also. Omodt and others (1975) suggested that minesoils should be constructed that have the same characteristics, range of properties, and arrangement of materials found in natural soils. The composition of target natural soils in North Dakota were discussed for a comparison. McCormack (1974) gave an example of how minesoils could be built from the best-available soil materials indicated on soil survey maps. The exclusion or burial of less favorable horizons was suggested. In addition, the potential for use of favorable material from below the soil zone was discussed. Many different experiments have been aimed at evaluating varying topsoil, subsoil, and spoil depths and mixtures for growing plants (Power, and others, 1978; Schuman and Taylor, 1977; Barth, 1971). Specific recommendations have been formulated

for some regions. Federal regulations now require minimum application rates of topsoil, and of subsoil in some cases (OSM, 1979).

Recently, it has been recognized that veneering a mined area with suitable plant growth media to a sufficient depth is not a broad enough approach to soil restoration. Moran and others (1978) developed a whole-landscape approach to reclamation which they termed "Engineered Cast Overburden" or ECO. Changes in soil characteristics, and slope morphology through mining lead to a change in the forces acting upon the mined landscape. As a result, the equilibrium form of the mined landscape must also be different to remain stable. The ECO concept of reclamation extends beyond sustained soil productivity and landscape stability to include groundwater quality and quantity. The whole-landscape approach to reclamation relies heavily on pre-mine studies of soil, water, and overburden resources. Similar post-mine studies of the mined area are also required to evaluate the function of the different systems.

Schafer (1978) developed a method to map soils on mines. Such an evaluation of minesoils is an integral part of the ECO approach to reclamation. In addition, federal law (OSM, 1979) requires that post-mine soil productivity be equal or higher than that which existed before mining for special resource areas like alluvial valley floors (section 822) and prime farmland (section 823). Interpretations about soil potential of minesoils are also needed to satisfy this

requirement. In short, soil survey methods must be adapted for and applied to soils on mined land in any comprehensive approach to mined land reclamation.

Soil Variability and Mapping

To be able to delineate the location of different soil bodies on maps, one must first understand the distribution of soils on the landscape. Various soil horizons such as organically-enriched A horizons and clayey B horizons can vary in thickness or disappear completely from place to place. As a result, soil characteristics can vary gradually or abruptly across the landscape. Lateral changes in soil properties result in different kinds of soils with different kinds and arrangements of soil horizons. To be able to map these changes, the array of observed soils must be classified into discrete units. The Soil Taxonomy (Soil Survey Staff, 1975) is often used for this purpose. In this study, phases of soil series were the units recognized on maps.

Soils typically form an extremely complex mosaic on the landscape so that an appropriate map scale must be chosen so that soil delineations are readable. Even with very large-scale maps, however, inclusions of several different soils often occur within a delineation so that soil maps never show all of the soils on a landscape. Different kinds of mapping unit and different scales or orders of mapping have been developed for natural soil landscapes (SCS, 1977).

These mapping techniques have been developed through a growing knowledge of the distribution of soils on landscapes. Minesoils are formed by man and are, therefore, unlike natural soils. For this reason, little is known about the pattern of minesoil variability (Schafer, 1979b). Most research on mined land has been on individual soils at a discrete location. Little consideration has been given to the variability of minesoil properties (Berg, 1978).

Several methods and sampling techniques have been used for studying soil variability of natural soils. Webster (1977) discussed several statistical methods appropriate for soil classification and survey. A staggered or unbalanced analysis of variance technique was developed by Krumbein and Slack (1956) for studying the variability of rock composition at different lateral spacings. This technique has been further developed by Miesch (1975) in regional geochemistry studies. Staggered analysis of variance design has also been applied to regional studies of trace element content of soils by Tidball (1975) and Tidball and Severson (1975). Other statistical techniques are often used to test the accuracy of soil maps. McCormack and Wilding (1969) used a nested analysis of variance to evaluate the extent to which various soil differences were identified by mapping. Hajek (1977) used a line-transect method for measuring the composition of mapping units in standard soil surveys. Often the amount of

inclusion of unnamed soils exceeded the amount of soil for which the mapping unit was named.

Minesoil Interpretation and Potential

The purpose of soil maps is primarily to provide information about the management and suitable uses of soils. Explanations about appropriate soil use are called soil interpretations. Many techniques have been developed for evaluating the suitability or performance of different soils for single uses like landfills, single-family dwellings, or grain production.

One interpretive grouping used to rate the agricultural suitability of soils is the USDA Land Capability Classification (LCC) system (Klingbiel and Montgomery, 1961). The LCC system places soils into eight classes (I to VIII) depending on limitations to agricultural use imposed by soil properties and climate. Schafer (1979a) developed criteria for placing minesoils into LCC classes based on fourteen soil and climatic properties including root zone depth, topsoil depth, surface soil texture, rock fragment content, water-holding capacity, permeability, drainage class, spoil type, slope, erosion, electrical conductivity, sodium adsorption ratio, pH, and PE index. A soil is considered Class I until it fails to meet any one criterion. It is lowered in class until it meets all the criteria in a particular class. Land Capability Classes are further subdivided

into subclasses based on which of four general factors are limiting: soil, climate, erosion, or wetness. Lastly soils are placed into LCC units based on specific management problems. For example, a IVs-7 soil would denote a class IV soil with a soil(s) limitation. The numeral 7 refers specifically to a low water-holding-capacity.

Singer (1978) and Reganold and Singer (1979) compared LCC to a similar agricultural suitability rating system, the Storie Index System. These two systems are used widely in California to identify prime agricultural land (LCC class I and II, Storie Index 60-100). It was found that both system identified similar acreages of prime agricultural land, but that the land areas selected did not necessarily coincide. Another problem with LCC is that it only ranks general agricultural suitability while specific crops (spring wheat, barley, rice) vary widely in their tolerance to specific soil conditions. Geographic variables in climate and soil conditions that are difficult to quantify also limit the usefulness of a single comprehensive rating system like LCC.

In recognition of the drawbacks of LCC a more specific rating system applied to small geographical areas (counties, regions) was developed. This new system called the Soil Potential Index (SPI) rates the expected yield or performance level of soils for specific land uses (SCS, 1977). The SPE is an equation consisting of three

variables

$$SPI = P - CT - CL$$

where P is a target productivity achieved by the better soils in an area. It can be rated in terms of bushels per acre, dollars per year, or on a relative scale (0-100). CT is a cost of treating or mitigating soil limitations such as the cost of a tile drain system for soils with a high water table. CL is a cost of continuing limitations, or factors which affect soil performance even after treatments have been applied. The SPI system has not been widely used because of the difficulties in data collection. Guidelines for rating SPI in soils have been published, however (SCS, 1977; Nielson, 1979).

CHAPTER 3

REGIONAL SETTING

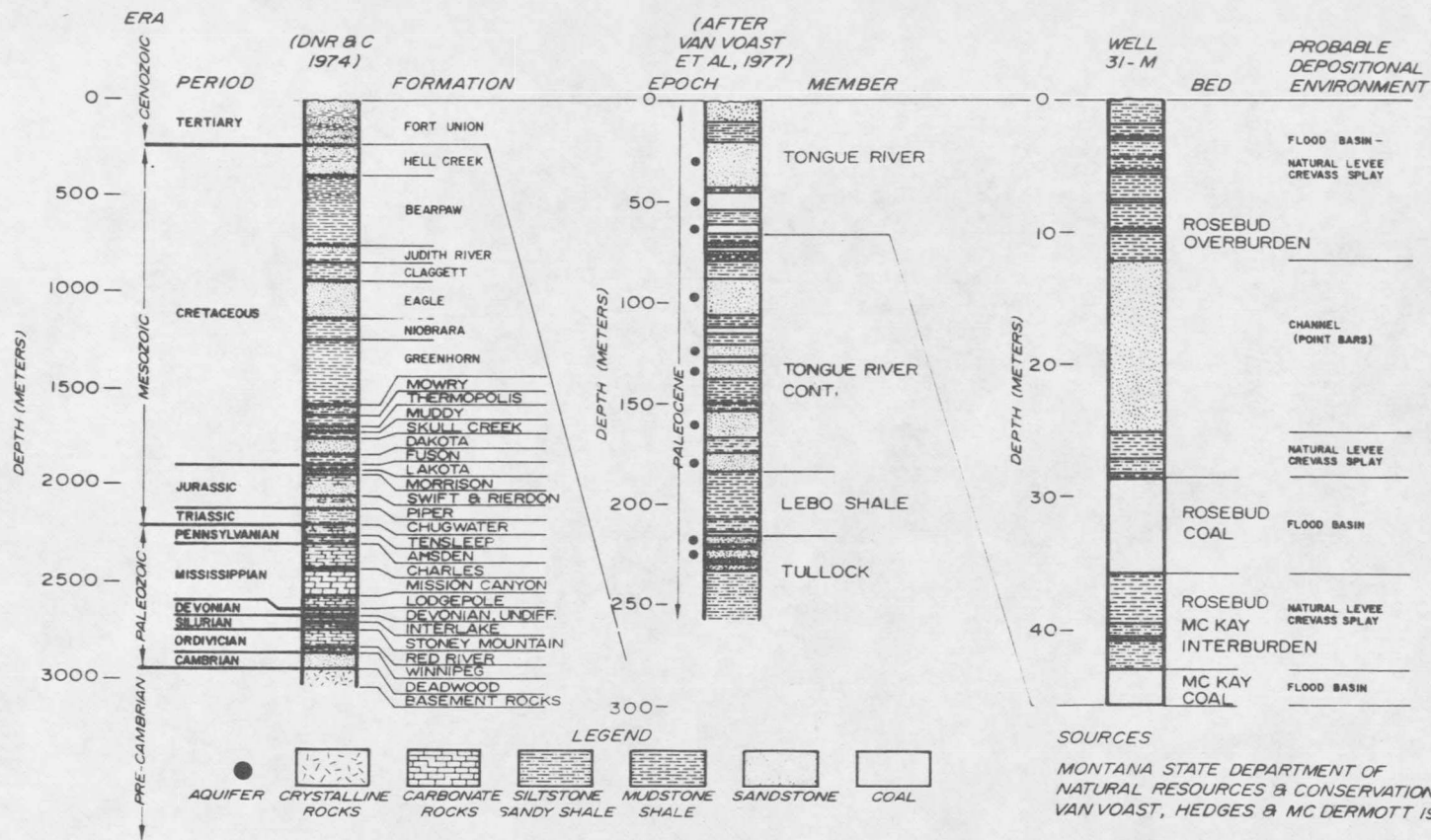
Historical Geology

The geologic history of the Northern Great Plains region since Pre-Cambrian time included periods of deposition, erosion, and deformation. During Paleozoic and Mesozoic time, a sequence of carbonates, sandstones, and shales was deposited (Figure 2) in a tectonically stable epicontinental sea (Schafer and others, 1979).

Several hundred meters of clastic rocks were deposited during Cretaceous time as a result of repeated transgressions and regressions of the sea. Broad regional uplift following deposition of the Bearpaw Shale is believed to have caused permanent withdrawal of marine water from the region (Gill and Cobban, 1973). The late Cretaceous Hell Creek Formation which overlies the Bearpaw Shale is of fluvial and lacustrine origin (Lewis and Roberts, 1977).

Subsidence of the present Powder River Basin began during deposition of the Hell Creek Formation in late Cretaceous time (Curry, 1971). Subsidence corresponded to the beginning of the Laramide orogeny during which the Black Hills and Big Horn Mountains bordering the basin were gently uplifted. The lack of coarse clastics and conglomerates in late Cretaceous and Paleocene deposits suggests that

COMPLETE STRATIGRAPHIC SECTION COLSTRIP, MONTANA



major uplift of the Big Horn Mountains and Black Hills did not occur until Eocene time. At the close of the Cretaceous, material from the Cordilleran uplift was deposited in swampy floodplains of what was later to become the Powder River Basin (Lewis and Roberts, 1977), setting the stage for deposition of the Paleocene Fort Union Formation.

The Fort Union Formation is divided into the Tullock, Lebo, and Tongue River Members in Montana. Other researchers in North Dakota treat these as formations in the Fort Union Group (Curry, 1971; Jacob, 1973). The basal Tullock Member of the Fort Union contains an abundance of sandstone and thin coal deposits. Sediments were deposited in a fluvial environment of low topographic relief with abundant temporary ponds and marshes (Lewis and Roberts, 1977). Intervals of erosion and nondeposition are common in this member as inferred from abrupt truncation of cross-bedding and channel sands cutting across shale and coal beds. The Lebo Member consists of shales and mudstones deposited in a similar environment. Locally, the Lebo Shale was deposited in a lacustrine environment. Deposition of the Lebo Shale corresponds to a period of rapid subsidence of the Powder River Basin. Uplands which currently border the basin were not yet a significant sediment source (Curry, 1971).

The Tongue River member of the Fort Union Formation contains some of the most extensive reserves of coal in the world. In western North Dakota, Tongue River sandstones are mostly fine to very fine

grained subangular subgraywacke commonly showing a characteristic "salt and pepper" speckling (Hickey, 1977). The dominant cement is calcite. The degree of induration depends on the amount of cement, but most rocks are weakly cemented. Limestone sand grains are common indicating exposure of carbonate rocks in the sediment source area (Jacob, 1973). Claystones in the Tongue River Member contained a mixture of illite and kaolinite with lesser amounts of smectite (Hickey, 1977).

In western North Dakota, four primary lithologic associations are common in the Fort Union Formation (Jacob, 1973): 1) Gray clay and silt units from 1 to 30 feet thick with disturbed stratification, and thin coal stringers are common. These represent floodplain deposits in a low relief fluvial environment. 2) Thick coal seams often overlie the gray silt and clay units and represent a swampy floodplain zone of deposition. The tabular blanket-like geometry of these seams may indicate a lower delta plain origin for the Fort Union in western North Dakota. 3) Yellow silt and sand deposits up to 50 feet thick overlie many coal seams. Sedimentary structures in this unit suggest these sands originated as a natural levee and crevasse splay deposit. These sandy units contain about 25 percent more iron than surrounding units. Natural levees form the highest land surfaces in the floodplain. A highly oxidized condition would be expected in this environment, favoring precipitation of iron and

perhaps other metals. 4) Sand occurs as linear bodies perhaps deposited as transverse bars in low-sinuosity meandering streams. Rarely, tabular sand bodies 8-10 feet thick extending for over 1000 feet laterally were encountered, and were interpreted as point bar deposits.

Jacob (1973), Royse (1970) and Cherven (1978) suggested a lower floodplain delta-plain environment for the Paleocene in western North Dakota. Workers in central (Shurr, 1972), and southeastern Montana (Widmayer, 1977) postulated a purely fluvial depositional environment without deltaic influence. Because of the fine grain-size and paleo-current indicators in southeastern Montana, a sediment source several hundred km to the west was suggested.

Early Eocene time was a period of strong folding and faulting (Glaze and Keller, 1965) which resulted in many of the present structural features of southeastern Montana. During the Oligocene and Miocene, the area is thought to have been buried by tuffaceous debris from volcanic activity to the west. Regional uplift during the Pliocene accentuated many structural features bordering the Powder River Basin. Rejuvenation of streams caused previously buried sediments to be exhumed. Erosion continued until Pleistocene time to form the present landscape.

Part of the Northern Great Plains region was covered by glaciers during the Wisconsin stage of continental glaciation (Lemke and

others, 1965). Generally, the area north of the Missouri River in eastern Montana and in western North Dakota was glaciated one or more times in Wisconsin time. Variable thicknesses of glacial till known in North Dakota as the Coleharbor Formation, were deposited in these areas.

Depositional Model

To a large extent, the texture, chemical composition, and arrangement of sedimentary materials is determined by their depositional environment. The Tongue River Member of the Fort Union Formation is the sedimentary unit most often containing coal in the Northern Great Plains. It has been suggested that Tongue River materials were deposited in a fluvial system in eastern Montana and Wyoming (Widmayer, 1977; Shurr, 1972; and Dollhopf and others, 1978) while a lower delta-plain environment was postulated for western North Dakota (Jacob, 1973; Cherven, 1978).

Reineck and Singh (1975) grouped fluvial deposits into three groups: channel deposits, bank deposits and floodbasin deposits (Figure 3). Channel deposits are the most extensive in fluvial systems. They include all materials created by the active stream channel like point bar, channel lag, channel fill, and point bar swale deposits. Bank deposits are formed during flooding when over-bank flows create natural levees and crevasse splays. These materials

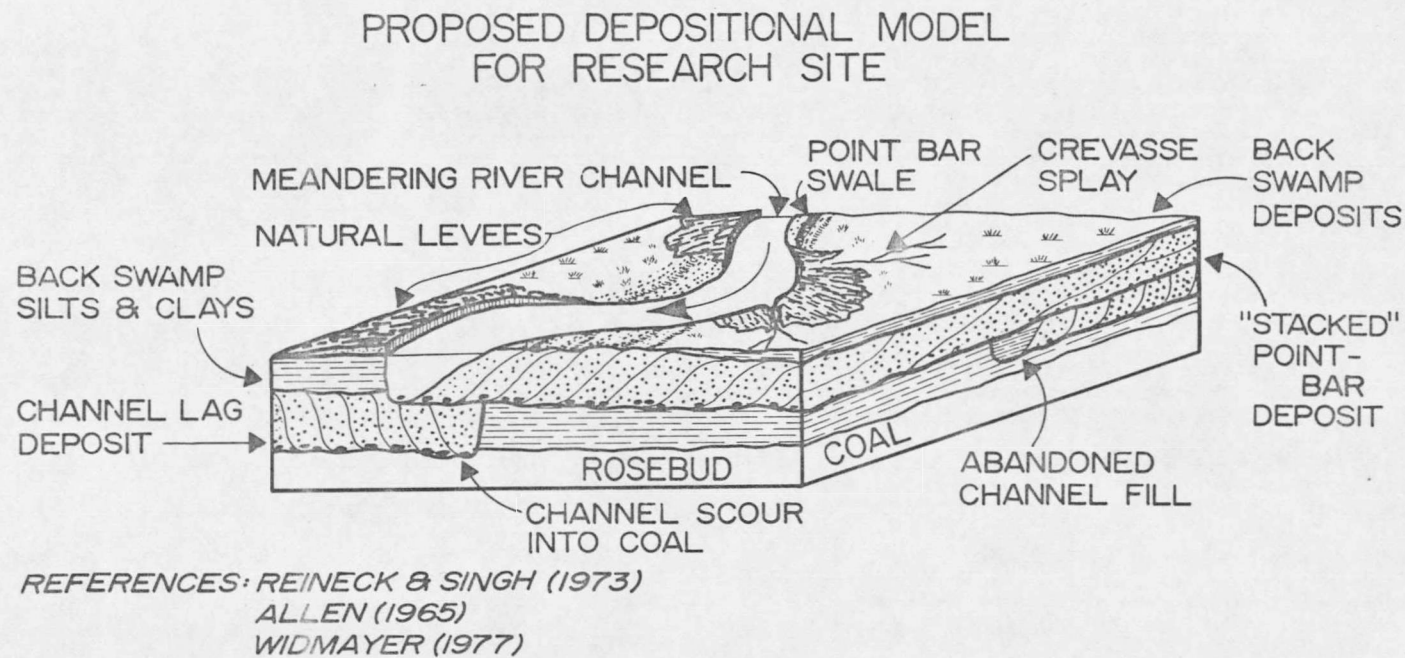


Figure 3. Schematic model of a fluvial depositional environment typical of western portions of the Northern Great Plains in Paleocene time (from Dollhopf and others, 1978).

are often fine sands and silts which become finer as distance from the channel increases. Flood basin deposits consist of silts and clays formed when heavy flooding inundates the flood basin. Coal deposits are often associated with clayey flood plain units.

The fluvial environment is a high energy system so that many fine detrital grains and soluble constituents that either flow into the system or that are created in it are swept downstream, out of the system. Fluvial sediments could be expected to be coarser-textured and less saline than deltaic-marine deposits, for example.

The lower delta-plain system differs from that of the fluvial system typical of eastern Montana. Deltas are located at the distal end of stream drainages and border relatively still, deep water (Reinecke and Singh, 1975). As sediments which were entrained by flowing water approach relatively still water at the delta front, they are deposited en masse as steep foreset delta front beds (Figure 4). Continued deposition of these materials causes the delta to prograde, creating new land area. The Tongue River in North Dakota was deposited in the alluvial plain of a high-constructive delta (Jacob, 1973). Because of the low gradient of deltas, streams tend to become choked with sediment and divide. Divided delta stream systems are called distributaries. Distributary channels create channel deposits (bar finger sands) and bank deposits similar to those in other fluvial systems. Fine-grained floodplain sediments

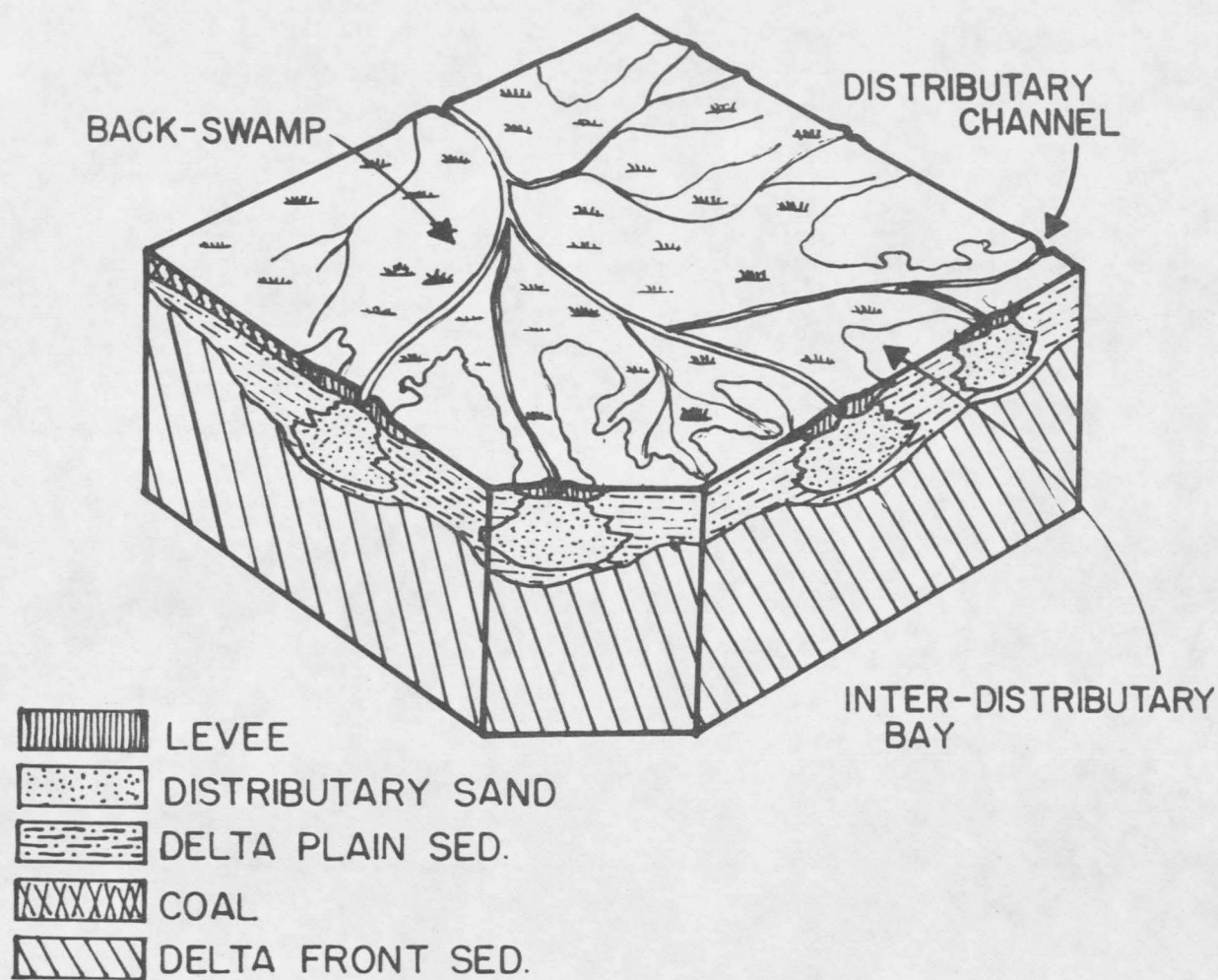


Figure 4. Schematic model of a deltaic depositional environment typical of western North Dakota in Paleocene time (after Reinick and Singh, 1975).

and coal form in intertributary marshes and backswamps. Materials deposits in lower delta-plain environments tend to be both finer and more saline than typical fluvial deposits due to their lower gradient.

Soils

The Northern Great Plains region is a soil transition zone of Aridisols, Alfisols, and Mollisols. Aridisols or desert soils increase in abundance in the southern Powder River basin where the climate is drier. Mollisols, prairie soils, are common in the more moist Great Plains of North and South Dakota to the east. Alfisols, or forest soils, occur in the neighboring Big Horn mountains and Black Hills regions. Entisols which are young, undeveloped soils are locally common due to steep slopes and recent fluvial activity.

Properties observed in soils result from the interaction of five soil-forming factors. Climate, organisms, parent material and relief, combine to create a set of processes which modify soils through time. The soils thus formed in turn affect vegetation, hydrology, and land-use patterns. Information on the distribution of different kinds of soils and their individual properties is basic to an understanding of the natural resources of an area.

Potential evapotranspiration far exceeds annual precipitation throughout the Great Plains. Run-off during snowmelt and high-intensity summer thunderstorms prevents some precipitation from ever

entering the soil profile. As a result, regional soils are dry in the root zone during much of the growing season. Limited penetration of water into the soil causes an accumulation of lime and other more soluble salts near the base of the root zone. Many coarse-textured or south-facing soils are dry long enough to have an aridic moisture regime typical of desert soils. Finer-textured and north-facing soils retain water longer into the summer and have an ustic moisture regime. Many soils in Wyoming and southeastern Montana have a mesic temperature regime while many North Dakota soils have frigid temperature regimes (mean annual soil temperature less than 8°C, 47°F). Climate plays an important role in the classification of soils in this region.

Vegetation also influences soil development. The Northern Great Plains is dominated by mixed-grass prairie with Ponderosa pine savannahs in upland areas. Soils under grassland tend to accumulate thick layers enriched in organic matter due to the turnover of fibrous grass root systems (Mollisols). Soils under coniferous forest often have an O horizon of relatively undecomposed litter underlain by a leached, acid mineral A horizon. Argillic B horizons (clay accumulation) are also common in forest soils (Alfisols).

Composition and texture of parent material affect soil properties especially in "young" soils. The Tongue River Member of the Fort Union Formation outcrops through many of the coal-producing

areas. Sandstone dominates this member with abundant lenses of siltstone. A sheet of clayey shale overlies the major coal seam. Scoria (porcelainite) resulting from combustion of exposed coal in some areas. Coarse-loamy and fine-loamy textural classes of soils are dominant locally. Some fine-silty soils occur on colluvium derived from siltstone. Skeletal and fragmental soils are common on top of scoria-capped buttes.

Both slope and aspect or exposure, influence soil properties. Due to the sufficiently steep gradient of streams in the region, the weakly consolidated nature of Fort Union rocks, and the youthful landscape; a moderately steep dissected topography has resulted around many tributaries to the Yellowstone and Missouri Rivers.

At these latitudes, differences in aspect strongly affect microclimate which influences soil development through vegetation differences. Soils on north-facing slopes are colder and wetter because less incident energy is available to warm and dry these soils. More organic matter accumulates and deeper solums develop on north- and east-facing slopes.

The rate of geologic erosion is high on steep slopes. As a result, only thin A horizons form because soil material is continuously removed from the surface. Steep surfaces are not stable long enough for cambic B horizons (horizon of alteration) to form. The resulting soils are Entisols. On midslopes, surfaces are more stable.

Cambic B horizons form and thicker A horizons accumulate creating Borollic Camborthids. On the lowest footslopes where slope flattens, material carried by overland flow from upslope is deposited due to a loss in energy of moving water. Retention of surface run-off in this geomorphic position results in more water moving through the profile than in other soils. Thick mollic epipedons and some argillic horizons may develop. Aridic Haploborolls and Aridic Argiborolls are common. In recent floodplains, materials are periodically reworked which prevents B horizons from forming. These stream-influenced soils are Fluvents.

Climate, organisms, parent material, and relief together create processes which modify soils through time. The length of time a surface is exposed to soil-forming processes thus influences the degree to which many soil properties are expressed. Pleistocene glaciers did not reach all parts of the region, yet changing Quaternary climate has probably influenced all soils. Uplift of the entire region in Pliocene time began a cycle of downcutting by rivers which rejuvenated the soil surface in recent times. Most soils in the area are probably less than 10,000 years old.

Vegetation and Land Use

Most native vegetation in the Northern Great Plains consists of mixed mid- and short-grass prairie, mid-grass prairie, or coniferous

woodland associations (Ross and Hunter, 1976). Dominant species in potential climax communities would often include a mixture of western, and thickspike wheatgrass, little bluestem, needle-and-thread, green needlegrass, bluebunch wheatgrass, big bluestem, and prairie junegrass. Shrubs would include silver sagebrush, skunkbrush sumac, winterfat, and western snowberry. Under heavy grazing pressure blue grama, prairie junegrass, and fringed sagewort increase in abundance.

Dominant land uses include livestock grazing in the western portion of the region, while cereal grain-summer fallow cropping is important in the eastern part. A limited acreage of land along sub-irrigated perennial streams is used for dryland alfalfa and other hay crops. Urban development is increasing rapidly due to energy resource extraction and power generation.

CHAPTER 4

MATERIALS AND METHODS

Spatial Variability

The first phase of this research involved a study of the spatial variability of selected soil properties on mined and adjacent unmined soil landscapes. The intent of this study was to 1) see if different kinds of soils existed in a single mine area, 2) determine at what scale these soils could be mapped, 3) find the number of taxonomic units required to map equal-sized parcels of mined and unmined land, and 4) relate variation in soil properties to landscape characteristics.

The study area was located near Colstrip in southeastern Montana. The Western Energy Company Pit 6 mine area was selected for study. Portions of this mine were active from 1930 to 1950, but these spoils were reshaped during 1969 to 1973. Most of the 400 hectare area was mined between 1970 and 1975. A diversity of mining techniques were used in this mine area so that minesoil variability should be as great as in any area in the Northern Great Plains. An adjacent 300 hectare unmined landscape was also selected for study.

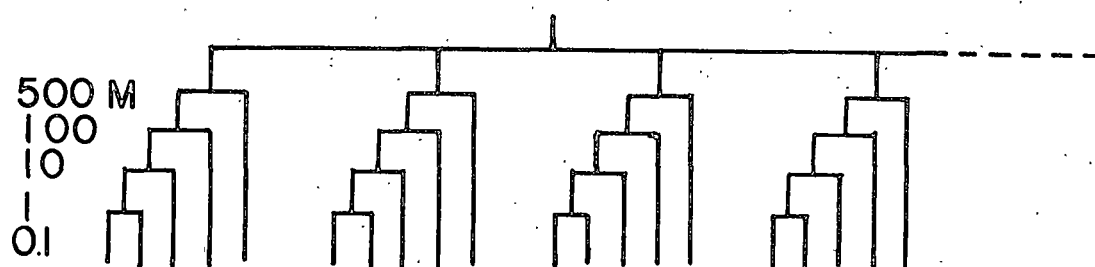
A staggered or bar-bell design was used to randomly select sample sites representing cells of increasing size (Miesch, 1975, Tidball, 1975). Soils were described at sites 10 cm, 1 m, 10 m,

100 m, and 500 m apart. Data were compared using an unbalanced or staggered analysis of variance technique commonly used in regional geochemistry studies (Tidball and Severson, 1975; Krumbein and Slack, 1956).

To select sample sites, each study area was first arbitrarily divided into 500 m x 500 m parcels by use of a grid system superimposed on 1:24,000 aerial photos. The 500 m cells were divided into twenty-five 100 m cells of which two were randomly selected. The 100 m cells were each divided into 100 10 m cells. Three 10 m cells were randomly chosen, two from one 100 m cell, and one from the other. Four 1 m cells were then selected, two from one 10 m cell and one from each of the others. Finally, five 10 cm cells were similarly selected. This sample selection resulted in five randomly-chosen 10 cm cells spaced 10 cm to 1 m, 1 m to 10 m, 10 m to 100 m, and 100 m to 500 m apart in each 500 m cell (Figure 5). Twelve 500 m cells were located in the natural landscape, and sixteen 500 m cells were on the mined area for a total of 60 and 80 observations, respectively.

Within each 10 cm cell, a soil pit was excavated and several soil morphological properties were recorded. In addition, several geomorphic properties were also measured. To aid in statistical analysis, observations were numerically coded as follows: aspect ranged from coldest NNE = 1, to warmest SSW = 5; texture: s = 1,

STAGGERED DESIGN



SAMPLE SELECTION

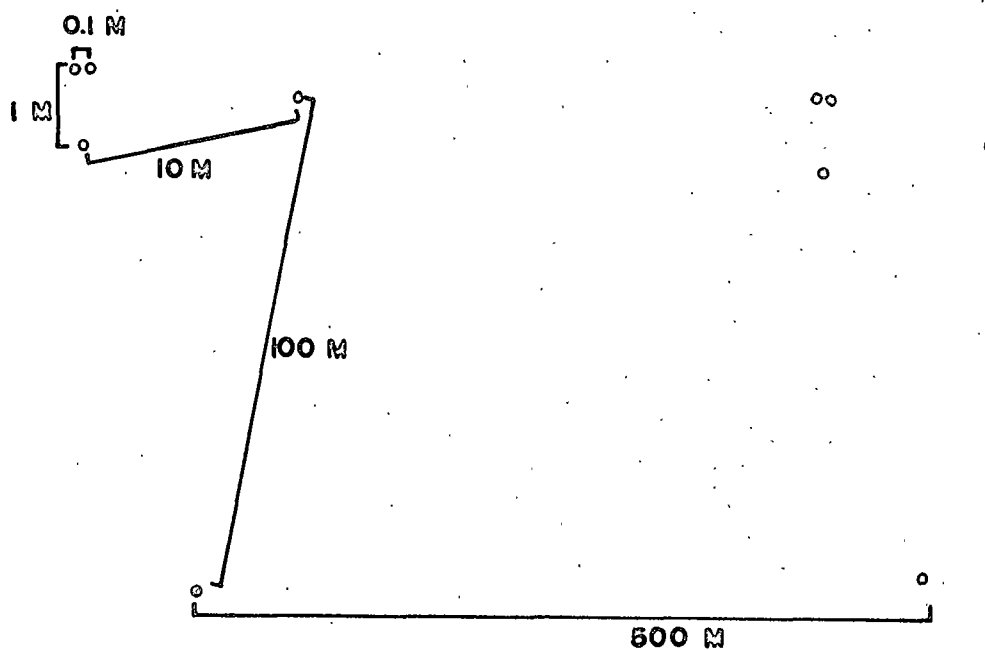


Figure 5. Conceptualization of the staggered analysis of variance design used to study soil variability at different spatial scales (above). An example of staggered sample selection as shown below.

vfs = 2, ls = 3, lfs = 4, sl = 6, fsl = 6, vfsl = 7, l = 8, sil = 9,
 scl = 10, cl = 11, sicil = 12, sc = 13, c = 14, and sic = 15; soil
 value and chroma: Munsell color notation; effervescence in 10% HCL:
 none = 1, weak = 2, moderate = 3, and violent = 4; root abundance:
 none = 0, trace = 1, few = 2, few to common = 3, common = 4, common
 to many = 5, and many = 6; slope: percent; rock fragments: percent
 by volume; topsoil depth: centimeters; mode of deposition: 1 if
 bulldozers were used in soil construction, or 2 if scrapers were
 used; soil structure: 1 = massive, 2 = platy, 3 = granular,
 4 = columnar, and 5 = blocky; geomorphic surface: ranked 1 for the
 recent surface and 2 for a relict upland surface; hillslope position:
 1 = crest, 2 = upper midslope, 3 = midslope, 4 = lower midslope,
 5 = footslope, and 6 = alluvial; diagnostic epipedons: 1 = ochric,
 2 = mollic; subsurface diagnostic horizons: 1 = none, 2 = cambic,
 and 3 = argillic; and family texture: 1 = coarse-loamy, 2 = fine-
 loamy, and 3 = fine. Soil morphological properties were measured at
 depths of 0-5 cm, 5-10 cm, 10-20 cm, 20-30 cm, and 30-50 cm.

The total variance observed in the study area for each soil
 property was compared to the estimated pooled variance found for
 samples within each cell size. The variance for each cell size
 (i.e., 10 cm, 1 m, 10 m, 100 m, or 500 m) was then expressed as a
 percentage of the total variance. A computer program developed by

the USGS, regional geochemistry branch in Denver was used for data reduction.

In addition, the correlation between soil properties and landscape features was investigated using linear regression techniques.

Mapping

Soil maps were prepared at six major coal stripmines in the Northern Great Plains (Figure 6). The pattern of variability found in minesoils as well as the limited size of individual mined areas made large-scale mapping necessary. The practical limitations of producing or of utilizing maps at less than about 1 to 6000 scale made this scale the preferred one for this study. A 1 to 6000 or 1 inch to 500 foot scale corresponded to an order 1 (ultra-detailed) soil survey (Orvedahl, 1977).

Aerial photographs enlarged to a scale of 1 to 6000 were used as base maps for mapping minesoils in each reclaimed area. Soil observations were made along selected random traverses of the area at a rate of one for each 1 to 4 acres. Soil features described at each location included topsoil depth, soil texture, color, lime content, rock fragment content, slope, aspect, and erosion, as well as other important characteristics. Mine company records, reclamation progress maps, topography, vegetation patterns, and recognition

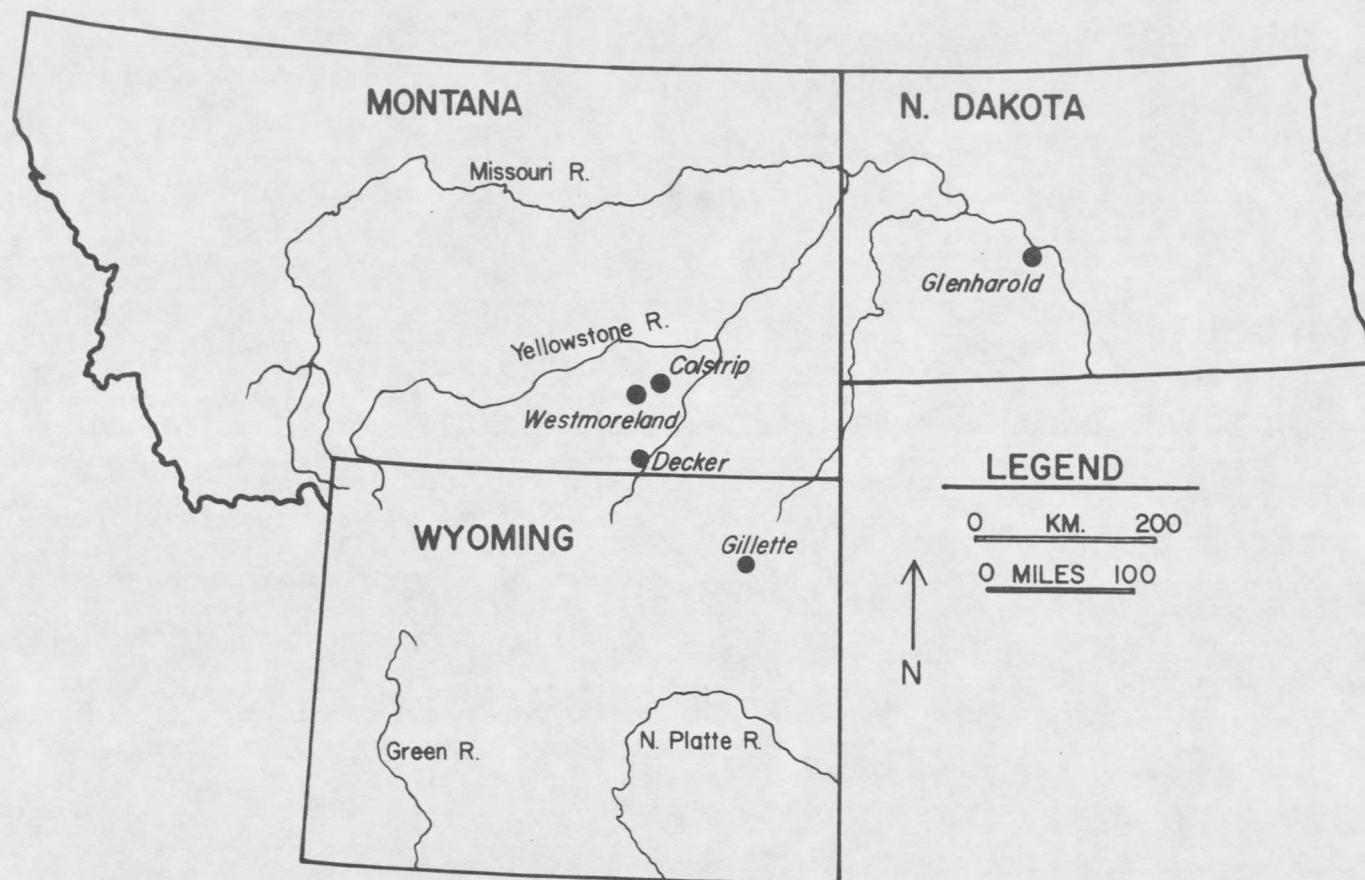


Figure 6. Location of research areas employed in the study of minesoil resources in the Northern Great Plains. Two mines were studied in the Colstrip area.

of features of the mined landscape (highwalls, box-end cut) were all utilized to delineate soil boundaries. Based on the soil observations made at each mine, informal soil series were developed to correspond to the soil characteristics observed. These soil series were named and classified according to the Soil Taxonomy (Soil Survey Staff, 1975), but were not proposed for recognition by the National Cooperative Soil Survey.

Mapping units consisted of consociations, which are areas consisting primarily of a single soil series or phase. The phases of series identified were based on topsoil thickness, slope, or other features which could affect soil management or use. Two legends were developed for each map. A general legend identifying different soil series by various shading patterns was used. In addition, a descriptive legend identifying each mapping unit by soil phase was developed which listed some of the characteristics of each mapping unit.

Characterization

Twelve soils were chosen from selected mapping units from all mined areas to be used as reference samples. Detailed chemical and physical analyses were performed on several horizons from each soil.

Mechanical analyses was performed using the method of Day (1965). Samples containing abundant soluble salts or gypsum were

pretreated with ammonium acetate buffered at pH 4.5 to remove excess salts and calcium which tend to promote clay flocculation. Despite this pretreatment several samples from the Belle Ayr mine near Gillette, Wyoming flocculated during mechanical analysis. The silt and clay content were estimated by hand texturing for these samples. The sodium adsorption ratio (SAR) as well electrical conductivity (EC) was performed on water extracted from a saturated soil paste while pH was measured on the soil paste (Richards, 1969).

Water-holding capacity of each sample was determined by measuring the water content of samples placed for three days at 0.3 and 15 bars of pressure. The difference in water content at these two soil water potentials corresponds roughly to the amount of water available for plant growth.

Published analyses from minesoils in the Northern Great Plains were collected from the literature to aid in interpreting the characteristics of soils mapped. These data are presented in Appendix B.

Interpretations

Application of soil maps to management situations requires that the capability of each mapping unit to support specific uses be estimated. The USDA Land Capability Classification (LCC) (Klingbiel and Montgomery, 1961) was used for this purpose. Using published

tables for placing natural soils into land capability units (SCS, 1975, Tables 3 and 4) as well as current literature in reclamation, guidelines were developed for placing minesoils into land capability classes (Schafer, 1979). Although not directly related to this research, similar guidelines for estimating the quality of soil and overburden materials for use as cover-soil were also developed (NCSS, 1978, Appendix A).

A soil rating system which goes a step beyond the LCC system is the Soil Potential Index (SPI). Yield or soil performance level, as well as the cost of mitigating soil limitations; and the social, economic, or environmental cost of continuing limitations are recognized by this system (SCS, 1977). Lack of adequate data makes it very difficult to apply the SPI system to minesoils in the Northern Great Plains. Nonetheless, the best available data were utilized to develop an SPI rating table for range forage production on minesoils.

Guidelines for rating SPI were based on 14 soil factors including root zone depth, topsoil depth, water-holding capacity, sandy or clayey surface texture, surface or subsoil salinity or toxicity, slope, erosion, wetness, and soil color (Table 5). Lack of a suitable data base makes the SPI guidelines developed somewhat speculative. Presentation of SPI ratings is intended to show relative ratings and illustrate the usefulness of the system. Future improvements will be made to the SPI rating system.

Table 3. Criteria for placing minesoils in the Northern Great Plains into Land Capability Classes for dryland agricultural uses.

Class 1/ A/	Root Zone Depth B/ (cm)	Topsoil Depth C/ (cm)	Surface Soil Texture E, S K/	Rock Fragment Content S	Available Water-Holding Capacity (in) S	Permeability (cm/hr) W, S L/	Drainage Class 2/ E/	Spoil Type F/ S	Slope X E	Erosion G/ E	EC (mmhos/ cm) S	SAR H/ S	pH S	Climate C
I	>200	>40	sl thru sil	< 5% lithic RF ----- < 5% soft RF D/	10" or 2"/ft	.5-12.5	3-5	weakly consolidated sandstones and siltstones and unconsolidated surface deposits (loess, till, recent alluvium, and colluvium)	< 2	none to slight	< 1	< 4	5.5-7.8	PE index >44 3/ not aridic, ustic or xeric 4/ not cryic, pergelic, or frigid
II	>150	>30	fs1 thru scl	< 10% lithic RF ----- < 10% soft RF	7.5" or 1.5"/ft	.2-25.0	3-5		< 8	none to slight	< 2	< 4	5.0-8.4	PE index 31-44 not aridic, not cryic or pergelic
III	>75	>15	vfs1 thru cl	< 35% lithic RF ---< 40% total < 35% soft RF	5" or 1"/ft	.2-25.0	2-5		< 8	none to moderate	< 2	< 10	4.5-8.7	PE index 25-31 not aridic not pergelic
IV	>50	any	vfs1 ----- sicl	< 35% lithic RF ----- < 50% soft RF	>3.5" or 0.8"/ft	any	2-5	any	< 15	none to moderate	< 4	< 20	4.5-9.0	PE index 19-25 any not pergelic
V	>50	any	any	any	>3.5"	any	any	any	< 15	none to slight	< 2	< 4	4.5-9.0	PE index < 19 any any
VI	>30	any	lfs thru sc	< 50% lithic RF ---< 65% total < 60% soft RF	>3"	any	2-6	any	< 22	none to moderate	< 6	< 30	4.5-9.0	PE index < 19 any any
VII	any	any	any	< 65% lithic RF ----- any	>2"	any	1-6	any	< 40	none to severe	< 8	< 50	4.0-9.0	PE index < 19 any any
VIII	any	any	any	any	any	any	any	any	any	any	any	any	any	PE index < 19 any any

FOOTNOTES:

- The key properties affecting soil potential are included in these guidelines. Other may be added as required. Chemical properties should be measured in the 0-100 cm control section. An interaction of 2 or more limiting properties can drop soil an additional capability class.
- The soil root zone is defined as the depth to any layer impenetrable to roots. A layer with high bulk density or an abrupt change in texture of 2 or more texture classes are assumed to restrict rooting.
- Depth of "topsoil" consisting of selected overburden or salvaged solum applied over spoils.
- Soft rock fragments, common in mine soils, are those fragments that break within minutes in water.
- Drainage class is coded: 1 = poorly drained, 2 = somewhat poorly drained, 3 = mod. well-drained, 4 = well-drained, 5 = somewhat excessively drained, 6 = excessively drained.
- Poor quality spoils will adversely affect mine soil potential even if buried under 100 cm of topsoil.
- Erosion: slight - small rills, little soil loss; moderate - rills and small gullies, soil loss is significant; severe - major gullies, extreme soil loss.
- Use 1/2 of amount shown as standard for the top 15 cm of the soil.
- The letters s, e, c, and w denote land capability subclasses corresponding to each class-determining factor.
- Subclass is E if soil is coarser than limits shown, S if finer.
- Subclass is W if soil has slower permeability than limits shown, S if more rapid.

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Table 4 . Criteria for assigning Land Capability Unit numbers to mine soils in the Northern Great Plains.

Land Capability Unit No.	Limitation
01	Shallow topsoil
02	Shallow root zone
03	Heavy surface texture (erosion, run-off, or crusting hazard)
04	Coarse surface texture (droughty, erodible or wind erosion)
05	High rock fragment content (may interfere with tillage, range improvement, or decrease the water-holding capacity)
06	High soft rock fragment content (limited soil root volume)
07	Low water-holding capacity
08	Slow permeability (run-off, erosion hazard, or decreased available water)
09	Rapid permeability (inadequate water-holding capacity)
10	Spoils present chemical or physical limitation for plant growth
11	Steep slope (erosion, decreased plant available water due to run-off)
12	Erosion evident (impairing use or productivity)
13	high EC (salinity hazard)
14	Sodic at surface (crusting, run-off, and erosion hazard)
15	Sodic at depth (dispersion of clays and low permeability, upward movement of Na^+ , physiological stress)
16	Too dry (high evapotranspiration or low ppt)
17	Excess boron
18	Excess molybdenum
19	Low $\text{Ca}^{++}/\text{Mg}^{++}$ ratio
20	Intermittent flooding
21	Other

Table 5. Soil factors influencing Soil Potential Index ratings for range forage production with native species on mined land in the Northern Great Plains.

EVALUATION FACTORS	SOIL CONDITION	DEGREE OF LIMITATION	CONTINUING LIMITATIONS		REDUCED YIELDS	
			KINDS	INDEX	KINDS	INDEX
Shallow root zone (depth to restricting layer)	<20 cm	severe	occ. replant	10	reduced stock rate	10
	20-40 cm	moderate			reduced stock rate	10
	40-75 cm	slight			reduced stock rate	5
	>75 cm	none			none	0
Shallow topsoil (cm)	0	moderate	main. fert.	5	reduced stock rate	5
	0-20	moderate	main. fert.	2	reduced stock rate	2
	20-40	slight				0
	>40	none			incr. stock rate	-2
Water-holding capacity (cm held in root zone or upper 100 cm)	0-4 cm	severe	occ. replant	10	reduced stock rate	10
	4-8 cm	moderate			reduced stock rate	5
	8-12 cm	slight				0
	>12 cm	none			incr. stock rate	-3
Sandy surface texture (upper 15 cm)	s,fs,rfs	severe	replant blowout areas	10	erosion damage	10
	ls,lfs,lrfs	moderate			erosion damage	5
	rfs1, fsl	slight			erosion damage	3
	sl or finer	none				0
Clayey surface texture (upper 15 cm)	c,sic	severe	crusting, poor seedling emerg.	5		
	sc,sic1	moderate			reduced stock rate	5
	cl	slight			reduced stock rate	4
	scl of coarser	none			reduced stock rate	2
Salinity (0-15cm)	>4	severe	poor seedling est. replant	10	water stress	5
	2-4	moderate			water stress	4
	<2	slight			water stress	2
	<1	none				0
Salinity (15-100cm) (rate as 0 if salinity present at 0-15cm)	>6	severe			water stress	5
	4-6	moderate			water stress	3
	2-4	slight			water stress	1
	<2	none				0
Sodicity (0-15cm) (SAR)	>15	severe	crusting, poor seedling est.	5	poor seedling est.	7
	8-15	moderate			poor seedling est.	4
	4-8	slight			poor seedling est.	2
	<4	none				0
Sodicity (15-100cm) (rate as 0 if sodium present at 0-15cm)	>25	severe			red. root growth	5
	15-25	moderate			red. root growth	3
	5-15	slight			red. root growth	1
	<5	none				0
Slope (%)	>22	severe	erosion susceptibility	5	erosion potl.	7
	15-22	moderate			erosion potl.	5
	8-15	slight			erosion potl.	2
	<8	none				0
Erosion	lg. gullies	severe	erosion control	15	erosion damage	10
	sm. gullies	moderate	erosion control	5	erosion damage	5
	sm. rills	slight			erosion damage	3
	not det.	none				0
Wetness (drainage class)	class 1	severe	occ. replant	10	damping off	5
	class 2	moderate			damping off	2
	class 6	slight			damping off	1
	class 3-5	none				0
Climate	PE index <19	severe			arid	16
	PE index 19-25	moderate			arid	8
	PE index 25-31	slight				0
	PE index >31	none			humid	-8
Soil color (0-15cm) (munsell color value)	7	severe			decr. fertility	5
	5-6	moderate			decr. fertility	2
	4	slight				0
	3	none			incr. fertility	-3
Unknown yield red. (amount yield below expected yield for unspecified reasons)	Y=20% <NAT	severe				20
	Y=10% <NAT	moderate				10
	Y=5% <NAT	slight				5
	Y= NAT	none				0

Using phase criteria, LCC, and SPI rating systems; several interpretive overlay maps were developed for each mined area. Maps exhibit soil mapping units within particular limits of various properties like topsoil depth, slope, LCC, or SPI. Interpretive maps like these are often simpler to apply to management needs than maps showing soil names.

Mapping Unit Purity

A common use of soil maps is to extend chemical or physical data from one delineation to others within the same mapping unit. However, large amounts of lateral variation are common in soils. Even within a single delineation many different soils with varying properties can be present. To evaluate the soil variability within and between delineations on soil maps, a study was designed to identify the amount of variability in different soil properties. Three replicate pedons were described in two delineations in each of three mapping units on both mined and unmined landscapes at the Amax mine. Three different soil depths 0 to 15, 15 to 30, and 30 to 45 cm were analyzed for particle-size distribution, pH, EC, and SAR. Several morphological properties were also observed in the field. A sample of the analysis of variance design is shown in Table 6. Components of variance explained by each level in the analysis of variance were also calculated using the expected mean squares.

Table 6 . Skeleton of analysis of variance framework
used to evaluate map unit purity.

Source	DF	Exp. MS
Map Unit	2	$\sigma_r^2 + 3\sigma_d^2 + 6\sigma_m^2$
Delineation/mu	3	$\sigma_r^2 + 3\sigma_d^2$
Reps/Del.	$\frac{12}{17}$	σ_r^2

Results of the analysis should be an index of the reliability of mapping units for predicting soil morphological and soil chemical properties from map data.

CHAPTER 5

SPATIAL VARIABILITY OF MINESOILS AND NATURAL SOILS

To properly inventory mined land, the techniques to map, classify, and interpret minesoils should be adapted from currently-used methods for conducting soil surveys on natural soil landscapes. A first step towards being able to map and classify different kinds of minesoils is to measure their spatial variability. For minesoils to be mappable 1) sufficient variability must exist for different kinds of soils to be recognizable, and 2) variability must exist at a sufficiently large spatial scale so that soils can be delineated on maps. The intent of this research was to compare the spatial variability of soils on mined land with the variability of soils in a natural, undisturbed soil landscape. Study objectives were to 1) see if different kinds of soils existed in a single mine area, 2) determine at what scale these soils could be mapped, 3) find the number of taxonomic units required to map equal-sized parcels of mined and unmined land, and 4) relate variation in soil properties to landscape characteristics.

Several soil morphological properties were observed in 140 natural soils and minesoils in the Colstrip, Montana area. The

levels of properties were numerically coded to aid in statistical analysis of the data.

Mean coded values for several soil morphological properties are shown for natural soils and minesoils (Figures 7 and 8). The average soil texture was loam in natural soils and fine sandy loam in minesoils. Minesoils had higher color values and lower chromas than natural soils. Soil color changed little with depth in minesoils unlike natural soils which averaged 10YR 3/3 near the surface and 10YR 5/4 at depth. Minesoils were nearly always massive with a significant volume of soft sandstone and siltstone fragments (30%) at all depths. Natural soils had few rock fragments and exhibited varying kinds of soil structure. Natural soils had more roots and less reaction to HCl than did minesoils (Figure 8). Effervescence in HCl increased with depth in natural soils but remained nearly constant in minesoils. Slope averaged 14% on the natural landscape and 13% on the mined landscape.

Large ranges existed in most soil properties indicating that significant soil differences existed in both study areas. For example, in the mined landscape, slope ranged from 0 to 82%, soil texture ranged from loamy sand to silty clay, and soil color ranged from 7.5YR 6/8 to 2.5YR 3/1. To identify soils with different management requirements in an area with such large ranges in soil

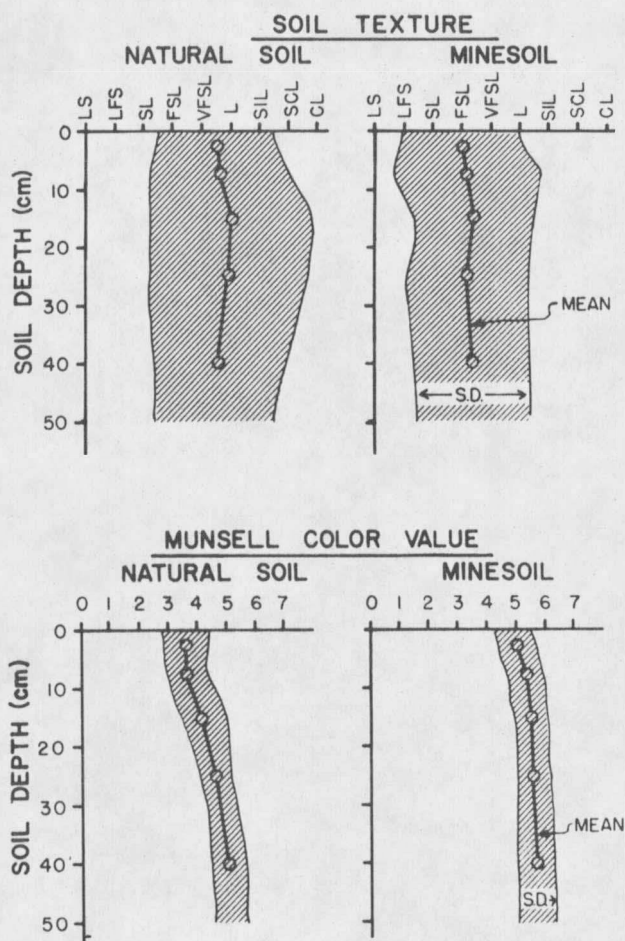


Figure 7. Mean levels (solid line) and standard deviation (shaded area) of soil texture and color value are shown for minesoils and natural soils.

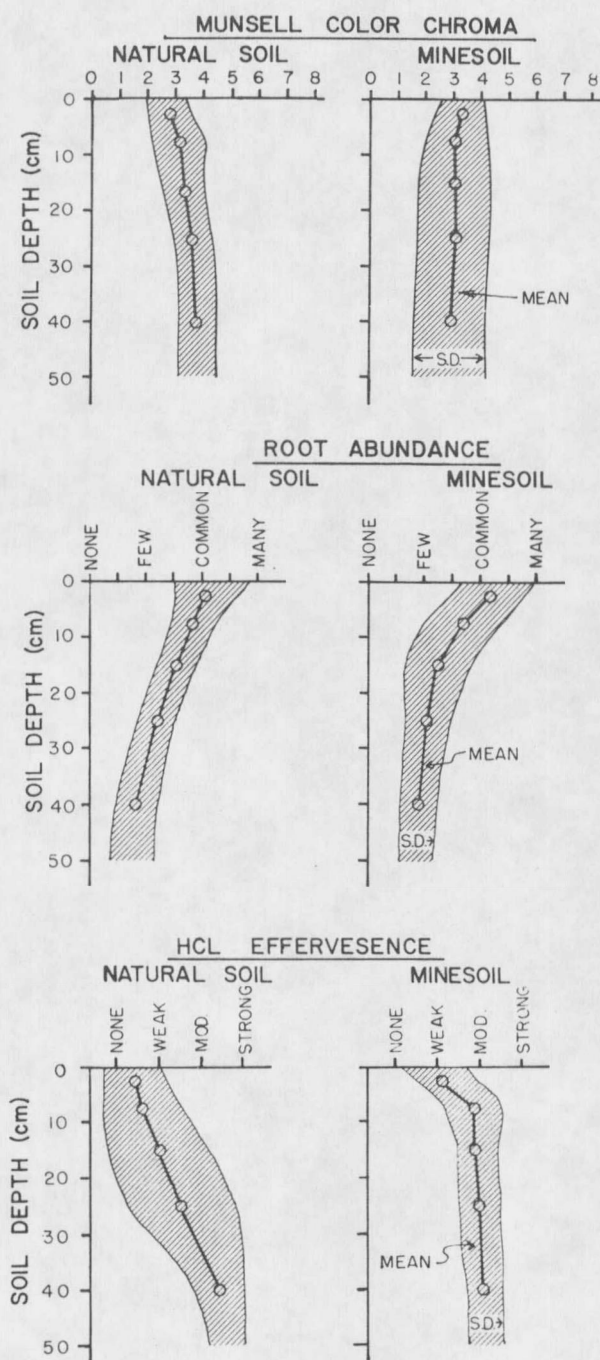


Figure 8. Mean levels (solid line) and standard deviation shaded region) of soil chroma, root abundance, and HCl effervescence are shown for minesoils and natural soils.

properties, taxonomically different kinds of soils would clearly need to be identified.

Soil texture in the upper 10 cm of minesoils is more variable than in natural soils, probably because sandy topsoil was added to some minesoils but not to others. Below 10 cm textural variability was the same in natural soils and mine soils. Color value was most variable from 5 to 20 cm in natural soils probably because of variation in A horizon thickness. Chroma was more variable in minesoils than in natural soils especially below the topsoil layer. Root abundance was more variable in minesoils than in natural soils while effervescence in HCl was less variable.

Components of Variance

Variance components, which indicate the proportion of variability in soil properties corresponding to given cell sizes, are shown in Figures 9 to 13. A larger proportion of total variability is accounted for by large cell sizes in the natural soil landscape than in the mined area. Often in natural soils, 50 to 75% of the total variability in soil texture, color, root abundance, effervescence, A horizon thickness, and depth to lime, exist at the 500 m cell size. Very little variation exists at less than 10-100 m for these properties in natural soils indicating that soil changes are gradual over the landscape and are probably influenced by broad differences in

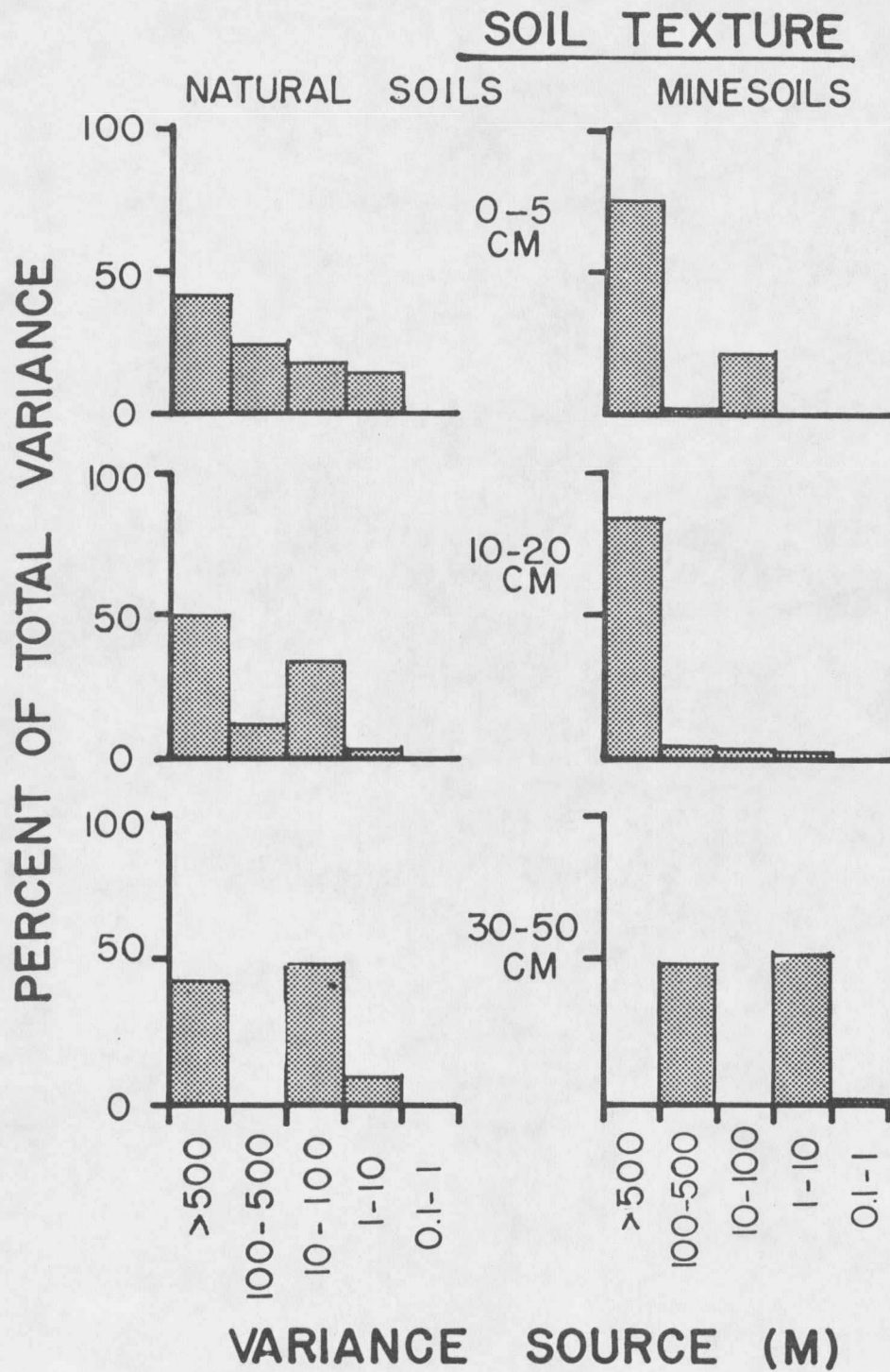


Figure 9. Components of variance are shown for soil texture at three depths on minesoils and natural soils.

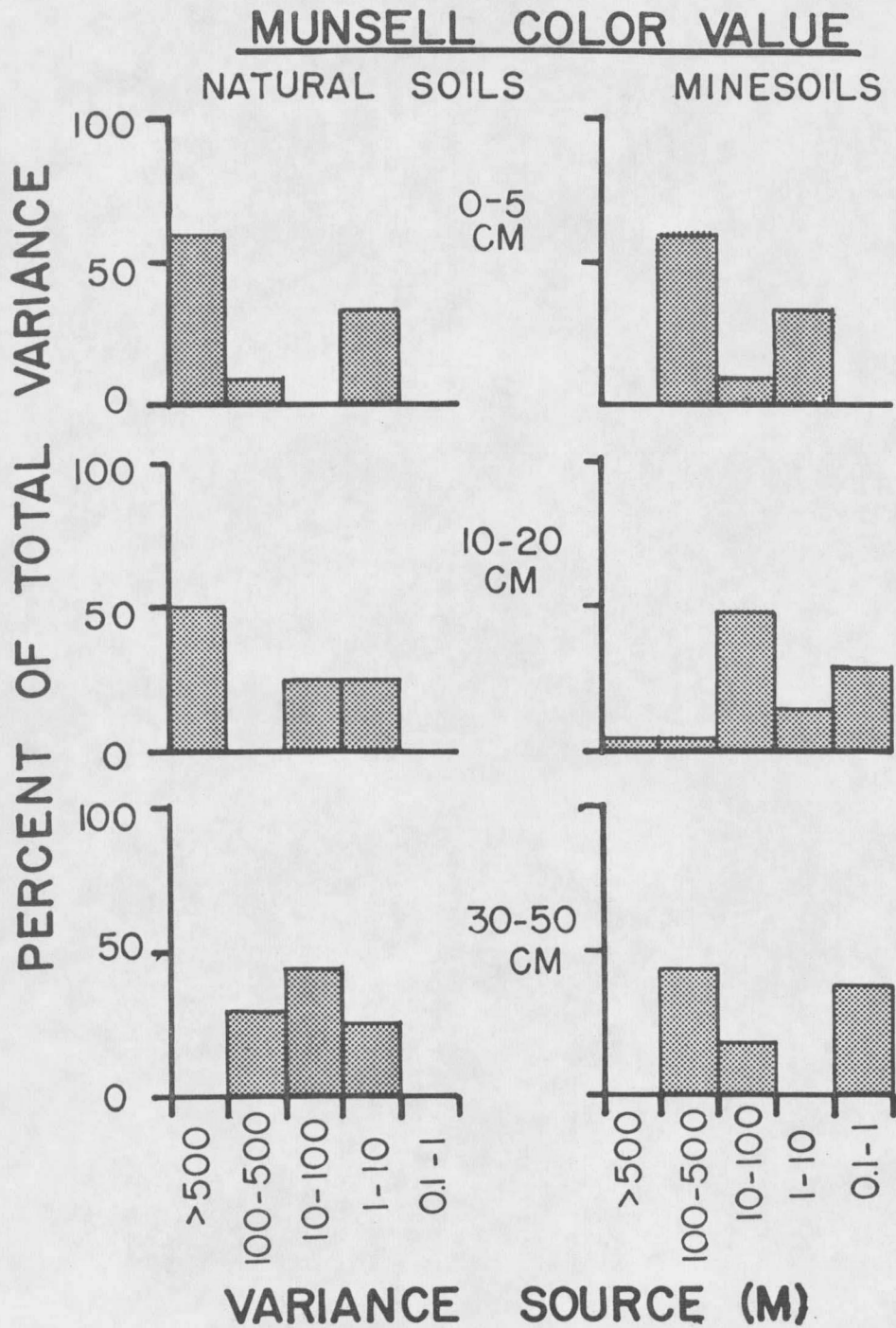


Figure 10. Components of variance are shown for color value at three depths in minesoils and natural soils.

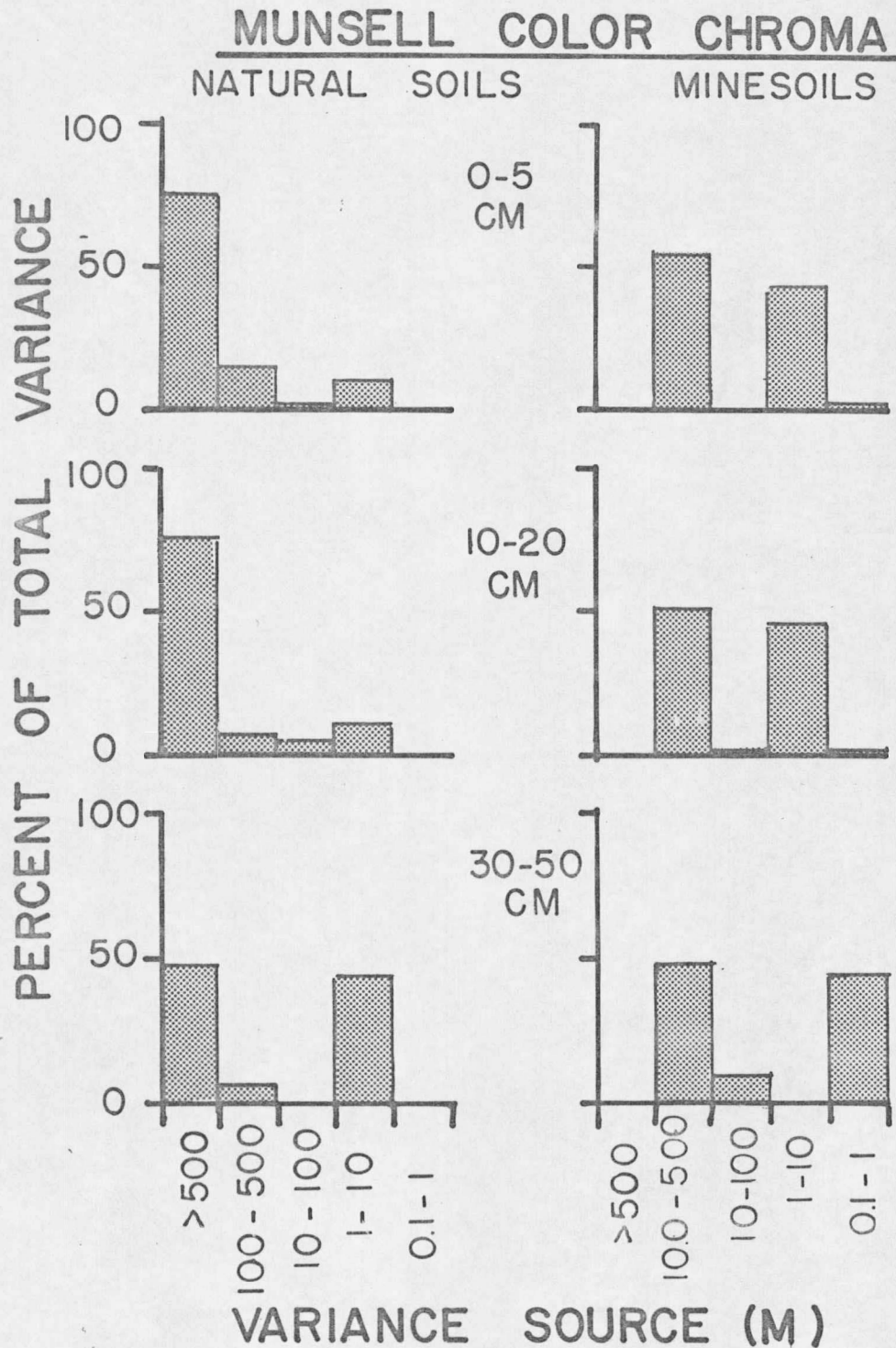


Figure 11. Components of variance are shown for color chroma at three depths in mine soils and natural soils.

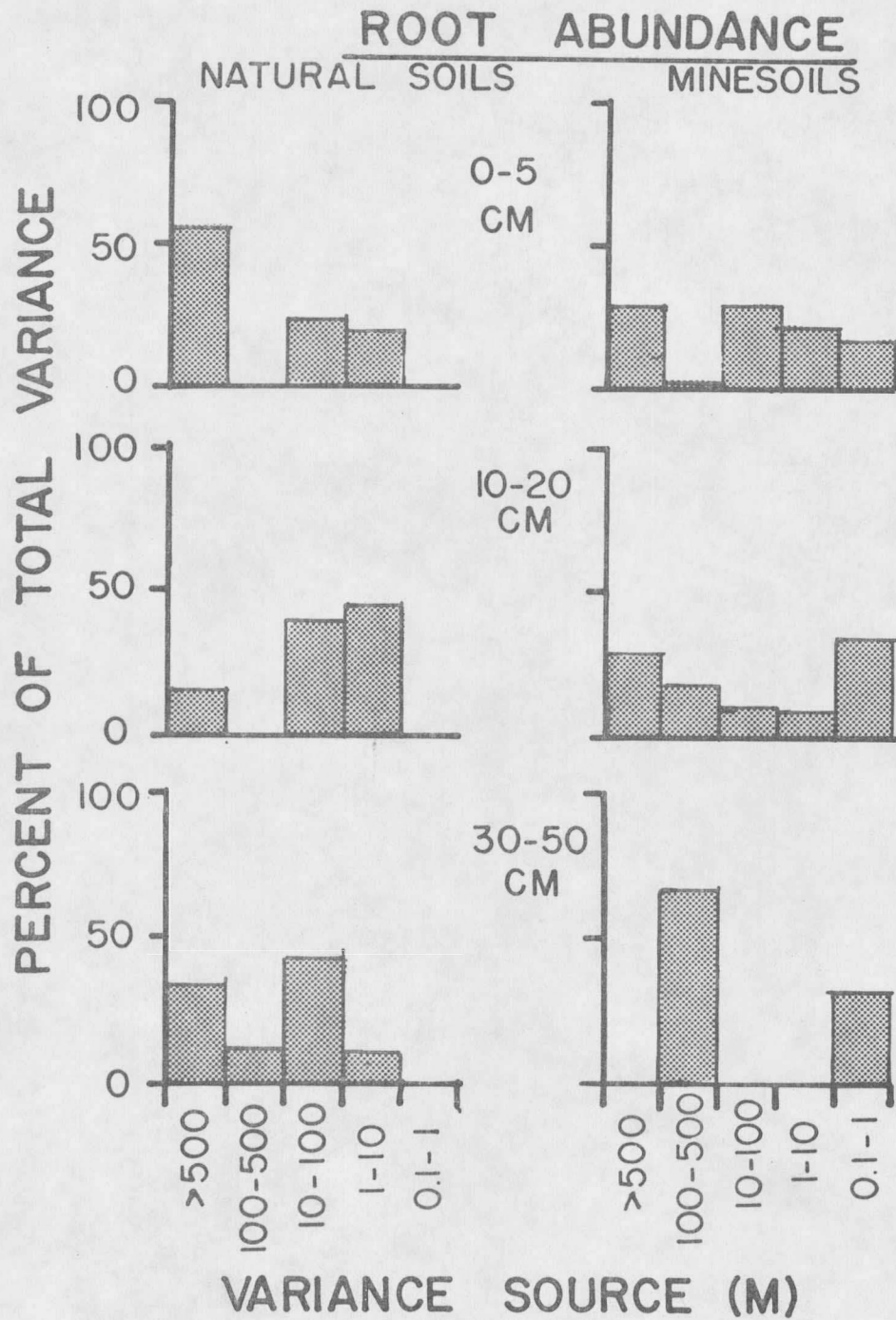


Figure 12. Components of variance are shown for root abundance at three depths in minesoils and natural soils.

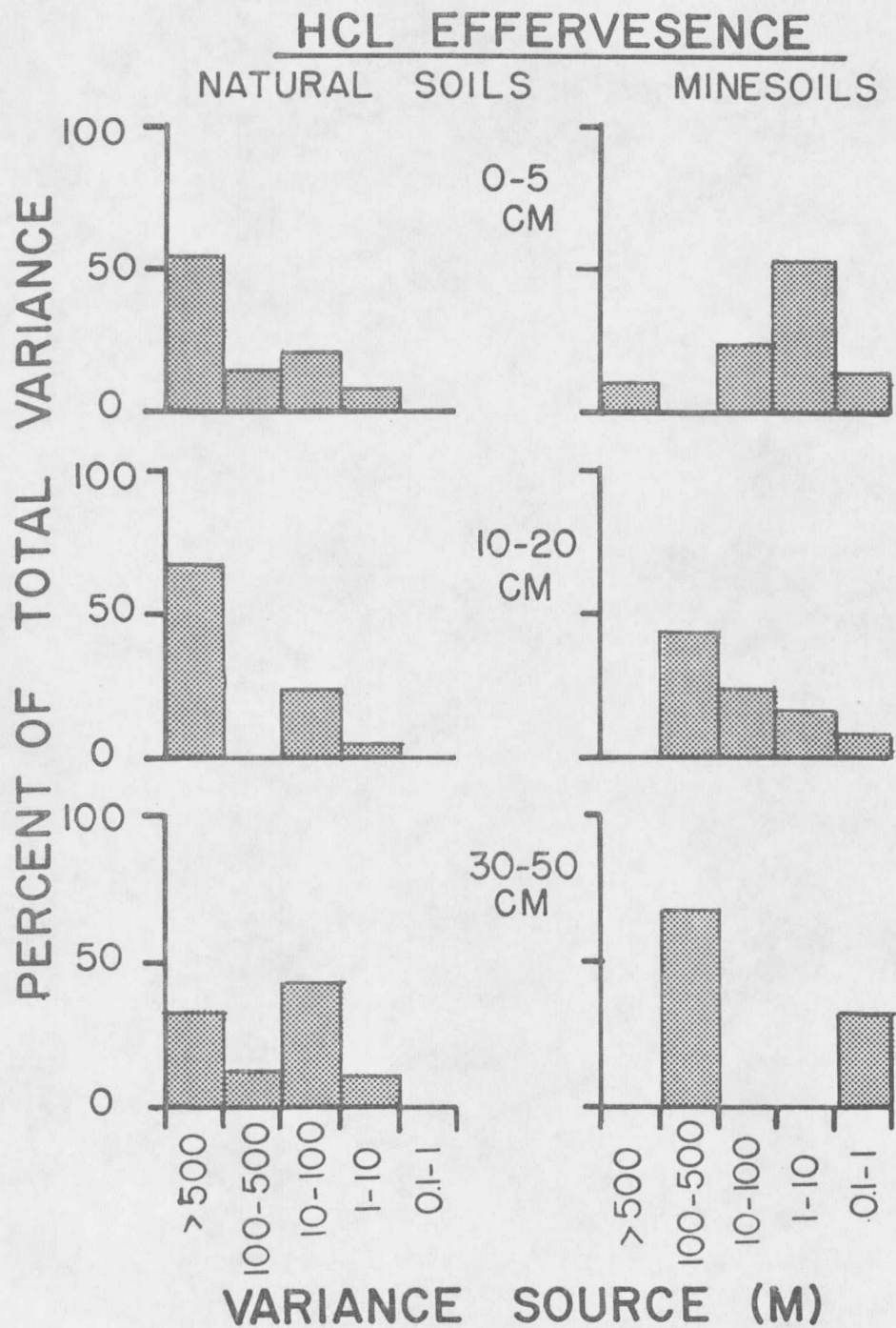


Figure 13. Components of variance are shown for HCl effervescence at three depths in minesoils and natural soils.

geomorphic position. The kind of soil structure is variable at smaller cell sizes. In minesoils few soil properties exhibit a large amount of variation at 500 m cell sizes. Soil texture, surface soil color, rock fragment content, and effervescence have a significant portion of their variability at the 100-500 m scale. Many properties of minesoils are extremely variable at the 1-10 m scale unlike natural soils. If the 0-10 cm cell size was studied as a separate variance component, it is probable that minesoils would have exhibited far more variability than natural soils in this range because of the mixed nature of spoils.

Estimated Pooled Variance

The estimated pooled variance for texture, soil chroma, and effervescence in HCl, was plotted for various cell sizes in natural soils and minesoils (Figure 14). In each case, the total variance at 500 m was greater in natural soils than in minesoils. However, in small cell sizes, variability of soil properties, like soil chroma, was often greater in minesoils than in natural soils. In general, minesoils were more variable than natural soils at 0 to 10 m lateral spacing (local scale), but natural soils were more variable at the 500 m spacing (landscape scale).

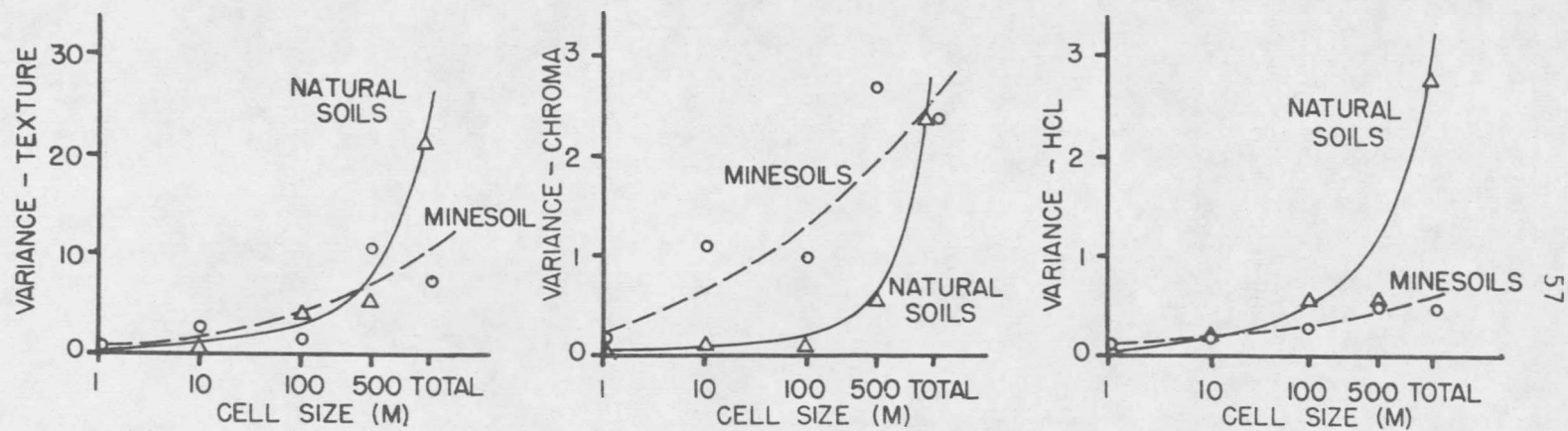


Figure 14. Estimated pooled variance for texture, soil chroma, and effervescence in HCl, was plotted for various cell sizes in natural soils and minesoils.

Correlation of Soils with Landscape Position

It was thought that differences in the pattern of variability of natural soils and minesoils could be explained in part by differences in the way soils were formed. Natural soils form under the influence of five soil-forming factors: parent materials, organisms, climate, relief, and time (Jenny, 1941). Differentiation of natural soils into different taxonomic groupings therefore results from differences in one or more soil-forming factors. In this study area, it appears that parent material in natural soils is fairly constant and that vegetation, climate, relief, and soil age vary gradually over the landscape. This graduation in soil-forming factors results in soil gradients encompassing

500 m in lateral distance. On mined land, however, climate organisms, and relief have had too little time to significantly influence soil properties. Minesoil properties are determined uniquely by the influence of parent material. The mining operation tends to intimately mix materials from several parts of the overburden column so that a somewhat random mixture results. It is for this reason that most minesoil properties vary on a smaller scale than natural soils, and that less total variation in minesoils was observed.

If the above hypothesis is correct, then soil properties in natural soils should be highly correlated with landscape features such as slope, aspect, and slope position. Minesoil properties

should not be correlated with similar measures of the mined landscape. Results in Table 7 tend to verify that natural soils are influenced by landscape factors while minesoils are not. Differences in aspect were correlated with soil properties in the upper layer of natural soils. Aspect was less highly correlated with soil properties below 5 cm where slope position, and geomorphic surface were both highly correlated with morphological characteristics. Using multiple linear regression techniques, often 30 to 50% of the variability in soil texture, color, structure, root abundance, and reaction in HCl could be explained by slope position, geomorphic surface, and aspect. On the minesoil landscape, differences in slope, aspect, cover-soil depth, and mode of deposition were seldom correlated with soil properties. When multiple linear regression was used to predict soil variables, mode of deposition was most often significantly correlated with minesoil properties.

Soil Classification

How do differences in the pattern of variability on mined land and natural landscapes affect the classification of the soil studied? Since total variability (500 m) was greatest in natural soils, more taxonomic variability would be expected on the natural landscape. Fourteen soil families were recognized in 60 observations of a 300 hectare tract of undisturbed soils. These families included six

Table 7. Correlation coefficients (r) significant at $P < .01$ between landscape variables and soil properties in natural soils and minesoils.

Depth (cm)	Soil Property	Natural Soils		Geomorphic Surface	Slope Position	Depth (cm)	Soil Properties	Minesoils Cover-Soil		Mode of Deposition
		Slope	Aspect					Depth	Slope	
	A hor. thick.	--	--	--	--	0-5	Texture	--	--	--
	B hor. thick	--	--	--	--	0-5	Value	--	--	--
	Depth to lime	--	--	--	--	0-5	Chroma	--	--	.46
	A hor. type	--	.48	--	.65	0-5	Sandstone	--	--	--
	B hor. type	--	--	.48	--	0-5	Siltstone	--	.44	--
	Family Text.	--	.46	.54	.47	0-5	HCl	--	--	.92
						0-5	Roots	--	--	.51
0-5	Texture	--	-.74	-.69	-.55					
0-5	Value	--	-.67	-.53	-.56	5-10	Texture	--	--	--
0-5	Chroma	--	-.62	-.56	-.38	5-10	Value	--	--	--
0-5	Structure	--	-.59	-.56	--	5-10	Chroma	--	.49	--
0-5	Roots	--	-.46	--	--	5-10	Sandstone	--	--	-.49
0-5	HCl	--	--	--	--	5-10	Siltstone	--	.34	--
						5-10	HCl	--	--	.82
						5-10	Roots	--	--	--
5-10	Texture	--	-.37	.48	--					
5-10	Value	.49	--	-.39	--					
5-10	Chroma	--	--	--	.69	10-20	Texture	--	--	--
5-10	Structure	--	--	--	.53	10-20	Value	--	--	--
5-10	Roots	--	.57	.37	--	10-20	Chroma	--	--	--
5-10	HCl	--	.67	.47	--	10-20	Sandstone	--	--	--
						10-20	Siltstone	--	--	--
						10-20	HCl	--	--	--
						10-20	Roots	--	--	--
10-20	Texture	--	.61	.41	--					
10-20	Value	--	--	--	--					
10-20	Chroma	--	--	--	.51					
10-20	Structure	--	--	--	.61	20-30	Texture	--	--	--
10-20	Roots	--	--	.51	--	20-30	Value	--	--	--
10-20	HCl	--	-.36	-.56	--	20-30	Chroma	--	--	--
						20-30	Sandstone	--	--	--
						20-30	Siltstone	--	--	--
20-30	Texture	--	--	.35	--	20-30	HCl	--	--	--
20-30	Value	--	--	-.69	--	20-30	Roots	--	--	--
20-30	Chroma	--	--	.44	--					
20-30	Structure	--	--	--	--					
20-30	Roots	--	--	--	--	30-50	Texture	--	--	--
20-30	HCl	--	--	--	--	30-50	Value	--	--	--
						30-50	Chroma	--	--	--
30-50	Texture	--	--	--	--	30-50	Sandstone	--	.38	--
30-50	Value	--	-.45	-.48	-.58	30-50	Siltstone	--	--	--
30-50	Chroma	--	.50	.53	--	30-50	HCl	--	--	.36
30-50	Structure	--	--	--	-.39	30-50	Roots	--	--	--
30-50	Roots	--	-.50	--	-.71					
30-50	HCl	--	--	--	-.65					

subgroups, five great groups, four suborders, and three orders including Mollisols, Aridisols, and Entisols (Soil Survey Staff, 1975). However, only 4 of the 14 soil families comprised 80% of the observations.

Only two soil families of Typic Ustorthents occurred on 400 hectares of mined land when soft rock fragments were disregarded in determining family particle-size class. Additional lab data might require similar families of Ustic Torriorthents to be recognized if electrical conductivity exceeded 2 mmhos/cm in the upper meter of some minesoils.

Although morphological differences were not evident in minesoils on different aspects, slopes, and hillslope positions, different soils may be recognized on the basis of soil microclimate, temperature, and water regimes. Differences in soil temperature and water regimes can often be predicted from slope, aspect, and slope position. These differences will strongly influence the productivity of minesoils.

CHAPTER 6

MAPPING SOILS ON MINED LAND

To create a soil map, all soils with similar properties were grouped together into a single delineation. Where soil properties either changed abruptly or gradually varied into a differing type of soil body, a boundary was drawn. Two or more similar or nearly identical soil bodies (delineations) made up a mapping unit.

To evaluate the similarities and differences between minesoils and to organize the array of minesoil characteristics from the different mined areas studied, a classification system, the Soil Taxonomy (Soil Survey Staff, 1975), was used. As in other classification systems, the Soil Taxonomy consists of different hierarchical levels or divisions. These levels include soil order, suborder, great group, subgroup, family, and series. A soils' order, suborder, and great group are determined by the kinds of soil horizons, other soil properties, or general climate. A soils great group is determined by its similarity with a typical or "typic" soil for that subgroup. Intergrades from the typic soil toward other great groups or towards non-soil can occur. Soil family is based on properties which affect soil management like texture, mineralogy, reaction, and climate. Finally, the soil series, the lowest level of the Soil

Taxonomy, consists of all pedons that lie within a defined range of soil properties. Many pedons may lie outside the defined limits of all established soil series. If this pedon is similar to an established series it is regarded as a "taxadjunct". If a pedon differs significantly from all established series it is considered a "variant" to the series it resembles most.

Differences in the pattern of soil variability on mined land and natural landscapes affects how soils can be mapped. On natural landscapes, soil maps can be prepared at varying levels of intensity and can consist of several different types of mapping units (SCS, 1977). The distribution of natural soils is related to geomorphic positions, regional geology, climate, and other broad geographic factors. For this reason, individual soil series can be mapped with order 1 (1:10,000 scale) or order 2 (1:100,000-1:30,000) surveys (Ovredahl, 1977) while distinct combinations of soil series or soil families can be mapped with lower intensity surveys (order 3-5). On mined land, soils are not correlated with landscape position. In addition, large contiguous mine areas are uncommon. Therefore, minesoils can only be mapped appropriately with order 1 or order 2 surveys.

While minesoils were found to be variable at local scales, only two families were found in an entire mine area. To avoid needless use of soil associations and soil complexes when mapping mined land,

soil series of minesoils were drafted to include local variability within the range of properties allowed for the series. In this way consociations (areas with a single series, SCS, 1977) were the primary mapping unit for mined land. Since Soil Taxonomy does not recognize many properties of minesoils which influence soil management, liberal use was made of soil phases for mined-land mapping.

Soil Families

Since minesoils lack genetic horizons for the most part, they fall in the Entisol order. Minesoils are not saturated with water (Aquepts), are not stream-derived (Fluents), are not primarily sandy (Psamments), and do not contain many fragments of diagnostic horizons (Arents). For this reason they fall in the Orthent suborder. Minesoils in the warmer, drier portions of the Northern Great Plains are in an aridic moisture regime bordering on ustic and thus are Ustic Torriorthents, while other minesoils are Typic Ustorthents because they are found in an ustic moisture regime. Within both of these subgroups minesoils fall into one of several soil families depending mostly upon soil texture. At one mine in North Dakota minesoils were classified as Entic Haploborolls because the topsoil applied to these soils contained enough organic carbon to be considered mollic epipedons or dark, organic-matter-rich surface horizons (Table 7).

Table 8 . Acreage of soil families and series recognized at six mine areas in the Northern Great Plains.

Family	Subgroup	Series*	Acreage
Coarse-loamy, mixed (calc.), mesic	Typic Ustorthent	Farley	934.5
Coarse-loamy, mixed (calc.), mesic	Typic Ustorthent	Castle Rock	134.7
Fine-loamy, mixed (calc.), mesic	Typic Ustorthent	Cow Creek	354.9
Fine-loamy, mixed (calc.), mesic	Typic Ustorthent	Dowlin	81.8
Loamy-skeletal, mixed (calc.), mesic	Typic Ustorthent	Absaloka	1.4
Coarse-loamy, mixed (calc.), mesic	Ustic Torriorthent	Roland	6.0
Coarse-loamy, mixed (calc.), mesic	Ustic Torriorthent	Thunder Basin	43.2
Fine-loamy, mixed (calc.), mesic	Ustic Torriorthent	Dietz	143.0
Fine-loamy, mixed (calc.), mesic	Ustic Torriorthent	Tanner Creek	18.5
Fine-lo./clayey, mixed (calc.), mesic	Ustic Torriorthent	Squirrel Creek	70.4
Fine-silty/fi-lo., mixed (calc.), mesic	Ustic Torriorthent	Belle Ayr	28.9
Fine-silty/clayey, mixed (calc.), frigid	Entic Haploboroll	Glenharold	266.9
Fine-loamy/sandy, mixed (calc.), frigid	Entic Haploboroll	Lignite	42.8
		Total	2,127.00

*these are not officially recognized soil series names

Development of Soil Series

From soil observations made in the field, the central concept and range of properties for several soil series were developed. Minesoils did not fit the definition of established series consisting of natural soils. Standard terminology and format from the National Soils Handbook (SCS, 1977) was used to draft working concepts of soil series. However, these series were not proposed for formal acceptance by the National Cooperative Soil Survey. The taxonomic name of the minesoils did not always convey information about some of their key management properties. In this way, the Soil Taxonomy was inadequate to classify minesoils. Therefore, liberal use of phases of soil series was made in soil mapping. Phases are subdivisions of soil series that are not formally classified in the soil taxonomy.

Soil Series Descriptions

Descriptions of the 13 soil series developed in this study follow.

ABSALOKA SERIES

The Absaloka series consists of deep well drained soils formed by man from soil materials and fractured sedimentary rocks. These soils occur on 0 to 20% slopes on reclaimed mined land in any landscape position. The mean annual precipitation is about 40 cm (16 in.) and the mean annual temperature averages 8°C (46°F).

Soil Family: Loamy-skeletal, mixed (calcareous), mesic typic Ustorthent.

Typical Pedon: Absaloka gravelly sandy loam (colors are for moist soil).

All 0-40 cm (0-16 in.) strong brown (7.5YR 5/6) fine sandy loam; 45% scoria fragments; massive; soft, very friable, non-sticky, non-plastic; many very fine roots; few fine pores; pH 7.6; slight effervescence; clear wavy boundary.

A12 40-68 cm (16-27 in.) strong brown (7.5YR 5/6) loamy fine sand; 35% scoria fragments; massive; soft, loose, non-sticky, non-plastic; common fine roots around rock fragments; pH 7.8; slight effervescence; abrupt smooth boundary.

C1 68+ cm (27+ in.) light olive brown (2.5Y 5/2) silty clay loam, 35% N5/0 soft siltstone; 10% 10YR 2/2 leonardite, 5% 10YR 5/8 siltstone; massive; slightly hard, slightly firm, sticky, plastic; few fine roots; pH 7.8; no effervescence.

Comments: Rock fragments are randomly oriented in the C1 horizon.

Type Location: Big Horn Co., Montana, Absaloka Stripmine, T 1 N, R 40 E, 500 feet east, 500 feet south of the NW corner of section 21.

Range in Characteristics: Effervescence ranges from none to moderate in the profile. No soil structure is evident.

The A horizon varies from 50 to 100 cm thick. Texture ranges from loamy sand to loam. Rock fragment content varies from 35 to 60% but varies widely with depth.

The C horizon contains 30 to 70% soft rock fragments which slake readily in water. Small amounts of weathered coal may also be present. Fragments average 3 to 6 cm in diameter and are randomly mixed throughout the C horizon. Texture varies from clay loam to silty clay.

Competing Series: Few natural soils could be confused with those found on mined land. Soils on mined land lack diagnostic horizons and have randomly oriented rock fragments in the C horizon. Competing series on mined land include the Farley, Cow Creek, Dowlin, and Castle Rock series. These soils have less than 35% durable rock fragments.

Geographic Setting: The Absaloka series occurs on 0 to 20% slopes on man-made landscapes. They occur on reclaimed areas where loamy-skeletal or fragmental soil materials have been placed over graded spoils derived from silty shale. The mean annual precipitation is 40 to 50 cm (Ustic). The mean annual soil temperature is 8° to 12°C.

Associated Soils: Absaloka soils may occur anywhere on the landscape where mining has occurred. Associated natural soils will often include Kirby, Armells, and Birney series'. Associated soils on disturbed land include Farley, Cow Creek, Castle Rock, and Dowlin soils.

Drainage and Permeability: Absaloka soils are somewhat excessively drained, have moderate permeability, and have slow to moderate runoff depending on landscape position.

Use and Vegetation: Most of these soils are found in carefully managed reclaimed areas used for livestock and wildlife forage production.

Distribution and Extent: Absaloka series occur in southeastern Montana in reclaimed areas. It is very inextensive.

BELLE AYR SERIES

The Belle Ayr series consists of deep, well drained soils formed by man from soil materials and fractured sedimentary rocks. These soils occur on 0 to 20% slopes in any landscape position. The mean annual precipitation is about 35 cm (14 in.), and the mean annual temperature averages 9°C (48°F).

Soil Family: Fine-loamy, mixed (calcareous), mesic Ustic Torriorthent.

Typical Pedon: Belle Ayr silt loam (colors are for moist soil).

A1 0-55 cm (0-20 in.) brown (10 YR 4/3) silty clay loam; massive; slightly hard, slightly firm, sticky, plastic; many fine roots; few fine pores; pH 7.5; slight effervescence; abrupt smooth boundary.

C1 55+ cm (22+ cm) dark yellowish brown (10YR 4/3) clay loam, 30% N4/0 soft shale; massive; slightly hard, slightly firm, sticky plastic; few to common fine roots; pH 7.8; moderate effervescence.

Comments: Rock fragments are randomly oriented in the C horizon.

Type Location: Campbell Co., Wyoming, Belle Ayr Stripmine. T 48 N R 71 W, 3000 feet E, 1000 feet S of the NW corner of section 34.

Range in Characteristics: Effervescence ranges from none to moderate throughout the profile. Salt or gypsum crystals occur in the A and C horizons in places. The A horizon varies from 30 to 60 cm in thickness, and from silt loam to silty clay loam in texture.

The C horizon contains 30 to 60% soft shale and siltstone fragments which readily slake in water. Some coal fragments may also be present. Fragments average 3 to 6 cm in size and are randomly mixed throughout the C horizon. Textures include loam, clay loam, silty clay loam, and clay in irregular horizons.

Competing Series: Few natural soils could be confused with those found on mined land. Soils on mined land lack diagnostic horizons and have randomly oriented rock fragments in the C horizon. Competing series on mined land include the Dietz, Tanner Creek, Squirrel Creek, Roland and Thunder Basin series'. Dietz soils are fine-loamy throughout the control section, while Tanner Creek soils are coarse-loamy in the upper control section. Squirrel Creek soils are fine.

Roland and Thunder Basin soils average coarse-loamy in the control section. Geographic Setting: The Belle Ayr series occurs on 0 to 20% slopes on man-made landscapes. They are found on reclaimed areas where fine-silty soil materials have been placed over graded spoils derived from shale and siltstone. The mean annual precipitation is 20 to 40 cm (aridic). The mean annual soil temperature is 8° to 12°C.

Associated Soils: Belle Ayr soils occur anywhere on the landscape where mining has occurred. Associated natural soils will often include Colby and Keiser series. Associated soils on mined land include Dietz, Tanner Creek, Squirrel Creek, Roland and Thunder Basin series.

Drainage and Permeability: Belle Ayr soils are well-drained, have moderate permeability, and have slow to rapid run-off depending on landscape position.

Use and Vegetation: Most of these soils are found in carefully managed reclaimed areas used for range forage production.

Distribution and Extent: Belle Ayr series occurs in eastern Wyoming and southeastern Montana in reclaimed areas. It is very inextensive.

CASTLE ROCK SERIES

The Castle Rock Series consists of deep well drained soils formed by man from soil materials and fractured sedimentary rocks. These soils occur on 0 to 20% slopes on reclaimed mined land in any landscape position. The mean annual precipitation is about 40 cm (16 in.), and the mean annual temperature averages 8°C (46°F).

Soil Family: Coarse-loamy, mixed (calcareous), mesic Typic Ustorthent.

Typical Pedon: Castle Rock loam (colors are for moist soils)..

A11 0-21 cm (0-8 in.) dark yellowish brown (10YR 4/4) loam; massive; soft, friable, non-sticky, non-plastic; many very fine roots; few fine pores; pH 8.1; moderate effervescence; clear wavy boundary.

A12 21-57 cm (8-23 in.) dark yellowish brown (10YR 4/4) clay loam; massive; slightly hard, slightly firm, slightly sticky, slightly plastic; common fine roots; few fine pores; pH 8.4; moderate effervescence; abrupt smooth boundary.

C1 57 cm (23+ in.) light brownish gray (2.5YR 6/2) fine sandy loam, 20% N6/0 soft sandstone, 10% N5/0 soft siltstone, 5% 10YR 4/4 soft sandstone; massive; soft, very friable, non-sticky, non-plastic; few to common roots; pH 8.3; strong effervescence.

Comments: Rock fragments are randomly oriented in the C1 horizon. Irregular patches or horizons of varying color occur in the A1 horizon.

Type Location: Rosebud County, Montana. Rosebud stripmine. Area A, T 2 N, R 41 E, 1200 feet S, 800 feet E of the NW corner of section 33.

Range in Characteristics: The entire profile ranges from slight to strong effervescence. Little or no soil structure is evident.

The A horizon varies from 30 to 60 cm. thick. Texture includes loam, clay loam, silt loam, and silty clay loam. Color ranges from 10YR 4/3 to 10YR 5/4 with several different colors often present in a single profile.

The C horizon contains 20 to 60% soft rock fragments which readily slake in water. Fragments average 2 to 4 cm in size and are randomly mixed throughout the C horizon. Up to 10% hard scoria fragments may also be present. The C horizon texture varies from loamy sand to fine sandy loam.

Competing Series: Few natural soils could be confused with those found on mined land. Soils on mined land lack diagnostic horizons and have randomly oriented rock fragments in the C horizon. Competing series on mined land include the Farley, Cow Creek, Dowlin and Thunder Basin series. The Farley is loam or coarser throughout the profile. Cow Creek and Dowlin soils have a fine-loamy control section texture. The Thunder Basin series occurs in areas with less than 40 cm of precipitation.

Geographic Setting: The Castle Rock series occurs on 0 to 20% slopes on man-made landscapes. They occur on reclaimed areas where fine-loamy soil materials have been placed over graded spoil derived mostly from sandstone. The mean annual precipitation is 40 to 50 cm (Ustic). The mean annual soil temperature is 8 to 12°C.

Associated Soils: Castle Rock soils may occur anywhere on the landscape where mining has occurred. Associated natural soils will often include Yamac, Ethridge, and Delphill series. Associated soils on disturbed land include Farley, Cow Creek, Dowlin, and Absaloka series.

Drainage and Permeability: Castle Rock soils are well drained, and have moderately rapid permeability. Runoff is slow to rapid depending on landscape position.

Use and Vegetation: Most of these soils are found in carefully managed reclaimed areas used for range forage production.

Distribution and Extent: Castle Rock series occurs in Southeastern Montana in reclaimed areas. It is very inextensive.

COW CREEK SERIES

The Cow Creek series consists of deep well-drained soils formed by man from soil materials and fractured sedimentary rocks. These soils occur on 0 to 20% slopes on reclaimed mined land in any landscape position. The mean annual precipitation is about 40 cm (16 in.) and the mean annual temperature averages 8°C (46°F).

Soil Family: Fine-loamy, mixed (calcareous), mesic. Typic Ustorthent.

Typical Pedon: Cow Creek clay loam (colors are for moist soil).

A1 0-36 cm (0-14 in.) dark yellowish brown (10YR 4/4) clay loam; massive; slightly hard, slightly firm, slightly sticky, slightly plastic; many very fine roots; few fine pores; pH 8.1; moderate effervescence; abrupt smooth boundary.

C1 36-85+ cm (14-33+ in.) light brownish gray (2.5YR 6/2) heavy loam; 20% N5/0 soft siltstone; 10% 10YR 4/4 soft sandstone; massive; soft, friable, non-sticky, non-plastic; few to common roots; pH 8.5; slight effervescence.

Comments: Rock fragments are randomly oriented in the C horizon. Irregular patches or horizons of varying color occur in the A horizon.

Type Location: Rosebud County, Montana. Rosebud stripmine. Area A. T 2 N, R 41 E, 2400 feet S, of the NW corner of section 33.

Range in Characteristics: The entire profile ranges from slight to strong effervescence. Little or no soil structure is evident.

The A horizon varies from 0 to 85 cm thick. Texture may include loam, clay loam, silt loam, or silty clay loam. Color ranges from 10YR 3/4 to 10YR 5/4, with several different colors often present in a single profile.

The C horizon contains 20 to 60% soft rock fragments which readily slake in water. Fragments average 2 to 4 cm in size and are randomly mixed throughout the C horizon. Up to 10% hard scoria fragments may also be present. The C horizon texture varies from loam to silty clay loam.

Competing Series: Few natural soils could be confused with those found on mined land. Soils on mined land lack diagnostic horizons and have randomly oriented rock fragments in the C horizon. Competing series on mined land include the Dowlin, Farley, Castle Rock, and Dietz series. The Dowlin series is coarse-loamy in the upper control section. The Farley and Castle Rock average coarse-loamy texture in the control section. The Dietz series occurs in areas which receive less than 40 cm of precipitation.

Geographic Setting: The Cow Creek series occurs on 0 to 20% slopes on man-made landscapes. They occur on reclaimed areas where fine-loamy soil materials have been placed over graded spoil derived from siltstone, shale and sandstone. The mean annual precipitation is 40 to 50 cm (Ustic). The mean annual soil temperature is 8 to 12°C.

Associated Soils: Cow Creek soils may occur anywhere on the landscape where mining has occurred. Associated natural soils will often include Yamac, Ethridge, and Delphill series. Associated soils on disturbed land include Farley, Castle Rock, Dowlin, and Absaloka series.

Drainage and Permeability: Cow Creek soils are well-drained, and have moderately rapid permeability. Run-off is slow to rapid, depending on landscape position.

Use and Vegetation: Most of these soils are found in carefully managed reclaimed areas used for range forage production.

Distribution and Extent: Cow Creek series occurs in southeastern Montana in reclaimed areas. It is very inextensive.

DIETZ SERIES

The Dietz series consists of deep well-drained soils formed by man from soil materials and fractured sedimentary rocks. These soils occur on 0 to 20% slopes on reclaimed land in any landscape position. The mean annual precipitation is about 35 cm (14 in.) and the mean annual temperature averages 9°C (48°F).

Soil Family: Fine-loamy, mixed (calcareous), mesic. Ustic Torriorthent.

Typical Pedon: Dietz loam (colors for moist soil).

A11 0-15 cm (0-6 in.) dark brown (10YR 3/3) loam; massive; soft, very friable, non-sticky, non-plastic; many fine roots; few fine pores; pH 7.2; slight effervescence; clear smooth boundary.

A12 15-32 cm (6-13 in.) brown (10YR 4/3) loam; weak coarse platy structure; hard, very firm, non-sticky, non-plastic; few fine roots between peds; pH 7.5; slight effervescence; abrupt smooth boundary.

C1 32-60+ cm (13-24+ in.) dark yellowish brown (10YR 4/4) clay loam, 35% N4/0 soft shale, 10% 10YR 5/6 shale fragments; massive; slightly hard, slightly firm, sticky, slightly plastic; no roots; pH 7.6; slight effervescence.

Comments: Rock fragments are randomly oriented in the C horizon. The compacted A12 horizon impedes root penetration.

Type Location: Campbell County, Wyoming. T 48 N, R 71 W, 3800 feet east, 400 feet S of the NW corner of section 34.

Range of Characteristics: Effervescence ranges from none to moderate in the profile. Platy soil structure is present in compacted zones. Salt or gypsum crystals occur in the A and C horizons in places. The A horizon varies from 25 to 70 cm thick. Textures include loam, silt loam, and clay loam.

The C horizon contains 30 to 60% soft shale and siltstone fragments which readily slake in water. Some coal fragments may also be present. Fragments average 3 to 6 cm in diameter and are randomly mixed throughout the C horizon. Textures include loam, clay loam, silty clay loam, and clay in irregular horizons.

Competing Series: Few natural soils could be confused with those found in mined land. Soils on mined land lack diagnostic horizons and have randomly oriented rock fragments in the C horizon. Competing series on mined land include the Tanner Creek, Squirrel Creek, Belle Byr, Roland, Thunder Basin, and Cow Creek series. Tanner Creek soils are coarse-loamy in the upper control section. Squirrel Creek soils are fine. Belle Ayr soils are fine-silty in the upper control section. Roland and Thunder Basin soils are coarse-loamy. The Cow Creek series occurs in areas which receive more than 40 cm of precipitation.

Geographic Setting: The Dietz series occurs on 0 to 20% slopes on man-made landscapes. They are found on reclaimed areas where fine-loamy soil materials have been placed over graded spoils derived from shale and siltstone. The mean annual precipitation is 20 to 40 cm (aridic). The mean annual soil temperature is 8 to 12°C.

Associated Soils: Dietz soils may occur anywhere on the landscape where mining has occurred. Associated natural soils often include McRae, Olney, Maysdorf, Fort Collins, Spearman and Thedalund series. Associated soils on disturbed land include Tanner Creek, Squirrel Creek, Belle Ayr, Roland, and Thunder Basin series.

Drainage and Permeability: Dietz soils are well drained, have moderate permeability, and have slow to rapid runoff depending on landscape position.

Use and Vegetation: Most of these soils are found in carefully managed reclaimed areas used for range forage production.

Distribution and Extent: Dietz series occurs in eastern Wyoming and southeastern Montana in reclaimed areas. It is very inextensive.

DOWLIN SERIES

The Dowlin series consists of deep somewhat excessively drained soils formed by man from soil materials and fractured sedimentary rocks. These soils occur on 0 to 20% slopes on reclaimed mined land in any landscape position. The mean annual precipitation is about 40 cm (16 in.) and the mean annual temperature averages 8°C (46°F).

Soil Family: Fine-loamy, mixed (calcareous), mesic. Typic Ustorthent.

Typical Pedon: Dowlin fine sandy loam (colors are for moist soil).

A1 0-50 cm (0-20 in.) dark yellowish brown (10YR 4/4) fine sandy loam; massive; soft, very friable, non-sticky, non-plastic; many fine roots; few fine pores; pH 8.3; moderate effervescence; abrupt smooth boundary.

C1 50-93 cm (20-37 in.) light brownish gray (2.5YR 6/2) clay loam; 35% N5/0 soft siltstone, 10% 10YR 4/4 soft sandstone; massive; slightly hard, slightly firm, slightly sticky, slightly plastic; few fine roots; few fine pores; pH 8.5; slight effervescence.

Comments: Rock fragments are randomly oriented in the C horizon. Irregular patches or horizon of varying color occur in the A horizon.

Type Location: Rosebud County, Montana; Rosebud stripmine. Area A. T 2 N, R 41 E, 800 feet S, 400 feet W of the NE corner of section 33.

Range in Characteristics: The entire profile ranges from slight to strong effervescence. Little or no soil structure is evident.

The A horizon varies from 30 to 60 cm thick. Texture of the A horizon may include fine sandy loam, loam, or irregular patches of loamy sand. Color ranges from 10YR 3/4 to 10YR 5/4 with several different colors often present in a single profile.

The C horizon contains 20 to 60% soft rock fragments which readily slake in water. Fragments average 2 to 4 cm in diameter and are randomly mixed throughout the C horizon. Up to 10% scoria fragments may also be present. The C horizon texture varies from loam to silty clay loam.

Competing Series: Few natural soils could be confused with those found on mined land. Soils on mined land lack diagnostic horizons and have randomly oriented rock fragments in the C horizon. Competing series on mined land include the Cow Creek, Farley, Castle Rock, and Tanner Creek series. The Cow Creek series is fine-loamy throughout the profile. Farley and Castle Rock soils average coarse-loamy texture in the control section. Tanner Creek series occur in areas which receive less than 40 cm (16 in.) of precipitation.

Geographic Setting: The Dowlin series occurs on 0 to 20% slopes on man-made landscapes. They occur on reclaimed areas where coarse-loamy soil materials have been placed over graded spoils derived from siltstone and shale. The mean annual precipitation is 40 to 50 cm (Ustic). The mean annual soil temperature is 8 to 12°C.

Associated Soils: Dowlin soils may occur anywhere on the landscape where mining has occurred. Associated natural soils will often include Busby, Remmitt, and Chinook series. Associated soils on disturbed land include Farley, Castle Rock, Cow Creek, and Absaloka series.

Drainage and Permeability: Dowlin soils are somewhat excessively drained, and have moderately rapid or rapid permeability. Runoff is slow to rapid depending on landscape position.

Use and Vegetation: Most of these soils are found in carefully managed reclaimed areas used for range forage production.

Distribution and Extent: Dowlin series occurs in southeastern Montana in reclaimed mined areas. It is very inextensive.

FARLEY SERIES

The Farley series consists of deep, somewhat excessively drained soils formed by man from soil materials and fractured sedimentary rocks. These soils occur on 0 to 20% slopes on reclaimed mined land in any landscape position. The mean annual precipitation is about 40 cm (16 in.) and the mean annual temperature averages 8°C (46° F).

Soil Family: Coarse-loamy, mixed (calcareous), mesic Typic Ustorthent.

Typical Pedon: Farley sandy loam (colors are for moist soil).

A1 0-58 cm (0-23 in.) dark yellowish brown (10YR 4/4) fine sandy loam; massive; soft, very friable, non-sticky, non-plastic; many very fine roots; few fine pores; pH 8.0; moderate effervescence; abrupt smooth boundary.

C1 58-95+ cm (23-37+ in.) light brownish gray (2.5Y 6/2) fine sandy loam, 20% N6/0 soft sandstone fragments; 10% N5/0 soft siltstone; 5% 10YR 4/4 soft sandstone; massive; soft; very friable, non-sticky non-plastic; few to common fine roots; pH 8.3; strong effervescence.

Comments: Rock fragments are randomly oriented in the C1 horizon. Irregular patches or horizons of varying color occur in the A1 horizon.

Type Location: Rosebud County, Montana. Rosebud stripmine Area A. T 2N, R 41 E, 2400 feet S, 1600 feet E of the NW corner of section 33.

Range in Characteristics: The entire profile ranges from slight to strong effervescence. Little or no soil structure is evident.

The A horizon varies from 0 to 85 cm thick. Texture ranges from very fine sandy loam to light loam, irregular horizons of loamy sand are often present. Color ranges from 10YR 4/3 to 10YR 5/4 with several different colors often present in a single profile.

The C horizon contains 20 to 60% soft rock fragments which readily slake in water. Fragments average 2 to 4 cm in size and are randomly mixed throughout the C horizon. Up to 10% hard scoria fragments may also be present. The C horizon texture varies from loamy sand to loam.

Competing Series: Few natural soils could be confused with those found on mined land. Soils on mined land lack diagnostic horizons and have randomly oreinted rock fragments in the C horizon. Competing series on mined land include the Castle Rock, Cow Creek, Dowlin, and Roland Series. The Castle Rock has fine-loamy textures in the upper part of the profile, Cow Creek and Dowlin soils are fine-loamy in the control section, and the Roland series receives less than 40 cm (16 in.) of precipitation.

Geographic Setting: The Farley series occurs on 0 to 20% slopes on man-made landscapes. They occur on reclaimed areas where coarse-loamy soil materials have been placed over graded spoil derived mostly from sandstone. The mean annual precipitation is 40 to 50 cm (ustic). The mean annual soil temperature is 8°C to 12°C.

Associated Soils: Farley soils may occur anywhere on the landscape where mining has occurred. Associated natural soils will often have a coarse-loamy texture. These include Busby, Remmit, and Chinook series. Associated soils on distrubed land include Castle Rock, Cow Creek, Dowlin, and Absaloka series.

Drainage and Permeability: Farley soils ar excessively well-drained and have rapid permeability. Run-off is slow to rapid depending on landscape position.

Use and Vegetation: Most of these soils are found in carefully managed reclaimed areas used for range forage production.

Distribution and Extent: Farley series occurs in southeastern Montana in reclaimed mine areas. It is very inextensive.

GLENHAROLD SERIES

The Glenharold series consists of deep, somewhat poorly drained to moderately well drained soils formed by man from soil materials and fractured sedimentary rocks. These soils occur on 0 to 20% slopes on reclaimed mined land in any landscape position. The mean annual precipitation is about 40 cm (16 in.) and the mean annual temperature averages 5°C (41°F).

Soil Family: Fine-silty over clayey, mixed Entic Haploboroll.

Typical Pedon: Glenharold silt loam (colors are for moist soil).

A11 0 - 19 cm (0-7 in.) very dark grayish brown (10YR 3/2) silt loam; weak fine granular; soft, friable, slightly sticky, slightly plastic; many fine and very fine roots; few fine pores; slightly alkaline; moderate effervescence; clear smooth boundary.

A12 19-40 cm (7-16 in.) brown (10YR 4/3) silt loam; massive; slightly hard, friable, slightly sticky, slightly plastic; common fine and very fine roots; few fine pores; slightly alkaline; moderate effervescence; abrupt smooth boundary.

C1 40-75+ cm (16-30+ in.) dark yellowish brown (10YR 4/4) silty clay, 30% gray (N5/0) shale fragments, 15% black (N2/0) coal; massive; very hard, very firm, sticky, plastic; no roots; alkaline; slight effervescence.

Type Location: Mercer County, North Dakota; Glenharold-Stanton Strip mine, T 144 N, R 84 W, 500 feet W, 2800 feet N of the SE corner of section 29.

Range in Characteristics: The fine-silty A horizon ranges from 25 to 80 cm thick. The upper part of the control section is silt loam while the lower part is clay or silty clay. Non-calcareous horizons may occur locally but do not dominate the weakly to moderately calcareous control section.

The color in the upper horizon ranges from 10YR 3/1 to 10YR 3/3 with irregular mottles or horizons of 10YR 4/3 and 10YR 4/4. The color in the lower part of the control section is extremely variable but includes N/3 to N/5 siltstone, N/3 shale, N/2 lignite, 10YR 4/3 and 10YR 4/4 siltstone and shale and 7.5 YR 6/8 iron stains from pyrite weathering. Rock fragments that readily slake in water range from 20 to 60% in the lower control section.

Structure is generally lacking in these soils but weak granular structure may occur in the upper 10 to 20 cm.

Competing Series: Few natural soils could be confused with those found on mined land. Soils on mined land lack diagnostic subsurface horizons and have randomly oriented rock fragments in the C horizons. Many undefined soils exist on mined land that are coarse-loamy over clayey, or fine-loamy. The competing Lignite series has a fine-loamy over sandy control section.

Geographic Setting: The Glenharold series occurs on 0 to 20% slopes on man-made landscapes. They occur on reclaimed areas where loess-derived soil materials have been placed over graded spoil consisting of shale and siltstone. The mean annual precipitation is 40 to 50 cm (Ustic). The mean annual soil temperature is less than 8°C and the summer soil temperature is greater than 15°C.

Associated Soils: Glenharold soils may occur anywhere on the landscape where mining has occurred. Associated natural soils will often have a fine-silty control section including the Cherry, Colvin, Grassna, and Temuvik soils. Each of these soils has a cambic horizon. Associated soils on disturbed lands will usually differ in texture of the control section.

Drainage and Permeability: Glenharold soils are somewhat poorly to moderately well drained; they have slow permeability, and very slow to rapid run-off depending on landscape position.

Use and Vegetation: Most of these soils are carefully managed reclaimed areas used for range forage or dryland cereal grain production.

Distribution and Extent: Glenharold series occurs in western and central North Dakota reclaimed mine areas. It is very inextensive.

LIGNITE SERIES

The Lignite series consists of deep moderately well drained soils formed by man from soil materials and fractured sedimentary rocks. These soils occur on 0 to 20% slopes on reclaimed mined land in any landscape position. The mean annual precipitation is about 40 cm (16 in.) and the mean annual temperature averages 5°C (41°F).

Soil Family: Fine-loamy over sandy, mixed Entic Haploboroll.

Typical Dedon: Lignite loam (colors are for moist soil).

A1 0-49 cm (0-19 in.) very dark grayish brown (10YR 3/2) loam; massive; soft, friable, non-sticky, non-plastic; many fine and very fine roots; few fine pores; slightly alkaline; slight effervescence; abrupt smooth boundary.

C1 49-78 cm (19-31 in.) dark yellowish brown (10YR 4/4) loamy sand; massive; loose, non-sticky, non-plastic; few to common fine roots; slightly alkaline; slight effervescence; abrupt smooth boundary.

C2 78+ cm (31+ in.) grayish brown (2.5Y 5/2) clay loam, 20% gray N5/0 siltstone fragments, 10% black (N2/0) coal; massive; very hard, very firm, sticky, plastic; no roots; alkaline; slight effervescence.

Comments: The C2 horizon was dry perhaps due to restricted water movement into the sand layer.

Type Location: Mercer County, North Dakota; Glenharold-Stanton strip mine.

Range in Characteristics: The loamy A horizon ranges from 30 to 80 cm thick. The upper part of the control section consists of stratified layers of sandy loam, loam, or silt loam texture. The C1 horizon varies from 15 to 35 cm thick and is sand or loamy sand in texture. Non-calcareous horizons may occur locally but do not dominate the weakly to moderately calcareous control section.

Color in the A1 horizon ranges from 10YR 3/1 to 10YR 3/3 with irregular patches or horizons of 10YR 4/4 material. The C2 horizon is extremely variable and mottled in appearance but includes N/3 to N/5 siltstone and shale, N/2 lignite, and 7.5YR 6/8 iron stains from pyrite weathering. Rock fragments that readily slake in water range from 20 to 60% in the C2 horizon.

Competing Series: Few natural soils could be confused with those found on mined land. Soils on mined land lack diagnostic subsurface horizons and have randomly oriented rock fragments in the C horizon. Many undefined soils exist on disturbed areas that are coarse-loamy over clayey; or fine-loamy. The competing Glenharold series has a fine-silty over clayey control section.

Geographic Setting: The Lignite series occurs on 0 to 20% slopes on man-made landscapes. They occur on reclaimed areas where fine-loamy soil materials and windblown sand have been placed in layers over graded spoil consisting of siltstone and shale. The mean annual precipitation is 40 to 50 cm (Ustic). The mean annual soil temperature is less than 8°C, and the summer soil temperature is greater than 15°C.

Associated Soils: Lignite soils may occur anywhere on the landscape where mining has occurred. Associated soils will include those with a fine-loamy texture and others with sandy texture. These natural soils will differ from the Lignite series by having cambic horizons or some other genetic feature. Associated soils on disturbed lands will usually differ in texture.

Drainage and Permeability: Moderately well drained; slow permeability. The sand layer and the clay layer prevent much percolation of water below the A1 horizon.

Use and Vegetation: Most of these soils are in carefully managed reclaimed areas used for range forage or dryland cereal grain production.

Distribution and Extent: Lignite series occur in western and central North Dakota reclaimed mine areas. It is very inextensive.

ROLAND SERIES

The Roland series consists of deep somewhat excessively drained soils formed by man from soil materials and fractured sedimentary rocks. These soils occur on 0 to 20% slopes on reclaimed land in any landscape position. The mean annual precipitation is about 35 cm (14 in.), and the mean annual temperature averages 9°C (38°F).

Soil Family: Coarse-loamy, mixed (calcareous), mesic Ustic Torriorthent.

Typical Pedon: Roland sandy loam (colors are for moist soil).

A1 0-40 cm (0-16 in.) yellowish brown (10YR 5/4 fine sandy loam; massive; loose, non-sticky, non-plastic; many fine roots; pH 7.2; slight effervescence; abrupt smooth boundary.

C1 40-75+ cm (16-30+ in.) light brownish gray (10 YR 6/2) fine sandy loam; 20% N6/0 soft sandstone, few distinct 10YR 5/8 and 5YR 6/6 mottles; single-grained; loose, non-sticky, non-plastic; common fine roots; pH 7.4; no effervescence.

Comments: Pedon was located in a reconstructed alluvial channel. Rock fragments are randomly oriented in the C horizon.

Type Location: Campbell County, Wyoming, Belle Ayr Stripmine. T 48 N, R 71 W, 3700 feet E, 950 feet S of the NW corner of section 34.

Range in Characteristics: Effervescence ranges from none to slight throughout the profile. The A horizon varies from 0 to 80 cm thick. Loamy sand, sandy loam, and loam textures predominate with several different textures often present in a single pedon.

The C horizon contains 20 to 50% soft sandstone and shale fragments which readily slake in water. Some coal fragments may also be present. Fragments average 2 to 4 cm in diameter. Textures include loam, sandy loam, and occasional subhorizons of loamy sand.

Competing Series: Few natural soils could be confused with those found on mined land. Soils on mined land lack diagnostic horizons and have randomly oriented rock fragments in the C horizon. Competing series on mined land include the Dietz, Tanner Creek, Belle Ayr, Squirrel Creek, Thunder Basin, and Farley series. The Dietz, Tanner Creek, and Belle Ayr series' average fine-loamy in the

control section. Squirrel Creek soils are fine, while Thunder Basin soils are fine-loamy in the upper control section. Farley soils occur in areas which receive more than 40 cm (16 in.) of precipitation.

Geographic Setting: The Roland series occurs on 0 to 20% slopes on man-made landscapes. They are found on reclaimed areas where coarse-loamy soil materials have been placed over graded spoils derived from sandstone. The mean annual precipitation is 20 to 40 cm (aridic). The mean annual soil temperature is 8 to 12°C.

Associated Soils: Roland soils may occur anywhere on the landscape where mining has occurred. Associated natural soils often include Terry, Vona, Nelson, and Vebar series. Associated soils on disturbed areas include Dietz, Tanner Creek, Squirrel Creek, Belle Ayr, and Thunder Basin.

Drainage and Permeability: Roland soils are somewhat excessively drained, have rapid permeability, and have slow to rapid run-off depending on landscape position.

Use and Vegetation: Most of these soils are found in carefully managed reclaimed areas used for range forage production.

Distribution and Extent: Roland series occurs in eastern Wyoming and southeastern Montana in reclaimed areas. It is very inextensive.

SQUIRREL CREEK SERIES

The Squirrel Creek series consists of deep well drained soils formed by man from soil materials and fractured sedimentary rocks. These soils occur on 0 to 20% slopes on reclaimed land in any landscape position. The mean annual precipitation is about 35 cm (14 in.) and the mean annual temperature averages 9°C (48°F).

Soil Family: Fine, montmorillonitic (calcareous) mesic Ustic Torriorthent.

Typical Pedon: Squirrel Creek loam (colors are for moist soil).

A11 0-22 cm (0-9 in.) yellowish brown (10YR 5/4) loam; massive; soft; friable; non-sticky, non-plastic; many very fine roots; few fine pores; pH 8.0; moderate effervescence; clear smooth boundary.

A12 22-56 cm (9-22 in.) dark yellowish brown (10YR 4/4) sandy clay loam; massive; soft, friable, non-sticky, slightly plastic; common fine roots; pH 8.3; moderate effervescence; abrupt smooth boundary.

C1 56-90+ cm (22-35+ in.) very dark gray (10YR 3/1) silty clay; 35% N/3 shale; 5% coal, 5% N/5 sandstone; massive; slightly hard, slightly firm, very sticky, plastic; no roots; pH 8.7; moderate effervescence.

Comments: Rock fragments are randomly oriented in the C1 horizon.

Type Location: Big Horn County, Montana. Decker stripmine, T 9 S, R 40 E, 1050 feet E, 700 feet N of the SW corner of section 15/

Range in Characteristics: Effervescence ranges from slight to strong in the profile. The A horizon varies from 20 to 60 cm thick. Textures include sandy loam, loam, sandy clay loam, silt loam, silty clay loam, and clay loam. Many different subhorizons with varying texture are often present in a single pedon.

The C horizon contains 25 to 50% soft rock fragments which slake readily in water. Small amounts of coal may also be present. Fragments average 3 to 6 cm in diameter and are randomly mixed throughout the C horizon. Color varies from 10YR 3/1 to 10YR 4/4. Clay loam, silty clay loam, clay, and silty clay textures predominate.

Competing Series: Few natural soils could be confused with those on mined land. Soils on mined land lack diagnostic horizons and have randomly oriented rock fragments in the C horizon. Competing series on mined land include the Dietz, Tanner Creek, Belle Ayr, Roland, and Thunder Basin series. Dietz, Tanner Creek, and Belle Ayr soils are fine-loamy. Roland and Thunder Basin soils are coarse-loamy.

Geographic Setting: The Squirrel Creek series occurs on 0 to 20% slopes on man-made landscapes. They are found on reclaimed areas where up to 60 cm of fine-loamy or clayey soil materials have been placed over graded spoils derived from shale. The mean annual precipitation is 20 to 40 cm (aridic). The mean annual soil temperature is 8 to 12°C.

Associated Soils: Squirrel Creek soils may occur anywhere on the landscape where mining has occurred. Associated natural soils will often include McRae, Olney, Maysdorf, Fort Collins, Spearman, and Thedalund series. Associated soils on mined land include Dietz, Tanner Creek, Belle Ayr, Roland, and Thunder Basin.

Drainage and Permeability: Squirrel Creek soils are moderately well-drained, have slow permeability, and have slow to rapid run-off depending on landscape position.

Use and Vegetation: Most of these soils are found in carefully managed reclaimed areas used for range forage production.

Distribution and Extent: Squirrel Creek soils occurs in eastern Wyoming and southeastern Montana in reclaimed areas. It is very inextensive.

TANNER CREEK SERIES

The Tanner Creek series consists of deep well-drained soils formed by man from soil materials and fractured sedimentary rocks. These soils occur on 0 to 20% slopes on reclaimed land in any landscape position. The mean annual precipitation is about 35 cm (14 in.) and the mean annual temperature averages 9°C (48°F).

Soil Family: Fine-loamy, mixed (calcareous), mesic Ustic Torriorthent.

Typical Pedon: Tanner Creek sandy loam (colors are for moist soil).

A11 0-45 cm (0-18 in.) dark yellowish brown (10YR 4/4) sandy loam; massive; soft, very friable, non-sticky, non-plastic; many fine roots; few fine pores; pH 7.0; slight effervescence; clear smooth boundary.

A12 45-66 cm (18-26 in.) dark yellowish brown (10YR 4/4) loamy sand; loose, non-sticky, non-plastic; common fine roots; pH ; moderate effervescence; abrupt smooth boundary.

C1 66+ cm (26+ in.) dark yellowish brown (10YR 4/4) clay loam; 35% N4/0 soft shale, 5% N2/0 coal; massive, slightly hard, slightly firm, sticky, slightly plastic; few fine roots; pH 7.9.

Comments: Rock fragments are randomly oriented in the C horizon.

Type Location: Campbell County, Wyoming. Belle Ayr stripmine. T 48 N R 71 W, 3300 feet E, 600 feet S of the NW corner of section 34.

Range of Characteristics: Effervescence ranges from slight to strong throughout the profile. The A horizon varies from 25 to 70 cm thick. Loam, sandy loam, and loamy sand textures may occur in irregular horizons, but averages coarse-loamy.

The C horizon contains 30 to 60% soft shale which readily slake in water. Some coal fragments may also be present. Fragments average 3 to 6 cm in diameter and are randomly mixed throughout the C horizon. Textures include loam, clay loam, silty clay loam, and clay in irregular horizons.

Competing Series: Few natural soils could be confused with those found on mined land. Soils on mined land lack diagnostic horizons and have randomly oriented rock fragments in the C horizon. Competing series on mined land include the Dietz, Squirrel Creek, Belle Ayr, and Dowlin series. The Dietz series is fine-loamy throughout the profile. Squirrel Creek soils are fine and Belle Ayr soils are fine-silty in the upper control section. Dowlin soils occur in areas which receive more than 40 cm of precipitation.

Geographic Setting: The Tanner Creek series occurs on 0 to 20% slopes on man-made landscapes. They are found on reclaimed areas where coarse-loamy soil materials have been placed over graded spoils derived from siltstone and shale. The mean annual precipitation is 20 to 40 cm (aridic). The mean annual soil temperature is 8 to 12°C.

Associated Soils: Tanner Creek soils may occur anywhere on the landscape where mining has occurred. Associated natural soils will often include Terry, Vona, Nelson, and Vebar series. Associated soils on disturbed areas include Dietz, Squirrel Creek, Belle Ayr, Roland, and Thunder Basin series.

Drainage and Permeability: Tanner Creek soils are well-drained, have moderate permeability, and have slow to rapid run-off depending on landscape position.

Use and Vegetation: Most of these soils are found in carefully managed reclaimed areas used for range forage production.

Distribution and Extent: Tanner Creek series occurs in eastern Wyoming in reclaimed areas. It is very inextensive.

THUNDER BASIN SERIES

The Thunder Basin series consists of deep well-drained soils formed by man from soil materials and fractured sedimentary rocks. These soils occur on 0 to 20% slopes on reclaimed land in any landscape position. The mean annual precipitation is about 35 cm (14 in.), and the mean annual temperature averages 9°C (48°F).

Soil Family: Coarse-loamy, mixed (calcareous), mesic Ustic Torriorthent.

Typical Pedon: Thunder Basin clay loam (colors are for moist soil).

A1 0-55 cm (0-22 in.) dark yellowish brown (10YR 4/4) clay loam, massive; slightly hard, slightly firm, sticky, plastic; many fine roots; few fine pores; pH 7.6; moderate effervescence; abrupt smooth boundary.

C1 55-95+ cm (22-38+ in.) light brownish gray (10YR 6/2) sandy loam, 20% N6/0 soft sandstone, 10% N4/0 shale; massive; loose, non-sticky, non-plastic; few to common fine roots; pH 7.4; slight effervescence.

Comments: Rock fragments are randomly oriented in the C horizon.

Type Location: Campbell County, Wyoming, Belle Ayr stripmine. T 48 N, R 71 W, 3800 feet E, 1650 feet N, of the SW corner of section 27.

Range in Characteristics: Effervescence ranges from none to moderate throughout the profile. The A horizon varies from 30 to 65 cm thick, loam, clay loam, and silt loam textures predominate.

The C horizon contains 20 to 50% soft sandstone and shale fragments which readily slake in water. Some coal fragments may also be present. Fragments average 2 to 4 cm in diameter. Textures include loam, sandy loam, and intermittent subhorizons of loamy sand.

Competing Series: Few natural soils could be confused with those found on mined land. Soils on mined land lack diagnostic horizons and have randomly oriented rock fragments in the C horizon. Competing series on mined land include the Dietz, Tanner Creek, Belle Ayr, Squirrel Creek, Roland, and Castle Rock series. The Dietz, Tanner Creek, and Belle Ayr series average fine-loamy in the control section. Squirrel Creek soils are fine, while Roland soils are

coarse-loamy throughout the control section. Castle Rock soils occur in areas which receive more than 40 cm (16 in.) of precipitation.

Geographic Setting: Thunder Basin series occurs on 0 to 20% slopes on man-made landscapes. They are found on reclaimed areas where fine-loamy soil materials are placed over graded spoils derived from sandstone. The mean annual precipitation is 20 to 40 cm (aridic). The mean annual soil temperature is 8 to 12°C.

Associated Soils: Thunder Basin soils occur anywhere on the landscape where mining has occurred. Associated natural soils often include McRae, Olney, Maysdorf, Fort Collins, Spearman, and Thedalund series. Associated soil on disturbed areas include Dietz, Tanner Creek, Squirrel Creek, Belle Ayr, and Roland series.

Drainage and Permeability: Thunder Basin soils are well-drained, have moderate permeability, and have slow to rapid run-off depending on landscape position.

Use and Vegetation: Most of these soils are found in carefully managed reclaimed areas used for range forage production.

Distribution and Extent: Thunder Basin series occurs in eastern Wyoming and southeastern Montana in reclaimed areas. It is very inextensive.

Soil Phases

Phases of soil series were employed where two soil bodies (delineations) in the same series differed in some property that would affect management. Examples of phases applied to all mapping units included topsoil depth, and slope. Occasionally other properties such as degree of erosion, compaction, wetness, piping, or alluvial landscape position were also used as phase criteria.

Soil Maps

Using techniques outlined in earlier sections, soil maps were prepared at the AMAX Belle Ayr mine, Decker Mine, Westmoreland Absaloka Mine, Western Energy Rosebud Mine Pit 6, and Area A and at the Consolidation Glenharold Mine. A general legend and a more detailed descriptive legend are included with each map.

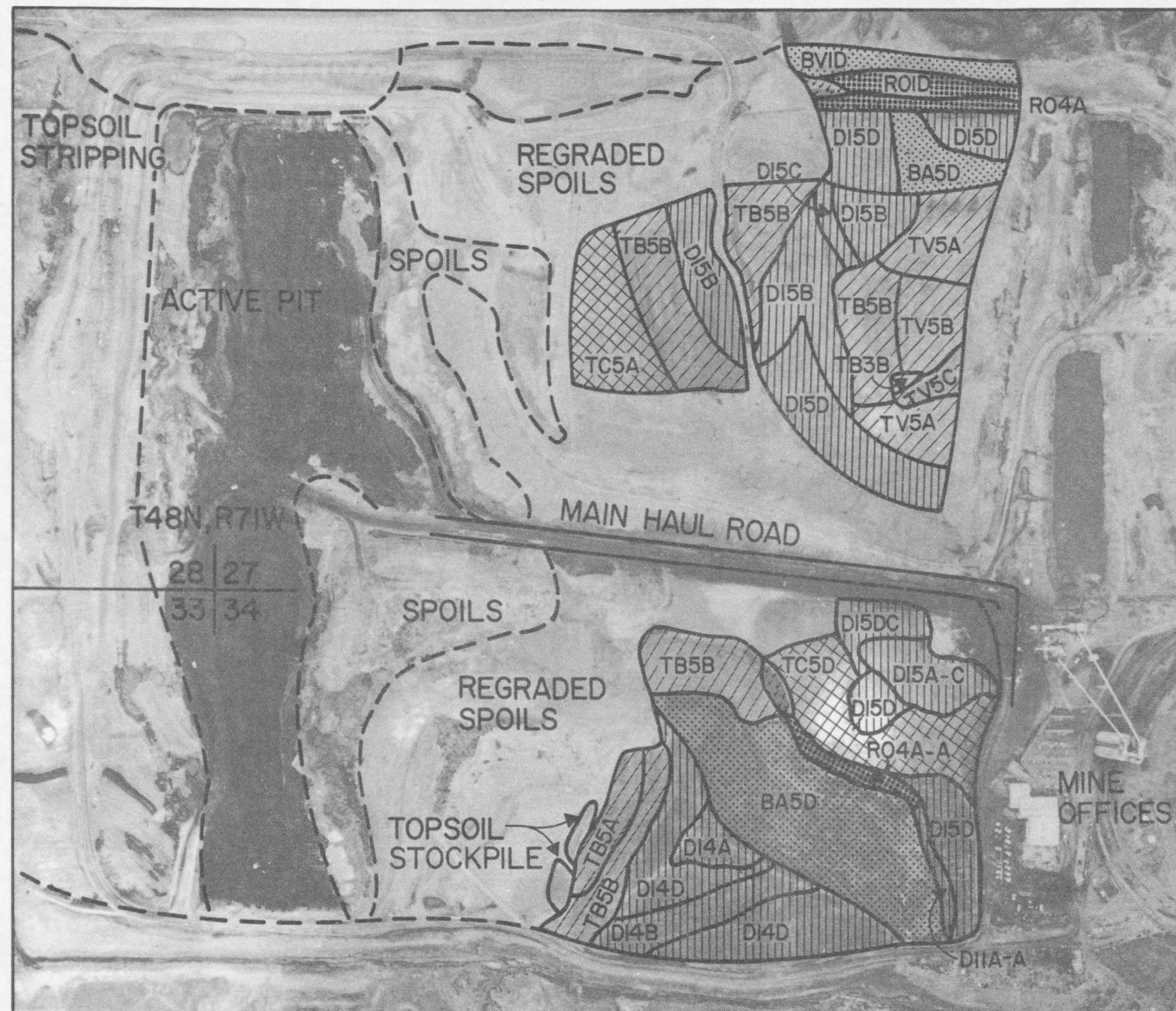
AMAX Mine

Five soil series were mapped at the AMAX mine (Figure 15; Table 9). All soils were in the same subgroup, Ustic Torriorthents. The five series were separated on the basis of topsoil and spoil texture.

Belle Ayr soils had fine-silty textures in the topsoil layer which ranged from 30 to 60 cm in thickness. The spoil material was fine-loamy in texture. A large area of Belle Ayr soils was found on a north-facing slope of the oldest minesoils at the AMAX mine. Some

SOIL MAP

BELLE AYR MINE
AMAX COAL CO.

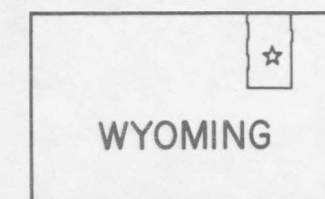


GENERAL LEGEND

SOIL SERIES

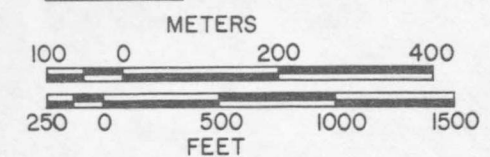
- THUNDER BASIN
- DIETZ
- ROLAND
- BELLE AYR
- WATER
- TANNER CREEK

LOCATION



CAMPBELL CO., WYO.

SCALE



APRIL, 1979

Figure 15. Soil map of the AMAX mine.

Table 9. Descriptive legend for soils mapped on the Amax Belle Ayr stripmine in Campbell Co., Wyoming.

Family	Series	Symbol	Acreage	No. Del.	Phase			LCC	SPI Range
					Topsoil Depth	Slope	Other		
fine-loamy, mixed (calc) mesic Ustic Torriorthent	Belle Ayr	BA5D	25.5	2	40-60	>15		VIe-11	62
			25.5						
fine-silty, mixed (calc) mesic Ustic Torriorthent	Belle Ayr taxadjunct	BV1D	3.4	1	0	>15		VIe-11	43
			3.4						
fine-loamy, mixed (calc) mesic Ustic Torriorthent	Dietz	DI1A-A	0.9	1	0	0-3	alluvial position	IVc-16	56
		DI4A	2.1	1	20-40	0-3		IVc-16	72
		DI4B	5.0	1	20-40	3-8		IVc-16	72
		DI4D	13.8	2	20-40	>15		VIe-11	64
		DI5B	14.9	3	40-60	3-8		IVc-16	74
		DI5C	1.1	1	40-60	8-15		IVc-16	69
		DI5D	20.7	5	40-60	>15		VIe-11	66
		DI5A-C	4.0	1	40-60	0-3	compact subsoil	VIIs-2	52
		DI5D-C	2.4	1	40-60	>15	compact subsoil	VIIs-2	46
			64.9						
coarse-loamy, mixed (calc) mesic Ustic Torriorthent	Roland	RO1D	2.9	1	0	>15	alluvial position	VIIe-11	46
		RO4A	1.8	1	20-40	0-3		VIIs-7	63
		RO4A-A	1.3	1	20-40	0-3		VIIs-7	59
			6.0						
fine-loamy, mixed (calc) mesic Ustic Torriorthent	Tanner Creek	TC5A	8.0	1	40-60	0-3		IVc-16	73
		TC5D	10.5	1	40-60	>15		VIIe-11	65
			18.5						
coarse-loamy, mixed (calc) mesic Ustic Torriorthent	Thunder Basin	TB3B	0.3	1	10-20	3-8		VIIs-7	71
		TB5A	2.7	1	40-60	0-3		IVc-16	71
		TB5B	26.7	5	40-60	3-8		IVc-16	71
			29.7						
coarse-loamy, mixed (calc) mesic Ustic Torriorthent	Thunder Basin taxadjunct	TV5A	8.2	2	40-60	0-3	sand substrata	VIIs-7	71
		TV5B	3.8	1	40-60	3-8	sand substrata	VIIs-7	71
		TV5C	1.5	1	40-60	8-15	sand substrata	VIIs-7	66
			13.5						
-	Water	-	1.0	2	-	-			
-	Topsoil	-	.9	2	-	-			
			163.4	39					

moderately saline, clayey patches were found in places within this mapping unit.

Dietz soils which were fine-loamy throughout the profile were the most common soils at the AMAX mine. They usually allowed deep rooting, had high water-holding capacity and were not highly erodible. In a few locations, Dietz soils had compacted subsoil layers which restricted rooting (Figure 16). Thunder Basin soils were similar to the Dietz series except they had coarse-textured spoil material at 30 to 65 cm which lowered their water-holding capacity.

Tanner Creek soils which were not common at the AMAX mine had coarse-textured topsoil over fine-loamy spoil. They were somewhat erodible on steep slopes. Roland soils which were coarse-textured throughout the profile were droughty and very erodible when on steep slopes. Roland soils often occurred in alluvial positions where sandy materials had been placed to simulate natural drainages.

Glenharold Mine

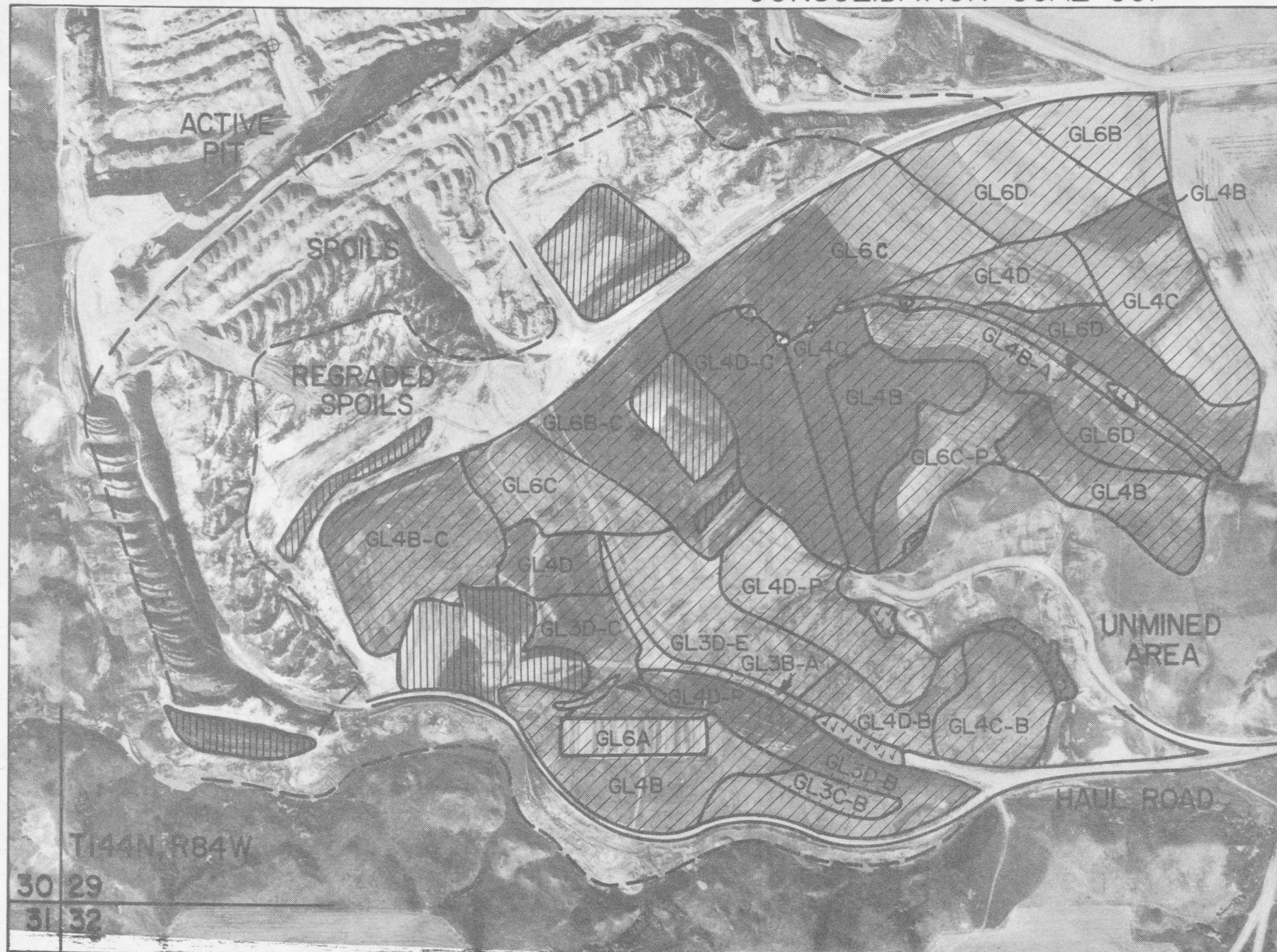
Only two soil series were mapped on over 330 acres at the Glenharold mine (Figures 17 and 18, Table 10). These series were the only Mollisols described in the study (Entic Haploborolls). Many different phases of the Glenharold series were recognized based on differences in topsoil depth, slope, degree of erosion, compaction, landscape position, and spoil characteristics. Topsoil materials



Figure 16. Compaction of the spoil surface before topsoil application can create a barrier to root penetration. The roots shown are flattened and horizontally-oriented on a compacted layer at 30 cm.

GLENHAROLD MINE - SOUTH CONSOLIDATION COAL CO.

SOIL MAP



GENERAL LEGEND

SOIL SERIES

-  GLENHAROLD
-  WATER
-  TOPSOIL STOCKPILE

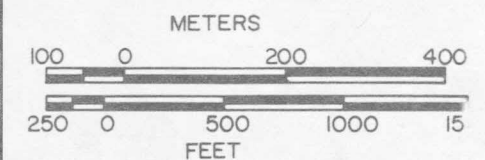
LOCATION



MERCER CO., N.D.



SCALE

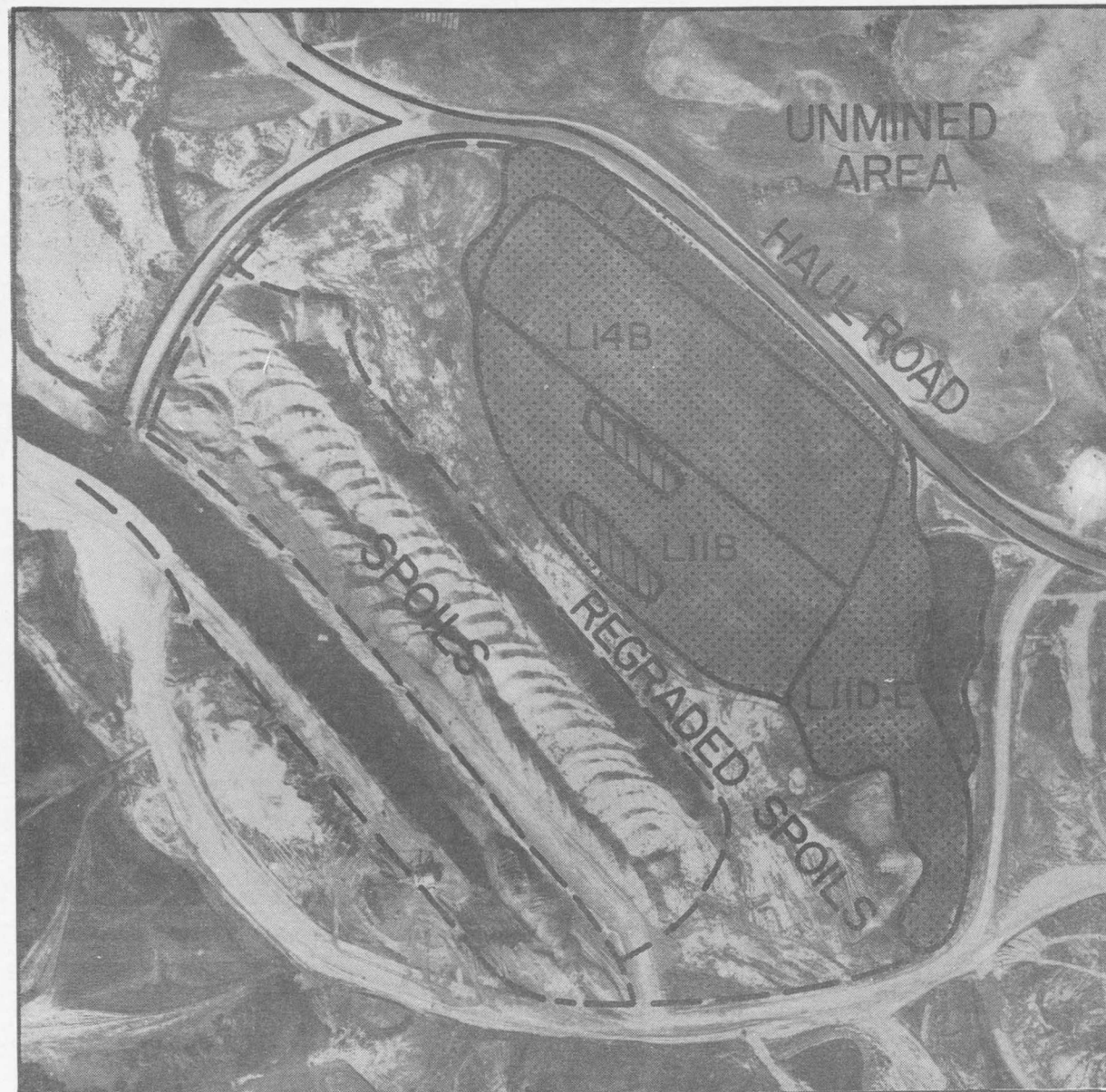


MAY, 1979

Figure 17. Soil map of the Glenharold Mine (south).

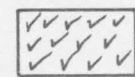
SOIL MAP

GLENHAROLD MINE - NORTH
CONSOLIDATION COAL CO.

GENERAL LEGEND

SOIL SERIES

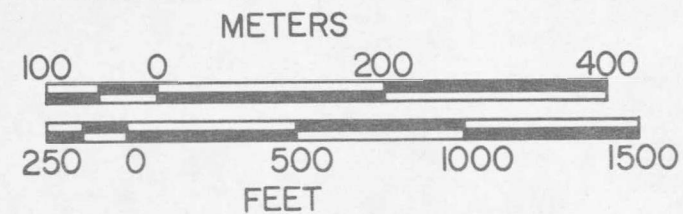
 LIGNITE

 WATER

 TOPSOIL
STOCKPILE

LOCATION

MERCER CO., N.D.

SCALE

MAY, 1979

Figure 18. Soil map of the Glenharold Mine (north).

Table 10. Descriptive legend for soils mapped on the Consolidation Coal Glenharold-Stanton stripmine in Mercer Co., North Dakota.

Family	Series	Symbol	Acreage	No. Del.	Phase			LCC	SPI Range
					Topsoil Depth	Slope	Other		
fine-silty over clayey, mixed (calc) Entic Haploboroll	Glenharold	GL3B-A	3.0	1	10-20	3-8	alluvial position	VIIs-2	86
		GL3C-B	4.0	1	10-20	8-15	carboniferous spoil	VIIIs-2	81
		GL3D-B	14.4	1	10-20	>15	carboniferous spoil	VIIe-11/2	74
		GL3D-C	7.4	1	10-20	>15	compacted subsoil	VIIe-11	57
		GL3D-E	13.5	1	10-20	>15	eroded	VIIIe-12	37
		GL4B	33.3	4	20-40	3-8		IVs-2	96
		GL4B-A	4.0	1	20-40	3-8	alluvial position	IVs-2	92
		GL4B-C	10.9	1	20-40	3-8	compacted subsoil	VIIs-2	81
		GL4C	22.5	2	20-40	8-15		VIIs -2/11	94
		GL4C-B	9.4	1	20-40	8-15	carboniferous spoil	VIIs -2/11	94
		GL4D	10.3	2	20-40	>15		VIe-11	86
		GL4D-B	5.9	1	20-40	>15	carboniferous spoil	VIe-11	86
		GL4D-C	14.2	1	20-40	>15	compacted subsoil	VIIe-11	64
		GL4D-P	13.5	2	20-40	>15	piping erosion	VIIe-12	64
		GL6A	4.0	1	60-100	0-3		IIIs-2	105
		GL6B	7.7	1	60-100	3-8		IIIs-2	105
		GL6B-C	13.8	1	60-100	3-8	compacted subsoil	IVs-2	93
		GL6C	32.5	2	60-100	8-15		IVs-2	98
		GL6C-P	9.5	1	60-100	8-15	piping erosion	VIe-12	72
		GL6D	33.1	3	60-100	>15		VIe-11	86
			266.9	29					
fine-loamy over sandy, mixed (calc) Entic Haploboroll	Lignite	LI7B	12.8	1	0	3-8		VIIs-1	70
		LI1D-E	9.5	1	0	>15	eroded	VIIe-12	40
		LI3D	6.0	1	10-20	>15		VIe-11	81
		LI4B	14.5	1	20-40	3-8		IVs-2	100
			42.8	4					
-	Water	-	7.7	11	-	-			
-	Topsoil	-	15.1	3	-	-			
			332.5	47					

were very permeable while spoil had low permeability. As a result excess water accumulated in the topsoil zone and flowed laterally to cause piping (Figure 19). This process occurred most frequently in snow accumulation zones like below a hill creast on an east-facing slope. Surface erosion occurred in other areas completely removing the topsoil (Figure 20). The Lignite series was similar to Glenharold soils except a sandy layer occurred between the spoil and topsoil. This layer seemed to cause water to perch in the topsoil because spoil material in Lignite soils was dry while spoil in Glenharold soils was moist. This sand layer which impeded liquid water movement may also prevent upward sodium movement which is a problem in North Dakota minesoils.

Decker Mine

Only two series were mapped at the Decker Mine, Dietz which was fine-loamy and Squirrel Creek which was fine-loamy over fine in texture (Figures 21 and 22, Table 11). Soils at the Decker mine were less sloping than at most other mine areas which decreased the amount of erosion evident. Squirrel Creek soils with fine-textured spoil had shallower rooting depths and had piping occurring in some places. Upward sodium movement occurred from spoil into topsoil material as evidenced by the gradual increase in sodium levels in the lower topsoil depths which were originally non-sodic (Table 12).

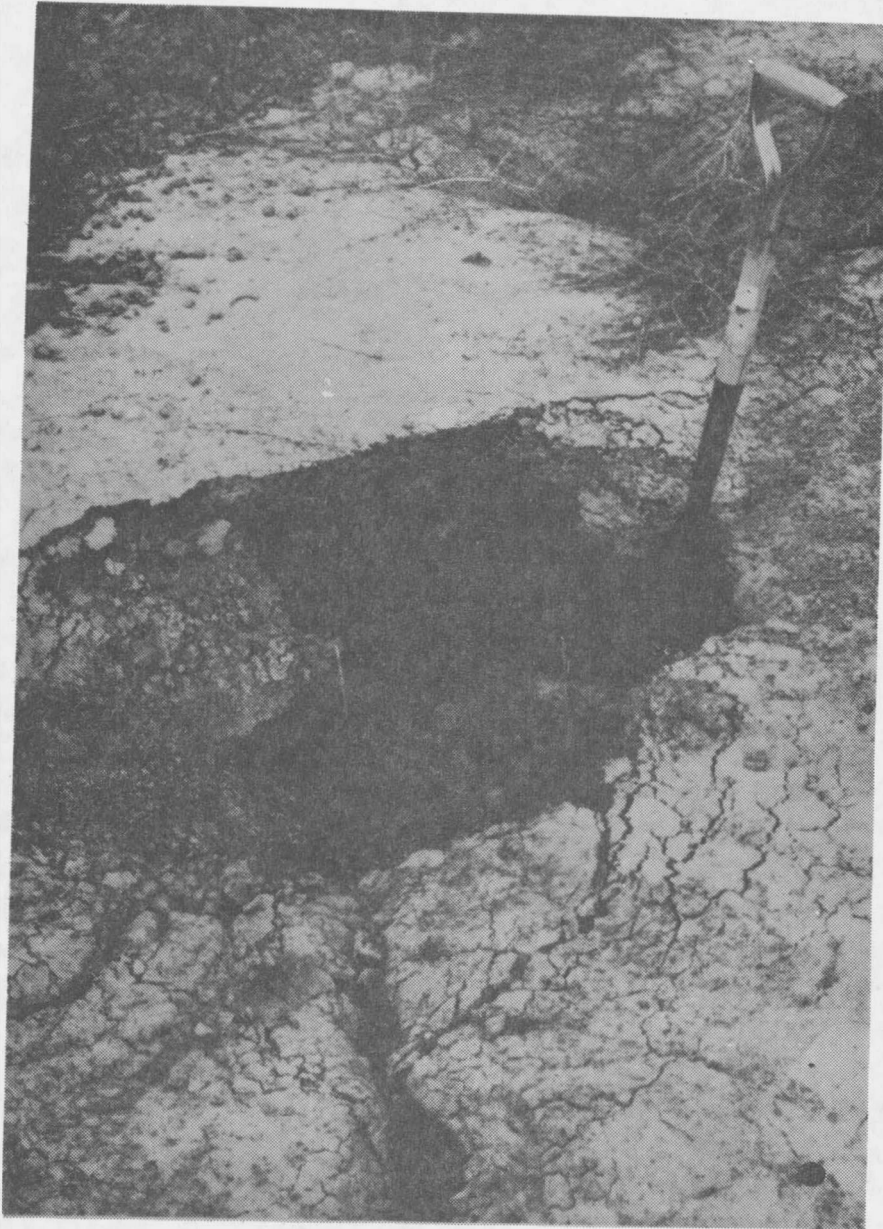


Figure 19. Example of "piping" type erosion is shown which occurs when water flows laterally in cracks due to the low permeability of sodic, clayey spoils (Glenharold Mine).

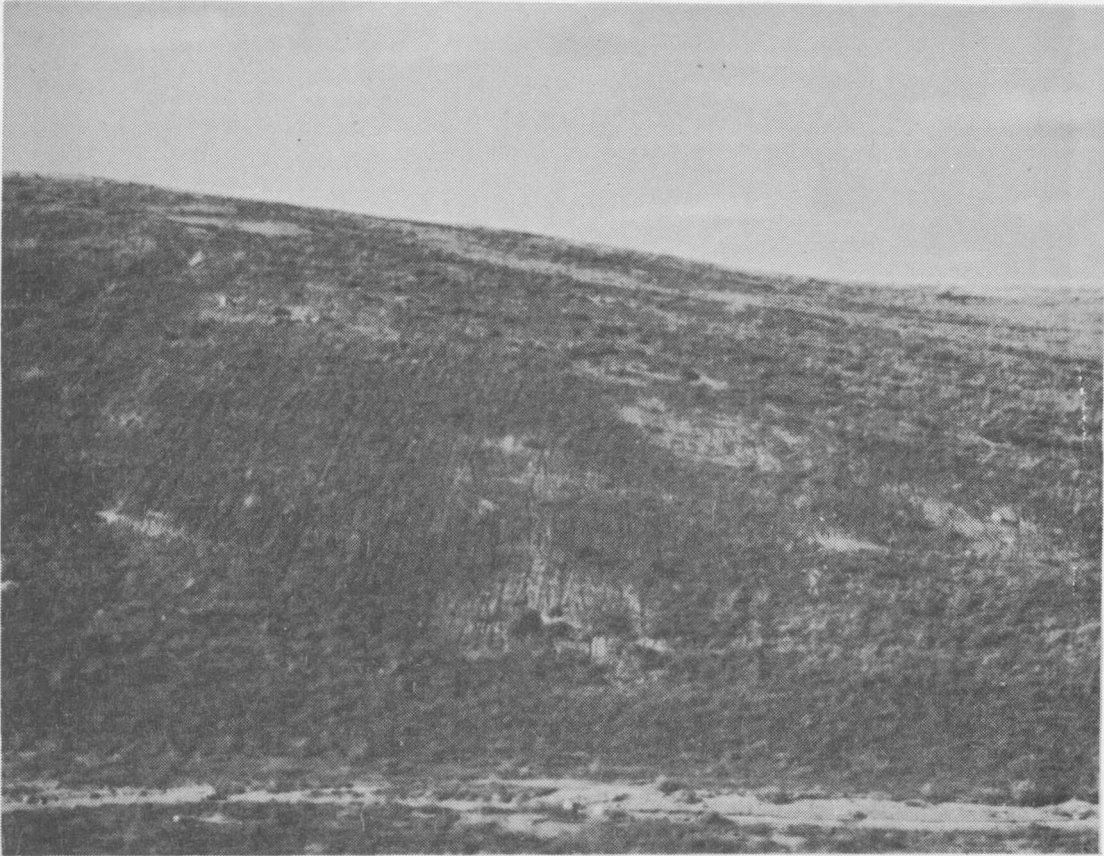
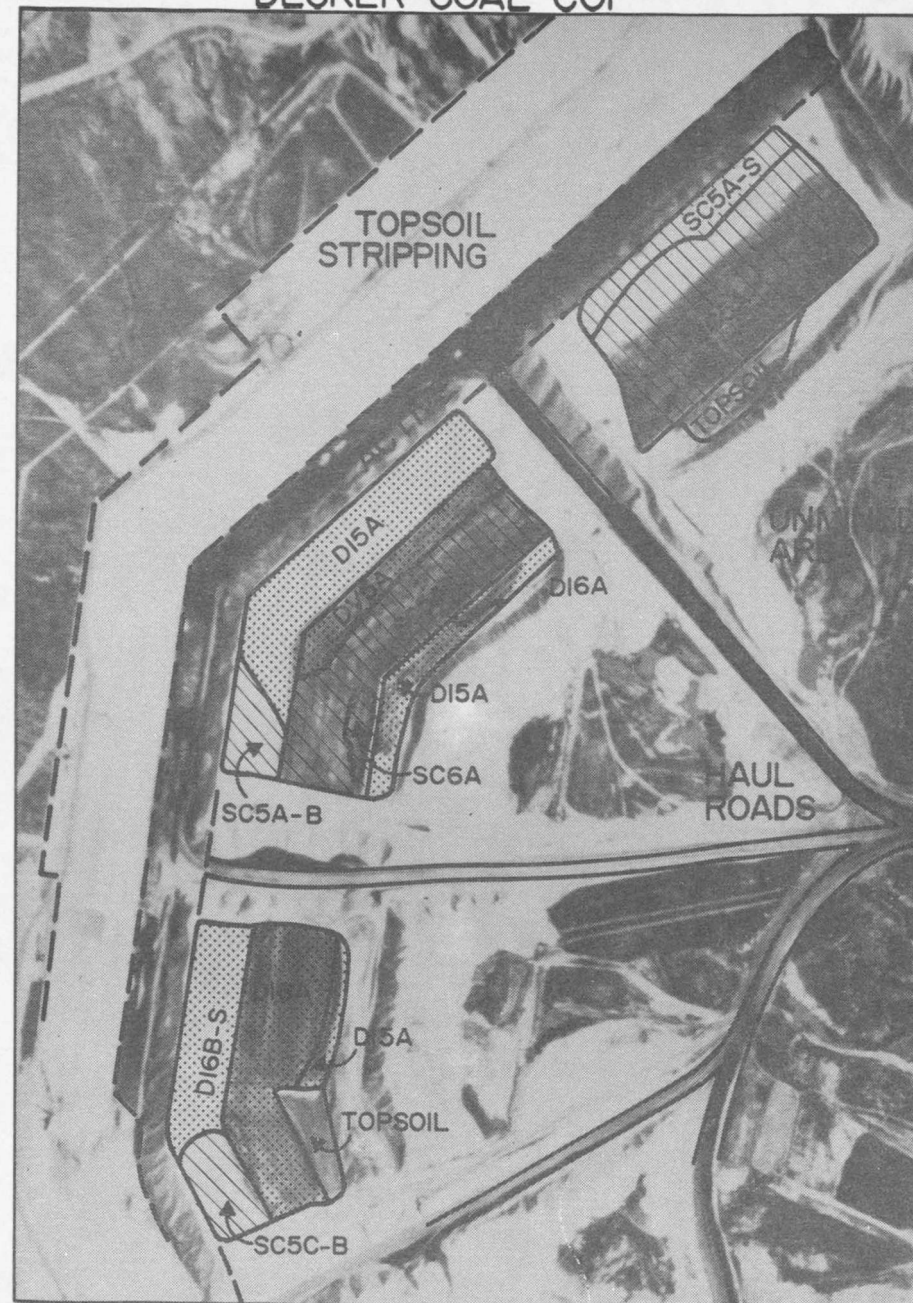


Figure 20. A badly-eroded hillslope at the Glenharold Mine shows light areas where topsoil has been completely removed.

SOIL MAP

DECKER WEST MINE - NORTH HALF
DECKER COAL CO.



GENERAL LEGEND

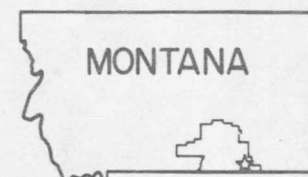
SOIL SERIES

 SQUIRREL CREEK

 DIETZ

 TOPSOIL

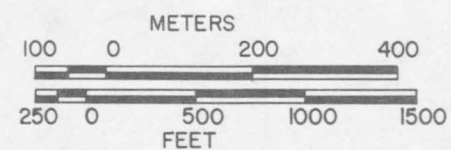
LOCATION



BIG HORN CO., MT.



SCALE



AUGUST, 1978

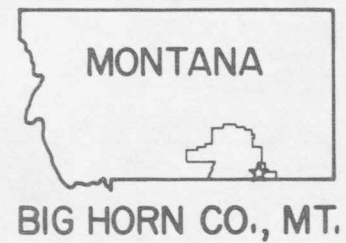
Figure 21. Soil map at the Decker Mine (north).

SOIL MAP

GENERAL LEGEND

-  SQUIRREL CREEK
 DIETZ
 TOPSOIL

LOCATION



AUGUST, 1978

SCALE

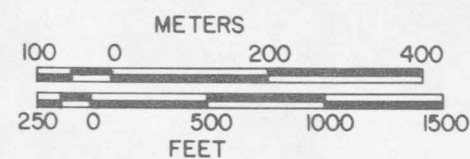
DECKER WEST MINE - SOUTH HALF
DECKER COAL CO.

Figure 22. Soil map of the Decker Mine (south).

Table 11. Descriptive legend for soils mapped on the Decker West stripmine in Bighorn Co., Montana.

Family	Series	Symbol	Acreage	No. Del.	Phase			LCC	SPI Range
					Topsoil Depth	Slope	Other		
fine-loamy, mixed (calc) mesic Ustic Torriorthent	Dietz	DI5A	14.2	3	40-60	0-3		IVs-2	77
		DI5B	1.7	1	40-60	3-8		IV5-2	77
		DI5C	6.0	2	40-60	8-15		IVe-11/3	75
		DI6A	10.1	2	60-100	0-3		IIIs-2	83
		DI6A-B	2.9	1	60-100	3-8	carboniferous spoil	IVs-10	76
		DI6B	27.8	2	60-100	3-8		IVs-2	83
		DI6B-S	4.5	1	60-100	3-8	scoria derived	IVs-5	83
		DI6C	1.7	1	60-100	8-15		IVe-11	78
		DI6C-B	4.9	1	60-100	8-15	carboniferous spoil	IVe-11	75
		DI6D-B	5.3	1	60-100	>15	carboniferous spoil	VIe-11	68
			74.2						
fine-loamy, mixed (calc) mesic Ustic Torriorthent	Dietz	DV5A	3.9	1	40-60	0-3		IVs-3	82
			3.9						
fine-loamy over fine, mixed (calc) mesic Ustic Torriorthent	Squirrel Creek	SC4B	7.7	2	20-40	3-8		VIe-12/1	68
		SC4B-B	4.7	1	20-40	3-8	carboniferous spoil	VIIs-2/10	66
		SC4C	3.1	2	20-40	8-15		VIe-1/12	66
		SC5A	26.3	2	40-60	0-3		IV5-2	77
		SC5A-B	2.9	2	40-60	0-3	carboniferous spoil	IVs-2/10	73
		SC5A-S	2.1	1	40-60	0-3	scoria derived	IVs-2	77
		SC5B	3.9	1	40-60	3-8		IVs-2	77
		SC5C	2.9	3	40-60	8-15		IVs-2	73
		SC5C-B	2.1	1	40-60	8-15	carboniferous spoil	IVs-2/10	68
		SC6A	0.9	1	60-100	0-3		IVs-10	82
		SC6B-H	4.1	1	60-100	3-8	saline	VIIs-13	65
		SC6C	2.8	3	60-100	8-15		IVe-11	75
		SC6D	6.9	1	60-100	>15		VIe-11	63
			70.4						
-	Water	-	0.6	1	-	-	-		
-	Topsoil	-	7.4	3	-	-	-		
			156.5	41					

Table 12. Chemical analysis of the series at the Decker Mine shows an increase in sodium in the lower topsoil layers due to upward movement from the spoil. Horizon designations refer to separate topsoil layers or spoil layers.

HORIZON	DEPTH (cm)	pH	EC mmhos/cm	Ca	Mg (meq/l)	Na	SAR
topsoil A11	0-5	8.4	.6	2.9	3.0	2.1	1.2
topsoil A11	5-13	8.6	.6	2.1	2.1	3.5	2.4
topsoil A11	13-18	8.6	1.0	3.3	3.9	6.7	3.5
topsoil A12	18-28	8.2	1.6	4.0	5.8	11.4	5.2
topsoil A12	28-46	7.9	5.3	29.8	23.4	40.0	7.8
topsoil A13	46-56	7.7	7.5	25.5	40.1	90.5	15.8
topsoil A13	56-71	8.0	7.0	22.7	34.1	80.9	15.2
SPOIL C1	71-79	8.5	5.5	8.4	14.4	60.9	18.0

Western Energy Mine-Area A

Four soil series were recognized at the Western Energy Area A mine (Figures 23 and 24, Table 13). Two coarse-loamy soils occurred one with fine-loamy topsoil, Castle Rock, one with coarse, Farley. Two fine-loamy soils also were found one with fine-loamy topsoil, Cow Creek, one with coarse, Dowlin. The coarse-textured minesoils were the most common in Area A comprising 79% of the area. Mapping unit boundaries between soils with fine-loamy versus coarse-loamy topsoil appeared to parallel distinct mine passes where reclamation had occurred at different times and where different topsoil sources were employed. A small area of Dowlin soils on a highwall was severely eroded perhaps because erodible sandy loam topsoil was underlain by impermeable fine textured spoil. This arrangement of material on steep slopes probably favored high run-off rates which caused the gully formation. A two-lift topsoiling method (A and B horizons replaced separately) was practiced on the southern portion of the Area A mine (Figure 25). About 80 cm of topsoil and subsoil combined was applied in this area. Productivity of these soils is expected to be quite high.

Western Energy Mine-Pit 6

The Pit 6 mine was the largest of any surveyed (933.7 acres). It contained two soil series, the coarse-loamy Farley and fine-loamy

SOIL MAP

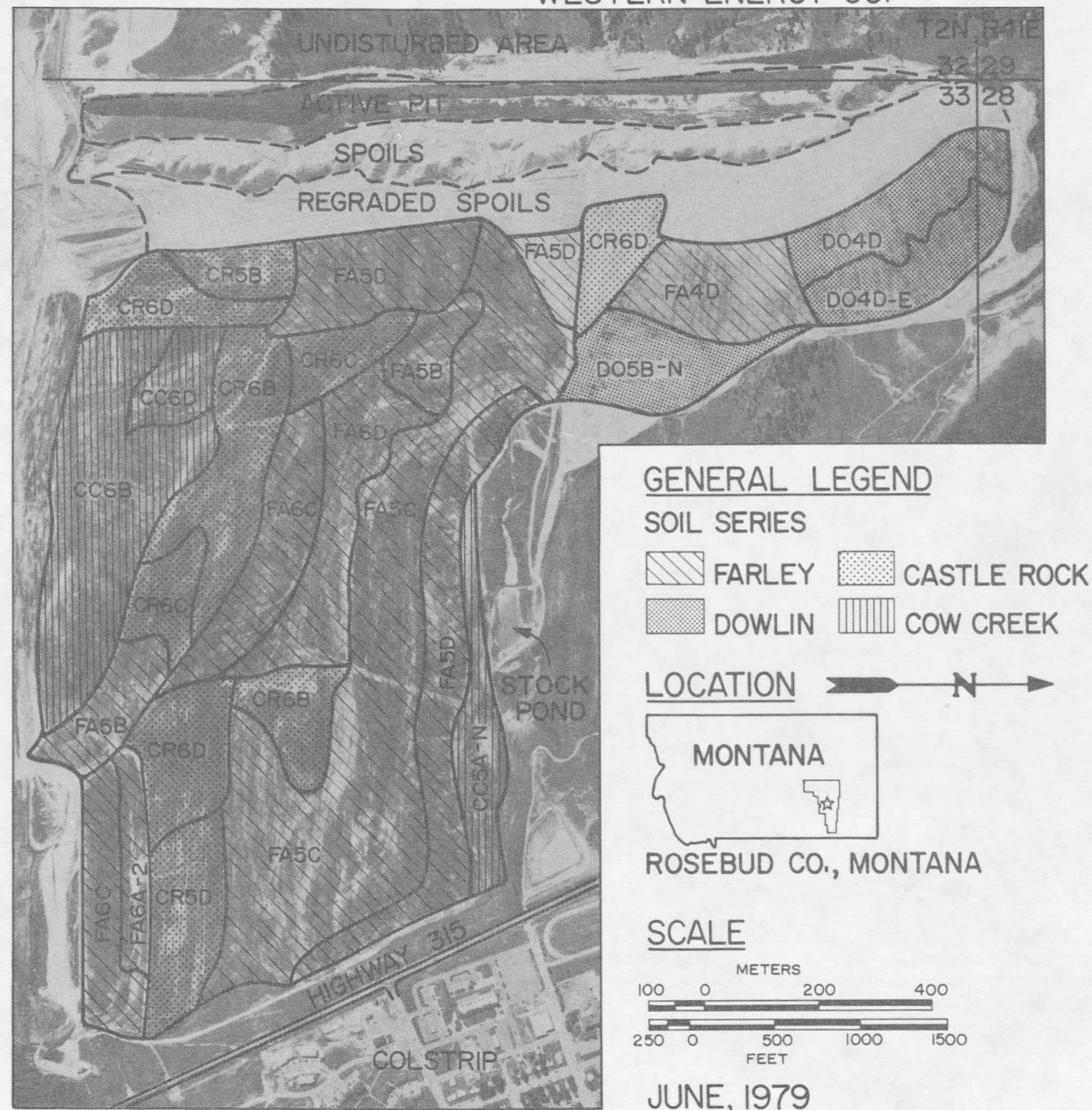
ROSEBUD MINE - AREA A - NORTH
WESTERN ENERGY CO.

Figure 23. Soil map of the Western Energy-Area A Mine (north).

SOIL MAP

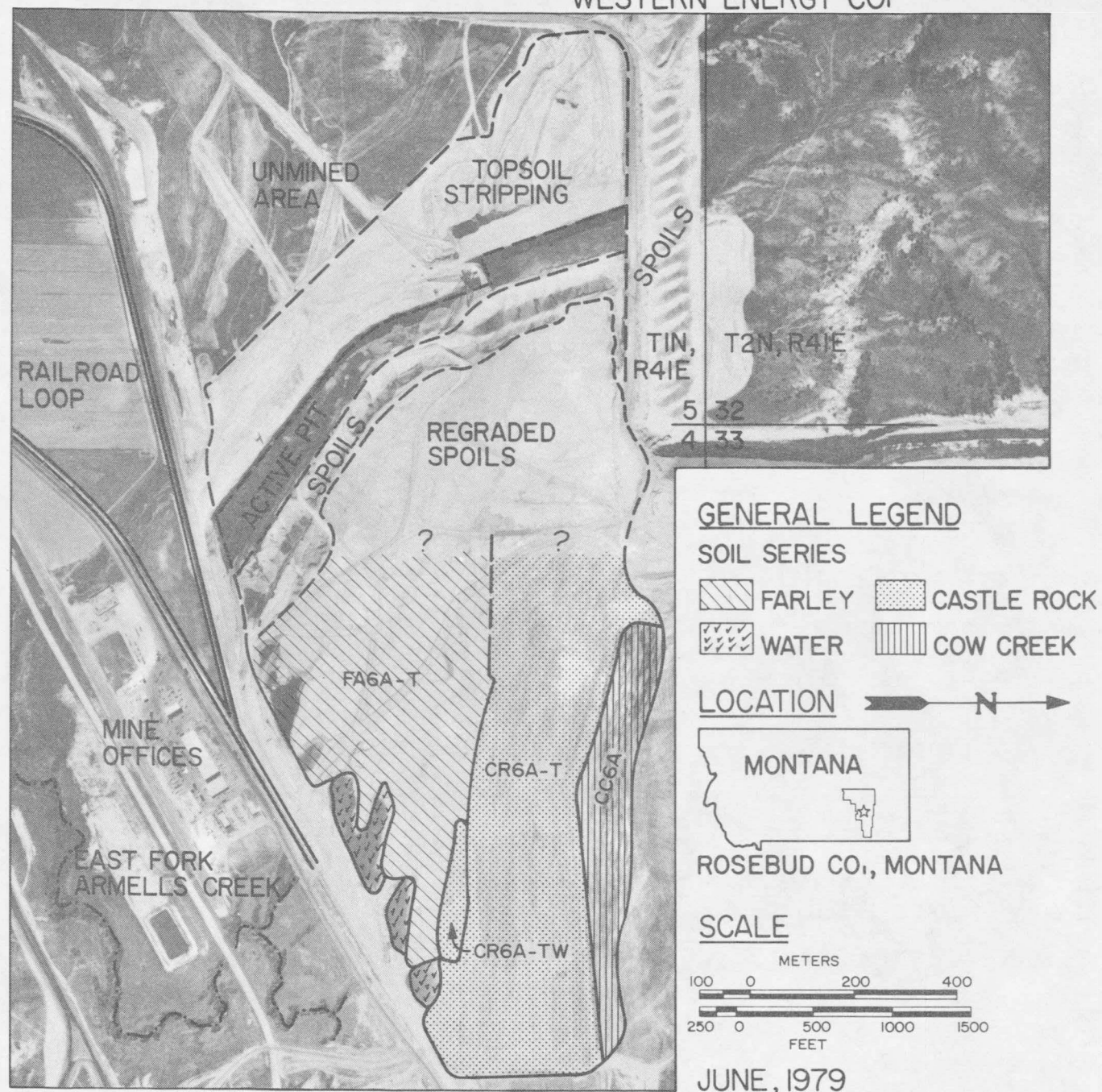
ROSEBUD MINE - AREA A - SOUTH
WESTERN ENERGY CO.

Figure 24. Soil map of the Western Energy-Area A Mine (south).

Table 13. Descriptive legend for soil mapped at the Western Energy Mine Area A stripmine in Rosebud Co., Montana.

Family	Series	Symbol	Acreage	No.De1.	Phase			LCC	SPI Range
					Topsoil Depth	Slope	Other		
coarse-loamy, mixed (calc) mesic Typic Ustorthent	Castle Rock	CR5B	4.7	1	40-60	3-8		IVs-7	92
		CR5D	10.3	1	40-60	>15		VIe-11	84
		CR6A	63.4	1	60-100	0-3	two-lift topsoil " , wetness	IIIs-7	92
		CR6A-TN	2.5	1	60-100	0-3		VIw-8	77
		CR6B	21.8	2	60-100	3-8		IIIs-7	92
		CR6C	9.8	2	60-100	8-15		IVs-7	90
		CR6D	22.2	3	60-100	>15		VIe-11	84
			134.7						
fine-loamy, mixed (calc) mesic Typic Ustorthent	Cow Creek	CC5A-N	8.2	1	40-60	0-3	undisturbed subsoil	IIIs-7	95
		CC6A	15.9	1	60-100	0-3		IIIs-7	95
		CC6B	29.7	1	60-100	3-8		IIIs-7	95
		CC6D	4.9	1	60-100	>15		VIe-11	87
			58.7						
fine-loamy, mixed (calc) mesic Typic Ustorthent	Dowlin	DO4D	10.6	1	20-40	>15	eroded undisturbed subsoil	VIe-11	79
		DO4D-E	9.4	1	20-40	>15		VIIe-12	57
		DO5B-N	11.3	1	40-60	3-8		IVs-7	87
			31.3						
coarse-loamy, mixed (calc)	Farley	FA4D	11.8	1	20-40	>15	two-lift topsoil alluvial position	VIe-11	67
		FA5B	12.4	2	40-60	3-8		IVs-7	89
		FA5C	67.2	1	40-60	8-15		IVs-7	84
		FA5D	41.9	3	40-60	>15		VIe-11	74
		FA6A-T	52.3	1	60-100	0-3		IVs-7	89
		FA6A-A	4.7	1	60-100	0-3		IVs-7	87
		FA6C	21.2	2	60-100	8-15		IVs-7	84
		FA6D	15.3	1	60-100	>15		VIe-11	81
			226.8						
	Water	-	6.1	3	-	-			
			457.6	33					

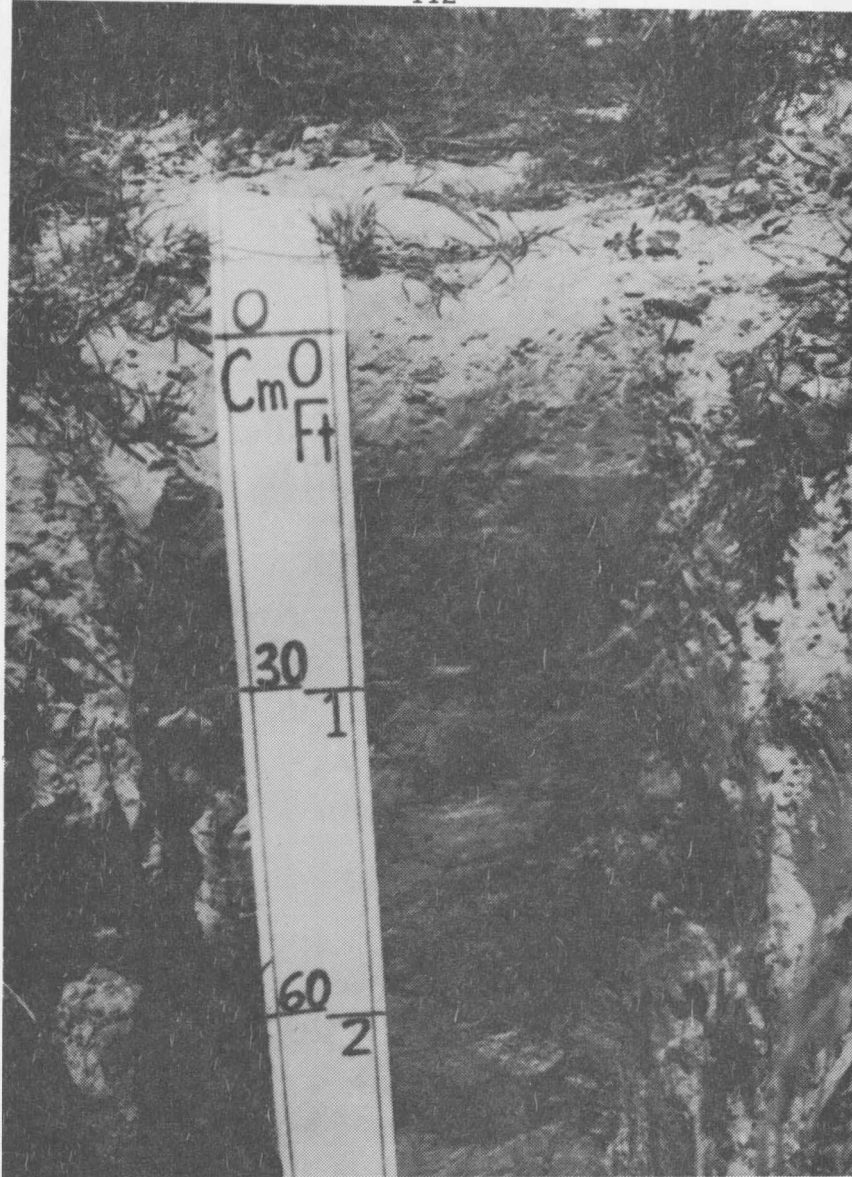


Figure 25. The Farley series at the Area A Mine was constructed with a two-lift topsoiling method which replaces subsoil and A horizon separately. The spoil layer is shown at 70 cm in this pedon.

Cow Creek series (Figures 26 and 27, Table 14). Cow Creek soils occurred on areas mined before 1970. Some areas consisted of ungraded spoilbanks with little vegetation after more than 20 years.

Farley soils, where they occurred on long steep slopes, were extremely eroded especially on regraded highwalls (Figure 28). Farley soils in Pit 6 had from 0 to 20 cm of topsoil and had very low water-holding capacity. Small ponds were common on the Pit 6 mine due to disruption of natural drainage patterns (Figure 29).

Westmoreland Mine

Four soils were mapped on the Westmoreland mine; Cow Creek, Dowlin, Farley, and Absaloka (Figure 30, Table 15). Absaloka soils (discussed further in Chapter 7) were loamy-skeletal and favored Ponderosa pine establishment. Farley and Dowlin soils were the most common on the mine. Both had coarse-loamy topsoil but Farley soils had coarse-loamy oxidized spoil (overburden) while Dowlin soils had reduced clayey spoil (interburden). The clayey interburden which occurred in areas mapped as Dowlin and Cow Creek series was more saline and had elevated Ni concentrations unlike oxidized overburden material (Swain, personal communication). Erosion was most common on soils which were underlain by interburden (Figure 31).

SOIL MAP

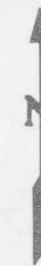
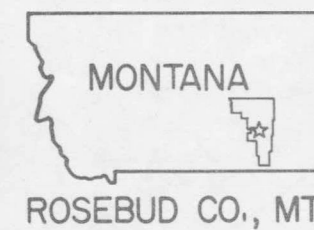
ROSEBUD MINE PIT 6 - EAST
WESTERN ENERGY CO.

GENERAL LEGEND

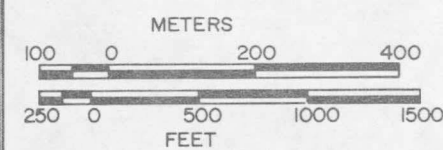
SOIL SERIES

-  FARLEY
-  COW CREEK
-  WATER

LOCATION



SCALE



JULY, 1978

Figure 26. Soil map of the Western Energy-Pit 6 Mine (east).

SOIL MAP

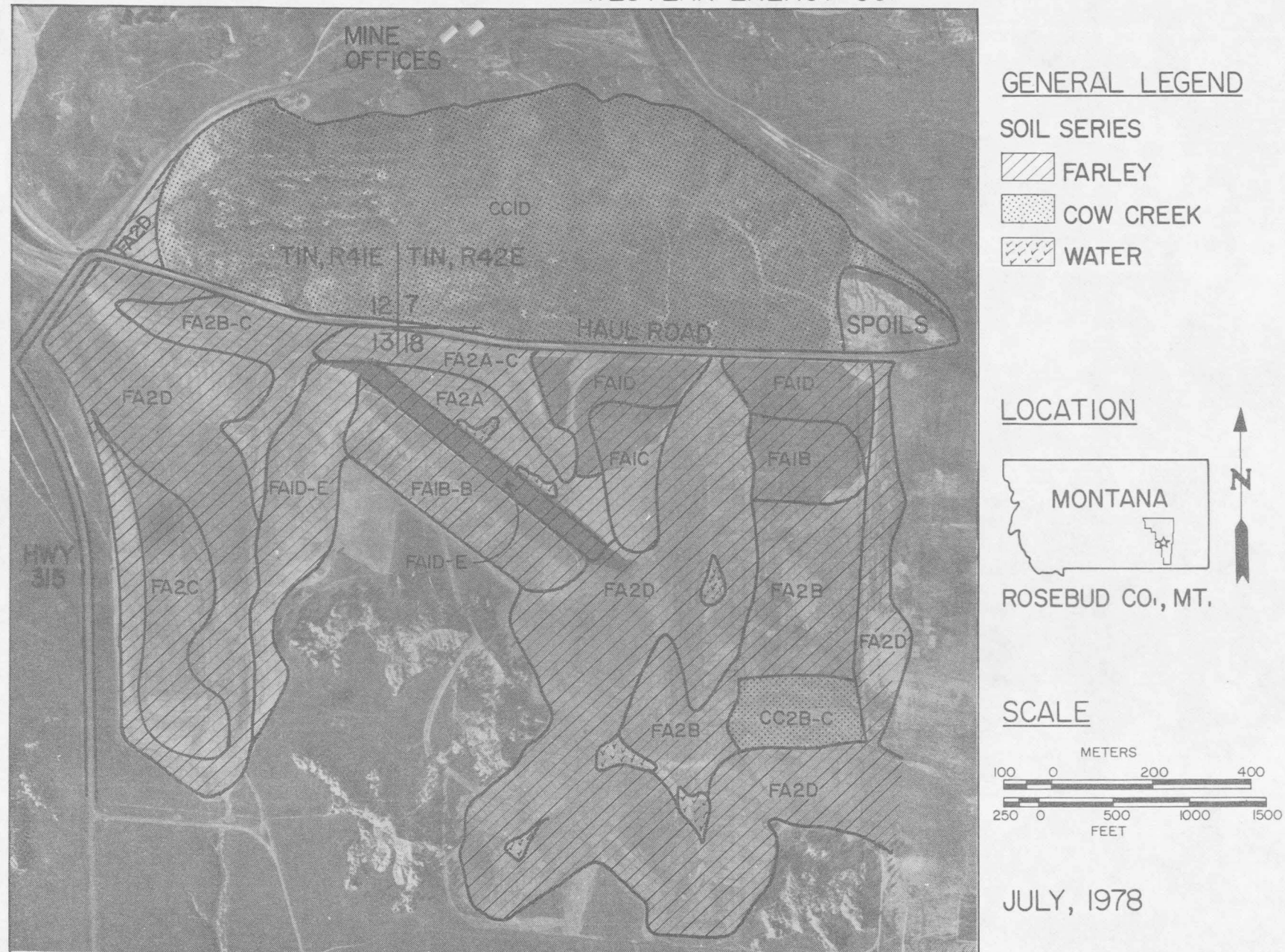
ROSEBUD MINE PIT 6-WEST
WESTERN ENERGY CO.

Figure 27. Soil map of the Western Energy-Pit 6 Mine (west).

Table 14. Descriptive legend for soils mapped at the Western Energy Pit 6 stripmine in Rosebud Co., Montana.

Family	Series	Symbol	Acreage	No. Del.	Phase			LCC	SPI Range
					Topsoil Depth	Slope	Other		
fine-loamy, mixed (calc) mesic Typic Ustorthent	Cow Creek	CC1B	20.6	1	0	3-8		VIIIs-1/3	67
		CC1C	19.0	1	0	8-15		VIIIs-1/3	65
		CC1D	197.1	4	0	>15		VIIIs-1/11	52
		CC2B	8-2	1	0-10	3-8		IVs-2	74
		CC2B-C	8.5	1	0-10	3-8	compacted subsoil	VIIs-2	64
		CC2C-C	16.8	2	0-10	8-15	compacted subsoil	VIIIs-2	52
		CC2D	20.6	1	0-10	>15		VIe-11	59
			290.8						
coarse-loamy, mixed (calc) mesic Typic Ustorthent	Farley	FA1B	43.0	3	0	3-8		IVs-1	68
		FA1B-B	17.7	1	0	3-8	carboniferous spoil	VIIs-1/10	68
		FA1C	57.8	3	0	8-15		IVe-11	63
		FA1D	43.6	3	0	<15		VIe-11	53
		FA1D-E	26.1	1	0	<15	eroded	VIIe-12	31
		FA2A	9.6	1	0-10	0-3		IVs-7	76
		FA2A-C	7.6	1	0-10	0-3	compacted subsoil	VIIs-2/7	66
		FA2B	48.5	2	0-10	3-8		IVs-7	76
		FA2B-C	13.8	1	0-10	3-8	compacted subsoil	VIIs-2/7	63
		FA2C	58.9	2	0-10	8-15		IVe-11	71
		FA2D	254.0	4	0-10	<15		VIe-11	61
		FA3A	8.6	1	10-20	0-3		IVs-7	78
		FA3B	34.5	2	10-20	3-8		IVs-7	78
		FA3C	5.9	1	10-20	8-15		IVe-11	70
			629.3						
			13.6	12	-	-			
			933.70	37					
	Water	-							

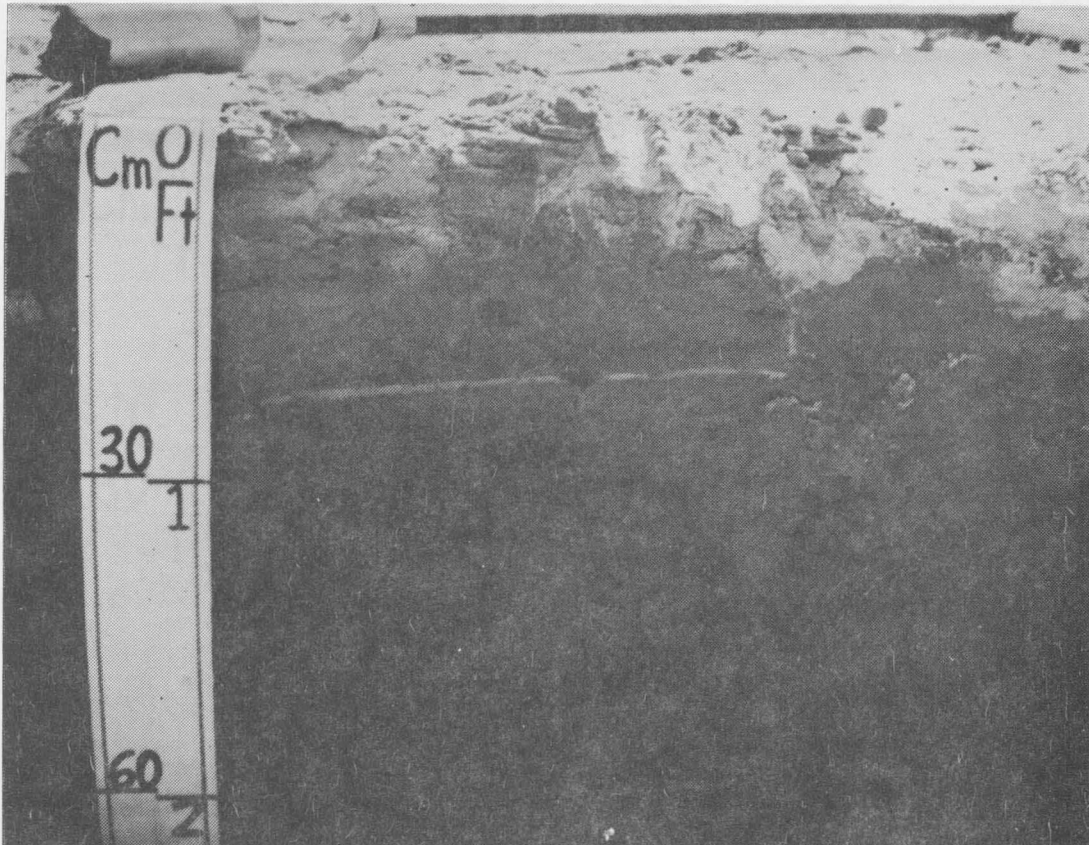


Figure 28. In many places where erosion has occurred, bordering areas have also been adversely affected due to position of sandy material on top of topsoiled minesoils with reestablished plant communities.

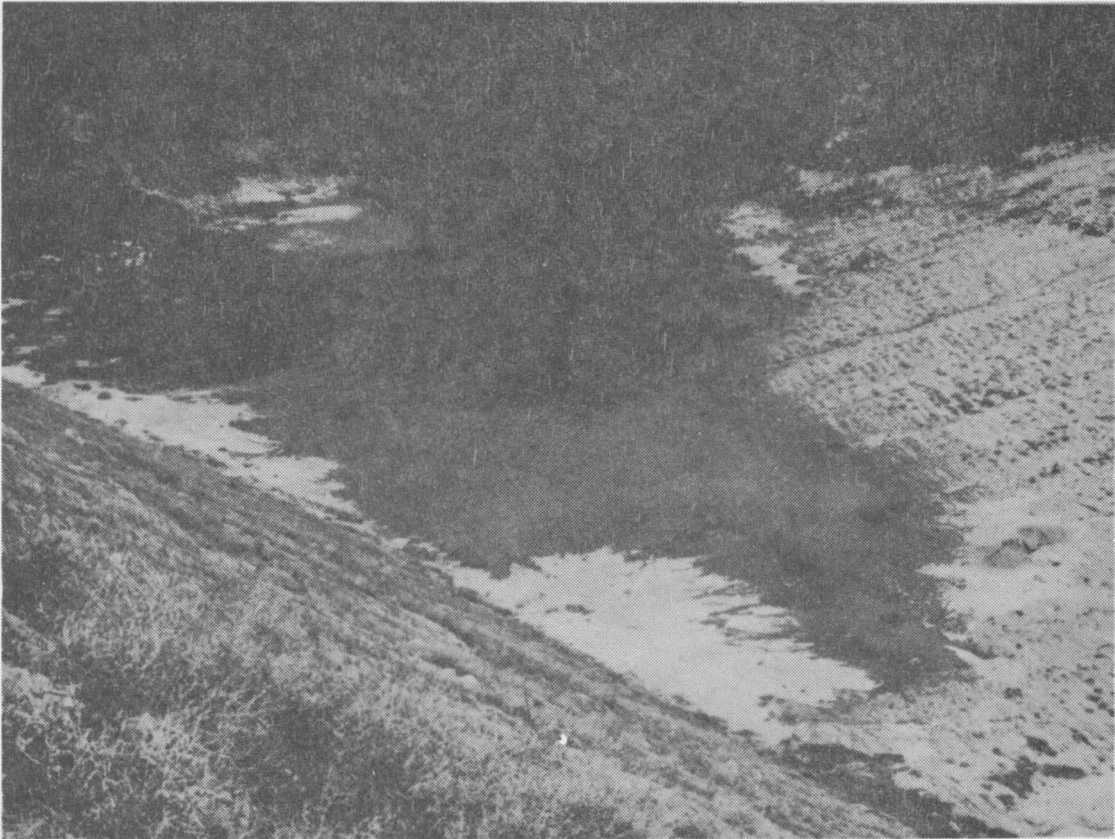


Figure 29. Temporary ponds were a common component of most Northern Great Plains mines due to the disruption of natural drainage patterns and lack of sufficient reconstructed drainages on mined land.

SOIL MAP

ABSALOKA MINE
WESTMORELAND COAL CO.

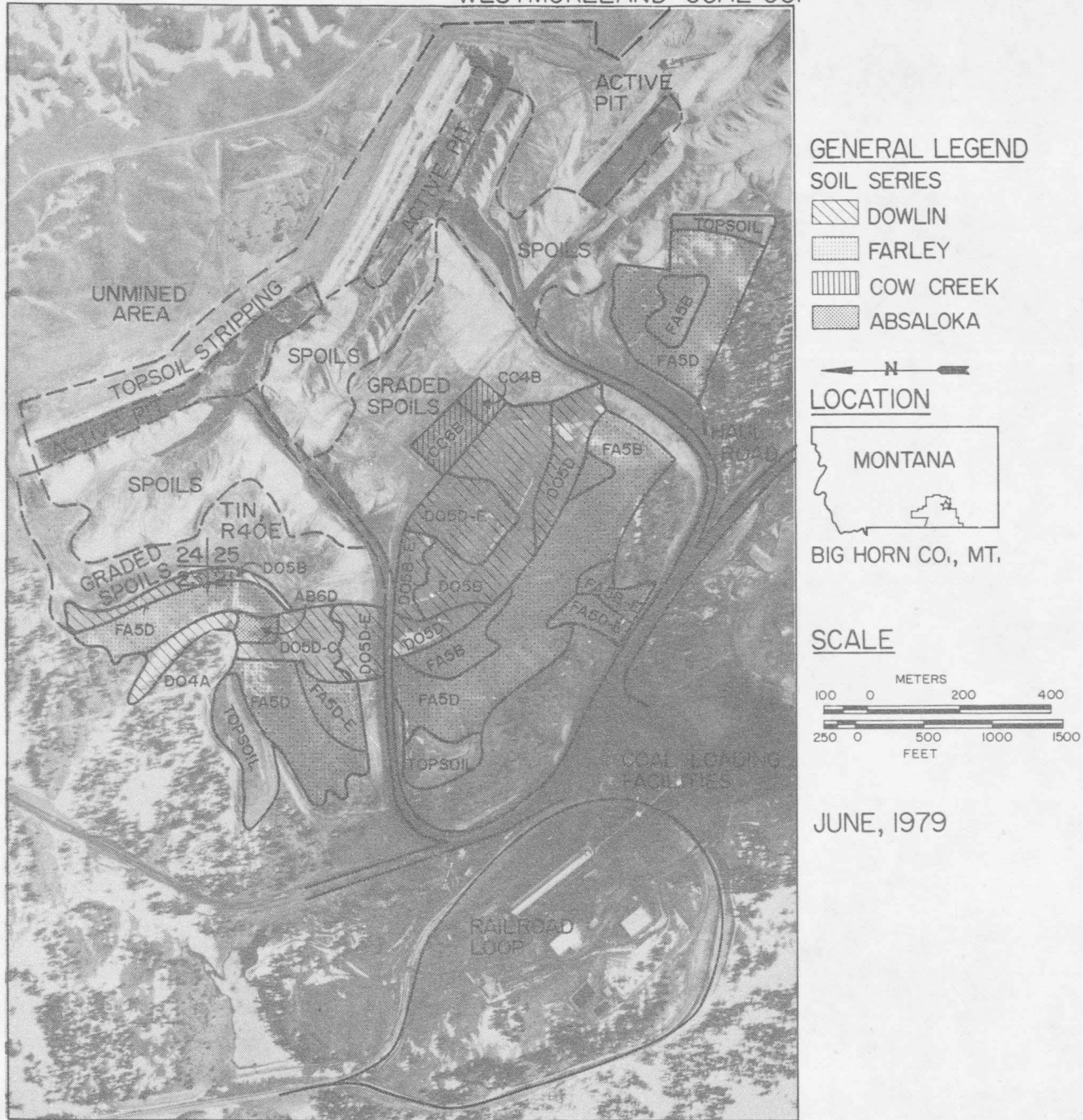


Figure 30. Soil map of the Westmoreland Mine.

Table 15. Descriptive legend for soils mapped on the Westmoreland Absaloka stripmine in Bighorn Co., Montana.

Family	Series	Symbol	Acreage	No. Del.	Phase			LCC	SPI Range
					Topsoil Depth	Slope	Other		
loamy-skeletal, mixed (calc) mesic Typic Ustorthent	Absaloka	AB6D	1.4	1	60-100	>15		VIs-5	79
			1.4						
fine-loamy, mixed (calc) mesic Typic Ustorthent	Cow Creek	CC4B	1.8	1	20-40	3-8		IVs-13	81
		CC6B	3.6	1	60-100	3-8		IIIs-7	88
			5.4						
fine-loamy, mixed (calc) mesic Typic Ustorthent	Dowlin	D04A	2.8	1	20-40	0-3		IVs-13	82
		D05B	18.6	2	40-60	3-8		IVs-7	89
		D05B-E	3.1	1	40-60	3-8	eroded	VIe-12	62
		D05D	8.9	2	40-60	>15		VIe-11	74
		D05D-C	5.5	1	40-60	>15	compacted subsoil	VIIe-11/2	64
		D05D-E	11.6	2	40-60	>15	eroded	VIIe-12	57
			50.5						
coarse-loamy, mixed (calc) mesic Typic Ustorthent	Farley	FA5B	9.2	3	40-60	3-8		IVs-7	82
		FASB-E	2.7	1	40-60	3-8	eroded	VIe-12	57
		FA5D	60.7	4	40-60	>15		VIe-11	67
		FA5D-E	5.8	2	40-60	>15	eroded	VIIe-12	52
			78.4						
-	Topsoil	-	11.7	3	-	-			
			147.4	25					



Figure 31. Head-cutting rills and gullies formed at the Westmoreland Mine as well as at other mines where long straight or convex slopes were created. Concave slopes which are often the equilibrium form in nature may be less susceptible to this kind of erosion.

CHAPTER 7

CHARACTERIZATION OF MINESOILS

Twelve minesoils and five natural soils were selected from five mine areas for detailed characterization. Sites chosen for study represented areas where little soils data were either on hand or available present in the literature.

AMAX Mine

At the AMAX Belle Ayr mine two minesoils were characterized (Table 16). Additional data were collected in a study of analytical variability of soils in different mapping units (Chapter 9). AMAX soils were medium-textured loams and silt loams with some sandy loams (Table 26). Topsoil depth averaged 43.2 cm in 18 pedons. Topsoil material was generally non-sodic ($SAR < 3$) with moderate to low levels of soluble salts. pH was near neutral ranging from 6.5 to 7.5. Overburden material often resembled topsoil material. It was usually oxidized, low in sodium, and had moderate levels of soluble salts. The truck-shovel mining method used at the Belle Ayr mine (Figure 32) enabled operators to selectively replace surficial overburden at the top of spoils which accounted for the oxidized condition of the spoil material. Water content at 15 bars appears to be too high in these samples due to analytical error.

Table 16. Characterization of minesoils at the AMAX-Belle Ayr Mine in Campbell Co., Wyoming.

Series	Location	Ref. No.	Hor.	Depth (cm)	Mechanical Analysis			Texture Class	H ₂ O extract				H ₂ O content			pH	EC mmhos cm
					Sand	Silt	Clay		Ca	Mg	Na	SAR	0	0.3	15		
					(%)				(ppm)				(%)				
Dietz	Amax mine (mined)	2-1	A11	0-15	39.7	41.6	18.7	L	260	36	140	2.2	39	18.4	13.1	7.6	1.8
		2-2	A12	15-32	41.8	39.0	19.2	L	200	26	80	1.4	42	20.7	18.1	7.7	1.5
		2-3	C1	32+	28.2	46.8*	25*	L	500	120	120	1.3	51	23.6	20.5	7.4	3.0
Roland	(mined)	4-1	A1	2-50	86.5	10.4	3.1	LS	77	11	18	.5	35	10.9	6.8	7.7	.5
		4-2	C1	50+	19.5	56.5*	24*	SiL	890	120	125	1.0	52	27.2	20.1	6.6	4.5

*estimate

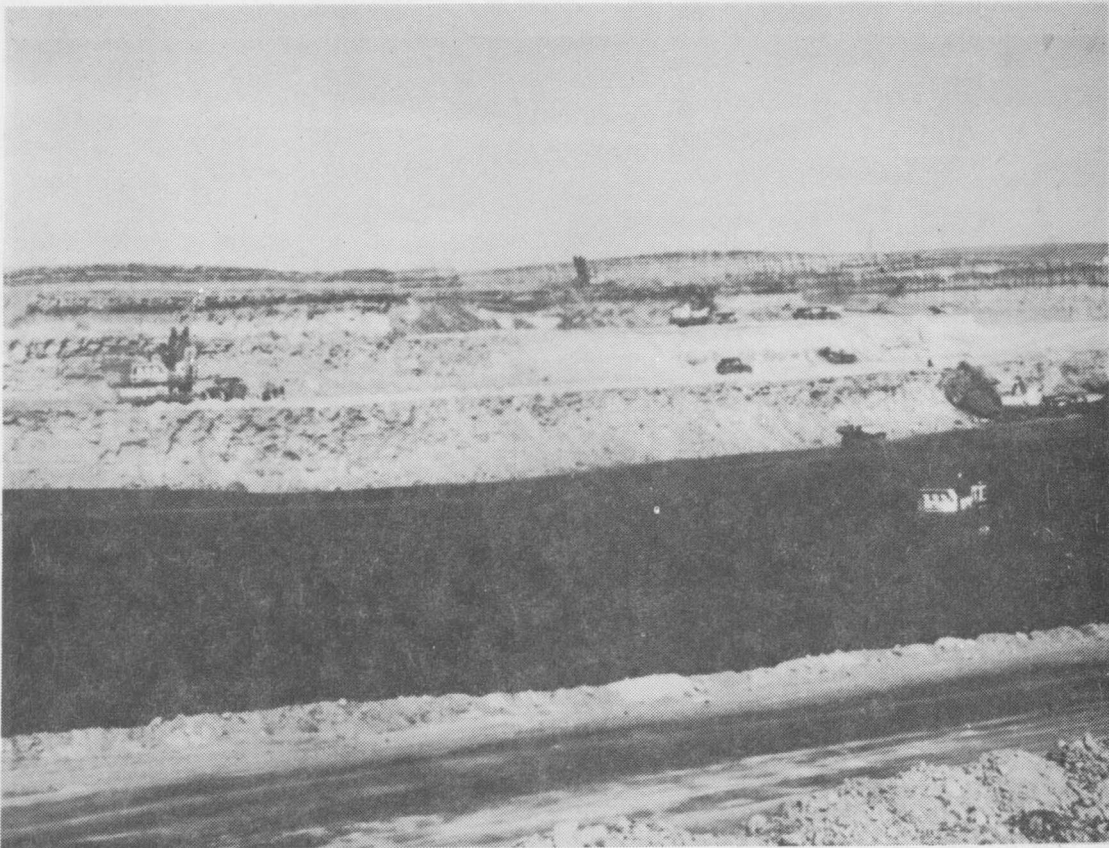


Figure 32. The truck-and-shovel mining operation at the AMAX Belle Ayr Mine removed overburden in separate benches thus facilitating selective replacement of high-quality overburden near the spoil surface.

Glenharold Mine

At the Consolidation Coal Glenharold Mine (Table 17) minesoils were composed of the highest-quality topsoil and the lowest-quality spoil, of any mine in the Northern Great Plains (Figure 33). As a result, abrupt changes in clay content (9-20%), SAR (1-12), and EC(1-3) occurred at the topsoil/spoil interface. Spoil material had very low permeability (Merill and others, 1979) and impeded root penetration. At this mine, it was found that cereal grain and forage production increased with increasing topsoil depth to three feet (ARS, 1977). Upward sodium migration has been identified as a major long-term problem in minesoils at the Glenharold Mine. A possible solution to this process is evidenced in Lignite soils which have a loamy sand buffer layer separating topsoil and spoil layers. This sandy zone may isolate the spoil from the topsoil by preventing significant amounts of liquid water flow upwards from the spoil.

Typical unmined soils near the Glenharold mine (Sen, and Temvik series) are deep, non-sodic, non-saline, and are silt loam in texture. They are loess-derived which accounts for their favorable characteristics. The sandy material used as a buffer in Lignite minesoils originated as dune sands which are common in the western part of the mine area (Seroco series). It is apparent that the depositional origin of materials at the Glenharold mine has a strong influence on their quality as plant growth media. Fort Union shale is low in

Table 17. Characterization of minesoils and natural soils at the Glenharold Stanton Mine in Mercer Co., North Dakota.

Series	Location	Ref. No.	Hor.	Depth (cm)	Mechanical Analysis				Texture Class	H ₂ O extract				H ₂ O content			pH	EC mmhos cm
					Sand	Silt	Clay	Ca		Mg	Na	SAR	0	0.3	15			
					(%)			(ppm)				(%)						
Lignite	Glen-Harold Mine (mined)	1-1	A11	0-20	54.1	35.0	10.8	SL	63	8	40	1.3	34	14.3	-	7.8	.5	
		1-2	A12	20-32	46.8	46.8	6.4	SL	470	120	440	4.7	30	19.6	-	7.7	3.2	
		1-3	IIA13	32-30	67.1	23.7	9.2	L	350	48	300	4.0	32	12.4	-	7.6	2.8	
		1-4	IIIC1	50-74	82.7	12.4	4.9	LS	180	14	54	1.1	32	6.1	-	7.5	1.1	
		1-5	IVC2	74+	39.1	39.1	21.9	L	50	11	180	5.6	35	17.6	-	8.0	1.1	
Glen-Harold	(mined)	2-1	A11	0-8	43.1	47.9	9.0	L	64	9	4	.1	31	19.1	-	7.4	.5	
		2-2	A12	8-19	51.3	39.8	9.0	L	56	9	9	.3	32	16.1	5.8	7.4	.5	
		2-3	IIA13	19-40	39.0	53.8	7.2	SiL	48	8	48	1.7	34	19.5	-	7.8	.4	
		2-4	IIIC1	40-58	21.8	59.8	18.4	SiL	170	32	440	8.3	71	29.5	-	7.6	2.8	
		2-5	IIIC2	58-75	68.0	8.5	23.5	SCL	110	21	500	11.6	86	29.2	-	7.8	2.6	
Sen	(unmined)	1-1	A1	0-23	25.9	51.5	22.6	SiL	150	17	3	.1	54	24.9	-	7.7		
		1-2	IIB2	23-48	8.9	67.0	24.1	SiL	43	9	4	.1	50	25.7	-	8.1		
		1-3	IIC1 _{ca}	48+	12.2	57.8	30.0	SiCL	33	15	8	.3	54	24.3	-	8.0		
Temvik	(unmined)	2-1	A11	0-10	19.8	58.0	22.3	SiL	78	12	12	.3	58	29.8	16.3	7.6	.7	
		2-2	A12	10-25	24.0	53.2	22.8	SiL	45	6	55	2.0	53	27.1	14.6	8.0	.5	
		2-3	B2	25-46	16.5	56.6	26.9	SiL	23	3	150	8.0	52	27.7	16.3	8.4	.8	
		2-4	C1	46+	21.0	53.7	25.3	SiL	27	3	440	19.1	61	27.9	17.0	8.4	2.2	
Seroco	(unmined)	3-1	A1	0-7	91.4	8.3	0.3	S	32	6	2	.1	32	4.2	-	7.0	.3	
		3-2	C1	7-18	92.2	6.0	1.8	S	26	4	2	.1	38	3.6	-	7.0	.2	
		3-3	C2	18-36	91.4	7.0	1.5	S	42	6	2	.1	31	4.3	-	7.4	.3	



Figure 33. The Glenharold series is composed of about 40 cm of high-quality silt loam topsoil (mollic epipedon) overlying poor-quality clayey, sodic spoils.

quality due to high SAR and low permeability. Loess-derived soil is medium-textured, low in sodium and salts and is thus high-quality. Dune sands are low quality because of their low water-holding capacity but have potential as a buffer material below the topsoil zone.

Velva Mine

The Consolidation Velva mine in the glaciated region of northern North Dakota was not mapped because it lacked recently-reclaimed minesoils. Several old minesoils of varying age (5, 20, and 35 years) were characterized (Table 18). All soils had fairly uniform texture (loam), EC (.5-2), and SAR (<1). Overburden consisted of Fort Union shale overlain by recent glacial till. Till material consisted mostly of mixed fragments of reworked Fort Union shale which accounts for the homogeneity of the minesoil characteristics.

The Velva mine lies just north of a terminal glacial moraine consisting of mixed unsorted materials in an undulating hummocky terrain (Figure 34). The mined area is similar in many ways to the recent glacially-derived landscape. Mining results in a similar unsorted arrangement of materials in a hummocky deranged landscape.

Table 18. Characterization of mine soils from the Velva mine in Ward Co., North Dakota.

Series	Location	Ref. No.	Hor.	Depth (cm)	Mechanical Analysis				H ₂ O extract				H ₂ O content			pH	EC mmhos cm
					Sand	Silt	Clay	Texture Class	Ca	Mg	Na	SAR	0	0.3	15		
					(%)				(ppm)				(%)				
Cow Creek (1974)	Velva mine	1-1		0-15	44.8	36.1	19.1	L	150	20	13	.3	41	22.2	12.4	7.8	.9
		1-2A11		15-48	47.1	33.6	19.3	L	510	50	34	.4	44	22.5	-	7.6	2.4
		1-2B	Olive	15-48	39.7	40.6	19.8	L	540	100	97	1.0	43	23.5	-	7.5	2.4
		1-2C	Oxi- dized	15-48	46.3	34.2	19.5	L	540	64	52	.6	38	20.8	-	7.6	2.3
		1-3		48-60					---	---	---	---					
Cow Creek (1955)		2-1		0-4	51.0	34.1	14.9	L	260	26	2	.0	44	23.1	9.9	7.5	1.8
		2-2		4-10	44.8	35.3	19.9	L	110	10	4	.1	39	19.6	8.6	7.8	.6
		2-3		10-22	45.8	35.3	18.9	L	85	8	3	.1	38	19.9	10.0	7.8	.5
		2-4		22-55	40.7	38.2	21.1	L	69	7	5	.2	41	23.2	-	7.8	.4
Cow Creek (1940)		3-1		0-4	55.1	33.3	11.7	SL	230	17	3	.1	40	20.3	-	7.4	1.1
		3-2		4-9	49.0	33.5	17.5	L	97	8	4	.1	34	18.9	-	7.8	.6
		3-3		9-17	44.8	36.5	18.7	L	79	8	3	.1	41	21.1	-	7.8	.5
		3-4		17-30	44.8	34.1	21.1	L	88	9	6	.2	43	22.0	-	7.9	.6
		3-5		30-80	40.7	38.5	20.8	L	47	6	10	.4	44	23.0	-	7.9	.4
Cow Creek (1940)		4-1		0-20	52.9	29.1	18.0	SL	100	10	4	.1	39	20.0	-	7.8	.6



Figure 34. Comparison of a young glacially-derived (moraine) landscape (above) and a recently-mined landscape (below) shows many similarities both in surface morphology and in internal arrangement of materials suggesting the two processes are similar.

Western Energy Mines

Two mined areas were mapped at the Western Energy Mine. Area A was reclaimed from the mid 1970's to the present (Table 19). Pit 6 was active in the 1950's and again from 1970 to 1975 when reclamation standards were less stringent than at present (Table C-2). Although the mines are only a few miles apart, minesoil characteristics are strikingly different. Minesoils in Area A have topsoil depths averaging 50 cm or more. A-horizon and subsoil were replaced in different layers in some places, thus keeping the more nutrient-rich topsoil near the minesoil surface. Minesoils in Pit 6 have either no topsoil or only 10 cm of added topsoil. Compacted spoil material underlies the topsoil in many areas thus restricting root penetration in Pit 6. Loose sandy soils on long steep slopes have been severely eroded. All Western Energy minesoils are fairly coarse-textured, non-saline, and non-sodic. Differences between minesoils in Area A and Pit 6 illustrate how improved reclamation techniques can improve minesoil properties.

Westmoreland Mine

Minesoils at the Westmoreland mine are generally coarse-to-medium-textured with low EC and SAR (Table 20). Several different coal seams are extracted at the Westmoreland mine so spoil material can consist of overburden (material above the upper coal) or

Table 19. Characterization of mine soils at the Western Energy Mine - Area A' in Rosebud Co., Montana.

Series	Location	Ref. No.	Hor.	Depth (cm)	Mechanical Analysis				Texture Class	H ₂ O extract				H ₂ O content			pH	EC
					Sand	Silt	Clay	Ca		Mg	Na	SAR	0	0.3	15	mmhos		
																		(%)
Castle Rock	West Energy Area A - Mined	1-1		0-12	58.0	27.9	14.1	SL	150	13	26	.6	32	14.6	-	7.6	.9	
		1-2		12-24	59.0	26.9	14.1	SL	140	17	16	.3	34	13.3	-	7.2	.8	
		1-3		24-46	69.2	23.7	7.2	SL	180	12	18	.4	35	13.0	-	7.7	1.0	
		1-4		46-77	43.5	42.5	14.0	L	260	40	120	1.8	37	17.4	-	7.8	1.5	
		1-5		77+	79.1	13.5	7.5	LS	60	11	60	1.9	32	8.1	-	8.2	.6	
Castle Rock		2-1		0-12	21.9	54.7	23.5	SiL	130	16	15	.3	39	19.2	-	7.8	.8	
		2-2		12-26	43.2	36.5	20.2	L	86	10	17	.5	33	15.4	-	8.0	.5	
		2-3		26+	77.2	17.9	4.9	SL	20	3	14	.8	30	6.7	-	8.2	.2	
Farley		3-1		0-14	75.9	17.0	7.2	LS	100	7	12	.3	30	11.9	-	7.8	.4	
		3-2		14-24	41.8	41.4	16.8	L	18	10	120	3.0	36	19.7	-	7.9	.9	
		3-3		24-38	74	5	130		74	5	130	3.9	34	17.0	-	8.0	.8	
		3-4		38+	73.3	17.2	9.5	SL	75	4	40	1.3	28	10.2	-	8.1	.5	

Table 20. Characterization of minesoils and natural soils at the Westmoreland Absaloka mine in Big Horn Co., Montana.

Series	Location	Ref. No.	Hor.	Depth (cm)	Mechanical Analysis				Texture Class	H ₂ O extract				H ₂ O content			pH	EC
					Sand	Silt (%)	Clay	Ca		Mg (ppm)	Na	SAR	0	0.3 (%)	15	mmhos/cm		
Absa-loka	West-moreland mine	1-1		0-20	62.6	23.2	14.2	SL	100	14	28	.7	37	18.7	-	7.9	.7	
		1-2		20-40	61.3	29.5	9.2	SL	150	16	14	.3	32	15.8	-	7.5	.7	
		1-3		40-50	75.0	16.1	8.9	LS	57	17	59	1.77	34	10.2	-	8.0	.7	
		1-4		50+	9.7	60.9	29.4	SiCL	380	120	290	3.29	41	21.3	-	7.6	3.2	
Farley		2-1		0-30	28.2	53.0	18.7	SiL	110	6	4	.1	37	20.4	-	7.8	.5	
		2-2		30-60	37.4	46.5	16.1	L	290	31	53	.8	36	18.7	-	7.9	.8	
		2-3		60-100	47.0	38.1	15.0	L	180	21	31	.7	35	17.2	-	7.8	1.2	
		2-4		100+	19.7	58.3	22.0	SiL	410	82	320	3.8	43	22.1	-	7.5	2.8	
Nelson	Unmined	1-1	A1	0-8	82.7	12.9	4.3	LS	170	10	7	.1	37	9.2	-	7.2	.8	
		1-2	C1	8-18	82.7	12.9	4.3	LS	120	5	6	.2	33	8.2	-	7.8	.5	
		1-3	C2	18-32	78.9	18.2	2.9	LS	86	4	4	.1	34	8.9	-	7.9	.4	
		1-4	C3	32-49	80.9	15.7	3.3	SL	71	3	5	.2	35	9.5	-	8.0	.3	
Theda-lund		2-1		0-8	45.2	49.1	5.7	SL	340	21	8	.1	46	16.5	-	7.2	1.1	
		2-2		8-28	38.8	48.5	12.7	L	220	15	10	.2	39	18.4	-	7.7	.8	
		2-3		28-46	18.7	53.2	28.1	SiCL	66	7	18	.6	41	22.8	-	8.1	.4	
		2-4		46+	1.9	59.7	38.4	SiCL	56	10	55	1.8	57	25.1	-	8.2	.5	

interburden (material between seams). Interburden is typically more saline, finer-textured, and more reduced than overburden material. Selective handling techniques to bury interburden would improve minesoil quality at the Westmoreland mine.

One experiment at the Westmoreland mine to re-establish Ponderosa Pine plant communities involved the reconstruction of soils similar to those which support Ponderosa Pine on the natural landscape. This reconstructed soil, Absaloka series, contained more than 35% rock fragments and was on a north-facing slope. Very high pine survival rates have been reported on Absaloka soils (Simpson, personal communication).

Regional Patterns

Characterization data of minesoils from throughout the Northern Great Plains (Figure 35) were collected from various literature sources (Appendix B). Interpretation of these data along with those collected in this study revealed some interesting patterns. When moving from west to east in the region, clay content, SAR, EC, K, and NO_3 levels all increased. In addition Ca/Mg ratios decreased while Smectite abundance in the clay fraction increased with a corresponding decrease in kaolinite and illite. It is postulated that many of these trends could be explained by differences in the depositional environment of the Fort Union materials. As discussed in Chapter 3,

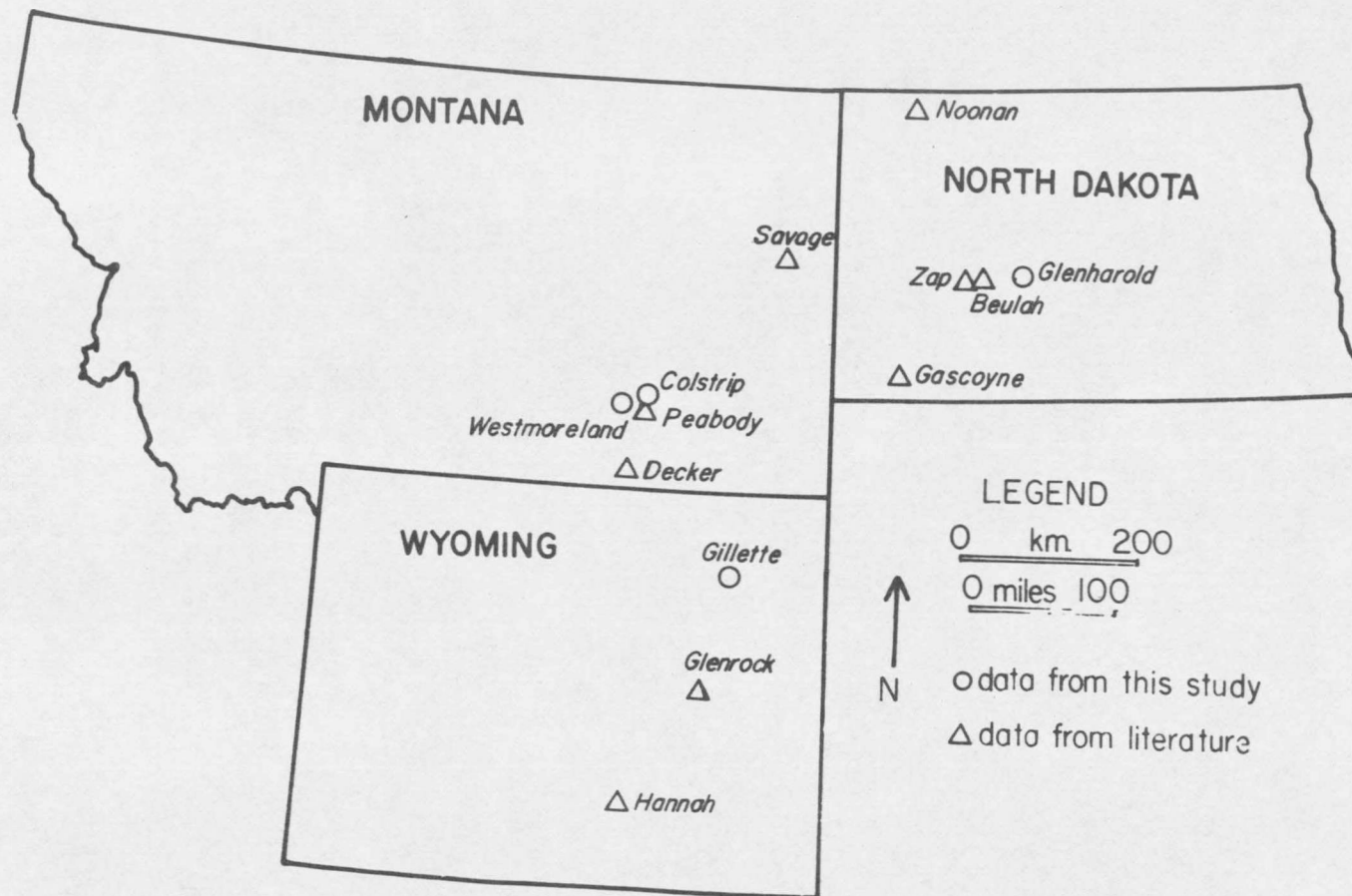


Figure 35. Location of data on minesoils in the Northern Great Plains from published literature and from this study.

eastern Montana and Wyoming was a meandering stream environment in Paleocene time while western North Dakota was a lower delta-plain system. The low-delta plain system would be a lower energy environment thus accounting for higher clay content, higher salinity, higher Na and perhaps Mg levels. Smectite clays form more readily in alkaline environments while kaolinite formation is favored in more acid humid environments like that probably found in eastern Montana during the Paleocene (Grim, 1968), thus accounting for the clay mineral differences.

It would appear from the previous discussion that minesoil parent materials in the western Northern Great Plains should be superior to those in the east due to differences in the Paleocene depositional environment. An opposing trend exists in soil quality, however. Because the climate is more humid as one moves east, soils tend to have more organic matter and are free of soluble salts and lime to a deeper depth in North Dakota than in either Montana or Wyoming. Many soils in North Dakota are loess-derived which gives them favorable physical conditions. Minesoil potential is determined by both the topsoil applied and by the spoil, thus so the two trends, for decreasing spoil quality and increasing topsoil quality from west to east, tend to cancel.

Classification and Morphology of Minesoils

Several problems were encountered in applying Soil Taxonomy to minesoils. For example, a large volume of weakly consolidated sandstone and siltstone fragments occurred in minesoils. These fragments act in part like soil because they deliver water to roots, and in part like rock because they prevent root penetration (Schafer, and others, 1979). Soft rock fragments weather rapidly near the surface of minesoils and disintegrate into soil material during standard mechanical analysis. Since soft rock fragments respond differently than rock fragments found in most soils, it was unknown if they should be classified as rock fragments in determining family particle-size class. Minesoils could either be coarse-loamy or loamy-skeletal depending on how soft rock fragments are classified. Other more subtle complications arise when using Soil Taxonomy. Diagnostic horizons have genetic implication in natural soils. It is possible for diagnostic horizons and properties to be mimicked in minesoils while the features genetically associated with these horizons in natural soils are lacking. For example, sulfuric horizons (Fanning and others, 1977) or low chroma mottles can occur in minesoils without the influence of a high water table which is associated with these features in natural soils. More often, diagnostic properties that are used to infer the presence of a chemical or physical condition in natural soils are lacking in minesoils. For example, the presence of

a natric horizon is used to infer the presence of high levels of exchangeable sodium in natural soils. Natric horizons are lacking in minesoils with excess sodium as well as some natural soils, however, because of their genetic youth. Revisions of Soil Taxonomy may be needed to recognize man's influence on soils before minesoils can be appropriately classified (Smith and Sobek, 1978). Until formal revisions are adopted, the use of soil phases may be adequate to identify key properties of minesoils affecting soil management.

Although morphological differences were not evident in minesoils on different aspects, slopes, and hill-slope positions, different soils may be recognized on the basis of soil microclimate, temperature, and water regimes. Differences in soil temperature and water regimes can often be predicted from slope, aspect, and slope position. These differences will strongly influence the productivity of minesoils.

CHAPTER 8

SOIL INTERPRETATIONS AND POTENTIAL

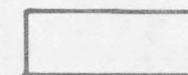
Land Capability Classification

The Land Capability Classification (LCC) system (Klingbiel and Montgomery, 1961) was used to group soils with similar management needs and equal agricultural capability. Guidelines proposed by Schafer (1979a) were used for rating the LCC unit of each mapping unit on the mined area soil maps.

Overlay maps were prepared to show the distribution of land capability classes on each of the mined areas (Figures 36-45). The percentage of each mine falling in various classes is shown in Table 21. In general, a few of the best soils at most mines were placed in class III which are somewhat comparable with better natural soils used for cereal grain production. Often the majority of soils at a mine, having only slight soil or climatic limitations, were placed in class IV. Soils which had shallow root zones, shallow topsoil, steep slopes, low water-holding-capacity, or evident erosion were considered class VI. Severe soil limitations caused some mapping units to be ranked as class VII or VIII.

LAND CAPABILITY CLASS

BELLE AYR MINE

LEGENDLCC CLASS

IV



VI

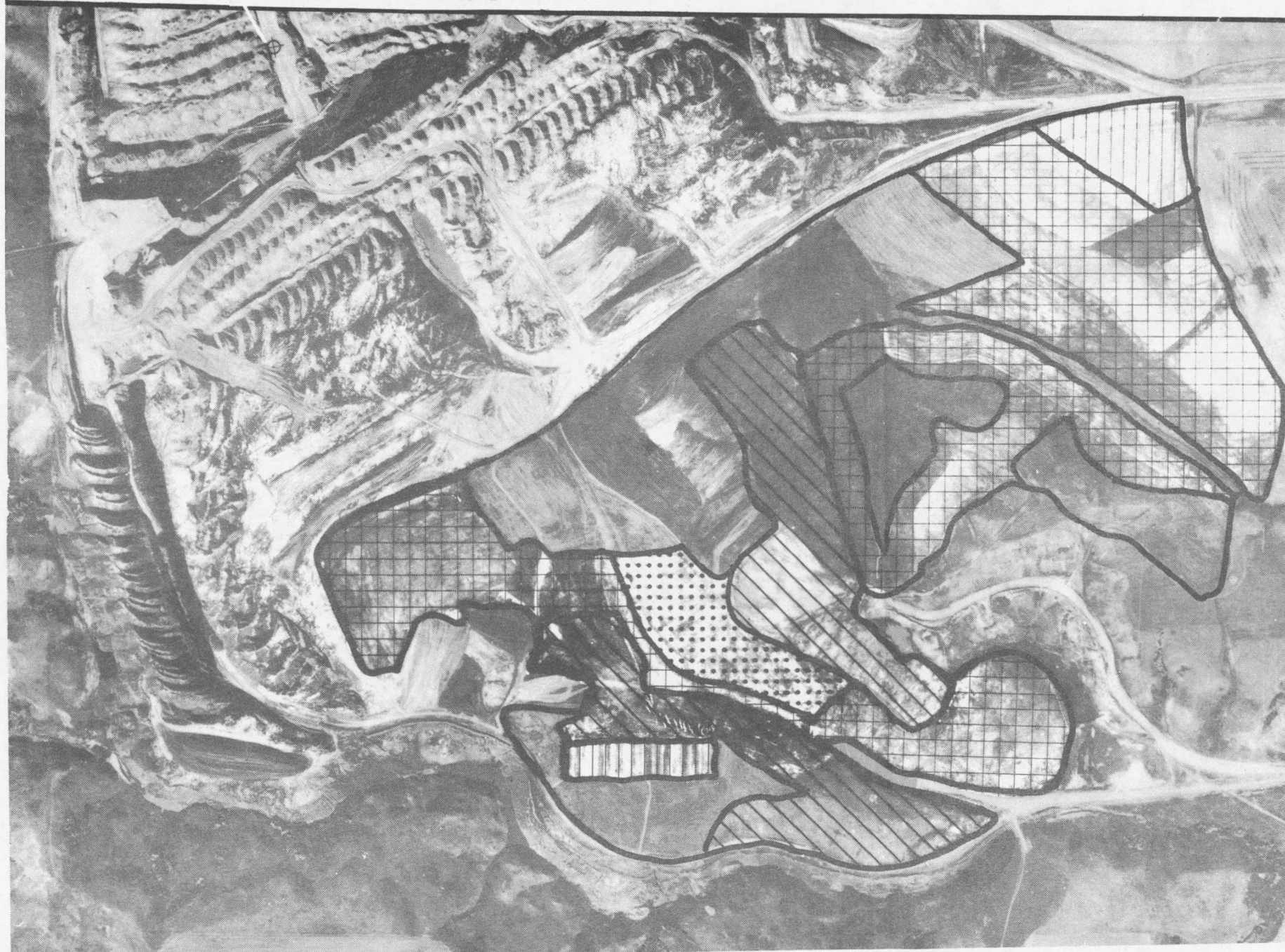
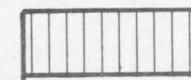


VII

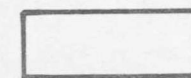
Figure 36. Land Capability Classes at the AMAX Mine.

LAND CAPABILITY CLASS

GLENHAROLD MINE - SOUTH

LEGENDLCC CLASS

III



IV



VI



VII

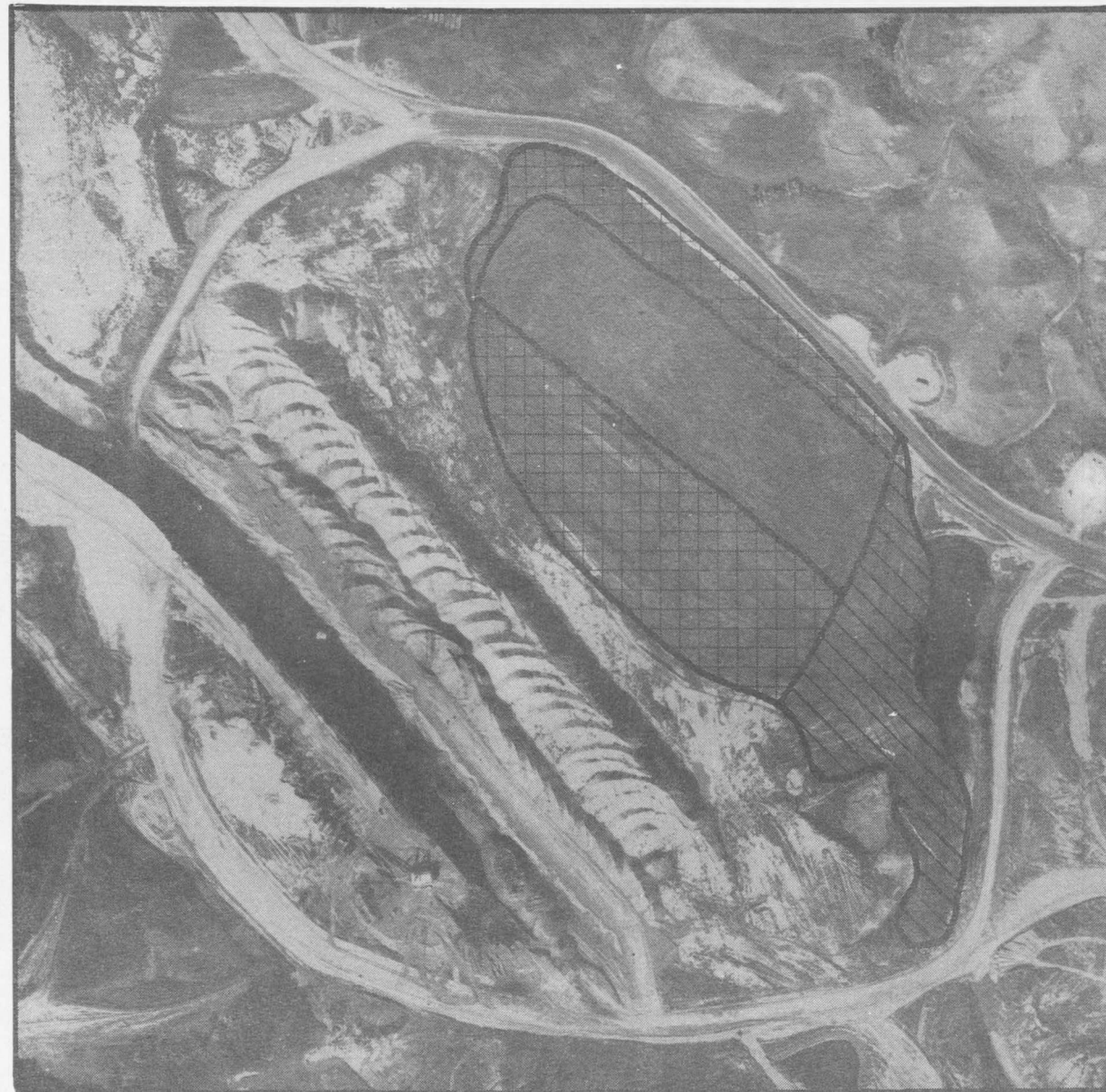
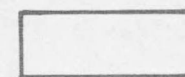


VIII

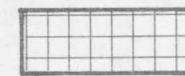
Figure 37. Land Capability Classes at the Glenharold Mine (south).

LAND CAPABILITY
CLASS

GLENHAROLD MINE-NORTH

LEGENDLCC CLASS

IV



VI



VII

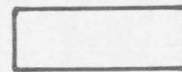
Figure 38. Land Capability Classes at the Glenharold Mine (north).

LAND CAPABILITY
CLASS

DECKER MINE - NORTH

LEGENDLCC CLASS

III



IV

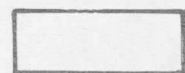
Figure 39. Land Capability Classes at the Decker West Mine (north).

LAND
CAPABILITY
CLASS

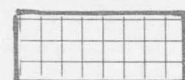
DECKER MINE - SOUTH

LEGENDLCC CLASS

III



IV



VI



VII

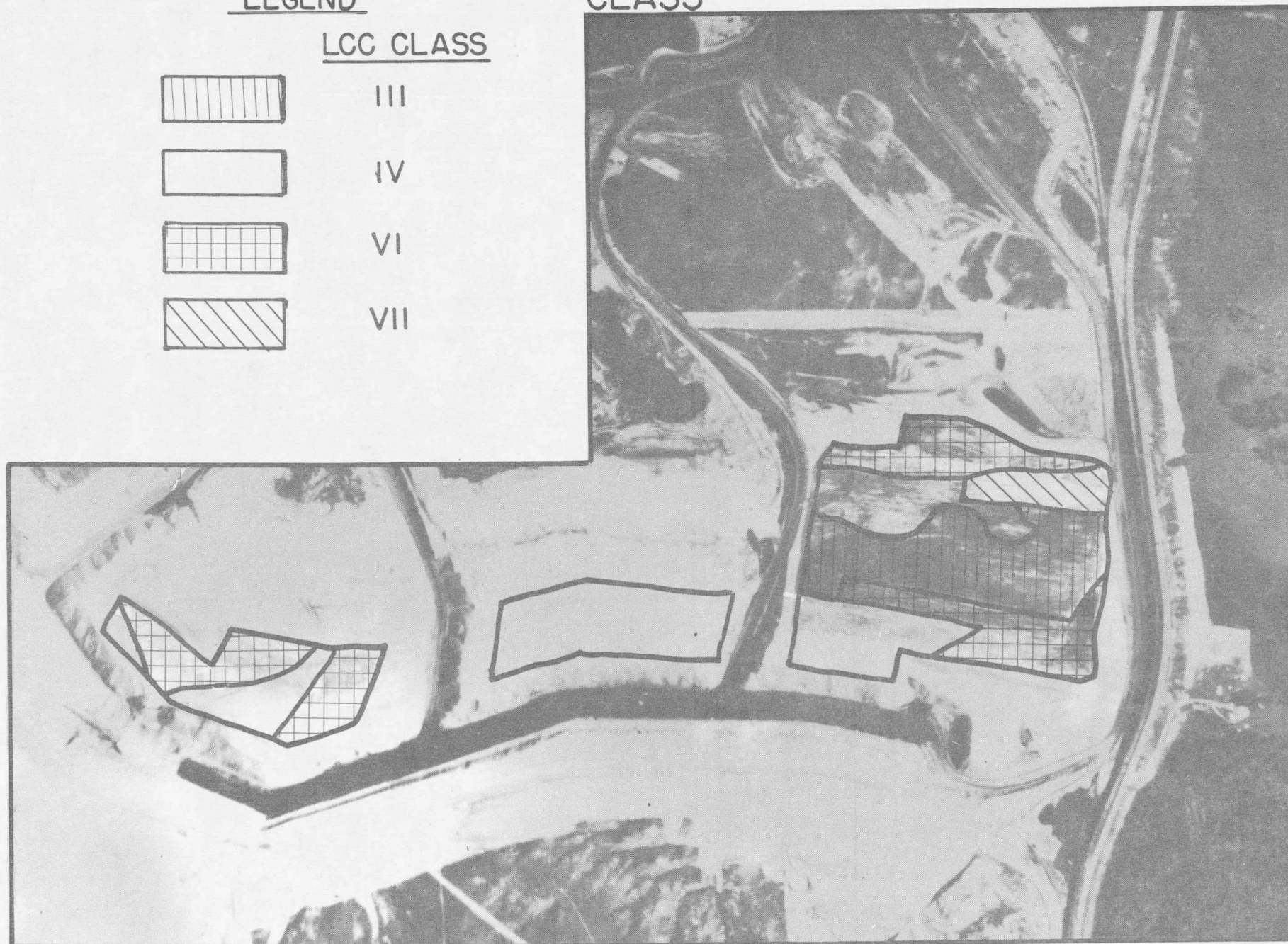


Figure 40. Land Capability Classes at the Decker West Mine (south).

LAND CAPABILITY
CLASS

WEST. ENERGY - AREA A - NORTH

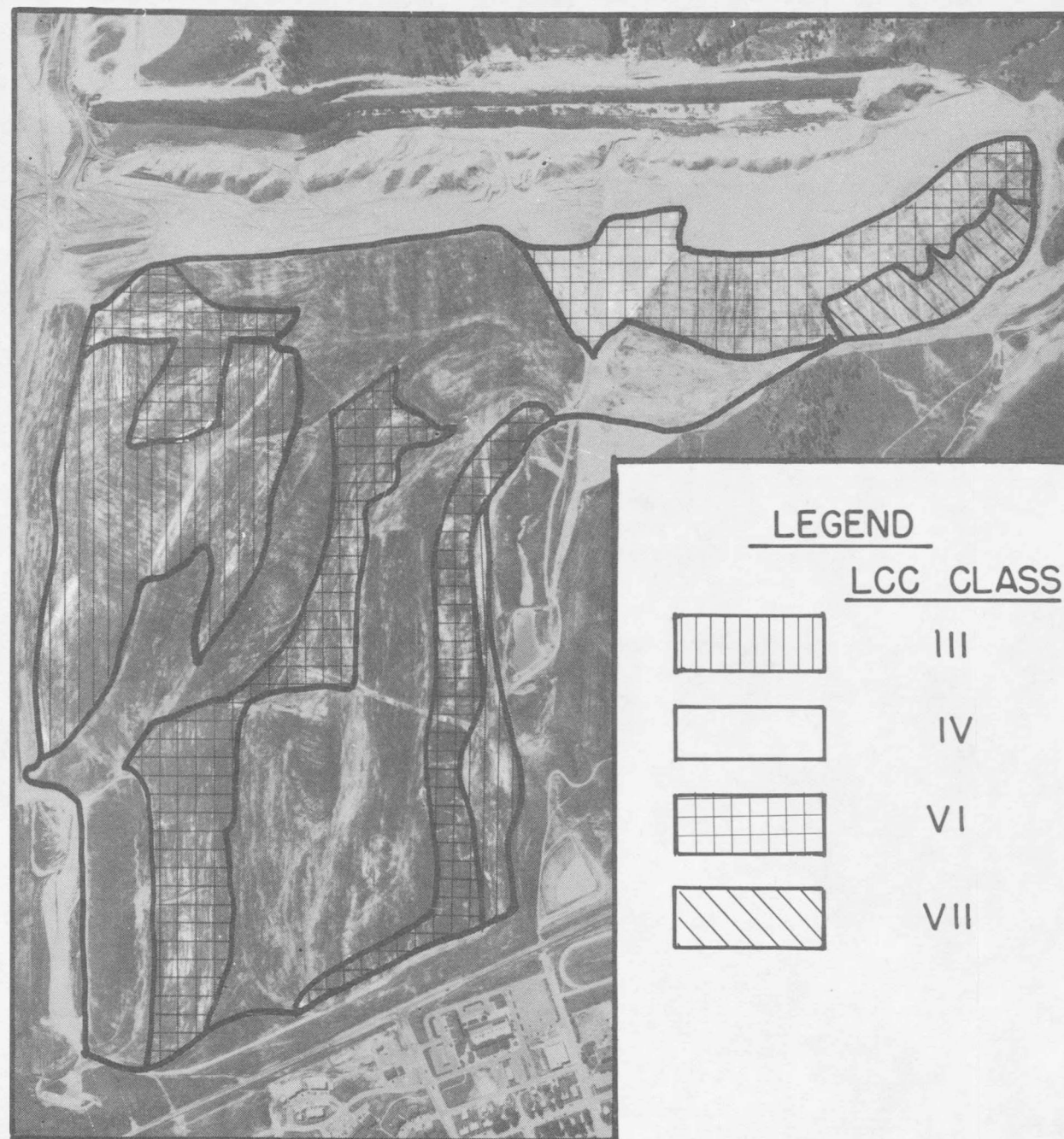


Figure 41. Land Capability Classes at the Western Energy-Area A Mine (north).

LAND CAPABILITY
CLASS

WEST. ENERGY-AREA A - SOUTH

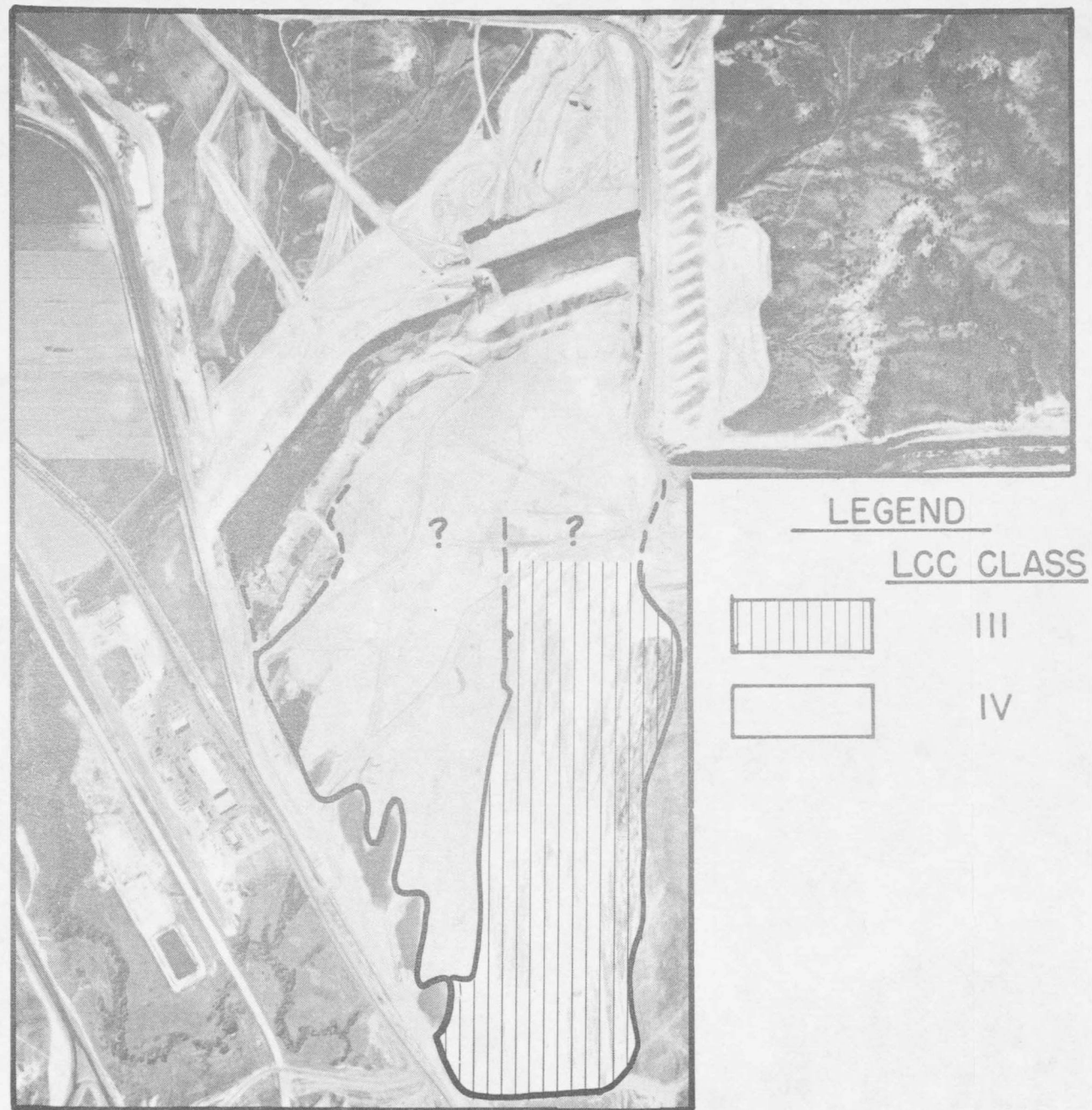
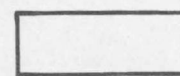


Figure 42. Land Capability Classes at the Western Energy-Area A Mine (south).

LAND CAPABILITY
CLASS

WEST. EN. PIT 6 - EAST

LEGENDLCC CLASS

IV



VI

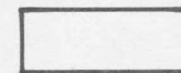


VII

Figure 43. Land Capability Classes at the Western Energy-Pit 6 Mine (east).

LAND CAPABILITY
CLASS

WEST. EN. PIT 6 - WEST

LEGENDLCC CLASS

IV



VI

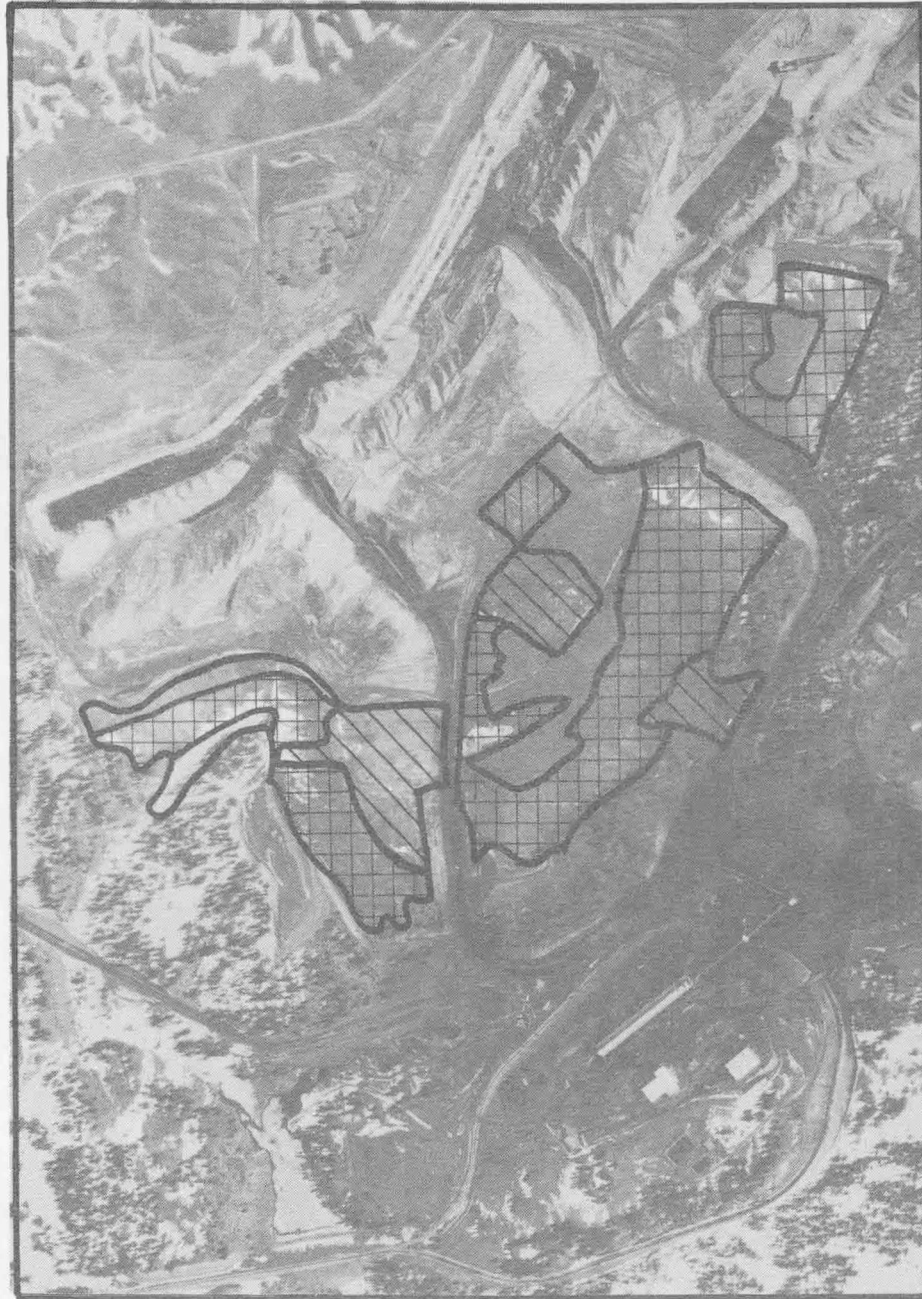


VII

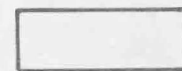
Figure 44. Land Capability Classes at the Western Energy-Pit 6 Mine (west).

LAND CAPABILITY
CLASS

WESTMORELAND

LEGENDLCC CLASS

III



IV



VI



VII

Figure 45. Land Capability Classes at the Westmoreland Mine.

Table 21. Percentage of area at each of six mines in the Northern Great Plains falling in specified Land Capability Classes.

Mine	Land Capability Class				
	III	IV	VI	VII	VIII
AMAX	0	38	53	8	0
Consol-Glen	4	30	37	19	4
Decker	6	67	18	3	0
Weco-Area A	30	40	26	2	0
Weco-Pit 6	0	29	26	44	0
Westmoreland	<u>2</u>	<u>22</u>	<u>52</u>	<u>16</u>	<u>0</u>
Average	7	38	35	15	1

Soil Potential Index

Another more specific interpretive grouping is the Soil Potential Index (SCS, 1977). Since livestock grazing is the most common post-mine land use on Northern Great Plains mines (Figure 46), an SPI rating system was developed for range forage production. Because of a lack of data, the SPI ratings developed are tentative. They are intended only for relative soil comparisons and to demonstrate the usefulness of the SPI system. A sample calculation of SPI for a soil at the AMAX mine is included (Table 22). A computer program was developed for calculating SPI. An interactive computer system has the advantage that actual management costs, and market prices, can be

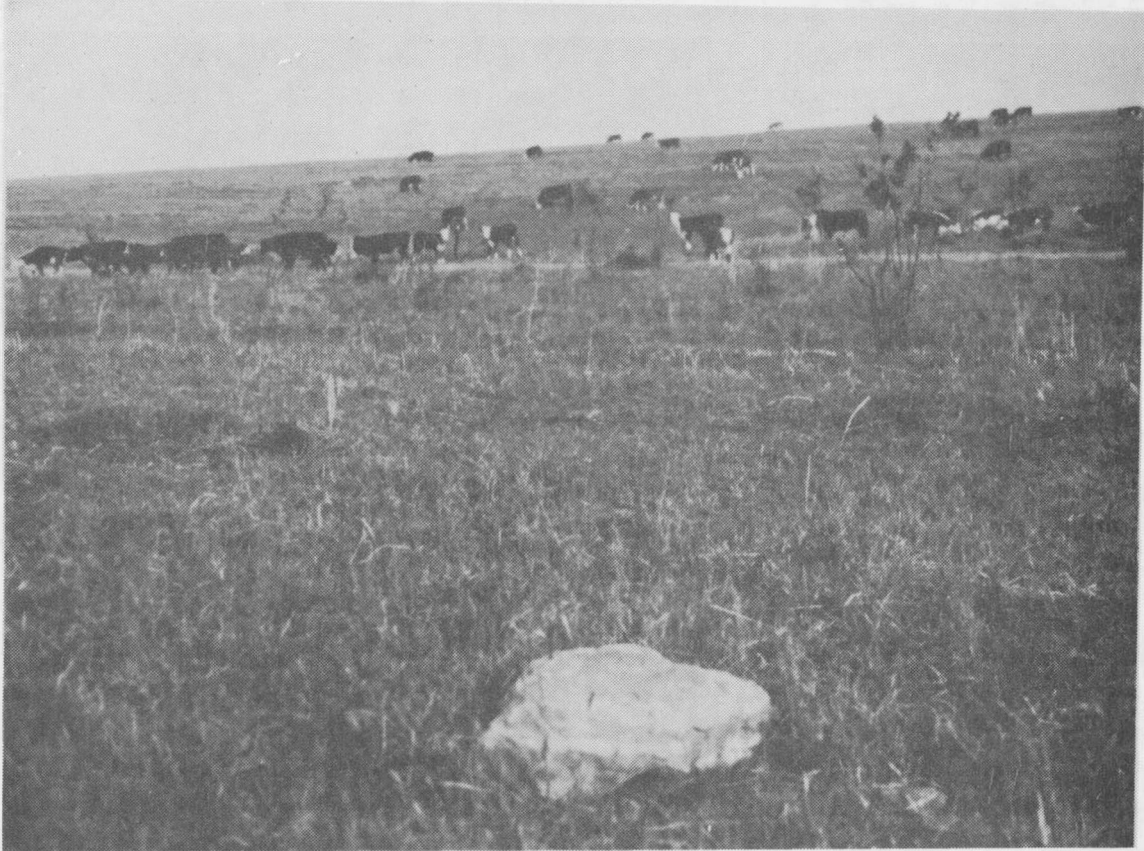


Figure 46. Livestock grazing in cow-calf operations is the final post-mine land use at most Northern Great Plains mines (Western Energy Co.-Area A).

Table 22. Sample calculation of SPI for range forage production at the AMAX Belle Ayr Mine.

Evaluation Factors	Degree of Limitation	Trt. Cost	Cont. Limit.	Reduced Yield
1 Shal. Root Zone	Sev.	0	10	10
2 Shal. Topsoil	None	0	0	-2
3 Wat. Hold. Cap.	Sli.	0	0	0
4 Sandy Surf.	None	0	0	0
5 Clayey Surf.	Sli.	0	0	2
6 EC Surf.	None	0	0	0
7 EC Sub.	None	0	0	0
8 Sar Surf.	None	0	0	0
9 Sar Sub.	None	0	0	0
10 Slope	Mod.	0	0	5
11 Erosion	Sli.	0	0	3
12 Wetness	None	0	0	0
13 Climate	Sev.	0	0	16
14 Soil Color	Slt.	0	0	0
15 Unknown Yld. Rd.	Mod.	0	0	10
Total		0	10	44

$$\begin{aligned}
 \text{SPI} &= P - \text{CT} - \text{CL} - \text{CY} \\
 &= 100 - 0 - 10 - 44 \\
 &= 46
 \end{aligned}$$

updated in calculating SPI. Thus the SPI system can be a valuable empirical tool for evaluating different management strategies, land use conversions, or changes in management cost or commodity price.

Soils with similar SPI values were grouped into broad ranges and displayed on maps similar to the LCC overlays (Figures 47-56). It is

SOIL POTENTIAL INDEX

BELLE AYR MINE

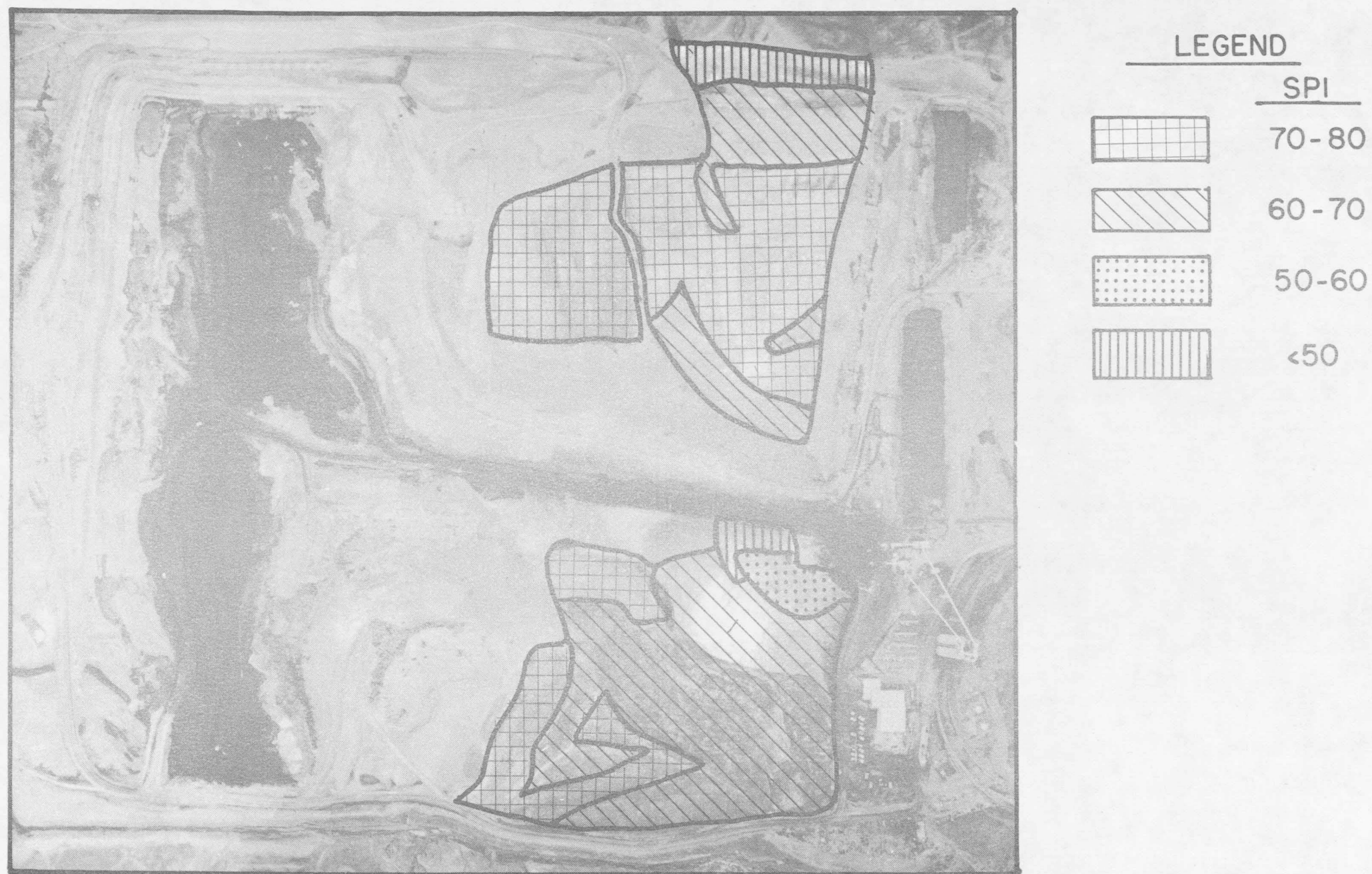


Figure 47. Soil Potential Index ranges at the AMAX Mine.

SOIL POTENTIAL INDEX

GLENHAROLD MINE - SOUTH

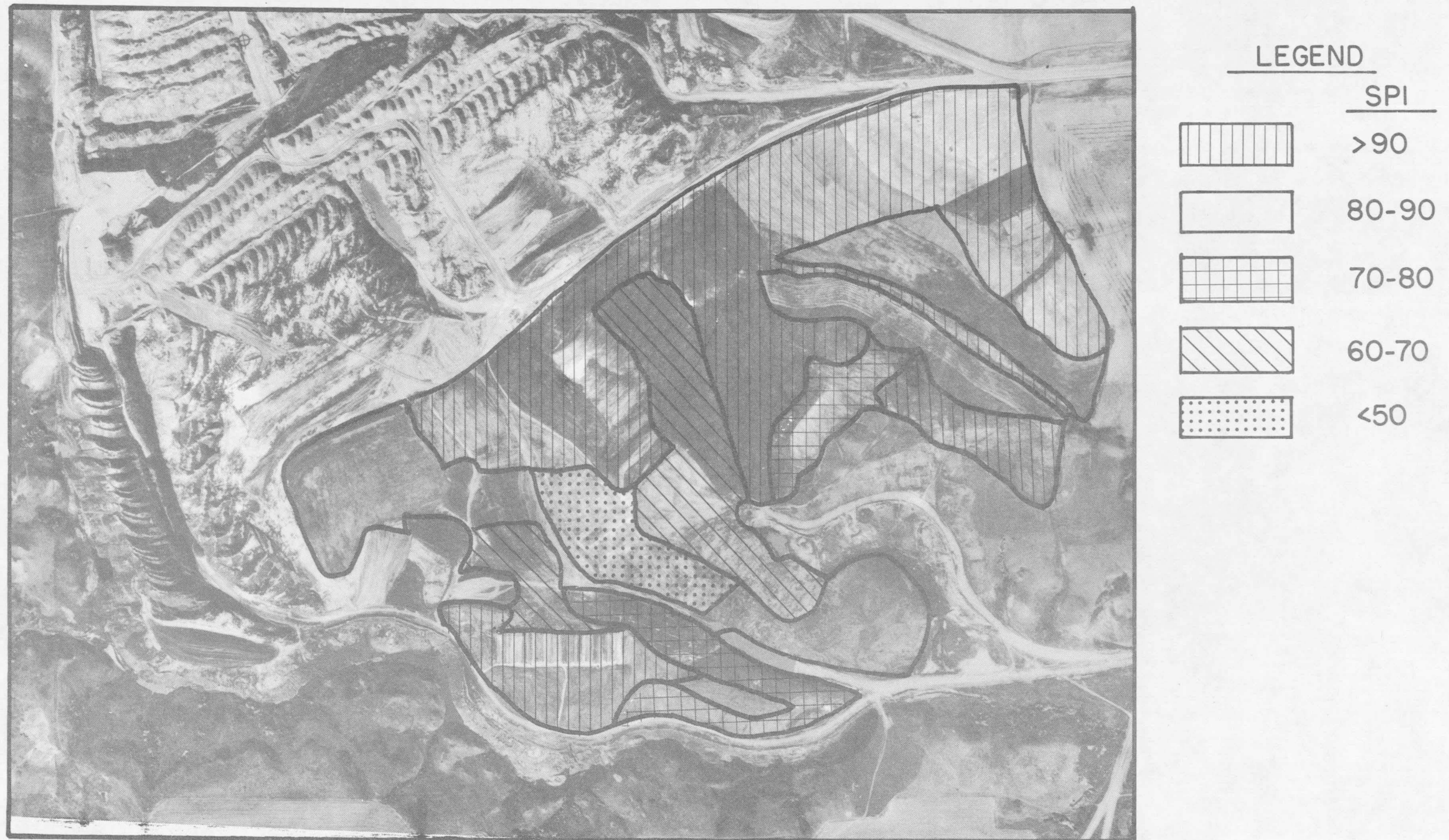
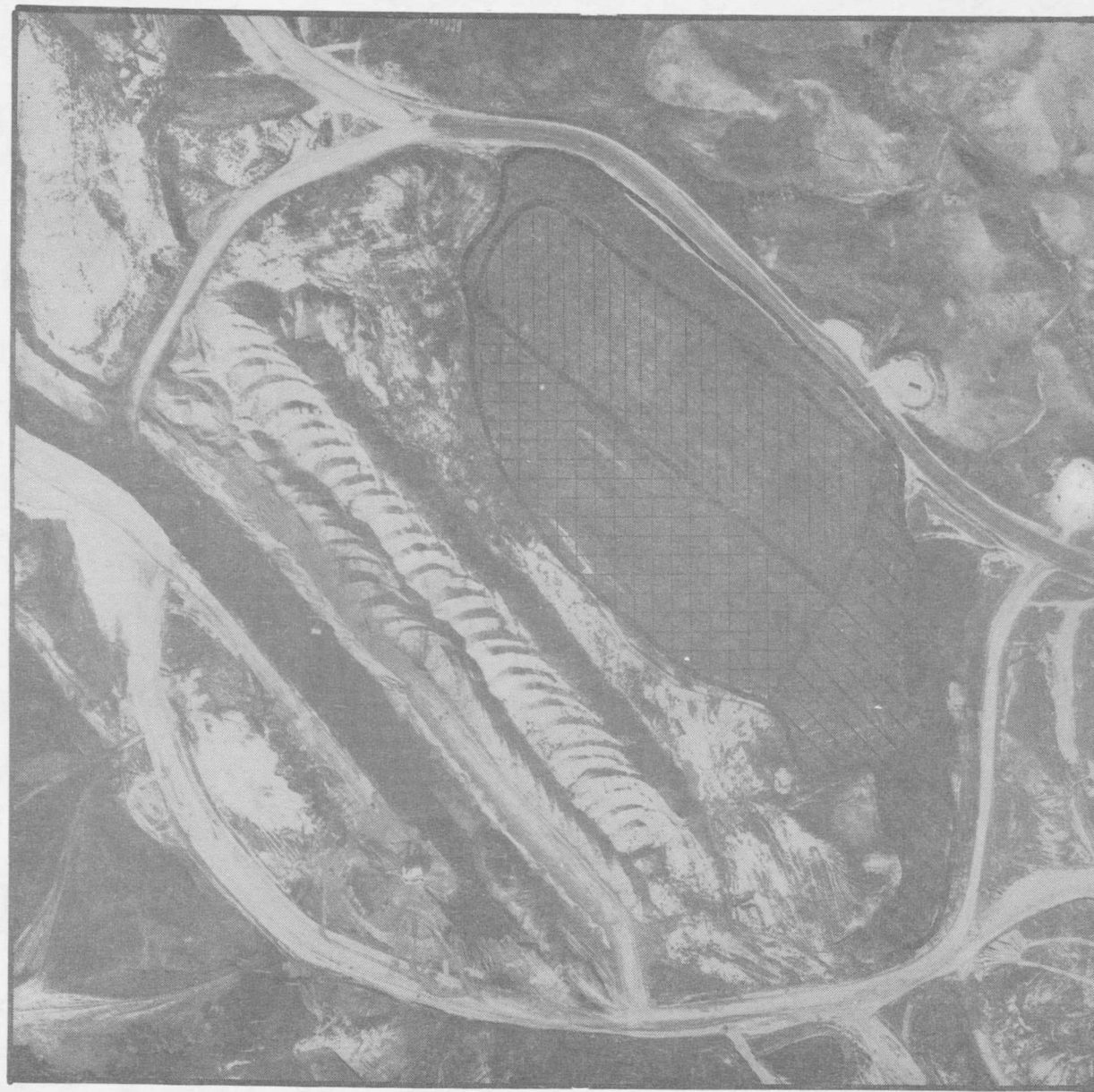


Figure 48. Soil Potential Index ranges at the Glenharold Mine (south).

SOIL POTENTIAL
INDEX

GLENHAROLD MINE - NORTH



LEGEND

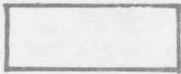
	SPI
	>90
	80-90
	70-80
	<50

Figure 49. Soil Potential Index ranges at the Glenharold Mine (north).

SOIL POTENTIAL
INDEX

DECKER MINE-NORTH



LEGEND

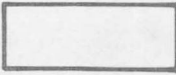
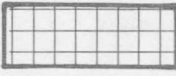
	<u>SPI</u>
	80-90
	70-80
	60-70

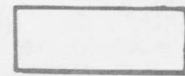
Figure 50. Soil Potential Index ranges at the Decker West Mine (north).

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SOIL
POTENTIAL
INDEX

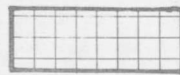
DECKER MINE - SOUTH

LEGEND

SPI



80-90



70-80



60-70



Figure 51. Soil Potential Index ranges at the Decker West Mine (south).

SOIL POTENTIAL
INDEX

WEST. ENERGY AREA - NORTH

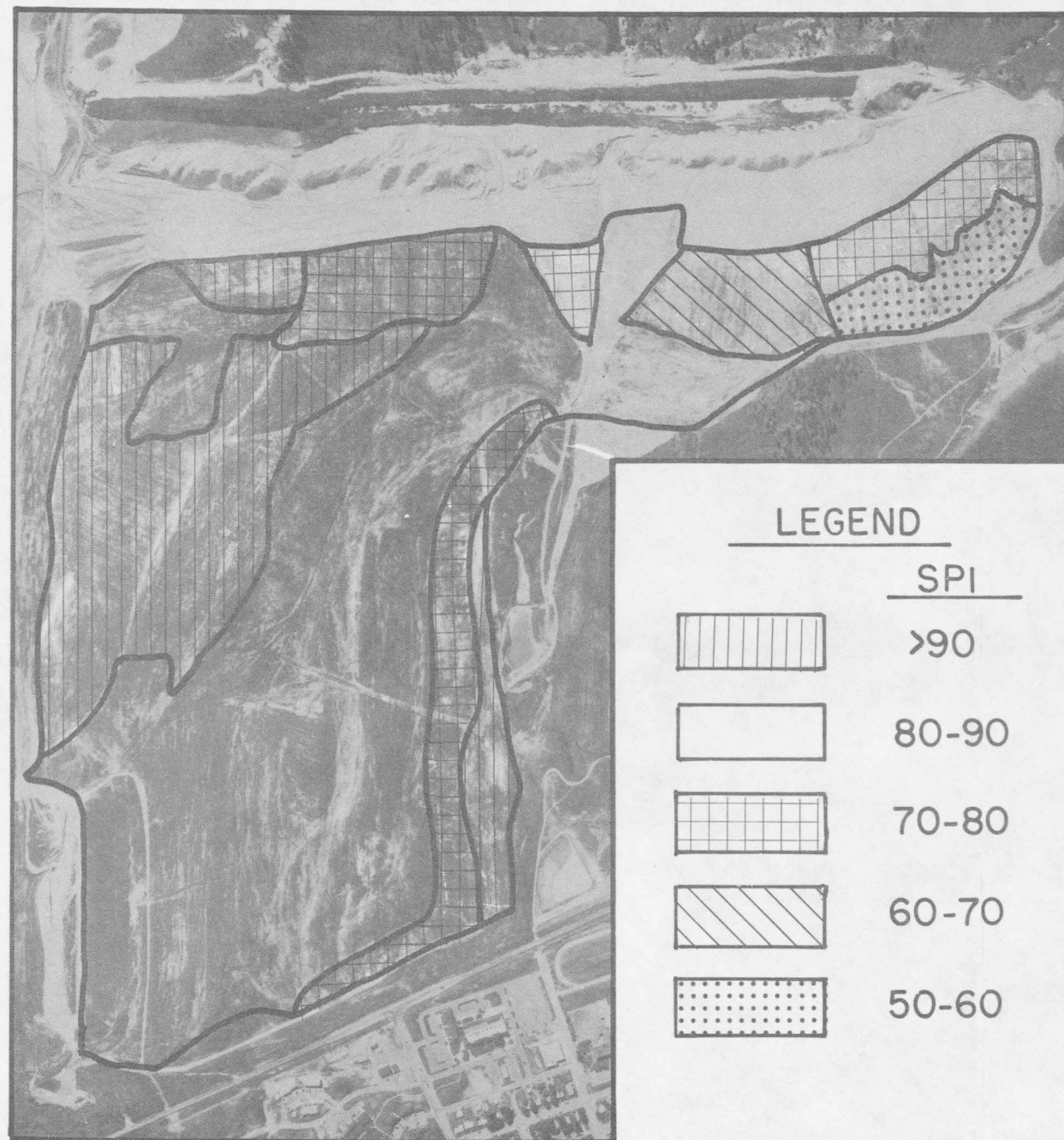


Figure 52. Soil Potential Index ranges at the Western Energy-Area A Mine (north).

SOIL POTENTIAL
INDEX

WEST. ENERGY-AREA A - SOUTH

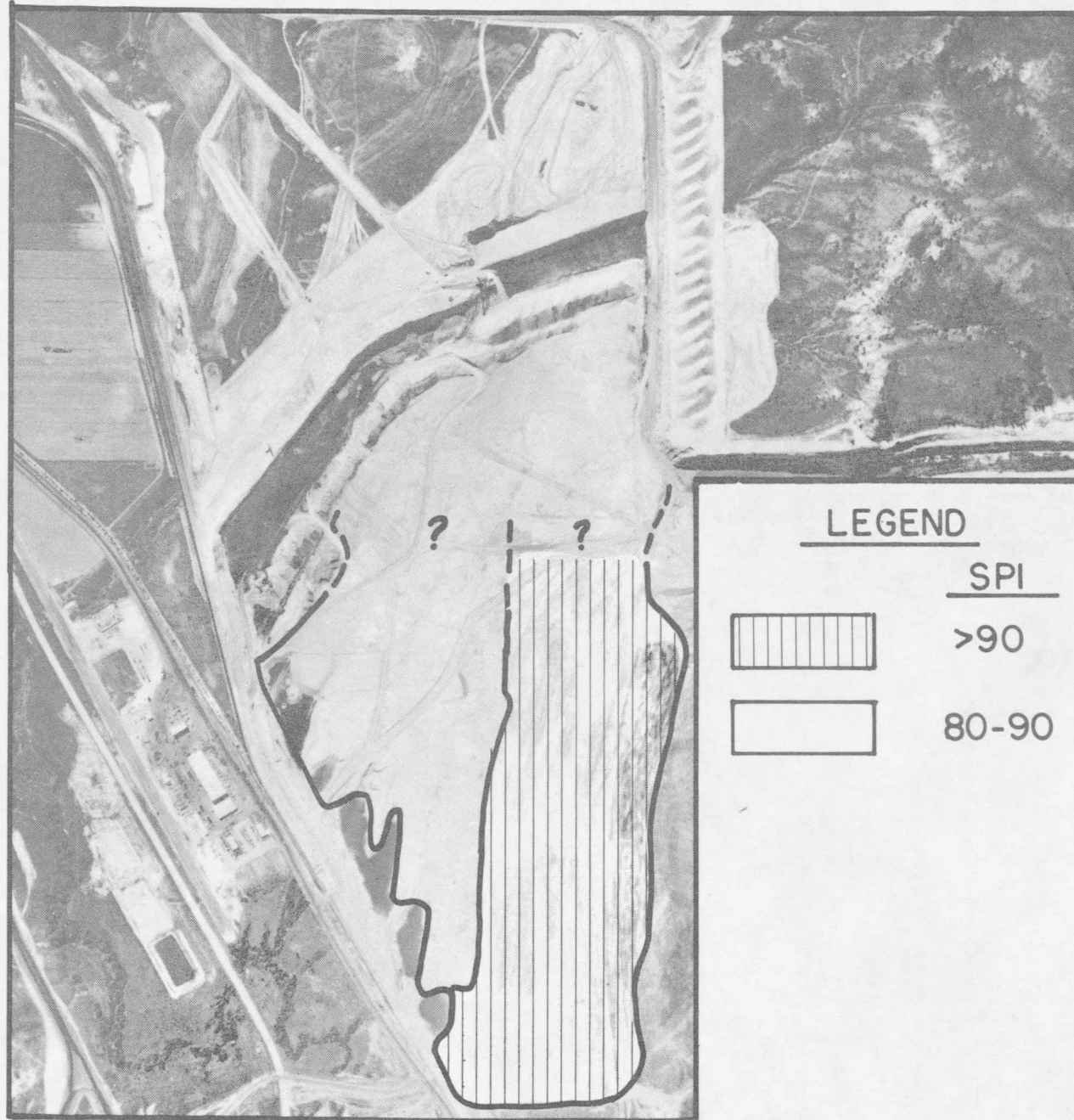


Figure 53. Soil Potential Index ranges at the Western Energy-Area A Mine (south).

SOIL POTENTIAL
INDEX

WEST. EN. PIT 6 - EAST



Figure 54. Soil Potential Index ranges at the Western Energy-Pit 6 Mine (east).

SOIL POTENTIAL
INDEX

WEST. EN. PIT 6 - WEST



Figure 55. Soil Potential Index ranges at the Western Energy-Pit 6 Mine (west).

SOIL POTENTIAL
INDEX

WESTMORELAND

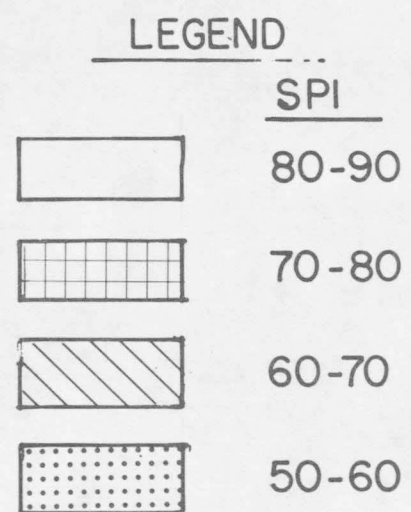
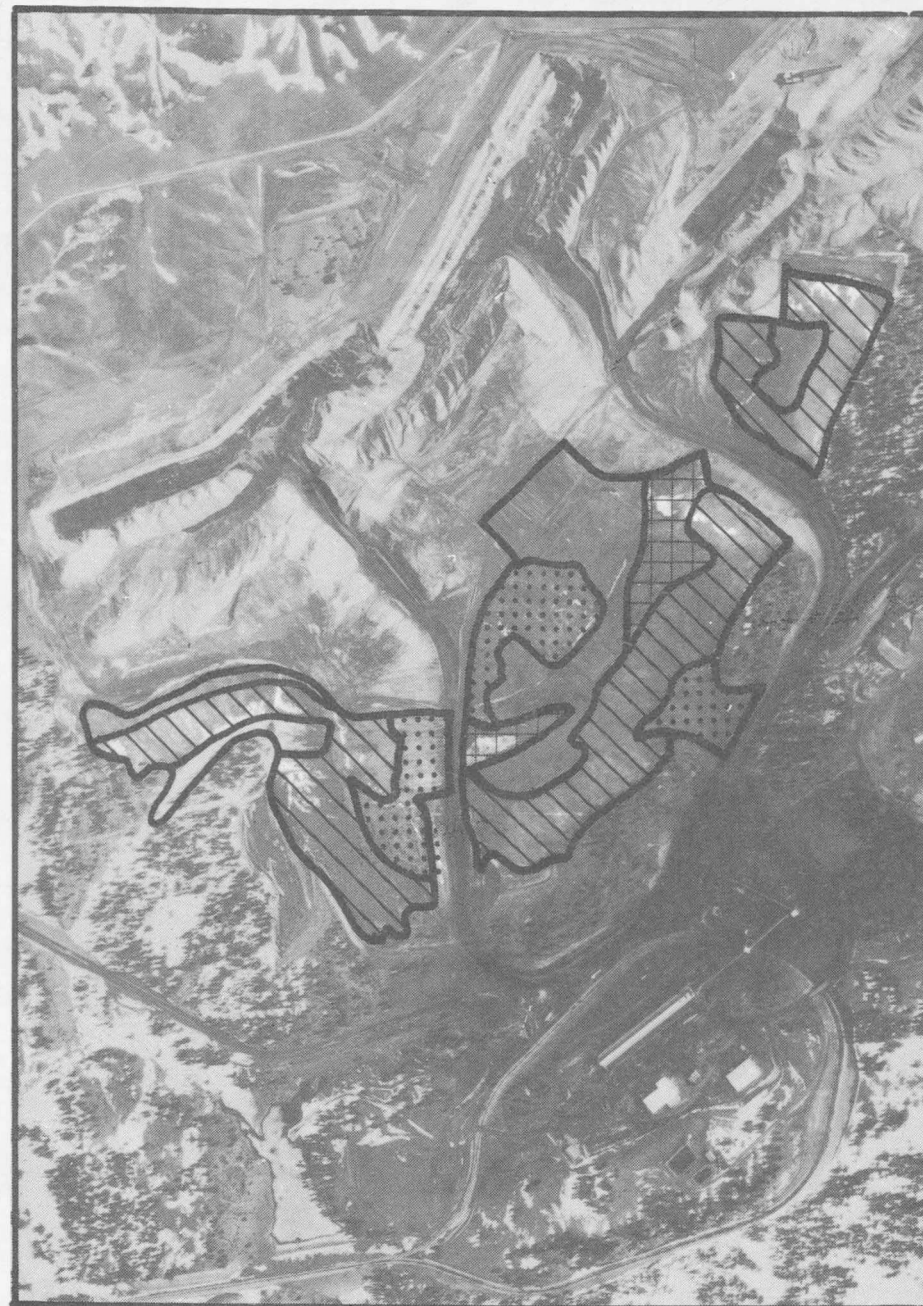


Figure 56. Soil Potential Index ranges at the Westmoreland Mine.

interesting that soils with higher SPI ratings were nearly always in the youngest portions of each mine. Passage of increasingly restrictive reclamation laws at both the State and Federal levels (MDSL, 1977; OSM, 1979) has therefore been reflected in improving minesoil quality. The weighted average SPI for each mined area was calculated both with and without climatic corrections (Table 23). Mines with both the highest and lowest average SPI are at Colstrip Montana. The minesoils with the lowest SPI were reclaimed before passage of the 1973 state reclamation law while the best minesoils were reclaimed after passage of the 1977 federal law (SMCRA, 1977). This also indicates the influence that changing reclamation techniques can have on minesoil potential.

Interpretive Overlay Maps

In order to demonstrate how specific soil information can be derived from soil maps, additional interpretive overlay maps were developed for the AMAX mine. Maps showing slope classes, topsoil texture, and spoil texture are shown (Figures 57-59).

Table 23. Weighted-average SPI at six stripmines in the Northern Great Plains.

Mine	SPI	
	Corrected for Climate	Not Corrected for Climate
AMAX	66.2	82.2
Glenharold	82.8	74.8
Decker	76.2	84.2
Weco-Area A	85.7	85.7
Weco-Pit 6	61.1	61.1
Westmoreland	70.7	70.7

SLOPE CLASS

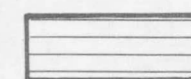
165

BELLE AYR MINE

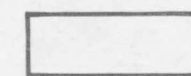


LEGEND

SLOPE(%)



0-3



3-8



8-15



>15

Figure 57. Slope percent phases at the AMAX Mine.

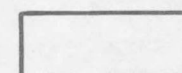
TOPSOIL TEXTURE

166
BELLE AYR MINE

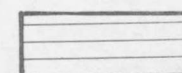


LEGEND

TEXTURE



COARSE-LO.



FINE-LO.



FINE-SI.

Figure 58. Topsoil texture phases at the AMAX Mine.

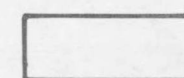
SPOIL TEXTURE

167

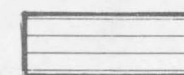


LEGEND

TEXTURE



COARSE-LO.



FINE-LO.

Figure 59. Soil texture phases at the AMAX Mine.

CHAPTER 9

MAPPING UNIT PURITY

A study was conducted to evaluate to what extent physical and chemical properties in one delineation of a mapping unit could be used to predict that property in another delineation. Soils were collected from three locations within each of six map delineations representing three mapping units. Soils were analyzed from three depths on both mined and unmined landscapes for a total of 108 samples.

The components of variance at each level (map unit, delineation within map unit, reps within delineation) were used to interpret the results (Tables 24 and 25). Mapping unit differences accounted for only 17.4% of the analytical variability observed in minesoils and 11.2% of that in natural soils. Another way of stating this trend is that of the total variability observed on the mined landscape in measured soil properties, only 17.4% could be attributed to differences in soils A, B, and C. The variation attributed to delineations within mapping units was 21.0% and 41.4% for minesoils and natural soils, respectively. In preparing soil maps, the goal is to keep individual delineations of a mapping unit as similar to each other as possible meaning 0% of the variance. On the mined and unmined soils, 61.6 and 42.7% of the observed variance was contained within delineations which means it was not accounted for in the mapping process.

Table 24. Percent of total variance in various soil properties on the mined landscape accounted for by mapping units, delineations, and replicate measurements.

DEPTH (cm)	SOURCE	COLOR			CONS.	HCl Eff.	SAND	SILT	CLAY	pH	EC	Ca	Mg	Na	SAR	TOPSOIL DEPTH	AVE.
		HUE	VALUE	CHROMA													
0-15	Map Unit	28.6	0.	12.2	20.4*	14.3	.2	0.	37. *	0	43.2	12.9	9.8	1.4	0.	0.	12.9
	Delineations	7.1	0.	0.	0.	0.	0.	6.9	0.	36.4	8.3	25.6	5.2	39.3	71.4*	88.1*	13.8
	Reps.	64.3	100.	87.8	79.6	85.7	99.8	93.1	63.	63.6	48.5	61.6	85.0	59.3	28.6	11.9	73.3
15-30	Map Unit	45.5	30.8	0.	25.8	9.8	12.5	6.3	16.1	0.	37.5	52.7	7.3	29.3	0	--	19.5
	Delineations	27.3*	23.1	57.1*	28.8	2.4	0.	0.	45.8*	9.3	6.6	7.5	33.8	0.	15.0	--	8.4
	Reps.	27.3	46.2	42.9	45.5	87.8	87.5	93.8	28.1	90.7	55.9	39.8	59.0	70.7	85.0	--	72.1
SPOIL	Map Unit	61.3*	0.	44.0	48.2	0.	21.6	0.	25.6	0.	11.7	58.8*	0.	4.3	0.	--	19.7
	Delineations	0.	25.0	0.	50.0*	35.7	57.6*	50.1	50.5*	0.	59.1*	4.7	74.7*	9.3	6.9	--	30.3
	Reps.	38.7	75.0	56.0	1.8	64.3	20.9	49.9	23.9	100.	29.2	36.5	25.3	86.5	93.1	--	50.0
AVE.	Map Unit	45.1	10.3	18.7	31.5	8.0	11.4	2.1	26.2	0.	30.8	41.5	5.7	11.7	0.	--	17.4
	Delineations	11.5	16.0	19.0	26.3	12.7	19.2	19.0	32.1	15.2	24.7	12.6	37.9	16.2	31.1	--	21.0
	Reps.	43.4	73.7	62.3	42.2	79.3	69.4	78.9	41.7	84.8	44.5	45.9	56.4	72.1	68.9	--	61.6

*Significant at P<.05 based on F value, not applicable to variation due to reps.

Table 25. Percent of total variance in various soil properties on the unmined landscape accounted for by mapping units, delineations, and replicate measurements.

DEPTH (cm)	SOURCE	COLOR			CONS.	HCl Eff.	SAND	SILT	CLAY	pH	EC	Ca	Mg	Na	SAR	A.Hor. THICK.	B.Hor. THICK.	C.Hor. DEPTH.	Depth TO LIME	B.Hor. TYPE AVE.
		HUE	VALUE	CHROMA																
0-15	Map Unit	--	0.	0.	2.1	0.	0.	0.	0.	0.	2.9	0.	23.0	17.4	13.6	0.	70.3*	51.2	0.	90.6* 4.2
	Delineations	--	59.1*	75. *	29.2	88.9*	91.1*	88.8	91.3*	65.8*	15.0	1.2	19.6	0.8	13.3	75.7*	0.	10.5	72.7*	0 45.7
	Reps.	--	40.9	25.	68.8	11.1	8.9	11.2	8.7	34.2	82.1	98.8	57.4	81.8	73.3	24.3	29.7	38.3	27.4	9.4 43.0
15-30	Map Unit	--	0.	22.6	7.7	0.	0.	8.8	0.	0.	4.0	0.	12.6	15.0	4.8	--	--	--	--	-- 5.4
	Delineations	--	75.*	19.4	0.	80.*	45.9*	29.9	48.0	52.3*	57.4*	90.4*	13.8	39.8	10.2	--	--	--	--	-- 40.8
	Reps.	--	25.	58.0	92.3	20.	45.1	61.3	52.0	47.7	38.6	9.6	73.6	45.2	85.0	--	--	--	--	-- 46.7
30-45	Map Unit	0.	0.	0.	10.2	0.	0.	0.	8.9	0.	52.9	72.8*	64.6*	57.9*	68.3*	--	--	--	--	-- 24.0
	Delineations	50.*	37.5	50.*	69.5*	56.*	67.5*	80.6*	37.0	57.0*	21.0	0.	2.8	0.	0.	--	--	--	--	-- 37.8
	Reps.	50.	62.5	50.	20.3	44.	32.5	19.4	54.1	43.0	26.2	27.2	32.6	42.1	31.7	--	--	--	--	-- 38.3
AVE	Map Unit	--	0.	7.5	6.7	0.	0.	2.7	3.0	0.	19.9	24.3	33.3	30.1	28.9					11.2
	Delineations	--	57.2	48.1	32.9	75.0	71.2	66.4	58.8	58.4	31.1	30.5	12.1	13.5	7.8					41.4
	Reps.	00	42.8	44.3	60.5	25.0	28.8	30.6	38.3	41.6	49.0	45.2	54.5	56.4	63.3					42.7

*Significant at $p < .05$ based on F value, not applicable to variation due to reps.

On the mined area, color hue, chroma, moist consistence, clay content, EC, and Ca content were all fairly well explained by mapping unit differences, meaning the soil map should predict these properties better than others. On the undisturbed area, variability of EC, Ca, Mg, Na content and SAR were related to mapping unit differences.

In general, soil measurements for the spoil layer were better related to mapping unit differences than corresponding values in the topsoil layer. In natural soils, surface sample analyses were more poorly related to mapping unit differences than properties measured below 30 cm. Perhaps surface mixing by machines on mined land and by geomorphic agents on unmined land tends to mask the correlation of soil properties with mapping units.

For every soil property measured, considerable error would result from extending analyses from one delineation to another in the same mapping unit. It is apparent that because of extreme soil variability, several samples would be needed within a single delineation to adequately predict the mean of that property. It must be emphasized that the inability of maps to isolate totally homogeneous soil areas applies to both mined and unmined land. The commonplace practice of extending soil analytical data from a single pedon to all similar soils on a map must be regarded with apprehension. More sophisticated, statistically sound sampling designs should be applied

to soil resource characterization (Webster, 1977), but the additional cost necessitated by increased replication will often be prohibitive.

It is interesting that on unmined land variation in morphological properties emphasized in Soil Taxonomy (Soil Survey Staff, 1975) were well explained by mapping unit differences. Properties like B horizon thickness, depth to the C horizon, and type of B horizon have 70.3, 51.2, and 90.6% of their variation explained by mapped soil differences. In this instance, the bias of Soil Taxonomy toward morphogenetic properties does not serve a major purpose of mapping; to isolate differences in soil properties that affect soil management.

In the AMAX area where this study was conducted, minesoils and natural soils were similar in color; consistence; sand, silt, and clay content; and SAR (Tables 26 and 27). Minesoils had lower pH and Mg content; and higher EC, Ca and Mg content. Lime content was higher from 0-30 cm in minesoils than natural soils but lower below 30 cm.

Table 26. Mean levels of several soil properties for 18 selected minesoils at three depths.

Depth (cm)	Color			Cons.	HCL eff.	Sand	Silt (%)	Clay	H ₂ O Saturation Extract						Topsoil Depth (cm)
	HUE	Value	Chroma						pH	EC (mmhos/cm)	Ca	Mg (ppm)	Na	SAR	
0-15	10.0	4.1	3.2	3.6	.8	48.3	33.2	18.5	6.8	2.1	597.	15.4	43.0	.5	43.2
15-30	10.3	4.3	3.8	3.5	.8	48.5	31.2	20.1	6.8	1.9	395.	13.7	62.7	.7	-
Spoil	10.8	3.9	3.3	3.6	.7	47.7	31.8	20.5	6.7	2.5	452.	19.0	149.	2.1	-

Table 27. Mean levels of several soil properties for 18 selected natural soils at three depths.

depth (cm)	color			Cons:	HCL Eff.	Sand	Silt	Clay	pH	H ₂ O Saturation Extract				SAR	A.HOR. THICK.	B.HOR. THICK.	C.HOR. DEPTH	DEPTH TO LIME
	hue	value	chroma							EC	Ca	Mg	Na					
						(%)				(mmhos/cm)		(ppm)					(cm)	
0-15	10.0	4.0	3.2	3.1	.4	42.8	37.1	19.7	7.3	1.0	117.	34.6	24.7	.8	12.3	11.1	23.3	21.7
15-30	10.0	4.2	3.6	3.3	.9	43.4	35.8	20.9	7.3	1.3	154.	48.5	39.5	1.4	-	-	-	-
30-45	10.3	4.4	3.6	3.8	1.5	42.5	35.8	21.6	7.6	1.4	200.	99.0	89.5	1.2	-	-	-	-

CHAPTER 10

CONCLUSIONS

Variability

1. Large variations in soil properties on mined land necessitated the recognition of different soil series.
2. Natural soils were more variable than minesoils on a landscape scale (>500 m lateral spacing) while minesoils were more variable on a local scale (<100 m lateral spacing).
3. In 400 ha study areas, natural soils exhibited more variability than minesoils, thus 14 natural soil families were recognized compared to only 2 minesoil families.
4. The patterns of variability in natural soils were related to landscape position and other geomorphic variables. In mapping natural soils, landscape position is often useful in predicting where soils occur. Minesoils were not related to landscape position because they were formed by man, not by natural processes. Therefore, to map minesoils one must rely on a knowledge of the mining process, reclamation techniques, and on more intensive soil observations.

Mapping

5. Thirteen new soil series were described on the 2,191 acres of reclaimed land which was mapped at six major mines in the Northern Great Plains. Minesoils did not fit the series concept of any established soil series.
6. Phases of soil series were needed extensively to identify key management properties of minesoils. Series descriptions and classification alone did not differentiate all of the important soil differences.
7. Temporary ponds were a common feature of many mined areas. They occurred because established drainage networks disrupted by mining were not adequately reconstructed.

Characterization

8. Truck-shovel mining operations enabled placement of the best-quality overburden at the spoil surface thus improving minesoil quality. Selective placement was not evident in dragline-deposited spoils.
9. Piping and upward sodium movement is a problem in minesoils with sodic spoils. Upward sodium movement may be slowed by placement of a sandy buffer layer between topsoil and spoil.
10. Compacted spoil was common at the topsoil/spoil interface which restricted deep rooting.

11. Minesoils with high rock fragment content appeared to favor Ponderosa Pine and shrub establishment.
12. When moving from west to east across the Northern Great Plains, clay content, SAR, EC, K, and NO_3 content, and smectite abundance all increased while the Ca/Mg ratio, illite, and kaolinite levels decrease. These trends were related to the Paleocene depositional environment which was fluvial in Montana and Wyoming but deltaic in western North Dakota.
13. Another, opposing trend was found from west to east in topsoil quality. In North Dakota soils are higher in organic matter and have salts and lime leached to a deeper depth than in Montana or Wyoming.
14. Soil Taxonomy did not adequately separate minesoils with widely different management needs which is one of its objectives. Revisions of Soil Taxonomy are needed to adequately classify minesoils. Use of phases are necessary at present to identify minesoil differences.

Interpretations and Potential

15. A common conception of mining is that it leaves totally useless land in its wake (i.e., LCC class VIII). Only 1% of all minesoils studied which were reclaimed since 1970 were class VIII. Seven percent of all minesoils were class III which compares

favorably with better agricultural soils in the region. Class IV, VI, and VII soils accounted for 38, 35, and 15% of the minesoils, respectively.

16. The Soil Potential Index (SPI) was used to rate minesoils for range forage production on a 0 to 100 relative scale with 100 representing better local natural soils. Overall the SPI of minesoils reclaimed since 1970 was 71.5, while for individual mines SPI ranged from 61 to 86.
17. Younger minesoils constructed in accordance with new restrictive State and Federal reclamation laws had consistently higher SPI and LCC than older minesoils indicating reclamation standards have resulted in better minesoils.

Map Unit Purity

18. Chemical variability within soil delineations, in separate delineations of the same mapping unit, and between different mapping units was evaluated. Only 17.4% of the observed variability in minesoils and 11.2% in natural soils was explained by mapping unit differences which is much lower than commonly assumed. Variability attributed to delineations within mapping unit was 21 and 41.4% for minesoils and natural soils leaving 43 to 62% of the analytical variability not accounted for by mapping.

Differences in soil morphological features were better related to mapping unit differences.

19. Considerable error would result from extending chemical analyses from one delineation to another in the same mapping unit. Such extrapolation of soils data is a commonplace practice that should be regarded with apprehension.

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LITERATURE CITED

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APPENDICES

APPENDIX A

GUIDELINES FOR RATING TOPSOIL AND SPOIL QUALITY

FOR USE AS COVER-SOIL IN STRIPMINE

RECLAMATION

Table A-1. Proposed guidelines for rating the suitability of topsoil and subsoil for use as cover-soil material in stripmine reclamation.

Factor affecting use	Good	Fair ^a	Poor ^a	Ref. ^b	Methods
Texture class	vfs1,fsl,sl,l,sil	lfs,ls,cl,scl,sicl	s,c,sc,skc	16,17,20	ASA. Agron. Mono. Methods of Soil Analysis II. 75-4. pp. 1062-1063.
Moist consistence	vfr,fr	lo,fi	vfi,exfi	16,17,20	Soil Survey Manual. p. 233.
EC (mmhos/cm)	<4	4-8	>8	16,17,20	USDA Hndbk. 60. pp. 88-89.
ESP	0-5	5-15	>15	3	Soil Survey Investigations. Rpt. 1. p. 21. Method 5D1.
pH	5.6-7.8	4.5-5.6;7.8-8.4	<4.5,>8.4	3,20,24	Soil Survey Investigations. Rpt. 1. 0. 59. Method 8cla. Use indicator dyes for field estimate.
Stoniness class	0	1	2-5	16,17	Soil Survey Manual. pp. 217-219.
Available water (% by volume)	>10	5-10	<5	3,20	Soil Survey Investigations. Rpt. 1. p. 14 Method 4C1
Rock fragments (%)	<15	15-35	>35	3,20	Estimate
Saturation water (%)		25-80	<25;>80	24	USDA Hndbk. 60. p. 84. Method 2,3a.

^aMitigation of adverse properties will increase reclamation potential.

^bMaterials rated as poor may be suitable as topsoil only if adverse factor can be treated.

^cNumbers relate to literature citations at the end of this report.

Table A-2. Proposed guidelines for rating the suitability of selected overburden for use as cover-soil material in stripmine reclamation.

Factor affecting use	Good	Fair	Poor	Ref.	Methods
Texture class	vfs1,fs1,sl,l,sil	lfs,ls,cl,scl,sicl	s,c,sc,sic		See Table 1
EC (mmhos/cm)	<4	4-8	>8		See Table 1
ESP	0-5	5-15	>15		See Table 1
Material or rock type	Weakly consolidated sandstones & siltstones, & unconsolidated surface deposits (i.e., loess; till; recent alluvium; and colluvium)		indurated sandstone & siltstone, shale, clayey or gravelly material	1,13	Observation
Water slaking [†]		2-10	0-2	22	See ref.
Trace elements [‡]	less than limits at right		ppm B > 1 Cd > 0.1-1.0 Cu > 40 Fe[§] Pb > 10-20 Mn > 60 Hg > 0.4-0.5 Mo > 0.3 Ni > 1.0 Se > 2.0 Zn > 40.0	8	

^{*} Other tests may be suitable. At least 30% of material should weather into <2 mm particles within 1 year in the surface 10 cm. A rating of 0-2 in the slaking test indicates that 0-20% of a fragment has passed a 5 mm sieve after 30 minutes submerged in water.

[†] Selected trace elements should be analyzed from this list if they are a demonstrated regional problem or if required by state or federal law. Many quantitative limits shown in this section are not supported by research findings. Measurement of these elements is costly and should be considered optional.

[§] Iron is analyzed because of antagonism with other nutrients. High Fe may mitigate high levels of other metals. Iron deficiency could also occur.

APPENDIX B

ACCESORY MINESOIL CHARACTERIZATION DATA

Table B-1. Characterization of minesoils at the Beulah South, Gascoyne, Zap, and Baukol-Noonan mines in North Dakota (from Schroer, 1977).

Location	Depth (cm)	Texture	Bulk Dens ₃ ^{1/} g/cm ³	pH (paste)	EC (mmhos/cm)	H ₂ O soluble ions								SAR	H ₂ O satn (%)	Soil Test			
						HCO ₃	Cl	SO ₄	Ca (ppm)	Mg	Na	K	NH ₄			NO ₃	P	K	
																			(lbs/ac)
Beulah South	0- 15	cL	1.40	7.4	3.2	5.5	0.3	33.6	6.2	5.0	27.6	0.6	11.7	55	18	18	9	420	
	15- 30	SiCL	1.46	8.0	3.8	4.3	0.2	39.0	3.4	4.2	35.1	0.8	18.1	76	42	<5	5	450	
	30- 60	SiL	1.32	7.8	4.9	3.0	0.1	58.2	8.8	10.4	41.2	0.9	11.8	68	34	5	6	420	
	60- 90	VfSL	1.15	7.7	5.2	2.7	0.2	64.3	10.8	14.3	41.2	0.9	11.6	59	24	<5	4	360	
	90-120	VfSL	1.23	7.8	5.6	2.6	0.2	73.8	13.2	19.6	42.8	1.0	10.6	60	22	<5	7	350	
	120-150	VfSL	1.13	7.7	5.5	2.5	0.1	70.5	13.0	15.2	44.0	0.9	11.7	57	24	<5	7	340	
Beulah South	0- 30	SiCL	1.66	7.4	3.4	2.9	0.4	45.7	21.7	21.6	4.8	0.9	1.0	58	12	8	8	400	
	30- 60	SiCL	1.46	7.5	3.8	2.1	0.2	54.9	20.4	30.2	5.6	1.0	1.1	69	18	<5	5	400	
	60- 90	SiL	1.49	7.4	3.8	1.7	0.3	56.0	20.4	31.4	5.4	0.8	1.1	56	6	<5	2	350	
	90-120	SiL	1.31	7.5	3.7	1.6	0.2	54.6	20.0	30.8	4.8	0.8	1.0	58	8	<5	3	360	
	120-150	SiL	1.30	7.5	3.6	1.9	0.4	54.0	24.8	26.4	4.4	0.7	0.9	60	8	<5	2	360	
Beulah South	0- 15	SL	-	6.6	2.0	3.8	0.5	21.3	10.7	7.5	6.6	0.8	2.2	43	8	9	7	500	
	15- 45	SiC	-	7.7	5.4	2.7	0.2	78.1	14.2	18.5	47.2	1.1	11.7	86	18	7	7	500	
	45- 90	C	-	7.3	5.2	4.4	0.2	66.5	9.8	15.0	45.2	1.1	12.8	84	22	6	7	610	
	90-120	SiC	-	7.6	5.3	3.8	0.5	68.7	11.4	16.0	44.4	1.2	12.0	92	28	6	6	630	
	120-150	SiC	-	7.8	4.7	3.6	0.3	66.3	7.6	13.4	48.0	1.2	14.8	102	30	9	5	650	
Gascoyne	0- 15	SiL	1.32	7.5	3.4	3.6	0.5	52.5	28.8	26.0	1.0	0.8	0.2	53	6	5	7	210	
	15- 30	SiL	1.46	7.7	5.1	2.1	0.7	93.0	25.0	64.4	6.0	0.4	0.9	50	6	5	2	140	
	30- 60	L	1.25	7.3	3.0	4.5	1.2	160.4	23.5	125.0	17.0	0.6	2.0	46	16	5	5	250	
	60- 90	L	1.03	7.9	11.5	3.0	2.4	160.7	22.4	169.0	50.0	0.9	5.1	48	30	<5	5	200	
	90-120	FSL	1.31	8.3	15.0	2.0	1.5	362.0	22.4	284.0	58.5	0.6	11.6	40	26	<5	3	130	
	120-150	VfSL	1.12	8.3	18.5	2.3	1.5	393.7	19.0	308.0	70.0	0.5	5.5	42	10	<5	4	120	
Gascoyne	0- 15	VfSL	-	7.0	4.7	5.2	2.6	75.0	31.2	42.0	9.4	0.2	1.6	50	22	25	18	100	
	15- 30	SiL	-	7.6	3.9	3.5	1.2	48.6	9.9	35.2	8.0	0.2	1.7	47	14	21	4	90	
	30- 60	L	-	7.0	4.7	5.5	1.7	69.9	30.0	37.6	9.2	0.3	1.6	53	16	71	25	110	
	60- 90	L	-	7.0	4.2	4.6	0.8	65.0	28.8	34.2	7.0	0.4	1.2	53	14	65	36	140	
	90-120	VfSL	-	7.0	4.3	4.4	0.7	65.7	27.2	34.4	8.8	0.4	1.6	50	12	54	42	140	
	120-150	VfSL	-	6.6	4.2	7.4	0.7	62.2	28.8	33.6	7.6	0.3	1.4	64	16	29	32	110	
Zap	0- 30	C	1.33	7.9	3.6	7.1	0.2	32.4	1.0	1.4	36.8	0.5	33.8	113	28	57	7	440	
	30- 60	C	1.26	7.9	3.8	7.5	0.3	35.3	1.2	1.7	39.6	0.6	33.0	109	28	56	7	440	
	60- 90	SiC	1.23	7.8	4.3	5.2	0.3	40.5	1.8	2.2	42.0	0.6	29.8	98	24	64	6	420	
	90-120	C	1.24	7.9	3.7	6.0	0.3	33.7	1.2	1.4	37.5	0.5	32.9	109	28	42	6	460	
	120-150	SiC	1.25	7.9	3.7	5.8	0.2	44.1	9.5	1.5	39.0	0.5	16.7	111	30	50	6	420	

^{1/} air dry core

Table B-1 (continued)

Table C-1. (continued)

Location	Depth (cm)	Texture	Bulk ₁ / Dens ₃ g/cm ³	pH (paste)	EC (mmhos/cm)	H ₂ O soluble ions								SAR	satn (%)	Soil Test			
						HCO ₃	Cl	SO ₄	Ca		Mg	Na	K			NH ₄	NO ₃	P	K
									(ppm)										
Zap	0- 30	C	-	7.4	5.7	4.2	0.5	70.1	14.8	15.4	43.6	1.0	11.2	87	56	22	23	400	
	30- 60	C	-	7.6	4.6	4.2	0.5	51.2	8.0	9.4	37.6	0.9	12.8	90	60	27	9	410	
	60- 90	SiCL	-	7.8	4.0	5.0	0.4	32.1	4.0	5.0	27.7	0.8	13.1	88	56	18	6	400	
	90-120	SiC	-	7.2	6.4	4.2	0.4	81.3	19.2	17.6	48.0	1.1	11.2	78	42	25	11	390	
	120-150	SiC	-	7.1	6.4	4.8	0.5	84.7	20.4	20.4	48.0	1.2	10.6	80	74	29	15	380	
Zap	0- 30	CL	1.50	7.5	4.4	2.9	0.4	69.5	54.4		18.0	-	3.5	45	-	<5	10	290	
	30- 60	SiCL	1.50	7.8	4.7	1.4	1.2	76.9	56.0		23.0	-	4.4	48	-	<5	5	380	
	60- 90	CL	1.34	7.9	4.5	1.3	0.8	71.2	53.3		20.0	-	3.9	60	-	8	5	360	
	90-120	SiCL	1.30	7.8	5.3	1.2	0.8	82.3	58.3		26.0	-	4.8	62	-	7	5	380	
	120-150	SiCL	1.28	7.9	5.0	1.4	0.5	84.3	63.2		23.0	-	4.1	59	-	8	7	340	
Baukol- Noonan	0- 15	SL	1.67	7.5	0.8	5.0	1.6	2.8	5.2	3.0	0.8	0.4	0.4	50	24	-	10	370	
	15- 30	-	1.29	7.5	2.3	2.0	0.5	26.0	12.4	12.8	2.6	0.7	0.7	56	-	-	-	-	
	30- 60	SiL	1.54	7.5	2.1	2.3	0.7	22.9	12.0	10.8	2.8	0.3	0.8	61	14	6	8	350	
	60- 90	SiL	1.36	7.7	1.8	2.8	0.4	18.4	8.8	9.4	2.2	1.2	0.7	60	18	7	5	450	
	90-120	SiL	1.44	7.6	2.5	2.7	0.4	32.6	15.8	16.0	2.8	1.1	0.7	58	16	5	5	370	
Baukol- Noonan	120-150	SiCL	-	7.7	2.4	2.8	0.4	28.3	13.4	14.8	2.2	1.1	0.6	65	32	-	4	450	
	0- 30	CL	1.33	7.5	2.0	1.7	0.4	23.0	10.6	11.0	3.0	0.5	0.9	57	8	<5	8	350	
	30- 60	CL	1.37	7.4	2.6	2.2	0.3	32.8	14.8	14.8	5.2	0.5	1.4	57	6	<5	9	300	
	60- 90	SiCL	1.35	7.3	3.0	2.3	0.4	37.6	16.8	19.6	3.0	0.9	0.7	59	10	<5	5	360	
	90-120	SiL	1.21	7.5	3.2	0.8	0.4	43.0	19.0	21.4	3.2	0.6	0.7	54	6	<5	5	260	
Baukol- Noonan	120-150	SiL	1.05	7.5	4.2	1.3	0.5	67.7	28.0	34.4	6.4	0.7	1.2	54	6	<5	4	270	

Table B-2. Characterization of minesoils from the Western Energy mine - Pit 6 area. The date indicates the year soils were last disturbed (from Schafer and others, 1979).

Soil Age	Depth (cm)	Horizon	Sand	Silt %	Clay	Bulk Dens. g/cm ³	H ₂ O content			CaCO ₃ %	pH	OC (%)	C/N	CEC meq/100g	EC (mmhos/cm)
							15 Bar	1/3 Bar (%)	0. Bar						
1975	0- 1	A11	13.1	76.8	10.1	1.5	3.7	11.7	25.1	11	8.3	.46	13	4.2	.64
	1- 2	A12	75.7	15.0	9.3	1.5	3.7	11.7	26.0	11	8.3	.44	12	4.1	.56
	2- 5	A13	74.6	16.9	8.5	1.5	4.1	11.7	25.9	11	8.4	.43	11	4.1	.55
	5- 10	A14	75.9	16.4	7.7	-	4.2	-	-	10	8.4	.50	13	4.5	-
	10- 28	A15	75.7	15.4	8.9	-	4.0	-	-	10	8.4	.40	10	3.8	-
	28- 50	C1	73.1	19.2	7.7	-	4.3	-	-	12	8.3	.24	7	3.9	-
	50- 80	C2	68.8	22.7	8.5	1.62	3.8	9.7	28.2	14	8.3	.18	9	3.5	.7
	80-100	C3	61.3	33.1	5.6	1.79	3.4	14.2	26.0	17	8.0	.16	15	2.6	1.67
	100-200	C4	74.6	19.7	5.7	-	4.0	-	26.9	9	8.1	.29	21	3.5	1.47
1973	0- 1	A11	56.1	31.9	12.0	1.57	9.7	15.7	47.3	12	7.6	2.42	15	8.1	2.22
	1- 2	A12	64.6	24.4	11.0	1.57	4.9	15.7	36.7	13	7.8	.86	16	5.0	1.42
	2- 5	A13	58.8	28.2	13.0	1.57	5.0	15.7	34.8	13	8.1	.49	15	4.5	1.08
	5- 10	A14	62.7	26.4	10.9	-	6.0	-	34.1	14	8.2	.38	14	4.4	.81
	10- 50	C1	68.0	23.5	8.5	1.75	4.8	9.8	27.7	13	8.2	.50	22	4.6	1.13
	50- 80	C2	78.2	15.0	6.8	-	2.6	-	-	14	8.6	.09	6	3.0	-
	80-100	C3	33.1	49.5	17.4	-	7.6	-	41.5	18	8.1	.35	15	4.6	1.66
	100-200	C4	81.0	12.5	6.5	1.71	2.6	8.6	29.1	13	8.4	.09	10	2.7	1.31
1972	0- 1	A11	61.4	28.1	10.5	1.39	9.8	-	60.5	T	7.3	10.00	32	24.9	2.09
	1- 2	A12	79.1	11.1	9.8	1.39	3.7	-	33.9	3	7.8	1.72	22	7.0	.95
	2- 5	A13	80.8	13.1	6.1	1.39	3.8	-	31.5	3	8.9	1.07	16	6.1	1.01
	5- 10	A14	81.6	11.5	6.9	-	3.5	-	31.0	3	8.1	.54	10	5.1	.56
	10- 50	C1	75.5	16.8	7.7	-	3.5	-	-	11	8.4	.12	9	3.7	-
	50-100	C2	71.2	25.0	3.8	-	2.1	-	-	12	8.5	.05	8	2.3	-
	100-200	C3	-	-	-	-	2.0	-	28.8	12	8.3	.07	14	2.2	1.34
1970	0- 1	A11	78.4	15.6	6.0	1.38	10.3	-	58.7	6	7.3	2.24	13	6.7	3.34
	1- 2	A12	81.4	12.7	5.9	1.38	4.2	-	38.3	8	8.0	.83	10	4.4	1.50
	2- 5	A13	56.8	38.3	4.9	1.38	3.3	-	32.5	9	8.1	.80	15	4.2	1.26
	5- 10	C1	65.9	26.0	8.1	-	2.9	-	26.8	12	8.3	.30	13	3.1	.69
	10- 50	C2	60.4	30.3	9.3	1.70	3.5	9.6	-	15	8.3	.16	9	3.4	-
	50-100	C3	71.2	21.5	7.3	-	3.3	-	-	15	8.5	.11	6	2.7	-
	100-200	C4	66.2	27.3	6.5	1.67	3.6	10.5	29.9	16	8.4	.13	7	3.0	1.30

Table B-3. Characterization of minesoils at Colstrip and Savage, Montana, Beulah, North Dakota, and Glenrock and Hanna, Wyoming (from Dollhopf and others, 1977).

Location	Depth (cm)	Org. Matter (%)	pH (paste)	EC (mmhos/ cm)	Text.	H ₂ O Soluble			NO ₃ -N	NH ₄ -N	H ₂ O Sol. K (ppm)	NH ₄ OAc Extr. SO ₄	Bray PO ₄ -P (ppm)	DTPA Extr.							
						Ca	Mg	Na						Zn	Fe	Cu	Mn	Pb	Cd	Ni	B
COLSTRIP non-topsoil	0-30	<.15	8.6	.34	SL	29.8	3.6	.1	4.1	6.8	113	6.1	5.1	.28	7.8	.2	1.2	.8	.2	.4	.21
	30-90	<.15	8.5	.52	SL	25.5	3.2	.1	2.9	<1.0	113	>138	1.5	.58	11.2	.5	1.2	1.0	.2	.5	.01
	90-100	<.15	8.5	.46	SL	25.9	3.0	.1	10.0	<1.0	63	>138	1.5	.72	15.5	.6	2.0	1.0	.4	.6	.09
	150-275	<.15	8.5	.55	SL	10.0	1.6	.1	8.0	3.4	63	>138	2.5	.86	10.9	.4	1.8	1.0	.2	.4	.10
COLSTRIP topsoil	0-30	.63	8.8	.23	SL	21.1	2.2	.1	2.2	3.4	63	17.1	2.5	1.0	12.2	.2	3.6	1.0	.2	.6	.01
	30-90	.34	9.0	.27	SL	9.1	2.0	.1	1.6	10.1	63	1.4	1.1	1.4	15.5	.1	3.6	1.3	.2	.6	.02
	90-150	<.15	8.5	.42	SL	14.6	2.4	.1	8.6	10.1	88	61.1	2.0	1.2	20.6	1.1	3.6	1.3	.2	.4	.05
	150-275	.63	8.6	.54	SL	17.7	1.8	.1	8.6	10.1	63	5.5	4.0	0.4	11.9	.4	1.4	.7	.2	.4	.03
SAVAGE non-topsoil	0-30	.63	8.1	.76	SCL-	26.3	5.3	.1	2.9	-	63	13.8	14.5	.2	6.3	.8	1.4	.2	.1	.1	-
	30-90	2.26	7.5	2.55	SCL	29.8	6.9	.1	.3	-	63	>138	14.5	.1	14.4	.8	1.8	.2	.1	.1	-
	90-150	.92	7.7	1.68	SL+	28.5	5.4	.1	.4	-	63	>138	5.0	.1	10.0	.6	2.0	.2	.1	.3	-
	150-275	.63	7.5	1.75	SL-	25.9	4.8	.1	.4	-	63	>138	7.7	.0	7.8	.6	1.8	.5	.1	.1	-
SAVAGE topsoil	0-30	.15	8.3	.73	FSL	30.7	6.6	.1	2.85	3.4	113	1.38	21.0	.0	5.8	.8	1.4	.2	.1	.4	-
	30-90	1.20	7.9	.92	L-	29.8	5.9	.1	.15	5.1	113	>138	29.5	.1	7.5	.6	1.4	.2	.1	.1	-
	90-150	<.15	8.3	1.09	L+	29.8	6.2	.1	.15	1.7	83	>138	12.5	.1	5.8	.8	1.2	.8	.6	.4	-
	150-275	<.15	8.3	1.56	FSL	26.3	6.2	.1	.15	-	88	>138	17.5	.0	5.5	.6	1.0	.2	.1	.4	-
BEULAH non-topsoil	0-30	2.06	8.1	6.82	SiCL	21.9	10.0	7.3	7.95	3.4	213	-	7.7	4.2	102	6.6	1.8	1.9	.2	4.6	.56
	30-90	1.11	8.6	5.74	SiCL	21.9	8.7	8.9	8.55	5.0	213	>138	5.0	5.0	98	4.9	4.8	1.9	.2	3.9	.81
	90-150	.44	8.8	5.02	SiCL	21.9	8.7	12.4	7.95	35.3	275	>138	7.7	3.6	100	7.0	8.2	2.4	.2	3.9	.58
	150-275	.92	8.7	4.96	SiCL	21.9	7.6	9.3	8.55	13.4	238	>138	7.7	5.9	90	4.9	6.2	1.0	.2	3.4	.42
BEULAH topsoil	0-30	2.45	8.1	2.02	CL	21.9	8.0	.1	4.9	5.0	213	>138	14.5	.5	58	1.5	3.4	.8	.1	1.2	.40
	30-90	2.45	7.9	6.10	CL	21.0	10.6	4.2	18.0	6.7	213	>138	12.5	2.6	109	3.6	1.4	1.3	.1	2.6	.48
	90-150	2.93	7.7	7.57	CL	26.3	12.4	5.8	12.0	10.1	188	>138	7.7	4.4	152	4.1	1.4	1.1	.1	4.6	.53
	150-275	.44	8.4	5.38	CL	24.1	10.6	6.5	11.1	6.7	213	>138	5.0	4.8	78	4.6	2.8	1.9	.1	3.7	.38

Table B-3. (continued)

Location	Depth (cm)	Org. Matt. (%)	pH (paste)	EC (mmhos/ cm)	Text.	H ₂ O Soluble			NO ₃ -N	NH ₄ -N	H ₂ O Sol. K (ppm)	NH ₄ OAc Extr. SO ₄	Bray PO ₄ -P (ppm)	DTPA Extr.							
						Ca	Mg	Na						Zn	Fe	Cu	Mn	Pb	Cd	Ni	B
HANNA topsoiled	0-30	2.54	7.3	3.7	CL	30.7	6.4	.3	13.1	14.4	113	>138	7.0	2.2	19.2	1.9	7.0	2.2	.1	1.4	.66
	30-90	3.12	7.2	3.7	CL	30.7	6.9	.3	14.9	14.4	113	>138	4.0	2.2	20.6	2.3	8.0	4.0	<.1	.8	.52
	90-150	2.06	7.3	2.9	L	30.7	6.6	.1	11.3	16.2	113	>138	5.0	2.9	21.5	2.1	8.6	1.8	.1	.9	.58
	150-275	5.70	6.5	4.0	L	25.0	5.4	.1	9.7	37.8	113	>138	8.0	5.6	83.0	3.2	16.5	2.0	<.1	1.1	1.00
HANNA non-topsoil	0-30	2.45	7.8	3.1	SiL	31.5	6.6	.1	23.4	16.1	78	>138	6.5	2.3	14.4	1.4	5.4	1.2	<.1	.8	.38
	30-90	1.87	7.6	3.4	CL	34.6	7.1	.1	51.5	10.7	25	>138	3.0	1.5	11.2	1.0	5.2	.8	<.1	.6	.44
	90-150	2.16	7.6	3.3	CL	31.5	7.1	0	43.1	12.5	51	>138	8.0	2.2	14.4	1.3	6.2	1.0	<.1	.6	.40
	150-275	2.83	7.5	2.9	CL	28.9	5.9	0	30.1	12.5	113	>138	3.5	2.5	13.3	1.3	7.0	.8	<.1	.8	.32
GLENROCK non-topsoil	0-30	1.30	7.4	1.68	SL	13.9	3.8	.1	.1	3.6	51	>138	5.5	.8	11.5	.8	2.4	1.0	<.1	.5	.50
	30-90	.15	7.8	1.32	SL	13.9	3.8	.1	2.6	5.4	51	>138	4.0	.5	59.5	.5	8.0	.5	<.1	.3	.66
	90-150	.15	7.7	1.16	SCL	8.8	3.6	.1	2.6	5.4	78	>138	3.5	.5	17.2	.4	2.4	2.2	<.1	.6	.58
	150-275	.72	7.6	1.12	CL	12.1	4.6	.1	.3	14.4	113	>138	3.0	.8	8.4	.4	1.8	4.0	<.1	2.0	.50
GLENROCK topsoiled	0-30	.53	6.5	.38	SL	7.5	2.2	.1	2.1	1.8	51	44	5.5	.6	13.3	.5	3.2	.2	<.1	.5	.26
	30-90	.15	6.8	1.16	SL	10.0	3.6	.1	.3	5.4	113	>138	6.0	1.4	5.8	1.1	1.4	1.0	<.1	1.1	.44
	90-150	2.54	7.1	.24	C	20.6	5.9	.1	.1	10.8	168	>138	3.5	1.2	4.9	.9	1.8	4.4	.1	2.3	.34
	150-275	.15	7.8	.22	SL	7.9	2.7	.1	.3	0.	51	>138	2.5	1.4	13.5	1.9	1.2	0.1	<.1	.2	.38

Table B-4. Physical characterization of three minesoils and one natural soil (Yamac series) from the Peabody Big Sky Mine, Montana (from Arnold and Dollhopf, 1977).

Treatment	Depth (cm)	Bulk Dens. (g/cm ³)	Part. Dens.	Modulus of Rupture (bars)	Sand	Silt (%)	Clay	Clay Mineral Abundance			
								Smectite	Illite	Kaolinite	Chlorite
topsoil/non-veg	0-15	1.56	2.42	1.36	62	22	16	low	mod.	mod.	low
topsoil/reveg	0-15	1.58	2.39	.73	67	19	14	0	mod.	mod.	low
nontopsoil/reveg	0-15	1.54	2.47	2.17	25	54	21	0	mod.	mod.	low
native range	0-15	1.48	2.38	.66	52	34	14	0	high	mod.	low

Table B-5. Chemical and physical characteristics of three minesoils and one natural soil (Yamac series) from the Peabody Big Sky Mine, Montana (from Arnold and Dollhopf, 1977).

	DEPTH (cm)	Bulk ^{1/}	Hydr.	NO ₃ N	NH ₄ -N	Bray	NH ₄ OAc				H ₂ O Soluble			SAR	EC (mmhos/cm)	pH
		Dens.	Cond.			PO ₄ -D	Ca	Mg	K	Na	Ca	Mg	Na			
		(g/cm ³)	(cm/day)			(ppm)	meq/100g				ppm					
topsoil/non-veg	0-120	1.78	1.74													
	0-480	1.81	1.52	2.53	1.7	1.98	30.3	6.8	.16	.27	26.5	22.1	2.4	.5	5.5	7.5
topsoil/reveg	0-120	1.64	2.10													
	0-540	1.70	1.31	3.94	4.1	2.20	40.8	6.7	.28	.70	27.7	25.8	5.0	1.0	4.6	6.8
nontopsoil/reveg	0-120	1.71	1.44													
	0-600	1.75	1.30	7.20	1.5	1.10	41.2	6.6	.22	.55	25.1	14.4	6.0	1.2	4.2	7.2
native range	0-120	1.46	4.87													
	0-600	1.83	4.87	1.60	3.7	2.50	37.4	6.1	.32	.34	11.7	12.9	2.7	.8	3.1	8.2

^{1/} oven-dry core

Table B-6. Properties of surface mine spoils at several Northern Great Plains mine sites (from Power and others, 1978).

Location	pH	CaCO ₃ Equivalent (%)	Clay (%)	Concentration in the Saturation Extract					
				EC $\frac{\text{mmhos}}{\text{cm}}$	Ca	Mg	Na	SO ₄	SAR
					meq/l				
Beulah, N. Dak.	8.4	12	37	3	1	1	34	30	41
Center, N. Dak.	7.6	10	26	4	14	29	7	48	2
Stanton, N. Dak.	8.3	12	52	2	1	1	20	16	19
Zap, N. Dak.	8.8	10	54	2	1	1	19	7	48
Colstrip, Mont.	7.2	--	--	3	15	19	3	--	1
Sheridan, Wyo.	6.1	--	--	7	29	28	45	--	8
Gillette, Wyo.	7.4	--	--	8	25	73	31	--	5

Table B-7. Electrical conductivity and SAR measured at the Decker Mine, Montana (From Wendt and others, 1977).

Reclaimed Area	Date Sampled	N	Depth (cm)	EC mmhos/cm	SAR
A	4/77	14	0-46	4.32	13.6
C	4/77	16	0-46	2.70	6.9
D	4/77	10	0-46	2.72	7.3
A	7/77	5	0-30	3.20	22.6
A	7/77	5	30-60	3.18	23.6
A	7/77	5	60-90	3.46	23.2
A	7/77	5	90-120	3.32	24.2
E	7/77	12	0-30	2.73	27.1
E	7/77	12	30-60	2.78	27.1
E	7/77	9	60-90	2.88	27.4
E	7/77	6	90-120	2.50	31.0

Table B-8. Chemical characteristics of mine spoils at the Amax-Belle Ayr mine. Each number is the mean of five samples (from Yamamoto, 1975).

Depth (cm)	EC		H ₂ O Sol. Na (ppm)	SAR	OC (%)	CEC Bray		NH ₄ OA _c			DTPA			HCl	Sand	Silt (%)	Clay	H ₂ O Content		
	pH	(mmhos/ cm)				(meq/ P 100g)	(ppm)	K	Ca	Mg	Mn	Cu	Fe	Zn				OD	1/3 Bar	15 Bar
0- 15	7.6	4.2	10.4	2.6	1.0	8.2	4.1	.32	20.4	13.1	1.25	.92	1.12	3.1	--	--	--	--	--	--
15- 45	7.5	3.9	12.8	2.0	1.2	7.5	4.9	.28	16.8	11.9	1.64	1.09	1.20	4.0	--	--	--	--	--	--
45- 75	7.5	4.2	11.5	1.5	1.1	8.7	6.5	.28	25.4	17.5	.57	.55	.73	4.3	--	--	--	--	--	--
0-135	--	--	--	--	--	--	--	--	--	--	--	--	--	--	65.3	10.2	24.4	41.8	23.2	11.0

Table B-9. Clay mineralogy analyses for the Colstrip, Savage and Beulah Mine areas. Samples were collected during the summer of 1975 from the surface 15 cm of each treatment watershed (from Dollhopf and others, 1977).

Watershed Treatment	Type and Predominance* of Clay Mineral					
	Smectite	Illite	Kaolinite	Quartz	Chlorite	Vermiculite
<u>Colstrip</u>						
nontopsoil-gouged	low-mod	low-mod	mod	0	low	trace
topsoil-gouged	low	mod	mod	0	low	0
nontopsoil-chiseled	mod	low	low-mod	trace	tr-low	low
topsoil-chiseled	0	mod	mod	0		0
topsoil-dozer basin	low	mod	mod	0	low	0
<u>Savage</u>						
nontopsoil-gouged	mod	mod	low	0	low	trace
topsoil-gouged	mod-high	low-mod	low	trace	low	0
nontopsoil-chiseled	mod	mod	low	0	low	0
topsoil-chiseled	mod-high	low-mod	low	trace	low	0
topsoil-dozer basin	mod-high	low-mod	low	trace	low	0
<u>Beulah</u>						
nontopsoil-gouged	high	low	tr-low	0	low	0
topsoil-gouged	mod-high	mod	low	0	low	0
nontopsoil-chiseled	high	low	trace	tr-low	low	0
topsoil-chiseled	mod-high	low	tr-low	0	low	0
topsoil-dozer basin	high	low	tr-low	0	low	0

*very high = 75-100%

high = 50- 75%

moderate = 25- 50%

low = 5- 25%

trace = less than 5%

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