DEVELOPMENT OF A PRE-MINING GEOLOGICAL FRAMEWORK FOR LANDSCAPE DESIGN RECLAMATION IN NORTH DAKOTA

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INTRODUCTION

Two principal environmental concerns associated with the large-scale mining of lignite in western North Dakota are the preservation of agricultural productivity and the maintainence of high-quality groundwater supplies.

The first of these concerns, the return to agricultural productivity, is widely felt and has been recognized by Governor Link as the most important factor in determing the type and rate of lignite development in North Dakota. The stated reclamation goal for the state is a return to a level of productivity no less than 100% of the level prior to mining.

Just as is the case throughout the areas farther to the west and south, there is concern in North Dakota that precious water supplies not be damaged by coal development. In many areas, lignite beds may serve as important aquifers or play important roles in groundwater recharge. There is concern that the amount of water available may be adversely affected as a result of coal development. In other areas there is concern that the total dissolved solids of surface water and groundwater may be increased by leaching from spoil materials or waste-disposal facilities.

Working through the Mined Land Planning Group, a group of university, state, and federal scientists appointed by Governor Link, the North Dakota Geological Survey (NDGS) and North Dakota Agricultural Experiment Station have begun research to develop the methodology needed to achieve these reclamation goals. These studies, which have been funded by the Old West Regional Commission, have had the support and active cooperation of a number of mining companies and potential coal developers, especially the North American Coal Corp. and the Natural Gas Pipeline Company of America.

Three subprojects of the overall study are being conducted by the Agricultural Experiment Station. These studies are related to revegetation, root-zone hydrology, and the chemical and physical characterization of overburden materials. The fourth subproject is being conducted by the North Dakota Geological Survey. This study is directed at developing techniques to determine the detailed stratigraphy of overburden and utilizing of the data in planning reclamation procedures. The NDGS study is also designed to examine techniques for monitoring groundwater conditions for regulatory purposes.

One principal that emerged very early in these studies is

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that each mining area must be treated individually. Legislation and regulation can define a set of general guidelines within which each site can be evaluated, but because of the variability between areas in geology, climate, soils and hydrology it is not possible to write specific regulations for reclamation throughout the state.

CONCEPTUAL FRAMEWORK FOR RECLAMATION

We will first explore the ideas that underlie the approach and philosphy of NDGS reclamation research. This is an idealized, theoretical analysis of the direction that our thoughts trend.

Soil Repair

Initial work on reclamation of strip-mine spoils was based on a philosphy of "soil repair" or "salvage reclamation." That is to say, mining was begun, carried out, and completed without regard to any further use of the area. Reclamation was not begun until mining was completed. The reclamation officer attempted to salvage what he could on the spoil banks. Plants that could be grown on steep slopes in poor material were planted. The next step in developing the modern concept of reclamation was to partially level the steep slopes, but still reclamation was a salvage operation that was begun after the mining was finished.

Soil Design

Modern reclamation in North Dakota is a far more sophisticated procedure that begins far earlier in the mining process. By law, the operator must determine the suitability of soil and other overburden material for supporting vegetation and take steps to segregate and save as much as 5 feet of this material before mining. It has been stated that "reclamation begins with the placement of the first bucketful of overburden removed from above a vein of coal on the area from which the coal has been removed" (8). We would carry it even farther back: reclamation begins as the mine is being planned. The reclamation plan is synonomous with the mining plan.

Landscape Design

In order to reclaim a mined area, not only the soil but the entire landscape must be redesigned. The makeup of a landscape, in the sense we are using it, and the processes acting on and in it must be explored to understand the reason for this.

Landscape, as we are using it, includes the substance, as well as the form of the earth's surface. It includes the morphology of the surface, the soils on that surface, the structure of the rock and sediment beneath the surface, and the water that moves over and beneath the surface. The form of the surface, the soils on the surface, and the hydrologic regime beneath and upon the surface represent a more or less delicately balanced equilibrium with the forces acting on and beneath that surface. When there is a big enough change in the forces acting on a landscape, (for example during a climatic change) the landscape adjusts itself to a new equilibrium that is stable under these new conditions (2). During the Dirty Thirties, when the climate was warmer and drier than it is today, vegetation cover was decreased on hillslopes throughout the semiarid Great Plains. Although rainfall was less, runoff from the partially denuded hillslopes was greater, resulting in increased erosion on the slopes. The valley bottoms were clogged with sediment and gully cutting ceased as the floors of the arroyos were aggraded. Dust was blown from these valley floors and deposited on the flat upland surfaces. Through these changes in the rates and the processes of erosion and deposition, the form of the landscape was altered to one better adjusted to the new climatic conditions.

In the same way that a change in the forces acting on the landscape results in the establishment of a new equilibrium landscape, a change in the material making up the landscape will require an adjustment of the landscape. In areas of potential strip mining, the landscape consists of a surfce that is the quasi-stable resultant of the interaction between the climate and the underlying structure, which consists of a series of alternating, relatively thin beds of sediment that differ from each other in physical, chemical, and hydrological properties. Where this landscape is disturbed by surface mining, the horizontal layering is destroyed, and a new, generally more homogeneous, structure results. In some cases, the characteristics of this new landscape may be sufficiently similar to the original landscape that the equilibrium surface form will not be markedly different. However, in most cases, it seems probable that a different morpholohy will be required for stability.

The adjustments within the new landscape can take many forms. Slopes that are too steep will be flattened by erosion high on the slopes, and by deposition on the lower slopes, or by mass movement. Soils that contain organic matter in excess of the amount that can be maintained under the conditions will lose organic matter by oxidization or erosion.

Many of these changes in the landscape are complexly interlinked so that a seemingly minor alteration in one characteristic of the landscape may manifest itself in completely unexpected ways elsewhere in the landscape. For example, a change in the form or permeability of the surface will generally produce a change in groundwater levels and flow patterns. This in turn, can result in changes in slope stability or in water chemistry. These changes can then result in modifications in the landscape that will either amplify or nulify the original change in morphology. Changes in water chemistry and groundwater-flow patterns can result in marked changes in the characteristics of soils.

The goal of landscape-design reclamation is to design and construct a post-mining landscape that approximates, as closely as possible, the equilibrium landscape for the material as it is emplaced following mining. In this way, the natural adjustments that will be made to achieve equilibrium will be minimized. Smaller natural adjustment produces less gullying, surface subsidence, and landsliding, less soil erosion and destruction, less degradation of quality of groundwater and surface water. All of which results in better and cheaper reclamation.

RECLAMATION DESIGN

The first step in reclamation design is to make an inventory of the materials present. It is not possible to evaluate alternative designsof soil or landscape until the designer is aware of what materials he has at hand. The inventory includes a knowledge of the soils, of the geology, and of the hydrology of the area to be mined. In addition, it should include a thorough understanding of the existing state of equilibrium.

The inventory of soils in the proposed mining area involves detailed soil mapping. In addition, analytical data on the chemical characteristics of the soils should be obtained.

The geologic inventory involves mapping in detail the three-dimensional distribution of materials in the overburden. The first step of this mapping is lithologic mapping. These data are then supplemented with other physical and chemical data that are of particular importance for reclamation. The basic unit by which these data are summarized is the "reclamation unit," which consists of a volume of sediment or rock, which possesses a unity of lithologic, physical, and chemical characteristics such that the material in it will respond in the same way when subjected to the same stress induced by a change in its physical or chemical environment. The work being conducted by the North Dakota Geological Survey is directed toward the identification and characterization of the "reclamation units" present in areas of proposed lignite mining in the state. The characteristics of a given "reclamation unit" are probably most strongly determined by the lithology (the type of material present). Where the material is near the surface, these inherent characteristics are modified by weathering and the transportation of weathering products either away from or into the material by groundwater.

The third concern in developing an inventory of the proposed mining area is the groundwater. Groundwater is of concern because of its importance as a supply of water in many areas and because it is complexly involved in the nature and quality of soils, the chemical characteristics of geologic materials, and in the stability of the surface form of the landscape. For these reasons, it is important to know the areas of groundwater recharge and discharge and the paths and rates of flow between them.

The fourth item in the premining inventory is, at the same time, the most important and the most difficult to obtain of all. It can probably never be attained completely. This is an understanding of the nature of the existing equilibrium in the landscape. Initially, this has the appearance of an academic concern, but deeper examination shows that it is far more than that. If, as we indicate above, the goals of reclamation can be met best by the construction of a landscape in equilibrium with its environment, then it is necessary to understand the relations which generate such an equilibrium in order to design a landscape which is stable. Since understanding is possible only through knowledge, and since there is no equilibrium landscape on earth about which more can be known than one that is about to be disrupted by strip mining, the best possible way to design an equilibrium landscape following mining is to thoroughly understand the existing landscape before it is disrupted. Only in this way, can we develop the causal generalizations that relate the complex interactions of internal structure, permeability, and strength, surface form, climate, and hydrology.

Landscape Modeling

Once we have a complete inventory of existing conditions in an area of proposed mining, we can procede to the next step of landscape design, the construction of models of potential post-mining landscapes. In this phase of reclamation planning, the various materials available are examined to determine how they will respond to the different physical and chemical environments that will result from each of the landscapes being considered. The types of models that are used in this phase of planning range from simple, nearly intuitive, qualitative or semi-quantitative mental models to highly sophisticated digital computor models capable of handling large multicomponent arrays of interacting variables.

By analyzing the various components of alternative proposed landscapes, the morphology and stratigraphy that is most stable and best meets the requirements of alternative possible land uses will be determined. For example, if a certain surface morphology is constructed with a particular permeability distribution within the material, then the hydrological regime of the landscape is set. This hydrological regime will govern the amount of runoff and infiltration, the nature of stable soils, the mobilization and migration of soluable ions, along with a multitude of other factors. By changing either the morphology or the premeability distributions, the hydrological regime can be modified to a new equilibrium. The resultant equilibrium surfaces for a series of alternative designs can be evaluated, in this way, using the modeling approach to select the landscape that maximizes the three constraints of serving the intended use, being in stable equilibrium with the climate, and being economically feasible.

Through this procedure of landscape-design reclamation, the dual goals of reclamation, the return to agricultural productivity and the protection of water supply, can be best met. The first step in developing the capability to implement such an approach to reclamation is to develop an information base on existing conditions and the inter-action between them in landscapes that are about to be mined. The reclamation research project of the North Dakota Geological Survey is directed at developing a portion of this information base, and is the subject of the remainder of this paper.

GEOLOGY AND RECLAMATION

Geology of Lignite Occurrence

Potentially minable lignite occurs, in North Dakota, in the Sentinel Butte, Tongue River and Ludlow Formations of the Ft. Union Group. The lignite, which occurs in beds that range in thickness from a few millimetres to nearly 10 metres in places, is a minor constituent of these units, comprising less than 5% of the total thickness. About 60% to 80% of these formations consist of interbedded silt and clay that occurs in beds ranging from millimetres to ten's of metres in thickness. From 15% to

35% of these formations consists of silty, fine-grained to medium-grained sand in beds that range from 1 m to 30 m in thickness.

The glacial sediment that overlies the northeastern third of the region consists of pebble-loam (commonly called till), laminated silt and clay, and sand and gravel. The total thickness of these unconsolidated materials ranges from less than a metre to more than 100 metres in many places. The presence and thickness of glacial pebble-loam in the overburden of a proposed mining area is a very important factor influencing the physical and chemical characteristics of the overburden.

Figure 1 is a cross-section of part of the Tongue River Formation exposed in a cliff near Medora, North Dakota (3, 5). This section was completely exposed so the stratigraphic relations shown were actually observed, not inferred. Two very important observations can be made from this cross section. The first is that these rocks are complex. Different materials grade laterally into one another within fairly short distances. The same unit changes elevation markedly within short distances. The second, very important, observation that can be made from Figure 1, is that these rocks are simple. Although there is considerable change in lithology laterally, there is a rather simple repetitive sequence to the section. Lignite beds are generally continuous, and separate sequences of gray silt and clay, brown silt and clay, and sand. In short, the apparent complexity consists of the repetition of simple, coal-bounded cyclic-sequences.

A productive way to study these coal-bounded units is to determine the sedimentary environment in which they were formed, using the gross distribution of the various types of material and the small-scale sedimentary structures contained in the material. By relating the characteristics of these sediments to similar sediments that are being currently deposited, it is possible to develop a conceptual, depositional model that relates the various types of material to one another. Thus, the geometry of each body of sediment can be visualized and related to the other bodies of sediment found in the same environment. In approaching an unknown sequence of rock, the observed characteristics of the new rocks are compared with those of the various possible models. The model which seems best to fit the characteristics of the unknown rocks is then selected and used as a guide to interpret the three-dimensional relationships among the bodies of sediment within the area of interest.

This type of approach has been used successfully in North Dakota by Jacob and his associates (1, 3, 4, 5, 6, 7). They have studied both the Tongue River and Sentinel Butte Formations in considerable detail in several different small areas. Their findings are that the model that seems to fit these rocks in the areas studied is that of an alluvial flood plain. The sand beds and lenses represent channel fills or accretionary deposits formed by channel migration. The sandy silt to clayey silt beds that tend to weather to yellowish colors were deposited as natural levees along the channels. The gray clayey, silt, silty clay, and clay beds were deposited in the back-basin areas of the flood plain (3, 5).

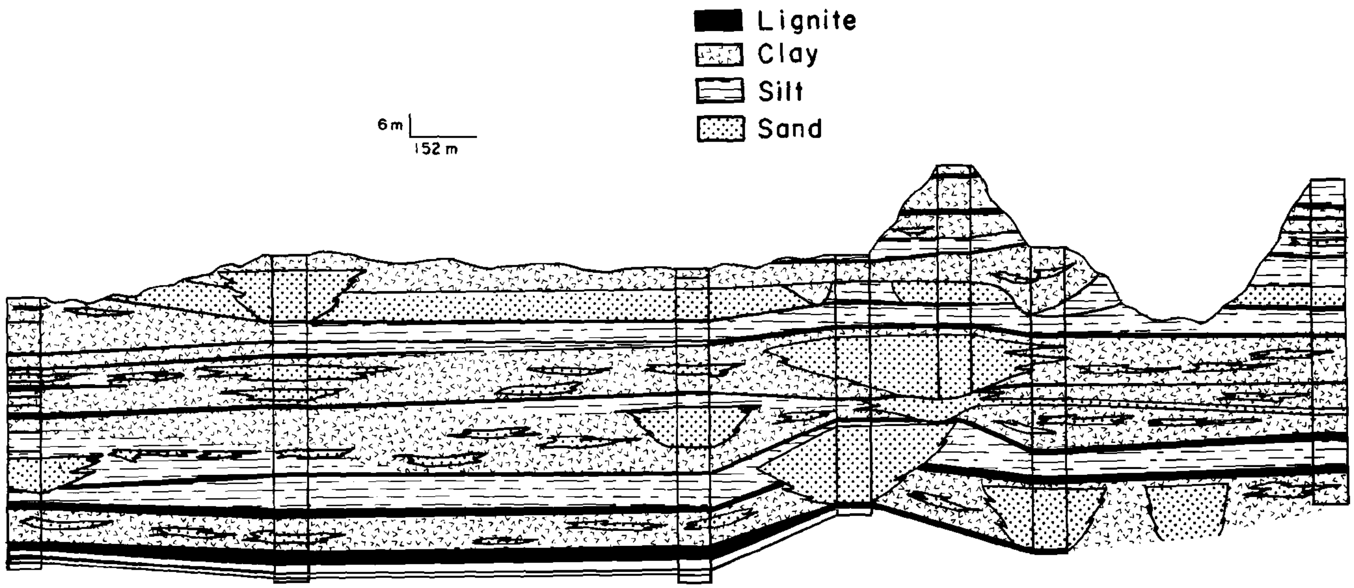

Fig 1: Cross section of Tongue River Formation at Medora, North Dakota (from Jacob, 1972)

This model has been successfully applied by NDGS personnel to study the overburden in areas of porposed mining.

The first step in the NDGS study was to collect stratigraphic data from three proposed mining areas. Samples were collected at intervals of five feet or less during the drilling testholes and core holes that were drilled by the operator to obtain data on the coal. Descriptive logs of these samples were combined with geophysical logs that included resistivity, spontaneous potential, natural gamma-ray, and gamma-gamma density to construct a final interpretive log of each site. These intrepretive logs were then combined into cross sections to depict the relations of the bodies of sediment in three dimensions. At this stage, the correlations were constantly being checked against the depositional models and modified to fit the most appropriate one. Using the cross-sections as a guide, contour maps of various important surfaces in the overburden have been constructed.

Samples collected from some of the testholes have been analyzed for a large suite of soluable ions as part of the Agricultural Experiment Station subproject. The data obtained include pH, electrical conductivity, Na^+, Ca^{++}, Mg^{++}, K^+, Cl^-, SO_4^{--}, HCO_3^-, CO_3^{--}, $CaCO_3$ equivalent, and SAR. The chemical composition of material is the result of a number of complex interactions. It is largely a function of the type of material. In general, glacial pebble-loam contains much less sodium, has a lower SAR and electrical conductivity, but generally has a higher lime carbonate content than do any of the bedrock materials. In general, the soluable-ion content of clayey sediment in the bedrock is greater than that of sandy material. This pattern is then modified by the various geochemical processes at and near the earth's surface. Ionic constituents are freed by weathering and transported by groundwater to produce geochemical patterns that reflect depth below surface and position in the groundwater-flow system.

SUMMARY

The focus of reclamation studies in North Dakota is on the development of a premining geochemical framework, which consists of physically and chemically defined "reclamation units," to serve as the basis for mine-plan design. The "reclamation units" are used to identify materials as deleterious or favorable for soil development and for the establishment of vegetation; they can then be placed at the surface of the reclaimed spoil or buried far from the surface depending on their characteristics.

The first step in development of "reclamation units" for a proposed mine area is the collection of geologic data on the overburden. Detailed descriptions of samples collected at 5-foot intervals from coal-exploration testholes are combined with geophysical logs to develop an interpretation of the geology at each hole. The materials are then correlated between testholes on the basis of established models of the environment of sedimentation of coal-bearing rocks. The resulting three-dimensional picture of the geology of the overburden forms the physical framework of the "reclamation units."

Samples collected from a portion of the testholes are

analyzed to determine the abundance and type of readily soluble ions. By and large, the chemical composition is directly related to the type of material. This pattern is modified to a greater or lesser degree by weathering, the position of material in the modern groundwater-flow system, or the position of material in a flow system that resulted from climatic or topographic conditions no longer in existence. The chemical data are integrated with the physical framework to develop the final "reclamation units."

Studies are also underway to develop the information base necessary to design the optimum landscape in reclaimed areas. The resulting landscape must assure a minimum of surface subsidence, slope instability, erosion by gullying, and contamination of groundwater and surface water with ions leached from the spoil material. The interactions of all the physical, chemical, and biological systems operating in a landscape make landscape design considerably more complex than it has been considered by many.

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