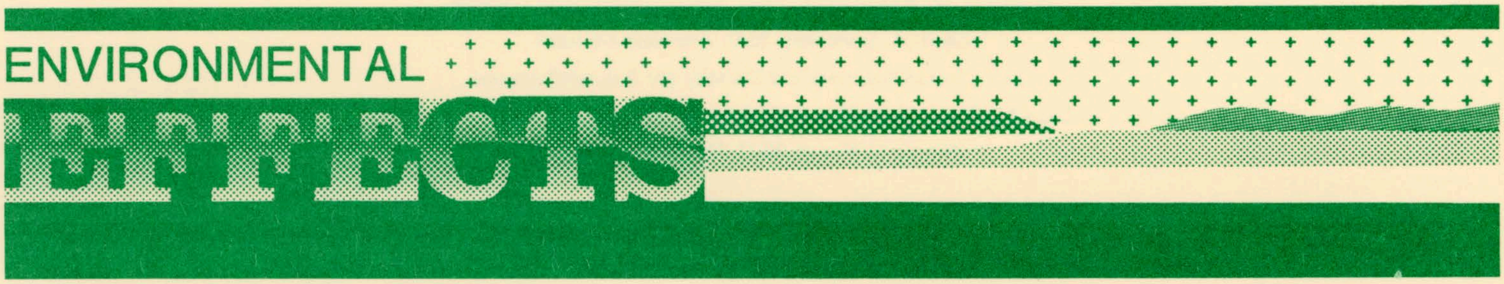
Kansas Geological Survey Mineral Resources Series 7



ENVIRONMENTAL EFFECTS of COAL SURFACE MINING and RECLAMATION on LAND and WATER in SOUTHEASTERN KANSAS

Jerome E. Welch and William W. Hambleton

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KANSAS GEOLOGICAL SURVEY, THE UNIVERSITY OF KANSAS

1930 Avenue A, Campus West, Lawrence, Kansas 66044
Telephone: 913-864-3965

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by

Jerome E. Welch
and
William W. Hambleton

with contributions
to sections by

Harold P. Dickey
David A. Grisafe
Lawrence L. Brady
Donald O. Whittemore

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AUTHORS

The authors are all affiliated with the Kansas Geological Survey at The University of Kansas, Lawrence, Kansas. Jerome E. Welch is a soil geochemist in the Geochemistry Section. William W. Hambleton is a geophysicist and Director of the Survey. Harold P. Dickey is a soil scientist with the Soil Conservation Service, assigned to the Environmental Geology and Geophysics Section of the Survey under a cooperative agreement. David A. Grisafe is a ceramic and material scientist in the Mineral Resources Section. Lawrence L. Brady is a coal geologist and Chief of the Mineral Resources Section. Donald O. Whittemore is a water geochemist in the Geochemistry Section.

EXECUTIVE SUMMARY

Introduction

The Kansas Geological Survey undertook a study of the soil and water environments of a surface coal mine site in southeastern Kansas for the purpose of comparing data from unmined land to those of reclaimed and unreclaimed mined land.

Bore-hole records of the Kansas Geological Survey, numerous records of coal-company drillings, and high wall channel sites were used to characterize the overburden of the unmined land. Rock-core samples were analyzed by x-ray diffraction and fluorescence. Soil samples were taken at depth to determine the morphological, physical, and chemical properties of the predominant natural soil and minesoil in the area. Surface samples of these soils were also taken for fertility analysis. Soil samples were analyzed by x-ray diffraction for their mineral composition. Surface waters were sampled in unmined land and in reclaimed and unreclaimed mined land at the mine site. Concentrations of major and minor constituents and trace elements were determined in these samples. Two observation wells were drilled to investigate recharge to the shallow aquifers in unmined land and reclaimed mined land.

Geology

The rocks at the mine site consist of shale, siltstone, sandstone, coal, underclay, and several thin beds of clay-ironstone nodules of the Krebs Formation, Cherokee Group, Desmoinesian Stage, Middle Pennsylvanian Series. The lowermost unit of the measured section is the Rowe coal, which ranges in thickness from 14 to 18 inches. Strata between the Rowe coal and the overlying Dry Wood coal consist mostly of shale and underclay beds, ranging from 6 to 9 feet in thickness. The Dry Wood coal ranges in thickness from 0.25 to 1.25 feet. Above the Dry Wood coal is a dark-gray shale several feet thick, and a thin coal bed locally known as the "Pilot coal." Above this coal is a dark-gray silty shale with interbedded light-gray shale and very finely laminated siltstone. The upper part of the shale interval also contains interbedded sandstone considered to be equivalent to the Bluejacket sandstone.

The interval between the coals thickens appreciably to the east.

The coals are absent in places. Circular depressions and ridges, which are typical of the area, occur in the coals, possibly reflecting an older karst surface. The most prominent structural feature is a southwest- to northeast-trending trough or syncline that plunges to the northeast. The deeper parts of the syncline are not mined because of the increased overburden thickness.

X-ray diffraction analysis showed that clays, quartz, and feldspars are the predominant minerals. Kaolinite and illite are the predominant clay minerals, with appreciable amounts of montmorillonite found in places. Calcite, iron oxides, pyrite, and siderite are also present. X-ray fluorescence analysis indicated the absence of any elements of economic importance in the rocks.

Coal

The Rowe and Dry Wood coals from the mine site were ranked as high-volatile A, bituminous coals. Both these coals average a higher ash content and lower heat of combustion and contain more total sulfur than the average southeastern Kansas coal. Most of the sulfur in the Rowe and Dry Wood coals is present as pyritic sulfur. Compared to the Rowe coal, the Dry Wood coal contained higher amounts of 31 of the 43 elements analyzed. The Rowe and Dry Wood coals are both markedly enriched on an average basis in arsenic, lead, and selenium. The Dry Wood coal is additionally markedly enriched in cadmium and zinc. The extremely high amounts of cadmium and zinc in the Dry Wood coal seem to be related to sphalerite mineralization in the Tri-State Mining District.

The average ash content of the Kansas Dry Wood coal is 12.9 percent higher than the average ash content of Interior Province coals, and the average carbon content of the Kansas Dry Wood is 10.9 percent less than the Province average. As a result, of the above, the average heat of combustion of the Kansas Dry Wood is less than that of the Province average. The Rowe and Dry Wood coals both average more total sulfur than Interior Province coal, and their average pyritic sulfur contents are 3 times those of Interior Province coal. Both the Rowe and Dry Wood coals average more iron, copper, mercury, nickel, and lead than Interior Province coal. Additionally, the Dry Wood also contains more silicon, aluminum, potassium, titanium, cadmium, cobalt, gallium, strontium, vanadium, yttrium, ytterbium, and zinc. Comparisons of reported average enrichment values of elements in Interior Province coal based on crustal abundance and those calculated for the Rowe and Dry Wood coals at the mine site show both the Rowe and Dry Wood coals are more enriched in arsenic, mercury, and lead. Additionally, the Dry Wood coal is more enriched in antimony.

Compared to the Rowe coal from Missouri, the Kansas Rowe contains an average of 4.0 percent more sulfur, of which 3.6 percent is pyritic sulfur, and more iron, manganese, arsenic, lead, strontium, and zinc. The Missouri Rowe contains more cobalt, lithium, molybdenum, selenium, uranium, vanadium, and zircon. The Kansas Dry Wood coal contains an average of 10 percent more ash, 13 percent less carbon, 5 percent more sulfur, and more calcium, iron, manganese, arsenic, cadmium, cobalt, copper, gallium, mercury, lanthanum, neodymium, nickel, lead, strontium, yttrium, and zinc than the Missouri Dry Wood. However, the Missouri Dry Wood coal contains more boron and selenium.

Soil

The principal soil of the unmined area is the Parsons silt loam, a deep, somewhat poorly drained, moderately acidic, upland soil, with well-developed and contrasting horizons. Weathering of the soil was found to extend to a depth of 8 to 12 feet. Extensive leaching has resulted in the accumulation of calcium, magnesium, sodium, and potassium with depth. Less-soluble elements such as zinc, iron, copper, and manganese were concentrated in the surface. Fertility analysis of the surface showed the Parsons soil to be low in calcium, nitrogen, phosphorus, potassium, and boron, and high in zinc, iron, copper, and manganese.

The most prominent characteristics of the minesoil were the absence of well-developed horizons and the presence of large amounts of rock fragments. Minesoil samples showed variation within and among sites, reflecting the mixing of soil and overburden that occurred during mining and releveling. The only pedogenic development observed in the minesoil was the physical weathering of surface shale fragments.

The particle-size distribution of the minesoil varied within and among sites, again reflecting the mixing of soil and overburden that occurred as a result of the mining and releveling operations. The minesoil has greater amounts of material in all particle-size ranges except the <0.074 mm fraction. The size range with the greatest amount was 2-0.074 mm. The minesoil contained 85 percent (by weight) material <2 mm, whereas in the Parsons soil nearly all the material (98-99 percent) was <2 mm. Silt and clay were more uniformly distributed with depth in the minesoil. However, when averaged over depth, the amounts of clay in the minesoil and Parsons soil were essentially identical, whereas the amount of silt in the minesoil was less than that of the Parsons soil.

The bulk density of the minesoil decreased with depth, whereas that of the Parsons soil increased with depth. The bulk density of the 0-12 inch depth of the minesoil was higher than that of the 12-40 inch depth, due to filling of void spaces by fine materials during smoothing of the minesoil and tilling of the minesoil for planting.

The surface 12 inches of the minesoil contained 35 percent (by weight) less plant-available water than the Parsons soil. However, the water data and the high wheat yields indicate that the minesoil supplied sufficient water to the wheat.

In terms of the usual measures of fertility the minesoil differed markedly from the Parsons soil. The pH of the minesoil was more acid than the Parsons soil. Consequently, the liming requirement of the minesoil was also greater. The cation exchange capacity of the minesoil was less than for the Parsons soil, but exchangeable magnesium was 5 times greater in the minesoil. Boron was slightly more abundant in the minesoil and extractable iron and manganese were 1.5 and 10 times greater respectively. The lower pH and the greater amounts of the above elements in the minesoil were attributed to the weathering of pyrite-containing shale particles in the surface of the minesoil.

Water

Comparisons of the quality of surface waters draining from unmined land and from the reclaimed and unreclaimed mined land showed major differences. Water in the tributary draining the unreclaimed mined land was severely affected by strip pit drainages (overflow and seepage). The water was highly acidic, extremely hard, and had very high concentrations of most of the major and minor dissolved constituents and trace elements. The high acidity makes this water unsuitable for most uses. As a result of the low pH, many minor and trace-element concentrations exceeded recommended permissible levels for various uses. Recommended concentrations in irrigation water were exceeded for iron, manganese, nickel, zinc, and fluoride. National Drinking Water Contaminant Levels were exceeded for iron, manganese, sulfate, zinc, and fluoride. Effluent Limitations for Coal Mining Point Sources were not met or were exceeded for pH, manganese, and iron.

Water draining from the reclaimed mined land was appreciably better in quality than that from the unreclaimed mined land, but not as good as water draining from the unmined land. The concentrations of iron, manganese, and sulfate were still too high for most uses.

Dilution and partial neutralization of waters draining from both the reclaimed and unreclaimed mined land occurred with mixing of the water in the larger creeks that drain the area. However, even after dilution, the concentrations of iron, manganese, and sulfate were too high for most uses.

Water-level measurements of observation wells in the unmined land and in the reclaimed mined land showed a relatively rapid recharge from rainfall of the shallow aquifer in the reclaimed mined land. Recharge of the shallow aquifer in the unmined land was slight. Thus, the quantity of water available from reclaimed mined land should be much greater than that from unmined land in the area.

Land Reclamation

Wheat yields from the 5 fields showed that wheat was well suited to the minesoil and produced relatively high yields where good management practices were employed. Among these practices were the burial of dark-colored acid-producing shale fragments, good seedbed preparation, the use of quality seed, and the proper application of sufficient amounts of lime and fertilizer, as indicated by soil-fertility tests.

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LIST OF CHEMICAL ABBREVIATIONS

Ag	Silver
Al	Aluminum
Al_2O_3	Aluminum oxide
As	Arsenic
B	Boron
Ba	Barium
Be	Beryllium
Ca	Calcium
CaO	Calcium oxide
Cd	Cadmium
Ce	Cerium
Cl	Chloride
Co	Cobalt
Cr	Chromium
Cu	Copper
DTPA	Diethylenetriaminepentaacetic acid
EDTA	Ethylenediaminetetraacetic acid
F	Fluoride
Fe	Iron
Fe_2O_3	Iron oxide
Ga	Gallium
Ge	Germanium
H_3BO_3	Boric acid
HCl	Hydrochloric acid
Hg	Mercury
H_2SO_4	Sulfuric acid
K	Potassium
KCl	Potassium chloride
$K_2Cr_2O_7$	Potassium dichromate
K_2O	Potassium oxide
La	Lanthanum
Li	Lithium
Mg	Magnesium
MgO	Magnesium oxide
Mn	Manganese
MnO	Manganese oxide
Mo	Molybdenum
Na	Sodium
Na_2O	Sodium oxide
NH_4	Ammonium
$NH_4C_2H_3O_2$	Ammonium acetate
NH_4F	Ammonium fluoride
NO_3	Nitrate
Nb	Niobium
Nd	Neodymium
Ni	Nickel
P	Phosphorus
P_2O_5	Phosphorus pentoxide
Pb	Lead
Rb	Rubidium
Sb	Antimony
Sc	Scandium
Se	Selenium
Si	Silicon
SiO_2	Silicon dioxide
SO_3	Sulfite
SO_4	Sulfate
Sr	Strontium
Th	Thorium
Ti	Titanium
TiO_2	Titanium dioxide
U	Uranium
V	Vanadium
Y	Yttrium
Yb	Ytterbium
Zn	Zinc
ZnS	Zinc sulfide (sphalerite)
Zr	Zirconium

INTRODUCTION

Purpose of Study

The Kansas Geological Survey has long been interested in the strippable coal reserves of southeastern Kansas (Haworth and Crane, 1898; Pierce and Courtier, 1938; Brady and others, 1976), and in the reclamation of the approximately 50,000 acres of land that were surface-mined for coal prior to enactment of the Kansas Mined-Land Conservation and Reclamation Act in January 1969 (Hardy and Camin, 1970; Camin and others, 1971; Camin and Hardy, 1972; Kansas Geological Survey, 1971, 1972). Many questions remain concerning the environmental effects of coal surface-mining and reclamation, particularly with respect to changes in the soil and water. Accordingly, the Kansas Geological Survey implemented this study to obtain comparative data for unmined land and reclaimed and unreclaimed mined land in southeastern Kansas. Another goal of the study was to provide information for the selection of a land-treatment methodology for returning mined land to pasture and grain production. The study was conducted from August 1975 to September 1976 at the Clemens Coal Company Mine 25 site in Crawford County, Kansas (Fig. 1, Pl. 1).

Mining History

Mine 25 is a surface coal mining operation of the Clemens Coal Company of Pittsburg, Kansas. As shown in Figure 2 it encompasses parts of Secs. 26, 27, 34, and 35, T.30S, R.25E and parts of Secs. 2, 3, 10, and 11, T.31S, R.25E, Crawford County, Kansas. The older areas of the mine are located in Secs. 26, 27, 34, and 35, T.30S, R.25E, and in the N 1/2, NE 1/4 and the NE 1/4, NW 1/4 of Sec. 2, T.31S, R.25E. Early attempts at reclamation were performed in the NW 1/4 (west of the railroad tracks) and the N 1/2, SW 1/4 of Sec. 2. The results were not satisfactory.

At the time of the initiation of this study in August 1975, the land in the S 1/2, SW 1/4 of Sec. 2 (Fields 1 and 2) had been reclaimed for 1 year. Leveling of the spoil banks in the NW 1/4 of Sec. 11, north of the pipeline (Fields 3, 4, and 5), had just been completed. The land in the E 1/2, SE 1/4 of Sec. 10 and the W 1/2, SW 1/4 of Sec. 11, south of the pipeline (Field 6), awaited mining. Mining

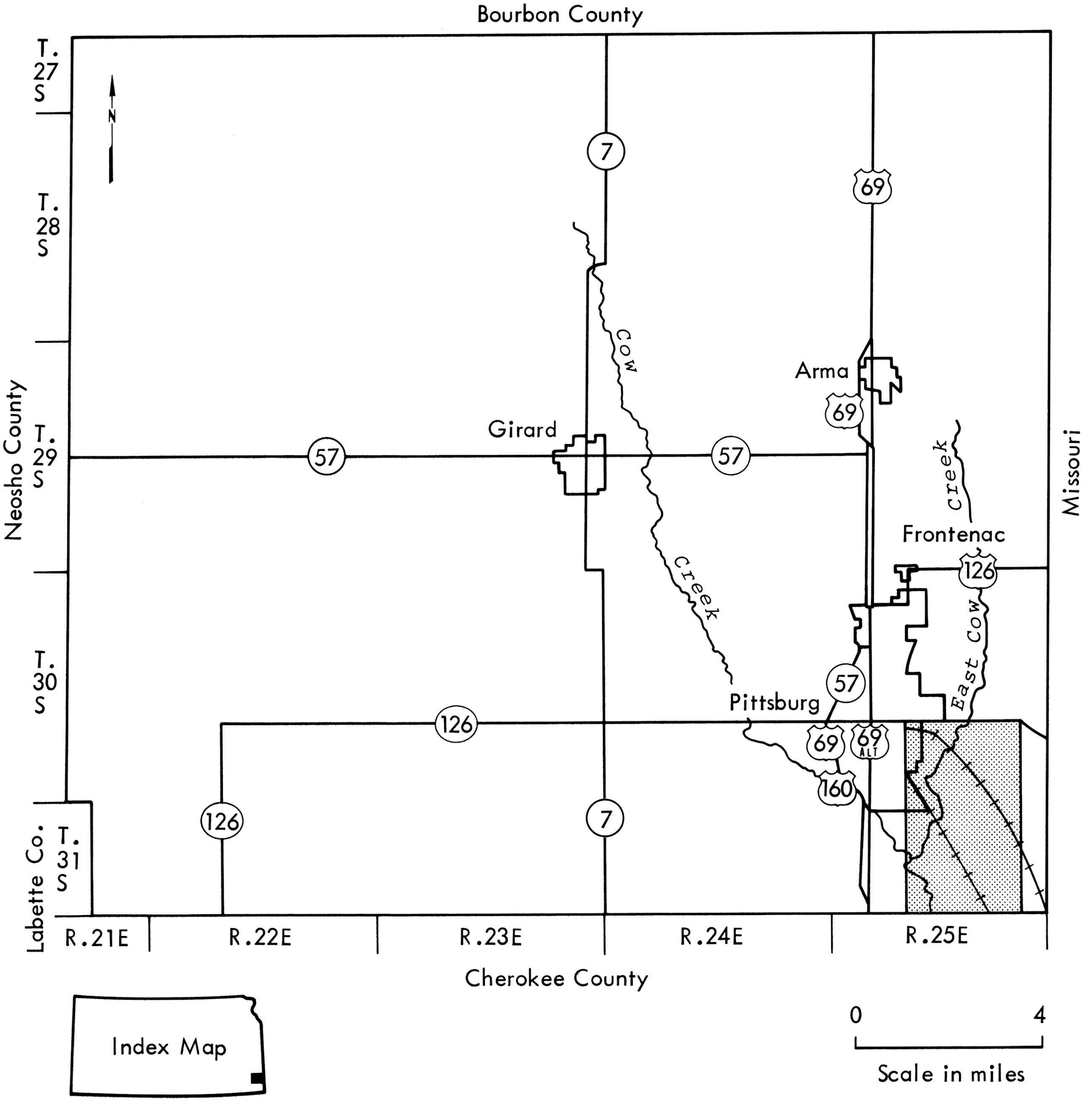


Figure 1. Map of Crawford County, Kansas, showing location of Mine 25.

was still in progress on the land in the E 1/2, NE 1/4 and NE 1/4, SE 1/4 of Sec. 10, north of the pipeline (Field 7).

The mine site afforded an excellent opportunity for comparisons of unmined land and reclaimed and unreclaimed mined land, as well as the opportunity to evaluate a new reclamation method.

Topography and Drainage

The study area is located in the extreme southeast corner of Crawford County on the Cherokee Plain, an erosional surface that

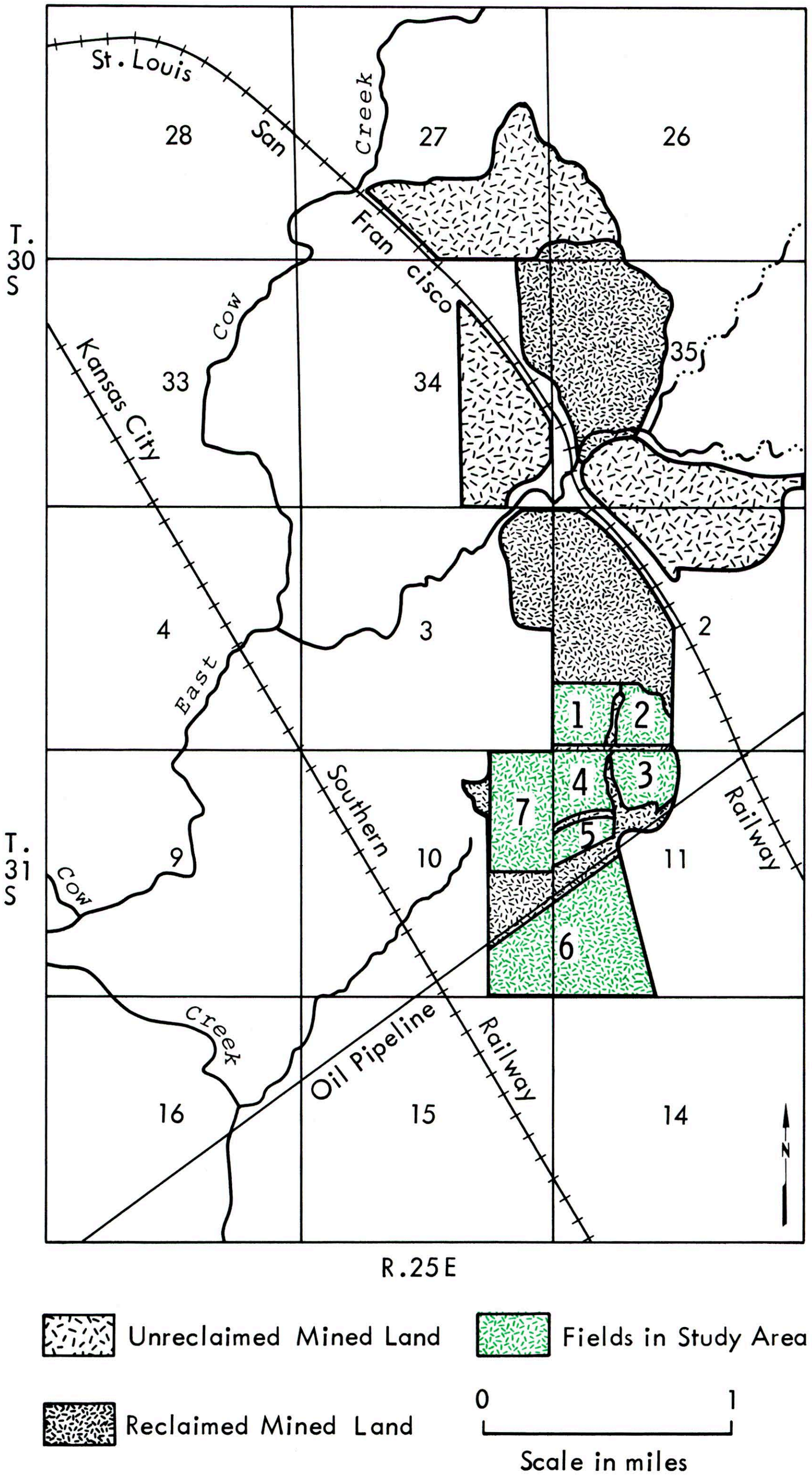


Figure 2. Map of study area.

rises in slope to the west at an average of 10 feet per mile. The land surface of Crawford County is gently rolling and consists of low hills and broad flat-bottomed valleys with breaks and narrow bluffs adjacent to the larger stream valleys. The southeastern part of this plain, where the study area is located, has the smoothest relief in the county.

Large creeks, but no rivers, drain the area. Cow Creek and East Cow Creek, which flows into Cow Creek, drain the area southward. Cow Creek flows into the Neosho River, which flows into the Arkansas River Basin. East Cow Creek flows intermittently during the summer.

Geology

Bedrock units in the study area are part of the Krebs Formation of the Cherokee Group, Desmoinesian Stage, Middle Pennsylvanian age. Lithologically, the formation is composed mostly of dark-gray to black shales, some sandstones and sandy shale, coal beds, and underclays. Limestone is rare. The coals of interest are the Dry Wood and the Rowe.

Climate

Winter temperatures in this area are relatively mild. The average daily maximum temperature for the coldest month of January is above freezing at 44°F. Temperatures may fall well below freezing and occasionally below zero, but extremely cold weather is usually of short duration. Snowfall is light and averages 13 inches per year. Accumulated snow usually melts within a few days. Summers are warm to hot. Summer temperatures may rise above 100°F, but seldom continue at this extreme for more than a few days. The average daily maximum temperature for the warmest months of July and August is 91°F. The average annual temperature is 57°F.

The study site is in the area of the greatest precipitation in Kansas. Precipitation ranges from 20 to 60 inches per year with the annual average being 40 inches. There is no official dry season, although there are periods of drought. An average of three-fourths of the precipitation occurs during the warmer season from April through October, with May and June being the wettest months. Relative humidity is generally high.

Vegetation

Natural ecological succession in this area resulted in the growth of tall prairie grasses, such as big bluestem and little bluestem, switch grass, Indian grass, and others. Trees are distributed primarily along stream banks and other naturally disturbed areas. The number of species of trees is small and includes American elm, cottonwood, black willow, pin oak, hickory, black walnut, and a few other closely related species.

Settlement of the prairie resulted in the conversion of the prairie to farmland. The main crops currently grown in the county are wheat, corn, sorghum, soybean, and alfalfa. Minor crops are oats, rye, barley, and sweet clover. Tame grass pastures of brome and fescue are common and are used for cattle grazing.

Soils

The moderately acidic soils, which weathered from the shale bedrock or alluvium derived from the shale bedrock in this area, are well developed and relatively deep and have a distinct clay layer in the subsoil formed as a result of downward leaching of clay particles by water. This clay layer impedes deeper downward water movement and hence prevents any substantial subsoil water storage. As a result, drought is a serious hazard on these soils. These soils are well adapted to general farming, provided good management practices are employed.

Water

In this area the Krebs Formation yields small amounts of fresh to moderately saline groundwater to shallow wells for domestic and livestock use. However, water from these wells is greatly diminished during drought periods. Fortunately, deep carbonate and sandstone aquifers of the Arbuckle Group yield large quantities of good-quality water to wells in southeast Crawford County used by municipalities, rural water districts, and industries. Water is also available from Mississippian rocks, but the water is of lesser quality and yields to wells are smaller.

The main sources of surface water in this area are East Cow Creek and its tributaries and water-filled strip pits. Strip pits comprise approximately 6 percent of the approximately 22,000 acres of land surface-mined for coal in Crawford County prior to January 1969. The water quality of many of the tributaries and strip pits has been severely degraded by acid drainage.

GEOLOGY

by L. L. Brady, W. W. Hambleton, and D. A. Grisafe

Introduction

The geology of the unmined area was determined from 3 sources. In August 1975, the Kansas Geological Survey bored 4 nearly complete 4-inch cores in the southern unmined area (Field 6), located south of the Texaco-Cities Service oil pipeline. In addition, drill records for 109 borings that covered the entire unmined area were provided by the Clemens Coal Company. Also, at the time mining commenced south of the oil pipeline, stratigraphic sections were described from the mine highwall. These stratigraphic sections coincided approximately with the location of the Kansas Geological Survey boreholes.

Experimental Procedures

Borings of the soil and rock overlying the coal beds were drilled by the Kansas Geological Survey with a 4-inch-diameter core barrel with a carbide-tipped bit. Locations of the boreholes are shown in Figure 3 with descriptions given in Appendix A. The entire length of rock core C-2 was sawed to obtain a quarter section for mineralogical and chemical analysis. This section was divided into 11 units, based upon identifiable stratigraphic change. Samples of these units were dried, pulverized to a fine powder in a pan mill, and further crushed using an alumina mortar and pestle. The resulting powder was screened through a 200-mesh (75 micron) sieve and pressed into pellets on a Carver press at 10,000 psi. The mineralogy of the pellets was then analyzed with a Norelco x-ray diffractometer using CuK^{α} radiation and a single-crystal monochromator.

Elemental composition of the pellets was determined by x-ray fluorescence spectrometry. A scan of the spectra was recorded and the peak height of the strongest line of each element in a sample was measured. The concentration of each element was determined from a standard curve prepared from the scans of a multi-element standard diluted to different concentrations with silica. Values of copper, zinc, nickel, rubidium, strontium, barium, and zirconium were corrected for matrix effects using scattered radiation as an internal standard.

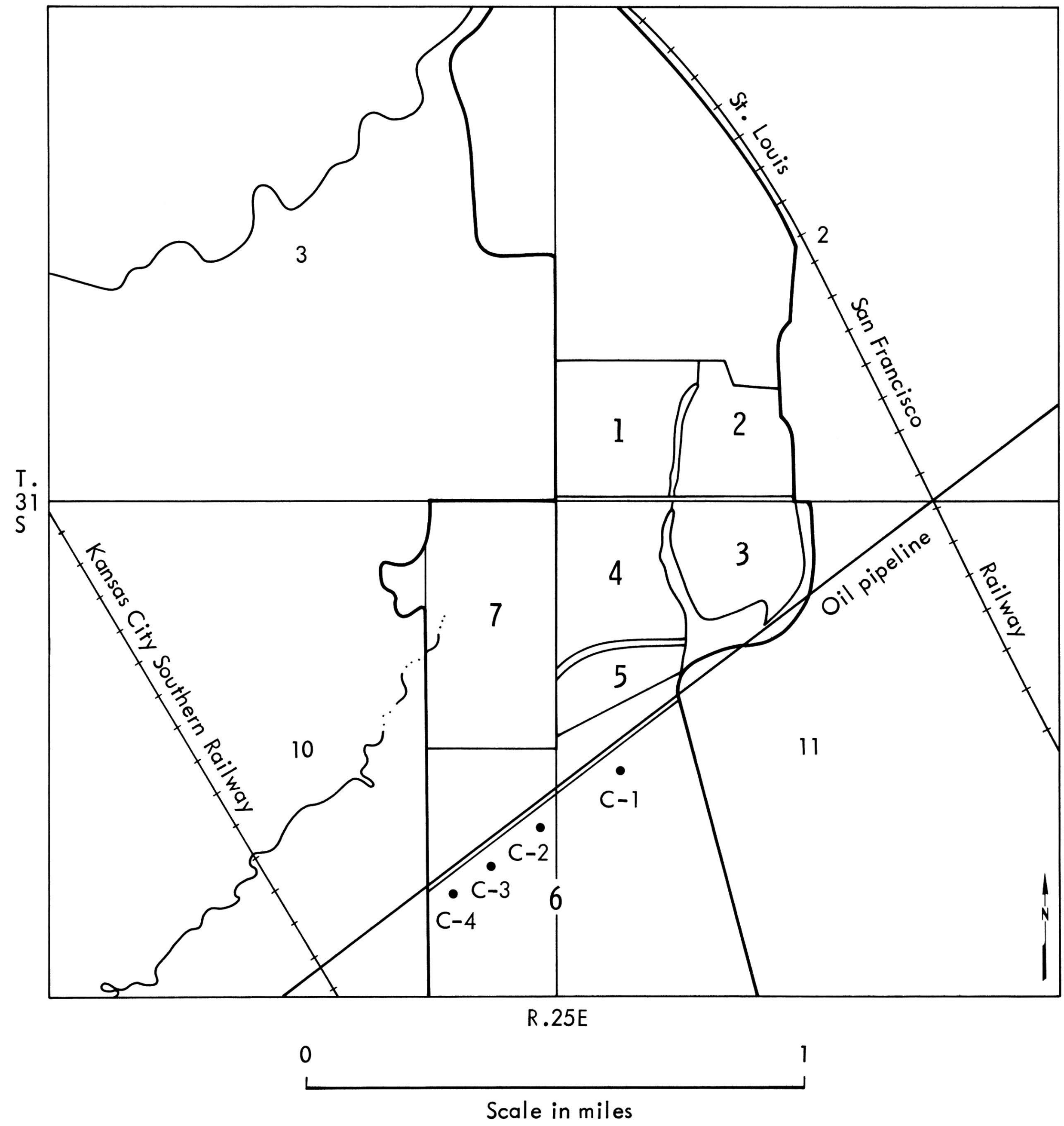
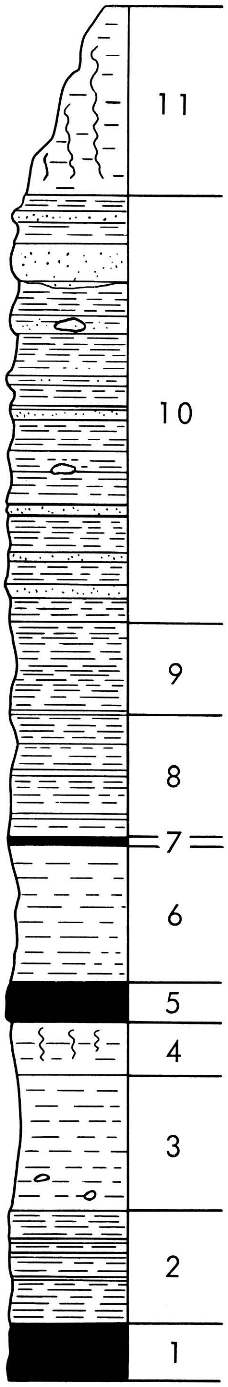


Figure 3. Map of location of rock-core sampling sites.

Stratigraphy and Structure

The rock units of the mine site consist of shale, siltstone, sandstone, coal, underclay, and several thin beds of clay-ironstone nodules of the Krebs Formation, Cherokee Group, which is the lowest major division of the Desmoinesian Stage of the Middle Pennsylvanian Series. A composite section (Fig. 4) that was measured along the highwall of the mine (NE 1/4, SE 1/4, SE 1/4, Sec. 10, T.31S, R.25E) is representative of the general

Figure 4. Composite stratigraphic section at mine highwall, NE 1/4, SE 1/4, SE 1/4, Sec. 10, T.31S, R.25E, March 23, 1976.



	Description	Thickness in feet
11.	Soil, clay, gray with light-brown mottling	5±
	<u>Krebs Formation - Cherokee Group</u>	
10.	Shale, with interbedded sandstone and siltstone, sandstone is very fine grained, thin-bedded, commonly forming lenticular bedding with the shale. Occasional discontinuous clay ironstone bands and nodules present. Light-gray to gray in color with light-brown staining. A dark-gray carbonaceous claystone band (0.5 ft.) occurs approximately 7 ft. above base of unit	11±
9.	Shale, well-bedded, dark-gray with light-brown stained areas	2.2
8.	Shale, well-bedded, with thin siltstone beds and partings (.02-.05 ft.), dark-gray with light-gray silty shale laminae and light-gray to light-brown siltstone layers	3.1
7.	Coal, banded	0.3
6.	Claystone, poorly bedded, slakes on exposure, upper 0.5 ft. is carbonaceous, gray	3.5
5.	Coal (Dry Wood), banded, some pyrite present along bedding planes	1.0
4.	Claystone, poorly bedded, some burrowing, some gypsum, light-brown	1.5
3.	Claystone, poorly bedded, some burrowing, silty ironstone nodules in lower part, light-gray with light-brown and reddish-brown mottling	3.5
2.	Shale, well-bedded, with some thin, hard siltstone beds, well-indurated, dark-gray with brown siltstone	3.0
1.	Coal (Rowe), banded, with discontinuous pyrite parting up to 1/4 inch, pyrite also occurs along some bedding planes	1.5

stratigraphy of the mine site. Additional stratigraphic information was derived from the 4 bore holes drilled by the Kansas Geological Survey prior to mining.

The lowermost unit shown on the composite section is the Rowe coal, which ranges in thickness from 14 to 18 inches. The coal is banded and contains pyrite and gypsum along cleats and bedding planes. Strata beneath the Rowe coal, as interpreted from the deepest core (core C-4), include at least 8 feet of dark-gray shale, as well as a thin siltstone. The shale contains light-brown nodules, which also occur in the form of thin clay-ironstone bands, 0.3 to 1.4 cm wide. The upper 1.5 feet of the shale unit contain interbedded thin laminae of siltstone, 0.1 to 0.5 cm wide. Overlying the shale unit and grading downward is a light-gray, well-consolidated siltstone that is present in all the cores. The siltstone is extensively burrowed, and contains abundant carbonaceous material.

Strata between the Rowe coal and overlying Dry Wood coal consist mostly of shale and underclay beds. This interval ranges from 6 to 9 feet in thickness. The shale is finely laminated, very carbonaceous, and contains light-brown clay-ironstone lenses, 1 to 3 cm wide. Color of the shale interval grades from dark-gray to black in the lower part to a brownish-gray in the upper part. The lighter-colored shale contains irregular laminae, with burrowing evident. The underclay below the Dry Wood coal ranges from 1.5 to 3 feet in thickness. It is poorly consolidated, and slakes extensively when exposed. The Dry Wood coal ranges in thickness from 0.25 to 1.25 feet, is banded, and has some pyrite along bedding planes.

Above the Dry Wood coal is a dark-gray, poorly bedded carbonaceous shale that is several feet thick. In some places, a thin coal is found above this shale. Locally this coal is known as the "Pilot coal." Above this coal is a dark-gray silty shale with interbedded light-gray shale and very finely laminated siltstone.

The upper part of the shale interval also contains interbedded sandstone that is very fine grained and light-brown in color. Evidence of burrowing is present, as are a number of iron-rich zones. This sandstone is considered to be equivalent to the Bluejacket Sandstone, which can be traced over a wide area of southeastern Kansas. In an evaluation of the Bluejacket Sandstone for heavy-oil potential, Ebanks and others (1977) recognized the presence of 2 distinct intervals of sandstone occurrence and referred to these sandstone intervals as the upper and lower Bluejacket Sandstone intervals. Based on their work, the Bluejacket Sandstone that is present in the cores, and was observed in the mine highwall, would be equivalent to the lower Bluejacket Sandstone.

Where the "Pilot coal" is thin or absent, the Bluejacket Sandstone is thick, suggesting a pre-Bluejacket erosional surface. A light-brown, finely laminated shale lies above the Bluejacket Sandstone, and lenticular laminae of light-gray, fine-grained sandstone are interbedded within the shale. Burrows and iron oxide nodules also are present within the shale.

A cross section drawn from the 4 boreholes is shown in Figure 5. The lithologic descriptions of rock cores C-1 and C-2 (Appendix A) resemble the composite stratigraphic section of Figure 4. An appreciable thickening of the interval between the Rowe and Dry Wood coals to the east is noticeable. Rock core C-3

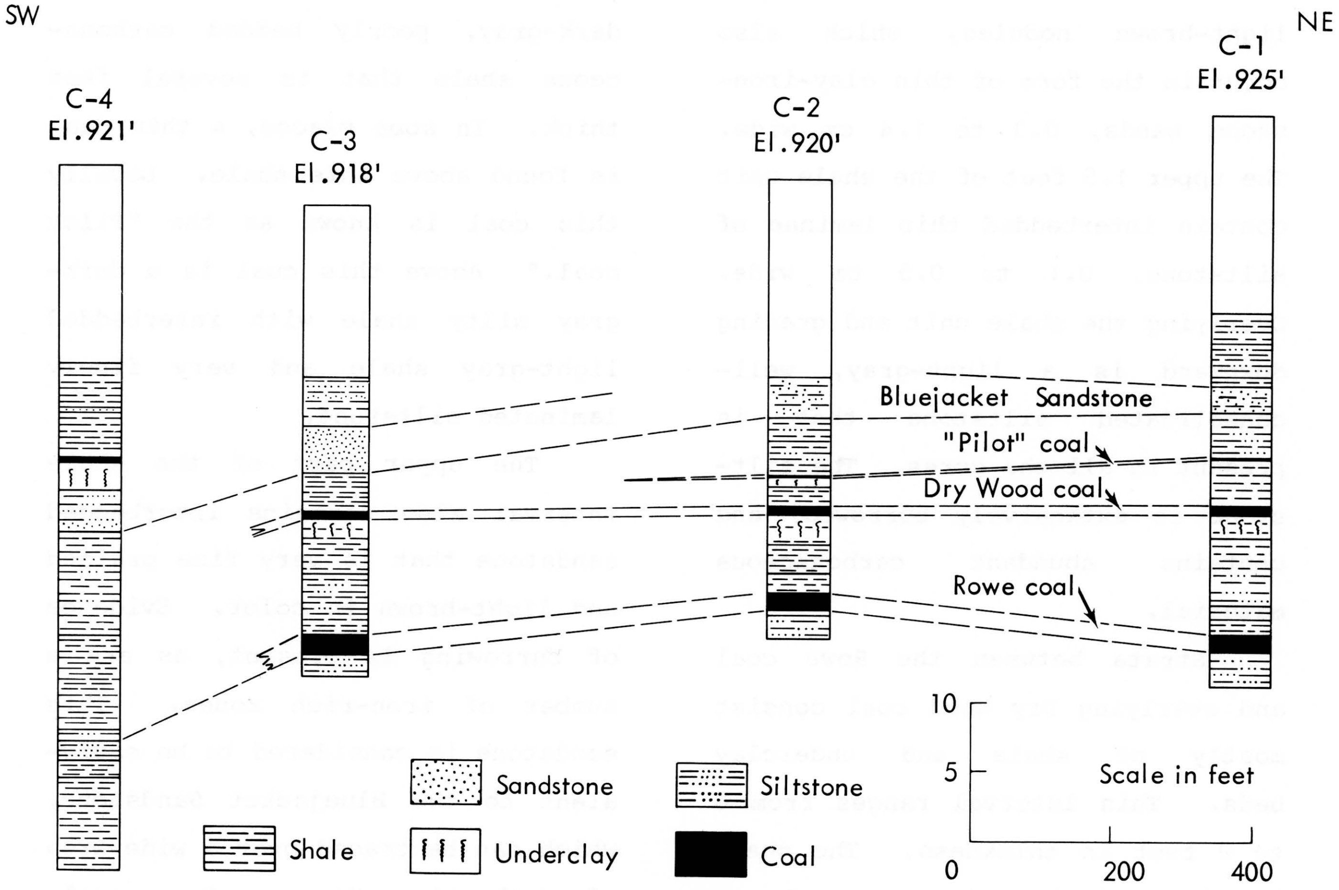


Figure 5. Cross section of stratigraphy along the line of rock cores at the mine site (northeast to southwest).

exhibits the thickening of the Bluejacket Sandstone and the disappearance of the "Pilot coal" as mentioned earlier. All 3 coals are missing from rock core C-4, and stratigraphic correlation with the other 3 cores is somewhat difficult. The base of the sandy unit is considered to be stratigraphically equivalent to the base of the Bluejacket Sandstone. Because a siltstone is present beneath the Rowe coal in the other 3 cores, the appearance of a similar siltstone in core C-4 is considered to be in position below the missing Rowe coal.

The structural and stratigraphic relations are further illustrated by Clemens Coal Company drill records. These records and the Kansas Geological Survey boreholes were used to construct isopach maps of the thickness of the Rowe and Dry Wood coals, shown in Figures 6A and

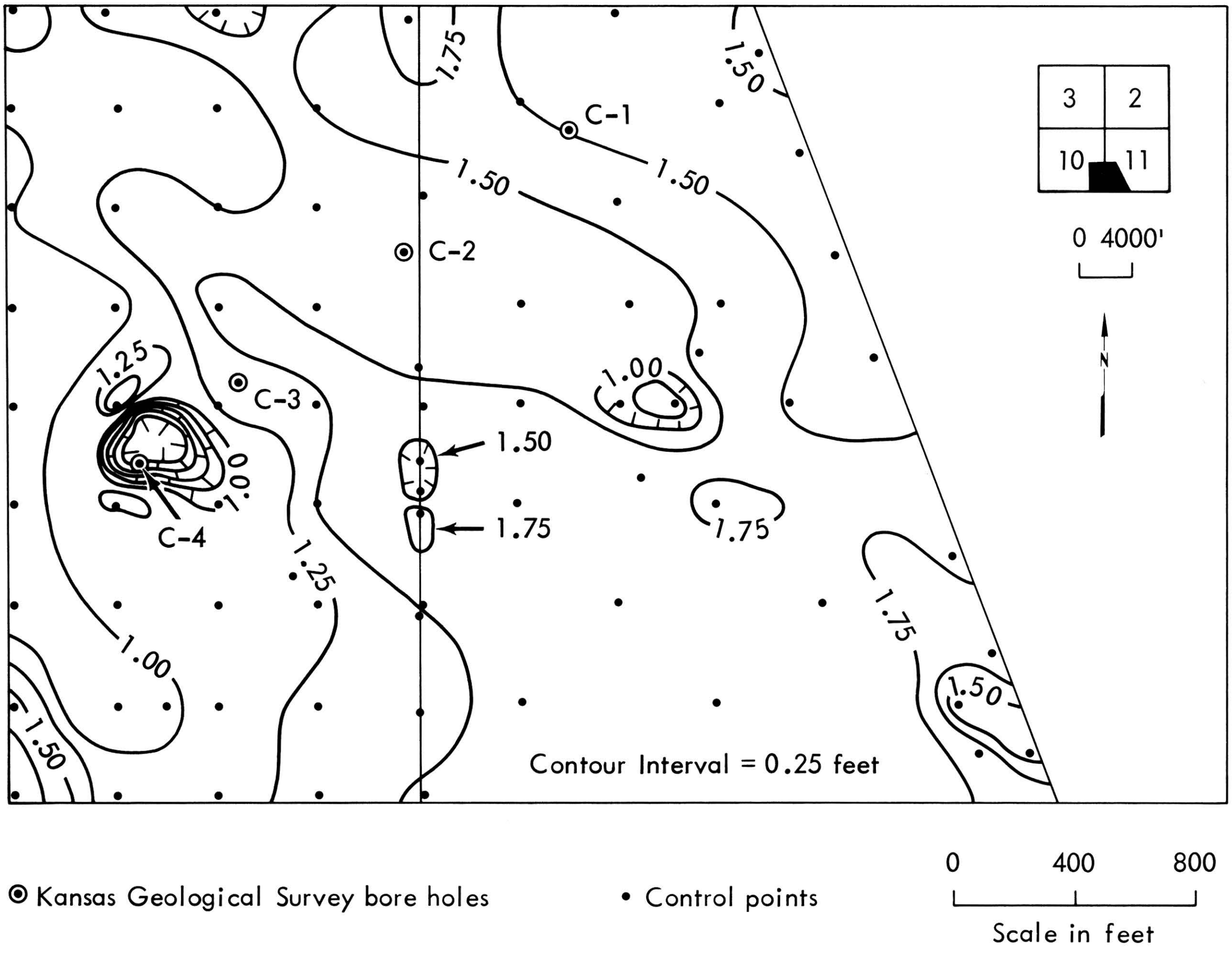


Figure 6A. Map of the thickness of the Rowe coal, E 1/2, SE 1/4, Sec. 10 and W 1/2, SW 1/4, Sec. 11, T.31S, R.25E. Data from Clemens Coal Company drilling records.

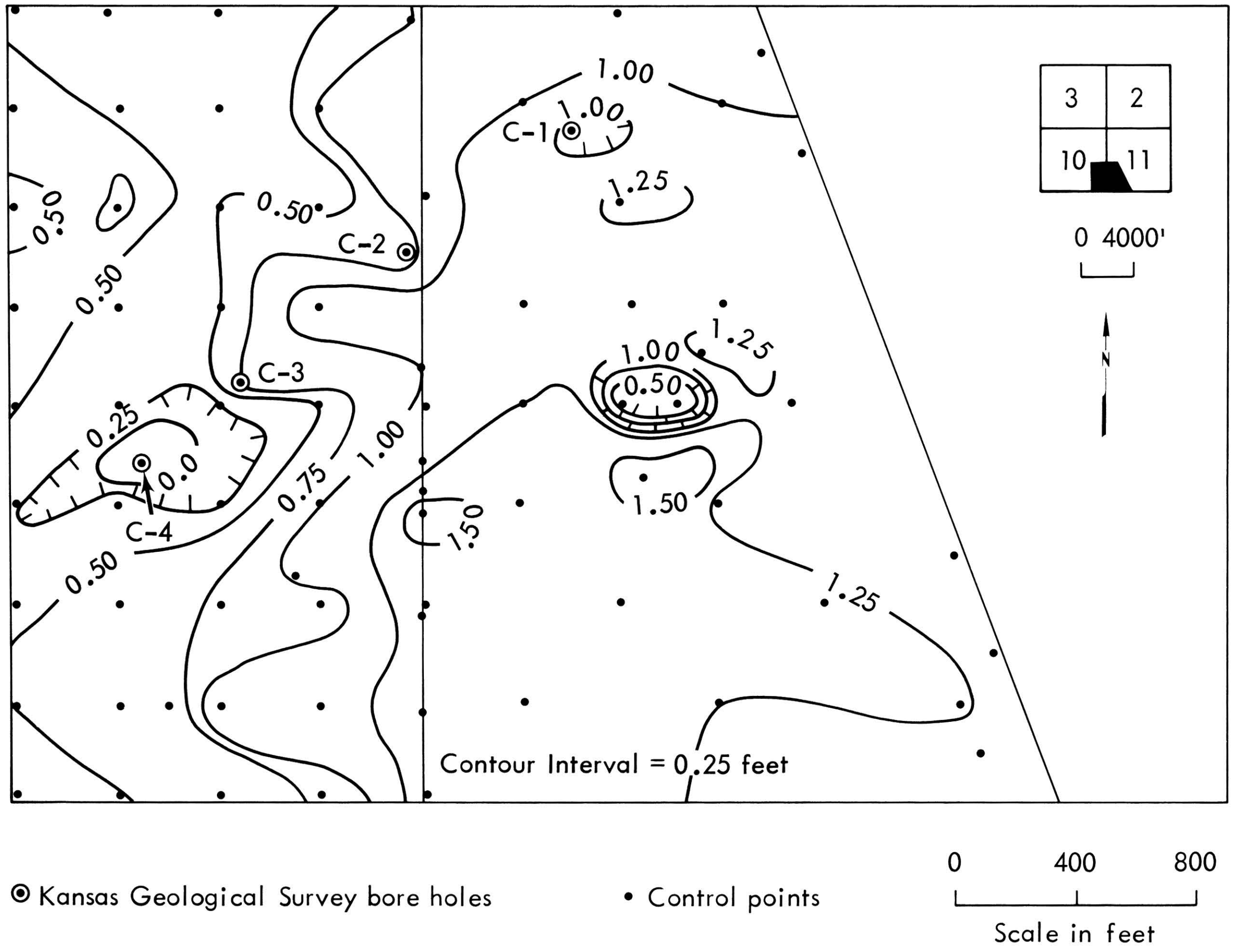


Figure 6B. Map of the thickness of the Dry Wood coal, E 1/2, SE 1/4, Sec. 10 and W 1/2, SW 1/4, Sec. 11, T.31S, R.25E. Data from Clemens Coal Company drilling records.

6B respectively. The Rowe coal, where present, ranges in thickness from 0.85 to 1.85 feet, as shown by Clemens Coal Company data. However, Kansas Geological Survey borehole data show the Rowe coal is absent in the west-central section of the mine site. The Rowe coal is thickest to the southeast and thins slightly to the west. Circular depressions and ridges represent the typical small rolls that occur in the coal beds in southeastern Kansas. A karst surface on older Mississippian rocks may be responsible, in part, for the typical circular depressions. The Dry Wood coal ranges in thickness from 0.25 to 1.25 feet, and also thins toward the west, according to Clemens Coal Company drill records. However, Kansas Geological Survey borehole data also show the Dry Wood coal to be absent in the west-central section of the mine site.

Structure maps were drawn of

the top of the Rowe and Dry Wood coals and these are shown in Figures 7A and 7B respectively. Elevation of the Rowe coal ranged from 870 to 890 feet above mean sea level; the Dry Wood coal ranged in elevation from 870 to 900 feet. The most prominent feature on both structure maps is a southwesterly trending trough or syncline across the area. There is suggestion that the syncline also plunges to the northeast.

Overburden thickness maps for the Rowe and Dry Wood coals are shown in Figures 8A and 8B respectively. Overburden thickness for the Rowe coal ranges from 20 feet in the northwest to 65 feet in the east-central section of the mine site. The Dry Wood has a minimum overburden thickness of 10 feet and a maximum of 55 feet. Overburden thicknesses are greatest in the synclinal areas. As a result, the deeper parts of the syncline have

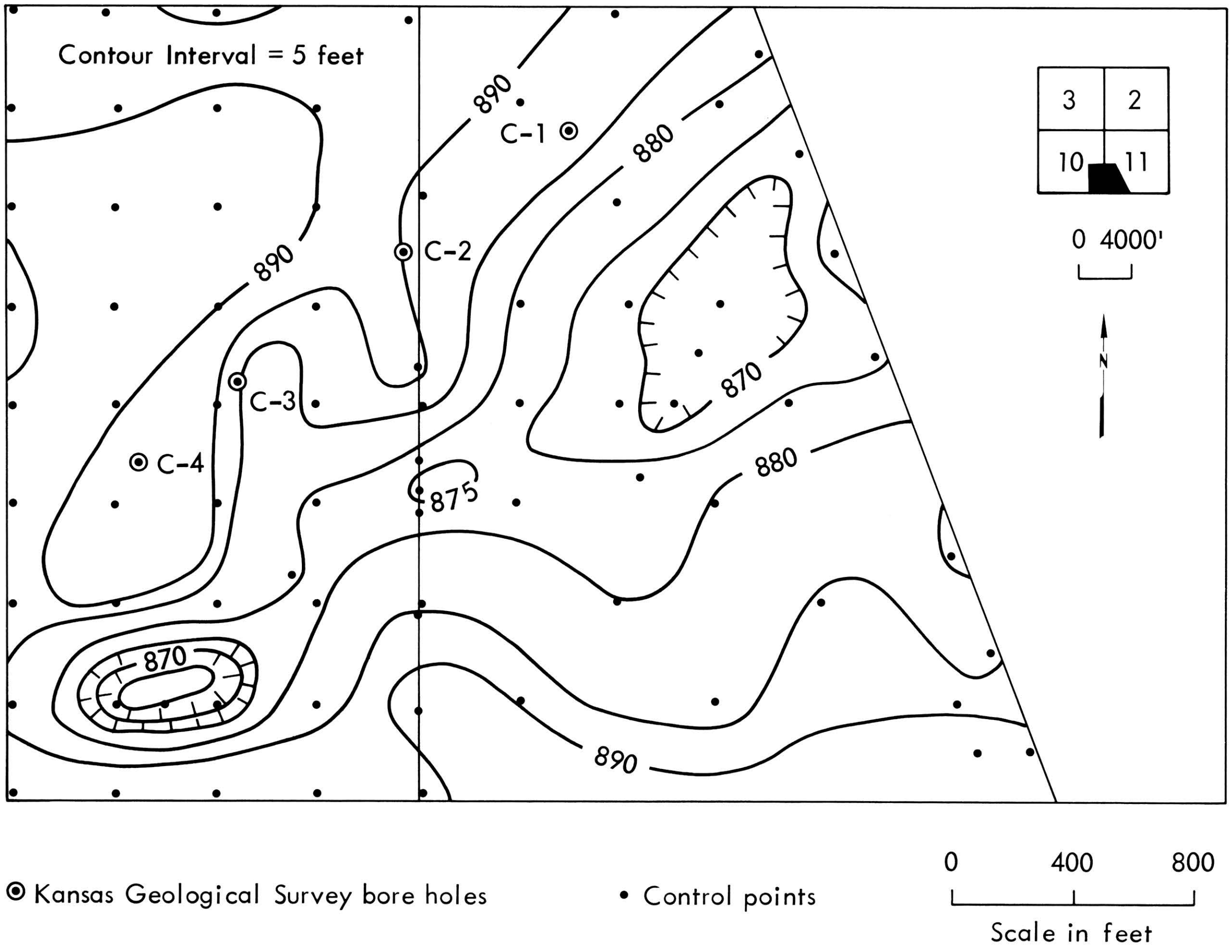


Figure 7A. Structure map of the top of the Rowe coal, E 1/2, SE 1/4, Sec. 10 and W 1/2, SW 1/4, Sec. 11, T.31S, R.25E. Data from Clemens Coal Company drilling records.

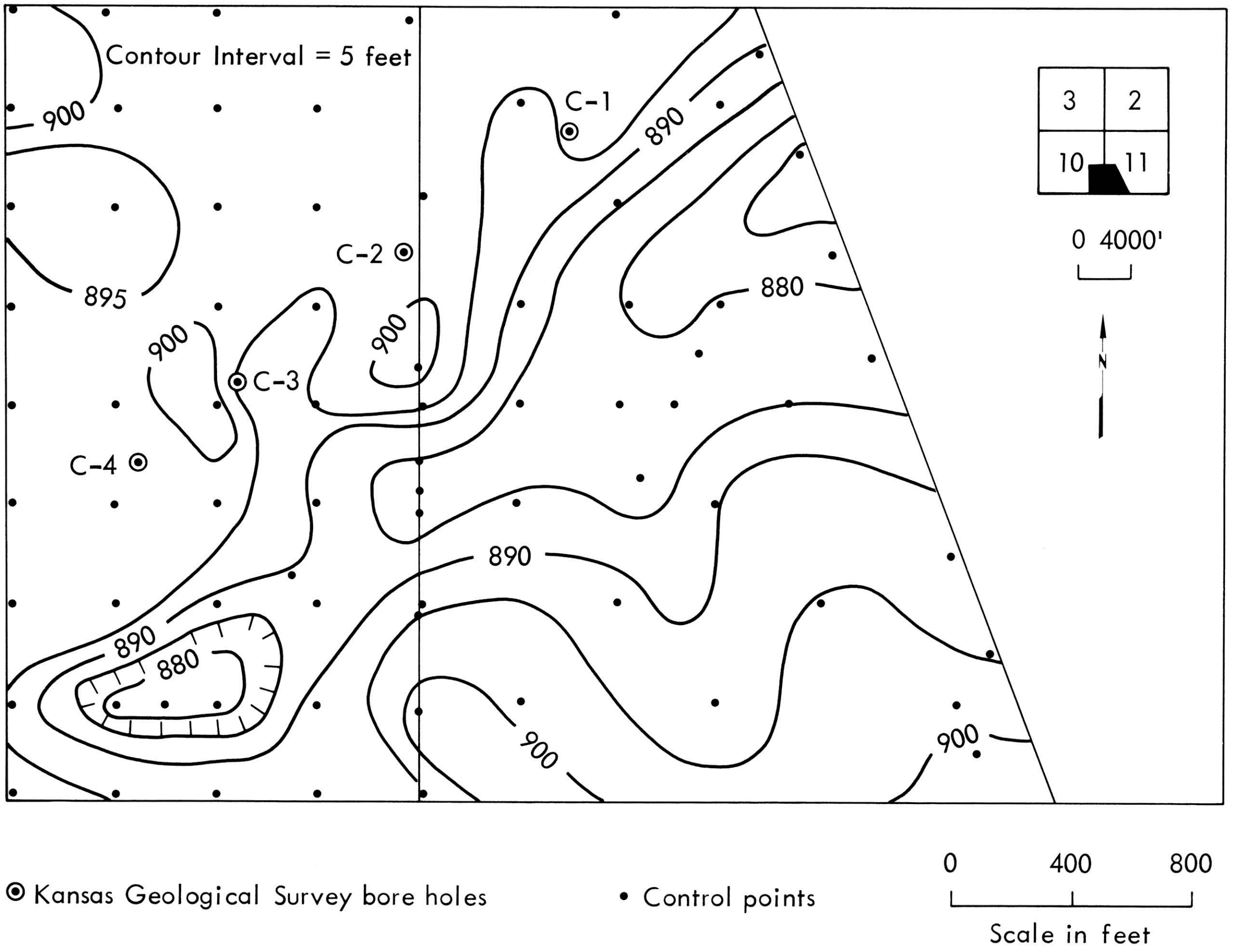


Figure 7B. Structure map of the top of the Dry Wood coal, E 1/2, SE 1/4, Sec. 10 and W 1/2, SW 1/4, Sec. 11, T.31S, R.25E. Data from Clemens Coal Company drilling records.

not been mined because the increased overburden thickness makes mining uneconomical.

Mineralogy and Chemistry

Mineralogical and chemical characterizations of the rock units were determined from samples of rock core C-2, which were subjected to x-ray diffraction and x-ray fluorescence analyses.

X-ray diffraction analysis of rock core C-2 from 15 to 35 feet (Table 1) indicates the rock units consist predominantly of quartz, feldspar, and clay. Many of the rock units contain small amounts of calcite, iron oxides, and pyrite. For purposes of this study, only clay-mineral groups are distinguished. Any clay giving a 7Å basal reflection is assumed to be kaolinite; a 10Å reflection, illite; and a 14Å reflection, montmorillonite. All

Table 1. Major line intensities of principal minerals from x-ray diffraction analysis of rock core C-2.[a]

Depth (feet)	Q	F	M	I	K	Q+F	M+I+K	$\frac{Q+F}{M+I+K}$	Lithology
15-18	78	35	12	56	53	113	121	0.93	Siltstone
18-19.8	49	20	10	61	55	69	126	0.55	Shale
19.8-22.3	38	12	10	61	68	50	139	0.36	Shale
22.3-22.5									"Pilot coal"
22.5-22.7	72	17	0	71	48	89	119	0.75	Silty - Non-slaking "underclay"
22.7-24.6	48	12	0	60	71	60	131	0.46	Slakable underclay
24.6-25.3									Dry Wood coal
25.3-27.6	37	10	0	46	78	47	124	0.38	Slakable underclay
27.6-28.8	39	7	9	52	75	46	136	0.34	Shale
28.8-29.7	46	10	13	65	87	56	165	0.34	Shale
29.7-31.3	47	8	8	55	62	55	125	0.44	Shale
31.3-32.5									Rowe coal
32.5-32.7	35	10	0	10	44	45	54	0.83	Silty-slaking "underclay"
32.7-34.7	86	12	0	39	42	98	81	1.21	Siltstone

[a] Q = Quartz, F = Feldspar } non-plastic minerals

M = Montmorillonite, I = Illite, K = Kaolinite } plastic minerals

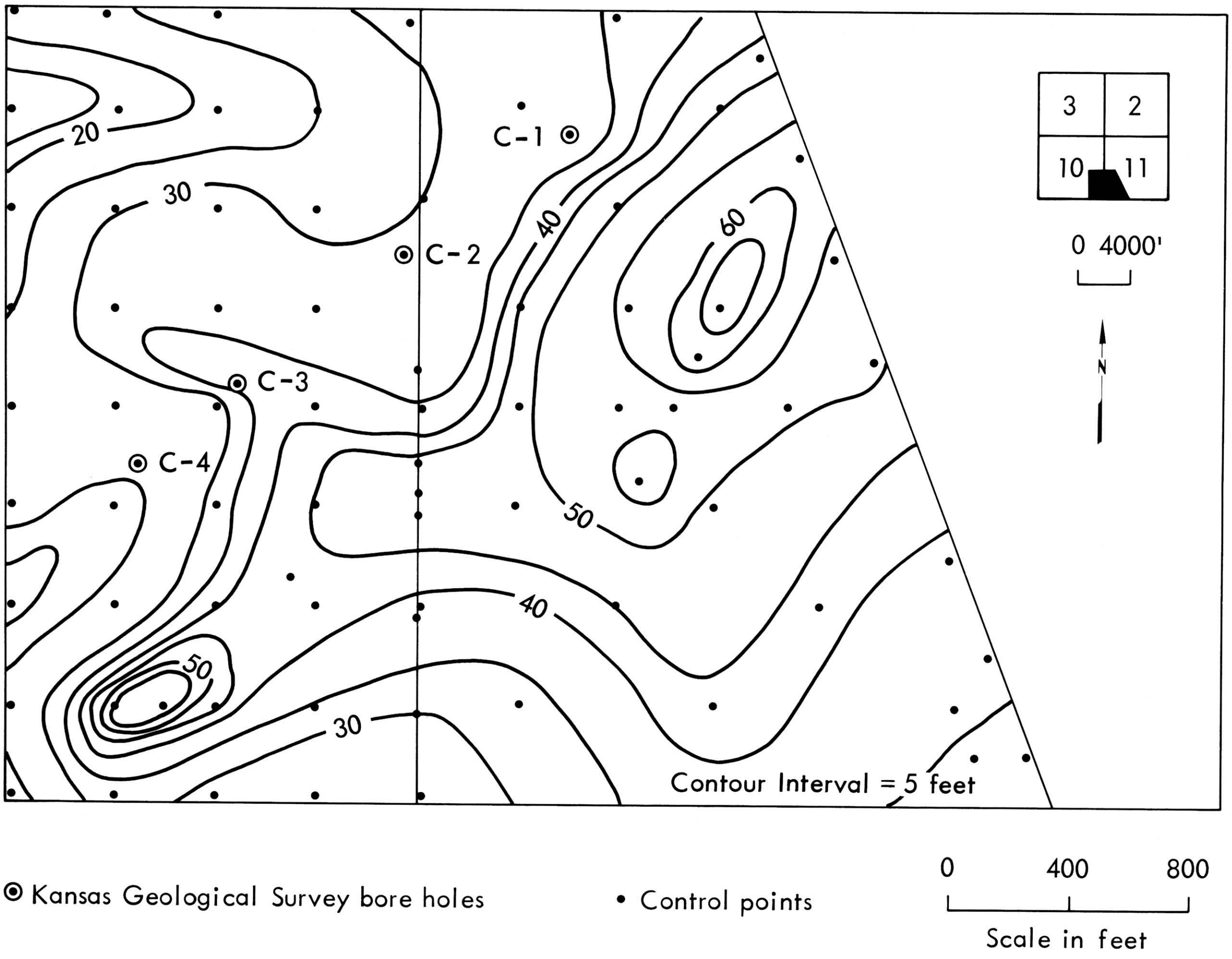


Figure 8A. Map of the thickness of overburden above the Rowe coal, E 1/2, SE 1/4, Sec. 10 and W 1/2, SW 1/4, Sec. 11, T.31S, R.25E. Data from Clemens Coal Company drilling records.

rock units were found to contain kaolinite and illite. Also, an appreciable amount of montmorillonite was found in some of the rock units.

Initial visual inspection of rock core C-2 led to classification of most units as clay and shale. Observations supported by x-ray diffraction analysis suggest that some of the units are more properly categorized as siltstone. Units containing the most non-plastic minerals (quartz and feldspar) as compared with plastic minerals (kaolinite, illite, and montmorillonite) were determined by measuring major diffraction-line intensities. Table 1 lists the measured line intensities and the ratio of non-plastic to plastic minerals. These ratios in turn were used to identify silty material or siltstone for the lithology column. Although these characterizations are somewhat uncertain because of the range in crystallinity and particle size of

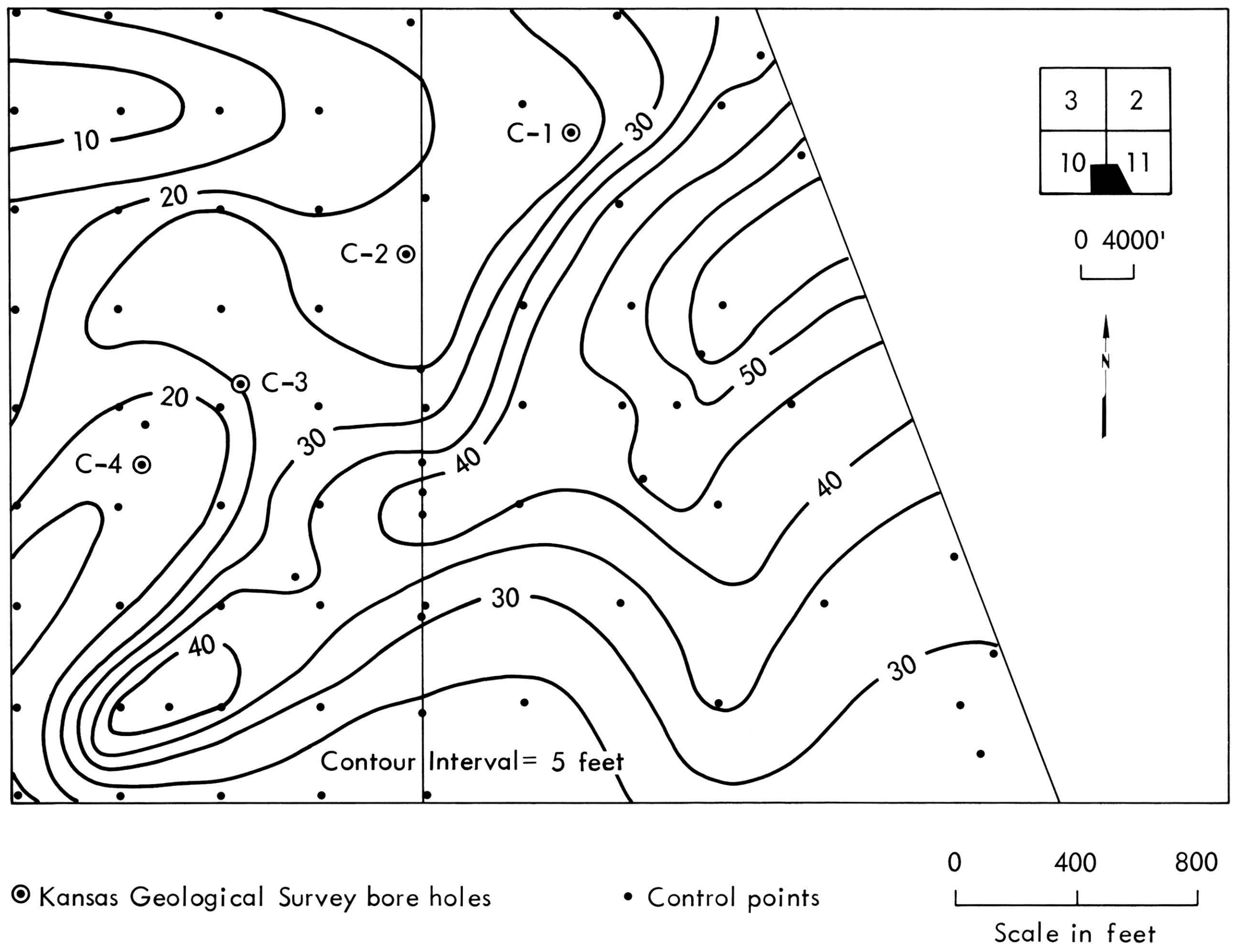


Figure 8B. Map of the thickness of overburden above the Dry Wood coal, E 1/2, SE 1/4, Sec. 10 and W 1/2, SW 1/4, Sec. 11, T.31S, R.25E. Data from Clemens Coal Company drilling records.

the clay minerals, the ratios are useful in showing the error in referring to a unit below a coal seam as "underclay" when such a unit may be quite silty and may be a siltstone. The silty "underclay" found immediately below the "Pilot" and Rowe coals is a good example of this.

The results of the x-ray fluorescence analysis of rock core C-2 from 15 to 35 feet are shown in Table 2. All elements show a wide range in concentration except titanium, which is relatively constant with depth. Rock units 1, 3, 7, and 9 are highest in manganese (expressed as MnO), with the largest values found above the "Pilot" and Rowe coals. By contrast, the lowest manganese value is found above the Dry Wood coal. In general, the samples found to be high in manganese were also found to have a relatively high iron content (expressed as Fe_2O_3).

Table 2. Semiquantitative analysis of trace elements of rock core C-2 by x-ray fluorescence spectrometry.

Depth (feet)	Sample No.	Fe_2O_3 %	MnO %	TiO_2 %	Cu	Zn	Ni	Rb	Sr	Ba	Zr
					ppm[a]						
15-18	1	8.3	0.17	0.9	BD[b]	240	80	60	110	400	360
18-19.8	2	6.5	0.04	1.0	BD	70	70	100	140	200	360
19.8-22.3	3	7.8	0.29	1.0	60	100	80	100	100	400	240
22.3-22.5				"Pilot coal"							
22.5-22.7	4	1.5	0.02	1.0	110	80	140	150	420	800	690
22.7-24.6	5	2.0	0.01	1.1	BD	40	110	220	210	500	310
24.6-25.3				Dry Wood coal							
25.3-27.6	6	3.8	0.08	1.1	BD	40	110	160	150	500	300
27.6-28.8	7	8.7	0.25	1.0	BD	60	80	90	390	600	140
28.8-29.7	8	3.6	0.02	1.1	100	80	120	190	150	500	310
29.7-31.3	9	6.4	0.29	1.0	BD	50	110	140	130	400	270
31.3-32.5				Rowe coal							
32.5-32.7	10	6.4	0.03	1.1	160	40	190	140	880	500	390
32.7-34.7	11	2.2	0.06	1.0	70	30	90	110	60	200	790
Detection Limit					20	10	10	10	10	100	20

[a] Parts per million ($\mu g/g$)
[b] Below detection limit

COAL

By J. E. Welch and L. L. Brady

Introduction

Since 1971 the U.S. Geological Survey and the U.S. Bureau of Mines have had an ongoing coal geochemistry program to sample and analyze the nation's coal. This type of basic data is necessary to determine the economic value of the coal and to evaluate the potential environmental effects related to coal mining, processing, and utilization, and also to determine the adaptability of the coal to beneficiation (cleaning), gasification, and liquefaction. The state geological surveys cooperate in this program by collecting and submitting samples for analysis. All the chemical analyses are stored in the U.S. Geological Survey's National Coal Resource Data System. Analytical results are also tabulated and sent to the state surveys for the samples they submit. Such arrangements make the program of mutual benefit to the parties involved. Depending on the coals that have been sampled and analyzed, these data can be used for comparison of coal on a local, state, regional, or national basis.

This section of the report consists of comparisons of the Rowe and Dry Wood coals from the mine site to each other, to southeastern Kansas coal, to Interior Province coal, and to the Rowe and Dry Wood coals from southwestern Missouri.

Most contamination from surface mining of coal at a mine site does not result from coal, but from other exposed overburden material. Most environmental contamination of soil and water directly by coal is related to coal-cleaning waste piles, coal storage piles, and fly and bottom ash piles related to coal processing and utilization. It was not an objective of the present study to investigate the redistribution of elements in the environment from the processing and utilization of the Rowe and Dry Wood coals.

Experimental Procedures

Channel samples of the Rowe and Dry Wood coals were taken from the mine highwall at the locations shown in Figure 9. Samples R-1, R-2, D-1, and D-2 were collected on January 20, 1976. Samples R-3 and D-3 were collected on March 10, 1976. Each sample weighed approximately 2 kilograms and all were sealed at the time of collection in plastic bags

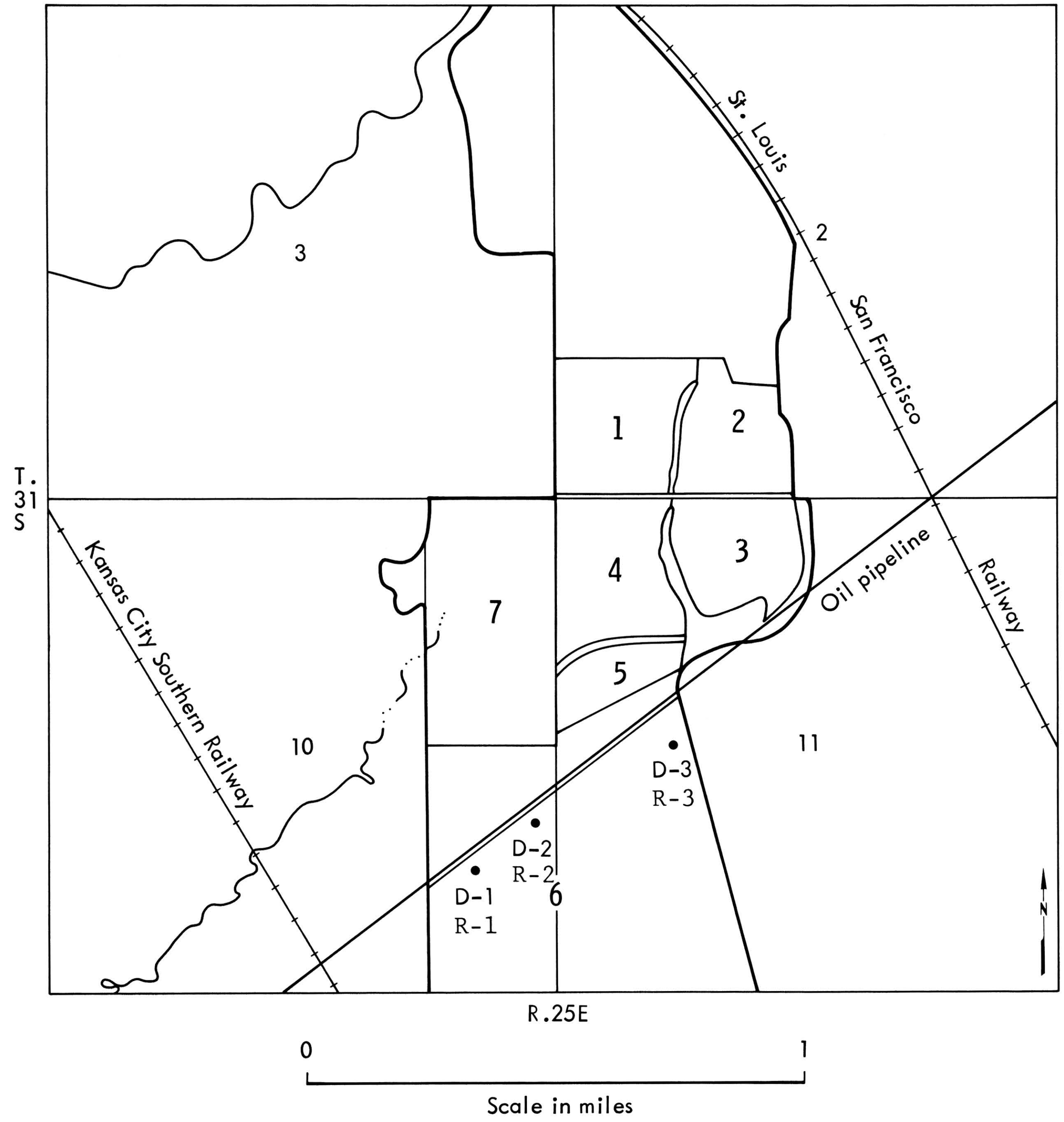


Figure 9. Map of location of coal-sampling sites.

to prevent moisture loss. The samples were sent to the U.S. Geological Survey laboratory in Denver, Colorado, for analysis of major and minor oxides and trace elements. (The analytical methods used by the U.S. Geological Survey are described in Swanson and Huffman [1976].) The U.S. Geological Survey sent subsamples of approximately 600 grams each to the Coal Analysis Section of the U.S. Department of Energy (formerly of the Bureau of Mines, U.S. Department of the Interior), Pittsburgh, Pennsylvania, for proximate analysis (percent moisture, volatile matter, fixed carbon, and ash), ultimate analysis (percent hydrogen, carbon, nitrogen, oxygen, and sulfur), heat of combustion, and percent forms of sulfur. The analytical methods used by the Coal Analysis Section are described in U.S. Bureau of Mines Bulletin 638 (U.S Bureau of Mines, 1967).

Rowe and Dry Wood Coals from the Mine Site

The fixed carbon, volatile matter, and heat of combustion values of the Rowe and Dry Wood coals (Table 3) were quite similar and high. Averages of these parameters on a moisture- and ash-free basis were 57.0 percent fixed carbon, 43.0 percent volatile matter, and 14,507 Btu/lb (British thermal units per pound) heat of combustion for the Rowe coal; and 57.7 percent fixed carbon, 42.2 percent volatile matter, and 14,435 Btu/lb heat of combustion for the Dry Wood coal (averages of samples D-2 and D-3). These values are typical of Cherokee Group coals in southeastern Kansas (Brady and Hatch, 1977) and rank the Rowe and Dry Wood as high-volatile A, bituminous coals (American Society for Testing Materials, 1978).

The average ash content of the Dry Wood coal on an as-received basis was 25.5 percent compared to 18.0 percent for the Rowe coal (Table 3). Both of these values are higher than the 13.7 percent average ash content of southeastern Kansas coal. The high ash contents of these 2 coals are a result of the higher-than-normal amounts of silt and clay that were deposited with the organic material that formed these particular coals. A negative result of the high ash contents of the Rowe and Dry Wood coals is lower heats of combustion. The average heat of combustion of 10,310 Btu/lb for the Dry Wood coal on an as-received basis is less than the 11,473 Btu/lb for the Rowe coal and both of these values are well below the 12,177 Btu/lb average for southeastern Kansas coal.

The average sulfur content of 10.3 percent for the Dry Wood coal on an as-received basis compares quite well with the 9.7 percent for the Rowe coal (Table 3). These values are well above the 4.0 percent average sulfur content of southeastern Kansas coal. As shown by the forms of sulfur (Table 4), most of the sulfur in the Rowe and Dry Wood coals is pyritic. On as as-received basis, the average amount of total

Table 3. Proximate and ultimate analyses, and heats of combustion for the Rowe and Dry Wood coals.

		Proximate Analysis				Ultimate Analysis					Heat of Combustion	
Sample Site	Type[a]	Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Kcal/kg	Btu/lb
		%										
Rowe												
R-1	A	2.3	33.4	43.3	21.0	4.1	57.6	0.9	4.1	12.3	6,090	10,970
	B	---	34.2	44.3	21.5	3.9	59.0	0.9	2.1	12.6	6,240	11,230
	C	---	43.5	56.5	---	5.0	75.1	1.2	2.7	16.0	7,940	14,300
R-2	A	2.5	33.9	43.8	19.8	4.7	59.9	1.0	4.4	10.2	6,290	11,320
	B	---	34.8	44.9	20.3	4.5	61.4	1.0	2.2	10.5	6,450	11,610
	C	---	43.6	56.4	---	5.7	77.1	1.3	2.8	13.1	8,100	14,570
R-3	A	3.9	34.6	48.2	13.3	4.9	65.6	1.0	8.4	6.7	6,740	12,130
	B	---	36.0	50.2	13.8	4.6	68.3	1.0	5.1	7.0	7,010	12,630
	C	---	41.8	58.2	---	5.4	79.2	1.2	6.0	8.1	8,140	14,650
Dry Wood												
D-1[b]	A	22.5	25.0	43.8	8.7	5.3	52.4	0.8	31.8	1.0	4,809	8,650
	B	---	32.3	56.5	11.2	3.6	67.7	1.1	15.2	1.3	6,210	11,170
	C	---	36.3	63.7	---	4.0	76.2	1.2	17.1	1.4	6,989	12,570
D-2	A	2.5	31.9	45.6	20.0	4.5	60.8	1.0	5.9	7.9	6,290	11,330
	B	---	32.7	46.8	20.5	4.3	62.4	1.0	3.8	8.1	6,450	11,620
	C	---	41.2	58.8	---	5.4	78.5	1.3	4.7	10.1	8,120	14,620
D-3	A	3.7	28.2	37.0	31.1	3.8	47.8	0.8	3.7	12.8	5,160	9,290
	B	---	29.3	38.4	32.3	3.5	49.6	0.8	0.4	13.3	5,360	9,650
	C	---	43.3	56.7	---	5.2	73.3	1.2	0.6	19.6	7,910	14,250

[a] Determinations are reported 3 ways: A) as-received basis; B) moisture-free basis; and C) moisture- and ash-free basis.

[b] Sample D-1 was determined to be from a weathered zone.

Table 4. Air-dried loss, forms of sulfur, free swelling index, and ash-fusion temperatures for the Rowe and Dry Wood coals.

			Forms of Sulfur				Ash Fusion-Temperature, °C		
Sample Site	Type[a]	Air-dried loss	Sulfate	Pyritic	Organic	Free Swelling Index	Initial Deformation	Softening	Fluid
		%							
Rowe									
R-1	A	0.7	.70	10.73	.86	7.5	1,315	1,375	1,420
	B	---	.72	10.98	.88				
	C	---	.91	13.99	1.12				
R-2	A	0.5	.71	8.43	1.07	8.5	1,270	1,325	1,380
	B	---	.73	8.65	1.10				
	C	---	.91	10.85	1.38				
R-3	A	1.8	.69	5.18	.85	9.0	1,170	1,225	1,290
	B	---	.72	5.39	.88				
	C	---	.83	6.26	1.03				
Dry Wood									
D-1[b]	A	16.8	.01	.06	.92	0	1,235	1,295	1,345
	B	---	.01	.08	1.18				
	C	---	.01	.08	1.33				
D-2	A	0.5	.48	5.97	1.41	8.5	1,175	1,215	1,265
	B	---	.49	6.12	1.45				
	C	---	.62	7.70	1.82				
D-3	A	1.1	.96	8.88	2.95	4.0	1,070	1,125	1,175
	B	---	1.00	9.22	3.06				
	C	---	1.47	13.62	4.52				

[a] Determinations are reported 3 ways: A) as-received basis; B) moisture-free basis; and C) moisture- and ash-free basis.

[b] Sample D-1 was determined to be from a weathered zone.

Table 5. Major, minor, and trace-element composition of the Rowe and Dry Wood coals.^{a}

Sample Site	Si	Al	Ca	Mg	Na	K	Fe	Ti	Cl	Mn	P	Ag	As	B
	%									ppm				
Rowe														
R-1	1.8	1.1	.064	.036	.019	.15	7.5	.053	.038	101	414	0^{b}	41	9
R-2	2.3	1.2	.059	.045	.021	.14	6.3	.068	.036	69	394	0	39	12
R-3	1.7	1.1	.14	.038	.020	.095	4.9	.044	.028	54	306	0	25	27
Dry Wood														
D-1^{d}	2.2	1.2	.48	.14	.048	.16	2.3	.088	.023	222	253	.8	4	8
D-2	3.5	2.3	.47	.052	.017	.21	5.3	.073	.042	81	460	.4	27	10
D-3	3.2	1.7	.60	.077	.017	.23	7.0	.056	.064	124	710	0	31	0

Sample Site	Ba	Be	Cd	Ce	Co	Cr	Cu	F	Ga	Ge	Hg	La	Li	Mo
	ppm													
Rowe														
R-1	19	3	<.19	0	13	13	40	40	--^{c}	9	.21	0	9.6	0
R-2	27	3	<.18	0	5	12	31	55	5	12	.20	0	24	0
R-3	70	2	.2	0	10	14	42	30	4	14	.14	0	12	0
Dry Wood														
D-1	80	2	.9	0	6	23	37	105	3	6	.46	8	5.6	2
D-2	31	2	16	0	63	15	42	75	10	4	.23	15	12	0
D-3	32	1.5	158	0	32	16	75	65	32	6	.83	22	10	0

Sample Site	Nb	Nd	Ni	Pb	Sb	Sc	Se	Sr	Th	U	V	Y	Yb
	ppm												
Rowe													
R-1	0	--	56	169	.9	2	3.1	56	<3.0	.9	19	9	--
R-2	0	--	27	215	.6	2	2.7	36	<3.0	.6	18	12	--
R-3	0	--	28	167	.6	2	3.3	42	<3.0	.8	28	14	--
Dry Wood													
D-1	2	23	23	52	1.3	8	3.2	80	<3.0	6.7	34	80	8
D-2	0	42	105	48	1.7	4	4.5	31	<3.0	1.6	31	63	6
D-3	0	0	97	145	1.5	3	3.0	97	<3.0	1.7	32	48	--

Sample Site	Zn	Zr
	ppm	
Rowe		
R-1	38	9
R-2	16	18
R-3	142	14
Dry Wood		
D-1	89	17
D-2	5,335	21
D-3	50,968	16

[a] As, F, Hg, Sb, Se, Th, and U values from direct determinations on oven air-dried (32°C) coal (<80 mesh); other values calculated from analyses of ash.

[b] None detected.

[c] Not determined.

[d] Sample D-1 was from a weathered zone.

sulfur present as pyritic sulfur is 83.6 percent for the Rowe and 72.1 percent for the Dry Wood coal. The lower percentage of pyritic sulfur in the Dry Wood coal is a result of the higher organic sulfur content in this coal. Pyrite is present in these coals as bands up to 1 cm thick, as thin films along bedding planes, as filling material in fractures, as individual nodules, and as small disseminated grains.

The elemental compositions of the Rowe and Dry Wood coals given in Table 5 show differences within and between the coals that in part reflect variations in the transport and deposition of inorganic materials in the respective peat swamps from which these coals developed. Elements showing variations within both the Rowe and Dry Wood coals are calcium, potassium, iron, titanium, manganese, phosphorus, arsenic, boron, barium, cobalt, copper, fluoride, nickel, lead, strontium, and zinc. In addition to these elements the Dry Wood coal also showed variations in magnesium, silver, cadmium, gallium, mercury, lanthanum, neodymium, and yttrium.

Compared to the Rowe coal, the Dry Wood coal contains higher amounts of 31 of the 43 elements analyzed. Of these 31 elements those showing significantly higher amounts are calcium, manganese, phosphorus, cadmium, cobalt, copper, fluoride, gallium, mercury, lanthanum, nickel, strontium, and zinc. The Rowe coal contains higher amounts of 8 elements. These are sodium, arsenic, boron, barium, beryllium, germanium, lithium, and lead. Of these 8 elements only 3 (boron, germanium, and lead) show significantly higher amounts. Elements analyzed for, but not detected, in both coals were cerium, molybdenum, and niobium. These 2 coals contain nearly equal amounts of iron.

A convenient way of measuring the relative enrichment of elements in coal is by comparison to their average crustal abundance. This is done by looking at values calculated by dividing an element's average concentration in coal by that element's average crustal abundance. These are known as enrichment factors. Elements enriched in the Rowe and Dry Wood coals are shown in Table 6.

The Rowe coal is slightly enriched in iron, chloride, boron, mercury, and antimony; moderately enriched in germanium; and markedly enriched in arsenic, lead, and selenium. The Dry Wood coal is slightly enriched in iron, chloride, cobalt, gallium, germanium, and nickel; mod-

Table 6. Elements enriched in the Rowe and Dry Wood coals with respect to their average composition in the earth's crust.[a]

Element	Enrichment Factor	
	Rowe	Dry Wood
Fe	1.1	1.1
Cl	2.6	4.1
As	19.4 (6.6)[b]	16.1
B	1.9 (5)	
Cd		435
Co		1.9
Ga		1.4
Ge	8.0	3.3
Hg	2.2 (1.2)	6.6
Ni		1.3
Pb	14.7 (1.5)	7.7
Sb	3.5 (4)	8.0
Se	60 (56)	74
Y		1.7
Zn		402

[a] Calculated using values from Taylor, 1964.

[b] Numbers in parentheses are reported enrichment values for Interior Province coal (from Commission on Natural Resources, 1979).

erately enriched in mercury, lead, and antimony; and markedly enriched in cadmium, arsenic, selenium, and zinc. Of the elements listed above, those of concern from a health and environmental aspect that show significantly marked enrichment are arsenic, cadmium, germanium, mercury, lead, antimony, selenium, and zinc. These are all potentially hazardous elements but with varying degrees of concern. Those of greatest concern are arsenic, cadmium, mercury, lead, and selenium. Zinc is of moderate concern, germanium is of minor concern, and antimony is of no immediate concern (U.S. National Committee for Geochemistry, 1980).

As shown in Table 5, the Dry Wood coal contains extremely high amounts of cadmium and zinc. The higher-than-normal amounts of these elements in the Dry Wood coal have been documented previously (Hatch, Avcin, and others, 1976). These higher amounts of cadmium and zinc seem to be related to sphalerite mineralization in the Tri-State Mining District (southeastern Kansas, southwestern Missouri, and northeastern Oklahoma). The association of cadmium and zinc in sphalerite-filled fractures in Illinois coals has been observed and discussed by Hatch, Gluskoter, and Lindahl (1976) and Gluskoter and others (1977).

Comparison of Rowe and Dry Wood Coals from Kansas with Interior Province Coals

Table 7 compares the average proximate and ultimate analyses, heats of combustion, and forms of sulfur (on an as-received basis) of the Rowe and Dry Wood coals from Kansas with Interior Province coal. Table 8 compares their average elemental compositions. The element averages for Interior Province coal are based on 143 coal samples (Swanson and others, 1976). Of the 143 samples, 118 (82 percent) were from the Western Region of the Province (Iowa, Nebraska, Missouri, Kansas, Oklahoma, and Arkansas). Of the remaining 25 samples, 3 were from the Northern Region of the Province (Michigan) and 22 were from the Eastern Region (Indiana). The averages for proximate and ultimate analyses, heats of combustion, and forms of sulfur for Interior Province coal are based on only 90 samples. The reduction in the number of samples resulted from the common practice by the Coal Analysis Section of the U.S. Department of Energy of compositing samples from the same mine location (outcrop, mine highwall, or drill core) or the same coal bed within an area. Since the majority of the Interior Province samples are from the Western Region, the averages better reflect the coal from that Region; and it would be more appropriate to refer to the values as representative of Western Interior Province coal.

The 25.5 percent average ash content of the Dry Wood coal is twice that of the 12.6 percent average of Interior Province coal. Its average carbon content is 10.9 percent less than the Province average, while that of the Rowe coal is only 4.2 percent less. Because of its higher ash content the Dry Wood coal has a lower average heat of combustion than Interior Province coal, while the average for the Rowe coal is essentially the same. The Rowe coal contains 5.8 percent more average total sulfur than the Province average and the Dry Wood contains 6.4 percent more. Most of the sulfur found in Interior Province coal is present as pyritic sulfur, and the Rowe and Dry Wood coals are no exception. However, their average

Table 7. Average proximate and ultimate analyses, and forms-of-sulfur for the Rowe and Dry Wood coals from Kansas and Interior Province coal on an as-received basis.[a]

	Proximate Analysis				Ultimate Analysis					Heat of Combustion	
Coal	Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur		
	%									Kcal/kg	Btu/lb
Rowe	2.3	33.9	45.1	18.0	4.6	61.0	1.0	5.6	9.7	6,373	11,473
Dry Wood	3.1	30.0	41.3	25.5	4.1	54.3	.9	4.8	10.3	5,725	10,310
Interior Province	7.2	32.2	48.0	12.6	4.9	65.2	1.2	12.2	3.9	6,431	11,580

Forms of Sulfur

Coal	Sulfate	Pyritic	Organic
	%		
Rowe	.70	8.11	.93
Dry Wood	.72	7.42	2.18
Interior Province	.27	2.37	1.25

[a] Kansas Rowe values were averaged from 3 samples (R-1, 2, and 3) and Kansas Dry Wood values were averaged from 2 samples (D-2 and D-3); sample D-1 was from a weathered zone. Interior Province values were averaged from 90 coal samples (Swanson and others, 1976).

Table 8. Average major, minor, and trace-element composition of the Rowe and Dry Wood coals from Kansas and Interior Province coal.[a,b]

Coal	Si	Al	Ca	Mg	Na	K	Fe	Ti	Mn	As	B	Ba	Be
	%								ppm				
Rowe	1.9	1.1	.088	.042	.020	.13	6.2	.055	75	35	19	39	2.5
Dry Wood	3.3	2.0	.53	.064	.017	.22	6.1	.064	102	29	5	31	1.7
Interior Province	2.0	.97	1.2	.089	.035	.16	3.3	.052	138	21	100	70	3.0

Coal	Cd	Co	Cr	Cu	F	Ga	Hg	Li	Mo	Nb	Ni	Pb	Sb
	ppm												
Rowe	<.19	9	13	38	42	4	.18	15	0[c]	0	37	184	.7
Dry Wood	87	47	16	58	70	21	.53	11	0	0	101	96	1.6
Interior Province	7.1	7	15	20	71	5	.14	11	5	1.5	30	55	1.7

Coal	Sc	Se	Sr	Th	U	V	Y	Yb	Zn	Zr
	ppm									
Rowe	2	3.0	45	<3.0	.8	22	12	0	65	14
Dry Wood	4	3.7	64	<3.0	1.6	31	55	3	28,151	18
Interior Province	3	4.6	50	5.2	3.3	20	10	.7	373	15

[a] As, F, Hg, Sb, Se, Th, and U are from direct determination on oven air-dried (32°) coal (<80 mesh); other values calculated from analyses of ash.

[b] Kansas Rowe values were averaged from 3 samples (R-1, 2, and 3), and Kansas Dry Wood samples were averaged from 2 samples (D-2 and D-3); sample D-1 was from a weathered zone. Interior Province values were averaged from 143 coal samples (Swanson and others, 1976).

[c] None detected.

concentrations of pyritic sulfur are 3 times that of Interior Province coal.

Both the Rowe and Dry Wood average more iron, copper, mercury, nickel, and lead than Interior Province coal. The Dry Wood coal also contains more silicon, aluminum, potassium, titanium, cadmium, cobalt, gallium, strontium, vanadium, yttrium, ytterbium, and zinc.

To date the only trace elements documented to be enriched in Interior Province coal in relation to their average crustal abundance are arsenic, boron, mercury, molybdenum, lead, antimony, and selenium (Commission on Natural Resources, 1979). The average enrichment values for these elements in Interior Province coal are shown in parentheses in Table 6 along with those for the Rowe and Dry Wood coals at the mine site. Comparisons of these enrichment values show the Rowe coal is more enriched in arsenic, mercury, and lead than Interior Province coal by factors of 2.9, 1.8, and 9.8, respectively. The Dry Wood coal is enriched more in arsenic, mercury, lead, and antimony by factors of 2.4, 5.5, 5, and 2, respectively.

Comparison of Rowe and Dry Wood Coals from Kansas and Missouri

Table 9 compares the average proximate and ultimate analyses and heats of combustion (on an as-received basis) of the Rowe and Dry Wood coals from the mine site and from Barton County in southwestern Missouri.* Except for the 4.0 percent average higher content of sulfur in the Rowe coal from Kansas, there are essentially no differences in the above parameters for this coal from the 2 states. As shown in Table 10, the sulfur in the Rowe coal from both states is mostly pyritic. Of the 4.0 percent greater amount of sulfur in the Rowe coal from Kansas, 3.6 percent is pyritic sulfur.

Compared to the Dry Wood coal from Missouri, the Kansas Dry Wood contains an average 10 percent more ash and 13 percent less carbon. The higher ash content results in a lower average heat value of 2,013 Btu/lb for the Kansas Dry Wood coal. The average sulfur content of the Dry Wood coal from Kansas is 5.0 percent more than that of the Missouri Dry Wood. As calculated from the forms of sulfur given in Table 10, 3.0 percent of this greater

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*It must be noted here that Missouri's spelling of the Dry Wood coal is as one word, "Drywood." For uniformity and to avoid confusion, the spelling in this report will be as two words, "Dry Wood."

Table 9. Average proximate and ultimate analyses, and heats of combustion for the Rowe and Dry Wood coals from Kansas and Missouri on an as-received basis.[a]

Coal	Proximate Analysis				Ultimate Analysis					Heat of Combustion	
	Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur		
	%									Kcal/kg	Btu/lb
Rowe											
Kansas	2.3	33.9	45.1	18.0	4.6	61.0	1.0	5.6	9.7	6,373	11,473
Missouri	2.4	33.2	46.1	18.3	4.7	64.3	1.1	5.9	5.7	6,560	11,810
Dry Wood											
Kansas	3.1	30.0	41.3	25.5	4.1	54.3	.9	4.8	10.3	5,725	10,310
Missouri	2.3	33.3	49.3	15.1	4.8	67.3	1.1	6.4	5.3	6,847	12,323

[a] Missouri Rowe and Dry Wood values were averaged from 3 samples for each coal, from data taken from Wedge and Hatch, 1980; Kansas Rowe values were averaged from 3 samples (R-1, 2, and 3), and Kansas Dry Wood values were averaged from 2 samples (D-2 and D-3); sample D-1 was from a weathered zone.

Table 10. Average air-dried loss, forms of sulfur, free swelling index, and ash fusion temperatures for the Rowe and Dry Wood coals from Kansas and Missouri on as as-received basis.[a]

		Forms of Sulfur				Ash Fusion Temperature, °C		
Coal	Air-dried loss	Sulfate	Pyritic	Organic	Free Swelling Index	Initial Deformation	Softening	Fluid
	%							
Rowe								
Kansas	1.0	.70	8.11	.93	8.3	1,252	1,308	1,363
Missouri	1.0	.29	4.46	.91	7.7	1,273	1,343	1,400
Dry Wood								
Kansas	.8	.72	7.42	2.18	6.2	1,122	1,170	1,220
Missouri	.7	.27	4.37	.66	7.8	1,202	1,250	1,293

[a] Missouri Rowe and Dry Wood values were averaged from 3 samples for each coal from data taken from Wedge and Hatch, 1980; Kansas Rowe values were averaged from 3 samples (R-1, 2, and 3), and Kansas Dry Wood values were averaged from 2 samples (D-2 and D-3); sample D-1 was from a weathered zone.

amount is pyritic sulfur. This is because the Kansas Dry Wood coal has a high organic-sulfur content.

The average elemental compositions of the Rowe and Dry Wood coals from the mine site and Missouri are compared in Table 11. The Rowe coal from Kansas averages more iron, manganese, arsenic, lead, strontium, and zinc than the Missouri Rowe. However, the Rowe coal from Missouri contains more cobalt, lithium, molybdenum, selenium, uranium, vanadium, and zircon.

The Dry Wood coal from Kansas averages more calcium, iron, manganese, arsenic, cadmium, cobalt, copper, gallium, mercury, lanthanum, neodymium, nickel, lead, strontium, yttrium, and zinc than the Missouri Dry Wood. The Dry Wood coal from Missouri does, however, contain more boron and selenium.

Summary

The Rowe and Dry Wood coals from the mine site were ranked as high-volatile A, bituminous coals. The average ash content of 25.5 percent for the Dry Wood coal is greater than the 18.0 percent for the Rowe coal and both values are higher than the 13.7 percent average of southeastern Kansas coal. As a result these 2 coals have lower average heats of combustion than the average southeastern Kansas coal. The average amounts of total sulfur in the Rowe and Dry Wood coals are 2.4 and 2.6 times higher than the 4.0 percent average of southeastern Kansas coal. Most of the sulfur is pyritic. In the Rowe coal 83.6 percent of the sulfur is pyritic and in the Dry Wood coal 72.1 percent is pyritic. Compared to the Rowe coal, the Dry Wood coal contains higher amounts of 31 of the 43 elements analyzed. Of these 31 elements, those showing significantly higher amounts are calcium, manganese, phosphorus, cadmium, cobalt, copper, fluoride, gallium, mercury, lanthanum, nickel, strontium, and zinc. Of the 8 elements that have higher concentrations in the Rowe coal, only 3--boron, germanium, and lead--show significantly higher amounts. Trace elements markedly enriched in the Rowe coal (on an average basis) in relation to their crustal abundance are arsenic, lead, and selenium. In addition to being markedly enriched in arsenic and selenium, the Dry Wood coal is also markedly enriched in cadmium and zinc. All the above-mentioned trace elements are potentially hazardous in varying degrees to human health and the environment. The extremely high amounts of cadmium and zinc in the Dry Wood coal seem to be related to sphalerite mineralization in the Tri-State Mining District.

The average ash content of 25.5 percent for the Dry Wood coal from Kansas is twice the 12.6 percent average of Interior Province coal. The average carbon content of the Kansas Dry Wood is 10.9 percent less than the Province average. As a result the Kansas Dry Wood has a lower average heat of combustion than Interior Province coal. Both the Rowe and Dry Wood coals contain more average total sulfur than Interior Province coal by 5.8 and 6.4 percent respectively and their average pyritic sulfur contents are both 3 times the Province average. Both the Rowe and Dry Wood coals average more iron, copper, mercury, nickel, and lead than Interior Province coal. Additionally, the Dry Wood coal also contains more silicon, aluminum, potassium, titanium, cadmium, cobalt, gallium, strontium, vanadium, yttrium, ytterbium, and zinc. Comparisons of reported average enrichment values of elements in Interior Province coal based on crustal abundance and those calculated for the Rowe and Dry Wood coals at the mine site show the Rowe coal is more enriched in arsenic, mercury, and lead by factors of 2.9, 1.8, and 9.8, respectively. The Dry Wood coal is more enriched in arsenic, mercury, lead, and antimony by factors of 2.4, 5.5, 5, and 2, respectively.

Compared to the Rowe coal from Missouri on an average basis, the Kansas Rowe contains 4.0 percent more sulfur, of which 3.6 is pyritic sulfur, and more iron, manganese, arsenic, lead, strontium, and zinc. The Missouri Rowe contains more cobalt, lithium, molybdenum, selenium, uranium, vanadium, and zircon. The Dry Wood coal from Kansas averages 10 percent more ash, 13 percent less carbon, 5 percent more sulfur, and more calcium, iron, manganese, arsenic, cadmium, cobalt, copper, gallium, mercury, lanthanum, neodymium, nickel, lead, strontium, yttrium, and zinc than the Missouri Dry Wood. However, the Missouri Dry Wood contains more boron and selenium.

Table 11. Average major, minor, and trace-element composition of the Rowe and Dry Wood coals from Kansas and Missouri.[a,b]

Coal	Si	Al	Ca	Mg	Na	K	Fe	Ti	Cl	Mn	P	Ag	As	B
	%									ppm				
Rowe														
Kansas	1.9	1.1	.088	.042	.020	.13	6.2	.055	.034	75	371	0[c]	35	19
Missouri	3.2	1.7	.12	.066	.024	.29	3.1	.094	--[d]	38	---	.1	16	17
Dry Wood														
Kansas	3.3	2.0	.53	.064	.017	.22	6.1	.064	.053	102	585	.2	29	5
Missouri	2.5	1.2	.064	.051	.015	.21	3.1	.070	--	27	---	.1	10	15

Coal	Ba	Be	Cd	Ce	Co	Cr	Cu	F	Ga	Ge	Hg	La	Li	Mo
	ppm													
Rowe														
Kansas	39	2.5	<.19	0	9	13	38	42	4	12	.18	0	15	0
Missouri	35	2	<.18	--	12	19	30	49	8	10	.14	<9	28	5
Dry Wood														
Kansas	31	1.7	87	0	47	16	58	70	21	5	.53	19	11	0
Missouri	28	1.5	<.15	0	15	15	16	80	7	6	.13	2	13	0

Coal	Nb	Nd	Ni	Pb	Sb	Sc	Se	Sr	Th	U	V	Y	Yb
	ppm												
Rowe													
Kansas	0	--	37	184	.7	2	3.0	45	<3.0	.8	22	12	0
Missouri	2	--	45	60	.8	4	8.2	20	<3.0	8.0	35	9	1
Dry Wood													
Kansas	0	21	101	96	1.6	4	3.7	64	<3.0	1.6	31	55	3
Missouri	1.5	0	40	32	.4	4	6.4	20	<3.0	1.2	32	7	.5

Coal	Zn	Zr
	ppm	
Rowe		
Kansas	65	14
Missouri	19	20
Dry Wood		
Kansas	28,151	18
Missouri	16	19

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[a] As, F, Hg, Sb, Se, Th, and U are from direct determinations on oven-dried (32°C) coal (<80 mesh); other values calculated from analyses of ash.

[b] Missouri Rowe and Dry Wood values were averaged from 4 samples for each coal from data taken from Wedge and Hatch, 1980; Rowe values were averaged from 3 samples (R-1, 2, and 3), Kansas Dry Wood values were averaged from 2 samples (D-2 and D-3); sample D-1 was from a weathered zone.

[c] None detected.

[d] Not determined.

SOIL

by J. E. Welch and H. P. Dickey

Introduction

Surface coal mining drastically alters the natural environment in a mined area. Vegetation is removed, topographic features and characteristics are changed, and the natural soil profile is destroyed. Soil is a natural resource and in the long term its value may equal or exceed that of coal. Natural processes of soil formation are slow and can take decades to form new soil (Caspall, 1975). To hasten the process and put mined land back into productive use as quickly as possible, man implements his own land reclamation procedures and reconstructs a new soil.

One of the major problems associated with minesoils is the generation of acid from oxidation of iron sulfides in the disturbed overburden when exposed to the atmosphere. During weathering, the sulfide in pyrite and marcasite (both FeS_2) oxidizes first to sulfur, releasing ferrous ions. In the next step of the oxidation, sulfur is oxidized to sulfate and hydrogen ions are produced, decreasing the pH of the soil solution. The ferrous iron will remain in solution for quite some time, as long as the soil solution is acidic ($pH \leq 4$). The oxidation rate at the iron-sulfide surface depends primarily on the availability of ferric iron ions. The production of ferric ions in acid solutions is greatly facilitated by iron-oxidizing bacteria. After the acidic water leaves the sulfide mineral surfaces, the dissolved ferrous iron can oxidize and hydrolyze to precipitate ferric oxyhydroxides of hydrous ferric sulfate minerals in the soil, depending on the acid, iron, and sulfate content of the soil solution (Nordstrom and others, 1979). This process further acidifies the soil solution. Neutralization of the acid in minesoils with lime or limestone increases the oxidation rate of ferrous iron and supplies calcium, which can combine with sulfate to precipitate gypsum ($CaSO_4 \cdot 2H_2O$). The overall reaction for the weathering of pyrite (the most common iron sulfide) and the precipitation of ferric oxyhydroxides can produce 4 moles of acidity (H^+) for every mole of pyrite oxidized:

$$FeS_2 + \frac{7}{2} H_2O + \frac{15}{4} O_2 \rightarrow Fe(OH)_3$$

$$+ 2SO_4^{2} + 4H^+.$$

In minesoils the rate of this process is usually inversely related to the depth in the soil due to the decreasing availability of oxygen with depth. Many studies on the acidity aspect of minesoils appear in the reclamation literature (Gleason, 1979).

To date, however, little research has been done on comparing properties of minesoils to natural soils. Minesoil properties need to be compared to the properties of the natural soils to evaluate the impact of surface mining and reclamation practices on land in order to devise sound management and land-use practices on minesoils. The Clemens Coal Company site provided such an opportunity to investigate the effects of surface coal mining and reclamation on land.

Experimental Procedures

For purposes of this study, the mining area was subdivided into 7 fields. All fields and the location of sample sites within the appropriate fields, as well as type and date of sampling, are shown in Figure 10. Core samples of natural soil were obtained using a hydraulic Bull Soil Sampler equipped with a 4-foot core, 1-1/2 inches in diameter. Three core samples were taken at each site at depths of 0-16 inches, 0-4 feet, and 4-8 feet. The cores were taken at the same time the deep 4-inch cores of the rock units were bored, and were located within 2 to 3 feet of the deep bore holes. Samples below 8 feet were taken for x-ray diffraction analysis from the deep 4-inch core at site C-2 at 1-foot intervals from 9 to 15 feet.

Spade samples for fertility analysis of minesoil were dug to plow depth (6 inches) with a sharpshooter spade. Each spade sample was a composite of 5 samples taken at each site around the perimeter of a circle 5 feet in diameter. Auger samples of the minesoil were taken to a depth of 40 inches using a 3-1/2-inch diameter standard hand bucket auger, or in some cases by channel sampling of the 40-inch vertical wall of a hole dug with the sharpshooter spade. Both spade and auger sampling sites selected were determined by extensive observations to be representative of the variability of the minesoil. Auger samples of the minesoil were sealed in containers at the site for later gravimetric moisture determinations.

The mineralogy of the Parsons soil and minesoil spade samples was determined by x-ray diffractom-

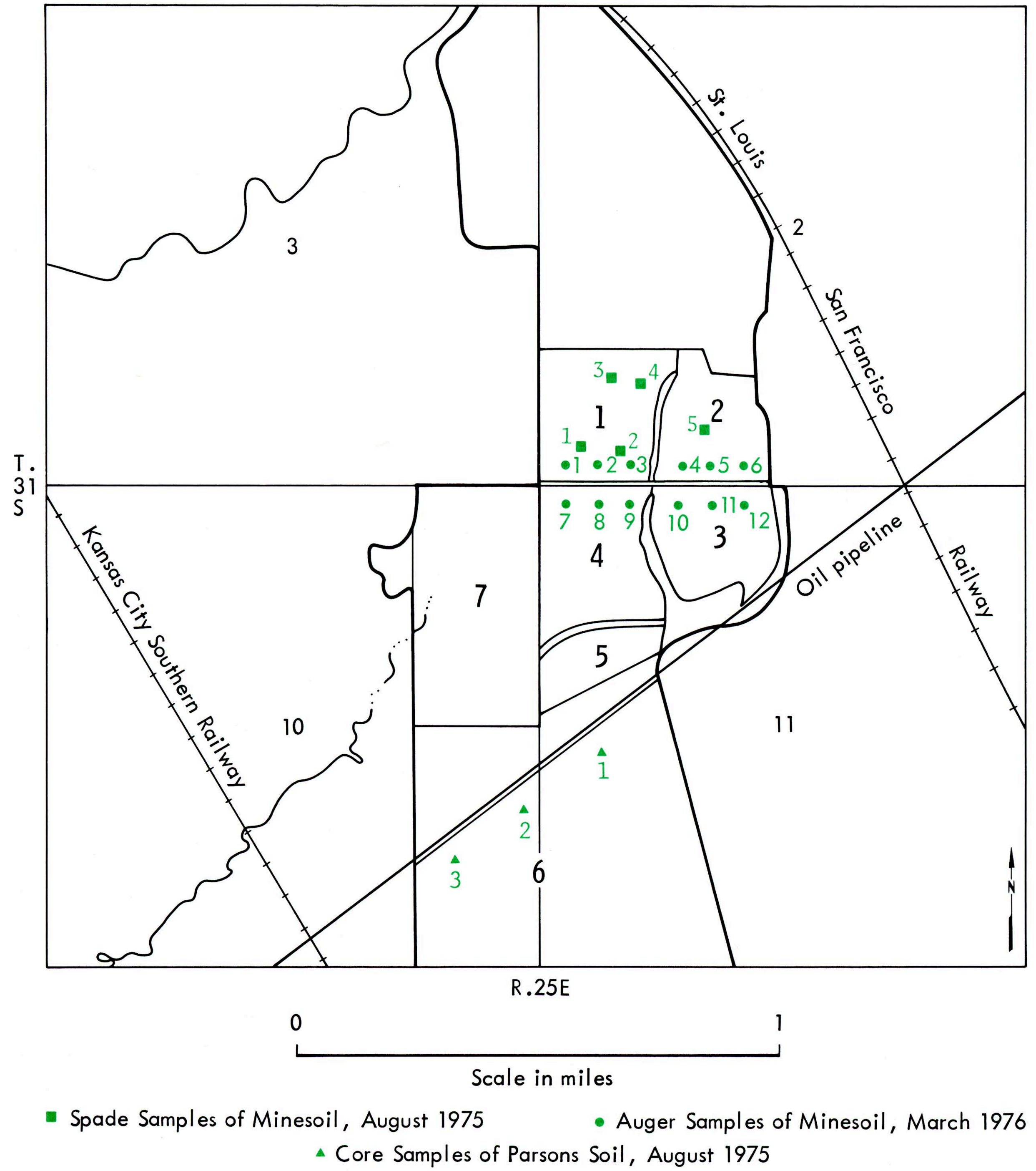

Figure 10. *Map of location of soil samples taken for physical and chemical analyses of minesoil. Auger samples were located 200 feet north and south of section-line road, 500 feet apart. Core samples were located 350 feet south of pipeline, 600 feet apart.*

etry. Samples were dried, pulverized to a fine powder, and hand packed into aluminum sample holders. All samples were examined on a Norelco diffractometer using CuKα radiation and a single-crystal monochromator.

Portions of the Parsons soil core and minesoil spade samples were sent to the Soil Testing Laboratory of the Department of Agronomy and the Cooperative Extension Service at Kansas State University for chemical analysis and fertility evaluation. Chemical analyses of minesoil auger samples were performed by the Geochemistry Section of the Kansas Geological Survey, using the procedures of the Kansas State Soil Testing Laboratory.

Procedures used in the chemical analysis of soil samples are given in Table 12. All soil samples were first air-dried, and then ground to pass a 2 mm sieve. Subsequently all chemical analyses were done on a <2 mm size fraction. Aliquots of the $NH_4C_2H_3O_2$ leachates used for determinations of exchangeable calcium and magnesium were made to contain 1 percent lanthanum to eliminate chemical interferences during analysis by atomic absorption. Lithium was added to give a concentration of 0.1 percent in aliquots of the $NH_4C_2H_3O_2$ leachates used for determinations of exchangeable calcium and potassium, to suppress ionization. Exchangeable acidity was determined by the $BaCl_2$-triethanolamine II procedure (U.S. Department of Agriculture, Soil Conservation Service, 1972). Cation exchange capacity was calculated by summation of exchangeable bases and acidity. Base saturation was calculated by dividing the sum of the exchangeable bases by the cation exchange capacity.

Particle-size distribution of the <2 mm size fraction of soil was determined by the pipette method (U.S. Department of Agriculture, Soil Conservation Service, 1972). With this procedure, sand-size particles are separated from silt- and clay-size particles in suspension by wet sieving through a 300-mesh sieve (50 micron). The sand is then dried and sieved into different size fractions and weighed. The amounts of silt- and clay-size particles are determined from aliquots pipetted from a suspension held in a sedimentation cylinder, at depths dependent on the temperature of the suspension and time of settling according to Stoke's Law. After evaporating the water by oven drying at 105°C, the silt and clay are weighed and, through appropriate calculations, the amounts of total silt and clay of the sample are determined.

Table 12. Procedures used in chemical analysis of soil samples.[a]

Parameter	Extractant	Method
Available N		
NH_4	2N KCl 1:10 soil/solution	Steam distillation with MgO into H_3BO_3 and titration with standard acid
NO_3	2N KCl 1:10 soil/solution	MgO and Devarda's Alloy, steam distillation into H_3BO_3 and titration with standard acid
Available P	0.025N HCl and 0.03N NH_4F 1:10 soil/solution (Bray Method)	Colorimetric (Fiske-Subbarrow Method)
Available K	1N $NH_4C_2H_3O$ 1:5 soil/solution	Flame emission
Exchangeable Bases	1N $NH_4C_2H_3O$ 1:5 soil/solution	
Ca		Atomic absorption
Mg		Atomic absorption
Na		Flame emission
K		Flame emission
Available Micronutrients	0.005 M DTPA 1:2 soil/solution (Lindsay method)	
Zn		Atomic absorption
Fe		Atomic absorption
Cu		Atomic absorption
Mn		Atomic absorption
B	Hot water (boiling) 1:2 soil/water (Berger and Troug method)	Colorimetric (curcurmin)
pH	Distilled-deionized water 1:1 soil/water	pH meter
	Reagent	
Lime Requirement	Equilibrium with SMP buffer solution 1:1:2 soil/water/solution	pH meter
Organic Matter	Wet oxidation with 1N $K_2Cr_2O_7$ and conc. H_2SO_4 1:10:20 soil/$K_2Cr_2O_7$/H_2SO_4 (Walkley-Black Method)	Colorimetry (qualitative) (Graham Method)

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[a] Procedures used by Kansas State University Soil Testing Laboratory.

Particle-size distribution of the >2 mm size fraction of soil was determined gravimetrically. After drying, samples were separated into different size ranges by sieving. The material remaining on each sieve was then weighed. The distributions of the >2 mm (coarse particles) and <2 mm (fine particles) size fractions were expressed as weight percentages.

Moisture content of soil was determined by the direct gravimetric method, which measures the loss of weight of a soil sample after oven drying at 105°C. The amount of moisture was then expressed as a percent of the oven dry soil (Gardner, 1965).

Soil Types Present at the Mining Site

Soils present on the mining site are shown in Figure 11. The Parsons silt loam, 1 to 3 percent slopes (map symbol Pb), is the predominant soil type, with lesser amounts of Breaks-Alluvial land complex (map symbol Bk); Dennis silt loam, 1 to 4 percent slopes (map symbol De); and Bates loam, 1 to 4 percent slopes (map symbol Ba), also present. The Breaks-Alluvial land complex, the Bates loam, and Dennis silt loam occupied considerably smaller acreage within the mining area, compared to the Parsons silt loam. Thus, it would have been impractical to compare such a heterogeneous mixture as minesoil to soils whose input to the minesoil was small compared to the Parsons soil. Therefore, comparisons between properties of minesoil and natural soil were based on the properties of Parsons soil. To adequately compare the properties of Parsons soil and minesoil required extensive profile sampling by depth in both the Parsons soil and minesoil. This was done for the minesoil, but not for the Parsons soil. Therefore, other published and unpublished data on the Parsons soil were utilized.

Field 6 of Figure 10 is the unmined field within the study area (also shown in Pl. 2). The 3 core profiles described from this field were of the Parsons soil and are given in Appendix C. The field descriptions of the 3 cores are very similar to each other and to the field description of the Parsons soil in Jarvis and others (1959) (see Appendix F) and the U. S. Department of Agriculture, Soil Conservation Service (1981) (see Appendix G). The same recognizable surface (A) and subsurface (B and C) horizons were present at essentially the same depths. Other diagnostic

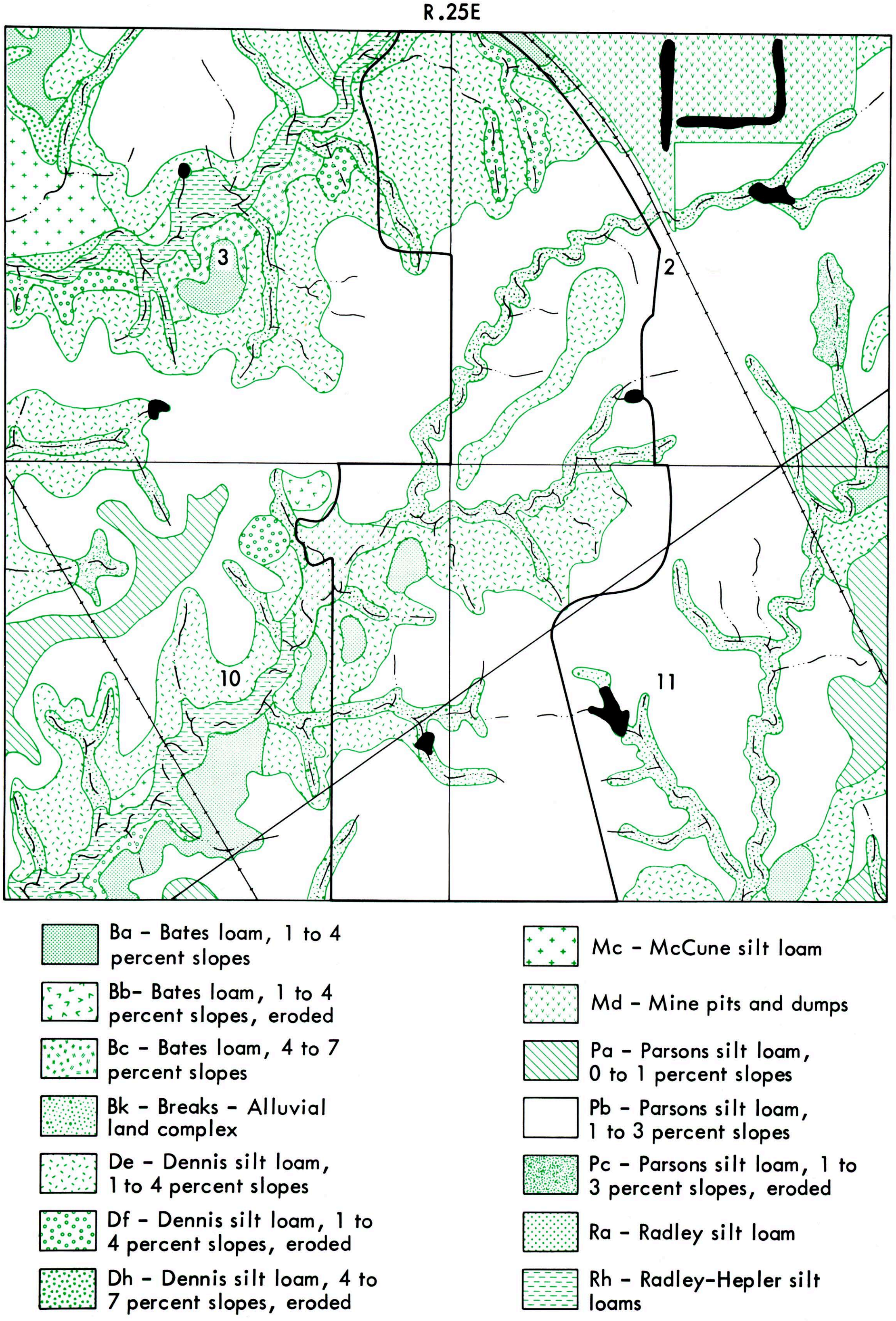

Figure 11. Map of soils of Fields 1-7 before mining. From Soil Survey of Crawford County, Kansas (U.S. Department of Agriculture, Soil Conservation service, 1973). Scale 1:20,000.

properties of horizons, such as color, texture, structure, consistence, pH, thickness, and distinctness and topography of horizon boundaries, were also essentially the same for the respective horizons. Based on field descriptions and chemical and physical data reported later in this report, the Parsons soil was classified as a fine, mixed, thermic, Mollic Albaqualf.

The lack of variation among the field descriptions of the Parsons soil at the 3 separate locations is not surprising when one considers that all 3 locations are in approximately the same position on the landscape. This landscape consists of nearly level, upland areas that are relatively stable and free of erosion and have been subjected to the same pattern and intensity of weathering for the same period of time. In addition, the parent material at the 3 locations is identical. The Parsons soil formed in alluvium material weathered from shale.

Properties of Parsons Soil

Mineralogy

The data from the x-ray diffraction analysis of the soil cores at depths of 0-16 inches, 0-4 feet, and 4-8 feet showed no significant differences with depth within and among the 3 cores. All the patterns indicated mainly quartz, feldspars, and clay minerals. Comparisons of these diffraction patterns to those of rock core C-2 confirmed that siltstones and shales form the parent rock of the Parsons soil. Absence of the intense, narrow, sharp peaks for the clay minerals in the soil compared to those of the rock units is due mainly to weathering of clay particles to smaller sizes and/or partial coating with mineral precipitates such as iron-manganese oxyhydroxides. Iron-manganese oxide stains were observed in the soil cores from 15-120 inches (Appendix C).

Those samples from drill cuttings obtained over the depth interval of 9-15 feet that were examined by x-ray diffraction showed a gradual increase with depth in the diffraction-line intensity for clay minerals. These results suggest an increase in clay-particle size with depth. An absence of weathering of clay particles at these depths, and/or smaller amounts of iron oxyhydroxide coatings on clay particles at these depths, would account for this observation.

From the x-ray diffraction data and the field descriptions, it was concluded that extensive weathering extended to a depth of approximately 9 feet, and that no extensive alteration of clay particles had occurred.

Chemistry

Extensive leaching results in the removal of soluble cations and anions and clay particles from surface (A) horizons and their deposition and accumulation in subsurface (B) horizons. As the more common soluble cations are leached, hydrogen and aluminum ions increase in the soil solution, causing an increase in acidity and hence lowering of pH. Chemical analysis confirms that these processes have occurred in the Parsons soil (Table 13). The pH of the surface horizon, based on data from the 0-16 inch depth of each core site, ranged from very strongly acid (4.5-5.0) to medium acid (5.6-6.0). Soluble cations such as calcium, manganese, sodium, and potassium show accumulation with depth. Less-soluble elements such as zinc, iron, copper, and manganese were concentrated more in the surface horizon. Also, the distribution of the less-soluble elements with depth in the subsoil was essentially constant. This pattern is typical of plant recycling of these trace elements. These elements are taken up by plants and deposited in the upper portion of the soil profile upon the death of the plant, where they accumulate due to their limited solubility (Tisdale and Nelson, 1975).

Fertility

The chemical analysis of the Parsons soil from the unmined field is given in Table 13. To evaluate the fertility status, the data of the 0-16 inch depth of the 3 core sites were averaged.

The exchangeable calcium and magnesium averaged 3.2 and 1.1 milliequivalents/100 grams of soil respectively. The recommended ranges of exchangeable calcium and magnesium required for adequate growth of most crops on the Parsons soil, based on recommendations of Graham (1959) and using the cation exchange capacity of 20 meq/100 grams of soil for the Parsons soil, are 13-16 meq/100 grams of soil for calcium and 1.2-2.4 for magnesium. These data show the Parsons soil to be quite low in calcium and possibly low in magnesium. However, it must be noted that adequate plant growth can occur at magnesium concentrations less than the lower limit recommended by Graham (1959), as shown by Adams and Henderson (1962). Using the recommendations of both and a cation exchange capacity of 20

Table 13. Chemical analysis of the Parsons soil from the unmined area. (Analyses by the Soil Testing Laboratory, Kansas State University.)

Sample[a] Site	pH (1:1)	Lime Require- ment (lbs/ac ECC)[b]	Avail. P (lbs/ ac)[c]	Exchangeable Bases				Organic Matter (wt%)	DTPA[e]				Avail. N		Avail. B[g] (ppm)
				Ca	Mg	Na	K		Zn	Fe	Cu	Mn	NH_4	NO_3	
				(meq/100g)[d]					(ppm)[f]				(ppm N)		
C-1															
0-16 in.	5.4	3000	10	3.9	0.9	0.2	0.2	1.0	2.2	59.4	2.1	25.9	6.7	2.8	0.3
0-4 ft.				6.6	2.9	0.9	0.4		0.6	27.8	0.6	15.1			
4-8 ft.				7.1	3.1	1.1	0.4		0.7	24.2	1.0	13.9			
C-2															
0-16 in.	5.0	9500	20	2.5	1.5	0.2	0.2	1.7	10.7	122.2	1.2	33.5	11.5	4.8	0.2
0-4 ft.				3.9	3.1	0.7	0.3		2.7	55.0	0.6	35.4			
4-8 ft.				4.3	3.5	1.0	0.3		1.6	39.3	0.6	24.4			
C-3															
0-16 in.	5.8	2500	11	3.3	1.0	0.2	0.2	1.2	3.0	86.0	0.9	20.0	8.7	3.9	0.4
0-4 ft.				5.6	3.5	1.1	0.3		0.7	55.0	0.9	6.0			
4-8 ft.				5.9	4.2	1.7	0.4		0.6	58.0	0.9	60.8			

[a] Core samples.
[b] Pounds/acre of effective $CaCO_3$ (ECC) to raise pH to 6.8.
[c] Pounds/acre.
[d] Milliequivalents/100 grams of soil.
[e] Diethylenetriaminepentaacetic acid method.
[f] Parts per million (µg/g) on an oven-dry (105°C) soil weight basis.
[g] Hot-water-soluble boron.

meq/100 grams of soil, the concentration at which the Parsons soil would be considered low in magnesium is 0.8 meq/100 grams of soil. Magnesium may occur in soils in a somewhat slowly available form (nonexchangeable) in which it is thought to be in equilibrium with that which is exchangeable (Tisdale and Nelson, 1975). The formation of the slowly available form is favored by conditions in acid soils with expanding type clays, such as the Parsons soil. When exchangeable magnesium is low, the slowly available magnesium becomes available for plant growth (Rice and Kamprath, 1968; Christenson and Doll, 1973).

Comparisons of the average available nitrogen, phosphorus, and potassium concentrations of the Parsons soil with the recommended soil levels required for adequate growth of the major crops in Kansas (Whitney, 1976) showed the Parsons soils to also be low in these elements. Most soils contain on a total basis more than sufficient potassium (around 10 percent) for adequate plant growth. However, most of this is fixed (not available) in mineral compounds that are relatively insoluble and release potassium slowly (Tisdale and Nelson, 1975). Therefore, most soils cannot supply potassium quickly enough and in quantities sufficient for fast-growing crops. Consequently, fertilizer potassium, along with nitrogen and phosphorus, must be added to agricultural soils to produce high yields of high-quality grasses. In most uncultivated soils only nitrogen and phosphorus are the major limitations in grass production.

Concentrations of the DTPA-extractable micronutrients iron, copper, manganese, and zinc of the Parsons soil averaged 89.2 ppm (parts per million) (dry soil weight basis) for iron, 1.4 for copper, 26.5 for manganese, and 5.3 for zinc. Except for copper, these concentrations were well above the deficiency levels suggested by Lindsay and Norvell (1978) for these DTPA-extractable micronutrients. Their suggested minimum concentrations are 4.5 ppm for iron, 0.2 for copper, 1.0 for manganese, and 0.8 for zinc. Based on these minimum concentrations, the Parsons soil should provide more than sufficient amounts of these micronutrients to plants.

The average available boron concentration of the Parsons soil indicates a possible deficiency of this element for some crops. In general, a boron concentration of <0.5 ppm (dry soil weight basis) indicates a boron deficiency. Requirements of different crops for boron vary, but the range between them is small. Therefore, the boron status of a soil should be evaluated as to the boron needs of the particular crop to be planted. For example, a concentration of 0.1 ppm boron is considered adequate for optimum growth of small grains and grasses, whereas alfalfa and clover require 0.5 ppm (Bingham, 1973). Based on the above requirements the Parsons soil should provide sufficient boron for the growth of wheat and fescue.

The organic matter content of the Parsons soil averaged 1.3 percent, which, compared to most mineral soils, is considered moderately low on a scale where <0.5 percent is very low and >4 percent is high (U.S. Department of Agriculture, Soil Conservation Service, 1975).

Comparison of Properties of Parsons Soil and Minesoil

Morphology of Minesoil

Field descriptions of minesoil profiles are given in Appendix E. The most prominent characteristics of the minesoil were the absence of the well-developed and contrasting horizons that were present in the Parsons soil, and the presence of coarse shale fragments up to a maximum of approximately 50 mm in length and ranging in amounts from <5 to 25 percent. The only pedogenic development visually observed in the minesoil was the physical weathering and breakdown of shale fragments on the surface, due mostly to freeze-thaw cycles. This process is most effective in climates such as in southeast Kansas where the surface temperatures fluctuate across freezing many times each year (Birkeland, 1974). Any other pedogenic development that had occurred over the course of 1 year would also have been limited mainly to the C1 (0-6 inches) horizon. This development would probably have been physical, such as the disintegration of clods by water and roots, and the binding together of soil aggregates by plant roots.

Since the terms used to describe soil structure are intended only for describing natural aggregates in the soil ("peds"), it is not appropriate to use them to describe structure in disturbed and reconstructed soils such as minesoils, which are composed mainly of clods of the original soil structure and rock fragments. The term that is appropriate to use is "clods."

The structure of the minesoil was mostly clods, spheroidal to irregular in shape, varying in size, with many visible voids present in the C2 (6-12 inches) and C3 (12-40 inches) horizons. No voids were observed in the C1 horizon. The voids in the C2 and C3 horizons were attributed to the large volume of rock fragments in these horizons. The difference in the amount of rock fragments would not alone explain the absence of voids in the C1 horizon. However, the bulk density of the C1 horizon was observed to be greater than that of the C2 and C3 horizons. This was attributed to the filling of the void spaces in the C1 horizon by fine materials during smoothing of the minesoil and tilling of the minesoil prior to planting.

Based on field observations and chemical and physical properties determined from minesoil samples, the minesoil was classified as a loamy-skeletal, mixed, thermic Udalfic Arent. This classification characterizes a soil with little or no pedogenic horizon development, a mixed mineralogy, and a silty clay loam texture of the <2 mm size fraction, which would be found in a climate similar to that of southeast Kansas.

Mineralogy

Results from the x-ray diffraction analysis of minesoil spade samples of sites S-1 to S-5 were compared to those from C-horizons and rock units from boring C-2. The diffraction patterns were essentially identical, with all samples containing quartz, feldspars, and clays. The spade samples exhibited strong diffraction line intensities for the clay minerals kaolinite and illite almost identical to those of the C-horizons (9-15 feet) and parent siltstones and shales, which suggested that a considerable amount of the material present in the surface of the minesoil was derived from both upper and lower overburden. This was confirmed by presence in the minesoil of fragments of shale, ferruginous siltstone, sandstone, coal, and iron-manganese oxide nodules. Shale fragments varied in size, with a maximum length of 50 mm.

The x-ray diffraction patterns of minesoil spade samples of sites S-3 and S-4 also showed the presence of gypsum, often a by-product of the oxidation of pyrite. Sample sites S-3 and S-4 were in areas of Field 1 that were practically devoid of wheat and were identified as being extremely acid. Field observations of these 2 sample sites showed fragments of dark shale that contained pyrite. These shale fragments were exposed to the extremes of surface weathering and were rapidly disintegrated. The difference in the percentages of coarse particles (>2 mm) found between spade sites S-5 and the 0-6 inch depth of auger site A-4 taken in Field 2 (Appendices D and E) confirmed this disintegration. Spade sample S-5, taken in August 1975, was estimated by field observation to contain 15-25 percent coarse shale fragments, whereas the 0-6 inch depth of auger sample A-4, taken in March 1976, was found to contain only 10 percent coarse shale fragments.

Physical Properties

Particle-Size Distribution: The particle-size data from laboratory determinations of minesoil auger samples from sites A-2, A-3, A-4, A-8, and A-11 are given in Tables 14 and 15. These sites were chosen for additional laboratory analysis because they were determined from field observations of 12 auger sites to be representative of the range of particle sizes found in the minesoil. The particle-size distributions for whole minesoil samples by weight percentage with depth are given in Table 14. The particle-size distributions of the <2 mm size fraction (fine material) of minesoil samples by weight percentage with depths are given in Table 15. The <2 mm size fractions were used to determine soil texture.

The particle-size distribution of whole minesoil for each size range showed variations at each site and among sites. This reflects the considerable mixing of soil and overburden that occurred during leveling and smoothing of the spoil banks. Particles in the <0.074 mm range showed the most uniform distribution with depth.

Auger sites A-2 and A-3 were located in Field 1, in low areas. At these sites, the quantity of particles >2 mm (coarse material) at depths above 12 inches ranged from 13 to 22 percent (Table 14). These figures are in good agreement with the estimated range of 15-25 percent reported from visual observations in the field (Appendix D). Compared to site A-2, site A-3 showed a larger amount of particles <2 mm in the surface 12 inches, and also had an unusually large amount of particles >20 mm, approximately the size of the smallest shale fragment observed in the field in the 12-40 inch depth. The large amount of particles <2 mm at site A-3 was attributed to the fact that the area of Field 1 where site A-3 was located had received sediment from storm

Table 14. Particle-size analysis of whole minesoil samples. (Values are weight percentages.)

Sample[a] Site	Depth (inches)	Size Class of Particles (diameter in millimeters)							
		>75	75-20	20-5	5-2	2-0.074	<0.074	>2	<2
A-2	0-6	0	0	8.3	13.8	9.3	68.6	22.1	77.9
	6-12	0	1.2	6.8	5.4	10.9	75.7	13.4	86.6
	12-40	0	4.1	7.8	4.9	9.6	73.6	16.8	83.2
A-3	0-6	0	.4	4.6	3.3	16.4	75.3	8.3	91.7
	6-12	0	.3	1.5	1.4	6.5	90.3	3.2	96.8
	12-40	5.7	13.7	9.7	3.9	10.9	56.7	33.0	67.0
A-4	0-6	0	.3	3.0	2.8	9.9	84.0	6.1	93.9
	6-12	0	1.8	4.7	3.2	10.1	80.2	9.7	90.3
	12-30	0	.3	7.0	7.8	11.8	73.1	15.1	84.9
	30-40	0	2.2	8.3	4.0	11.9	73.6	14.5	85.5
A-8	0-6	0	0	10.1	7.8	8.8	74.3	16.9	83.1
	6-12	0	.6	8.4	7.2	10.6	73.2	16.2	83.8
	12-40	0	11.0	3.4	2.0	6.0	77.6	16.4	83.6
A-11	0-6	0	2.3	6.5	4.4	10.3	76.5	13.2	86.8
	6-12	0	6.7	8.9	4.8	6.7	72.9	20.4	79.6
	12-40	0	1.2	8.2	5.3	8.0	77.3	14.7	85.3

[a] Auger samples.

Table 15. Particle-size analysis of the <2 mm size fraction of minesoil. (Values are weight percentages.)

Sample[a] Site	Depth (inches)	Size Class of Particles (diameter in millimeters)						
		SAND						
		Very Coarse (2.0-1.0)	Coarse (1.0-0.5)	Medium (0.5-0.25)	Fine (0.25-0.10)	Very Fine (0.10-0.05)	SILT (0.05-0.002)	CLAY (<0.002)
A-2	0-6	2.6	2.6	1.8	2.5	10.7	49.8	30.0
	6-12	3.2	4.0	1.5	2.2	8.1	52.9	28.1
	12-40	3.0	2.5	1.1	2.4	10.9	51.5	28.6
A-3	0-6	2.0	1.8	9.4	2.1	13.4	43.3	28.0
	6-12	1.1	1.2	.7	1.3	13.9	57.1	24.7
	12-40	5.8	3.7	1.6	2.8	8.8	47.5	29.8
A-4	0-6	2.3	2.4	1.3	2.6	7.8	47.4	36.2
	6-12	2.6	2.8	1.3	2.5	7.9	49.8	33.1
	12-30	3.9	2.9	1.5	3.1	9.6	43.5	35.5
	30-40	1.6	2.0	1.5	2.8	10.9	45.7	35.5
A-8	0-6	3.3	2.3	1.0	2.2	7.6	51.6	32.0
	6-12	2.7	3.1	1.1	3.6	8.4	57.5	23.6
	12-40	2.7	3.4	1.5	3.3	8.5	53.1	27.5
A-11	0-6	3.0	2.6	1.4	2.9	7.7	48.2	34.2
	6-12	2.4	1.8	.9	1.8	5.7	51.5	35.9
	12-40	2.6	2.3	1.0	1.9	6.6	52.4	33.2

[a] Auger samples.

runoff.

Site A-4 was located in Field 3 and was also in a low area. The particle-size distribution of whole minesoil in the 0-12 inch depth at this site was also characterized by a greater amount of particles <2 mm, and the 12-40 inch depth was characterized by a larger amount of particles >2 mm. As at site A-3, the greatest number of particles was found in the 20-5 and 5-2 mm size ranges.

The particle-size distributions of the <2 mm size fraction at sites A-3 and A-4 were not similar (Table 15). The very fine sand fraction at site A-3 averaged 13.7 percent by weight in the 0-12 inch depth, whereas at site A-4 the average was 7.8 percent. The average amount of clay in the 0-12 inch depth at site A-4 was 34.6 percent, whereas at site A-3 the average amount of clay was 26.3 percent. The amount of medium sand at site A-3 in the 0-6 inch depth was 9.4 percent compared to 1.3 percent at site A-4.

Other than the differences between sites A-3 and A-4 discussed above, the particle-size distribution in each size range of the <2 mm size fraction was more uniform with depth at each site and among sites than was the particle-size distribution of the >2 mm size fraction (Table 14). Site A-8 showed the most uniform distribution of particles with depth for both the >2 and <2 mm size fractions.

Particle-size analyses of the Parsons soil are given in Tables 16 and 17. At all depths in the Parsons soil only trace amounts of material >2 mm were detected (Table 16). Nearly all the material (98-99 weight percent) was <2 mm in diameter. The average of all minesoil sites showed 15 percent by weight of the material was >2 mm in diameter and 85 percent was <2 mm. Both the minesoil and the Parsons soil had no material >75 mm in size. Except for the <0.074 mm fraction, the minesoil had greater amounts of material present in all size fractions compared to the Parsons soil. The <0.074 mm size range of the minesoil had the greatest amounts of material at all depths. This was also the case for the Parsons soil. The size range in the minesoil that showed the greatest increase in amount of material was the 2-0.074 mm range. The particle-size data of the <2 mm size fraction of the minesoil and the Parsons soil, given in Tables 15 and 17 respectively, also show the last observation. Sand sizes of the <2 mm size fraction encompassed in the 2-0.074 mm range are very coarse, coarse, medium, fine, and a

Table 16. Particle-size analysis of whole samples of Parsons soil.[a] (Values are weight percentages).

Horizon	Depth (inches)	Size Class of Particles (diameter in millimeters)							
		>75	75-20	20-5	5-2	2-0.074	<0.074	>2	<2
AP	0-7	0	0	TR[b]	TR	3	95	TR	98
A21	7-11	0	0	0	TR	4	95	TR	99
A22	11-15	0	0	0	TR	4	95	TR	99
B21t	15-20	0	0	0	TR	2	97	TR	99
B22t	20-27	0	0	0	TR	1	98	TR	99
B3	27-39	0	0	TR	TR	4	94	TR	98
C1	39-52	0	0	TR	TR	6	92	TR	98
C2	52-63	0	0	TR	TR	8	90	TR	98

[a] Data derived from U.S. Department of Agriculture, Soil Conservation Service (1981).

[b] TR (trace) - assumed to be <1 percent by weight.

portion of the very fine sand. The data show significant differences in the amounts of material of all these sand sizes for the minesoil compared to the Parsons soil, except for fine sand.

Comparison of the amounts and distribution of silt and clay in the 0-39 inch depth of the Parsons soil and the 0-40 inch depth of the minesoil showed a greater uniformity of the silt and clay distribution in the minesoil. Averaging the data over these depths showed the amount of clay in the minesoil to be essentially the same as that in the Parsons soil, 31.0 percent compared to 31.3 percent. However, the amount of silt in the minesoil was less than that in the Parsons soil, 50 percent compared to 63 percent.

Bulk Density: The bulk density of the Parsons soil increased with depth, whereas minesoil bulk density decreased with depth (Table 18). The higher bulk density of the 0-12 inch depth of the minesoil compared

Table 17. Particle-size analysis of the <2 mm size fraction of Parsons soil.[a] (Values are weight percentages.)

		Size Class of Particles (diameter in millimeters)						
		SAND						
Horizon	Depth (inches)	Very Coarse (2.0-1.0)	Coarse (1.0-0.5)	Medium (0.5-0.25)	Fine (0.25-0.10)	Very Fine (0.10-0.05)	SILT (0.05-0.002)	CLAY (<0.002)
AP	0-7	.2	.4	.4	2.4	2.9	77.1	16.6
A21	7-11	.1	.7	.5	2.4	2.6	77.0	16.7
A22	11-15	.2	1.0	.4	2.5	2.5	75.7	17.7
B21t	15-20	.2	.4	.2	1.7	1.8	52.9	42.8
B22t	20-27	TR[b]	TR	.1	1.5	1.7	46.0	50.7
B3	27-39	.5	.6	.3	3.5	3.5	48.4	43.2
C1	39-52	.8	.9	.6	4.4	4.3	51.0	38.0
C2	52-63	1.6	1.3	.6	4.7	4.8	51.9	35.1

[a] Data from U.S. Department of Agriculture, Soil Conservation Service (1981).

[b] TR (trace)--represents <0.1 percent by weight.

Table 18. Bulk density of Parsons soil and minesoil.

Depth (inches)	Parsons Soil[a] g/cm^3	Minesoil[b] g/cm^3
0-6	1.44	1.45
6-12	1.39	1.44
12-40	1.65	1.20

[a] Data derived from U.S. Department of Agriculture, Soil Conservation Service (1981).

[b] Average of 5 sites (A-2, A-3, A-4, A-8, A-11); B.D. of the 0-6 and 6-12 inch depths determined by the sand funnel method, B.D. of 12-40 inch depth estimated from water content and porosity measurements.

to that of the Parsons soil was caused by filling of void spaces by fine materials during smoothing of the minesoil and tilling of the minesoil for planting. The higher bulk density and lack of voids in the 0-12 inch depth (observed in field descriptions, Appendix E) may result in the minesoil's having a lower infiltration rate and a higher surface runoff rate than the Parsons soil. However, in time plant roots will aid the development of a crumb structure in the surface of the minesoil, thus increasing the infiltration rate and decreasing the runoff rate.

A substantial difference was found between the 2 soils in the 12-40 inch depth. Although the bulk density of the 12-40 inch depth of the minesoil was estimated, it compares quite well with bulk densities of spoils reported to be in the range of 1.10-1.40 g/cm^3 (grams per cubic centimeter) (Power and others, 1978). The lower bulk density of the minesoil at this depth indicated the presence of large voids, a fact confirmed by field descriptions of the minesoil (Appendix E). The presence of large voids at this depth will aid deeper root penetration in the minesoil. The Parsons soil has an extremely firm silty clay subsoil layer, as indicated by the bulk density of 1.65 g/cm^3 in the 12-40 inch depth (horizons B21t, B22t, and B3), which is difficult for roots to penetrate.

This layer impedes water percolation in the Parsons soil, resulting in a temporary perched water table above the layer during periods of prolonged rainfall (Miller, 1973). Since this layer is not present in the minesoil, water should percolate faster through the minesoil, allowing for quick access to fields after rainfall. With time, the percolation rate of the minesoil should increase as the large voids in the subsoil become interconnected to the smaller voids of the surface from the penetration of plant roots.

Water-Holding Capacity: The water content of the March 1976 minesoil auger samples (Table 19) may well depict the field capacity of the minesoil as a result of the occurrence of a 2.8 inch rainfall 2 days prior to sampling. Field capacity is defined as the amount of water held in the soil after the excess gravitational water has drained away, and represents the upper or wet limit of plant-available water under general field conditions. For many soils the field capacity has been closely correlated to the amount of water held at 1/3 bar tension (Richards and Weaver, 1944). Most soils have been found to drain to field capacity in 2 to 3 days (Veihmeyer and Hendrickson, 1931).

The average wilting point percentage for the 0-11 inch depth of the Parsons soil, calculated from data in Table 20, was 7.8 percent. The wilting point represents the dry limit of plant-available water, and is defined as the soil water condition at which the release of water to plant roots is just barely too small to counterbalance the loss of water from plants by transpiration; this results in a net loss of plant water and hence wilting. The wilting point for many soils has been closely correlated to the amount of water held at 15 bar tension (Richards and Weaver, 1943).

The difference between the field-capacity percentage and the wilting-point percentage is assumed by agronomists to be the amount of soil water available to plants. The amount of plant-available water for any depth of a soil can be calculated using the equation $I = B.D.P$ (Peters, 1965)--where I represents inches of plant-available soil water, B represents bulk density (g/cm^3), D represents depth (inches), and P represents the percentage of water between the field capacity and wilting point. Using the average bulk density of 1.41

Table 19. Gravimetric water content of minesoil auger sites.

Sample Site	Depth (inches)	Percent Moisture[a]		
		Date of Sampling		
		03/11/76[b]	05/06/76[c]	07/14/76[d]
A-3	0-6	19.2	8.3	6.9
	6-12	15.7	11.2	19.2
	12-24	19.1	15.8	22.2
	24-40	13.5	16.6	22.1
A-4	0-6	24.8	15.1	16.1
	6-12	24.2	15.6	21.5
	12-30	24.6	12.8	24.7
	30-40	24.4	16.8	22.3
A-8	0-6	17.4	11.4	22.2
	6-12	22.7	17.4	21.2
	12-24	25.6	19.4	28.3
	24-40	25.1	26.2	----

[a] Oven-dry soil weight basis.

[b] Rainfall from 09/01/75 to 03/09/76 measured 15.45 inches; of this amount 2.83 inches fell over the period of 03/04/76 to 03/09/76. Vegetation was growing wheat.

[c] Rainfall from 03/12/76 to 05/05/76 measured 6.57 inches; of this amount 1.46 inches fell over the period of 04/28/76 to 05/05/76. Vegetation was growing wheat.

[d] Rainfall from 05/07/76 to 07/14/76 measured 12.22 inches; of this amount 4.13 inches fell over the period of 07/03/76 to 07/04/76. Wheat had been harvested, stubble remained.

g/cm^3, an average field capacity of 27.8 percent, and an average wilting point of 7.8 percent, the amount of plant-available water in the surface 12 inches of the Parsons soil was calculated to be 3.4 inches. Using the same equation with the average bulk density of 1.44 g/cm^3, an average field capacity of 20.7 percent, and an average wilting point of 7.8 percent, the amount of plant-available water in the surface 12 inches

Table 20. Gravimetric water content of Parsons soil at field capacity and wilting point.[a]

Horizon	Depth (inches)	Field Capacity %	Wilting Point %
AP	0-7	29.1	8.6
A21	7-11	26.6	7.1
A22	11-15	23.0	7.4
B21t	15-20	27.6	17.6
B22t	20-27	30.4	20.5
B3	27-39	----[b]	18.4
C1	39-52	23.3	16.1
C2	52-63	24.0	14.9
C3	63-73	----	15.6
C4	73-85	25.8	18.0

[a] Data from U.S. Department of Agriculture, Soil Conservation Service (1981).

[b] Data missing.

of the minesoil was calculated to be 2.2 inches. These calculations show the surface 12 inches of the minesoil retain 35 percent less plant-available water than the Parsons soil. However, it must be noted that the permanent wilting percentage of the minesoil was not determined; thus that of the Parsons soil was used in the calculation of plant-available water in the minesoil. The permanent wilting percentage of the minesoil may have been less, thus expanding the range between field capacity and wilting point, and in effect supplying more water than was calculated. This has been shown to be the situation in other minesoils (Jones and others, 1975; Verma and Thames, 1975).

Also, others have shown that shale fragments in minesoil retain water that is plant available, adding to the total amount of water available to plants in minesoil (Hanson and Blevins, 1979).

The sampling dates represent early spring, mid-spring, and early summer, the time of year this area of Kansas receives its heaviest rainfall (U.S. Department of Agriculture, Soil Conservation Service, 1973). Also, this is the period of most vigorous plant growth. As discussed earlier, the March date represents a base period of maximum water buildup. The average amount of water in the 0-40 inch depth in March was 21.3 percent. The average amount of water in May, which represents a time of maximum water utilization by plants, was 15.5 percent. Although 6.57 inches of rain fell between March 12 and May 5, the water content did not return to the March amount. There are 2 reasons for this: (1) the rainfall was spread out over the period and the water had time to percolate deeper than 40 inches, whereas just prior to the March sampling approximately 3 inches of rain fell, and (2) during May the wheat was growing vigorously and using the available water in the transpiration and growth processes. Four inches of rain fell 10 days prior to the July sampling, which was almost a sufficient amount to bring the water content up to that of March. Also, since the wheat had been harvested, most of the water was still present in the 0-40 inch depth.

Overall the data show the minesoil can supply sufficient water for the growth of wheat under typical southeastern-Kansas rainfall conditions.

Chemical Properties

The chemistry of the minesoil is given in Table 21. The lowest depth sampled was 12-40 inches. Most routine soil-survey sampling in the United States is done to a depth of 40 inches. Also, where the soil has no B horizon, the control section is from 10-40 inches, especially if the soil is deep and has a subtle lower boundary (U.S. Department of Agriculture, Soil Conservation Service, 1962).

Overall, the data show variation among sites and within sites, except for potassium. Calcium was higher in the 0-6 inch depth than at lower depths at sites (A-2, A-3, and A-4) in limed fields. Calcium concentration in the 6-12 and 12-30 inch depths at site A-4 was comparable to that of the 0-6 inch depth, reflecting the larger application

Table 21. Chemical analysis of minesoil.

Sample[a] Site	Depth (inches)	pH (1:1)	Exchangeable Bases Ca	Mg	Na	K	Exchangeable Acidity	Cation[c] Exchange Capacity (meq/100g)	Base[d] Saturation (%)
			(meq/100g)[b]						
A-2	0-6	5.2	6.3	3.2	1.0	0.2	6.7	17.4	61
	6-12	5.4	6.4	3.6	1.3	0.2	4.7	16.2	71
	12-40	4.5	5.2	3.4	0.9	0.2	7.2	16.9	57
A-3	0-6	4.9	8.4	2.6	0.4	0.3	6.3	18.0	65
	6-12	5.2	3.4	1.9	0.3	0.2	6.8	12.6	46
	12-40	4.5	7.2	4.5	0.6	0.2	7.6	20.1	62
A-4	0-6	6.1	18.3	3.8	0.3	0.4	6.1	28.9	79
	6-12	5.1	16.4	5.2	0.5	0.3	6.8	29.2	77
	12-30	5.6	18.9	5.9	0.5	0.3	12.5	38.1	67
	30-40	5.5	11.6	4.5	0.4	0.3	8.2	25.0	67
A-8	0-6	4.9	10.1	3.8	0.2	0.3	8.8	23.3	62
	6-12	4.9	5.2	2.0	0.2	0.2	9.6	17.2	44
	12-40	4.9	5.7	2.5	0.2	0.2	9.7	18.3	47
A-11	0-6	5.8	14.6	3.2	0.8	0.2	3.3	22.1	85
	6-12	5.9	12.3	3.8	1.0	0.2	3.6	20.9	83
	12-40	6.0	10.7	3.6	1.0	0.2	5.3	20.8	74

[a] Auger samples.

[b] Milliequivalents/100 grams of soil.

[c] Sum of exchangeable bases and acidity.

[d] $\frac{\Sigma \text{ Ca, Mg, Na, K}}{\text{CEC}} \times 100.$

and deeper incorporation of lime in this area of Field 2. Sites A-8 and A-11 were in fields that were not limed. At these 2 sites calcium concentrations were also higher in the 0-6 inch depth, probably because of chemical and physical weathering of the recently exposed primary minerals. Magnesium showed no definite pattern with depth at sites in both limed and unlimed fields. The average magnesium concentration of all sites was approximately one-third the average calcium concentration. Sodium varied among the sites, but varied little within a site. Potassium varied least among sites and showed essentially no variation within a site.

The pH's of the 0-6 and 6-12 inch depths at sites A-2, A-3, and A-4 were higher than in the 12-40 inch depth, directly reflecting lime incorporation to 12 inches. Sites A-8 and A-11, which were not limed, showed a more uniform pH distribution with depth. The exchangeable acidity at sites A-2, A-3, and A-4 also reflected liming. Lower values were found in the 0-6 and 6-12 inch depths, compared to higher values in the 12-40 inch depth. However, not all the exchangeable acidity data correlated well with pH, because pH is a measure of present or active acidity in the soil solution, whereas exchangeable acidity is a measure of present acidity and reserve acidity, that due mainly to the hydrolysis of exchangeable aluminum.

Base saturation, a measure of the soil exchange sites occupied by the exchangeable bases (Ca, Mg, Na, and K), and used as a general indicator of the clay mineralogy of a soil, was calculated only to show the overall variation of exchangeable bases among and within sites. The base saturation was higher in the 0-6 inch depth than in the 6-12 and 12-40 inch depths at sites A-2, A-3, and A-4, due to the greater amounts of calcium present in the 0-6 inch depth from the addition of lime. The cation exchange capacity, which is more a function of the clay mineralogy of the soil, varied among sites, but varied little within sites. The cation exchange capacity was slightly higher in the 0-6 inch depth because of the weathering of shale particles and subsequent increase in the amount of clay and also because of the oxidation of organic matter.

The more extensive chemistry of the Parsons soil given in Table 22 also shows changes with depth similar to those shown by the more generalized core-site chemistry (Table 13). The depth of accumulation for exchangeable calcium, magnesium,

Table 22. Chemical data for Parsons Soil, Bourbon County.[a]

Horizon	Depth (inches)	pH (1:1)	Exchangeable Bases Ca	Mg	Na	K	Exchangeable Acidity	Cation[c] Exchange Capacity (meq/100g)	Base[d] Saturation (%)
			(meq/100g)[b]						
AP	0-7	5.4	10.3	1.6	0.1	0.4	6.8	19.2	65
A21	7-11	5.4	5.9	1.4	0.1	0.2	6.8	14.4	53
A22	11-15	5.4	5.2	1.7	0.2	0.2	6.1	13.4	54
B21t	15-20	5.0	12.8	4.8	0.8	0.5	13.6	32.5	58
B22t	20-27	5.1	16.1	5.9	1.4	0.6	13.4	37.4	64
B3	27-39	5.5	15.1	5.5	1.4	0.5	8.5	31.0	73
C1	39-52	6.0	13.4	5.0	1.6	0.4	5.6	26.0	78
C2	52-63	6.6	12.9	4.8	2.2	0.4	4.6	24.9	82

[a] Data from U.S. Department of Agriculture, Soil Conservation Service (1981).

[b] Milliequivalents/100 grams of soil.

[c] Sum of exchangeable bases and acidity.

[d] $\frac{\Sigma \text{ Ca, Mg, Na, K}}{\text{CEC}} \times 100.$

potassium, and acidity extends from the 15-20 inch depth to the 52-63 inch depth, with maximum concentration occurring in the 20-27 inch depth. The higher potassium content in the 0-7 inch depth, compared to the 7-11 and 11-15 inch depths, was presumed to be from fertilizer applications. Exchangeable sodium also shows accumulation from the 15-20 inch depth to the 52-63 inch depth, but the maximum accumulation occurs in the 52-63 inch depth.

The pH does not show a significant change until the 39-52 inch depth, where it increases. Although pH increases in the 39-52 inch depth, the exchangeable acidity increases substantially in the 15-20, 20-27, and 27-39 inch depths, with a maximum in the 15-20 and 20-27 inch depths. The reason for the lack of a correlation between pH and exchangeable acidity was discussed earlier, and was attributed to exchangeable aluminum.

The cation-exchange capacity, calculated from the exchangeable bases and acidity, is higher from the 15-20 inch depth to the 52-63 inch depth, with a maximum in the 20-27 inch depth due to the accumulation of clay at this depth (Table 17). The higher cation-exchange capacity in the 0-7 inch depth compared to the 7-11 and 11-15 inch depths was attributed to the accumulation and oxidation of organic matter and weathering of primary minerals.

The base saturation, calculated from the exchangeable bases (Ca, Mg, Na, and K) and the cation-exchange capacity are higher from the 15-20 inch depth to the 52-63 inch depth with a maximum in the 52-63 inch depth, which is also the depth of the maximum concentration of sodium. The higher base saturation of the 0-7 inch depth, compared to the 7-11 and 11-15 inch depths, was attributed to a high calcium concentration from liming.

Based on data in Tables 21 and 22, the major differences between the chemical properties of the Parsons soil and the minesoil are essentially in the chemical distribution. Table 23 is a comparison of the chemistry of the Parsons soil and minesoil averaged over the 0-39 inch and 0-40 inch depths respectively. Besides being the logical cut-off point for comparison purposes, 39 inches is also approximately the lower limit of the control section for the Parsons soil.

As expected, the averages show the Parsons soil and minesoil to be quite comparable chemically. The Parsons soil has a slightly higher calcium content (10.9 meq/100 grams

Table 23. Comparison of chemical properties of Parsons soil and cropped minesoil.

Property	Parsons Soil[a]	Minesoil[b]
pH (1:1)	5.3	5.3
Exchangeable Bases (meq/100g)[c]		
Ca	10.9	9.6
Mg	3.5	3.5
Na	0.7	0.6
K	0.4	0.2
Exchangeable Acidity (meq/100g)	9.2	7.0
Cation Exchange Capacity (meq/100g)	24.6	20.1
Base Saturation (%)	61	65

[a] Average for 0-30 inch depth (AP-B3 horizons), Table 22.

[b] Average of auger sites A-2, 3, 4, 8, and 11 for the 0-40 inch depth (C-1, 2, and 3 horizons), Table 21.

[c] Milliequivalents/100 grams of soil.

of soil) than the minesoil (9.6 meq/100 grams). Also, the Parsons soil has a slightly higher potassium content (0.4 meq/100 grams) than the minesoil (0.2 meq/100 grams). The higher contents of calcium and potassium are reflected in the greater base saturation of the Parsons soil compared to the minesoil. The differences in the calcium and potassium contents of the 2 soils are probably a result of the fertilizer management history of the soils. It is probable that, if the 2 soils had the same fertilizer management history, the calcium and potassium contents would have been identical.

The minesoil has a more favorable exchangeable acidity than the Parsons soil, because of the high exchangeable acidity in the 15-20 and 20-27 inch depths of the Parsons soil (Table 22). The cation exchange capacity of the minesoil was 19 percent less than that of the Parsons soil. As discussed earlier, the cation-exchange capacity is more a function of the mineralogy of a soil.

The particle-size analysis of the <2 mm size fraction of the minesoil (Table 15) showed the minesoil has more sand and less silt, but essentially the same amount of clay as the Parsons soil. The greater amount of sand in the minesoil is probably the reason for the difference in the cation-exchange capacities.

Because reclamation results in a soil with a more uniform distribution of chemical properties with depth, the growth of most crops, under similar management practices, should be somewhat better on the minesoil than on the Parsons soil.

Fertility

Analyses of minesoil spade sample sites for fertility evaluation are given in Table 24. Sites S-1, S-2, S-3, and S-4 were in Field 1 and represent minesoil after 1 year of cropping. The data show the minesoil was quite variable within the same field. Also, the data of sites S-3 and S-4 confirm the acid condition in the north part of the field. Sites S-3 and S-4 had lime requirements of 11,000 and 22,000 pounds per acre, compared to 1,500 and 3,000 lb/ac for samples S-1 and S-2; and pH's of 4.0 and 3.2 compared to a pH of 5.4 for both samples S-1 and S-2. Smith and others (1976) recommend that, if the lime requirement of coal mine spoils exceeds 10,000 lb/ac, the spoil should be considered toxic and should not be placed on or near the surface. The acid condition at sites S-3 and S-4 was also reflected in the greater amounts of DTPA-extractable zinc, iron, and manganese at these sites, compared to sites S-1 and S-2.

To compare the fertility status of the Parsons soil to that of the 1-year-old cropped minesoil, the data of the 0-16 inch depth of the Parsons soil (Table 13) averaged from the 3 cores were compared to those of minesoil averaged from spade sample sites S-1, S-2, S-3, and S-4 (Table 24). The results (Table 25) show the minesoil differs markedly from the Parsons soil. The pH of the minesoil was 4.5 compared to 5.4 for the Parsons soil. The liming requirement of the minesoil was greater than that of the Parsons soil by 3,875 lb/ac. The lower pH and higher lime requirement of the minesoil were attributed to the oxidation of pyrite contained in shale fragments that were observed in the surface of the minesoil.

The average concentration of available ammonium nitrogen of the Parsons soil was 9.0 ppm compared to

Table 24. Chemical analysis of minesoil for fertility evaluation. (Analysis by the Soil Testing Laboratory, Kansas State University.)

Sample[a] Site	pH (1:1)	Lime Requirement ($\frac{lbs}{ac}$ ECC)[b]	Avail. P (lbs/A)[c]	Exchangeable Bases (meq/100g)[d]			
				Ca	Mg	Na	K
S-1	5.4	1,500	33	3.6	2.8	0.4	0.3
S-2	5.4	3,000	26	3.8	3.6	0.5	0.4
S-3	4.0	11,000	16	3.4	9.5	0.3	0.3
S-4	3.2	20,000	50	4.7	4.8	0.2	0.2

Sample Site	Organic Matter (wt%)	DTPA[e] (ppm)[f]				Avail. N (ppm N)		Avail. B[g] (ppm)
		Zn	Fe	Cu	Mn	NH_4	NO_3	
S-1	0.9	2.0	29	1.7	32	2.5	0.3	0.5
S-2	0.8	2.3	60	2.8	64	3.1	9.2	0.2
S-3	1.4	15.1	116	1.6	535	7.3	0.8	0.5
S-4	1.3	4.6	353	0.6	431	7.6	1.4	1.0

[a] Spade samples.

[b] Pounds/acre of effective $CaCO_3$ (ECC) to raise pH to 6.8.

[c] Pounds/acre.

[d] Milliequivalents/100 grams of soil.

[e] Diethylenetriaminepentaacetic acid method.

[f] (see f on Table 13)

[g] Hot-water-soluble boron.

Table 25. Comparison of fertility properties of Parsons soil and 1-year-old cropped minesoil.

Property	Parsons Soil[a]	Minesoil[b]
pH	5.4	4.5
Lime Requirement (lb/ac ECC)	5000	8875
Available P (lb/ac)	17	31
Available N (ppm)[c]		
NH_4	9.0	5.1
NO_3	3.8	2.9
Available B (ppm)	0.3	0.5
Exchangeable Bases (meq/100g)		
Ca	3.2	3.9
Mg	1.1	5.2
Na	0.2	0.4
K	0.2	0.3
DTPA Extractable (ppm)		
Zn	5.3	6.0
Fe	89.2	139.9
Cu	1.4	1.7
Mn	26.5	265.8
Organic Matter (%)	1.3	1.1

[a] Average of 3 sites (0-16 inches), C-1, 2, and 3, Table 13.

[b] Minesoil (Field 1) cropped to hard red winter wheat, no lime applied; average of 4 sites (0-6 inches), S-1, 2, 3, and 4, Table 24.

[c] Parts per million (μg/g) on an oven-dry (105°C) soil weight basis.

5.4 ppm for the minesoil. The higher ammonium concentration in the Parsons soil was attributed to organic-matter accumulation in the surface horizon. Mining disturbed this natural accumulation and the organic matter was redistributed with depth when the spoil banks were leveled. The concentration of ammonium was greater than the concentration of nitrate in both the Parsons soil and the minesoil. The ratios of ammonium to nitrate were 2.3 for the Parsons soil and 1.7 for the minesoil.

Nitrogen usually accumulates as nitrate in most mineral soils. The conversion of organic nitrogen to nitrate takes place largely in 2 steps, ammonification and nitrification. Ammonification is the release of nitrogen in organic matter and its conversion to ammonium. Nitrification is the oxidation of ammonium to nitrate, which is the form of nitrogen most readily used by higher plants. The conversion of ammonium to nitrate is affected by chemautotrophic bacteria that obtain their energy from the oxidation of inorganic salts and carbon from the carbon dioxide of the surrounding soil atmosphere. The range of pH over which nitrification takes place has generally been found to be between 5.5 and 10.0, with optimum at around 8.5 (Alexander, 1977). The pH of the Parsons soil was 5.4, which is on the low side of the range, and the pH of the minesoil was 4.5, below the lowest pH at which nitrification normally occurs.

The available phosphorus concentration of the minesoil was 31 lb/ac compared to 17 lb/ac for the Parsons soil. The greater amount of phosphorus in the minesoil reflects phosphorus added as fertilizer. Except for magnesium, exchangeable-cation concentrations of the minesoil and the Parsons soil were not appreciably different. In most mineral soils exchangeable calcium is usually much greater than exchangeable magnesium, especially if the soil has been limed. Cummins and others (1965) reported that magnesium was more abundant than calcium in the mine spoils they sampled. The average minesoil magnesium concentration of Field 1, which was not limed in the fall of 1974, was 5.2 meq/100 grams of soil compared to 1.1 meq/100 grams for the Parsons soil. This difference was attributed to the weathering of shale fragments in the minesoil, with the subsequent release of magnesium from clay crystal lattices.

The weathering of shale particles also contributed to the greater concentration of DTPA-extractable iron and manganese found in the minesoil. Average minesoil concentrations were 139.9 meq/100 grams of soil for iron and 265.8 meq/100 grams for manganese, compared to Parsons concentrations of 89.2 meq/100 grams for iron and 26.5 meq/100 grams for manganese. There were no appreciable differences in DTPA-extractable zinc and copper concentrations between the minesoil and Parsons soil, possibly because shales are much lower in zinc and copper than in iron and manganese (Krauskopf, 1972).

The average available boron concentration of the minesoil was 0.5 ppm compared to 0.3 ppm for the Parsons soil. The higher amount of boron in the minesoil was also attributed to the weathering of the shale fragments. Shales in general have high concentrations of boron, with boron residing principally in the clay minerals (Krauskopf, 1972). Dissolved boron derived from the weathering of shale occurs chiefly as boric acid (H_3BO_3). Boron compounds in soil are all quite soluble, and thus are easily leached to greater depths, especially in acid soils. This could explain the small amount of boron found in the surface of the minesoil, compared to magnesium, iron, and manganese (Table 24). Iron and manganese are quite insoluble compared to boron, and in young minesoil, where weathering occurs mostly in the surface horizon, these elements would be expected to have higher concentrations in the surface than in the subsoil.

Summary

Morphology

The most prominent morphological characteristics of the minesoil were the absence of well-developed and contrasting horizons and the presence of large amounts of rock fragments. The structure of the minesoils was mostly clods with many visible voids present in the 6-12 and 12-40 inch depths. The only pedogenic development observed in the minesoil was the physical weathering of surface shale fragments.

Physical Properties

The particle-size distribution of the minesoil varied within and among sites, reflecting the mixing of soil and overburden that occurred as a result of the mining and releveling operations.

The minesoil had greater amounts of material in all particle-size ranges, except for the <0.074 mm fraction. The greatest difference was found in the 2-0.074 mm range. The minesoil contained 85 percent (by weight) material <2 mm, whereas in the Parsons soil nearly all the material (98-99 percent) was <2 mm. Silt and clay were more uniformly distributed with depth in the minesoil. However, when averaged over depth, the amounts of clay in the minesoil and Parsons soil were essentially identical, whereas the amount of silt in the minesoil was less than that of the Parsons soil.

The bulk density of the minesoil was found to decrease with depth, whereas that of the Parsons soil increased with depth. The bulk density of the 0-12 inch depth of the minesoil was higher than the 12-40 inch depth, and was attributed to the filling of void spaces with fine materials during the smoothing of the minesoil and the tilling of the minesoil for planting.

Estimates show that the surface 12 inches of the minesoil contained 35 percent (by weight) less plant-available water than the Parsons soil. However, the moisture data indicate, and the high yields tend to confirm, that the minesoil supplied available moisture sufficient for the growth of wheat under typical southeast Kansas rainfall conditions. It was assumed that the moisture deficit found in the surface 12 inches of the minesoil was effectively overcome by an overall increase in the amount of plant-available water in the minesoil, due in part to the deeper rooting zone of the minesoil, and also to the moisture present in shale particles.

Chemical Properties

In general the chemistry of the minesoil showed variations within and among sites, reflecting, as did the particle-size distribution, the mixing of soil and overburden from the mining and releveling operations.

The chemistry of the minesoil and Parsons soil averaged over depth showed the 2 soils to be quite comparable. Essentially, the only differences were that the minesoil had less exchange acidity and cation-exchange capacity. These differences were attributed to the larger amount of sand-size material in the <2 mm size fraction of the minesoil.

Fertility

The fertility of 1-year-old cropped minesoil differed markedly from that of the Parsons soil. The pH of the minesoil was lower and thus the acidity was higher than that of the Parsons soil. Additionally, the liming requirement of the minesoil was greater. There was more available phosphorus in the minesoil due to fertilizer additions. The amount of exchangeable magnesium was 5 times greater in the minesoil. The respective concentrations of extractable iron and manganese were 1.5 and 10 times greater in the minesoil. Except for phosphorus, all these differences were attributed to the weathering of pyrite-containing shale particles in the surface of the minesoil.

WATER

by J. E. Welch, D. O. Whittemore, and D. A. Grisafe

Introduction

Approximately 11,000 miles of streams in the United States have been affected by mine drainage, primarily in the coal-mining areas of Appalachia (Martin and Hill, 1968). The acidic waters draining from coal mines are derived from the weathering of the iron sulfide minerals, pyrite and marcasite, occuring in the coal and associated shales. Mining exposes the sulfides to moist air or oxygenated surface and ground waters, causing oxidation of the sulfide to sulfate and the production of hydrogen ions, which decrease the pH of the water present. The ferrous iron released remains in solution or oxidizes to ferric iron, depending on the pH of the water. The ferric iron either forms sulfate salts in soils and on the surface (given drier conditions) or precipitates as ferric oxyhydroxides, reactions that further increase the concentration of hydrogen ions and thus decrease the pH of the water. The highly acidic waters can leach high concentrations of elements such as manganese, aluminum, and other trace metals from the shales. The precipitated ferric oxyhydroxides and sulfates coat particles in spoil material or stream beds, giving them a red to orange to yellow color. In some cases where natural waters partially neutralize acidic drainages in streams, accumulations of several inches of muddy precipitates occur. Neutralized mine drainages are often less than desirable for many uses, because they generally are extremely hard and contain high concentrations of dissolved sulfate.

In certain areas of the United States coal mining exposes coal and overburden containing appreciable pyrite, but acid mine drainage is not generated. Generally, in these areas carbonate rocks or calcareous shales and siltstones overlie the coal. The carbonate minerals present dissolve in surface waters and groundwaters, producing well-buffered solutions that can both prevent the formation of much acidic water and neutralize what is produced. In the study areas of this report, however, there are no carbonate rocks or appreciable amounts of calcite in the shales, siltstones, and sandstones (see Geology section). Thus, wherever pyrite-containing overburden and coal-processing wastes are located near the surface at the mine site, acidic drainages can form that are low in pH and high in hardness, dissolved iron, manganese, and sulfate.

The chemistry of surface waters at the mine site was examined to compare the extent and severity of acid generation and associated pollutants from unreclaimed and reclaimed mined land. Water samples were collected from 2 streams, 1 draining farm land and unreclaimed mined land and 1 draining reclaimed mined land. In addition, 2 drilled wells, 1 in unmined land and 1 in reclaimed mined land, were utilized to study and compare the recharge of shallow aquifers in unmined land and reclaimed mined land.

Experimental Procedures

To determine the effects of unreclaimed mined land on water quality, the tributary to East Cow Creek that drains the area of unreclaimed mined land (S 1/2, Sec. 35, T.30S, R.25E; Fig. 12) just north of the reclaimed mined land was sampled (sites W-2 to W-8). This tributary also drains Sec. 3, T.31S, R.25E and flows into East Cow Creek in NE 1/4, SE 1/4, Sec. 4, T.31S, R.25E. The upper reaches of the tributary (not shown on Fig. 12), as well as site W-1, drain farm land and experience intermittent flow, whereas some flow was detected at sites W-7 and W-8 at all sampling times. The sample locations chosen represent a range of drainage environments that includes farm land, mined land, farm and mined land, and strip pit drainage.

Drainage from the reclaimed mined land (Field 7) was sampled at site W-10. This site is on a tributary that drains Sec. 10, T.31S, R.25E and flows into Cow Creek in the SW 1/4, NE 1/4, Sec. 16, T.31S, R.25E. The major source of water of this tributary is strip pit overflow from the north-south-aligned strip pit at the western edge of Field 7. When the spoil banks were leveled the field was contoured to drain into the strip pit. The north half of the field drains to the south and west and the south half drains to the north and west into the pit.

East Cow Creek was sampled at site W-9 and Cow Creek at site W-11. Site W-9 was located just south of the point where the tributary draining the unreclaimed mined land flows into East Cow Creek. Sample W-11 was located just south of the point where the tributary draining the reclaimed mined land flows into Cow Creek. Sample sites W-12 and W-13 were strip pits in the reclaimed

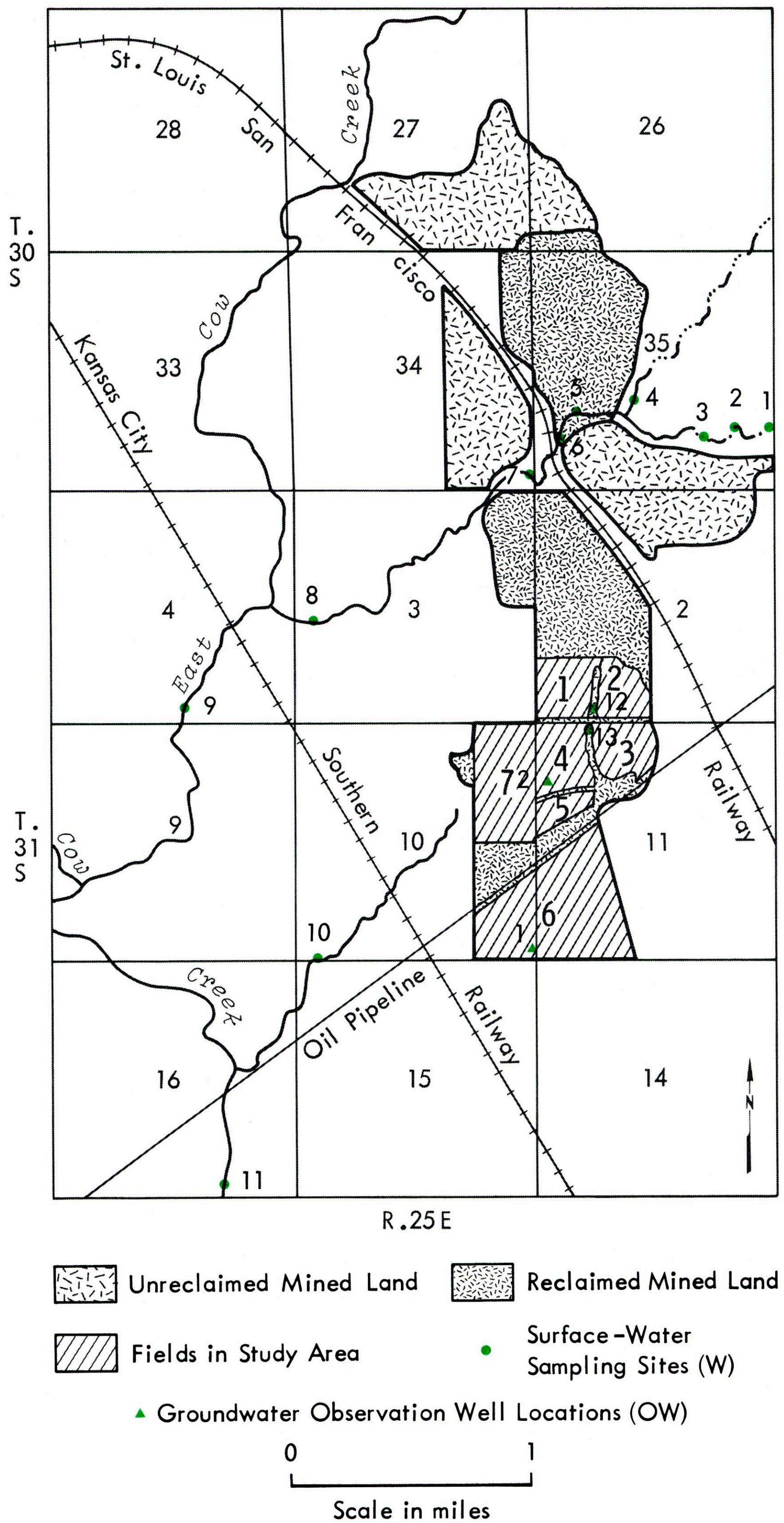

Figure 12. Map of surface-water sampling sites and groundwater observation-well locations.

mined land.

Sites W-1 and W-7 to W-11 were monitored over time to assess and compare the quality of water draining from farm land and from unreclaimed and reclaimed mined land. These data are given with the appropriate dates in Appendix H. Samples were taken at sites W-2 to W-6 only once, at the scheduled July 1976 sampling date. Sites W-2 and W-6 were sampled to determine the source of the acidity from the unreclaimed mined land, which was detected routinely at sites W-7 and W-8. Samples were taken at sites W-12 and W-13 only once to investigate and compare the effect on the water quality of the strip pits of the acid drainage observed flowing in Field 2 in the reclaimed mined land from the coal cleaning and loading area in the northeast corner of the field.

At each stream-water site flowing water was collected in 2 polyethylene bottles (250 and 1,000 ml); the smaller sample was acidified to prevent precipitation of metal cations by adding 1.0 ml of concentrated HNO_3. Field measurements of pH of the non-acidified samples were obtained with a Beckman Expand-Mate pH meter. These same procedures were also used on the samples from the strip pits in the reclaimed land. All samples were analyzed by the Kansas Department of Health and Environment using the methods given in Table 26.

A chemical analysis for each sample site is given in Table 27. The data for sites W-1 to W-8 represent water quality of the tributary draining farm land (W-1) and unreclaimed mined land (W-2 to W-8) on 1 day, while site W-9 represents the effect of the tributary water on the quality of water of East Cow Creek on the same day. The data for sample sites W-10 and W-11 represent drainage from reclaimed mined land and its effect on Cow Creek, respectively, on 1 day.

Table 28 is a summary of the pH values for all sites by sampling date, along with a description of the drainage environment represented by each site.

Surface Water

At site W-1 water flow is intermittent and drains from farm land. As shown in Table 27 and Appendix H, the water at this location has a slightly acidic pH (6-7) and low concentration of the major and minor solutes and trace elements. Downstream from site W-1 strip pit drainages from the unreclaimed mined land (seepage and overflow) enter directly into the tributary. The

Table 26. Methods used for analysis of water samples.

Determination	Method
pH	pH meter, glass-calomel electrode
Hardness	Titration, ethylenediaminetetraacetic acid (EDTA)
Calcium	Titration, EDTA, pH 12-13
Magnesium	Calculation, difference between hardness (Ca + Mg) and calcium (Ca)
Sodium	Flame photometry
Potassium	Flame photometry
Iron	Atomic absorption
Manganese	Atomic absorption
Alkalinity	Titration, sulfuric acid
Chloride	Titration, mercuric nitrate
Sulfate	Gravimetric, barium chloride
Nitrate	Colorimetric, Technicon Auto Analyzer
Fluoride	Colorimetric, alizarin visual
Phosphate	Colorimetric, vanadomolybdophosphoric acid
Boron	Colorimetric, carmine
Copper	Atomic absorption
Lead	Atomic absorption
Zinc	Atomic absorption
Chromium	Atomic absorption
Cadmium	Atomic absorption
Silver	Atomic absorption
Nickel	Atomic absorption
Silica (SiO_2)	Colorimetric, molybdosilicate

waters from the strip pits, sites W-3 and W-6 (Table 27), are highly acidic, extremely hard, and have very high dissolved sulfate, iron, and manganese concentrations, all of which are typical of acid mine drainage. The chemistry of the tributary is strongly influenced by these strip pit drainages, as shown by an overall decrease in water

Table 27. Chemical analysis of surface-water samples. (Concentrations in ppm [mg/l], except pH.)

Sample[a]	W-1	W-2	W-3	W-4	W-5	W-6	W-7	W-8	W-9	W-10	W-11	W-12	W-13
pH	6.0	4.3	2.8	5.2	3.2	2.7	3.0	3.7	6.7	6.4	7.1	3.8	7.1
Hard.[b]	100	481	1520	1160	1370	1640	1230	1300	820	615	515	570	755
Ca	28	84	240	268	288	312	228	256	172	141	114	132	192
Mg	7.3	66	224	120	158	210	161	161	95	64	56	59	67
Na	9.8	14	36	32	34	43	29	40	57	44	52	28	46
K	3.2	4.0	3.6	5.5	5.6	5.0	5.0	5.8	5.8	4.6	4.9	5.8	5.0
Fe	.30	.68	39	.08	7.0	84	21	.63	.27	.72	1.4	.88	.13
Mn	.96	40	210	22	75	310	110	56	11	12	3.9	19	2.4
Alk[c]	12	8	0	14	0	0	0	0	38	20	82	0	44
Cl	4	8	14	5	6	14	10	10	8	8	17	7	6
SO_4	107	560	2090	1140	1580	2420	1528	1460	884	653	483	690	736
NO_3	.3	.3	1.4	.1	1.9	2.8	5.7	.4	1.1	1.2	7.1	.2	.1
F	.1	.9	2.0	.8	1.0	3.4	1.1	1.0	.8	.4	.6	.4	.1
PO_4	.16	.09	.01	.07	.07	.01	.05	.06	.09	.17	.7	.01	.01
B	.07	.09	.11	.12	.13	.15	.13	.20	.18	.13	.21	.18	.12
Cu	.00[d]	.01	.03	.00	.01	.07	.04	.02	.00	.01	.00	.01	.00
Pb	.00	.02	.02	.02	.06	.04	.04	.02	.02	.00	.02	.00	.00
Zn	.03	.57	1.3	.13	.80	6.5	4.0	2.0	.28	.28	.19	.90	.07
Cr	.00	.00	.01	.01	.01	.01	.01	.00	.00	.00	.00	.00	.00
Cd	.00	.01	.00	.01	.01	.01	.01	.01	.01	.01	.00	.00	.00
Ag	.00	.00	.00	.00	.0	.00	.00	.00	.00	.00	.00	.00	.00
Ni	.00	.50	2.9	.10	1.0	4.3	1.9	.90	.10	--[e]	--	.37	.05
SiO_2	12	29	54	5	23	48	27	18	12	11	11	2.2	1.3

[a] Locations and dates listed below.
[b] Hardness as $CaCO_3$ (total).
[c] Alkalinity as $CaCO_3$ (total).
[d] Below detection limit.
[e] Not determined.

Sample	Location			Date
	Section-Township-Range			
W-1	SE 1/4 SE 1/4 35	30S	25E	07/13/76
W-2	SE 1/4 SE 1/4 35	30S	25E	07/13/76
W-3	SW 1/4 SE 1/4 35	30S	25E	07/13/76
W-4	NE 1/4 SW 1/4 35	30S	25E	07/13/76
W-5	NW 1/4 SW 1/4 35	30S	25E	07/13/76
W-6	SW 1/4 SW 1/4 35	30S	25E	07/13/76
W-7	SE 1/4 SE 1/4 34	30S	25E	07/13/76
W-8	NW 1/4 SW 1/4 3	31S	25E	07/13/76
W-9	SW 1/4 SE 1/4 4	31S	25E	07/13/76
W-10	SW 1/4 SW 1/4 10	31S	25E	05/04/76
W-11	SW 1/4 SE 1/4 16	31S	25E	05/04/76
W-12	SW 1/4 2	31S	25E	11/17/76
W-13	NW 1/4 11	31S	25E	11/17/76

Table 28. pH values of surface-water samples.

Sample Site	Drainage Environment of Sample	Date of Sample				
		11/25/76	01/20/76	05/04/76	07/13/76	11/17/76
	Tributary of East Cow Creek					
W-1	Farm Land		6.4	6.5	6.0	
W-2	Mined Land and Farm Land				4.3	
W-3	Mined Land Strip Pit					2.8
W-4	Mined Land and Farm Land				5.2	
W-5	Mined Land				3.2	
W-6	Mined Land Strip Pit					2.7
W-7	Mined Land	3.0	3.0	3.2	3.0	
W-8	Mined Land and Farm Land	3.4	3.4	3.8	3.7	
W-9	East Cow Creek	5.4	6.5	6.8	6.7	
	Tributary of Cow Creek					
W-10	Reclaimed Mined Land	5.1	4.9	6.4		
W-11	Cow Creek	6.3	6.8	7.1		
W-12	Reclaimed Mined Land Strip Pit					3.8
W-13	Reclaimed Mined Land Strip Pit					7.1

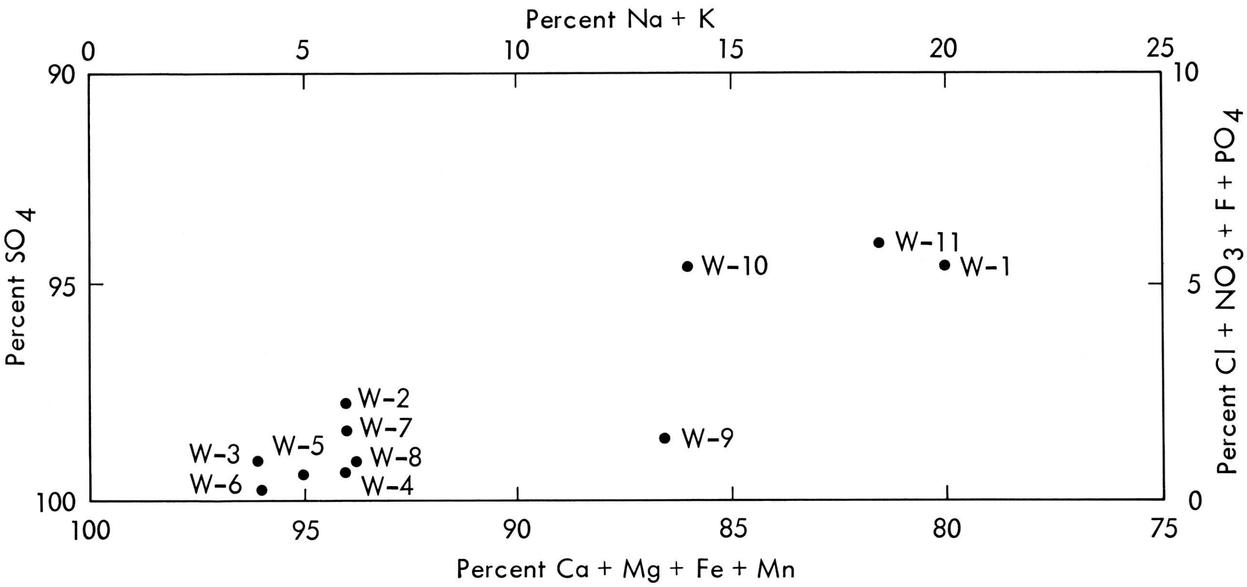

Figure 13. Modified Piper diagram of water samples from the tributary of East Cow Creek, East Cow Creek, and Cow Creek.

quality from sites W-1 to W-8 in Table 27 and Figure 13.

Surface water draining from the reclaimed mined land was appreciably better in quality than that from the unreclaimed mined land, but not of as good quality as that from the unmined land. As shown in Appendix H, site W-10 had a higher pH and a lower concentration of dissolved constituents than sites W-7 and W-8 on the May 1976 sampling dates.

The higher concentrations of nitrate and phosphorus routinely detected at site W-11 are from effluent discharged into Cow Creek from the city of Pittsburg's sewage treatment plant located approximately 3.5 miles upstream. On the November 1975 sampling date the north half of Field 7 had been leveled and planted to wheat. Active mining was still in progress in the south half of the field. Thus, the water quality at that time at site W-10 was more similar to that at sites W-7 and W-8 because of exposure of pyrite-bearing overburden. By the January 1976 sampling date the south half of Field 7 had been leveled. The high nitrate concentration in the January sample at site W-10 reflects the addition of nitrogen fertilizer to the north half of the field.

As the streams from the mined areas are mixed downstream with East Cow Creek and Cow Creek, the waters are both diluted and partially neutralized. The pH values increase and concentrations of dissolved constituents decrease at sites W-9 and

W-11 as shown in Tables 27 and 28 and Figure 13. The neutralization and dilution processes occur continually at sites W-9 and W-11 (Appendix H). However, even though pH's are near neutral and slightly alkaline at these sites, the concentrations of such dissolved species as calcium, magnesium, iron, manganese, and sulfate are still greater than those at site W-1, which represents drainage from unmined (farm) land. Additionally, the concentrations of sulfate, iron, and manganese were too high for most uses.

Variability in the composition of spoil material and the source of drainage water also greatly affected the chemistry of the water in the reclaimed mined area. Water samples at sites W-12 and W-13 (Table 28) were taken from strip pits that are almost contiguous in a north-south direction, but are separated by a gravel road. Both pits are in reclaimed mined land. Site W-13, the southern pit, has a nearly neutral pH of 7.1. The minesoil around site W-12 (Fields 1 and 2) contains an unusually large amount of pyrite on and near the surface. Also, drainage from a coal cleaning and loading site in the northeast corner of Field 2 enters the northern pit. Contents of major dissolved constituents are relatively similar, indicating that the pit at site W-13, which receives drainage from Fields 3 and 4, has a source of drainage that neutralizes acidic weathering products, a fact confirmed by the pH data for Field 3 (Table 31).

Temporal as well as spatial variability in water chemistry was pronounced at the mine site. A rise in pH and a drop in the concentrations of major dissolved species occurred at sites W-7, W-8, and W-9 on May 4 (Appendix H). During the 2 weeks prior to sampling, 4.6 inches of rain provided greater runoff for dilution and partial neutralization. This effect is also well illustrated in the surface-water-quality records for Kansas of the U.S. Geological Survey, water year 1977, for Little Cherry Creek near West Mineral, Cherry Creek near Hallowell, and Brush Creek near Weir. All of these streams drain land surface mined for coal in Cherokee County. Values of pH as low as 3.1 and sulfate concentrations as high as 1,200 milligrams per liter during low flow in Little Cherry Creek near West Mineral changed to pH 6.2 and 47 mg/l sulfate during a period of high flow.

Mine drainages affected by the weathering of pyrite are unusable or less than desirable for many uses. Present major uses of the surface waters in this area are recreation, swimming and fishing, and livestock watering, mainly of beef cattle. Low pH would first preclude the use of the waters draining from the unreclaimed mined land (sites W-7 and W-8) and from the strip pits (sites W-3, W-6, and W-12). A pH <5 is not recommended for drinking water for humans and livestock. A pH <6.5 is not recommended for water used for swimming. For fresh-water aquatic organisms a pH <5 is considered to afford a low level of protection. A pH <4 is considered to be undesirable for irrigation of acid soils such as the Parsons soil. For industrial purposes, specifically for cooling-water use, a water with a pH <6.0 with dissolved solids greater than 1,000 mg/l would cause considerable corrosion problems (National Academy of Sciences, 1973).

At the lower pH's, dissolved concentrations of many minor and trace elements can surpass recommended or maximum permissible levels established for safe concentrations of potentially toxic substances. Recommended concentrations in irrigation waters for continuous use on all soils (National Academy of Sciences, 1973) were exceeded for iron (5.0 mg/l) at sites W-3, W-5, W-6, and W-7, fluoride (1.0 mg/l) at sites W-3 and W-6, manganese (0.2 mg/l) at all sites, zinc (2.0 mg/l) at sites W-6 and W-7, and nickel (0.2 mg/l) at sites W-2, W-3, W-5 to W-8, and W-12. Recommended concentrations in livestock water (National Research Council, 1974) were exceeded only for fluoride (2 mg/l) at site W-6.

National Secondary Drinking Water Standards (U.S. Environmental Protection Agency, 1979a) were exceeded for soluble iron (0.3 mg/l) at nearly all of the sites, but were greatly exceeded at sites W-3, W-5, W-6, and W-7. The standard for manganese (0.05 mg/l) was greatly exceeded at all sample sites, except W-1. The recommended maximum concentration for zinc (5 mg/l) was exceeded only at site W-6, while the maximum contaminant level for sulfate (250 mg/l) was greatly exceeded at sites W-2 to W-13.

Maximum contaminant levels of the National Interim Primary Drinking Water Regulations (U.S. Environmental Protection Agency, 1976) were exceeded only for fluoride and only at 2 sites, W-3 and W-6.

Regulations of the Federal Water Pollution Control Act exist for the control of acid mine drainages discharged from active coal-mining areas. The U.S. Environmental Protection Agency promulgated standards based on the "best practical control technology currently available" for existing point sources in 1977 and more stringent standards for new point sources of pollution discharged to water courses. Limitations are required for total iron and manganese, total suspended solids, and pH of point sources of acid or ferruginous mine drainage, alkaline mine drainage, and effluents from coal-preparation plants and associated areas (Table 29). These limitations are not applicable to large precipitation events, which can transport great amounts of sediment in streams.

Samples from sites W-2 to W-8 and W-12 do not meet the pH standard and samples from sites W-2 to W-9, W-10, and W-12 exceed the manganese standard for any 1 day. Additionally, sites W-3, W-6, and W-7 exceed the iron standard.

Dissolved manganese concentrations were always higher than iron in all the samples. Ferrous iron in solution oxidizes and precipitates as ferric oxyhydroxides at lower pH's than for the oxidation and precipitation of manganese. This would be shown by a decrease in the iron concentration relative to that of

Table 29. Effluent limitations for the Coal Mining Point Source Category.[a] Concentrations (mg/liter) of pollutants that may be discharged from existing sources after application of the best practicable control technology currently available.

Parameter	Maximum for any 1 day	Average of daily values for 30 consecutive discharge days
Iron, total[b]	7.0	3.5
Manganese, total	4.0	2.0
Total suspended solids	70.0	35.0
pH	Within range of 6.0-9.0	

[a] Derived from U.S. Environmental Protection Agency (1979b) regulations.

[b] Discharges of iron from new sources after application of the best available demonstrated control technology are limited to 6.0 mg/liter (maximum allowable) and 3.0 mg/liter (average of daily values for 30 consecutive discharge days).

manganese in the pH range 3 to 5. For surface waters with near-neutral pH (sites W-9, W-11, and W-13) the dissolved iron contents would be expected to be lower than the recommended drinking-water standard. For surface waters with pH <3.0 (sites W-3 and W-6) the dissolved-iron concentrations would be expected to be much higher than the standard. Most of the iron present in water with a pH near 7 would be as colloidal ferric oxyhydroxide. Manganese in water with a neutral to slightly alkaline pH would be in the process of oxidizing and precipitating, and thus would leave undesirable accumulations of dark scale if used untreated.

Groundwater

The condition of the shallow aquifers at the mine site was determined by measurements at 2 observation wells. One of these wells was located in unmined land (Field 6) south of the mining operation. This was observation well OW-1, which was drilled in January 1976 to a depth of 40 feet in SE 1/4, SE 1/4, SE 1/4, Sec. 10 (86 feet north of the south line of the section and 12 feet west of the east line), T.31S, R.25E. The well had a 2-inch diameter casing, perforated from 30 to 40 feet, and was sandpacked. The ground elevation was 920 feet above sea level. A pumping and recovery test on January 20, 1976, yielded a specific capacity of 0.4 gallons per minute per foot of drawdown.

Observation well OW-2 was located in SW 1/4, NW 1/4, NW 1/4, Sec. 11 (1,229 feet south of the north line of the section and 5 feet east of the west line), T.31S, R.25E, in the reclaimed mined land. This well was drilled in January 1976 to a depth of 35 feet and was sandpacked. Ground elevation was 916 feet above sea level. A pumping and recovery test in January 1976, preceding a period of virtually no rainfall, was unsuccessful, as the water table had not yet built up and risen high enough in the reclaimed mined land. A test in August 1976, taken with a 1-inch baler, yielded 0.14 gallons per minute, with little change in water level.

Recovery tests from the well in the unmined land (OW-1) showed a specific capacity value of 0.04 gallons per minute per foot of drawdown, indicating an extremely small storage capacity and a very low permeability. Inspection of the rocks indicated an extremely low porosity, and hence storativity, for these rocks. The baler test of well OW-2 in August 1976 suggested a higher storativity and transmissivity for the reclaimed mined land. The mechanical breaking of strata associated with the surface-mining process resulted in an unconsolidated material with a higher porosity and permeability compared to the unmined land.

A series of water-level measurements for these observation wells is recorded in Table 30. The rise in the elevation of the water level on March 11, 1976, in OW-2, as compared with OW-1, was attributed to recharge by direct infiltration of rain due to the greater permeability of the reclaimed mined land. Rainfall for the period September 1, 1975, to March 11, 1976, measured 15.45 inches. Prior to March 11, no water level was detected in OW-2 because the water table was building up and rising in the reclaimed mined land. Rainfall for the period March 11 to August 20, 1976, was 21.84 inches. On August 20, 1976, the elevation of the water in a nearby strip pit was the same as that in well OW-2, which indicated the water in the strip pit and the minesoil was connected. As such, the water level in the pit in the future should indicate the water level in the reclaimed mined land.

The lowering of the elevation of the water level in OW-1 during January through March was attributed

Table 30. Static water levels from land surface in observation wells. (Depth to water in feet below land surface.)

Date	OW-1	OW-2
January 20, 1976	15.18	--[a]
March 11, 1976	11.66	16.25
March 23, 1976	12.44	15.42
June 2, 1976	15.83	10.58
July 14, 1976	15.90	6.25
August 20, 1976	16.04	6.55

[a] No water level detected.

to an interruption in the flow by cuts made during the mining operation. The rise in water level in OW-1 from June through August was attributed to flow from the reclaimed mined land. The data for OW-1 show that little, if any, water from direct rainfall reaches the water table in the unmined land. This is not unusual for an area such as southeastern Kansas that has soils with extremely clayey subsoils, which impede downward water percolation. This is one reason for the observation that, although this area receives the greatest amount of rainfall in the State, it also has the greatest amount of runoff.

Summary

Comparisons of the quality of surface waters draining the unmined land and reclaimed and unreclaimed mined land showed major differences. Water in the tributary draining the unreclaimed mined land was severely affected by strip pit drainages (overflow and seepage). The water was highly acidic, extremely hard, and had very high concentrations of most of the major and minor solutes and trace elements. The high acidity makes this water unsuitable for drinking for humans and animals, for swimming, for irrigation of the soils in the area, and for most industrial purposes.

As a result of the low pH, many minor and trace-element concentrations exceeded recommended permissible levels for various uses. Recommended concentrations in irrigation water for continuous use on all soils were exceeded for iron, manganese, nickel, zinc, and fluoride. National Secondary Water Contaminant Levels were exceeded for iron, manganese, zinc, and sulfate. Maximum Contaminant Levels of the National Interim Primary Drinking Water Regulations were exceeded only for fluoride. Effluent Limitations for the Coal Mining Point Source Category of the Federal Water Pollution Control Act were exceeded or not met for pH, manganese, and iron.

Water draining from the reclaimed mined land was appreciably better in quality than that from the unreclaimed mined land, but not as good quality as water draining from the unmined land. The concentrations of iron, manganese, and sulfate were still too high for most uses.

Dilution and partial neutralization of the tributary waters draining from both the reclaimed and unreclaimed mined land occurred after mixing with water in the larger creeks that drain the area. However, even after dilution, iron, manganese, and sulfate concentrations were too high for most water uses.

Temporal variability in the water quality was also pronounced. A rise in pH and a drop in the concentrations of the major dissolved constituents occurred as a result of greater runoff from rainfall that allowed for greater dilution and neutralization.

Water-level measurements of observation wells in the unmined land and reclaimed mined land showed a relatively rapid recharge of the shallow aquifer of the reclaimed mined land by direct rainfall. This was attributed to a higher permeability of the reclaimed mined land as a result of its unconsolidated nature. The water level in the reclaimed mined land also fluctuates due to seepage from adjacent strip pits. Recharge of the shallow aquifer in the unmined land from direct rainfall was slight. Thus, the quantity of water available from reclaimed mined land will be much greater than that from unmined land in the area.

LAND RECLAMATION

by J. E. Welch

Method

The method used by the Clemens Coal Company in reclaiming the mined land included the following procedures:

1. Spoil banks leveled and area smoothed with a bulldozer to a gently rolling terrain allowing for needed drainage.
2. Lime applied by conventional lime-spreading truck (half of total applied).
3. Field tilled deeply (10-12 inches) with an offset (Rome) disc.
4. Field dragged with a 20-foot steel I-beam.
5. Lime applied by conventional lime-spreading truck (half of total applied).
6. Field tilled with standard farm disc to approximately 6 inch depth.
7. Additional dragging and mechanical picking of field to remove large rock fragments from the surface.
8. Seed bed prepared with farm disc and harrow.
9. Field planted to wheat at the rate of 90 lbs/ac or wheat and fescue at the rate of 90 and 20 lbs/ac and fertilized with 70 pounds of nitrogen, 70 pounds of phosphorus (P_2O_5), and 70 pounds of potassium (K_2O) per acre, based on soil-test data (Fig. 14 and Table 31) using a conventional grain drill.
10. Additional fescue seeded by broadcasting at the rate of 20 lbs/ac.

Leveling to a gently rolling terrain allows usage of conventional farm machinery and grazing of livestock, as well as adequate drainage. Offset discing results in deeper application of lime, which increases the depth of minesoil acceptable for plant root growth. Dragging the field insures a smooth surface and prepares the surface for tillage equipment. Removing large rock fragments from the surface allows the use of farm machinery, such as the grain drill, without damage. Multiple discing breaks down the shale fragments to finer sizes, increases water infiltration and retention, and improves seed-soil contact.

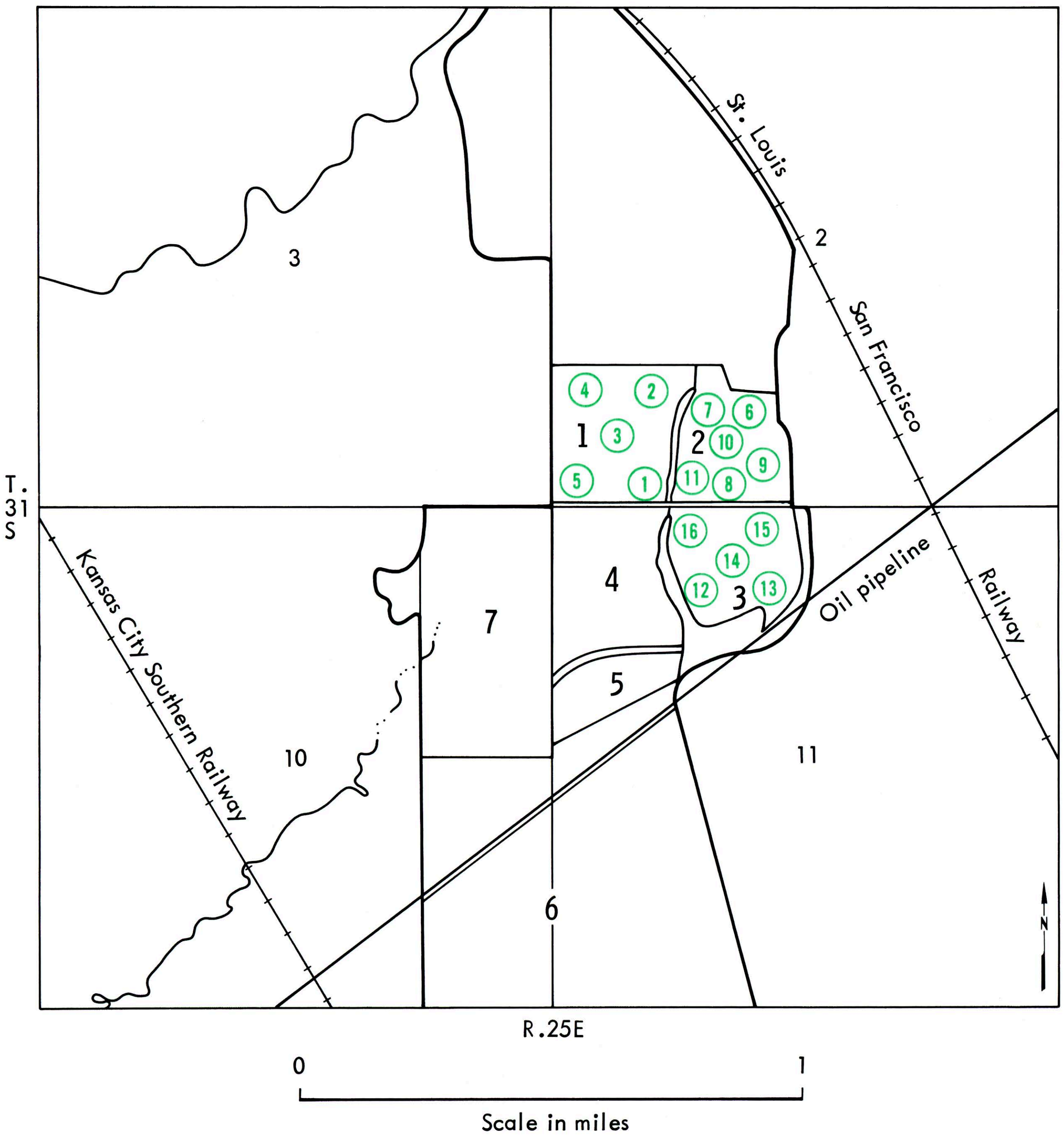

Figure 14. Map of location of soil samples taken to determine lime and fertilizer application rates. Data from Clemens Coal Company records.

Field Treatments and Crop Yields

Field 1

Mining was completed in 1973. Leveling and smoothing of the spoil banks were completed in the fall of 1974. Numerous depression areas remained after smoothing. During that same fall the field was fertilized with nitrogen, phosphorus, and potassium, and seeded to soft red

Table 31. Soil-test data and lime and fertilizer recommendations.[a]

Sample	pH	Available P	Exchangeable K	Recommendations N	P_2O_5	K_2O	ECC[b]
		(lb/ac)	(lb/ac)	(lb/ac)	(lb/ac)	(lb/ac)	(lb/ac)
Field 1							
1	4.8	4	120	50-70	70	70	4000
2	4.7	4	100	50-70	70	70-80	5000
3	5.2	6	80	50-70	70	80	3000
4	4.4	4	110	50-70	70	70-80	6000
5	4.8	4	100	50-70	70	70-80	5000
Field 2							
6	4.4	6	190	50-70	70	40-50	7500
7	4.4	4	170	50-70	70	50-60	7500
8	5.0	2	10	50-70	80	100	4000
9	4.8	2	100	50-70	80	70-80	4000
10	4.6	2	140	50-70	80	60-70	5000
11	4.3	2	130	50-70	80	70	6000
Field 3							
12	6.6	6	110	50-70	70	70-80	None
13	7.2	4	160	50-70	70	60	None
14	6.9	4	140	50-70	70	60-70	None
15	7.2	6	90	50-70	70	70-80	None
16	5.2	10	150	50-70	60	60-70	3000

[a] Data supplied by Clemens Coal Company; analysis by Kansas State University Soil Testing Laboratory.

[b] Effective Calcium Carbonate in pounds/acre needed to raise soil pH to 6.8 (Woodruff, 1967).

winter wheat (Arthur 71). Wheat was selected because it is an annual plant species that returns a profit if yields are high, and quickly provides a good ground cover and a root mass to aid in controlling soil erosion. Growth of wheat in the depression areas of the field was poor due to water saturation of the soil, which caused a significant reduction in the amount of oxygen available to plant roots. The field yielded only about 15 bu/ac (bushels per acre). As a result of the mining method of piling overburden onto upper overburden, considerable mixing of the 2 overburdens and soil occurred, which resulted in dark-gray shale fragments containing pyrite (FeS_2) being deposited in the surface of 7 to 10 acres in the north part of the field (Pls. 3 and 4). Few wheat plants grew in this area (Pl. 5). Studies in Ohio show the sulfur in dark-gray to black shales located nearest the coal seems to be the major cause of acidity in coal mining areas (Sutton, 1970).

During the early fall of 1975, the depression areas in the field were drained and filled, and the acid areas in the north part of the field were covered with soil. The field was tilled and fertilized with nitrogen, phosphorus, and potassium, and seeded to soft red winter wheat (Arthur 71) and tall fescue (Kentucky 31) in November. The wheat in this instance was planted as a nurse crop to aid in establishing the perennial fescue. Tall fescue lives for a number of years. It dies back to the ground annually, but regenerates itself each growing season. Five tons per acre of agricultural limestone (ECC-65 percent) were also added. A good stand of wheat was produced that yielded about 30 bu/ac, compared to 15 bu/ac the previous year. However, little fescue germinated and that which did showed poor growth.

Field 2

Mining was completed in 1973. Leveling and smoothing of the spoil banks were completed during the fall of 1974. No other treatments were performed on the field during 1974.

Additional smoothing to bury shale particles and fill in depression areas was done during the spring and summer of 1975, as a result of the poor growth of wheat in Field 1 the previous year. In November 1975 the field was fertilized with nitrogen, phosphorus, and potassium, and seeded to soft red winter wheat (Arthur 71) as a nurse crop to tall fescue (Kentucky 31). Five tons of agricultural limestone

(ECC-65 percent) per acre were also applied. A good stand of wheat was produced and yielded about 30 bu/ac (Pl. 6). As was the case in Field 1, little fescue germinated and that which did showed poor growth.

Field 3

Mining was completed during the summer of 1974, and leveling and smoothing of the spoil banks were completed during the summer of 1975. In November 1975 the field was fertilized with nitrogen, phosphorus, and potassium. The field was seeded to hard red winter wheat (Early Triumph), in place of the soft red winter wheat (Arthur 71) that had been planted in Fields 1 and 2 (Pl. 7). Based on soil-test data (Table 31), no lime was applied. A fair stand of wheat was produced that yielded about 25 bu/ac (Pls. 8 and 9). This yield compared well with the 30 bu/ac yield of Fields 1 and 2 (wheat planted in the fall of 1975).

Field 4

Mining was completed during the summer of 1975 and leveling and smoothing of the spoil banks were also completed during the same summer. In November 1975 the field was fertilized with nitrogen, phosphorus, and potassium, and seeded to hard red winter wheat (Early Triumph) as was done in Field 3. No lime was applied to the field. A poor stand of wheat was produced that yielded only about 10 bu/ac (Pl. 10).

Field 5

Mining was completed during the summer of 1975. Leveling and smoothing of the spoil banks were also completed that same summer. In November 1975, the field was fertilized with nitrogen, phosphorus, and potassium, and seeded to hard red winter wheat (Early Triumph), as had been done in Fields 3 and 4. No lime was added. A good stand of wheat was produced that yielded about 40 bu/ac.

Conclusions

From comparisons of yield data from the 5 fields, some general conclusions were reached concerning the efficacy of the various procedures added to and deleted from the original land treatment method employed in Field 1 to promote the growth of grass on minesoil.

The higher yield in Field 1 of wheat planted in 1975 compared to that planted in 1974 showed the need for liming to raise the soil pH to a level that would not adversely affect plant growth. Also, the difference in yields showed the need to bury acid-producing shale fragments below the depth of oxidation.

The identical yields of wheat planted in 1975 in Fields 1 and 2 showed the land treatment method to be quite successful in promoting a relatively high yield of wheat. Also, the yields showed that soft wheat will yield high if the pH is raised to a level that does not adversely affect wheat growth. The failure of fescue to germinate and grow after planting in both fields showed the method to be ineffective in promoting the growth of fescue in conjunction with wheat on minesoil. The failure of the fescue to germinate and survive could have been due to planting the seed too deep with the grain drill. Some seeds will not germinate if planted deep, especially if the soil surface crusts over, as it does on minesoils with silty clay loam textures (Barnhisel and others, 1975). Also, in coarse materials such as minesoil, the larger wheat seed will have better contact with soil and hence greater access to soil moisture than will the smaller fescue seed. The growth of tall fescue has been shown to be affected by differences in particle-size distribution (texture) (Van Lear, 1971). In addition, wheat seeds can germinate with little available moisture (Greb and Smika, 1979). Another possibility is aluminum toxicity. Fleming and others (1974) found that 4 mg/l dissolved aluminum severely inhibited tall fescue top and root growth. At around pH 5.5 aluminum concentration in soil solution is increased and greatly exceeds normal background levels in soil solution (Bohn and others, 1979). Wheat has been shown to be highly tolerant of excessive amounts of aluminum in soil solution (Reid, 1976); however, some plant species cannot tolerate excessive amounts of aluminum and fail to germinate. Some plant scientists think that the seed coat of some grass species may be highly permeable to toxic ions such as aluminum at low soil pH, thus making aluminum readily available for seed uptake in amounts that affect the seed embryo during imbibition (Maddox and others, 1977).

Since wheat is an annual grass species, its growth would be expected to be considerably greater than that of fescue during the first year. As such it would utilize most of the available light, nutrients, and moisture. Fescue would be expected to germinate and some survive the first year, but with less growth than if planted alone. In the second year increased fescue growth would be expected, as wheat would no longer be present to compete for available light, nutrients, and moisture. Erosion would be expected to be reduced by the presence of wheat stubble, which would intercept rainfall, and the wheat root mass, which would hold the soil particles together. Also, if additional fescue seeding is done by broadcasting, the stubble will help prevent the light fescue seed's being carried away by surface runoff. This is especially important on the steeper slopes and drainage ways.

The yields of wheat planted in 1975 in Fields 2 and 3 were similar, which showed again that to produce high yields of wheat on minesoil the pH must be at a level that will not adversely affect plant growth. In the case of Field 3 the natural soil pH was sufficiently high to promote plant growth, whereas in the case of Field 2 lime was added to raise the pH to a level adequate for plant growth.

The higher yield of wheat planted in 1975 in Field 3 compared to that in Field 4 showed the necessity for measuring the pH in each field before planting. Also, the yields showed that hard wheat, like soft wheat, will not yield high unless the pH is at a level that does not adversely affect plant growth.

The exceptionally high yield of wheat of about 40 bu/ac produced in Field 5 showed the efficacy of fertilizing and burying shale fragments deeper in the minesoil to minimize the oxidation of pyrite.

Overall the wheat yields of the 5 fields showed that wheat is well suited to minesoil, providing the pH is high enough and sufficient nitrogen, phosphorus, and potassium are available to insure the development of a good stand of wheat. Additionally, the comparisons showed the efficacy of burying acid-producing shale fragments deeper in the minesoil in producing good stands of wheat on minesoil. The wheat yield of Fields 1, 2, 3, and 5 (wheat planted November 1975) averaged 31 bu/ac, which compares well to the average yield of wheat of 28-40 bu/ac expected on Parsons soil in Crawford County, depending on the management techniques employed and how they are employed (U.S. Department of Agriculture, Soil Conservation Service, 1973).

Plate 1. An aerial view from the south showing the mine site, December 1975.

Plate 2. View of unmined area (Field 6) south of the mining operation, August 1975; crop is tall fescue growing on the Parsons soil.

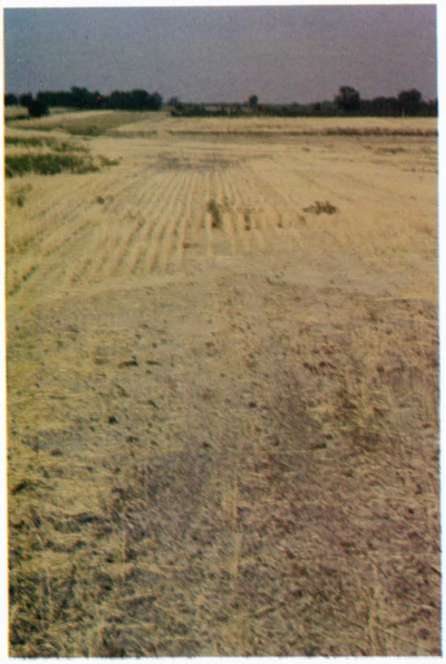

Plate 3. View of wheat stubble and an excessively acid spot (hotspot) in the northern half of Field 1, August 1975.

Plate 4. Close-up view of an excessively acid spot (hotspot) in northern half of Field 1 showing acid-producing dark-gray shale fragments and other rock fragments.

Plate 5. *Aerial view of northern half of Field 1 (lower right) showing acid areas devoid of wheat, May 1976.*

Plate 6. *Aerial view of Field 2 (lower right) showing a good stand of wheat with a few low spots devoid of wheat, May 1976.*

Plate 7. View of Field 3 showing surface appearance after seeding, November 1975.

Plate 8. Aerial view of Field 3 showing a fair stand of wheat with a few low spots devoid of wheat, May 1976.

Plate 9. Close-up view of stand of wheat in Field 3 that yielded about 30 bushels per acre, June 1976.

Plate 10. Aerial view of Field 4 showing the overall poor stand of wheat, and the southwest quarter of the field practically devoid of wheat.

CONCLUSIONS

Since 1977 operators of surface coal mines have been required by the Surface Mining Control and Reclamation Act (PL 95-87) to remove, store, and replace the topsoil on surface-mined land. The intent of the law is to return the land as quickly as possible to a condition capable of supporting the productive use that the land was capable of supporting prior to mining or to a higher productive use. On land that falls under the prime farm land category the A and B horizons of the soil must be replaced to a depth of 48 inches or to a depth equal to the depth of a subsurface horizon in the natural soil that inhibits root penetration, whichever is shallower. On other lands only the A horizon must be replaced. If the A horizon is less than 6 inches thick, the A horizon and the consolidated or unconsolidated material immediately below the A horizon to a depth of 6 inches must be replaced.

The regulatory authority in each state (in Kansas the Mined Land Conservation and Reclamation Board) may authorize the use of substiture or supplemental materials, such as selected subsurface soil horizons and overburden layers, that will result in a soil equal to or more suitable for sustaining vegetation than the available topsoil. The determination must be supported by results from chemical and physical analyses of soil and overburden, and shown to be feasible by field demonstrations.

Today, laws and regulations concerning the environment are passed and implemented before adequate background information is obtained from research. With regard to mined-land reclamation, research is needed to determine if, and when, it is appropriate to blend soil horizons with each other or with selected overburden layers to improve the physical and chemical properties of a minesoil, and in so doing to effectively create a soil of greater productive capacity than that which existed prior to mining.

The results of this study, based on wheat yields and comparisons of various chemical and physical properties of a minesoil and a natural soil, show the minesoil, which was not topsoiled, to be quite comparable to the natural soil. The results also suggest that replacing the A and B horizons as present in the natural soil may result in a soil less productive than if these horizons are mixed together or with

C horizon and/or other selected overburden. Mixing these materials will result in an increase in the amount of coarse particles in the minesoil, allowing more infiltration and percolation of rainfall, decreasing surface runoff, and hence reducing erosion and sedimentation. Also, since more rainfall enters the minesoil and moves deeper, there is more moisture available for plant growth. This is especially important during drought conditions. The more uniform texture that results from the mixing of horizons produces a deeper rooting zone for plants.

The problems of water quality and land-productivity degradation associated with acid conditions at the sites of coal surface mines can be prevented. Overburden analysis of core samples taken prior to mining can aid in identifying possible toxic and acid-producing strata. These can then be separated out during the excavation process for deep burial during backfilling. With the excess acidity eliminated it would then not be necessary to add large amounts of lime to raise the minesoil pH. However, to successfully establish such vegetation as grasses, it would still be necessary to apply sufficient fertilizer nitrogen, phosphorus, and potassium.

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APPENDIX A. Rock Core Descriptions (Pre-Mined)

Boring C-1

Surface elevation 925 feet
SE 1/4, NW 1/4, NW 1/4, SW 1/4, Sec. 11, T.31S, R.25E

DEPTH (feet)	
15.0-20.6	Shale, with laminated siltstone beds, and clay-ironstone nodules, highly weathered. Light-brown with brownish-gray areas.
20.6-22.5	Siltstone and sandstone, sandstone is very fine grained, with shaly laminae, ripple bedding. Light yellowish-brown with some gray areas.
22.5-26.0	Shale, silty, with abundant thin lenticular laminae of siltstone, well-consolidated. Gray with light-gray siltstone laminae.
26.0-26.2	Coal ("Pilot"), banded.
26.2-29.4	Shale, silty, slakes on exposure. Gray to light-gray.
29.4-30.2	Coal (Dry Wood), banded, with pyrite nodules.
30.2-32.0	Claystone (underclay), very soft, slakes on exposure. Light-gray.
32.0-37.2	Shale, increasingly carbonaceous with depth, occasional siltstone lenses, burrowed, with less burrowing in lower part. Gray.
37.2-39.2	Shale, with abundant clay-ironstone lenses and nodules, thinly laminated. Dark-gray.
39.2-40.5	Coal (Rowe), banded.
40.5-43.2	Siltstone, with carbonaceous material, extensive burrowing, occasional pyrite nodules, hard. Light-gray.
43.2	Bottom of core.

Boring C-2

Surface elevation 920 feet
NE 1/4, SE 1/4, NE 1/4, SE 1/4, Sec. 10, T.31S, R.25E

DEPTH (feet)	
15.0-18.0	Sandstone and siltstone, sandstone is very fine grained, with shale partings. Light-gray with light-brown staining.
18.0-19.7	Shale, with thin laminae of siltstone and/or sandstone, very fine grained. Dark-gray with light-gray sandstone and siltstone, some light-brown staining.
19.7-22.3	Shale, with very thin siltstone partings, laminated, a few thin gypsum partings, many siltstone-filled borings. Dark-gray with light-gray siltstone, a few areas of light-brown staining.
22.3-22.5	Coal ("Pilot"), banded.

22.5-23.1	Claystone (underclay), structureless, top 0.2 foot firm, rest of zone slakes on exposure. Gray.
23.1-24.6	Shale, carbonaceous, very carbonaceous in upper 0.3 foot, poorly bedded. Slakes slightly on exposure. Dark-gray with light-gray zone near the top.
24.6-25.3	Coal (Dry Wood), banded, with some thin pyrite zones.
25.3-27.6	Claystone (underclay), structureless, slakes badly. Light-gray.
27.6-29.7	Shale, carbonaceous--increasing with depth, irregular laminae, some burrowing. Gray, dark-gray in lower 0.9 foot.
29.7-31.3	Shale, with clay-ironstone nodules and laminae up to 0.5 inch thick. Dark-gray.
31.3-32.5	Coal (Rowe), banded with pyrite and secondary gypsum.
32.5-32.7	Claystone (underclay), slakes on exposure. Light-gray.
32.7-34.7	Siltstone, extensively burrowed, contains carbonaceous material. Gray and light-gray mottles.
34.7	Bottom of core.

Boring C-3

Surface elevation 918 feet
SW 1/4, SE 1/4, NE 1/4, SE 1/4, Sec. 10, T.31S, R.25E

DEPTH (feet)	
13.0-16.8	Shale, with thin lenses of fine-grained sandstones in upper 2.0 feet, laminated, occasional clay-ironstone nodules, gypsum present between some shale laminae, some burrowing. Light-brown.
16.8-20.3	Sandstone (Bluejacket), fine-grained, contains several ironstone zones, moderately well cemented, burrowed. Purplish-brown at top to yellowish-brown at the bottom.
20.3-23.2	Shale, finely laminated, some burrowing. Gray with light-brown staining.
23.2-23.8	Coal (Dry Wood), banded.
23.8-24.3	Claystone (underclay), soft, slakes badly. Gray with reddish-brown staining.
24.3-28.0	Shale, soft at top becoming increasingly consolidated toward bottom--represents transition from underclay to shale, pyrite nodules present. Upper part slakes on exposure. Gray with some light-brown staining.
28.0-32.5	Shale, carbonaceous, laminated, abundant siltstone nodules and lenses. Dark-gray.

32.5-34.0	Coal (Rowe), banded.
34.0-35.8	Siltstone, carbonaceous material present, extensive burrows, pyrite nodules. Light-gray.
35.8	Bottom of core.

Boring C-4

Surface elevation 921 feet
NW 1/4, NW 1/4, SE 1/4, SE 1/4, Sec. 10, T.31S, R.25E

DEPTH (feet)	
15.0-18.4	Shale, very thin laminae, small amount of gypsum. Light-gray with yellowish-brown staining, upper 1.0 foot is reddish-purple.
18.4-18.6	Sandstone (Bluejacket), very fine grained. Light-gray.
18.6-22.2	Shale, very thin laminae, some secondary gypsum mineralization, slakes on exposure. Light-gray.
22.2-22.5	Coal, banded.
22.5-24.4	Claystone (underclay), soft, some sulfur present, slakes on exposure. Gray.
24.4-27.9	Siltstone, argillaceous, well-consolidated, burrows present, some iron-oxide staining. Gray to light-brown.
27.9-35.7	Shale, with siltstone laminae, finely laminated, minor amount of burrowing, some cross-bedding, several clay-ironstone nodules in bottom 1.0 foot. Light-gray to gray, with light-gray siltstone.
35.7-42.8	Shale, carbonaceous, very finely laminated, with a few thin clay-ironstone laminae, traces of gypsum. Very dark gray.
42.8-43.6	Shale, with laminae of siltstone, phosphate nodules. Dark-gray. Siltstone is light-gray.
43.6-45.2	Siltstone, argillaceous, contains areas of coarse silt, burrowed. Light-gray.
45.2-46.4	Shale, silty, fine laminae, shale and siltstone interlaminated in bottom 0.5 foot. Gray.
46.4-53.5	Shale, with siltstone laminae, occasional clay-ironstone laminae and nodules, occasional pyrite nodules in lower 4.0 feet. Dark-gray, with light-gray siltstone.
53.5	Bottom of core. Boring continued to 75 feet but no additional cores were cut.

APPENDIX B. Elemental Composition of the Laboratory Ash of the Rowe and Dry Wood Coals.

Major and Minor Oxide Composition of the Laboratory Ash of the Rowe and Dry Wood Coals[a,b]

Sample	Ash	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	SO_3	Cl	MnO	P_2O_5
Site							%						
Rowe													
R-1	18.8	21	11	.47	.32	.14	.97	57	.47	1.6	.20	.07	<1.0
R-2	17.9	27	13	.46	.42	.16	.93	50	.63	1.6	.20	.05	<1.0
R-3	13.9	26	15	1.4	.46	.19	.82	50	.53	3.3	.20	.05	<1.0
Dry Wood													
D-1	11.5	41	20	5.8	2.1	.56	1.7	29	1.1	15.0	.20	.25	<1.0
D-2	20.9	36	21	3.1	.42	.11	1.2	36	.58	2.6	.20	.05	<1.0
D-3	32.3	21	10	2.6	.40	.07	.85	31	.29	15.0	.20	.05	<1.0

[a] Coal ashed in a muffle furnace at 525°C.
[b] All determinations by semiquantitative emission spectrography.

Trace-Element Composition of the Laboratory Ash of the Rowe and Dry Wood Coals[a,b]

Sample Site	Ash	Ag	B	Ba	Be	Cd	Ce	Co	Cr	Cu	Ga	Ge	La
	-%-	ppm											
Rowe													
R-1	18.8	0[c]	50	100	15	<1.0	0	70	70	213	--[d]	50	0
R-2	17.9	0	70	150	15	<1.0	0	30	70	176	30	70	0
R-3	13.9	0	70	500	15	1.5	0	70	100	306	30	100	0
Dry Wood													
D-1	11.5	7	70	700	20	8	0	50	200	326	30	50	70
D-2	20.9	2	50	150	10	77	0	300	70	200	50	20	70
D-3	32.3	0	0	100	5	490	0	100	50	232	100	20	70

Sample Site	Li	Mo	Nb	Nd	Ni	Pb	Sc	Sr	V	Y	Yb	Zn	Zr
	ppm												
Rowe													
R-1	51	0	0	--	300	900	10	300	100	50	--	204	50
R-2	137	0	0	--	150	1,200	10	200	100	70	--	89	100
R-3	90	0	0	--	200	1,200	15	300	200	100	--	1,020	100
Dry Wood													
D-1	49	20	20	200	200	450	70	700	300	700	70	770	150
D-2	60	0	0	200	500	230	20	150	150	300	30	25,500	100
D-3	30	0	0	0	300	450	10	300	100	150	--	158,000	50

[a] Coal ashed in a muffle furnace at 525°C.

[b] All determinations by semiquantitative emission spectrography except Cd, Cu, Li, Pb, and Zn, which were determined by quantitative flame atomic absorption spectrophotometry.

[c] None detected.

[d] Not determined.

APPENDIX C. Field Descriptions of Cores of Parsons Soil[a]

Horizon	Depth (inches)	Core 1
AP	0-7	Very dark grayish-brown (10YR 3/2) silt loam, grayish-brown (10YR 5/2) when dry; weak medium and fine granular structure; slightly hard when dry, very friable when moist; strongly acid, clear smooth boundary.
A2	7-15	Dark grayish-brown (10YR 4/2) silt loam, light brownish-gray (10YR 6/2) when dry, with a few fine distinct strong brown mottles; weak medium and coarse granular structure; slightly hard when dry, friable when moist; strongly acid; abrupt wavy boundary.
B21t	15-25	Very dark grayish-brown (10YR 3/2) silty clay, dark grayish-brown (10YR 4/2) when dry; common, fine and medium distinct mottles that are reddish-brown and strong brown; weak coarse prismatic and moderate to weak blocky structure; extemely hard when dry, extremely firm when moist; shiny films on most ped surfaces, gray coatings on both vertical and horizontal ped surfaces; few, fine, iron-manganese oxide stains and nodules; strongly acid; gradual smooth boundary.
B22t	25-30	Dark grayish-brown (10YR 4/2) silty clay, grayish-brown (10YR 5/2) when dry; many fine and medium distinct mottles that are strong brown and yellowish-brown; weak coarse prismatic and weak coarse blocky structure; extemely hard when dry, extremely firm when moist; shiny films on a few ped surfaces; common, fine and medium iron-manganese oxide stains and nodules; strongly acid; diffuse boundary.
B3	30-39	Coarsely mottled grayish-brown (10YR 5/2), yellowish-brown (10YR 5/4), and dark-brown (7.5YR 4/3) light silty clay; weak coarse blocky structure; very hard when dry, very firm when moist; common fine and medium iron-manganese oxide stains and nodules; strongly acid; diffuse boundary.
C1	39-55	Coarsely mottled gray (10YR 5/1), dark yellowish-brown (10YR 4/4), and dark-brown (7.5YR 4/4) heavy silty clay loam; massive; hard when dry, very firm when moist; few fine and medium iron-manganese oxide stains and nodules; medium acid; diffuse boundary.

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[a] Procedures and terms are those used by the U.S. Department of Agriculture, Soil Conservation Service (1951, 1975).

Horizon	Depth (inches)	
C2	55-68	Coarsely mottled gray (10YR 5/1) and dark yellowish-brown (10YR 4/4) heavy silty clay loam; massive; hard when dry, firm when moist; few fine iron-manganese stains and nodules; medium acid; diffuse boundary.
C3	68-128	Coarsely mottled gray (10YR 5/1) and dark yellowish-brown (10YR 4/4) heavy silty clay loam; massive; hard when dry, firm when moist; few fine iron-manganese oxide nodules; medium acid; diffuse boundary.
C4	128-138	Yellowish-brown (10YR 5/4) silty clay loam, with many medium and coarse distinct mottles that are gray; massive; hard when dry, firm when moist; medium acid, clear boundary to shale.

Core 2

AP	0-8	Very dark grayish-brown (10YR 3/2) silt loam, grayish-brown (10YR 5/2) when dry; weak fine and medium granular structure; slightly hard when dry, very friable when moist; many roots; strongly acid; clear smooth boundary.
A2	8-17	Dark grayish-brown (10YR 4/2) silt loam, light brownish-gray (10YR 6/2) when dry, few fine distinct mottles that are strong brown; weak medium and coarse granular structure; slightly hard when dry, friable when moist; many very fine, fine, and medium roots; strongly acid; abrupt wavy boundary.
B2t	17-28	Very dark grayish-brown (10YR 3/2) silty clay, dark grayish-brown (10YR 4/2) when dry; weak coarse prismatic and moderate to weak medium and coarse blocky structure; extremely hard when dry, extremely firm when moist; gray coating on both vertical and horizontal ped surfaces in upper part and vertical ped surfaces in lower part; shiny films on some ped surfaces; common fine and few medium roots between peds and common very fine roots inside of peds; few fine iron-manganese oxide nodules; strongly acid; gradual smooth boundary.
B3	28-39	Coarsely mottled grayish-brown (10YR 5/2), dark yellowish-brown (10YR 4/4), and dark-brown (7.5YR 4/3) silty clay; weak blocky structure; very hard when dry, very firm when moist; few fine flattened roots between peds and few very fine roots inside of peds; common fine and medium iron-manganese oxide stains and fine nodules; strongly acid; diffuse boundary.

Horizon	Depth (inches)	
C1	39-53	Coarsely mottled gray (10YR 5/1), dark yellowish-brown (10YR 4/6), and dark-brown (7.5YR 4/4) heavy silty clay loam; massive; very hard when dry, very firm when moist; few very fine and fine flattened roots; common fine and medium iron-manganese oxide stains and fine nodules; strongly acid, diffuse boundary.
C2	53-65	Coarsely mottled gray (10YR 5/1), dark yellowish-brown (10YR 4/6), and yellowish-brown (10YR 5/6) heavy silty clay loam; massive; hard when dry, firm when moist; few fine iron-manganese oxide stains and nodules; medium acid; diffuse boundary.
C3	65-110	Coarsely mottled gray (10YR 5/1) and dark yellowish-brown (10YR 4/6) heavy silty clay loam; massive; hard when dry, firm when moist; few fine iron-manganese oxide stains and nodules; medium acid; diffuse boundary.
C4	110-120	Light olive-brown (2.5YR 5/4) silty clay loam, with common medium and coarse distinct gray (10YR 5/1) mottles; massive; hard when dry, firm when moist; medium acid; clear boundary to shale.

Core 3

AP	0-7	Very dark grayish-brown (10YR 3/2) silt loam, grayish-brown (10YR 5/2) when dry; weak fine and medium granular structure; slightly hard when dry, very friable when moist; medium acid; clear smooth boundary.
A2	7-11	Dark grayish-brown (10YR 4/2) silt loam, light brownish-gray (10YR 6/2) when dry; weak medium granular structure; slightly hard when dry, friable when moist; few fine iron-manganese oxide nodules; medium acid; abrupt wavy boundary.
B21t	11-20	Very dark brown (10YR 2/2) silty clay, dark grayish-brown (10YR 4/2) when dry; common fine faint mottles that are yellowish brown; weak coarse prismatic and moderate to weak medium blocky structure; extemely hard when dry, extremely firm when moist; gray coatings on many ped surfaces, both vertical and horizontal; shiny films on some ped surfaces; few fine iron-manganese oxide nodules; strongly acid; gradual smooth boundary.

Horizon	Depth (inches)	
B22t	20-26	Very dark grayish-brown (10YR 3/2) silty clay; dark grayish-brown (10YR 4/2) when dry; common fine faint mottles that are yellowish-brown; weak coarse prismatic and weak coarse blocky structure; extremely hard when dry, extremely firm when moist; shiny films on a few ped surfaces; common fine iron-manganese oxide stains and nodules; strongly acid; diffuse boundary.
B3	26-40	Coarsely mottled grayish-brown (10YR 5/2), yellowish-brown (10YR 5/4), and dark-brown (7.5YR 4/3) silty clay; weak coarse blocky structure; very hard when dry, very firm when moist; common fine and medium iron-manganese oxide stains and nodules; strongly acid; diffuse boundary.
C1	40-60	Coarsely mottled gray (10YR 5/1), dark yellowish-brown (10YR 4/4), and dark-brown (7.5YR 4/4) heavy silty clay loam; massive; hard when dry, very firm when moist; few fine and medium iron-manganese oxide stains and nodules; strongly acid; diffuse boundary.
C2	60-79	Coarsely mottled gray (10YR 5/1) and dark yellowish-brown (10YR 4/6) heavy silty clay loam; massive; very hard when dry, very firm when moist; common fine iron-manganese oxide stains and nodules; strongly acid; diffuse boundary.
C3	79-120	Coarsely mottled gray (10YR 5/1) and dark yellowish-brown (10YR 4/6) heavy silty clay loam; massive; very hard when dry, very firm when moist; few fine iron-manganese oxide stains and nodules; strongly acid; diffuse boundary.
C4	120-132	Yellowish-brown (10YR 5/4) silty clay loam with common medium and coarse distinct gray (10YR 5/1) mottles; massive; hard when dry, firm when moist; strongly acid; clear boundary to shale.

APPENDIX D. Field Descriptions of Minesoil Surface Samples[a]

S-1

Surface 6 inches sampled with a spade. Color is a mixture of brown (10YR 4/3), yellowish-brown (10YR 5/4), and grayish-brown (10YR 5/2). Texture is a shaly, silty clay loam. Coarse particles (>2 mm) make up 15 to 20 percent of sample; these are mostly shale fragments >50 mm in length with a few ferruginous siltstone and coal fragments and iron-manganese oxide nodules. The structure is clods, irregular to rounded in shape, which contain some small shale fragments.

S-2

Surface 6 inches sampled with a spade in the largest low area in Field 1. Appearance indicated some sediment, about 1/2 to 1 inch in depth, was deposited by runoff into this low area. Surface appearance was typical of natural areas where water ponds in low areas. Material below 1 inch is similar to sample S-1. Surface inch is a platy, brown (10YR 5/3, moist), heavy silt loam.

S-3

Surface 6 inches sampled with a spade near crest of highest point in northeast part of field. Color is a mixture of gray (2.5Y 5/), grayish-brown (10YR 5/2), and yellowish-brown (10YR 5/4). The texture is a shaly, silty clay loam. Coarse particles (>2 mm) make up about 40 to 50 percent of sample; these are mostly shale fragments, <70 mm in length, with a few ferruginous siltstone and coal fragments and iron-manganese oxide nodules. The structure is clods, irregular to rounded in shape, which contain many small shale fragments.

S-4

Surface 6 inches sampled with a spade. Similar to S-3, except more shale fragments gray in color (2.5Y 5/).

S-5

This sample is representative of the surface 6 inches of Field 2. Color is a mixture of brown (10YR 4/3), yellowish-brown (10YR 5/4), and grayish-brown (10YR 5/2). The texture is a shaly, silty clay loam. Coarse particles (>2 mm) make up about 20 to 25 percent of the sample; these are mostly shale fragments <70 mm in length, with a few ferruginous siltstone and coal fragments and iron-manganese oxide nodules. The structure is clods, irregular in shape, which contain many small shale fragments.

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[a] Procedures and terms are those used by the U.S. Department of Agriculture, Soil Conservation Service (1951, 1975).

APPENDIX E. Field Descriptions of Minesoil Auger Sites[a]

Horizon	Depth (inches)	
		A-2
C1	0-6	Light olive-brown (2.5Y 5/4) and brown (10YR 4/3) shaly clay loam, with common light-gray (10YR 6/) and yellowish-brown (10YR 5/6) clods, spheroidal to irregular in shape; coarse particles, >2 mm, make up about 20 to 25 percent of this layer, are mostly shale fragments with some ferruginous siltstone and sandstone fragments; a few iron-manganese oxide nodules.
C2	6-12	Yellowish-brown (10YR 5/4) shaly, silty clay loam, with common light-gray (10YR 6/) and brown (10YR 4/3) clods; coarse particles (>2 mm), about 15 percent, are mostly shale fragments with some ferruginous siltstone and sandstone fragments, some of the siltstone fragments have black coatings; a few iron-manganese oxide nodules; many visible clods.
C3	12-40	Brown (10YR 4/3) shaly, silty clay loam, with some yellowish brown (10YR 5/4), light-gray (10YR 6/) and light olive-brown (2.5Y 5/4) clods; coarse particles (>2 mm), about 15 to 20 percent, are mostly shale fragments with some ferruginous siltstone and sandstone fragments; a few iron-manganese oxide nodules; many visible voids. Less than 5 percent of fragments are more than 2 inches in length.
		A-3
C1	0-6	Brown (10YR 4/3) clay loam, with common yellowish-brown (10YR 5/4) and a few light-gray (10YR 6/) clods spheroidal to irregular in shape; coarse particles (>2 mm), about 10 percent are mostly shale fragments with some ferruginous siltstone, sandstone, and coal fragments, most of the siltstone fragments have black coatings; a few iron-manganese oxide nodules.
C2	6-12	Brown (10YR 5/3) silt loam, with common yellowish-brown (10YR 5/4) clods; coarse particles (>2 mm), about 5 percent, are mostly shale fragments with some ferruginous siltstone and sandstone fragments, most of the siltstone fragments have black coatings; a few iron-manganese oxide nodules; many visible voids.

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[a] Procedures and terms are those used by the U.S. Department of Agriculture, Soil Conservation Service (1951, 1975).

Horizon	Depth (inches)	
C3	12-40	Brown (7.5YR 4/4), yellowish-brown (10YR 5/4), and light-gray (10YR 6/) shaly clay loam; coarse particles (>2 mm), about 30 to 40 percent, are mostly ferruginous siltstone and shale fragments with some sandstone fragments, about 15 percent of the fragments are more than 2 inches in length and they are mostly ferruginous siltstone; a few iron-manganese oxide nodules; many visible voids.

A-4

C1	0-6	Brown (10YR 4/3) silty clay loam with common yellowish-brown (10YR 5/4) and light-gray (10YR 6/) clods, spheroidal to irregular in shape; coarse particles (>2 mm), about 10 percent, are mostly shale fragments with some ferruginous siltstone, sandstone, and coal fragments; a few iron-manganese nodules.
C2	6-12	Brown (10YR 4/3) silty clay loam, with common yellowish-brown (10YR 5/4) and light-gray (10YR 6/) clods; coarse particles (>2 mm), about 10 percent, are mostly ferruginous siltstone fragments with some shale, sandstone, and coal fragments, some of the shale fragments are gray (2.5Y 5/) in color; a few iron-manganese oxide nodules.
C3	12-30	Brown (10YR 4/3) and yellowish-brown (10YR 5/4) shaly clay loam, with common brown (7.5YR 4/4) and light-gray (10YR 7/) clods; coarse particles (>2 mm), about 15 percent, are mostly ferruginous siltstone fragments with some shale, sandstone, and coal fragments; a few iron-manganese oxide nodules; common visible voids.
C4	30-40	Yellowish-brown (10YR 5/4) and brown (10YR 4/3) shaly, silty clay loam, with common light-gray (10YR 6/) clods; coarse particles (>2 mm), about 15 percent, are mostly ferruginous siltstone fragments and some shale, sandstone, and coal fragments; a few iron-manganese oxide nodules; common visible voids.

A-8

C1	0-6	Brown (10YR 4/3) shaly, silty clay loam, with common yellowish-brown (10YR 5/4) clods, spheroidal to irregular in shape; coarse particles (>2 mm), about 20 percent, are mostly shale fragments with some sandstone and ferruginous siltstone fragments and a few gray (2.5Y 5/) shale fragments; a few iron-manganese oxide nodules.

Horizon	Depth (inches)	
C2	6-12	Brown (10YR 4/3) shaly silt loam; with common yellowish-brown (10YR 5/4) clods; coarse particles (>2 mm), about 20 percent, are mostly ferruginous siltstone with some sandstone and shale fragments; a few iron-manganese oxide nodules.
C3	12-40	Dark yellowish-brown (10YR 4/4) shaly, silty clay loam, with some dark-brown (7.5YR 4/4) and light-gray (10YR 6/) clods; coarse particles (>2 mm), about 20 percent, are mostly ferruginous siltstone and iron concretions of irregular shape with some shale and sandstone fragments; few iron-manganese oxide nodules; many visible voids; less than 10 percent of fragments are more than 2 inches in length.

A-11

C1	0-6	Dark grayish-brown (2.5Y 4/3) shaly, silty clay loam, with common yellowish-brown (10YR 5/4) clods, mostly spheroidal in shape; coarse particles (>2 mm), about 15 percent, are mostly shale fragments with some ferruginous siltstone, sandstone, and coal fragments; a few iron-manganese oxide nodules.
C2	6-12	Dark grayish-brown (2.5Y 4/3) shaly, silty clay loam, with common yellowish-brown (10YR 5/4) clods; coarse particles (>2 mm), about 20 percent, are mostly shale fragments with some ferruginous siltstone, sandstone, coal fragments; a few iron-manganese oxide nodules; many visible voids.
C3	12-40	Dark grayish-brown (2.5Y 4/3) shaly, silty clay loam, with common yellowish-brown (10YR 5/4) clods; coarse particles (>2 mm), about 15 percent, are mostly shale fragments with some sandstone, ferruginous siltstone, and coal fragments; a few iron-manganese oxide nodules; many visible voids.

APPENDIX F. Field Descriptions of Parsons Soil in Crawford County, Kansas[a]

Horizon	Depth (inches)	
A1	0-7	Dark-gray (10YR 4/1; 3/1 m) silt loam; weak granular; friable; pH 4.8.
A21	7-13	Grayish-brown (10YR 5/2; 3/1 m) silt loam; weak granular; friable; pH 5.4.
A22	13-16	Grayish-brown (10YR 5/2; 4/1 m) silt loam; few fine faint brownish-yellow mottles; weak granular; friable.
B21t	16-24	Dark grayish-brown (10YR 4/2; 3/2 m) silty clay; common coarse distinct brownish-yellow mottles; moderate medium subangular blocky breaking to moderate fine subangular block; very firm; pH 5.2.
B22t	24-36	Grayish-brown (10YR 5/2; 4/2 m) silty clay; many coarse prominent brownish-yellow mottles; weak subangular blocky; very firm; pH 5.3.
C1	36-47	Light brownish-gray (10YR 6/2; 2.5Y 5/2 m) silty clay; many coarse prominent brownish-yellow mottles; massive; very firm; many black iron concretions; pH 5.8.
C2	47-60+	Light brownish-gray (10YR 6/2; 2.5Y 6/2 m) silty clay loam; many coarse prominent brownish-yellow mottles; massive; firm; pH 6.2.

APPENDIX G. Field Description of Parsons Soil in Bourbon County, Kansas[b]

Horizon	Depth (inches)	
AP	0-7	Very dark gray (10YR 3/1) silt loam; weak very fine granular structure; slightly hard, very friable; many fine roots and worm casts; slightly acid; clear smooth boundary.
A21	7-11	Mixed dark-gray (10YR 4/1) and gray (10YR 5/1) silt loam; weak fine and very fine granular structure; slightly hard, very friable; many fine roots; strongly acid; clear smooth boundary.
A22	11-15	Gray (10YR 6/1) silt loam; few fine distinct yellowish-brown (10YR 5/6) mottles; weak fine granular structure;

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[a] Described by Jarvis and others (1959).

[b] Description from U.S. Department of Agriculture, Soil Conservation Service (1981).

Horizon	Depth (inches)	
		slightly hard, very friable; many fine roots; strongly acid; abrupt smooth boundary.
B21t	15-20	Dark-gray (10YR 4/1) silty clay, light-gray (10YR 7/1) silt coatings on peds; common fine and medium distinct strong brown (7.5YR 5/6) mottles; moderate fine and medium blocky structure; very hard, very firm; many fine roots, but less than above horizon; strongly acid; gradual smooth boundary.
B22t	20-27	Dark-gray (10YR 4/1) silty clay; common fine and medium distinct yellowish-brown (10YR 5/6) mottles; weak fine and medium blocky and subangular blocky structure; few fine roots; strongly acid; gradual smooth boundary.
B3	27-39	Mixed dark-gray (5Y 4/1) and gray (5Y 5/1) silty clay, common fine and medium distinct brown (7.5YR 4/4) mottles; weak medium subangular block structure; very hard, very firm; clay films on ped faces; few fine roots; black coatings through old root channels; few fine black concretions and stains; neutral; gradual smooth boundary.
C1	39-52	Coarsely mottled strong brown (7.5YR 5/6), gray (5Y 6/1), and reddish-brown (5YR 4/4) silty clay; massive; hard, firm; black coatings through old root channels; common soft black masses; neutral; gradual smooth boundary.
C2	52-63	Coarsely mottled strong brown (7.5YR 5/6), gray (5Y 6/1), and reddish-brown (5YR 4/4) silty clay; massive; hard, firm; black coatings through old root channels; common soft black masses; moderately alkaline.
C3	63-73	Continuation of above horizon; diffuse wavy boundary.
C4	73-85	Coarsely mottled gray (5Y 6/1) and strong brown (7.5 YR 5/6) silty clay; weak subangular block and blocky structure; extremely hard, very firm; few black concretions and common black stains; few rounded pebbles less than 1/4 inch in size; moderately alkaline.

APPENDIX H. Chemical Analysis of Surface-Water Samples

(Concentrations are ppm [mg/l], except pH)

W-1

Parameter	Date Collected		
	01/20/76	05/04/76	07/13/76
pH	6.4	6.5	6.0
Hardness[a]	72	100	100
Ca	16	26	28
Mg	7.8	8.5	7.3
Na	10	17	9.8
K	4.6	2.3	3.2
Fe	.69	1.5	.30
Mn	.30	2.3	.96
Alkalinity[b]	28	24	12
Cl	10	5	4
SO_4	86	105	107
NO_3	.6	.6	.3
F	.7	.3	.1
PO_4	.08	.15	.16
B	.16	.08	.07
Cu	.01	.00[d]	.00
Pb	.00	.00	.00
Zn	.02	.25	.03
Cr	.00	.00	.00
Cd	.00	.00	.00
Ag	.00	.00	.00
Ni	.01	--[c]	.00
SiO_2	--	13	12

[a] Hardness as $CaCO_3$ (total)

[b] Alkalinity as $CaCO_3$ (total)

[c] Not determined

[d] Below detection limit

W-7

Parameter	Date Collected			
	11/25/75	01/20/76	05/04/76	07/13/76
pH	3.0	3.0	3.2	3.0
Hardness[a]	1690	1428	990	1230
Ca	--[c]	304	176	228
Mg	--	163	134	161
Na	45	41	33	29
K	5.5	5.1	4.4	5.0
Fe	36	44	19	21
Mn	115	108	69	110
Alkalinity[b]	0	0	0	0
Cl	18	9	11	10
SO_4	2220	1890	1230	1828
NO_3	2.0	3.3	1.7	5.7
F	--	1.6	.9	1.1
PO_4	.00[d]	.06	.16	.05
B	.17	.25	.11	.13
Cu	.02	.02	.01	.04
Pb	.20	.00	.02	.04
Zn	1.7	1.8	2.8	4.0
Cr	.00	.01	.00	.01
Cd	.01	.00	.01	.01
Ag	.02	.00	.00	.00
Ni	--	1.6	--	1.9
SiO_2	--	25	21	27

[a] Hardness as $CaCO_3$ (total)
[b] Alkalinity as $CaCO_3$ (total)
[c] Not determined
[d] Below detection limit

W-8

Parameter	Date Collected			
	11/25/75	01/20/76	05/04/76	07/13/76
pH	3.4	3.4	3.8	3.7
Hardness[a]	1720	1529	1080	1300
Ca	--[c]	308	211	256
Mg	--	185	134	161
Na	63	59	45	40
K	6.8	6.1	4.9	5.8
Fe	4.6	14	2.1	0.63
Mn	66	65	40	56
Alkalinity[b]	0	0	10	0
Cl	9	7	10	10
SO_4	2040	1740	1232	1460
NO_3	.1	.8	.7	.4
F	--	1.2	.8	1.0
PO_4	.00[d]	.08	.18	.06
B	.17	.37	.14	.20
Cu	.01	.01	.01	.02
Pb	.20	.00	.03	.02
Zn	.98	.94	.93	2.0
Cr	.00	.00	.00	.00
Cd	.00	.00	.01	.01
Ag	.00	.00	.00	.00
Ni	--	0.78	--	.90
SiO	--	18	16	18

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[a] Hardness as $CaCO_3$ (total)

[b] Alkalinity as $CaCO_3$ (total)

[c] Not determined

[d] Below detection limit

W-9

Parameter	Date Collected			
	11/25/75	01/20/76	05/04/76	07/13/76
pH	5.4	6.5	6.8	6.7
Hardness[a]	1040	1008	745	820
Ca	--[c]	208	157	172
Mg	--	119	86	95
Na	82	75	60	57
K	7.5	6.0	4.8	5.8
Fe	.27	1.4	.56	.27
Mn	11	16	11	11
Alkalinity[b]	20	28	44	38
Cl	17	15	9	8
SO_4	1180	1095	772	884
NO_3	1.0	.9	1.2	1.1
F	--	0.6	0.8	0.8
PO_4	.00[d]	.00	.14	.09
B	.23	.32	.21	.18
Cu	.01	.01	.00	.00
Pb	.10	.00	.00	.02
Zn	.26	.50	.53	.28
Cr	.00	.00	.00	.00
Cd	.00	.00	.01	.01
Ag	.00	.00	.00	.00
Ni	--	.20	--	.10
SiO_2	--	11	12	12

[a] Hardness as $CaCO_3$ (total)
[b] Alkalinity as $CaCO_3$ (total)
[c] Not determined
[d] Below detection limit

W-10

Parameter	Date Collected 11/25/75	 01/20/76	 05/04/76
pH	5.1	4.9	6.4
Hardness[a]	1670	946	615
Ca	--[c]	206	141
Mg	--	105	64
Na	96	81	44
K	10	7.9	4.6
Fe	.86	.45	.72
Mn	40	18	12
Alkalinity[b]	12	10	20
Cl	13	18	8
SO_4	1770	1070	653
NO_3	.4	2.5	1.2
F	--	.8	.4
PO_4	.08	.00[d]	.17
B	.20	.29	.13
Cu	.01	.01	.01
Pb	.10	.00	.00
Zn	1.5	.72	.28
Cr	.01	.00	.00
Cd	.01	.00	.01
Ag	.00	.00	.00
Ni	--	.46	--
SiO_2	--	16	11

[a] Hardness as $CaCO_3$ (total)

[b] Alkalinity as $CaCO_3$ (total)

[c] Not determined

[d] Below detection limit

W-11

Parameter	Date Collected		
	11/25/75	01/20/76	05/04/76
pH	6.3	6.8	7.1
Hardness[a]	500	652	515
Ca	--[c]	138	114
Mg	--	75	56
Na	77	79	52
K	8.2	8.4	4.9
Fe	.36	1.2	1.4
Mn	4.0	4.7	3.9
Alkalinity[b]	72	84	82
Cl	45	41	17
SO_4	494	646	483
NO_3	26	7.6	7.1
F	--	.6	.6
PO_4	3.6	3.9	.7
B	.30	.36	.21
Cu	.01	.01	.00
Pb	.00[d]	.00	.02
Zn	.09	.18	.19
Cr	.01	.00	.00
Cd	.00	.00	.00
Ag	.00	.00	.00
Ni	--	.10	--
SiO_2	--	8	11

[a] Hardness as $CaCO_3$ (total)

[b] Alkalinity as $CaCO_3$ (total)

[c] Not determined

[d] Below detection limit

Kansas Geological Survey
The University of Kansas
Lawrence, Kansas 66044
1982