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Depositional Model of the Antelope Coal Field, Wyoming

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DEPOSITIONAL MODEL OF

THE ANTELOPE COAL FIELD, WYOMING

by

Christine M. Budai

A thesis submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE

in

GEOLOGY

Portland State University

TO THE OFFICE OF GRADUATE STUDIES AND RESEARCH:

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AN ABSTRACT OF THE THESIS OF Christine Marie Budai for the Master of Science in Geology presented June 9, 1983.

Title: Depositional Model of the Antelope Coal Field, Wyoming.

APPROVED BY MEMBERS OF THE THESIS COMMITTEE:

Michael L. Cummings, Chairman

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The coal-bearing sediments of the Antelope coal field in the southcentral Powder River Basin, Wyoming were deposited in paludal and tributary subsystems of the fluvial system that existed in the basin during the early Tertiary. A depositional model for the Antelope coal field was constructed from data collected from approximately 500 drill holes that penetrated the upper 90 meters (300 feet) of the Fort Union Formation. The depositional environments were interpreted from lithologic descriptions and guidelines established in the literature.

The two main coal seams at the Antelope coal field are the Anderson and stratigraphically lower Canyon coal seams. They represent poorly-drained swamp depositional environments. Each of the coal seams exhibit splits into multiple and thinner coal seams to the southwest. The parting rocks that lie between these splits, sedimentary structures, and isopach maps of the partings indicate that crevasse splaying with lacustrine and small channel development caused the observed splits in the coal seams. Distal overbank deposits occur at the top of the Canyon seam and at the base of the Anderson seam; well-drained swamp deposits and crevasse splay, lacustrine, lacustrine delta, and small channel-fill deposits occur in between the coal seams. The rocks underlying the Canyon coal seam suggest that the area of the Antelope coal field was a poorly-drained swamp that developed into a well-drained swamp with minor small channel development. The area once again digressed to a poorly-drained swamp which was the beginning of the Canyon coal swamp. The rocks overlying the Anderson seam represent a combination of the environments mentioned above with deposits from lacustrine and well-drained swamp environments dominating.

The observed splits in the Anderson and Canyon coal seams to the southwest at the Antelope coal field suggest that a change in the fluvial system and/or tectonic stability of the Powder River Basin occurred and affected deposition in the southcentral portion of the basin. A combination of 1) relative basin subsidence, 2) a prograding and aggrading trunk stream with a thick levee deposit, and 3) peat accumulation that kept pace with relative basin

subsidence are proposed mechanisms for the formation of the thick, continuous coal seams present in the basin and a disturbance or change in any of these processes could produce the splits observed in the Anderson and Canyon coal seams at the Antelope coal field.

Syn- and post-depositional processes that have affected the coal quality and reserves at the Antelope coal field include compaction, erosion and deposition from modern stream action, and burning and oxidation of the coal seams. The position of the paleowater table during stream downcutting and erosion of the coal seams controlled the occurrence and extent of oxidation and burning.

Exploration and development of the Antelope coal deposit can be executed in a more efficient manner by using the depositional model. Future exploration drilling programs, design of the mine site, mining and marketing the coal, and later reclamation of the mined area are all affected by the depositional model.

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CHAPTER I

INTRODUCTION

General

The Powder River Basin is a broad synclinal structure in south-
eastern Montana and northeastern Wyoming that is surrounded by moun-
tain ranges and structural upwarps. These uplifted areas were the
source of sediments that were transported into the developing basin
during the early Tertiary and were deposited to form the Fort Union
and Wasatch Formations. These fluvial sediments contain thick,
economically important coal seams. The components of this fluvial
system can be identified from lithologies and stratigraphic
relationships. A reconstruction of the paleoenvironments that were
present when the coal and its associated lithologies were deposited
is called a depositional model, a tool of increasing importance in
guiding coal exploration and mining.

The coal seams and associated sediments of the Tertiary Fort
Union Formation change continuously across the basin, thus limiting
basin-wide correlation of individual coal seams and their associated
lithologies. However, detailed study of portions of the basin in
conjunction with basin-wide studies provide the means to recon-
struct the fluvial system of the entire basin. The Antelope coal
field in the southcentral Powder River Basin has been investigated

for development by NERCO, Inc., who leases the coal. NERCO, Inc.
provided access to all drill data and supported field mapping
studies so that a detailed depositional model of the property could
be constructed.

Location and Access

The Antelope coal field (figure 1) is located approximately
85 km (53 miles) north of Douglas, Wyoming in northcentral Converse
county. The study area extends for approximately 7 km (4.5 miles)
southward from the Campbell-Converse county line. Its northern
border is approximately 6.8 km (4.25 miles) wide tapering to 3.2 km
(2 miles) wide at its southern border; these dimensions coincide
with the permit boundary for the Antelope coal field.

State highway 59, which runs north-south and connects Gillette
and Douglas, is 7 km (4.4 miles) west of the Antelope coal field.
The field is bounded on the east by tracks of the Burlington Northern
Railroad.

The coal field and surrounding lands are presently used by
sheep and cattle ranches, wild antelope herds, oil and gas explora-
tion and production companies, and coal mining companies.

Purpose and Scope

Ethridge and others (1981) defined several main components in
the fluvial system that developed during the Tertiary in the Powder
River Basin. The objectives of this study were to 1) develop a
depositional model for the Antelope coal field, 2) describe how the

components of the fluvial system defined by Ethridge and others (1981) influenced the distribution of the paleoenvironments described in the depositional model through time, and 3) relate what this depositional model indicates about the fluvial system near the southeastern edge of the Powder River Basin. The materials used in this study were limited to the area enclosed by the Antelope coal field permit boundary, while information in the literature was used to interpret regional patterns.

A further goal of the study was to use the depositional model to understand and predict potential problems in mining the coal seams and later reclamation of the mined areas, thus the model becomes a long-term guide whose final value will be known when mining and reclamation are completed.

Methods of Investigation

A literature search was conducted to establish the current understanding of the stratigraphy in the Powder River Basin, review the regional fluvial history, evaluate the basic components, environments, and relationships within a fluvial system, and develop the concept of depositional models.

Data collected from over 500 drill holes were systematically analyzed and coded on computer sheets for entry into the geologic database (IBM 3033 system used). This involved the inspection of geophysical logs (gamma, density, resistivity, spontaneous potential, and caliper), lithologic logs, core photographs, coal quality data, and overburden analyses and a synthesis of these data for each

drill hole (Appendix). A modified version of a computer program called LOG PLOT (Ferm and Berger, 1979) was used to generate individual stratigraphic columns or log plots for every drill hole.

Cross sections of the study area were made by placing the log plots for selected drill holes that were spaced less than 975 meters (3200 feet) apart at a specified horizontal scale (1"=500' or 1"=400'). Isopach maps of sand and silt and parting units, structure maps, and a fence diagram were constructed from drill data. Outcrops within the study area are sparse and occur along the valleys of small intermittent streams. An incomplete stratigraphic section, including sedimentary rocks overlying the Canyon and Anderson coal seams and portions of the rock underlying the Anderson seam, was sampled and measured in the summer of 1981. A map of the surficial geology was made during the 1981 field season showing the distribution of alluvium and colluvium and their contact relations with bedrock over the field area. Samples collected during field work were primarily used to help understand lithologic variability that might be encountered in drill holes and patterns of rock type distribution within the fluvial system. A detailed analysis of such samples was not undertaken since such detailed lithologic description and petrology of core and surface samples was beyond the scope of the study.

Depositional environments present in the Antelope coal field were interpreted from the information gathered from the various maps, cross sections, and inferred lithologies. Literature provided information on the modern understanding of each environment.

CHAPTER II

REGIONAL GEOLOGY

Introduction

The Powder River Basin is the second largest structural basin within the Rocky Mountain system surpassed in size only by the Williston Basin. It derives its name from the Powder River, which drains northward from the western edge of the basin. The basin is a northwest regionally trending syncline approximately 160 km (100 miles) in length and 80 km (50 miles) in width (West, 1964). It is flanked by the broad arch of the Black Hills to the east, the Big Horn Mountains to the west, the Laramie Range and Hartville Uplift to the south and southeast, and the Miles City Arch to the north (figure 1).

Geologic History and Structure

Northeastern Wyoming and southeastern Montana are underlain by approximately 3.3-5.5 km of Paleozoic, Mesozoic, and Cenozoic sedimentary rocks overlying a Precambrian basement. The Powder River Basin did not develop as a structural basin until the Late Cretaceous and Early Tertiary. It was at this time that deformation associated with the Laramide Orogeny produced uplift of the surrounding structural highlands. Isopach maps of older underlying sedimentary rocks

in northeastern Wyoming reveal that ancient folding and upwarps with the same regional trends as the present-day structures exist and are the precursors of the mountains and basins that formed during the Laramide Orogeny (West, 1964).

Deformation during the Laramide Orogeny formed an asymmetrical intermontane basin with the deepest portion of the basin next to the Big Horn Mountains. This western edge is marked by strongly folded and thrust faulted beds. The eastern edge of the basin was less severely deformed and a gentle monocline dipping westward off the Black Hills Arch formed.

Deposition in the area of the basin had been dominantly marine until the end of the Cretaceous. At the close of the Cretaceous the sea retreated for the last time to the south depositing the regressive sandstone sequence of the Fox Hills Formation (figure 2). A fluvial system began to develop in the basin at this time and is represented by the continental Lance Formation, which is composed of sandstones with carbonaceous shales and coals, and attains a thickness of almost 915 meters (3000 feet) in the central portion of the basin. The Fort Union Formation in the Powder River Basin is the basal Tertiary unit. It is composed of nonmarine sediments deposited in a developing fluvial system that drained adjacent uplifting highlands; the sources of clastic debris. Swamps, streams, and floodplains developed under warm to temperate climatic conditions (Brown, 1958).

Intermittent basin subsidence followed by periods of stability during the Paleocene - Eocene were related to sporadic orogenic
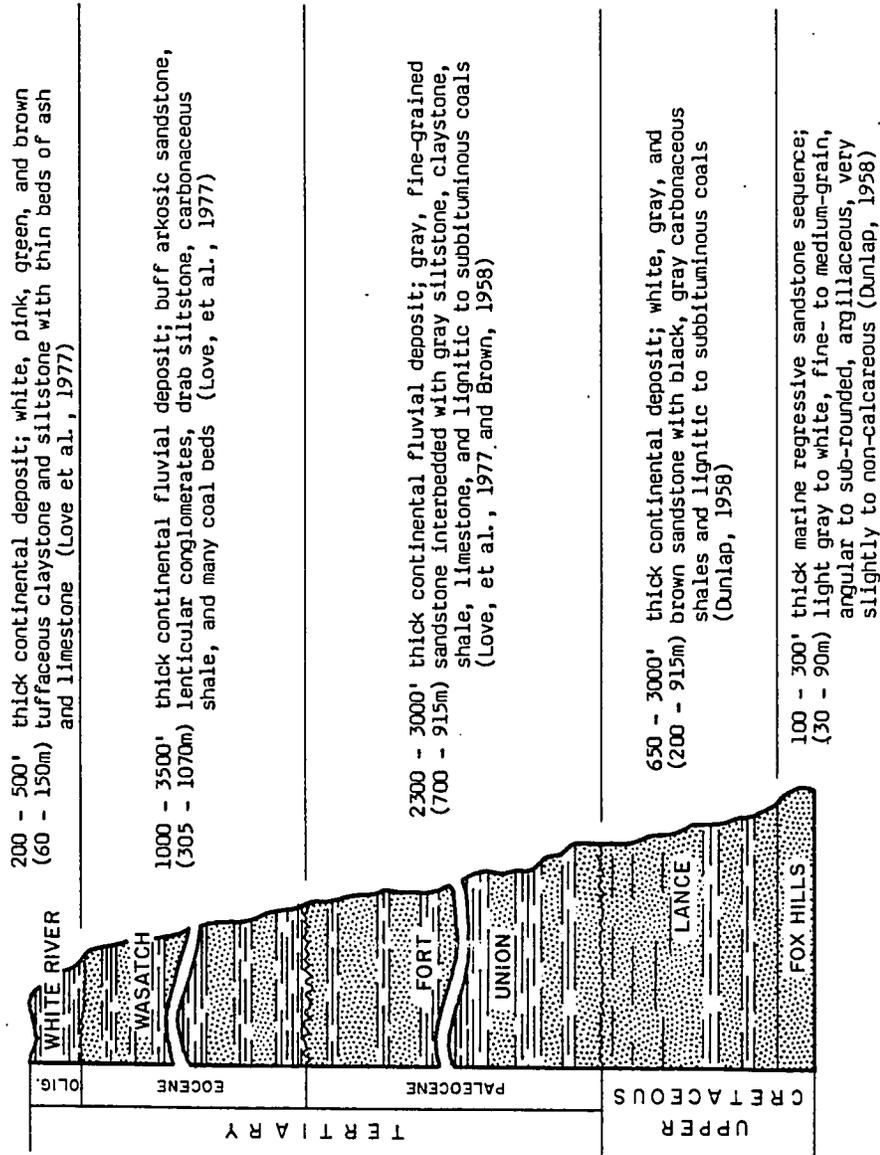
Figure 2. Stratigraphy of the Upper Cretaceous and Tertiary Formations in the Powder River Basin. Diagram not drawn to scale. Modified from West (1964).

200 - 500' thick continental deposit; white, pink, green, and brown (60 - 150m) tuffaceous claystone and siltstone with thin beds of ash and limestone (Love et al., 1977)

1000 - 3500' thick continental fluvial deposit; buff arkosic sandstone, (305 - 1070m) lenticular conglomerates, drab siltstone, carbonaceous shale, and many coal beds (Love, et al., 1977)

2300 - 3000' thick continental fluvial deposit; gray, fine-grained (700 - 915m) sandstone interbedded with gray siltstone, claystone, shale, limestone, and lignitic to subbituminous coals (Love, et al., 1977 and Brown, 1958)

650 - 3000' thick continental deposit; white, gray, and (200 - 915m) brown sandstone with black, gray carbonaceous shales and lignitic to subbituminous coals (Dunlap, 1958)

100 - 300' thick marine regressive sandstone sequence; (30 - 90m) light gray to white, fine- to medium-grain, angular to sub-rounded, argillaceous, very slightly to non-calcareous (Dunlap, 1958)

WHITE RIVER

WASATCH

FORT UNION

LANCE

FOX HILLS

OLIG.

EOCENE

PALEOCENE

CRETACEOUS

UPPER

TERTIARY

movements to the west of the basin. The fluvial system deposited the hundreds of meters of interbedded sandstones, siltstones, claystones, shales, coals, and limestones of the Fort Union Formation. The overlying Eocene age Wasatch Formation was also deposited by the constantly changing fluvial system. Orogenic movements at the basin's western edge temporarily raised the basin above the depositional plain so that the two formations are separated by an unconformity in that area (Ethridge and Jackson, 1980). In the eastern basin the formations are conformable and it is often not clear where the contact is located. This has resulted in a variety of interpretations as will be discussed later. The Powder River Basin was tilted westward during renewed uplift of the Black Hills at the end of the Eocene. Volcanism occurred to the west in the Yellowstone area during the Oligocene and Miocene and thick tuffaceous sediments completely covered the Powder River Basin (Love, et al., 1963). Only remnants of the Oligocene and Miocene age rocks remain in the basin where they underlie topographically high areas. During the Late Pliocene regional uplift, normal faulting, stream incision, and erosion produced the present topography of the basin.

The drainage system observed in the basin today varies markedly from early Tertiary time. During early Tertiary time the Powder River Basin experienced warm to temperate climatic conditions with moderate precipitation throughout the year (Brown, 1962). The basin presently sustains a temperate climate with relatively low precipitation occurring mostly as rain during the months of April through October and averaging between 12 to 16 inches total precipitation

(BLM, 1975). The lack of abundant precipitation to feed major water-
ways, like those that existed during the early Tertiary, creates the
drainage system characteristic of semiarid areas that is observed in
the basin today.

The major modern streams draining the Powder River Region
include the northward flowing Powder River, the northeastward
flowing Belle Fourche River, the eastward flowing Cheyenne River,
and the east - southeastward flowing North Platte River. Antelope
Creek is one of the numerous intermittent streams in the Powder
River Basin. It flows eastward across the Antelope coal field and
drains into the South Fork of the Cheyenne River.

Fort Union Formation Stratigraphy

The Fort Union Formation (figure 2) underlies almost the en-
tire Powder River Basin and varies in thickness from approximately
900 meters (3000 feet) in the western part of the basin to approxi-
mately 700 meters (2300 feet) in the eastern part of the basin
(Brown, 1958). The formation is divided into three members, the
Tullock member, the Lebo member (or Lebo Shale member), and the
Tongue River member (figure 3). The three members within the Fort
Union Formation exhibit gradational contacts and interfingering
relationships. The lowermost Tullock member is approximately 200
meters (650 feet) thick. It consists of light-colored sandstone,
sandy shale, carbonaceous shale, and coal beds. The overlying Lebo
member is approximately 150 meters (500 feet) thick and is composed
of dominantly shales, carbonaceous shales, and mudstones with some

FORT UNION FORMATION

(3000 FEET THICK)
(915 METERS)

TONGUE RIVER MEMBER

(1850 FEET THICK)
(560 METERS)

LEBO MEMBER

(500 FEET THICK)
(150 METERS)

TULLOCK MEMBER

(650 FEET THICK)
(200 METERS)

VERTICAL SCALE

METERS   FEET
300   1000
200   500
100
0   0

PALEOCENE
(58-65 MILLION YEARS OLD)

ARVADA
ROLAND
SMITH
ANDERSON
DIETZ
CANYON
WYODAK
COOK
WALL
UPPER PAWNEE
LOWER PAWNEE
CACHE
UNNAMED COALS

Figure 3. Members and principle coal seams of the Fort Union Formation in northern Campbell County, Wyoming. The coal seam names used at the Antelope coal field are the same, but they are part of the Lebo member, according to Denson and others (1978). Diagram modified from Breckenridge and others (1974).

siltstones and sandstones. The Tongue River member is the thickest of the three members and contains the most important, minable coal seams of the Fort Union Formation. It is approximately 560 meters (1850 feet) thick and consists of interbedded sandstone, siltstone, shale, and coal (Sholes and Cole, 1981).

The naming of coal seams in the Powder River Basin has not been consistent since the seams were first discovered and studied (figure 4). The numerous discontinuous coal swamps that were present during the deposition of the Fort Union Formation produced coal seams that cannot be correlated over great distances. A major swamp adjacent to the trunk stream of the basin did produce a thick traceable coal seam, but the splitting and merging nature of this seam as well as others in the basin compounds the problem of seam identification and correlation. The member to which the coal seams belong is also inconsistent in the literature. Denson and others (1978) state that "The Lebo member of the Reno Junction - Antelope Creek area is equivalent to the Lebo and overlying Tongue River members of the Fort Union Formation in the northern part of the Powder River Basin." This suggests that the coal seams encountered at the Antelope coal field are part of the Lebo member of the Fort Union Formation and not part of the Tongue River member. The nomenclature suggested by Denson and others (1978) will be used in this study. The names of coal seams in the Fort Union Formation used by Denson and others (1978) will also be adopted for use in this study and are shown in the stratigraphic column (figure 3).

Figure 4. Generalized correlation chart of coal bed nomenclature in the Fort Union Formation, Powder River Basin. Geographic locations illustrated by column number in Figure 1.

Wasatch Formation

The contact between the underlying Fort Union Formation and the overlying Wasatch Formation is uncertain and has long been debated. Love and others (1977) mapped the contact based on the lithologic description of "buff arkosic sandstones, siltstone, carbonaceous shale, and many coal beds". The contact shown by Love and others (1977) was transcribed to the surficial geologic map of the Antelope coal field (Plate 1).

However, other investigators have proposed Wasatch - Fort Union Formation contacts that appear to be as valid as the one used in this study. Ethridge and others (1981) suggested that the contact between the two formations be placed at the top of the first thick persistent coal bed because of the lack of an easily recognizable lithologic break in the overlying strata. Denson and others (1978) mapped the contact based on samples that were analyzed for heavy mineral content. They state that distinct heavy mineral suites can be found in the two formations. The only clearly identifiable contact between the two formations occurs at the western edge of the basin where an unconformity separates them.

The Wasatch Formation (figure 2) varies in thickness from 320 to 1070 meters (1050 - 3500 feet) and consists of interbedded sandstone, shale, and coal with conglomerate beds at its base along the western margin of the basin (BLM, 1975). The coal seams in the Wasatch Formation are also important economically, but they will not be discussed further because they are not present in the Antelope coal field and do not pertain to this study.

CHAPTER III

GEOLOGY OF THE STUDY AREA

Previous Work

Literature on the geology of the area around the Antelope coal field is sparse. Denson and others (1978, 1980) produced a structure contour map of the base of the Wyodak or Anderson coal seam, and an isopach map of coal thickness for the Reno Junction - Antelope Creek area, Wyoming (figure 1). Their work suggests that differential compaction, minor folding or upwarping, and possibly faulting produced the anomalies in coal thickness observed on the isopach map and the irregularities noted in the structure contour map. Regional mapping by Denson and others (1978) established the contact between the Fort Union and Wasatch Formations based on distinct heavy mineral suites from samples that were collected across the contact in the southcentral Powder River Basin. This regional work provides a general overview of the region, but has limited application to the detailed information available on the Antelope coal field. Denson and others (1980) show the Wyodak parting limit approximately 3.5 km (2.2 miles) north of the Antelope coal field. Generally, to the north of this line the Wyodak seam occurs as one thick coal seam and to the south it splits into the Anderson and stratigraphically lower Canyon coal seams. The Anderson and Canyon coal seams are the two economic seams within the Antelope coal field.

Unpublished reports produced within NERCO, Inc. of Portland, Oregon review the distribution and parting nature of the Anderson and Canyon coal seams within the permit boundaries of the Antelope coal field. The company's internal reports also examine the quality of each coal seam and the general geology of the immediate area.

The U.S. Forest Service funded a study of an area in the southeast corner of Campbell county approximately 11.5 km (7.2 miles) northeast of the Antelope coal field (figure 1), an area designated the SEAM study site. Ethridge, Jackson, and Youngberg (1981) conducted the study and concluded that the SEAM study site was located in a flood plain - tributary facies of the Powder River Basin's fluvial system. Depositional environments recognized in the SEAM study based on drill hole data include point bar, abandoned channel, levee, crevasse splay, lacustrine, lacustrine delta-fill, and well- and poorly-drained swamps.

Fort Union Formation

The Fort Union Formation observed and described in drill data at the Antelope coal field includes approximately the upper 90 meters (300 feet) of the formation. As indicated above, this portion of the formation is part of the Lebo member, according to Denson and others (1978). Ethridge and others (1981) described the stratigraphy in the SEAM study site as part of the Lebo member, thus the use of the Lebo member in the southcentral Powder River Basin is consistent with established usage.

The portion of the Lebo member of the Fort Union Formation sampled at the Antelope coal field consists approximately of sandstone (<12%) siltstone (18%), claystone, shale (claystone and shale 29%), coal (40%), and limestone (<1%). Figure 5 shows typical responses on a suite of geophysical logs to the different lithologies.

Lithology

Sandstone. The sandstones are generally very fine-grained, gray to olive gray, noncalcareous, massive to laminated, slightly carbonaceous, moderately sorted, and slightly to well-indurated. Bioturbation and ripple drift structures are often observed in laminated sandstones, while small-scale cross bedding is rarely observed. Slump features have been noted in one core sample. A fining upward trend is frequently noted in the sandstones and fining upward sequences are often formed with sandstone at the base grading into siltstone and overlain by claystone. Coarsening upward trends have been infrequently noted in the sandstones.

Siltstone. Siltstone is common in the Antelope coal field. It ranges in color from brown gray to gray to green gray and is usually massive to laminated, slightly carbonaceous, noncalcareous, and has slight- to moderate-induration. Frequently the siltstones have a clayey component and are identified as silty claystones. Leaf imprints can rarely be found on bedding planes. Bioturbation and ripple drift structures are present. Siltstone and sandstone are commonly associated in fining upward sequences.

GEOPHYSICAL LOGS   LOG PLOT   INTERPRETED DEPOSITIONAL
                                                  ENVIRONMENT
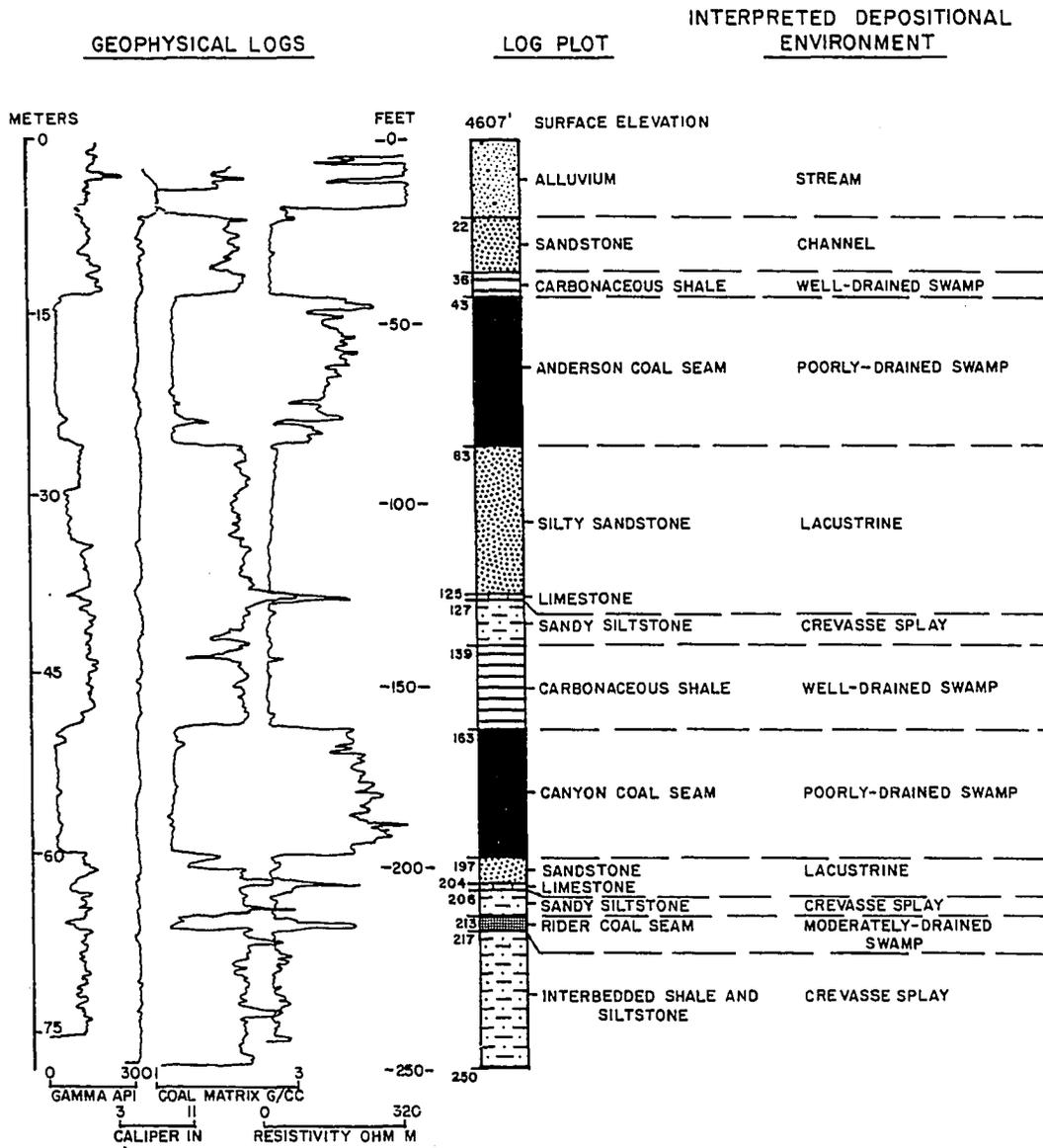
Figure 5. Generalized LOG PLOT with representative suite of geophysical logs and interpreted depositional environments.

Claystone. Claystone and shales are relatively abundant at Antelope. The claystone is usually brown gray to gray brown, soft, carbonaceous, massive, nonfissile, and commonly associated with coal seams and carbonaceous shales. Bioturbation structures are commonly present.

Shale. Shale is commonly gray brown to brown, laminated, fissile to slightly fissile, carbonaceous, and has slight- to moderate-induration. Gypsum crystals approximately .5 to 1.5 cm (.25-.5 inches) in length are frequently present in the carbonaceous shale units. Some of the carbonaceous shales that have been exposed at the surface to near surface waters contain gypsum crystals that are approximately 12 cm (4.5 inches) in length and 6 cm (2.5 inches) in width and commonly display twinning. Bioturbation structures are present.

Coal. The two main coal seams within the Antelope coal field are the Anderson and stratigraphically lower Canyon coal seams. The Anderson coal seam has an average thickness of 10 to 12 meters (35-40 feet), while the Canyon coal seam ranges between 9 and 10 meters (30-35 feet) in thickness. Both the Anderson and Canyon coal seams exhibit splits within the Antelope coal field, with an increase in the number of splits generally to the south, as shown in cross section A-A' (plate 2). It should be noted here that a split refers to a single coal seam that separates into two or more coal seams or splits. A parting refers to the rocks that occur between the splits

in a coal seam. The names representing the observed splits in the Anderson and Canyon coal seams were assigned by geologists working for NERCO, Inc. and have been retained in this study because there are no studies that have been published on the detailed and complex splits observed in the Anderson and Canyon coal seams at the Antelope coal field.

The physical properties of coal that are usually described from hand samples are color, banding, luster, texture, hardness, fracture, and secondary mineralization. Banded coal is heterogeneous coal containing bands of varying luster. There are five basic terms used to describe coal luster ranging from the most brilliant to the dullest. These include bright, moderately bright, midlustrous, moderately dull, and dull. Textural terms used in describing coal include smooth, silky, granular, and earthy. Fracture may be described as blocky, conchoidal, or hackly and secondary minerals include pyrite, marcasite, calcite, gypsum, and amber (Schopf, 1960).

In general, the Anderson coal seam and its respective splits (Upper Anderson, Lower Anderson, A3, A2, & A1) are brown black to black, banded, dull to moderately bright, commonly silky, and moderately hard to hard. The coal usually fractures conchoidally and contains disseminated, globular, and/or framboidal pyrite ($\pm$ marcasite), gypsum, and minor calcite and amber.

The Canyon coal seam and its respective splits (Upper Canyon, Lower Canyon, C5, C4, C3, and C21) are generally black, nonbanded to banded, moderately bright to bright, smooth to silky, and hard.

Conchoidal fracture is prevalent, while secondary minerals are not prominent.

Limestone. Limestone is the least abundant rock type present in the Antelope coal field. According to the American Geological Institute, a limestone is defined as "a sedimentary rock consisting chiefly (more than 50% by weight or by areal percentages under the microscope) of calcium carbonate, primarily in the form of the mineral calcite, and with or without magnesium carbonate". However, since detailed lithologic descriptions and petrology of core and surface samples was beyond the scope of this study, as stated earlier, the presence of limestone in the Antelope coal field is dubious. Recent work in the Tongue River member of the northcentral Powder River Basin (Flores, 1981) has identified described, and classified limestone exposed at surface outcrops and supports the probable presence of limestone in the Lebo member of the Antelope Creek area. At the Antelope coal field limestone is usually identified in drill hole data from drilling comments, such as very slow drilling through well-indurated rock. The chips of rocks retrieved from such drilling usually display a moderate to strong effervescence when tested with a dilute solution of HCl. The geophysical logs also respond in a characteristic manner, as shown in figure 5 at 38 meters (125 feet) below the ground surface. The limestone units indicated in drill data are usually gray, commonly laminated, and very fine-grained. They are very thin (1 meter or

1-4 feet thick) and laterally discontinuous, which makes them diffi-
cult to identify and correlate. Sparse outcrops within the Antelope
coal field and the physical characteristics of the limestone units
(thin and discontinuous) have prevented identification of limestone
at the surface; therefore, all limestone occurrences in the Antelope
coal field have been recognized from subsurface data.

Wasatch

The contact between the Fort Union and Wasatch Formations shown
on Plate 1 was taken from Love and others (1977), as previously dis-
cussed. The Wasatch Formation is only present in the extreme north-
west corner of the Antelope coal field and can be described generally
as containing interbedded sandstone and siltstone, with minor clay-
stone beds, based on sparse drill data (2 drill holes).

Recent Deposits

Modern processes have deposited younger sediments or changed
the character of older ones in the Antelope coal field. Antelope
Creek is an intermittent stream that flows across the northern half
of the Antelope coal field from west to east. Large meander scars
filled with alluvium were produced by Antelope Creek as it migrated
across the Antelope coal field and eroded the Wasatch and portions
of the Fort Union Formations. The erosion of these formations
caused the coal seams to be exposed to air and ignite spontaneously.
The coal seams burned until the overlying rocks collapsed and
smothered the fire. The burning of the coal seams caused thermal

alteration, fusing, and sometimes melting of the overlying rocks forming the rock type called clinker.

Plate 1 is a geologic map of the surficial deposits within the Antelope coal field, which was produced during the 1981 summer field season and modified during the 1982 summer field season. The map shows the distribution of alluvium and clinker deposits and their contacts with bedrock. The clinker deposits have been divided into clinker formed by the burning of the Anderson and Canyon coal seams respectively.

Alluvium. The alluvial deposits in the Antelope coal field include basal gravels that are poorly sorted, very coarse-grained, loosely consolidated, and interbedded with silty sands (figure 6). The basal gravels show distinct fining upward trends and are overlain by medium-grained sands that are yellow brown to light brown, calcare- ous to slightly calcareous, and unconsolidated to slightly- indurated. The medium-grained sands grade into fine-grained sands and silts with similar properties. Quartz is the dominant component with coal and clinker fragments present in minor amounts.

Figure 6. Contact (dashed line) between alluvium and bedrock in the northwest portion of the Antelope coal field. Several fining upward sequences with gravel at the base and silt at the top can be seen in the alluvium.

Clinker. The clinker deposits in the Antelope coal field are commonly bright red and orange in color (figure 7). Some clinker is deep purple to black with a fused appearance (figure 8). This partially melted clinker is usually very indurated and forms rigid pillars among the less severely altered and moderately indurated clinker, as seen in figure 7. Slightly altered overburden, or rocks that were overlying the coal seam when it burned, shows only a slight color alteration and sometimes no color alteration (figure 8). The original lithology is usually recognizable in less altered rocks, whereas it is not in the more severely altered rocks.

Figure 7. Brightly colored clinker deposit showing rigid pillars that form from partial melting.
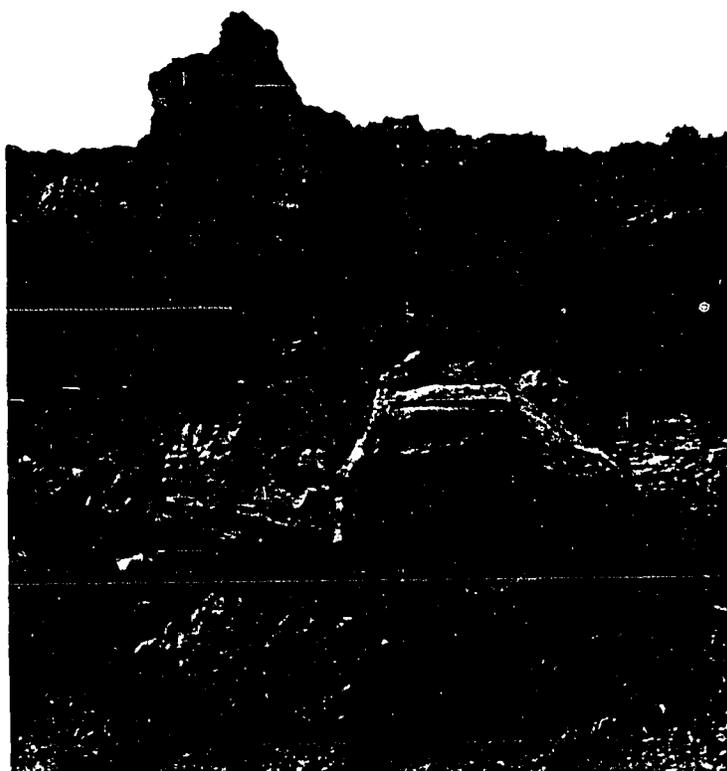
Figure 8. Clinker deposit showing varying degrees of thermal alteration.

CHAPTER IV

STRATIGRAPHY

Introduction

The stratigraphy of the Antelope coal field can be divided into five distinct sections for description purposes. The lowermost section includes the rocks stratigraphically below the Canyon coal seam or the underburden. These are overlain by the Canyon coal seam and its respective splits and partings, the interburden, the Anderson coal seam and its respective splits and partings, and the overburden.

Underburden

The underburden is known only from drill hole information. Since drill holes vary somewhat in depth under the Canyon coal seam, description of the underburden will arbitrarily start at a persistent coal seam designated here as the Rider coal seam.

The Rider seam is approximately 6-15 meters (20-25 feet) below the Canyon coal seam and is found to underlie most of the field, except in the extreme southern portions where it pinches out (plate 2 & 3). The Rider seam consists of low quality coal interbedded with carbonaceous shale, and ranges from 0.5-2 meters (2-7 feet) in thickness. The coal is brown black to black, dull to midlustrous, soft to moderately hard, and brittle. The Rider seam grades

vertically upward into carbonaceous shales and claystones. Infrequently, the Rider seam is overlain by siltstone and sandstone. These deposits tend to be very fine-grained and are continuous for up to 1.8 KM (6000 feet). Poorly developed fining upward trends can be seen in some core photographs of the underburden and some ripple drift and/or laminated bedding occurs in the sandstone and siltstone. Thin (0.5 meter or 2 feet) discontinuous limestone units are locally associated with the sandstone and siltstone bodies in the underburden. Shale and claystone occur at the contact with the Canyon coal seam over most of the Antelope coal field, except in the southern third of the field where sandstone and siltstone occur at the contact.

Canyon Coal Seam

The Canyon coal seam is approximately 9-10 meters (30-35 feet) thick in the northern part of the Antelope coal field and, as discussed above, splits into the Upper and Lower Canyon coal seams in a southwesterly direction (plate 2). The Upper Canyon splits into the C5 and C4 coal seams and the Lower Canyon splits into the C3 and C21 coal seams (note: The C21 seam was previously thought to be two separate seams - C2 & C1 - but improved data showed only one seam, so the names were combined and the seam was called the C21 seam).

The rocks that occur between the splits in the Canyon coal seam, or partings, have significant implications to the depositional model of the Antelope coal field and will be described separately in

the following sections, beginning with the lowermost parting. All of the parting descriptions are from drill hole data only.

C3/C21 Parting. A generalized isopach map of the C3/C21 parting thickness is shown in figure 9. The parting isopach map outlines a lobate-shaped feature with its axis running roughly east-west and its thickest portions being centrally located. A thickening trend can be seen in a west-southwest direction with a maximum thickness of 12 meters (40 feet). The parting limit on the map represents the position in the Antelope coal field where the parting thickness is at least 0.45 meters (1.5 feet) thick. The parting exists for a short distance to the north of this line, but is less than 0.45 meters (1.5 feet) thick.

The parting consists dominantly of sandstone and siltstone. Claystone and shale and minor limestone are present. Cross section A-A' (plate 2) shows distinct sandstone and siltstone bodies with a limestone stringer located near the central portion of the bodies.

Upper/Lower Canyon (C4/C3) Parting. The most extensive parting in the Canyon coal seam is shown on figure 10. This parting extends farther north than the other partings in the Canyon seam, as seen from the parting limit. The parting isopach map shows a multi-lobed feature with a general thickening to the west and southwest. The maximum parting thickness recorded from drill hole data is approximately 18 meters (60 feet).

The Upper Canyon/Lower Canyon (C4/C3) parting consists of very
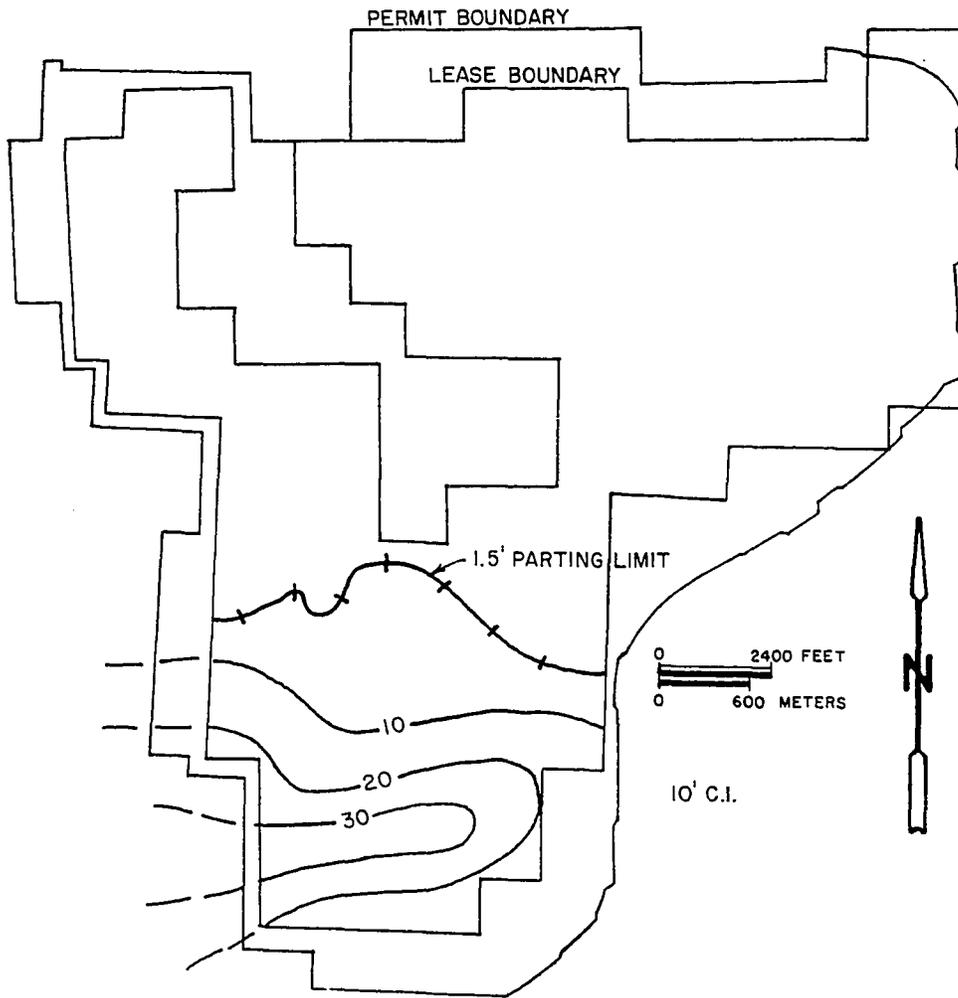
Figure 9. C3/C21 parting isopach map.
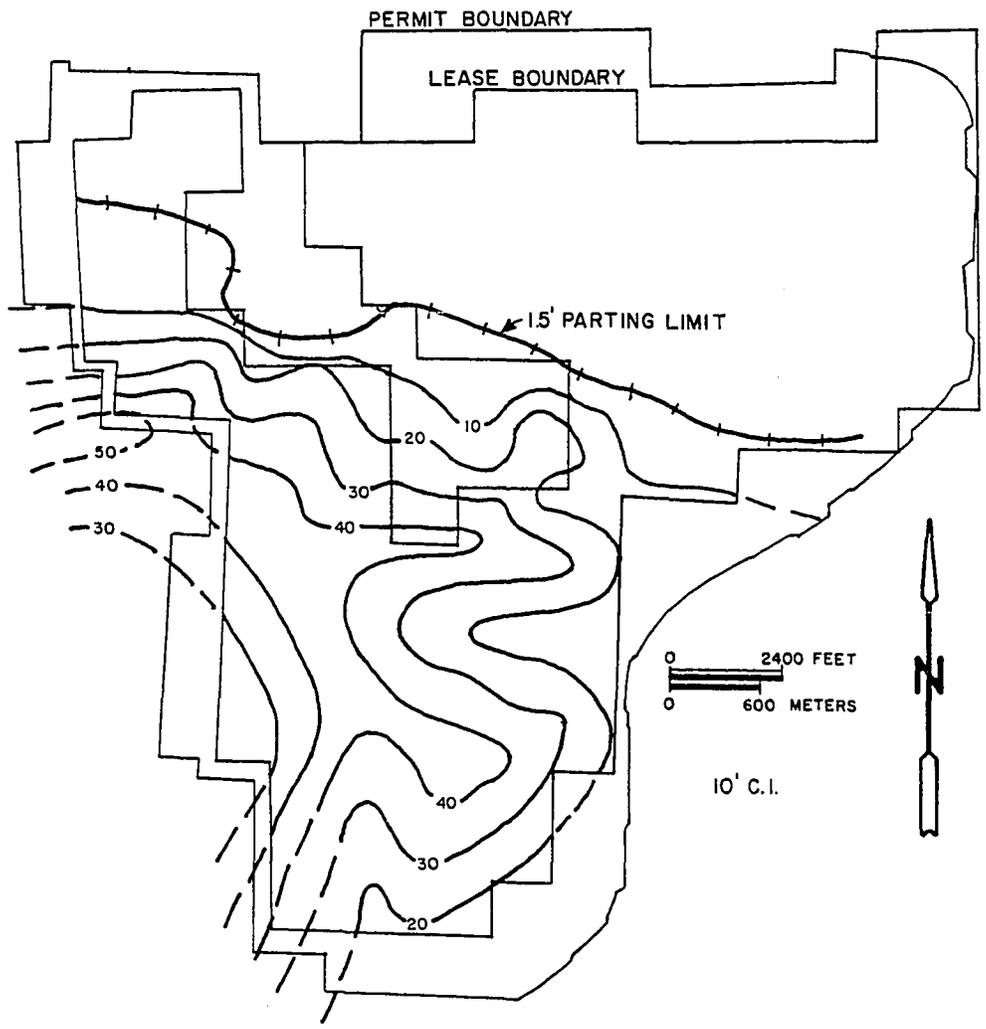
Figure 10. Upper Canyon/Lower Canyon (C4/C3) parting isopach map.

fine-grained, slightly carbonaceous sandstone and siltstone that is commonly associated with limestone. Carbonaceous shales and claystones are also present with thin, discontinuous coal stringers. Ripple drift structures and laminations are sometimes noted in the sandstone and siltstone. Fining upward trends are is also present in some drill holes and evidence of bioturbation was noted in one drill hole.

Parting lithology varies from south to north across the Antelope coal field. Generally, sandstone and siltstone with minor limestone stringers are more prevalent in the southern portions of the field and sandstone and siltstone interbedded with claystone, shale, and minor coal stringers are more common in the northern portions.

C5/C4 Parting. The C5/C4 parting isopach map (figure 11) also shows multi-lobed features, but with two distinct directions of thickening. One of the lobes has a west-southwest thickening trend that is consistent with the trends observed on the other parting isopach maps. However, the other lobed feature shows a northwest thickening trend. The maximum parting thickness recorded from drill hole data in the west-southwest direction is approximately 20 meters (65 feet), while a maximum thickness of 9 meters (30 feet) is found in the northwest direction.

The parting consists of carbonaceous shale, claystone, and coal stringers, along with very fine-grained sandstone and siltstone. Limestone is rare. A coarsening upward trend was observed in a
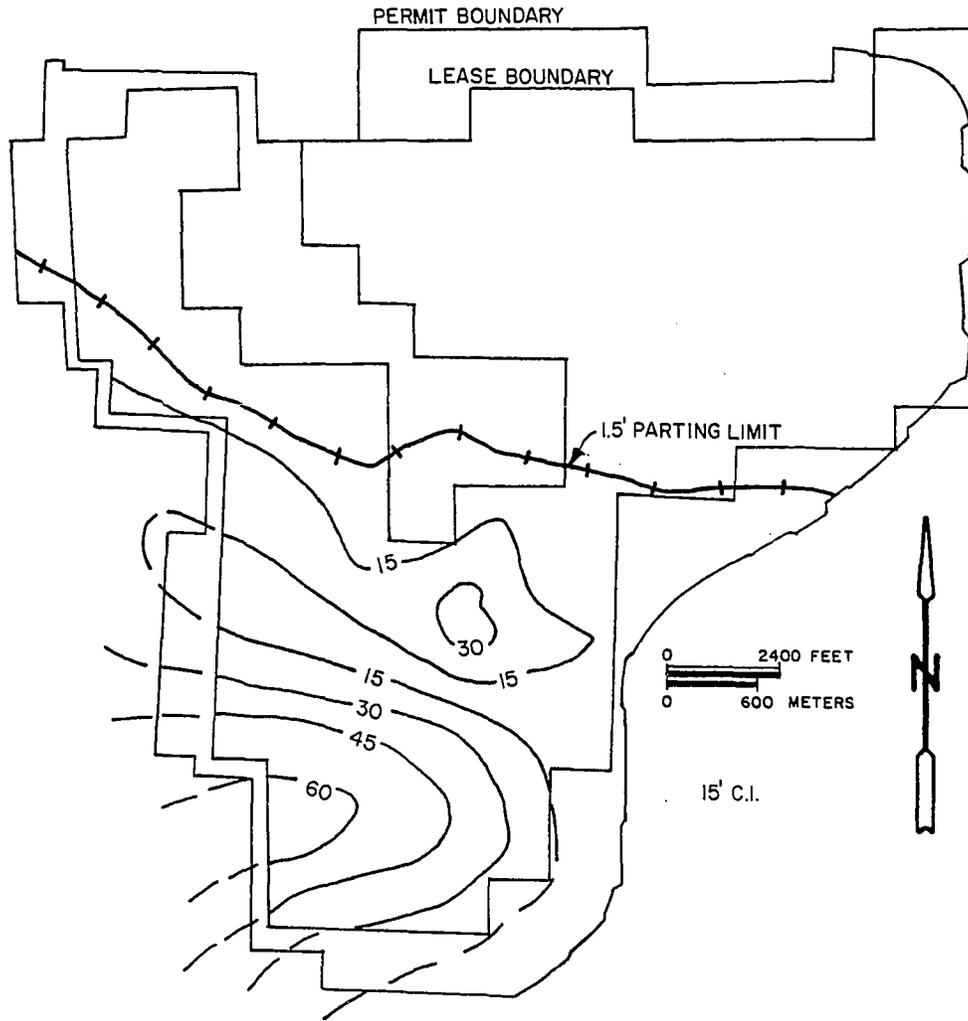
Figure 11. C5/C4 parting isopach map.

drill hole located near the center of the northwest trending lobed feature in figure 11. Sandstone and siltstone are the dominant lithologies in the thickest portions of the parting, as seen in cross section A-A' (plate 2). Shale, claystone, and coal are more prevalent elsewhere.

Interburden

The interburden, located between the Anderson and Canyon coal seams, varies in thickness from 7-21 meters (25-70 feet) in the northern portions of the field to 23-40 meters (75-130 feet) in the southern part of the field. It can be subdivided roughly into three sections based on lithology, as shown in figure 12. The outcrop in figure 12 includes all of the interburden, except 9-10.5 meters (30-35 feet) of rocks immediately overlying the Canyon coal seam. The small portion of clinker located at the top of the outcrop marks the base of the Anderson coal seam before it was burned away.

The lowermost subdivision of the interburden consists of a thick, continuous sandstone and siltstone body that forms a blanket type deposit at the top of the Canyon coal seam. The sandstone is very fine-grained and massive to finely laminated with rare occurrences of coal fragments.

The middle subdivision of the interburden contains thin, discontinuous, and interbedded sandstone, siltstone, shale, claystone, coal, and limestone. These lithologies are similar to the lithologies described in Chapter III. The dark carbonaceous zone that can be seen in this subdivision on figure 12 may actually be the Lower
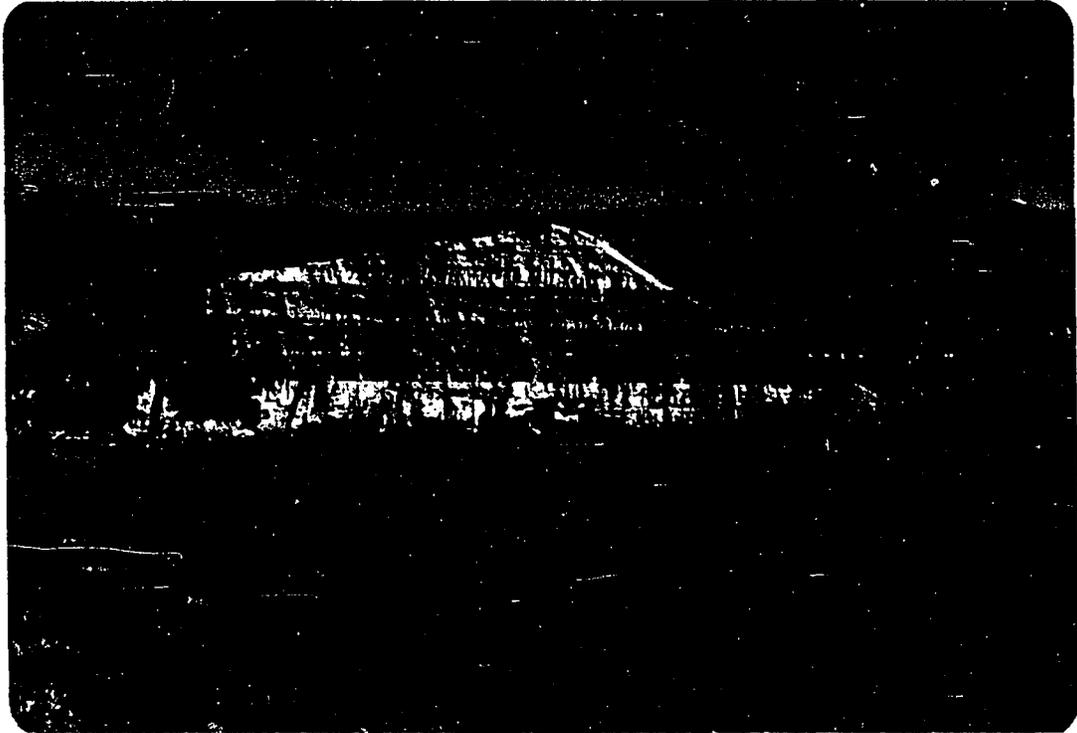
Figure 12. Outcrop of interburden with lower, middle, and upper subdivisions shown by dashed lines.

Anderson but sparse data prevents positive correlation.

The uppermost section of the interburden consists of another thick blanket type sandstone and siltstone body that is similar to the lowermost subdivision. It is commonly in contact with the base of the Anderson coal seam.

The subdivisions described above are a general characterization of the interburden. Portions of the Antelope coal field vary significantly from the discussed subdivisions. Figure 13 is a generalized isopach map of sandstone plus siltstone thickness in the interburden. The thickest portions of the isopach map represent areas where almost the entire interburden consists of sandstone and siltstone. However, this is not the norm at the Antelope coal field and the majority of drill holes show similar stratigraphic relationships to those expressed in the outcrop shown in figure 12.

Anderson Coal Seam

The Anderson coal seam is approximately 12 meters (40 feet) thick. The Upper Anderson is approximately 10 meters (32-35 feet) thick, and the Lower Anderson is approximately 1.5 meters (5 feet) thick. The A3, A2, and A1 splits (seams) were encountered in three 1982 drill holes at the southern border of the Antelope coal field. The average thickness of the A3 seam is 5 meters (16.5 feet), the A2 seam is .8 meters (2.7 feet), and the A1 seam is 1.1 meters (3.7 feet).

Description of the lithology forming the Upper Anderson/Lower Anderson parting will include only the area on the fence diagram
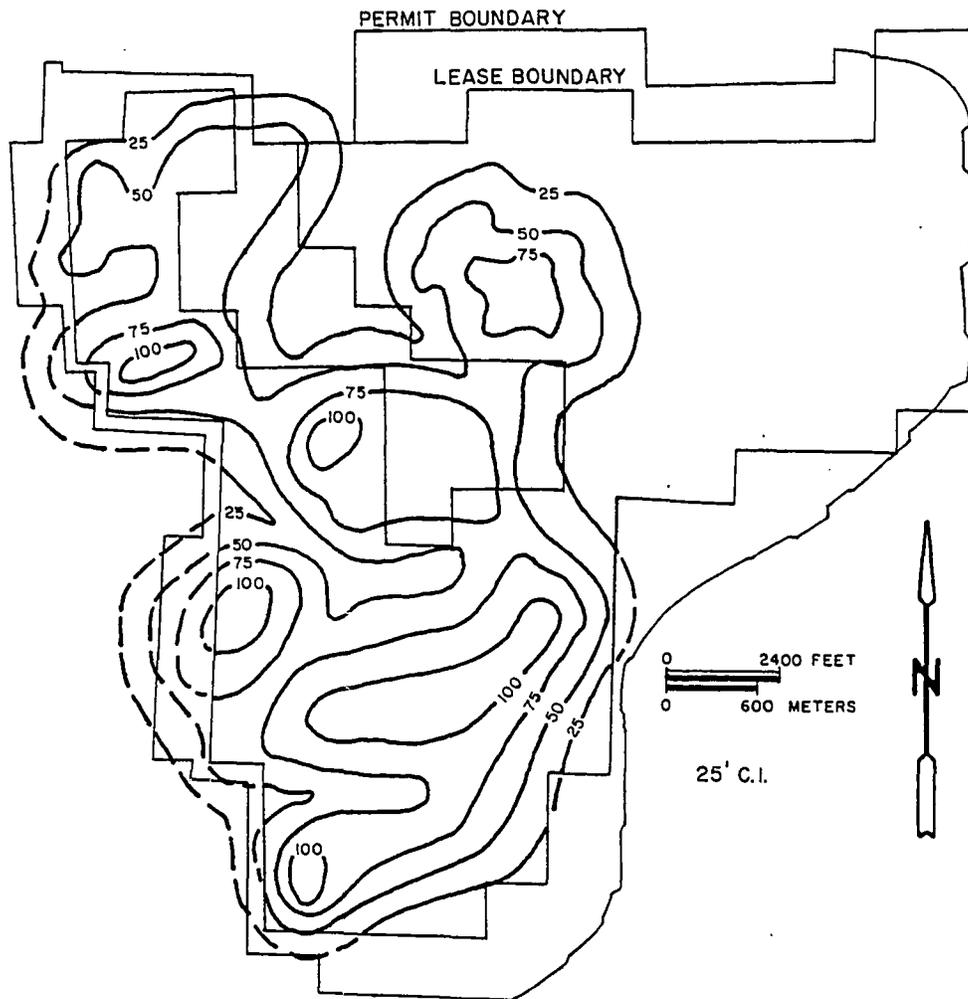
Figure 13. Sandstone + siltstone isopach map of the interburden.

(plate 3) where the Lower Anderson is shown. Cross section A-A' (plate 2) shows the Lower Anderson seam extending to the southern portions of the field, but drill hole data is insufficient to positively support this correlation, so discussion will be limited to the presently accepted limit of the Lower Anderson, which is illustrated on the fence diagram (plate 3).

The rocks described in drill hole data that comprise the Upper Anderson/Lower Anderson parting are similar to the parting rocks described for the A3/A2 and A2/A1 partings. All of these partings consist of carbonaceous shale and claystone with coal stringers frequently noted. However, the Upper Anderson/Lower Anderson parting displays a distinct change from these rock types in one area of the Antelope coal field. Cross section A-A' (plate 2) shows a thick sandstone and siltstone unit between the Upper and Lower Anderson coal seams. The sandstone and siltstone occurs between drill holes 81129 and 80013 OBC (80013 OBC marks the limit of the Lower Anderson according to the discussion above). The sandstone and siltstone form fining upward and coarsening upward sequences. Laminations, ripple drift, small-scale cross beds, and slump features are all noted in this area, as well as massive sandstone and siltstone. Limestone is also present and shown in cross section A-A' (plate 2). Carbonaceous fragments are sparse to common.

Overburden

The overburden thickness varies across the Antelope coal field. There is no overburden in regions where recent stream erosion has

cut down into and sometimes through the Anderson Coal seam. Such erosional features are illustrated on the fence diagram (plate 3) in drill hole 230 CW. The overburden reaches thicknesses of up to 30 meters (100 feet) in the southern portion of the Antelope coal field.

A variety of rock types are present immediately overlying the Anderson coal seam, where the Anderson seam and overburden rocks have not been eroded. Carbonaceous shale and claystone are commonly found in contact with the top of the Anderson coal seam, while sandstone and siltstone are also common at this stratigraphic level. An interfingering relationship of the carbonaceous shale and claystone with sandstone and siltstone in the overburden can be seen in cross section A-A' (plate 2). Small channel scours are preserved in surface exposures where sandstone and siltstone have formed channel-fill deposits (figure 14). Round concretions in some cross bedded sandstones attain a diameter of 2.54 cm (1 inch). These concretions are most evident where the rocks have been exposed to surface weathering (figure 15). Discontinuous coal and limestone stringers are also present in the overburden.

Figure 14. Small channel scour with sandstone and silt-stone as channel-fill deposits. Note brunton compass at base of scour for scale.
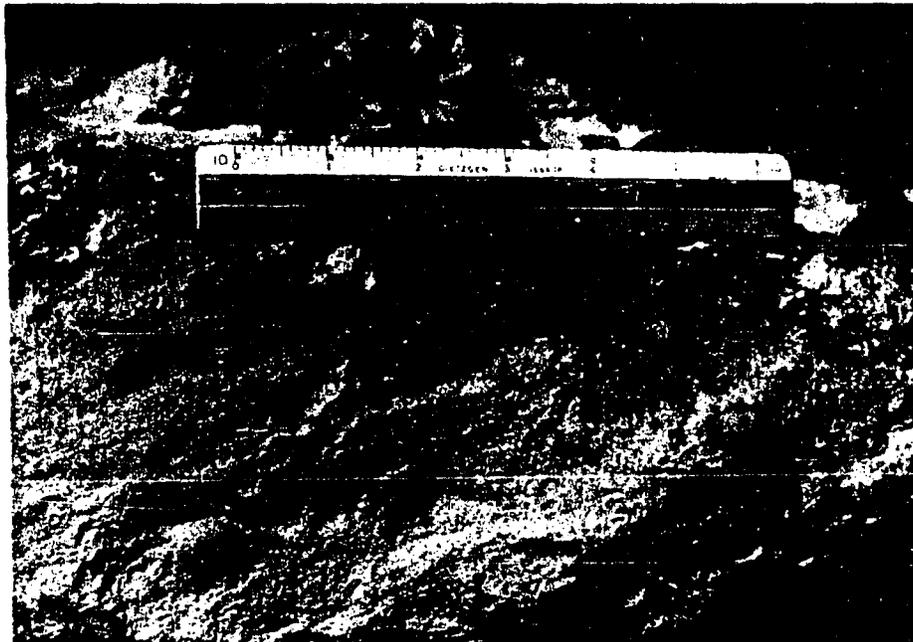
Figure 15. Round concretions in sandstone.

CHAPTER V

DEPOSITIONAL ENVIRONMENTS

Introduction

Modern fluvial systems, such as that developed in the
Atchafalaya River basin in Louisiana, provide a means to study and
understand depositional environments and their characteristic
sediments. By comparison to the sedimentary rocks of the Antelope
coal field a number of primary depositional environments have been
recognized. These include swamps, both well- and poorly-drained,
crevasse splay, small channel-fill, distal overbank, and lacustrine
and lacustrine delta deposits.

Swamp Deposits

Swamp deposits of one type or another are the most abundant
deposits at the Antelope coal field. Modern river basins also
contain extensive swamp lands; the Atchafalaya River basin consists
of approximately 90% swamp land (Coleman, 1966). Coleman (1966)
described well- and poorly-drained swamps in the Atchafalaya River
basin. Well-drained swamps contain an effective drainage system
with alternating oxidizing and reducing conditions, while a poorly-
drained swamp lacks an effective drainage system and sustains
reducing conditions (Flores, 1981).

These two types of swamps are represented in the Antelope coal field. Well-drained swamp deposits are common in the stratigraphic sections above and below the Anderson and Canyon coal seams. For example, the rocks in contact with the base of the Canyon coal seam are dominantly claystones and shales with varying amounts of carbonaceous material. Similar lithologies with bioturbation structures are present in the interburden and the overburden. Poorly-drained swamp deposits are represented at the Antelope coal field by the thick coal seams and the carbonaceous shales and claystones that are commonly associated with thin coal stringers, such as the Rider coal seam.

Ethridge and others (1981) described similar depositional environments at the SEAM study site. Their study also noted that well- and poorly-drained swamps are commonly associated and that crevasse splay deposits are usually associated with well-drained swamps.

Crevasse Splay Deposits

A Crevasse splay deposit forms where the natural levee of a channel is breached and part of the channel water temporarily drains through the breach and into the surrounding environments. The sediment load of the channel is deposited with distinct structures and geomorphic features that can be used to identify the type of deposit.

Coleman and Prior (1980) describe recent crevassing of the Mississippi River. They state that crevasses extend themselves "through a system of radial bifurcating channels similar in plan to the veins of a leaf." Crevasse splay deposits are present in the Antelope coal field, especially in the partings of the Canyon coal seam. The radial bifurcating channels described above produced the multi-lobed features illustrated by the isopach contours in figures 9-11. Coarsening upward trends, ripple drift, laminations, and infrequently small-scale cross bedding structures have been noted in these partings, which are dominantly fine-grained sandstones and siltstones.

Crevasse splay deposits grade upward into well-drained swamp deposits with the upper portions of the splay deposits containing abundant root and burrow structures. Crevasse splay deposits are laterally associated with lacustrine delta deposits where the splay empties into a lake.

Small Channel-Fill Deposits

Small channels develop on top of crevasse splays and aid in their extension into the surrounding environments (Coleman and Prior, 1980). The channel eventually fills itself or is filled in with sediment and a channel-fill deposit is formed. The presence of channel scours help to distinguish these deposits from other deposits with similar lithologies and structures.

Figure 14 shows a small channel scour (1-2 meters in width) in the overburden at the Antelope coal field. It contains very fine-

grained sandstone and siltstone as a channel-fill deposit. Drill hole data is too sparse to identify channel scours in the subsurface, but the presence of a scour at the surface suggests that this type of deposit is also present in the subsurface at the Antelope coal field and is probably common in crevasse splay deposits.

Distal Overbank Deposits

During periods of high precipitation and runoff, a channel will spill over its levee and flood the adjacent land. Such events are not necessarily associated with breaching of the levee system, but these sediments may be associated with crevass-splay deposits. The sediments deposited by the flood waters form overbank or distal overbank deposits, depending on the distance from the flooding channel. Coarser sediments are deposited closer to the channel while finer sands and silts are carried further and form the distal overbank deposits. The lateral extent of the overbank deposit depends on the energy of the flood water.

A distal overbank deposit is inferred at the upper contact of the Canyon coal seam and the bottom contact of the Anderson coal seam (Figure 12). The sandstone is very fine-grained and interbedded with siltstone. Both of these units contain little carbonaceous material and are massive to laminated with ripple drift and bioturbation structures in the upper portions of the deposit.

These units could represent a migrating channel deposit, but the lack of cross bedding and scour structures suggests that this is not a representative depositional environment. The distal overbank

deposits may also be part of an extensive levee system, but the position of the channel forming these deposits with respect to the Antelope coal field is unknown.

Lacustrine and Lacustrine Delta Deposits

Lakes are common environments in river basins, such as the Atchafalaya Basin where they cover approximately 518 km^2 (200 mi^2). They form from subsidence and sediment compaction with subsequent flooding or accumulation of standing water in the depressed area (Flores, 1981). A lacustrine delta is formed where a diverted stream or crevasse splay flows into the low-lying area of the lake.

The lacustrine deposits at the Antelope coal field are inferred primarily by the presence of limestone. The frequent but not exclusive association of limestone with sandstone and siltstone suggests that the lakes were formed during crevasse splaying events and received more sand and silt than clay and carbonaceous debris. Fresh water fossils, like the molluscs described by Flores (1980) in the Tongue River member of the Fort Union Formation, were not observed at the Antelope coal field. Lacustrine delta deposits are rare at the Antelope coal field and data is sparse to support their existence. One drill hole in the central part of the field contains evidence of slump and deformation structures within a coarsening upward sequence. A carbonate-bearing lacustrine deposit is laterally associated with this unit and supports the interpretation of a lacustrine delta deposit.

Ethridge and others (1981) also identified carbonate-bearing lacustrine and lacustrine delta deposits at the SEAM study site in the Powder River Basin. However, carbonate deposits are absent from the modern lake deposits of the Atchafalaya basin. Dean (1981) discusses the factors influencing the precipitation and accumulation of carbonates in temperate hard-water lakes. The most important controlling factor of carbonate precipitation in hard-water lakes is the assimilation of CO_2 by photosynthesis. The accumulation of carbonates is greater in the shallower parts of these lakes because production and accumulation of calcareous plant and animal debris is greater. Although Dean's (1981) work dealt with temperate hard-water lakes, his conclusions suggest that the Tertiary lakes of the Fort Union Formation in the Powder River Basin were shallow and existed under conditions where the production of carbonate precipitates was greater than their dissolution.

Summary

Figure 16 briefly summarizes the depositional environments present at the Antelope coal field. A general description has been given for each stratigraphic section discussed in Chapter IV and the interpreted depositional environment is listed in the right-hand column.

Stratigraphy		Description	Overburden	Representative Depositional Environments
Overburden		Interfingering SS & SL with CL & carbonaceous SH in contact with the top of the Anderson coal seam; LS may be present; small channel scours filled with SS & SL are present	Overburden	= crevasse splays, lacustrine, small channels, & well-drained swamps
Anderson Seam		Carbonaceous SH & CL partings + CO stringers; isolated area contains thick SS & SL parting with small-scale cross bedding and slump features	Partings in Anderson seam	= well-drained swamps with some crevasse splays, lacustrine & lacustrine delta
			Anderson seam & respective splits	= poorly drained-swamps
Interburden	Upper	Thick, continuous SS & SL body commonly in contact with base of Anderson coal seam	Upper interburden	= distal overbanking
	Middle	Thin, discontinuous & interbedded SS, SL, SH, CL, CO. & LS	Middle Interburden	= crevasse splays, lacustrine, small channel development, & minor well-drained swamps
	Lower	Thick, continuous SS & SL body commonly in contact with top of Canyon coal seam; very fine-grained & massive to finely laminated	Lower interburden	= distal overbanking
Canyon Seam	C5/C4	Carbonaceous SH & CL parting + CO stringers; minor SS & SL present; multi-lobed body	Partings in canyon seam	= crevasse splays & lacustrine with small channel development
	Upper/Lower Canyon	SS & SL parting with minor LS, carbonaceous SH, CL & CO stringers; multi-lobed body	Canyon seam & respective splits	= poorly-drained swamps
	C3/C21	SS & SL parting with minor LS: lobate-shaped body		
Underburden		Carbonaceous SH & CL that grades vertically upward into the Canyon coal seam & vertically downward into the Rider coal seam	Underburden	= well-drained swamps
			Rider seam	= poorly-drained swamps

Figure 16. Summary chart of depositional environments and their characteristics present at the Antelope coal field (SS = sandstone, SL = siltstone, SH = shale, CL = claystone, LS = limestone, CO = coal)

CHAPTER VI

DEPOSITIONAL MODEL

Introduction

A depositional model is a reconstruction of the environments
that were present during the deposition of the coal and its asso-
ciated lithologies. Each of the five stratigraphic sections dis-
cussed in chapter IV represent one or more of the depositional
environments described in chapter V. The environments present in
these stratigraphic sections will be discussed below.

Model

The underburden represents a poorly-drained swamp environment
(Rider coal seam) that developed into a well-drained swamp with
infrequent influxes of sediment from small channel development. The
drainage network became less effective across the Antelope coal
field when the Canyon coal swamp established itself and a poorly-
drained swamp environment developed. The great amount of organic
debris needed to form the thick Canyon coal seam suggests that the
poorly-drained swamp was present for a long time, and/or that rapid
subsidence was occurring (discussed later). The Canyon coal seam
partings that are present in the southern half of the Antelope coal
field represent crevasse splay, lacustrine, and well-drained swamp

environments, as shown on Figure 17. Figure 18 illustrates the environments that were present during the deposition of the inter-burden and Anderson coal seam. The blanket sandstones and silt-stones deposited by distal overbanking terminated the poorly-drained swamp that formed the Canyon coal seam. Well-drained swamps were established on top of the distal overbank deposits and were fre-quently interrupted by crevasse splaying and lake development. The uppermost unit of the interburden represents distal overbank depo-sits that formed a platform for the development of well-drained swamps. The well-drained swamps gradually developed into poorly-drained swamps and the organic debris that later formed the Anderson coal seam was deposited. Rapid subsidence and/or long-term estab-lishment of the poorly-drained swamp is also implied here because of the thick nature of the Anderson coal seam. Figure 19 shows a combination of depositional environments that contributed to the cessation of the poorly-drained swamp that formed the Anderson coal seam. These environments include extensive crevasse splaying and lake development with minor overbanking. Channels developed on top of the crevasse splays and were later filled with sediments, as seen in the photograph of a channel-fill deposit in the overburden in figure 14. Well-drained swamps were established adjacent to crevasse splays and lakes.
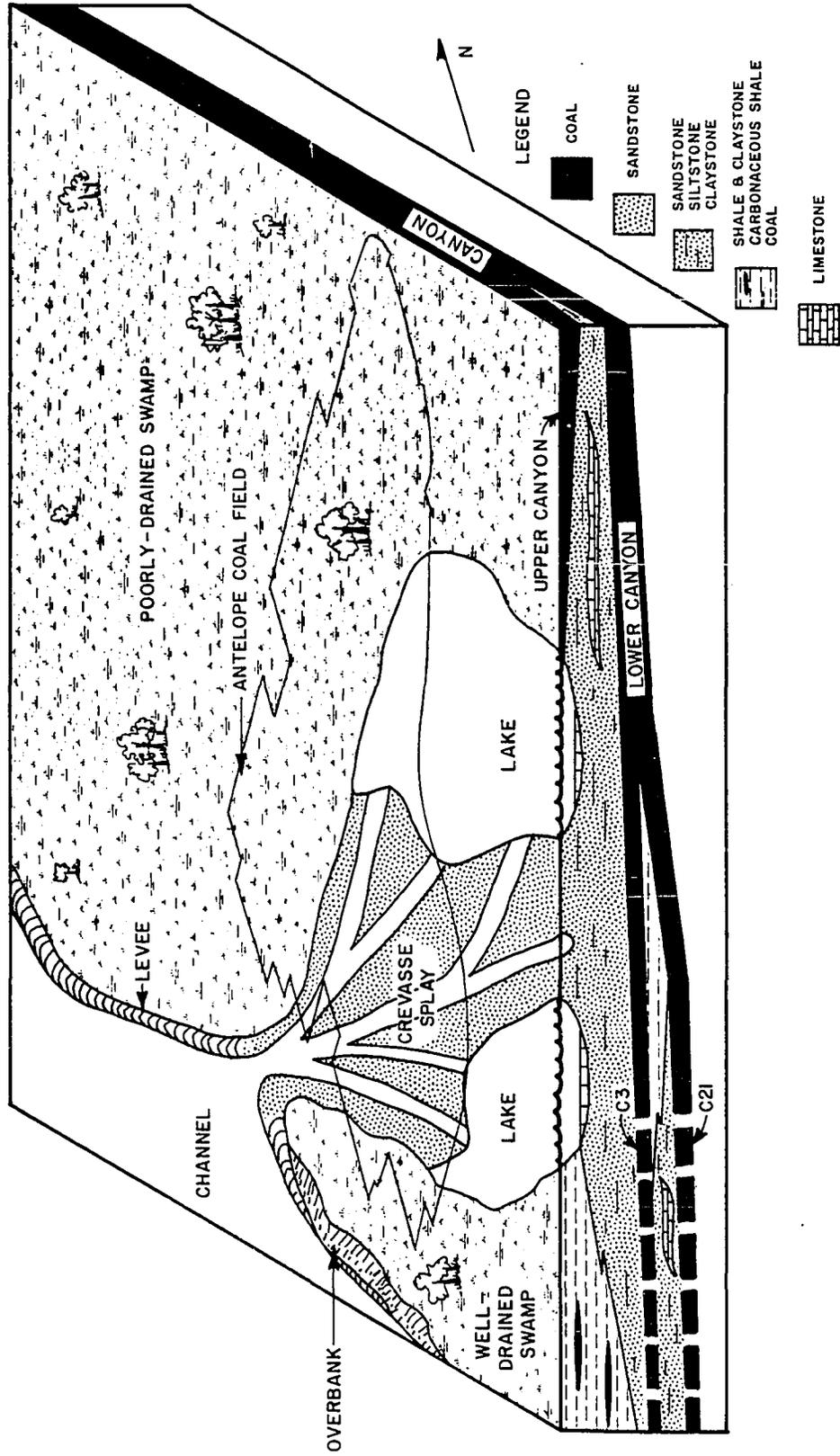
Figure 17. Block diagram illustrating depositional environments during the accumulation of the Canyon coal seam deposits.
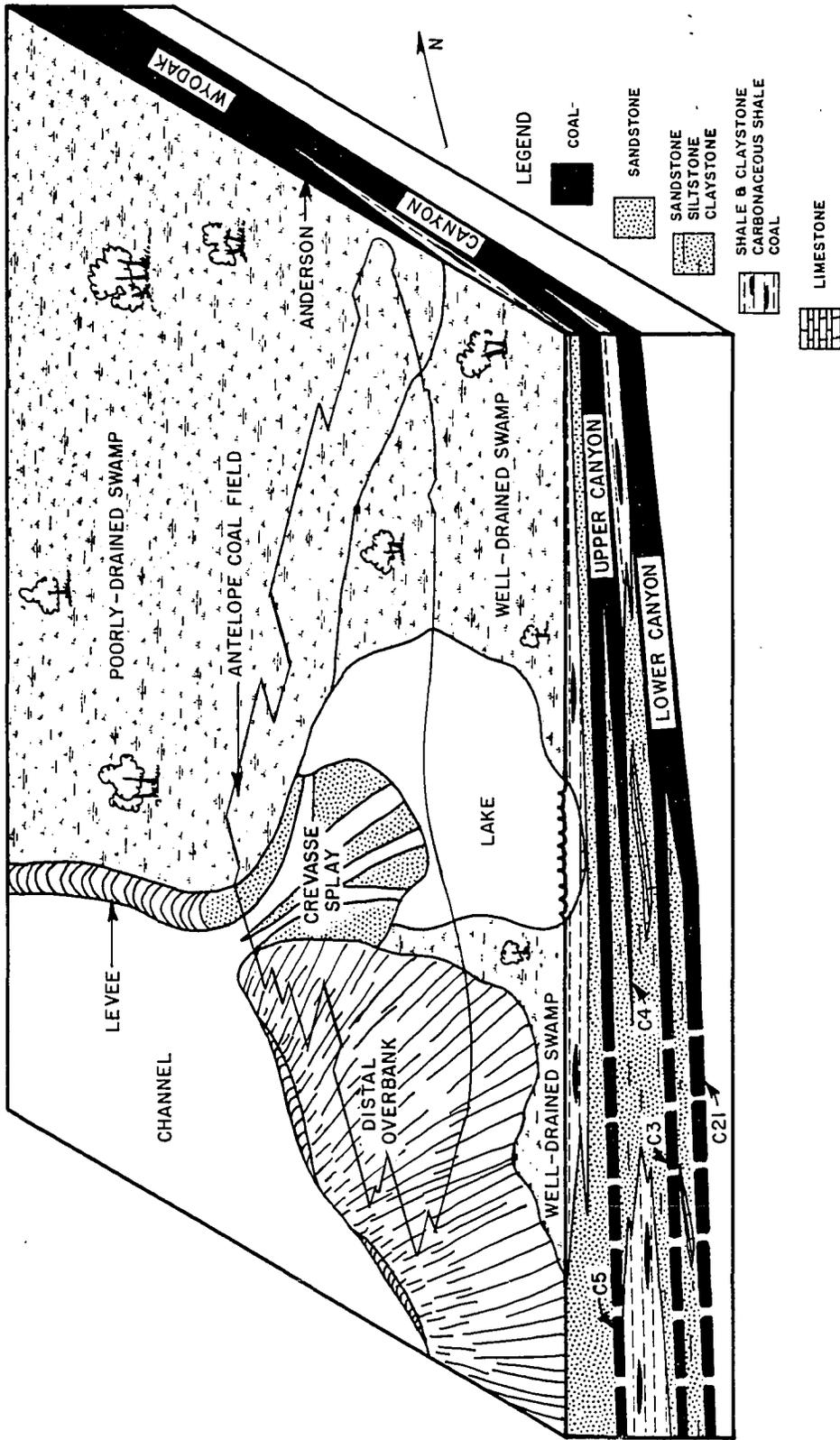
Figure 18. Block diagram illustrating depositional environments during the accumulation of the Anderson coal seam deposits.
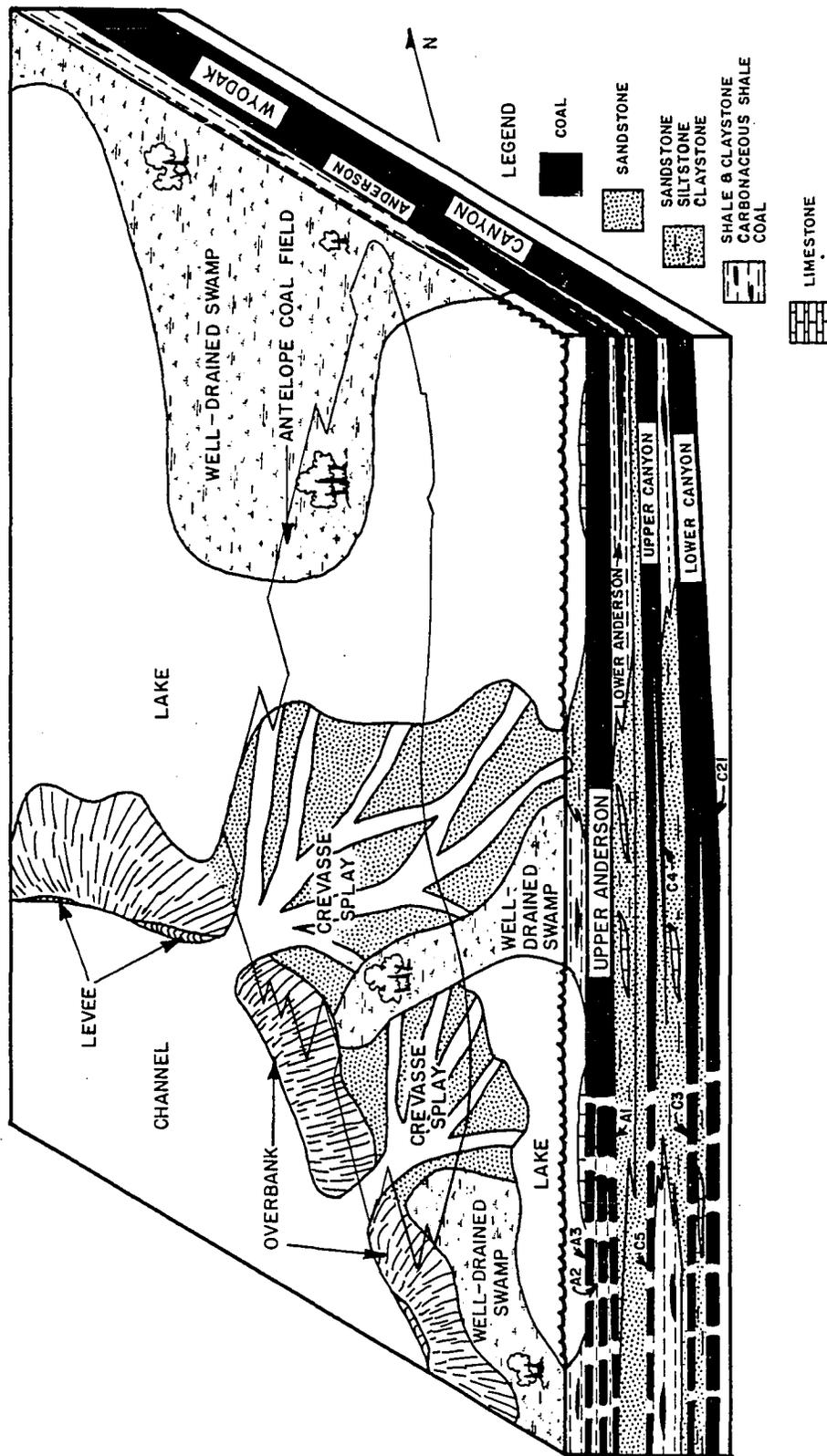
Figure 19. Block diagram illustrating the cessation of the major coal-forming swamps in the Fort Union Formation.

CHAPTER VII

POST-DEPOSITIONAL PROCESSES

Syn- and post-depositional processes have affected changes in the coal deposits. These processes can be considered as 1) compaction related processes and 2) erosion and deposition from modern stream action. Mining of the coal, coal quality, and reserves are strongly influenced by these processes.

Law (1976) described anomalous folding in the Wyodak coal seam near Gillette, Wyoming. He suggests that the Wyodak coal seam is not folded, but rather it, along with underlying and overlying strata, experienced differential compaction during and after peat deposition. Law (1976) based his hypothesis on the facts that 1) the original peat was deposited on a horizontal surface, 2) sand is less compactible than mud and clay, and 3) mud and clay are less compactible than peat.

Cross section A-A' (Plate 2) shows fold-like structures in the Anderson coal seam. The antiforms occur where the underlying rocks are mostly sandstones and siltstones, while the synforms occur where shale and claystone more commonly occur in the underlying stratigraphy. These observations are consistent with Law's (1976) hypothesis and suggests strongly that differential compaction of the lithologies caused the observed folds or rolls in the Anderson coal seam.

The Canyon coal seam does not show the same degree of rolling as the Anderson seam. This may be due, in part, to the more uniform lithologic character of the sediments beneath the Canyon coal seam. The thick sandstone and siltstone bodies present in the interburden are not present in the underburden. Instead, claystones and shales are the dominant lithologies in the underburden. Differential compaction of the peat during deposition may not have been as great and may be a further explanation for the absence of prominent rolling in the Canyon coal seam.

Drill hole data and surface exposures of the alluvial deposits suggest that several periods of downcutting with subsequent infilling occurred. Figure 6 shows multiple fining upward alluvial sequences with gravel at the base and very fine sand or silt at the top. Antelope Creek, the modern stream in the area, flows from west to east across the northern half of the Antelope coal field and is presently downcutting into these alluvial deposits. In general, each period of downcutting represents different base levels and are associated with different paleowater tables. Where the streams cut into the coal seams, the water table at that time was either at the surface or somewhere below the surface and probably within the coal seam. Although it is recognized that the channel cutting and alluviation of channels in the field is probably complex and the number of such cycles is unknown, a simplified three stage sequence can be presented which explains the essential characteristics of the system. The earliest stage was downcutting during which most of the Wasatch and portions of the Fort Union Formations were removed. The

depths of such channels were in places at least 18 meters (60 feet) beneath the modern valley floors. In places the valleys cut through the lower Canyon seam. During the second stage these valleys were alluviated to a level higher than the floodplains of modern streams. Alluvial fill ranges from 0.3 to 20 meters (1 to 66 feet) in different parts of the field. The third stage consists of modern streams downcutting into this alluvial fill. Each of these stages is associated with changes in water table levels. The interplay between ground water levels, stream valleys, stratigraphy of the Fort Union Formation and compaction features in the stratigraphic section explain the location of coal burns and oxidized zones. This is a simplified model presented to help explain the oxidation and burning processes discussed below that have affected the coal quality and reserves at the Antelope coal field. It is only one of many possible models that can be developed to explain and understand these processes.

During the most extensive downcutting stage, when the coal seams were oxidized or burned to form clinker deposits, the Anderson and Canyon coal seams were exposed and eroded in portions of the Antelope coal field. Stream erosion of the Anderson coal seam was greatest in areas where the seam was closer to the surface (figure 20). These areas coincide with areas where the underlying strata is dominantly sandstone and siltstone, hence where the coal seam rolled to form an antiform structure. An example of the erosion of an antiform structure can be seen between drill holes 81009 and 82230 on cross section A-A' (Plate 2). Part of the coal in this area has

Figure 20. Contact (dashed line) between alluvium and the top of the Anderson coal seam.

been oxidized so that the normal average BTU/lb of 8500 has been reduced to less than 5000 BTU/lb. As shown on the cross section, the oxidation does not occur throughout the portion of the coal seam exposed by surface erosion. Also, the base of the oxidized coal remains at a certain elevation while the coal seam itself changes elevations because of rolling. This suggests that the rolls in the coal seam elevated the seam through the surface of the water table present at that time and, where the coal was exposed by stream erosion, it oxidized down to the existing water table surface. Therefore, the base of the oxidized coal represents a paleowater table surface. Further evidence to support this hypothesis can be seen between drill holes 800240B and 81007C on cross section A-A' (Plate 2). The Anderson coal seam has been partially eroded by downcutting in this area also, but there is no oxidized coal present because the coal seam has not rolled up above the surface of the paleowater table and was probably under artesian conditions.

The use of a paleowater table to explain the limit of oxidation in the Anderson coal seam can also be related to the limits of burning that the coal seams experienced. The surficial geologic map of the Antelope coal field (Plate 1) shows the areas where the coal seams burned and thermally altered the overlying rocks to form clinker deposits.

These deposits are relatively flat-bottomed, as shown on cross section A-A' and the fence diagram (Plates 2 & 3). In most cases their bases mark the bottom of the coal seam that was burned to produce the clinker deposits. Where the coal seam was not completely

burned the clinker deposits are still relatively flatbottomed units. An example of this can be seen in drill hole 81129 on cross section A-A' (Plate 2). Like the oxidized coal, the base of the clinker deposit remains at a certain elevation, regardless of the roll structure seen in the Anderson coal seam.

Clinker deposits and partially burned coal commonly occur where the underlying strata is dominantly sandstone and siltstone, as seen on the Fence Diagram (Plate 3) in drill holes 80023, 81129, 80051, 80042 and 307GTW. This implies that the burned or partially burned coal was part of an antiform structure that was closer to the surface.

Similarities between clinker deposits and oxidized coal, such as the constant elevation of the base of both deposits and the vertical association with antiforms suggests that a paleowater table partially controlled the extent of oxidation and burning. The coal seam was burned completely in areas where the seam had rolled up through and out of the existing water table. Stream erosion exposed this coal which spontaneously ignited and burned. The coal seam partially burned in areas where the seam rolled up through the top surface of the existing water table but not completely out of it; the coal that was under the paleowater table did not burn. The burning continued along the coal seam from the top of the paleowater table to the top of the coal seam until the overlying strata collapsed and extinguished the fire. The contacts between these clinker deposits and the remaining coal represent the top of the paleowater table.

The surficial geologic map (Plate 1) shows only two small areas of clinker deposits associated with the Canyon coal seam, while the remaining clinker deposits formed from burning of the Anderson coal seam. This observation may be partially explained because the Canyon seam is the stratigraphically lower coal seam and thus more extensive downcutting is required in order for it to be exposed, especially since the coal seam lacks prominant roll structures which would be more readily exposed by stream erosion. However, part of the Antelope coal field shows extensive downcutting to the top and often through the Canyon coal seam, as shown in drill holes 80046 and 80048 on the Fence Diagram (Plate 3).

The Canyon coal seam is presently under artesian conditions (Antelope Permit, 1980) and it is believed that similar conditions existed in the past. Since the coal seam is saturated with water under these conditions, burning is not prevalent. Surface exposures that are partially dried out may experience limited burning. This is probably how the Canyon clinker deposits shown on the surficial geologic map (Plate 1) were formed.

Extensive alluviation has concealed most of the incised valleys, oxidation features, and evidence of burning or clinker deposits in the coal seams. Modern streams are presently down-cutting, but they expose only bits and pieces of the variety of features formed by post-depositional processes that have altered the quantity and quality of the coal deposit. Features of the deposi-tional model can be used to predict areas of potential reserve loss, reduced coal quality, or clinker deposits. The areas of greatest

potential difficulty are the areas near alluviated valleys, especially where rolls or sandstone and siltstone bodies occur in the interburden. Exploratory drilling at the field should utilize these features to effectively define such problem areas.

CHAPTER VIII

DISCUSSION

Regional Interpretation

An extensive and constantly developing fluvial system existed in the Powder River Basin during the deposition of the Early Tertiary Fort Union and Wasatch Formations. This fluvial system included three main components or subsystems, according to Schumm (1981) and Ethridge and others (1981). The drainage basin or tributary sub-system provided sediment and water to a river or major trunk stream that removed the material and transported it to a site of deposition. The trunk stream of the Powder River Basin flowed northward along the axis of the basin. The tributary subsystem drained the margins of the basin and a paludal subsystem lay between the tributary sub-system and the trunk stream, according to Ethridge and others (1981).

Depositional environments recognized at the Antelope coal field through lithologic identification, correlation, and analysis support the existence of both tributary and paludal subsystems in the south-ern Powder River Basin. Environments, such as crevasse splay, lacustrine and lacustrine delta, overbank, small channels, and well-drained swamps represent a tributary subsystem, while poorly-drained swamps are representative of a paludal subsystem.

The Wyodak coal seam in the Powder River Basin is a unique, poorly-drained swamp deposit. It contains no partings and reaches a maximum thickness of over 36 meters (120 feet) in the central portions of the basin. This unusually thick and laterally continuous coal deposit has a north-south orientation paralleling the basinal axis. The coal seam splits to the north and south and forms multiple thick and laterally continuous coal deposits, some of which are present in the Antelope coal field.

The mechanism for the formation of these unique coal deposits has been discussed by many investigators. Ethridge and others (1981) present a good summary of current hypotheses proposed to explain the formation of the thick Wyodak coal seam and its respective splits. Rich (1983) recently speculated that the tectonic activity of the Powder River Basin during the Tertiary may have been a factor in the formation of the unique coal deposits.

Schumm (1981) suggests that a change in any one component of a fluvial system will affect the entire system. He states that an episodic behavior or rapid deposition and erosion can result from a major geomorphic, climatic, or tectonic disruption in the fluvial system, while less severe episodic behavior or complex responses result from changes of smaller magnitude.

The Powder River Basin was tectonically active during the deposition of the Fort Union and Wasatch Formations (Love and others 1963). Evidence of multiple episodes of recent downcutting and alluviation at the Antelope coal field, discussed in chapter VII, suggests that the basin may still be tectonically active.

The Powder River Basin and adjacent highlands experienced regional uplift during the Tertiary. However, the basin could have experienced relative subsidence due to faster rates of uplift in the adjacent highlands. Subsidence of the basin would cause progradation and aggradation of the trunk stream so that the stream would trap itself in its channel and any flooding would probably add to the entrapment by developing levee deposits. Swamps that developed adjacent to the trunk stream would become well protected from flooding so that thick peat deposits could accumulate without interruption.

A delicate balance must have existed between the gradual relative basin subsidence, stream progradation to maintain its base level, and peat accumulation for the thick coal deposits to form. An imbalance in the system caused the observed partings to the north and south of the central portions of the basin where the thickest coal deposits formed.

The Antelope coal field is located in a transition zone where the poorly-drained swamp that formed the thick coals was well protected in the extreme northern Antelope coal field region but experienced progressively more flooding and crevasse splaying to the south. This suggests that an imbalance in the system existed near the Antelope coal field. Relative basin subsidence may have slowed and caused the trunk stream to discharge its excess water and sediment out into the floodplain or the protective levee may have weakened and caused similar flooding events. Further study and research are needed before these speculations and others can be proven or disproven.

Modern Analog

The fluvial system that existed in the Powder River Basin during the early Tertiary is, in general, similar to many modern inland river swamps of the southcentral U.S., such as the White-Arkansas River swamps and the Atchafalaya River Basin. Frazier and Osanik (1969) present a general overview of modern inland peat-forming environments of the Louisiana coastal plain. The depositional settings they described are similar to those described for the Tertiary Powder River Basin and provide a modern analog.

The freshwater swamplands of the Louisiana coastal plain are located on the inland portions of the deltaic plain. They form in higher, broad flood basins that are bordered by natural levee ridges formed by the multiple river courses of the Mississippi River. Hardwood trees are abundant in these basins because the low-lying wet ground is relatively firm, as compared to the swamplands located seaward which host mostly herbaceous plants.

Flores (1981) described the Tertiary vegetation that later formed the thick coal seams of the Fort Union Formation as consisting of relic tree islands or patchy forested areas surrounded by hollows where herbaceous plants flourished. Brown (1962) identified Paleocene palms in northern Wyoming, breadfruit and cinnamon in the central regions, and ginkos to the south, indicating climatic zoning. As previously discussed, the Tertiary Fort Union swamps that supported these types of vegetation were located in paludal and tributary subsystems of the fluvial system. These subsystems are similar to the modern inland peat-forming enviromments and consist

of floodplains that were bordered by the natural levee of the trunk stream that flowed along the axis of the basin.

Coleman (1966) discussed the formation of the numerous lakes that are present in the Atchafalaya River floodbasin in Louisiana and proposed that local subsidence and compaction were possible mechanisms. The diversion of streams into these low-lying areas formed lacustrine delta deposits in this modern river floodbasin. Similar mechanisms may have formed the lacustrine and lacustrine delta deposits observed in the Upper Fort Union Formation at the Antelope coal field. Other areas of swampland in Louisiana discussed by Frasier and Osanik (1969) show splits in the peat and clayey peat which resulted from sedimentation caused by crevasse splaying and natural levee and overbank flooding that was contemporaneous with peat development. Analogous events are recorded in the parting rocks at the Antelope coal field.

Frasier and Osanik (1969) proposed mechanisms of peat formation for the inland swamps of Louisiana that are similar to the ones discussed in the section above. They suggest that the swamps were first established adjacent to prograding and aggrading streams of the Mississippi River and were able to persist because the rate of peat accumulation kept pace with subsidence. The rate of peat accumulation according to Frasier and Osanik (1969) is 0.6 meter (2 feet) per century. These inland swamps are far removed from active stream courses, so there is minimal influx of sediment to inhibit the growth of vegetation.

Although there are many comparisons and similarities between modern river-swamp systems and the early Tertiary Powder River Basin, there is no modern river basin that is accumulating thick and laterally continuous peat deposits needed to form coal seams of the magnitude found in the Powder River Basin. Rich (1983) suggests that this may be because most river basins are relatively stable and it's this stability that prevents the necessary subsidence for the accumulation of extremely thick peat deposits.

Application

The depositional model of the Antelope coal field is a conceptual tool that can be used for exploration and development. Organization of data from the 500 drill holes at the Antelope coal field made the database uniform and computerized so that correlation by cross sections and analysis by isopach maps was speedy and simplified. Data from future drilling programs can easily be added to the existing database system for further development and modification of the depositional model.

As a conceptual tool for exploration and development, the depositional model can be used to identify where potential reserve problems may occur. For example, reduced reserves have been located at the Antelope coal field in alluviated, burned, and oxidized areas. The quality of the coal may be significantly altered in these areas and this affects the marketability of the coal deposit. The depositional model provides information to understand the controls on these post-depositional processes, such as rolling and

the position of the paleowater table. Future exploratory drilling at the Antelope coal field should concentrate on areas that show similar surface and subsurface features. These types of areas that show potential reserve loss and/or reduced coal quality can be approximately located through the use of the depositional model.

The type of equipment and procedures required for exploratory drilling and future mining of the coal deposit, as well as the actual planning of the mine site at the Antelope coal field are influenced by the depositional model. An exploratory drilling program can be designed with maximum efficiency because potential reserve and coal quality problem areas have been delineated on the surficial geologic map (Plate 1) that shows where unconsolidated alluvium and clinker deposits are present, which require special drilling procedures and equipment. Since alluvium is unconsolidated, it can be removed without blasting and with cost-effective equipment when the coal is mined. Knowledge of the distribution of alluvium also helps the engineer when designing the mine, such as high-wall stability. Hydrology conditions at the mine site can be evaluated more effectively; for example, the flow of water into a mine pit can be avoided by planning mine pits in areas away from sandstone and siltstone bodies, coal stringers, and alluvium, all of which can act as aquifers and are approximately located by the depositional model.

The depositional model not only provides a better understanding of the Tertiary fluvial system in the southern Powder River Basin, but it also has practical application to the exploration of

coal deposits and mine planning and operation. Further development of the depositional model with future drill hole data is necessary to 1) define areas of reserve loss and reduced coal quality more accurately, 2) design a safe and efficient mine site, and 3) develop cost-effective mining procedures.

CHAPTER IX

SUMMARY

The depositional model for the Antelope coal field involved a reconstruction of the paleoenvironments that were present when the Anderson and Canyon coal seams and their associated lithologies were deposited. The model indicates that a combination of crevasse splay with small channel development, distal overbank, and lacustrine and lacustrine delta processes caused the cessation of the poorly-drained swamps that later formed the coal seams. These processes occurred in paludal and tributary subsystems of the fluvial system that existed in the Powder River Basin during the Early Tertiary.

The presence of multiple splits in the Anderson and Canyon coal seams in the southern portion of the Antelope coal field implies that the fluvial system near the southcentral Powder River Basin behaved differently than to the north, where the two coal seams merge to form the thick Wyodak coal seam. These differences may be related to 1) relative basin subsidence, 2) a prograding and aggrading trunk stream with a thick levee deposit, and 3) peat accumulation that kept pace with relative basin subsidence. A change in any one of these processes could produce the splits observed in the Anderson and Canyon coal seams at the Antelope coal field.

Syn- and post-depositional processes that have affected the coal quality and reserves at the Antelope coal field include compaction and modern stream erosion and deposition. These processes, in relation to the paleowater table, have caused oxidation and burning of the coal seams. Knowledge of the controls on the burning and oxidation of coal and the distribution of sedimentary rocks related to these processes can be applied to the exploration and development of coal deposits.

The modern depositional environments observed on the Louisiana coastal plain are similar to the environments that existed in the Powder River Basin during the deposition of the Upper Fort Union Formation. However, the Powder River Basin and its fluvial deposits are rare because there is no modern river basin that is accumulating peat at a rate sufficient to form thick coal seams like those present in the Powder River Basin.

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APPENDIX A

SAMPLE DRILL HOLE DATA

This appendix contains representative samples of the drill hole data used in this study. Lithologic logs similar to those shown in figures 21A through 21F were available for all of the drill holes examined (approximately 500). Figure 22 shows a suite of geophysical logs. Most of the drill holes had a portion or all of the geophysical logs displayed. A modified version of the computer program called LOG PLOT (Ferm and Berger, 1979) was used to generate an individual stratigraphic column for each drill hole. The log plot shown in figure 23 accurately displays the total depth and elevation of the drill hole and the lithologies encountered and their thicknesses. The lithologic description of each unit is printed to the right of the stratigraphic column. Some of the drill holes had additional data available, such as, coal quality and overburden analyses. Figure 24A is a coal quality analysis on good coal and shows a relatively high BTU/lb and low percentages of moisture and ash. Figure 24B is the same analysis only on oxidized coal, as seen in the low BTU/lb and high percentages of ash and moisture. Figure 25 is a sample overburden analysis. The particle size analysis was especially useful in lithology determination.

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PAGE 1 OF 6	DRILL HOLE LOG						PROJ. AT	DRILL HOLE NUMBER 81012 Pilot

EST. E/W COORD	EST. N/S COORD.	EST. ELEV	SEC	TWNSHP	RANGE	MIN. CO.	CONTR.	FLD.REP	DATE START	DATE COMP
							JC	DJ	6/18/81	6/18/81

TOT. DEP	GEOPHYSICAL LOGS.					DRILL RIG MAKE & MODEL	DRILL BIT SIZE & TYPE	WEATHER
	GAM	DEN	RES	CAL	SP			
260						Failing 1500	5 1/8 claw	Sunny

COMMENTS

DEPTH	BOX	SAMP	LOSS	LITHOLOGIC DESCRIPTION	REMARKS
				cv, brn, uncons, Sand damp, f-mg, qtz, feldsp, poor sort, modrun w/ttle	using air
5				Same	
10					0-20 5/8 blade bit used.
				12' And.	
15				Co, blk, mid lust, silky, brittle. w/HD.CO,	And seam, is wx. brn-blk sooty
20				Same	20-30' using H_2O
25				Same	
30					30+ ↓ using air
35				Same as above, Dull co, sm amt is sooty.	
40				co is getting dull to semi dull	
45					
50				Same	

Figure 21A. Sample lithologic log

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DRILL HOLE LOG

PAGE 2 OF 6				PROJ. AT	DRILL HOLE NUMBER 81012 Pilot

EST. E/W COORD.	EST. N/S COORD.	EST. ELEV.	SEC	TWNSHP	RANGE	MIN. CO.	CONTR. r	FLD. REP DJD	DATE START 6 19 81	DATE COMP. 6 29 81

TOT. DEP 260	GEOPHYSICAL LOGS. GAM DEN RES CAL SP	DRILL RIG MAKE & MODEL failing 1500	DRILL BIT SIZE & TYPE 5/8 claw	WEATHER Sunny

COMMENTS

DEPTH	BOX	SAMP	LOSS	LITHOLOGIC DESCRIPTION	REMARKS

50'
SLT, brn gry, mod ind, damp,

Same

Same

65'
SS, Gry, fg, non ind, damp,
w/ SLT chips - wkly incl. no rxn w/HCl

Same as above no rxn w/HCl

Same vfg almost a SLT
85' gradational SS/SLT
SLT, Gry mod ind damp
w/ ss chips.

Same

≈95' injecting H₂O

Figure 21B. Sample lithologic log

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PAGE 3 OF 6			DRILL HOLE LOG						PROJ. JT	DRILL HOLE NUMBER 81012 Pilot	
EST. E/W COORD	EST. N/S COORD.	EST. ELEV.	SEC	TWNSHP	RANGE	MIN. CO.	CONTR. JC	FLD. REP D.JD	DATE START 6/26/81	DATE COMP. 6/24/81	

TOT. DEP 260'	GEOPHYSICAL LOGS.					DRILL RIG MAKE & MODEL	DRILL BIT SIZE & TYPE	WEATHER	
	GAM	DEN	RES	CAL	SP	failing 1500	5⅛ Claw	Sunny	

COMMENTS

DEPTH	BOX	SAMP	LOSS	LITHOLOGIC DESCRIPTION	REMARKS
				SS, gry, fn, mod-well ind, damp, qtz DK min. residual co chips from above	marginal SS / SLT. may be both interbed.
105					
				Same	
110					
				well ind	
115					
				Same; mod ind, more like SLT here. 121'	
120				SH, Gry, mod ind, crb, Silty	
125					
				Same as above w/CO flks	
130					
135					
				Same w/CO flks.	
140					
145					
				Same	
150					

Figure 21C. Sample lithologic log

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DRILL HOLE LOG

PAGE 4 OF 6					PROJ. AT.	DRILL HOLE NUMBER 51018 Pilot

EST. E/W COORD	EST. N/S COORD.	EST. ELEV.	SEC	TWNSHP	RANGE	MIN. CO.	CONTR.	FLD. REP	DATE START	DATE COMP.
							JC	DID	6/28/81	6/28/81

TOT. DEP 200'	GEOPHYSICAL LOGS. GAM DEN RES CAL SP	DRILL RIG MAKE & MODEL failing 1500	DRILL BIT SIZE & TYPE 5⅛ claw	WEATHER sunny

COMMENTS

DEPTH	BOX	SAMP	LOSS	LITHOLOGIC DESCRIPTION	REMARKS

Same
152'   Canyon Seam

CO, Blk, mid lust, silky brittle to
    hrd

155

160

Same

165

Same

170

175

Same   co chips are somewhat
duller - semi dull.

180

Same

185

Same   chips are real small.

191'

190

SLT, Gry brn, mcd ind, damp
w/ some clly material + residual
co chips

195

200   Same

Figure 21D. Sample lithologic log

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DRILL HOLE LOG

PAGE 5 OF 6						PROJ. H7	DRILL HOLE NUMBER 8162 Pilot

EST. E/W COORD.	EST. N/S COORD.	EST. ELEV.	SEC	TWNSHP	RANGE	MIN. CO.	CONTR. JC	FLD. REP. DID	DATE START 6/28/81	DATE COMP. 6/28/81

TOT. DEP 260'	GEOPHYSICAL LOGS. GAM DEN RES CAL SP	DRILL RIG MAKE & MODEL failing 1500	DRILL BIT SIZE & TYPE 5 1/8 clam	WEATHER sunny

COMMENTS

DEPTH	BOX	SAMP	LOSS	LITHOLOGIC DESCRIPTION	REMARKS
				some as above	could be a SLT part here
205				204' canyon co, Blk, mid lust, silky brittle	
210				209' SLT, Gry, mod ind, damp almost a vfg ss.	
215				216' gradational ss, lt Gry, mod ind, almost a SLT qtz, sm amt blk min	
220					
225				Some w/ residual co chips.	
230				Some	± 231' hrd stringer.
235				Some	
240				Some. Some chips look like they have little roots in them	
245				Some w/ SH chips	
250					

Figure 21E. Sample lithologic log

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DRILL HOLE LOG

PAGE 6 OF 6								PROJ. AT	DRILL HOLE NUMBER R1012-C Pilot

EST. E/W COORD	EST. N/S COORD.	EST. ELEV.	SEC	TWNSHP	RANGE	MIN. CO	CONTR. JC	FLD.REP DJD	DATE START 6/28/81	DATE COMP. 6/28/81

TOT. DEP 260	GEOPHYSICAL LOGS. GAM DEN RES CAL SP		DRILL RIG MAKE & MODEL Failing 1500	DRILL BIT SIZE & TYPE 5⅝ Claw	WEATHER cldy

COMMENTS

DEPTH	BOX	SAMP	LOSS	LITHOLOGIC DESCRIPTION	REMARKS
25				Some SLT w/ SH chips	
260				TD=260	

Figure 21F. Sample lithologic log

Figure 22. Sample suite of geophysical logs

Figure 23. Sample log plot

F-464

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▶ NERCO, INC.
111 S.W. Columbia
Suite 800
Portland, Oregon 97201

September 21, 1981

Sample identification
by

Kind of sample reported to us	Coal		Nerco, Inc.
Sample taken at	Antelope		Sample No. C-3
Sample taken by	Nerco, Inc.		Core Hole No. 81012-C
			Seam Anderson
			32.0 - 41.8'
Date sampled	xxxxx		
Date received	8-7-81		

Analysis report no. 72-111657

SHORT PROXIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	26.43	xxxxx
% Ash	3.40	4.62
Btu/lb	8828	11999
% Sulfur	0.15	0.21

Moisture, Ash-free Btu = 12580
Pounds of SO2 per 10^6 Btu = 0.35
Moist, Mineral matter free Btu * = 9165
(Based on as rec'd moisture)*
Pounds of Sulfur per 10^6 Btu = 0.18

Respectfully submitted
COMMERCIAL TESTING & ENGINEERING CO.

JAMES L. KENDRICK, Manager, Denver Laboratory

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Charter Member

OVER 40 BRANCH LABORATORIES STRATEGICALLY LOCATED IN PRINCIPAL COAL MINING AREAS,
. TIDEWATER AND GREAT LAKES PORTS, AND RIVER LOADING FACILITIES

Figure 24A. Sample coal quality analysis of good coal

F-464

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601   AREA CODE 312 726-8434

WESTERN DIVISION MANAGER
GAIL D. PALMER

NERCO, INC.
▶ 111 S.W. Columbia
  Suite 800
  Portland, Oregon 97201

PLEASE ADDRESS ALL CORRESPONDENCE TO:
10775 EAST 51st AVE., DENVER, CO 80239
OFFICE TEL. (303) 373-4772

September 17, 1981

Sample Identification
by

Kind of sample reported to us	Coal	Nerco, Inc.
Sample taken at	Antelope	Sample No. C-2
Sample taken by	Nerco, Inc.	Core Hole No. 81012-C Redrill Seam Anderson
Date sampled	xxxxx	17.6' - 24.0' *Core Loss 23.0' - 24.0'
Date received	8-7-81	

Analysis report no.   72-111655

SHORT PROXIMATE ANALYSIS

	As Received	Dry Basis
% Moisture	41.88	xxxxx
% Ash	7.46	12.83
Btu/lb	4953	8522
% Sulfur	0.13	0.22

Moisture, Ash-free Btu =	9776
Pounds of SO2 per 10^6 Btu =	0.52
Moist, Mineral matter free Btu * =	5384
(Based on as rec'd moisture)*	
Pounds of Sulfur per 10^6 Btu =	0.26

Respectfully submitted,
COMMERCIAL TESTING & ENGINEERING CO.

JAMES L. KENDRICK, Manager, Denver Laboratory

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. TIDEWATER AND GREAT LAKES PORTS, AND RIVER LOADING FACILITIES

Figure 243. Sample coal quality analysis of oxidized coal

COMPANY __NERCO, Inc.__   DATE __6-24-80   vlh__   PAGE NO. __3__

MINE __Antelope__   LAB NO. __16099__

80003-OB

SAMPLE NO.	16	17	18	19	20	21	22	23	24	25
HOLE NO.	OB1	OB2	OB3	OB4	OB5	OB6	OB7	OB8	OB9	OB10
DEPTH, FT.	0-10.0	10.0-12.1	12.1-20.8	20.8-27.1	27.1-29.8	29.8-33.3	33.3-39.9	39.9-44.6	44.6-49.8	49.8-52.4
pH[1]	7.5	4.7	4.5	6.3	7.6	7.7	7.9	7.5	7.9	7.8
COND., mmhos[2]	5.89	5.50	7.98	5.22	2.80	1.49	1.41	2.01	1.51	1.48
SATURATION,%[1]	64.6	105.4	33.8	93.2	78.4	47.8	58.0	88.5	49.4	44.4
PARTICLE SIZE										
% SAND	25	29	63	17	15	41	23	13	39	39
% SILT	37	21	21	29	39	35	39	29	31	35
% CLAY	38	50	16	54	46	24	38	58	30	26
TEXTURE*	ClyLm	Cly	SdyLm	Cly	Cly	Lm	ClyLm	Cly	ClyLm	Lm
CALCIUM, meq/l[3]	20.7	22.2	22.8	23.9	6.16	1.71	1.54	3.31	1.85	2.43
MAGNESIUM, meq/l[3]	22.9	27.4	40.7	19.0	3.67	1.09	1.04	1.54	1.19	1.73
SODIUM, meq/l[3]	29.7	22.8	26.4	25.6	18.7	10.3	9.89	13.4	10.0	8.95
SAR[4]	6.36	4.58	4.69	5.53	8.43	8.71	8.71	8.60	8.11	6.21
ESP**	8.34	6.35	4.10	7.58	11.3	9.88	11.3	9.17	10.2	9.64
LIME[5]	2.48	2.27	1.82	1.58	2.28	10.9	6.34	13.8	3.62	14.8
COPPER, ppm	2.1	7.9	4.7	5.7	.5.9	1.0	3.5	8.3	1.8	1.5
SELENIUM, ppm[6]	<0.02	<0.02	<0.02	0.12	0.52	0.12	0.20	0.24	0.14	0.10
BORON, ppm[6]	<0.1	0.2	0.1	0.1	<0.1	<0.1	<0.1	0.1	<0.1	<0.1
NITRATE-N, ppm[7]	9.0	14	<1.0	9.0	2.8	<1.0	<1.0	<1.0	<1.0	<1.0
MOLYBDENUM, ppm[8]	0.03	0.03	0.03	0.02	0.04	0.08	0.06	0.12	0.08	0.14
POT. ACIDITY (8)	0	0	0	0	3.40	1.13	0	2.26	1.13	4.53
NEUT. POT. (9)	24.8	22.7	18.2	15.8	22.8	109	63.4	138	36.2	148
ACID BASE POT. (10)	+24.8	+22.7	+18.2	+15.8	+21.1	+108	+63.4	+137	+35.6	+146

80003-OB

SAMPLE NO.	26	27	28	29	
HOLE NO.	OB11	OB12	OB13	OB14	
DEPTH, FT.	52.4-60.3	60.3-63.3	63.3-66.3	66.3-70.3	
pH[1]	7.8	7.8	7.9	7.6	
COND., mmhos[2]	1.79	1.90	1.89	1.42	
SATURATION, %[1]	73.5	58.7	37.5	69.5	
PARTICLE SIZE					
% SAND	19	17	45	22	
% SILT	29	43	31	27	
% CLAY	52	40	24	51	
TEXTURE*	Cly	StyCly	Lm	Cly	
CALCIUM, meq/l[3]	2.55	3.13	2.32	1.63	
MAGNESIUM, meq/l[3]	1.51	1.43	0.91	0.84	
SODIUM, meq/l[3]	11.9	13.2	12.8	9.53	
SAR[4]	8.35	8.74	10.1	8.56	
ESP**	11.3	9.91	10.4	11.1	
LIME[5]	0.45	2.04	5.65	3.41	
COPPER, ppm	9.0	4.4	2.3	14.9	
SELENIUM, ppm[6]	0.16	0.22	0.08	0.36	
BORON, ppm (6)	0.1	0.4	<0.1	0.3	
NITRATE-N, ppm (7)	<1.0	<1.0	<1.0	<1.0	
MOLYBDENUM, ppm[8]	0.07	0.06	0.14	0.13	
POT. ACIDITY (8)	6.79	4.53	2.26	3.40	
NEUT. POT. (9)	4.50	20.4	56.5	34.1	
ACID BASE POT. (10)	+1.10	+18.1	+55.4	+32.4	

70.3 - End of sampling

(See Notes page 1)

Figure 25. Sample overburden analysis