DR#0075-2

DOE/ET/10723-1545
(DE84003077)

**GEOLOGY OF THE HANNA FORMATION,
HANNA UNDERGROUND COAL GASIFICATION SITE,
HANNA, WYOMING**

By
R.L. Oliver
A.D. Youngberg

January 1984

Work Performed Under Cooperative Agreement No.: DE-AC07-76ET10723

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Laramie Project Office
Laramie, Wyoming

By
Associated Western Universities, Inc.
Salt Lake City, Utah

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Robert L. Oliver and Alv D. Youngberg

ABSTRACT

The Hanna Underground Coal Gasification (UCG) study area consists of the SW $\frac{1}{4}$ of Section 29 and the E $\frac{1}{2}$ SE $\frac{1}{4}$ of Section 30 in Township 22 North, Range 81 West, Wyoming. Regionally, this is located in the coal-bearing Hanna Syncline of the Hanna Basin in southeast Wyoming. The structure of the site is characterized by beds dipping gently to the northeast. An east-west fault graben complex interrupts this basic trend in the center of the area. The target coal bed of the UCG experiments was the Hanna No. 1 coal in the Hanna Formation. Sedimentary rocks comprising the Hanna Formation consist of a sequence of nonmarine shales, sandstones, coals and conglomerates. The overburden of the Hanna No. 1 coal bed at the Hanna UCG site was divided into four broad local stratigraphic units.

Analytical studies were made on overburden and coal samples taken from cores to determine their mineralogical composition. Textural and mineralogical characteristics of sandstones from local stratigraphic units A, B, and C were analyzed and compared. Petrographic analyses were done on the coal including oxides, forms of sulfur, pyrite types, maceral composition, and coal rank. Semi-quantitative spectrographic and analytic geochemical analyses were done on the overburden and coal and relative element concentrations were compared. Trends within each stratigraphic unit were also presented and related to depositional environments. The spectrographic analysis was also done by lithotype.

ACKNOWLEDGEMENTS

Theodore C. Bartke made this study possible by administering funding from the Department of Energy Underground Coal Gasification Project. Associated Western Universities, Inc., also provided support through research stipends. The authors also wish to thank the many people involved in reviewing, editing, drafting, and typing of the manuscripts, whose work and assistance were invaluable to the completion of this report.

INTRODUCTION

HANNA UCG STUDY AREA

The Hanna UCG study area consists of the SW $\frac{1}{4}$ of Section 29 and the east half of the SE $\frac{1}{4}$ of Section 30 in Township 22 North, Range 81 West, Carbon County, Wyoming. Regionally, this is located in the coal-bearing Hanna Syncline of the Hanna Basin in southeast Wyoming (Figure 1 and

Figure 2). The locations of the experimental burn sites are shown on Figure 2. The area is accessible by a service road joining U.S. Highway 30 approximately $\frac{1}{4}$ mile west of the U.S. Highway 30/Wyoming Highway 72 junction south of Hanna, Wyoming.

The area is a mildly dissected prairie land with low vegetative cover consisting of sagebrush and buffalo grass. The area experiences frequent strong winds and has a cool continental/temperate climate consisting of long cold winters and short warm summers. The average precipitation is low, generally being between 10 and 15 inches/year.

HANNA UCG PROJECT

A number of underground coal gasification (UCG) experiments were conducted at the Hanna, Wyoming, Department of Energy, site from 1973 to 1979. The individual experimental sites are referred to as Hanna I, Hanna II (Phases 1, 2, 3), Hanna III, and Hanna IV (a, b). All research was conducted under the direction of the Laramie Energy Technology Center with the intent of transferring the data and knowledge to the public domain for ultimate process commercialization by private industry. The UCG process has the potential to increase the utilization of coal reserves by obtaining energy from coals too deep and/or too thin to mine economically by conventional mining methods.

PURPOSE AND SCOPE

The purpose of this paper is to gather together all of the published and unpublished data and information on the geology of the Hanna UCG study area into one document. The paper will deal briefly with the regional geology of the Hanna Basin followed by a detailed analysis of the Hanna UCG site geology. This will include discussions on structure, joints and fractures, stratigraphy, geometry of deposits, mineralogy and petrology, and geochemistry of the overburden rocks and the Hanna No. 1 coal bed. The sections on structure and stratigraphy are dominantly a compilation of previously published data with some additional work. The mineralogy and petrology section contains both previously published work and new material. The geochemistry section is all original work.

PREVIOUS WORK

Early work on the Hanna/Carbon Basin area was done by Bowen in 1918 and Dobbin, Bowen, and Hoots in 1929. Later studies of the area were done by Knight (1961), Blackstone (1975), Brooks (1977), and Ryan (1977). These papers deal with the stratigraphy and depositional history of the Hanna/Carbon Basin area. Work was done on the depositional systems by Surdam and Stanley (1978) and Walker (1979). Glass and Roberts (1980) reported on the coals of the Hanna coal field.

Figure 1. Generalized location map of the Hanna Basin and surrounding mountains and uplifts (modified from Ryan, 1977, after Craig, et al., 1982).

Figure 2. Location map of Hanna UCG site.

The most significant site-specific studies relating to this paper are the various post-burn studies done on the Hanna UCG experimental burns. The Hanna II, Phase 1 experiment was evaluated by Youngberg, McClurg and Schmitt (1983). This paper evaluates the depositional environments, subsurface stratigraphy and postburn characteristics of the Hanna Formation. Youngberg and Sinks (1981) presented preliminary results for the postburn studies at Hanna II, Phases 2 and 3. Information about the pyrometamorphic rocks and minerals from the experiment was obtained from Burns et al. (1981, 1982). A petrographic study of unaltered and thermally metamorphosed coal from the site was presented by Youngberg (1981). Modeling of the Hanna II, Phase 2 experiment based upon postburn drilling was published by Levie et al. (1981). Details of the high resolution seismic survey at the Hanna II, Phases 2 and 3 site was presented by Youngberg et al. (1982). A detailed geologic study that included information from the Hanna II, Phases 2 and 3 experiments was given by Craig et al. (1982) and Craig (1982). A comparison of the Hoe Creek UCG site with the Hanna UCG site using data from the Hanna II, Phases 2 and 3 post-burn studies was published by Ethridge et al. (1983). The Hanna III experiment was evaluated in a report by Youngberg, McClurg and Schmitt (1983). This current report contains a summary of all the above referenced work, and also contains additional information that had not been previously published.

REGIONAL GEOLOGY

STRUCTURE

The Hanna Basin and adjacent Carbon Basin are bounded by Laramide-aged uplifts (Figure 1). To the north, a highland region comprised of the Freezeout, Shirley, and Granite Mountains parallels the axis of the Hanna-Carbon Basin complex. High granite peaks in the southeastern portion of the Granite Mountains are referred to as the Ferris and Seminoe Mountains. The Hanna Basin is separated from the ranges to the north by a high-angle reverse fault of large displacement. Movement along this fault likely began in the Upper Cretaceous prior to deposition of the Medicine Bow Formation and continued well into Eocene time (Knight, 1961). The western margin of the Hanna Basin is defined by the Rawlins Uplift and the southern margin by the northern end of the north-south trending Medicine Bow Mountains. The Hanna Basin is bounded on its eastern margin by the Saddleback Hills, a Laramide-aged anticline which appears to be a northerly extension of the Medicine Bow Mountains.

Numerous normal faults occur across the coal-bearing synclines of the area. These faults trend northwest-southeast with cross-faulting common. Faults often occur quite closely together and vertical displacements vary from a few feet to several hundred feet. Zones of closely spaced fractures are sometimes associated with these faults.

Much of the strata in the Hanna Basin are tightly folded. Several synclines exist in the basin with the outcrop of the Hanna No. 1 Coal Seam encircling the Hanna Syncline, a structure which plunges to the

northeast. A structure contour map of the Hanna No. 1 Coal Bed is shown in Figure 3. Dip of the rocks vary from almost vertical along the northern edge of the basin to nearly horizontal in the centers of the synclines (Glass, 1980).

The location of the Hanna UCG site is in the southeastern portion of the Hanna Basin (Figure 2). In this region, strata strike to the northwest and dip to the northeast at an average of 3° (Youngberg et al., 1981). Several normal faults are present at the Hanna site which create local structural dips of up to 8° . Fault displacements are generally less than 40 ft., but may be as great as 50 ft.

STRATIGRAPHY

A general geologic map of the Hanna Basin area is shown in Figure 4. Three Upper Cretaceous-Tertiary formations deposited during structural evolution of the Hanna Basin are recognized in this region. These include the Upper Cretaceous Medicine Bow, Paleocene (Tertiary) Ferris, and Paleocene-Eocene (Tertiary) Hanna Formations (Ryan, 1977; Figure 5). Aggregate thickness of these deposits is approximately 21,000 ft. Each of these units was deposited in the intermontane subsiding Hanna Basin in continental environments including alluvial fan, fluvial, and swamp settings. Coal beds are common in all three lithologic units, and many have been extensively exploited by both underground and strip mining (Glass, 1972; Glass and Roberts, 1980). The entire stratigraphic sequence in the Hanna Basin represents the thickest accumulation of sediments in any Wyoming basin.

Sedimentary rocks comprising the Hanna Formation consist of a sequence of nonmarine shales, sandstones, coals and conglomerates deposited after withdrawal of the Cretaceous epicontinental seas from this area (Craig et al., 1982). Coal appears throughout most of the Hanna Formation with thirty-two coal seams greater than five feet in thickness. While certain coals may be 20 to 38 feet thick, most coals are in the 5 to 11 feet thick range (Glass and Roberts, 1979). Glass and Roberts (1980) described the coal beds of the Hanna Mining District. Twenty-three out of twenty-five persistent coals in that district at least locally equal or exceed 5 feet in thickness (Figure 6). Of these 23 coal beds, 8 exceed 20 feet in thickness (Bed No. REM 93, Hanna No. 1, Bed No. 80, Bed No. 79, Bed No. 78, Hanna No. 2, Bed No. 76, and Hanna No. 5). The other coal beds are generally less than 12 feet thick. In places the thickest coals, Bed No. REM 93, Hanna No. 2, and Hanna No. 5, all exceed 30 feet in thickness.

The Hanna gasification project utilized a coal bed in the Hanna Formation, the Hanna No. 1 coal bed. This coal seam has a 4 to 32 foot thickness range (Figure 7) with overburden ranging from zero to over 450 feet (Figure 8).

Figure 3. Structure contour map of the Hanna No. 1 coal bed (modified from Glass and Roberts, 1980).

Figure 4. Geologic map of the Hanna Coal Field (modified from Glass and Roberts, 1980).

Figure 5. Upper Cretaceous and Lower Tertiary stratigraphy of the Hanna Basin (modified from Dobbin, 1929).

Figure 6. Coal nomenclature in the Hanna Mining District of the Hanna Coal Field (after Glass and Roberts, 1980).

Figure 7. Isopach map of the Hanna No. 1 coal bed (modified from Glass and Roberts, 1980).

Figure 8. Overburden isopach map of the Hanna No. 1 coal bed (modified from Glass and Roberts, 1980).

HANNA UCG SITE GEOLOGY

STRUCTURE

Folds and Faults

The study area is located southwest of the structural axis of the Hanna Basin. Rock units in the study area strike to the northwest and dip to the northeast with an average dip of 3° as determined from a structure contour map on top of the Hanna No. 1 coal bed (Youngberg et al., 1981; Figure 9). A number of normal faults at the test site disrupt the local structural configuration and dip as illustrated by the structure contour map in Figure 9 and in the northeast-southwest structural cross-section shown in Figure 10. The fault system that trends west to east through the study area was found to be a graben complex with numerous antithetic faults (Youngberg et al., 1981). This fault system has created local anticlinal structures (north-central portion of the study area, Figure 9) and structural dips of up to 8° (southwestern portion of the study area, Figure 9). Displacements across these faults are generally less than 40 ft but may be as high as 50 ft. A more recent interpretation of the site structure from seismic data acquired in 1983 was done by Berkman and Orange and is shown in Appendix C.

Joints and Fractures

Based on joint orientations taken at 32 different sites by Glass and Roberts (1980), four joint sets are recognized in the coals of the Hanna Basin:

Set A	290-295 $^{\circ}$	(N.70-65 $^{\circ}$ W.)
Set B	320-330 $^{\circ}$	(N.40-30 $^{\circ}$ W.)
Set C	23-25 $^{\circ}$	(N.23-25 $^{\circ}$ E.)
Set D	60-70 $^{\circ}$	(N.60-70 $^{\circ}$ E.)

Figure 11 shows these joint measurements plotted on a rose diagram. The Hanna Formation coal readings were taken in the Hanna Mining District or in the eastern portion of the basin. Joint Set A (290 $^{\circ}$) is almost unrecognizable in the Hanna coals. This joint set and Joint Set C comprise one orthogonal joint system in this area, as they are very nearly perpendicular to one another (Glass and Roberts, 1980). Joint Set B (320 $^{\circ}$), on the other hand, is obvious in the Hanna Formation coals. This joint set exhibits the same orientation as the predominant faulting in the basin. The existence of a second orthogonal joint system comprised by Set B and Set D is less convincing. Joint Set C (23 $^{\circ}$) is the most often observed joint set of the four, and as mentioned earlier, this joint set and Joint Set A comprise an obvious orthogonal joint system. Joint Set D (70 $^{\circ}$) is less commonly noted but nonetheless obvious in coals of the area.

Figure 9. Structural contour map on top of the Hanna No. 1 coal bed (after Youngberg et al., 1981). Note: structural contours in feet above sea level. SW-NE line is surface trace of cross section shown in Figure 10.

Figure 10. Generalized northeast-southwest structural cross section of the Hanna UCG area (after Craig et al., 1982). (Location of section shown on Figure 9.)

Figure 11. Joint sets in the coals of the Hanna Formation (after Glass and Roberts, 1980).

Some joint sets, most notably Joint Set C and to a lesser extent Joint Sets A and B, might best be termed systematic joints (Nickelsen and Hough, 1967). These systematic joints are vertically persistent; they do not terminate at petrographically different zones in the coal or at bedding planes within the coal. Instead, they persist for many inches to as much as several feet downward through the coal. They also do not terminate laterally against joints of other orientations but they cut through the other joint sets, exhibiting lateral extents on the order of many inches to several feet. In contrast, the less well developed joint sets terminate against the more persistent and pronounced systematic joints and seldom cross differing coal lithotypes or bedding planes in the coal. These joints are likened to the nonsystematic joints of Nickelsen and Hough (1967).

According to Glass and Roberts (1980), lithologies also affect the orientation of joints. Although not enough measurements were taken for a true comparison, the strikes exhibited by most joint sets vary as they pass through different lithologies. This phenomenon is much more pronounced when the joint orientations found in coals are compared with the orientations of the same joint sets in overlying sandstones and shales. Glass (1972) observed as much as a 2.5° shift in orientation as a joint passed from one lithology to another.

Joint spacing also varies considerably with lithology. Glass and Roberts (1980) state that, generally speaking, joints in sandstones are measured in terms of feet or yards apart; joints in shales are best thought of in feet or inches; and spacing in coals is more on the order of inches or centimeters.

Fractures in coal are important to consider when discussing UCG experiment areas since these determine, to some extent, the gas bearing capacity gas permeability, and fluid flow in coals. Ammosov (1963) discusses three basic genetic types of fractures in coal layers: 1) Endogenetic, 2) Exogenetic, and 3) Hypergenetic. Table 1 lists these types with accompanying descriptions of geologic factors and nature of forces involved.

Table 1 - Classification of fractures in coal.

TYPE	SUBTYPE	GEOLOGIC FACTORS	NATURE OF FORCES	PROCESSES
Endogenetic		Metamorphism	Tension	Inner contraction of the coal mass
Exogenetic	Cleavage Rupture	Tectonics	Compression Tension	Deformation of the coal mass caused by external factors
Hypergenetic		Weathering	Tension	External forces

The maximum permeability of layered coal coincides with the direction of the main endogenetic fracture system and of the wrench fractures of exogenetic origin (Ammosov, 1963). The presence of exogenetic shear fractures formed by compression will lower permeability.

Hanna No. 1 Coal Bed Core Study

A detailed study on the directional properties of Hanna Coal was conducted by Pasini et al (1972). In order to collect data necessary to support field operations to gasify coal in place, an oriented core was obtained by LETC and sent to Morgantown Energy Research Center for study. The primary purpose in conducting directional property studies is to determine the dominant direction in which gases generated and/or released by heat during the combustion process would move, and to subsequently drill wells in the most advantageous places to capture these liberated gases. Since the directional flow properties of the coal are a result of the interaction of a number of physical properties, several types of measurements were conducted by Morgantown on the oriented coal core. These measurements included orientation of joint strikes, directional permeability measurements of both whole core and smaller pieces, directional tensile strength, point-load induced failure, and directional sonic velocity tests.

1. Joint Measurements

Six readily identifiable joint sets are found in the coal at the Hanna site. Three of these directions are quite dominant over the others. One is prominent among the three dominant joint sets. The joint sets in order of the apparent prominence are set 1, N 60-68° E; set 2, N 20-30° E; and set 3, N 76-85° W. The diagram in Figure 12 illustrates azimuth versus frequency of joints mapped in the oriented core. (Note the pattern is similar but not identical to that shown in Figure 11.) Data from sections of the core in which the orientation was questionable was omitted in compiling this diagram. The photograph in Figure 13 illustrates the natural joint system observed in the oriented core. The relationship between the dominant direction of faulting interpreted from seismic data (N 68° W and N 88° W) and the dominant direction of jointing observed in the Hanna No. 1 coal oriented core samples (N 65° E followed by N 20° E, and N 80° W) is shown in Figure 14. This figure shows that the joint set trending N 20° E is nearly perpendicular to the fault directions found in the northeast part of the study area (N 68° W) and the joint set trending N 80° W is nearly parallel to the fault directions found in the central part of the study area (N 88° W). This tends to support an exogenetic origin for jointing at the Hanna UCG site. The joint set which trends N 65° E is nearly perpendicular to the regional trend of faulting visible on the surface of the Hanna Basin.

Figure 12. Azimuth versus frequency plot for all joints measured in oriented core from Hanna No. 1 coal seam (after Pasini et al, 1972). Scale: 1"= 8 percent.

Figure 13. Photograph of oriented core from CH-2, Hanna UCG site.

Figure 14. Diagram relating the dominant joint directions (N 65° E, N 20° E, and N 80° W) to the dominant directions of faulting (N 68° W and N 88° W).

2. Other Measurements

Directional permeability measurements show three maximum trends which in order of importance are: N 25-30° E, N 40-45° E, and N 25-30° W. The resultant vector of directional permeability is interpreted to be approximately N 30° E. Directional tensile strength measurements on sandstones above the coal indicate three directions of weakness in which failure might occur, or in which jointing and fracturing is now dominant. These are N 30° W, N 55° W, and N 30° E. The dominant of these two N-W trends is believed to be N 30° W. This is the predicted direction of induced hydraulic fracture orientation if the horizontal stress component differences are large enough (more than 250 psi) to exert positive control. Should the horizontal stresses be nearly equal, then the direction of hydraulically induced failure could be controlled either by jointing (as in point-load failure tests) or directional permeability. In either case it would either be N 30° E or N 60° E. Ultrasonic travel time measurements in the coal indicate open fractures dominantly in two directions. One of these directions (N 60° E) is partially filled with calcite material and apparently reduces the flow capacity in that direction. Minor calcite filling was noted in N 30° W joints (Pasini et al, 1972).

The accuracy of measurements conducted on the oriented core could have a range of $\pm 5^\circ$ since those are the values of accuracy established for the core orientation technique. The good correspondence between core jointing and surface jointing and faulting would confirm these values. There is generally good agreement ($\pm 5^\circ$) between the trends indicated by the various measurement techniques. All seem to point to the effects of jointing in the coal and roof rock as important factors to be considered in project planning. These tests could be misleading in that stresses acting on the coal in place may tend to enhance flow in another direction. At least the trends which may have considerable effects on the results of field in-place gasification have been identified and can be utilized in planning well locations (Pasini et al, 1972).

STRATIGRAPHY

Hanna Formation - General

The Hanna Formation was named by Bowen (1918) from exposures north and west of Hanna, Wyoming. The formation contains interbedded sandstones, shales, conglomerates and coals, and ranges in thickness from 6800 ft in the Hanna Basin to less than 500 ft in the Laramie Basin (Blackstone, 1975). The greater thickness of Hanna strata in the Hanna Basin likely reflects more continuous deposition during late Cretaceous through early Eocene time. Conglomerates are typically comprised of detritus derived from erosion of local highlands, including granite, quartzite, chert, and Mesozoic rock fragments. Massive Hanna conglomerates frequently grade into thick cross-bedded coarse-grained feldspathic sandstones which often form ledges. Thinner, finer-grained, less-resistant sandstones are also present. Hanna sandstones are usually broadly lenticular

(Ryan, 1977). Shale units contain abundant plant remains, freshwater gastropods, bivalves, ostracods, and vertebrate bone fragments (Dobbin et al., 1929). Detailed descriptions of measured surface sections are provided by Dobbin et al. (1929).

Deposition of Hanna strata in terrestrial environments has been suggested by several workers. Ryan (1977) interprets the Hanna sandstones as fluvial in origin. In a study of the Hanna Formation in the Carbon Basin, Brooks (1977) recognizes both braided and meandering channel depositional settings for conglomerates and sandstones and a meandering stream floodplain setting for shales and coals. In a more detailed study, Craig et al. (1982) analyzed cores from the Hanna UCG site, recognizing braided and meandering river channel, meandering river floodplain, and lacustrine depositional settings.

Paleocurrent analysis of Hanna fluvial sandstones reveal that the Granite Mountains to the north provided most detritus during Hanna deposition, with the Freezeout Mountains serving as a less important source (Ryan, 1977). The Medicine Bow Mountains to the south provided little clastic material.

Local Stratigraphic Units

The Hanna UCG site stratigraphic units and their depositional environments are discussed in the following paragraphs. The target of the Hanna UCG site is the Hanna No. 1 coal seam. The Hanna Formation overburden in this area may be grouped into four broad lithologic units on the basis of sedimentary structures, grain size, texture and faunal content. These lithologic variants have been informally named Units A, B, C and D with A being the oldest (Craig et al., 1982) (Figure 15).

Hanna No. 1 Coal Seam

The Hanna No. 1 coal seam consists of deposits of a poorly drained swamp in the flood plain of a fluvial system. The high ash content of the Hanna No. 1 coal seam suggests a large amount of clastic material that probably came from fluvial sources.

Unit A

Unit A is found directly above the Hanna No. 1 coal seam and consists of siltstones and fine-grained sandstones with lesser amounts of claystones. The unit contains numerous coarsening-up sequences. The typical sequence starts with claystone at the base and coarsens upward to siltstone and then fine-grained sandstone overlain by claystone of the next sequence. Primary sedimentary structures found in the sandstones and siltstones are ripple drift cross-stratification (often burrowed) and high-angle foreset beds (often contorted by slumping) (Figure 16). The claystones are finely laminated and often contain bands of siderite. Bioturbation is common throughout the claystones and some gastropod shells have been found (Craig et al., 1982).

Figure 15. Subdivision of the overburden of the Hanna No. 1 coal bed at the Hanna UCG site (after Craig et al., 1982). *- Not present at Hanna UCG III +- Not present at Hanna UCG II or Hanna UCG IV.

Figure 16. Core photographs from Unit A: a) high angle foreset beds; b) contorted and slumped beds.

The olive-gray, finely-laminated claystones interbedded throughout the unit were probably deposited in a lacustrine environment. This is suggested by the dark highly organic and laminated nature of the claystones and the shells of freshwater mollusks that have been found in some cores.

The climbing ripple-stratified sandstones and siltstones were deposited in a lacustrine delta. As the delta prograded into the lake, sandstones were deposited in high-angle foreset beds. Evidently the delta fill was not continuous because of the interfingering of deltaic sandstones and lacustrine claystones. During periods of rapid deposition from heavy runoff or floods, the ripple drift or climbing ripple stratification was formed. During normal flow the lacustrine processes and deposition of laminated clays occurred. The interbedding could also have been formed by delta lobe switching (Craig et al., 1982).

Unit B

This unit consists primarily of olive-gray to olive-black mudstones and carbonaceous shales. Finely-laminated claystones similar to those in Unit A are occasionally found. Most of the primary bedding has been destroyed by rooting and there is an abundance of organic partings and occasional coal lenses. Interspersed throughout the finer-grained rocks are isolated fine-grained to very fine-grained sandstone bodies.

These lenticular sandstone bodies show a fining-upward trend in grain size from fine-grained to very fine-grained sandstone near the top. There is also a vertical decrease in the size of bedform sedimentary structures from trough cross-bedding to ripple cross-stratification and the upper contacts are gradational with overlying shales. The basal contacts are erosional and usually overlain by a clay clast conglomerate.

The very fine-grained sandstone bodies are tabular in cross section and are rarely over 5 ft. thick. They display a vertical increase in grain size from muddy siltstone to very fine-grained sandstone. Sedimentary structures are mostly ripple drift cross-stratification with occasional occurrences of trough cross-stratification (Figure 17). The lower contacts are gradational with underlying mudstones and shales. The upper contacts are sharp with the overlying shales and show evidence of rooting.

This unit was probably deposited by a meandering river and flood plain system following lake infilling and abandonment of the lacustrine delta of Unit A. Quiet water environments would have formed the carbonaceous shales, mudstones, and claystones.

The dark olive-gray organic mudstones and carbonaceous shales were deposited in poorly drained swamps similar to the formation of the Hanna No. 1 coal seam. Overbank flooding was probably common because of the abundance of clastic materials that occur within the deposits. The lighter-colored gray mudstones that occur in Unit B were probably deposited in well drained swamps that occur along the margins of channel sandstones because most of the organic material would have oxidized when drained by the fluvial system.

Figure 17. Core photographs from Unit B: a) interbedded and burrowed mudstones and fine-grained sandstones; b) ripple cross-stratified fine-grained sandstone.

The claystones identical to those found in Unit A are interpreted as deposits in small lakes associated with the meandering river system.

The lenticular sandstone bodies were probably deposited as point bars in the meandering river system. The point bar deposits are characterized by a vertical sequence of features produced by lateral migration of the bar. First, a basal erosional contact overlain by clay clast lag and fine-grained trough cross-bedded sandstones represents deposition in a lower point bar. Second, the lower point bar grades into very fine-grained planar and ripple cross-stratified sandstones representing the upper point bar deposits. Third, the point bars are overlain by rooted siltstones and mudstones of the levee or abandoned channel fill.

The thin, tabular, very fine-grained sandstones (less than 5 ft) were deposited by crevasse splays that were formed during times of flooding when levees were breached, allowing sediment laden water to invade the floodplain. The combination of rapid sedimentation and slow water currents resulted in the deposition of climbing ripples (Craig et al., 1982).

Unit C

This unit truncates Unit B and consists of coarse-grained to fine-grained sandstones with conglomeratic beds. Some minor amounts of shale are found within the unit. There are numerous thin (6 to 12 in) fining-upward sandstone sequences bounded by erosional contacts. The predominant sedimentary structures are high-angle (up to 25 degrees) planar cross-stratification and rough cross-stratification (Figure 18). The conglomerate beds are composed of quartzite pebbles, clay clasts, and carbonized material in a sandstone matrix.

The medium to coarse-grained sandstones and conglomerates of Unit C were deposited in a braided river system. Four distinguishing features found in the cores indicate a braided river environment: (1) few stratification types, (2) rare ripple cross-lamination, (3) high sand and gravel content, and (4) multilateral sand body geometry indicated by numerous thin fining-upward cycles. There is evidence from core studies to indicate the presence of transverse bars (thick, fine to medium grained sandstone sequences with high-angle planar stratification), longitudinal bars (clast supported conglomerates with crude horizontal bedding), and interbar channels (fining-upward trough cross-bedded sandstones containing erosional basal contacts with clay clast lags) (Craig et al., 1982).

Unit D

The upper unit (D) contains characteristics similar to both unit A and unit B described above. Portions of this unit are characterized by mudstones and lenticular, cross-stratified sandstones. Other parts of the unit consist of fine-grained sandstones to siltstones with high-angle foresets, contorted beds, ripple cross-stratification, and bioturbation (Figure 19). Finally, thin coal beds are also present. This unit exhibits a sharp lower contact where observed in two continuous cores (Craig et al., 1982).

a **b**

Figure 18. Core photographs from Unit C: a) erosional contact between beds; b) planar cross-stratification.

Figure 19. Core photographs from Unit D: a) interbedded silt and sand with contorted bedding; b) medium-grained cross-stratified sandstone.

Sandstones and mudstones of unit D were deposited in meandering rivers, crevasse splays, and floodplains (Figure 20) similar to those that existed during the deposition of unit B and in lakes and lacustrine deltas similar to those that existed during accumulation of unit A.

Coal beds such as the Hanna No. 1 coal and also the thinner coals found in unit D represent accumulation of organic matter that were deposited in poorly drained swamps that covered an area much larger than the present-day extent of the study site (Craig et al., 1982).

Conclusions

Interpretations of the environments of deposition for each of the units described above are given and illustrated in Figure 20. Hanna Formation strata at the Hanna UCG sites were deposited in braided stream, meandering stream channel, fluvial floodplain, crevasse splay, and lacustrine delta depositional settings.

Stratigraphic relations of the several local stratigraphic units are depicted by four cross sections after Craig et al. (1982) (Figures 21 through 24). The location of each cross section is shown by a solid line in an insert map above the section. The location of all other cross sections is shown by dashed lines. All of the cross sections are stratigraphic sections using the top of the Hanna No. 1 coal as a horizontal datum. With this type of section, present-day structural relations and features are eliminated and stratigraphic relations are enhanced.

Significant vertical and lateral relations among the various rock units are illustrated in the cross-sections. These relations include:

- 1) The lateral interfingering of lacustrine delta deposits and lacustrine deposits in unit A (Figure 22).
- 2) The lenticular nature of channel deposits (CH) in unit B (Figures 22 and 23).
- 3) The relatively thin, tabular nature of crevasse splay deposits (CR) in unit B (Figures 21 and 23).
- 4) The lenticular nature of lake deposit (L) in unit B (Figures 22 and 23). These thin discontinuous lacustrine sequences may represent deposits of abandoned channels (oxbow lakes).
- 5) The erosional nature of the base of the braided stream deposits (unit C) which truncate several different underlying rock types (Figure 21).
- 6) The tabular uniform nature of the Hanna No. 1 coal bed below unit A (Figures 21 and 23).
- 7) The thin, lenticular nature of coal beds in unit B (Figure 21).

UNIT B

UNIT A

Figure 20. Schematic reconstruction of inferred depositional settings of the overburden units, Hanna UCG site (after Youngberg et al., 1983 and Craig et al, 1982).

UNIT D

UNIT C

Figure 20 (Continued).

Figure 21. Northeast to southwest stratigraphic cross section A-A' (after Craig et al., 1982).

Figure 22. Northwest to southeast stratigraphic cross section B-B' (after Craig et al., 1982).

Figure 23. Northwest to southeast stratigraphic cross section C-C' (after Craig et al., 1982).

Figure 24. Northwest to southeast stratigraphic cross section D-D' (after Craig et al., 1982).

Stratigraphic Unit Geometry

The Hanna No. 1 coal bed is relatively uniform in thickness throughout the study area as shown by the structural cross section (Figure 10). In eight continuous cores that penetrated the entire bed, the thickness ranged from 31 ft to 27 ft. Over 40 geophysical logs indicate a range of 23 ft to 32 ft. An isopach map of the Hanna No. 1 coal bed is shown in Figure 7 and Plate I.

The thickness of unit A directly above the Hanna No. 1 coal bed ranges from 115 ft to 35 ft. The unit forms a fan-shaped deposit which originates west of the west-central portion of the study area and fans out in an easterly to northeasterly direction (Plate II). The maximum dimensions of this unit are 2800 ft in a southwest to northeast direction and 2500 ft in a north to south direction. This is an excellent graphic representation of the lacustrine delta depositional environment of unit A.

The thickness of unit B ranges from 137 ft in the west-central portion of the study area to zero where it is truncated by erosion southwest of the study area (Plate III). The unit consists of a northwest to southeast oriented belt which thins to the northeast and southwest away from an axis of maximum thickness. The isopach map reveals a minor, secondary thickening orientation at right angles to the major trend in the southwest and central portions of the study area. This is a feasible geometry for the proposed meandering river channel-floodplain depositional environment of Unit B with the channel represented by the trends of the thicks and the floodplain represented by the thins on the flanks.

The thickness of unit C ranges from 214 ft near the northeast portion of the study area to zero where it is truncated by erosion southwest of the Hanna II burn cavity (Plate IV). This unit consists of a wedge shaped deposit that strikes northwest to southeast and thins to the southwest. This geometry is appropriate for the proposed braided stream depositional environment.

All of unit D is not present at the UCG site area, thus the development of an accurate isopach map is impossible. However, the unit attains a thickness of 154 ft in corehole CH-132 and is eroded completely away in the southwest corner of section 29 (Plate V). The geometry shown by the isopach in Plate V is strictly representative of the erosional pattern.

An isopach of the total overburden at the Hanna UCG site is shown in Plate IV. The overburden gets progressively thicker to the northeast which is the direction of bed dip in the area.

MINERALOGY AND PETROLOGY

Overburden

Composition

Unit A of the overburden lies directly above the Hanna No. 1 coal bed and is, therefore, the main overburden unit controlling spalling and cavity development. Its thickness and lateral continuity are sufficient to retain all spalling within itself. These characteristics listed above support a study of the unit's mineralogy. The five basic rock types found in overburden Unit A at the Hanna UCG study site are: 1) calcareous sandstone, 2) calcareous siltstone, 3) calcareous shale, 4) ironstone, and 5) carbonaceous shale (Colorado School of Mines, 1979). These rock types and their relative abundance in Unit A are shown in Figure 25. As shown in the diagram, the calcareous sandstone lithologic type is by far the most common, making up 72.2 percent of the total overburden based on 106.9 feet of core. The other four rock types make up only minor portions of the overburden.

The bulk mineralogy of overburden Unit A at the Hanna UCG site is shown in Figure 26 (Colorado School of Mines, 1979). As expected, due to the dominance of the calcareous sandstone lithofacies, the mineral quartz is by far the most common mineral in the unit. Quartz comprises 53.1 percent making it more common than the other nine mineral constituents combined. The calcareous nature of the overburden rock is shown by adding the amounts of calcite, dolomite, and siderite present. This combination shows that 18 percent of the overburden is made up of calcareous minerals.

The bulk mineralogies of the five basic rock types are shown in Figures 27 through 31. With the exception of the ironstone lithofacies, quartz retains its dominance of mineral types. In the ironstone lithofacies (Figure 30), siderite makes up over 80 percent of the rock. The calcareous or carbonate nature of four of the five lithofacies is shown by adding calcite, dolomite and siderite for each rock type, giving results as follows: 1) calcareous sandstone - 15.7 percent; 2) calcareous siltstone - 15.4 percent; 3) calcareous shale - 14.4 percent; and 4) ironstone - 81.3 percent.

Kaolinite, smectite, and illite are the clay mineral groups that were identified in overburden core samples. Kaolinite is the most abundant clay, followed by smectite and illite. Kaolinite forms from weathering under conditions of well drained acidic soils in temperate climates. Illite forms where potassium ions are abundant (Krauskopf, 1979). It appears that a large percentage of the clay minerals present at the Hanna UCG area were transported into the site of deposition. Some crystallization of new clay minerals was detected (Craig, 1982).

Sandstones from the three overburden units A, B and C have distinct compositional characteristics as summarized in Table 2. Lacustrine delta sandstones from Unit A are composed predominantly of quartz (80.8 percent) and lithic (3.7 percent) fragments. The point bar sandstones

Figure 25. Overburden rock types in Unit A at the Hanna UCG study site.

Figure 26. Overburden bulk mineralogy in Unit A at the Hanna UCG study site.

Figure 27. Bulk mineralogy of the calcareous sandstone rock type from Unit A, Hanna UCG site.

Figure 28. Bulk mineralogy of the calcareous siltstone rock type from Unit A, Hanna UCG site.

Figure 29. Bulk mineralogy of the calcareous shale rock type from Unit A, Hanna UCG site.

Figure 30. Bulk mineralogy of the ironstone rock type from Unit A, Hanna UCG site.

Figure 31. Bulk mineralogy of the carbonaceous shale rock type from Unit A, Hanna UCG site.

Table 2. Average composition of fifty-nine sandstone samples from the Hanna Formation, Hanna, Wyoming (after Craig, 1982).

	% DETRITAL FRACTION													
	Qp	Qm	Qt	K	P	Fr _x	F _t	L _v	L _m	L _s	L _t	A	M	Ma
LACUSTRINE DELTA (A)	0.2	63.6	80.8	2.0	0.4	0.1	2.4	0.3	0.2	3.1	3.7	7.8	4.5	5.0
POINT BARS (B)	23.2	48.3	71.4	7.4	1.2	3.0	11.6	1.4	0.5	10.1	12.0	1.8	3.5	2.3
BRAIDED RIVER (C)	23.1	39.0	62.1	8.9	0.0	3.7	12.6	5.2	2.9	11.9	19.0	1.5	2.9	0.0

28 samples from lacustrine delta, ten from point bars, and 21 from braided rivers.

(Qp = polycrystalline quartz, Qm = monocrystalline quartz, Qt = total quartz, K = potash feldspar, P = plagioclase feldspar, Fr_x = feldspar bearing plutonic fragments, F_t = total feldspar plus feldspar bearing plutonic fragments, L_v = volcanic fragments, L_m = metamorphic fragments, L_s = sedimentary fragments, L_t = total lithic fragments, A = accessories, M = mica, Ma = matrix)

from Unit B contain lesser amounts of quartz (71.4 percent) than the lacustrine delta sandstones, and larger amounts of feldspar (9.6 percent) and lithic fragments (12.0 percent). The braided river sandstones from C contain significantly larger amounts of feldspar (12.6 percent) and lithic fragments (19.0 percent), but contain the least quartz (62.1 percent). This is a direct indicator of depositional energy and/or proximity to the sediment source. As energy is reduced and/or distance from the source is increased, heavy minerals (feldspars and lithic fragments) drop out of the sediment load increasing the quartz to heavy mineral ratio. Therefore, the sands of Unit C (braided stream) represent a higher depositional energy than Unit B (point bar) which represents a higher depositional energy than Unit A (lacustrine delta). This supports the models of deposition postulated for these units and is further supported in the textural analysis which follows.

Texture

The lacustrine delta deposits of Unit A are very fine grained and well sorted. The average mean quartz grain size is 0.10 mm (very fine sand). The point bar deposits of Unit B have intermediate sand sizes and sorting values. The average mean quartz grain size is 0.28 mm (medium sand). The braided river deposits of Unit C have the coarsest quartz grain size at the Hanna site and are poorly sorted. The average mean quartz grain size is 0.48 mm (medium sand). Textural data for the Hanna site is summarized in Table 3. Roundness values for the quartz grains vary from angular to rounded. Textural maturities vary with the environment of deposition. The lacustrine delta sandstones (Unit A) are classified as mature to supermature. The point bar sandstones (Unit B) range from immature to mature-supermature. Samples from the braided river deposits (Unit C) are classified as submature.

In summary, the characteristics of the lacustrine delta sands of Unit A are very fine grained, well sorted, subangular to rounded, with a mature to supermature texture. This is representative of a low energy depositional environment and probably traveled a fair distance from the sediment source. The characteristics of the point bar sands of Unit B are medium grained, moderately sorted, subangular to rounded with a submature to supermature texture. This represents a higher energy environment than represented in Unit A above. The characteristics of the braided river sands of Unit C are medium to coarse grained, poorly sorted, angular to rounded with a submature texture. This represents the highest energy environment of the three units.

Porosity

Most of the porosity observed in this section is the result of dissolution of grains or cement and is considered secondary (Craig, 1982). The porosity data is summarized in Table 3 and indicates a wide variation in the amount of porosity between the sandstones of each environment. No porosity was noted in point counts of the lacustrine delta (Unit A). Since the sandstones in Unit A are water-bearing (Youngberg and Santoro, 1981) it may be that most of the porosity and

Table 3. Average textural and porosity values for fifty-nine sandstone samples from the Hanna Formation, Hanna UCG site (after Craig, 1982).

	Mean Quartz Size mm	Maximum Quartz Size mm	Standard Deviation of Quartz Size mm	Roundness	Textural Maturity	Porosity Percent	Standard Deviation for Porosity
UNIT A Lacustrine Delta	0.1	0.19	0.37	Subangular- Rounded	Mature- Supermature	0	0
UNIT B Point Bars	0.28	1.62	0.17	Subangular- Rounded	Submature- Supermature	2.88	2.40
UNIT C Braided River	0.48	1.16	0.22	Angular- Rounded	Submature	6.36	3.80

permeability in Unit A is due to joints in the rock. The point bar sandstones of Unit B have a porosity of 2.88 percent. The braided river sandstones of Unit C have the highest porosity values with an average of 6.36 percent.

Diagenesis

A number of diagenetic features have been observed in the overburden sandstones at the Hanna UCG site. The most commonly observed diagenetic processes were compaction and cementation. In some cases porosity has been destroyed by compaction, cementation, and replacement. In other cases, secondary porosity has been created by dissolution of grains of cement (Craig, 1982).

The cement types found in the overburden sandstones are kaolinite, calcite, smectite, siderite, silica, chlorite, and pyrite. Kaolinite cement was present in almost all sandstone samples where it occurs as a pore-filling cement. Calcite in some samples filled all the pores, replacing feldspar grains and the edges of quartz grains. In other samples, calcite occurred as single crystals or small groups of crystals filling in the pore spaces. Siderite was found in sandstones containing significant amounts of clay matrix or clay clasts. Siderite was not found in the sandstones of Unit C. Smectite was found sporadically distributed throughout the overburden as a pore lining. Silica was found scattered throughout the overburden in minor amounts. Pyrite and chlorite were found in very few samples in minor concentrations. Pyrite occurred as mass enclosing detrital grains. Chlorite was found as isolated pore fills (Craig, 1982).

COAL

Proximate and Ultimate Analysis

Data for proximate and ultimate analyses on an as received basis are given in Table 4. The proximate analysis information shows the average moisture content is 8.4 percent, the average ash content is 27.4 percent, the average volatile matter content is 32.7 percent, and the average fixed carbon content is 31.5 percent. Profiles of as received and moisture free analyses for CH-133 are shown in Figures 32 and 33 respectively. A comparison of these two plates shows that the volatile matter decreases while the fixed carbon and ash content increases in the moisture free analysis. The ultimate analysis shows an ash content of 27.4 percent and a sulfur content of 0.7 percent. A profile of a moisture and ash free ultimate analysis for CH-133 is shown in Figure 34. The mineralogy of the ash and the forms of sulfur will be discussed in the following sections. The distributions of total sulfur for cores II-4, III-2, and IV-2 are shown in Figures 35, 36 and 37. A concentration of sulfur was found near the top of the coal bed in each corehole.

Some of the 176 samples used for the figures in Table 4 contained ash contents of up to 75.9 percent. Although these figures give a true representation of what the coal seam is like that was gasified, some of

Table 4. Summary of proximate, ultimate and calorific value analyses of coal from the Hanna UCG site.

	Number of Samples	Mean	Standard Deviation	Maximum	Minimum
Proximate Analysis Percent (as received)					
Moisture	176	8.4	1.22	11.7	4.3
Ash	176	27.4	18.56	75.9	3.4
Volatile Matter	176	32.7	7.65	49.9	11.0
Fixed Carbon	176	31.5	11.05	49.2	1.2
Ultimate Analysis Percent (as received)					
Moisture	176	8.4	1.22	11.7	4.3
Carbon	176	46.7	14.49	67.1	11.8
Hydrogen	176	4.3	1.11	6.0	1.6
Nitrogen	176	1.1	0.33	1.7	0.1
Sulfur	176	0.7	0.56	3.9	0.1
Ash	176	27.4	18.56	75.9	3.4
Oxygen	176	11.4	4.79	23.5	6.0
Calorific Value (BTU/LB)	176	8,196	2,656	12,060	1,930

Proximate Analysis (as received)

DEPTH (FEET)

Figure 32. As received proximate analysis for CH-133, Hanna UCG site.

Figure 33. Moisture-free proximate analysis for CH-133, Hanna UCG site.

Figure 34. Moisture and ash-free ultimate analysis for CH-133, Hanna UCG site.

Figure 35. Distribution of total sulfur in Hanna No. 1 coal for Corehole II-4, Hanna UCG Site.

Figure 36. Distribution of total sulfur in Hanna No. 1 coal for Corehole III-2, Hanna UCG site.

CORE IV-2

Figure 37. Distribution of total sulfur in Hanna No. 1 coal for Corehole IV-2, Hanna UCG site.

Table 5. *Ash percentage values for six coreholes at the Hanna UCG site.

Corehole	Mean	High	Low	Top 5 ft.	Bottom 5 ft.
CH-133	30.42%	76.7%	5.1%	50.06%	52.70%
2HP-170	29.40%	68.1%	5.2%	42.34%	35.04%
I-16	25.57%	78.7%	3.8%	26.74%	64.52%
III-2	32.38%	73.6%	5.9%	53.96%	33.80%
IV-2	28.28%	64.4%	5.5%	38.66%	39.48%
II-4	30.79%	78.9%	3.7%	34.04%	52.40%

* Moisture-free basis

the high ash content coals can be classified as carbonaceous shale rather than coal. Table 5 shows mean, high, low, top five feet and bottom five feet ash percent values for six coreholes in the Hanna UCG area.

Ash Analysis

The mineralogy of the Hanna No. 1 coal bed is shown in Figure 38. This chart illustrates the relative abundance of mineral constituents in the ash of the coal after most of the free carbon has been burned off. As expected for coal, a low energy sedimentary deposit, fine-grained clay minerals (kaolinite and illite) make up nearly half of the coal ash. Quartz is the next most abundant mineral at 18.1 percent. This is quite different from the pattern of the overburden where quartz makes up over half of the total and clay minerals are only 8.9 percent of the mineral constituents (see Figure 26).

Figure 39 shows an even distribution of calcite/aragonite minerals throughout the coal bed of core I-16. The concentration of calcium appears to be unrelated to ash concentration. Field observations support the idea that calcite in the coal is a secondary fracture filling occurrence. Sulfur distribution (Figures 35-37 and Appendix B) is concentrated at the top and bottom of the coal and seems to be directly related to ash content. The direct relationship between ash percentage and element concentrations is valid for nearly all elements (compare profiles in Appendix B).

The oxides comprising the ash of the Hanna bituminous coals are shown in Table 6. The most abundant oxide in the ash is silicon dioxide with a mean level of almost 47 percent. The least common occurring oxide is manganese oxide with a mean level of 0.11 percent. The highest value is found for iron oxide (71.53 percent). The distribution and mineral form of iron oxide for the coal bed in Core I-16 is shown in Figure 40. Note the rather even distribution of pyrite through the bed with a large concentration of siderite in the middle of the bed. A profile of an ash analysis of oxides for CH-133 is shown in Figure 41.

Minerals Identified in Hanna I Coal Bed (Low Temperature Ash)

Figure 38. Minerals in the Hanna No. 1 coal bed (low temperature ash), Hanna UCG site.

Distribution of Calcite/Aragonite Minerals in Coal Bed Core I-16

Figure 39. Distribution of calcite/aragonite minerals in the Hanna No. 1 coal bed for Corehole I-16, Hanna UCG site.

Figure 40. Distribution and mineral form of iron in the Hanna No. 1 coal in Corehole I-16, Hanna UCG site.

Figure 41. Ash analysis of oxides for CH-133, Hanna UCG site.

An elemental analysis of the ash of Hanna bituminous coal is shown in Table 7. The most abundant elements are chlorine, fluorine, and phosphorous with mean concentrations close to 100 ppm. Gold and mercury are the least common elements with mean concentrations of 0.02 and 0.01 ppm respectively. A comparison of concentrations of some of the elements in Table 7 for coal and carbonaceous shale in core 2HP-170 is shown in Figure 42. The concentrations of all elements except calcium is greater in the carbonaceous shale as compared to the coal.

Table 6. Oxides in ash of Hanna bituminous coals.

Oxide	# Samples	High%	Low%	Mean%	Standard Deviation%
SiO ₂	64	66.22	6.61	46.92	11.10
Al ₂ O ₃	64	28.25	3.32	22.49	4.20
Fe ₂ O ₃	64	71.53	3.01	10.30	11.39
CaO	64	21.95	0.34	7.23	4.44
SO ₃	64	12.66	0.29	4.80	3.04
MgO	64	5.87	1.49	2.43	0.76
Na ₂ O	64	2.92	0.84	1.33	0.47
K ₂ O	64	2.83	0.19	1.26	0.43
TiO ₂	64	1.99	0.13	0.84	0.27
P ₂ O ₅	64	6.15	0.01	0.78	1.14
MnO ₂	64	1.88	0.0	0.11	0.33

Table 7. Element analysis of Hanna bituminous coals.

Element	# Samples	High(ppm)	Low(ppm)	Mean(ppm)	Standard Deviation
Aluminum	64	10	0.2	2.84	1.82
Antimony	64	65	< 1.0	16.94	21.99
Arsenic	64	< 10	< 10	10	0.0
Bismuth	64	< 5	< 5	5	0.0
Cadmium	64	< 5	< 5	5	0.0
Calcium	64	3.6	0.03	0.47	0.47
Chlorine	64	<100	<100	100	0.0
Copper (oxide)	64	79	< 3	9.2	14.41
Copper (sulfide)	64	70	< 3	12.89	10.81
Flourine	64	100	10	98.59	11.16
Gold	64	0.02	< 0.01	0.02	0.02
Heavy Metals	64	< 1.0	< 0.3	0.60	0.21
Indium	64	< 1.0	< 1.0	1.0	0.0
Iron (ferrous)	64	3.5	0.05	0.84	0.76
Lead	64	70	7	22.52	11.84
Lead Oxide	64	49	< 3	9.95	10.27
Lead Sulfide	64	73	< 3	16.67	13.67
Lithium	64	220	< 1	35.13	50.13
Magnesium	64	1.25	0.09	0.36	0.18
Mercury	64	0.01	< 0.01	0.01	--
Molybdenum(oxide)	64	3.0	< 3.0	3.0	0.0
Molybdenum(sulfide)	64	< 3.0	< 3.0	3.0	0.0
Phosphorous	64	351	< 50	96.91	74.87
Potassium	64	1.87	0.02	0.31	0.29
Rubidium	64	160	< 1.0	5.78	26.85
Selenium	64	< 50	< 1	2.73	6.0
Silica	64	15.0	0.03	1.46	2.70
Sodium	64	3.0	0.1	0.60	0.49
Sulfate	64	5.35	0.21	2.08	0.79
Sulfur (total)	64	2.61	0.31	0.79	0.42
Sulfide	64	1.9	0.1	0.51	0.33
Sulfur (soluble)	64	1.25	0.16	0.54	0.29
Tellurium	64	0.1	< 0.1	0.1	0.0
Thallium	64	< 10	< 1	1.14	1.13
Tin	64	< 10	< 10	10	0.0
Tungsten	64	2	< 2.0	2.0	0.0
Uranium	64	4	< 2.0	2.31	0.61
Zinc	64	105	14	64.69	29.29
Zinc (oxide)	64	56	< 3.0	19.58	15.64
Zinc (sulfide)	64	111	< 3.0	51.09	37.44

Figure 42. Element concentration of coal vs. carbonaceous shale in Corehole 2HP-170, Hanna UCG site.
(continued next page)

Figure 42. Continued

Forms of Sulfur

Three forms of sulfur were analyzed for in coal samples. These are: 1) organic, 2) pyritic, and 3) sulfate sulfur. Pyrite in Hanna coal will be discussed in later paragraphs. Data was available for these three sulfur forms in 278 samples taken at one foot intervals from several coreholes around the Hanna UCG Site. These values were analyzed to show the average percentage of each sulfur form in the Hanna No. 1 coal bed at the Hanna UCG site. The results are shown in Table 8 along with high and low value for each form. High total sulfur values were usually caused by an anomalously high pyritic sulfur value (compare Figures 43, 44 & 46). The "As Received" values were used.

Table 8. Sulfur forms in Hanna No. 1 coal bed.

	Average	High	Low
Organic	0.44%	1.55%	0.0%
Pyritic	0.19%	3.38%	0.02%
Sulfate	<u>0.01%</u>	<u>0.18%</u>	<u>0.0%</u>
Total	0.64%	3.88%	0.08%

Generally speaking, about two-thirds of the sulfur present in the Hanna coal is in organic form. The other one third is in pyritic form with only traces of sulfate present. The distributions of organic, pyritic, sulfate and total sulfur for the Hanna No. 1 coal bed in Core I-16 are shown in Figures 43-46. The average total sulfur obtained from the 278 samples is very close to the percentage listed on the ultimate analysis table (Table 4) for 176 samples (0.64 percent as compared to 0.7 percent).

Although the average values show organic sulfur as the most abundant sulfur form, the largest value is that for pyritic sulfur and that at least some pyritic sulfur was present in all 278 samples.

An analysis of pyrite forms in Hanna coal is shown in Table 9. The analysis was done on 34 core samples from several holes drilled on the Hanna UCG site. Seven types of pyrite were identified and included: 1) irregular, 2) dispersed euhedra, 3) clustered euhedra, 4) fracture filling, 5) blebs, 6) framboids, and 7) dendritic. No cell filling pyrite was found in the 34 samples. Dispersed euhedra pyrite was the most widespread followed by clustered euhedra and irregular pyrite. Examples of some of these pyrite forms are shown in Figure 47.

Figure 43. Distribution of organic sulfur in the Hanna No. 1 coal for Corehole I-16, Hanna UCG site.

Figure 44. Distribution of pyritic sulfur in the Hanna No. 1 coal for Corehole I-16, Hanna UCG site.

Figure 45. Distribution of sulfate sulfure in the Hanna No. 1 coal for Corehole I-16, Hanna UCG site.

Core I-16

Figure 46. Distribution of total sulfur in the Hanna No. 1 coal for Corehole I-16, Hanna UCG site.

Table 9. Analysis of pyrite forms in Hanna No. 1 coals.
(Mean Values)

	Irregular	Dispersed Euhedra	Clustered Euhedra	Fracture Filling	Blebs	Framboids	Cell Filling	Dendritic
Total Area	5,337.62							
Area (Microns)	854.79	21.96	2,168.09	105.35	1,935.97	90.06	0.0	0.18
% of Total Area	14.34	40.03	21.71	8.31	4.42	2.37	0.0	0.0
Total Occurrences	12.26							
Occurrence	1.21	5.35	2.47	0.21	0.97	0.46	0.0	0.0
% of Total Occurrences	8.61	62.17	11.08	2.24	5.54	1.56	0.0	0.0
Volume %	1.11							

(Analysis done on 34 core samples from holes drilled on Hanna UCG Site)

NOTE: The values on this chart are mean values of evenly weighted samples which have greatly varying total areas and total occurrences.

a

b

c

Figure 47. Pyrite forms in the Hanna No. 1 coal, Hanna UCG site.
a) framboid (center) and dispersed euhedra
b) framboid (upper left) and clustered euhedra
c) fracture filling

Maceral Analysis

The maceral classification system used by many laboratories is shown in Table 10. This classification system organizes macerals into three primary groups: vitrinite, exinite, and inertinite. Each maceral group is subdivided into many individual macerals on the basis of their optical properties, morphology, source material, and nature of formation.

The vitrinite group is the most abundant suite of macerals. It is composed primarily of coalified woody tissue derived from stems, roots, and vascular tissues of leaves (Figure 48a,c). Vitrinites occur in coal as bright, thin bands, lenses, and attrital matrix. In reflected light vitrinites appear light to dark grey. The differences in reflectance of vitrinite are due to different plant materials and to different degrees of preservation of the plant material. The carbon and hydrogen content of vitrinites at any given rank are intermediate between those of the exinite and inertinite groups. Vitrinite reacts during carbonization (i.e. coking) to form the bulk of the char mass.

The second group of macerals is the exinite group (Figure 48b,c) derived from the waxy and resinous parts of plants such as cuticles, spore and pollen exines, resins, and algal remains. The exinite group appears grey, dark grey, or black in reflected light. Exinites have the highest hydrogen content and the lowest carbon content among the maceral groups. During the carbonization process most of the exinite macerals devolatilize as gases or tars.

The third group of macerals is the inertinite group (Figure 48b,d) derived from plant material that was highly altered and degraded in the peat stage of coal formation (i.e. fossil charcoal). The inertinites appear bright yellow or white in reflected light. Inertinites contain the highest carbon content and lowest hydrogen content of the maceral groups. The inertinite group is inert or semi-inert during the carbonization process and becomes physically incorporated into the char mass.

The following method, standard in most U.S. laboratories, was used for determining maceral composition. A petrographic examination of polished coal pellets was made in reflected light using an oil immersion lens. The relative abundance of macerals was obtained by a point-count method. Five hundred point counts were made on each of two specimens made from the same coal sample, for a total of one thousand maceral determinations per sample. The data were combined and reported as volume percentages. Table 11 lists the macerals and volume percent for each maceral that was determined for the Hanna No. 1 coal seam. One hundred and eight coal samples were analyzed for maceral composition from the Hanna site. A profile of a maceral analysis of CH-133 is shown in Figure 49. A profile of vitrinoid types in CH-133 is shown in Figure 50. The maceral types in CH-133 are consistent through the coal bed (Figure 49), while the vitrinoid types are more irregular (Figure 50).

Table 10. Maceral classification describing the macerals that were studied at the Hanna underground coal gasification site.

MACERAL CLASSIFICATION				
Maceral Group	Maceral	Origin	Chemistry	Carbonization Behavior
Vitrinite	Vitrinite Pseudovitrinite	Woody tissues, bark, leaves	Intermediate hydrogen content and volatiles	Reactive
Exinite	Resinite Exinite	Resins Spores, cuticles	High hydrogen content and volatiles	Reactive
Inertinite	Semi-fusinite Semi-macrinite Fusinite Macrinite Micrinite Sclerotinite	Strongly altered and degraded plant material Fungal remains	Low hydrogen content and volatiles	Generally inert

a

b

c

d

Figure 48. Photomicrographs of coal macerals. (a) Vitrinite (bright) with resinite (X200). (b) Sclerotinite (left center) with semi-fusinite, vitrinite, exinite, and pyrite (upper right) (X200). (c) Vitrinite with exinite and semi-fusinite (X400). (d) Vitrinite with pseudovitrinite, sclerotinite, semi-fusinite, semi-macrinite, and micrinite (X200).

Figure 49. Maceral analysis profile of CH-133, Hanna UCG site.

Figure 50. Distribution of vitrinoid types of CH-133, Hanna UCG site.

Table 11. Maceral analysis (mineral-matter free basis) from the Hanna UCG site.

MACERAL GROUP	VOLUME %	MACERAL	VOLUME %
Vitrinite	91.8	Vitrinite	90.3
		Pseudovitrinite	1.5
Exinite	6.1	Exinite	5.5
		Resinite	0.6
Inertinite	2.1	Semi-Fusinite	1.0
		Semi-Macrinite	0.1
		Fusinite	0.3
		Macrinite	0.1
		Micrinite	0.5
		Sclerotinite	0.1

Mean-Maximum Vitrinite Reflectance

Reflectance is the amount of light that is reflected from a surface and expressed as a ratio or percentage of the amount of incident light. Reflectance studies on coal macerals are carried out under standardized conditions and are correlated with the reflectance of glass or synthetic standards. Vitrinite reflectance is determined because the vitrinites are the most abundant macerals in coal, and vitrinites also exhibit a wide range of reflectance in the coalification series. Maximum vitrinite reflectance is measured on a polished surface of a vitrinite maceral using a polarized light microscope and an oil immersion lens. After the vitrinite grain is centered, the circular stage of the microscope is rotated slowly for 360° and the maximum reflectance (R_{max}) is recorded. The average of at least one hundred readings is called the mean-maximum reflectance. The average mean-maximum vitrinite reflectance for 104 samples at the Hanna UCG site was 0.47.

Rank

The process that alters peat into coal is called coalification. Rank is a classification of the degree of coalification, or progressive alteration from lignite to anthracite coal. In the United States, coals are classified into various ranks in accordance with an ASTM standard. Fixed carbon and calorific values are the two basic parameters used for this classification (Table 12). High-rank coals are classified according to fixed carbon or volatile matter content on a dry, mineral-matter-free basis. Low rank coals are classified according to calorific value on a moist, mineral-matter-free basis. Some coal ranks are also differentiated according to their agglomerating (caking) properties.

Class	Group	Fixed carbon limits (%) (dry, mineral-matter-free basis)		Volatile matter limits (%) (dry, mineral-matter-free basis)		Calorific value limits (Btu/lb) (moist mineral-matter-free basis)		Agglomerating character
		≥	<	>	≥	≥	<	
I. Anthracitic								
1. Meta-anthracite		98	—	—	2	—	—	} nonagglomerating
2. Anthracite		92	98	2	8	—	—	
3. Semianthracite		86	92	8	14	—	—	
II. Bituminous								
1. Low volatile bituminous coal		78	86	14	22	—	—	} commonly agglomerating
2. Medium volatile bituminous coal		69	78	22	31	—	—	
3. High volatile A bituminous coal		—	69	31	—	14,000	—	
4. High volatile B bituminous coal		—	—	—	—	13,000	14,000	} agglomerating
5. High volatile C bituminous coal		—	—	—	—	11,500	13,000	
						10,500	11,500	
III. Subbituminous								
1. Subbituminous A coal		—	—	—	—	10,500	11,500	} nonagglomerating
2. Subbituminous B coal		—	—	—	—	9,500	10,500	
3. Subbituminous C coal		—	—	—	—	8,300	9,500	
IV. Lignitic								
1. Lignite A		—	—	—	—	6,300	8,300	} nonagglomerating
2. Lignite B		—	—	—	—	—	6,300	

Table 12. Classification of coals by rank.

In order to classify coal using the ASTM system it is necessary to carry out a proximate analysis (moisture, ash, volatile matter, fixed carbon) and determine calorific value. The rank classification for 137 coal samples from the Hanna No. 1 coal seam is shown in Figure 51. A majority of the samples fall into the High Volatile C Bituminous rank; however, a number of samples fall into the subbituminous ranks.

There is a correlation between high ash content and rank using coal samples from the Hanna site. The higher the ash content, the lower the rank. Figure 52 shows percent ash content calculated for three sample categories that were obtained from the Hanna No. 1 coal seam: carbonaceous shale, subbituminous coal, and bituminous coal. Rank was not calculated on the carbonaceous shale samples (greater than 50 percent ash content by weight). The rank calculated on coal samples (less than 50 percent ash content by weight) fell into two coal classes, subbituminous coal and bituminous coal. Thirty-three carbonaceous shale samples had a mean of 63.95 percent ash content. Twenty-three subbituminous coal samples had a mean of 34.81 percent ash content. One hundred and fourteen High Volatile C Bituminous samples had a mean of 18.81 percent. Distribution of ash percent for cores I-16, II-4, and III-2 is shown in Figure 53. Those footages in black have ash percentages of less than 12 percent. This figure shows that ash content is extremely variable through the Hanna No. 1 coal bed with values as low as 4 percent and as high as 79 percent. It appears that the rank calculations for high ash content samples are inaccurate for determination of coal rank on the Hanna coals.

Measurement of coal rank was also done using mean-maximum vitrinite reflectance information. The degree of coal metamorphism has a linear relationship to the reflectance of vitrinite in coal. The higher the vitrinite reflectance, the higher the rank of the coal. Davis (1978) (Table 13) has related maximum vitrinite reflectance directly to the ASTM coal rank classification system. Using the maximum reflectance categories from Table 13, the rank of the coal from the Hanna gasification site was calculated and a histogram of the sample data is shown in Figure 54. The calculation of rank using vitrinite reflectance is very similar to the classification results obtained by using the ASTM method. Sixty-four percent of all the coal samples fell into the High Volatile C Bituminous rank.

Table 13. Classification of coals by rank using maximum reflectance percent.

<u>Rank</u>	<u>% Maximum Reflectance</u>
Subbituminous	< 0.47
High Volatile Bituminous C	0.47 - 0.57
High Volatile Bituminous B	0.57 - 0.71
High Volatile Bituminous A	0.71 - 1.10
Medium Volatile Bituminous	1.10 - 1.50
Low Volatile Bituminous	1.50 - 2.05
Semianthracite	2.05 - 3.00
Anthracite	> 3.00

Figure 51. Classification of coal from the Hanna No. 1 coal seam using ASTM methods.

Figure 52. Percent ash content in carbonaceous shale, subbituminous coal, and bituminous coal from the Hanna No. 1 coal seam.

PERCENT ASH (MOISTURE-FREE) IN COAL CORES

Figure 53. Distribution of ash percentage in the Hanna No. 1 seam for three coreholes from the Hanna UCG site.

Figure 54. Classification of coal from the Hanna No. 1 coal seam using mean-maximum vitrinite reflectance.

GEOCHEMISTRY

Semi-Quantitative Spectrographic Analysis

General

Samples from cores taken at the Hanna UCG site were tested using the semi-quantitative spectrographic analysis technique. Six-hundred and twenty-eight samples from coreholes CH-131, CH-132, CH-133, and CH-134 were evaluated to establish baseline values (not heat altered) for the overburden units in the area. The results are shown in Tables 14 through 17. Values were averaged for each local stratigraphic unit and for the total overburden in each corehole. Coreholes 2HP-170 and 2HP-171 were also included for the baseline calculations of the Hanna No. 1 coal (Table 18). An overall site average was calculated for all of the units present (Table 19). Several correlations by element were done with this data: 1) site average coal to site average total overburden; 2) site average stratigraphic unit to site average stratigraphic unit; 3) coal bed correlated hole to hole; 4) local stratigraphic units correlated hole to hole; 5) local stratigraphic unit to local stratigraphic unit within each hole; and 6) coal bed to total overburden within each hole.

Correlations

1. Average Coal to Average Overburden

The average element concentrations in the coal bed when correlated with corresponding values for the overburden shows that with the exception of copper, the concentrations are greater for the overburden. Some elements where the concentrations in the overburden are slightly higher than in the coal are Cr, Pb, and V (see Table 19).

2. Average Stratigraphic Units

The correlation of average stratigraphic units (see Table 19) is shown in Table 20. This ranks the units from highest to lowest concentration values for each element. The table shows a dominance of Units A and B in the higher concentrations and a dominance of Unit C and the Hanna No. 1 in the lower concentrations. Unit D seems to have dominance in the middle part of the table.

Unit A is present eleven times in the highest column and Unit B is present ten times in this column. Unit C appears only once in this column, for the element barium. Unit D appears twice for the element boron and in a tie with Units A and B for the element beryllium. Unit A also appears seven times in the second column. These seven appearances are for all but one of the eight elements in the highest column that did not have Unit A present. Therefore, eighteen of Unit A's nineteen appearances are in columns 1 and 2. Twelve of nineteen Unit B appearances are in columns 1 and 2.

Table 14. Average semi-quantitative spectrographic analysis of CH-131.

OVERBURDEN UNITS																				
Unit (# Samp)	(.05) Fe%	(.02) Mg%	(.05) Ca%	(.002) Ti%	(10) Mn	(.5) Ag	(10) B	(20) Ba	(1) Be	(5) Co	(10) Cr	(5) Cu	(20) La	(5) Ni	(10) Pb	(5) Sc	(10) V	(10) Y	(10) Zr	(10) Ga
Unit D (26)	2.5	1.3	0.67	0.21	438	N	56	700	1.4	7	59	21	42	17	23	13	65	27	167	77
Unit C (73)	1.9	1.1	0.55	0.20	633	L	32	870	1.2	7	44	*7	*28	12	13	8	50	24	262	52
Unit B (50)	2.5	0.9	0.21	0.27	480	*0.5	39	638	1.1	9	66	*18	*36	28	18	12	87	25	208	68
Unit A (50)	1.9	1.7	2.23	0.26	689	N	43	834	1.4	9	53	19	39	23	24	13	75	31	250	101
TOTAL OVERBURDEN																				
Units A-D (199)	2.1	1.2	0.90	0.24	583	*L	40	780	1.3	8	54	*15	*35	19	18	11	68	26	233	72
COAL																				
No. 1 (19)	0.5	0.3	0.12	0.09	*22	N	47	202	*L	*L	31	14	*L	*7	*14	*6	59	*13	76	34

Remarks: Fe, Mg, Ca and Ti reported in %; all other elements reported in ppm. Results are in the series 1, 1.5, 2, 3, 5, 7, 10, etc. Lower limits of determination are in parentheses. N=Not detected at limit of detection; L=Detected, but below limit of determination; L(N)=L and N both common in the data averaged; N(L)=Only sporadic L in data. *-In data where number values and letter denotations are both common, L was assigned a value of ½ the detection limit and N was assigned a value of zero.

Table 15. Average semi-quantitative spectrographic analysis of CH-132.

OVERBURDEN UNITS																				
Unit (# Samp)	(.05) Fe%	(.02) Mg%	(.05) Ca%	(.002) Ti%	(10) Mn	(.5) Ag	(10) B	(20) Ba	(1) Be	(5) Co	(10) Cr	(5) Cu	(20) La	(5) Ni	(10) Pb	(5) Sc	(10) V	(10) Y	(10) Zr	(10) Ga
Unit D (35)	2.1	1.0	0.44	0.20	544	N	69	749	1.4	8	68	19	38	20	21	12	90	23	163	109
Unit C (108)	1.9	0.8	0.57	0.17	547	2.3	19	1179	1.2	7	44	*6	*41	27	15	7	49	20	204	46
Unit B (27)	2.9	1.5	0.66	0.34	477	*L	107	1081	1.5	10	107	29	62	38	30	16	122	34	170	125
Unit A (37)	3.0	1.7	1.01	0.38	506	*L	90	905	1.4	13	76	32	52	32	35	13	119	31	304	151
TOTAL OVERBURDEN																				
Units A-D (207)	2.3	1.1	0.64	0.23	530	*1.4	52	1045	1.3	9	62	*16	45	28	22	10	78	24	211	86
COAL																				
No. 1 (21)	1.0	0.6	0.17	0.19	175	*L	52	461	*1.0	*L	55	21	20	16	23	*9	80	*18	70	64

Remarks: Fe, Mg, Ca and Ti reported in %; all other elements in ppm. Results are in the series 1, 1.5, 2, 3, 5, 7, 10, etc. Lower limits of determination are in parentheses. N=Not detected at limit of detection; L=Detected, but below limit of determination. L(N)=L and N both common in the data averaged; N(L)=Only sporadic L in data.
*-In data where number values and letter denotations are both common, L was assigned a value of ½ the detection limit and N was assigned a value of zero.

Table 16. Average semi-quantitative spectrographic analysis of CH-133.

OVERBURDEN UNITS																				
Unit (# Samp)	(.05) Fe%	(.02) Mg%	(.05) Ca%	(.002) Ti%	(10) Mn	(1.5) Ag	(10) B	(20) Ba	(1) Be	(5) Co	(10) Cr	(5) Cu	(20) La	(5) Ni	(10) Pb	(5) Sc	(10) V	(10) Y	(10) Zr	(10) Ga
Unit C (25)	1.4	0.3	0.30	0.14	268	N	12	928	1.2	*9	*28	*7	*27	*8	22	6	25	*13	168	21
Unit B (27)	2.2	0.7	0.69	0.30	185	N	20	763	1.6	13	75	22	57	18	41	13	53	26	174	95
Unit A (22)	1.9	0.7	2.27	0.16	398	N	15	868	1.5	10	*36	10	51	*12	21	9	38	26	218	23
TOTAL OVERBURDEN																				
Units A-C (74)	1.8	0.6	1.03	0.20	276	N	16	850	1.4	11	*48	*13	*45	*13	29	9	39	*22	185	49
COAL																				
No. 1 (32)	0.9	0.3	0.19	0.06	*92	N(L)	*20	*164	*L	*L	33	21	N(L)	*L	*18	*5	46	*15	*25	*40

Remarks: Fe, Mg, Ca and Ti reported in %; all other elements in ppm. Results are in the series 1, 1.5, 2, 3, 5, 7, 10, etc. Lower limits of determination are in parentheses. N=Not detected at limit of detection; L=Detected, but below limit of determination. L(N)=L and N both common in the data averaged; N(L)=Only sporadic L in data. *=In data where number values and letter denotations are both common, L was assigned a value of $\frac{1}{2}$ the detection limit and N was assigned a value of zero.

Table 17. Average semi-quantitative spectrographic analysis of CH-134.

OVERBURDEN UNITS																				
Unit (# Samp)	(.05) Fe%	(.02) Mg%	(.05) Ca%	(.002) Ti%	(10) Mn	(.5) Ag	(10) B	(20) Ba	(1) Be	(5) Co	(10) Cr	(5) Cu	(20) La	(5) Ni	(10) Pb	(5) Sc	(10) V	(10) Y	(10) Zr	(10) Ga
Unit B (17)	4.7	1.0	0.36	0.29	731	L(N)	73	718	1.5	10	78	26	45	30	27	13	120	30	132	118
Unit A (27)	2.5	1.5	1.00	0.26	681	L(N)	71	700	1.5	13	68	25	48	35	28	14	90	34	190	139

TOTAL OVERBURDEN																				
Units A-B (44)	3.4	1.3	0.75	0.27	700	L(N)	72	707	1.5	12	72	25	47	33	28	14	102	32	168	131

COAL																				
No. 1 (32)	1.2	0.4	0.31	0.14	147	*L(N)	42	397	*1.1	*L	51	25	*L	*9	23	*6	62	*22	80	65

Remarks: Fe, Mg, Ca and Ti reported in %; all other elements in ppm. Results are in the series 1, 1.5, 2, 3, 5, 7, 10, etc. Lower limits of determination are in parentheses. N=Not detected at limit of detection; L=Detected, but below limit of determination. L(N)=L and N both common in the data averaged; N(L)=Only sporadic L in data. *=In data where number values and letter detonations are both common, L was assigned a value of $\frac{1}{2}$ the detection limit and N was assigned a value of zero.

Table 18. Average semi-quantitative spectrographic analysis of 2HP-170 and 2HP-171.

2HP-170: COAL

Unit (# Samp)	(.05) Fe%	(.02) Mg%	(.05) Ca%	(.002) Ti%	(10) Mn	(.5) Ag	(10) B	(20) Ba	(1) Be	(5) Co	(10) Cr	(5) Cu	(20) La	(5) Ni	(10) Pb	(5) Sc	(10) V	(10) Y	(10) Zr	(10) Ga
No. 1 (29)	0.7	0.2	0.46	0.05	*78	N	L(N)	84	*L	N	*18	11	L	*L	24	*L	45	*11	21	*21

2HP-171: COAL

No. 1 (20)	0.4	0.1	0.37	0.03	*37	N	N(L)	90	*L	N	N	8	L	L(N)	*17	N	30	*L	*18	*L
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Remarks: Fe, Mg, Ca and Ti reported in %; all other elements in ppm. Results are in the series 1, 1.5, 2, 3, 5, 7, 10, etc. Lower limits of determination are in parentheses. N=Not detected at limit of detection; L=Detected, but below limit of determination. L(N)=L and N both common in the data averaged; N(L)=Only sporadic L in data. *=In data where number values and letter denotations are both common, L was assigned a value of $\frac{1}{2}$ the detection limit and N was assigned a value of zero.

Table 19. Average baseline values for the Hanna UCG site.

AVERAGE OVERBURDEN UNITS																				
Unit (# Samp)	(.05) Fe%	(.02) Mg%	(.05) Ca%	(.002) Ti%	(10) Mn	(.5) Ag	(10) B	(20) Ba	(1) Be	(5) Co	(10) Cr	(5) Cu	(20) La	(5) Ni	(10) Pb	(5) Sc	(10) V	(10) Y	(10) Zr	(10) Ga
Unit D (61)	2.3	1.1	0.54	0.20	499	N	63	728	1.4	8	64	20	40	19	22	12	79	25	165	95
Unit C (206)	1.8	0.9	0.53	0.18	544	*L	23	1039	1.2	7	42	6	35	19	15	7	46	21	220	45
Unit B (121)	2.8	0.7	0.44	0.30	449	*L	55	776	1.4	10	79	22	48	28	27	13	92	28	181	94
Unit A (136)	2.3	1.5	1.66	0.28	591	L(N)	57	832	1.4	11	59	22	46	26	27	13	84	31	248	110

TOTAL AVERAGE OVERBURDEN																				
Units A-D (524)	2.2	1.0	0.80	0.24	529	*L	44	888	1.3	9	58	16	41	23	22	11	70	26	212	79

AVERAGE COAL																				
No. 1 (153)	0.8	0.4	0.28	0.09	96	*L(N)	*27	234	*L	*L(N)	*33	17	*L	*8	20	*5	53	*14	47	*L

Remarks: Unit D - Average of CH-131 and CH-132.
 Unit C - Average of CH-131, CH-132, and CH-133.
 Unit B - Average of CH-131, CH-132, CH-133, and CH-134.
 Unit A - Average of CH-131, CH-132, CH-133, and CH-134.
 Hanna No. 1 - Average of CH-131, CH-132, CH-133, CH-134, 2HP-170, and 2HP-171.

Table 20. Average stratigraphic unit correlation.

ELEMENT	HIGHEST	2	3	4	LEAST
Fe	B	A	D	C	No. 1
Mg	A	D	C	B	No. 1
Ca	A	D	C	B	No. 1
Ti	B	A	D	C	No. 1
Mn	A	C	D	B	No. 1
B	D	A	B	No. 1	C
Ba	C	A	B	D	No. 1
Be	A,B,D	--	--	C	No. 1
Co	A	B	D	C	No. 1
Cr	B	D	A	No. 1	C
Cu	A,B	--	No. 1	D	C
La	B	A	D	C	No. 1
Ni	B	A	C,D	--	No. 1
Pb	A,B	--	D	No. 1	C
Sc	A,B	--	D	C	No. 1
V	B	A	D	No. 1	C
Y	A	B	D	C	No. 1
Zr	A	C	B	D	No. 1
Ga	A	D	B	No. 1	C

Unit D's dominance in the middle column is also shown by a similar evaluation. Seventeen of Unit D's nineteen appearances are in the middle columns 2, 3 and 4, with 10 in column 3. Thirteen of nineteen Unit C appearances are in columns 4 and 5 (least) and, as expected, eighteen of nineteen appearances of the Hanna No. 1 are in columns 4 and 5 with 13 in column 5, with thirteen in column 5 or the least column.

This correlation shows a definite trend for the average values of the local stratigraphic units in the Hanna UCG area. The highest concentrations are generally found in Unit A and Unit B respectively. The moderate values are found in Unit D with the lowest values found in Unit C and in the Hanna No. 1 coal seam. This is expected for the coal as it was previously shown in the coal to overburden correlation. The trend in the overburden units, Units A, B, C and D, are probably representative of sandstone content in the unit. The unit with the highest sandstone percentage would have the lowest values due to a silicon dilution effect. Conversely, the unit with the lowest sandstone percentage (or highest siltstone/shale percentage) would have the highest values. This suggests that Unit C has the highest sandstone percentage, followed by Unit D, Unit B and finally Unit A. The depositional environments and core analysis previously discussed in this paper support this hypothesis.

3. Hanna No. 1 - Hole to Hole

The correlations for the Hanna No. 1 coal bed from hole to hole is shown in Table 21. An evaluation of this table shows a strong dominance of CH-132 and CH-134 in the higher values columns (1 and 2). CH-132 and CH-134 both have sixteen of eighteen appearances in these two columns. CH-132 has ten in the highest column and CH-134 has six. Also note that CH-132 and CH-134 do not appear in the least column. In the middle of the spectrum, CH-133 has fifteen of eighteen appearances in the middle columns (3 and 4) while CH-131 has nine of eighteen. 2HP-170 and 2HP-171 dominate the lower concentration columns (5 and 6) with twelve of eighteen appearances in these columns for 2HP-170 and sixteen of eighteen appearances for 2HP-171. The concentration trend for the Hanna No. 1 coal bed is shown diagrammatically in Figure 55.

The explanation for this strong trend may be that the arrows on Figure 55 point toward the margins of the poorly drained overbank swamp in which the Hanna No. 1 coal bed was deposited. More coal impurities would be expected as the swamp margins were approached. The ash content of the coal should increase in the direction of the arrows on Figure 55. This hypothesis is partially supported by the ash percent isogram shown in Plate VII (data taken from Table 5). A further comparison of element concentrations versus ash percent can be made by comparing the profiles for CH-133 contained in Appendix B.

Table 21. Hanna No. 1 - hole to hole correlation.

ELEMENT	HIGHEST	2	3	4	5	LEAST
Fe	134	132	133	170	131	171
Mg	132	134	131,133	---	170	171
Ca	170	171	134	133	132	131
Ti	132	134	131	133	170	171
Mn	132	134	133	170	171	131
B	132	131	134	133	170	171
Ba	132	134	131	133	171	170
Be	134	132	---	---	---	131,133,170,171
Cr	132	134	133	131	170	171
Cu	134	132,133	---	131	170	171
La	132	131,134	---	170,171	---	133
Ni	132	134	131	133,170	---	171
Pb	170	132,134	---	133	171	131
Sc	132	131,134	---	133	170	171
V	132	134	131	133	170	171
Y	134	132	133	131	170	171
Zr	134	131	132	133	170	171
Ga	134	132	133	131	170	171

HANNA NO.1 COAL

Figure 55. Diagrammatic representation of element concentration trends in the Hanna No. 1 coal seam, Hanna UCG site.

4. Local Overburden Units - Hole to Hole

Only the more dominant elements Fe, Mg, Ca, Mn, B and Ba will be used for this correlation. Table 22 shows the results. The table consists of four parts which represent Units A, B, C and D.

An evaluation of Unit A shows a dominance of CH-132 in the highest column followed by CH-131 dominating the middle columns. CH-133 and CH-134 are dominant in the least column. The basic trend of relative elemental concentrations represented is shown in Figure 56. When this trend is compared with the isopach map of Unit A in Plate II, the trend nearly bisects the lacustrine delta form represented and increases in a direction from the shore towards the lake center. The element concentrations are lower in the sandier upper delta deposits and become higher towards the more siltstone dominated lower delta and pro-delta deposits. The trend, core analysis and depositional model all support each other.

An evaluation of Unit B shows a dominance of CH-132 and CH-134 in the higher concentration columns and a dominance of CH-131 and CH-133 in the lower concentration columns. The trend represented is identical to that shown in Figure 55 for the Hanna No. 1 coal bed. When this trend is compared to the isopach map of Unit B in Plate III, the arrows representing increasing concentrations point in the direction of thinning. It is proposed that this is away from the thick, sandy channel deposits and towards the thinner silty overbank and back-swamp deposits. The geochemistry supports the proposed depositional model.

An evaluation of trends in Unit C shows a dominance of CH-131 and CH-132 in the higher concentration columns and a strong dominance of CH-133 in the least column. The trend definitely increases towards the northeast from CH-133 to CH-131 and then remains the same from CH-131 to CH-132 (Figure 57). (Note: Unit C is not present in CH-134.) The trend, when compared to the isopach map of Unit C in Plate IV, is increasing towards the thick portion of the unit. This is explained by the presence of more heavy minerals in the coarser sand of the thicker, higher energy channel deposits of the braided river system.

With Unit D present in only two of the coreholes, CH-131 and CH-132, and with the similarities of values represented, no real trend is proposed for the unit. The chart on Table 22 does show a slight dominance of CH-132 over CH-131.

5. Local Stratigraphic Units - Within Each Hole

This relative elemental concentration comparison is similar to that done for the local stratigraphic units on a site average basis in correlation #2. This correlation, however, looks at each corehole separately to identify any trends anomalous to that shown in #2, namely, Units A and B with the highest concentrations, followed by Unit D, Unit C and the Hanna No. 1 coal respectively. Only the elements Fe, Mg, Ca, Mn, B, and Ba will be used for this correlation. The results are shown in Table 23. An examination of Table 23 showed the No. 1 coal to dominate least

Table 22. Local stratigraphic units - hole to hole correlation.

UNIT A					UNIT B				
Element	Highest	2	3	Least	Element	Highest	2	3	Least
Fe	132	131,133	--	134	Fe	134	132	131	133
Mg	131,132	--	134	133	Mg	132	134	131	133
Ca	133	131	132	134	Ca	133	132	134	131
Mn	131	134	132	133	Mn	134	131	132	133
B	132	134	131	133	B	132	134	131	133
Ba	132	133	131	134	Ba	132	133	134	131

UNIT C				UNIT D		
Element	Highest	2	Least	Element	Highest	Least
Fe	131,132	--	133	Fe	132	131
Mg	131	132	133	Mg	131	132
Ca	132	131	133	Ca	131	132
Mn	131	132	133	Mn	132	131
B	131	132	133	B	132	131
Ba	132	133	131	Ba	132	131

Figure 56. Diagrammatic representation of element concentration trends in Unit A, Hanna UCG site.

Figure 57. Diagrammatic representation of element concentration trends in Unit C, Hanna UCG site.

values in all holes. The general pattern is represented fairly well in three of the four coreholes, CH-132, CH-133, and CH-134. The pattern in CH-132 is identical to the overall average pattern with element concentration values decreasing from A, B, D, C, to No. 1. CH-133 has no Unit D present but its pattern fits the trend being A, B, C, to No. 1. No real comparison can be done for CH-134 as both Unit D and Unit C are eroded away in this area. CH-134 is somewhat anomalous as Unit B seems to dominate over Unit A. CH-131 fits the general trend with Unit A being highest and the No. 1 coal being least, but Units D and C have higher concentration levels than Unit B. The patterns are shown in Figure 58.

Table 23. Local stratigraphic units - within each hole.

CH-131					CH-132				
Element	Highest	2	3	Least	Element	Highest	2	3	Least
Fe	B,D	--	A,C	--	Fe	A	B	D	C
Mg	A	D	C	B	Mg	A	B	D	C
Ca	A	D	C	B	Ca	A	B	C	D
Mn	A	C	B	D	Mn	C	D	A	B
B	D	A	B	C	B	B	A	D	C
Ba	C	A	D	B	Ba	C	B	A	D

CH-133				CH-134		
Element	Highest	2	Least	Element	Highest	Least
Fe	B	A	C	Fe	B	A
Mg	A,B	--	C	Mg	A	B
Ca	A	B	C	Ca	A	B
Mn	A	C	B	Mn	B	A
B	B	A	C	B	B	A
Ba	C	A	B	Ba	B	A

HIGHEST TO LOWEST

AVERAGE
A, B, D, C, No. 1

CH-131
A, D, C, B, No. 1

CH-132
A, B, D, C, No. 1

CH-133
A, B, C, No. 1

CH-134
B, A, No. 1

Figure 58. Graphic representation of local stratigraphic unit correlations within each hole, Hanna UCG site.

The anomaly in CH-131 is probably the result of overlapping of trends discussed in the previous correlation #4. Units A, C and D all have higher concentration values in this corehole (CH-131) as compared to the other coreholes, whereas Unit B has lower values in CH-131 compared to the others. The trend for Unit B is opposite to that for Units A, C and D, trending away from CH-131 (Figure 55) instead of towards CH-131 (Figures 56 and 57). So, Units C and D have anomalously higher values in CH-131 than does Unit B.

6. Coal to Total Overburden - Within Each Hole

This correlation is similar to that done for the site average but takes each hole separately to locate any anomalies. Inspection of the lower halves of Tables 14 through 17 shows the trends in each hole to be very similar to that shown for the whole site. However, CH-132 tends to have coal values more similar to overburden values.

7. Conclusions

From the preceding correlations, the proposed depositional environments and unit distribution patterns for the local stratigraphic units are supported. It also appears that element concentration is related to sandstone percentage. Elemental concentrations tend to be lower in lithologies with higher sandstone content due to the greater dominance of silicon in the rock. Evidently the rock lithotype has a strong effect on element concentrations and an analysis from this viewpoint would be appropriate and useful.

Lithotype Analysis

In this section the geochemistry of the Hanna UCG site will be evaluated on the basis of rock lithotype. Three lithotype groups will be discussed as follows: 1) sandstones and conglomerates, 2) silts and silty sandstones, and 3) mudstones and shales. Coals will not be discussed because their geochemistry has already been established in the previous section (correlations #1, #2, #3 and #6).

The data from CH-131, CH-132, CH-133 and CH-134 used in the previous section was used for accurate comparative value and to establish pre-burn baseline values. CH-131 and CH-132 are shown in Table 24, CH-133 and 134 are on Table 25, and an average of the four coreholes is shown in Table 26. The values in Table 26 average somewhat higher as compared to the average total overburden values shown in the bottom of Table 19 because the coal beds in the overburden units were omitted.

The lithotype correlations are shown in Tables 27-29. The average trend shown in Table 29 is a dominance of the mudstones and shales lithotype in the high column, followed by a dominance of the siltstones and silty sandstones lithotype in the middle column and a dominance of the sandstones and conglomerates lithotype in the low values column. This is shown numerically in Figure 59 verifying many of the observations in the previous section on correlations done by local stratigraphic units. The sandier lithologies exhibit a dominance toward lower concentration values. The counterpart is also true. As the sandstones become "dirtier" and silty, the concentration values tend to rise. The depositional environment speculations made for the various units in the previous section would seem to be valid hypotheses.

<u>High</u>	<u>2</u>	<u>Low</u>
*MS-11	MS-5	MS-4
SS-7	*SS-12	SS-1
SC-2	SC-3	*SC-15

Figure 59. Numeric representation of relative element concentrations in three basic lithotypes. (*-dominant lithotype)

Table 24. Semi-quantitative spectrographic analysis by lithotype for CH-131 and CH-132, Hanna UCG site.

CH-131

Lithotype (# Samples)	(.05) Fe%	(.02) Mg%	(.05) Ca%	(.002) Ti%	(10) Mn	(.5) Ag	(10) B	(20) Ba	(1) Be	(5) Co	(10) Cr	(5) Cu	(20) La	(5) Ni	(10) Pb	(5) Sc	(10) V	(10) Y	(10) Zr	(10) Ga
Sandstones & Cgls. (112)	2.13	1.06	0.96	0.22	618	*L (0.26)	28	837	*1.1	7	45	8	24	15	15	9	50	23	303	54
Silts & Silty Sands (37)	3.46	1.68	1.65	0.25	714	*L (0.06)	47	792	1.4	9	56	16	38	21	21	13	72	32	322	95
Mudstones & Shales (42)	2.70	1.20	0.21	0.26	457	*L (0.08)	60	655	1.5	9	73	29	47	30	25	15	104	30	130	96
Sandstones & Conglomerates: 21.4-24; 55-61; 71-188.5; 190-200; 207.5-220; 228.5-231; 232-240; 243-265; 311.5-313.5; 316-318; 322-324; 331-335; 341-343; 345-347; 349-353; 354.5-356; 363-371; 376-388.																				
Silts & Sands: 10-14; 17.2-19.6; 24-31; 61-71; 206-207.5; 226-228.5; 241-243; 313.5-316; 318-322; 324-331; 335-341; 343-344.6; 347-349; 353-354.5; 356-363; 371-376; 388-394.																				
Mudstones & Shales: 14-17.2; 31-40; 48.6-55; 200-206; 220-226; 231-232; 265-299.5; 394-402.																				

CH-132

Lithotype (# Samples)	(.05) Fe%	(.02) Mg%	(.05) Ca%	(.002) Ti%	(10) Mn	(.5) Ag	(10) B	(20) Ba	(1) Be	(5) Co	(10) Cr	(5) Cu	(20) La	(5) Ni	(10) Pb	(5) Sc	(10) V	(10) Y	(10) Zr	(10) Ga
Sandstones & Cgls. (109)	1.92	0.71	0.60	0.17	542	2.3	20	1171	*1.2	7	44	*5	*40	27	15	7	51	20	206	46
Silts & Silty Sands (42)	2.96	1.52	1.13	0.33	595	*L (0.17)	83	948	1.4	12	69	24	50	30	26	13	102	32	284	133
Mudstones & Shales (43)	2.94	1.50	0.39	0.33	578	*L (0.21)	103	1007	1.5	11	104	33	57	36	35	15	127	32	174	141
Sandstones & Conglomerates: 110-116; 132-133.4; 154.5-242; 249.5-302; 303-367.																				
Silts & Sands: 100-110; 116-119; 133.4-138; 242-243.5; 367-373; 392.8-395; 420-442; 448-468; 470-478.																				
Mudstones & Shales: 119-121; 138-154; 302-303; 373-392.8; 395-420; 442-448; 468-470; 478-495.																				
Lithotypes picked from Lithologic Logs in Craig and Others, 1982.)																				

Table 25. Semi-quantitative spectrographic analysis by lithotype for CH-133 and CH-134, Hanna UCG site.

CH-133																					
Lithotype (# Samples)	(.05) Fe%	(.02) Mg%	(.05) Ca%	(.002) Ti%	(10) Mn	(.5) Ag	(10) B	(20) Ba	(1) Be	(5) Co	(10) Cr	(5) Cu	(20) La	(5) Ni	(10) Pb	(5) Sc	(10) V	(10) Y	(10) Zr	(10) Ga	
Sandstones & Cgls. (49)	1.64	0.49	1.23	0.16	322	N	15	929	1.3	10	*36	*9	*43	11	22	6	31	21	209	29	
Silts & Silty Sands (4)	2.00	0.73	0.33	0.30	213	N	15	850	1.8	16	80	21	50	15	38	14	50	23	175	74	
Mudstones & Shales (18)	1.94	0.67	0.36	0.32	146	N	18	711	1.8	13	79	25	55	19	44	13	59	24	147	97	
Sandstones & Conglomerates: 19-103; 135.5-156; 215-217; 221.5-310.																					
Silts & Sands: 103-104; 109-111; 310-315.																					
Mudstones & Shales: 104-105; 111-129; 130-135; 156-179; 184-211; 217-221.5.																					
CH-134																					
Lithotype (# Samples)	(.05) Fe%	(.02) Mg%	(.05) Ca%	(.002) Ti%	(10) Mn	(.5) Ag	(10) B	(20) Ba	(1) Be	(5) Co	(10) Cr	(5) Cu	(20) La	(5) Ni	(10) Pb	(5) Sc	(10) V	(10) Y	(10) Zr	(10) Ga	
Sandstones & Cgls. (-0-)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Silts & Silty Sands (26)	3.04	1.42	0.89	0.27	730	N	69	712	1.5	12	69	24	52	35	28	14	96	35	200	124	
Mudstones & Shales (18)	3.83	1.16	0.55	0.27	737	L	77	700	1.5	11	76	28	42	31	28	13	110	29	121	140	
Sandstones & Conglomerates: None present in this local.																					
Silts & Sands: 24.5-31.5; 75-122.																					
Mudstones & Shales: 31.5-74.5; 122-123.																					

Table 26. Semi-quantitative spectrographic analysis by lithotype, Hanna UCG site.

AVERAGE																				
Lithotype (# Samples)	(.05) Fe%	(.02) Mg%	(.05) Ca%	(.002) Ti%	(10) Mn	(.5) Ag	(10) B	(20) Ba	(1) Be	(5) Co	(10) Cr	(5) Cu	(20) La	(5) Ni	(10) Pb	(5) Sc	(10) V	(10) Y	(10) Zr	(10) Ga
Sandstones & Cgls. (270)	1.96	0.82	0.86	0.19	534	1.04	22	989	1.2	8	43	7	34	19	16	8	47	21	247	46
Silts & Silty Sands (109)	3.11	1.52	1.22	0.29	654	*L	65	835	1.4	11	65	21	46	28	25	13	88	32	273	116
Mudstones & Shales (121)	2.84	1.22	0.35	0.30	495	*L (0.11)	69	795	1.5	11	85	30	51	31	32	14	106	30	147	119

Table 27. Lithotype correlations for CH-131 and CH-132, Hanna UCG site.

CH-131				CH-132			
Element	Highest	2	Least	Element	Highest	2	Least
Fe	SS	MS	SC	Fe	SS	MS	SC
Mg	SS	MS	SC	Mg	SS	MS	SC
Ca	SS	SC	MS	Ca	SS	SC	MS
Ti	MS	SS	SC	Ti	MS,SS	--	SC
Mn	SS	SC	MS	Mn	SS	MS	SC
Ag	SC	MS	SS	Ag	SC	MS	SS
B	MS	SS	SC	B	MS	SS	SC
Ba	SC	SS	MS	Ba	SC	MS	SS
Be	MS	SS	SC	Be	MS	SS	SC
Co	MS,SS	--	SC	Co	SS	MS	SC
Cr	MS	SS	SC	Cr	MS	SS	SC
Cu	MS	SS	SC	Cu	MS	SS	SC
La	MS	SS	SC	La	MS	SS	SC
Ni	MS	SS	SC	Ni	MS	SS	SC
Pb	MS	SS	SC	Pb	MS	SS	SC
Sc	MS	SS	SC	Sc	MS	SS	SC
V	MS	SS	SC	V	MS	SS	SC
Y	SS	MS	SC	Y	SS,MS	--	SC
Zr	SS	SC	MS	Zr	SS	SC	MS
Ga	MS	SS	SC	Ga	MS	SS	SC

SC - Sandstones & Conglomerates

SS - Silts & Silty Sandstones

MS - Mudstones & Shales

Table 28. Lithotype correlations for CH-133 and CH-134, Hanna UCG site.

CH-133				CH-134 (Note: No sandstones & conglomerates lithotype present.)		
Element	Highest	2	Least	Element	Highest	Least
Fe	SS	MS	SC	Fe	MS	SS
Mg	SS	MS	SC	Mg	SS	MS
Ca	SC	MS	SS	Ca	SS	MS
Ti	MS	SS	SC	Ti	SS,MS	--
Mn	SC	SS	MS	Mn	MS	SS
Ag	--	--	--	Ag	MS	SS
B	MS	SS,SC	--	B	MS	SS
Ba	SC	SS	MS	Ba	SS	MS
Be	SS,MS	--	SC	Be	SS,MS	--
Co	SS	MS	SC	Co	SS	MS
Cr	SS	MS	SC	Cr	MS	SS
Cu	MS	SS	SC	Cu	MS	SS
La	MS	SS	SC	La	SS	MS
Ni	MS	SS	SC	Ni	SS	MS
Pb	MS	SS	SC	Pb	SS,MS	--
Sc	SS	MS	SC	Sc	SS	MS
V	MS	SS	SC	V	MS	SS
Y	MS	SS	SC	Y	SS	MS
Zr	SC	SS	MS	Zr	SS	MS
Ga	MS	SS	SC	Ga	MS	SS

SC - Sandstones & Conglomerates

SS - Silts & Silty Sandstones

MS - Mudstones & Shales

Table 29. Lithotype correlations of average baseline,
Hanna UCG site.

AVERAGE			
Element	High	2	Low
Fe	SS	MS	SC
Mg	SS	MS	SC
Ca	SS	SC	MS
Ti	MS	SS	SC
Mn	SS	SC	MS
Ag	SC	MS	SS
B	MS	SS	SC
Ba	SC	SS	MS
Be	MS	SS	SC
Co	SS	MS	SC
Cr	MS	SS	SC
Cu	MS	SS	SC
La	MS	SS	SC
Ni	MS	SS	SC
Pb	MS	SS	SC
Sc	MS	SS	SC
V	MS	SS	SC
Y	SS	MS	SC
Zr	SS	SC	MS
Ga	MS	SS	SC

SC - Sandstones & Conglomerates; SS - Silts and Silty Sandstones;
MS - Mudstones and Shales

Some anomalies to the previously discussed trend are: 1) the sandstones and conglomerates lithotype has the highest average concentrations of silver and barium, and 2) the mudstones and shales lithotype has the lowest average concentrations for calcium, manganese, barium and zirconium (see Table 29).

From corehole to corehole, CH-131, CH-132 and CH-133 (Tables 27 and 28) match the average trend very well. CH-134 (Table 28) contains no rocks of the sandstones and conglomerates lithotype but does provide a good relative comparison of the silts and silty sandstones lithotype with the mudstones and shales lithotype. In this particular corehole the trend is somewhat anomalous as the two lithotypes are equally represented in both columns.

Analytical Analysis

General

Several hundred analytical analyses were done on samples from the Hanna UCG Site. A complete sequence was done on CH-133 from 19 ft. to the bottom of the Hanna No. 1 coal (346 ft.). This core section was analyzed to establish baseline values for Unit C, Unit B, Unit A and the Hanna No. 1 coal. No Unit D is present in CH-133. One-hundred and five samples were analyzed and averaged. The results are shown in Table 30. Aluminum, lithium, magnesium, rubidium, silicon, sodium, and potassium were analyzed using the Atomic Absorption Spectrophotometer. Phosphorous analyses were completed using a colorimetric method. The sulfur forms were determined using gravimetric methods.

Correlations

The coal bed, as expected, is highest in Sb, Li, P, SO_4 , S(tot), and $\text{S(H}_2\text{O)}$. It is also highest in CuO , PbO , and Fe^{+2} . The value obtained for Fe^{+2} is 1.58 percent as compared to 0.90 percent obtained for Fe in the spectrographic analysis (Table 16). An interesting observation is that the values for CuO , PbO , and ZnO are significantly higher compared to those for CuS , PbS , and ZnS . The coal bed has the lowest values for Al, Ca, Pb(tot), PbS , Mg, K, Rb, Si, S, Zn(tot), ZnO , and ZnS . The low values for most of these elements is due to the low content of feldspars, micas, and quartz as compared to the overburden units.

Among the overburden units, Unit A is highest in Ca, Fe^{+2} , Pb(tot), PbS , Mg, P, Rb, the sulfurs, Zn(tot), and ZnS . It is lowest in Al, Li, Si, Na, and ZnO . This is due to a higher percentage of siltstones and 'dirty' sandstones in this unit as compared with Units B and C. The high sulfur content is indicative of a more reducing environment of deposition, and supports the lacustrine depositional model and core descriptions of Unit A.

Unit B is highest in Al, CuO , CuS , Si, and ZnO . It is lowest in Ca, K, Rb, Zn(tot), and ZnS . This represents a somewhat less reducing environment than Unit A. High Al content is probably due to the higher

Table 30. Analytical analysis of CH-133, Hanna UCG site.

Unit (# Samples)	Al	Ca	CuO	CuS	Fe ⁺²	Pb _{tot}	PbO	PbS	Li	Mg	P	K
Unit C (23)	7.8%	0.68%	*3.8	*13.1	0.19%	26	*3.0	26	29.8	0.80%	*62	2.56%
Unit B (27)	8.7%	0.55%	*9.3	32.3	1.01%	32	*3.0	30	20.5	1.10%	*71	1.67%
Unit A (23)	7.8%	2.73%	*8.0	15.3	1.35%	52	*3.0	49	10.9	3.09%	*77	2.25%
No. 1 (32)	4.1%	0.29%	25.6	19.4	1.58%	26	26	9	94.0	0.39%	152	0.32%

Unit (# Samples)	Rb	Si	Na	SO ₄	S _{tot}	S _{H₂O}	S _{ide}	Sb	Zn _{tot}	ZnO	ZnS
Unit C (23)	21	35.2%	1.56%	0.51%	0.30%	0.22%	0.62%	*1.0	51	38	19
Unit B (27)	20	35.2%	0.58%	0.68%	0.42%	0.22%	0.79%	*1.0	44	46	11
Unit A (23)	51	32.7%	0.52%	0.63%	0.50%	0.29%	0.90%	*1.0	65	36	33
No. 1 (32)	*13	6.8%	0.88%	1.53%	0.62%	0.48%	0.24%	44	36	34	*7

Units picked from lithologic log in Craig et al, 1982. Section continuous from 19 ft. to 346 ft.

* - Values in the data denoted with < were valued equal to the number (e.g. <2.0 = 2.0).

percentage of shales and mudstones in the unit as compared with Units A and C. This proposed higher percentage of shales and mudstones in Unit B is supported by depositional models and core descriptions. Unit B is generally bounded on both the top and bottom by thick (10'-50') shale beds whereas Unit A generally has only a thin shale underneath. Unit C has practically no shale in the sequence.

Unit C is highest in Li, K, Si and Na and is lowest in Al, CuO, CuS, Fe⁺², Pb(tot), PbS, Mg, P, and the sulfurs. These element concentrations are representative of the high sand content of this unit with practically no silts or shales to add Al, Mg, P, and S. The Li, K and Na is probably representative of the heavy mineral constituents in the conglomerates and coarse sands of the unit as compared to the finer-grained character of Units A and B where these minerals would not be so abundant.

The Hanna No. 1 coal was analyzed in five baseline coreholes (CH-131, CH-132, CH-133, CH-134, and 2HP-170) and the results are shown in Table 31. Average baseline values for the Hanna UCG Site are shown on the bottom row. The trends among the five baseline coreholes are shown in Figure 60.

CH-131 tends towards slightly lower elemental concentrations than CH-132, and the higher Si content suggests that CH-132 was nearer the swamp margin receiving a higher sediment influx. The relationship of CH-133 to CH-134 is opposite of that represented in Figure 55 and Table 21. Previous correlations showed a strong tendency for CH-134 to have higher concentrations than CH-133, but CH-133 is higher than CH-134 in this analysis for nearly all elements. In fact, CH-133 represents the highest concentration values for many elements over all five coreholes. CH-133's highest concentration values for Al, Li, Mg, Si and Na strongly suggest that this locale was so situated in the depositional environment as to have received the highest influx of detrital sediments (quartz, plagioclase, feldspar, etc.). The trend for the Hanna No. 1 coal represented in this analysis is shown in Figure 60 (compare to Figure 55). This anomaly may be due to the poorer quality data of the analytical analyses as compared to the semi-quantitative spectrographic analyses.

Table 31. Analytical analysis of the Hanna No. 1 coal, Hanna UCG site.

Corehole (# Samples)	Al	Ca	CuO	CuS	Fe ⁺²	Pb _{tot}	PbO	PbS	Li	Mg	P	K
CH-131 (17)	1.3%	0.71%	11.4	*10.4	0.29%	18	14	13	40.0	0.17%	*50	0.17%
CH-132 (18)	1.6%	0.57%	12.5	10.5	0.72%	16	16	11	63.8	0.17%	*50	0.23%
CH-133 (32)	4.1%	0.29%	25.6	19.4	1.58%	26	26	9	94.0	0.39%	152	0.32%
CH-134 (29)	2.2%	0.70%	20.7	12.4	0.75%	15	15	10	74.8	0.35%	*50	0.37%
2HP-170 (28)	4.2%	0.64%	*3.0	13.5	0.73%	30	*3	30	*5.0	0.33%	*50	0.55%
Average (124)	2.9%	0.56%	15.5	13.9	0.89%	22	15	15	57.6	0.31%	*76	0.35%

* - values in the data denoted with < were valued equal to the number (e.g. <2.0 = 2.0).

Corehole (# Samples)	Rb	Si	Na	SO ₄	S _{tot}	S _{H2O}	S _{ide}	Sb	Zn _{tot}	ZnO	ZnS
CH-131 (17)	41	3.2%	0.23%	--	--	--	--	*1.0	72	24	56
CH-132 (18)	53	3.8%	0.30%	--	--	--	--	*1.0	62	25	44
CH-133 (32)	*13	6.8%	0.88%	1.53%	0.62%	0.48%	0.24%	44	36	34	*7
CH-134 (29)	65	5.0%	0.28%	--	--	--	--	*1.0	64	37	35
2HP-170 (28)	*1	0.8%	0.32%	2.44%	1.11%	0.74%	0.92%	*1.0	87	*12	80
Average (124)	*32	4.1%	0.44%	1.95%	0.85%	0.60%	0.56%	*12	63	27	42

* - Values in the data denoted with < were valued equal to the number (e.g. <2.0 = 2.0).

Note: Only 60 samples were used for SO₄, S_{tot}, S_{H2O}, S_{ide}.

HANNA NO.1 COAL ANALYTICAL ANALYSIS TRENDS

Figure 60. Diagrammatic representation of analytical analysis trend in the Hanna No. 1 coal seam, Hanna UCG site.

SUMMARY

The structure of the Hanna UCG site is characterized by beds dipping gently to the northeast. An east-west fault system near the center of the site interrupts this general trend. This system was found to be a graben complex with numerous antithetic faults (Fig. 9).

The joint sets present in the coal in order of apparent prominence are: 1) N60-68°E, 2) N20-30°E, and 3) N76-85°W. These sets either strike perpendicularly or parallel to the dominant direction of faulting (Figure 14).

The Hanna Formation above the Hanna No. 1 target coal bed may be divided into four broad local stratigraphic units (from oldest to youngest). 1) Unit A - a lacustrine delta and lacustrine deposit; 2) Unit B - a lower meandering river with floodplain deposit; 3) Unit C - a braided river deposit; and 4) Unit D - an upper meandering river with floodplain deposit (Figs. 15 and 20). The Hanna No. 1 coal bed was deposited in a poorly drained swamp environment.

Unit A of the overburden at the Hanna UCG site may be divided into five basic rock types. These are in order of prevalence: 1) calcareous sandstone (72.2 percent), 2) calcareous siltstone (15.1 percent), 3) calcareous shale (8.1 percent), 4) ironstone (3.9 percent), and 5) carbonaceous shale (0.7 percent). The bulk mineralogy of the overburden is dominated by Quartz (53.1 percent). Other minerals are in the 3-8 percent range and include kaolinite, K-feldspar, dolomite, siderite, plagioclase, mica and calcite. Quartz dominates in all rock types except the ironstone lithofacies which is dominated by siderite (81.3 percent).

The sandstones from overburden units A, B and C have distinct compositional and textural characteristics. The lacustrine delta sandstones of Unit A are composed dominantly of quartz and are texturally the most mature. The point bar sandstones of Unit B contain lesser quartz and more lithic fragments and are texturally less mature. The braided river sandstones of Unit C have even less quartz and more lithic fragments and are texturally the most immature. These characteristics are indicators of both depositional energy and their proximity to the sediment source.

The proximate analysis of 176 samples of the Hanna No. 1 coal bed shows the average ash content is 27.4 percent, average moisture is 8.4 percent, average volatile matter is 32.7 percent, and the average fixed carbon content is 31.5 percent.

Minerals present in the coal ash in order of abundance are kaolinite (23.5 percent), illite (22.6 percent), quartz (18.1 percent), k-feldspar (3.1 percent), gypsum (2.9 percent), aragonite (2.0 percent), siderite (1.5 percent), calcite (1.4 percent), pyrite (0.8 percent), plagioclase (0.8 percent), rutile (0.5 percent), and goethite (0.2 percent). 22.6 percent of the minerals in ash were amorphous or unidentified. A table showing the elemental analysis of the coal is provided.

The forms of sulfur in the coal are organic (0.44 percent), pyritic (0.19 percent), and sulfate (0.01 percent). Seven types of pyrite were identified and include in order of abundance: dispersed euhedra, clustered euhedra, irregular, blebs, fracture filling, framboids, and dendritic.

A maceral analysis was done on the coal with vitrinite being the most abundant followed by exinite and inertinite respectively. Maceral types present include vitrinite (90.3 percent), pseudovitrinite (1.5 percent), exinite (5.5 percent), resinite (0.6 percent), semi-fusinite (1.0 percent), semi-macrinite (0.1 percent), fusinite (0.3 percent), macrinite (0.1 percent), micrinite (0.5 percent), and sclerotinite (0.1 percent). The classification of Hanna coals fall predominantly into the bituminous high volatile C class using ASTM, mean-maximum vitrinite reflectance, and percent ash methods.

Semi-quantitative spectrographic and analytic geochemical analyses were done on the overburden rocks and coal. Six correlative relationships were established for the element concentrations of the semi-quantitative spectrographic analysis for the local overburden units and the coal. 1) The total average overburden values are dominantly higher than the values for the total average coal probably due to a higher percentage of carbon in coal than silica in the overburden rocks. 2) The total average concentration values in Unit A are generally higher than Unit B followed by Unit D and Unit C due to percentage of sandstone in the Unit. Therefore, Unit C (lowest concentration values) has the highest sandstone percentage followed by Unit D, Unit B and Unit A (highest concentration values) with the lowest sandstone percentage. 3) The element concentration trends for the Hanna No. 1 coal from hole to hole show an increase from the middle outward. Perhaps this direction of increase is towards the swamp margins where more impurities would be expected. 4) Unit A increases concentration values towards the northeast which is towards the delta front of the lacustrine delta. Unit B trends are very similar to that of the Hanna No. 1 coal and represents an increase in element concentrations away from the channel or towards the floodplain. Unit C, like Unit A, also represents an increase in element concentrations towards the northeast which is towards the thickest deposits of the braided stream where the presence of more lithic fragments is expected. No trend was established for Unit D. 5) The trend of local stratigraphic units within each hole is essentially identical to the trend described in #2 above, that is highest concentrations in Units A and B followed by Unit D and Unit C respectively. 6) The relationship of concentration values in the coal as compared to the total overburden from hole to hole was very similar to that shown in #1 above, that is lower concentrations for the coal.

The spectrographic analysis was also done by lithotype, with the mudstones and shales lithotype having the highest average element concentrations followed by the siltstones and silty sandstones lithotype and the sandstones and conglomerates lithotype respectively. The proposed inverse relationship of element concentrations to percentage of sandstone in the overburden units is well supported by this analysis.

The analytical analysis was done by stratigraphic unit. The coal, as expected, was highest in Li, P, SO_4 , S(tot) and S(H₂O). It was lowest in Al, Mg, K, Rb, Si, and Sulfide due to the low content of feldspars and quartz minerals as compared to the overburden units. Among the overburden units, Unit A was highest in Mg, P, Rb and the sulfurs and lowest in Al, Li and Si due to a higher percentage of siltstones and 'dirty' sandstones as compared to Units B and C. Unit B was highest in Al and showed middle values for the other elements due to a higher percentage of shales and mudstones in the unit as compared with Units A and C. Unit C was highest in Li, K, Si, and Na and was lowest in Al, Mg, P and the sulfurs due to the very high sand content of this unit with practically no siltstones or shales to add Al, Mg, P and S. No data on Unit D was available. The average baseline values of the Hanna No. 1 coal bed were calculated from 124 samples from five core-holes.

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APPENDIX A

Depth Intervals from Geophysical Logs of Local
Stratigraphic Units at the Hanna UCG Site Area

Well No.		D	C	B	A	Hanna No. 1
Ground Elev.	(Thickness, ft)	(Thickness, ft)	(Thickness, ft)	(Thickness, ft)	(Thickness, ft)	(Thickness, ft)
CH 3	6,979	0-131 (131)	131-297 (166)	297-382 (85)	382-467 (85)	467-495 (28)
CH 4	7,023	--	0-48 (48)	48-153 (105)	153-268 (115)	268-295 (27)
CH 131	6,987	0-55 (55)	55-202 (147)	202-302 (100)	302-405 (103)	405-434 (29)
CH 132	6,959	0-154 (154)	154-368 (214)	368-425 (57)	425-497 (72)	497-526 (29)
CH 133	7,004	--	0-106 (106)	106-223 (117)	223-317 (94)	317-348 (31)
CH 134	7,010	--	--	0-67 (67)	67-123 (56)	123-155 (32)
2 HP 170		--	0-51 (51)	51-158 (107)	158-273 (115)	273-303 (30)
2 HP 171		--	0-47? (47)	47-152 (105)	152-264 (112)	264-293 (29)
2 HP 172		--	0-46 (46)	46-156 (110)	156-266? (110)	266?-*
2 HP 173		--	0-45 (45)	45-155 (110)	155-263 (108)	263-291 (28)
2 HP 174		--	0-46 (46)	46-160 (114)	160-271 (111)	271-298? (27)
2 HP 175		--	0-49 (49)	49-163 (114)	163-270 (107)	270-300 (30)
2 HP 176		--	0-45 (45)	45-160 (115)	160-270? (110)	270?-*
2 HP 177		--	0-44 (44)	44-158 (114)	158-271? (113)	271?-*
2 HP 178		--	0-50 (50)	50-163 (113)	163-268 (105)	268-297 (29)
2 HP 180		--	0-40 (40)	40-155 (115)	155-260 (105)	260-290? (30)
2 HP 181		--	0-48 (48)	48-162 (114)	162-273? (111)	273?-*
2 HP 182		--	0-42 (42)	42-155 (113)	155-266? (111)	266?-294 (28)
CBO 142	6,950	--	0-27 (27)	27-120 (93)	120-186 (66)	186-214 (28)
CBO 143	6,964	0-145 (145)	145-366 (221)	366-418 (52)	418-493 (75)	493-524 (31)
CBO 144	7,013	--	0-19? (19)	19?-94? (75)	94?-134? (40)	134?-158 (24)
CBO 145	6,993	--	0-105 (105)	105-230 (125)	230-344 (114)	344-372 (28)
CBO 146	6,992	0-84 (84)	84-218 (134)	218-315 (97)	315-425 (110)	425-455 (30)
CBO 147	7,019	--	0-71 (71)	71-184? (113)	184?-289 (105)	289-319 (30)
CBO 148	7,020	--	0-70 (70)	70-179 (109)	179-287 (108)	287-317 (30)
CBO 149	7,018	--	0-66 (66)	66-174 (108)	174-281 (107)	281-312 (31)
CBO 150	7,017	--	0-61 (61)	61-170 (109)	170-276 (106)	276-308 (32)
CBO 151	7,012	--	--	0-61 (61)	61-132 (71)	132?-157 (25)
CBO 152	6,977	0-68 (68)	68-197 (129)	197-331 (134)	331-374 (43)	374-402 (28)
CBO 153	7,014	--	0-4? (4)	4?-130 (126)	130-184 (54)	184-215 (31)
CBO 154	6,946	0-102? (102)	102-267 (165)	267-317? (50)	317-*	*
(OVB 156)						
CBO 154B	6,951	0-77 (77)	77-242 (165)	242-291 (49)	291-372 (81)	372-402 (30)
CBO 155	6,951	--	0-35 (35)	35-141 (106)	141-191 (50)	191?-219 (28)
OVB 135	6,952	--	0-30 (30)	30-126? (96)	126-*	*
OVB 136	6,952	0-66 (66)	66-219 (153)	219-*	*	*
OVB 137	6,990	0-82 (82)	82-*	*	*	*
OVB 138	6,978	0-67 (67)	67-178? (111)	178?-*	*	*
OVB 139	7,013	--	0-2? (2)	2-132 (130)	132-*	*
OVB 140	7,019	--	0-76 (76)	76-181? (105)	181?-*	*
OVB 141	6,963	0-150 (150)	150-*	*	*	*

? - pick is approximate or indistinct; * - insufficient TD

NOTE: Exact footage may not correlate from logs to cores.
Picks for UP wells are from driller's logs.

Well No.	D	C	B	A	Hanna No. 1
Ground Elev. (Thickness, ft)	(Thickness, ft)	(Thickness, ft)	(Thickness, ft)	(Thickness, ft)	(Thickness, ft)
I-1	0-57? (57)	57-187 (130)	187-297 (110)	297-399 (102)	399-*
I-3	0-56? (56)	56-167 (111)	167-269 (102)	269-365 (96)	365-*
I-4 6,990	0-56? (56)	56-176 (120)	176-280 (104)	280-384 (104)	384-*
I-6 6,992	0-54? (54)	54-156 (102)	156-252 (96)	252-353 (101)	353-*
I-7	0-49? (49)	49-153 (104)	153-257 (104)	257-349? (92)	349?-*
I-8 6,994	0-38? (38)	38-156 (118)	156-259 (103)	259-355? (96)	355?-*
I-9 6,992	0-50? (50)	50-158 (108)	158-253 (95)	253-362? (109)	362?-*
I-10	0-38? (38)	38-155 (117)	155-263? (108)	263?-357 (94)	357-*
I-11	0-36? (36)	36-150 (114)	150-240 (90)	240-349 (109)	349-*
I-11A	0-25? (25)	25-150 (125)	150-238 (88)	238-345 (107)	345-*
I-12 6,997	0-36? (36)	36-150 (114)	150-242 (92)	242-342? (100)	*
I-13	0-33? (33)	33-148 (115)	148-244 (96)	244-356? (102)	356?-*
I-15	0-53? (53)	53-171 (118)	171-264 (93)	264-361? (97)	361?-*
H2-1 7,027	--	0-54 (54)	54-174 (120)	174-*	*
H2-2 7,020	--	0-71 (71)	71-192 (121)	192-284 (92)	284-315 (31)
H2-3 7,025	--	0-56 (56)	56-178 (122)	178-262 (84)	262-*
II-S1	--	0-46 (46)	46-162? (116)	162-262 (100)	262-297? (35?)
II-1 7,028	--	0-60 (60)	60-178 (118)	178-274 (96)	274-*
II-2	--	0-51 (51)	51-165 (114)	165-270 (105)	270-*
II-3	--	0-51 (51)	51-165 (114)	165-260? (95)	260-?
II-4	--	0-55 (55)	55-166 (111)	166-267 (101)	267-291? (24)
II-5 7,024	--	0-50 (50)	50-158 (108)	158-272 (114)	276-*
II-6 7,027	--	0-44 (44)	44-156 (112)	156-263 (107)	263-294 (31)
II-7	--	0-51 (51)	51-158 (107)	158-267 (109)	267-296? (29)
II-8	--	0-45 (45)	45-155 (110)	155-263 (108)	263-292 (29)
II-20	--	0-55 (55)	55-165 (110)	165-276 (111)	276-307 (31)
III-1	--	--	0-96? (96)	96-158 (62)	158-*
III-2	--	--	0-94 (94)	94-155? (61)	155-185? (30?)
III-3	--	--	0-93? (93)	93-*	*
III-4	--	--	0-90? (90)	90-*	*
III-5	--	--	0-92? (92)	92-*	*
III-6	--	--	0-92? (92)	92-158 (66)	158-198 (30)
III-7	--	0-31? (31)	31-122 (91)	122-168 (46)	168-*
III-8	--	0-33 (33)	33-124 (91)	124-169 (45)	169-196 (27)
III-9	--	0-35 (35)	35-127 (92)	127-171 (44)	171-*
III-10	--	0-4 (4)	4-110 (106)	110-163 (53)	163-*
III-11	--	0-30 (30)	30-126 (96)	126-169 (43)	169-*
III-12	--	0-26 (26)	26-126 (100)	126-170 (44)	170-*
III-13	--	0-5 (5)	5-113 (108)	113-169 (56)	169-*
IV-3 7,000	--	0-130 (130)	130-235 (105)	235-332 (97)	322-360? (28)
IV-4	--	0-112 (112)	112-220 (108)	220-322 (102)	322-350 (28)
IV-8 6,998	--	0-124 (124)	124-226 (102)	226-326 (100)	326-*
CH-212	--	0-62 (62)	62-177 (115)	177-276 (99)	276-306 (30)
CH-215	--	0-76 (67)	67-162 (95)	162-260 (98)	260-? (?)

Well No.	D	C	B	A	Hanna No. 1
Ground Elev.	(Thickness, ft)	(Thickness, ft)	(Thickness, ft)	(Thickness, ft)	(Thickness, ft)
UP 44 Est. 6,985	--	0-89 (89)	89-226 (137)	226-296 (70)	296-326 (30)
UP 45 Est. 7,035	--	0-34 (34)	34-157 (123)	157-210 (53)	210-240 (30)
UP 46 Est. 6,985	--	0-83 (83)	83-195 (112)	195-281 (86)	281-311 (30)
UP 47 Est. 6,980	0-47 (47)	47-155?(108)	155?-309 (154)	309-344 (35)	344-367 (23)
UP 50 Est. 6,975	0-147 (147)	147-310(163)	310-401 (91)	401-465 (64)	465-493 (28)

APPENDIX B

Element and Ash Concentration Profiles of the Hanna No. 1
Coal Bed for CH-133, Hanna UCG Site

ALUMINUM

CH-133

CH-133

CH-133

CH-133

CH-133

CH-133

CH-133

MAGNESIUM

CH-133

CH-133

CH-133

CH-133

SODIUM

CH-133

CH-133

CH-133

CH-133

CH-133

CH-133

ASH

CH-I33

APPENDIX C

Structural Contour Map on Top of the Hanna No. 1
Coal Bed Using 1983 Seismic Data
(After Berkman and Orange)

CONTOUR INTERVAL = 50 FT.

FAULT-
DOWN SIDE

ELEVATION — 6700 —

SCALE