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**OVERBURDEN CHARACTERIZATION AND
POST-BURN STUDY OF THE HANNA IV,
UNDERGROUND COAL GASIFICATION SITE,
WYOMING, AND COMPARISON TO OTHER
WYOMING UCG SITES**

By
**B.A. Marcouiller
L.K. Burns
F.G. Ethridge**

November 1984

Work Performed Under Contract No.: DE-AS20-83LC11010

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
Colorado State University
Fort Collins, Colorado

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ABSTRACT

Analysis of 21 post-burn cores taken from the Hanna IV UCG site allows 96 m (315 ft) of overburden to be subdivided into four local stratigraphic units. The 7.6 m (25 ft) thick Hanna No. 1 coal seam is overlain by a laterally discontinuous, 3.3 m (11 ft) thick shaley mudstone (Unit A') in part of the Hanna IV site. A more widespread, 30 m (90 ft) thick well-indurated sandstone (Unit A) overlies the A' unit. Unit A is the roof rock for both of the Hanna IV cavities. Overlying Unit A is a 33 m (108 ft) thick sequence of mudstone and claystone (Unit B), and the uppermost unit at the Hanna IV site (Unit C) is a coarse-grained sandstone that ranges in thickness from 40 to 67 m (131 to 220 ft). Two elliptical cavities were formed during the two phases of the Hanna IV experiment. The larger cavity, Hanna IVa, is 45 x 15 m in plan and has a maximum height of 18 m (59 ft) from the base of the coal seam to the top of the cavity; the Hanna IVb cavity is 40 x 15 m in plan and has a maximum height of 11 m (36 ft) from the base of the coal seam to the top of the cavity.

The rock strata at the Hanna site dip gently (6°) to the northeast, and a prominent graben system cuts the area. The Hanna IV cavities lie in this graben system; however, only one of the faults is near the cavity and this fault has no measurable displacement at the cavity site. The presence of the fault likely had an effect on the operation of the Hanna IVb experiment, however.

Rocks taken from within the burn cavity show a layering that has formed during and after the cavity formation. The lowermost unit is char, and this is overlain by buchite and paralava breccias that contain the highest temperature minerals found in the cavities. The minerals mullite, cristobalite, cordierite, tridymite, plagioclase (oligoclase and andesine) and sanidine in glass-rich paralava and buchite breccia indicate that they formed at temperatures in excess of 1200°C . In the upper part of the cavity, hornfels is the dominant rock type and the high temperature minerals listed above are not commonly found in this zone. A suite of rocks taken from the intact roof of the cavities contained the low temperature mineral kaolinite in samples as close as 8 cm to the cavity ceiling indicating that temperatures did not exceed 550°C in overburden just above the cavity.

Geotechnical tests indicated that the Hanna IV overburden rocks were moderately strong to strong, based on the empirical classification of Broch and Franklin (1972), and a positive, linear correlation exists between rock strength and volume percent calcite cement. There is an inverse linear correlation between rock strength and porosity for the Hanna IV overburden rocks.

The rock strength of overburden at the Hanna IV site is about the same as at the Hanna II site, which is expected since they are essentially the same units. The Rawlins overburden, especially the unit that forms the roof rock of the cavity at Rawlins, is slightly stronger than the overburden at the Hanna II site. In contrast, the overburden at the Hoe Creek III site is an order of magnitude weaker than that at the Hanna II site. These comparisons help to explain the roof rock failure at Hoe Creek, and the relative stability of the roof rock at the two Hanna sites and the Rawlins site.

SUMMARY

Post-burn core and geophysical well log analyses of the Hanna IV UCG site overburden confirm and refine the results and interpretations of Craig, et al., 1982, in terms of overburden characterization.

The overburden averages 96 m (320 ft) in thickness above the Hanna No. 1 coal seam at the Hanna IV site. It consists of a sequence of sandstones, siltstones, and mudstones which are divided into 4 local lithologic units on the basis of differences in lithology and sedimentary structures.

Unit C, the uppermost unit, consists of coarse sandstone with planar and trough cross-bedding. Unit C truncates underlying unit B, a sequence of mudstones and claystones with lesser amounts of ripple and trough cross-stratified siltstones. Unit B grades into unit A, which forms the roof rock to the burn cavities. Unit A consists of fine-grained sandstones with interbedded siltstones and mudstones. Sedimentary structures include high angle foreset beds and trough and ripple cross stratification. Unit A has a gradational contact with unit A', a thin mudstone layer which directly overlies the Hanna No. 1 coal seam in most core locations. Its contact with the seam is gradational to abrupt.

Unit C ranges in thickness from 39.6 m (130 ft) to 67.4 m (221 ft) in thickness. The sandstones comprising this unit form wedge-shaped deposit which strikes northwest-southwest through the study area, thinning to the south and west. Unit B ranges in thickness from less than 12.2 m (40 ft) to greater than 39.6 m (130 ft). Sandstones in this unit make up a northwest southeast trending belt-shaped deposit. Units A and A' in a combined thickness range from less than 9.1 m (30 ft) to greater than 33.5 m (110 ft). The sandstones form a fan-shaped deposit which spreads in an easterly to northeasterly direction from the west central portion of the study areas. These geometries are refined, but basically remain unchanged from those presented by Craig, et al. (1982).

The interpretations of the depositional environments of each of the local lithologic units remains unchanged from those of Craig, et al. (1982). The coarse-grained sandstones of unit C represent a braided stream environment. The finer grained unit B represents a lower meandering river and floodplain deposit. The fine-grained sandstones of unit A make up a lacustrine deltaic deposit overlying the bottomset mudstones of unit A'.

The stratigraphic units dip to the northeast at $<6^{\circ}$ at the Hanna IV experimental site. The process wells are situated in a graben structure, and a fault, which does not offset the top of the coal seam, was identified between process wells 7 and 4.

Two reactor cavities were formed as the result of the two-phased experiment. The total thickness of the lithologic unit directly overlying the coal seam, unit A', collapsed into the cavity in most all of the cores studied. The cavities were contained in unit A, which experienced limited collapse into the cavities.

The thermal effects of the overburden are seen in the altered rocks found inside of the two burn cavities. High temperature minerals identified by petrographic, X-ray diffraction, and SEM analyses of paralava and buchite pyrometamorphic rock samples taken from the burn cavities include: mullite, cristobalite, tridymite, cordierite, plagioclase, and glass. Based on the minerals present, temperatures of over 1200°C were obtained in the lower part of the burn cavities. The overlying zone of hornfels was not formed at such high temperatures. Clay mineral studies of rock samples taken from just above the cavity roofs indicate that temperatures did not exceed 550°C in overburden within centimeters of the roof.

Geotechnical tests quantitatively distinguished the Hanna IV, Hanna II, and Rawlins sites, which experienced limited overburden collapse, from the Hoe Creek III site, which experienced collapse extending to the ground surface. The point-load index and uniaxial compressive strength values are the basis for classifying Hoe Creek III overburden units as 'very low strength' and 'very weak'. Conversely, the overburden units at the Hanna and Rawlins sites are comprised of 'high strength' rocks.

The integrity of the roof rocks of the Hanna and Rawlins sites, in terms of limited collapse, is attributable to the relatively high volume percent of calcite cement and low volume percent porosity and clay cement in the overburden units. The close well-spacing relative to the thickness, as well as the lateral and vertical homogeneity of the overburden units may have also contributed to the successful outcome of these experiments. In contrast, the Hoe Creek III overburden was unstable due to the high volume percents of porosity and clay cement and low volume percent calcite cement comprising the roof rock units. In addition, the wide well-spacing relative to the total overburden thickness at the Hoe Creek III site contributed to the instability of the cavity roof.

INTRODUCTION

A total of four underground coal gasification (UCG) experiments have been performed on the Hanna No. 1 coal seam, the last of which, Hanna IV phases a and b, was completed in 1979. It is this experimental site with which this report is concerned.

Previous studies by Craig, et al. (1982), Ethridge, et al. (1983a), and Ethridge, et al. (1983b) provide data and interpretations on the nature, distribution, and mineralogical and textural characteristics of the overburden, underburden and pyrometamorphosed rock units for the Hanna II, Hoe Creek III, and Rawlins (North Knobs) UCG sites respectively.

The study reported here provides: 1) data which updates the interpretation of structure, stratigraphy and distribution of the overburden units and coal beds at the Hanna UCG site made during the Hanna II study; 2) the location and dimensions of the two burn cavities formed at Hanna IV and the distribution of char, paralava, rubble, and void space within these cavities; 3) data on the mineralogical and textural characteristics of the unaltered and altered overburden and pyrometamorphic rocks found in post-burn core; 4) data on geotechnical properties of altered and unaltered core samples from the Hanna IV, Hanna II, and Hoe Creek III sites.

The data and interpretations presented in this report are based on detailed studies of twenty-one (21) post-burn cores and geophysical logs from these drill holes. Lithologic logs of all core are presented in Appendix A along with a key to all lithologic, sedimentary structure and accessory symbols used in the text illustrations.

OBJECTIVES AND SCOPE OF INVESTIGATION

The objectives of this study were to: 1) integrate new data collected on the sedimentology of the overburden lithologic units with data previously collected from the Hanna II site; 2) delineate the location and dimensions of the reactor cavities and the distribution of char, pyrometamorphosed rock, rubble, and void space within the Hanna IV cavities; 3) determine the temperatures reached in the cavities and in the adjacent overburden; 4) determine the geotechnical properties of the overburden units at the Hanna IV, Hanna II, and Hoe Creek III sites and relate these to measurable lithologic and technological parameters and relative roof rock stability at the three sites; and 5) compare results of objective four (4) with those of a similar study of the Rawlins (North Knobs) UCG site.

The investigation included:

1. lithologic descriptions of cores from twenty-one (21) post-burn drill holes at the Hanna IV site;
2. revision of isopach and isolith maps and re-evaluation of the trend and geometry of the overburden rock units;
3. collection of textural and mineralogical data from unaltered overburden and pyrometamorphosed overburden and cavity materials;
4. determination of the extent of thermal alteration of the Hanna IV overburden on the basis of changes in clay mineralogy;
5. determination of the temperatures reached in the burn cavities during the experiment on the basis of pyrometamorphic mineralogical relationships;
6. determination of strength characteristics of the lithologic units on the basis of geotechnical tests performed on core samples from each site.

SITE GEOLOGY

Regional Setting and Stratigraphy

The Hanna IV UCG site is located in the central portion of the Hanna Basin, a deep intermontane depression containing up to 10.7 km (35,000 ft) of sediment in south-central Wyoming (Fig. 1). The basin (Fig. 2) is bounded by the Shirley, Freezeout and Granite Mountains to the north, the Medicine Bow Mountains to the south, and the Rawlins Uplift to the west. A structural high separates the Hanna Basin from the Carbon Basin on the east (Dobbin, 1929).

The Paleocene-Eocene Hanna Formation, which contains the Hanna No. 1 coal bed is the fourth oldest of five Tertiary formations which crop out within the basin. It is underlain, unconformably, by the Paleocene to Upper Cretaceous Ferris Formation (Fig. 3). Sedimentary rocks comprising the Hanna Formation consist of a 731.5 m (2,400 ft) to 2438.4 m (8,000 ft) sequence of non-marine conglomerates, sandstones, siltstones, mudstones, and coal. The Hanna No. 1 coal seam, the subject of the Hanna IV UCG experiment, is just one of 30 coal beds greater than .9 m (3 ft) thick in the Hanna Formation.

Overburden sedimentary rocks above the Hanna No. 1 coal bed at the Hanna IV UCG site (Fig. 3, interval studied) are the principal rocks studied in this research effort.

Figure 1. Generalized map of the state of Wyoming showing the location of the Hanna II and IV, Hoe Creek III and Rawlins UCG sites.

Figure 2. Location map of Hanna UCG site, SW 1/4, Section 29, and E 1/2, SE 1/4, Section 30, T22N, R81W, Carbon County, Wyoming. (from Craig, et al., 1982).

Figure 3. Late Cretaceous and Early Tertiary stratigraphy of the Hanna Basin, south-central Wyoming and study interval (modified from Dobbin, et al., 1929).

Local Stratigraphic Units

Craig, et al. (1982) divided the overburden above the Hanna No. 1 coal seam at the Hanna II UCG site into 4 local units based upon characteristic lithologies and sedimentary structures. These units were designated D through A from the ground surface down to the No. 1 coal bed. Because of the proximity of the Hanna IV experimental site to the Hanna II site and the similarity of the overburden at both sites, a similar but modified scheme was adopted for the purposes of this study (Fig. 4). Similar schemes have also been adopted by Youngberg, et al. (1983 a & b).

Detailed lithologic logs of the overburden in the 21 post-burn cores from Hanna IV are presented in Appendix A, and the depth intervals for each local stratigraphic unit in each core hole are given in Table 1. Continuous core from the ground surface to the overburden beneath the Hanna No. 1 coal seam was recovered from two post-burn core holes, 4PB1 and 4PB2. Therefore, thicknesses reported below for units C and B are determined in part from wireline log patterns (gamma and neutron logs) (Fig. 4).

Unit D, the uppermost unit, does not occur at the Hanna IV study site as its erosional limit lies to the east of this area.

Unit C, the uppermost unit present at the study site (Fig. 4), is characterized by medium- to coarse-grained sandstones with conglomeratic beds (Fig. 5 A & B) and numerous erosional contacts (Fig. 5 A) between adjacent beds. Primary depositional sedimentary structures include high angle, trough cross-beds (Fig. 5 B), horizontal to low-angle planar stratification (Fig. 5 C) and high-angle planar cross-stratification (Fig. 5 D). The lower portion of Unit C represented in core from Hanna IV ranged in thickness from 27.4 - 40.0 m (90 to 131 ft) and averages 33.1 m (108 ft) (Table 1). This unit has an erosional contact with unit B which underlies it locally (Fig. 4).

Unit B is characterized by interbedded mudstones, claystones, and siltstones which may display burrow and root structures. Also present in the unit are lenticular-shaped, fine-grained trough cross-stratified sandstones and tabular-shaped, ripple cross-stratified sandstones (Craig, et al., 1982). Unit B ranges in thickness from 26.8 - 40.0 m (88 to 131 ft) and averages 32.9 m (108 ft) in the 21 cored holes examined in this study (Table 1). The unit has a gradational contact with the underlying Unit A (Fig. 4). Unit A, the unit that directly overlies the Hanna No. 1 coal seam, is divided into two subunits for the purposes of this study (A and A'; Fig. 4).

Unit A consists primarily of fine-grained sandstones, siltstones, and mudstones. Primary depositional sedimentary structures include high-angle forset beds with slump structures (Fig. 6 A); micro-trough cross-stratification (Fig. 6 B) and ripple-drift cross-stratification. Other features include micro faults (Fig. 6 A); clay clast conglomerates, cut-and-fill structures, and minor bioturbation (Fig. 6 C & D). Unit A varies in thickness from 23.8 - 30.5 m (78 to 100 ft) and averages 27.1 m (88.8 ft) (Table 1). Unit A has a gradational lower contact with Unit A', which directly overlies the Hanna No. 1 coal in 17 of the 21 cores from the Hanna IV

Figure 4. Generalized stratigraphic column of a portion of the Hanna Formation, Hanna UCG site, Hanna Basin, Wyoming, with wireline logs and local lithologic units. Lithology, sedimentary structure and accessory symbols are given in Appendix A.

Table 1. Depth Intervals from post-burn cores and geophysical logs of local lithologic units in the overburden and of the Hanna No. I coal seam at the Hanna IV UCG site. All thicknesses in feet. All intervals measured from ground surface.

Well Number	Unit C Braided	Unit B Meandering	Unit A Lac. Delta	Unit A' Lacustrine	Hanna No. I Coal
4PB 1	0-90	90-201	201- *	* - *	315-336
4PB 2	0-118	118-228	228-316	316- *	* -348
4PB 3	0-131	131-231	231-321	321-332	332-363
4PB 4	0-107	107-222	222-307	307-319	319-344
4PB 5	0-121	121-231	231-313	313-325	325-350
4PB 6	0-105	105-236	236-314	314-324	326-348
4PB 7	0-90	90-198	198-291	291-302	302-328
4PB 8	0-124	124-212	212-312	312-321	321-352
4PB 9	0-115	115-226	226-318	318-328	328-352
4PB 10	0-91	91-197	197- *	* - *	* -330
4PB 11	0-99	99-216	216-296	296- *	* -332
4PB 12	0-107	107-204	204-289	289- *	* -333
4PB 13	0-91	91-197	197- *	* - *	* -340

Table 1. (continued).

Well Number	Unit C Braided	Unit B Meandering	Unit A Lac. Delta	Unit A' Lacustrine	Hanna No. I Coal
4PB 14	0-90	90-209	209- *	* - *	* -336
4PB 15	0-112	112-223	223-315	315-325	325-350
4PB 16	0-123	123-228	228- *	* - *	* -358
4PB 17	0-124	124-224	224-317	317-330	330-358
4PB 18	0-114	114-230	230-312	312-325	325-350
4PB 19	0-104	104-203	203-294	294- *	* -337
4PB 20	0-102	102-208	208-302	302-311	311-332
4PB 21	0-123	123-222	222-321	321-331	331-357

* Information unobtainable from lithologic or geophysical logs.

Figure 5. Core photos of sedimentary structures in local lithologic unit C:

- A) Conglomeratic sandstone overlying sandstone and erosional contact; 4PB1-56.0.
- B) High-angle trough cross-bedding in conglomeratic sandstone; 4PB2-82.5.
- C) Horizontal to low-angle laminations in medium to coarse-grained sandstone; 4PB2-89.0.
- D) Large-scale, planar cross-beds in medium-grained sandstone; 4PB2-76.6.

A.

B.

C.

D.

Figure 6. Core photos of sedimentary structures in local lithologic unit A:

- A) High-angle foreset beds with slump structures; 4PB1-271.0.
- B) Micro faults in micro trough cross-bedded and laminated siltstones and mudstones; 4PB2-4PB2-279.0.
- C) Clay clast conglomerate, cut-and-fill structures and minor bioturbation in foreset laminations; 4PB2-292.8.
- D) Bioturbation and ripple drift stratification in interbedded siltstones and mudstones; 4PB2-245.8.

A.

B.

C.

D.

site. Unit A' is a horizontally laminated, bioturbated mudstone. Craig (1982) reported the occurrence of non-marine gastropods and pelecypods from within this unit. Unit A' varies in thickness from 2.7 - 4.9 m (9 to 16 ft) and averages 3.6 m (12 ft). The contact between this unit and the underlying Hanna No. 1 coal is gradational to abrupt.

The Hanna No. 1 coal seam is a highly volatile C Bituminous coal (Youngberg, et al., 1983c). At the Hanna IV site the seam varies in thickness from 6.1 m (20 ft) to 9.4 m (31 ft) and averages 7.6 m (25 ft) (Table 1).

Unit U, the unit directly beneath the Hanna No. 1 coal seam, consists of bioturbated, rippled, mudstones and siltstones. The unit was only penetrated in a few cored wells and never in its entire thickness.

Structural Geology of Site

The study area is located on the southwest limb of the Hanna syncline, where, locally, the sedimentary units strike northwest-southwest and have an average dip of approximately 6° to the northeast.

The local structure is characterized by an arcuate, east-west trending graben complex with numerous antithetic faults. All eight process wells and twenty-one post-burn core holes are situated within this graben system (Fig. 7).

A high resolution seismic survey conducted in 1980 identified and characterized the shallow fault system at the Hanna site (Youngberg, et al., 1982). A similar survey conducted in 1983 modified the interpretation of the fault complex in the vicinity of the Hanna IV site (Berkman and Orange, 1983). This study identified an east-west trending discontinuity which intersects the line of process wells at an oblique angle near process well 4 (Fig. 7). No apparent vertical or horizontal displacement of the top of the Hanna No. 1 coal seam has occurred at the experimental site according to the survey.

Construction of a structural cross-section through the site (Fig. 8), based upon post-burn core analyses, supports the geophysical interpretation that no discernible displacement has occurred along this fault.

Covell, et al. (1980) suggested a 1.5 to 3.0 meter (4.9 to 9.8 ft) displacement had occurred along this fault. Evidence included injection flow tests which confirmed the existence of air movement through the overburden in this area. This displacement estimate is not supported by the results of the 1980 and 1983 seismic surveys nor by the post-burn core analysis reported in this study.

T 22N R 81 W

CONTOUR INTERVAL =
50 Feet

SCALE

0 600 1200 FT.

0 180 360 METERS

Figure 7. Structure contour map on top of Hanna No. 1 coal bed (modified from Berkman and Orange, 1983). Note: Structural contours in feet above sea level. Line of section shown is for structural cross section shown in Figure 8. Burn detail is shown in Figure 26.

Figure 8. Structural cross-section NE - SW. Line of section shown on structure contour map (Figure 7).

Thickness, Geometry, and Trend of Local Stratigraphic Units

Isopach and isolith maps of local stratigraphic units C, B, and A in the SE 1/4, Section 30 and Section 29, T22N, R81W, Carbon County, Wyoming were constructed by Craig, et al. (1982). The post-burn coring program at the Hanna IV UCG site provided additional data in the west-central portion of Section 29, and these data have been used to refine the isopach and isolith maps of Craig, et al. (1982).

Unit C (Fig. 9) ranges in thickness from 39.6 m (130 ft) where it is truncated by erosion southeast of the Hanna IV cavities to 67.4 m (221.0 ft) near the northeast portion of the study site. Sandstones which constitute the majority of the deposits in this unit consist of a wedge-shaped deposit that strikes northwest-southeast through Section 29 and thins to the south and west (Fig. 10) in part due to post-depositional erosion. Isopach and isolith maps of this unit remain unchanged from that presented in Craig, et al. (1982) since the Hanna IV cores are south and west in the area of post-depositional erosion.

Unit B ranges in thickness from less than 12.2 m (40 ft) in the northern portion of the study area to greater than 39.6 m (130 ft) in a linear northwest to southeast trend across the area (Fig. 11). Along the western portion of the study area it is truncated by post-depositional erosion. Sandstones of this unit constitute a northwest to southeast belt-shaped deposit which attains a maximum thickness of greater than 18.3 m (60 ft). The maximum sandstone thickness of 20.4 m (67 ft) is found slightly northeast of the center of the study area (Fig. 12).

Units A and A', which are combined for mapping purposes, range in thickness from less than 9.1 m (30 ft) in the southeast portion of the study area to greater than 33.5 m (110 ft) along and just south of the west-central portion of this area (Fig. 13). Based on sandstone thickness, units A and A' form a fan shaped deposit which originates west of the west-central portion of the study area and fans out in a easterly to northeasterly direction (Fig. 14).

LITHOLOGIC CHARACTERIZATION OF OVERBURDEN

Sandstone Composition and Texture

General

Fifty-five thin section samples from sandstones, coarse siltstones and mudstones from Hanna IV post-burn cores were analyzed using a petrographic microscope to determine composition and textural parameters. Two hundred point counts and 40 measurements of the apparent long axes of quartz grains

Figure 9. Isopach map of local lithologic unit C, Hanna Formation, Hanna UCG site, Hanna Basin, Wyoming. Note this and succeeding maps were constructed omitting all present-day structural complications (modified from Craig, et al., 1982). Black dots are drill hole data points.

Figure 10. Sandstone isolith map of local lithologic unit C, Hanna Formation, Hanna UCG site, Hanna Basin, Wyoming (modified from Craig, et al., 1982). Black dots are drill hole data points.

Figure 11. Isopach map of local lithologic unit B, Hanna Formation, Hanna UCG site Hanna Basin, Wyoming (modified from Craig, et al., 1982). Black dots are drill hole data points.

Figure 12. Sandstone isolith map of local lithologic unit B, Hanna Formation, Hanna UCG site, Hanna Basin, Wyoming (modified from Craig, et al., 1982). Black dots are drill hole data points.

Figure 13. Isopach map of local lithologic unit A & A', Hanna Formation, Hanna UCG site, Hanna Basin, Wyoming (modified from Craig, et al., 1982). Black dots are drill hole data points.

Figure 14. Sandstone isolith map of local lithologic unit A & A', Hanna Formation, Hanna UCG site, Hanna Basin, Wyoming (modified from Craig, et al., 1982). Black dots are drill hole data points.

were made on each thin section sample. Scanning electron microscope (SEM) analyses were performed on 7 sandstone samples to identify interstitial mineral constituents that were difficult or impossible to identify in thin section. Compositional and textural parameters for each thin section sample are given in Appendix B.

Average compositional data for all sandstone and coarse siltstone samples are presented in Tables 2 and 3 and on four triangular diagrams (Fig. 15 & 16). The major detrital framework constituents include quartz, feldspar and plutonic lithic fragments (combined), and other lithic fragments, averaging 50.4, 7.9, and 5.3 percent of the total rock volume, respectively (Table 2). The remaining rock volume is occupied by cement (27.4 percent), pore space (3.4 percent), mica grains (3.8 percent), matrix (1.9 percent) and accessory minerals (0.4 percent) (Table 2). Local lithologic units B, A and A' are similar in terms of most components with unit A' having the highest percentage of lithic fragments and unit B the lowest percentage of cement of these three units. Unit C has the highest percentages of feldspar plus plutonic lithic fragments, total lithic fragments and pore space as well as the lowest percentage of cement. Unit U, beneath the Hanna No. 1 coal seam, has the highest percentage of quartz. Units A and A', which lie directly above the burn cavity, have the highest percentage of cement and the lowest percentage of feldspar plus plutonic lithic fragments (Table 2). Using the triangular classification scheme of Dott (1964) the average sandstones of units C, B, and A are classified as sublithic arenites (Fig. 16). In general the sandstones from the Hanna IV UCG site are less feldspathic and contain fewer lithic fragments than those from the Hanna II site (Craig, et al., 1982). This result is probably a consequence of having analyzed a higher percentage of fine-grained samples from the Hanna IV site.

Detrital Constituents

Polycrystalline (Q_p) and monocrystalline (Q_m) quartz grains average 7.3 and 43.1 percent of the total constituents point counted for all sandstone and coarse siltstone samples. Polycrystalline quartz grains are of two types: those that contain less than 5 crystal units per grain and generally exhibit undulose, equant, straight-bounded, unimodal sized crystal units; and those with greater than 5 crystal units which are elongate, strongly undulose and which have sutured boundaries (Fig. 17 A). Monocrystalline quartz grains show undulose to strongly undulose extinction and some grains show evidence of multiple cycles of deposition in the form of abraded overgrowths (Craig, 1982).

Feldspars account for a total of 6.3 percent of the total constituents counted (Table 2) and include microcline and perthite ($K = 4.4$ percent) (Figs. 17 B and 18 A), and plagioclase ($P = 1.9$ percent) (Fig. 18 B). Most feldspars show some degree of alteration and/or dissolution. Plutonic lithic fragments, which are included with the feldspars for classification purposes, are present in small amounts in the coarser-grained samples (Fig. 19 A) of units C and A.

Lithic fragments, other than plutonic fragments, include sedimentary fragments ($L = 3.3$ percent), volcanic fragments ($L_v = 1.8$ percent) and

Table 2. Average composition of sandstones and coarse siltstones, Hanna IV UCG site, Wyoming.

Unit	No. of Samples	Q _p	Q _m	Q _t	K	P	F _{rx}	F _t	L _v	L _m	L _s	L _t	A	M	M _a	C	P _O
C	5	11.2	43.9	55.1	9.4	2.1	2.2	13.7	3.4	0.4	4.7	8.5	0.4	3.7	0.3	10.8	7.7
B	4	8.1	39.0	47.1	3.8	2.8	0.0	6.5	2.4	0.0	3.2	5.6	2.1	6.0	11.6	17.6	3.4
A	35	6.0	43.4	49.4	3.8	1.7	0.4	5.9	1.4	0.2	2.7	4.4	0.2	3.7	1.0	31.7	2.9
A'	2	10.2	38.0	48.2	3.8	2.2	0.0	6.0	1.8	0.0	5.8	8.0	0.0	5.2	0.0	30.5	2.5
U	3	12.3	47.5	59.8	4.7	2.8	0.0	7.5	2.2	0.0	5.8	8.0	0.8	2.0	3.0	16.0	2.8
Total/Average (49/___)		7.3	43.1	50.4	4.4	1.9	0.5	6.9	1.8	0.2	3.3	5.3	0.4	3.8	1.9	27.4	3.4

Abbreviations: Q_p-polycrystalline quartz; Q_m-monocrystalline quartz; Q_t-total quartz; K-potassium feldspars; P-plagioclase feldspars; F_{rx}-plutonic rock fragments; F_t-feldspars and plutonic rock fragments; L_v-volcanic rock fragments; L_m-metamorphic rock fragments; L_s-sedimentary rock fragments; L_t-total lithic fragments, excluding plutonic rock fragments; A-accessories; M-mica; M_a-matrix; C-cement; P_O- porosity.

Table 3. Mean percentage of cement types in sandstone and coarse siltstones, Hanna IV, UCG site, Wyoming.

Unit	Number of Samples	Percent Cement of Total Volume	% Total Volume of Specific Cements			
			Phyllosilicate	Calcite	Hematite	Siderite
C	5	10.8	6.9	0.1	0.3	3.5
B	4	17.6	7.4	5.7	2.1	2.4
A	35	31.7	9.8	14.9	3.8	3.2
A'	2	30.5	4.5	5.5	1.8	18.7
U	3	16.0	5.8	6.4	2.0	1.8
Total/Average (49/___)		27.4	8.9	11.7	3.1	3.7

Figure 15. Composition and classification of sandstone samples for local lithologic units, Hanna IV UCG site, Hanna Basin, Wyoming:

- A) Compositional Fields for local lithologic units C,B & U. PRF = plutonic rock fragments.
- B) Compositional Fields for local lithologic units A & A' (Classification scheme modified from Dott, 1964). PRF = plutonic rock fragments.

A

B

Figure 16. Composition and classification of sandstone averages for local lithologic units, Hanna IV UCG site, Hanna Basin, Wyoming:

- A) Average compositions of local lithologic units C, B, A, A' & U. PRF = plutonic rock fragments.
- B) Average compositions of lithic fragments of local lithologic units C, B, A, A' & U (Classification scheme modified from Dott, 1964).
Ls = sedimentary rock fragments; Lv = volcanic rock fragments; Im = metamorphic rock fragments.

- Figure 17. A) Photomicrograph of polycrystalline quartz grain (Qp); 4PB1-87.6, unit C. Width of field of view 1.7mm.
- B) Photomicrograph of microcline grain (M) and chert (C) lithic fragments; 4PB2-47.6; unit C. Width of field of view 0.7mm.

A.

B.

- Figure 18. A) Photomicrograph of perthite grain (PE);
4PB1-87.6, unit C. Width of field of view
2.7mm.
- B) Photomicrograph of plagioclase grain (P);
4PB2-47.6, unit C. Width of field of view
1.7mm.

A.

B.

- Figure 19. A) Photomicrograph of plutonic lithic fragment (PL); 4PB1-87.6, unit C. Width of field of view 2.7mm.
- B) Photomicrograph of chalcedony lithic fragment (CH); 4PB1-87.6, unit C. Width of field of view 2.7mm.

A.

B.

metamorphic fragments ($L_m = 0.2$ percent). This relative abundance of lithic types is also illustrated by the triangular lithic fragment plot (Fig. 16 B). Sedimentary lithic fragments include chalcedony (Fig. 19 B), chert, and mudstone (clay balls).

Micas, including muscovite and biotite, are present in small amounts in most samples and average 3.8 percent. Accessory minerals include various unidentifiable heavy mineral and opaque mineral grains. Detrital matrix (finer grained clays and quartz particles between the larger framework grains) average 1.9 percent of the total constituents counted but are only abundant in the samples from unit B (11.6 percent, Table 2).

Cements

Cements include kaolinite, smectite, calcite, dolomite, siderite, iron oxide (hematite?) and silica. Kaolinite, which occurs as a pore-fill material and is the second most abundant cement, is easily recognized in thin section by its vermicular texture and microporosity (Fig. 20 A). SEM pictures reveal the typical well-developed loose books of pseudo-hexagonal crystals (Fig. 20 B). The only other phyllosilicate cement is smectite which is difficult to identify in thin section. Under the SEM it is readily identified by its highly crenulated, honeycombed, interlocking crystal nature (Fig. 21 A) and by its elemental constituents (Fig. 21 B). Calcite is easily recognized in thin section (Fig. 23 A) and often occurs as a pervasive cement completely filling pore spaces. In some samples it is seen to replace other minerals along grain boundaries. Dolomite, although not positively identified in thin section, was found in one sample from unit A by SEM analysis (Fig. 22) where it consists of small, submicroscopic rhombs. Siderite, which is most abundant in samples from unit A', occurs in clusters of very small rhombohedral crystals (Craig, 1982). Hematite occurs as brown opaque coatings and as fracture fillings particularly in the finer-grained samples from units B, A, A', and U. Quartz overgrowths, although not abundant and not counted in thin section, are recognized by euhedral faces on quartz grains.

Table 3 shows the average percentage of various cements in each of the local lithologic units. Units A and A', which directly overlie the burn cavities, contain the highest percentages of cement by volume and the highest percentages of calcite and siderite, respectively. Unit A also contains the highest percentages of phyllosilicates and hematite cements. Units C, B, and U contain relatively low percentages of calcite, siderite, and hematite, and intermediate percentages of phyllosilicates. These differences in type and amount of cementing materials are critical factors in evaluation of rock strength and roof rock stability (See sections on Geotechnical Studies and Overburden Stability Study).

Porosity

Secondary porosity is the most common type observed in thin section. Dissolution of feldspar grains and calcite cement probably accounts for the

- Figure 20. A) Photomicrograph of kaolinite (K) and calcite (CA) pore-fill cement; 4PB2-275.4, unit A. Width of field of view 0.7mm.
- B) SEM photograph of kaolinite booklets (K); 4PB3-324.0, unit A'. Each division on bar scale equals 1 micron.

A.

B.

- Figure 21. A) SEM photograph of smectite pore-fill cement (S); 4PBl-30.4, unit C. Each division on bar scale equals 10 microns.
- B) Elemental energy dispersion analysis of smectite; 4PBl-30.4, unit C.

A.

24-JUL-84 05:01:08
RATE: CPS TIME 120LSEC
00-20KEV: 10EV/CH PRST: 120LSEC
A: 4-1-30.4 SMEC B:
FS= 186 MEM: A FS= 50

B.

- Figure 22. A) SEM photograph of dolomite pore-fill cement (D); 4PB16-313.8, unit A? Each division on bar scale equals 10 microns.
- B) Elemental energy dispersion analysis of dolomite; 4PB16-313.8, unit A?

A.

24-JUL-84 02:18:18
RATE: CPS TIME 119LSEC
00-20KEV: 10EV/CH PRST: 120LSEC
A: 4-16-313.8 B:
FS= 718 MEM: A/B FS= 200

B.

- Figure 23. A) Photomicrograph of calcite pore-fill cement (CA); 4PBl7-276.2, unit A. Width of field of view 0.7mm.
- B) SEM photograph of quartz overgrowth (Q); 4PBl-246.3, unit A. Each division on bar scale equals 10 microns.

A.

B.

- Figure 24.
- A) Photomicrograph of partially dissolved feldspar grain (F) and resulting secondary porosity (PO); 4PB2-275.4, unit A. Width of field of view equals 10 microns.
 - B) Photomicrograph of oversized pores (PO) created by dissolution of grains or cement; 4PB1-30.4, unit C. Width of field of view 1.7mm.

A.

B.

majority of this porosity. Evidence for the secondary origin of most porosity includes partially dissolved grains (Fig. 24 A), oversized pores (Fig. 24 B), alternating areas of abundant porosity and closely packed grains, and scattered patches of undissolved cement. Only minor amounts of reduced intergranular (primary) porosity were observed in thin section. Unit C has the highest porosity and units A and A' have the lowest porosities (Table 2). There is a clear relationship between percent porosity and percent total cement with the highest porosity occurring in samples with the least cement. A relationship also exists between percent calcite or siderite cement with the lowest porosities occurring in the samples with the highest percent calcite or siderite (Tables 2 and 3).

Texture

Unit C has the coarsest mean and maximum quartz grain size and the poorest sorting (standard deviation) while units B and A' have the finest mean and maximum size and the best sorting (Table 4). Units A and U are intermediate between these two end members in terms of all textural parameters examined. Textural characteristics determined are based on measurement of apparent long axes of quartz grains in thin section. Other textural estimates such as sieving (Ethridge, et al., 1983b) involved the measurement of the intermediate axes of all grains in a sample. Differences between the two techniques result in a higher mean and maximum grain size using the sieving technique over the thin section technique, and also significant differences in sorting values. For example, unit C, with the worst sorting as determined by thin section technique, would undoubtedly have one of the best sorting values as determined by sieving (Ethridge, et al., 1983b). The sieving technique, therefore, provides a more reliable estimate of grain size and sorting for the entire rock mass, but the technique suffers from the inability to accurately disaggregate the rock into single mineral grains.

Unit C exhibits the highest mean and maximum size, the lowest percent cement, and the highest percent pore space. No relationships exist between the other units and these variables, probably because of the restricted average grain size present.

Clay Mineralogy

Methodology

The clay-size fraction of 21 sandstone and coarse siltstone samples from unit A and four mudstone samples from units B and A' were analyzed using X-ray diffraction techniques. The purpose of these analyses was to identify and determine the relative abundances of clay minerals in Hanna IV overburden and to augment results obtained by thin section and SEM analyses.

Table 4. Average textural values for sandstones and coarse siltstone, Hanna IV UCG site, Wyoming.

Unit	Number of Samples	Mean Qtz. Size (mm)	Max Qtz. Size (mm)	Standard Deviation	Verbal Grain Size
C	5	0.31	0.74	0.16	mgss
B	4	0.06	0.17	0.03	cgsiltst- vfgss
A	35	0.10	0.20	0.04	vfgss
A'	2	0.06	0.14	0.03	cgsiltst- vfgss
U	3	0.11	0.27	0.06	vfgss
Total/Average (49/___)		0.11	0.25	0.05	

ABBREVIATIONS: mgss: medium-grained sandstone (1/4 to 1/2mm); vfgss: very fine-grained sandstone (1/16 to 1/8mm); cgsiltst: coarse-grained siltstone (1/32 to 1/16mm).

Thirty-gram samples were crushed, and the clay-size fraction was separated by centrifuge, as outlined by Jackson (1956). These samples were not chemically treated for the removal of soluble salts, divalent cations, organic matter, or free iron oxide, as these constituents were not present in amounts sufficient to alter the results of the analyses.

Three smear mounts were prepared for each sample. One mount was air-dried at room temperature; a second was air-dried at room temperature for 24 hours and then saturated with ethylene glycol at 60°C for 1 to 2 hours; and a third was air-dried at room temperature for 24 hours and then heated to 550°C for 1 hour. These three treatments facilitate an accurate identification of the clay fraction due to the characteristic effects they impart on the d-spacings of the clay minerals.

In order to determine the average relative percentages of the clay minerals, diffraction patterns were generated for three air-dried, standardized (of known weight percent) mixtures of kaolinite, illite, smectite, and quartz. Quartz was included as it is a ubiquitous contaminant in the clay mineral X-ray diffraction patterns. From these patterns, a calibration curve was constructed for each of the four minerals, relating area under the peak to its corresponding relative percentage. This procedure accounts for the inherent peak intensity differences in the patterns of the four minerals.

Interpretation

All of the X-ray patterns essentially fall into two categories (Fig. 25 A & B): those which correspond to the interstitial clays in sandstones and coarse siltstones of unit A and those of the clays of the mudstones of units B and A'.

Kaolinite is the predominant clay present in all sandstone and coarse siltstone samples of unit A (Table 5). It is characterized on the air-dried and glycolated diffraction patterns by a sharp, high intensity peak at 7.1 Å (angstroms) (Fig. 25 A). Upon heating to 550°C, the kaolinite structure is destroyed, therefore, the peak is greatly diminished or altogether absent on the diffraction patterns reflecting heat-treated samples (Fig. 25 A). Sharpness of the reflection suggests that the mineral is in a well-ordered, crystalline state. Indeed, the kaolinite observed in SEM analyses displays well-formed books of pseudohexagonal crystals (Fig. 20 B) occurring as pore-filling material. This habit and mode of occurrence suggests an authigenic (diagenetic) origin. Illite, which was not recognized in thin section or in SEM analyses, comprises an average of 24.3 percent of the total clay-size fraction of unit A. A sharp 10 Å (001 peak) reflection for each of the three treatments is diagnostic of illite with a well-developed crystalline habit. Lesser amounts of smectite and/or an interlayered smectite-chlorite (average = 4.9 percent) make up the remaining portion of the clay-size constituents. The interpretation of the interstratified clay (not recognized in thin section or SEM) is based on the presence of a diffuse, irregular reflection at 15 Å, which characterizes poorly crystalline or mixed-layered

Figure 25. Selected X-ray patterns of clay minerals, Hanna Formation, Hanna IV UCG site, Wyoming.

- A) X-ray pattern of interstitial clay in sandstone (4PB14-263; unit A).
- B) X-ray pattern of claystone (4PB2-215; unit B).

A

B

Table 5. Relative percentages of interstitial clays in sandstones and coarse siltstone (determined by areas under peaks in the X-ray diffraction pattern), Unit A, Hanna IV UCG site, Wyoming.

SAMPLE (HOLE-DEPTH)	UNIT	LITHOLOGY	KAOLINITE	ILLITE	SMECTITE (*SMEC.-CHLOR.)	QUARTZ
4PB10-246.0	A	vfgss	73.7	23.1	3.2	---
4PB10-250.7	A	fgss	69.6	22.6	7.8*	---
4PB10-256.6	A	mgss	62.3	23.7	14.0	---
4PB12-269.0	A	fgss	79.9	18.0	1.1	1.1
4PB12-279.0	A	vfgss	36.6	53.4	3.7	6.3
4PB12-284.0	A	vfgss	51.0	44.1	2.3*	2.6
4PB12-287.0	A	fgss	62.5	29.7	5.8*	1.9
4PB12-288.0	A	fgss	69.7	26.4	3.3	0.6
4PB12-288.5	A	fgss	71.2	22.5	5.4*	0.9
4PB12-290.0	A	fgss	63.5	25.7	10.4	0.5
4PB13-244.9	A	vfgss	63.7	18.1	18.1	---
4PB13-265.2	A	vfgss	70.1	26.3	3.6*	---
4PB13-272.9	A	fgss	70.8	25.6	2.2	1.3
4PB13-274.8	A	mgss	77.2	17.7	4.5	0.6
4PB14-253.0	A	vfgss	63.4	30.2	5.6	0.8
4PB14-263.0	A	sltst	74.5	21.3	3.3*	0.8
4PB14-268.0	A	fgss	83.7	13.3	2.1	0.9
4PB14-271.0	A	fgss	77.2	17.2	5.0	0.7
4PB14-272.0	A	fgss	80.1	18.2	0.8*	0.8
4PB14-272.5	A	fgss	80.8	18.2	0.2	0.8
4PB14-272.75	A	fgss	83.6	15.3	0.2*	0.8
AVERAGE			69.8	24.3	4.9	1.0

ABBREVIATIONS: mgss: medium-grained sandstone ($1/4$ to $1/2$ mm); fgss: fine (to medium) grained sandstone (2^{-3} to 2^{-1} mm); vfgss: very fine-grained sandstone (2^{-4} to 2^{-3} mm); sltst: siltstone (2^{-9} to 2^{-4} mm).

smectite. Glycolation produces a shift in the smectite (001 peak) to 17 Å as well as an increase in its relative intensity. A similar shift, which is characterized by swelling chlorite, however, and may mask its presence. Upon heating to 550°C, water is driven from the smectite structure causing its collapse and resulting in a decrease in the mineral's d-spacing. The diffraction pattern reflects this structural change by a peak shift to 10 Å, which happens to coincide with the illite peak. The less intense peak occurring at approximately 14 Å represents the chlorite interlayer which has, until heat treatment of the samples, been masked by the reflection of the more dominant smectite structure. Preservation of the delicate clay structure as seen in SEM photographs (Fig. 21 A) suggests an authigenic origin for the smectite.

The relative abundance of clay minerals in mudstone samples from units B and A' are 27.8 percent kaolinite, 34.2 percent illite, and 35.6 percent smectite and/or smectite-chlorite (Table 6; Fig. 25 B). The relatively fine grain size of these samples coupled with the clastic nature of the clay size material in mudstone thin sections suggests that most of the clays in the mudstones from units B and A' originated as detrital particles. This inference does not, however, mean that recrystallization and/or grain growth has not taken place during burial, compaction, and diagenesis. In samples from unit B the relative percentage of kaolinite remains constant while the illite-smectite ratio increases with increasing depth (0.40 at 45.5 m (149 ft) to 3.18 at 65.5 m (215 ft). This trend toward a relative increase in the abundance of illite to smectite was also observed by Craig (1982), who offered two possible explanations: (1) a change in the composition of crystalline source rock, from which the clays were weathered with time and (2) diagenetic processes. In terms of the former explanation, illite formation is favored where potassium-rich granite or gneiss is the dominant source rock. In the latter situation smectite sheets convert to illite sheets with increasing depth and temperature.

Sandstone Diagenesis

Compaction, cementation, and the creation of secondary porosity by dissolution of grains and cement were the principal diagenetic processes noted in thin section. Evidence for compaction includes the fracturing of quartz grains and the brittle and ductile deformation of mica grains. Large oversized pores, uneven packing of grains and the partial dissolution of cements and detrital grains are the primary evidence for the formation of secondary porosity.

A sequence of diagenetic events from earliest to latest (paragenetic sequence) is shown by Craig (1982) for the Hanna Formation at the Hanna II UCG experimental site. The sequence presented below for the overburden sediments at the Hanna IV site differs somewhat from that presented by Craig of the Hanna II site. From earliest to latest the sequence would include seven stages: (1) deposition of the sediments; (2) silica cementation as overgrowths on detrital quartz grains; (3) early calcite cementation; (4) partial dissolution of calcite cement and feldspar grains; (5) precipitation of kaolinite pore-fill cement (probably in conjunction with the dissolution

Table 6. Relative percentage of clay minerals in mudstones (determined by areas under peaks in the X-ray diffraction pattern), units B and A', Hanna IV UCG site, Wyoming.

SAMPLE (HOLE-DEPTH)	UNIT	LITHOLOGY	KAOLINITE	ILLITE	SMECTITE (*SMEC.-CHLOR.)	QUARTZ
4PB1-149.0	B	mdst	25.3	20.5	51.4	2.7
4PB2-215.0	B	mdst	30.4	50.3	15.8	3.5
4PB13-198.6	B	mdst	31.2	23.3	43.9 *	1.6
AVERAGE	B		29.0	31.4	37.0	2.6
4PB5-317.5	A'	mdst	24.2	42.5	31.4	2.0
AVERAGE	B and A'		27.8	34.2	35.6	2.4

event (stage 4); (6) precipitation of smectite pore-lining and/or dolomite and/or siderite cement (depending on grain size and presence or absence of detrital clays); and (7) precipitation of hematite cement (probably after uplift and exposure to meteoric ground water flow). Compaction of sediments proceeded through all diagenetic stages but was not important during stages 2 and 3. Evidence for this sequence of diagenetic events is supported by the spatial relationships between various cements in thin section and SEM pictures and by the absence of kaolinite from primary pores and its presence only in secondary pores.

Illite, recognized in X-ray diffraction patterns as having a well-crystallized habit, is not included in this diagenetic sequence of events because of the lack of physical evidence for its position in the sequence.

DEPOSITIONAL ENVIRONMENTS

The original interpretations of Craig, et al. (1982) and Craig (1982) of depositional environments of the local stratigraphic units are supported by data collected during this study.

Sandstones and conglomerates of unit C were deposited in a series of braided bars and channels in a braided river that traversed the area from northwest to southeast. Sandstones and siltstones of unit B were deposited as point bars in a meandering river and in overbank/crevasse splay deposits that formed lateral to the channels of the meandering river system. Mudstones and carbonaceous shales of this unit were deposited in floodplain settings adjacent to the point bar and crevasse splay deposits. Sandstones and siltstones of unit A were deposited in a lacustrine delta that prograded to the northeast from the lake margin, located west of the study area. Mudstones of unit A' were deposited as lake bottom sediments. The Hanna No. 1 coal bed originated as organic matter in a poorly drained swamp environment.

MINERALOGY AND TEXTURE OF THERMALLY ALTERED OVERBURDEN ROCKS

General

Samples of thermally altered overburden rock were selected from the 7 post-burn core holes which penetrated the burn cavities. The location of the core holes relative to the process wells and cavity boundaries is shown on Figures 26 and 27. The detailed lithologic descriptions of these wells (Appendix A), combined with petrographic, X-ray diffraction, and SEM analyses

PLAN VIEW AND WELL LOCATIONS FOR THE HANNA IV, PHASES A AND B UCG SITE

Figure 26. Plan view of the Hanna IV UCG site showing projected outline of the cavities, location of post-burn core holes and cross-section A - A' of Figure 27.

Figure 27. Cross-section of cavities formed by the Hanna IV UCG experiments. Section along line A - A' of Figure 26.

of samples, characterize the high temperature mineralogy of the thermally altered overburden. The mineral assemblages, in turn, allow estimates of the temperatures reached in the burn cavities. In addition, a stratigraphic distribution of pyrometamorphic rock types can be depicted on the basis of these analyses.

Lithology of the Pyrometamorphic Rocks

The overburden rocks that experienced minimal effects of heat alteration, the hornfels, have few detectible high temperature minerals. Alteration is most clearly seen in X-ray diffraction analysis which can detect partial to complete destruction of the original clay minerals, especially kaolinite. The hornfels may be slightly hardened and/or bluish compared to unaltered overburden and typically display relict primary sedimentary structures.

Buchites are partially melted rocks that are noticeably harder than unaltered sandstones, and glass can often be seen in core samples of buchites. In such buchites the glass is vesicular and often occurs in discrete layers, usually dark to medium gray in the lighter gray sandstones and siltstones.

Buchite breccias are partially melted overburden rocks that have broken into angular blocks and have been reindurated as a breccia. Paralava breccias differ in having all of the relict sedimentary structures destroyed by the more or less complete melting of the original rock. Breccias often show pumaceous to scoraceous texture.

Petrography of the Pyrometamorphic Rocks

In order to determine the extent and nature of alteration, samples from overburden above the cavity as well as samples from within the cavity were examined petrographically. In all, 87 samples were point counted to quantify the mineralogy. Of the total samples counted, 32 were altered enough to have either glass and/or new high temperature alteration minerals present. The mineralogy and glass content of these 32 pyrometamorphic rocks are given in Table 7.

Quartz and clay minerals are the most abundant constituents of the unaltered overburden comprising units A and A' (Table 7). All of the samples listed in Table 7 have been altered such that their clay mineralogy has been destroyed, and samples that contain clay minerals are given in Appendix B for unaltered overburden rocks. Six samples in Table 7 contain relict phyllosilicate minerals, most commonly biotite or muscovite. Quartz persists as a relict mineral in all but 9 of the altered samples. The 9 samples with no relict quartz have been completely melted; glass and new, high temperature pyrometamorphic minerals are the only constituents of these rocks. Many of the altered samples contain relict minerals (other than quartz and phyllosilicates) and rock fragments; a few have some of the cements preserved.

Table 7. Petrology of pyrometamorphic rock samples from the Hanna IV UCG site. Mineral percentages based on 200 point counts in thin section.

SAMPLE NUMBER	GLS	VES	QTZ	PLAG	MULL	CORD	OPQ	TRID	SPHER	PXN	PHYLL	PORO	CFM	CHT	MIX	TOTALS
4PB 1 313.9	76	11	3	0	0	0	1	0	9	0	0	0	0	0	0	100
4PB 1 314.6	76	22	0	0	0	0	2	0	0	0	0	0	0	0	0	100
4PB 1 314.8	20	16	0	0	48	0	8	8	0	0	0	0	0	0	0	100
4PB 2 328.9	41	9	37	0	1	2	10	0	0	0	0	0	0	0	0	100
4PB 2 329.8	32	40	0	8	0	0	17	2	0	2	0	0	0	0	0	101
4PB 16 329.0	39	9	40	0	0	0	10	0	0	0	2	0	0	0	0	100
4PB 16 340.0	15	17	0	18	20	0	25	0	0	5	0	0	0	0	0	100
4PB 10 273.0	3	3	36	3	0	0	10	0	0	11	9	0	17	0	16	99
4PB 10 280.0	25	28	36	2	5	1	2	2	0	0	0	0	0	0	0	101
4PB 10 283.4	1	0	46	8	0	0	14	0	0	1	4	4	21	1	0	100
4PB 10 285.8	8	2	46	6	0	0	20	0	0	4	0	7	6	1	0	100
4PB 10 295.1	29	12	40	2	0	2	8	0	0	0	0	1	6	0	0	100
4PB 10 297.9	10	0	37	4	0	0	8	0	0	0	0	1	40	0	0	100
4PB 10 302.9	9	0	42	1	0	0	0	0	0	1	0	18	17	7	0	100
4PB 10 304.0	49	20	22	0	0	0	9	0	0	0	0	0	0	0	0	100

Table 7. (continued).

SAMPLE NUMBER	GLS	VES	QTZ	PLAG	MULL	CORD	OPQ	TRID	SPHER	PXN	PHYLL	PORO	CEM	CHT	MTX	TOTALS
4PB 10 309.0	55	32	10	0	0	0	3	0	0	0	0	0	0	0	0	100
4PB 10 314.0B	62	27	5	0	0	0	6	0	0	0	0	0	0	0	0	100
4PB 10 316.0	53	18	9	0	0	0	20	1	0	1	0	0	0	0	0	102
4PB 10 317.7A	72	6	0	0	20	0	2	0	0	0	0	0	0	0	0	100
4PB 10 317.7B	46	30	0	0	12	0	12	0	0	0	0	0	0	0	0	100
4PB 10 330.6	22	24	0	20	2	2	30	0	0	0	0	0	0	0	0	100
4PB 13 279.0	48	21	16	2	1	1	6	5	0	0	0	0	0	0	0	100
4PB 13 283.0	38	0	23	1	0	0	0	0	1	0	0	15	0	0	0	100
4PB 13 288.5	16	0	42	1	0	0	32*	0	0	0	4	22	0	0	5	100
4PB 13 293.5	14	5	40	4	0	2	10	0	0	0	4	13	0	0	8	100
4PB 13 302.0	58	16	18	3	1	0	2	0	1	0	0	0	0	0	0	99
4PB 13 303.0	62	14	18	0	0	1	2	0	2	0	0	0	0	0	0	99
4PB 13 311.2	44	15	10	5	0	3	8	8	7	0	0	0	0	0	0	100
4PB 13 313.2	50	26	6	0	0	0	2	0	16	0	0	0	0	0	0	100
4PB 13 315.8	55	45	0	0	0	0	0	0	0	0	0	0	0	0	0	100

Table 7. (continued).

SAMPLE NUMBER	GLS	VFS	QTZ	PLAG	MULL	CORD	OPQ	TRID	SPHER	PXN	PHYLL	PORO	CEM	CHT	MTX	TOTALS
4PB 13 316.2	57	41	0	0	0	0	0	0	2	0	0	0	0	0	0	100
4PB 13 317.7	50	35	0	2	0	2	11	0	0	0	0	0	0	0	0	100

ABBREVIATIONS: Gls-Glass; Ves-vesicles; Qtz-Relict Quartz; Plag-Plagioclase; Mull-Mullite; Cord-Cordierite
Opq-Opakes; Trid-Tridymite; Spher-Spherulite; Px -Pyroxene and other heavy minerals; Phyll-
Phyllosilicate; Poro-Porosity; Cem-Undifferentiated cement; Cht-chert; Mtx-Matrix and rock frag-
ments.

* Char is 22%

The relict minerals and rock fragments recognized include potassium and plagioclase feldspars, zircon, and chert.

Table 7 lists spherulites as one of the constituents. These clusters of microlites are too fine grained to be identified optically; however, a comparison of the X-ray results (Table 8) for samples containing spherulites shows that they are probably composed of either tridymite or cristobalite (both high temperature polymorphs of quartz).

The pyrometamorphic minerals identified in thin section in this study are plagioclase (Fig. 28 A) (oligoclase and andesine), cordierite (Fig. 28 B), tridymite, mullite (Fig. 28 C), cristobalite (Fig. 28 D), and a minor amount of monoclinic pyroxene. All of these minerals have euhedral to subhedral crystal habits indicating that they crystallized directly from the melt formed during the high temperature thermal alteration of the overburden.

The textures of the pyrometamorphic rocks are primarily dependent on the degree of melting. Samples 4PB1-313.9, 4PB1-314.6, 4PB1-314.8, 4PB2-329.8, 4PB10-317.7, 4PB10-330.6, 4PB13-313.2, 4PB13-315.8, 4PB13-316.2, 4PB13-317.7 and 4PB16-340.0 have only minor amounts or no relict minerals and are composed of only glass, vesicles, and minerals that have crystallized directly from the melt. These rocks are the most thoroughly altered pyrometamorphic rocks having formed from completely melted overburden. These rocks are paralava rocks and paralava breccias. Other samples have undergone only partial melting, which is shown by the fact that they contain glass and new high temperature minerals in addition to relict minerals, mainly relict quartz. These rocks are the buchites and buchite breccias. The hornfels generally do not contain much glass, but have been altered to high enough temperatures to have their clay minerals destroyed. Many hornfels contain significant amounts of relict minerals as shown on Table 7.

X-Ray Diffraction and SEM Studies of Pyrometamorphic Rocks

Fifty-three core samples were crushed and prepared for X-ray diffraction studies in this investigation. These samples were taken from both thermally altered rock and from intact samples taken from above the cavity formed by the UCG burns. The mineralogy of the samples indicate the degree of thermal alteration in and above the burn cavities. Of these 53 samples, 28 samples had new, high temperature pyrometamorphic minerals and glass. These 28 samples with new minerals produced by the UCG burn provide the data base (Table 8) for the interpretation of the temperatures reached during the burn. The 25 samples that were not detectably altered provide information on the extent of heat effects on the original clay mineral content of the overburden and these samples are included in the mineral summary given in Tables 5 and 6.

The pyrometamorphic minerals formed in the UCG experiments and identified by X-ray diffraction are cordierite, mullite, cristobalite, tridymite, plagioclase (high temperature oligoclase and andesine) and sanidine. Figures 29 and 30 show SEM micrographs and elemental energy dispersion analyses of

Table 8. Summary of X-ray mineralogy of pyrometamorphic rocks from the Hanna IV, UCG site, Wyoming.

Sample Number	QTZ	CORD	MULL	CRIST	TRID	PLAG	SANID	GLS
4PB1 302.0	x	tr.	-	-	-	x	-	x
4PB1 313.5	-	-	x	x	-	-	-	x
4PB1 314.4	-	x	x	x	tr.	-	-	x
4PB1 314.6	-	x	x	x	tr.	-	-	x
4PB1 314.8	-	x	x	x	-	-	-	x
4PB2 328.9	x	x	-	-	-	-	-	x
4PB2 329.8	x	x	x	-	-	-	-	x
4PB2 334.9	x	-	x	x	-	-	-	x
4PB10 273.0	x	-	tr.	-	-	-	-	tr.
4PB10 280.0	x	x	-	-	-	-	x	x
4PB10 283.4	x	-	-	tr.	x	-	-	tr.
4PB10 314.0	-	x	x	tr.	-	-	-	x
4PB10 317.7A	-	x	x	tr.	-	-	-	x
4PB10 317.7B	-	-	x	x	-	-	-	x
4PB10 330.6	-	-	-	-	-	x	-	x
4PB13 278.8	-	-	-	-	-	-	-	tr. (?)
4PB13 279.0	x	x	-	x	-	-	-	x
4PB13 283.0	x	-	-	-	-	-	x	x
4PB13 288.5	x	x	-	-	-	-	-	x
4PB13 293.5	x	x	-	-	-	-	-	x
4PB13 302.0	x	-	-	-	-	x	-	x
4PB13 313.2	-	x	-	tr.	x	-	-	x
4PB13 314.8	-	x	x	x	-	-	-	x
4PB13 316.2	-	x	x	tr.	-	-	-	x

Table 8. (continued).

Sample Number	QTZ	CORD	MULL	CRIST	TRID	PLAG	SANID	GLS
4PB14 283.0	x	tr.	-	x	-	-	-	x
4PB14 289.3	x	tr.	-	x	-	-	-	x
4PB16 329.0	-	-	-	-	-	-	-	x
4PB16 340.0	-	-	x	x	x	x	-	x

Abbreviations: QTZ-Quartz; CORD-Cordierite and Ferrocordierite; MULL-Mullite; CRIST-Cristobalite; TRID-Tridymite; PLAG-Plagioclase(oligoclase); SANID-Sanidine; GLS-Glass

x:Present in X-ray patterns; Glass detected microscopically
tr:Trace amounts near limit of detection

- Figure 28. A) Photomicrograph of plagioclase laths in glass; 4PB10-330.6. Width of field of view 1.6mm.
- B) Photomicrograph of cordierite crystal (Cd); 4PB10-314.0. Width of field of view 2.7mm.
- C) Photomicrograph of needles of mullite and irregularly-shaped vesicles in a glass matrix; 4PB10-313.7. Width of field of view 2.7mm.
- D) Photomicrograph of ball-like clusters of cristobalite and needles of mullite in a glass matrix; 4PB1-314.8. Width of field of view 0.5mm.

A.

B.

C.

D.

- Figure 29. A) SEM photograph of mullite needles; 4PB1-314.8. Each division on bar scale equals 0.1mm.
- B) Elemental energy dispersion analysis of mullite ($3\text{Al}_2\text{O}_3 \cdot 2\text{Si}_2\text{O}_2$); 4PB1-314.8. Peaks for gold (Au) are from gold coating on sample. Al and Si peaks are from the mullite.

A.

06-SEP-84 00:47:13
RATE: CPS TIME 26LSEC
00-20KEV: 10EV/CH PRST: OFF
A: MULLITE1-314.8B:
FS= 277 MEM: A FS= 100

B.

- Figure 30. A) SEM photograph of platy crystals of plagioclase (P) with unknown mineral growing on plagioclase plates; 4PB10-330.6. Each division on bar scale equals 10 microns.
- B) Elemental energy dispersion analysis of plagioclase 4PB10-330.6; peaks for gold (Au) are from gold coating on sample. Ca, Al and Si peaks are from the plagioclase; Na peaks were not detected because of energy of Na-radiation is below the detection limit of the system.

A.

06-SEP-84 00:41:37
RATE: CPS TIME 110LSEC
00-20KEV: 10EV/CH PRST: OFF
A: PLAG10-330.6 B:
FS= 1694 MEM: A FS= 200

CURSOR (KEV) = 03.040

EDAX

B.

mullite and plagioclase crystals. Mullite and plagioclase are the most abundant pyrometamorphic minerals found in the altered rocks. Magnetite is also a common constituent of the rocks, but is removed with a hand magnet before the X-ray patterns are made in order to reduce the background caused by secondary fluorescence from iron. Other constituents that are present, but do not give identifiable peaks on the X-ray patterns, are glass and thermally altered coal (char). Glass is a common constituent and char was obviously present in several samples. Volumetrically the pyrometamorphic minerals make up only a few percent of the thermally altered rock, while glass, vesicles, and opaque constituents (char, magnetite and opaque glass) make up a large percentage of the pyrometamorphic samples. The sample preparation for the X-ray diffraction analysis concentrates the mineral constituents and allows the identification of the high temperature pyrometamorphic minerals to be made even though they are present in only minor amounts.

Temperature Estimates Based on Pyrometamorphic Minerals

The constituents of the pyrometamorphic rocks formed by the Hanna IV UCG burns are glass, mullite, cristobalite, tridymite, plagioclase, cordierite, and sanidine. The plagioclase feldspars are high temperature oligoclase and andesine, and the cordierite is iron rich. The texture of the high temperature minerals indicates that the minerals and glass formed directly from molten overburden rock material during the experiments.

Estimates of the temperatures of formation of the high temperature pyrometamorphic minerals are based on phase equilibria studies (e.g., Schairer and Yaki, 1952 and Levin, et al., 1964). These estimates have been discussed in previous publications on high temperature minerals formed during UCG experiments (Craig, et al., 1982; Ethridge, et al., 1983a and 1983b).

The occurrence of mullite, tridymite, cordierite, and glass in a rock indicates temperatures of about 1200°C. Where cristobalite is more abundant in the rocks than tridymite, the temperatures may have been higher than 1200°C.

Extent of Thermal Alteration Outside the Cavity

In order to determine the extent of heating and thermal alteration of intact overburden above the cavity, 14 samples from two cores from the Hanna IV A were selected from an interval of 3 centimeters to over 6 meters from the top of the inferred cavity roof. The relative extent of alteration was determined on the basis of changes in clay mineralogy as detected by X-ray diffraction techniques.

The clay minerals identified in overburden units A and A' include kaolinite, illite, smectite, and smectite/chlorite. The kaolinite structure is destroyed upon heating at temperatures of 550°C or higher (Thorez, 1975); therefore, kaolinite can be used as an index mineral of heat transfer through the overburden adjacent to the cavity roof.

The sample numbers for this analysis of clay alteration in the intact overburden are given in Appendix C, along with their distances from the cavity roof. The X-ray patterns of all these samples showed no destruction of the kaolinite of the rocks; therefore, the temperatures did not exceed 550°C, even in very close proximity (within 8 cm) of the cavity roof. In contrast, no clay minerals of any type are detected in the partially melted rocks common within the cavity.

CHARACTERIZATION OF THE BURN CAVITIES

Dimensions

The cavity reconstructions, as shown on Figure 27, are based on detailed descriptions of the 21 post burn cores (Appendix A) and analyses of geophysical logs. Location of the core holes and inferred cavity boundaries are shown on Figure 26. The first phase of the experiment, Hanna IVa, produced a cavity with a maximum dimension of 45 m (146 ft) and a minimum dimension of 15.4 m (50 ft). It reached a maximum height of 18 m (59 ft) as measured from the lowest extent of the altered coal layer. The second cavity as produced from the Hanna IVb phase of the experiment, has a maximum dimension of 40 m (132 ft) and a minimum dimension of 15 m (48 ft). It reached a maximum height of 11 m (36 ft).

The steep side walls, convex upward roofs (as inferred from post-burn core analyses), and dimensions of the long and short axes delineate the typical elliptical shape of UCG burn cavities.

Cavity Stratigraphy

The Hanna IVa and Hanna IVb cavities (Fig. 27) show similar stratification of pyrometamorphic rocks and altered coal (char). The bottom layer in both of the cavities is a rubblized layer of char ranging from 2.1 to 5.5 meters (7 to 18 ft) in thickness in the cores drilled through the cavities. This bottom layer of char is overlain by a rubblized layer containing paralava, paralava breccia, and buchite. The layer of paralava rock, paralava breccia, and buchite is thickest (4.0 meters [13 ft]) in core 4PB16 and thins to about .6 meters (2 ft) in core 4PB2 of the Hanna IVb cavity (Fig. 30). The thickness of the paralava rock, paralava breccia, and buchite layer is more

uniform in the Hanna IVa cavity at about 2.1 to 2.4 meters (7 to 8 ft) in both core holes shown in Figure 27.

The uppermost pyrometamorphic rock type in both cavities is hornfels. In the hornfels layer in cores 4PB10, 4PB13, and 4PB14, the rock is not all rubblized and relict sedimentary bedding retain its original orientation. Since there is a void space above this zone, it is hypothesized that these sections of altered overburden dropped as large unrotated and unrubblized blocks. It is not possible to determine the exact size of the blocks from the core data, however. It must be noted that not all of the hornfels are intact. Cores 4PB1, 4PB2, and 4PB16 all have mostly rubblized sections in the hornfels unit.

The thickness of the void space in the upper part of the cavities cannot be determined with absolute precision. Since core recovery is rarely 100 percent in zones of rubblized rock, the thicknesses depicted on Figure 4 are maximums and the void space may contain some rubble. As is the case at other UCG sites, the highest temperatures were attained in the lower portions of the cavity. Significant melting of collapsed overburden took place during or immediately following coal gasification as evidenced by the lithology and mineralogy of the pyrometamorphic rocks.

GEOTECHNICAL STUDIES

General

Thirty-eight unaltered siltstone and sandstone samples from 12 Hanna IV post-burn core holes were selected for geotechnical analyses. The locations of post-burn wells are shown on Figure 26, and the relationship between core samples tested and the cavities formed by the Hanna IV experiments is shown on cross section A-A' (Fig. 27). All core holes from which samples were taken could not be shown on the cross section as some of the core holes are not on the section line depicted. Samples are identified by core hole number and depth (in feet) to the center of the length of core tested in Table 9.

In addition to Hanna IV data, samples representing overburden lithologies at the Hanna II (10 samples) and Hoe Creek III (18 samples) UCG sites were taken from post-burn core holes for geotechnical analyses (Table 10). These three data sets, along with rock strength data originally reported in Ethridge, et al. (1983) for the Rawlins-North Knobs site, provide a basis for a comparative overburden stability study.

Table 9. Results of ultrasonic and point load tests on rocks samples from the Hanna IV UCG site, Wyoming.

SAMPLE NUMBER	V_{P1} M_s^{-1}	V_{S1} M_s^{-1}	G	E	K	ν	$I_s(50)$	T_s (Mpa)	q_u (Mpa)	Unit
4PB1 32.7	1397.1	636.2	.84	2.32	3.23	.369	.220	7.609	4.78	C
4PB1 132.8	2021.3	1073.4	3.03	7.90	7.72	.304	1.481	4.102	32.59	B
4PB1 204.6	1718.6	1125.0	3.27	6.07	2.86	.125	2.356	6.526	51.59	B
4PB1 246.3	1166.1	799.0	1.42	3.01	1.61	.058	1.263	3.498	27.47	A
4PB1 250.0	2019.7	1281.2	4.01	9.32	5.95	.163	1.514	4.194	33.16	A
4PB1 257.0	1909.1	663.2	.96	2.74	6.99	.431	.220	.609	4.61	A
4PB1 270.5	993.7	480.9	.49	1.33	1.62	.347	.378	1.047	8.29	A
4PB1 279.5	1413.0	885.6	1.73	4.08	2.68	.176	.988	2.737	21.73	A
4PB1 299.2	970.1	560.3	.74	1.84	1.47	.250	1.010	2.798	22.11	A
4PB2 47.6	2138.7	1335.7	.84	2.32	3.23	.180	.252	.698	5.53	C
4PB2 116.6	1237.4	643.0	.92	2.41	2.48	.315	.785	2.174	17.43	C
4PB2 120.8	1295.4	805.1	1.65	3.92	2.63	.185	1.136	3.147	24.87	B
4PB2 167.2	1204.2	552.9	7.15	6.62	4.41	.367	1.599	4.429	34.37	B
4PB2 234.5	1645.0	1279.5	3.98	5.84	2.60	.361	1.746	4.836	38.13	A
4PB2 251.5	1618.9	1026.0	2.46	5.74	3.67	.164	1.608	4.454	34.74	A
4PB2 253.0	1730.8	1082.0	2.80	6.62	4.41	.183	.988	2.737	21.73	A
4PB2 275.4	2291.7	1253.6	3.36	8.65	7.88	.286	1.662	4.604	36.39	A
4PB2 292.4	1295.4	736.3	1.13	2.84	2.36	.261	4.390	1.216	9.55	A
4PB2 305.5	2761.9	1074.1	2.88	8.14	16.19	.411	4.873	13.498	108.18	A
4PB3 261.5	1805.5	714.2	1.14	3.20	5.75	.407	2.176	5.728	60.12	A
4PB3 312.0	1337.0	875.9	1.64	3.69	1.64	.124	.412	1.075	11.28	A
4PB3 324.0	1549.2	854.9	1.72	4.40	3.35	.281	2.631	6.804	71.41	A'
4PB10 238.8	1242.0	900.6	1.77	3.34	1.01	.054	.846	2.227	23.37	A
4PB10 252.8	1877.5	1000.0	2.43	6.33	5.32	.302	3.022	7.956	83.49	A
4PB10 255.2	1857.7	1121.7	3.61	8.76	5.09	.213	2.417	6.363	66.78	A
4PB11 241.5	1815.5	921.4	2.28	6.04	6.56	.327	1.083	3.000	23.72	A
4PB11 294.0	1578.9	914.6	1.82	4.55	3.61	.247	2.391	6.623	52.49	A
4PB11 351.0	2024.5	896.7	1.99	5.47	8.14	.378	2.263	6.268	49.79	U
4PB16 313.8	1377.2	804.2	1.38	3.44	2.67	.241	.641	1.776	14.05	A
4PB16 365.0	2410.7	1017.6	2.44	6.80	11.27	.392	2.482	6.875	54.35	M
4PB17 276.2	1829.9	986.1	2.28	5.90	5.56	.295	2.797	7.748	61.54	A
4PB17 286.8	1408.4	869.6	1.60	3.82	2.60	.192	.610	1.690	13.37	A
4PB17 293.5	2025.6	1135.1	2.98	7.57	6.50	.271	1.704	4.720	37.31	A
4PB18 224.7	2124.4	1045.9	2.59	6.95	8.10	.340	1.704	4.720	37.31	A
4PB18 264.5	3235.3	2062.5	10.29	23.84	15.04	.158	4.267	11.820	93.45	A
4PB19 343.7	1792.8	1015.8	2.34	5.92	4.17	.264	1.262	3.264	34.25	U
4PB21 288.2	1998.7	1298.0	4.13	9.35	4.25	.133	2.692	6.962	73.07	A
4PB21 317.2	1780.3	1187.8	3.58	7.87	3.28	.100	2.229	5.767	60.50	A'

V_p - Compressional wave velocity; V_s - Shear wave velocity; G - shear modulus
E - Young's modulus; K - Bulk modulus; ν - Poisson's ratio; I_s - Point load index
 T_s - Tensile strength; q_u - uniaxial compressive strength.

Table 10. Results of point load tests on unaltered rock samples from the Hanna II and Hoe Creek III UCG sites, Wyoming.

Sample Number		Site	Unit	Lithology/ W,D	I _s (50)	T _s (MPa)	q _u (MPa)
CH 131	66.8	H II	D	vfgss/D	.258	.715	7.50
CH 131	171.0	H II	C	mgss/D	.243	.672	7.06
CH 131	192.5	H II	B	vfgss/D	.874	2.420	25.40
CH 131	213.0	H II	B	fgss/D	.391	1.083	11.37
2HP 174	33.0	H II	C	fgss/D	.485	1.344	14.11
2HP 175	258.5	H II	A	fgss/D	2.847	7.885	82.75
2HP 177	226.0	H II	A	vfgss/D	.513	1.422	14.93
2HP 177	304.8	H II	U	vfgss/D	1.526	4.227	44.36
2HP 178	229.0	H II	A	vfgss/D	1.615	4.474	46.96
2HP 181	299.0	H II	U	fgss/D	1.306	3.618	37.97
PBC 1	118.3	HC	E	mgss/W	.143	.396	4.15
PBC 1	146.6	HC	C	mgss/W	.008	.022	.23
PBC 1	148.0	HC	C	vfgss/W	.003	.010	.10
PBC 3	78.8	HC	F	clst/W	.017	.048	.50

Table 10. (continued)

Sample Number		Site	Unit	Lithology/ W,D	I _s (50)	Ts (MPa)	qu (MPa)
PBC 3	97.3	HC	E	vfgss/W	.007	.019	.20
PBC 4	90.2	HC	F	sltst/W	.107	.296	3.11
PBC 4	91.2	HC	F	sltst/W	.052	.143	1.50
PBC 4	95.2	HC	F	sltst/W	.082	.226	2.38
PBC 6	94.8	HC	F	fgss/W	.041	.115	1.21
PBC 6	112.8	HC	E	mgss/W	.017	.047	.50
PBC 6	124.3	HC	E	mgss/W	.007	.20	0.19
PBC 6	155.6	HC	C	clst/W	.078	.217	2.28
PBC 6	158.4	HC	C	clst/W	.128	.354	3.72
PBS 1	129.4	HC	E	fgss/W	.005	.013	.13
PBC 9	48.6	HC	F	vfgss/D	.591	1.636	17.17
PBC 9	101.2	HC	E	mgss/W	.007	.019	.20
PBC 10	177.0	HC	B	mdst/D	.002	.061	.64
PBS 3	186.5	HC	A	sltst/D	.783	2.17	22.76

ABBREVIATIONS: W - Wet; D - Dry; I_s(50) - Point load index corrected for 50mm diameter core; Ts - Tensile strength; qu - uniaxial compressive strength; MPa - Megapascals.

Mechanical Tests

Static Test: Point Load Test

The point load test is widely used in rock mechanics studies as it quickly and easily provides reliable estimates of the tensile (Ts) and uniaxial compressive (qu) strengths of intact rock samples. It should be pointed out that the strength of an intact sample is not completely representative of the strength of the in-situ rock mass as it does not take into account the effects of the type, orientation or frequency of discontinuities. These discontinuities need to be identified and assessed when determining overburden strength and failure potential at the site of a UCG experiment. Preferably, this should be done before the test. In any event, the point load test is an accurate measurement of the intact strength, is economical to apply, and suitable for use in the field (Bieniawski, 1975; Broch and Franklin, 1972).

Cylindrical core samples, with a minimum of length of 1.5 times the core diameter (core diameter = 26 mm or 1.8 in), were used for the point load tests. Techniques and apparatus used were the same as described by Ethridge, et al. (1983b). The point load index (Eq. 1) is the minimum pressure required to cause failure of the specimen divided by the square of the distance between the contact points of the standard point load platens (Broch and Franklin, 1972):

$$I_s = P/D^2 \quad (1)$$

The uniaxial compressive and tensile strengths of the rock samples can be derived from the point load index using Equations 2 and 3 respectively:

$$q_u \text{ (MPa)} = 29.07 \times I_s \text{ (50 mm)} \quad (2)$$

$$T_s \text{ (MPa)} = 2.77 \times I_s \text{ (50 mm)} \quad (3)$$

where I_s (50 mm) is the point load index corrected to a standard core diameter of 50 millimeters. A nomogram giving this correction and a discussion of the correction is given in Burns, et al. (1983).

The storage history of the core samples used has an effect on the derived strength measures, as this affects the water content of the samples at the time of testing. The Hanna IV, Rawlins, Hanna II, and two Hoe Creek III core samples had been air-dried for several months prior to testing. The remaining Hoe Creek III core samples had been sealed in paraffin immediately upon extraction at the drilling site, thereby preserving the in-situ water content. It has been estimated that there can be a 30 percent increase in rock strength upon drying of a sample (Broch and Franklin, 1972). This test condition and its effect on the interpretations of this study are discussed below.

A second inherent source of error is in the index calculations for very friable or shaley core samples. Due to the indentation of the point-load platens on softer rocks during loading, the core diameter values used in core strength index calculations will be greater than the actual core diameter of

the sample at failure. Strength indices will therefore be slightly higher than the actual values. However, this effect is negligible for the purposes of this study.

Results of the point-load tests are given in Table 9 for Hanna IV unaltered core samples (Marcouiller, et al., 1984). New data on point-load results for the Hanna II and Hoe Creek III unaltered cores are presented in Table 10. Point-load strength data from the Rawlins overburden units are given in Burns, et al. (1983). These data are summarized in Table 11, which lists the strength parameter averages for each overburden unit found at each of the four experimental sites. The most notable aspect of these test results is the extremely low strength parameter values for the lithologic units reported for the overburden units from the Hoe Creek III site. While it is true these averages are for "wet" core samples (those sealed in paraffin until several days before point-load testing), strength values for units B, C, E, and F are an order of magnitude lower than those characterizing the other three sites. This is far less than a 30 percent strength decrease for "wet" samples, an amount which can be reasonably expected.

One sample from the Hoe Creek III underburden, unit A, was tested as well. This sample was not "wet" when tested, however, no petrographic data is available for further study of this unit. Since this sample is from below the gasified coal seam, the higher strength of the sample would have no affect on roof rock stability in any event.

Figure 31 illustrates the correlation between the point-load and uniaxial compressive strength indices and the local lithologic units at Hanna IV, Hanna II, Hoe Creek III, and Rawlins. Two strength classification schemes are shown; the upper scheme was proposed by Broch and Franklin and the lower by the Geological Society of London (Broch and Franklin, 1972). This figure and applications of point-load test results are discussed in detail in the comparative study section of this report.

Dynamic Test: Seismic Wave Velocities

The dynamic elastic constants which quantify directional strength characteristics of a rock mass are dependent upon the compression (V_p) and shear (V_s) wave velocities as well as the density of a rock mass (Burns, et al., 1983; Rinehart, et al., 1961).

A seismic analyzer with P- and S-seismic wave generators and receiver-transducers was used to measure the compressional (V_p) and shear (V_s) wave velocities in core samples, as outlined by Burns, et al. (1983). The dynamic elastic constants derived from these velocity measurements are given in Table 9. This test was performed on Hanna IV samples for the purpose of defining the relationship existing between the seismic wave velocities and uniaxial and compressive (q_u) and tensile (T_s) strengths. Uniaxial compressive (q_u) and tensile strength (T_s) as determined by the point-load test have positive, linear relationships with compressional (P) and shear (S) wave velocities (Marcouiller, et al., 1984). Figure 32 shows uniaxial compressive strength plotted against P-wave velocity for 38 samples from the Hanna IV overburden

Table 11. Strength parameter averages for unaltered overburden rock units of the Hanna IV, Hanna II, Hoe Creek III and North Knobs UCG sites, Wyoming.

SITE	UNIT	$I_s(50)$	T_s (MPa)	q_u (MPa)
Hanna IV	A	1.643	4.56	39.13
	B	1.462	4.55	35.86
	C	.397	1.16	9.25
Hanna II	A	2.197	4.59	48.21
	B	.632	1.75	18.39
	C	.606	1.01	10.59
	D	.258	.72	7.50
Hoe Creek III	A	.783	2.17	22.76
	B	.022	.06	.64
	C(W)	.054	.15	1.58
	E(W)	.031	.12	.90
	F(W)	.052	.17	1.74
Rawlins	A	1.538	4.25	44.60
	B	.690	1.91	20.00
	C	no data		
	D	2.222	6.14	64.44
	E	2.189	6.05	63.49
	F	.758	2.10	22.00

ABBREVIATIONS: $I_s(50)$ -Point load index for 50mm core; T_s -Tensile strength; q_u -Uniaxial compressive strength; MPa-Megapascals; W-Wet samples

Figure 32. Uniaxial compressive strength (q_u) versus compressional wave velocity for 38 samples tested from the Hanna IV UCG site, Wyoming.

units, and the least squares line of best fit for these data. An r^2 value of .66 was computed for this line, which defines a moderately good correlation for these two variables.

The application of a correlation between uniaxial compressive strength and compressional and shear wave velocities lies in the use of high resolution seismic techniques during pre-burn field evaluations. Overburden strength may possibly be estimated on the basis of seismic wave velocity measurement and geophysical sonic logs.

OVERBURDEN STABILITY: COMPARISON WITH OTHER SITES

General

Significant geological and lithological differences exist between the Hoe Creek III UCG site, which experienced overburden collapse extending to the ground surface, and the Hanna and Rawlins sites, which experienced only limited collapse of the rock unit directly overlying the coal bed into the burn cavities.

Results of the overburden characterization and geotechnical studies may be used in conjunction with similar previously published data from the Hanna II (Craig, et al., 1982) and the Hoe Creek III and Rawlins sites (Ethridge, et al., 1983 a & b), to facilitate a comparison of the geological factors controlling overburden stability.

Geological parameters that affect overall roof rock stability include total overburden thickness, lateral and vertical homogeneity of the overburden lithologies, frequency and type of discontinuities, and lithology. These parameters are determined by the original composition, depositional environment, diagenesis and structural deformation of the overburden units. Geotechnical factors which affect overall roof stability include process well-spacing and the maximum and minimum burn cavity dimensions. These factors determine the span of unsupported roof rock left by the gasified coal seam.

Summary of Site Geology

Hanna

The Hanna No. 1 coal at the Hanna II and Hanna IV sites is a relatively flat-lying (dips range from 3 to 6 degrees NE), 7.6 to 9.1 m (25 to 30 ft) thick seam. It is directly overlain at the Hanna IV site by a laterally discontinuous, 3.3 m (11.0 ft) thick, indurated but shaley mudstone (unit A'). Above the mudstone facies lies unit A, a laterally-continuous, well indurated sandstone with lesser amounts of siltstone and mudstone. This unit is the roof rock to the burn cavities at both sites. It has an average thickness of 27.3 m (89.0 ft) at the Hanna IV site and 36.0 (118 ft) at the Hanna II site.

The major structural feature of the two sites is an east-west trending graben complex. Though this fault system adversely affected the linkage and gasification process during the Hanna IV, Phase b test (Covall, 1980), it did not seem to affect the overall stability of the overburden units. It is suspected that there is an associated fracture system, but its exact location remains undefined.

Rawlins

The steeply-dipping (65 degrees) G coal seam at the Rawlins-North Knobs experimental site is directly overlain by a laterally continuous sequence of fine-grained sandstones and siltstones (unit D). It has an average thickness of 25.9 m (85.0 ft). Total overburden thickness averages 69.5 m (228 ft). There is no major fault complex within the study area, however, well-developed joints are observed in outcrop (Ethridge, et al., 1983b).

Hoe Creek III

The Felix No. 1 and 2 coal seams at the Hoe Creek III site are essentially flat-lying. The upper seam is directly overlain by laterally discontinuous, poorly-indurated channel sandstones with interbedded siltstones and mudstones (unit E). It averages 9.4 m (31 ft) in thickness. The interburden, unit C, averages 5.2 m (17 ft) in thickness and is primarily massive to laminated claystones with interbedded mudstone, siltstone, and sandstone. Total overburden thickness averages 39.0 m (130 ft). There has been no evidence of faulting reported at this site.

Overburden Lithology, Rock Strength, and Roof Stability

Statistical Analyses

Intact rock strengths have been determined by the point-load test for core samples from the Hanna IV (Marcouiller, et al., 1984), Rawlins (Burns, et al., 1983), and the Hoe Creek III and Hanna II (this report) overburden units. Computed strength indices have been related to petrographic data in order to determine which lithologic parameters contribute to the overall stability or instability of a cavity roof rock.

It has been shown that the type and volume percent of cementing material is related to intact rock strength (Burns, et al., 1983; Marcouiller, et al., 1984). Percent calcite cement is linearly and positively related to the uniaxial and tensile strengths of sandstones and siltstones. Figure 34 shows uniaxial compressive strength plotted against volume percent calcite cement ($r^2 = .60$). It has also been shown that for a given quartz content, strength is greater for an intact specimen which has a relatively greater volume percent carbonate cement than for a similar sample having a greater abundance clay cement (Farmer, 1983). A non-linear inverse relationship has been reported by Burns, et al. (1983), for uniaxial compressive strength and volume percent clay cement.

Figure 33. Uniaxial compressive strength (q_u) versus volume percent porosity for 38 samples tested from the Hanna IV UCG site, Wyoming.

Figure 34. Uniaxial compressive strength (q_u) versus volume percent calcite cement for 38 samples tested from the Hanna IV UCG site, Wyoming.

Volume percent porosity bears a curvilinear inverse relationship to uniaxial compressive strength ($r^2 = .60$), as shown in Figure 33. This can be attributed to the direct and inverse relationship percent porosity shares with percent of total cementing material.

Comparative Study

Strength averages as determined for each local lithologic unit at each site are graphically displayed on Figure 31. The units fall into one of three strength classes: moderately strong to strong (high), moderately weak to moderately strong (medium), and very weak to weak (extra low to very low). These average strength values are controlled in part by the following geological factors: grain size, composition, porosity, and depositional environment. Table 12 summarizes these geologic parameters for each of the three classes of rock strength for the overburden units at the Wyoming UCG sites.

The moderately strong to strong (high) strength class is comprised of the overburden units which form the cavity roof rocks at the Hanna IV (unit A), Hanna II (unit A), and Rawlins (unit D) sites. Also in this class are the units which directly overlie the roof rock units at the Hanna IV (unit B) and Rawlins (unit E) sites, as well as the Rawlins underburden (unit A). As shown in Table 12, these units are all dominantly fine-grained, ranging from very fine to fine-grained sandstones. The average grain size is .13 mm. Noteworthy is the relatively high average volume percent of calcite cement (9.1 percent) and low average percents of clay cement (9.0 percent) and porosity (3.5 percent). In addition, these high strength units have, on the average, a smaller percentage of total cementing material (24.1 percent) than that of the low strength units (27.9 percent). This illustrates the importance of differentiating cement types when correlating petrographic data with rock strength. The six high strength units have been interpreted to be either point bar or lacustrine deltaic depositional environments.

The moderately weak to moderately strong class is comprised of the uppermost unit at Hanna IV (unit C), the three upper units at Hanna II (units B, C, D), and the uppermost unit and underburden unit at Rawlins (units B, F). No petrographic data base is available for the underburden unit at Hoe Creek III (unit A). These units are predominantly fine- to coarse-grained sandstones, with an average grain size of .25 mm. The average percent total cement is moderate at 15.6. Clay cement is the dominant cement type (11.2 percent), with small amounts of calcite cement (average 1.1 percent). Four of the five units for which data are available have been interpreted to represent braided stream environments.

The four overburden units which are classified as 'very weak to weak' are the overburden and interburden units of the Hoe Creek III site. The dominant lithology of these units is very fine to fine grained sandstone; the average grain size being .11 mm. Important to note is the amount and type of cements in these rocks. Though there is a high percentage of total cement (27.9 percent), the dominant type by far is clay cement (19.8 percent), with lesser amounts of calcite cement (6.2 percent). The unit directly overlying the coal seam, unit E, has the lowest percentage of total cement and a negligible amount of calcite (0.8 percent). The units represent a variety of fluvial

Table 12. Rock strength and lithologic properties of local stratigraphic units at Wyoming UCG sites.

LOCAL LITHOLOGIC UNITS AND ROCK STRENGTH	DOMINANT ROCK TYPE	AVERAGE GRAIN SIZE (MM)	% CEMENT	% CALCITE	% CLAY	% POROSITY	ENVIRONMENT	COMMENTS
<u>Mod Weak to Mod Strong Rocks</u>								
Hanna IV-C	mgss	0.31	10.8	0.1	6.9	7.7	Br. Str.	Top Unit Present
Hanna II-B	fgss	0.17	16.6	No Data	No Data	2.9	Pt. Bars	Include some ss below Coal
Hanna II-C	fgss	0.21	12.2	No Data	No Data	6.4	Br. Str.	Top Unit Present
Hanna II-D	No Data	--	--	--	--	--	--	Uppermost Unit
Rawlins-B	mgss	0.281	20.7	3.2	14.7	6.2	Br. Str.	Below Coal
Rawlins-F	mgss	0.266	17.8	0.1	11.9	5.2	Br. Str.	Top Unit Present
Av. Mod Strength Rocks	mgss - fgss	0.25	15.6	1.1	11.2	5.7	Br. Str.	
<u>Mod Strong to Strong Rocks</u>								
Hanna IV-A	vfgss	0.10	31.7	14.9	9.8	2.9	Lacustrine Delta	A' not included
Hanna IV-B	cgsilt- vfgss	0.06	17.6	5.7	7.4	3.4	Pt. Bars	Above A
Hanna II-A	vfgss	0.10	27.1	No Data	No Data	0.0	Lacustrine Delta	A' included

Table 12 (continued).

LOCAL LITHOLOGIC UNITS AND ROCK STRENGTH	DOMINANT ROCK TYPE	AVERAGE GRAIN SIZE (MM)	% CEMENT	% CALCITE	% CLAY	% POROSITY	ENVIRONMENT	COMMENTS
Rawlins-A	fgss	0.219	19.8	3.0	8.3	4.2	Pt. Bars	Below Coal
Rawlins-D	fgss	0.142	33.3	15.6	13.1	2.6	Pt. Bars	Immediately Above Coal
Rawlins-E	fgss	0.178	14.9	6.2	6.3	7.8	Pt. Bars	Above D
Av.-Strong Rocks	vfgss- fgss	0.13	24.1	9.1	9.0	3.5	Pt. Bars + Lacustrine Delta	
<u>Very Weak & Weak</u>								
Hoe Creek III-B	No Data	--	--	--	--	--	--	Interbed of Mudstone in Coal
Hoe Creek III-C	vfgss	0.08	31.9	9.7	21.2	3.4	Crevasse Splay + levee	Interburden
Hoe Creek III-E	fgss	0.18	18.7	0.8	15.9	10.1	Pt. Bars	Immediately Above Coal
Hoe Creek III-F	vfgss	0.07	33.0	8.2	22.4	1.8	Floodplain	Top Unit Present
Average Weak Rocks	vfgss	0.11	27.9	6.2	19.8	5.1	Floodplain + Pt. Bars	

Abbreviations: mgss: medium-grained sandstone; fgss: fine-grained sandstone; vfgss: very fine-grained sandstone;
cgsilt: coarse-grained siltstone; Pt. Bars: point bars; Br. Str.: braided stream.

depositional environments including crevasse splay, levee, floodplain, and point bars.

Geotechnology and Roof Rock Stability

In addition to lithologic characteristics of the overburden units, other parameters contributing to the ultimate stability of the roof rock over a burned-out cavity in a coal seam are geological and geotechnical in nature. Table 13 summarizes those parameters determined to affect roof stability and the probability of surficial depression or pit formation over a gasification zone.

Commercialization of underground coal gasification involves attainment of the maximum areal sweep of gasified coal for a given process well-spacing. However, overburden thickness must be considered when positioning the injection and production wells. This thickness of rock must be sufficient to contain a burn cavity after it has become filled with caved debris, and to accommodate the subsidence that will occur due to this inevitable roof rock collapse.

Injection well-spacing at the Hanna II and Rawlins sites are comparable at 18.3 m (60 ft) and 12.2 m (40 ft), respectively (Table 13). The resulting cavity dimensions and span of roof rock left unsupported by cavity formation were compensated for by sufficient material into which containment could occur. This favorable condition is illustrated by two indices, the overburden thickness/maximum cavity dimension and overburden thickness/well-spacing ratios. These are significantly greater than 1.0 for these two sites (Table 13).

In contrast, the Hoe Creek III site had a process well-spacing of 39.6 m (130 ft), more than twice that of the Hanna II test and three times that of the Rawlins test. This excessive spacing, coupled with a total overburden thickness of 39 m (128 ft), resulted with up to 1 m of surficial subsidence (Ganow, 1984) above the burn cavity. The overburden indices are equal to or less than 1.0 for this site, reflecting the unsatisfactory geotechnical and geological conditions.

Because the Hanna IV experiment was geared towards the near-term commercialization of underground coal gasification, the process well-spacing was significantly increased relative to that of the Hanna II experiment. However, the total overburden thickness of 97.6 m (320 ft) proved to be sufficient to contain the burn cavities and maintain a seal over the gasified zone. This condition is reflected in the overburden indices, which are significantly greater than 1.0 (Table 13).

Table 13. Geological and technological parameters affecting roof stability and experiment success at the Hanna IVa, Hanna IVb, Hanna II, Hoe Creek III and Rawlins UCG sites. (after Ethridge, et al., 1983c). Meters (feet)

	Hanna IVa	Hanna IVb	Hanna II	Hoe Creek III	Rawlins North Knobs
Coal Seam(s)	Hanna No. I	Hanna No. I	Hanna No. I	Felix 1 Felix 2	G Coal
Maximum Thickness Burned Coal	7.5 (25)	7.5 (25)	9.4 (31)	7.6 (25)	7.0 (23)
Total Overburden Thickness	97.6 (320)	97.6 (320)	95.0 (312)	39.0 (130)	69.5 (228)
Injection Well Spacing	30.5 (100)	34.3 (112)	18.3 (60)	39.6 (130)	12.2 (40)
Maximum Cavity Dimension	45.0 (146)	40.0 (132)	43.0 (141)	52.0 (170)	70.0 (230)
Minimum Cavity Dimension	15.0 (49)	11.0 (36)	35.1 (115)	17.0 (56)	30.5 (est.) (100)
Maximum Cavity Height	18.0 (59)	11.0 (36)	21.3 (70)	13.0 (43)	20.0 (66)
Overburden Thickness/ Well Spacing	3.2	2.8	5.2	1.0	5.7
Overburden Thickness/ Well Spacing	2.2	2.4	2.2	.75	1.7

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APPENDICES

APPENDIX A

DETAILED LITHOLOGIC LOGS OF CONTINUOUS CORES AND
KEY TO SYMBOLS USED

CODES FOR ABBREVIATIONS AND SYMBOLS USED
IN CONSTRUCTION OF LITHOLOGIC LOG

BEDDING THICKNESS

H -	Homogenous (no lamination)
H - DM	Homogenous, distinctly mottled
H - IM	Homogenous, indistinctly mottled
L -	Laminated - <1 cm thick
F -	Thin Bedded - 1-10 cm thick
M -	Medium Bedded - 10-30 cm thick
T -	Thick Bedded - 30-100 cm thick
VT	Very Thick Bedded - >100 cm thick
L/F	Thin bedded sets of cross-lamination; etc.

INDURATION

U -	Unconsolidated
I -	Indurated
IP -	Indurated but plastic
IS -	Indurated but shaly
IF -	Indurated but friable
WI -	Well indurated

SORTING

WS -	Well sorted
MWS -	Moderately well sorted
MS -	Moderately sorted
PS -	Poorly sorted

ROUNDNESS

A -	Angular
S -	Sub-rounded to Sub-angular
R -	Rounded

PERCENT LIMESTONE (Scale of 1 - 10)

<1 -	Trace of effervescence
1 -	Slight effervescence
3 -	Moderate effervescence
5 -	Strong effervescence
10 -	Very strong effervescence
>10 -	Limestone

SEDIMENTARY STRUCTURE SYMBOLS

	large-scale planar cross-bedding (foreset beds)
	planar cross-bedding
	parallel bedding
	trough cross-bedding
	scours (with channel lag)
	scour and fill
	ripples in drift (lee and stoss side preserved)
	ripple-tabular cross-lamination
	ripple-trough cross-lamination
	ripples in drift
	wavey (irregular) bedding
	flaser bedding
	lenticular bedding
	weak bioturbation
	moderate bioturbation
	strong bioturbation
	rooting
	contorted (slumped) beds
	micro faults
	growth faults
	loadcasting
	sand dike

ROCK TYPE SYMBOLS

	conglomerate
	intraclastic conglomerate
	sandstones (with granule layers,
	clayey sandstones
	siltstone
	sandstone and siltstone
	mudstone
	claystone
	coal or peat
	limestone
	micritic limestone
	algal limestone
	marlstone (clayey limestone)
	gypsum
	lost core

ACCESSORY SYMBOLS

	sulfur
	calcareous (>3%)
	marcasite nodules
	pyrite nodule
	oxydized pyrite nodule
	plant fragments and carbonaceous matter
	pelletoids
	limonitic
	gypsum
	organic partings
	clay gall
	siderite zone
	glauconite
	megafossils
	mica
	chert
	oxydized colors (reddish)
	bentonite
	feldspar
	clayey
	iron oxide nodules
	manganese
	wood fragments

PROJECT NAME HANNA IV HOLE NO: 4PBIDEPTH: FROM 10 FT TO 35 FT. BOX NOS: 1,2,3LOCATION: T S R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	GLAY MID	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
10		5Y7/2		H									MWS	S		R	1	IF	Yellowish gray, medium grained, moderately well-sorted sandstone, predominantly structureless with trace of low angle planar cross-bedding.		
15		10YR 8/4		H												R		U	Pale grayish orange coarse-grained, well sorted sandstone, with no apparent structure.		
20		10YR 8/4		H									PS	S		⊖		IF	Pale grayish orange, coarse-grained moderately well-sorted sandstone. Conglomeratic from 20.01 ft. to 22.7 ft.		
25		10YR 8/5		H									MWS	A		R ⊖		U	Pale grayish orange medium-grained, moderately well-sorted sandstone.		
30		10YR 7/4		F												R		IF I	Grayish orange medium-grained, moderately well-sorted sandstone with trough cross bedding and granule layers.		
35																					

PROJECT NAME HAWAII IV HOLE NO: 4PR1
 DEPTH: FROM 35 FT TO 60 FT. BOX NOS: 3,4,5,6
 LOCATION: T R S S

m. DEPTH	ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
35			10YR 7/4	€	H										
					F										
					H		PS	S							
40			10YR 8/3	///	F		PS			☉	1	IF	Pale yellowish orange , coarse-grained, moderately well-sorted sandstone with planar cross-bedding and granule layers.		
				///	H		MWS								
45			10YR 8/3	///	F										
				///								U	Pale yellowish orange, medium-grained, moderately well-sorted thin bedded sandstone with planar cross bedding and granule layers.		
50			10YR 8/3	€			WS			☉		I	Tan, medium-grained grading into coarse-grained, well to moderately sorted thin-bedded sandstone with slight trough cross-bedding, planar cross bedding and conglomeratic layers. Coarsening upward sequences of conglomerate to fine and medium-grained sandstone.		
				€			MWS			☉					
55			N9	///			PS			☉			LOST CORE		
			N9	///			PS			☉					
			10YR 8/4	///	L		PS			☉		IF	Gray-white, coarse-grained, moderately sorted, sandstone, with no apparent structure, interlayered with tan, fine-grained, well-sorted sandstone with thin beds (.5 to 1.0 cm) and conglomeratic layers.		
60							PS			R					

PROJECT NAME HANNA IV HOLE NO: 4PPT1
 DEPTH: FROM 60 FT TO 85 FT. BOX NOS: 6,7,8
 LOCATION: T R S

DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
60		10YR 8/4											MS			①		I	Pale orange, coarse to fine-grained, poorly to well sorted, sandstone with planar crossbedding and conglomeratic layers.		
65		N 8.5		F									PS			①			Gray- white, medium to fine-grained, moderately well-sorted, sandstone with trough crossbedding.		
70		5Y7/2		1									MS			①		U			
75		5Y8/1											MS	S		①		I	Yellowish gray, fine to very fine, moderately well sorted sandstone with wavy laminations and organics along the bedding planes		
80		10YR 8/2		F									MS			①		I	Yellowish gray, fine to very fine, well sorted sandstone with interlayers, convoluted and slumped bedding, organic "threads", planar cross bedding.		
85		N9											MS			①		IF	Very pale orange fine-grained, moderately well-sorted sandstone with trough crossbedding, conglomeratic layers.		
																①			Grayish white, fine-grained, moderately to well-sorted sandstone with organic "threads" throughout, concentration of large clay clasts at 72.5 to 74 ft.		

PROJECT NAME HAWA IV HOLE NO: 4PRL
 DEPTH: FROM 85 FT TO 110 FT BOX NOS: 8, 9, 10
 LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
85									R			Grayish white, coarse to very coarse-grained, moderately well sorted sandstone with no apparent structure. Conglomeratic 87.4-88.9 ft.		
90		N1										LOST CORE		
		5Y6/1									IS	Olive gray, carbonaceous mudstone, very carbonaceous at 89-90.5 ft.		
		5Y4/1									U			
95											IS	Light to medium olive gray, mudstone, with some carbonaceous material.		
30														
100		5Y5/1		H							1 IS	Medium olive gray, well sorted mudstone with no apparent structures grading into medium gray claystone.		
105														
110														

PROJECT NAME HAWA IV HOLE NO: 4PB1
 DEPTH: FROM 110 FT TO 135 FT. BOX NOS: 11,12,13
 LOCATION: T R S

m.	DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
	110		N2														⊕			Grayish black to black carbonaceous claystone with organic partings.		
			N1																			
85	115		N2														≈					
			5Y3/1																			
			5Y4/1																			
			5Y5/1																			
	120																					
			5Y3/1														⊕					
			5Y4/1														⊕					
	125	++++	5Y3/1														⊕					
			5Y4/1																			
			5Y6/1														⊕					
	130		5Y6/1														⊕	1	I	Medium gray, clayey siltstone with bioturbated wavy laminations.		
40			N6.5	≈≈		L								WS			⊕					
				}													S					
	135																R					

PROJECT NAME HANNA IV HOLE NO: 4P21
 DEPTH: FROM 135 FT TO 160 FT. BOX NOS: 12,13,14,15
 LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
135																					
				H															Medium gray mudstone with bioturbation and horizontal laminations.		
140		N4.5																			
		N5.5		L															Medium gray siltstone with wavy bedding.		
		N6																			
145		N5		H															Medium gray mudstone with no apparent structure		
45																					
150		N7																			
		N5																			
155																			Medium grading to dark gray mudstone with increasing amounts of organics.		
		N3																	medium gray silty layer.		
160																					

PROJECT NAME HAWA IV HOLE NO: 4PE1

DEPTH: FROM 160 FT TO 185 FT. BOX NOS: 15, 16, 17

LOCATION: T R S S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
160		N3		1'									WS				1	IS	Dark to medium gray mudstone, laminated, carbonaceous.		
50		N4																			
165		N5	SS																As Above with silty layers and wavy bedding.		
		N4																			
		N3																			
		N1																			
170		N3																	Extremely carbonaceous		
		N2																	Dark to medium gray mudstone laminated, carbonaceous, small amount of pyrite.		
		N3																			
175		N4																	Medium dark gray, mudstone, laminated, carbonaceous.		
		N3																			
180		N4																	Medium gray grading into olive gray mudstone, indurated but very shaley, carbonaceous matter decreases from 184 to 188 ft, increased from 189 to 190.2 ft.		
55		SGY 5/1																			
185		N3, 5																			

PROJECT NAME HANNA IV HOLE NO. 4PBI
 DEPTH: FROM 210 FT TO 235 FT BOX NOS: 20, 21, 22, 23
 LOCATION: T R S

m. DEPTH ft	ROCK TYPE	COLOR	SEDIMENTARY STR	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
210												Light gray, well-sorted siltstone, alternating dark and light layers, carbonaceous threads horizontal to wavy bedding. Laminated to thin bedded.		
65												As Above, higher percentage clay layers relative to silt layers, abundant ripples in drift.		
215														
220		N8		F F L		WS				1	I	Light gray, well-sorted siltstone with interlaminated clay ripples in drift, macrofaulting and bioturbation.		
225		N7 N5 N8 N7										Light gray, very fine-grained, well sorted sandstone interlaminated with siltstone and mudstone.		
230		N5.5 N8 N7 N5										Light to medium gray silty sandstone with alternating light and dark horizontal laminations, bioturbation and ripple drift cross lamination		
235														

PROJECT NAME HANNA IV HOLE NO: 4PRI
 DEPTH: FROM 235 FT TO 260 FT. BOX NOS: 22, 23, 24, 25
 LOCATION: T R S S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
235		N7														①			Light to medium gray sandstone with slumped lenticular bedding, interlaminated silt and mud layers, ripples, trough crossbedding.		
240		N8														①			Slightly coarser. Light gray, very fine sandstone with organics concentrated on bedding planes.		
245																R +	8 4		Same as above with 1.5 ft. calcareous zone.		
250		N7											WS	S		+	4 2 7 1	I	Light to very light gray, very fine-grained well-sorted sandstone with 1.75 ft calcareous zone, minor ripples and tabular small scale cross bedding.		
255		N8																			
260																					

PROJECT NAME HANNA IV HOLE NO: 4PR1
 DEPTH: FROM 260 FT TO 285 FT. BOX NOS: 26, 27, 28
 LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
260		N7	///						⊗			Very light gray, very fine-grained, well sorted sandstone with ripple drift cross laminations and small-scale tabular bedding.		
80		N8	///						⊗					
265			///											
270			///											
275			///									Lost Core		
85			///											
280		N8	///									Light gray very fine-grained, well sorted sandstone with ripples in drift.		
285			///									Lost Core		

PROJECT NAME HANNA IV HOLE NO: 4PR1DEPTH: FROM 285 FT TO 310 FT. BOX NOS: 27, 28, 29LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
285		N5										Lost Core.		
		N5										Medium gray, very fine grained sandstone Hornfels with preserved trough Cross bedding. Rubblized.		
290		N6												
		N4												
		N6										Lost Core.		
		N5										Medium to dark gray, very fine grained sandstone hornfels with preserved trough cross bedding. Rubblized.		
295		N4												
		N3												
300		N4										Lost Core.		
												As above, with planer cross bedding.		
305														
												Lost Core.		
310														

DEPTH	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
310		N5-N3																	Medium gray grading into darker gray sandstone hornfels.		
315		N4																	Vesicular.		
320		N2																	Medium gray, vesicular sandstone hornfels becoming scoriaceous, grading into dark gray buchite.		
325		N2																	Lost Core.		
330		N1																	Black Coal. Rubblized.		
335		N1																			

PROJECT NAME: HANNA IV
 HOLE NO: 4PB1
 DEPTH: FROM 310 FT TO 335 FT
 BOX NOS: 29, 30, 31, 32
 LOCATION: T

DEPTH m.	DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
335														334.9 to 336.8 Coal		
			5Y2/1											Dark olive gray carbonaceous mudstone.		
340			5Y4/1											Dark gray carbonaceous mudstone.		
105														LOST CORE		
345			N6											Light gray siltstone with wavy bedding.		
			N8											Light gray, fine to medium-grained sandstone with trough crossbedding.		
350			N4											Light gray mudstone, carbonaceous at 355-356 ft.		
			N6													
			5Y5/1													
355			N4													
			N5											Light gray muddy siltstone.		
360																

PROJECT NAME: HANNA IV
 HOLE NO: 4PB1
 DEPTH: FROM 335 FT TO 360 FT.
 BOX NOS: 32, 33, 34
 LOCATION: T R S

PROJECT NAME HANNA IV HOLE NO: 2PP2
 DEPTH: FROM 20 FT TO 45 FT. BOX NOS: 1,2,3
 LOCATION: T R S S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
20		N8		H		MWS	S		R	1	IF	Light gray to grayish orange, coarse-grained, moderately well sorted sandstone and interbedded conglomerate with horizontal bedding and trough cross bedding; orange mottling.		
25		10YR 7/4		F		MWS	S		R	1	IF			
30		10YR 7/4		F					R					
35		10YR 7/4		F		MS	S			1	IF	Organics concentrated along bedding planes.		
40		10YR 7/4		F		MS	S			1	IF			
45				H		PS	S							

PROJECT NAME HANIA IV HOLE NO: 1202
 DEPTH: FROM 45 FT TO 70 FT. BOX NOS: 3,4,5
 LOCATION: T R S S

DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
45		10YR 7/4		F		PS	S							
50		10YR 7/4		F H		PS	S			1	I	Grayish orange poorly sorted conglomerate with quartz, feldspar and rock fragment clasts up to 1 cm in diameter, interbedded with medium and coarse, moderately well to poorly sorted sandstones with trough cross bedding		
55				F H		MS PS	S S			1	IF I			
60		10YR 7/4				PS	S			1	I			
65		10YR 7/4 5Y 8/1				MS	S			1	I	Yellowish gray, coarse-grained, moderately sorted sandstone with scattered organics, granule beds and no apparent sedimentary structures.		
70				F										

PROJECT NAME HANNA IV HOLE NO: 4PR2
 DEPTH: FROM 70 FT TO 95 FT. BOX NOS: 4.5.6.7.
 LOCATION: T R S S

DEPTH m. ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRAINULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
70												Grayish orange conglomerate, same as above		
75		10YR 4/2		L		MS	S			1	WI	Dark yellowish brown, coarse-grained, moderately sorted sandstone with horizontal laminations and ripple trough cross-laminations.		
80		10YR 7/4		H						1	I	Grayish orange conglomerate, same as above.		
25		10YR 7/4		F						1	I	Organics concentrated along bedding planes.		
85		10YR 4/2		H		PS S						Dark yellowish brown highly organic muddy siltstone with interbeds of very coarse-grained sandstone.		
		5Y 7/2		H		MMS S				1	WI	Yellowish gray, coarse-grained, moderately well sorted sandstone with numerous graded bedding sequences, trough cross-bedding and horizontal bedding. Iron staining and organics are concentrated along bedding planes.		
90														
95														

PROJECT NAME HAWA IV HOLE NO: 4PR2

DEPTH: FROM 95 FT TO 120 FT. BOX NOS: 9, 10, 11

LOCATION: T S R S

DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
95																					
30																	1	WI	Moderate yellowish brown conglomeratic sandstone with detrital coal fragments and clay clasts coal fragments up to 6 cm long.		
100		5YR 5/4 5Y 8/1		H													1	WI	Yellowish gray sandstone, similar to above except organics occur as thin irregular wisps not concentrated in any one direction. No other apparent structures.		
105																					
		N8		H													1	I	Very light gray conglomerate grades into yellowish gray, medium-grained moderately well sorted sandstone with ripple trough cross laminations, organics along bedding planes and detrital coal fragments. grades into conglomerate		
		5Y 8/1		L									MS	S			1	WI			
110																					
		5Y 8/1		L									MWS	S			1	I	Interbedded conglomerate and sandstone. Abundant detrital coal in conglomerate and at erosional contacts.		
		N7		H													1	IF			
35																					
115		N7.5		H									WS	S			1	WI	Light gray, coarse-grained, well sorted sandstone with occasional clay clasts and organic partings.		
		N7		L													1	WI	Light gray siltstone with wavy bedding, climbing ripples and some bioturbation. some very fine-grained sand lenses.		
120																					

DEPTH m ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS TS MS CS VCS	GRAINULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	DURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
120															
125		N6		L						R	1	I	Medium gray mudstone with wavy bioturbated bedding.		
130		N4		H							1	IF	Dark Gray rubblized claystone.		
135		N 3.5													
140		N3.5		H											
145		N3													

PROJECT NAME: HANNA IV
 DEPTH: FROM 120 FT TO 145 FT
 BOX NOS: 12, 13, 14
 HOLE NO: 4PR2
 LOCATION: T R S

PROJECT NAME HANNA IV HOLE NO: 4PR2
 DEPTH: FROM 145 FT TO 170 FT. BOX NOS: 13, 14, 15, 16
 LOCATION: T S R S

m DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
145											I			
45														
150		N4												
				H										
155		N5												
				H								Medium gray homogeneous mudstone with some carbonaceous matter.		
				H								Medium light gray homogeneous siltstone with some organic partings along bedding planes and wavy bioturbated bedding.		
160		N6												
				L										
				H										
				L										
50														
165		N6.5												
				H										
170		N4												
										1	IS	Medium to light gray homogeneous mudstone with no apparent structure.		

PROJECT NAME HANNA IV HOLE NO: 4PP2
 DEPTH: FROM 170 FT TO 195 FT BOX NOS: 16, 17, 18
 LOCATION: T S R S

DEPTH m. ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
170		N4		H						1	IS			
175														
180		N8												
185		N6.5		L						1	I	Light gray, slightly bioturbated siltstone.		
		N4		H						1	IS	Medium dark gray homogeneous mudstone with occasional patches of organic matter and no apparent structures.		
190		N3												
		N2												
195		N3												
												Highly organic (coal fragments).		

PROJECT NAME	HANNA IV	HOLE NO:	4PB2
DEPTH: FROM	195	FT TO	225
	FT.	BOX NOS:	18,19,20,21
LOCATION: T	R	S	

PROJECT NAME HANNA IV HOLE NO: 4PR2
 DEPTH: FROM 225 FT TO 250 FT. BOX NOS: 21,22,23
 LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS								SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
					CLAY MIN	SLT	VFS	FS	MS	CS	VCS									
225																		Light gray siltstone with bioturbation wavy and horizontal beds and some ripple cross-lamination.		
70 230																		Lost Core.		
235																				
240																		Light gray, very fined grained well-sorted sandstone with coarser sand lenses and wavy bioturbated bedding; Some rippled trough cross laminations; Grades down and into fine sand interlaminated with darker silt/mudstone.		
245																				
75 250																				

PROJECT NAME HAWA IV HOLE NO. 4PB2
 DEPTH FROM 250 FT TO 275 FT BOX NOS: 23, 24, 25
 LOCATION: T R S

DEPTH m ft	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	SEDIMENTARY TEXTURE								SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
					CLAY	MUD	SLT	VFS	FS	MS	CS	VCS									
250																					
255																					
260																					
265																					
270																					
275																					

PROJECT NAME HANNA IV HOLE NO: 4PR2
 DEPTH: FROM 300 FT TO 325 FT. BOX NOS: 27, 28, 29
 LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
300																					
305																					
310		N6.5																			
95																					
315																			Light olive gray siltstone with wavy bioturbated bedding and some ripple trough cross lamination.		
320																			Brownish gray bioturbated mudstone grading downward into brownish black, highly organic unconsolidated mudstone.		
																			Black, slightly rubblized coal.		
325																			Lost Core (cavity?)		

PROJECT NAME HANNA IV HOLE NO: 4PR2
 DEPTH: FROM 325 FT TO 350 FT. BOX NOS: 29,30
 LOCATION: T S R S

DEPTH m. ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
325														
100	H p											Medium dark gray scoraceous hornfels with relict sedimentary structures. Irregular to spherical vesicles may grade downward into paralava.		
330														
	B pb											Lost Core. Grayish brown scoraceous buchite or paralava. Some pieces of pumaceous buchite with numerous small vesicles. Some clay clasts are identified in the paralava breccia.		
335														
	H H											Lost Core. Scoraceous Hornfels.		
340												Lost Core. Altered coal or carbonaceous mudstones Lost Core. Altered Coal Lost Core.		
105														
345												Altered Coal Lost Core. Altered Coal Lost Core. Brownish black altered Carbonaceous mudstone and altered coal.		
350														

PROJECT NAME HANNA IV HOLE NO: 4P2
 DEPTH: FROM 350 FT TO 375 FT. BOX NOS: 31, 32, 33
 LOCATION: T S R S

DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
350												Lost Core.		
355												Black coal (altered?) Grading down into black highly organic mudstone.		
360												Light gray slightly bioturbated siltstone with thin mudstone lenses.		
365												Medium gray horizontally laminated mudstone.		
370												Medium light gray bioturbated siltstone with some ripple cross lamination.		
375												Medium gray silty mudstone with bioturbated wavy bedding.		

PROJECT NAME HANNA IV HOLE NO: 4PB3

DEPTH: FROM 200 FT TO 225 FT. BOX NOS: 1,2,3

LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY								SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
					CLAY	MUD	SLT	VFS	FS	MS	CS	VCS									
200		N4		L													1	IS	Medium dark to dark gray carbonaceous mudstone with no sedimentary structures.		
205		N3																			
210																					
65		5Y4/1																			
215		5Y3/1																			
		5Y4/1																			
220		N4																			
		N5																			
		5Y5/1																			
225																					

PROJECT NAME HANNA IV HOLE NO: 4PB3
 DEPTH: FROM 225 FT TO 250 FT. BOX NOS: 3,4,5
 LOCATION: T R S S

DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
225		5Y4/1		1						1	IS	Olive gray mudstone grading into medium-gray clayey siltstone with wavy laminations.		
70 230		N4.5									I			
235		N6									IS	Medium-gray mudstone with no structure grading into medium-light gray siltstone with clayey layers, wavy laminations, oxidized zones, bioturbation.		
240		N5 N6									I			
245		N7 N6												
75 250		N7												
												Light gray siltstone with dark and light wavy laminations grading into light gray, very fine-grained sandstone with clayey layers.		

PROJECT NAME HANNA IV HOLE NO: 4PB3DEPTH: FROM 250 FT TO 275 FT. BOX NOS: 6,7,8LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY							SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
					CLAY	MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE							
250		N7		L												1	I			
		N5	≡													1	1-2			
255			≡													1	1	Medium gray, clayey siltstone with horizontal laminations grading into light gray, very fine-grained, moderately well sorted sandstone with calcite cementation, light and dark laminations, silty and clayey zones.		
			≡													1	1			
260		N7	≡													1	4			
			≡													1	1			
265			≡													3	3			
			≡													2	2			
270			≡													1	1			
275			≡																	

PROJECT NAME HANNA IV HOLE NO: 4PB3
 DEPTH: FROM 275 FT TO 300 FT. BOX NOS: 8,9,10
 LOCATION: T R S

m. DEPTH	ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
275			N7		L		WS				2	I	Light gray, fine-grained well sorted sandstone with wavy bedding, thin organic partings, planar cross bedding trough cross bedding.		
85			N7.5								1				
280			N7												
285															
290											7				
295											5				
90											2				
300											1				

PROJECT NAME HAWA IV HOLE NO: 4PB3
 DEPTH: FROM 300 FT TO 325 FT. BOX NOS: 10,11,12,13
 LOCATION: T R S S

DEPTH m. ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
300		N7	≡	L		NS				1	I	Light gray fine-grained well sorted sandstone with planar cross bedding, wavy bedding, climbing ripples.		
305			≡											
310			≡											
95			≡											
315		N6	≡						R	2		Medium light gray siltstone with planar cross bedding, organic partings.		
320		N5	≡									Medium gray carbonaceous mudstone.		
325														

HOLE NO: 4PB3

BOX NOS: 13

LOCATION: T _____ R _____ S _____

[illegible]

PROJECT NAME HANNA IV HOLE NO: 4PB3

DEPTH: FROM 350 FT TO 375 FT. BOX NOS: _____

LOCATION: T _____ R _____ S _____

DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
350										1		Altered Coal		
355		N1										Coal		
		N2		L							IS	Grayish black carbonaceous mudstone		
360		N1												
110		N2		L							IS	Coal Grayish black carbonaceous mudstone		
365		N6 5Y3/1										Extremely carbonaceous mudstone grading into gray mudstone with no apparent sedimentary structures and occasional carbonaceous material.		
		N5												
370		N4												
375														

PROJECT NAME HANNA IV HOLE NO: 4023

DEPTH: FROM 375 FT TO 390 FT. BOX NOS: _____

LOCATION: T _____ R _____ S _____

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD							SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
375	-	N4		L												1	IS	Gray mudstone with no apparent sedimentary structures		
115		N4																		
380		N3																		
385		N4																		
390																		Lost Core 388.2-390 ft.		

PROJECT NAME HANNA IV HOLE NO: 48PR4
 DEPTH: FROM 200 FT. TO 225 FT. BOX NOS: 1,2,3
 LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS											PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
					CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS					
200		N3		L											IS	Dark gray horizontally laminated claystone			
205		N5		L												IS	Medium gray horizontally bedded mudstone.		
210
65
215
220
		N7															Light gray siltstone with interbeds of very fine grained sandstone and mudstone and wavy bedding and ripple cross laminations.		
225

PROJECT NAME HANNA IV HOLE NO: 4PB4
 DEPTH: FROM 225 FT TO 250 FT. BOX NOS: 3,4,5,6
 LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
225														
230		N7										Light gray, very fine grained well sorted sandstone with climbing ripples and bioturbation. Grades downward into interbeds of mudstone and siltstone		
235		N6												
240		N6										Medium light gray siltstone with horizontal, wavy and bioturbated bedding		
245														
250		N7										Light gray, very fine grained moderately well sorted sandstones interbedded with siltstone.		

PROJECT NAME HANNA IV HOLE NO: 4PB4

DEPTH: FROM 250 FT. TO 275 FT. BOX NOS: 6,7,8

LOCATION: T _____ R _____ S _____

DEPTH	
m.	ft.
250	250
255	255
260	260
265	265
270	270
275	275
ROCK TYPE	
COLOR	
SEDIMENTARY STR.	
BEDDING THICKNESS	
CLAY MUD SLT VFS FS MS CS VCS GRANULE	
SORTING	
ROUNDNESS	
% FRAMEWORK	
ACCESSORIES AND BIOLOGICAL CONSTITUENTS	
PERCENT LS	
INDURATION	
DESCRIPTION	
INFERRED ENVIRONMENT OF DEPOSITION	
SAMPLE NO AND TYPE	

PROJECT NAME HANNA IV HOLE NO: 4PR4DEPTH: FROM 275 FT TO 300 FT. BOX NOS: 8,9,10,11

LOCATION: T _____ R _____ S _____

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
275		N6												
280		N7.5												
285														
290														
295		N8												
300														

Light olive gray siltstone with wavy bioturbated bedding grades into very light gray, very fine-grained well-sorted sandstone with interbeds of siltstones and mudstone.

PROJECT NAME HANNA IVHOLE NO: 4PC4DEPTH: FROM 300 FT TO 325 FT.BOX NOS: 11, 12, 13

LOCATION: T _____ R _____ S _____

DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
300												Interlamated siltstone and mudstone with bioturbated wavy bedding.		
305												Medium gray horizontally bedded mudstone.		
310												Interlamated siltstone and mudstone grading into medium dark gray carbonaceous mudstone.		
315														
320												Black Coal.		
325												LOST CORE		

HOLE NO: 4PB4

DEPTH: FROM 325 FT TO 350 FT. BOX NOS: 13,14

LOCATION: T _____ R _____ S _____

[illegible]

LOCATION: T _____ R _____ S _____

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LOCATION: T _____ R _____ S _____

m.		ft.		DEPTH	
				ROCK TYPE	
				COLOR	
				SEDIMENTARY STR.	
				BEDDING THICKNESS	
				CLAY MUD	
				SLT	
				VFS	
				FS	
				MS	
				CS	
				VCS	
				GRANULE	
				SORTING	
				ROUNDNESS	
				% FRAMEWORK	
				ACCESSORIES AND BIOLOGICAL CONSTITUENTS	
				PERCENT LS	
				INDURATION	
				DESCRIPTION	
				INFERRED ENVIRONMENT OF DEPOSITION	
				SAMPLE NO. AND TYPE	

PROJECT NAME HAWA IV HOLE NO: 4PB5
 DEPTH: FROM 250 FT TO 275 FT. BOX NOS: 5,6,7,3
 LOCATION: T R S S

DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	GLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
250									~					
255														
260		N7		L		MS	S				I	Light gray, very fine-grained well sorted sandstone with interbeds of siltstone and mudstone.		
265		N6												
270		N7				MS	S		~	1		Light gray, fine-grained moderately well sorted sandstone with cross-bedding and bioturbation.		
275									~	3	WT			
										F				

DEPTH FT.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY INDU.	SLT VFS	MS CS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
275													5				
280																	
285													1				
290																	
295		5Y6/1													LOST CORE.		
300		N7													Interbedded organics.		
															Interbedded sandstone, siltstone and mudstone.		

PROJECT NAME: HANNA IV
 HOLE NO: 4P85
 DEPTH: FROM 275 FT TO 300 FT.
 BOX NOS: 8, 9, 10
 LOCATION: T R S

PROJECT NAME HANNA IV HOLE NO: 4PB5

DEPTH: FROM 300 FT TO 325 FT. BOX NOS: 10,11,12,13

LOCATION: T R S

DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
300		N4												
305														
310														
315														
320		N3												
325

PROJECT NAME HANNA IV HOLE NO: 4PB6

DEPTH: FROM 200 FT TO 225 FT. BOX NOS: 1,2,3

LOCATION: T _____ R _____ S _____

DEPTH ft.	DEPTH m.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	NS	S	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
200			NS		L								Dusky yellow, fine-grained moderately sorted sandstone		
205													Medium gray horizontally bedded mudstone.		
210															
215															
220															
225															

PROJECT NAME HANNA IV HOLE NO: 4PB6

DEPTH: FROM 225 FT TO 250 FT BOX NCS: 3,4,5,6

LOCATION: T R S S

m	DEPTH	ft	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
225																			1	I	Medium light gray siltstone with bioturbated wavy bedding and climbing ripples.		
70																							
230																							
235																							
240																							
245																							
75																			2	WI			
																			3		Light gray, very fine-grained moderately well sorted sandstone with ripple trough cross laminations.		
250																			5				

PROJECT NAME HANNA IV HOLE NO: 4PB6
 DEPTH: FROM 250 FT TO 275 FT. BOX NOS: 6,7,8
 LOCATION: T _____ R _____ S _____

275	270	265	260	255	250	m. DEPTH ft.
						ROCK TYPE
						COLOR
						SEDIMENTARY STR.
						BEDDING THICKNESS
						CLAY MUD SLT VFS FS MS CS VCS GRANULE
						SORTING
						ROUNDNESS
						% FRAMEWORK
						ACCESSORIES AND BIOLOGICAL CONSTITUENTS
3 5 10 5 3						PERCENT LS
						INDURATION
						DESCRIPTION
						INFERRED ENVIRONMENT OF DEPOSITION
						SAMPLE NO AND TYPE

PROJECT NAME HANNA IV HOLE NO. 4PB6

DEPTH: FROM 275 FT TO 300 FT BOX NOS. 3,9,10,11

LOCATION: T _____ R _____ S _____

DEPTH		ROCK TYPE	COLOR	SEDIMENTARY STR	BEDDING THICKNESS	CLAY MUD ALT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION
m	ft												
275	275												
280	280												
285	285												
290	290												
295	295												
300	300												

PROJECT NAME HAWA IV HOLE NO. 4286
 DEPTH: FROM 300 FT TO 325 FT. BOX NOS: 11,12,13
 LOCATION: T R S

m. DEPTH	ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS IFS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
300															
305															
310			N5 N7 N4									IS	Interbedded siltstone and mudstone.		
95												I	Dark gray carbonaceous mudstone		
315			N3												
320															
325													Lost Core.		

PROJECT NAME HANNA IV HOLE NO: 4PBE

DEPTH: FROM 325 FT TO 350 FT. BOX NOS: 13,14,15

LOCATION: T _____ R _____ S _____

DEPTH m. ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
325		N1	Rubblized									Lost Core		
330												Black rubblized coal - possibly altered		
335		N1										Lost Core		
340												Black Coal		
345												Lost Core		
350												Coal becomes silty		

PROJECT NAME HANNA IV HOLE NO: 4886

DEPTH FROM 350 FT TO 374.4 FT. BOX NOS: 15, 16

LOCATION: 1 R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS IFS MS CS VCC GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
350		N1								1	I	Light gray, very fine-grained, moderately well sorted sandstone.		
355		N7								1	I			
		N6		L						1	WI	Medium light gray siltstone with bioturbated wavy bedding		
360		N3										Dark gray horizontally bedded mudstone.		
110														
365														
370														
375														

PROJECT NAME HAWAII IV HOLE NO: 10P27
 DEPTH FROM 200 FT TO 225 FT BOX NOS: 1,2,3
 LOCATION: T _____ R _____ S _____

DEPTH m ft	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD GLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
200		N6.5		I		MWS	S		(R)	1	I	Medium-Light gray siltstone with very fine grained sandlayers, extensive microfaulting, trough cross bedding and horizontal bedding		
205		5Y6/1 N6.5								IS I				
210		N7.5 N6.5							(R)	1.5 1		207.6-209.0 lost core		
215		N7.5 N6.5										medium light gray siltstone with coarsening upward sequence of medium gray claystone grading upward into siltstone and very light gray, very fine grained sandstone with dark and light lamination.		
220		N7.5 N6 5Y6/1 N7.5				MWS MWS	S S		(R)	3 1		Horizontal laminations and bioturbation are the predominant structures		
225		N6 N5 N6 N7 N6				MWS	S			3 1				

PROJECT NAME HAWA IV HOLE NO: 4PZ
 DEPTH FROM 225 FT TO 250 FT BOX NOS: 3,4,5
 LOCATION: T R S

m	DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
70	230		5Y6/1	N7	L									MWS	S		R	4	I			
	230		5Y6/1	N6	L													1	I	228.4-229.0 Lost Core		
	235		7.5											MWS	S					Light gray, medium-grained sandstone with bioturbation, climbing ripples and ripple trough cross lamination		
	240																					
	245													WS	S			3		Very light gray, fine-grained sandstone with trough crossbedding.		
	250																	4				

PROJECT NAME HANNA IV HOLE NO. 4PB7
 DEPTH: FROM 250 FT TO 275 FT BOX NOS: 5, 6, 7, 8
 LOCATION: T R S

m. DEPTH	ft.	ROCK TYPE	COLOR	SEDIMENTARY STR	BEDDING THICKNESS	CLAY								SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
						CLAY	MUD	SLT	VFS	FS	MS	CS	VCS									
250			N8	€	F									MS	S			1	I	Very light gray, fine-grained sandstone with clayey layers, horizontal and trough cross-bedding		
				€															IF			
255				€															I			
				€														7				
260			N7	≡										MWS	S					Lost Core 258.6 to 259.0		
			N8	≡																		
80			N7	€																		
			N8	€																Very light gray, fine-grained sandstone with coarsening upward sequences into light gray siltstone and very fine-grained sandstone with clayey layers and trough cross-bedding.		
65			N7	€																		
			N8	€																		
				€																		
270			5Y6/1 N8	≡	L																	
			N7	€																		
			5Y6/1 N8	€																		
275				€																		

PROJECT NAME HANNA IV HOLE NO. 4PBZDEPTH FROM 275 FT TO 300 FT BOX NOS. 3, 9, 10LOCATION: T R S

DEPTH m ft	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
275		N8		F						1	I	Very light to light gray very fine-grained moderately well sorted sandstone interlayered with medium light gray siltstone with wavy bedding and bioturbation.		
85		N6.5		L										
280		N6										grading into siltstone.		
		N6.5								2				
285		N6								1		Interlayered medium-gray and fine-grained sandstone and siltstone with trough cross bedding; abundant clayey layers		
		N7												
290		N6												
		N5									IS	Medium dark gray mudstone, increasingly carbonaceous.		
295		N4												
90														
300		N3												

PROJECT NAME HANNA IV HOLE NO: 4PB7
 DEPTH: FROM 300 FT TO 325 FT. BOX NOS: 10,11,12,13
 LOCATION: T _____ R _____ S _____

DEPTH m. ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS L	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
300	N3											Brownish black altered coal		
305	2/1											Rubble 302.1 to 306.6		
310	N1											Lost Core 306.6 to 309.0		
315												Black Coal		
320	N2											Brownish black extremely carbonaceous mudstone.		
325	2/1											322.4 to 323.0 lost core		
	N2											coal		

PROJECT NAME HANNA IV HOLE NO: 4PBZDEPTH: FROM 325 FT TO 350 FT. BOX NOS: 13,14,15LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY							SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
					CLAY	MUD	SLT	VFS	FS	MS	CS	VCS								
325		N1													⊕	4	I	Coal, altered coal interlayered		
100																				
330		5YR 2.1		I											⊕		I	328.9-330.4 Lost Core Extremely carbonaceous mudstone		
		N6													⊕					
335		N7																Medium gray mudstone with little organic matter interlayered with medium-gray siltstone with wavy laminations and bioturbation.		
		N6																		
		N7																		
340		N6																		
		N5.5																		
105		N5																		
345																				
350																				

LOCATION: T _____ R _____ S _____

DEPTH		DESCRIPTION
m.	ft.	
		ROCK TYPE
		COLOR
		SEDIMENTARY STR.
		BEDDING THICKNESS
		CLAY MUD SLT VFS FS MS CS VCS GRANULE
		SORTING
		ROUNDNESS
		% FRAMEWORK
		ACCESSORIES AND BIOLOGICAL CONSTITUENTS
		PERCENT LS
		INDURATION
		same as above.
		INFERRED ENVIRONMENT OF DEPOSITION
		SAMPLE NO AND TYPE

PROJECT NAME HANNA IV HOLE NO: 4PB8
 DEPTH: FROM 200 FT TO 225 FT. BOX NOS: 1,2,3
 LOCATION: T R S

DEPTH m. ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	DURATION	DESCRIPTION	REFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
200		N4		L													1	IS	Medium dark gray to olive gray carbonaceous mudstone, horizontally laminated.		
205																⊗					
210		N3.5 5Y4/1														⊗					
215																⊗		I	Medium gray slightly carbonaceous, indurated silty mudstone with horizontal laminations.		
220		N5														⊗					
225																⊗			Medium gray carbonaceous clayey siltstone with wavy laminations.		

PROJECT NAME HANNA IV HOLE NO: 4PB3
 DEPTH: FROM 225 FT TO 250 FT. BOX NOS: 3,4,5
 LOCATION: T 75 R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
225		N6	~	L					⊗	1	I	Medium light gray siltstone with sandy layers, wavy bedding, ripple trough cross lamination, bioturbation less carbonaceous than preceding 25 feet. Alternating light and dark laminations.		
70			~						⊗					
230			ε						⊗					
235			~ // ε						⊗ 					
240			ε ε ε											
245			ε ε						 ~					
250			ε ε ε						~					

PROJECT NAME HANNA IV HOLE NO: 4P23
 DEPTH: FROM 250 FT TO 275 FT. BOX NOS: 5,6,7,8
 LOCATION: T R S S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	GLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
250		N6		F					≈	1	I			
255		N7							R			Light gray very fine grained, moderately well sorted sandstone and siltstone with bioturbation horizontal and trough crossbedding, ripples in drift, dark and light laminations grading into silty sandstone.		
260		N8												
265									R					
270									⊗					
275									≈					

PROJECT NAME HAINA IV HOLE NO: 4PB8
 DEPTH: FROM 275 FT TO 300 FT. BOX NOS: 3, 9, 10, 11
 LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS IFS MS CS VCS GRAINULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
275		N8	///	F		MS			~	1	I	Very light gray, very fine to fine-grained moderately well sorted sandstone with dark and light laminations, high angle planer bedding.		
85			€	L					~					
280			€ ///											
285			/// SS ///						⊗ 					
290			€ € € €									As above with ripple trough cross lamination lenticular bedding. Increasingly carbonaceous.		
295			88 € € €											
300		N7.5	€ € €						⊗					

4938

HOLE NO:

HARRY IV

11,12,13

BOX NOS:

LOCATION: T _____ R _____ S _____

[illegible]

PROJECT NAME HANNA IV HOLE NO: 4PB8
 DEPTH: FROM 325 FT TO 350 FT. BOX NOS: 13
 LOCATION: T _____ R _____ S _____

DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
325		N1										Rubblized coal 325.0 to 339.1		
330			RUBBLIZED											
335														
340												Coal 339.1 to 345.6		
345												Extremely carbonaceous mudstone.		
350	AC	N2		L					»»			Altered coal.		

PROJECT NAME HANNA IV HOLE NO: 4PB8DEPTH: FROM 325 FT TO 350 FT. BOX NOS: 13, 14, 15

LOCATION: T _____ R _____ S _____

350	345	340	335	330	325	m. DEPTH ft.
AC						ROCK TYPE
N2					N1	COLOR
			RUBBLIZED			SEDIMENTARY STR.
L						BEDDING THICKNESS
						CLAY MUD SLT VFS FS MS CS VCS GRANULE
						SORTING
						ROUNDNESS
						% FRAMEWORK
≈ ≈						ACCESSORIES AND BIOLOGICAL CONSTITUENTS
						PERCENT LS
					D	INDURATION
Altered coal.	Extremely carbonaceous mudstone.	Coal 339.1 to 345.6		Rubblized coal 325.0 to 339.1		DESCRIPTION
						INFERRED ENVIRONMENT OF DEPOSITION
						SAMPLE NO AND TYPE

PROJECT NAME HANNA IV HOLE NO: 4PB3
 DEPTH: FROM 350 FT TO 373 FT. BOX NOS: 15,16,17
 LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
350	AC	N2								1	IS	Altered coal		
355		N7		H										
		N6		L								Carbonaceous mudstone, sharp contact with with light gray homogeneous siltstone grading into medium dark gray mudstone.		
360		N5												
365		N6												
		N5		L										
370														
375														

PROJECT NAME HANNA IV HOLE NO: 4PB9

DEPTH: FROM 200 FT TO 225 FT. BOX NOS: 1,2,3

LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
200		N3								1	IS	Dark gray to medium dark gray carbonaceous mudstone, grading into a less carbonaceous mudstone, with no apparent sedimentary structures.		
205														
210		N4												
215		N5												
220														
225														

PROJECT NAME HANNA IV HOLE NO: 4PR9
 DEPTH: FROM 225 FT TO 250 FT. BOX NOS: 3,4,5
 LOCATION: T 75 R 70 S 75

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
225		N6								1	I	Same as above with silt and wavy bedding.		
230		N7									IF			
235				F							I	Light gray siltstone with wavy bedding, bioturbation and mudstone lenses.		
240		N6												
245				L								Medium light gray silty mudstone.		
250														

PROJECT NAME HANNA IV HOLE NO: 4PBG

DEPTH: FROM 250 FT TO 275 FT. BOX NOS: 5,6,7,8

LOCATION: T R S S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS LS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
250		N8								1	I			
255		N7 N6 N7		L								Light gray muddy siltstone with horizontal bedding and bioturbation.		
260														
265		N8												
270						MMS	S				IS	Very light gray very fine sandstone with horizontal bedding		
												Lost core.		
275														

PROJECT NAME HANNA IV HOLE NO. 4PR9
DEPTH: FROM 275 FT TO 300 FT BOX NO. 8,9,10
LOCATION: T R S

[illegible]

PROJECT NAME HANNA IVHOLE NO: 4PR9DEPTH: FROM 300 FT TO 325 FT. BOX NOS: 10,11,12,13

LOCATION: T _____ R _____ S _____

DEPTH	
m.	ft.
300	300
305	305
310	310
315	315
320	320
325	325
ROCK TYPE	
COLOR	
SEDIMENTARY STR.	
BEDDING THICKNESS	
CLAY MUD SLT VFS FS MS CS VC3 GRANULE	
SORTING	
ROUNDNESS	
% FRAMEWORK	
ACCESSORIES AND BIOLOGICAL CONSTITUENTS	
PERCENT LS	
INDURATION	
DESCRIPTION	
INFERRED ENVIRONMENT OF DEPOSITION	
SAMPLE NO AND TYPE	

Medium dark gray carbonaceous mudstone.

Medium gray mudstone with horizontal and wavy bedding.

PROJECT NAME HANNA IVHOLE NO: 4PBODEPTH: FROM 325 FT TO 350 FT. BOX NOS: 13,14,15,16

LOCATION: T _____ R _____ S _____

DEPTH	
m.	ft.
325	100
330	330
335	335
340	340
345	345
350	350

ROCK TYPE	
NL	
COLOR	
SEDIMENTARY STR.	
BEDDING THICKNESS	
CLAY MUD SLT VFS FS MS CS VCS GRANULE	
SORTING	
ROUNDNESS	
% FRAMEWORK

ACCESSORIES AND BIOLOGICAL CONSTITUENTS	
PERCENT LS	
INDURATION	
DESCRIPTION	
Black Coal	
INFERRED ENVIRONMENT OF DEPOSITION	
SAMPLE NO AND TYPE	

PROJECT NAME HANNA IV HOLE NO: 4PB9

DEPTH: FROM 350 FT TO 375 FT. BOX NOS: 16, 17, 18

LOCATION: T R S

m DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
350														
355			N2								IS	Grayish black carbonaceous mudstone grading into medium gray bioturbated siltstone.		
			N5											
			N7				S	MS			WI			
360														
110			N6									Light gray, very fine-grained, moderately sorted bioturbated sandstone. Possibly slightly altered, grades downward into medium light gray bioturbated siltstone and medium dark gray horizontally bedded mudstone and claystone.		
			N4											
365														
370														
375														

PROJECT NAME HANNA IV HOLE NO: 4PB9

DEPTH: FROM 375 FT TO 380.2 FT. BOX NOS: 13

LOCATION: T _____ R _____ S _____

					m.	DEPTH
					ft.	
					375	ROCK TYPE
					380	COLOR
					385	SEDIMENTARY STR.
					115	BEDDING THICKNESS
						CLAY
						MUD
						SLT
						VFS
						FS
						MS
						CS
						VCS
						GRANULE
						SORTING
						ROUNDNESS
						% FRAMEWORK
						ACCESSORIES AND BIOLOGICAL CONSTITUENTS
						PERCENT LS
						INDURATION
						DESCRIPTION
						INFERRED ENVIRONMENT OF DEPOSITION
						SAMPLE NO AND TYPE

PROJECT NAME HANNA IV HOLE NO. 4PB10

DEPTH: FROM 200 FT TO 225 FT BOX NOS: 1,2,3

LOCATION: T R S

m DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
200		N6.5	~	1													2	I	Medium light gray siltstone with clayey layers, very fine-grained sandstone layers, bioturbation, wavy bedding.		
			~														1				
			~														2				
205			~														4				
		N6	~																		
			~																		
210		N7	~														2				
		N7.5	~														3				
65		N6	~																		
215			~														2				
		N7	~																		
		N6.5	~														1		Medium light gray very fine-grained moderately well sorted sandstone with interlaminated silt and clay layers, horizontal bedding.		
		N6	~																		
220			~																		
			~																		
			~																		
225		N5.5	~																		

PROJEC: NAME HANJA IV HOLE NO: 4P310
 DEPTH: FROM 225 FT TO 250 FT BOX NOS: 3,4,5,6
 LOCATION: T 11 S 1

DEPTH m ft	ROCK TYPE	COLOR	SEDIMENTARY STR	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
225		N8		L						2	I	Light gray, fine-grained moderately well sorted sandstone with wavy bedding, bioturbation, grading into medium light gray siltstone with horizontal laminations.		
70		N6								4				
230		N6.5												
235		N7.5										Light gray, very fine to fine-grained moderately well sorted sandstone with trough cross bedding.		
240		N6								1				
		N7.5		F						2				
245										3				
75														
250										1				
										2				

PROJECT NAME HANNA IV HOLE NO: 4PB10
 DEPTH: FROM 250 FT TO 275 FT. BOX NOS: 6,7
 LOCATION: T R S S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
250		N8	€	F		WS	S		⊗	1	I	Very light gray medium-grained, well-sorted sandstone wth trough cross bedding.		
255			€						⊥	4				
260										1				
265										4				
265.6 to 268.5										3		255.6 to 268.5 Lost Core		
270		5B8-1		F					⊥	3	I	Bluish white sandstone hornfels with no recognizable sedimentary structures grading into very light gray sandstone with intact and recognizable structure; steeply dipping planer trough cross bedding as well as horizontal bedding.		
275		N8	≡							4				

PROJECT NAME HANNA IV HOLE NO: 4PB10

DEPTH: FROM 275 FT TO 300 FT. BOX NOS: 7,8,9

LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
275				F							I			
85			RUBBLIZED	F								276.8 to 278.6 Lost Core		
280											U			
											I			
285		N7 SY 5-1		RUBBLIZED						1	U	Light gray sandstone hornfels with preserved trough crossbedding and dark and light laminations.		
		N7												
290														
295			RUBBLE									291.1 to 295 Lost Core		
90		N5		F							U	Medium gray pumaceous sandstone hornfels grading into well indurated (non-rubblized) sandstone hornfels with preserved trough crossbedding.		
		N7									I			
300														

PROJECT NAME HANNA IVHOLE NO: 4PP10DEPTH: FROM 300 FT TO 325 FT.BOX NOS: 9LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
300		N6		L						I	I	Medium gray sandstone hornfels grading into bucbite. Pinnaceous in areas. Laminations through cross-bedding preserved		
305		N4 N5 5/5/1								U	U	303.4 to 305.0 lost core Structures less apparent.		
310		N3										As above, laminated through cross-bedding preserved		
315		N3 SGV 6/1										Bucbite more pinnaceous Lost core 309.2 to 313.7		
320												Dark gray scoriaceous bucbite breccia grading into dark gray scoriaceous paralava breccia with xenoliths of light gray light green and white.		
325												Rubblized Grading into vesicular paralava breccia with organics. (alteration?) colors surrounding xenoliths light green, white colored zones 318.4 to 330.0 lost core.		

PROJECT NAME HANNA IV HOLE NO: 4PR10
 DEPTH: FROM 325 FT TO 350 FT. BOX NOS: 10, 11, 12
 LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
325												Lost Core		
100														
330		5YR2/1										330 to 331.5: vesicular paralava breccia of gray, bright orange, yellow, white		
335		NZ.5										Brownish black extremely carbonaceous mudstone grading into light gray clayey siltstone with bright orange reaction rims around dark clasts.		
340		N6 N5									I IS	Medium light gray mudstone with siltstone interlayered and horizontal laminations.		
105														
345												Lost Core 346.9 to 347.8		
350														

HOLE NO: 4PR10

DEPTH: FROM 350 FT TO 360 FT. BOX NOS: 12,13

LOCATION: T _____ R _____ S _____

DEPTH		DESCRIPTION
m.	ft.	
350	1110	Medium gray mudstone with no apparent sedimentary structures.
355	1160	
360	1210	
365	1260	
370	1310	
375	1360	
380	1410	
385	1460	
390	1510	
395	1560	
400	1610	
405	1660	
410	1710	
415	1760	
420	1810	
425	1860	
430	1910	
435	1960	
440	2010	
445	2060	
450	2110	
455	2160	
460	2210	
465	2260	
470	2310	
475	2360	
480	2410	
485	2460	
490	2510	
495	2560	
500	2610	
505	2660	
510	2710	
515	2760	
520	2810	
525	2860	
530	2910	
535	2960	
540	3010	
545	3060	
550	3110	
555	3160	
560	3210	
565	3260	
570	3310	
575	3360	
580	3410	
585	3460	
590	3510	
595	3560	
600	3610	
605	3660	
610	3710	
615	3760	
620	3810	
625	3860	
630	3910	
635	3960	
640	4010	
645	4060	
650	4110	
655	4160	
660	4210	
665	4260	
670	4310	
675	4360	
680	4410	
685	4460	
690	4510	
695	4560	
700	4610	
705	4660	
710	4710	
715	4760	
720	4810	
725	4860	
730	4910	
735	4960	
740	5010	
745	5060	
750	5110	
755	5160	
760	5210	
765	5260	
770	5310	
775	5360	
780	5410	
785	5460	
790	5510	
795	5560	
800	5610	
805	5660	
810	5710	
815	5760	
820	5810	
825	5860	
830	5910	
835	5960	
840	6010	
845	6060	
850	6110	
855	6160	
860	6210	
865	6260	
870	6310	
875	6360	
880	6410	
885	6460	
890	6510	
895	6560	
900	6610	
905	6660	
910	6710	
915	6760	
920	6810	
925	6860	
930	6910	
935	6960	
940	7010	
945	7060	
950	7110	
955	7160	
960	7210	
965	7260	
970	7310	
975	7360	
980	7410	
985	7460	
990	7510	
995	7560	

PROJECT NAME HANNA IV HOLE NO: 4PR11DEPTH: FROM 195.0 FT TO 220.0 FT. BOX NOS: 1,2,3LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
195		N5		L												~	1	I	Medium gray mudstone with horizontal bedding and bioturbation.		
60																~					
200			~													~					
205			~													~					
210			~													~					
65			~													⊙					
215		N6		L															Medium light gray siltstone with wavy bedding and bioturbation.		
220				L																	
																	U				
																	I				

PROJECT NAME HANNA IV HOLE NO: 4PR11DEPTH: FROM 220 FT TO 245 FT BOX NOS: 3,4,5LOCATION: T R S

m DEPTH ft	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS											PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE	
					CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS						% FRAMEWORK
220				L														Very light gray, very fine-grained, moderately well sorted sandstone with small scale trough cross bedding and some wavy bioturbated bedding.		
225		N8								MWS	S			1	I		Fining upward sequences of medium dark gray mudstones, medium light gray siltstone and light gray moderately well sorted, fine-grained sandstone.			
230		N4																		
		N6																		
235		N7								MWS	S									
		N4																		
		N6								MWS	S									
240		N7																		
		N4																		
		N6								MWS	S									
		N7																		
245														3						

PROJECT NAME HANNA IV HOLE NO: 4PB11

DEPTH: FROM 245 FT TO 270 FT. BOX NOS: 4,5,6,7

LOCATION: T R S

DEPTH		ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION
270	245												
265													
260													
255													
250													
245													

PROJECT NAME HAWAII IV HOLE NO: 4PB11
 DEPTH: FROM 270 FT TO 295 FT. BOX NOS: 3, 9, 10
 LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
270										1	I			
275											I			
85											I			
280											I			
285											I			
		N7		L							I			
		N6		L							U	Medium light gray unconsolidated mudstone.		
		N7		L							I	Light gray fine-grained mud.		
290														
295											U	Well sorted sandstone with climbing ripples, ripple trough cross laminations and some bio- turbation. Grades down into slightly altered Hornfels with relict sedimentary structures.		

PROJECT NAME HANNA IV HOLE NO: 4PB11
 DEPTH: FROM 295 FT TO 320 FT. BOX NOS: 11,12,13
 LOCATION: T R S S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
90 295		N2		L							I	Grayish black extremely carbonaceous mudstone grading into coal		
300		N1 N2										Grayish black, extremely carbonaceous mudstone		
		N4										Lost Core		
305		N5										Slightly altered interbedded siltstone and mudstone with relict sedimentary structures some hornfelsic appearing pieces. Some fragments have rounded corners.		
310		N5										Lost Core		
95		N5										Scoraceous buthites with black veinlettes and angular vesicles up to 2cm large. Vesicles become more numerous and smaller downward.		
315		N6 N5 N2								1	I	Buthites grade downward into altered coal with .1 to 1.0 cm vesicles.		
320												Lost Core		

PROJECT NAME HAWA IV HOLE NO: 4PB11DEPTH: FROM 320 FT TO 345 FT. BOX NOS: 12,13,14LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	MS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
320																			
325		N1														U	Slightly altered black coal with well developed cleavage. Becomes less altered downward.		
100																	Lost Core		
330		N1														IS	Black coal grading downward into grayish black carbonaceous mudstone		
335		N2		L												IS			
340																			
105		N6														I	Medium light gray siltstone with some detrital coal fragments, wavy bioturbated bedding and horizontal bedding.		
345																			

PROJECT NAME HANNA IV HOLE NO: APR11
 DEPTH: FROM 345 FT TO 353.0 FT. BOX NOS: 14,15
 LOCATION: T R S

m.	DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
	345		N6		L													1	I	Interbedded siltstone, fine-grained sandstone and mudstone grading downward into medium gray horizontally bedded mudstone.		
	350		N5											MMS	S							
	355																					
	360																					
110																						

PROJECT NAME HAUNA IV HOLE NO: 4PB-12
 DEPTH: FROM 103 FT TO 220 FT. BOX NOS: 1,2,3
 LOCATION: T _____ R _____ S _____

DEPTH m. ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
195 60														
200		N5									I	Medium gray slightly calcareous silty mudstone grading into a less calcareous medium light gray silty mudstone with horizontal bedding.		
205		N6								1				
210		N7		L					~	3		Light gray siltstone with horizontal bedding and bioturbation.		
215									~	1				
220									① ①			Light gray muddy siltstone with wavy bedding and bioturbation.		

PROJECT NAME HANNA IV HOLE NO: 4PB12
 DEPTH: FROM 220 FT TO 245 FT. BOX NOS: 3,4,5
 LOCATION: T R S

DEPTH m ft	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY							SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
					CLAY	MUD	SLT	VFS	FS	MS	CS									
220		N7		F												1	I	Light gray siltstone with horizontal bedding and bioturbation.		
225																				
230																				
235																				
240		N8		F														Very light gray very fine-grained sandstone with siltstone lenses. Trough cross-bedding and bioturbation.		
245																				

PROJECT NAME HANNA IV HOLE NO: 4PB12

DEPTH: FROM 245 FT TO 270 FT. BOX NOS: 5,6,7,8

LOCATION: T R S

m DEPTH ft	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS								SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
					CLAY	MUD	SLT	VFS	FS	MS	VCS									
245		N5		L													I	Very light gray fine-grained moderately well sorted sandstone with coarsening upward sequence of medium light gray horizontally laminated siltstone.		
75		N7		F									MMS S			1				
250																				
255																				
260		N5		L														Very light gray fine-grained moderately well-sorted sandstone and coarsening upward sequence of medium gray siltstone.		
80		N7		F																
265				L																
				F																
270																				

PROJECT NAME HAINA IV HOLE NO: 4PB12
 DEPTH: FROM 270 FT TO 295 FT. BOX NOS: 3,9,10
 LOCATION: T R S S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
270		N7		F		MMS								
275		N6												
280														
285		N6										Medium light gray fine to medium-grained moderately well sorted sandstone with layers of medium gray mudstone with horizontal laminations, and bioturbation .		
290												Lost Core.		
295												Lost Core		
												Lost Core.		

DEPTH m.	DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	DURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
295	96												Lost Core.		
300			NI										Slightly altered black coal with good cleavage.		
305													Lost Core.		
310	95												Slightly altered black coal.		
315													Lost Core.		
320															

PROJECT NAME: HANNA IV
 HOLE NO: 4PD12
 BOX NOS: 10, 11, 12
 DEPTH: FROM 295 FT TO 320 FT
 LOCATION: T R S

PROJECT NAME HAINA IV HOLE NO: 4PR12
 DEPTH: FROM 320 FT TO 345 FT BOX NOS: 10, 11
 LOCATION: T R S

m. DEPTH	ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
320																						
325																						
100																						
330			N2 N1 N2																			
335			N5																			
340			N6															1	I	Alternating layers of slightly altered coal and black carbonaceous mudstone.		
105			N5																	Medium gray mudstone grading into wavy bedded and bioturbated siltstone.		
345																						
																				Lost Core.		

PROJECT NAME HANNA IV HOLE NO: 4PB12
 DEPTH: FROM 345 FT TO 352.5 FT. BOX NOS: 12, 13
 LOCATION: T R S S

m.	DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
	345		N5															1	I	Medium gray mudstone interbedded with light gray medium-grained moderately well sorted sandstone with bioturbation.		
	350		N7																			
	355																					

PROJECT NAME HVNA IV HOLE NO: 1pp13

DEPTH: FROM 193.5 FT TO 220.0 FT. BOX NOS: 1,2,3

LOCATION: T R S

m.	DEPTH	ROCK	COLOR	SEDIMENTARY	BEDDING	CLAY	MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES	AND BIOLOGICAL	PERCENT LS	INDURATION	DESCRIPTION	INFERRED	SAMPLE NO
ft.		TYPE		STR.	THICKNESS													CONSTITUENTS				ENVIRONMENT	AND TYPE	
195	60																							
																				2	IS	Medium light gray silty mudstone grading into..		
200			N6.5		L															1	I	Medium light gray siltstone with horizontal bedding, bioturbation and some organics.		
																				4				
205				~																				
				~																				
			N7	~																				
210				~																				
			5Y6/1																					
	65		N7	~																				
215				~																				
				~																				
			N6.5																	3				
220				~																4				

PROJECT NAME HANNA IV HOLE NO: 4PB13DEPTH: FROM 220.0 FT TO 245 FT. BOX NOS: 3,4,5LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD								SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
					GLY	MUD	SLT	VFS	FS	MS	CS	VCS									
220		N6		L													1	I			
		5Y6/															2		Lost Core 22.5-223.0		
		N5															1		Medium gray silty mudstone		
225		N6		L															Medium light gray clayey siltstone		
																			with horizontal laminations.		
													MMS	S			2		Light gray very fine-grained moderately		
		N7															1		well sorted sandstone grading into medium		
230		N5.5																	gray siltstone.		
		N5.5		L															Lost Core 231.2 to 232.4		
		N7																IF			
235		N6																I	Medium gray siltstone grading into...		
																			Light gray, very fine-grained sandstone with		
																			interlayered siltstone, trough cross		
																			bedding and bioturbation.		
		N7.5											MMS	S			3				
240		N7.0															1				
																			Lost Core 242.0-242.5		
		N6.5																			
245		N7.5																			

PROJECT NAME HANNA IV HOLE NO: 4PB13
 DEPTH: FROM 245 FT TO 270 FT. BOX NOS: 5,6,7
 LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
245		N7.5	SS	L						1	I	Lost Core 246.6-247.0		
250		N7.5	SS	L						3	I	Very light gray fine to medium-grained, moderately well sorted sandstone with ripple trough cross bedding.		
255				F						1				
260										2				
265		N6	SS	L								257.1 to 258.4		
270		N7	SS	F								Coarsening upward sequence of medium light gray, horizontally laminated siltstone grading into light gray fine-grained moderate ¹ , well sorted sandstone with wavy laminations.		
												Lost Core 265.3-270.6		

PROJECT NAME HAWAII IV HOLE NO: 4PR13
 DEPTH: FROM 270 FT TO 295 FT. BOX NOS: 7, 8, 9
 LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
270		N7		F									MVS	S			1	I	Very light gray, fine-grained sandstone.		
		N5 N4.5 N6.5															6 3 4		Medium dark gray, fine to medium-grained, calcareous sandstone.		
275																					
																			Lost Core 274.8 to 279.0		
280		N5 5B9/1 N8 N5 N7		L													1		Medium gray/white pumaceous to scoriaceous sandstone hornfels grading into a light gray more massive sandstone. Sedimentary structures recognizable.		
285																					
		N6																	Lost Core 285.3 to 288.0		
290																					
		N7																	292-293.5 More massive less pumaceous sandstone hornfels		
295																			294.9-298.0 (Lost Core).		

HOLE NO: 4 PB13

BOX NOS: 9,10

5

m.	DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO. AND TYPE
295	90	H	N6	L																Medium gray, massive sandstone hornfels (siltstone?) laminations, horizontal bedding recognizable.		
300		H	N4	Rubble															U			
305		H	N5																	303.9 to 310.4 Lost Core.		
310	95	B	N5	I																Medium gray scoraceous buchite grading into vesicular paralava rock.		
315		P		Rubble																		
320		AC	5YR2/1																	318-319.3 Altered Coal.		

PROJECT NAME HAWA II HOLE NO: 4PB13

DEPTH: FROM 320 FT TO 345 FT. BOX NOS: 10, 11, 12

LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS								SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
					CLAY	MUD	SLT	VFS	FS	MS	CS									
320																		319.3 to 331.4 Lost Core.		
325																				
330																				
335		5YR 2/1																331.4 to 334.0 extremely carbonaceous mudstone. Coal 334-335.0		
340		N7																		
345																		Light gray to medium light gray siltstone with wavy and horizontal laminations grading into medium light gray to medium dark gray mudstone with no apparent sedimentary structures.		
105

DEPTH m. ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	DURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
345		N5												
350														
355														
355												353.7-354.0 Lost Core.		
355														
355														
355														
355														
355														
355														
355														
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PROJECT NAME HWA IV HOLE NO: 4P114

DEPTH: FROM 200.0 FT TO 225 FT. BOX NOS: 1,2,3

LOCATION: T R S

INL DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
200		N5		I						1	I	Medium gray, horizontally bedded mudstone some climbing ripples and ripple trough cross laminations.		
205														
210		N6										Medium light gray siltstone with wavy biotur- bated bedding and thin interbeds of very fine-grained sandstone.		
65														
215		N7									WI			
220		N6									I			
225														

PROJECT NAME HANNA IV HOLE NO: 4PB14
 DEPTH: FROM 225 FT TO 250 FT. BOX NOS: 3,4,5
 LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
225														
230		N5										Medium gray horizontally bedded mudstone.		
235		N7										Light gray, very fine-grained, well sorted sandstone with wavy bioturbated bedding and ripple cross laminations		
240		N6										Medium light gray, horizontally bedded siltstone.		
245		N7										Light gray sandstone, same as above with fewer sedimentary structures.		
250														

PROJECT NAME HANNA IV HOLE NO: 4PR14

DEPTH: FROM 250 FT TO 275 FT. BOX NOS: 6,7,8

LOCATION: T _____ R _____ S _____

m. DEPTH ft.	
275	ROCK TYPE
270	COLOR
265	SEDIMENTARY STR.
260	BEDDING THICKNESS
255	CLAY MUD SLT VFS FS MS CS VCS
250	GRANULE
	SORTING
	ROUNDNESS
	% FRAMEWORK
	ACCESSORIES AND BIOLOGICAL CONSTITUENTS
	PERCENT LS
	INDURATION
	DESCRIPTION
	INFERRED ENVIRONMENT OF DEPOSITION
	SAMPLE NO AND TYPE

PROJECT NAME HANNA IV HOLE NO: 4PB14

DEPTH: FROM 275 FT TO 300 FT. BOX NOS: 3.9

LOCATION: T S R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS											DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
					CLAY	MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING				ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																										
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Lost Core.

Very light gray hornfelsic sandstone grading downward into medium gray scoraceous para-lava breccia and back into hornfelsic sandstone.

Lost Core.

PROJECT NAME HANNA IV HOLE NO: 4PB14
 DEPTH: FROM 300 FT TO 325 FT. BOX NOS: 9,10
 LOCATION: T _____ R _____ S _____

325	320	315	310	305	300	m. DEPTH ft.
						ROCK TYPE
						COLOR
						SEDIMENTARY STR.
						BEDDING THICKNESS
						CLAY MUD SLT VFS FS MS CS VCS GRANULE
						SORTING
						ROUNDNESS
						% FRAMEWORK
						ACCESSORIES AND BIOLOGICAL CONSTITUENTS
						PERCENT LS
						INDURATION
<p>Lost Core.</p> <p>Light bluish gray scoriaceous buchite.</p> <p>Lost Core.</p>						DESCRIPTION
						INFERRED ENVIRONMENT OF DEPOSITION
						SAMPLE NO AND TYPE

PROJECT NAME HANNA IV HOLE NO: 4PB14

DEPTH: FROM 325 FT TO 350 FT. BOX NOS: 10, 11

LOCATION: T R S

DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
325		M																	Black coal, possibly altered		
100		SYR2/A																	Brownish black carbonaceous mudstone.		
330		N1																	Black coal with vitreous appearance		
		N3															IS		Dark gray carbonaceous mudstone.		
335		N6																I	Medium light gray siltstone with wavy bioturbated bedding, ripple trough cross laminations and interbeds of sandstone and mudstone.		
340																					
105																					
345		N3																IS	Dark gray horizontally bedded mudstone.		
350																					

PROJECT NAME WATA IV HOLE NO: 48015
 DEPTH: FROM 100 FT TO 220 FT. BOX NOS: 1,2,3
 LOCATION: T S R S

DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
195														
200		5Y3/1		H					⊗	1	IS	Dark olive gray to grayish black homogeneous mudstone with no apparent sedimentary structures.		
205		N2							⊗					
210		5Y3/1							⊗					
215		N4							⊗	I				
220		5Y4/1		L					⊗		IS			
		N5							⊗					
		N6							⊗					
		N7							⊗					

PROJECT NAME HANNA IV HOLE NO: 4PB15

DEPTH: FROM 220 FT TO 245 FT. BOX NOS: 3,4,5,6

LOCATION: T R S

DEPTH m. ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
220		N6.5								1	I	As above, grading into light gray laminated siltstone with bioturbation wavy and horizontal bedding.		
225		N7		L			WS			1	I	Light gray, very fine-grained, well sorted sandstone with dark and light laminations.		
230		N5								IS	I	Medium light gray very fine-grained sandstone with interlayered (laminated to thin bedded) mudstone. Horizontal to steeply dipping planar bedding.		
235		N7										Light gray, very fine-grained sandstone with ripples in drift grading into medium light gray very fine-grained silty sandstone with horizontal light and dark laminations.		
240		N7.5								3				
245										1-2		Light gray, very fine-grained sandstone with horizontal bedding, bioturbation, some ripples in drift, clayey interlayers.		

LOCATION: T _____ R _____ S _____

[illegible]

PROJECT NAME HANNA IV HOLE NO: 4PR15

DEPTH: FROM 270 FT TO 295 FT. BOX NOS: 8,9,10

LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS								SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
					CLAY	MUD	SLT	WFS	FS	MS	CS									
270																				
275																				
85																				
280																				
285		N8		L								WS	S							
290																				
295																				
90																				

PROJECT NAME HANNA IV HOLE NO: 4PR15DEPTH: FROM 205 FT TO 320 FT. BOX NOS: 10.11.12LOCATION: T R S

DEPTH m. ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
295												Lost Core 295.5 to 296.2		
300		N7												
305		N6										Medium light gray, very fine-grained, well-sorted sandstone with horizontal laminations, bioturbation, occasional organic partings.		
310										1	IS	Medium light gray, siltstone, clayey with wavy horizontal laminations.		
315		N4		L						1	IS	Lost 311.0 to 311.5; 312.6 to 313.1 Medium gray mudstone with wavy laminations, some bioturbation and organics.		
320		N5									U	Medium dark gray mudstone highly carbonaceous.		

PROJECT NAME HMTA IV HOLE NO: 4PB15

DEPTH: FROM 320 FT TO 345 FT. BOX NOS: 12,13,14,15

LOCATION: T S R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
320		N4																IS			
325		N1																I	Lost Core 323.4-323.9		
		5Y2/1																U	Coal		
330		N1																I	Brownish black extremely carbonaceous mudstone		
		5Y2/1																U	Coal		
335		N1																I	Lost Core 323.4-323.9		
		5Y2/1																	Brownish black extremely carbonaceous mudstone.		
340		N1																	Coal.		
		5Y3/1																	Brownish black carbonaceous mudstone		
345		N1																	Olive black carbonaceous mudstone 338.8-339.0 Lost Core.		
105																			Coal		

PROJECT NAME HAWA IV HOLE NO: 4PR15

DEPTH: FROM 345 FT TO 357.9 FT. BOX NOS: 15,16

LOCATION: T R S S

m DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
345		N1								1	IS	Coal		
		5Y2/1										Olive black extremely carbonaceous mudstone.		
												Coal layer		
350		5Y4/1 5Y5/1		L										
		N7										Light gray fine to very fine-grained sandstone with bioturbation, wavy bedding, organics on bedding planes.		
355		N4-5										Medium gray siltstone with wavy bedding, some bioturbation.		
360														
110														

PROJECT NAME HAINA IV HOLE NO: 4PR16
 DEPTH: FROM 100 FT TO 220 FT. BOX NOS: 1,2
 LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
195																				
60																				
200		5Y4/1		L												1	IS			
205		N3 N4																Medium olive gray to dark gray carbonaceous mudstone, grading into less carbonaceous mudstone, with no apparent sedimentary structures.		
210		5Y3/1 5Y4/1																		
65																	U			
215																	IS			
220		5Y3/1																		

PROJECT NAME HAIFA IV HOLE NO: 4PB16

DEPTH: FROM 220 FT TO 245 FT. BOX NOS: 3,4,5

LOCATION: T R S

DEPTH m. ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
220		5Y6/1									I	Medium olive gray silty mudstone with wavy bedding and bioturbation.		
		5Y5/1									FS I			
225		N6												
		N6.5												
		N7												
230		N6.5										Medium to medium light gray siltstone with wavy bedding and bioturbation. Organics altered/rusty colored at 230.2		
235												Medium light gray alternating siltstone and very fine-grained, well-sorted sandstone with horizontal and planar bedding.		
240														
245		N7												

PROJECT NAME HAIFA IV HOLE NO: 4PR16
 DEPTH: FROM 245 FT TO 270 FT. BOX NOS: 6,7,8
 LOCATION: T R S

DEPTH m. ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
245																			Light gray silty, very fine-grained well sorted sandstone with alternating dark and light ripple trough cross laminations and thin organic partings.		
75																					
250		N5.5																	Medium gray siltstone with bioturbation and trough cross bedding		
		N6																			
255		N6.5																			
		N6.5															1	I	Medium light to light gray very fine-grained sandstone with ripples on cross-bedding, bioturbation, dark and light laminations, silty layers		
																	1-2		Lost Core.		
260		N7															2				
		N6.5															1				
80		N7																			
265		N6.5																U			
		N7																I			
		N6.5																			
270																					

PROJECT NAME HAWA IV HOLE NO: 4PB16

DEPTH: FROM 270 FT TO 295 FT. BOX NOS: 6,7,3,9

LOCATION: T R S

IN. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
270		N7												
275						WS	S		~	1	I			
280		N6 N7		L					~					
285									~			Light gray interbedded siltstone and very fine-grained sandstone. The siltstones are bioturbated and the sandstones contain ripple trough cross laminations. Climbing ripples and thin organic partings.		
290		N6 N7		L		WS	S		~	1	I	Light gray, very fine-grained well sorted sandstone with bioturbation, wavy bioturbated bedding and trough cross-bedding. Becomes coarser grained downward.		
295														

PROJECT NAME HANNA IV HOLE NO: 4PB16

DEPTH: FROM 295 FT TO 320 FT. BOX NOS: 10,11,12

LOCATION: T _____ R _____ S _____

PROJECT NAME HAWAII IV HOLE NO: 14PB16DEPTH: FROM 320 FT TO 345 FT. BOX NOS: 12, 13LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
320												Lost Core.		
325														
100	B	N4									I	Medium dark gray scoraceous buchite with linearly arranged vesicles, apparently along bedding planes and round (up to .8 cm) vesicles.		
330	Pb	N3										Relict sedimentary structures are also present. Grades downward into scoraceous paralava breccia		
		N6												
335												Lost Core.		
340	Pb	N5 N2 5Y5/2										Scoraceous to vesicular paralava breccia becoming carbonaceous downward		
		N2												
105														
345												Lost Core.		

PROJECT NAME HAINA IV HOLE NO: 4PB16

DEPTH: FROM 345 FT TO 363 FT. BOX NOS: 13,14,15

LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
345		N1								1		Black coal, possibly altered.		
350		N1								1		Lost Core.		
355		N1								5		Some calcareous nodules and stringers in coal.		
360		N2		L						4				
365		N7								5		Lost Core		
370										1	IS	Grayish black carbonaceous mudstone interbedded with some coal.		
										I		Light gray horizontally bedded siltstone with detrital fragments.		
												Light gray very fine-grained well sorted sandstone interbedded with siltstone.		

PROJECT NAME HANNA IV HOLE NO: 4PR17
 DEPTH: FROM 195 FT TO 220 FT. BOX NOS: 1,2,3
 LOCATION: T S R S

m.	DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
60	195																					
	200		N7		H													1	IS	Light to medium dark gray, carbonaceous mudstone with no sedimentary structure		
			N6																			
			N5																			
			N4																			
	205		N3.5																			
			N4																			
			5Y4/1																			
	210																					
			N4																			
			N4.5																			
	215		5Y4/1																			
			5Y5/1																			
			N7		L																	
	220		5Y5/1		H														I	Light gray siltstone with wavy bedding.		

PROJECT NAME HAWA II HOLE NO: 4PR17
 DEPTH: FROM 220 FT TO 245 FT. BOX NOS: 3,4,5
 LOCATION: T R S S

DEPTH m ft	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
220		5Y4/1		L							IS	Medium gray to olive gray , silty mudstone with wavy, occasionally lenticular bedding and bioturbation grading into medium light gray siltstone with bioturbation, wavy and horizontal bedding.		
		5Y5/1												
		N6												
225		N6.5		L						1	I			
230		N6												
235		N6.5												
240		N5									1-2			
		N6										Medium light gray sandy siltstone with wavy and horizontal bedding.		
		N6.5												
		5Y5/1								1		Very light gray fine-grained sandstone with wavy bioturbated bedding and organics concentrated on the bedding planes.		
245		N8												

PROJECT NAME HANNA IV HOLE NO: 4PB17
 DEPTH: FROM 245 FT TO 270 FT. BOX NOS: 5,6,7
 LOCATION: T R S

INL DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
245		N6.5																			
75		N5.5																IS	Medium gray clayey siltstone with dark and light laminations, trough cross bedding.		
250		5X5/1 N6.5																I	Light gray very fine-grained sandstone with clayey layers, wavy and horizontal bedding, dark and light laminations.		
255		N6.5															1	I			
260		N5.5 N7																IS I			
80		N6																	Lost Core 262.2 to 263.0		
265		N6.5															1-2 1		Light gray, fine-grained sandstone with dark and light laminations, clayey layers, ripples-in-drift.		
270		N6 N7															1-2 1				

PROJECT NAME HANNA IV HOLE NO: 4PR17DEPTH: FROM 270 FT TO 295 FT. BOX NOS: 5,6,7,8

LOCATION: T _____ R _____ S _____

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
270		N7.5										Same as above with trough crossbedding.		
275														
280														
285		N7.5												
290														
295		N6 SV4/L												
												292.5 to 293.0 Lost Core Brownish gray interlamimated fine-grained sandstone and siltstone. Fine clayey sandstone with organics at 294.0		

PROJECT NAME HAVINA IV HOLE NO: 4PB17
 DEPTH: FROM 295 FT TO 320 FT. BOX NOS: 8,9,10,11
 LOCATION: T _____ R _____ S _____

DEPTH m. ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
295												Light gray, fine-grained sandstone, bioturbated with planar cross bedding.		
300														
305														
310												Medium light gray siltstone with light and dark sandy and clayey laminations, bioturbation and wavy bedding.		
315														
320												Medium gray to olive gray carbonaceous mudstone with no apparent sedimentary structures.		

PROJECT NAME HANNA IV HOLE NO: 4PB17

DEPTH: FROM 320 FT TO 345 FT. BOX NOS: 13, 14, 15

LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
320	N4.5													
325	SY5/L													
330	SY4/L													
335	SYR 27L													
340	N1													
345														

PROJECT NAME HANNA IV HOLE NO: 4PB1Z

DEPTH: FROM 345 FT TO 370 FT. BOX NOS: 15,16,17,18

LOCATION: T R S

m.	DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
	345																					
	350																					
	355		5Y2/1																I			
			N1																			
	360		5Y2/1																I			
110			N7																			
	365		N6																IS			
			N5																			
	370		N6																			

PROJECT NAME HANNA IV HOLE NO: 4PB17
 DEPTH: FROM 370 FT TO 375 FT. BOX NOS: 13
 LOCATION: T R S S

DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
370		N6																	Medium gray siltstone with wavy laminations Carbonaceous pelletoids (.5 cm) have rusty reaction rims.		
375																					
115																					

HOLE NO: 4PB13

DEPTH: FROM 195 FT TO 220 FT. BOX NOS: 1,2,3

LOCATION: T _____ R _____ S _____

[illegible]

PROJECT NAME HANNA IV HOLE NO: 4PB13

DEPTH: FROM 220 FT TO 245 FT. BOX NOS: 3,4,5

LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
220		N5																	Medium gray siltstone with horizontal and wavy bedding, bioturbation and ripple trough cross lamination		
225																					
70																					
230		N7		L									WS	S			1	I	Light gray, very fine-grained well sorted sandstone with trough cross bedding, bioturbated wavy beds and organic partings. Also contains thin coarser sand beds with erosional contacts and interbedded siltstones and mudstones.		
235																					
240		N6																			
		N7																			
		N6																			
		N5																			
245		N6																			

PROJECT NAME HAWA II HOLE NO: 4PB13
 DEPTH: FROM 245 FT TO 270 FT. BOX NOS: 7,8
 LOCATION: T R S

IN. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	GLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
245		N6																			
75		N7											MMS	S				IF			
250													Ws	S				I			
255		N4 N6 N7																	Medium dark gray mudstone grading down into medium light gray bioturbated siltstone.		
260		N7		L									MMS	S			1	I	Light gray, very fine-grained, moderately well sorted sandstone with ripple trough cross lamination, microfaults, slumped bedding and wavy bioturbated beds.		
80																					
265																		WI			
270				H																	

PROJECT NAME HANNA IV HOLE NO: 4PB13

DEPTH: FROM 270 FT TO 295 FT. BOX NOS: 9,10,

LOCATION: T R S

DEPTH ft.		ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
270															
275															
280															
285															
290															
295															

PROJECT NAME HANNA IV HOLE NO: 4PR13
 DEPTH: FROM 345 FT TO 363 FT. BOX NOS: 14,15
 LOCATION: T R S

DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
345		N2														≈					
350		N1 N2														≈					
355		N7	≈ ≈ ≈ ≈	L												⊙ ⊙	1	I	Light gray fine-grained, moderately well sorted sandstone becoming finer-grained downward. Bioturbation and wavy bedding are the most common sedimentary structures.		
360		N5	≈ ≈ ≈													⊙ ⊙			Interbedded sand and silt.		
365		N4		L												≈			Medium dark gray horizontally bedded mudstone.		

PROJECT NAME HANNA IV HOLE NO: 4PB19DEPTH: FROM 195 FT TO 220 FT. BOX NOS: 1,2

LOCATION: T _____ R _____ S _____

DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
195														
200		N3										Dark gray horizontally bedded mudstone.		
205		N5										Medium gray siltstone with wavy bedding and climbing ripples. Some bioturbation.		
210												Lost Core.		
215		N7 N6 N7										Interbedded mudstone siltstone and very fine-grained siltstone		
220														

PROJECT NAME HANNA IV HOLE NO: 4PB-19
 DEPTH: FROM 220 FT TO 245 FT. BOX NOS: 2,3,4,5
 LOCATION: T R S

DEPTH m. ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
220		N3		L						5	WI			
225										1	I	Dark gray horizontally bedded mudstone.		
230		N7												
235		N4								1		Medium dark gray horizontally bedded mudstone grading downward into siltstone with wavy bioturbated beds.		
240		N5								3				
245		N7		L						3		Light gray, very fine-grained, moderately well-sorted sandstone		
										5	WI			

PROJECT NAME HANNA IV HOLE NO: 4PB19

DEPTH: FROM 245 FT TO 270 FT. BOX NOS: 5,6,7,8

LOCATION: T _____ R _____ S _____

270	265	260	255	250	245	m. DEPTH ft.
						ROCK TYPE
						COLOR
						SEDIMENTARY STR.
						BEDDING THICKNESS
						CLAY MUD SLT VFS FS MS CS VCS GRANULE
						SORTING
						ROUNDNESS
						% FRAMEWORK
						ACCESSORIES AND BIOLOGICAL CONSTITUENTS
						PERCENT LS
						INDURATION
						DESCRIPTION
						INFERRED ENVIRONMENT OF DEPOSITION
						SAMPLE NO AND TYPE

PROJECT NAME HANNA IV HOLE NO: 4PB19

DEPTH: FROM 295 FT TO 320 FT. BOX NOS: 10, 11, 12

LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SILT	SAND	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
295	H	N2																I	Slightly altered carbonaceous mudstone		
300	H	N6		L															Medium light gray hornfels with relict sedimentary structures		
305	H	N4																I	Lost Core.		
310	Pb																		Medium dark gray Hornfels and paralave breccia becoming more vitreous and scoraceous downward relict structures less recognizable downward.		
315		N2																U	Grayish black, altered rubblized coal.		
320																			Lost Core		

PROJECT NAME HAWA IV HOLE NO: 4010
 DEPTH: FROM 320 FT TO 345 FT. BOX NOS: 12,13,14,15
 LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY							SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
					CLAY	MUD	SLT	VFS	FS	MS	CS									
320		N1																Lost Core		
325																				
100		N1																Black coal slightly altered; becoming less altered downward.		
330																				
335		N7																Light gray, fine-grained, moderately well sorted sandstone.		
340																				
105
345																				

PROJECT NAME HVHA IV HOLE NO: 11PR20
 DEPTH: FROM 193 FT TO 220 FT. BOX NOS: 1,2,3
 LOCATION: T R S S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	GLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
195														
60		N5.5	≈ ≈	L					⊗	1	I	Medium light gray mudstone with horizontal laminations, and little bioturbation.		
200			≡						≈			LOST CORE		
		N6.5	≈						≈					
205			≡						≈					
			≈ ≈	L		WS	S					Medium light gray siltstone with horizontal laminations, interlayered sandstone, some ripple trough cross-laminations and bioturbation.		
210										2				
										1				
65										2				
215		N7	≈											
		N6	≡							4				
		N7	≈							2				
220														

PROJECT NAME HANNA IV HOLE NO: 4PR20
 DEPTH: FROM 220 FT TO 245 FT. BOX NOS: 3,4,5
 LOCATION: T R S S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
220		5Y6/1		L		WS	S			1	I	Fining upward sequences of medium gray mudstone, light gray siltstone and fine-grained sandstone.		
		N7												
		N6								3				
225		N1								4				
		N7.5				MWS	S							
230														
		N6				MWS	S							
235														
		N5												
		N6												
240		N7				MWS	S					Very light gray, fine-grained sandstone with wavy, horizontal bedding, high angle planar bedding.		
245														

PROJECT NAME HANNA IV HOLE NO: 10P20

DEPTH: FROM 270 FT TO 295 FT. BOX NOS: 3, 9, 10

LOCATION: T R S

m DEPTH ft	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
270		N7.5		L									MWS	S			1	I	Light gray, moderately well sorted, medium-grained sandstone with horizontal laminations and intermittent clayey lenses		
275																	2				
280																					
285		5Y8/1																	LOST CORE		
		N6																	Yellowish gray very fine-grained moderately well sorted clayey sandstone grading into		
		N5															4		medium gray mudstone.		
290		N6		L									MWS	S				I	Medium light gray to medium dark gray, clayey carbonaceous siltstone with wavy bedding.		
																			LOST CORE		
295		N6																			
		N4																			

PROJECT NAME HANNA IV HOLE NO: 4PR20
 DEPTH: FROM 295 FT TO 320 FT. BOX NOS: 10,11,12
 LOCATION: T R S

DEPTH m. ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
295		N3		L		WS				1	I			
90		5Y6/1												
		5Y5/1												
300		N3										Lost core.		
		N2									IS	Dark gray carbonaceous silty mudstone grading into carbonaceous shaley mudstone. (in bags, rubble 303.7 to 310.8).		
305		N3		L										
		N2												
310			Rubblized									Lost Core		
95														
315		N1										317.0-318.9 coal (rubblized in bag).		
320														

PROJECT NAME HANNA IV HOLE NO: 4PR20
 DEPTH: FROM 320 FT TO 345 FT. BOX NOS: 12, 13, 14, 15
 LOCATION: T S R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS									SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
					CLAY	MUD	SLT	VFS	FS	MS	CS	VCS									
320		N1																Coal (whole core)			
325																					
100																					
330		5Y2/1																Brownish black extremely carbonaceous mudstone			
335																					
340																					
345		N3		L														Extremely carbonaceous mudstone grading into very light gray siltstone and sandstone with wavy laminations and bioturbation.			
		N5																			
		N7.5																			
105																					
345																					

DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS CS VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
345		N7.5													
350		N6													
355		N4													
360															
365															
370															
375															
380															
385															
390															
395															
400															
405															
410															
415															
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815															
820															
825															
830															
835															
840															
845															
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855															
860															
865															
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875															
880															
885															
890															
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945															
950															
955															
960															
965															
970															
975															
980															
985															
990															
995															
1000															

PROJECT NAME: HANNA IV
 HOLE NO: 4PB20
 DEPTH: FROM 345 FT. TO 353

PROJECT NAME HANNA IV HOLE NO: 4PR21

DEPTH: FROM 245 FT TO 270 FT. BOX NOS: 1, 2, 3

LOCATION: T R S

DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	GLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
245														
250			N5 N6							1		Medium gray mudstone grading into medium light gray siltstone		
255			N6	L						I		LOST CORE		
260			N7	L		MS	S			5		Light gray, very fine grained, moderately sorted sandstone with interlamination of siltstone.		
265										WI				
270										5

PROJECT NAME HAWA IV HOLE NO: 4PP21 BOX NOS: 3,4,5 DEPTH: FROM 270 FT TO 295 FT LOCATION: T R S

PROJECT NAME HANNA IV HOLE NO: AD821

DEPTH: FROM 295 FT TO 320 FT. BOX NOS: 5,6

LOCATION: T R S

m. DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD SLT VFS FS MS CS VCS GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
295										1	WI			
300														
305														
		N4		L						4	I			
		N7		H										
310				L										
		N4									WI	Interlaminated sandstone and mudstone with wavy bioturbated bedding.		
		N6												
315														
		N4		L						1	I	Medium dark gray horizontally bedded mudstone with organic fragments.		
320														

PROJECT NAME HAINA IV HOLE NO: 4P21

DEPTH: FROM 320 FT TO 345 FT. BOX NOS: 5, 7, 8, 9

LOCATION: T R S

DEPTH ft.	ROCK TYPE	COLOR	SEDIMENTARY STR.	BEDDING THICKNESS	CLAY MUD	SLT	VFS	FS	MS	CS	VCS	GRANULE	SORTING	ROUNDNESS	% FRAMEWORK	ACCESSORIES AND BIOLOGICAL CONSTITUENTS	PERCENT LS	INDURATION	DESCRIPTION	INFERRED ENVIRONMENT OF DEPOSITION	SAMPLE NO AND TYPE
320		N7		L									P	S			1	I	Interlaminated sandstone and mudstone.		
325		N3																	Dark gray carbonaceous mudstone.		
100		N1																	Black coal.		
330																					
335																					
340																					
345																					

APPENDIX B

PETROGRAPHIC AND TEXTURAL DATA FROM UNALTERED LITHOLOGIC UNITS

COMPOSITION of SANDSTONES and COARSE SILTSTONES

SAMPLE NO.	UNIT	Q _p	Q _m	Q _t	K	P	F _{rx}	F _t	L _v	L _m	L _s	L _t	A	M	M _a	C	P _O
4-1-246.3	A	9.00	36.00	45.00	8.00	2.00	3.00	13.00	3.00	0.00	6.50	9.50	3.00	3.00	0.00	28.00	5.50
4-1-250.0	A	7.50	38.50	46.00	7.50	2.00	2.50	12.00	2.00	0.00	3.00	5.00	0.00	2.00	0.00	33.50	1.50
4-1-257.0	A	9.00	42.50	51.50	5.00	1.50	1.00	7.50	1.50	0.00	3.00	4.50	0.00	2.50	0.00	24.50	9.50
4-1-270.5	A	9.00	51.00	60.00	2.50	0.50	0.00	3.00	0.50	0.00	1.00	1.50	0.00	5.00	0.00	25.50	5.00
4-1-279.5	A	4.50	46.80	51.30	3.00	0.50	0.00	3.50	0.00	0.50	2.50	3.00	0.00	4.00	0.00	34.20	4.00
4-1-299.2	A	11.50	48.00	59.50	5.50	1.50	0.00	7.00	3.50	0.00	6.00	9.50	0.00	1.50	1.00	9.00	12.50
4-2-234.5	A	6.50	42.50	49.00	1.50	1.00	1.00	3.50	2.00	0.00	3.00	5.00	0.00	8.00	0.00	32.50	2.00
4-2-251.5	A	6.00	42.00	48.00	3.00	0.50	1.00	4.50	2.00	0.00	2.50	4.50	0.00	6.00	0.00	36.00	1.00
4-2-253.0	A	5.50	47.50	53.00	1.50	2.00	0.00	3.50	1.50	0.00	3.00	4.50	0.00	4.50	3.50	31.50	0.00
4-2-275.4	A	6.00	50.50	56.50	2.00	0.50	0.50	3.00	2.00	0.00	3.00	5.00	0.00	1.00	0.00	32.00	2.00
4-2-292.4	A	5.00	53.00	58.00	2.50	1.50	0.00	4.00	2.00	1.00	1.50	4.50	0.00	5.00	0.00	21.50	7.50
4-2-305.5	A	4.00	31.00	35.00	2.00	1.50	0.00	3.50	2.00	0.00	0.50	2.50	0.00	4.00	0.00	54.50	0.50
4-3-261.5	A	6.00	39.00	45.00	6.00	4.00	0.00	10.00	0.00	0.00	2.00	2.00	0.00	2.00	0.00	41.00	0.00
4-3-312.0	A	6.50	54.50	61.00	2.50	1.00	0.00	3.50	2.50	0.00	3.50	6.00	0.00	3.50	0.00	23.00	1.00
4-10-238.8	A	15.00	43.00	58.00	2.00	2.00	0.00	4.00	2.00	0.00	7.50	9.50	0.00	5.00	0.00	23.00	0.50
4-10-250.7	A	0.00	35.50	35.50	4.50	1.50	0.00	6.00	0.00	0.00	0.00	0.00	0.00	0.50	1.50	47.50	2.50
4-10-252.8	A	5.50	44.00	49.50	2.00	2.00	0.00	4.00	1.50	1.00	5.50	8.00	0.00	3.50	0.00	34.00	1.00
4-10-255.2	A	7.50	28.50	36.00	3.50	3.00	0.00	6.50	4.00	0.00	7.00	11.00	0.00	7.50	0.00	31.00	8.00
4-10-270.1	A	0.00	33.00	33.00	7.50	1.50	0.00	9.00	0.00	0.00	1.00	1.00	0.50	1.50	0.50	52.00	2.50
4-11-241.5	A	6.50	41.00	47.50	2.00	2.00	0.00	4.00	1.50	0.00	0.50	2.00	0.00	4.50	0.00	40.50	1.50
4-11-294.0	A	5.50	51.50	57.00	3.00	1.50	0.50	5.00	1.50	0.00	3.50	5.00	0.00	5.00	0.00	25.00	3.00

SAMPLE NO.	UNIT	Q _p	Q _m	Q _t	K	P	F _{rx}	F _t	L _v	L _m	L _s	L _t	A	M	M _a	C	P _O
4-13-253.2	A	1.00	51.50	52.50	10.00	0.00	0.00	10.00	0.00	3.00	1.00	4.00	0.00	1.00	5.50	31.00	1.00
4-13-265.2	A	0.50	49.00	49.50	2.00	2.00	0.00	4.00	0.00	0.00	1.50	1.50	0.00	2.50	12.50	29.50	0.50
4-13-272.9	A	0.00	48.00	48.00	3.50	1.50	0.00	5.00	0.00	0.00	2.00	2.00	0.00	1.00	3.00	41.00	0.50
4-13-274.0	A	1.50	39.00	40.50	4.50	1.00	0.50	6.00	0.00	0.00	0.00	0.00	0.00	3.00	0.00	49.50	1.00
4-13-274.8	A	1.50	40.50	42.00	6.50	2.00	0.50	9.00	0.00	0.00	0.00	0.00	1.50	1.50	1.00	19.00	0.00
4-15-260.0	A	6.00	42.50	48.50	3.00	1.50	0.50	5.00	2.00	0.50	3.50	6.00	0.00	5.00	0.00	30.50	5.00
4-16-313.8	A	8.00	50.50	58.50	1.00	1.00	0.00	2.00	2.00	0.50	1.00	3.50	1.00	2.00	0.00	28.00	5.00
4-17-276.2	A	6.00	46.00	52.00	3.50	2.50	1.50	7.50	3.50	0.00	3.00	6.50	0.00	5.00	0.00	29.00	0.00
4-17-286.8	A	8.00	46.50	54.50	4.00	2.50	0.00	6.50	1.50	1.00	3.00	5.50	0.00	6.50	0.00	20.50	6.50
4-17-293.5	A	6.50	42.50	49.00	2.50	2.00	0.00	4.50	1.00	0.00	0.50	1.50	0.00	3.50	6.00	35.50	0.00
4-18-224.7	A	9.50	43.00	52.50	3.50	3.00	0.00	6.50	0.00	0.00	2.50	2.50	0.00	10.00	2.00	26.50	0.00
4-18-269.5	A	6.50	41.50	48.00	4.00	2.00	0.00	6.00	1.00	0.00	2.00	3.00	0.00	3.00	0.00	34.50	0.50
4-19-290.0	A	11.00	39.00	50.00	5.50	4.00	0.00	9.50	4.50	0.00	6.50	11.00	0.00	3.50	0.00	13.50	10.50
4-21-288.2	A	7.50	40.50	48.00	4.00	1.50	0.00	5.50	0.00	0.00	2.50	2.50	0.00	2.00	0.00	41.50	0.00
4-3-324.0	A'	9.00	41.00	50.00	3.50	1.50	0.00	5.00	1.50	0.00	2.50	4.00	0.00	7.00	0.00	29.00	5.00
4-19-295.0	A'	11.50	35.00	46.50	4.00	3.00	0.00	7.00	2.00	0.00	9.00	11.00	0.00	3.50	0.00	32.00	0.00
4-1-132.8	B	7.00	43.00	50.00	2.00	1.50	0.00	3.50	3.00	0.00	3.00	6.00	2.50	4.00	19.50	12.00	2.50
4-1-204.6	B	6.00	40.00	46.00	4.00	5.50	0.00	9.50	2.00	0.00	2.00	4.00	1.00	4.00	1.50	30.50	3.50
4-2-120.8	B	10.00	41.00	51.00	4.50	1.50	0.00	6.00	2.50	0.00	4.50	7.00	0.00	8.50	1.00	20.00	6.50

SAMPLE NO.	UNIT	Q _p	Q _m	Q _t	K	P	F _{rx}	F _t	L _v	L _m	L _s	L _t	A	M	M _a	C	P _O
4-2-167.2	B	9.50	32.00	41.50	4.50	2.50	0.00	7.00	2.00	2.00	3.50	5.50	5.00	7.50	24.50	8.00	1.00
4-1- 30.4	C	13.00	44.00	57.00	11.50	1.50	2.00	15.00	2.50	0.00	2.50	5.00	9.50	2.00	0.00	12.00	9.00
4-1- 32.7	C	9.50	42.00	51.50	11.50	1.50	2.50	15.50	3.50	1.00	5.00	9.50	2.00	2.00	1.50	13.50	5.50
4-1- 87.6	C	14.00	44.00	58.00	11.00	1.00	4.50	16.50	5.50	0.50	5.50	11.50	0.00	1.50	0.00	7.00	5.50
4-2- 47.6	C	10.00	41.50	51.50	8.00	3.50	1.50	13.00	2.00	0.00	5.00	7.00	0.00	9.00	0.00	7.50	12.00
4-2-116.5	C	9.50	48.00	57.50	5.00	3.00	0.50	8.50	3.50	0.50	5.50	9.50	0.00	4.00	0.00	14.00	6.50
4-11-351.0	U	8.50	44.50	53.00	3.50	2.00	0.00	5.50	2.50	0.00	3.00	5.50	0.00	2.00	3.50	30.00	0.50
4-16-365.0	U	19.00	49.00	68.00	4.00	3.00	0.00	7.00	2.00	0.00	3.50	5.50	2.50	3.50	5.50	8.00	0.00
4-19-343.7	U	9.50	49.00	58.50	6.50	3.50	0.00	10.00	2.00	0.00	11.00	13.00	0.00	0.50	0.00	10.00	8.00

Textural Data

SAMPLE NO.	UNIT	MEAN (MM)	MAX (MM)	ST DEV (MM)
4-1-246.3	A	0.07	0.13	0.03
4-1-250.0	A	0.13	0.19	0.04
4-1-257.0	A	0.11	0.18	0.04
4-1-270.5	A	0.10	0.17	0.03
4-1-279.5	A	0.11	0.19	0.03
4-1-299.2	A	0.14	0.23	0.05
4-2-234.5	A	0.06	0.12	0.02
4-2-251.5	A	0.06	0.10	0.02
4-2-253.0	A	0.05	0.11	0.02
4-2-275.4	A	0.15	0.27	0.05
4-2-292.4	A	0.11	0.21	0.03
4-2-305.5	A	0.09	0.16	0.03
4-3-261.5	A	0.07	0.16	0.03
4-3-312.0	A	0.09	0.32	0.05
4-10-238.8	A	0.10	0.22	0.05
4-10-250.7	A	0.11	0.21	0.04
4-10-252.8	A	0.10	0.35	0.06
4-10-255.2	A	0.13	0.25	0.05
4-10-270.1	A	0.11	0.21	0.03
4-11-241.5	A	0.06	0.14	0.03
4-11-294.0	A	0.07	0.14	0.03
4-13-253.2	A	0.14	0.21	0.04
4-13-265.2	A	0.09	0.15	0.03
4-13-272.9	A	0.10	0.17	0.03
4-13-274.0	A	0.11	0.22	0.04

SAMPLE NO.	UNIT	MEAN (MM)	MAX (MM)	ST DEV (MM)
4-13-274.8	A	0.11	0.20	0.03
4-15-260.8	A	0.12	0.26	0.05
4-16-313.8	A	0.09	0.19	0.04
4-17-276.2	A	0.11	0.24	0.06
4-17-286.8	A	0.08	0.14	0.02
4-17-293.5	A	0.07	0.16	0.03
4-18-224.7	A	0.05	0.07	0.02
4-18-269.5	A	0.12	0.24	0.05
4-19-290.0	A	0.14	0.34	0.07
4-21-288.2	A	0.07	0.18	0.04
4-3-324.0	A'	0.05	0.10	0.02
4-19-295.0	A'	0.06	0.17	0.03
4-1-132.8	B	0.07	0.24	0.05
4-1-204.6	B	0.04	0.10	0.02
4-2-120.8	B	0.08	0.19	0.03
4-2-167.2	B	0.05	0.14	0.03
4-1- 30.4	C	0.34	0.57	0.12
4-1- 32.7	C	0.31	0.74	0.13
4-1- 87.6	C	0.51	1.52	0.41
4-2- 47.6	C	0.24	0.54	0.10
4-2-116.5	C	0.15	0.32	0.06
4-11-351.0	U	0.10	0.19	0.04
4-16-365.0	U	0.07	0.18	0.05
4-19-343.7	U	0.17	0.43	0.09

SAMPLE NO.	UNIT	PERCENT TOTAL VALUE of SPECIFIC CEMENTS			
		PHYLOSILICATE	CALCITE	IRON OXIDE	SIDERITE
4-1-246.3	A	6.50	6.50	1.00	14.00
4-1-250.0	A	6.00	26.50	0.00	1.00
4-1-257.0	A	11.00	12.50	0.00	1.00
4-1-270.5	A	17.50	5.00	0.00	3.00
4-1-279.5	A	13.90	18.80	0.00	1.50
4-1-299.2	A	4.50	1.00	0.00	3.50
4-2-234.5	A	13.00	11.50	8.00	0.00
4-2-251.5	A	12.00	12.50	8.50	3.00
4-2-253.0	A	1.50	24.00	4.00	2.00
4-2-275.4	A	13.00	19.00	0.00	0.00
4-2-292.4	A	13.50	4.50	0.00	3.50
4-2-305.5	A	6.00	44.00	1.00	3.50
4-3-261.5	A	0.00	28.00	0.00	13.00
4-3-312.0	A	7.50	7.50	0.00	8.00
4-10-238.8	A	5.50	8.50	0.00	9.00
4-10-250.7	A	6.50	46.50	1.00	0.00
4-10-252.8	A	5.00	28.00	1.00	0.00
4-10-255.2	A	6.50	24.50	0.00	0.00
4-10-270.1	A	23.00	1.50	27.50	0.00
4-11-241.5	A	13.00	18.00	5.50	4.00
4-11-294.0	A	11.00	9.00	2.00	3.00
4-13-253.2	A	18.50	4.50	8.00	0.00
4-13-265.2	A	16.50	13.00	0.00	0.00
4-13-272.9	A	9.00	32.00	0.00	0.00
4-13-274.0	A	14.00	2.00	33.50	0.00
4-13-274.8	A	3.50	3.00	12.50	0.00

SAMPLE NO.	UNIT	PERCENT TOTAL VALUE OF SPECIFIC CEMENT			
		PHYLOSILICATE	CALCITE	IRON OXIDE	SIDERITE
4-15-260.8	A	19.50	7.50	1.00	2.50
4-16-313.8	A	19.00	6.50	1.00	1.50
4-17-276.2	A	10.00	19.00	0.00	0.00
4-17-286.8	A	11.50	6.50	0.00	2.50
4-17-293.5	A	3.50	9.00	18.00	5.00
4-18-224.7	A	7.50	13.00	0.00	6.00
4-18-269.5	A	10.00	23.50	0.00	1.00
4-19-290.0	A	6.00	0.00	0.00	7.50
4-21-288.2	A	0.00	28.50	0.00	13.00
4-3-324.0	A'	9.00	11.00	3.50	5.50
4-19-295.0	A'	0.00	0.00	0.00	32.00
4-1-132.8	B	4.00	7.50	0.00	0.50
4-1-204.6	B	12.00	12.00	1.50	5.00
4-2-120.8	B	9.50	3.50	7.00	0.00
4-2-167.2	B	4.00	0.00	0.00	4.00
4-1- 30.4	C	8.00	0.00	0.00	4.00
4-1- 32.7	C	7.00	0.00	0.00	6.50
4-1- 87.6	C	5.00	0.00	0.00	2.00
4-2- 47.6	C	5.00	0.00	1.00	1.50
4-2-116.5	C	9.50	0.50	0.50	3.50
4-11-351.0	U	6.50	16.00	2.00	5.50
4-16-365.0	U	6.50	1.50	0.00	0.00
4-19-343.7	U	4.50	1.50	4.00	0.00

APPENDIX C

SAMPLES FOR X-RAY DIFFRACTION ANALYSES WITH
DISTANCES TO INFERRED CAVITY ROOF
METERS (FEET)

Corehole	Sample Number	Distance from Cavity Roof
4 PB 12	269.0	6.43 (21.1)
4 PB 12	279.0	3.38 (11.1)
4 PB 12	284.0	1.86 (6.1)
4 PB 12	287.0	.94 (3.1)
4 PB 12	288.0	.64 (2.1)
4 PB 12	288.5	.48 (1.6)
4 PB 12	290.0	.03 (0.1)
4 PB 14	253.0	6.43 (21.1)
4 PB 14	263.0	3.38 (11.1)
4 PB 14	268.0	1.86 (6.1)
4 PB 14	271.0	.94 (3.1)
4 PB 14	272.0	.64 (2.1)
4 PB 14	272.5	.48 (1.6)
4 PB 14	272.75	.41 (1.35)
4 PB 14	274.0	.03 (0.1)