CONF-800716--6

RESULTS OF THE CHARACTERIZATION OF AN IN SITU COAL GASIFICATION SITE IN THE STATE OF WASHINGTON*

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Abstract

Sandia Laboratories, Lawrence Livermore Laboratory, and the Laramie Energy Technology Center participated in a Department of Energy funded program to select and characterize a potential underground coal gasification test site in the State of Washington. A site in the Centralia-Chehalis coal district, satisfying certain criteria, was selected for characterization. The characterization procedures included surface and borehole techniques and hydrology tests. Geologic structure and coal seam structure and continuity were determined using surface geophysical prospecting (seismic and electromagnetic surveys) and borehole geophysical (logging and cross-borehole, inseam seismic) techniques. A complete suite of geophysical logs was taken in eight exploratory boreholes to determine lithology and properties of the coal and surrounding strata. Coal cores taken from four different exploratory boreholes were analyzed to determine coal quality. Results of the characterization show that the coal seam of interest is approximately 47 ft thick at a depth of 570-600 ft at the site. The seam is characterized by high ash content, relatively low overall heating value, and a low permeability. The site appears suitable for conducting an underground coal gasification test.

Introduction

The underground coal gasification (UCG) program contributes to basic Department of Energy (DOE) policies by developing technologies to produce synthetic fuels from coal deposits that are unsuitable for commercial exploitation by conventional surface and underground mining techniques. The highest priority is to develop and demonstrate, in conjunction with industry, a commercially feasible process for underground gasification of low-rank coal. The amount of coal that can be recovered by UCG has been estimated at 1.8 trillion tons (in the lower 48 states), or roughly four times the amount that is exploitable through conventional mining.[1]

In underground gasification of coal, two major areas strongly affect the ultimate success of the process and gas quality. The first consists of all factors concerning quality connected with the coal itself. Examples of these coal quality factors are: moisture, volatile matter, fixed carbon calorific value, content of ash in the coal, content of sulfur in the coal, content of other deleterious constituents in the coal, content of partings, coking quality, and the free swelling index.[2]

The second area encompasses the geologic environment surrounding the coal as it is physically situated in the ground. The success of the UCG process is strongly affected by the geologic environment. These geologic factors include: areal extension of seams, strike and dip of seams, depth and number of seams, intervals between seams, structure of seams with regard to folding and faulting, fracture and joint systems, intrusions, thickness of partings, total seam thickness, continuity and areal regularity of all these geometric conditions. In addition, conditions of interest are the structural characteristics for subsidence determination and fluid flow characteristics of the coal seam and surrounding strata: some specific properties of interest are strength, hardness, and permeability, and their continuity and areal regularity with regard to the seams (coal and partings), the immediately underlying and overlying strata, and overburden strata.[2] Hydrogeological conditions of interest are the location of aquifers, the water influx rates for an UCG process, and the subsequent transport of pollutants, etc., for environmental concerns.

Boreholes are an absolute necessity to provide the first type of information and also provide some of the second type of information such as exact thickness, intervals, etc.; however, areal structure and especially the seam continuity and regularity factors are often difficult to establish by boreholes alone. Surface geophysical surveys and cross borehole surveys can help by more precisely defining the geologic environment of the coal occurrence as well as the lateral continuity or areal distribution of the coal.

The DOE is completing a program to select and characterize a site (or sites)

*This work was supported by the United States Department of Energy (DOE) under contract number DE-AC04-76DP00789.

in the State of Washington suitable for the underground gasification of coal. The specific goal of the program, as it is presently defined and funded, is to identify and thoroughly investigate at least one site for underground coal gasification (UCG) and design a relatively simple UCG test which is to be carried out at the site at some later time with other funding. Emphasis is being placed on identification of coal-bearing districts whose demonstrated coal resources hold the promise of supporting a commercial UCG development. Detailing potential problem areas for the UCG process requires a thorough understanding of these factors which is the primary objective of the site selection and characterization program carried out at a site near Centralia, WA.

Sandia National Laboratories is serving as technical manager for this DOE program. Other DOE sponsored laboratories participating in this activity are Lawrence Livermore National Laboratory and the Laramie Energy Technology Center. The State of Washington Department of Natural Resources and the Department of Ecology provided valuable support.

Selection of a Potential Site

The following are some rather general, desirable characteristics that were sought in selecting coalbearing districts for further study in Washington. The order of presentation of the characteristics has no intended significance.

1. Coal seam thickness should be in excess of 6 ft. Heat loss to base and cap rock during the UCG process decreases the thermal energy available to drive the endothermic gasification reactions and can result in reduced gas heating value. This heat loss becomes an unacceptable fraction of the available thermal energy in seams less than 4 ft thick according to Soviet experience.[3]

2. Depth to coal should be at least 300 ft and preferably no more than 1000 ft by considering coal at depths in excess of 300 ft, containment is provided for the UCG process and competition is avoided for coal resources that may best be recoverable by surface mining techniques. The 1000-ft depth limit is imposed primarily for economic reasons in this characterization program and any subsequent test.

3. A demonstrated resource should be available for a commercial operation. Defined in terms of electric power generating station for a period of 30-35 years; this will require a demonstrated resource of 50 to 60 million tons of subbituminous coal or 40 to 50 million tons of bituminous coal. A subbituminous coal resource is preferred because it shrinks upon heating which is a desirable characteristic.

4. The structural geology should be relatively simple. It is desired to have areas free of major faulting and major structural folds in which the coal can be gasified. The faulting and folding need to be identified so that an appropriate gasification test can be designed.

5. The coal seam(s) of interest should be overlain by thick (2 or 3 times seam thickness), relatively competent and impermeable strata. Seams directly overlain by an aquifer should be avoided. The coal seams should be only moderately permeable (up to several hundred millidarcies) so that groundwater intrusion into a gasification zone can be controlled with acceptable gas losses. The seam(s) of interest should be underlain by relatively impermeable strata.

6. Good ground access is important. The district should be separated from major urban areas to avoid environmental problems, yet close enough to provide for gas markets.

A point of departure in obtaining an overview of coal resources in Washington is the Beikman, Gower, and Dana report.[4] Some new information has been obtained on the occurrence of coal in Washington since publication of this work, but little of it is in the public domain. Figure 1 shows the major coal districts in Washington. Review of information in Reference 4 reveals several districts with substantial coal resources suitable for gasification. These districts are the Bellingham Field in Whatcom County, the Roslyn Field in Kittitas County, and the Centralia-Chehalis district in Lewis and Thurston Counties.

These three districts seem to have large enough resources to hold the promise for commercial UCG development. All other districts in Washington were reviewed, but none with known measured and indicated reserves of sufficiently thick coal seams met or approached the tonnage requirements save the three. The Centralia-Chehalis district was ranked as the primary area for further study. It contains subbituminous coal, which has been gasified several times and in several places in this country. There is a large resource present and a potential market (the Centralia Steam Plant) is available. There is complex and sharp structure in the Centralia-Chehalis

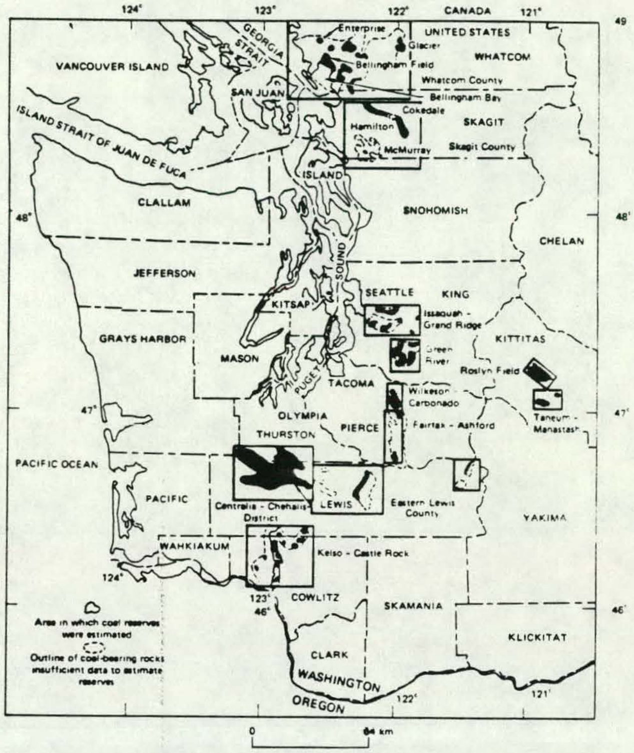


Figure 1. Coal-bearing areas of Washington State from Beikman, et al., reference 4. Areas suitable resources for commercial UCG exploitation are the Centralia-Chehalis district in Lewis and Thurston Counties, Roslyn Field in Kittitas County, and the Bellinghan Field in Whatcom County.

district, but enough area of gentle to moderate structure exists to provide for UCG sites.

According to Reference 4, there were 52.3 million tons of demonstrated coal resources in the Upper Thompson seam of the Centralia-Chehalis district in thicknesses greater than 10 ft between the surface and 1000-ft depth. The Upper Thompson seam ranges in thickness from 2 to 16 ft and averages about 10 ft thick. From Reference 4, it was also estimated that within the district 305.0 million tons of demonstrated resources exist in the Big Dirty seam in seam thickness greater than 10 ft and at depths ranging from the surface to 1000 ft. The Big Dirty seam ranges in thickness from 18 to 50 ft in the Tono Basin in the eastern part of the district. It is characterized by abundant partings that are generally tuffaceous.[5] The Big Dirty has been mined by surface methods at the presently active Washington Irrigation and Development Company (WIDCO) mine for about seven years. Total annual production from the mine has been about 5-7 million tons from the Big Dirty and other seams. Much of the Big Dirty resource remains in place. Both the Upper Thompson and the Big Dirty seams are largely composed of subbituminous C coal. The outcrop line of the Big Dirty seam, along with other seams and the general geologic structure, are shown in Figure 2.

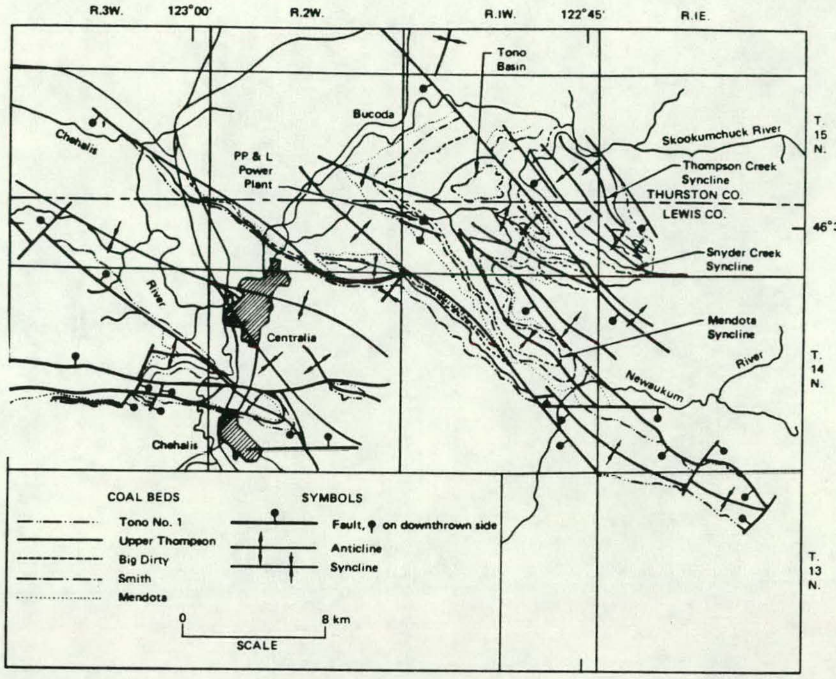
Within the Centralia-Chehalis coal district, the site selected for characterization is near the old townsite of Tono in Sections 20 and 21 of Township 15N, Range 1W. In this area the Tono seam[5] was mined by underground methods for a number of years; however, there has been no active mining for about 40 years.

In the Tono area the Big Dirty seam is the seam of primary interest and lies at a depth of approximately 600 ft and ranges in thickness of 40-50 ft with parting material. The Washington Irrigation and Development Company (WIDCO) owns (both surface and coal) the site which was characterized.

Characterization of the Site

The site characterization activities consisted of using surface geophysical techniques, borehole and cross-borehole geophysical techniques, taking and analyzing overburden and coal cores, and hydrological testing.[6] The surface geophysical techniques were used to delineate geologic structure and determine coal seam continuity. The borehole geophysical logs were used to identify coal seams and their thicknesses, determine overburden and coal quality, help determine lithology, and used for stratigraphic correlation between exploratory boreholes. The cross-borehole, in-

Figure 2. Centralia-Chehalis District, Washington. After Snavely, et al., reference 5. Area selected for characterization is in the Tono Basin area.



seam seismic wave studies were used to determine coal seam continuity. The coal quality was determined from chemical analyses of coal cores. The hydrology tests were used to determine the permeability of the overburden and coal seam and estimate water influx rates.

Seismic Reflection

A high resolution, seismic reflection survey was performed at the Tono site. The objective of this survey was to determine geologic structural detail and coal seam continuity. Preliminary analysis of these data has yielded some interesting results. The locations of survey lines, along with the locations of exploratory boreholes DOE 1-7, are shown in Figure 3.

The structure of the Big Dirty seam as determined from the reflection data is shown in Figure 3. The seam is displaced by a major east-west trending fault system in the southern part of the characterized area as shown. Cross faults (the north-south trending faults) were detected in the northern part of the site. Minor folding is also apparent from the two-way transit time contours. The area depicted in Figure 3 comprises approximately 28 acres. Within this site an area of sufficient size exists on which to conduct a test. It is noteworthy that additional seismic reflection data were obtained to the west of the site in Figure 3; this additional area comprises approximately 34 acres.

Borehole Geophysical Logs

A full suite of geophysical logs was taken in eight exploratory boreholes in the characterized area. The locations of the exploratory boreholes, along with two hydrology test wells, are shown in Figure 3.

Geophysical logs taken in conjunction with this characterization included: natural gamma, electrical (spontaneous potential, 40 cm and 1.6 cm normal, 1.8 m laterolog, single point resistance, Dakhnov micro-normal, and induced polarization), sonic, gamma-gamma density, caliper, and neutron porosity.

Coal seams, when compared to adjacent strata, exhibit characteristics that generally stand out clearly on most logs. The logs used to identify coal seams are: natural gamma (low radioactivity compared to adjacent strata), density (bulk density usually less than 1.6 gm/cc), sonic (interval transit time higher than adjacent strata), neutron porosity (porosity index high caused by the carbon), and electric (generally a higher resistivity than adjacent strata). A stratigraphic section is shown in Figure 4.

The density and resistivity geophysical logs from the various exploratory boreholes display qualitative features of the Big Dirty coal seam. Regions of lower density (< 1.6 gm/cc) and higher electrical resistivity indicate regions of the better quality coal. The higher resistivity values are indicative of a lower ash content.

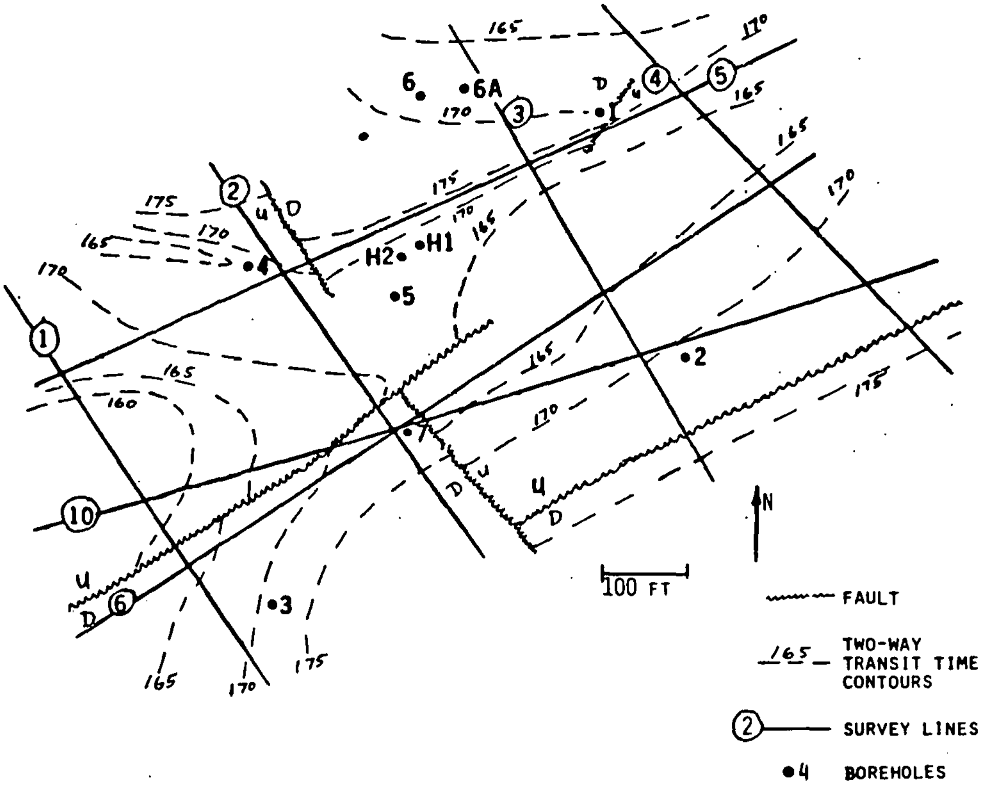


Figure 3. Structure of the Big Dirty seam as determined from the reflection seismic survey. Locations are shown of the reflection seismic lines (1-6 and 10) and the exploratory boreholes (1-7) and hydrology test wells (H1 and H2). The two-way transit time contours and fault locations depict the structure.

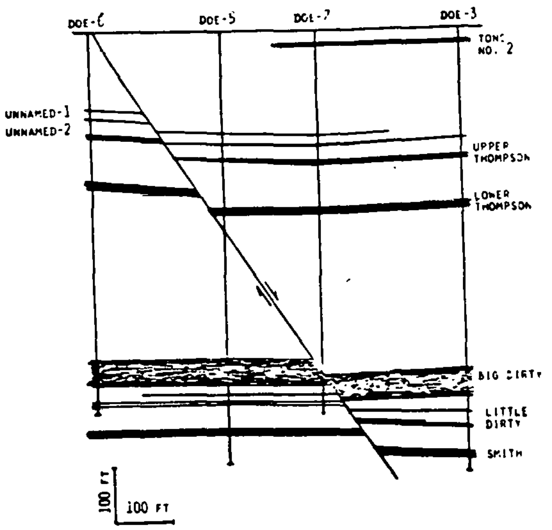


Figure 4. Stratigraphic crossection for DOE-6, -5, -7, -3. See Figure 3 for borehole locations.

The sonic logs taken in various boreholes indicate the phenomenon of cycle skipping[7] in the upper portion of the Big Dirty coal seam. Cycle skipping is generally indicative of a fractured medium. Core log records indicate the coal is fractured. This apparent fracturing might be indicative of an increased permeability in the upper portion of the seam. However, the incremental slug withdrawal hydrology tests performed in DOE-H2 do not indicate a significant permeability variation throughout the seam. Any future work must address determining the directional (horizontal and vertical) permeability and the permeability distribution throughout the seam.

The mass fractions of carbon, ash, and moisture can be determined from the density and sonic logs. The coal is treated as consisting entirely of carbon, ash, and moisture. The percentages of each are determined by solving a set of simultaneous equations for the bulk volume fractions.[8] Geophysical log values for the density and transit time for carbon and ash used here were from sonic-density crossplots for Illinois No. 6 coal.[8]

The mass fractions of carbon, ash, and moisture determined from the density and sonic geophysical logs are shown in Figure 5 for exploratory boreholes 4 and 5. The Big Dirty seam is characterized by numerous partings (smaller fractions of carbon), high ash content, uniform moisture throughout the seam, and the better quality coal is located in the upper portion of the seam. The dashed lines are regions where core samples were taken for chemical analysis. The proximate analysis of the core samples are given in Table I.

Seismic Seam Wave Test

Prior results of refraction and reflection seismics and electrical surveys,[6] as well as from the drilling and logging program, have shown that several faults have displaced the coal seams in the site area. Earlier field studies,[9,10] as well as numerous model studies,[11,12] have established the presence of a seam wave, or seismic trapped wave when an explosive source is detonated within a low velocity coal seam and detected at another point within the same seam. The coal, bounded by higher velocity beds, acts as a wave guide, and, if the seam is wholly or partially continuous, the seam wave is transmitted with little attenuation. A disruption of the seam (e.g., a fault) will result in a diminished or absent seam wave if the source and detector are not located in the same fault block. It was felt, then, that a seam wave study between the various pairs of borings at the site could add to knowledge of the continuity of the coal seam between given pairs of holes.

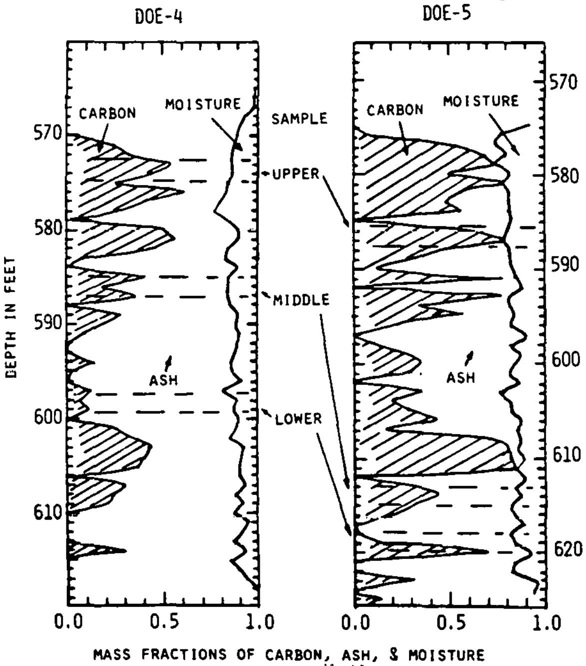


Figure 5. Mass fractions of carbon, ash, and moisture calculated from the density and sonic geophysical logs for the Big Dirty seam in DOE-4 and 5.

Table I.

Proximate Analyses of Selected Samples Taken from the Big Dirty Seam

	As received proximate analysis	
	DOE-4	DOE-5
% Moisture	16.78*	19.23
	21.03	16.38
	18.80	16.49
% Ash	21.65	18.99
	18.94	25.19
	39.83	49.91
% Volatile	34.06	31.09
	27.46	29.82
	21.71	17.41
% Fixed Carbon	27.51	30.69
	32.57	28.61
	19.66	16.22
% Sulfur	1.91	0.48
	0.59	5.54
	0.52	2.71
Btu/lb	8070	7757
	7477	7168
	4860	3423

*Numbers are for sample taken from upper, middle, and lower portions of the seam

Figure 6 shows the results of "seam wave" tests at the Tono site. Figure 6a represents transmission between holes straddling a suspected fault while Figure 6b is between boreholes in a suspected continuous coal block. Although conditions are not good for setting up a true seam wave (velocity contrast is small; seam very thick), a curious, late arriving pulse is recorded when no fault is suspected which is absent where the fault is believed to exist. Whether or not this pulse is a true seam wave is questionable. The fact that the wave is absent where faulting is suspected lends confidence to the interpretation that the seam is significantly disrupted between those boreholes.

Stratigraphic Sections

Stratigraphic correlations between boreholes were primarily made using the single point resistance log and to a lesser extent the natural gamma and density logs. By comparing the logs taken from various boreholes, strata missing in a particular borehole indicates a normal fault (strata added would indicate a reverse angle fault). All the missing log sections are referred to DOE-1. It is noteworthy that coal seams in this area tend to be lenticular; several of the seams apparently display this characteristic. A stratigraphic section along the DOE 6-5-7-3 line is shown in Figure 4. The fault apparently passes through DOE-7 at the level of the Big Dirty seam. The structure shown in Figure 4 is consistent with the seismic reflection data shown in Figure 3.

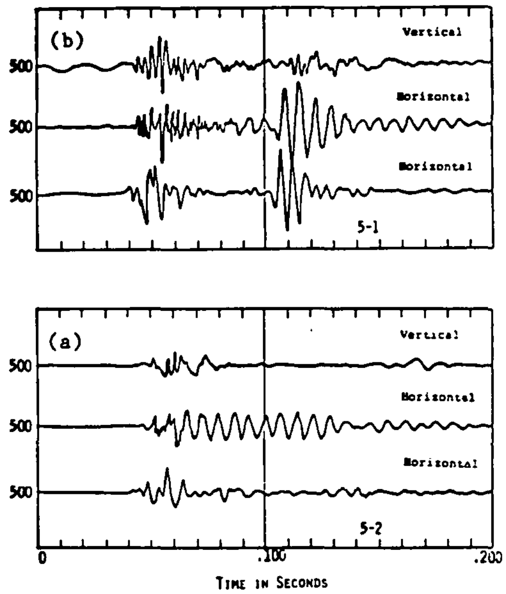


Figure 6. In-seam, cross-borehole seismic results. All the gains are 500 for the two horizontal and one vertical axis geophones. Geophones are in DOE-5 and source is in DOE-1 and -2, respectively.

Hydrology Testing

Two hydrology test wells, DOE-H1 and H2, were drilled and completed to assess the hydrological characteristics of the proposed UCG site. The hydrological findings are summarized below. DOE-H1 was drilled, cased, and cemented to approximately 20 ft above the Big Dirty seam to determine the hydrologic character of the near overburden. After completion, a 10 ft open hole was drilled out the bottom of the well using fresh water so as not to "plug" the formation. Following a slug withdrawal of a known volume of water, the rate of water recovery was measured, and the permeability is determined to be less than 1 millidarcy. DOE-H2 was drilled, cased, and cemented to approximately 5 ft above the Big Dirty. An open hole was drilled out the bottom of the well, again with fresh water, to the bottom of the Big Dirty in five segments. For each segment a slug of water was withdrawn, and the rate of water recovery was measured. The overall permeability of the Big Dirty seam is determined to be less than 20 millidarcies, and the overall rate of water recovery from the Big Dirty is approximately 0.006 cubic feet per minute in a 5-7/8 in borehole.

Because of the slow rate of water recovery, the permeabilities were measured before static equilibrium had been established; thus the permeabilities measured are maximum values. The two hydrology test wells have well-screens, have been fitted with well-heads, and will remain open for further testing.

Conclusions

The proper selection and characterization of UCG sites is important to insure a successful process. A program is outlined which addresses identifying geologic and hydrogeologic features which will impact the UCG process for a commercial operation. From this characterization work, the pretest conditions can be compared with any subsequent test results. This comparison will allow the establishment and validation of selection criteria and characterization procedures.

A site selection and characterization program was conducted in the State of Washington for a potential commercial application of UCG. The site selected and characterized is near the old town site of Tono, WA. To date nothing has been uncovered that would preclude a gasification test, and this site appears suitable to conduct an UCG test.

As part of the characterization program environmental and subsidence studies are being conducted. The results of these studies do not detract from the suitability of this site. Their results are reported elsewhere.[13,14]

Acknowledgements

The authors wish to thank T. Sterner of the Laramie Energy Technology Center who supervised the drilling, S. L. Love, C. W. Ray, P. M. Drozda, J. E. Uhl, and L. D. Moritz of Sandia for their valuable assistance in the project, and L. Rogers of Lawrence Livermore National Laboratory for her assistance in the hydrology studies. The authors especially wish to thank R. A. Paul, Washington Irrigation and Development Co. (WIDCO), for his assistance in selecting the proposed UCG site and WIDCO for their perimission to characterize that site. The authors also wish to thank E. R. Vonheeder, Department of Natural Resources State of Washington, for his valuable assistance in surveying the coal resources of the state of Washington.

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