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UNDERGROUND GASIFICATION FOR STEEPLY DIPPING COAL BEDS

Phase I Report: Appendix A. Site Selection

September 30, 1977—February 28, 1978

May 1978

Work Performed Under Contract No. EF-77-C-03-1472

Gulf Research and Development Company
Pittsburgh, Pennsylvania

and

TRW Energy Systems Planning Division
McLean, Virginia

MASTER

U. S. DEPARTMENT OF ENERGY

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APPENDIX A

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APPENDIX A

SITE SELECTION ACTIVITIES

Gulf Research & Development Company and TRW, Inc., have investigated the U.S. coal resources to identify a site for the first UCG-SDB test program. Based on the investigation to date, the best site for that first test is the North Knobs site near Rawlins, Wyoming. The criteria used to select a site are as follows:

- The coal seam shall have a dip angle between 45° and 75°,
- The coal gasification shall be below the water table,
- The coal shall be subbituminous (shrinking upon heating),
- The bed thickness shall be between 10 feet and 30 feet,
- The geology shall be relatively simple,
- GR&DC shall be able to obtain a lease for doing UCG tests on the site.

Additionally, the relative ease of site construction, access, and restoration were evaluated, prior to contract award.

A.1.0 INTRODUCTION

The national coal resource was reviewed to identify the magnitude and geographic extent of the SDB resource which met the criteria. The U.S. SDB resource contains approximately 100 billion tons of coal in four large geographic areas: 50 billion tons in the Rocky Mountain states, 20 billion tons in the Pacific Coast states, and 15 billion tons each in the Appalachian states and Alaska. A detailed geotechnical literature and on-site review was conducted to locate representative SDB-UCG sites in the three (3) geographic regions within the continental U.S. From these activities, the following seven areas were selected: North Knobs, Wyoming, and the Johnny Moore Syncline and Grand Hogback,

Colorado (the Rocky Mountain region), Green River, Roslyn and Wilkeson, Carbonado Fields, Washington (Pacific Coast region), and Burton Ford, Virginia (Appalachian region). Activities were indicated to conduct preliminary on-site geotechnical investigations, and to obtain leases for SDB-UCG field sites within the seven areas. Leases were obtained within the North Knobs, Wyoming, and Johnny Moore Syncline, Colorado, areas.

After the DOE-ERDA SDB-UCG contract was awarded to GR&DC and TRW on October 1, 1977, detailed geotechnical review of the two leased sites was conducted. This review consisted of an intensive program to collect and analyze all available site specific geologic and hydrologic data for the leased sites; to examine the data from the ongoing exploratory drilling program being conducted by the lessor in the Johnny Moore Syncline; and to conduct a preliminary geologic and hydrology exploratory drilling program at North Knobs, Wyoming, site. As a result of these activities, the North Knobs, Wyoming, site was selected by Gulf and TRW as the prime site for their SDB-UCG experiments.

Independent of this contract, GR&DC is proceeding to select, obtain, and investigate two additional SDB sites. These sites will be available if either the North Knobs site is determined to be geotechnically unacceptable during Phase II or the project is expanded to a multi-site operation.

A.2.0 SDB REQUIREMENTS FOR UCG

The resources defined by the RFP include bituminous or sub-bituminous coals contained in seams with dip angles with respect to the horizontal plane of 45° or greater and with thicknesses normal to the angle of dip of at least 5 feet. However, coal resources in the U.S. potentially suitable for in situ gasification by the SDB concept have broader limits than the 45° dip and 5-foot thickness required for the initial test sites. In a study included as part of the original Gulf/TRW proposal, the probable limits for minimum coal-bed dip and thickness values were determined to be 35° and 3 feet, respectively. The SDB

deposits identified and the resource estimates made are based on the 35° dip and 3-foot thickness values.

Steeply dipping bed (SDB) deposits are identified by dip angle and bed thickness. Based on analysis and inquiry, general working limits for dip angle are: <35° flat-lying and low-angle to intermediate angle (mining); ≥35° steeply dipping (gasification). We have assumed a 35° lower and 90° upper limit for our resource estimates.

Unlike dip angle, coal-bed thickness requirements have been derived from practice. Thicknesses greater than 3 feet and less than 50 feet are desirable. The relationship of seam thickness to product gas heating value, as well as the water intrusion rate, is shown in Figure A-1. The increased heat loss to wall rocks becomes a prohibitively large fraction of the total heat at less than 3-foot thicknesses.

Figure A-1. EFFECT OF SEAM THICKNESS ON GAS HEATING VALUE

Partings and other rock impurities significantly affect the large percent of U.S. SDB coal that exists as multiple thin beds. While combustible impurities (e.g., carbonaceous shale) do not impede gasification at sufficiently high temperatures, an unbroken non-combustible impurity (e.g., sandstone) even a few inches thick could block heat transfer. An acceptable limit for impurities depends on their composition, continuity, permeability, and distribution within or with respect to the coal seam being gasified, and not strictly on thickness.

Finally, the DOE RFP requirements for SDB-UCG stated that the field experimentation should be conducted below the water table. The presence of groundwater within the coal seam is important for two reasons. First, water is consumed in the gasification process and, therefore, it is an important contributor to the composition of the product gas. Secondly, operation below the water table will decrease the potential for an uncontrolled underground fire during or after experimentation. Since the water table depth varies greatly with geographic location, it was decided that this parameter would be evaluated on a site by site basis rather than on the regional level.

RFP requirements were reviewed and reassessed in terms of their impact on the operating stages of a SDB-UCG experiment. From this, a list of eighteen (18) specific geologic parameters of the coal bed and seven (7) specific geologic parameters external to the coal bed was established. Table A-I provides a summary of the geologic site selection criteria.

The original RFP requirements for an acceptable SDB site are:

- dip greater than 45°
- bituminous or subbituminous coal
- seam thickness greater than 5 feet
- below the water table

Table A-I

SITE SELECTION CONSIDERATIONS FOR IN SITU
GASIFICATION OF STEEPLY DIPPING COAL BEDS

Geological Characteristics of the Coal Bed						Geological Considerations External to the Coal Bed					

- representative of a national resource.

The initial test of UCG of SDB should be at a site where a low level of technical risk exists. The site criteria for the project were tightened to reduce level of risk.

- An upper limit of dip of 75° was established. This represents the upper limit of seams gasified by the Russians.
- Subbituminous coal was the designated rank of coal. Linking option and existing field experience are greater than on bituminous coals.
- Seam thicknesses of 10-30 feet. The lower limit of 10 feet is more consistent with current experience in UCG. The upper limit of 30 feet is much more arbitrary but again represents the range of field experience.
- Roof and floor integrity. The competence of the boundary strata and its ability to contain the product gas are important considerations for technical success and site safety. The initial test site should not introduce these additional problems.

A.2.1 DISTRIBUTION OF NATIONAL SDB RESOURCES

Steeply dipping coal beds are restricted mainly to coal provinces within, or marginal to, the great tectonic belts comprising the north-south-trending, major mountain chains of the United States:

- The Rocky Mountain Province, including the Rocky Mountain Foreland, Cordilleran Foldbelt, and Colorado Plateau structural complex,
- The Pacific Coast Province, including the Cascade Range of Washington and the Coast Ranges of California,

- The Eastern Province, consisting of portions of the Appalachian Mountains, and
- The Alaska Province, specifically deposits on the southern flank of the Alaska Range, adjacent to Cook Inlet.

Steeply dipping coal beds are essentially absent from provinces lacking major deformational folding, such as the Northern Great Plains, Gulf, and Interior provinces.

Western coal fields and areas are of the most immediate interest because they tend to occur in thick, readily combustible beds and present minimal environmental problems. Many occur near major markets or gas pipelines.

Though eastern deposits are a potentially valuable resource, they are generally of higher rank than most western coals and, therefore, difficult to burn in situ.

Alaskan coal is too far from major markets for its development by any gasification process to be economically feasible in the near future.

At least 40 coal fields or areas, distributed through seven western states, contain steeply dipping coal beds (Figure A-2). Table A-II gives a highly preliminary estimate of the resources available in each field.

A total of approximately 100 billion tons of coal is estimated to occur within the United States in beds dipping greater than 35°, at depths less than 3000 feet (Table A-III). This resource comprises 70 billion tons in the western United States, including 50 billion tons in the Rocky Mountain Province and 20 billion tons in the Pacific Coast Province, as well as approximately 15 billion tons each in the Eastern Province and Alaska.

Table A-11. CHARACTERISTICS AND RESOURCE ESTIMATES OF SDB DEPOSITS IN THE WESTERN UNITED STATES

COAL FIELDS AND AREAS	ROCKY MOUNTAIN PROVINCE										
	WYOMING				MONTANA				UTAH		
	Bighorn Basin	Great Divide Basin (East Rim)	Hanna Basin	Kemmerer (S. Heystack Area)	Electric	Livingston - Trell Creek	Silvertip	Silverstar	Cookville	Henry's Fork	Henry Mountains (Waterpocket Monocline)
CRITERIA											
DIP (degrees)	20 - 80	25 - 80	20 - 80	45 - 85	24 - 80	40 - 85	28 - 75	25	20 - 70	80 - 85	20 - 45
BED THICKNESS (feet)	3 - 32	5 - 22	5 - 30	10 - 25	3 - 5	2 - 5	4 - 8	4 - 5	5 - 13	≤ 10	2 - 10
RANK	$E_2 - E_3$	E_1	$E_2 - E_3$	E_1	$E_2 - E_3$	$E_2 - E_3$	E_2	$E_2 - E_3$	E_1	$E_1 - E_3$	$E_2 - E_3$
RESOURCE QUANTITY (millions of short tons)	280	780	240	55	10	28	48	SMALL	88	NOT KNOWN	30
											230
											36

COAL FIELDS AND AREAS	ROCKY MOUNTAIN PROVINCE										
	COLORADO								NEW MEXICO		
	UINTA (PICEANCE) BASIN								SAN JUAN BASIN		
CRITERIA	Denver Basin	Durango Area	Green River Region	North Park	Carbonate	Orebed Butte	Dartmouth Hills	Grand Hogback	Lower White River	Fort Defiance Monocline	Northern Monocline
DIP (degrees)	20 - 85	20 - 80	20 - 80	20 - 80	20 - 70	20 - 80	20 - 85	20 - 85	20 - 70	≤ 45	≤ 45
BED THICKNESS (feet)	5 - 25	3 - 80	4 - 42	10 - 50	4 - 15	4 - 22	5 - 34	4 - 48	4 - 12	3 - 15	3 - 13
RANK	$E_2 - E_3$	$E_1 - E_3$	$E_2 - E_3$	E_2	$E_2 - E_3$	$E_2 - A$	E_2	$E_2 - E_3$	E_2	$E_1 - E_3$	
RESOURCE QUANTITY (millions of short tons)	80	8,200	4,800	280	2,180	120	3,000	1,200	230	8,800	

- ① A ANTHRACITE
 E_1 LOW-VOLATILE BITUMINOUS
 E_2 MEDIUM-VOLATILE BITUMINOUS
 E_3 HIGH-VOLATILE A BITUMINOUS
 E_4 HIGH-VOLATILE B BITUMINOUS
 E_5 HIGH-VOLATILE C BITUMINOUS
- S_1 SUBBITUMINOUS A
 S_2 SUBBITUMINOUS B
 S_3 SUBBITUMINOUS C
- ② PERCENT OF TOTAL FIELD RESOURCE ESTIMATED TO BE IN STEEPLY DIPPING BEDS.

COAL FIELDS AND AREAS	PACIFIC COAST PROVINCE										
	WASHINGTON									CALIFORNIA	
	KING COUNTY (MAPLE VALLEY, HODART, AND CUMBERLAND QUADRANGLES)				KITTITAS COUNTY	PIERCE COUNTY	SKAGIT COUNTY	THURSTON AND LEWIS COUNTIES	WHATCOM COUNTY		
CRITERIA	Odeh Mountain	Green River	Palmer-Bayne	Ravenstide - Georgetown	Superior Mountain	Roslyn	Fairfax - Montezuma - Ashford	Wilkeson - Carbonado	Hamilton - Coltsdale	Centralia - Chelalis	Blue Canyon
DIP (degrees)	20 - 80	20 - 80	35 - 70	80 - 90	30 - 80	20 - 40	≤ 80	55	20 - 80	≤ 80	50 - 80
BED THICKNESS (feet)	3 - 12	5 - 40	3 - 10	5 - 21	4 - 14	3 - 19	10	3 - 8	10	≤ 40	≤ 12
RANK	$E_2 - E_3$				$E_4 - E_5$	$E_2 - E_3$	$E_2 - E_3$	$E_2 - E_3$	E_1	$E_2 - E_3$	E_1
RESOURCE QUANTITY (millions of short tons)	4,080				80	48	31	200	250	1,100	51
											8
											180
											8

Figure A-2. WESTERN U.S. STEEPLY DIPPING COAL BEDS

Individual totals (in billions of short tons) for the seven western states are included in Table A-III:

Rocky Mountain Province

Colorado	26
New Mexico	9
Wyoming	8
Montana	4
Utah	2

Pacific Coast Province

Washington	21
California	0.3

Table A-III gives known and hypothetical U.S. SDB resources. The steeply dipping resource total for the 40 individual fields shown in Table A-II (approximately 70 billion tons) is a reasonable lower limit for the indicated seven western states. It is probably highly conservative, as it does not allow for resources likely to be present outside the boundaries of these individual fields.

Table A-III. PRELIMINARY SDB COAL RESOURCE ESTIMATE (BILLIONS OF SHORT TONS)

AREA	TOTAL IDENTIFIED RESOURCES (All dip angles)			IDENTIFIED AND HYPOTHETICAL RESOURCES		RESOURCES IN BEDS DIPPING > 35°	
	Bituminous	Subbituminous	Total	Factor	Total	% of State (est.)	Total
ROCKY MOUNTAIN PROVINCE							
Colorado	109	20	129	X 2	258	10	26
New Mexico	11	51	62	X 3	186	5	9
Wyoming	13	13	26	X 2	52	15	8
Montana	4	6	10	X 2	20	20	4
Utah	23	0.2	23		45	5	2
Five-State Subtotal	160	90	250		~560		~50
PACIFIC COAST PROVINCE							
Washington	1.9	4.2	6	X 10	60	35	21
California		0.1	0.1	X 5	0.5	50	0.3
Two-State Subtotal	2	4	3		60		~20
Seven Western States Total	~160	~95	~255		~620		~70
EASTERN PROVINCE	260	0	260		320	5	16
ALASKA	19	111	130		260	5	13

A.2.2 EVALUATION AND COMPARISON OF POTENTIAL SITES

The selection of the two principal test sites at North Knobs, Wyoming, and North Park, Colorado, resulted from an extensive program of site evaluation by both Gulf and TRW. This site evaluation and selection process progressed from an overview of the entire contiguous United States where each major coal province was evaluated, to a relatively detailed field evaluation of each of the two final sites. The overview study showed (as discussed in the preceding sections) that three coal provinces in the contiguous United States contain major SDB resources--the Rocky Mountain, Pacific Coast and Eastern (Appalachian Region) provinces. Further, the study showed that of these three provinces the majority of the resource and the SDB deposits with the most favorable in situ gasification characteristics are in the Rocky Mountain Province. Also, it was shown that the state of Washington contains the great majority of SDB deposits of the Pacific Coast Province, and probably is second only to Colorado in total deposits. Because of the above, the GR&DC-TRW site selection team decided to select tentative test sites in each of the three provinces, with the objective of finding at least two primary sites in the Rocky Mountain Province, one or more alternate sites in the state of Washington, and a possible secondary site in the Appalachian Region.

In order to select tentative sites, geologic data critical to experiment objectives was obtained on each of the 40 coal fields or areas determined to contain SDB deposits in the western United States. Some of these data are shown in Table A-II, which includes the range in values at each field of bed dip angle, thickness, coal rank, and size of resource. A trade-off evaluation of these characteristics along with a number of others was then made of the 40 SDB areas. Other characteristics included were closeness of each SDB deposit to established support facilities, presence of access roads, roughness of terrain, probable environmental impact, and land ownership.

Results of the trade-off study and information on land availability for test site use indicated that further data should be collected by field investigations at the North Park and Grand Hogback areas in

Colorado; the North Knobs area in Wyoming; the Roslyn, Green River, and Wilkinson-Carbonado areas in Washington; and the Burtons Ford area in Virginia.

A.3.0 INVESTIGATION OF SPECIFIC POTENTIAL SITES

After selecting the seven possible test sites shown on Figure A-3, a substantial effort was made by GR&DC and TRW to evaluate each site before selecting and acquiring the two final sites. For final site selection, GR&DC:

- Retained three groups of consulting coal geologists, each group of which specializes in one of the areas containing steeply dipping bed deposits--the Rocky Mountain Region, the state of Washington, and Appalachia;
- Performed on-site geological evaluation, reconnaissance mapping, and land-coal-right ownership searches for the North Knobs, Wyoming, and the North Park and Grand Hogback, Colorado, sites.
- Prepared formal reports on the Wyoming and Colorado sites;
- Performed electrical resistivity surveys for determination of water-table levels at North Knobs and North Park.
- Performed on-site evaluations of the Roslyn, Wilkeson-Carbonado, and Green River sites in the state of Washington;
- Prepared summary reports on the applicability of Roslyn and Wilkeson-Carbonado SDB deposits for in situ gasification;
- Performed on-site evaluation of the Burtons Ford Site;
- Inspected all of the Rocky Mountain Region sites and prioritized them.

Figure A-3. INDEX MAP OF PRIMARY AND ALTERNATE TEST SITES

A.3.1 RECOMMENDED SITES

After an extensive program of office research and field investigations of potential sites, two primary sites were selected for Phase I, detailed geological definition. These are the North Knobs site and the Johnny Moore Syncline sites near Rawlins, Wyoming, and Walden, Colorado. Data on the location, geology, coal-bed attitude and thickness, coal chemical properties, and reserves present are described below. Table A-IV presents a comparison of the two sites by the individual site selection criteria.

A.3.1.1 North Knobs Site, Carbon County, WY

Location and Legal Description. The North Knobs area is located approximately eight miles west of the town of Rawlins, WY (Figure A-4). Rawlins, the county seat for Carbon County, has a population of over 7800. Interstate Highway 80 passes east-west through the southern edge of the area, and the Union Pacific Railroad passes within one half mile of the area. The site selected from this area is located in Section 11, T21N, R89W.

Access within the study area is by unimproved dirt roads. Traversing ground where no roads exist is relatively easy, and no serious access problems are foreseen.

Site Acquisition. An agreement to use the site for purposes of conducting UCG tests has been consummated with RME.

Geology. Two (2) different nomenclatures for the stratigraphic column of interest have been used in the North Knobs Area, an older nomenclature described by Smith and a current nomenclature used by RME and others (Table A-V).

Table A-IV

COMPARISON OF NORTH KNOBS AREA (NK) SITE AND JOHNNY MOORE
SYNCLINE AREA (JMS) SITE BY THE INDIVIDUAL SITE SELECTION CRITERIA

<u>Site Preference</u>	<u>Geological Characteristics of Coal Bed</u>	<u>Importance* Index</u>	<u>Project** Phase (\$)</u>
Structural Considerations			
NK	- Dip and Consistency of Dip with Depth	3	I-II
NK	- Folding	3	I-II
X	- Faulting	3	I-II
X	- Cleating and Other Minidislocations	3	I-II
0	- Tectonic Thickening	1	II
Stratigraphic Considerations			
?	- Detailed Lithologic Column	2	I-II
NK	- Thickness	3	I-II
JMS	- Lenticularity and Continuity	3	I-II
0	- Endogenic Cleating	3	I-II
Outcrop and/or Subcrop			
X	- Length of Outcrop and/or Subcrop Trace	3	I
NK	- Thickness and Lithology of Surficial Deposits	2	I-II
Crop Reserves			
X	- Reserve Requirement for Pilot Plant	3	I-II
NK	- Reserve Expansion Potential	3	I
Ground Water			
0	- Water Influx	3	II
0	- Hydrostatic Pressure	3	II
0	- Permeability	1	II
<u>Geological Considerations External to the Coal Bed</u>			
Physical Geology			
X	- Topography/Terrain	1	I
NK	- Surface Water	1	I
0	Aquifers	3	II
Roof and Floor Characteristics			
X	- "Container Tightness"	3	I-III
X	- Rood Fall Characteristics	2	III
Overburden			
NK	- Drilling Characteristics	2	I-III
0	- Subsidence Characteristics	3	III

Table A-IV (Cont'd)

<u>Site Preference</u>	<u>Physical and Chemical Properties of Coal</u>	<u>Importance* Index</u>	<u>Project** Phase (\$)</u>
	Physical Properties		
X	- Expansion Characteristics	3	I-II
O	- Shrinking and Spalling Characteristics	3	II-III
X	- Agglomerating Characteristics	1	I-II
O	- Directional Permeability	3	I-II
X	Chemical Properties		
X	- Properties Reported in Proximate Analyses		
	- Volatile Matter Content	3	I-II
	- Ash Content	1	I-II
	- Moisture Content	2	I-II
	- Fixed Carbon Content	1	I-II
	- Sulfur Content	1	I-II
	- Most Value	2	I-II
O	- Properties Reported in Ultimate Analyses		
	- % Carbon	1	I-II
	- % Hydrogen	1	I-II
	- % Nitrogen	1	I-II
	- % Chlorine	1	I-II
	- % Oxygen	2	I-II
O	- Reactivity		
	- Carbon Dioxide - Reactivity	2	II
	- Oxy-reactivity	2	II
	- Hydroreactivity	2	II
O	- Trace Elements	1	II
	Land Status		
NK	- Ownership		
	- Coal Ownership	3	I
	- Surface Ownership	3	I
NK	- Lease		
	- Coal Leases	3	I
	- Surface Leases	3	I
	Acquireability		
O	- Availability	3	I
NK	- Terms and Conditions of Agreements	3	I
JMS	- Number of Owners and/or Lessors and Interest of Each	2	I
X	- Severed Surface and Minerals	2	I

Table A-IV(Cont'd)

<u>Site Preference</u>	<u>Acquisition Considerations</u>	<u>Importance* Index</u>	<u>Phase** Project (\$)</u>
	Land Status		
NK	- Ownership		
	- Coal Ownership	3	I
	- Surface Ownership	3	I
NK	- Leases		
	- Coal Leases	3	I
	- Surface Lease	3	I
	Acquireability		
O	- Availability	3	I
NK	- Terms and Conditions of Agreements	3	I
JMS	- Number of Owners and/or Leasers and Interest of Each	2	I
X	- Severed Surface and Minerals	3	I
	<u>Governmental and Political Considerations</u>		
NK	Permits		
	- Regulating Agencies	2	I
	- Types and Numbers of Permits	2	I
	- Ease in Obtained Permits	3	I
X	Political Sensitivity of Site		
	- Proximity to National Forests, Parks, Recreation Areas, etc.	3	I
	- History of Industrial Support	3	I
	<u>Infrastructure</u>		
X	Existing	2	I
NK	Housing	1	I
O	Utilities	1	I
X	Proximity to Terms	2	I
	<u>Past, Current, and Proposed Industry</u>		
X	Underground Coal Mining	2	I
JMS	Surface Coal Mining	2	I
X	Oil and Gas Development	2	I
X	Other Industry	2	I

Table A-IV (Cont'd)

<u>Site Preference</u>	<u>Marketing and Long-Range Planning</u>	<u>Importance* Index</u>	<u>Phase** Project (\$)</u>
X	Proximity to Markets	2	I
X	Proximity to Pipelines	2	I
	Resource Extent		
JMS	- Expansion Potential of Reserves	2	I
NK	- Non-Uniques of Reserves	3	I
	<u>Environmental Considerations</u>		
JMS	Present Land Use	3	I
X	Surface and Subsurface Water Use	2	I
JMS	Out of Sight of Public	3	I
X	Impact of Surface Subsidence	2	I
X	Impact of Gas Leakage	2	I

Explanation of Symbols Used

NK	North Knobs Area Site is preferable for this criterion
JMS	Johnny Moore Syncline Area Site is preferable for this criterion
X	Sites are same or equal for this criterion
0	No measurement is available for evaluating this criterion
?	The best values of this criterion are undecided
*	Importance of the parameter 1 = least important 2 = moderately important 3 = most important
**	Most likely project phase(s) during which the value of this parameter can be evaluated.

Figure A-4. INDEX MAP OF NORTH KNOBS AREA, CARBON COUNTY, WYOMING
A-19

Table A-V. STRATIGRAPHIC COLUMN INTEREST

System	Formation		Thickness*
Tertiary Cretaceous	Smith (1907) Nomenclature	Current Nomenclature	
	Undifferentiated	Fort Union**	7250 feet
	Laramie	Lance**	4800 feet
	Lewis Shale	Lewis Shale	1360 feet

*Thickness of units estimated from outcrop width and dip of beds

**Coal bearing formations

Three (3) steeply dipping coal beds that have potential for UCG underlie the North Knobs SDB-UCG site. All three of these beds are in the tertiary Fort Union Formation.

	Range of Thickness	
Wally Bed	0.0 -	13.0 ft
Interval	155.0 -	250.0 ft
G Bed	7.0 -	25.0 ft
Interval	140.0 -	210.0 ft
I Bed	5.5 -	16.0 ft

The G bed and I bed are particularly well developed on the North Knobs Site as illustrated in Table A-VI.

Strata within the study area generally strike about N 20° W and commonly dip southwesterly from 60 to 68°. An exception to this general trend is in the S/2 of Section 13, T21N, R89W, where the Fort Union Formation bends to a strike of nearly north-south and dips flatten to 17°. Dips on the North Knobs Test Site are about 64° SW.

Table A-VI. REPRESENTATIVE NORTH KNOBS SITE BED LITHOLOGY

Typical G Bed Lithology		Typical I Bed Lithology		
Description	True Thickness	Description	True Thickness	Bench
Coal, rider	0.9 ft	Shale, dark gray		
Shale	2.4 ft	COAL, hard		
COAL, clean	6.0 ft	bright luster	4.8 ft	Middle
COAL, shaly or bony	0.5 ft 15.5 ft	COAL, shaly	0.4 ft	Middle
COAL, clean	9.0	Shale, with bony		
Shale	2.6	coal, carbonaceous	0.4 ft	
COAL, shaly or bony	1.9 ft	COAL, shaly	0.4 ft	Lower
COAL, clean	1.3 ft 3.2 ft	COAL, hard,		
Shale		bright luster	2.1 ft	Lower
		COAL, bony,		
		dull luster	2.1 ft	Lower
		COAL, hard,		
		bright luster	2.6 ft	Lower
		Shale, dark gray,		
		carbonaceous		

Coal Quality. Table A-VII gives analytical values for the various coal beds in the study area; these values are based on reports of analytical work conducted by the Energy Development Company at their lab at Hanna, Wyoming. All of the Fort Union coal beds are subbituminous B rank according ASTM classification. Well-developed cleats were observed in an exposure of I bed about 1000 feet south of the site.

Table VII. REPRESENTATIVE COAL QUALITY

Bed	As Received Basis			
	% Moisture	% Ash	% Sulfur	Btu/lb
Wally	20.5	15.0	0.45	8070
G	20.8	6.4	--	9429
I	19.5	10.8	--	8738
Nebraska	No reports available			

Hydrology. A resistivity survey conducted by Group 7 of Golden, Colorado indicates that the water table is at a depth of about 70 feet on the site.

Coal Resource Representative of North Knobs Test Site. The coal resources extending from the North Knobs Test Site are of suitable size for commercial development of UCG.

Surface attitudes indicate that steep dips continue basinward from the coal outcrop for approximately one mile. This is good evidence that the coal beds continue to dip steeply into the subsurface for at least 1/2 mile from their outcrop; this conclusion is a basic assumption used to estimate the resource of dipping coal beds. The length of coal down dip available for UCG, assuming 1/2 mile width, varies with the dip:

Dip	Down Dip Length (feet)
45°	3733
50°	4107
55°	4603
60°	5280
65°	6247

Estimated reserves of steeply dipping coal beds for the North Knobs Area and its extension to the north are given in Table A-VIII. The total estimated resource of steeply dipping coal beds is approximately 400 million tons. This estimate probably is conservative.

Table A-VIII. ESTIMATED NORTH KNOBS AREA RESERVES

Area	Dip	Reserve Calculations			
		Outcrop Trace	Coal Thickness	Down Dip Length	*Ton ⁶ (x10 ⁶)
North Knobs	65°	26 400 ft	35.0 ft	6247 ft	230.9
Extension	45°	10 560 ft	10.0 ft	3733 ft	15.8
Extension	50°	39 600 ft	10.0 ft	4107 ft	65.0
Extension	35°	2 640 ft	10.0 ft	4603 ft	4.9
Extension	60°	39 960	10.0 ft	5280 ft	78.1
Total Tons					394.7
*Assumes 0.04 tons, in place/ft ³					

Site Selection Criteria and Rationale. Three considerations dominated in the selection of the North Knobs Site:

- Coal bed thickness is a major consideration. The G bed and I bed are about 13.0 feet and 15.0 feet thick, respectively, on the site.
- Coal bed lenticularity and continuity is a concern. Areas where the coal beds split into several benches were culled before the site was selected.
- Detailed coal bed lithology is a consideration. Beds with an apparent high ash content are avoided in the site selection.

Dip is not a major consideration in the site selection because it is very constant throughout the area from about 60° to 68°.

It appears that all of the coal beds in the North Knobs Area are subbituminous B in rank and, therefore, rank is not used as a site selection criterion.

Estimates reserves for the G and I beds are more than adequate on the acquired North Knobs Site to conduct the test burns (Table A-IX).

Table A-IX. ESTIMATES IN-PLACE RESERVES
200 FEET DOWN DIP TO 1000 FEET DOWN DIP

Bed	Outcrop Length	Thickness	In Place Tons (x10 ⁶)
G	4500 feet	15.5 feet	2232
I	4000 feet	12.8 feet	<u>1638</u>
		Total Tons	3,870

Chances of Successful Demonstration of UCG. Chances of successful demonstration of UCG on the North Knobs Site are very good because:

- The dip of the coal beds exceeds 45°.
- The G bed and I bed have a true thickness of about 12.8 feet and 15.5 feet, respectively, on the site.
- The coal beds are subbituminous in rank and are non-expanding and non-agglomerating which are considered desirable features for UCG.
- It appears that cleats are well developed in these coal beds. This is a desirable feature for countercurrent combustion linking and gasification.
- Ground water studies conducted on the site indicate that gasification can be designed below the water table.
- The site is only about eight (8) miles west of Rawlins, Wyoming, the Carbon County seat.
- Access to and on the site is good, and terrain is not rugged.

A.3.1.2 Johnny Moore Syncline, Jackson County, Colorado

Location and Description of Site. The Johnny Moore Syncline Area is located in the eastern extremity of North Park, Jackson County, Colorado (Figure A-5). The town of Walden, Colorado, is located approximately eight (8) miles west of the area.

Coal of sufficient thickness that is dipping at 45° or greater is restricted to an area within the following twelve (12) sections:

T8N, R78W	T9N, R78W
Sections 1 & 2	Sections 8, 9, 15, 16, 22, 23, 25, 26, 35, & 36

The legal description of the test sites acquired for this project was:

Jackson County, Colorado

<u>Area</u>	<u>Description</u>	<u>Acres</u>
1	T9N, R78W Section 16: S/2; NW/4; S/2 NE/4; NW/4 NE/4	600
2	T9N, R78W Section 25: S/2; SW/4; NW/4 SW/4 Section 26: S/2; SE/4; NE/4 SE/4	240

Of these, only two were available for use in SDB-UCG experiments. The legal description of these two areas is presented above.

Ownership and Acquisition of the Site. Area 1 has been leased from the state of Colorado and Area 2 from the Marr Company, for operation of underground gasification experiments.

Geology. Sedimentary rocks in North Park form a large basin bounded on the north by the Independence Mountain Fault, on the east by the Medicine Bow Mountains, on the south by Middle Park and on the west by the Park Range (Figure A-5). The Johnny Moore Syncline lies along the northeast portion of the basin.

The stratigraphic column in the study area includes sedimentary rocks of upper Cretaceous and Tertiary systems.

Coal of economic importance is contained in the Coalmont Formation which is considered to be of Paleocene or Eocene age. The coal seam of interest for underground gasification is the Sudduth Seam which occurs 30 to 40 feet above the base of the Coalmont Formation.

Early mining efforts in the Sudduth Seam have been described in detail by Beekly (1915). A number of prospects and adits were opened on the Sudduth Seam on or near the test site.

The old Sudduth Mine is located in the NW/4 SW/4 Section 15, T9N, R78W, and is less than 500 feet from Area 1 (Figure A-6). A section measured through the Sudduth Seam at the Sudduth Mine follows:

Shale - gray-black, sandy in part, coal laminae	2.8 feet
Coal - black, well-developed cleats	0.9 feet
Shale - gray-black, sandy in part, coal laminae	2.5 feet
Coal - black, well-developed cleats and "bedding"	26.4 feet
Clay - gray, soft	0.1 foot
Coal - dirty	0.4 foot
Shale - brown to yellow, clayey, carbonaceous	7.5 feet

A vertical shaft, the Lange Shaft, was driven into the steeply dipping (80°) subcrop on Area 2. Coal at this locality was reported by Beekly (1915) to be 50 feet thick. Only a trace of the shaft remains today.

Figure A-5. INDEX MAP OF JOHNNY MOORE SYNCLINE AREA, JACKSON COUNTY, COLORADO

Figure A-6. JOHNNY MOORE SYNCLINE AREAS

An old working, the Marr Mine, has recently been reopened as a surface mine in the SW/4 SE/4 Section 26, T9N, R78W, less than a mile west of Area 2. The true thickness of the Sudduth Seam at the Marr Mine exceeds 40 feet, and the coal dip ranges from 55-60°.

The Johnny Moore Syncline trends NW-SE for about eight miles across the study area. Outcrops of the Sudduth Seam can be traced along both flanks of the syncline. Dips at outcrops within the study area range from 36° to 85° on the southwest flank and from 27° to 85° on the northeast flank.

The Sudduth Seam strikes about N45°W and dips about 85°NE on Area 1. At Area 2 the dip ranges from 55° to 85°.

Coal Quality and Rank. The Sudduth Seam is subbituminous in rank. Proximate analyses of coal from the Sudduth and Marr Mines as published in U.S.G.C. Bulletin 596, by Beekly, 1915, are in Table A-X.

Table A-X. SUDDUTH SEAM COAL QUALITY

	Sudduth Mine (Near Area 1)		Marr Mine (Near Area 2)	
	<u>As Rec'd Basis</u>	<u>Dry Basis</u>	<u>As Rec'd Basis</u>	<u>Dry Basis</u>
Btu/lb	9750	12 190	10 360	12 440
Moisture	20.0%	--	16.7%	--
Fixed Carbon	42.5%	53.1%	46.7%	56.0%
Volatile Matter	32.5%	40.7%	33.0%	39.7%
Ash	5.0%	6.2%	3.6%	4.3%
Sulfur	0.59%	0.75%	0.16%	0.19%

Hydrology. A resistivity survey conducted by group 7 of Golden, Colorado, on Area 1 indicates that the water table is at about 30 to 60 feet below the surface. This interpretation is consistent with the depth to water in several drill holes located on Area 1. A resistivity survey was not conducted on Area 2.

Coal Resource Representative of Johnny Moore Test Sites. The Sudduth Seam is representative of a major coal resource suitable in size for commercial development by in situ gasification. Estimated reserves in the study area alone are 215 million short tons in place. Reserves of Sudduth Seam coal extending from the study area in dips exceeding 20° would probably be in the order of twice that defined in the study area.

Site Selection Criteria and Rationale. Parameters considered in the selection of this site are outlined below:

- Seam Thickness - All blocks in the study area contain acceptable thicknesses of coal.
- Dip - Sites with dips 45° or greater were the only targets considered.
- Reserves - Coal reserves on the site together with the depth of the reserve is considered. Both areas contain an adequate amount of coal outcrop which is considered a desirable geologic criterion.
- Access and Terrain - The site has good access by way of paved and improved gravel road. Terrain on the site is not rugged.
- Coal Quality - The non-expanding, non-agglomerating character of the subbituminous coal on the sites is considered desirable.
- Cleating - Well-developed cleats have been recognized in the Sudduth Seam. Well-developed cleats are considered a very desirable feature in reverse combustion linking and gasification.

A.3.1.3 Other Sites Investigated

Five sites in addition to the two prime sites were investigated as potential candidates. Brief discussions of these sites are included.

- Roslyn, Washington
- Grand Hogback, Colorado
- Wilkeson-Carbonado, Washington
- Green River, Washington
- Burtons Ford, Virginia

Leases were not obtained for sites at these locations.

A.4.0 PHASE I - SITE REVIEW

After the DOE-ERDA contract for SDB-UCG was awarded to Gulf/TRW, Phase I site review activities were initiated for both leased sites. These activities consisted of:

- reviewing available federal and state geotechnical publications;
- reviewing consulting reports prepared on the area;
- discussions with geotechnical personnel from the federal, state, and county levels, academia, and local consulting firms; and

A.4.1 PHASE I REVIEW - NORTH KNOBS, WYOMING

In addition to activities listed above, the Phase I review of the North Knobs site included:

- an exploratory drilling and hydrologic testing program;
- a preliminary surface geologic mapping program; and
- collection of available geotechnical data on Section 11, T21N, R89W.
- collection of soils and meteorologic data for the Rawlins area.

The following is a description of the data obtained from each of these activities:

The Exploratory Drilling Program. In early December, 1977, an exploratory drilling program was conducted in Section 11 to determine the subsurface stratigraphic, structural, and hydrologic character of the rock units about the G and I coal seams. This program consisted of:

- air drilling three holes into the rock sequence.
- running geophysical logs in each of the three holes.
- installing a piezometer in each of the three holes.

The three holes that were drilled were labeled Hydro I, Hydro II, and Hydro III; and the location of the three holes on Section 11 is illustrated in Figure A-7. The subsurface physical characteristics of each hole are as follows:

	<u>Hydro I</u>	<u>Hydro II</u>	<u>Hydro III</u>
Surface Elevation	6913 feet	6919 feet	6850 feet
Depth to Top of Coal	423 feet	520 feet	545 feet
Elevation of Top of Coal	6490 feet	6399 feet	6305 feet
Coal Seam Penetrated	G	I	G
Drilled Thickness of Coal	31.5 feet	19.7 feet	34.0 feet
True Thickness of Coal	15.7 feet	8.6 feet	14.9 feet
Total Depth	520 feet	580 feet	600 feet

Drill cuttings were collected at 10-foot intervals during the drilling of each hole; however, they have not been described to date. Preliminary examination indicates that the subsurface section consists of a sedimentary sequence of sandstones, siltstones, and shales.

The depth data from the holes indicate that the subsurface structural dip is consistent with that observed on the surface. In addition, the subsurface coal seam thickness was consistent with that observed in outcrop.

Figure A-7. LOCATION OF HYDROLOGY TESTING WELLS IN SECTION 11

As indicated above, four types of geophysical logs were run in each hole. The following is an outline of the descriptive characteristics of each of these logs:

- Gamma Ray Log
 - measure the natural radioactivity of rocks
 - interpretation of the shaliness of a lithologic unit.
- Gamma-Gamma Density Log
 - measures the average density of formations, including the rock matrix and contained fluids, within short distances from the borehole.
 - uses for the log include:
 - porosity determination
 - lithologic interpretation and correlation
- Resistivity Log
 - measures the natural electrical resistivity response of formations and their contained fluids.
 - uses for the log include:
 - identification of the presence of fluids within the formations.
 - lithologic interpretation and correlation.
- Drift Survey Log
 - measures the amount of vertical and horizontal deviation in the hole.

- uses for the log include:
 - location of the bottom of the hole
 - determination of the affects of stratigraphy and structure on the drilling operation.

Figures A-8, A-9, and A-10 illustrate sections of the gamma ray, gamma-gamma density and resistivity logs. The coal section and observed water level is marked on each figure.

All three of the holes deviated in the subsurface to the south-east. The amounts of azimuthal (horizontal) deviation for each hole was as follows:

	<u>Hydro I</u>	<u>Hydro II</u>	<u>Hydro III</u>
Outcrop Strike Direction	N26°W	N22°W	N25°W
Outcrop Dip Direction	S64°W	S68°W	S65°W
Amount of Outcrop Dip	60°	64°	62°
Direction of Hole Deviation	S63.5°E	S87.4°E	S69.2°E
Amount of Hole Deviation	127.9 feet	114.9 feet	113.5 feet

Figure A-11 illustrates the amount of vertical deviation in each of the three holes. The holes deviated into the geologic section, that is, they deviated down dip.

While both the horizontal and vertical deviations appear large, they can be considered normal for the drilling methods and speeds used to complete the program. Greater control will be implemented during the Phase II drilling program, thereby reducing the amounts of deviation.

The final phase of the exploratory drilling program consisted of installing a 1-1/2" inside diameter piezometer in each of the three holes. The piezometers were installed to monitor the water level in the stratigraphic units near the G and I coal seams. Figure A-12 illustrates the

HYDRO I

Figure A-8. SECTIONS OF THE GEOPHYSICAL LOGS FROM HYDRO I

HYDRO II

Figure A-9. SECTIONS OF THE GEOPHYSICAL LOGS FROM HYDRO II

HYDRO III

Figure A-10. SECTIONS OF THE GEOPHYSICAL LOGS FROM HYDRO III

Figure A-11. DEVIATION (IN FEET) FROM VERTICAL OF THE HYDROLOGIC TESTING WELLS

Figure A-12. CROSS SECTIONS OF HYDROLOGIC TESTING WELLS
A-40

method of installation of the piezometers in each well. The data obtained from the piezometers are listed below:

<u>Date</u>	<u>Hydro I Depth</u>	<u>Hydro II Depth</u>	<u>Hydro III Depth</u>
12-7-77	109 feet	181 feet	93 feet
12-14-77	106 feet	107 feet	89 feet
12-28-77	106 feet	112 feet	92 feet
Coal Seam	G	I	G
Depth to Top of Coal	426 feet	520 feet	545 feet

From the measurements taken to date, the potentiometric surface is apparently about 100 feet below the ground surface.

In December, 1977, water samples were collected from the three hydrologic wells. Laboratory analyses of the samples are given in Table A-XI. These analyses are presented only as information and are not to be interpreted as part of a baseline sampling program. This is because the samples were not collected in accordance with accepted sampling procedures. That is, the wells were lined with PVC pipe and were not pumped prior to sampling. The data shown in Table A-XI, although preliminary, indicate selenium and lead contents which are much greater than the state of Wyoming allowable limits.

The Surface Geologic Mapping Program. A preliminary surface geologic mapping program was also initiated in early December, 1977, on Section 11. The area investigated characterized the bedrock exposures around the Hydro I and Hydro II wells. The data obtained from this program may be found in the pocket and at the end of the Appendix. These data include:

- a surface geologic map at a scale of 1" = 50 feet.
- a geologic cross section.
- a detailed description of the exposed rocks (a geologic column).

Table A-XI

PRELIMINARY ANALYSIS ON GROUNDWATER OBTAINED
FROM WELLS 1, 2, AND 3*

	Livestock Impoundments Limits	Well 1 G Seam	Well 2 I Seam	Well 3 G Seam
Bicarbonate		142 ppm	0 ppm	380 ppm
Carbonate		0	1790	0
Conductivity		1790	7000	2000 μ mhos/cm
Total Solids @103		2310 ppm	3930 ppm	3005 ppm
Nitrogen as Ammonia		7.2	50	3.9
Nitrate NO ₃		<0.01	<0.01	<0.01
Nitrite NO ₂		0.01	<0.01	0.01
Aluminum	5	2.1	1.0	2.1
Arsenic	0.2	<0.2	<0.2	<0.2
Barium		0.3	1.0	0.5
Boron	5	0.20	0.15	0.53
Cadmium	0.05	0.023	0.014	0.006
Calcium		300	680	345
Chloride	2000	97	460	19
Chromium	10	0.03	0.10	0.02
Copper	0.5	0.10	0.07	0.03
Fluoride	2.0	0.5	0.7	0.8
Iron		2.7	0.8	0.3
Lead	0.1	1.2	3.4	0.45
Magnesium		130	430	370
Manganese		0.15	0.04	0.11
Mercury	0.01	<0.01	<0.01	<0.01
Nickel		0.025	0.05	0.025
Potassium		25 ppm	100 ppm	10 ppm
Selenium	0.05	0.65	0.52	0.30
Sodium		330	730	190
Sulfate	3000	11	8.8	12
Sulfide		0.3	-	0.6
Chemical Oxygen Demand		172	201	109
Cyanide		<0.05	<0.05	<0.05
Phenol		<0.01	0.02	<0.01
Organic Carbon	~2-5 (D.W.)	75	69.0	59
pH	6-9	6	11	-
Zinc	25	0.46	0.13	0.31

*These data are preliminary because they were obtained from PVC lined wells which were not pumped out prior to grabbing samples.

The data obtained from this activity indicate that the geologic column is composed of a stratigraphical complex interbedded sequence of sandstones, siltstones, shales and coals which vary in thickness within the sequence as a function of their paleo-environment of deposition. A surface geologic map, geologic cross section and geologic column are included in the pocket at the end of Appendix A.

Collection of Geotechnical Data. In addition to the above data, descriptive chemical and physical property data were obtained for the G and I coal seams from Section 11, T21N, R89W. These data were obtained from samples collected during an exploratory drilling program conducted on Section 11. Figure A-13 illustrates the locations of the drill holes and Tables A-XII through A-XIV summarize the coal seam descriptive data.

The coal seam descriptive data includes:

- proximate analysis data for the Wally, G and I coal seams on Section 11 (Table A-XII);
- trace element data for the G coal seam on Section 11 (Table A-XIII);
and

Figure A-13. EXPLORATORY HOLES DRILLED ON SECTION 11 PRIOR TO 1977

- ash softening temperatures for the G and I coal seams on Section 11 (Table A-XIV).

Based upon these data, the Wally, G, and I coal seams would be classified as having a subbituminous B rank according to ASTM standards.

There are no active or inactive coal mines located on Section 11, T21N, R89W; and, there is only one inactive mine on the adjacent sections. This mine is located in the SW1/4 of the SW1/4 of Section 12, T21N, R89W (Figure A-15). This mine was a strip mine that was operated in the I coal seam. On-site inspection of the location has indicated that the upper 20 to 50 feet of coal has been removed for a few hundred feet along the coal outcrop. No date was located as to when this mine was operational.

Table A-XII

PROXIMATE ANALYSIS DATA FOR THE WALLY, G, AND I
COAL SEAMS ON SECTION 11, T21N, R89W

Coal Seam	Sample II	% Moisture	% Ash	% S	Btu
Wally	1	20.5	15.0	-	8070
	2	21.0	13.9	-	7960
G	1	20.8	6.4	-	9424
	2				
	3	16.9	5.9	-	9687
	4	15.4	21.6	-	7916
	5	18.8	6.3	-	8598
I	1	18.6	17.1	-	8031
	2	19.5	10.8	-	8738
	3	18.8	13.2	-	8671

Table A-XIII

TRACE ELEMENT DATA FOR THE G COAL SEAM FROM
SECTION 11, T21N, R89W*

<u>Element</u>	<u>Coal (Raw)</u>	<u>Ash</u>
As	-	-
Ba	270	2840
Cd	-	-
Cr	15	160
Cu	6	60
Pb	2	20
Zn	0.1	10
Hg	0.15	
Se	0.5	
U	1.13	10.7
Sb	-	
Th	-	
F	80	

Moisture: 10.9% as received.

Ash: 10.3%

*All values in ppm.

Table A-XIV

ASH SOFTENING TEMPERATURES FOR THE G AND I COAL SEAMS
FROM SECTION 11, T21N, R89W

	G Coal Seam	I Coal Seam
Reducing Atmosphere*		
Initial	2156 - 2309	2174 - 2246
Softening	2192 - 2318	2192 - 2264
Hemispherical	2201 - 2327	2201 - 2282
Fluidization	2210 - 2336	2210 - 2300

Table A-XIV (Cont'd)

	G Coal Seam	I Coal Seam
Oxidizing Atmosphere*		
Initial	2201 - 2318	2300 - 2372
Softening	2210 - 2327	2318 - 2309
Hemispherical	2219 - 2336	2336 - 2408
Fluidization	2228 - 2345	2354 - 2426

*All data in °F.

In addition to the chemical and physical property data, soil survey information was obtained for Section 11 from the Saratoga Soil Conservation Service (SCS) office. These data consisted of a reconnaissance soil survey map (Figure A-16) and preliminary soil characteristic data.

The coal outcrop belt on Section 11 is covered by the Shinbara-Blazon-Rock Outcrop Complex (map unit number 252) and the Ryan Park-Rock River Association (map unit number 260). The characteristics of these can be summarized as follows:

	<u>Shinbara-Blazon- Rock Outcrop</u>	<u>Ryan Park-Rock River Association</u>
Slopes	10-40%	2-20%
Depth	0-20"	0-60"

Finally, climatologic data were obtained for the area around Section 11, T21N, R89W. Unfortunately, no data have been systematically collected on Section 11; however, data have been collected at Rawlins, WY, about 8 miles to the east of Section 11.

The climatic data for Rawlins, WY, are characterized by a low annual rainfall, high daily evaporation rates, and wide diurnal and seasonal temperature variations. The summer days are usually dry and mild, and summer nights are relatively cool due to the low relative humidity and

Figure A-14. PROJECTED STRIP MINE PLAN
FOR SECTION 11

Figure A-15. INACTIVE COAL MINES ON SECTIONS ADJACENT TO SECTION 11

Sec. 11 T21N R89W

Unit No.

242	Blackhall-Blazon Complex
252	Shinbara-Blazon-Rock Outcrop Complex
260	Ryan Park-Rock River association
300	Monte-Clowers Complex
317	Littsan, deep variant-Sage Creek, coarse variant complex

Figure A-16. SOIL ASSOCIATIONS IN SECTION 11, T21N, R89W

almost constantly blowing winds. The winters are also relatively dry; however, they are very cold due to the high winds.

The normal annual precipitation in Rawlins is 7.74 inches (Table A-XV). The wettest season of the year is generally the spring with the highest rainfall occurring in May (1.05 inches). The highest observed annual precipitation was 17.00 inches in 1912, and the lowest was 3.80 inches in 1907.

The mean annual temperature is 42.6°F (Table A-XV). Mean monthly minimum temperatures are generally below freezing (32°F) from October to April; therefore, the effective length of the growing season is usually about four months. Below freezing nightly temperatures have, however, been recorded in all months of the year.

Winds at Rawlins are predominately from the west; however, the presence of the mountains to the north and west of town (the Rawlins uplift) modify the westerly pattern. Table A-XV indicates that this mean range in seasonal wind speeds is from 8 to 14 miles per hour; however, daily winds commonly exceed 50 miles per hour throughout the year.

The recorded climatic data for Rawlins, Wyoming, would be classified as a BSh climate in the Koppen Climatic Classification System.

Finally, because of the rural setting of the area, the ambient air quality is generally good and free of chemical pollutants. In addition, the amounts of total suspended particulates (TSP) are normally much less than federal ambient air quality standards. Table A-XV presents TSP data for Rawlins on a seasonal basis. The federal standards for TSP are:

- o primary standards:
 - 75 $\mu\text{g}/\text{m}^3$ annual geometric mean
 - 260 $\mu\text{g}/\text{m}^3$ maximum 24-hour concentration

Table A-XV. CLIMATOLOGIC DATA FOR RAWLINS, WYOMING

	<u>Jan.</u>	<u>Feb.</u>	<u>Mar.</u>	<u>Apri.</u>	<u>May</u>	<u>June</u>	<u>July</u>	<u>Aug.</u>	<u>Sept.</u>	<u>Oct.</u>	<u>Nov.</u>	<u>Dec.</u>	<u>Annual</u>
Temperature (°F)													
Mean maximum	31.6	32.8	38.7	52.2	64.1	75.7	83.6	80.9	71.9	57.7	40.2	33.7	55.3
Mean minimum	13.5	14.0	17.6	26.8	36.2	44.4	50.8	49.9	40.4	30.6	18.5	15.1	29.8
Mean	22.6	23.4	28.2	39.5	50.2	60.1	67.2	65.4	55.2	44.2	29.4	24.4	42.6
Precipitation (inches)													
Total	0.45	0.63	0.75	0.79	1.05	0.73	0.57	0.58	0.47	0.77	0.51	0.43	7.74
Mean Seasonal Wind Speed (mph)	13.9			12.4			8.9			11.1			
Particulate Geometric Mean ($\mu\text{g}/\text{m}^3$ -seasonal)	7.6			17.3			24.2			14.1			
Particulate Geometric Mean ($\mu\text{g}/\text{m}^3$ - monthly)	7.9	5.8	12.8	17.8	22.6	28.2	18.4	26.6	19.3	15.0	9.6	9.5	14.7
Pittsburgh, Pennsylvania Data (Airport Station)													
Temperature (mean °F)	30.6	31.4	40.0	51.1	61.9	70.5	74.5	72.7	66.5	55.1	43.1	33.5	52.6
Precipitation (inches)	2.89	2.50	3.31	3.09	3.30	3.70	4.00	3.17	2.64	2.49	2.36	2.70	36.15

- secondary standards:
 - 60 $\mu\text{g}/\text{m}^3$ annual geometric mean
 - 150 $\mu\text{g}/\text{m}^3$ maximum 24-hour concentration.

Even though the air quality is well within acceptable standards throughout the year, it is possible that a few days each year will be over the 24-hour standard due to naturally occurring dust storms. The UCG experiments should not appreciably increase the amounts of TSP around the UCG site since extensive disruption of the ground surface will not occur during the life of the experiments.

The following is a seasonal integration of the Rawlins seasonal climatic data:

- Winter: The winter season has the coldest temperatures, the lowest amount of precipitation, the highest average wind speed, and the least amount of TSP. The mean daily temperatures are generally below freezing; therefore, the daily evaporation rates are low and the ground surface normally is frozen. In addition, the precipitation occurring at this time of the year is snow. Thus, large amounts of TSP are not generated despite the presence of strong winds due to the passage of winter weather systems during this season.
- Spring: The spring season has mean monthly temperatures which begin to rise above freezing early in the season and continue to rise throughout the season, the highest amount of precipitation which changes its form from snow to rain as the temperatures change, lower wind speeds, and significantly higher amounts of TSP. Since the temperatures are rising to above freezing at this time of the year, the ground is thawing and individual soil particles are exposed to the winds. In addition, the soil evaporation rates increase, thereby drying out the soil. As a result of these factors, the winds during this season are able to substantially increase the amounts of TSP which cause the spring to have the second highest TSP concentration for the year.

- Summer: The summer season has the highest mean monthly temperatures, lower amounts of precipitation, the lowest seasonal wind speeds, and the highest amount of TSP. Both the mean monthly temperature and evaporation rates continue to rise during the summer. In addition, large differences in wind speeds occur due to the differential heating and cooling of the land surface during the diurnal cycle. These factors contribute to the soils being their driest in this season and most accessible to eolian erosion during the daylight hours and especially in the early to midafternoon hours.
- Fall: The fall season has steadily decreasing mean monthly temperatures and evaporation rates, decreasing amounts of precipitation, and increasing wind speeds. As a result, the TSP content of the air remains relatively high during the early fall; however, the precipitation increases slightly and temperatures begin to fall below freezing by mid-fall, and TSP concentrations begin to decline.

A.4.2 PHASE I REVIEW - WALDEN, COLORADO, SITES

Phase I of the Johnny Moore Syncline sites consisted of:

- reviewing available federal and state geotechnical publications;
- reviewing consulting reports prepared on the area;
- discussions with geotechnical personnel from the federal, state, and county levels, academia, and local consulting firms; and
- field observations made on the site.

Based upon the data collected from the sources outlined above, both sites (Area 1 - Section 16 and Area 2 - Sections 25 and 26) were rejected as potential locations for SDB-UCG experimentation.

Rejection of Area 1 - Section 16. The following is a summary of the data which led to the rejection of the site in Section 16:

- The Colorado Land Board leased the acreage to Gulf three years after it had awarded a 10-year lease for same acreage to a coal mining company. Therefore, the Gulf lease is invalid.
- Much of the coal outcrop is covered by 6-30 m (20-100 feet) of terrace gravels or soils. Therefore, the actual location of the syncline cannot be confirmed by field mapping. An expensive seismic or exploratory drilling program would have to be initiated to determine the coal location and dip, prior to drilling the module wells. The overburden characteristics present potential drilling problems during the UCG test.
- Where the coal seam is exposed in an existing mine east of Section 16, measured dip approaches 90°. The near verticality of the coal seam would present possible subsidence problems as a result of UCG.
- The measured thickness of the coal seam has been reported to be as much as 15 m (50 feet). This is considered too thick for testing UCG of SDB.
- There are two producing oil wells in the SW1/4 of Section 16 and several more in the adjoining sections to the south and west. The petroleum which is obtained from these wells is pumped through a surface piping system to a central collection system.
- The narrow width of the syncline in this area is an indicator of a higher intensity of deformation. As a result of this, the folded rock layers have probably also experienced a higher degree of fracturing.

- The soil and glacial cover, the intensity of the folding, and the nature of the internal stratigraphic variability of the formations will complicate the interpretations of the data.
- The actual hydrologic character of the area may be masked due the soil and glacial cover, stratigraphic variations within the sedimentary formations, and structural discontinuities imposed by the folding.
- The units within the syncline in the subsurface are thought to be discontinuous (faulted).

Rejection of Area 2 - Sections 25 and 26. The following is a summary of the data which led to the rejection of the sites in Sections 25 and 26:

- The coal seam in Section 26 is presently being strip mined to 60 m (200 feet). This means that UCG operations would have to be conducted either in the bottom of the strip mine or on top of a reclaimed area. Rock falls and poor air circulation due to the strip mine configuration would make operations in the bottom of the strip mine hazardous. Adequate control of drill holes would be extremely difficult in the reclaimed areas. All drill holes would have to be cased throughout the reclaimed interval. In addition, the reclaimed material would be undergoing compaction/subsidence. This would affect any surface facility placed on the reclaimed material.
- A potential site in the same coal seam but further south (in Section 35) will be mined in the next two years to a depth of 122 m (400 feet).
- With the exception of one drill hole in a fracture zone, no water was encountered in any exploration drill holes in the area. Also, ground water flow into the bottom of the existing strip mine has not been a problem to date.

- The coal seam in Section 25 dips 85-90°.
- The coal seam in Section 25 has a measured thickness of 15 m (50 feet).
- An existing county road runs very near the coal seam for about 100 m (300 feet). In order to provide a sufficient area for UCG surface operations, this road would have to be relocated. This would be an added expense.
- Strip mining operations are scheduled to begin prior to 1980 in Section 25. It is undesirable to run a UCG test in close proximity to a commercial mining operation.

A.4.3 PHASE I REVIEW - OTHER SITES

In addition to the review of the Johnny Moore Syncline and North Knobs SDB-UCG sites, visits were made to sites near:

- the Grand Hogback and Danforth Hills area of west-central Colorado;
- the southern San Juan Basin in New Mexico;
- Kemmerer, Wyoming;
- the Wilkeson-Carbonado mining districts in Washington; and
- the Centralia mining district in Washington.

Intensive review of these areas was not undertaken due to scheduling and funding constraints. It is hoped that additional funding will be forthcoming so that a backup site can be located.

A.5.0 RECOMMENDATIONS

Based on the data accumulated to date, the North Knob site can be considered to be a feasible location for a SDB-UCG field test. Among the factors to be considered are:

- the G and I coal seam dips are between 60-65°, and the dip appears to be maintained to a depth of 600 feet.
- the G and I coal seams outcrop for distances in excess of 2000 feet.
- the G and I coal seams have thicknesses in excess of 6 feet, and less than 20 feet.
- both coals are subbituminous in rank.
- both coal seams do not appear to be offset by small-scale local faults along the outcrop.
- both coal seams do not appear to be cut out by sandstone washouts (paleo-stream channels) in outcrop.
- both coal seams appear to contain groundwater, and they have a water table at a depth of approximately 100 feet.
- both coal seams are overlain by semi-competent (poorly cemented) sedimentary rock units.
- the surface terrain along the coal seam outcrops is not exceptionally rugged.
- the vegetative cover over the outcrop belt is not excessive and consists of sparse growths of grass, cacti, and greasewood.
- access to Section 11 is good.

- To assist in making the final decision as to the suitability of
this site, further site evaluation studies will be initiated during
- Phase II of the project. These studies include the following:

- geologic characterization
 - surface geologic mapping
 - fracture trace analysis
 - coal seam trenching and description
 - core drilling
 - geographical logging
 - lab analysis
- hydrologic characterization
 - well drilling
 - geophysical logging
 - piezometer installation
 - drawdown/recovery testing of the aquifers

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STRATIGRAPHIC COLUMN
North Knobs UCG Site
T.21N., R.89W., Carbon County, Wyoming
(Entire Column Within The Fort Union Fm.)

<u>Unit No.</u>	<u>Bed Designation</u>	<u>True Thickness</u>	<u>Description</u>
91		5.3'	Shale, med. dk. gray, (N4) slightly carbonaceous.
90		9.8'	Sandstone, grayish orange (10 YR 7/4), clayey, very soft.
89		0.9'	Shale, dark gray (N3), soft, carbonaceous.
88		114.0'	Sandstone, grayish orange (10 YR 7/4), clayey, very soft.
87	K-11	16.9'	Sandstone, very light gray (N8), weathers very pale orange (10 YR 8/2). Medium grained, well sorted. Mostly quartz w/less than 5% associated minerals. trace of biotite. Poorly cemented, friable. Massive bedding. "Knobby" weathering.
86		27.6'	Sandstone, very pale yellowish brown (10 YR 7/2), clayey, very soft, grades to shale at base.
85		1.8'	Shale, dark gray (N3), slightly carbonaceous, fissle, grades to sandstone at top.
84		6.2'	Sandstone, very pale yellowish brown (10 YR 7/2), clayey, very soft.
83	K-10	3.0'	Sandstone, yellowish gray (5Y 8/1), weathers moderate yellowish orange (10 YR 6/4). Medium grained, well sorted. Contains + 60% quartz, - 25% muscovite and biotite, + 15% feldspars and others. Very hard, well cemented (silica? cement). Resistant. Locally not cemented and very soft. Mostly massive bedding, continuous.
82		12.5'	Sandstone, very pale yellowish brown (10 YR 7/2), clayey. Very soft. Grades to shale at base.
81		0.3'	Shale, medium light gray (N6), soft.
80		93.6'	Sandstone, very pale yellowish brown (10 YR 7/2), clayey, very soft, locally slightly cemented forming a few slightly resistant lenses. Much of section covered. Grades to shale at top.
79		0.5'	Sandstone, weathers to very pale yellowish brown (10 YR 7/2) poorly cemented, but slightly resistant, moderately soft. Laminated bedding, fairly continuous.

<u>Unit No.</u>	<u>Bed Designation</u>	<u>True Thickness</u>	<u>Description</u>
78		7.1'	Sandstone, grayish orange (10 YR 7/4), clayey, very soft.
77		3.2'	Shale, medium light gray (N6), includes 0.5' bone, weathers to dark brown (5 YR 2/4) with carbonaceous partings.
76		0.1'	Coal, black, soft.
75		2.0'	Shale, medium light gray (N6)
74		6.2'	Sandstone, grayish orange (10 YR 7/4), clayey, very soft.
73		0.1'	Ironstone, moderately dark reddish brown (10 R 4/4), very fine grained very slightly resistant, continuous.
72		4.5'	Soil, moderate grayish brown (5 YR 4/2), very sandy.
71		0.4'	Shale, light gray (N7), moderately soft, includes small sandstone "pods" ($\frac{1}{2}$ 2" across and $\frac{1}{4}$ - $\frac{1}{2}$ " thick), fine grained, very light gray (N8).
70		0.9'	Shale, medium brownish gray (5 YR 5/1), slightly platy, grades to sandstone at base.
69		30.3'	Sandy soil, grayish orange (10 YR 7/4), clayey, slope former, very soft.
68	K-9	5.5'	Sandstone, yellowish gray (5 Y 8/1), weathers to grayish orange (10 YR 7/4) and moderately dark reddish brown (10 R 4/4). Medium to medium coarse grained, moderately sorted. Quartz = $\frac{1}{2}$ 60%, feldspar $\frac{1}{2}$ 25%, micas and others $\frac{1}{2}$ 15%. Fairly well cemented, moderately hard. Lower 3.0 - 3.5 feet is mostly massive bedding with individual beds up to 2.0' thick. Upper portion is from 0.5 - 2.0' thick and is mostly cross bedded, with channel type laminated beds and planar type thinly bedded units. Weathering is highly irregular, and commonly shows "tubular" columns as resistant structures. Iron staining is common. Erosion is irregular with locally consistent zones and locally discontinuous zones.
67		16.9'	Sandstone, very pale orange (10 YR 8/2), clayey, very soft.

<u>Unit No.</u>	<u>Bed Designation</u>	<u>True Thickness</u>	<u>Description</u>
66		13.4'	Shale, light gray (N7), soft, grades to sandstone at top.
65		18.7'	Covered section, probably soft clayey sandstone.
64		0.5'	Sandstone, weathers moderate reddish brown (10 R 4/6). Sort, forms slight ridge. Cross bedded, contains local ironstone.
63		6.2'	Sandstone, pale brown (5 YR 5/2), clayey, shaley, very soft. Soil.
62		1.0'	Shale, medium light gray (N6), sandy, contains iron staining.
61		1.5'	Shale, medium dark gray (N4) carbonaceous, contains boney coal and coal fragments.
60		2.7'	Shale, medium gray (N5), sandy, grades to carbonaceous shale at top.
59		1.7'	Sandstone, very pale yellowish brown (10 YR 7/2), clayey, soft.
58	K-8	1.0'	Sandstone, light gray (5 Y 7/1) weathers yellowish brown (10 YR 5/2), medium fine grained, well sorted, quartz - 90%, other - 10%. Well cemented, cement is silica (?) medium bedded (1/2" - 3"), beds are irregular. Contains plant fragments.
57		2.6'	Shale, light gray (N7), sandy, sand content increases toward top. Upper 0.5' is interbedded sandstone lenses and shale, containing burrows or tube fillings. - 1 cm. dia-.
56		0.1'	Coal stringer
55		13.4'	Shale, medium light gray (N6) at top, slightly sandy, mostly fissile, moderately soft, grades down into sandy shale, weathers grayish orange (10 YR 7/4). Includes very dark reddish brown (10 R 2/4) carbonaceous shale near base, with platy, carbonaceous partings, and plant fragments.
54		20.5'	Sandstone, pale brown (5 YR 5/2), clayey and shaley, forms soil slope.
53	K-7	18.7'	Sandstone, very pale orange (10 YR 8/2) weathers grayish orange (10 YR 7/4). Medium to medium coarse grained. Sorting fair to poor. Quartz = -40%, Feldspar = - 35%, micas and others = - 25%. Well cemented, moderately hard. Bedding is 1-2" thick, fairly continuous but lenticular. Thickness of entire unit inconsistent. Local load compaction.

<u>Unit No.</u>	<u>Bed Designation</u>	<u>True Thickness</u>	<u>Description</u>
52		29.4'	Sandstone, grayish orange (10 YR 7/4), clayey, soft.
51		46.5'	Sandstone, very pale brown (5 YR 6/2) at top, becomes lighter, very pale orange (10 YR 8/2) toward base. Clayey, very soft, forms soil slope.
50		5.9'	Coal, black (N1), soft, weathered, contains bone, shaley toward base.
49		0.4'	Bone, Grayish black (N2), soft.
48		0.9'	Clay, white to very light gray (N8-N9), silty.
47		0.7'	Shale, very dark reddish brown (10 R2/4), carbonaceous, soft.
46		0.3'	Sandstone, pale brown (5 YR 5/2), soft.
45		2.2	Shale, very light gray (N8), silty, moderately soft.
44		240.6'	Sandstone, grayish orange (10 YR 7/4), clayey, very soft, forms slope of soil and is mostly covered.
43		56.1'	Sandstone, grayish orange (10 YR 7/4), clayey, very soft, poorly sorted. Contains zones of local cement forming resistant lenses, moderately hard, containing feldspars which are weathering. Partially covered. Contains projected outcrop of "Walley" seam, not observed in field.
42		39.2'	Shale, moderate brownish gray (5 YR 5/1), sandy, sand content increases toward top. Unit is variable in color and lithology.
41	K-6	4.5'	Sandstone, yellowish gray (5 Y 8/1), weathers grayish orange (10 YR 7/4). Fine to medium grained, poorly sorted. - 70% quartz, remainder is in feldspars, micas, and small grain sizes. Fairly well cemented, but locally not cemented and nonresistant. Top is locally cross-bedded but unit is typically more massive toward base.
40		1.5'	Shale, medium gray (N5), sandy near top, grades downward to less sandy, more carbonaceous shale.
39		2.2'	Shale, very dark reddish brown (10 R 2/4), carbonaceous, platy.
38		8.9'	Shale, moderate brownish gray (5 YR 5/1), grades from carbonaceous at top to very sandy at base.

<u>Unit No.</u>	<u>Bed Designation</u>	<u>True Thickness</u>	<u>Description</u>
37	K-5	1.5'	Sandstone, light olive gray (5 Y 6/1), weathers pale yellowish brown (10 YR 6/2). Medium fine grained, well sorted. Composition mostly quartz, well cemented. Resistant. Laminated cross bedding. Thickness laterally variable.
36		5.3'	Shale, medium light gray (N6) moderately soft. Contains thinly laminated, medium grained sandstone beds.
35	K-4-B	1.8'	Sandstone, very light gray (N8), weathers very pale yellowish brown (10 YR 7/2). Medium grained, fairly well sorted. Quartz - 60%, Biotite (?) 10 - 15%. Friable, very soft, poorly indurated. Massive. Slightly resistant.
34		4.5'	Sandstone, very light gray (N8), shaley, very soft, non-resistant.
33	K-4-A	2.0'	Sandstone, very light gray (N8). Exactly as K-4-B except two 1.0' thick beds combine to form K-4-A.
32		7.1'	Sandstone, pale yellowish brown (10 YR 6/2), shaley, soft, grades to shale near base, forms slope.
31		0.3'	Shale, very dark reddish brown (10 R 2/4), clayey, slightly carbonaceous.
30		20.0'	Sandstone, pale yellowish brown (10 YR 6/2), shaley, soft. Grades from shale at top., forms slope.
29		1.9'	Sandstone, weathers grayish orange (10 YR 7/4), mostly quartz with - 30 feldspars, trace of biotite. Iron stained. Moderately hard locally, probably local cementation. Laminated cross-bedding at low angle. Lenticular and discontinuous. Locally resistant.
28		29.4'	Covered section - some dark gray to brown slightly carbonaceous. Shale near top.
27	K-3-B	0.5'	Sandstone, dark yellowish orange fresh (10 YR 6/6), grayish orange weathered (10 YR 7/4). Medium to medium fine grained, moderately well sorted. Contains high percentage of feldspars. Totally iron-stained throughout. Fairly well cemented and moderately hard, but very slightly friable. Bedding is discontinuous and overlaps to form zone which is laterally persistent. Thinly bedded. Contains well defined ripple marks on top surface.

<u>Unit No.</u>	<u>Bed Designation</u>	<u>True Thickness</u>	<u>Description</u>
26		4.5'	Sandstone, very pale orange (10 YR 8/2), clayey, soft.
25	K-3-A	0.5'	Sandstone, pale yellowish brown (10 YR 6/2), weathers grayish orange (10 YR 7/4). Medium to medium-coarse grained, moderately well sorted. Mixed composition, very well cemented. "Platy" bedding results in scalloped surfaces where weathered. Very continuous and consistent. Hard.
24		18.7'	Sandstone, very pale orange (10 YR 8/2), clayey, very soft, poorly consolidated, forms slope.
23		1.5'	Sandstone, weathers grayish orange (10 YR 7/4), Iron stained, local exposures are moderately hard, probably due to local cementation. Laminated cross bedding at high angles (30-35°). Lenticular and discontinuous, locally resistant.
22		19.1'	Sandstone, very pale orange, (10 YR 8/2), very soft, poorly cemented. Contains 5-10% feldspars, local ironstone. Massive. Forms slope.
21		2.7'	Sandstone, weathers grayish orange (10 YR 7/4), Iron stained. Local exposures are moderately hard, probably due to local cementation. Laminated cross-bedding. Lenticular and discontinuous. Locally resistant.
20		38.8	Sandstone, very pale orange (10 YR 8/2), very soft, massive, weathers to slope, base is covered.
19	G Seam	19.2'	Coal bed projected to outcrop from drill hole #261. Actual crop is soil and sage covered.
18		41.0'	Covered section, sandy soil. Probably soft clayey sandstone.
17	K-2-B	1.3'	Sandstone, weathers grayish orange (10 YR 7/4). Contains maybe as much as 50% feldspar. Fairly well cemented, moderately hard. Thin bedding is cross-laminated and locally channels down into or completely removes K-2-A. Locally discontinuous. Thickness variable.
16	K-2-A	4.5'	Sandstone, yellowish gray (5 Y 8/1), weathers same. Medium to coarse grained, poorly (?) sorted, possibly contains some fines and clays. Moderately well cemented and moderately hard, very slightly friable. Mixed composition. Salt and pepper appearance. Cross-bedded, beds are fairly thick, to massive. Thickness highly variable.

<u>Unit No.</u>	<u>Bed Designation</u>	<u>True Thickness</u>	<u>Description</u>
15		73.1'	Sandy soil, may be weathered soft sandstone or soil. Very pale orange in color (10 YR 8/2), unconsolidated.
14		1.6'	Sandstone, weathers pale grayish orange (10 YR 8/4). Poorly sorted, contains clay, feldspar + 50%, biotite (?) and iron staining. Lenticular, discontinuous, cross-bedded lenses. Locally resistant and variable.
13		14.3'	Shale, medium light gray (N6), moderately soft, grades to black shale at base, carbonaceous.
12		1.4'	Coal, grayish black (N2), bony, weathers badly.
11		14.0'	Shale, medium light gray (N6), moderately soft, contains scattered local sandstone lenses, cross-bedded, includes plant fragments, moderately hard. Grades to black carbonaceous shale at top.
10	K-1-C	0.5'	Sandstone, weathers grayish orange (10 YR 7/4), moderately hard, slightly cross-bedded. Very local, discontinuous.
9		1.2'	Sandstone, very pale orange (10 YR 8/2), soft, non-resistant.
8	K-1-B	0.5'	Sandstone, grayish red (10 R 4/2), weathers grayish orange (10 YR 7/4). Medium-fine grained. Iron stained. Contains root casts, plant fragments, leaves. Bedding is laminated to thinly bedded. Very continuous. Well cemented and hard.
7		2.8'	Sandstone, very light gray (N8), shaley, very soft.
6	K-1-A	0.5'	Sandstone, same as K-1-B except bedding is discontinuous, but "overlap" of beds results in persistent ridge. Thickness variable.
5		7.1'	Sandstone, very pale orange (10 YR 8/2), shaley, soft. Contains ironstone.

<u>Unit No.</u>	<u>Bed Designation</u>	<u>True Thickness</u>	<u>Description</u>
4	I Seam	13.3'	Coal with partings. Seam details as follows: 5.3' Coal 1.6' clayey red boney shale parting, plant fragments. 2.0' Coal 0.4' clayey red boney shale parting. 0.3' interbedded dirty coal and boney red shale. 0.3' clayey red boney shale parting. 3.4' Coal
3		24.9'	Shale, light gray (N7), clayey, contains scattered small sandstone lenses.
2		17.8'	Sandstone, verry pale orange (10 YR 8/2), soft, massive. Contains ironstone concretions.
1		20.1'	Covered section, soil to base of measured section on line 3 + 50., on baseline.
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		1317.7'	TOTAL SECTION