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Site Qualification Studies of the UCG-SDB at North Knobs, Wyoming

MASTER

by

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Table of Contents

		Page No.
Acknowledgments		i
Abstract		ii
1.0	Summary	1
2.0	Introduction	4
3.0	Objectives/Scope	6
4.0	Geotechnical Test Plan	10
4.1	Activity Descriptions	10
4.1.1	Topographic Definition and Mapping	10
4.1.2	Surface Geologic Evaluation and Mapping	12
4.1.3	The Subsurface Characterization Program	16
4.2	Products	23
4.2.1	Topographic Mapping	23
4.2.2	Surface Geologic Evaluation and Mapping	24
4.2.3	Subsurface Characterization	24
4.2.4	Core Analysis	25
5.0	Geotechnical Activities	26
5.1	Geology	26
5.1.1	Location	26
5.1.2	Regional Geology	26
5.1.3	Site Geology	30
5.1.4	Type Description for the G Coal Seam	43
5.2	Surface Description	48
5.2.1	Climatology	48
5.2.2	Surface Hydrology	57
5.2.3	Soils and Vegetation	60
5.2.4	History/Arch	77
5.3	Boundary Stata Studies	85
5.3.1	Description	85
5.3.2	Rock Quality Designation	85
5.3.3	Mechanical Properties	87
5.3.4	Subsidence Calculations	98
5.3.5	Conclusions and Recommendations	98
5.4	Coal Core Analysis	100
5.4.1	Core Hole Description	100
5.4.2	Continuity of the G Seam	100
5.4.3	Coal Analyses	102
5.5	Hydrology	122
5.5.1	Field Activities Log	123
5.5.2	Discussion of Results	124
5.5.3	Baseline Water Quality	127
6.0	Results	134
7.0	Recommendations	139

List of Figures

		Page No.
3.0-1	The Modified γ Well Configuration Consisting of One Production Well and One Injection Well	9
4.0-1	Summary of Phase II Geology Activities	11
4.1-1	Outline of Outcrop Belt Topographic Map	13
4.1-2	Location of Facility Topographic Map	14
4.1-3	Plan View of Well Field	19
4.1-4	Well Completion Activities	20
4.1-5	Well Completion Plan	21
4.1-6	Well Design for Drawdown Testing	22
5.1-1	Regional Geology of the Study Area	28
5.1-2	Thin Sandstone Unit	34
5.1-3	Geometry of Dominant & Subordinate Joint Set	37
5.1-4	Predicting Attitude of Dominant Joint	39
5.1-5	Predicting Attitude of Face Cleat from Bedding Attitude	42
5.1-6	Type Log of the G Seam, Core Hole No. 1	44
5.2-1	Soils Distribution Map for the North Knobs UCG Site	62
5.2-2	Range Site Map for the UCG Facility	63
5.2-3	Isopach Map for the Main Part of the G Coal Seam	70
5.2-4	Isopach Map for the G Coal Seam	71
5.2-5	Inactive Coal Mines on Sections Adjacent to Section 11	80
5.2-6	Location of Archeological Sites Within the North Knobs Study Area	82

List of Figures (cont'd.)

		Page No.
5.3-1	Location of Samples Selected from CH-4 for Boundary Strata Testing	86
5.3-2	Variation of Reduction Factor with Rock Quality	88
5.3-3	A Typical Stress-Strain Curve for a Uniaxial Compression Test	93
5.4-1	Core Hole Placement	101
5.4-2	Water Saturation Average Relative Permeability of Six Coals to Gas	113

List of Tables

		Page No.
1.0-1	Comparison of Site Acceptance Criteria and the North Knobs Data	2-3
3.0-1	Site Acceptance Criteria	7
4.1-1	Total Depths and Locations of Hydrologic Observation Zones for 1978 Geotechnical Drilling Program	17
5.1-1	Penetrated Depth to Units Recognizable in the Subsurface	32
5.1-2	Summary of Average True Thickness G Coal Seam	45
5.1-3	Summary of Estimated Reserves	47
5.2-1	Meterological Data	49-50
5.2-2	Glossary of General Terms	51
5.2-3	Parameters for Airfield Area and Climatic Area	52-53-54
5.2-4	Wind Direction and Average Speed Data from the Rawlins Airport	55
5.2-5	Wind Direction Data and Speed Data from the North Knobs Site	56
5.2-6	Legend for Range Sites	64-66
5.2-7 to 5.2-11	Range Conditions Worksheets	72-76
5.3-1	Rock Quality Designation for the Rock Units in Core Hole 4	89
5.3-2	Results of Uniaxial Compression Tests	91
5.3-3	Engineering Classification of Intact Rock	92
5.3-4	Classification of Tested Rock Units Based on their Uniaxial Compressive Strength	94
5.3-5	Classification of Tested Rock Units Based on Their Modulus Ratio	95

List of Tables (Cont'd.)

		Page No.
5.3-6	Triaxial Compression Tests Results	97
5.3-7	Results of Brazilian Tests	99
5.4-1	Core Hole 3 G Seam Proximate Analysis Results	103
5.4-2	Core Hole 4 G Seam Proximate Analysis Results	105
5.4-3	Core Hole 4 G Seam Upper Bench Proximate Analysis Results	106
5.4-4	Core Hole 3 I Seam Proximate Analysis Results	107
5.4-5	Core Hole 2 G Seam Drill Cuttings - Average Proximate Analysis Results	108
5.4-6	"As Received" Ultimates - G Seam	109
5.4-7	MAF Ultimates - G Seam	110
5.4-8	Effective Permeabilities of North Knobs, Hanna, and Gillette Coals	114
5.4-9	Physical Properties Determined by Core Labs, Inc	115
5.4-10	Density of the G Seam Coal and Ash	116
5.4-11	Petrographic Analysis of the G Seam from Core Hole 4 on a Moisture Ash-free Basis	118
5.5-1	Water Analysis Data	129
5.5-2	Water Sampling Physical Property Data	130
5.5-3	Summary of the Hydrologic Data for the North Knobs Facility	132
5.5-4	Assessment of the Hydrologic Testing Program	133
6.0-1	Comparison of Proximate and Ultimate Analysis Data for Coals from the North Knobs, Hanna, and Hoe Creek UCG Sites	136

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Abstract

The site qualification program for the North Knobs UCG site near Rawlins, Wyoming has been completed. This site will be the location for the field tests of Underground Coal Gasification of Steeply Dipping Beds undertaken by Gulf Research and Development Company for DOE in a cost shared contract.

Site characterization included a comprehensive geotechnical analysis along with vegetation, historical, and archeological studies. The G coal seam chosen for these tests is a subbituminous B coal with a true seam thickness of 22 feet and has thin coal benches above and below the main seam. The water table is at 90 feet below the surface. Hydrologic studies have defined the seam as an aquiclude (non-aquifer). The site is deemed restorable to regulatory requirements.

Evaluation of this site indicates total acceptability for the three-test program planned by GR&DC.

1.0 SUMMARY

The site qualification information was obtained from data collected during geotechnical field activities.

The geotechnical field activities included:

- Surface mapping
- Aerial photos
- Soil and vegetation surveys
- Geophysical logs of drill holes
- Chemical and physical testing of cores
- Well drawdown studies
- Water analysis
- Trenching and augering of outcrop zones
- Review of available data

Data documents produced by the field activities included:

- Geologic cross-sections along coal outcrop
- Lithologic columns of drill holes
- Proximate, ultimate, and petrographic analyses of coal cores
- Physical properties of boundary strata
- Fracture patterns of strata
- Fault patterns in the area
- Aerial photographs
- Topographic maps
- Drawdown and recovery data on coal seam
- Water quality from coal seam zone

Analyses of collected data documents shows that the North Knobs site meets the DOE and Project site acceptance criteria listed in Table 1.0-1.

TABLE 1.0-1

Comparison of Site Acceptance Criteria and the North Knobs Data

Site Acceptance Criteria	North Knobs Data
1. Coal Seam Geometry	
a. Seam dip between 45-75°	65°
b. Minor dip variation	<2°
c. Seam thickness between 10-30 ft*	22.7 ft (main part of seam) (37.5 ft seam including partings)
d. Minor thickness variation	Range = ±6 ft+ (seam including partings)
e. Outcrop of coal seam available	No
2. Coal Seam Consistency	
a. Absence of major seam partings (<20% seam thickness)	19%
b. Absence of major paleo-stream channels	Criteria met
c. Absence of major faults	Criteria met
d. Absence of extensive cleating	Criteria met
3. Coal Chemistry	
a. Subbituminous rank	Subbituminous B
b. Non-agglomerating	Free swelling index = 0
c. Ash fusion >1900°F	2331
d. Sulfur content <1%	0.19
e. Ash content <30%	5.2
4. Boundary Strata	
a. No coal seams within 50 ft above and 30 ft below test seam	Criteria met
b. No fractures/faults continuous to the surface	Criteria met
c. No unconsolidated formations adjacent to or stratigraphically near the test seam	Criteria met
5. Hydrology	
a. No potable aquifers less than 100 ft above or 50 ft below test seam	Criteria met
b. No high yield aquifers less than 50 ft above or 30 ft below test seam	Criteria met
c. No significant communication between the test seam and boundary strata	Criteria met
d. Low groundwater yield from the test seam	Criteria met (<0.1 gal/day/ft^2)
e. Definable water table	(Depth = 90 ft) Criteria met
6. Logistics	
a. Low topographic relief	<150 ft
b. Minimal soil/alluvium cover	0-60 ft
c. Minimal vegetative cover	Sparse sagebrush

* True thickness + Within the zone of gasification

In addition to the above criteria, the process implications of the geologic parameters found are:

- Injection of supplemental water into the injected air will probably be required to reach desirable levels of product gas quality.
- Water will probably have to be trucked since no high yield aquifers were detected on site.
- Low permeability of the coal seam may create problems in establishing air communications between process wells. Supplemental fracturing options may be required.
- The homogeneous nature of the coal seam suggests that once the link is established, the reactor should be relatively leak-free unless subsidence is extreme.
- No surface subsidence is expected.
- Restoration of site is feasible.
- The site appears to be nearly ideal for UCG-SDB.

2.0 INTRODUCTION

In situ gasification of coal offers many advantages over conventional methods for utilizing U.S. coal reserves:

- It permits recovery of deeper coal resources without the dangers associated with underground mining procedures.
- It extends the utilization of coal reserves beyond those recoverable by conventional mining techniques.
- It offers an alternative to strip mining.
- It is potentially a less expensive source of gas than mining and surface gasification.

The UCG process has proven "commercially feasible" in the USSR and has been field tested on several sites in the U.S. However, there are several notable elements involved in a UCG field test:

- Remoteness of the reactor. Although a great deal of experience has been obtained on surface gasifiers, transfer of the technology to a reactor of unknown dimensions is difficult. There are few direct means of monitoring the reactor.
- Variability of the reactor. Engineers have difficulty dealing with a reactor constantly changing in size and shape in an unpredictable manner.
- Definition of the reactor. Variability of the reactor in a geologic domain must be defined in as much detail as possible.

- Environmental factors. Control of environmental effects produced by implementation of the process in the field is somewhat limited.

- Geologic parameters. Seam continuity, roof, and floor characteristics, coal chemistry, and water flow into and out of the reactor are major factors in the process.

The GR&DC field test of the UCG-SDB process under DOE contract #DE-AC03-77-ET-13108 is to be performed at the North Knobs area west of Rawlins, Wyoming. A comprehensive geotechnical program was considered essential for completion of a successful test. This program has been completed and provided the required data necessary for design of the test, design of the surface facility, input for permits, a foundation for the environmental program, and to ensure correct placement of the process module.

A preliminary evaluation of the site was described in Appendix A of the Phase I Report for this project. Certain elements were also included in the application for the Permit to Mine submitted to the Wyoming Department of Environmental Quality on October 2, 1978. Very little of that information is repeated in this document.

This report consists of three parts:

Main Report: Presents the geotechnical plan, introduces and analyzes data, discusses process implications. Conclusions and recommendations are part of the main report.

Appendix A: Includes detailed descriptions of field activities, well completion data, and core analysis data.

Appendix B: Includes supplemental field data, oversize geologic drawings, maps, and lithologic logs.

3.0 OBJECTIVES/SCOPE

The technical objectives associated with underground coal gasification of steeply dipping beds are as follows:

- To demonstrate gasification of steeply dipping coal beds for the first time in the U.S.
- To increase scientific understanding of the process.
- To determine environmental acceptability of the process.
- To provide an engineering basis for planning and designing future UCG-SDB operations and estimating their cost and performance.

An experimental program consisting of three field tests was developed to provide data to meet the project objectives. In order to carry out the project, a site capable of supporting the UCG test program with a minimum of site-specific problems had to be found.

Requirements were established to select an ideal site for the tests. Preliminary evaluation at North Knobs indicated that it was a potentially satisfactory site. The geotechnical program was carried out to provide data necessary for determining whether North Knobs test site met all the defined site criteria. These criteria were established by the technical staff and the DOE and are listed in Table 3.0-1. Additional data such as topographic maps, geologic cross-sections, soil surveys, and climatic trends were collected to aid in the design and structure of the site facility.

The very nature of the gasification process makes the coal seam both a reactor and a reactant. Definition of the coal seam is extremely important for proper design and performance of the tests. The chemical composition of the coal as a reactant is also needed to analyze the process. In addition,

TABLE 3.0-1

Site Acceptance Criteria

1. Coal Seam Geometry
   - a.* Seam dip between 45-75°*
   - b. Minor dip variation
   - c.* Seam thickness between 10-30 ft
   - d. Minor thickness variation
   - e. Outcrop of coal seam available

2. Coal Seam Consistency
   - a. Absence of major seam partings (<20% of seam thickness)
   - b. Absence of major paleo-stream channels
   - c. Absence of major faults
   - d. Absence of extensive cleating

3. Coal Chemistry
   - a.* Subbituminous rank
   - b. Non-agglomerating
   - c. Ash fusion >1900°F
   - d. Sulfur content <1%
   - e. Ash content <30%

4. Boundary Strata
   - a. No coal seams within 50 ft above and 30 ft below test seam
   - b. No fractures/faults continuous to the surface
   - c. No unconsolidated formations adjacent to or stratigraphically near the test seam

5. Hydrology
   - a. No potable aquifers less than 100 ft above or 50 ft below test seam
   - b. No high yield aquifers less than 50 ft above or 30 ft below test seam
   - c. No significant communication between the test seam and boundary strata
   - d. Low groundwater yield from the test seam
   - e.* Definable water table

6. Logistics
   - a. Low topographic relief
   - b. Minimal soil/alluvium cover
   - c. Minimal vegetative cover

*DOE contractual criteria.

groundwater influx is a critical process parameter for the production of high-quality gas.

Gasification of steeply dipping coal requires installation of process modules utilizing slant drilling technology. The module for the first test is shown in Figure 3.0-1. Detailed information on geologic strata is also necessary before installation of the process wells can begin.

The environmental effects projected are from ground water contamination and subsidence estimations. Hydrologic properties, groundwater quality, and boundary strata properties are the primary sources of data for evaluating these effects. The goal of the overall geotechnical program was to provide the site-specific data required to meet the needs of all the different elements of this project.

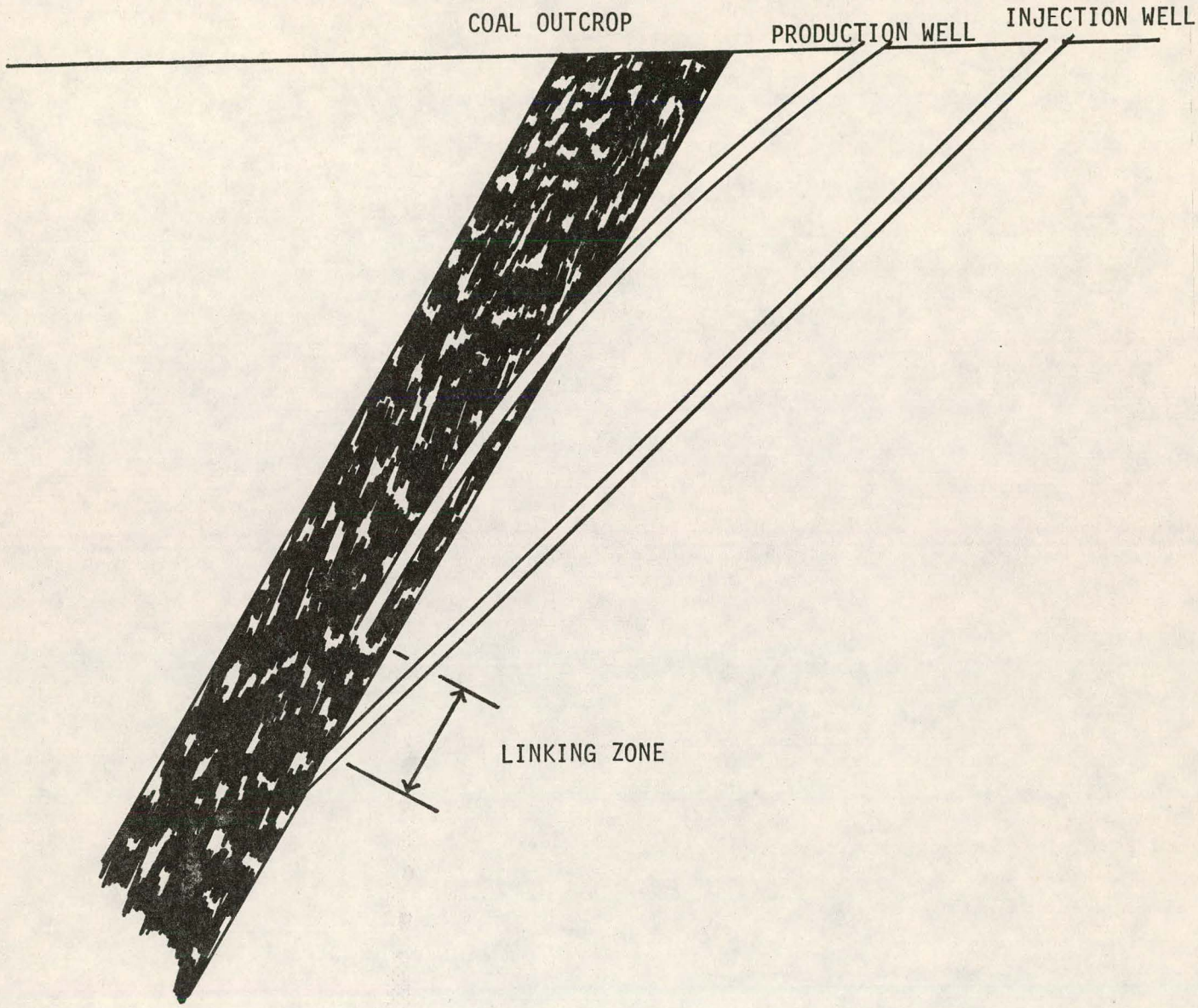


FIGURE 3.0-1

THE MODIFIED Y WELL CONFIGURATION CONSISTING
OF ONE PRODUCTION WELL AND ONE INJECTION WELL

4.0 GEOTECHNICAL TEST PLAN

The test plan has been designed to achieve project objectives within time, budget, and regulatory constraints imposed by the DOE contract and regulatory agencies. The project objectives have been translated into specific activities required to achieve those objectives.

This program is an attempt to achieve a balance between the level of detail required to meet the data objectives and operate within budgetary and time constraints. For example, a high resolution seismic survey was originally planned to obtain subsurface coal seam data; however, it had to be eliminated due to cost constraints. In other cases, certain characterization activities were expanded where it was crucial to the project. The final program produced the geotechnical information. Figure 4.0-1 describes the flow of geotechnical activities necessary to make logical judgments and assumptions about the test plan and to achieve project objectives.

4.1 ACTIVITY DESCRIPTIONS

4.1.1 Topographic Definition and Mapping

This activity produced aerial photographs and topographic maps for the UCG site and facility.

Prior to any field work, a knowledge of existing geotechnical data was gained by review of available data, such as geophysical logs, geologic maps, and aerial photographs.

Initial activities involved a field surveying program to establish horizontal and vertical control at the UCG site. This program established the surface location and/or elevation of:

- The corners of Section 11 and the Section 11 boundary lines.
- Aerial photograph control points.
- The Energy Development Company (EDC) and GR&DC drill holes.
- A baseline subparallel to the G coal seam outcrop. A baseline was established which runs N 25° 30' W. Points were located at 100 ft

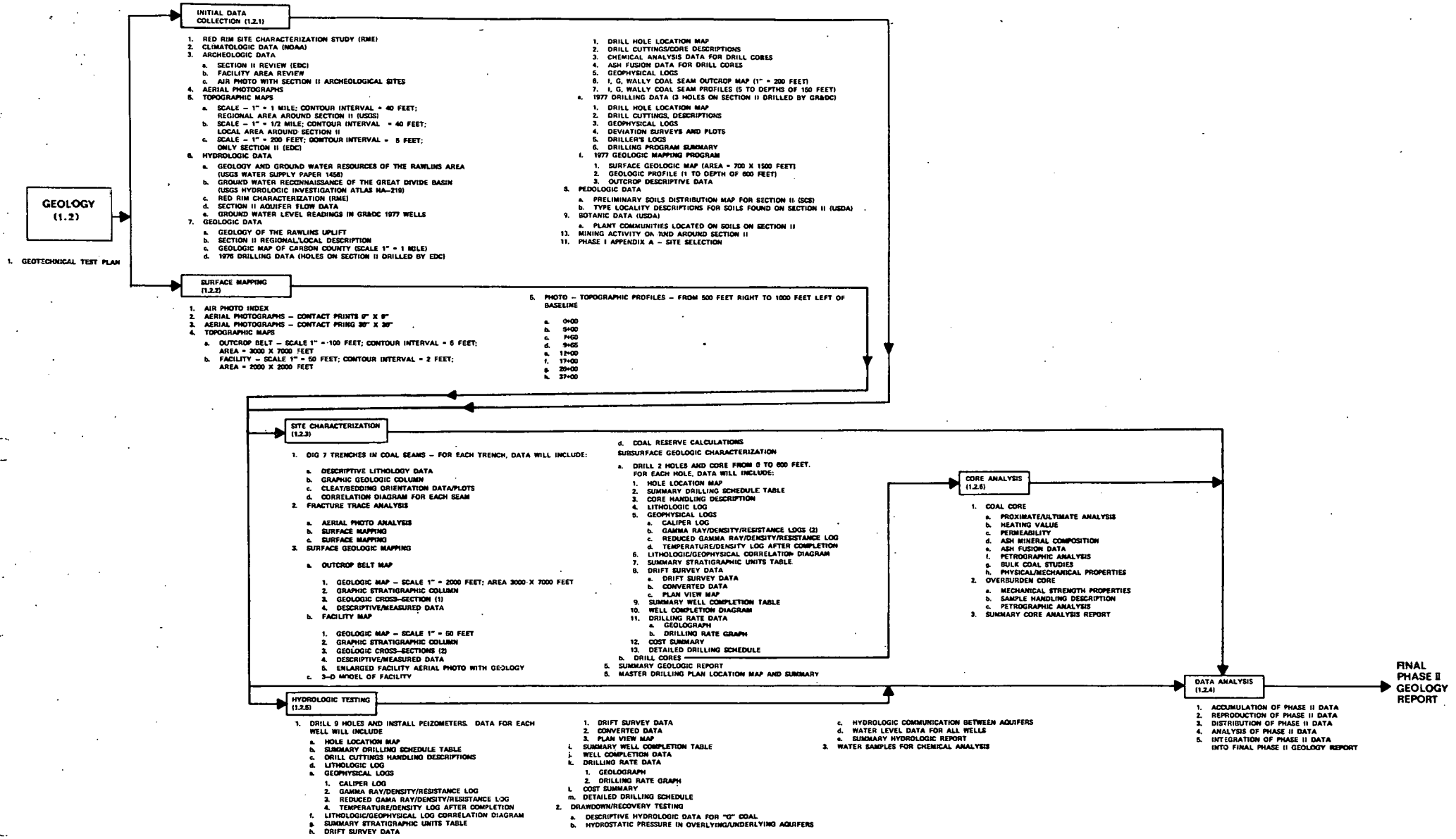


FIGURE 4.0-1 SUMMARY OF PHASE II GEOLOGY ACTIVITIES

intervals. In addition, lines were run perpendicular to this baseline at 0 + 00, 5 + 00, 7 + 60, 9 + 65, 11 + 00, 17 + 00, 26 + 00, and 37 + 00 and staked at 100' intervals.

Black and white aerial photography provided stereographic coverage meeting standard U.S. Geological Survey specifications. The area covered included the UCG site outcrop belt and access road areas. This effort provided 9 in x 9 in and enlarged (36 in x 36 in) black and white contact prints. Topographic maps were prepared using the surveyed horizontal and vertical control data and the aerial photographs. A map of the UCG site outcrop belt (area equal to 3000 ft x 7000 ft) was constructed with a scale 1 in = 100 ft and a contour interval of 5 ft (Figure B-48 in Appendix B). A map of the UCG facility was also produced. It covers an area 2000 ft x 2000 ft. This map has a horizontal scale of 1 in = 50 ft and a contour interval of 2 ft. The areas that these maps include are shown in Figures 4.1-1 and 4.1-2.

Eight photo/topographic profiles across the outcrop belt were constructed for illustration and correlation of the surface and subsurface geology. These were located at 0 + 00, 5 + 00, 7 + 60, 9 + 65, 12 + 00, 17 + 00, 26 + 00, and 37 + 00 on the baseline and were used in the design of the Phase II hydrologic testing and facility design. (Figures B-6 and B-7 are examples of photo/topographic profiles with geology plotted.) They will also be used in the process module drilling program and to determine the reactor shape during and after gasification. The horizontal scale is 1 in = 50 ft and the vertical scale is 1 in = 50 ft.

4.1.2 Surface Geologic Evaluation and Mapping

The purpose of activities under this section was to obtain surface data to aid in characterizing the UCG facility and defining the drilling techniques to be used.

During the surface geologic mapping program, regional and site specific geologic data were collected in order to construct geologic maps, cross sections, geologic columns and a 3-D model of the site. The geologic

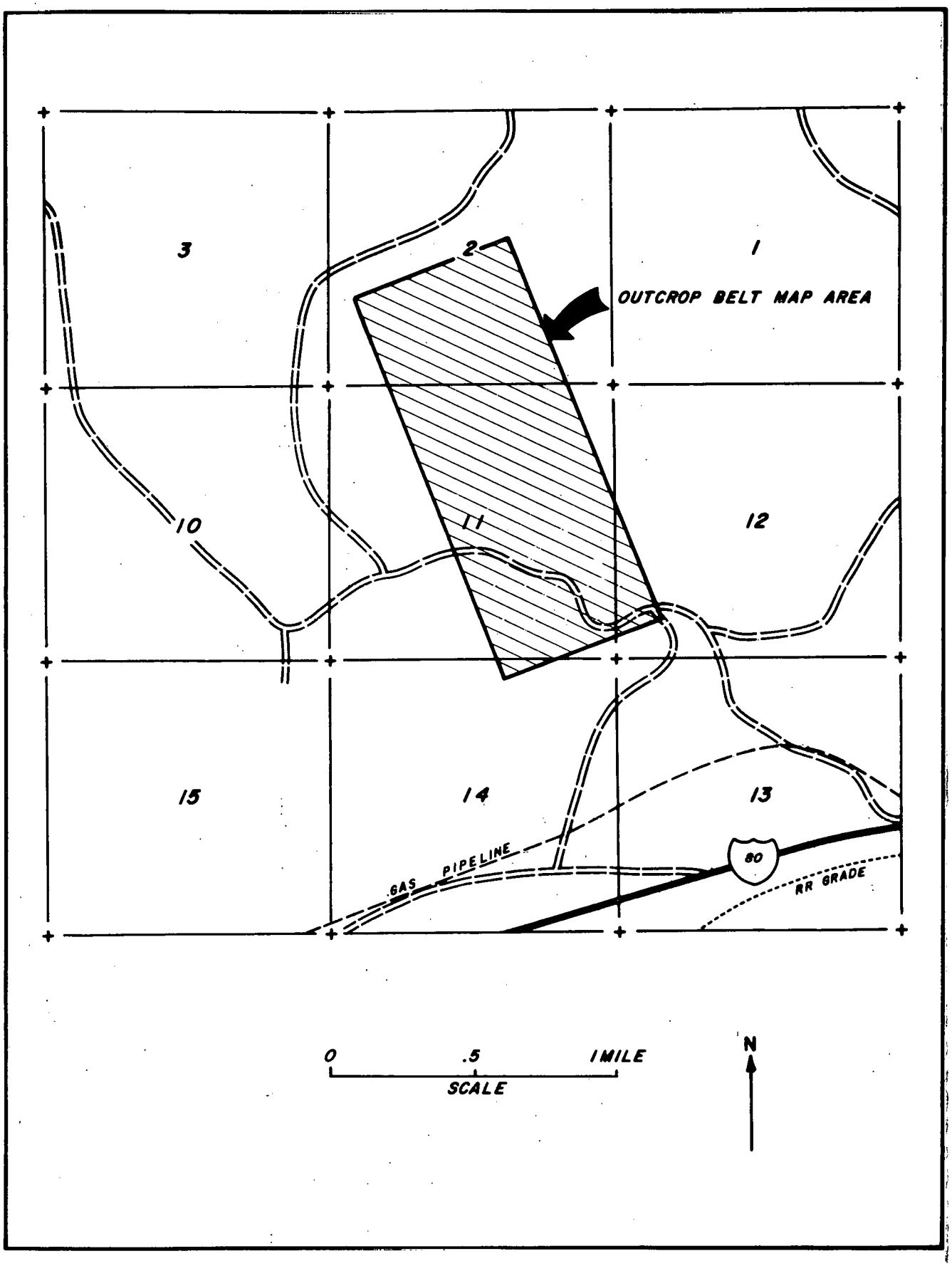


FIGURE 4.1-1 OUTLINE OF OUTCROP BELT TOPOGRAPHIC MAP

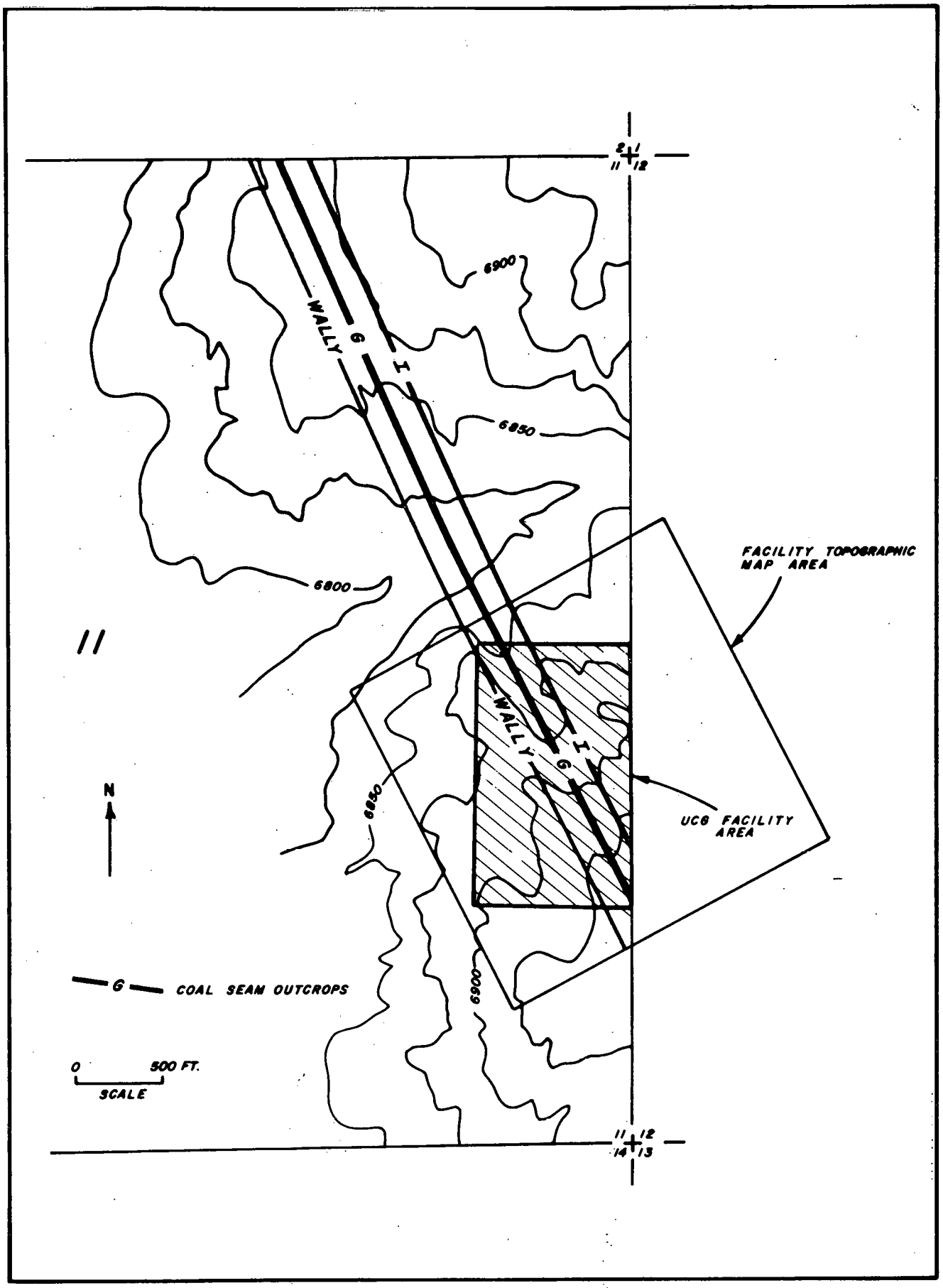


FIGURE 4.1-2 LOCATION OF FACILITY TOPOGRAPHIC MAP

data were collected by: (1) field observations of outcrops; (2) trenching, bulldozing, and augering operations to expose the coal seams; and (3) description and mapping of fracture traces observed on aerial photographs and in outcrops. The field geologic mapping was done on both large and small scale topographic maps and aerial photographs.

A regional geologic map was made of Section 11 and the adjacent eight sections at a scale of 1 in = 2000 ft with an accompanying stratigraphic column at a scale of 1 in = 50 ft. (Figure B-2 in Appendix B.) One geologic/topographic profile was constructed perpendicular to the G coal seam outcrop on the UCG facility. The profile was projected to a depth of 3000 ft in a cross-section, in which the horizontal scale is 1 in = 1000 ft, and the vertical scale is 1 in = 500 ft.

A detailed surface geologic map (scale 1 in = 50 ft), (Figure B-4 in Appendix B) geologic cross sections, and stratigraphic column (scale 1 in = 10 ft) of the UCG facility was produced. Geologic/topographic profiles of the facility were made with subsurface geology projected to 700 ft. The horizontal scale for these diagrams is 1 in = 50 ft and the vertical scale, 1 in = 50 ft.

Trenches were dug across the I, G, and Wally coal seam outcrops to expose the coal seam and the beds immediately above and below the coal. The trenches were logged for lithologic, structural, and textural data that includes the nature of lithologic changes, bedding, attitude and character, thickness, coal cleat orientation and cleat character. Large-scale geologic columns (scale 1 in = 1 ft) were produced along with correlation diagrams for the coal seams. A graphic plot of the relationship between the bedding attitudes and cleat directions was made. (B39-44 in Appendix B).

A surface fracture trace map was produced incorporating field observations and analysis of aerial photographs. A geologic representation of the density, distribution, and orientation of fracture traces and lithologic bedding attitudes was placed on a topographic map (scale 1 in = 100 ft) and an enlarged aerial photograph at the facility.

4.1.3 The Subsurface Characterization Program

The subsurface characterization program consisted of collecting data from two types of holes; vertical core holes (2) and vertical hydrologic observation wells (10). Information from these holes was used to:

- determine the subsurface structural and stratigraphic character of the G coal seam and over/underlying strata.
- determine the hydrologic characterisitics of the G coal seam.
- obtain coal and boundary strata samples for chemical analysis and physical property testing.
- obtain water samples for chemical analysis.

The drilling program was designed to include:

- surveying the surface location and elevation of each drill hole.
- describing the drill cores and cuttings.
- logging the holes with geophysical techniques.

4.1.3.1 Core Hole Analysis

Two vertical holes with a nominal diameter of 6 1/2 in were drilled on locations specified by the GR&DC site representative (see Figure 4.1-3). These holes were continuously cored to a depth of 25 ft below the coal seam (one through the G and one through the I seam) for a total depth of about 600 ft each (Table 4.1-1). After coring, the wells were completed as shown in Figures 4.1-4 and 4.1-5.

The geologic information obtained from core examination provided data for the local stratigraphic and structural characterization of the UCG site. This information was integrated with the surface geology data to produce cross-sections and stratigraphic columns which graphically show the G seam thickness, facies changes, and reserve estimates.

Table 4.1-1

Total Depths and Locations of Hydrologic
Observation Zones for 1978 Geotechnical Drilling Program

Hole No:	Projected Total Depth (ft)	Piezometer Installed In
CH-1	550	Coal
CH-2	575	Coal
CH-3	600	Coal
CH-4	600	Coal
Hydro 7	450	Coal
Hydro 8	550	Coal
Hydro 9	650	Coal
Hydro 11	450	Over Burden
Hydro 12	550	Coal
Hydro 13	800	Under Burden
Hydro 15	600	Coal
Pump 1	550	Coal

Each hole was geophysically logged after drilling and before a piezometer was installed. The following logs were taken:

- caliper
- gamma ray
- gamma gamma
- resistivity
- temperature
- drift survey

The logs were compared with the cores to further characterize the surface dip integrity of the coal seam and overburden character beneath the UCG facility. The logs from core hole 3 and 4 are included in B-48 and B-49 of Appendix B.

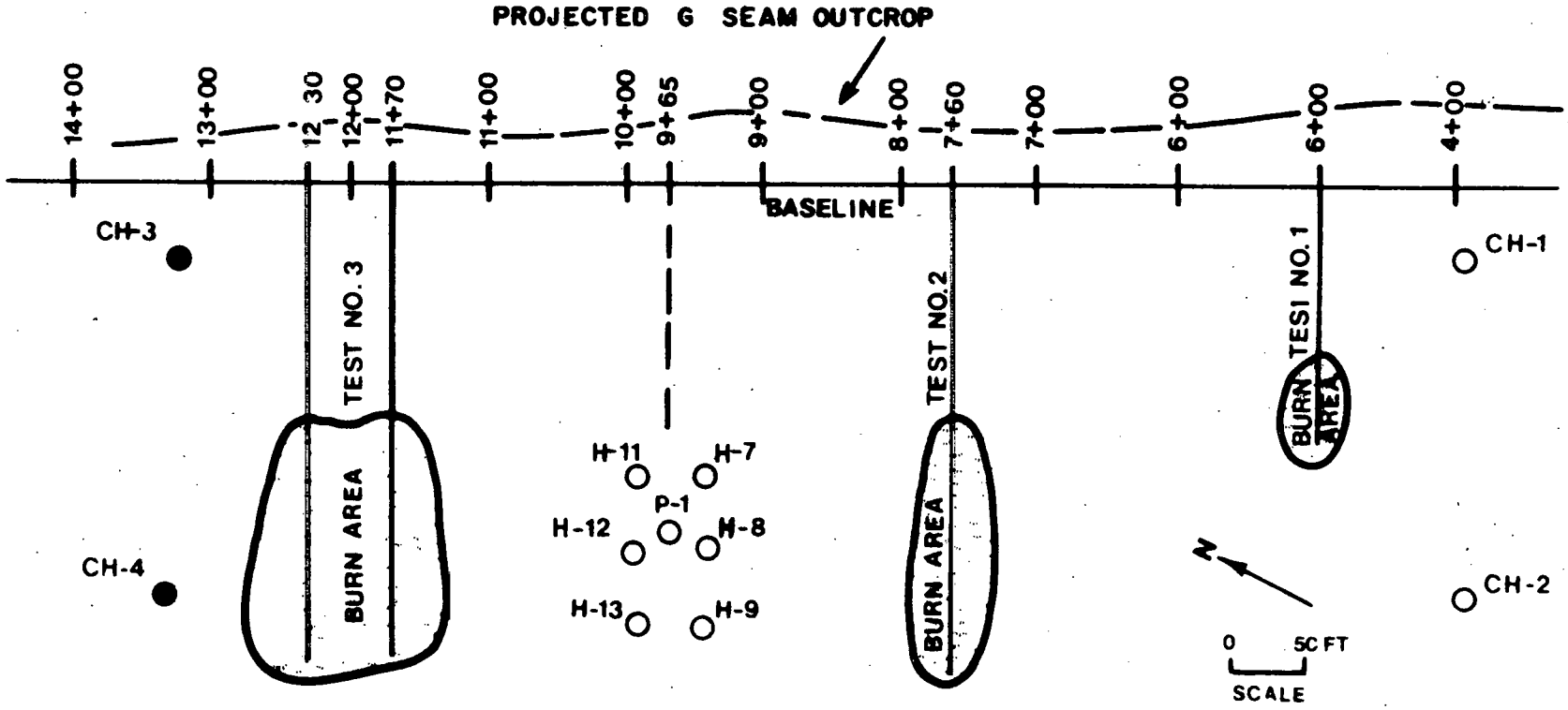
The core analysis program consisted of evaluating the following:

- directional permeability of the G seam coal.
- petrographic properties of the G seam coal and boundary strata.
- proximate and ultimate composition of the G and I coal seams.
- heating value of the G and I seams.
- mineral composition of coal ash from the G and I coal seams.
- strength properties of the boundary strata.

4.1.3.2 Hydrologic Characterization

In order to determine the subsurface hydrologic characteristics of the UCG site, a series of 10 observation wells and one pump well were drilled (Figure 4.1-3). All wells were drilled to a 6 1/2-in nominal diameter and completed as illustrated in Figures 4.1-4 and 4.1-5 with steel casing (3 or 4 in ID). The piezometers in H-7, H-8, H-9, H-12, and H-15 monitored the coal seam. The overlying and underlying rock was monitored from piezometers in H-11 and H-13, respectively.

The pump well was used to withdraw water from the coal seam. The pump well was drilled 25 ft below the G coal seam. A well design for the pump well is shown in Figure 4.1-6.



NOTE: 1. H-13 IS LOCATED APPROXIMATELY 235 FT. SOUTH OF POINT 36+75 ON THE BASELINE

2. POINT 0+00 ON THE BASELINE IS LOCATED ON THE EAST SECTION LINE OF SECTION 11, 11+24 FT. NORTH OF THE SOUTHEAST CORNER OF SECTION 11. THE BASELINE TRENDS N25°-30'W

LEGEND

HYDROLOGIC OBSERVATION WELLS

● CORED (0' TO TOTAL DEPTH)

○ NOT CORED

FIGURE 4.1-3
PLAN VIEW OF WELL FIELD

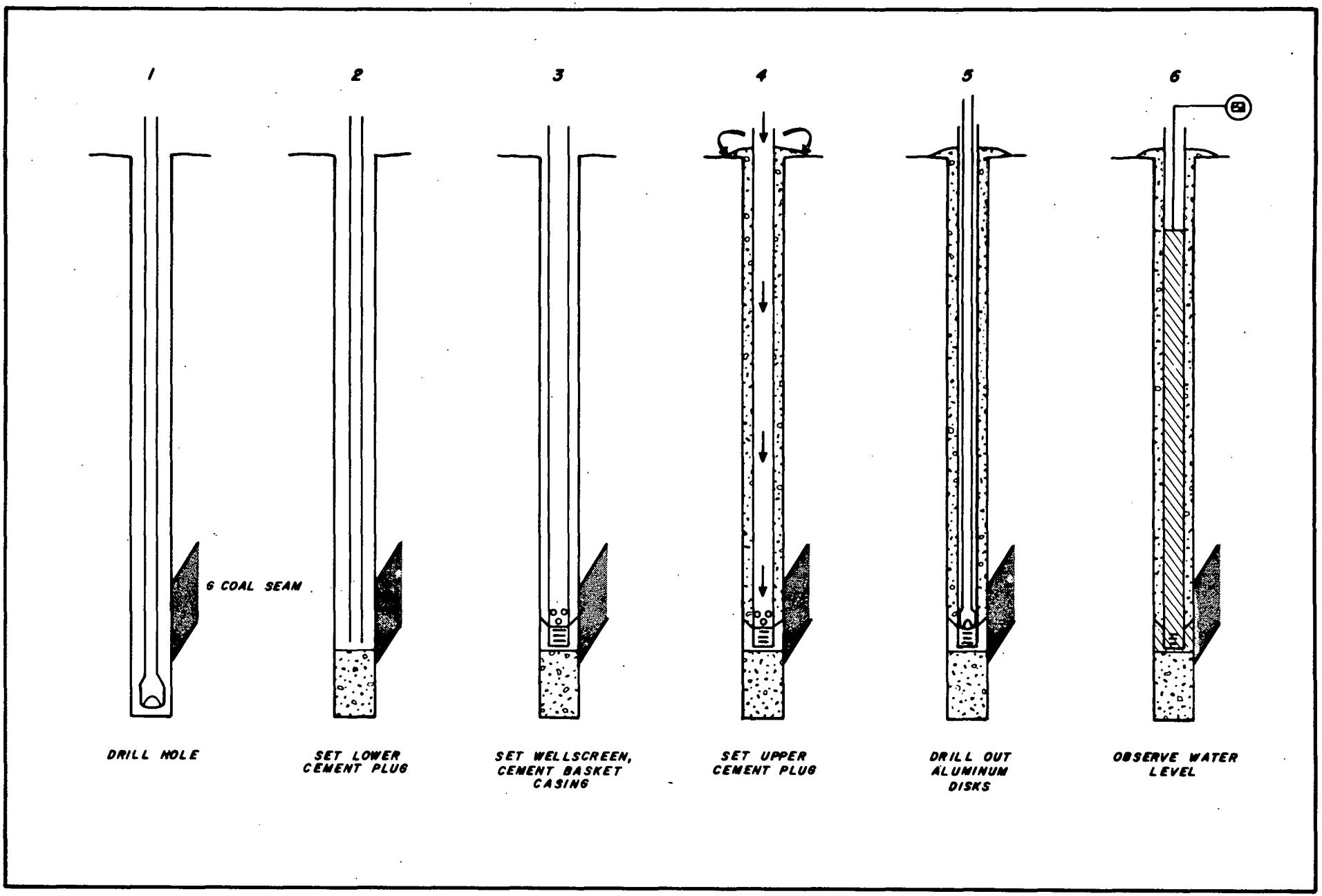


FIGURE 4.1-4 WELL COMPLETION ACTIVITIES

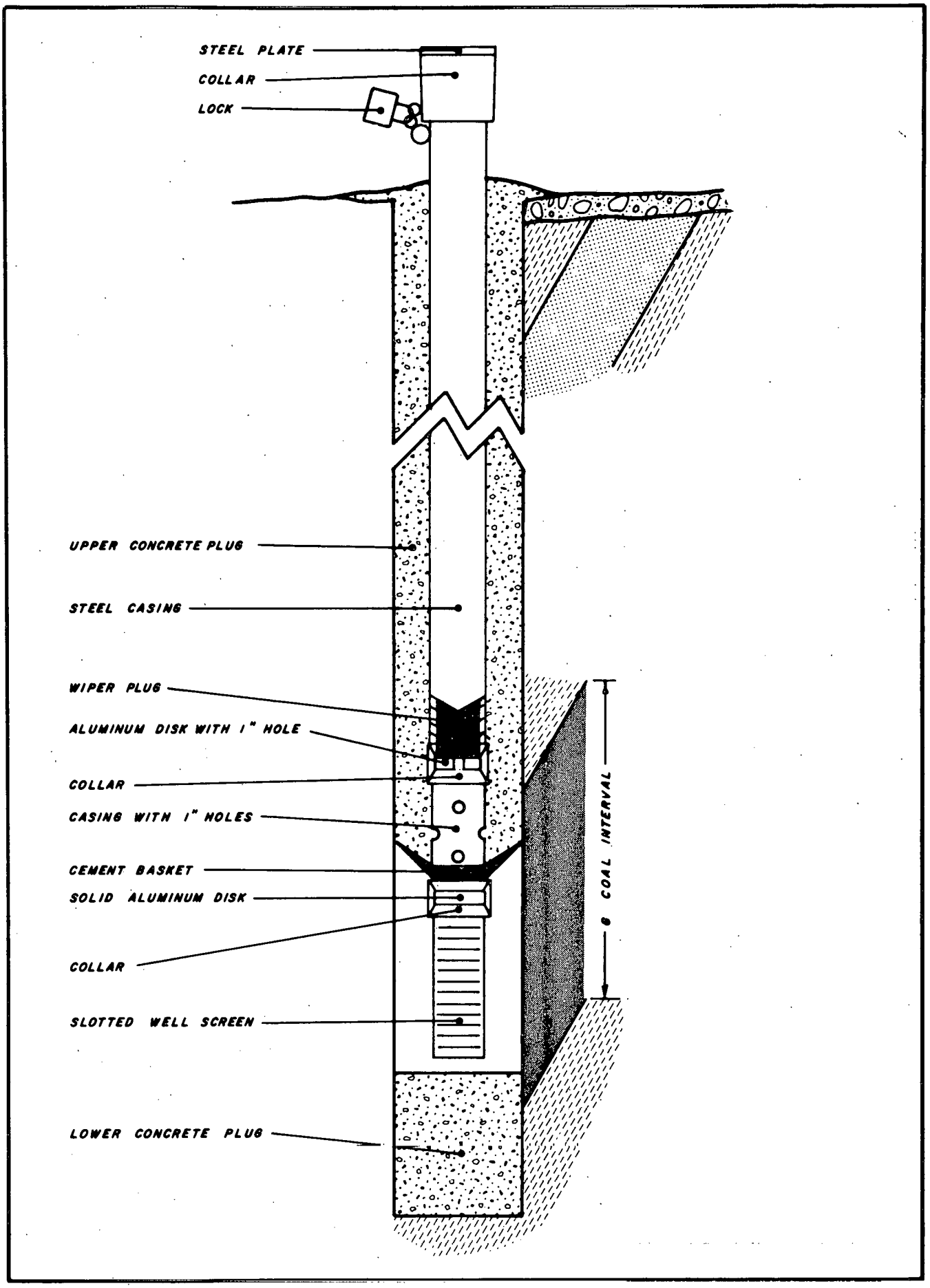


FIGURE 4.1-5 WELL COMPLETION PLAN

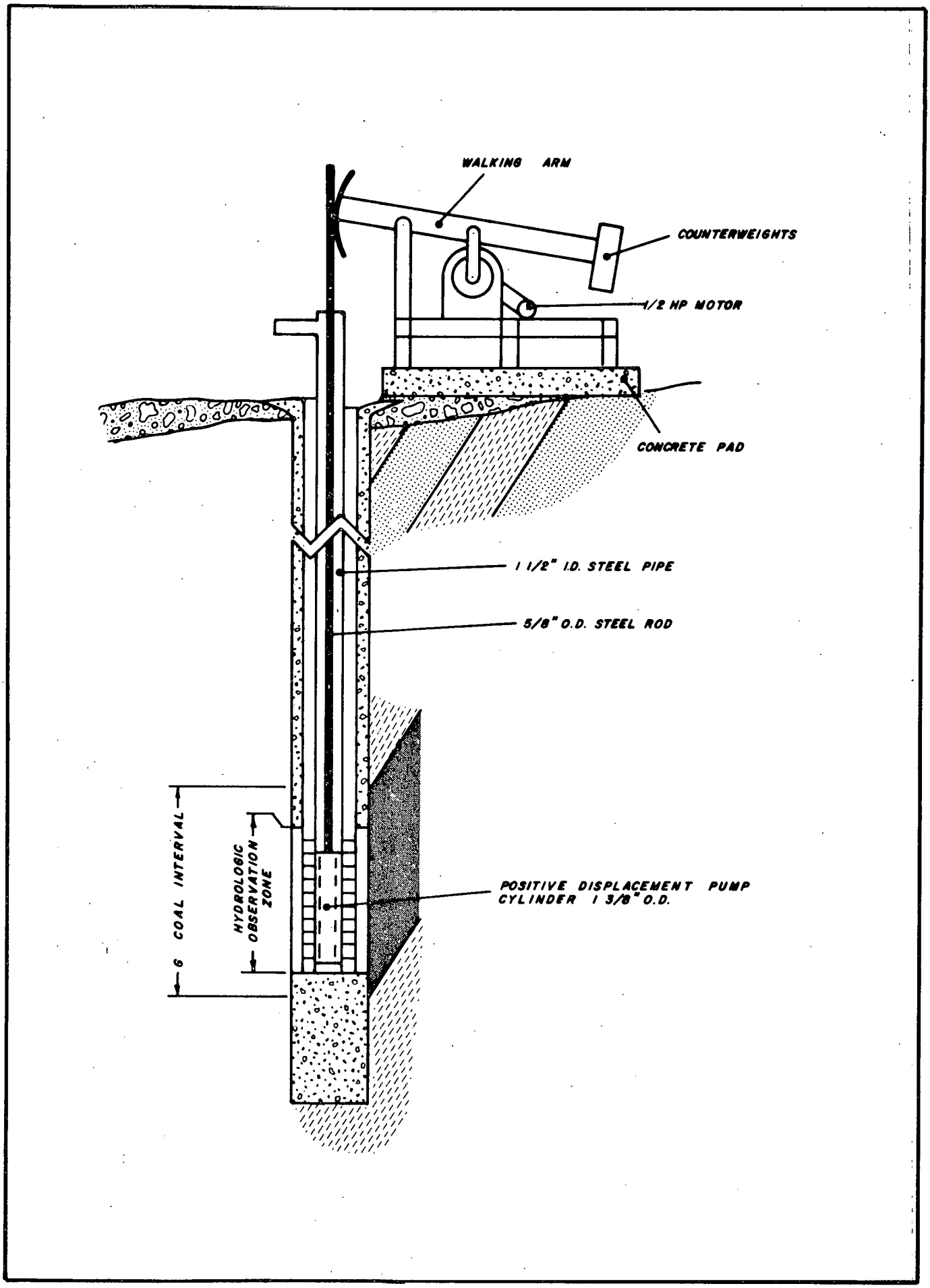


FIGURE 4.1-6 WELL DESIGN FOR DRAWDOWN TESTING

Water was pumped from the pump well, and changes in the water levels in the observation wells were recorded.

The hydrologic tests provided the following information:

- the extent of hydraulic connection between aquifer and surface sources.
- the direction of preferred flow in the coal seam.
- the transmissivity of the coal.
- the potentiometric surface within the coal seam.
- the quantity of water present in the coal seam.

Water samples were collected and shipped to a nearby water analysis laboratory for chemical analysis.

A more detailed description of these activities can be found in Section 5.5.

4.2 PRODUCTS

4.2.1 Topographic Mapping

Aerial photographs and topographic maps constructed for the UCG site and facility included:

- stereographic, black and white aerial photographs meeting USGS specifications.
- an enlarged aerial photograph of the site (scale 1 in = 50 ft).
- a topographic map of the UCG site outcrop belt (area 3000 ft x 7000 ft).
- a topographic map of the UCG site (area 2000 ft x 2000 ft).
- eight photo-topographic profiles across the site outcrop belt.

The map establishes the surface locations of:

- the corners of Section 11.
- the Energy Development Company (EDC) and GR&DC/TRW drill holes.
- a baseline subparallel to the G coal seam outcrop.
- 5 radial lines from the baseline.
- the north, east, south and west section lines of Section 11.

4.2.2 Surface Geologic Evaluation and Mapping

Surface geologic mapping of the site/facility includes:

- a geologic map of Section 11 and the 8 adjacent sections (scale 1 in = 2000 ft).
- a geologic cross section projected to a depth of 3000 ft.
- a stratigraphic column (1 in = 50 ft) for the 9-section area.
- a detailed surface geologic map (scale 1 in = 50 ft) of the facility (site).
- a stratigraphic column (scale 1 in = 10 ft) for the facility based on surface data.
- two geologic/topographic cross-sections of the facility projected to a 700 ft depth (vertical and horizontal scale of 1 in = 50 ft).
- trenching and augering to expose the coal seam and lithology immediately above and below the coal.
- a surface fracture trace map.
- a graphic plot of the relationship between the coal bedding attitudes and cleat directions.

4.2.3 Subsurface Characterization

Data collected from the subsurface characterization included:

- drill core cuttings and core descriptions. These were used to construct lithologic logs and geologic cross-sections.

- geophysical logs of each hole. These included:

  - caliper
  - gamma ray
  - gamma gamma
  - resistance
  - temperature
  - drift survey

- descriptive hydrologic data and interpretations for the G coal seam. These included:

  - transmissivity of the coal seam.
  - the directional permeability within the seam.
  - a map of the potentiometric surface in the coal aquifer.
  - water samples for chemical analysis.
  - the extent of hydraulic communication between the coal and over/underlying aquifers.

4.2.4 Core Analysis

Data collected from the core analysis program was derived from:

- tests performed on the coal; included proximate and ultimate analyses, ash fusion, heating value, permeability, petrographic analysis and mineral inclusion studies; tests performed on the boundary strata included physical property tests (uniaxial/triaxial compression and Brazilian tests) and petrographic analysis.

- boundary strata analysis.

5.0 GEOTECHNICAL ACTIVITIES

5.1 GEOLOGY

Site specific geologic details of the North Knobs UCG test site were collected and utilized for permit applications, reactor design, modeling and design of the facility and the aquifer restoration plan. The major objective was to measure all relevant geologic details of the North Knobs site.

5.1.1 LOCATION

The North Knobs UCG/SDB site is located in Carbon County, Wyoming (Section 11, Township 21 North, Range 89 West), approximately eight miles west of the town of Rawlins.

5.1.2 Regional Geology

5.1.2.1 Regional Stratigraphy

The North Knobs study area contains surface outcroppings rocks from 5 formations. These are:

Geologic Age	Formation
Tertiary Paleocene	Fort Union Formation*
Late Cretaceous	Medicine Bow Formation Lewis Shale Mesaverde Formation

*Contains coals of interest

The regional stratigraphy of the study area is illustrated in Figure 5.1-1 which is a regional geologic map showing the aerial distribution of the exposed Cretaceous and Tertiary units; Figure B-1 in Appendix B a cross section illustrating the study area's subsurface geology along line A-A' and Figure B-2 in Appendix B is a regional geologic column detailing the thickness and lithology of the measured units.

Upper Mesaverde Formation (Oldest Formation)

This formation consists of medium grained sandstones which contain abundant ophiomorpha (shrimp burrows), silty sandstones and shales, and a coquina limestone bed about 1-foot thick, which is of shallow marine origin. The Mesaverde-Lewis contact is sharp, and forms a distinct lithologic and topographic break in the geologic section.

Lewis Shale The Lewis shale has a total thickness of approximately 1890 feet, and predominately composed of marine shales. The shales locally become silty and are interbedded with very fine-grained, thinly laminated sandstones. Changes in silt and sand content are gradational and rare bentonitic zones were observed. The Lewis-Medicine Bow contact is gradational showing an upward increase in silt and sand content, and the basal Medicine Bow unit is arbitrarily assigned to the lower most laterally consistent sandstone bed.

Medicine Bow Formation This formation consists of alternating beds of medium to fine-grained sandstone, silty sandstones and shales, shales, carbonaceous shales, and coal, totaling 4426 feet in thickness. Coal and carbonaceous shale beds are stratigraphically the most continuous units. Sandstones become thinner and finer grained near the formation contacts. Well developed sandstone units commonly exhibit cross-bedding and contain abundant plant fragments and leaf imprints. The most important coal is the Nebraska bed which occurs about 457 ft above the basal contact. The uppermost 1600 ft of Medicine Bow units consist mainly of shale beds which are poorly exposed due to soil cover. The Medicine Bow-Fort Union contact is not exposed.

Fort Union Formation The Fort Union Formation (youngest formation) is divided into three informal members. The lower member is composed of conglomerate and coarse grained sandstones which appears to unconformably overlie the Medicine Bow Formation. Alternating sandstones, silty sandstones and shales, grey shales, carbonaceous shales and coal make up the middle member which in turn is overlain by poorly exposed, alternating, silty sandstones and shale units of the upper member. The Fort Union beds measured along A-A' are 3723 ft thick.

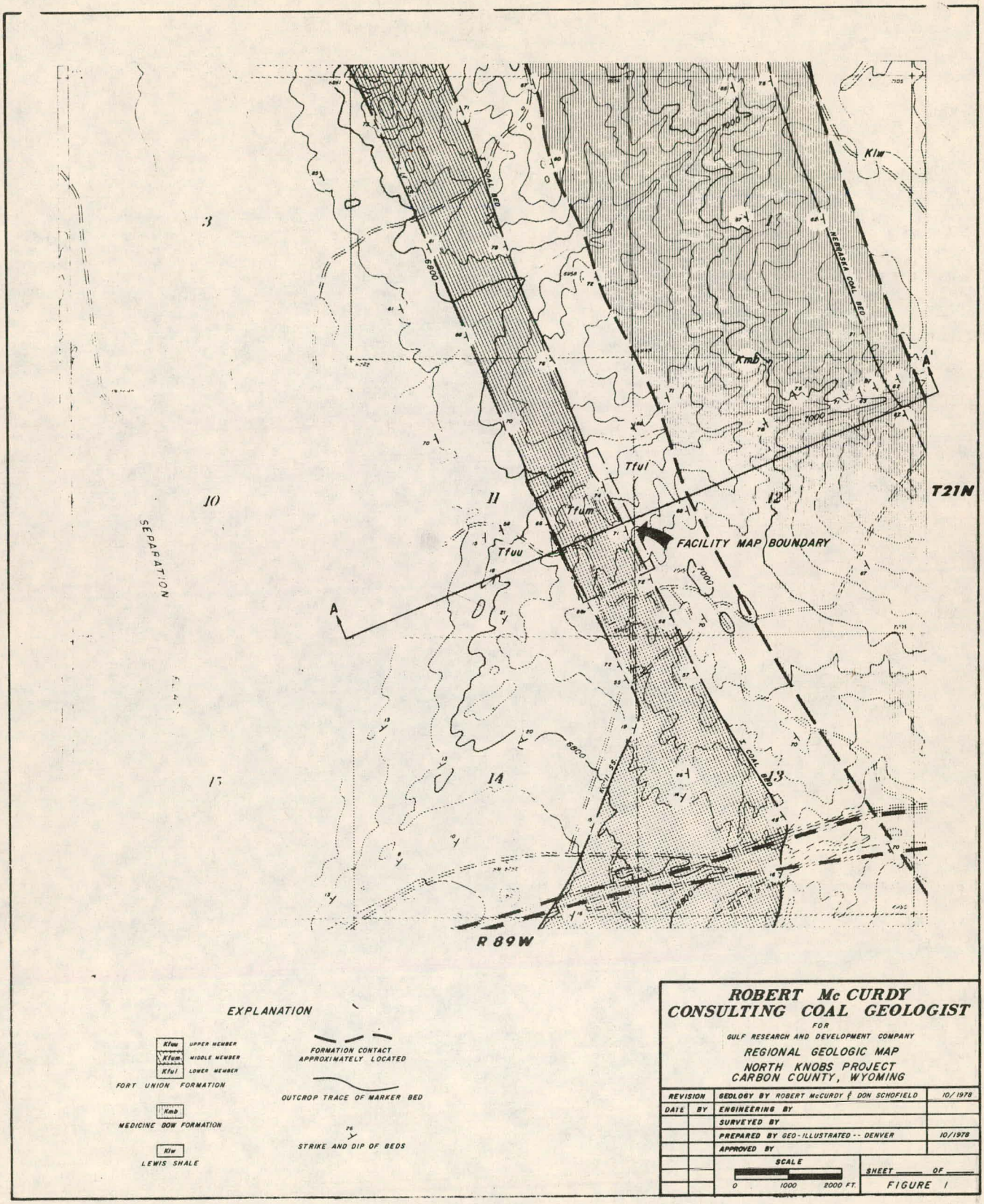


FIGURE 5.1-1
REGIONAL GEOLOGY OF THE STUDY AREA

The lower member is 1475 ft thick and is conglomeratic in the basal 936 ft. The pebble conglomerate has a matrix of moderately soft, white, medium to coarse grained sandstone which is highly calcareous. The pebbles are very well rounded and consist mostly of quartz and chert. A thick, massive, very coarse grained sandstone with well developed joints occurs near the base of the pebble conglomerate zone, and it can be used to recognize the bottom of the Fort Union.

The middle member contains the coals of interest for UCG-SDB, and is 1148 feet in thickness. The basal unit of the middle member is the I coal bed and the top was defined as being the K-11 sandstone bed. (Informal units are discussed in the Site Geology Section.)

The upper member of the Fort Union Formation contains all beds stratigraphically above the K-11 sandstone. The contact of the Fort Union is not exposed due to heavy soil cover of Separation Flats (See Figure 5.1-1). Measured thickness of the upper member is 1100 feet. Units are poorly exposed with the exception of scattered lenticular outcroppings of soft, medium-grained sandstone.

5.1.2.2 Regional Structure

The North Knobs area lies on the western flank of the Rawlins Uplift, a large northwest trending anticlinal fold separating the Hanna Basin on the east and the Great Divide Basin on the west. The uplift deformation is associated with the Late Cretaceous-Early Tertiary Laramide Orogeny and structural relief between the uplift and the adjoining basin is approximately 30 000 ft.

The general trend of the uplift is reflected in the strike of the Upper Cretaceous and Tertiary rocks of the North Knobs area (Figure 5.1-1). Typical ranges in formational strikes are N12°W to N35°W and formational dips are 55°W to 80°W. In Sections 13, 14 and 15, strikes range from N14°E to N66°E with NW dips of 8° to 21°. The change in attitudes is due to a synclinal fold with its axis trending approximately N45°W, and a plunging NW. No other folds are apparent in the mapped area except minor, small scale local warping of the steeply dipping bends.

No faults were mapped during the geological field work nor aerial photogeologic analysis.

Joints are well developed in the steeply dipping resistant sandstone units. Orientation of joints and cleats is discussed in the Site Geology section of this report.

5.1.3 Site Geology

5.1.3.1 Site Stratigraphy

The North Knobs UCG-SDB site has outcropping of rocks from the Fort Union Formation (Figure 5.1-1). Coal beds and rock units of particular interest are contained in the middle member of the Fort Union Formation.

The middle member of the Fort Union Formation consists of alternating sandstone, shale, silty sandstone and shale, carbonaceous shale and coal. Clean sandstones are often resistant to weathering and stand as ridges due to the steeply dipping attitude of the units. Non-resistant shales, silty and carbonaceous sandstones and shale, and coal beds form small topographic lows between the resistant sandstone ridges. This subdued ridge and valley nature in the outcrops lends itself to a system of designating certain of the resistant sandstones as key beds. The lowest key bed was designated as the K-1 sandstone and each successively higher key bed was numbered consecutively through K-11, which is the highest resistant sandstone and forms the top of the middle member of the Fort Union Formation. Each key bed was found to have a characteristic color, texture and bedding sturcture. Complete and detailed descriptions of all rock units are given on the geologic column of the site area (Figure B-3 in the Appendix B). Outcrop traces of mappable beds as well as soil covered zones are shown on the geologic map and the photogeologic map of the facility (Figure B-4 and 5 in the Appendix B).

Three coal beds were identified in the Middle Member of the Fort Union Formation: the I, G, and Wally coal seams. The coal seam characteristics are as follows:

Coal Seam	Stratigraphic Level	Thickness
Wally	Highest Seam	6.0-7.5 ft
G		19-24 ft
I	Lowest Seam	13.0-16.0 ft

Field observations indicate that many beds are laterally consistent in both lithology and thickness, while others have significant lateral variation in thickness, lithology and stratigraphic position (see Figure B-4 in Appendix B). An example of lateral variability in stratigraphic position is the K-7 sandstone. Lateral variability in thickness is shown by the K-6 sandstone, and facies change (variability in lithology) and is characteristic of the K-8 sandstone near radial line 5+00. Key bed K-5 is an example of lateral consistency. Similar variability of rock units in the subsurface can be expected.

Many units mapped on the surface can be identified and correlated in the subsurface from geophysical logs of drill holes. Table 5.1-1 lists the penetrated depths to various units which are recognizable in the subsurface. Section B-50 of Appendix B, contains the lithologic logs of the holes drilled on site.

5.1.3.2 Site Structure

Surface exposures of the steeply dipping beds at North Knobs have the appearance of being very consistent in dip; however, measured dips varied from 55°W to 70°W (Figure B-4 in Appendix B). This variance is probably not entirely due to structural conditions since the rock units exhibit significant fluctuation in thickness and stratigraphic position. Cross-bedding and soft sediment deformation structures (slumps) add to the difficulty in obtaining accurate bedding attitudes.

Data from shallow drill holes suggest that some relatively small scale folds, or warps, are present at the surface and down to at least a few hundred feet of cover. This interpreted folding of the G coal bed near the surface is illustrated in detailed cross-sections along radial lines 5+00 and

TABLE 5.1-1

Penetrated Depth to Units Recognizable in the Subsurface (ft.)
North Knobs SDB Project
CARBON COUNTY, WYOMING

Hole Number	Base, "Wally" Coal Bed	Base Key Bed K-5 (Sandstone)	Base "Sub K-5" Coaly Sandstone	Base Key Bed K-4 A Horizon	Base "Super G" Sandstone	"G" Coal Bed (Base,Glc)	Top, "Sub G" Sandstone	Top, Key Bed K-2 Sandstone	Base Super "I" Coal Bed	Base "I" Coal Bed
CH 1	DB	DB	DB	DB	50.5	153.0	181.8	199.3	385.9	489.0
CH 2	115.4	216.7	229.5	265.2	461.0	529.0	NR	NP	NP	NP
CH 3	DB	DB	DB	DB	25.2	126.8	163.3	193.8	405.2	515.2
CH 4	148.6	247.6	258.8	293.0	465.3	583.0	NP	NP	NP	NP
DH 1	104.8	202.0	211.0	239.6	411.1	472.7	NP	NP	NP	NP
DH 2	DB	DB	DB	DB	205.5	279.9	306.9	NR	470.2	541.2
DH 3*	278.3	NR	342.0	392.8	499.0	596.9	NP	NP	NP	NP
H 7	NR	NR	137.3	175.6	362.7	446.9	481.0	NP	NP	NP
H 8	108.8	210.0	272.3	260.1	425.7	516.7	NP	NP	NP	NP
H 9	184.3	NR	309.4	343.2	489.0	598.9	625.7	NP	NP	NP
H 11	NR	125.4	140.4	182.3	355.9	454.3	484.5	505.3	NP	NP
H 12	106.7	203.1	222.2	257.8	422.7	523.5	556.4	NP	NP	NP
H 13	180.2	283.2	299.9	334.3	483.2	589.6	618.0	637.7	NP	NP
H 15*	265.3	327.9	345.3	410.3	544.2	677.2	NP	NP	NP	NP
Pump 1	88.7	190.6	205.4	242.7	419.0	514.6	NP	NP	NP	NP
E 6	DB	DB	DB	DB	DB	29.9	NP	NP	NP	NP
E 7	DB	DB	DB	DB	DB	68.9	NR	NP	NP	NP
E 11	DB	DB	Collar	37.0	NP	NP	NP	NP	NP	NP
E 12	DB	DB	DB	DB	E/B	107.9	NP	NP	NP	NP
E 13	DB	DB	DB	DB	57.7	147.6	NP	NP	NP	NP
E 17	DB	DB	DB	DB	E/B	99.9	NP	NP	NP	NP
E 18	DB	DB	DB	DB	39.9	120.8	NP	NP	NP	NP
E 19	DB	DB	DB	DB	DB	DB	NR	26.3	NP	NP
E 20	DB	DB	DB	DB	DB	30.6	61.5	NP	NP	NP
E 22	DB	DB	DB	DB	NR	128.6	NR	NP	NP	NP
E 23	DB	DB	DB	DB	63.9	165.8	NP	NP	NP	NP
E 24	DB	DB	DB	DB	DB	DB	NR	29.4	NP	NP
E 26	DB	DB	DB	DB	DB	71.0	NP	NP	NP	NP
E 27	DB	DB	DB	DB	E/B	119.4	NR	NP	NP	NP
EDC 230	DB	DB	DB	DB	DB	DB	DB	DB	62.0	148.2
EDC 231	DB	DB	DB	DB	47.5	125.1	NP	NP	NP	NP
EDC 232	DB	DB	DB	DB	DB	DB	DB	DB	82.5	157.6
EDC 233	DB	DB	DB	DB	DB	61.8	NP	NP	NP	NP
EDC 234	DB	DB	DB	DB	NR	109.3	NP	NP	NP	NP
EDC 235*	DB	DB	DB	DB	DB	DB	DB	DB	E/B	148.8
EDC 236*	DB	DB	DB	DB	DB	DB	DB	DB	E/B	103.4
EDC 239*	DB	DB	DB	DB	DB	DB	DB	DB	DB	78.7
EDC 242*	137.0	NP	NP	NP	NP	NP	NP	NP	NP	NP
EDC 244	DB	DB	DB	DB	104.6	161.0	NP	NP	NP	NP
EDC 246*	DB	DB	DB	DB	DB	DB	DB	DB	E/B	128.2
EDC 247	DB	DB	DB	DB	97.2	NP	NP	NP	NP	NP
EDC 253*	DB	DB	DB	DB	E/B	112.4	NP	NP	NP	NP
EDC 254*	DB	DB	DB	DB	33.2	114.9	NR	NP	NP	NP
EDC 255*	DB	DB	DB	DB	DB	83.8	NP	NP	NP	NP
EDC 257*	46.5	NP	NP	NP	NP	NP	NP	NP	NP	NP
EDC 261	DB	DB	DB	DB	DB	77.9	NP	NP	NP	NP
EDC 262	DB	DB	DB	DB	DB	49.1	NP	NP	NP	NP

*-On Section 11 - Out of facility area

E/B - Unit entirely or partially eroded or burned

NP - Unit not penetrated or geophysically logged

DB - Drillhole started stratigraphically below unit

NR - Unit not recognizable or geophysically logged

11+00 (Figures B-6 and 7 in Appendix B). The term "interpreted folding" is used because available data does not conclusively prove these folds exist. It has been assumed that the exploration holes were drilled vertically for purposes of geological interpretation; however, it is unlikely that these shallow drill holes were drilled vertically. Perhaps the "interpreted folding" is an artifact of the survey--this could be verified if directional surveys were available.

The formational dips appear to decrease with depth at North Knobs. At depths of 400-700 feet the dip is 58-60° and decreases gradually to 45° at approximately 1500 ft (Figure B-1 in the Appendix B).

No faults were observed in the facility area; however, many of the sandstones exhibit well developed joints.

5.1.3.3 Joints

Joints in rock are fractures in which the movement is essentially perpendicular to the fracture plane. They are usually developed normal and parallel to bedding surface. In the following discussion the term joint refers only to those fractures in beds other than coal. The term cleat is used for joints in coal beds.

Joint attitudes were measured at 35 localities on the site (Figure B-4 in Appendix B). Bedding attitudes were also measured at these localities wherever possible (the dominance of cross bedding prohibited bedding attitude measurements at some localities). More than 75 joint attitudes and more than 25 bedding attitudes were measured at the 35 localities.

Joints are best developed in the resistant siltstone and sandstone units less than 3.0 feet (Figure 5.1-2). The joint surfaces with few exceptions were nearly normal to bedding, and generally were terminated at the contacts of the thin, resistant units. Very few joints are apparent in the non-resistant units, even where they were well exposed.

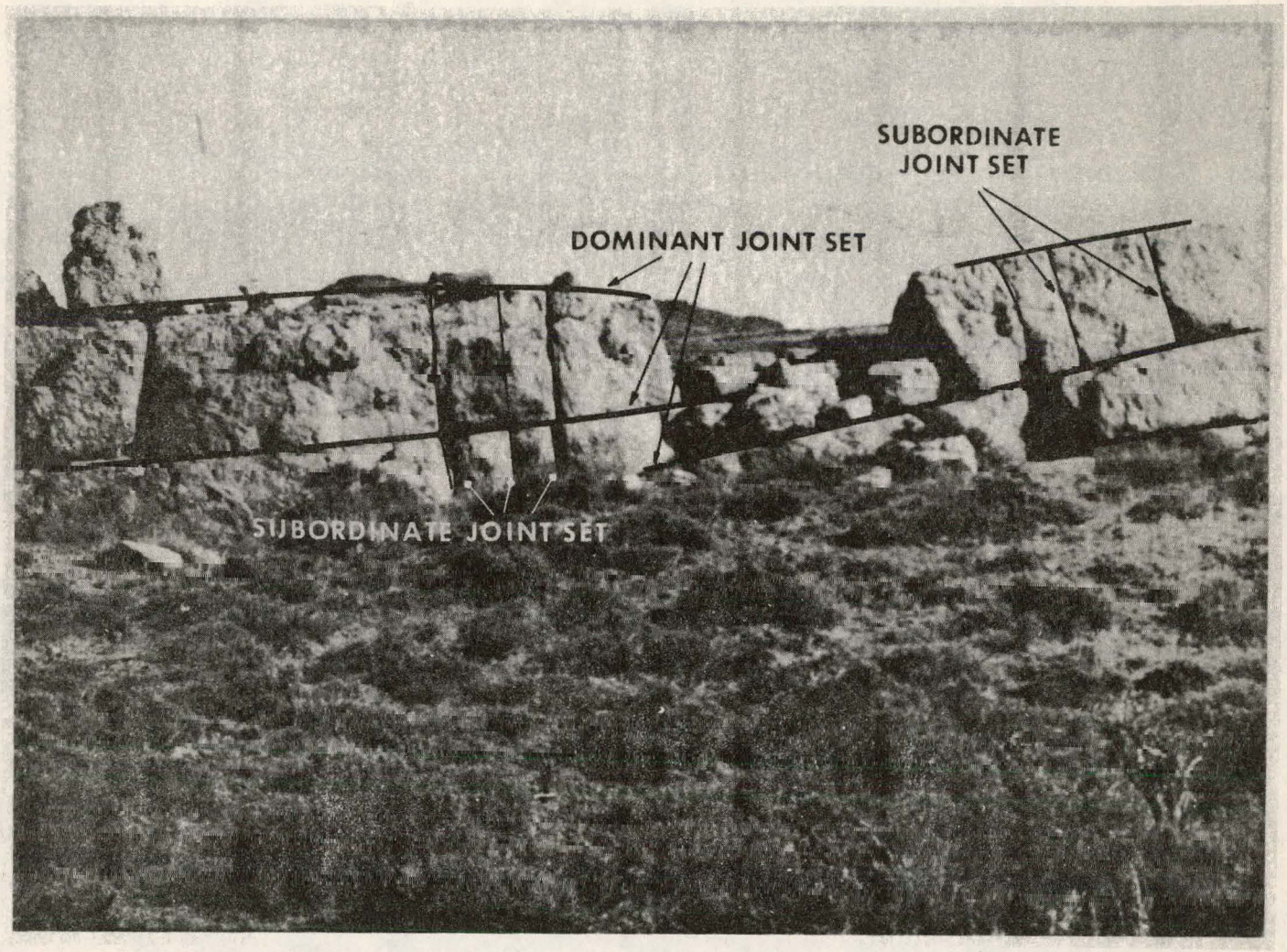


Figure 5.1 - 2 -- THIN SANDSTONE UNIT DIPPING TOWARDS VIEWER AT ABOUT 70° EXHIBITING TYPICAL DOMINANT AND SUBORDINATE JOINT SETS.

Two types of joint sets were identified on the site, dominant sets and subordinate sets. Their characteristics are discussed below.

1. Dominant Joint Set - Best developed joint set with smooth, planar to arcuate surfaces that can be traced over relatively long distances. Generally, strikes were nearly parallel to the strike of bedding, and dips were nearly normal to the bedding (Figure 5.1-2). Spacings of joints range from 0.5 feet to 4.0 feet and are fairly regular.
2. Subordinate Joint Set - Poorly to moderately developed set with smooth to rough, irregular surfaces that normally terminated against the dominant set. Generally, strikes of 50° to 90° from the dominant set were observed and dips were nearly vertical. Spacing of joints range from 1.0 to 10.09 ft.

Figure 5.1-2 differentiates between dominant and subordinate joint sets.

In addition to the field description of the joints, an analysis of the aerial photographs was undertaken to map the surface orientation and density of fracture traces. These data are consistent with that obtained in the field study.

5.1.3.4 Prediction of Directional Joint Permeability

Joints provide avenues for the migration of fluids. It appears from field observation that the joints are confined to thin, sandstone and siltstone beds. Directional permeability within thin zones with well developed jointing may be predicted by evaluating the orientation of lines formed by the intersection of joint surfaces with bedding.

Stereographic projection techniques were used to determine plunge of the line formed by the intersection of joint surfaces with bedding for all localities where bedding attitudes were measured. (Figure B-4 in Appendix B illustrates the plunge of dominant and subordinate joints with bedding at 29 localities.)

Migration of fluids through joint surfaces is expected primarily along the bearing of plunge formed by the intersection of bedding with the dominant joint surface. This line plunges at an average of about 6° and has a bearing very near that of strike of bedding. Upward migration of gas along the dominant joint surface from a depth of 500 feet would reach the surface 4783 feet horizontally from the starting point, assuming flat topography and a 6° plunge.

Upward migration of gas along a network of subordinate and dominant joint surfaces is conceivable. From a starting point at a depth of 500 feet, the horizontal distance to expect the gas to reach the surface is about 295 feet, assuming the following:

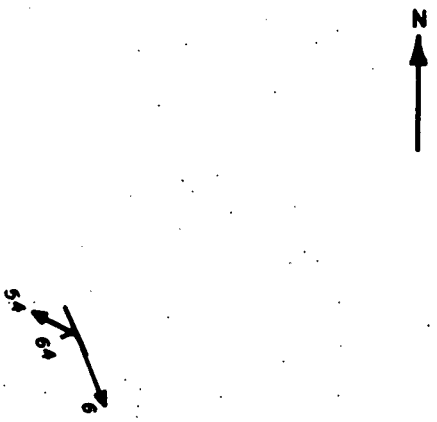
1. The geometry of dominant and subordinate joints shown for the location at 11+00, 74 feet left, which approximates average conditions (Figure 5.1-3).
2. Spacing of dominant joint set of 2.0 feet measured on bedding surface (Figure 5.1-3).
3. Spacing of subordinate set of 4.0 feet measured on bedding surface and evenly staggered to produce an effective spacing of 2.0 feet (Figure 5.1-3).
4. Flat topography.

Changes in joint and bedding orientation can substantially change the path of gas migration through a network of joint surfaces.

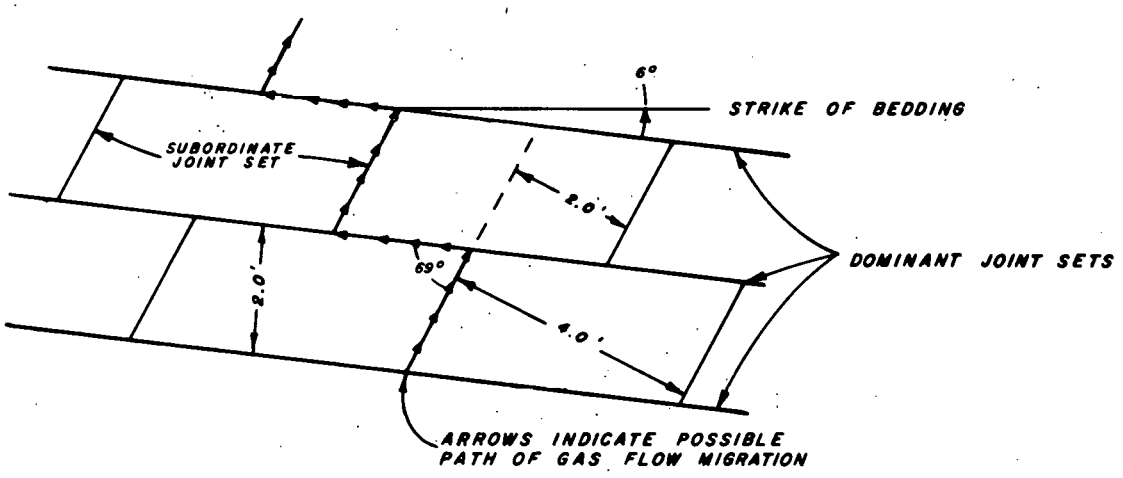
5.1.3.5 Prediction of Dominant Joint Orientation from Bedding Attitude

Analysis of field observations indicates that the dominant joint set generally has a strike very close to that of bedding and a dip nearly normal to bedding (Figure B-4 in Appendix B). This relationship is used to predict the dominant orientation when the bedding attitude is known.

Stereographic projection techniques were used to rotate the joint surfaces around the strike of bedding and through the angle required to bring



BEDDING ATTITUDE AND PLUNGE OF LINE
FORMED BY INTERSECTION OF JOINT SURFACES WITH BEDDING



VIEW NORMAL TO BEDDING.

FIGURE 5.1-3 GEOMETRY OF DOMINANT AND SUBORDINATE JOINT SET USED TO ESTIMATE MIGRATION OF GAS THROUGH JOINT NETWORK, ADAPTED FROM GEOMETRY AT 11+00, 74 FT. LEFT.

bedding to horizontal. This technique allows for the quantification of the following two parameters:

1. The strike of joint surfaces relative to strike of bedding following rotation around strike of bedding through the angle of bedding dip.
2. The dip of joint surfaces following rotation around strike of bedding through the angle of bedding dip.

Stated differently, the technique quantified the orientation of joint surfaces relative to bedding. Figures B-9 to 38 in Appendix B illustrate each case of rotation.

Following is a statistical summary of the orientation of the dominant joint set following rotation.

Orientation of Dominant Joint Set Following
Rotation Around Strike of Bedding Through Angle of Bedding Dip

Looking North

Strike of Dominant Joint Set Relative to Strike of Bedding
Mean.....7.8° West of bedding strike
Median.....5.5° West of bedding strike
1 Standard Deviation.....14.2° or 68.27% of cases fall between
.....22.0° West of bedding strike and 6.4°
.....East of bedding strike.

Dip of Dominant Joint Set Relative to Bedding
Mean.....85.7° East
Median.....85.5° East
1 Standard Deviation.....12.0° or 68.27% of cases fall between
.....73.7° East to 82.3° West

Figure 5.1-4 is a graph that can be used to predict the orientation of the dominant joint set if the attitude of bedding is known. The graph was constructed from the calculated mean values, and rotating them backwards to determine joint orientation for bedding dips of 50°, 60°, 70°, and 80°. Two curves were drawn to determine the joint orientation from a known bedding attitude. One is used to determine the strike of the joint surface, and the other to determine the dip of the joint surface. In the example given on

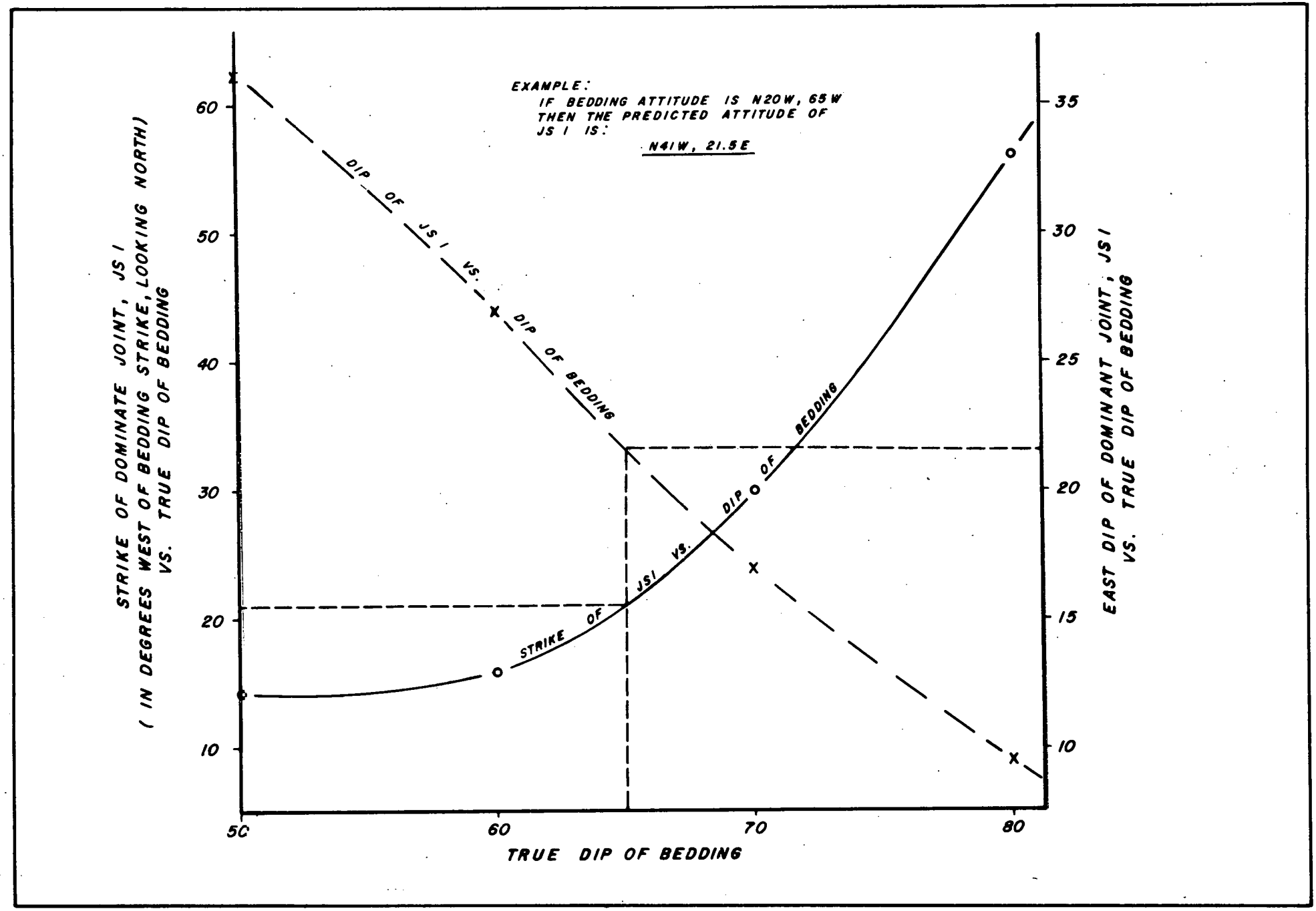


FIGURE 5.1-4 PREDICTING ATTITUDE OF DOMINANT JOINT, JS I, FROM BEDDING ATTITUDE

Figure 5.1-4, a dominant joint set with an attitude of N41°W, 21.5°E is predicted from a bedding attitude of N20°W, 65°W.

Cleating Cleat attitudes were measured in the five trenches -- T-I-1, T-I-2, T-G-1, T-W-1 and T-W-2 (Figure B-4 in the Appendix B). The trenches designated with the prefix T-I are in the I coal bed; T-G prefixes are in the the G coal bed; and T-W prefixes are in the Wally coal bed. Three trenches were dug in an attempt to expose the G coal bed, but only one, T-G-1, reached the bed beneath surficial deposits. Two trenches exposed the I coal bed and two exposed the Wally coal bed.

Well developed cleats were observed in trenches T-I-2, T-W-1 and T-W-2. Only poorly developed cleats were observed in trenches T-I-1 and T-G-1. This is probably because of weathering effects on the coal.

Two types of cleat sets were observed in trenches T-I-2, T-W-1 and T-W-2, face cleats and butt cleats. The face cleat is the major well developed joint in a coal bed, and the butt cleat is a short, poorly developed joint at nearly right angles to the face cleat and commonly terminates against it. Figure B-4 in Appendix B differentiates between face cleats and butt cleats wherever that determination is possible. Bedding attitudes measured in the trenches also are indicated on Figure B-4 in Appendix B.

Stereographic projection techniques were used to determine cleat orientation relative to bedding. Results of these determinations are illustrated in Figures B-39 to 44 in Appendix B. The trace of the face cleat on the bedding surface forms an acute 40-45° angle with bedding strike ranging from 46° to 88° measured on the bedding surface; the angle averages 65.2°. The acute angle between the face cleat and butt cleat, measured on the bedding surface, ranges from 16° to 82°, and averages 45°. It is difficult to draw definite conclusions from these orientations because of the very limited number of observations.

5.1.3.6 Prediction of Directional Permeability in the Coal Beds

Face and butt cleats provide most of the permeability in a coal bed. The primary direction of permeability is parallel to the face cleat. Knowledge

of directional permeability in a coal bed is useful in designing drill hole layout for reverse combustion linking and gasification.

An evaluation of the plunge of the line formed by the intersection of the face cleat with bedding provides a means of predicting directional permeability in a coal bed. Plunge of this line and of the line formed with the butt cleat is illustrated on Figure B-4 in Appendix B.

The plunge angle of the line formed with the face cleat ranges from 39° to 66°, and averages 54.6°. The direction of plunge ranges from 28° to 88° west of bedding strike when viewed to the north, and averages 44°. These conclusions are based on measurements from a limited number of sampling points provided by the trenches. However, it can be concluded that the face cleats and butt cleats are not oriented normal and parallel respectively, to bedding strike. Furthermore, any drill hole layout designed to take advantage of cleat orientation and directional permeability will required careful planning regarding hole depth, hole density and hole angle.

5.1.3.7 Prediction of Face Cleat Orientation from Bedding Attitude

Stereographic techniques were used to rotate the cleat sets around strike of bedding through the angle of bedding dip (Figures B-39 to 44 in Appendix B). The results of this rotation allow a quantification of the cleat surface orientation relative to bedding.

The average acute angle between bedding strike and the face cleat, measured on the bedding surface, is 54.2° west of bedding strike when viewed to the north. The rotated dip of the face cleat averages 85.2° west. These average values were rotated downdip to determine face cleat orientation for four cases of bedding dips; 50°, 60°, 70° and 80°. Figure 5.1-5 is a graph drawn from the four cases to predict face cleat orientation from a known bedding attitude. In the example given on Figure 5.1-5, a face cleat with an attitude of S86°W, 69.5°N is predicted from a bedding attitude of N20°W, 65°W.

Again, caution is advised in using the above data because of the very limited number of cleat observations.

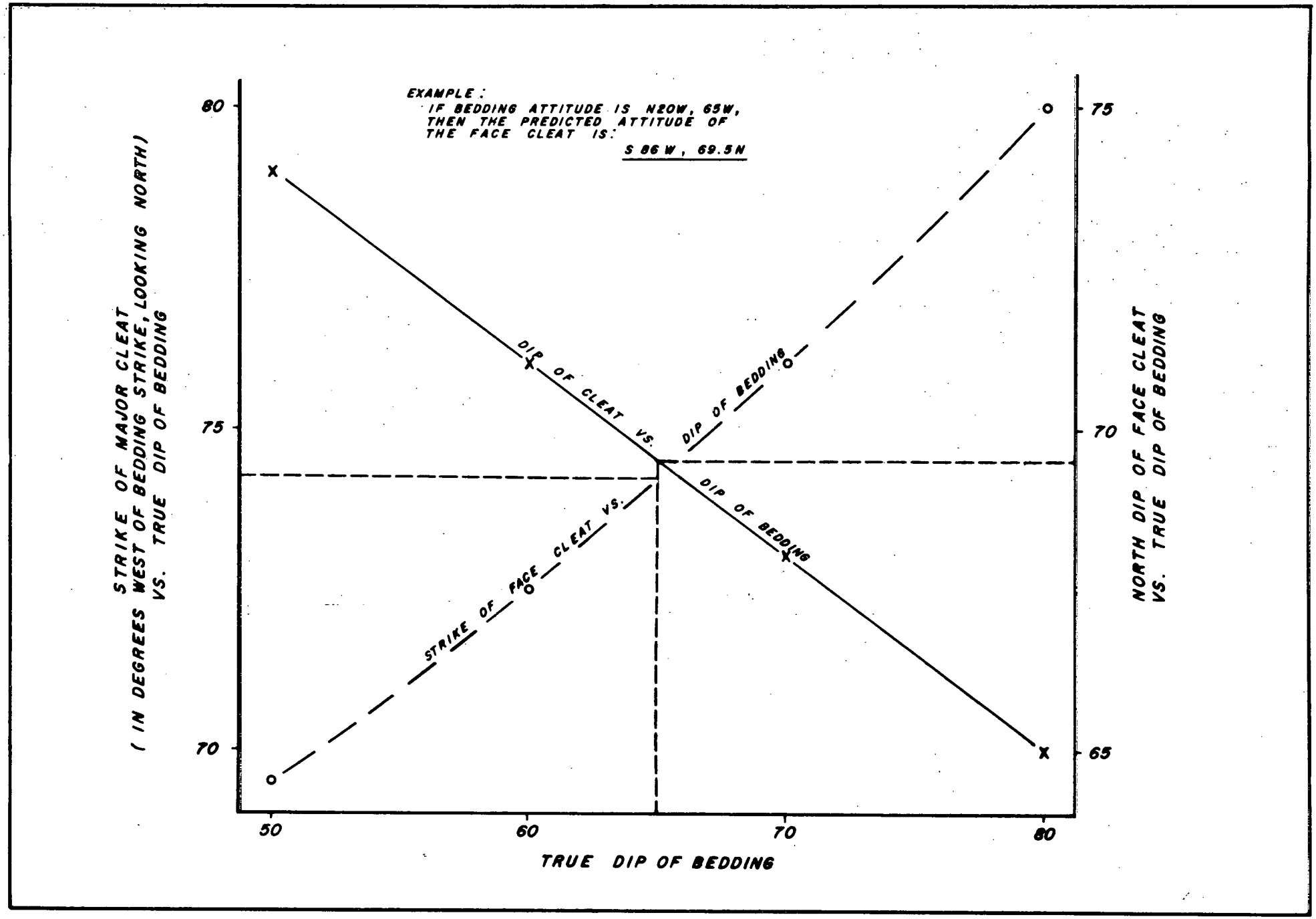


FIGURE 5.1-5 PREDICTING ATTITUDE OF FACE CLEAT FROM BEDDING ATTITUDE

G Coal Seam Character

Only one of the three trenches (T-G-1) dug to expose the G seam was successful in reaching the coal because of thick surficial deposits. A bulldozer was used to remove the first 10 feet of soil at the T-G-1 location. Detailed descriptions and correlation of the coal and other units exposed in the trenches are illustrated on Figure B-46 in the Appendix B.

5.1.4 Type Description for the G Coal Seam

Detail of the G seam was determined from the geophysical logs of drill holes, the coal core, and the observation made in trench T-G-1. The geophysical log from Core Hole 1 was selected as the type log for the G seam (Figure 5.1-6).

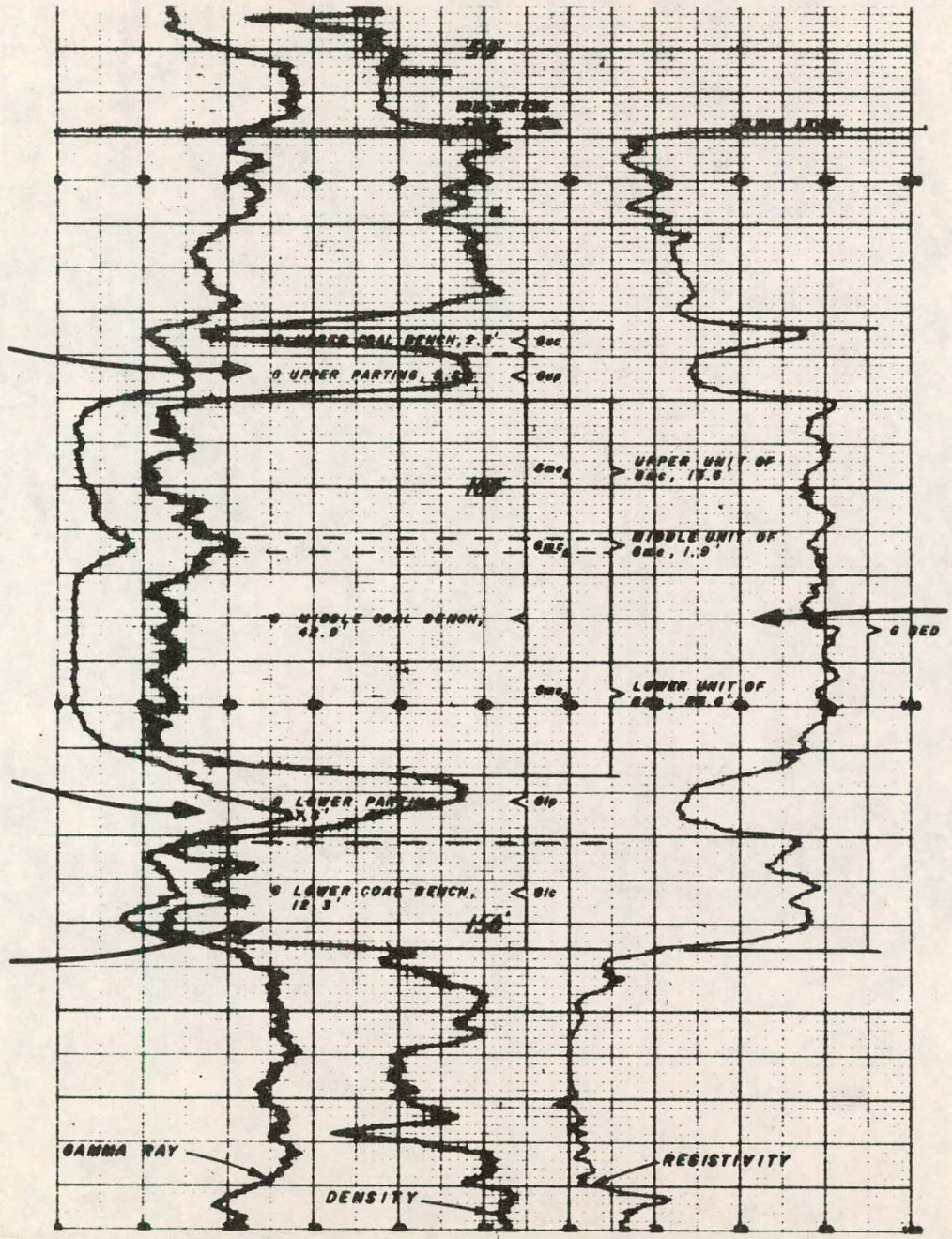
The G seam was divided into five main parts, based on characteristics observed on the log signatures. The parts were:

Subdivision of G Coal Seam	Geophysical Log Designation
Upper Coal Bench	Guc
Upper Parting	Gup
Middle Coal Bench	Gmc
Lower Parting	Glp
Lower Coal Bench	Glc

A thin, easily recognizable and persistent log signature in the middle coal bench allows a tripartite breakdown of the Gmc into upper, middle and lower units which are designated as follows:

Subdivision of Middle Coal Bench	Geophysical Log Designation
	Gmc
Upper Unit	Gmc_3
Middle Unit	Gmc_2
Lower Unit	Gmc_1

Contacts between each division are picked on the geophysical logs using the density curve as illustrated on Figure 5.1-6.



UPPER PARTING IS MODERATELY HIGH COUNT, HIGH DENSITY, AND LOW RESISTIVITY, SHARP UPPER AND LOWER CONTACT ON DENSITY AND RESISTANCE CURVES.

LOWER PARTING IS HIGH COUNT, HIGH DENSITY AND LOWER RESISTIVITY. UPPER AND LOWER CONTACTS ARE SLUGGISH AND SLOPING ON ALL CURVES.

LOWER COAL BENCH IS MODERATELY HIGH GAMMA COUNT, MODERATELY LOW DENSITY, AND MODERATELY HIGH RESISTIVITY; ALL CURVES ARE IRREGULAR, UPPER CONTACT IS SLUGGISH AND SLOPING, AND LOWER CONTACT IS SHARP AND DISTINCT ON DENSITY AND RESISTIVITY CURVES. LOWER PORTION OF 6lc TYPICALLY IS LOWEST GAMMA COUNT OF THIS COAL BENCH

UPPER THIN COAL BENCH IS RELATIVELY HIGH GAMMA COUNT, RELATIVELY LOW DENSITY, AND RELATIVELY LOW RESISTIVITY. HAS SHARP DISTINCT UPPER AND LOWER CONTACTS ON DENSITY AND RESISTIVITY CURVES.

MIDDLE COAL BENCH IS THE THICKEST BENCH CHARACTERIZED BY LOW COUNT, LOW DENSITY, AND HIGH RESISTIVITY. UPPER CONTACT IS SHARP AND DISTINCT ON DENSITY AND RESISTIVITY CURVES. LOWER CONTACT IS MORE SLUGGISH AND MORE SLOPING. THE MIDDLE COAL BENCH CONTAINS A THIN, BUT VERY PERSISTANT AND EASILY IDENTIFIED UNIT. $6mc_2$, LOCATED ABOUT 1/3 THE WAY DOWN FROM THE TOP OF THE BENCH. THIS UNIT GENERALLY MODERATELY HIGH COUNT AND MODERATELY HIGH DENSITY; BUT CHARACTERISTICALLY CANNOT BE RECOGNIZED ON THE RESISTIVITY CURVE. THIS UNIT SERVES AS A MEANS OF DIVIDING THE MIDDLE COAL BENCH INTO THREE PARTS, $6mc_1$, $6mc_2$, $6mc_3$

FIGURE 5.1-6 TYPE LOG OF THE 6 SEAM, CORE HOLE NO. 1

Log curves in the lower coal bench, Glc, were irregular and variable. This feature coupled with the moderately high gamma count indicates that the lower coal bench is boney or dirty coal. Log signatures correlate with the trench descriptions from trench T-G-1. The lower parting, Glp, consists of sandy siltstone and shale. The middle coal bench, Gmc, should be the primary gasification target and consists mostly of clean, hard coal. The core and trench descriptions do not conclusively identify Gmc_2 which suggests that the differences of Gmc_2 to Gmc_1 and Gmc_3 are slight. The upper parting consists mostly of carbonaceous shale, and the upper coal bench is slightly dirty or boney and thin.

A drill hole summary of the G coal bed, including penetrated and true thicknesses is given in Table 5.1-2. True thickness was determined only for those holes in which a hole deviation survey was conducted. Thickness corrections were made mathematically from the penetrated thickness, borehole attitude, and subsurface bedding attitude.

A summary of the average true thicknesses of the G seam divisions is given below:

Table 5.1-2
Summary of Average True Thickness
G Coal Seam

G Seam Component		Thickness (ft)
Upper Coal Bench, Guc		1.46
Upper Parting, Gup		3.42
Middle Coal Bench, Gmc		22.66
Upper Unit, Gmc_3	8.59	
Middle Unit, Gmc_2	0.84	
Lower Unit, Gmc_1	13.23	
Lower Parting, Glp		3.72
Lower Coal Bench, Glc		6.03
Total		37.29

5.1.4.1 Nature of G Seam Subcrop

The G seam is entirely covered by soil and alluvium on the UCG site; and, consequently it does not outcrop. The only G seam outcrop observed during field work was located in Section 2, about 9000 feet northwest of the

site. Only one of three backhoe trenches dug to expose the G subcrop was successful. Four auger holes were drilled within the facility area to determine the general depth to the seam (Figure B-46 in Appendix B.) Cover depths ranged from 16 feet to 25 feet in the auger holes. Due to this unusually thick cover, 27 exploration drill holes (E-1 through E-27) were drilled to characterize the nature of the G seam subcrop (Figure B-46 in Appendix B). Overburden of up to 40 feet was encountered in the exploration drill holes.

Data obtained from the augering and exploration drilling programs have been used to compile maps showing the topography of the bedrock surface and thickness of soil cover. Detail of the bedrock surface is also illustrated on the geologic cross sections 5+00 and 11+00 (Figures 6 and 7 in Appendix B).

Thermally altered material was encountered in several of the exploration holes, particularly those in the area south of the baseline from radial line 0+00 to radial line 3+00. Thermal alteration was also reported in several of the holes drilled by Energy Development Company in 1976. No evidence of burning was visible on the surface; however, the burning and any subsequent roof collapse appears to have taken place prior to the deposition of the thick alluvium now covering the G seam. All or most of the upper unit of the middle coal bench of the G seam, Gmc_3, and the upper coal bench, Guc, were burned out in trench T-G-1. Lost circulation in many of the exploration drill holes was an indication that fractures may have been formed by either thermal expansion and contraction due to burning or to roof collapse.

5.1.4.2 Coal Reserves

Coal reserves have been estimated for Section 11, T21N, R89W for the I, G and Wally coal beds along the baseline from 0+00 to 20+00 (Table 5.1-3). Reserves are calculated in three categories: 0-250' cover, 250-600' cover, and 600-1000' cover.

Reserves were estimated by the end area method. Cross sections were prepared every 200 feet along the baseline. Tons/foot of influence were determined for each seam and each depth category assuming a factor of 25.03 ft^3/ton of coal, in place. The tons/foot of influence were multiplied

times the lateral feet of influence for each section (200 feet) to determine the reserves representative of each section.

Estimated in-place reserves are summarized below:

Table 5.1-3

Summary of Estimated Reserves
Tons, In-Place

	0-250 ft	250-600 ft	600-1000 ft	0-1000 ft
I Coal Bed	257 747	400 094	490 680	1 148 531
G Coal Bed	571 444	968 569	1 098 929	2 638 942
Wally Coal Bed	154 824	217 371	249 485	621 680
Total	984 015	1 586 034	1 839 094	4 409 153

5.2. SURFACE DESCRIPTION

In order to establish the acceptability of the North Knobs site for the field test program, the surface characteristics had to be evaluated. This section describes activities concerned with climatology, surface hydrology, soil/vegetation, and history/archeology. Surface data was utilized to determine that site-specific problems would be minimal.

5.2.1 Climatology

The North Knobs site is approximately eight miles west of Rawlins and 18 miles east of the continental divide along the southeastern edge of the gently rolling prairie terrain that characterizes the Great Divide basin. The elevation is about 6800 feet. The climate may be described as semi-arid with a mean relative humidity of 55%. Humidity seldom exceeds 30% at temperatures above 80°F.

Meteorological data obtained at the Rawlins, Wyoming airport is presented in Table 5.2-1, along with a glossary of terms in Table 5.2-2, and parameter definition in Table 5.2-3. These data may be representative of general climatological conditions of the area; but specific site conditions, particularly wind vectors, may differ because the meteorological stations is separated from the site by a ridge or hogback approximately 1100 feet high. The hogback runs in a northwest-southeast direction and is of sufficient height to affect the local winds measured at the airport. Wind direction data is listed in Table 5.2-4.

Table 5.2-5 represents wind direction and speed data from the North Knob site taken from 5/26/78 to 8/11/78. Data from the North Knobs site indicates that average wind speeds are higher at North Knobs than at the Rawlins airport, (see Table 5.2-4 and 5.2-5).

Windy days are quite frequent during the winter and spring months. During January at Rawlins, about 27 days of the month have winds during the day of greater than 11.5 mph. During the summer months, the wind frequency is reduced with about 15 days having wind velocities greater than 11.5 during July. The nighttime winds tend to be calmer due to decreased thermal activity.

METEORLOGICAL DATA
RAWLINS MUNICIPAL, WYOMING

MEAN NUMBER OF DAYS

PARAMETER DESCRIPTION		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN	POR (YRS)	NO. OBS
CIG = GTR 1000 FT AND	17 LST	30.7	26.0	29.2	28.7	31.0	30.0	31.0	31.0	30.0	30.5	29.7	30.2	358.0	4	1401
VSBY = GTR 3 MI	23 LST	30.3	27.7	29.5	28.2	30.7	30.0	31.0	31.0	30.0	30.5	29.7	30.5	359.1	4	1401
	05 LST	30.7	27.0	28.2	28.5	30.0	30.0	30.7	31.0	29.7	30.2	28.7	30.5	355.2	4	1401
	11 LST	30.0	27.3	28.7	28.5	30.2	30.0	31.0	31.0	30.0	30.5	28.5	29.7	355.4	4	1401
CIG =GTR 2000 FT AND VSBY =GTR	17 LST	10.0	8.2	7.8	9.8	11.0	6.8	13.2	9.5	12.2	17.5	18.5	13.3	137.8	4	1401
3 MI W/SFC WND LES 10 KTS	23 LST	10.7	13.2	14.7	20.0	21.0	24.2	25.7	25.7	23.0	24.2	17.5	12.1	232.0	4	1401
	05 LST	7.3	14.1	16.5	17.7	22.5	24.5	28.0	28.2	24.2	22.7	18.8	14.4	238.9	4	1401
	11 LST	3.0	4.6	7.5	8.3	10.7	10.7	15.5	13.2	12.5	9.2	9.2	7.8	112.2	4	1401
SFC WND = GTR 17 KTS AND	17 LST	10.9	9.1	7.4	7.4	7.5	7.6	5.5	4.0	5.0	1.8	2.8	6.6	75.6	4	1376
NO PRECIP.	23 LST	8.1	5.6	4.0	1.9	1.3	0.8	1.0	0.7	1.2	0.5	4.2	5.8	35.1	4	1361
	05 LST	8.5	4.9	4.5	1.8	1.6	0.2	0.2	0.0	0.2	1.3	3.4	5.7	32.3	4	1365
	11 LST	15.0	13.6	11.4	8.9	5.6	7.5	4.7	4.2	5.3	5.4	7.2	11.7	100.5	4	1369
SFC WND 4-10 KTS AND TMP 33-89	17 LST	1.7	3.5	5.2	9.7	12.3	10.6	13.2	11.5	13.0	14.6	10.1	1.3	106.7	4	1372
DEG F AND NO PRECIP.	23 LST	2.4	1.4	3.0	8.6	13.3	13.5	15.5	16.7	13.2	13.2	3.9	0.8	105.5	4	1357
	05 LST	1.7	1.0	1.6	5.4	8.1	8.7	9.0	10.0	10.7	6.1	2.9	0.2	65.4	4	1360
	11 LST	0.7	1.0	3.7	8.1	12.4	11.5	13.0	13.7	9.8	10.0	3.9	1.1	88.9	4	1364
SKY COVER LES 3/10 AND	17 LST	7.0	6.6	6.2	5.5	4.0	7.7	8.5	6.0	12.0	13.0	9.0	10.3	95.8	4	1397
VSBY = GTR 3 MI	23 LST	12.6	14.1	12.4	13.2	13.5	17.7	20.0	19.0	21.2	18.5	18.5	14.4	195.1	4	1397
	05 LST	12.0	13.8	11.4	11.5	10.5	14.0	15.5	15.2	21.5	20.0	17.3	14.4	177.1	4	1396
	11 LST	6.7	8.2	8.1	6.5	5.2	11.0	13.0	12.5	18.2	14.5	11.3	10.3	125.5	4	1396
CIG = GTR 2500 FT AND	17 LST	29.6	25.3	27.7	28.2	29.7	29.7	31.0	31.0	30.0	29.5	28.5	28.7	348.9	4	1401
VSBY = GTR 3 MI	23 LST	29.6	27.3	27.2	26.3	28.5	29.7	30.5	31.0	29.5	28.7	28.2	29.2	345.7	4	1401
	05 LST	29.3	26.7	26.0	26.8	28.2	29.3	30.0	30.5	29.5	27.5	28.0	29.2	340.7	4	1401
	11 LST	28.6	25.0	27.2	26.3	29.2	30.0	31.0	30.7	29.7	29.5	27.0	27.7	341.9	4	1401
CIG = GTR 6000 FT AND	17 LST	26.3	23.7	22.5	23.0	24.0	27.8	30.0	30.0	29.0	26.7	26.0	24.9	313.9	4	1401
VSBY = GTR 3 MI	23 LST	25.0	23.4	24.0	23.5	26.2	29.0	30.2	30.2	29.0	28.0	26.7	23.9	319.1	4	1401
	05 LST	25.6	25.0	22.7	23.3	25.0	28.0	30.0	30.0	28.2	27.0	25.7	23.2	313.7	4	1401
	11 LST	25.0	22.4	19.7	17.7	23.0	25.7	30.5	29.5	28.7	26.2	25.2	24.9	298.5	4	1401
CIG = GTR 10000 FT AND	17 LST	24.6	21.7	20.2	19.5	18.5	19.7	21.0	23.3	25.0	25.2	24.2	23.7	266.6	4	1401
VSBY = GTR 3 MI	23 LST	24.3	21.4	22.7	20.7	23.3	26.5	27.2	28.2	27.5	26.0	25.2	22.9	295.9	4	1401
	05 LST	23.7	23.4	21.0	21.5	23.0	25.5	26.5	26.2	26.7	25.2	24.2	21.4	292.3	4	1401
	11 LST	23.0	20.1	18.5	16.7	19.0	22.7	27.7	27.7	26.7	25.2	24.0	23.2	274.5	4	1401

Table 5.2-1

RAWLINS MUNICIPAL, WYOMING

STA NO. 73618 (IN AREA NUMBER 09) LATITUDE 4148N LONGITUDE 10712W ELEVATION(FT) 06784

PARAMETER DESCRIPTION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN	POR (YRS)	NO. OBS
ABS MAX TMP (F)	56	58	65	75	86	97	98	96	87	81	63	57	98	13	4378
MEAN MAX TMP (F)	31	34	39	52	64	76	83	81	71	58	40	33	55	13	4378
MEAN MIN TMP (F)	11	15	18	27	37	44	51	50	40	31	19	15	30	13	4378
ABS MIN TMP (F)	-36	-20	-16	5	16	21	33	28	19	8	-18	-22	-36	13	4378
MEAN NO DYS TMP = OR GTR 90(F)	0.0	0.0	0.0	0.0	0.0	0.6	3.1	1.2	0.0	0.0	0.0	0.0	4.9	13	4378
MEAN NO DYS TMP = OR LES 32(F)	30.5	27.1	30.1	22.2	7.7	0.8	0.0	0.2	5.4	19.1	26.9	30.2	200.2	13	4378
MEAN NO DYS TMP = OR LES 0(F)	5.1	3.6	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	3.5	17.8	13	4378
MEAN DEW PT TMP (F)	16	14	17	24	31	33	40	39	31	24	17	14	25	4	33478
MEAN RFL HUM (PCT)	65	64	65	57	55	42	41	44	42	51	60	68	55	4	33477
MEAN PRESS ALT (FT)	6593	6622	6720	6768	6815	6830	6781	6771	6739	6676	6601	6581	6708	0	-50
MEAN PRECIP (IN)	0.49	0.62	0.67	0.77	1.08	0.67	0.54	0.57	0.58	0.79	0.49	0.39	7.7	13	4376
MEAN SNOW FALL (IN)	5.8	9.0	6.7	4.4	1.2	0.0	0.0	0.0	0.3	1.8	5.2	4.5	38.9	13	4372
MEAN NO DYS PRCP = OR GTR 0.1 IN	2.0	2.4	2.4	2.9	3.8	1.8	1.7	2.0	2.4	2.4	1.9	1.1	26.8	13	4376
MEAN NO DYS SNFL = OR GTR 1.5 IN	1.4	2.1	1.7	1.1	0.2	0.0	0.0	0.0	0.1	0.3	1.3	0.9	9.1	13	4372
MEAN NO DYS W/OCUR VSBY LES 1/2 MI	0.3	0.6	2.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.0	5.9	4	1401
MEAN NO DYS TSTMS	0.0	0.0	0.2	0.9	4.8	5.7	6.9	5.8	3.2	0.6	0.0	0.0	28.1	13	4378
P FREQ WND SPD = OR GTR 17 KTS	38.1	30.3	22.1	16.5	12.8	14.2	7.5	8.5	8.9	9.2	15.4	25.0	17.4	4	33600
P FREQ WND SPD = OR GTR 28 KTS	4.5	2.4	1.3	1.3	0.3	0.5	0.0	0.3	0.3	0.6	1.3	2.3	1.3	4	33600
P FRFQ LES 5000 FT A/O LES 5 MI	16.5	15.3	25.6	21.8	17.6	6.0	2.5	1.7	2.8	11.3	12.5	17.8	12.6	4	33597
P FREQ LES 1500 FT A/U LES 3 MI															
FOR 00-02 LST	1.8	2.0	5.1	4.7	4.8	1.4	1.3	0.0	1.1	2.4	3.9	2.7	2.6	4	4198
03-05 LST	2.2	3.1	7.3	6.4	4.0	0.8	2.2	1.3	1.7	4.3	5.3	3.5	3.5	4	4199
06-08 LST	2.5	7.8	7.5	9.7	5.4	1.4	1.9	0.8	1.4	4.6	4.7	4.1	4.3	4	4201
09-11 LST	4.3	5.9	8.4	6.2	4.0	0.0	0.0	0.0	0.3	4.3	4.7	5.7	3.7	4	4198
12-14 LST	3.6	3.9	6.7	2.2	1.9	0.0	0.0	0.0	0.0	4.0	4.4	4.6	2.6	4	4201
15-17 LST	2.2	6.7	7.5	3.1	1.1	0.3	0.0	0.0	0.0	4.6	1.4	3.5	2.5	4	4200
18-20 LST	4.3	5.5	4.9	6.1	0.6	0.0	0.0	0.0	0.3	3.8	2.2	3.0	2.6	4	4200
21-23 LST	2.5	3.1	4.8	7.8	3.8	0.3	0.3	0.0	0.6	2.2	1.7	3.3	2.5	4	4200
P FRFQ LES 300 FT A/O LES 1 MI															
FOR 00-02 LST	0.4	0.4	1.1	0.3	0.8	0.0	0.0	0.0	0.0	0.0	1.7	1.1	0.5	4	4198
03-05 LST	0.0	1.2	1.3	1.4	0.3	0.0	0.0	0.0	0.3	0.5	1.1	1.4	0.6	4	4199
06-08 LST	0.4	3.1	2.4	1.9	0.5	0.0	0.0	0.0	0.0	0.3	1.4	1.9	1.0	4	4201
09-11 LST	0.7	1.6	3.5	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.1	0.7	4	4198
12-14 LST	0.0	0.4	3.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.5	0.5	4	4201
15-17 LST	0.0	1.2	4.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.6	4	4200
18-20 LST	2.5	1.2	1.6	1.7	0.0	0.0	0.0	0.0	0.0	0.5	0.3	0.8	0.7	4	4200
21-23 LST	0.0	0.4	2.2	1.4	0.0	0.0	0.0	0.0	0.0	0.3	1.1	0.3	0.5	4	4200

Table 5.2-1 (cont'd)

TABLE 5.2-2

GLOSSARY OF GENERAL TERMS

AIRFIELD DATA AND AIRFIELD AREA DATA

Climatological data applicable only to a specified airfield. The data consists of statistical parameters based on actual weather observations made at the airfield. If actual weather observations are not available, the data consist of estimates of the statistical parameters, prepared by a climatologist, based on actual meterological data from surrounding weather station.

CLIMATIC AREA DATA

Climatological data representative of a nearly homogeneous climatic area. The data are average (or representative) values based on a sample of climatological data available from weather stations within the area. The area data do not imply that the specific conditions simultaneously exists at all locations within a country or large climatic area. In rolling and mountainous terrain there may be considerable variation in the data from one location to another within the climatic area.

LOCAL STANDARD TIME

Standard time applicable to a 15° meridional zone. (Zones proceed east and west from the zone centered on the prime meridian and extending from 00730E to 00730W.) No consideration is given to local deviation from the 15° zone boundaries.

AIRFIELD PARAMETERS [Absolute maximum (minimum) temperature - °F]

The highest (lowest) temperature observed in the specified month during the whole period for which observations are available.

TABLE 5.2-3

PARAMETERS FOR AIRFIELD AREA AND CLIMATIC AREA

MEAN NO. DAYS WITH CEILING GREATER THAN 1000 FEET (GREATER THAN 2500 FEET, GREATER THAN 6000 FEET, ETC.) AND VISIBILITY GREATER THAN 3 MILES

The average of the number of days when, at a specified hour during the day in the specified month, the ceiling was observed to be equal to or greater than 1000 feet (2500 feet, 6000 feet, etc.) and the visibility was observed to be equal to or greater than three miles.

MEAN NO. DAYS WITH CEILING GREATER THAN 2000 FEET AND VISIBILITY GREATER THAN 3 MILES AND SURFACE WIND LESS THAN 10 KNOTS

The average of the number of days when, at a specified hour during the day in the specified month, the ceiling was observed to be equal to or greater than 2000 feet, the visibility was observed to be equal to or greater than 3 miles, and the surface wind speed less than 10 knots.

MEAN NO. DAYS WITH SURFACE WIND GREATER THAN 16 KNOTS AND NO PRECIPITATION

The average of the number of days when, at a specified hour during the day in the specified month, the surface wind speed was observed to be greater than 16 knots, and there was no precipitation.

MEAN NO. DAYS WITH SURFACE WIND 4-10 KNOTS AND TEMPERATURE 33-89°F AND NO PRECIPITATION

The average of the number of days when, at a specified hour during the day in the specified month, the surface wind speed was equal to or greater than 4 knots, but not greater than 10 knots, the temperature was equal to or greater than 33°F but not greater than 89°F and there was no precipitation.

MEAN NO. DAYS WITH SKY COVER LESS THAN 0.3 AND VISIBILITY GREATER THAN 3 MILES

The average of the number of days when, at a specified hour during the day in the specified month, the portion of the sky covered with clouds was observed to be less than 0.3 and the visibility was observed to be equal to or greater than 3 miles.

MEAN NO. DAYS WITH PRECIPITATION GREATER THAN 0.1 INCH (SNOWFALL GREATER THAN 1.5 INCHES)

The average of the number of days in the specified month on which the daily amount of precipitation (snowfall) was observed to be equal to or greater than 0.1 inches (1.5 inches).

Table 5.2-3 (cont'd)

MEAN NO. DAYS WITH AN OCCURRENCE OF VISIBILITY LESS THAN 0.5 MILE

The average of the number of days in the specified month on which there was at least one observation of visibility less than 0.5 mile.

MEAN NO. DAYS WITH THUNDERSTORMS

The average of the number of days in the specified month on which the weather observer heard thunder.

PERCENT FREQUENCY SURFACE WIND SPEED GREATER THAN 16 KNOTS (GREATER THAN 27 KNOTS)

The frequency, expressed as a percent of the total number of hourly weather observations considered, during the specified month, in which the surface wind speed was observed to be greater than 16 knots (27 knots).

PERCENT FREQUENCY CEILING LESS THAN 5,000 FEET OR VISIBILITY LESS THAN 5 MILES

The frequency, expressed as a percent of the total number of hourly weather observations considered, during the specified month, in which the ceiling was observed to be less than 5,000 feet and/or the visibility was observed to be less than 5 miles.

PERCENT FREQUENCY CEILING LESS THAN 1,500 FEET (LESS THAN 300 FEET) OR VISIBILITY LESS THAN 3 MILES (LESS THAN 1 MILE)

The frequency, expressed as a percent of the total number of hourly weather observations considered, during the specified month, in which the ceiling was observed to be less than 5,000 feet and/or the visibility was observed to be less than 5 miles.

PERCENT FREQUENCY CEILING LESS THAN 1,500 FEET (LESS THAN 300 FEET) OR VISIBILITY LESS THAN 3 MILES (LESS THAN 1 MILE)

The frequency, expressed as a percent of all the hourly weather observations considered, in a specified 3-hour period during the day for a specified month in which the ceiling was observed to be less than 1,500 feet (300 feet) and/or the visibility was observed to be less than 3 miles (one mile).

MEAN DAILY MAXIMUM (MINIMUM) TEMPERATURE - °F

The average of all of the daily maximum (minimum) temperatures observed in the specified month.

Table 5.2-3 (cont'd)

MEAN NO. DAYS WITH MAXIMUM TEMPERATURE GREATER THAN 90°F

The average of the number of days in the specified month on which the maximum temperature was observed to be equal to or greater than 90°F.

MEAN DEW POINT TEMPERATURE - °F

The average of all hourly dew point temperatures observed in the specified month.

MEAN RELATIVE HUMIDITY-PERCENT

The average of all hourly relative humidity values observed in a specified month.

MEAN PRESSURE ALTITUDE TEST

The average station pressure observed at the airfield in the specified month converted to an altitude by using the U.S. Standard Atmosphere.

MEAN MONTHLY PRECIPITATION - INCHES

The average of the monthly total amount of all forms of precipitation, reduced to its liquid equivalent, observed in the specified month.

MEAN MONTHLY SNOWFALL - INCHES

The average of the monthly total amount of snowfall observed in the specified month.

TABLE 5.2-4

WIND DIRECTION AND AVERAGE SPEED DATA
FROM THE RAWLINS AIRPORT

Direction	Percent of Occurrences in Different Months				
	DJF	MAM	JJA	SON	Annual
N	1.8	2.5	2.7	2.4	2.4
NNE	0.7	1.5	1.8	1.1	1.3
NE	1.6	2.8	2.9	1.9	2.3
ENE	1.3	2.8	2.8	2.2	2.3
E	1.1	4.0	3.3	2.4	2.7
ESE	0.3	1.1	1.7	0.7	0.9
SE	0.3	0.6	1.3	0.5	0.7
SSE	0.2	0.3	0.7	0.3	0.4
S	0.6	1.3	1.7	0.7	1.0
SSW	1.6	2.7	2.3	1.3	2.0
SW	13.0	11.6	9.5	11.3	11.3
WSW	30.6	21.9	15.4	22.5	22.6
W	23.2	17.4	13.6	20.1	18.6
WNW	4.1	6.5	6.4	5.5	5.6
NW	1.5	2.9	3.9	2.3	2.6
NNW	1.1	1.6	2.0	1.7	1.6
CALMS	17.1	18.5	28.3	23.1	21.8
TOTAL	100.1	100.0	100.3	100.0	100.1
AVERAGE WINDSPEED KTS (MPH)	12.1 (13.9)	10.8 (12.4)	7.7 (8.9)	9.6 (11.1)	10.0 (11.5)

TABLE 5.2-5

WIND DIRECTION DATA[1] AND SPEED DATA
FROM THE NORTH KNOBS SITE

Direction	Percent of Occurrence in Different Months				
	May	June	July	August	Total Monitoring Period[2]
N	3.8	6.1			6.2
NE	5.4	8.9			6.8
E	17.5	11.0			15.9
SE	13.3	13.0			14.0
S	10.0	11.4			9.7
SW	21.7	22.0			19.6
W	18.3	14.2			14.8
NW	10.0	13.4			13.0
AVERAGE WINDSPEED KTS (MPH)	9.9 (11.4)	9.9 (11.4)	8.6 (9.9)	9.6 (11.1)	

[1] June and July have monitoring data for entire month.

[2] This period covers from May 25 through August 11, 1978.

Velocity readings may vary by a factor of 2-3 between daytime and nighttime on the average. Wind directions are predominantly westerly ranging from the SW to NW quadrant. During periods of relative calm, local drainage wind may occur from the ridge to the east. The main range in seasonal wind speeds is from 8 to 14 mph. It is not uncommon for winds to exceed 50 mph throughout the year.

The average monthly temperature means vary between a low of 11°F and a high of 31°F for January to 51°F and 83°F for July. The high elevation allows average diurnal variations of 20° in the winter and 32° in the summer. High and low extremes have been 98°F and -36°F, respectively.

Precipitation has averaged 7.7 inches annually with about half of the moisture occurring as rain during May to September and the remainder as snow. May is the wettest month. The average snowfall is 39 inches. On the average, precipitation greater than 0.1 inch occurs only on 27 days of the year. The normal annual precipitation computed by the Weather Bureau from measurements up to 1950 is 11.37 inches. The average annual precipitation, computed from the 1953 and 1955-through-1976 measurements, is 8.92 inches, significantly lower than that given by the Weather Bureau from earlier records. The annual precipitation records show a high variability--between 3.8 inches in 1907 and 17.0 inches in 1912.

The monthly distribution of the precipitation is typical of the region when low winter precipitations recognizably increase around May with a smaller peak again in September and October. Summer precipitation commonly occurs in localized small thundershowers which are rarely of an amount to generate local surface runoff. The winter snows are subject to redistribution by wind and also to large sublimation losses.

It is expected that prevailing winds at the North Knobs site will prevent any accumulation of air pollutants from the construction or from the operation of the underground coal gasification facilities.

5.2.2 Surface Hydrology

The test area is on the west side of the Rawlins anticline on a hill slope approximately 1.8 miles to the east from Separation Creek. Separation

Creek originates on the southwest side of Separation Peak, approximately 13 miles to the southwest from Rawlins at an elevation of about 8400 feet. The original southwestern course of Separation Creek on the left side of the Atlantic Rim changes to a westerly course, then turns toward the north on the west side of Red Rim. After crossing the railroad line and I-80 it continues in a general northern direction over about 18 miles passing by the test area and proceeding on the west side of the Rawlins uplift. In Section 8, T23N, R89W, Separation Creek turns northeast for a distance of 10 miles, then after a short travel in a southeasterly direction, it terminates in Separation Lake about 14 miles to the north of Rawlins at an elevation of about 6400 feet.

Separation Lake is a dry lake bed throughout most of the year and does not have a surface outflow from the basin. Surface drainage indicates Separation Lake as a sink hole, collecting runoff water at times of high spring runoff or heavy storms. A larger part of the water collecting in Separation Lake is subject to evaporation, and only a minor portion of it will join the unconfined ground water of the alluvium surrounding the lake. Although there are not substantiating data, general geologic information of the area indicates that it is possible that the alluvium is connected to an alluvium tributary to the North Platte River and some of the underflow from the Separation Lake aquifer probably will eventually join the North Platte River. If this is the case, the time required for water to percolate from Separation Creek to the North Platte River is of the magnitude of hundreds of years.

Separation Creek is intermittent near the test area and up to an elevation of about 7000 feet above which elevation it has perennial flow. The altitude of the channel of Separation Creek at its closest proximity to the test area is about 6640 feet.

From the test area and its vicinity there are no recognizable side channels leading to Separation Creek. On the steeper portion of the rising landscape there are some minor erosion channels running toward the west. However, with the smaller slopes of Separation Flats, these channels disappear, indicating that the runoff does not have the necessary volume and energy to continue channel formation to Separation Creek.

In 1975 the USGS installed a gaging station on Separation Creek (Station No. 09216527) in Section 32, T20N, R90W, about 8.2 miles south of the UCG test site. Flow records at this station are available from October 1975 through the current year. This gaging station is sufficiently close to the headwaters of the creek to record a representative channel flow from snowmelt and the more significant storm events. The 2 years of records available at the present time are shown below in monthly acre-feet units.

	Feb.	Mar.	Apr.	May	June	July	Aug.	Water year total
1976	17	383	717	607	302	15	0.1	2040
1977	0	12	91	17	0	67	3	190

Based upon estimation methods developed by Lowham (1976), using the latest geomorphologic techniques, the average annual runoff is estimated at the above station as 1500 acre-feet.

Proceeding from the gaging station in the downstream direction toward the north, channel-flows become greatly reduced. The creek enters the rather flat and open basin of Separation Flats. As the cross section of the stream-connected alluvium increases, the water from the creek channel enters the aquifer and continues its northward movement along Separation Creek as underflow.

The underflow, which is generally protected from evaporation losses which occur with an open water surface, spreads out under the flood plain and subirrigates substantial areas on both sides of the creek. Loss of water from the underground in this case is twofold. Where the water table approaches the surface to a sufficient distance for the capillary rise representative of the particular soil group to intercept the surface, there is a direct upward transport and loss of water. The grassy and shrubby vegetation covering the subirrigated areas consume large amounts of ground water thereby reducing the available supply in a downstream direction.

The small amount of precipitation falling on the area during the growing season of the native vegetation (that season is longer than the one considered for agricultural crops) is entirely used up by the vegetation or evaporates from the upper soil layers, rarely producing local runoff. The inadequacy of the precipitation to sustain even a healthy range-type vegetation is perceivably portrayed by the sparse grass and sagebrush cover of the higher lying hillside areas. For this reason, the recharge of the lower consolidated formations through their outcrop areas is rather limited.

Preliminary information on the coal seam and the embedding formations indicate that the water supply stored in these formations is very limited, and the water-yield characteristics of these formations are extremely poor. It appears that the processing water requirements of the experiments will have to be met either by water import or from a water supply eventually developed from more remote strata of the Fort Union formation or from other formations with significantly better water-yield characteristics. Information available at this time does indicate that the experiment will not require the removal of any appreciable amount of excess water from the G seam or from the neighboring formations close to the proposed burns. It is not anticipated that the proposed, rather limited, localized burning experiment will cause problems with the disposal of excess water or will contaminate the surface hydrologic system.

5.2.3 Soils and Vegetation

Activities to identify and map the distribution of soils and vegetation on the UCG facility were completed in August 1978 by the U.S. Department of Agriculture and subcontracted personnel. Reconnaissance soil and vegetation mapping techniques were utilized to compile these data. A detailed soil thickness map for the facility and physical property data for each soil series were not obtained at this time because of budgetary allotments. The reconnaissance data will be used to partially fulfill permit application requirements and serve as a foundation for preliminary design of the surface facility.

5.2.3.1 Soil

The soil types found on the UCG site were described, classified, and mapped by personnel from the Saratoga District Office of the soil conservation service (U.S. Department of Agriculture). This work involved:

1. Traversing the site to observe the surface characteristics of the soils.
2. Obtaining soil horizon samples with a soil probe at various traverse points.
3. Describing the composition, color, and texture of the sampled soil horizons.
4. Classifying the soil types observed by comparing the observed horizon characteristics with type location soil descriptions.
5. Mapping the soil distribution on low-altitude aerial photographs.

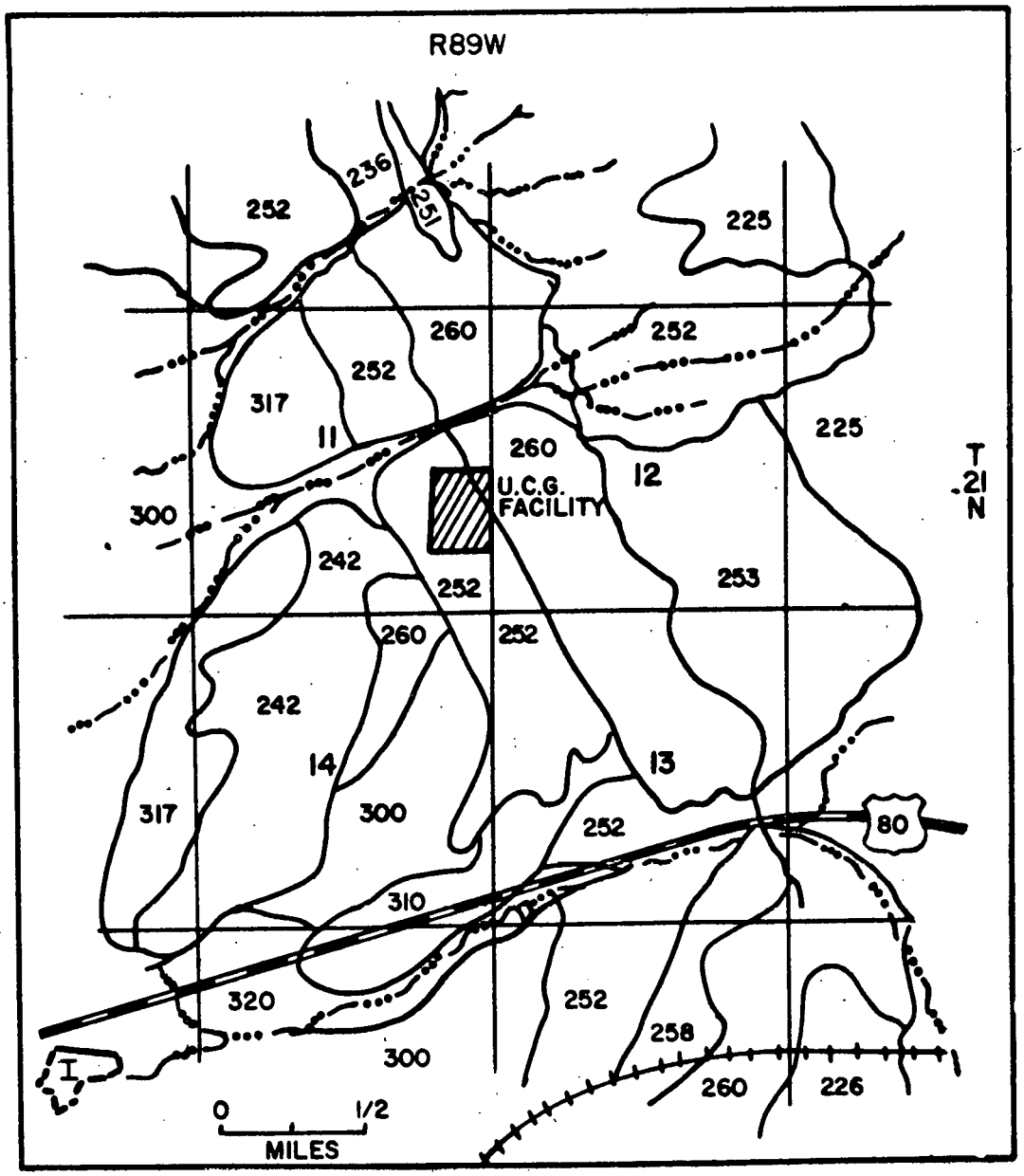
Data compiled by the soil conservation services (SCS) includes a soils distribution map for the North Knobs UCG site area. Figure 5.2-1 and a range site map for the UCG facility (Figure 5.2-2) with a legend (Table 5.2-6). The SCS identified two part complexes. These are described below.

260-Ryan Park-Rock River Association. This mapping unit consists of gently sloping to moderate steep alluvial fans at elevations of 6500 to 7800 feet. The average annual precipitation is about 11 inches, average annual air temperature is about 42°F, and the average frost-free season is about 90 days. Slopes range from 2 to 20%.

Ryan Park sandy loam makes up about 45% of the mapping unit, and Rock River sandy loam makes up about 30%. Ryan Park soils occur on the middle and upper portions of alluvial fans. Rock River soils occur on the lower portions of alluvial fans and alluvial bottoms.

Included in this unit are areas of Grieves and Blackhall soils. These inclusions make up about 25% of the total acreage.

The Ryan Park soil is a deep, well-drained soil forming an alluvium. Typically, the surface layer is brown sandy loam about one-inch thick. The



KEY FOR SOIL TYPES ON SECTION 11

MAP UNIT NUMBER	SOIL FAMILIES (SERIES)	SLOPES
242	BLACKHALL, BLAZON	6 – 30%
252	SHINBARA, BLAZON, ROCK OUTCROP	10 – 40%
260	RYAN PARK, ROCK RIVER	2 – 20%
300	MONTE, CLOWERS	0 – 10%
317	LITTSAN (DEEP VARIANT), SAGE CREEK (COARSE VARIANT)	3 – 10%

Figure 5.2-1

SOILS DISTRIBUTION MAP FOR THE NORTH KNOBS UCG SITE

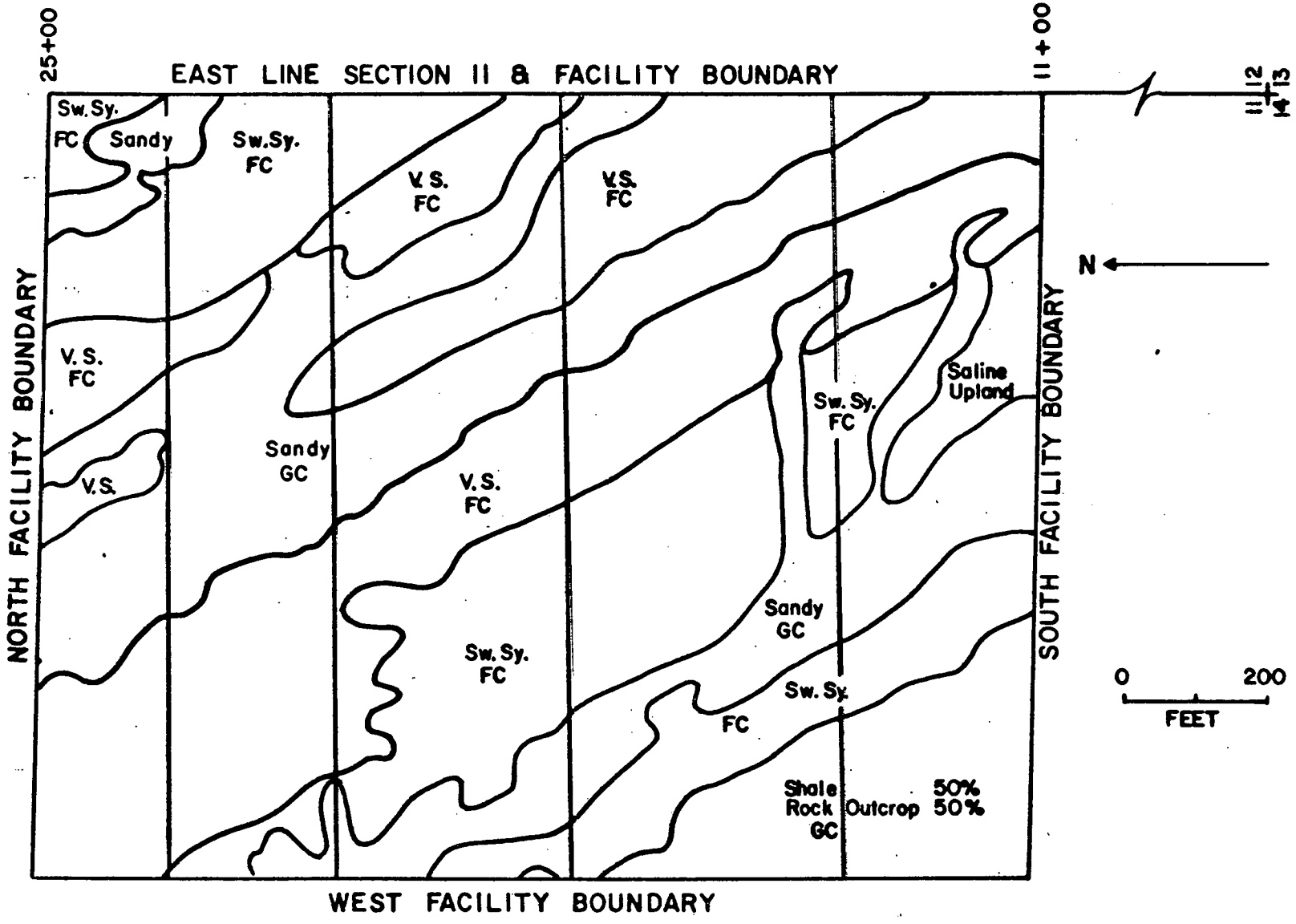


Figure 5.2-2

RANGE SITE MAP FOR THE UCG FACILITY

Table 5.2-6

Legend for Range Sites

Range sites are kinds of native rangelands that differ from each other in their ability to produce significantly different kinds or amounts of original vegetation. Soils, precipitation and geographical location are combined to designate a specific range site. The following range sites are listed in the normally presumed order of the productivity in "Excellent" condition.

Names of the range sites occurring on your ranch are underlined, and these sites are separated by solid lines on your conservation plan map.

Symbol	Range Site Name	Brief Description for GREEN River and GREAT Divide Basin - 7"-9" p.z.
WL	Wetland	These soils are poorly drained with water above the surface for part of the growing season. The main vegetation is: decreasers - Nebraska sedge, northern reedgrass, tufted hairgrass and bluejoint reedgrass: Increasers - inland sedge, Baltic rush, forbs and willows.
Sb	Subirrigated	These are deep, organic soils with a water table near the surface for most of the growing season. The principal vegetation is: decreasers - basin wildrye, tufted hairgrass and Nebraska sedge; increasers - western wheatgrass, inland sedge, forbs, shrubby cinquefoil and willows.
SS	Saline Subirrigated	These are deep saline soils that have a water table near the surface for most of the growing season. The main vegetation is: decreasers - alkali sacaton, basin wildrye and Nuttall alkaligrass, increasers - alkali muhly, inland saltgrass, western wheatgrass and greasewood.
LL	Lowland	The soils of this site are deep, well drained, with a water table below 3 ft, and are found along streams. The principal vegetation is: decreasers - basin wildrye, Letterman needlegrass, needleandthread grass, and bluebunch wheatgrass; increases - thickspike wheatgrass, needleleaf sedge, cottonwoods and silver buffaloberry.
SL	Saline Lowland	The soils of this site are deep, saline, and usually found along streams. The principal vegetation is: decreasers - western wheatgrass, alkali sacaton, four-wing saltbush and Gardners saltbush; increasers - inland saltgrass, inland sedge, alkali muhly, greasewood and rubber rabbitbrush.
Sa	Sands	The soils of this site are coarse textured sands that sometimes form dunes. The vegetation is: decreasers - needleandthread, thickspike wheatgrass, Indian ricegrass and bottlebrush squirreltail; increasers - needleleaf sedge, big sagebrush and low rabbitbrush.
Sy	Sandy	The soils of this site are mainly loamy kinds of sands that are deep. The main vegetation is: decreasers - needleandthread grass, bluebunch wheatgrass and Canby bluegrass; increasers - thickspike wheatgrass, needleleaf sedge, big sagebrush and low rabbitbrush.
Ly	Loamy	The soils of this site are deep loams that usually occur in an upland position. The principal vegetation is: decreasers - needleandthread grass, bluebunch wheatgrass, Indian ricegrass and winterfat; increasers - thickspike wheatgrass, Sandberg bluegrass, big sagebrush and low rabbitbrush.
Cy	Clayey	The soils of this site are deep and fine textured that usually occur in the lowland position. The main vegetation is: decreasers - western wheatgrass, bottlebrush squirreltail, bud sagebrush and Gardners saltbush; increasers - needleleaf sedge, Sandberg bluegrass, big sagebrush and low rabbitbrush.

Table 5.2-6 (Cont'd.)

Symbol	Range Site Name	Brief Description for GREEN River and GREAT Divide Basin - 7"-9" p.z.
DC	Dense Clay	The soils of this site are deep heavy clays that take up water very slowly. The main vegetation is: decreasers - western wheatgrass, Indian ricegrass and bud sagebrush; increasers - Sandberg bluegrass, low sagebrush and birdsfoot sagebrush.
SwSy	Shallow Sandy	The soils of this site are sandy loams that are sometimes rather coarse and usually found on southwest facing slopes. The main vegetation is: decreasers - needleandthread grass, bluebunch wheatgrass, Indian ricegrass and winterfat; increasers - galleta, needleleaf sedge, forbs and low rabbitbrush.
SwLy	Shallow Loamy	The soils of this site are shallow loams over limestones and shales. The principal vegetation is: decreasers - bluebunch wheatgrass, Indian ricegrass, needleandthread grass and thickspike wheatgrass; increasers - needleleaf sedge, Sandberg bluegrass, forbs, low rabbitbrush, low sagebrush and big sagebrush.
SwCy	Shallow Clayey	The soils of this site are shallow heavy clays, usually over shale. The main vegetation is: decreasers - western wheatgrass, bottlebrush squirreltail and bud sagebrush; increasers - Sandberg bluegrass, needleleaf sedge, forbs, birdsfoot sagebrush, winterfat and low sagebrush.
SwB	Shallow Breaks	The soils of this site are shallow with outcrops of sedimentary rock, usually on south and west facing slopes. The principal vegetation is: decreasers - bluebunch wheatgrass, Indian ricegrass, needleandthread grass and thickspike wheatgrass; increasers - needleleaf sedge, Sandberg bluegrass, juniper and big sagebrush.
IC	Impervious Clay	The soils of this site are very tight clays with high amounts of sodium. The main vegetation is: decreasers - western wheatgrass, bottlebrush squirreltail, Indian ricegrass and Gardners saltbush; increasers - Sandberg bluegrass, forbs and birdsfoot sagebrush.
SU	Saline Upland	The soils of this site are heavy saline clays that are usually in a lowland position. The main vegetation is: decreasers - bottlebrush squirreltail, Indian ricegrass and Gardners saltbush; increasers - Sandberg bluegrass, winterfat and birdsfoot sagebrush.
GR	Gravelly	The soils of this site are very gravelly, sandy and normally occur along streams. The principal vegetation is: decreasers - bluebunch wheatgrass, Indian ricegrass and needleandthread grass; increasers - Sandberg bluegrass, needleleaf sedge and low rabbitbrush.
VS	Very Shallow	The soils of this site are very shallow and rocky and usually occur on steep slopes. The principal vegetation is: decreasers - bluebunch wheatgrass, thickspike wheatgrass and needleandthread grass; increasers - needleleaf sedge, Sandberg bluegrass, forbs and juniper.
Sh	Shale	The soils of this site are very shallow clays over shale. The main vegetation is: decreasers - thickspike wheatgrass, Indian ricegrass and Gardners saltbush; increasers - birdsfoot sagebrush, greenmolly summercypress and forbs.

Table 5.2-6 (cont'd.)

LEGEND FOR RANGE CONDITION

Range condition is the present stage of vegetation in relation to climax condition for that range site. Range condition provides an approximate measure of any deterioration that has taken place in plant cover and serves as a basis for predicting the degree of improvement possible.

Map Symbol	Range Condition Class	Percent of Present Composition that is Potential for the Range Site
EC	Excellent Condition	76 - 100
GC	Good Condition	51 - 75
FC	Fair Condition	26 - 50
PC	Poor Condition	0 - 25

Range condition classes, within the same range site, are separated by a dotted line.

subsoil is yellowish brown sandy loam about 16 inches thick. The upper part of the substratum is pale brown, sandy loam about 25 inches thick. The lower part of the substratum is yellowish brown, sandy loam to a depth of 60 inches.

Permeability is moderate. The available water capacity is moderate. Effective rooting depth is 60 inches or more. Surface runoff is medium, and erosion hazard is moderate.

The Rock River soil is deep, well-drained soil forming in alluvium. Typically, the surface layer is brown, sandy loam about 2 inches thick. The subsoil is brown, sandy clay loam about 10 inches thick. The substratum is calcareous, yellowish brown, sandy loam to a depth of 60 inches.

Permeability is moderate. The available water capacity is moderate. Effective rooting depth is 60 inches or more. Surface runoff is medium and erosion hazard is moderate.

Rangeland management practices such as proper grazing use and planned grazing systems can be used to minimize deterioration of range conditions. Practices such as cross fencing and water development help to utilize range plants by livestock more effectively.

These soils provide some food and cover for antelope, deer, and sage grouse.

Ryan Park part: sandy, 7-9 inches P.Z. range site
Rock River part: loam, 7-9 inches P.Z. range site

Shinbara, Blazon, Rock Outcrop Complex, 6-30% Slopes. These sloping to steep soils are on bedrock controlled uplands in the Hanna basin at elevations between 6500 and 7300 feet. The average annual precipitation is about 12 inches and the mean annual air temperature is about 42°F. The Shinbara soil makes up about 35% of the mapping unit, the Blazon soil about 30%, and Rock outcrops about 25%. The Shinbara soils differ from the Blazon soils by being shallower to bedrock. About 10% of the unit is Delphill and Tassleman soils.

The Shinbara series are a very shallow, excessively drained soil. It formed in very shallow loamy deposits weathered from shale interbedded with sandstone.

Typically, the surface layer is brown, strongly alkaline loam about 3 inches thick. The substratum is strongly alkaline silty clay loam about 3 inches thick. Soft fractured shale and coal occurs at 6 inches.

Permeability is moderate to slow. The effective rooting depth is 3 to 10 inches, and the available water capacity is very low. Surface runoff is medium to rapid, and erosion hazard is moderate to severe.

The Blazon series is a shallow, well-drained soil. It formed from shallow loamy deposits weathered from interbedded sandstone and shale.

Typically, the surface layer is brown, moderately alkaline clay loam about 11 inches thick. Interbedded sandstone and shale deposits occur at 16 inches.

Permeability is moderate. The effective rooting depth is 10 to 20 inches and the available water capacity is very low. Surface runoff is medium to rapid and erosion hazard is moderate to severe.

These soils are used for rangeland and wildlife habitat.

Very shallow or shale: 7-9 inches, P.Z. range site, Shinbara
Shallow loamy: 7-9 inches, P.Z. range site, Blazon

Detailed mapping of the soil and rock outcrop distribution on the facility and the determination of the soil (and/or alluvium) thickness over the G seam subcrop was conducted by personnel from Robert McCurdy and Associates. These data were obtained by:

1. Observing the low-altitude aerial photographs.
2. Traversing the facility to observe its surface character.
3. Mapping the soil/outcrop distribution on the aerial photographs.

The data obtained from McCurdy and Associates includes:

1. A surface geological map which delineates the distribution of soils and rock outcrop on the facility (see Figure B-4 in Appendix B).
2. Soil isopach maps which indicate the thickness of soil on top of the G seam subcrop at each burn location (see Figures 5.2-3 and 5.2-4).

No data were obtained on the physical properties of the soils, the soil thickness in locations other than over the G seam subcrop, or the distribution of specific soil series on the facility because of budget and scheduling constraints.

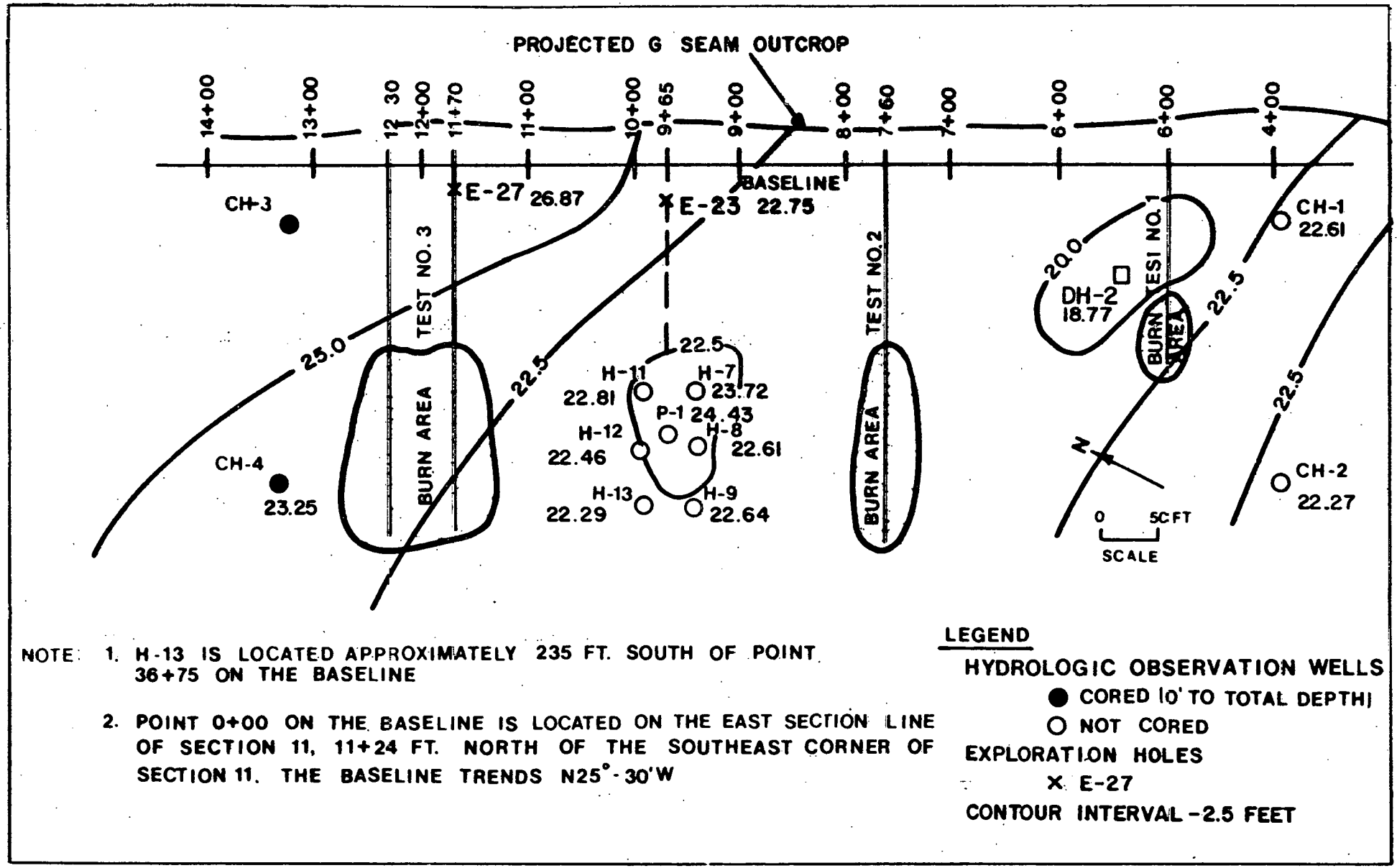
VEGETATION

Vegetation assemblages on the UCG facility were mapped by personnel from the Saratoga office of the Soil Conservation Service. This work was completed by (1) observing and mapping vegetative zones on low-altitude aerial photographs of the facility, (2) traversing the facility to observe its surface vegetative characteristics, and by (3) identifying the types and amounts of vegetation on each range site.

Vegetation species occurring in the area and present land conditions at the North Knobs site are described in Tables 5.2-7 to 11, Range Condition Worksheets. Five range sites occur in the area with condition classes ranging from fair to good. Shallow-sandy and sandy sites dominate the permit area, especially in the area to be disturbed.

Five range sites were identified within the two soil families found on the facility (Figure 5.2-2). These are:

Range Site	Characteristics	Map Symbol
Sandy	Deep, loamy sands	Sandy
Shallow sandy	Coarse, sandy loams	SWSY
Saline upland	Saline clays	SU
Very shallow	Shallow, rocky	VS
Shale	Very shallow clays	Sh



NOTE:
1. H-13 IS LOCATED APPROXIMATELY 235 FT. SOUTH OF POINT 36+75 ON THE BASELINE
2. POINT 0+00 ON THE BASELINE IS LOCATED ON THE EAST SECTION LINE OF SECTION 11, 11+24 FT. NORTH OF THE SOUTHEAST CORNER OF SECTION 11. THE BASELINE TRENDS N25°-30'W

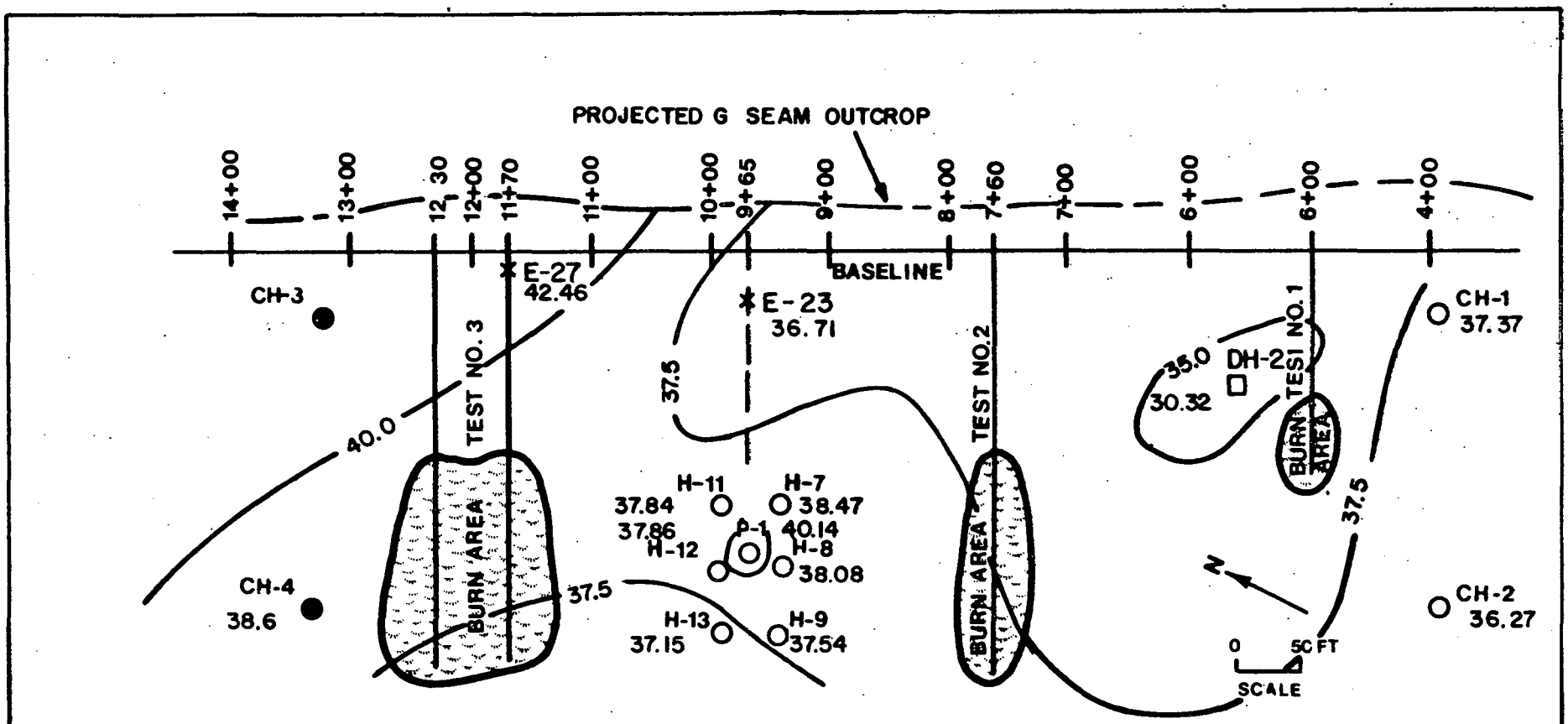
LEGEND

HYDROLOGIC OBSERVATION WELLS
- ● CORED (0' TO TOTAL DEPTH)
- ○ NOT CORED

EXPLORATION HOLES
- × E-27

CONTOUR INTERVAL - 2.5 FEET

FIGURE 5.2-3
ISOPACH MAP FOR THE MAIN PART (G_{mc}) OF THE G COAL SEAM



NOTE: 1. H-13 IS LOCATED APPROXIMATELY 235 FT. SOUTH OF POINT 36+75 ON THE BASELINE

2. POINT 0+00 ON THE BASELINE IS LOCATED ON THE EAST SECTION LINE OF SECTION 11, 11+24 FT. NORTH OF THE SOUTHEAST CORNER OF SECTION 11. THE BASELINE TRENDS N25°-30'W

LEGEND

HYDROLOGIC OBSERVATION WELLS

● CORED (0' TO TOTAL DEPTH)

○ NOT CORED

EXPLORATION HOLES

× E-27

CONTOUR INTERVAL-2.5 FEET

FIGURE 5.2-4

ISOPACH MAP FOR THE G COAL SEAM

United States Department of Agriculture
Soil Conservation Service

Table 5.2-7

WY Range-19
11/77
File Code Range-18

RANGE CONDITION WORKSHEET

LOCATION SE¼ Sect 11 T21N R89W UNIT _____ PASTURE _____
PRECIPITATION ZONE 7-9" RANGE SITE Very Shallow DATE 8/7/78 BY E Bainter - N V Hayes

Species		Approx. Potential Production (lb./ac.)	Present Production Estimated Amount (lb./ac.)	Percent Normally Found in Potential	Present Composition Present Percent Composition	Present Composition Percent 1/ Allowable in Potential
Needleleaf Sedge				5	30	5
Phlox					T	
Needle & Thread	Stco			5-10	20	10
Nail Wart					T	
Rabbitbrush	Chvi			5	10	5
Spinless Horsebush					T	
Astragalus					T	
Indian Ricegrass	Orhy			5-10	15	10
Thickspike Wheatgrass	Agda			5	25	5
		200-400#			100	35

TOTALS
Range Condition 35%
Range Condition Class Fair
Estimated Plant Cover _____ Range Trend -- UP DOWN STATIC (Circle One)
Key Grazing Plants Needle & Thread - Ricegrass Key Browse Species _____

1/ Can be equal to, but not in excess of the approximate potential production or composition.

United States Department of Agriculture
Soil Conservation Service

WY Range-19
11/77
File Code Range-18

Table 5.2-8

RANGE CONDITION WORKSHEET

LOCATION SE¼ Sect 11 T21N R89W UNIT PASTURE
PRECIPITATION ZONE 7-9" RANGE SITE Shale DATE 8/7/78 BY E Bainter-N V Hayes

Species		Approx. Potential Production (lb./ac.)	Present Production Estimated Amount (lb./ac.)	Percent Normally Found in Potential	Present Composition Present Percent Composition	Present Composition Percent 1/ Allowable in Potential
Birdsfoot				5	10	5
Saltbush	Atr			25	45	25
Thickspike Wheatgrass	Agda			35	25	35
Needle & Thread	Stco				5	5
Indian Ricegrass	Orhy			5	5	5
Winterfat	Eula			5	T	
Needleleaf Sedge					T	
Phlox						
Nailwart						
Astragalus	All Forbs			10	10	10
Unknown						
		150-300#			100	85

TOTALS
Range Condition 85%
Range Condition Class Good
Estimated Plant Cover Range Trend -- UP DOWN STATIC (Circle One)
Key Grazing Plants Indian Ricegrass-Rhizomatous Wheatgrass Key Browse Species

1/ Can be equal to, but not in excess of the approximate potential production or composition.

United States Department of Agriculture
Soil Conservation Service

WY Range-19
11/77
File Code Range-18

Table 5.2-9

RANGE CONDITION WORKSHEET

LOCATION SE¼ Sect 11 T21N R89W UNIT PASTURE
PRECIPITATION ZONE 7-9" RANGE SITE Shallow Sandy DATE 8/7/78 BY E Bainter - N V Hayes

Species		Approx. Potential Production (lb./ac.)	Present Production Estimated Amount (lb./ac.)	Percent Normally Found in Potential	Present Composition Present Percent Composition	Present Composition Percent 1/ Allowable in Potential
Indian Ricegrass	Orhy			20	15	15
Thickspike Wheatgrass	Agda			10	35	10
Needle & Thread	Stco			25	10	10
Sandburg Blue	Posa			5/	20	5
Spiney Hopsage	Grsp			0	5	0
Broom Smakeweed	Gusa				T	
Cactus					T	
Phlox					T	
Winterfat	Eula				T	
Threadleaf Sage					T	
		200-450#			100	45

TOTALS
Range Condition 45%
Range Condition Class Fair
Estimated Plant Cover Range Trend -- UP DOWN STATIC (Circle One)
Key Grazing Plants Needle & Thread - Ricegrass Key Browse Species

1/ Can be equal to, but not in excess of the approximate potential production or composition.

United States Department of Agriculture
Soil Conservation Service

Table 5.2-10

WY Range-19
11/77
File Code Range-18

RANGE CONDITION WORKSHEET

LOCATION SE¼ Sect 11 T21N R89W UNIT PASTURE
PRECIPITATION ZONE 7-9" RANGE SITE Saline Upland DATE 8/7/78 BY E Bainter -N V Hayes

Species		Approx. Potential Production (lb./ac.)	Present Production Estimated Amount (lb./ac.)	Percent Normally Found in Potential	Present Composition Present Percent Composition	Present Composition Percent 1/ Allowable in Potential
Indian Ricegrass	Orhy			20	55	20
Bottlebrush	Sihy			25	5	5
Sandburg Bluegrass	Posa			5	10	5
Saltbush	Attr			35	10	10
Bud Sage				5	5	5
Needle & Thread	Stco			5	T	
Gardner Saltbush	Atnu			25-35	10	10
Kochia americana						
Cactus				-	5	-
		300-600#			100	55

TOTALS
Range Condition 55%
Range Condition Class Good
Estimated Plant Cover Range Trend -- UP DOWN STATIC (Circle One)
Key Grazing Plants Bottlebrush - Ricegrass Key Browse Species

1/ Can be equal to, but not in excess of the approximate potential production or composition.

United States Department of Agriculture
Soil Conservation Service

WY Range-19
11/77
File Code Range-18

Table 5.2-11

RANGE CONDITION WORKSHEET

LOCATION SE¼ Sect 11 T21N R89W UNIT _____ PASTURE _____
PRECIPITATION ZONE 7-9" RANGE SITE Sandy DATE 8/7/78 BY E. Painter-V.V. Hayes

Species		Approx. Potential Production (lb./ac.)	Present Production Estimated Amount (lb./ac.)	Percent Normally Found in Potential	Present Composition Present Percent Composition	Present Composition Percent 1/ Allowable in Potential
Indian Ricegrass	Orhy			5-10	T	10
Spiney Hopsage				5	5	10
Big Sage	Artr			10	55	10
Bottlebrush	Sihy			10	30	10
Canby Blue	Poca				5	5
Low Rabbitbrush	Chvi			5 Allowable	5	5
Sandburg Blue	Posa				T	
Bushy Birdsbeak					T	
Mustard					T	
		300-700#			100	50

TOTALS _____
Range Condition 50%
Range Condition Class Fair to Good
Estimated Plant Cover _____ Range Trend -- UP DOWN STATIC (Circle One)
Key Grazing Plants Ricegrass Key Browse Species _____

1/ Can be equal to, but not in excess of the approximate potential production or composition.

The G coal seam did not outcrop on the facility, and its subcrop was covered by from 0 to 40 inches of soil and from 10 to 60+ feet of alluvium below the soil, depending upon location. The range site overlying the G seam subcrop is the sandy range site. Specific physical and strength property data were not obtained for any of the soils found on the facility area.

Thirty-three types of plants were identified as commonly occurring on the five range sites and facility. The plant series and assemblages are presented in Tables 5.2-7 through 11.

Plants found on the range site occurring directly over the G seam subcrop include:

Plant Species	% of Total
Big Sage	55
Bottlebush	30
Canby Blue	5
Low Rabbit Bush	5
Sandburg Blue	Trace
Bushy Birdsbeak	"
Mustard	"
Indian Ricegrass	"
Spiney Hopsage	"

These plants have a range in heights from 42 inches and their growth density varies greatly depending upon the local topography soil and drainage conditions.

5.2.4 History/Archeology

History of Area. The proposed UCG/SDB site is located eight miles west of Rawlins in Carbon County, Wyoming. Rawlins, the county seat for Carbon County, has a population of 11 840 as of 1976. 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" comprises all of the Section 11, Township 21N, Range 89W. The facility will be located on a rectangular shaped 36 ha (90 acre) plot on the northeastern side of the section.

Not much is known about the Indians who occupied this region of Wyoming prior to 1500 A.D., and some things still aren't known about them even after that date. However, the presence of a number of tribes of Indians has been established. These nomadic tribes included Shoshoni, Arapahoe, Comanche, and Cheyenne. They were primitive people who subsisted by hunting, fishing, and gathering. None of the tribes practiced any kind of cultivation or agriculture. After 1750 A.D. when horses were introduced from the south and guns were brought in from the northeast, major changes in several facets of life occurred to Indians of this area in Wyoming. The Comanche left entirely. The Shoshoni migrated west. The tribes of this region of Eastern Wyoming came to depend upon the buffalo. Eventually, in the middle of the 19th century, Sioux tribes came into the region. After 1880, Indians were moved to reservations.

As the tracks of the Union Pacific Railroad approached the Wyoming area from Nebraska and the east in the spring of 1867, the region began to get its first permanent settlers with a European heritage. During the next ten years, population in the southern portion of Carbon Country grew, largely with the railroad. This was a settling down period when the basic business was running a railroad, maintaining it by mining coal, and performing other services necessary to make a success of the nation's first transcontinental line. Other fundamental activities included government at several levels and increased livestock grazing. By 1980, Carbon County ranked fourth in the state in terms of population. The largest percentage of the population was clustered around the Union Pacific railway. The population of Rawlins, the nearest town, was 2235. In the decade preceeding 1900, the population growth rate declined. The 1900 census showed 2317 people living in Rawlins. More rural areas to the north were being settled mainly due to more advanced means of transportation. By 1950, the population of Wyoming lived largely in the urban center. The population of Rawlins had risen to 7415. At present, farm and ranch population continue to decline, and the most significant growth is in urban areas.

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 (see Figure 5.2-5). This mine was a strip mine that was operated in the I coal seam. No data was located as to when this mine was operational.

The following inactive mine activities occurred prior to 1907 at locations close to Section 11:

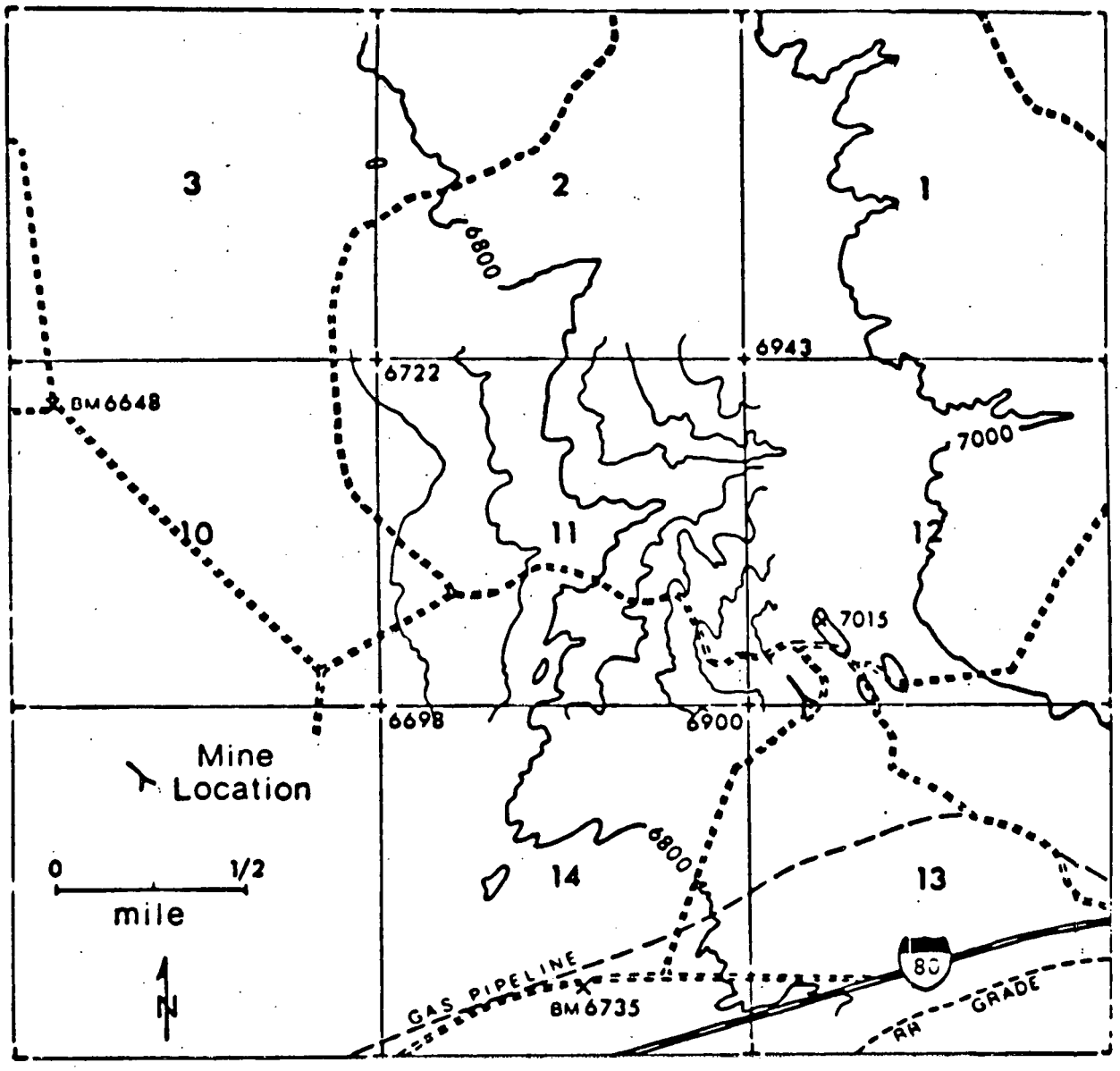
a. Section 36, T21N, R88W. The Dillion mine was a shaft mine which operated in a coal seam in the Mesaverde Formation. The coal is inclined about 45°S at the mine. The mine produced coal for several years prior to 1900, and the coal was sold to local residents in Rawlins. The mine was closed down because faults were encountered in the underground mine rooms which made the operation of the mine unsafe.

b. Section 6, T20N, R88W. The Nebraska coal mine was a slope mine operating in the Medicine Bow Formation. The mine had a 10-15°W dip and it extended downdip along the bedding inclination for several hundred feet in a seam that is approximately 15 feet thick. The coal is composed of alternating layers of clean vitreous coal and softer carbonaceous shales. The Nebraska mine also operated around 1900.

c. Section 24-25, T21N, R89W. This mine was operated by the Union Pacific Railroad Company in 1868, and it was the first mine developed in the Rawlins area. The coal was about 11 feet thick and had a westerly dip at 10°. The coal was reported to be of excellent quality. Mining activity continued several hundred feet downdip until haulage and drainage problems arose.

d. Section 22, T21N, R88W. This mine operated in a coal bed of Mesaverde age that had a thickness of 8 feet and a near vertical dip. To mine this coal, a slope was installed within the bed along strike with an inclination of 34°. The slope was abandoned when substantial quantities of water were encountered at a depth of 80 feet.

e. Section 18, T27N, R89W. This was a small glory hole developed in beds of Laramie age.



INACTIVE COAL MINES ON SECTIONS ADJACENT TO SECTION 11

Figure 5.2-5

f. Sections 4 and 16, T26N, R89W. This was a small glory hole developed in beds of Laramie age.

g. Section 8, T27N, R89W. Two mines were developed in different seams of approximately the same age to a depth of 100 feet. The mines were slope mines and were abandoned when the groundwater table was reached.

h. Section 6, T28N, R89W. This was a 75-foot long slope mine in a 16-foot coal bed which dipped 26°SW. Again the coal was mined for local use in Rawlins.

i. Section 27, T28N, R90W. This was a shaft mine in a near vertical coal bed which was a Laramie age and 5 feet thick. The shaft was 4-foot square and 40 feet deep.

j. Section 20, T26N, R90W. This was a small mine developed in the Fort Union coals for use at the Lost Soldier stage station.

A representative of the state of Wyoming evaluated the proposed UCG/SDB area for historic sites. No historic sites were found on Section 11.

Archeological Resources

During the summer of 1977, an archeological survey was completed on nine sections of land west of Rawlins, WY. The survey was conducted by personnel from the Wyoming State Archeologists Office for the Energy Development Company.

Twenty-eight prehistoric archeological sites and one historic site were recorded in the North Knobs study area (Figure 5.2-6). These sites were located by means of an on-foot reconnaissance which is estimated to have covered 80% of the area. Of the 28 sites, 3 were located on Section 11. Following are the locations and descriptions of these sites.[1]

1. 48CR565 - Red Shirt
   N 1/2 / SW 1/4 Section 11, T21N, R89W

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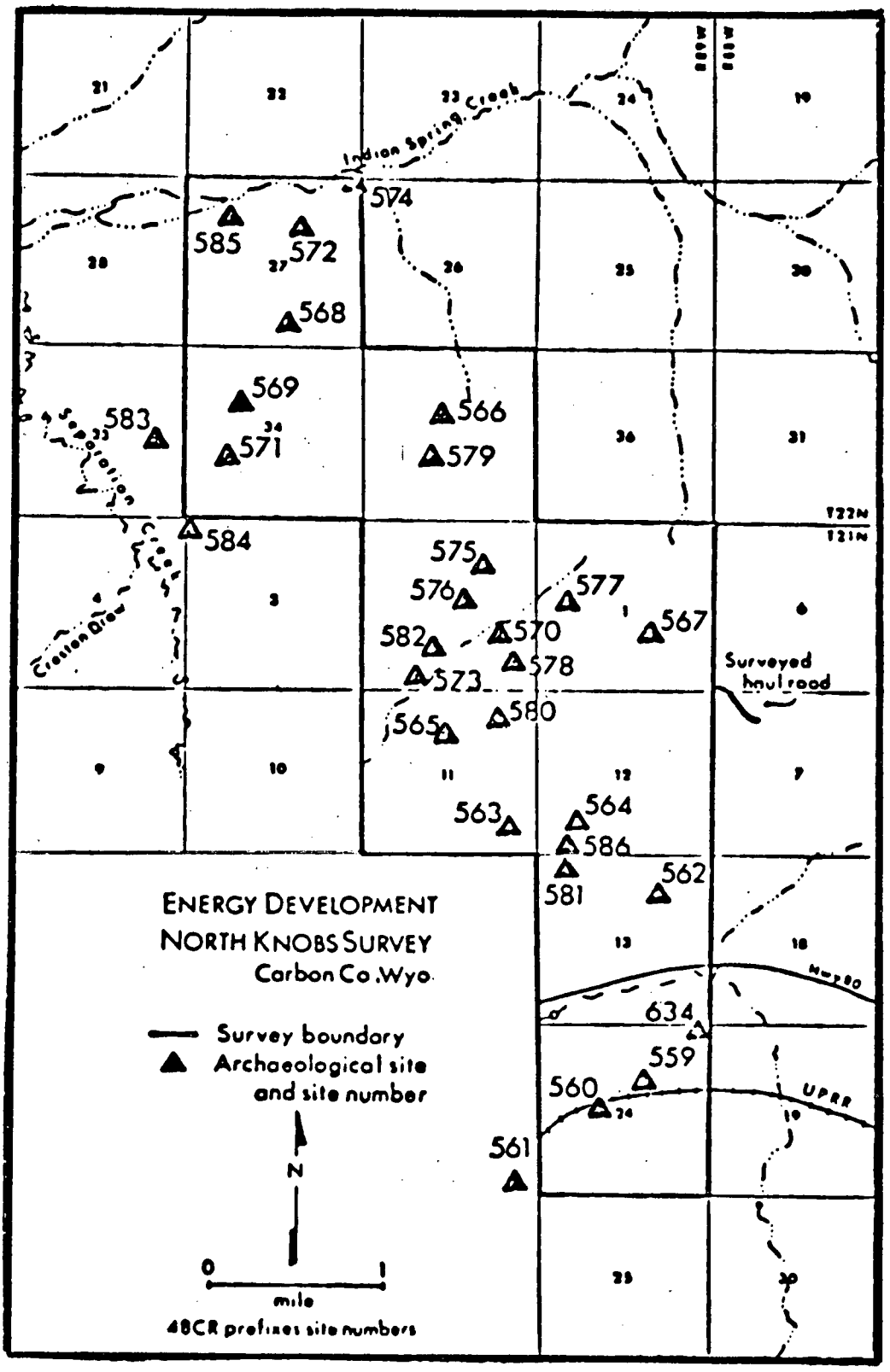
[1]Larson, Thomas K., "Archeological Investigations of North Knobs Area, Carbon County, WY," Office of State Archeologist, Box 3431, University Station, Laramie, WY 82071, March 1978.



Location of Archeological Sites
Within the North Knobs Study Area

Figure 5.2-6

This site is located near the base of the hogback ridges which run through the study area. It extends over a large area and may represent a number of separate activity areas. A corner notched point base from the site indicates occupation of the site during the Late Plains Archaic, between 1500 and 3000 years ago.

At the time the site was discovered, a vehicle trail which passes through the site had exposed a fire hearth. In order to prevent further destruction, this feature was excavated and recorded. The excavation revealed a large, basin-shaped hearth with a second, smaller hearth superimposed over one edge of it. Carbon samples were taken from both and will hopefully yield good dates for the occupation of the site. No artifacts or debris were found in association with these hearths.

It is believed that the Red Shirt site may be multi-component in nature and contain buried deposits in other areas. Further testing is therefore recommended. The National Register potential of the Red Shirt site is unknown at this time.

2. 48CR563 - United States
   E 1/2 / SE 1/4 Section 11, T21N, R89W

48CR563 is a very large occupation site covered with numerous fire hearths and at least two stone circles. The site is along a north-south ridge top between Separation Flats and the Knobs.

Testing is recommended at this site to determine the extent of the buried deposits. Eligibility for the National Register of Historic Places is unknown at this time.

3. 48CR580 - T.P.I.
   NW 1/4 / NE 1/4 / NE 1/4 Section 11, T21N, R89W

A concentration of lithic debitage was collected at the T.P.I. site which is located between two hogback ridges and overlooks Separation Flats to the west. No subsurface features were encountered and further work is not recommended at this location. The site is not eligible for nomination to the National Register of Historic Places.

5.3 BOUNDARY STRATA STUDIES

The purpose of the boundary strata analysis was to determine the suitability of the rock overlying the G coal seam to act as a stable overburden for the coal gasification cavity. For this purpose, a twofold study was carried out. First the rock quality designation (RQD) was studied to determine the overall quality of the overlying rock mass from the engineering point of view. RQD reflects the relative amount of fracturing and alteration. This method utilizes a modified core recovery procedure. The second part of the program involved the study of mechanical properties and the strength parameters of the major rock units. The Young's modulus, Poisson's ratio, compressive (uniaxial and triaxial) and tensile strengths were determined by conducting compression (uniaxial and triaxial) and Brazilian tests on specimens obtained from core hole CH-4.

5.3.1 Description

The rock strata overlying the G seam consists mainly of a thick (300-ft) sandstone bed of the Fort Union Formation (Figure 5.3-1). This bed is a medium grained sandstone locally changing in nature to finer grained and carbonaceous sandstones. It is interbedded with four thin beds of carbonaceous shale and siltstone ranging in thickness from 2 to 45 ft. The rock strata immediately under and overlying the main G seam is carbonaceous shale.

5.3.2 Rock Quality Designation (RQD)

The rock quality designation (RQD) is based on a modified core recovery procedure. This procedure is based indirectly on the number of fractures and the amount of softening and alteration in the rock mass as observed in rock cores.* The RQD is used for evaluating the quality of rock at a site and the variations, both within a borehole and from borehole to

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* Deere, D. U., A. J. Henderson, F. D. Patton, and E. J. Cording, "Design of Surface and Near Surface Construction in Rock," Eighth Symp. on Rock Mechanics, Minnesota, 1966.

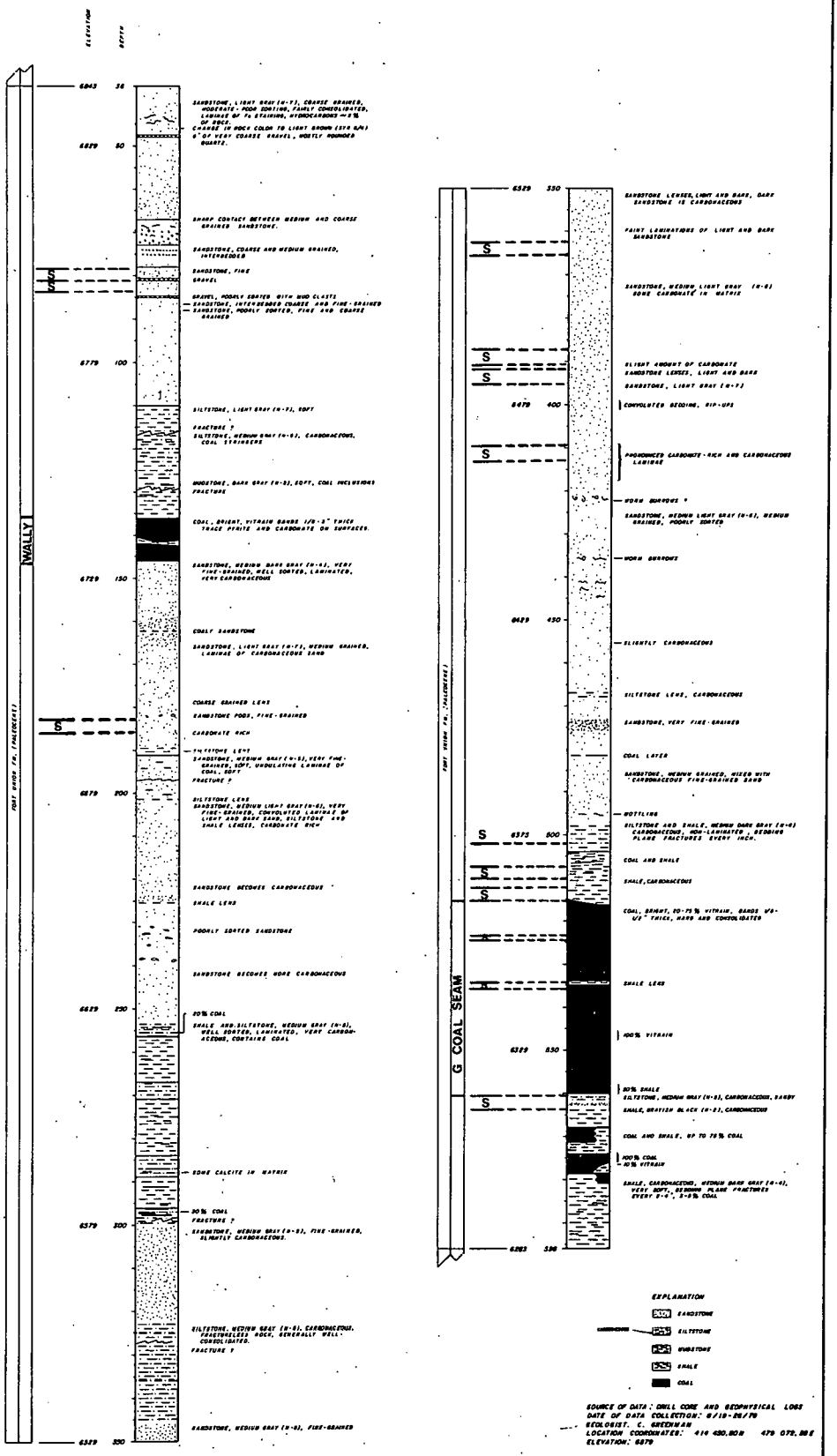

Figure 5.3-1

LOCATION OF SAMPLES SELECTED FROM CORE HOLE 4 FOR BOUNDARY STRATA TESTING

borehole, across the site. The availability of RQD information makes it possible to evaluate the ratio of the observed modulus of deformation, E_r, to the modulus of the intact core, E_{core}; i.e., the reduction factor E_r/E_{core}, (see Figure 5.3-2)* can be correlated with the variation in rock quality.

At the North Knobs site, only the rock core from CH-4 was available for RQD study. This core was studied by GR&DC personnel in detail and two kinds of RQD were prepared. The first one was for each individual rock unit identified in the lithologic log (Figure 5.3-1) and is given in Table 5.3-1. The other was for overall rock mass and was calculated to be 66.1%, classifying the rock mass in the "fair" category (refer to Figure A.5.1-1 in Appendix A). The variation of RQD ranging from 10% to 92.7% can be observed in Table 5.3-1. It is clear that RQD is dependent upon the individual rock type. Most of the sandstone units have a RQD as high as 92.7%, but some near-surface (36-27 ft) units have one as low as 32%. The lowest RQD of 10% was observed in siltstone and mudstone (at 110-136 ft depths), and, in general, weaker rocks of shale and siltstone exhibit a "poor" category RQD of 45.5-48.5%. These rocks occur as thin layers within the very thick sandstone unit. It is important to note that except for some weaker shale and siltstone units near the G coal seam, most of the rock mass is composed of sandstone, which ranges in quality from "good" to "excellent."

5.3.3 Mechanical Properties

The objective of this investigation was to determine the basic mechanical properties and the strength parameters of the major rock units which constitute the rock mass above the G coal seam. The following tests were conducted for this study:

*Deere, D. V., A. J. Henderson, F. D. Patton, and E. J. Cording, "Design of Surface and Near Surface Construction in Rock," Eighth Symp. on Rock Mechanics, Minnesota, 1966.

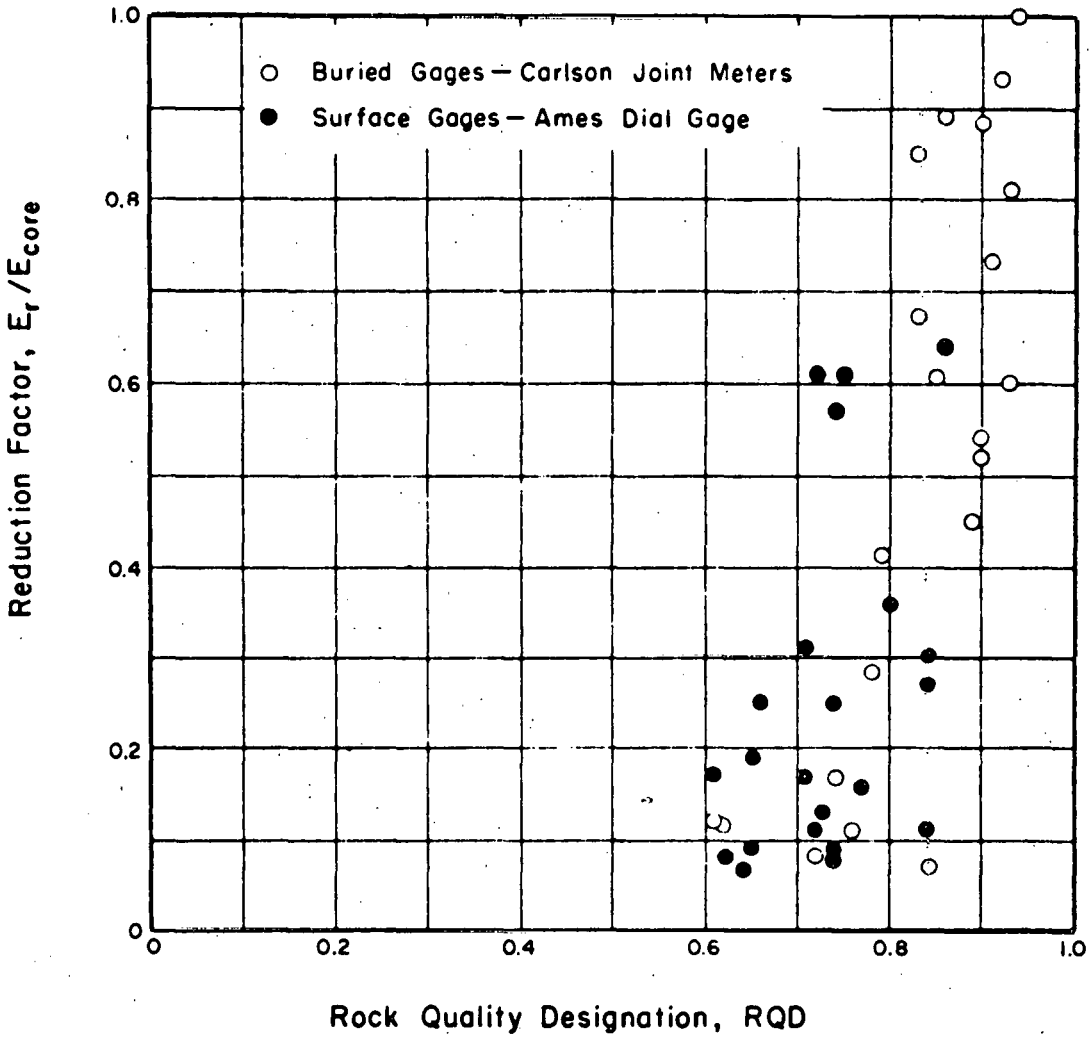

Figure 5.3-2 Variation of Reduction Factor with Rock Quality

Table 5.3-1

Rock Quality Designation for the
Rock Units in Core Hole 4

Depth (ft)	Rock Type	RQD (%)	Description of Rock Quality*
36-49	Sandstone - Coarse-grained	32.0	Poor
49-67	Sandstone - Medium-grained	32.0	Poor
67-78	Sandstone - Coarse-grained	62.5	Fair
78-81	Sandstone - Fine-grained	62.5	Fair
81-110	Sandstone - Fine- & coarse-grained Siltstone	62.5	Fair
110-136	Mudstone - Carbonaceous	10.0	Very Poor
136-146	Wally Coal	--	Not Available
146-165	Sandstone - Very fine-grained	70.0	Fair
165-190	Sandstone - Medium-grained	79.5	Good
190-225	Sandstone - Very fine-grained	71.4	Fair
225-253	Sandstone - Medium-grained Shale	61.0	Fair
253-285	Siltstone - Very carbonaceous Shale	80.0	Good
285-300	Siltstone - Very carbonaceous	48.5	Poor
300-323	Sandstone - Fine-grained	80.0	Good
323-345	Siltstone - Carbonaceous	80.0	Good
345-425	Sandstone - Fine-grained	92.7	Excellent
425-473	Sandstone - Medium-grained	90.5	Excellent
473-476	Sandstone - Very fine-grained	90.8	Excellent
476-498	Sandstone - Medium-grained	90.8	Excellent
498-506	Siltstone - Carbonaceous	64.4	Fair
504-515	Shale - Carbonaceous	64.4	Fair
515-560	G-Coal	--	Not Available
560-568	Siltstone - Carbonaceous	45.5	Poor
568-580	Coal/Shale - Carbonaceous	45.5	Poor
580-596	Shale - Carbonaceous	45.5	Poor

*Refer to Figure A.5-1 (Appendix A).

1. Uniaxial compression tests for compressive strength, Young's modulus, and Poisson's ratio.

2. Triaxial compression tests for compressive strength at various confining pressures.

3. Brazilian tests for tensile strength.

The specimens for all these tests were prepared from 3-inch diameter core (3 1/2 inch diameter from 36 to 136 ft depth) obtained from core hole 4. The specimen preparation and test description are given in Appendix A.5-1.

5.3.3.1 Uniaxial Compression Tests

A typical stress-strain curve obtained for a uniaxial compression test is shown in Figure 5.3-3. All the uniaxial compression tests results are given in Table 5.3-2. The test results show that the properties of the rocks in mutually perpendicular directions are different due to their anisotropic nature. This quantitative difference is larger in shale and most sandstone units than in siltstone. The apparent reason for the difference seems to be the prominent bedding in sandstone and shale.

To conduct a comparative study of the uniaxial compression test results, the engineering classification for intact rocks (Table 5.3-3) based on strength and the modulus ratio* was used. Tables 5.3-4 and 5.3-5 give the comparative study of the rocks tested on the basis of average compressive strength and modulus ratio, respectively. Table 5.3-4 shows that all rocks are characterized as either low or very low strength. The average compressive strength of sandstone ranges from 1925 to 5271 psi, whereas siltstone and shale exhibit higher compressive strengths of 5748 to 7298 psi and 6389 to 7420 psi, respectively. Table 5.3-5 shows that all tested rocks are of either

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* Deere, D. U. and R. P. Miller - "Engineering Classification and Index Properties for Intact Rock," Tech. Report No. AFWL-TR-62-116, Air Force Weapons Lab., Kirkland Air Force Base, New Mexico, 1966.

Table 5.3-2

Results of Uniaxial Compression Tests

Rock	Type	Depth (ft.)	Density (gm/cc)	Loading Axis With Respect Bedding plane	Compressive Strength C_o (Psi)	Average Comp. st. C_o(Psi)	Young's Modulus E x 10^6 (Psi)	Average E x 10^6 (Psi)	Poisson's Ratio ν	Average Poisson's Ratio ν
Sandstone	Coarse Grained	78-81	2.00	Parallel	1888		1.01		0.22	
			1.91	"	1544	1925.0	0.43	0.72	0.06	0.126
			2.00	"	2343		0.74		0.10	
			2.02	Perpendicular	2970		1.64		0.09	
			2.01	"	3021		1.66		0.05	
			2.02	"	3157	2846.2	1.25	1.24	0.23	0.136
			2.01	"	2846		0.67		0.20	
			1.97	"	2237		0.99		0.14	
Sandstone	Fine grained	81-83.1	2.03	Parallel	1073	1007.5	----	----	----	------
			2.01	"	942		0.23		0.38	
Sandstone	Fine grained	183-186	1.85	Parallel	3424	3458.0	----	----	----	------
			1.81	"	3492		----	----	----	------
Sandstone	Fine grained	362-365	2.24	Parallel	3207		3.39	2.41	0.05	0.085
			2.30	"	2736	3368.2	1.44		0.12	
			2.27	"	4522		----		----	
			2.24	"	3008		----		----	
			2.32	Perpendicular	4257	4292.0	1.13	0.74	0.08	0.095
			2.33	"	4327		0.35		0.11	
Sandstone	Fine grained	387-390	2.17	Perpendicular	7241		0.72		0.22	
			2.19	"	3929	5271.7	0.77	0.786	0.23	0.183
			2.17	"	4645		0.87		0.10	
Sandstone	Fine grained	391.3-394.3	2.19	Parallel	4214	4214.0	0.74	0.74	0.45	0.45
			2.19	Perpendicular	4602	4602.0	0.59	0.59	0.15	0.15
Sandstone	Fine grained	410-413	2.14	Parallel	3832		0.50		0.26	
			2.11	"	3592	3469.7	0.70	0.72	0.24	0.18
			2.19	"	4069		0.82		0.10	
			2.09	"	2386		0.86		0.12	
			2.09	Perpendicular	3646		0.60		0.29	
			2.22	"	4292	4385.0	0.97	1.013	0.27	0.225
			2.19	"	5125		1.47		0.12	
			2.23	"	4477		----	-----	----	-----
Siltstone	Carbonaceous	499-501	2.21	Parallel	5469		0.94		0.25	
			2.20	"	6389	6072.7	1.20	1.407	0.08	0.130
			2.19	"	5880		1.87		0.03	
			2.23	"	6554		1.62		0.16	
			2.29	Perpendicular	6308		1.19		0.19	
			2.31	"	5188	5748.0	1.86	0.525	0.10	0.145
Siltstone	Carbonaceous	560-563	2.34	Perpendicular	8104		1.00		0.13	
			2.38	"	8589	7277.7	1.21	1.10	0.18	0.092
			2.29	"	6022		1.26		0.01	
			2.26	"	6396		0.93		0.05	
Shale	Carbonaceous	507-510	2.29	Perpendicular	7473	6386.0	1.18	1.185	0.11	0.115
			2.30	"	5299		1.19		0.12	
			2.18	Parallel	1291	1291.0	----	-----	----	-----
Shale	Carbonaceous	511.9-514.8	2.26	Parallel	6551		1.18		0.14	
			2.28	"	7325	6384.5	1.39	1.355	0.29	0.176
			2.27	"	5109		1.61		----	
			2.28	"	6553		1.24		0.10	
			2.28	Perpendicular	7471	7420.5	0.87	0.895	0.25	0.175
			2.29	"	7420		0.92		0.10	
Coal	6 Seam	534.8-535.2	1.30	-----	762	762	----	-----	----	-----

Table 5.3-3

Engineering Classification of Intact Rock

I. On basis of strength ($s_{a(ult)}$)

Description	Uniaxial compressive strength (lb/in^2)
Very high strength	Over 32 000
High strength	16 000-32 000
Medium strength	8000-16 000
Low strength	4000-8000
Very low strength	Less than 4000

II. On basis of modulus ratio ($E_t/s_{a(ult)}$)

Description	Modulus Ratio*
High modulus ratio	Over 500
Average (medium) ratio	200-500
Low modulus ratio	Less than 200

*Modulus ratio = $E_t/s_{a(ult)}$,

where E_t = tangent modulus at 50% ultimate strength,

$s_{a(ult)}$ = uniaxial compressive strength.

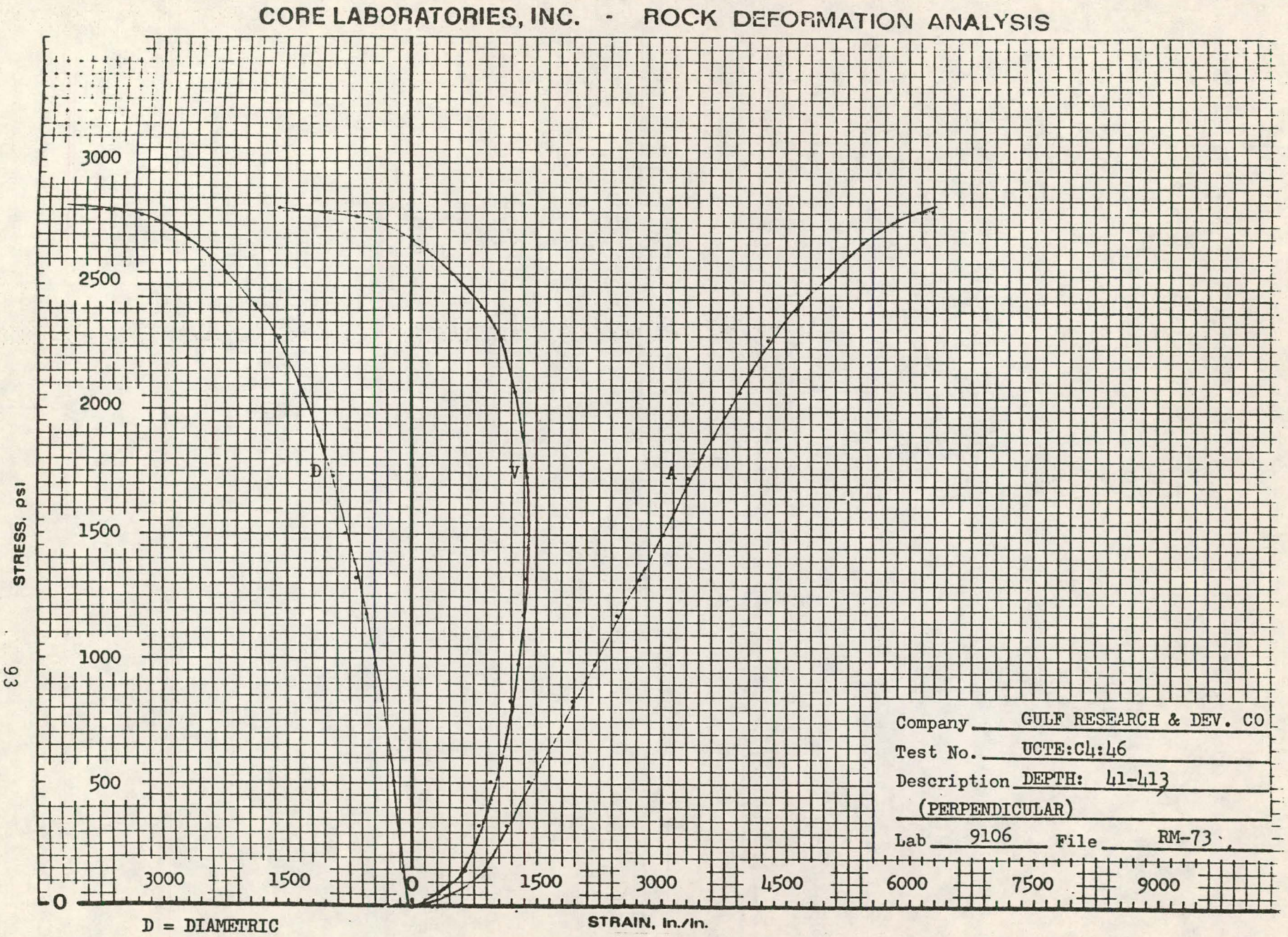

Figure 5.3-3 A Typical Stress-Strain Curve for a Uniaxial Compression Test

Table 5.3-4

Classification of Tested Rock Units Based on Their Uniaxial Compressive Strength

Rock	Type	Depth	Loading axis with respect to bedding plane	Average compressive strength	Description
Sandstone	Coarse grained	78-81	Parallel	1925	Very low strength
			Perpendicular	2846	" " "
	Fine grained	81-83.1	Parallel	1007	" " "
	" "	183-186	"	3458	" " "
	" "	362-365	"	3368	" " "
			Perpendicular	4292	Low strength
	Fine grained	387-390	"	5271	" "
	" "	391.2-386.3	Parallel	4216	" "
			Perpendicular	4602	" "
	Fine grained	410-613	Parallel	3470	Very low strength
			Perpendicular	4385	Low strength
Siltstone	Carbonaceous	699-501	Parallel	6072	" "
			Perpendicular	5748	" "
	Carbonaceous	560-563	"	7278	" "
Shale	"	507-510	"	6386	" "
	"	511.9-519.8	Parallel	6384	" "
			Perpendicular	7420	" "

Table 5.3-5

Classification of Tested Rock Units Based on Their Modulus Ratio

Rock	Type	Depth	Loading Axis With Respect To Bedding Plane	Young's Modulus Ratio	Description
Sandstone	Coarse grained	78-81	Parallel	374	Low modulus ratio
			Perpendicular	435	Med " "
	Fine grained	81-83.1	Parallel	44	Low " "
	" "	362-365	Parallel	715	High " "
			Perpendicular	172	Low " "
	Fine grained	387-380	"	148	Low " "
	" "	391-394.3	Parallel	175	" " "
			Perpendicular	128	" " "
	Fine grained	410-413	Parallel	207	Med " "
			Perpendicular	231	" " "
Siltstone	Carbonaceous	499-501	Parallel	231	" " "
			Perpendicular	265	" " "
	Carbonaceous	560-563	"	151	Low " "
Shale	"	507-510	"	185	" " "
	"	511.9-519.8	Parallel	212	Med " "
		"	Perpendicular	120	Low " "

low or medium modulus ratio, except one sandstone unit (362-365 ft) which exhibited high modulus ratio of 715. Generally, the sandstone has a varied modulus ratio of 99 to 435, with the one exception indicated earlier. The siltstone and shale exhibit less varied modulus ratios of 151 to 265 and 120-212, respectively.

5.3.3.2 Triaxial Compression Tests

The results of the triaxial compression tests are given in Table 5.3-6. The increase in the compressive strength values with increasing confining pressures can be observed in all cases. The shale and siltstone specimens exhibit higher compressive strength than the sandstone specimens for the same confining pressure, showing that shale and siltstone are stronger than sandstone under confined conditions. A limited number (3) of coal specimens were available for testing. These were tested at confining pressure value of 600 psi. An average compressive strength of 3148 psi for 600 psi confining pressure was obtained for the coal specimens. This is much lower than the rock compressive strength range of 6200-4600 psi, for confining pressure of 600 psi.

5.3.3.3 Brazilian Tests

Since an accurate determination of tensile strength of intact rock by the uniaxial tension test is cumbersome, the tensile strength is commonly measured by indirect methods. The "Brazilian" test is one method frequently used for determining the tensile strength of the rock. In this test, a rock disc of length (L) and diameter (D) is loaded diametrically with a line load (P). The specimen usually fails by splitting along the line of diametrical loading. The tensile strength is then calculated at failure from the following equation:

$$\text{Tensile strength} = \frac{2P}{\pi DL}$$

Table 5.3-6
Triaxial Compression Test Results

Rock	Type	Depth (ft)	Density (gms/cc)	Loading Axis with Respect to Bedding Plane	Confining Pressure (psi)	Compressive Strength (psi)
Sandstone	Coarse-grained	78-81	2.00	Parallel	400	2631
			1.94	"	600	4199
			2.03	Perpendicular	100	4899
			2.05	"	200	4605
			2.01	"	400	5611
			2.01	"	600	5578
Sandstone	Fine-grained	183-186	1.88	Parallel	100	2387
			1.85	"	200	2750
			1.86	"	400	4197
			1.86	"	600	5063
			1.89	Perpendicular	100	2368
			1.89	"	200	2465
			1.88	"	400	3622
			1.87	"	600	4676
Sandstone	Fine-grained	362-365	2.23	Parallel	200	6010
			2.21	"	400	5199
			2.21	"	600	6464
Sandstone	Fine-grained	387-390	2.10	Perpendicular	100	3704
			2.11	"	200	4901
			2.13	"	400	5977
			2.13	"	600	7120
Sandstone	Fine-grained	391.3-394.4	2.21	"	100	4752
			2.18	"	200	6296
Sandstone	Fine-grained	410-413	2.16	Parallel	100	3915
			2.18	"	200	5761
			2.19	"	400	6983
			2.18	"	600	7676
			2.51	Perpendicular	200	6315
			2.63	"	600	9519
Siltstone	Carbonaceous	499-501	2.27	Parallel	100	5549
			2.26	"	200	6988
			2.30	"	400	8970
			2.29	"	600	9609
			2.23	Perpendicular	100	6227
Siltstone	Carbonaceous	560-563	2.23	"	400	8770
			2.25	"	600	9444
Shale	Carbonaceous	507-510	2.16	"	200	4985
		"	2.27	"	600	9141
Shale	Carbonaceous	511.9-514.9	2.23	Parallel	200	7058
			2.27	"	400	9556
			2.24	"	600	7881
Coal	G seam	522.8-523.2	1.32		600	3191
			1.30		600	3574
			1.26		600	2678

The results of the Brazilian test are given in Table 5.3-7. No trend due to bedding plane orientation is observed. On the average, specimens drilled perpendicular to the bedding plane show lower tensile strength. Usually this difference in tensile strength is within 20%. However, one sandstone specimen (387-390 ft) had tensile strength seven times higher in parallel direction than that of perpendicular. This difference may be explained due to a local change in lithology. With the exception of this sandstone from depth 387-390 ft drilled parallel to bedding, the tensile strength of sandstone and shale generally is relatively low.

5.3.4 Subsidence Calculations

Subsidence calculations were made based on the beam theory and from procedures published by the National Coal Board (of England). Both of these calculations predicted negligible or no vertical subsidence for the expected UCG cavity dimensions (Refer to memo in Appendix A.5). However, these calculations do not take into consideration the effects of in situ and thermal stresses and the structural effects on the coal seam and surrounding rock mass created by the high UCG temperatures.

5.3.5 Conclusions and Recommendations

The boundary strata analysis for core hole 4 indicates that the rock mass above the G seam is of varying nature. The overall rock mass quality, based on the rock quality designation index, is good. The mechanical properties and the strength parameter values indicate that all rock units forming overburden above the G coal seam are of low modulus and strength. A limited number of tests in the third direction to determine anisotropy are advisable. Dynamic and beam tests would improve the accuracy of these determinations.

Table 5.3-7

Results of Brazilian Tests

Rock	Type	Depth (ft)	Density (gm/cc)	Drilling Direction With Respect to Bedding Plane	Orientation of Loading Axis with with Respect to Bedding Plane	Tensile Strength (psi)	Average
Sandstone	Fine grained	81-83.1	2.01	Parallel	0°	175	)
			2.02	"	45°	234	)220.5
			2.01	"	67.5°	193	)
			2.01	"	90°	280	)
			2.02	Perpendicular	--	161	)
			1.95	"	--	172	)174.25
			1.96	"	--	183	)
			1.93	"	--	226	)
Sandstone	Fine grained	387-390	2.79	Parallel	0°	2220	)
			2.88	"	22.5°	2741	)
			2.88	"	45°	2213	)2269.0
			2.77	"	67.5°	2378	)
			2.77	"	90°	1793	)
			2.06	Perpendicular	--	288	)
			2.13	"	--	331	)321.25
			2.11	"	--	365	)
			2.08	"	--	301	)
Sandstone	Fine grained	391.3-394.3	2.19	Parallel	0°	260	)
			2.18	"	22.5°	286	)
			2.15	"	45°	206	286.8
			2.16	"	67.5°	368	)
			2.17	"	90°	314	)
			2.15	Perpendicular	--	293	)
			2.75	"	--	278	)257.3
			2.14	"	--	201	)
Shale	Carbonaceous	511.9-514.8	2.23	Parallel	0°	747	)
			2.23	"	45°	686	)748.3
			2.26	"	90°	814	
			2.29	Perpendicular	--	807	)
			2.21	"	--	623	)725.8
			2.23	"	--	756	)
			2.22	"	--	743	)
			2.27	"	--	702	)

5.4 COAL CORE ANALYSIS

During August and September, 1978, core holes were drilled at the underground coal gasification site. The cores were used to obtain detailed lithologic, chemical and physical characteristics of the G coal seam and surrounding boundary strata. Four core holes were originally planned; however, only two were drilled due to budgetary and scheduling constraints. These holes were designated core holes 1-4 (CH 1-4) and core hole 3 (CH-3) and core hole 4 (CH-4) were the holes selected for coring (Figure 5.4-1).

5.4.1 Core Hole Description

The descriptive statistics for each core hole are as follows:

	CH-3	CH-4
Core Diameter	3.5 inches	3.0 inches
Depth of G Seam	59.0-103.0 feet	517.0-560.0 feet
Depth of I Seam	479.5-512.0 feet	Not intersected
Total Depth	578 feet	596 feet

5.4.2 Continuity of the G Seam

The lithologic columns and the core analysis results show the consistency of the G coal seam. The gamma ray logs compared with the proximate analysis logs of the coal shown in Figures 5.4-2 and 5.4-3 give a good indication of how similar the G seam is up and down dip. These figures also show a good correlation between the proximate analysis and the geophysical logs. The lighologic columns found in Appendix B also indicate a strong consistency across strike.

The main G seam has a characteristic high count zone about one-third of the way down from the top. The ash content of this zone is not high enough to impede gasification.

The main G seam, G_{mc}, has a low average ash and sulfur content of 5.2% and 0.19% respectively. The chemical composition of the main seam is highly consistent. It is separated from the upper and lower "benches" by

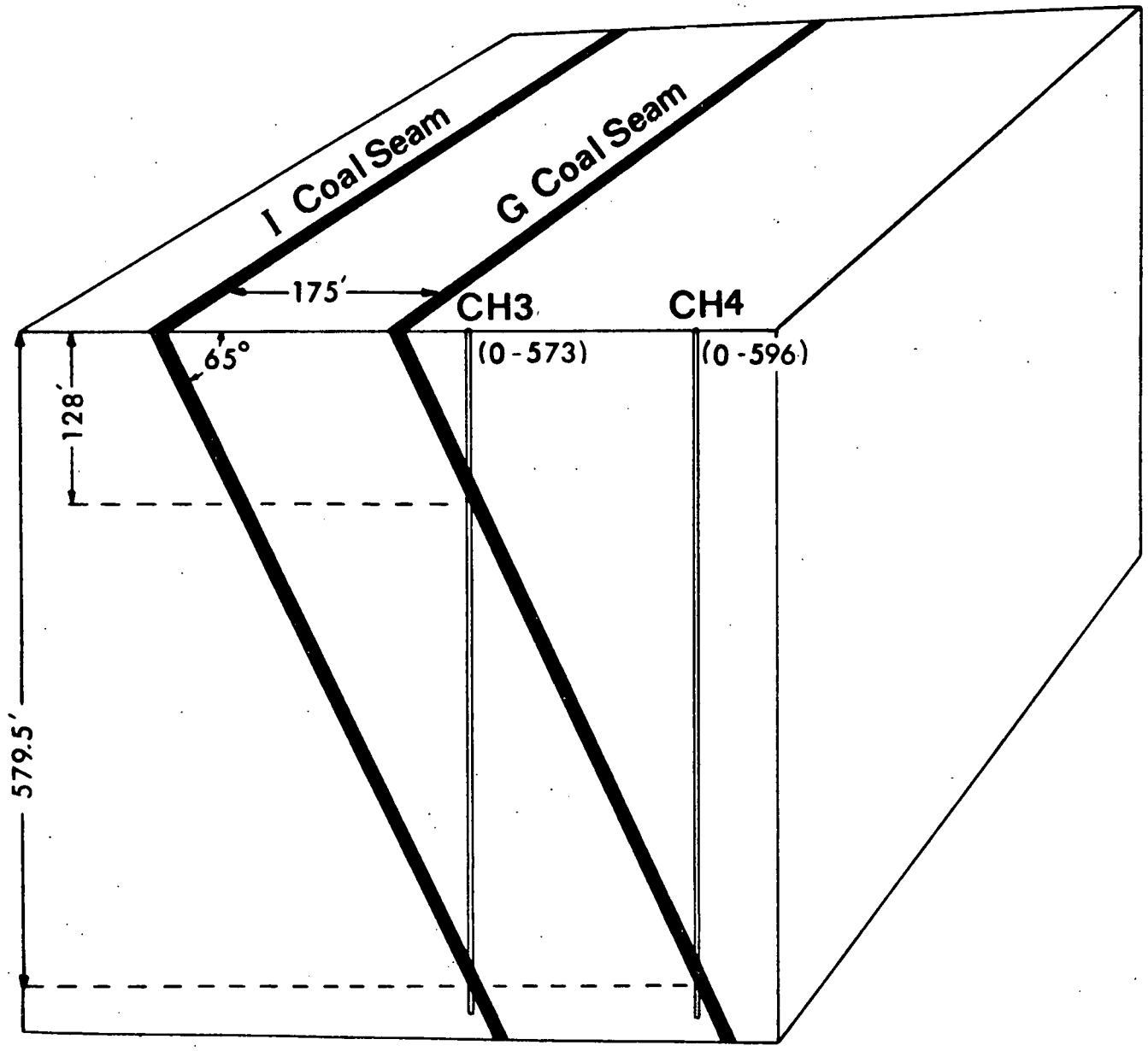

Figure 5.4-1 Core Hole Placement

three to four feet of carbonaceous shale parting. The upper "bench" may participate in the gasification reaction because of roof fall. The lower stringer is not expected to participate.

5.4.3 Coal Analyses

The 3.5-inch diameter cores were inspected and megascopically characterized on the site by the GR&DC field personnel. The coal core was split longitudinally and separated into samples 1.5 feet long. Each half was enclosed wet in plastic to prevent oxidation. One half was sent to Hazen Research, Inc. for chemical analysis, the other half shipped to Harmarville for use in a laboratory-scale gasifier. About 4.5 feet of consolidated coal core was isolated for permeability testing and minor amounts of coal were segregated for physical testings and maceral studies.

5.4.3.1 Analysis Performed. Hazen Research, Inc. performed proximate, ultimate, ash fusion, and elemental analyses of the ash on the coal cores. The University of Pittsburgh conducted permeability studies, Core Labs, Inc. tested the coal for physical properties, and Penn State University carried out maceral studies.

5.4.3.2 Proximate Analysis. Proximate analysis provides the moisture, volatile matter, fixed carbon and ash content of the coal samples. This information will be used to predict pyrolysis products and for resource volume calculations. Sulfur content and heating value are also included on the proximate analysis data sheets. Sulfur content indicates potential sulfur in the product gas which is an important environmental consideration. The heating value data are incorporated into the efficiency ratio: energy produced from burning the product gas vs energy from direct combustion of the coal. The moisture ash-free heating value is a reliable analytical tool which relates both the consistency of the coal and of the data.

The proximate mean and range results for the main G seam and the upper and lower stringers from CH-3 are given in Table 5.4-1. The on-site geologist defined the intervals to be sent to the Hazen Research laboratory

Table 5.4-1
Core Hole (CH-3) G Seam Proximate Analysis Results

As Received

(Interval Depth in ft) No. of Samples	Moisture % Mean (Range)	Ash % Mean (Range)	Volatile Matter % Mean (Range)	Fixed Carbon % Mean (Range)	Calorific Value Btu/lb Mean (Range)	Sulfur % Mean (Range)
(47.0-52.0) 4 samples	10.76 (6.87-12.83)	44.27 (19.86-65.25)	22.69 (13.71-31.45)	22.28 (14.17-35.86)	5331 (2986-8382)	0.49 (0.25-0.64)
(59.0-103.0) 29 samples	15.57 (13.64-17.57)	5.34 (3.09-16.89)	34.75 31.87-37.11)	42.77 (36.96-47.16)	9760 (8835-10 146)	0.20 0.08-0.71)
(117.0-121.5) 3 samples	16.34 (15.24-17.02)	6.00 (5.17-7.32)	35.47 (34.44-36.33)	42.18 (41.38-43.00)	9723 (9644-9780)	0.58 (0.49-0.73)
(126.0-128.0) 2 samples	15.11 (13.86-16.36)	8.94 (7.10-10.77)	34.38 (34.32-34.43)	41.58 41.05-42.11)	9502 9469-9536)	0.80 (0.56-1.03)

Dry

(Interval Depth in ft) No. of Samples	Ash % Mean (Range)	Volatile Matter % Mean (Range)	Fixed Carbon % Mean (Range)	Calorific Value Btu/lb Mean (Range)	Sulfur % Mean (Range)	Mineral Matter Free Btu/lb Mean (Range)
(47.0-52.0) 4 samples	49.30 (22.78-70.07)	25.61 (14.72-36.08)	22.64 (15.21-41.14)	6024 (3207-9616)	0.56 (0.27-0.73)	12 947 (12 771-13 205)
(59.0-103.0) 29 samples	6.14 (3.68-19.56)	41.25 (36.91-45.15)	52.43 43.53-56.87)	11 589 (9854-12 086)	0.24 (0.10-0.83)	12 443 (12 148-12 797)
(117.0-121.5) 3 samples	7.17 (6.23-8.64)	42.41 (40.63-43.65	50.42 (49.71-50.81)	11 624 (11 378-11 786)	0.69 0.59-0.86)	12 614 (12 568-12 648)
(126.0-128.0) 2 samples	10.49 (8.49-12.50)	40.50 (39.85-41.16)	49.00 (47.65-50.35)	11 197 (10 992-11 402)	0.94 (.67-1.20)	12 652 (12 567-12 736)

for analysis. Table 5.4-2 shows the results from CH-4. In this case the upper stringer was less coaly than in CH-3 and was not sent to Hazen until November. The high ash parting interval from 572.0 to 575.0 feet was not included in Table 5.4-2 to facilitate a comparison with Table 5.4-1. The complete set of data sheets is included in Appendix A-5. Table 5.4-3 gives the proximate analysis results for the coal interval above the G seam in CH-4. Table 5.4-4 shows the proximate analysis results for the I seam intersected from 479.5 to 512.0 feet in CH-3.

Table 5.4-5 shows the average proximate analyses from drill cuttings from CH-2, which intersects the G seam from 480 to 540 feet.

5.4.3.3 Ultimate Analysis give the percent moisture, carbon, hydrogen, nitrogen, sulfur, ash, and oxygen. Mass balance calculations require this elemental composition of the coal.

Table 5.4-6 is the "as-received" ultimate results for the main G seam from CH-3 and CH-4. Average ultimate values for the two core holes are included. Table 5.4-7 shows the moisture ash-free (MAF) ultimate values.

5.4.3.4 Ash Fusion in a reducing atmosphere results in the temperatures of initial deformation, softening, hemispherical and fluid stages.

The main importance of ash fusion data to underground coal gasification is the prevention of process well blockage and narrow linking path blockage. The ash fusion data can be compared with the elemental analysis of the ash.

The averaged ash fusion temperature data for the main part of the G coal seam (G_{mc}) were:

Deformation Stage	Temperature Mean, °F
Initial Deformation	2331
Softening	2359
Hemispherical	2379
Fluid	2393

Table 5.4-2
Core Hole (CH-4) G Seam Proximate Analysis Results

As Received

Interval Depth in ft No. of Samples	Moisture % Mean (Range)	Ash % Mean (Range)	Volatile Matter % Mean (Range)	Fixed Carbon % Mean (Range)	Calorific Value Btu/lb Mean (Range)	Sulfur % Mean (Range)
(517.0-560.0) 27 samples	14.62 (12.73-16.35)	5.07 (3.10-14.96)	35.41 (31.75-38.07)	44.64 (39.27-48.63)	10 130 (9233-10 597)	0.18 (0.09-0.64)
(566.0-572.0) 4 samples	12.06 (9.72-13.73)	18.00 (9.91-29.45)	32.76 (31.02-33.67)	37.19 (29.81-42.93)	8815 (7769-9621)	1.10 (0.80-1.69)
(575.0-579.5) 3 samples	13.51 (13.25-13.83)	6.62 (4.69-8.56)	37.22 (36.07-38.16)	42.65 (41.79-44.04)	10 149 (10 050-10 330)	0.58 (0.47-0.76)

Dry

Interval Depth in ft No. of Samples	Ash % Mean (Range)	Volatile Matter % Mean (Range)	Fixed Carbon % Mean (Range)	Calorific Value Btu/lb Mean (Range)	Sulfur % Mean (Range)	Mineral Matter Free Btu/lb Mean (Range)
(517.0-560.0) 27 samples	6.22 (3.64-17.27)	41.47 (37.45-44.18)	52.31 (45.29-58.12)	11 868 (10 649-12 350)	0.21 (0.10-0.73)	12 730 (12 264-13 093)
(566.0-572.0) 4 samples	20.35 (11.49-32.62)	37.27 (34.36-38.75)	42.38 (33.02-49.76)	10 038 (8606-11 152)	1.25 (0.91-1.87)	12 925 (12 754-13 355)
(575.0-579.5) 3 samples	7.64 (5.44-9.87)	43.04 (41.58-44.09)	49.32 (48.29-51.11)	11 734 (11 604-11 988)	0.66 (0.54-0.87)	12 807 (12 663-13 010)

Table 5.4-3
Core Hole (CH-4) G Seam Upper Bench (G) Proximate Analysis Results

As Received

Interval Depth in ft	Moisture %	Ash %	Volatile Matter %	Fixed Carbon %	Calorific Value Btu/lb	Sulfur %
497.0-498.0	0.55	90.43	8.61	0.41	252	0.02
501.0-502.5	3.82	75.18	12.80	8.20	2123	0.72
502.5-504.0	6.77	55.01	20.85	17.37	4630	0.61
504.0-505.5	10.73	12.47	35.81	40.99	9809	0.70
505.5-507.0	6.64	47.42	21.73	24.21	5543	0.35
Mean (Range)	5.70 (0.55-10.73)	56.10 (12.47-90.43)	19.96 (8.61-35.81)	18.24 (0.41-40.99)	4471 (252-9809)	0.48 (0.02-0.72)

Dry

Interval Depth in ft	Ash %	Volatile	Fixed Carbon %	Calorific Value Btu/lb	Sulfur %	Mineral Matter Free Btu/lb
497.0-498.0	90.94	8.65	0.41	253	0.02	14 169
501.0-502.5	78.16	13.30	8.54	2207	0.75	14 302
502.5-504.0	59.01	22.36	18.63	4967	0.65	13 742
504.0-505.5	13.96	40.12	45.92	10 988	0.78	12 959
505.5-507.0	50.79	23.27	25.94	5938	0.37	13 171
Mean (Range)	58.57 (13.96-90.94)	21.54 (8.65-40.12)	19.89 (0.41-45.92)	4871 (253-10 988)	0.51 (0.02-0.78)	13 669

Table 5.4-4
Core Hole (CH-3) I Seam Proximate Analysis

As Received

Interval Depth in ft No. of Samples	Moisture % Mean (Range)	Ash % Mean (Range)	Volatile Matter % Mean (Range)	Fixed Carbon % Mean (Range)	Calorific Value Btu/lb Mean (Range)	Sulfur % Mean (Range)
(479.5-512.0) 22 samples	14.56 (11.26-17.40)	10.36 (3.37-27.71)	33.03 (28.75-37.95	42.09 (30.69-47.79)	9389.3 (7758-10 371)	0.30 (0.11-0.71)

Dry Basis

Interval Depth in ft No. of Samples	Ash % Mean (Range)	Volatile Matter % Mean (Range)	Fixed Carbon % Mean (Range)	Calorific Value Btu/lb Mean (Range)	Sulfur % Mean (Range)	Mineral Matter Free Btu/lb Mean (Range)
(479.5-512.0 22 samples	12.00 (4.03-31.22)	38.68 (32.56-44.27)	49.32 (34.59-57.01)	11 006.3 (8345-12 188)	0.35 (0.13-0.81)	12 661 (12 159-13 109)

Table 5.4-5
Core Hole CH-2 G Seam Drill Cuttings
Average Proximate Analysis Results

As Received

Interval Depth in ft	Moisture %	Ash %	Volatile Matter %	Fixed Carbon %	Calorific Value Btu/lb	Sulfur %
480-540	29.31	16.97	25.06	28.66	6541	0.43

Dry

Interval Depth in ft	Ash %	Volatile Matter %	Fixed Carbon %	Calorific Value Btu/lb	Sulfur %	Mineral Matter Free Btu/lb
	23.71	35.46	40.73	9313	0.62	12 276

Table 5.4-6
"As-Received" Ultimates - G Seam

	Interval	Moisture	Carbon	Hydrogen	Nitrogen	Sulfur	Ash	Oxygen*
	63.5-65.0	15.22	59.85	4.28	0.70	0.19	3.57	16.19
	69.5-71.0	16.29	59.15	4.26	0.75	0.15	3.50	15.90
	77.0-78.5	14.82	58.99	4.25	0.81	0.14	4.81	16.18
Core	83.0-84.5	14.85	58.74	3.60	0.64	0.14	5.77	16.26
Hole	89.0-90.0	16.58	59.13	3.77	0.61	0.10	3.75	16.06
CH-3	94.5-96.0	16.01	59.62	3.94	0.69	0.14	3.21	16.39
	100.5-102.0	14.81	58.64	4.30	0.68	0.44	6.27	14.86
	Core Hole CH-3 Average	15.51	59.16	4.05	0.70	0.19	3.98	15.97
	521.5-523	15.22	60.06	4.22	1.05	0.15	4.12	15.18
	527.5-529	14.48	58.18	3.91	0.68	0.13	7.64	14.98
Core	533.5-535	12.73	56.76	4.07	0.64	0.27	10.28	15.25
Hole	539.5-541	15.83	59.65	3.96	0.62	0.11	3.97	15.86
CH-4	548-549.5	14.89	61.37	4.15	0.60	0.11	3.16	15.72
	554-555.5	14.38	60.60	4.34	0.76	0.18	4.07	15.67
	Core Hole 4 Average	14.59	59.44	4.11	0.73	0.17	5.54	15.44
	GRAND AVERAGE	15.05	59.30	4.08	0.72	0.18	4.76	15.91*

*By Difference.

Table 5.4-7
MAF Ultimates - G Seam

Sample	Interval	C	H	N	S	O
3G-8	63.5-65.0	73.71	5.27	0.87	0.23	19.92
3G-12	69.5-71.0	73.75	5.30	0.94	0.19	19.82
3G-16	77.0-78.5	73.40	5.28	1.02	0.18	20.13
3G-20	83.0-84.5	74.01	4.54	0.80	0.18	20.47
3G-24	89.0-90.0	74.22	4.74	0.76	0.13	20.14
3G-28	94.5-96.0	73.80	4.89	0.85	0.17	20.30
3G-32	100.5-102.0	74.31	5.44	0.86	0.56	18.83
Average CH-3		73.89	5.07	0.87	0.23	19.94
4G-4	521.5-523	74.46	5.23	1.30	0.18	18.82
4G-8	527.5-529	74.70	5.02	0.87	0.16	19.25
4G-12	533.5-535	73.71	5.28	0.83	0.35	19.83
4G-16	539.5-541	74.36	4.93	0.77	0.14	19.80
4G-20	548-549.5	74.89	5.06	0.74	0.14	19.17
4G-24	554-555.5	74.31	5.32	0.93	0.22	19.20
Average CH-4		74.41	5.14	0.91	0.20	19.35
Grand Average (CH-3 and CH-4)		74.15	5.11	0.89	0.22	19.65

These temperatures are above the temperature likely to occur at the fire front. The slagging of coal ash should not occur during the gasification test at North Knobs.

5.4.3.5 Elemental Analysis of the Ash provides the percentage of the oxides of silicon, aluminum, titanium, iron, calcium, magnesium, sodium, potassium, phosphorus, and sulfur in the ash. In addition to correlation with the properties of the ash, this information impacts on the hydrology and air quality monitoring. The oxidized elements in the ash are more readily dissolved in the ground water than these same elements in the ungasified coal. The particulates produced with the product gas will in large part be ash.

Conventional wet chemical methods were used to analyze the ash. Ash viscosity calculations, which are derived from the elemental analysis of the ash, appear on the data sheets with the elemental analysis. This information is used chiefly for appraising the suitability of coals for slag-tap operations and is not addressed in this report.

The averaged ash analyses data for the main part of the G coal seam (G_{mc}) were:

Ash Component	%
SiO_2	18.55
Al_2O_3	13.02
TiO_2	0.53
Fe_2O_3	12.46
CaO	35.55
MgO	6.27
Na_2O	2.22
K_2O	0.23
SO_3	8.36

The data indicate that clay minerals are probably the major sources of ash. The residues should be relatively insoluble and nonabrasive to the process piping.

5.4.3.6 Permeability and porosity values of the coal were determined experimentally.* The effective and relative permeabilities to nitrogen were measured as functions of water saturation and overburden pressure. Porosity, absolute permeability, and shrinkage values were also obtained. Permeability data become important in UCG linking in the absence of major fractures in the coal seam.

Figure 5.4-2 shows the average relative permeabilities of coal to gas of six coal samples tested by the University of Pittsburgh. Table 5.4-8 shows the effective permeabilities of the North Knobs coal compared with Hanna and Gillette coal in the fraction of water saturation range of 0.2 to 0.6.

5.4.3.7 Physical testing of the coal was performed on two small samples of the coal. Values for modified Fischer Assay, electrical conductivity, bulk density, and uniaxial and triaxial compressive strengths were obtained. These values are required for mathemetical modeling of the UCG process.

The physical properties of samples from CH-4 were determined by Core Labs, Inc. and are shown in Table 5.4-9. The modified Fischer Assay, electrical conductivity, bulk density, and strength properties are included in this table.

Hazen Research, Inc. found the specific gravity of the coal and the ash from the top, middle, and bottom of the main G seam in CH-3. These values, along with percent ash are shown in Table 5.4-10.

The coal has no coking tendency and an electrical conductivity of less than 15 micromhos. The specific gravities of the coal and ash were determined (by means of a Hogarth bottle) to be 1.36 and 2.83 from CH-3.

Fischer Assay is a distillation procedure giving the liquid content of the coal. Uniaxial and triaxial compressive strengths are standard rock mechanics tests which are explained in the boundary strata section (5.3) of this report.

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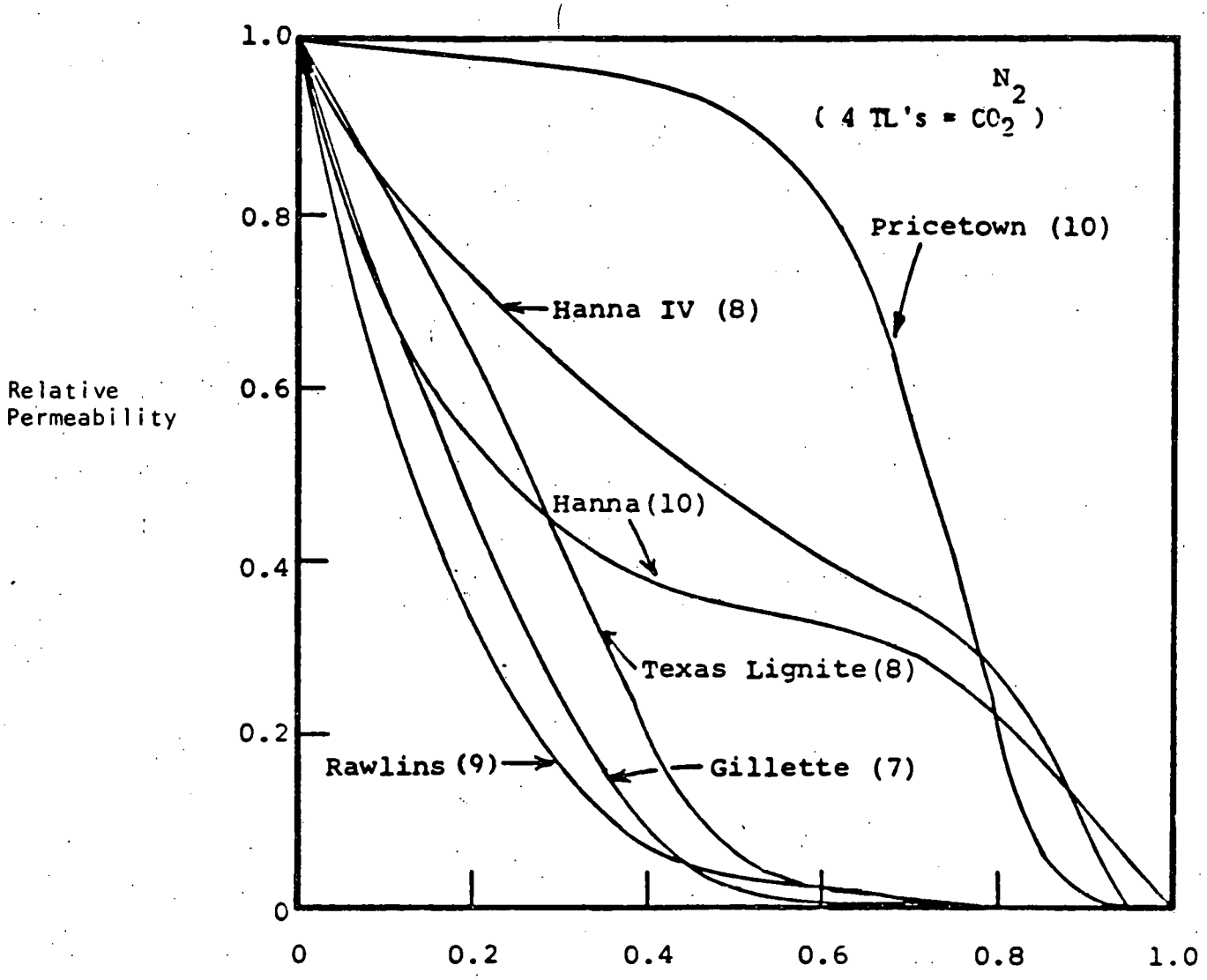
*Reznick, A. A., Fulton, P. F., Cheng, L. L., "The Measurement of Flow Properties of Coals for In Situ Gasification," Final Report 12/77 to 11/78.



Average Relative Permeability of Six Coals to Gas

Figure 5.4-2

Table 5.4-8

Effective Permeabilities of North Knobs, Hanna, and Gillette Coals

Location	Average Absolute Permeability	Effective Permeability as a Function of Fraction of Water Saturation (md)		
Fraction		0.2	0.4	0.6
North Knobs (Rawlins)	2186	729	153	66
Hanna	131	72	49	43
Gillette	1625	764	146	16.2

Table 5.4-9
Physical Properties Determined by Core Labs, Inc.

Modified Fischer Assay	Core Hole 4	
	522.8-523.2	534.8-535.2
Oil $\frac{\text{gal oil}}{\text{ton coal}}$	11.7	12.7
Wt%	4.9	5.3
Water $\frac{\text{gal } H_2O}{\text{ton coal}}$	45.1	44.1
Wt%	18.8	18.4
Oil Gravity	0.997	0.997
Solids Wt%	69.3	69.8
Gas + Loss Wt%	7.0	6.5
Tendency to Coke	0.0	0.0

Electrical Conductivity <15 micromho per meter

Bulk Density Average 1.3 g/cc

Uniaxial Compressive Strength 762 psi

Triaxial Compressive Strength
at 600 psi Confining Pressure 2678, 3574, 3191 psi

Table 5.4-10
Density of the G Seam Coal and Ash

Core Hole 3 - Hazen Research, Inc.

Depth in Feet	Specific Gravity As-Received	Specific Gravity Dry	MAF
63.5-65	1.32	1.38	1.32
74.0-75.5	1.41	1.48	1.34
100.5-102.0	1.335	1.41	1.30
Average	1.36	1.42	1.32

	Ash Composite Specific Gravity
47.0-128.0	2.83

Core Hole 4	Core Laboratories, Inc.		
Depth in feet		Density gm/cc	
522.8-523.2	1.26	1.30	1.32
543.8-535.2	1.30		
Average	1.30		

5.4.3.8 Petrographic Studies to determine the maceral content of the coal were performed. Macerals, or homogeneous optical components of coal, are characterized microscopically by the amount of light normally reflected from polished surfaces with an oil-immersion lens. The reactivity of coal to gasification is correlated with certain macerals. The results of the petrographic study made by the Coal Research Lab at Penn State are shown in Table 5.4-11.

The average maceral content* for the G_{mc} coal was:

Maceral	%
Vitrinite	83.5
Pseudovitrinite	1.1
Fusinite	2.5
Semifusinite	9.3
Massive Micinite	0.7
Granular Micrinite	1.5
Exinite	1.3
Resinite	0.1
Sclerotinite	0.0

*Moisture/Ash Free Basis

The petrographic study done by Penn State shows a high vitrinite content of the North Knobs coal on an ash-free basis. There appears to be a high fusinite and semi-fusinite zone at 539.5 feet but this does not correspond to the high ash zone in the main G seam. Vitrinite is desirable because of its high reactivity to gasification compared to fusinite and semi-fusinite.

5.4.4 Conclusions and Recommendations

The main G seam, G_{mc}, was shown to have an average of 5.2% ash and 0.19% sulfur, as derived from proximate analysis. Based upon the proximate analyses data, the main part of the G seam is classified as a subbituminous B coal. The average moisture ash-free (MAF) heating value is 12 587 Btu/lb. There is a thin interval of coal about one third of the way down the main G seam with about 15% ash. This 1-foot inclined thickness interval is definitely

Table 5.4-11
Petrographic Analysis of the G Seam from Core Hole 4 (CH-4)
on a Moisture Ash-free Basis

Depth in Feet	Vitrinite	Pseudo-vitrinite	Fusinite	Semi-Fusinite	Massive Micrinite	Granular Micrinite	Exinite	Resinite	Sclerotinite
521	85.4	1.2	1.4	7.9	0.9	1.2	1.5	0.4	0.1
526.5	59.9	0.7	5.6	23.3	2.6	5.0	2.9	0.0	
532	87.7	2.6	3.7	4.5	0.2	0.5	0.5	0.3	
539.5	54.6	0.3	7.6	32.7	1.4	2.8	0.6	0.0	
550.5	86.5	0.0	1.4	8.9	0.5	2.0	0.6	0.1	
558	90.8	0.0	1.6	4.6	0.4	0.4	2.1	0.1	
564	96.6	0.0	0.2	0.7	0.3	1.5	0.6	0.1	
577	92.7	1.7	1.4	2.9	0.1	0.5	0.6	0.1	
583	88.9	2.2	2.2	5.2	0.3	0.2	1.0	0.0	
586	91.5	2.7	0.3	2.0	0.1	1.1	2.2	0.1	

combustible. The main seam otherwise is very uniform. It is separated from its upper and lower benches by three to four feet of carbonaceous shale parting.

Samples from the five parts of the G coal seam were not analyzed to obtain the proximate and ultimate analysis data; therefore, average proximate and ultimate analysis are available for the main G coal seam only. The upper and lower partings in the G coal seam contain carbonaceous shale which the gasification process could consume. Because of the possibility of roof fall, the upper parting and bench are more likely to participate in the gasification reaction than the lower parting and stringer.

When the upper bench results, which include some of the upper parting, are averaged into the above values, the ash and sulfur values increase to 11.6% ash and 0.23% sulfur. The MAF heating value increases marginally to 12 690 Btu/lb. The extent of roof fall and bench gasification may be discernable from the sulfur content of the product gas.

Moisture ash-free ultimate analysis results show slightly less fixed carbon and greater oxygen content from CH-3 than CH-4 due to the difference in depths. Since only every fourth sample was analyzed for ultimate values, the only ultimate above the G seam is from the upper parting and is not included in Table 5.4-7. The results from CH-4 alone are 74.41% fixed carbon, 5.14% hydrogen, 0.91% nitrogen, 0.20% sulfur, and 19.35% oxygen.

The ultimate results on an "as-received" basis will be useful as input into certain math models. The results from CH-4 are 14.59% moisture, 59.44% carbon, 4.11% hydrogen, 0.73% nitrogen, 0.17% sulfur, 5.54% ash, and 15.44% oxygen.

For both core holes there is a good correlation of the proximate analysis performed on core in the laboratory and the geophysical logs measured down-hole in the field.

The results of the ash fusion data indicate that there should be no problem with ash slagging impeding gas flow in the UCG field test at North Knobs. The lowest temperature for initial deformation, 2170°F is above the maximum temperature expected.

The effective permeability of the North Knobs coal seam is closer to the Gillette than the Hanna values, the other sub-bituminous coals from UCG field test sites in Wyoming. The water saturation range of 0.2 to 0.6 times complete saturation is most likely to represent field conditions. These effective permeabilities were calculated by multiplying the relative permeability by the average absolute permeability for each coal.

For saturated coal, the North Knobs permeability is extremely low. From the data (refer to D. W. Bailey's memo of 12/27/78 to B. E. Davis, Reference No. 6240FT40) in the Hydrology section of the Permit to Mine, this permeability is calculated to be 0.02-0.03 millidarcy compared to 4.7 md for Hanna IV (refer to "Hydrologic Characterization for Hanna III", by Harold L. Hutchinson, R. Michael Boyd, and Dennis D. Fischer [University of Wyoming, and ERDA, Laramie Energy Research Center, Laramie, Wyoming]).

During gasification, the permeability will greatly increase from the cracks and fissures created by the drying coal. GR&DC is currently planning to drill link rather than backward burn link; the permeability data will be relevant for air communication only if the direct drill link is not successful.

The G seam coal bed is low in sulfur and ash content. The relatively high ash lens one-third of the way down the main seam is about 15% ash and will not hinder gasification. At some point during gasification, the carbonaceous shale and coal stringer above the main seam may collapse into the reaction zone and slightly increase the sulfur and ash content of the product.

The proximate and ultimate analyses are necessary for mass balance and resource recovery calculations.

The ash fusion data indicate that there will be no problem with the ash slagging and impeding gas flow.

The permeability and petrographic studies were done under separate contracts with the DOE. The results from these studies are expected to be of increasing significance as more information about the UCG process is acquired. These and other physical testing results will be used to construct mathematical models of the UCG process.

The elemental analysis of the ash provides necessary information for predicting the environmental impact of UCG. A more complete analysis that includes chlorine, uranium, and trace element analysis would be of greater service for this purpose but was not performed due to budgetary constraints.

It is recommended that an additional core hole which intersects the G seam at gasification depths below 300 feet be drilled for data across strike and for additional physical testing. The parting above the main G seam should be analyzed to determine the effect of this material falling into the reactor cavity. It is also recommended that a post-burn analysis be conducted to determine the extent of participation of the coal stringers in the gasification reactions.

5.5 HYDROLOGY

After completing the core hole and hydrologic observation well drilling program at the North Knobs facility, a hydrologic characterization study was undertaken. The study was initiated to obtain hydrologic data for:

1. Predicting the effects of the UCG process on the existing groundwater system.

2. Providing input to the computer modeling of the UCG process.

3. Designing an aquifer restoration plan.

4. Completing required permit applications.

The hydrologic characterization study consisted of:

1. Collecting and analyzing groundwater samples from the G coal seam and boundary strata.

2. Characterizing the pre-burn, groundwater pressure surface in the G coal seam.

3. Installing a pump in well P-1 for drawdown testing.

4. Conducting a drawdown test.

5. Calculating a set of descriptive hydrologic parameters for the G coal seam.

5.5.1 Field Activities Log

5.5.1.1 Activities for Observation Wells

Date	Activity
November 28, 1978	Measure water level on dates listed for P-1 activities

5.5.1.2 Field Activities for P-1

Date	Activity
November 28, 1978	Begin drawdown testing. Pre-test water level was approximately 95 ft. Operation problems encountered with downhole pump assembly. Pumped water level down to approximately 104 ft.
November 29, 1978	Remove pump assembly from well; clean, repair and reinstall pump in well. Measure water level (approximately 103 ft).
November 30, 1978	Begin pumping again. Operational problems encountered with pump. Pump removed, repaired and reinstalled. Pumped water level down to 334 ft.
December 1, 1978	Measure water level (approximately 331 ft). Pump water level down to design depth (approximately 455 ft).
December 2, 1978	Measure water level (approximately 455 ft) essentially no recharge occurred.
December 3, 1978	Measure water level (approximately 450 ft).
December 4, 1978	Measure water level (approximately 448 ft).
December 5, 1978	Measure water level (approximately 440 ft). Pumped water level down to approximately 455 ft.
December 6, 1978	Measure water level (approximately 453 ft). Because of the low recharge rates observed in P-1. the test plan was modified to visiting the facility on a 10-day interval, pumping the water level in P-1 down to approximately 455 ft, and measuring the water levels in the surrounding observation wells.

December 15, 1978	Operational problems encountered in measuring the water level; therefore, no reading taken. Water levels down to approximately 458 ft.
December 18, 1978	Measure water level (approximately 414 ft).
December 19, 1978	Measure water level (approximately 414 ft).
January 9, 1979	Operational problems encountered in measuring the water level; therefore, no reading taken. P-1 pumped dry (approximately 480 ft).
January 17, 1979	Measure water level (approximately 468 ft).
February 8, 1979	Measure water level (approximately 443 ft).
February 13, 1979	Measure water level (approximately 436 ft). Test terminated.

The hydrologic testing procedure, theory, and interpretation are explained in detail in Appendix A-6.

Water level measurements of each well are tabulated in Appendix A-6.

5.5.2 Discussion of Results

The G seam and the embedding formations at the site are saturated to an average elevation of 6800 ft; this is approximately 90 ft below the land surface.

In the dynamic test of an unconfined aquifer, water is removed from a drill hole in the formation at a rate consistent with the flow or re-supply in the aquifer. The pumping of the hole will create a cone of depression around that hole which gradually increases and extends away from the pumped hole as time of pumping progresses. The shape of this cone and its progress with time is representative to the transmissibility and storage characteristics of the aquifer. Observing this cone through various observation holes located around the production hole as a function of time will allow the computation of the formation transmissibility and, under favorable conditions, the specific yield of the aquifer.

The hydraulic test did not provide sufficient data that would allow the determination of the quantity of water in storage in the formation of the site. The recorded aquifer responses indicate that the specific yield of the formation is quite small.

The collected data on the piezometric surfaces do not show an appreciable difference between that recorded in the coal seam and those observed in the overlying and underlying formations. If there is a true difference in pressures, it could not be detected during the time of the observation, either because the differences are sufficiently small or because there has been insufficient time for these different elevations to reestablish themselves.

The slope of the piezometric surface under the site is estimated at slightly over 5 degrees toward an azimuth of 268 degrees (S 88° W).

The duration of the dynamic test of the aquifer was not sufficient to allow a conclusive determination of the formation transmissibility. The observed response in the observation holes after the 2 1/2-month test did produce some lowering of the water in two of the holes; however, not to the extent that is required by the computational procedures. The rest of the holes did not show any recognizable decline. The recorded responses indicate a necessary test duration of over 1 year with the present layout of the observation-hole networks. The magnitude of the response clearly characterizes the formation as an aquiclude rather than an aquifer for all practical considerations of the definition. The recorded formation responses to the pressure duration in the coal seam are smaller orders of magnitude than was generally reported in the literature; particularly at the Hanna and Gillette sites.

As detailed in Appendix A, a continuous pump test of P-1 was not possible due to the extremely low water-yield characteristics of the formation. Visits to the site were made at a 2 to 3-week intervals at which time water level measurements were made in all of the hydrologic holes and occasionally from P-1. From the water-level measurements in the pump hole and the

measurements of quantitites of water removed by pumping, two recovery rates could be computed. Between December 1 and December 5, roughly a 4-day period, the computed recovery rate was 1.08 gallons per day. Over the subsequent 70-day period, the average recovery rate was 0.85 gallons/day. The inflow rate to the hole appeared to be steady and did not show any improvement with the progression of the testing.

Based upon partial recovery records in different holes collected after quality sampling, the average transmissibility of the formation is estimated to range between 0.007 gallons/day/foot (0.87 cm^2/day) and 0.013 gallons/day/foot (1.61 cm^2/day).

The results of the hydraulic testing do not warrant a specific determination of the permeability of the coal seam. There is no evidence that the G seam under the test site acts as a confined aquifer with a significantly different permeability than that of the embedding formations.

Due to the low transmissibility estimated in the test and considering the hydraulic implications of the proposed experimental burning process, a continuation of the hydraulic testing is not recommended. Indications are that it will be necessary in the near future to draw additional water samples from some of the holes for chemical analysis that could be used for reinforcing the presently derived transmissibility estimates. It is, therefore, recommended that before water samples are extracted from any hole, a water-level reading be made, and similarly, after the sampling is complete, the water-level measurement be repeated. Following the sampling, water-level readings should be made over the following 2 to 4-week period at a daily frequency during the beginning of the period, gradually lowering the observation frequency after a week to every other day, and after 2 weeks to 2 measurements per week. Such recovery tests coupled with the necessary quality sampling could improve the estimated transmissibility values in the vicinity of the wells.

In conclusion, from the standpoint of the proposed gasification experiment, the hydraulic test results indicate that water storage in the

formation is extremely limited and cannot be considered as significantly influencing the burning process. Similarly, inflow to the burn area during and after the burn will be almost nonexistent, probably much less than 50 gallons per day. The water requirements of the gas quality and the possible quenching of the fire will have to be accomplished in large part from outside sources, with practically no water supply expected from the formation.

The presence of a defined water table and the low permeability of the strata will insure a gas seal during the gasification process. Vertical subsidence to near the surface will probably be required to break the gas seal. Subsidence to this extent is extremely unlikely based upon boundary strata studies (Section 5.3).

After conclusion of the experiment, the natural piezometric conditions will be established over a number of years, and any constituent transport from the test zone will not be recognizable for hundreds of years, unless conditions found in this hydraulic testing become drastically altered by the burn at the test site and extend across the site boundaries.

5.5.3 Baseline Water Quality

Baseline studies on groundwater quality were initiated in order to investigate the effects of UCG on groundwater and to meet permitting requirements. The sampling plan included the water in the formations immediately above and below the G coal seam as well as the G seam itself.

5.5.3.1 Baseline Water Quality Plan

The baseline water quality plan included the following:

1. Collecting water samples from 6 of the completed wells on a 3-month sampling interval so that seasonal variations in water quality could be assessed. The designated water monitoring wells are:

Well Number	Hydrologic Observation Zone
CH-2	G coal
CH-4	G coal
H-11	Aquifer above G coal
H-13	Aquifer below G coal
H-15	G coal
P-1	G coal

2. Determining the physical properties (temperature, pH, and conductivity) of the samples on-site.

3. Preserving the samples on site in accordance with EPA-recommended procedures (EPA methods for chemical analysis of water and wastes, Section 4) and shipping the samples to water analysis laboratories.

4. Analyzing the water sample for selected inorganics, organics, and radioactivity. (See Table 5.5-1).

5.5.3.2 Results and Discussion

The first series of baseline samples was taken according to the procedures listed in Appendix A-6. The water analysis data from the series is given in Tables 5.5-1 and 5.5-2. The data from Well H-15 collected on 9/19/78 and 10/30/78 is the most representative of the G seam water since this well was pumped dry on 9/1/79 and allowed to recharge prior to sampling on 9/19/78 and 10/30/78.

Due to the severe time constraints imposed by the extremely slow recharge rates of all the wells and the need to begin the hydrological studies as soon as possible, the wells (except H-15) were first pumped dry as part of the normal cleaning procedure and then refilled to within 10-20 ft of their original water level with water from either Wamsutter water service (H-11, H-13, P-1, H-4) or from the Red Desert Drilling Company (CH-2). The samples taken from these wells, therefore, were contaminated with external source

Table 5.5-1 Water Analysis Data

Well No.			H-15		CH-2[a]	CH-4[a]	P-1[b]	H-13[b]	H-11[b]	Brine
Sampling Date		9-1-78	9-19-78[c]	10-30-78[c]	11-2-78	11-2-78	11-1-78	10-31-78	11-1-78	9-19-78
Completion Zone			G Coal		G Coal	G Coal	G Coal	Underburden	Overburden	
Drilling Fluid			Drilling Mud		Water	Water	Brine	Brine	Brine	
Species	Units		Concentration							
Aluminum	mg/L	1.3	1.0	<.5	1.84	1.63	2.20	1.48	1.60	
Arsenic	ug/L	<5	13	6	<5	<5	5	5	6	
Barium	ug/L	100	<100	<100	230	100	400	<100	160	
Beryllium	ug/L	--	--	<10	<10	<10	<10	<10	<10	
Cadmium	ug/L	<2	<2	6	4	4	83	6	15	
Calcium	mg/L	290	3.4	2.7	118	34	1.9	28	200	5200
Chromium	ug/L	20	<20	<20	48	39	91	88	50	
Cobalt	ug/L	--	--	30	35	30	680	50	130	
Copper	ug/L	<20	<20	66	110	117	234	57	300	
Iron	ug/L	54	<30	290	2.70	2.50	4.70	3.20	2.80	
Lead	ug/L	<50	<50	<50	50	105	228	83	110	
Lithium	ug/L	--	--	160	150	160	<100	140	290	
Magnesium	mg/L	<.01	0.8	0.290	1.00	0.630	0.010	0.890	1.60	15.5
Manganese	ug/L	<10	<10	11	110	68	320	160	120	
Mercury	ug/L	<1	<1	<10	<10	<10	<10	<10	<10	
Molybdenum	ug/L	150	10	113	21	<10	45	50	16	
Nickel	ug/L	41	<20	<20	<20	<20	<20	<20	<20	
Potassium	mg/L	109	55	88	21	28	5	9	27	5000
Selenium	ug/L	<2	<2	<2	<2	<2	<2	<2	<2	
Silver	ug/L	--	--	<10	<10	<10	110	10	23	
Sodium	mg/L	443	460	727	33	358	8180	610	1300	106 000
Vanadium	ug/L	<100	100	<100	<100	<100	<100	<100	<100	
Zinc	ug/L	<10	<10	60	180	680	528	290	610	
Organic Nitrogen	mg/L	3.0	16.0	0.9	1.4	<.5	<.5	1.1	<.5	
pH		10.9	9.9	10.0	11.8	11.4	12.1	11.0	11.9	
Phenols	ug/L	3	<1	4	<1	2	9	14	<1	
Sulfide(total)	mg/L	<.1	<.1	0.82	<.01	<.01	0.82	1.60	<.01	
Chloride	mg/L	52	645	54.4	28.6	15.1	14900	637	2190	
Fluoride	mg/L	0.6	1.3	1.6	0.6	0.8	0.8	1.0	0.7	
Sulfate	mg/L	765	316	70.0	18.1	490	247	494	370	1290
Total Dissolved Solids	mg/L	1470	2800	1900	560	1030	23 200	1840	4680	
Total Suspended Solids	mg/L	3110	696							
Boron	mg/L	<1	<1	0.390	0.030	0.160	0.080	0.400	0.100	
Residual Sodium Carbonate	meq/L	--	--	1447	-36	172	163	106	1.4	
Sodium Adsorption Ratio		--	--	595	4.3	86	122	160	188	
Total Organic Carbon	mg/L	1.4	<1	46	7	<1	<1	27	<1	
Uranium	ug/L	<.50	<50	<50	<50	<50	<50	<50	<50	
Alkalinity (as $CaCO_3$)	mg/L	--	--	1450	432	263	1320	186	696	
Ammonia (as N)	mg/L	1.0	1.3	0.7	0.2	1.4	1.0	0.2	0.4	
Bicarbonate (as $CaCO_3$)	mg/L	0	495	378	0	0	0	0	0	86.3
Bromide	mg/L	--	--	0.380	0.140	0.010	6.97	0.080	0.850	
Carbonate (as $CaCO_3$)	mg/L	770	990	1072	83	207	165	135	203	0.0
Cyanide	ug/L	--	--	<10	<10	<10	<10	<10	<10	
Nitrate (as N)	mg/L	0.11	0.008	2.4	5.8	5.2	78	4.6	28	
Nitrite (as N)	ug/L	<100	370	<100	<100	<100	<10	<100	<100	
Chemical Oxygen Demand	mg/L	--	--	79	38	38	60	60	120	
Oil & Grease	mg/L	--	--	0.5	0.7	0.5	0.6	0.6	0.7	
Gross α Radioactivity	pCi/L	--	--	0.0±53	35±12	14±11	0.0±8.0	1.4±4.2	4.3±5.4	
Gross β Radioactivity	pCi/L		--	00±34	92±46	150±60	105±42	21±20	0.0±400	

[a]These samples are contaminated with externally supplied water and are not representative of G seam water. [b]These samples are contaminated with externally supplied water and brine drilling fluid. [c]These samples are most representative of G coal seam water.

Table 5.5-2 Water Sampling Physical Property Data

Date	Well No.*	Volume of Water Removed Prior to Collection	Time of Sample Collection	pH	Temperature	Conductivity	Salinity
10/30 1978	H-15	4 gal	16:25	10.00	9° C	2010 Mhos	
10/31 1978	H-13	25 gal	9:55	11.50	9.5°C	23000 "	2ppt
11/1 1978	P-1	45 gal	12:45	11.80	9°C	27000 "	24ppt
11/1 1978	H-11	15 gal	15:10	11.95	9°C	7000 "	5.5ppt
11/2 1978	CH-4	22 gal	14:25	11.40	9.5°C	1350 "	1ppt
11/2 1978	CH-2	18 gal	16:25	11.75	9°C	1400 "	1ppt

*Casing size in CH-2, CH-4 and HI-S was 3-in I.D.
Casing size in H-11, H-13 and P-1 was 4-in I.D.

water. Comparison of the Wamsutter analyses[1] with CH-4 data tends to confirm this. The analysis of water from the Red Desert Drilling Co. is presently not in hand. The data from P-1, H-13, and H-11 are questionable also since, in addition to being recharged with externally supplied water, there is evidence of contamination with the brine drilling fluid used to drill these wells. (Refer to Tables 5.5-1 and 5.5-2).

The two latter samples from H-15 (9/19 and 10/30) are the most representative of the water in the coal seam. The first sample was affected to some extent by the drilling mud and/or the water used to wash the well after drilling. Strictly speaking, the H-15 water does not fit into any groundwater class since its pH is above 9. If the pH standard was waived, however, it would be in Class III according to the proposed Wyoming DEQ Water Quality Rules and Regulations, Chapter VIII. Additional analyses would be required before any definite classification could be made.

Table 5.5-3 presents a summary of the hydrologic data for the North Knobs Facility.

Table 5.5-4 presents an assessment of the hydrologic testing program.

---

[1]Letter from E. W. Bond to S. A. Krajewski, March 26, 1979.

Table 5.5-3 Summary of the Hydrologic Data for the North Knobs Facility

	Resource Consultants
1. Depth to Water Table	90 ft
2. G Seam Piezometric Surface Map	
1. Slope	5°
2. Direction	S88°W
3. G Seam Permeability During Testing	
1. Rate	0.02-0.03 millidarcies
2. Direction	Unknown
4. G Seam Transmissivity During Testing	
1. Rate gal/ft/day	.007-.013
2. Direction	Unknown
5. Ground Water Recovery into Well P-1	
1. Rate	0.85-1.08 gal/day
6. G Seam Ground Water Volumetric Flow to a Burnfront	Extremely low
7. Ground Water Migration Rates in G Seam	350-70° Years/ft
8. Hydrologic Characteristics of Adjacent Aquifers Seam	Similar to the G

Table 5.5-4 Assessment of the Hydrologic Testing Program

	Resource Consultants
1. Well Completion Methods	
1. Communication with over/underburden	None
2. Well Design	Adequate
2. Hydrologic Testing Methods	
1. Wellfield Configuration	Adequate to define coal seam parameters inadequate to define boundary strata parameters.
2. Test Procedures	Adequate
3. Need for Follow-up Testing	None
3. Ground Water Availability from the G coal seam or boundary strata for gasification	Extremely low amounts available
4. Hydraulic Characteristics of Boundary Strata Adjacent to Coal	Not determined
5. Hydraulic Characteristics of Observed boundary strata as compared to G coal seam (ft above/below)	No difference
6. Degree of hydraulic connection between G coal and boundary strata	High
7. Rate of migration for ground water downslope (hydraulic) from the gasification chamber	Very low
8. Correlation between the hydrologic data from the wellfield and the Burn 1 location.	Very low

6.0 RESULTS

Data collected during the geotechnical field program described in this report met the following project requirements:

- Site criteria were established by the technical staff of the project to supplement contractual criteria from DOE. These criteria were judged sufficient to define an acceptable site for the field test of gasification of steeply dipping coal beds.

- Detailed information was provided on the surface and geology of the site required for design and installation of facilities and process wells.

- Groundwater influx, coal chemistry, and boundary strata properties were obtained for test planning and implementation.

- Descriptions of the surface, hydrology, and geology to establish baseline environmental parameters.

- Studies were made to meet Wyoming State regulatory requirements concerning both groundwater and surface restoration.

Facilities

The site is easily accessible, located 1 1/2 miles from an interchange off I-80. The proximity to Rawlins (8 miles) reduces on-site requirements for personnel support and maintenance services. Soil and surface relief are good for construction.

Well Installation

The geology is consistent throughout the test site. Correlations of geophysical logs with core analysis data will prove useful during the drilling of the slant process and instrument wells. Experience gained during the geotechnical field test will be utilized for process well installations.

Coal Seam Continuity

The coal seam can be defined as a nearly planar surface within the test area. There are no local dislocations apparent at the depths of the reactor zones. Even thin beds and seams are remarkably continuous laterally and can be utilized as markers during drilling operations.

The dip of the coal seam is relatively constant over the test site. Lateral variations within the coal seam are small. Comparisons of core analysis and geophysical logs indicate a high ash zone one third of the way down the main coal seam. This zone could have lower permeability than the surrounding strata but should not present a major problem; it may actually help keep air flow near the bottom of the coal seam during air communication and backward burn linking (if required).

Coal Chemistry

The main G seam is a low ash, low sulfur subbituminous B coal. The organic matrix is relatively constant throughout the seam. Consistent levels of vitrionic macerals indicate that vertical gasification behavior should not change as the gasification front moves to the roof of the seam. Comparisons of the proximate and ultimate analyses of the North Knobs G seam with Hanna and Hoe Creek coal are seen in Table 6.0-1.

There are thin coal stringers (benches) above and below the main seam separated by shale partings. It is anticipated that the upper coal stringer will be involved in the test, but that the lower stringer will not be exposed during the burn.

Coal Seam Permeability

Permeability measurements of cores gave values comparable to those obtained for Hoe Creek and Hanna coals. However, on-site structure and photogeologic studies, and hydrologic data indicate that the coal seam is remarkably free of local fractures. The density of local fractures are the dominant factor in the high permeability seen at other UCG sites. The G seam will be expected to have a relatively low overall permeability.

Table 6.0-1
Comparison of Proximate and Ultimate Analysis Data
For Coals from the North Knobs, Hanna and Hoe Creek UCG Sites

Analysis	North Knobs (G Seam) As Received	North Knobs (G Seam) Dry	Hanna[1] (Hanna No. 1 Seam) As Received	Hanna[1] (Hanna No. 1 Seam) Dry	Hoe Creek[2] (Felix No. 2 Seam) As Received	Hoe Creek[2] (Felix No. 2 Seam) Dry
Proximate						
Moisture (%)	15.10	--	9.51	--	30.11	--
Ash (%)	5.21	6.81	23.76	26.26	4.05	5.80
Volatile Matter(%)	35.08	41.36	32.63	36.07	32.12	45.96
Fixed Carbon(%)	44.61	52.46	34.09	37.67	33.72	48.24
Calorific Value (BTU/lb)	9945	11 729	8660	9580	8359	11 960
Sulfur(%)	0.19	0.23	N.D.	N.D.	N.D.	N.D.
Ultimate						
Moisture(%)	15.05	--	N.D.		30.11	--
Ash(%)	4.76	--	23.76	26.26	4.05	5.80
Carbon(%)	59.30	74.15	49.60	54.81	48.38	69.23
Hydrogen(%)	4.08	5.11	5.09	4.45	3.66	5.24
Nitrogen(%)	0.72	0.89	1.29	1.43	1.01	1.45
Sulfur(%)	0.18	0.22	.68	.75	.34	.49
Oxygen(%)	15.91	19.63	19.58	12.30	12.45	17.79
	Main Part of G Seam					

N.D. - No Data

[1]Campbell et al., October, 1974, Bureau of Mines Coal Gasification Program Technical Progress Report 82. Preliminary Evaluation of Underground Coal Gasification of Hanna Wyoming, p.4.

[2]Hill & Thorsness, February 15, 1977, Results from an in situ coal gasification experiment involving explosive fracturing. LLL Hoe Creek exp. #1 p. 6.

There are insufficient data to estimate the differences in permeability between boundary strata and the coal seam. There is evidence that boundary strata in zones 20-50 feet above and below the seam are of comparable permeability.

The low permeability will result in somewhat higher pressure requirements initially for air communication. Once the water is forced out of the zone, permeability will improve. Since drill linking will be employed, the shorter distances for final linking should reduce the magnitude of the problem. Options for permeability enhancement should be considered.

Water Influx

The water supply stored in the G seam and the embedding formation is very limited and the water-yield characteristics of these formations are extremely poor. It appears that the process-water requirements of the experiments will have to be met either by water import or from a water supply eventually developed from a more remote strata of the Fort Union Formation or a formation with significantly higher yield characteristics. Information available at this time does indicate that the experiment will not require the removal of any appreciable amount of excess water from the G-seam or from the neighboring formations close to the proposed burns. Problems connected to the disposal of excess water or contamination of the surface hydrologic system thereby is greatly reduced, if not eliminated.

Similarly, because of the very limited water-yield characteristics of this formation, there are no water users obtaining their supply from the coal or from closely related formations. The preliminary transmissibility figures indicate that fluid movement in the formations is extremely small, retaining any potential contaminant to its location of formation for long periods of time.

There is no live hydrologic connection between the test site and the channel of Separation Creek, providing sufficient protection for the surface-water rights downstream on the creek. Since not much water is present at the site, and the proposed burning experiment is of small scale, no appreciable reduction of the water supply is expected to result because of these tests.

Subsidence

No vertical migration of the reaction zone through roof strata is expected. The strength, quality and thickness of the overlying boundary strata will resist vertical extensions. The small size of the reaction zones will also reduce the liklihood of vertical growth of the UCG unit. Therefore, no surface subsidence effects are expected. Since no aquifers have been defined in the test zone, subsidence is not expected to effect any aquifers.

Product Excursion

Since the seam is extremely tight, there should be little leakage of product gas during the process. The low degree of fracturing has suggested leak paths of ≈4000 feet to the surface along cleat fractures. Although these projected path lengths are probably high, they do support the expectation that leakage will be minimal.

Regulatory Implications

Wyoming State regulatory requirements include provisions for restorations of the site to its original use value. This includes both groundwater and surface restoration. It has been determined that the UCG facility can be installed and operated in a manner acceptable to all governmental regulatory bodies. There will be very little impact on aquifers and the surface can be restored to its original use value. Known historic and archeological sites in the area will not be altered in any fashion.

7.0 RECOMMENDATIONS

This study has provided the project with site-specific data essential to the test program. The site criteria established by the technical staff and DOE have been satisfied. Based upon evaluation of the site data relative to the process, the following recommendations can be made:

1. The North Knobs test site defined in this report should be used for the field tests of the UCG-SDB project.

2. The geotechnical field program should be considered complete and no further work implemented.

3. A member of the geotechnical team should serve on the site staff during facility installation and test operations.

4. Quenching processes to be implemented following the burn phase must be consistent with a probable low level of water influx.

5. Process water should be provided to allow better control of process parameters. This water should be brought in since there is not sufficient groundwater on site to fill requirements.

6. Alternative fracturing methods should be investigated. The low permeability in the coal seam may create problems in establishing air communications.

APPENDIX A

Appendix A
Table of Contents

		Page
Appendix A		
A.1	Statement of Purpose	A-1
A.2	Surface Mapping	A-1
A.2.1	Introduction	A-1
A.2.2	Surface Mapping - Part I	A-2
A.2.2.1	Procedures	A-2
A.2.2.2	Data	A-3
A.2.3	Surface Mapping - Part II	A-10
A.2.3.1	Procedures	A-10
A.2.3.2	Data	A-11
A.2.4	Surface Mapping - Part III	A-11
A.2.4.1	Procedures	A-11
A.2.4.2	Data	A-12
A.2.5	Data Description	A-12
A.3	Well Installation	A-13
A.3.1	Introduction	A-13
A.3.2	Site Preparation	A-14
A.3.2.1	Procedures	A-14
A.3.2.2	Site Preparation Data	A-19
A.3.3	Drilling	A-19
A.3.3.1.1	Core/Hydro Observation Holes	A-19
A.3.3.1.2	Exploratory Holes (E_1-E_{27})	A-28
A.3.3.1.3	Soil Augering Holes	A-29
A.3.3.2	Drilling Data	A-31
A.3.3.2.1	Core/Hydro Observation Holes	A-31
A.3.3.2.2	Exploration Holes (E_1-E_{27})	A-34
A.3.3.2.3	Soil Augering Holes	A-34
A.3.4	Geophysical Logging	A-34
A.3.4.1	Procedures	A-35
A.3.4.2	Data	A-38
A.3.5	Well Completion	A-38
A.3.5.1	Procedures	A-47
A.3.5.2	Well Completion Data	A-47
A.3.6	Well Development	A-49
A.3.6.1	Procedures	A-50
A.3.6.2	Well Development Data	A-52
A.3.7	Site Restoration	A-53
A.3.8	Summary/Conclusions	A-54
A.3.8.1	Drilling Operations	A-54
A.3.8.2	Well Completion	A-55
A.3.8.3	Well Development	A-55
A.3.8.4	Site Preparation/Restoration	A-56

Appendix A
Table of Contents (Cont'd.)

		Page
A.4	Geology	A-57
A.4.1	Introduction	A-57
A.4.2	Regional Geology	A-57
A.4.2.1	Procedures	A-57
A.4.2.2	Data	A-58
A.4.3	Site Geology	A-59
A.4.3.1	Procedures	A-59
A.4.3.2	Data	A-59
A.5	Core Testing	A-61
A.5.1	Boundary Strata	A-61
A.5.1.1	Procedures	A-61
A.5.1.1.1	Rock Quality Designation	A-61
A.5.1.1.2	Laboratory Testing	A-61
A.5.1.2	Data	A-66
A.5.2	Coal Core Analysis	A-73
A.6	Hydrology	A-99
A.6.1	Water and Hydrology Test Program Sampling	A-99
A.6.1.1	Introduction	A-99
A.6.1.2	Procedures	A-99
A.6.1.3	Data	A-101
A.6.2	Water Table Depth	A-101
A.6.2.1	Data	A-102
A.6.3	Drawdown Testing	A-102
A.6.3.1	Pump Installation	A-102
A.6.3.1.1	Procedures	A-128
A.6.3.2	Drawdown Testing	A-130
A.6.3.3	Data	A-131
A.6.4	Summary/Conclusions	A-131
A.6.4.1	Water Sampling/Analysis	A-134
A.6.4.2	G Seam Potentiometric Surface	A-134
A.6.4.3	Drawdown Pump	A-135
A.6.4.4	Drawdown Testing	A-135
A.6.4.5	Hydrologic Parameters	A-135

APPENDIX A

List of Tables

		Page No.
A.2-1	Surface Coordinates and Elevation Summary	A-4 to A-9
A.3-1	Well Number: CORE HOLE 3	A-32
A.3-2	Well Number: CORE HOLE 4	A-33
A.5.1-1	Characteristics of Samples Collected for Laboratory Boundary Strata Analysis	A-63
A.5.2-1	Summary of Core Analysis Subcontractors, Tests and Handling Procedures	A-75
A.5.2-2	Proximate Analysis of G Seam Drill Cuttings from Core Hole 2	A-76
A.5.2-3	Proximate Analysis of G Coal Core from Core Hole 3	A-77
A.5.2-4	Proximate Analysis of I Coal Seam from Core Hole 3	A-78
A.5.2-5	Proximate Analysis of G Coal Seam from Core Hole 4	A-79
A.5.2-6	"As Received" Ultimate G Seam	A-80
A.5.2-7	MAF Ultimates - G Seam	A-81
A.5.2-8	Fusion Temperature of Ash From G and I Coal Core from Core Hole 3	A-82
A.5.2-9	Fusion Temperature of Ash from G Coal Core from Core Hole 4	A-83
A.5.2-10	Elemental Ash Analyses for G and I Seam Ash from Core Hole 3	A-84 to A-88
A.5.2-11	Elemental Ash Analyses for G Seam Ash from Core Hole 4	A-89 to A-90
A.5.2-12	Physical Property Data for the Main Part of the G Coal Seam	A-91
A.5.2-13	Maceral Composition of 10 Samples from GR&DC Coal Near Rawlins Wyoming	A-92
A.5.2-14	Summary of Laboratory Porosity and Permeability Testing on the G_{mc} Coal	A-93
A.6-1 to 12	Water Level Elevation Measurements for Observation Wells	A-104 to A-115
A.6-13	Pumping History for P-1 During Drawdown Testing	A-132 to A-133

APPENDIX A

List of Figures

		Page No.
A.2-1	Surveyors Surveying	A-3
A.3-1	Rat Hole Drilling	A-15
A.3-2	Grouting the Conductor Pipe	A-16
A.3-3	Anchor Bolt	A-17
A.3-4	Expansible Anchor Bolt Installation	A-18
A.3-5	Drilling Rig	A-20
A.3-6	Hydraulic Power Swivel	A-21
A.3-7	Circulation System	A-22 to A-23
A.3-8	Drill Collars	A-24
A.3-9	PVC Liner	A-25
A.3-10	Diamond Core Bit and Nozzles	A-26
A.3-11	Exploratory Hole Rig	A-29
A.3-12	Soil Augering Drilling	A-30
A.3-13	Logging Equipment	A-36
A.3-14	Johnson Well Screen	A-40
A.3-15	Cement Basket	A-41
A.3-16	Centralizers	A-41
A.3-17	Lowering the Production Assembly	A-42 to A-43
A.3-18	Injecting Cement	A-44 to A-46
A.3-19	Well Head	A-48
A.3-20	Perforating the Well	A-48 to A-49
A.5.1-1	Modified Core Recovery as an Index of Rock Quality	A-62
A.5.1-2	Mode of Specimen Preparation for Uniaxial Compression Test	A-65
A.5.1-3	A Rock Specimen in Uniaxial Compression Test	A-67
A.5.1-4	A Rock Specimen in Triaxial Compression Test	A-67
A.5.1-5	A Rock Specimen in Brazilian Test	A-68
A.5.2-1 to 5	Effective Permeability to Gas in md at Simulated Overburden Pressure of 200 psig	A-94
A.5.2-6 to 9	Effective Permeability to Gas in md at Simulated Overburden Pressure of 550 psig	A-95
A.5.2-10 to 14	Relative Permeability to Gas at 200 psig	A-96
A.5.2-15 to 18	Relative Permeability to Gas at 550 psig	A-98
A.5.2-19 to 22	Average Relative Permeabilities	A-98
A.6-1	Instrumentation Used for Water Level Measurement	A-103
A.6-2 to A.6-13	Graphic Plots of Water Levels in Observation Wells	A-116 to A-127
A.6-14	Well Design for Drawdown Testing	A-129

APPENDIX A

A.1 STATEMENT OF PURPOSE

Implementation of the geotechnical field program to collect data on the geology parameters of the UCG involved many tasks. Descriptions of these activities are useful in understanding the many problems associated with gathering site-specific data on a UCG site. Rather than expanding the main report with procedures data, they have been incorporated into a separate volume--Appendix A. The purpose of this appendix is twofold:

1. To present as complete a picture as possible for a thorough evaluation of the data and conclusions produced in the main volume.

2. To add to the state-of-the-art in characterizing a UCG test site.

A.2 SURFACE MAPPING

A.2.1 Introduction

The North Knobs surface mapping program consisted of the following three parts:

1. Part I - Defining the surface location of Section 11, the UCG facility, and the G coal seam; determining the ownership rights for Section 11 and the eight adjacent sections.

2. Part II - Obtaining low altitude aerial photographs, large-scale topographic maps, and photo-topographic profiles of the UCG site and facility.

3. Part III - Defining the surface locations and elevations of drill holes, anchor bolts, trenches, and access roads installed during the Phase II geotechnical field program.

These data were subsequently utilized for:

1.) Presenting and interpreting the geotechnical data.
2.) Designing the surface and subsurface data.
3.) Supplying data for permit applications.

The surface mapping task was subcontracted to Robert Jack Smith and Associates (surveying) and Horizons, Inc. (aerial photography and topographic and photo-topographic map construction). The mapping phase of this project began in December 1977 and was completed in February 1978.

A.2.2 Surface Mapping--Part I

A.2.2.1 Procedures

Part I of the surface mapping program consisted of using standard surveying techniques to obtain the surface elevations and coordinates of:

1. The corners of Section 11; the east and north half and quarter section points.
2. The aerial photography control points.
3. The section lines where they cross access roads.
4. The Energy Development Company and GR&DC/TRW drill holes on Section 11.
5. The points at 50-ft intervals on a baseline which were parallel to, but not on top of, the strike of the G coal seam outcrop.
6. The points at 100-ft intervals on radial lines run perpendicular to the baseline at 0 + 00, 7 + 60, 9 + 65, 12 + 00, 17 + 00, 26 + 00, and 37 + 00 ft on the baseline.

The survey work (Figure A.2-1) was performed by a three-man field crew using the following equipment:

1. A Wild T-2, 1 second theodolite.

2. A Hewlett Packard 3800 distance meter.
3. An AGA Prism reflector.

"Surveyor's Surveying"
Figure A.2-1

A.2.2.2 Data

The following data items were obtained from Part I of the surface mapping program:

1. A metes and bounds map for Section 11. This map presents the Section 11 surveying location and orientation data.
2. An ownership map for Section 11 and the 8 adjacent sections. This map presents the surface, mineral, water, and grazing rights ownership for the 9-section area; it also indicates mining claims and permitted water wells on the 9-section area.
3. The surface coordinates and elevations of the designated reference points (Table A.2-1).
4. A field reference system on the facility (the baseline and radial lines). The baseline was orientated N26°30'W on the east section-

TABLE A.2-1 SURFACE COORDINATES AND ELEVATIONS SUMMARY

	Point	Surface Coordinates North	East	Elevation
Section Coordinates Sec. 11 T21N, R89W	NE	417742.66	479640.42	6948.56
	SE	412470.36	479633.91	6900.0
	NW	417706.20	474390.72	6722.0
	SW	412433.14	474386.51	6698.0
1/2 Section Pts. Sec. 11 T21N, R89W	E	415104.02	479637.23	6880.00
	N	417721.65	477024.96	6800.00
	W	415073.17	474388.60	6716.00
	S	412438.77	477017.97	6819.00
Surveying Control Points	CP 901	413934.72	479733.71	6952.93
	CP 103	414157.02	478660.31	6884.68
Energy Development Company Drillholes (1976)	229	413800.000	479526.000	6937
	230	414149.401	479539.152	6818
	231	414331.434	479240.365	6899
	232	414942.736	479141.976	6864
	233	414871.279	479033.101	6855
	234	415341.386	478767.824	6825
	235	415464.888	478927.618	6827
	236	416000.962	478737.886	6829
	237	415791.379	478542.523	6816
	238	416308.199	478300.933	6842
	239	416551.925	478504.309	6867
	240	416949.560	477974.999	6865
	241	416963.135	478072.714	6867
	242	416867.115	477863.968	6858
	243	416971.743	478106.123	6869
	244	416957.592	478040.310	6865
	245	416959.128	478057.611	6866
	246	417405.237	478149.556	6884
	247	417749.194	477739.206	6847

TABLE A.2-1 SURFACE COORDINATES AND ELEVATIONS SUMMARY (Cont'd.)

	Point	Surface Coordinates		Elevation
		North	East	
P-1	NW#1	414418.38	478875.12	6879.92
	NE#2	414482.83	478991.22	6892.93
	SE#3	414308.70	479063.60	6894.75
	SW#4	414268.83	478951.06	6885.08
	SW of P-1	414256.71	478897.45	6879.95
	W/SW of P-1	414308.66	478869.82	6877.99
	W of P-1	414349.60	478846.76	6876.33
	NW of P-1	414401.52	478826.01	6874.07
	NE of P-1	414503.24	479021.85	6897.31
	E/NE of P-1	414457.11	479040.42	6896.38
	E/SE of P-1	414382.98	479073.92	6900.76
	SE of P-1	414338.90	479094.71	6904.16
	100' N of P-1	414459.33	478935.05	6886.82
	50' N of P-1	414413.61	478952.82	6886.82
	15' S of H-8	414333.19	478982.17	6888.22
	60' S of H-8	414288.55	478994.70	6888.58
Aerial Photography Control Points	200	407744.28	482004.38	6853.65
	201	408282.07	479234.23	6791.81
	202	408543.63	481945.00	6854.66
	203	408855.51	482860.38	6865.29
	204	409239.41	485729.62	6903.12
	205	411174.85	482406.63	6956.31
	206	412300.02	484159.50	6997.30
	207	410294.41	481362.32	6890.23
	208	411474.65	480897.45	6935.85
	209	413093.74	479209.91	6937.80
	210	413291.69	481062.95	7002.02
	211	414022.95	482787.38	7027.62
	212	415120.30	477380.61	6781.83
	213	416819.54	479529.91	6915.11
	214	417615.16	480507.00	6942.96
	215	417902.06	476298.20	6763.46
	216	419034.69	477280.10	6797.64

TABLE A.2-1 SURFACE COORDINATES AND ELEVATIONS SUMMARY (Cont'd.)

	Point	Surface Coordinates		Elevation
		North	East	
Trench Corners (SE corner)	G-1	413802.57	479620.53	6933.20
	G-2	414064.559	479447.604	6915.28
	G-3	414794.059	479056.684	6860.93
	I-1	414179.462	479606.309	6926.74
	I-2	414675.861	479355.974	6880.61
	W-1	413944.858	479216.934	6907.78
	W-2	414497.883	478974.059	6893.44
Anchor Bolt Locations	NE#1	414027.33	479482.26	6919.54
	SE#2	414898.08	479503.47	6930.01
	SW#3	413872.87	479409.32	6926.08
	NW#4	413995.46	479368.47	6924.37
CH-2	N#1	413892.95	479173.97	6902.06
	E#2	413861.65	479283.20	6913.79
	S#3	413750.72	479250.67	6907.60
	W#4	413790.60	479142.94	6900.94
CH-3	NE#1	414873.88	479077.34	6857.39
	SE#2	414749.79	479106.79	6862.84
	NW#3	414812.54	478931.52	6887.64
	SW#4	414717.44	478998.93	6881.57
CH-4	N#1	414777.00	478827.00	6892.60
	E#2	414676.00	478929.00	6885.80
	S#3	414576.00	478828.00	6877.30
	W#4	414678.00	478733.00	6874.90
H-15	NE#1	416880.23	477911.64	6860.18
	SE#2	416769.70	477952.94	6863.63
	SW#3	416729.30	477843.06	6860.81
	NE#4	416839.72	477802.41	6852.05

TABLE A.2-1 SURFACE COORDINATES AND ELEVATIONS SUMMARY (Cont'd.)

	Point	Surface Coordinates		Elevation
		North	East	
GR&DC Exploration Holes (1978)	1	413593.86	479630.23	6944
	2	413579.20	479595.56	6943
	3	413682.06	479578.19	6939
	4	413658.23	479540.62	6936
	5	413772.74	479634.01	6935
	6	413762.94	479611.52	6934
	7	413750.44	479590.95	6933
	8	413738.13	479566.10	6935
	9	413730.52	479540.27	6936
	10	413704.58	479519.48	6935
	11	413728.83	479438.94	6932
	12	413863.14	479509.57	6933
	13	413854.89	479483.44	6932
	14	414081.13	479486.51	6917
	15	414069.29	479464.62	6916
	16	414057.86	479442.55	6916
	17	414044.66	479417.29	6919
	18	414034.44	479398.48	6919
	19	414299.13	479352.67	6899
	20	414284.81	497337.02	6899
	21	414278.93	479305.74	6902
	22	414286.49	479264.28	6906
	23	414445.91	479188.68	6890
	24	414712.95	479182.19	6868
	25	414709.66	479154.33	6865
	26	414664.61	479129.13	6870
	27	414646.06	479110.31	6872
GR&DC Soil Auger Holes	AH1	413700.36	479626.31	6936
	AH2	413875.98	479544.43	6928
	AH3	414053.	479442.	6918
	AH4	414580.75	479165.35	6878
	AH5	415798.873	478601.793	6817.73
	AH6	415806.313	478618.476	6818.24
	AH7	415957.822	478540.011	6824.96

TABLE A.2-1 SURFACE COORDINATES AND ELEVATIONS SUMMARY (Cont'd.)

	Point	Surface Coordinates		Elevation
		North	East	
EDC Holes (1976)	248	417778.672	477759.316	6848
	249	417790.396	477542.260	6835
	250	416232.476	477842.330	6845
	251	416320.778	477323.481	6843
	252	416334.290	478343.476	6844
	253	416329.534	478332.228	6843
	254	415795.501	478578.165	6817
	255	415803.750	478594.982	6817
	256	415723.358	478389.429	6809
	257	415722.768	478405.416	6810
	258	415505.082	477714.620	6798
	259	415490.928	477676.663	6796
	260	413415.864	479448.661	6932
	261	413894.744	479509.103	6930
	262	413906.948	479523.397	6927
GR&DC/TRW Drill Holes (1977)	DH-1	413606.10	479387.20	6472.4
	DH-2	414043.03	479287.71	6919
	DH-3	416918.302	477815.485	6855.35
GR&DC Core Holes (1978)	1	413945.15	479436.96	6925
	2	413822.90	479213.55	6909
	3	414789.80	479034.02	6861
	4	414672.02	478822.16	6879
GR&DC Hydrologic Observation Wells (1978)	7	414374.73	479022.18	6893
	8	414352.57	478965.88	6888
	9	414334.35	478931.20	6884
	10	414549.04	478946.84	6895
	11	414421.00	479004.46	6892
	12	414400.40	478958.22	6886
	13	414380.36	478912.81	6884
	15	416804.58	477877.40	6859
	P-1	414378.93	479975.52	6887

TABLE A.2-1 SURFACE COORDINATES AND ELEVATIONS SUMMARY (Cont'd.)

	Point	Surface Coordinates		Elevation
		North	East	
Sign Hole	1	413253.26	479587.19	6944.31
	2	413250.53	479583.92	6944.15
	3	413248.09	479581.09	6944.29

line of Section 11, 11 + 24.52 ft north of the southeast corner of Section 11.

A.2.3 Surface Mapping--Part II

A.2.3.1 Procedures

Part II of the surface mapping program consisted of obtaining:

1. Low altitude, black and white aerial photographs of the G seam outcrop belt (an area 3000 x 7000 ft with the long axis centered on the G coal seam outcrop). The aerial photographs meet U.S. Geological Survey specifications and the aquisition scale was designed to produce topographic maps with intervals of 5 and 2 ft.
2. Large-scale topographic maps:

Map	Contour Interval	Scale	Area Covered
a. Outcrop belt	5 ft	1 in - 100 ft	3000 x 7000 ft
b. Facility	2 ft	1 in - 50 ft	2000 x 2000 ft

3. Photo-topographic profiles:

   a. Location - at radial lines 0 + 00, 5 + 00, 7 + 60, 9 + 65, 12 + 00, 17 + 00, 26 + 00, and 37 + 00 ft on the baseline.
   b. Length - from 5 + 00 ft northeast of baseline to 10 + 00 ft southwest.
   c. Scale = 1 inch = 50 ft for both horizontal and vertical scale.

This work was not completed on-site and descriptive information about the equipment used to construct the above was not obtained.

A.2.3.2 Data

The following data items were obtained from Part II of the surface mapping program:

1. An aerial photograph index map.
2. 9 x 9 inch prints of the aerial photographs. The photos are available in the UCG project files at Harmarville, Lakewood, and McLean.
3. 36 x 36 inch enlargement of aerial photograph No. 258 (Figure B-8 in Appendix B).
4. The outcrop belt and facility topographic maps.
5. The eight photo-topographic profiles.

The aerial photographs were prepared on contact paper and the enlarged aerial photographs, topographic maps, and photo-topographic profiles were constructed on matte mylar.

A.2.4 Surface Mapping--Part III

A.2.4.1 Procedures

Part III of the surface mapping program consisted of using standard surveying techniques to obtain the surface elevations and coordinates of:

1. The holes drilled during the Phase II Geotechnical Program. These included the core holes, hydrologic observation wells, anchor bolts, exploration holes, and soil augering holes.
2. The southeast corner of each trench.
3. Selected points on access roads.

A.2.4.2 Data

The following data items were obtained from Part III of the surface mapping program:

1. The surface coordinates and elevations of the drill holes, anchor bolts, trenches, and access roads installed during the Phase II Geotechnical Field Program (Table A.2-1).
2. A master geotechnical drill hole plan map illustrating the locations of all installed geotechnical items.

A.2.5 Data Description

Data from the mapping program included:

1. The surface elevations and coordinates of the reference points used to define the location of the UCG-SDB site and facility and the holders of ownership rights in the study area.
2. Low-altitude aerial photographs, large-scale topographic maps and photo-topographic profiles.
3. The surface elevations and coordinates for drill holes, anchor bolts, trenches, and access roads installed during the Phase II Geotechnical Program.

A.3 WELL INSTALLATION

A.3.1 INTRODUCTION

Well installation activities consisted of drill site preparation, hole drilling, geophysical logging, well completion, well development, and site restoration. The drilling activities were conducted to serve the following purposes:

1. To delineate the stratigraphic and structural characteristics of the G coal seam.
2. To obtain core samples for coal and boundary strata analysis.
3. To gain access to the coal gasification area for:
   a.) gathering baseline information regarding water quality
   b.) conducting hydrological tests to determine transmissivity of the coal seam and surrounding rock strata.
4. To delineate the G seam outcrop and to detect the presence of any past underground burning in the G coal seam.

A total of 46 holes were drilled on the site during the program:

Type	Number
Soil Auger Holes	7
Exploratory Holes	27
Hydrologic Observation Wells	
Cored	2
Non-cored	10

After drilling the boreholes, geophysical logging methods (gamma ray, gamma-gamma density and resistivity) were used to define the rock strata and characteristics of the G coal seam. Additional methods (caliper and drift surveys) were used to determine respectively, the diameter of the borehole and its deviation from the vertical. To ascertain the temperature of the ground water in the wells, temperature logs were run after the wells were completed. Well screens and casings were then installed in the holes for use in

determining the hydrologic characteristics of the coal seam and the aquifers adjacent to the coal.

Prior to water sampling and hydrologic testing of the wells, development activities were undertaken to remove any sediment and/or brine water from the well screen area, and to increase the permeability of the formation around the well screen. These activities included circulating clean water in the casing until clean returns were obtained.

Lastly, the drill sites were restored to their original contour after all the wells were drilled. Revegetation activities were not undertaken in this phase of preliminary drilling activities. The drill sites will be revegetated when the facility is abandoned at the completion of the experiment.

A.3.2 SITE PREPARATION

Site preparation activities consisted of designing the drill hole locations, locating the drill holes in the field and preparing the drill pads for drilling operations.

A.3.2.1 Procedures

Locations for the hydrologic observation wells were selected to characterize the stratigraphy, structure and hydrology of the facility, and to avoid drilling into the proposed burn areas. The exploration and soil auger holes were placed to determine the character of the G seam outcrop and to determine the existence of any past subsurface burning in the G seam. In the preliminary stages, hole locations were selected using the facility topographic map (1 inch = 50 feet).

When the field work was initiated, some drill locations were found to coincide with undesirable field conditions, such as drill locations occurring on top of resistant sandstones. Since excessive drill pad preparation costs would be incurred in such cases, the design locations were

moved either up-dip or down-dip in the geologic section. Major modifications in the original design, however, did not have to be made.

After the drill hole locations were fixed on the facility, drill pads were prepared by leveling off the ground surface, digging a mud pit, and installing conductor pipes and anchor bolts. The drill pad area required to set up the drill rig was approximately 75 feet x 100 feet.

The mud pit dimensions were approximately 35 feet long, 10 feet wide and at least 8 feet deep. The pit specifications required a 2-foot elevational difference between the conductor pipe return nipple and the top of the mud tank, and this was accounted for in the design structure.

For each hydrologic observations well, a conductor pipe was installed to allow vertical initiation of the borehole and to prevent surface erosion of the hole during drilling. The hole (rat hole) for the conductor pipe was drilled with an 18-inch diameter, 30-inches long, Morton Equipment dry hole drill bucket powered by a truck mounted, diesel, LM42 Earth Drill (Figure A.3-1). The drill had a 40-foot derrick and a 90-foot extendable kelly. No fluids were circulated during the drilling.

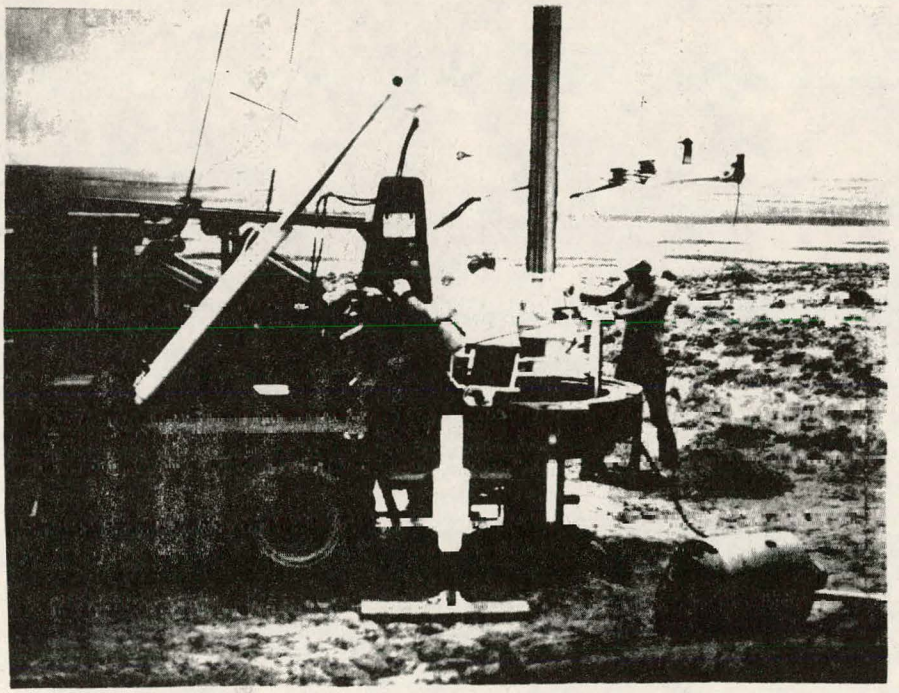


Figure A.3-1 Rat Hole Drilling

After drilling the rat hole, a 40-feet long, 10-inch I.D. corrugated galvanized steel pipe (conductor pipe) was set into the rat hole, hand leveled to vertical and grouted in place (Figure A.3-2). The grout was allowed to set for 24 hours and an 8-inch steel nipple was installed approximately 12 inches from the top of the conductor pipe.

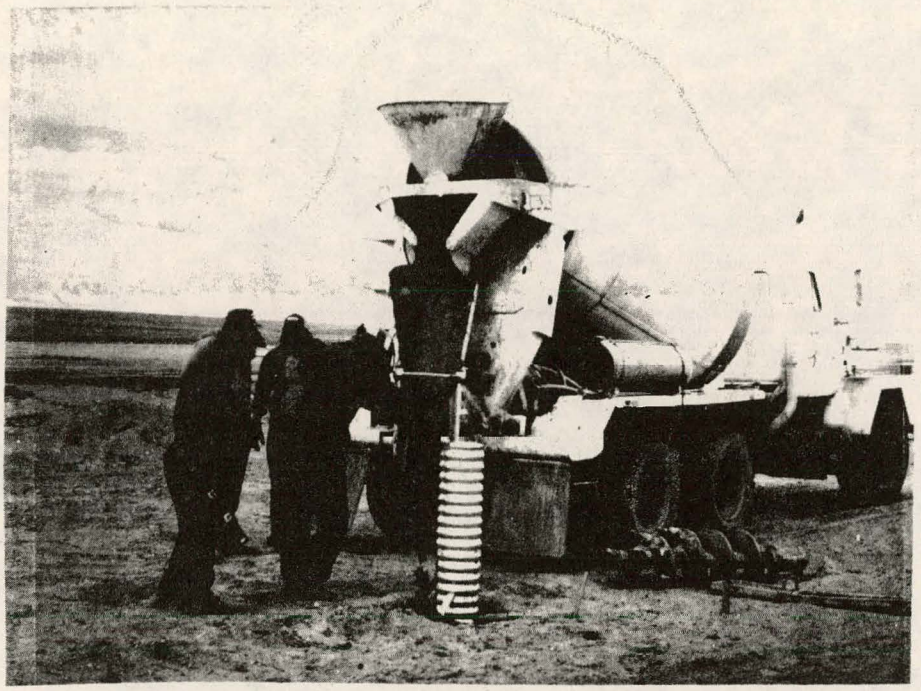


Figure A.3-2. Grouting the Conductor Pipe

Around each conductor pipe, four anchor bolts had to be installed in the ground to stabilize the drill rig mast during the drilling operations. These holes were located approximately 75 feet from the conductor pipe in a rectilinear pattern. For each anchor bolt, a nominal 10-inch diameter, 8-feet deep hole (mouse hole) was drilled with a 10-inch diameter, 7.5-feet long helical auger bit (Figure A.3-3). The auger bit was operated by a truck mounted, gasoline powered, TEXOMA 254 drill rig. No fluids were circulated during the drilling.

Figure A.3-3. Anchor Bolt

After drilling the mouse hole, a TUBECO expansible anchor bolt was placed into the hole and expanded (Figure A.3-4). Drill cuttings were then compacted into the open hole and the anchor bolt was tested to about 20 000 psi-tension.

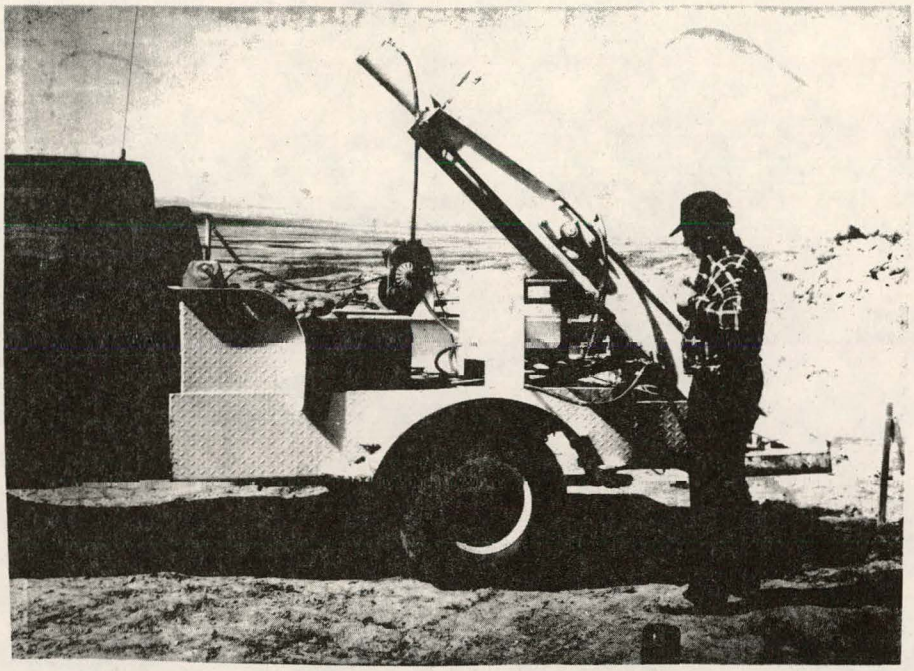


Figure A.3-4. Expansible Anchor Bolt Installation

No site preparation was needed for the exploratory and soil auger holes. The drilling rigs for these holes were four-wheel drive mounted and could be transported anywhere on the facility.

Surveying of all borehole locations was completed by Robert Jack Smith and Associates. The survey data included the location coordinates and elevation for each borehole (see Section A.2-Table A.2-1).

A.3.2.2 Site Preparation Data

Activities completed as part of site preparation included:

1. Obtaining the surface coordinates and elevations for all drill holes and anchor bolts.
2. Constructing access roads.
3. Constructing drill pads on the North Knobs facility.
4. Installing conductor pipes and anchor bolts at each hydrologic observation well location.

A.3.3 DRILLING

In Phase I of the SDB project, GR&DC/TRW drilled three exploration holes with a small-sized exploration/water well rig with a mechanical pull-down. These holes had diameters of 6 1/2 inch, depths of 600 feet, average horizontal drifts of 125 feet at total depth, and were so located that excessive hole drifting was not a problem.

The Phase II hydrologic wells were designed to have comparable diameters and depths; however, the drill locations required a higher degree of accuracy and excessive hole drifting could not be permitted. The hydrology well field was designed to have observation wells drilled on a 50-foot surface spacing and a pump well located 30 feet from two of the observation wells. To implement this plan, it was decided to use a larger-sized drill rig which could use drill collars, rotary drive, variable circulating rates, and a wider variety of bits.

A.3.3.1.1 Core/Hydro Observation Holes

The drilling rig used on-site was a truck mounted, diesel powered HOPPER 2, workover rig operated by A&M Well Service, Inc. (Figure A.3-5). It had a mechanical draw works, used a conventional crown traveling block assembly with a six part wire line, had a 96-foot hydraulically raised and extended derrick, used a drill floor which was a separate substructure, and was equipped with an Eastman STAR geolograph recorder.

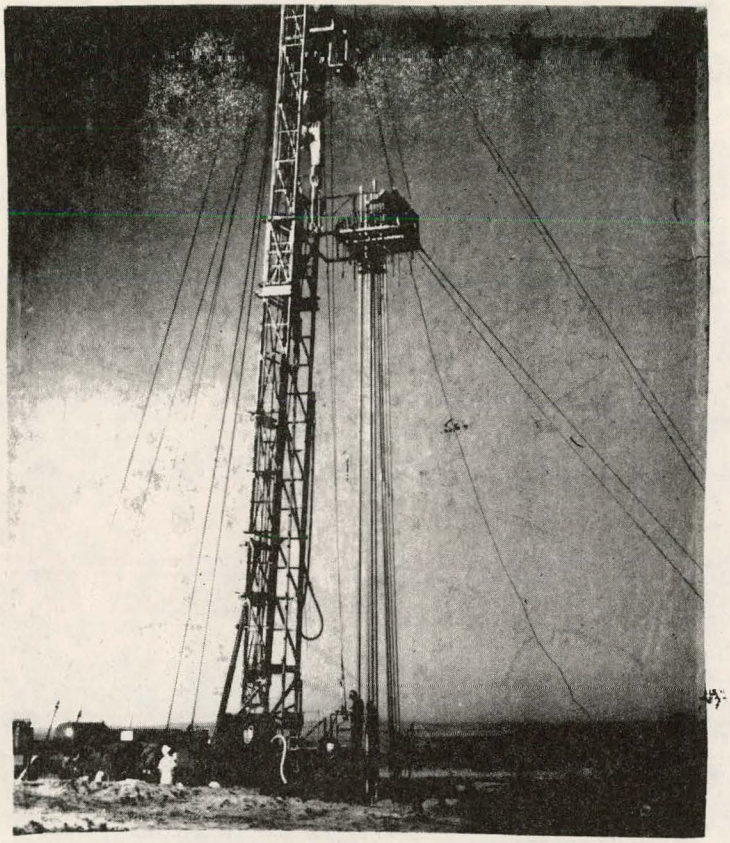


Figure A.3-5. Drilling Rig

The rig did not have its own rotary unit; therefore, a skid-mounted BOWEN S2.5 hydraulic power swivel was used to drive the drill stem and bit (Figure A.3.6). Throughout most of the drilling, a speed of 120-160 rpm was maintained and drilling weights of 8-12 000 pounds were used depending upon depth. The power swivel was used for drilling all holes except H-15 which was drilled with a rotary swivel.

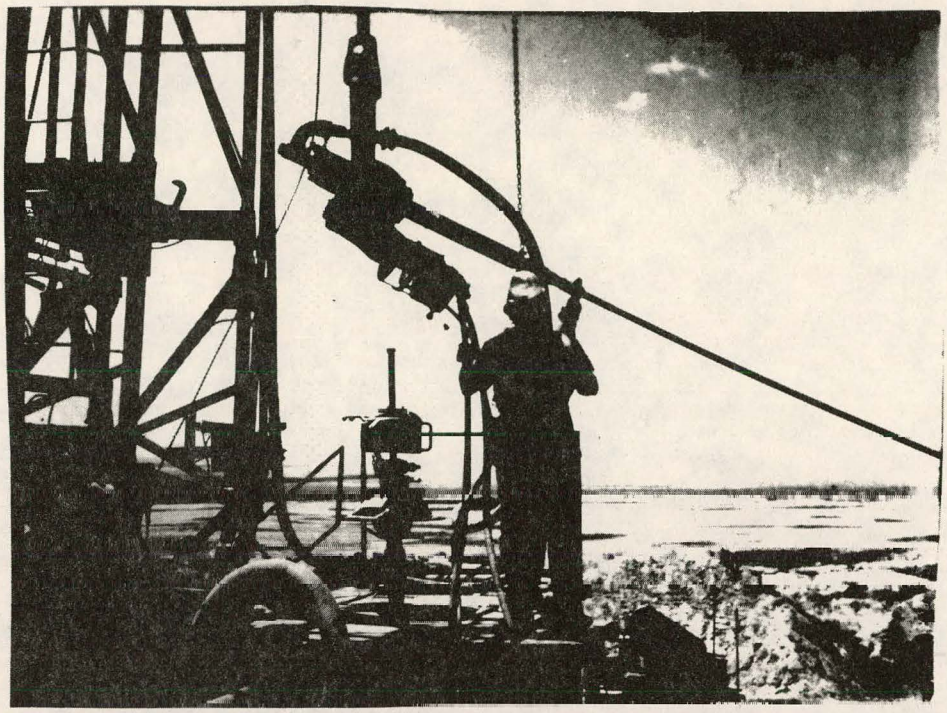


Figure A.3-6a. Hydraulic Power Swivel

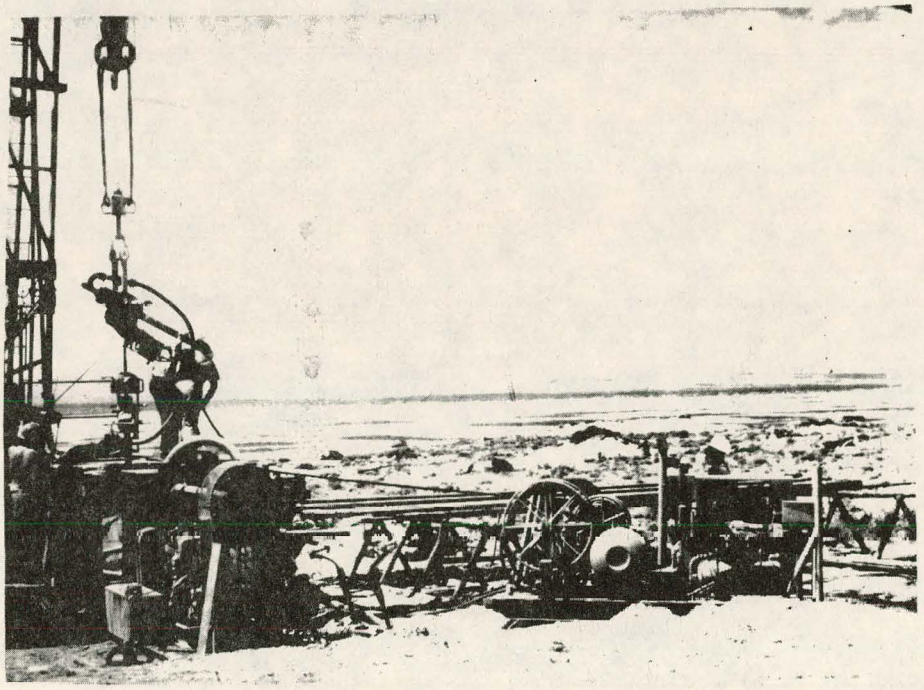


Figure A.3-6b. Hydraulic Power Swivel

The circulation system consisted of a 150-barrel steel mud tank (Figure A.3-7) (30 x 6 x 8 feet) equipped with a shale shaker, a Gardner-Denver Triplex pump (5 1/2-inch piston x 8-inch stroke); 2 to 6-inch suction lines; 2-inch steel discharge lines; the drill stem; 8-inch PVC return pipe, and the drilling fluid. The circulating fluid varied during the program as follows:

Hole	Fluid
Hydro-15 CH-1, 2, 3, 4	Water[+], Bentonite Mud*
Hydro-12 P-1	Water
Hydro-7, 8, 9, 11, 13	Brine

A pumping rate of 135 gpm was used throughout most of the drilling program.

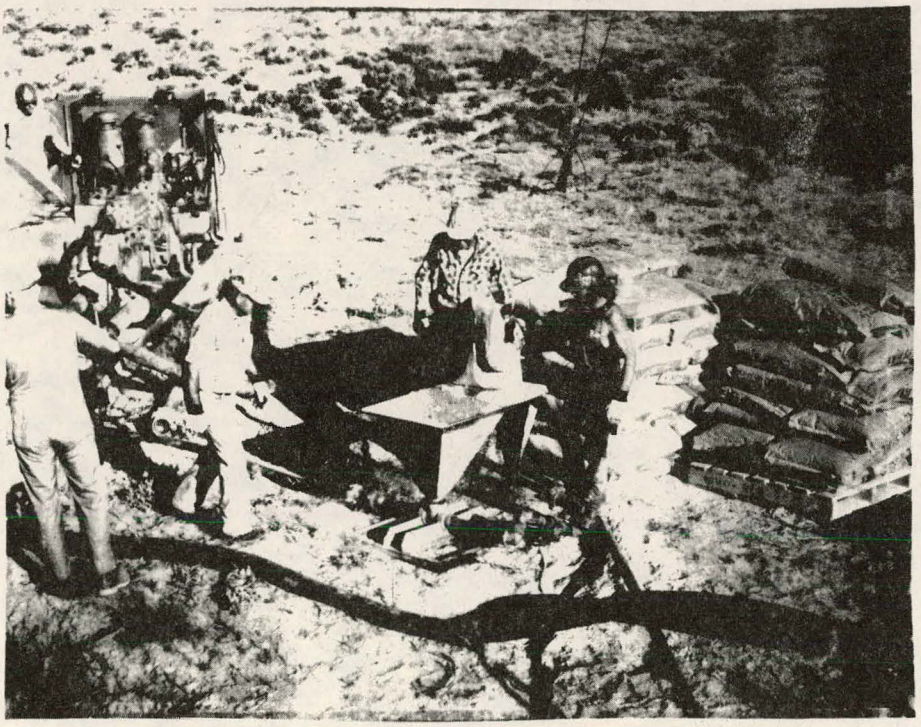


Figure A.3-7a
Circulation System

[+]At a depth of 100-150 ft the formation took 450 gal of water at a pumping rate of 100 gpm; therefore, mud was used to complete the remainder of the hole.

*The mud had a 38 SEC Marsh funnel viscosity and a 9 lb/gal weight.

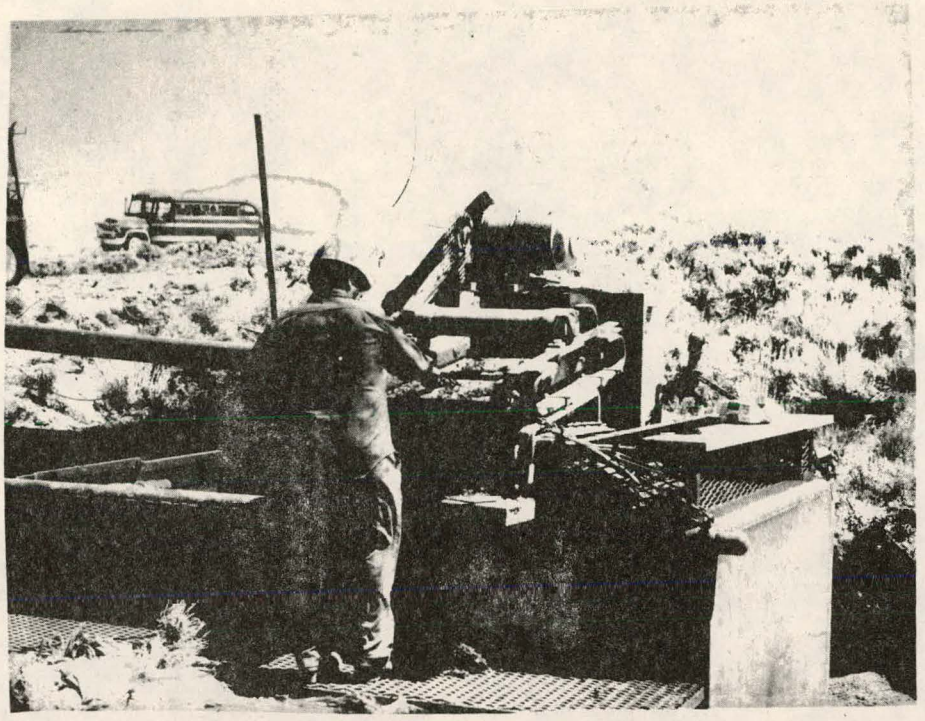


Figure A.3-7b

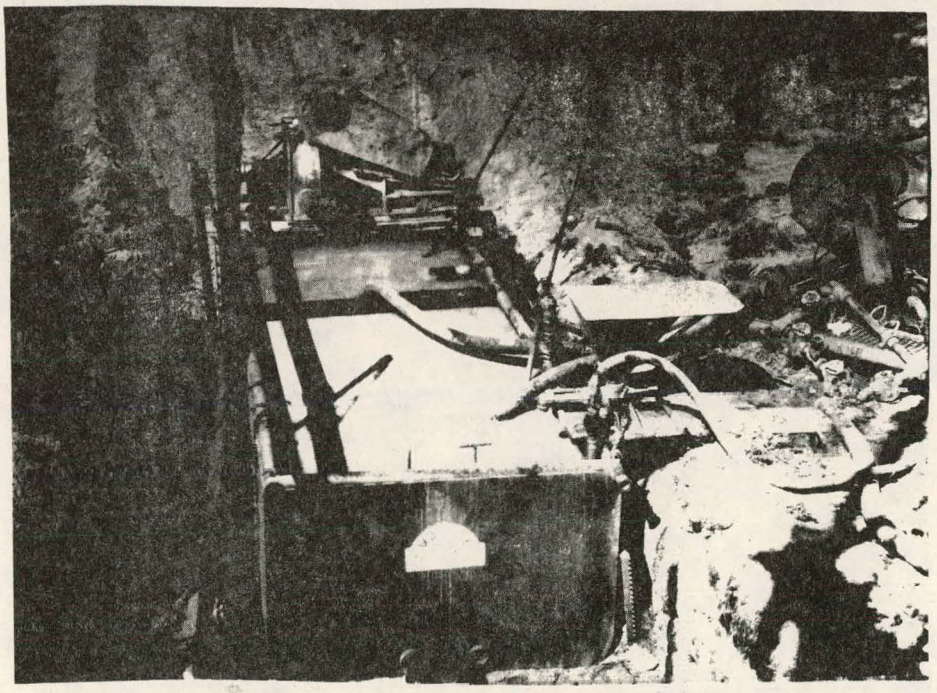


Figure A.3-7c

Figure A.3-7. Circulation System

The drill stem consisted of lengths of 30 feet long, 2 7/8-inch O.D. (4 7/8-inch tooljoints) drill pipe and up to eight drill collars; each 30 feet long, 5-inch O.D. and weighing 1550 lb. The drill collars made up the first eight joints above the bit (Figure A.3-8).

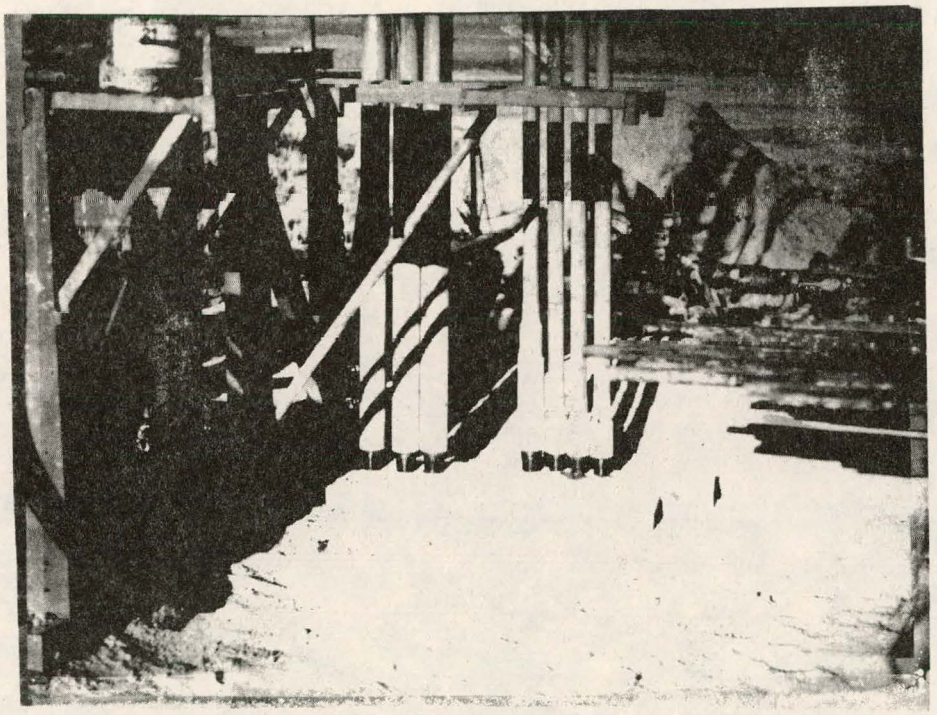


Figure A.3-8. Drill Collars

During the coring operations, a 30-foot long core barrel was added to the drill stem. The core barrel sleeve had 3 5/8-inch I.D. and held a 3 1/2-inch O.D. core. During the drilling of the second core hole, (CH-4) a 3 inch I.D. PVC liner was placed inside the core barrel to increase core recovery (Figure A.3-9), reducing the core diameter to 3 inches. In both holes plugging of the core barrel occurred infrequently, and full 30 feet lengths of core were obtained.

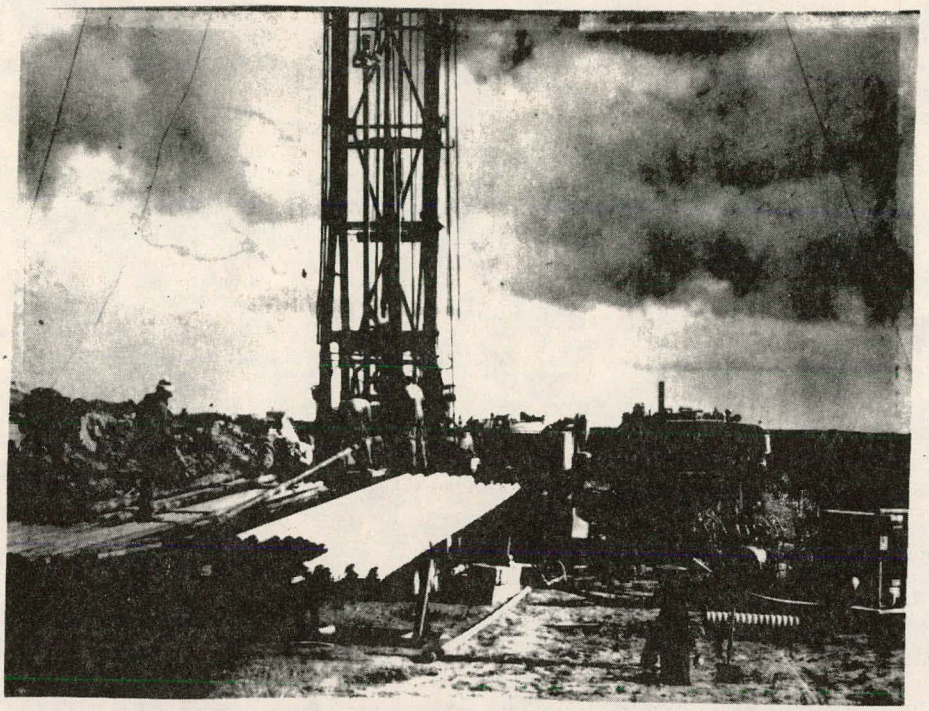


Figure A.3-9. PVC Liner

Two types of drill bits were used in the program:

Hole	Bit
Core Holes	6 1/2-in O.D., 3 1/2-in I.D. (CH-3) and 6 1/2-in O.D., 3-in I.D. (CH-4). Christensen diamond core bit with surface set diamonds. A soft formation core catcher was used (Figure A.3-10).
Non-Cored Wells	6-1/2 in O.D. Hughes J2 tri-cone roller bit with steel teeth. 3-10/32" nozzles were installed in the bit (Figure A.3-10).

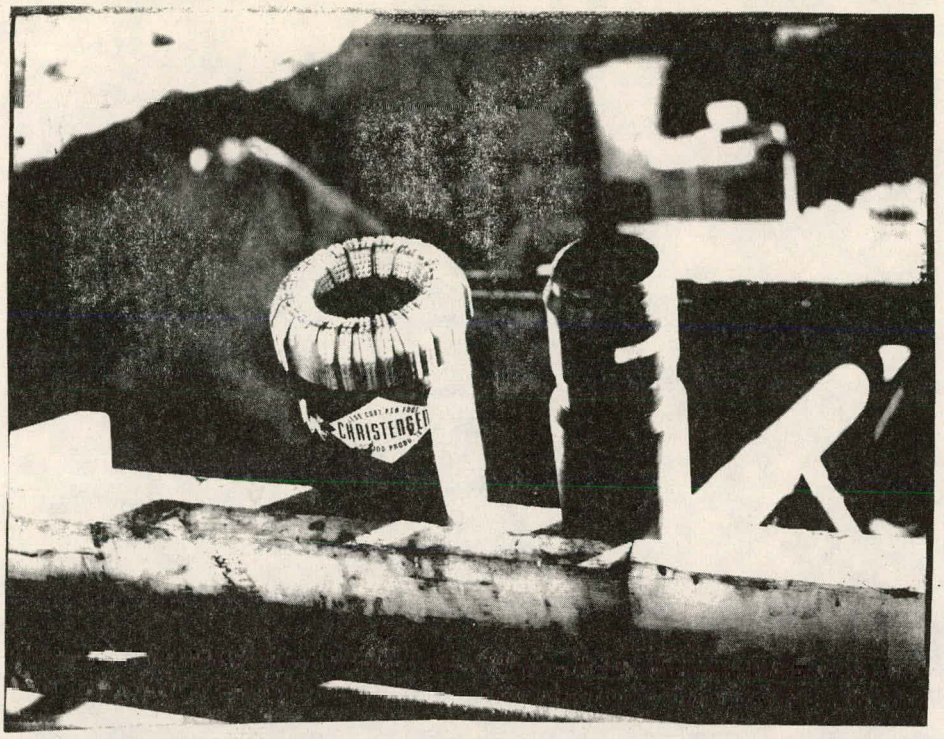


Figure A.3-10. Diamond Core Bit and Nozzles

The drilling crew consisted of a drilling supervisor, a tool pusher, a driller, a derrick man, and two helpers. In general, a 10 to 12-hr work day and a 6-day work week were used to complete the activities. The drilling work schedule generally consisted of:

	Activity	Amount of Time
1.	rigging up	1-2 days
2.	drilling the hole	1-10 days
3.	set production assembly	1 day
4.	wait on cement	1 day (off)
5.	drill out	1/2-1 days
6.	rig down	1-2 days

During the drilling, samples were collected as follows:

Hole	Sample Type
CH-1 & 2, H-7, 8, 9, 11, 12, 13	Drill cuttings at 10-foot intervals from the bottom of the conductor pipe to total depth

CH-3 and 4	Continuous core from bottom of the conductor pipe to total depth (CH-3 : 3 1/2-in O.D. core, CH-4 : 3-in O.D. core).

The drill cuttings samples were collected from the shale shaker at 10 feet intervals with a sieve, put in 3-inch x 4-inch cloth sample bags and labeled. After the samples dried, their compositional and textural characteristics were observed under a binocular microscope and recorded on core/description forms. The descriptive data were later plotted in the form of a graphic lithologic log and the drill cuttings were packaged for permanent storage in Rawlins.

Nominal 3 1/2 and 3-inch O.D. drill cores were obtained respectively from CH-3 and CH-4. The following procedure was used to handle and describe the core:

1. The inner core barrel was emptied either by standing the core barrel vertically against the drill floor, removing the core catcher and allowing the core to slide out, or by laying the core barrel down on the drill pipe stands and hydraulically forcing the core out of the liner.
2. The core was laid into a 32-foot long "V" shaped wooden core trough.
3. The core was photographed, measured and described.
4. The core was wrapped in plastic to avoid excessive drying, boxed in 3-foot long cardboard core boxes, and transported from the drill site to the office trailer.
5. The compositional, textural and bedding characteristics of the core were described with the aid of a hand lens and binocular microscope, and the data were recorded on the GR&DC core/cuttings description forms. The data was later plotted as a graphic lithologic log.
6. Samples were selected for compositional analysis and physical property testing and were packaged and shipped to a subcontractor as specified in the core analysis plan (see Section A.5, in this Appendix).

7. The remaining core was reboxed, labeled for storage (temporarily stored in Rawlins), and finally transported to Denver for permanent storage.

While drilling the second core hole (CH-4), a 3-inch I.D. PVC liner was added to the inside of the core barrel to increase core recovery and core handling efficiency. As a result, the core handling procedure was modified as such:

1. The inner core barrel was laid down on the drill pipe stands, and the core and PVC liner were manually removed. As it was removed, both core and liner were cut into 3-foot lengths with a 7 1/2-inch electric circular saw.
2. The 3-foot core sections were laid into the wooden core trough.
3. Two longitudinal cuts were made in each of the 3-foot sections of PVC pipe 180° to each other to expose the core.
4. The remaining steps in the handling procedure were the same as those outlined for CH-3.

A.3.3.1.2 Exploratory Holes (E_1-E_{27})

Twenty-seven exploration holes were drilled to locate the G seam subcrop and to define the extent of any subsurface natural burning in the facility area. These holes were drilled by the Red Desert Drilling Company with a truck mounted, diesel powered, MAYHEW 1000 drill rig equipped with a LEROI compressor (600 cu feet of free air at 125 psi maximum discharge) (Figure A.3-11). The drill stem was driven by a 20-foot long 2 7/8-in square kelly and, it consisted of 20-foot lengths of 2 7/8-inch O.D. drill pipe. A 4 3/4-inch O.D. drag bit with carbide inserts was used for the drilling. Air, water, and foam were used as circulating fluids depending upon the formation characteristics. Drill cutting samples were collected at 10-foot intervals and their compositional and textural characteristics were described.

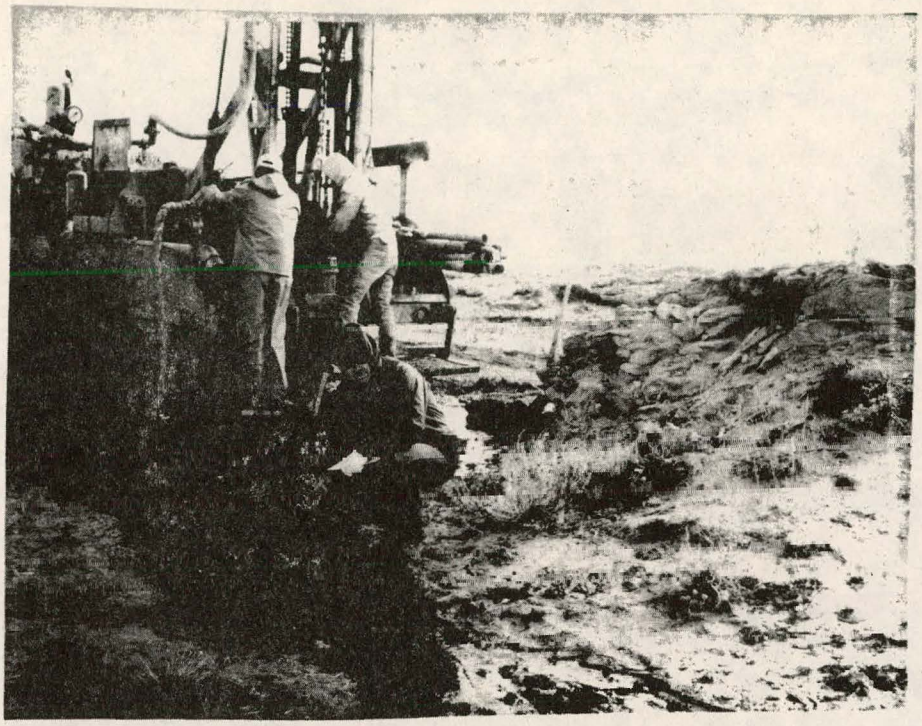


Figure A.3-11. Exploratory Hole Rig

A.3.3.1.3 Soil Augering Holes

Seven holes were drilled to determine the depth of soil cover on top of the G coal seam. These holes were drilled with a truck mounted, gasoline powered SIMCO drill rig with a 3 1/2-inch diameter 8-foot long helical auger (Figure A.3-12). Lengths of drill stem could be added so that depths of 30 feet could be reached with the rig. No circulating fluids were used during this drilling operation. Samples were collected at 3-foot intervals, classified, and described for analysis. The drilling was performed by Robert Jack Smith and Associates.

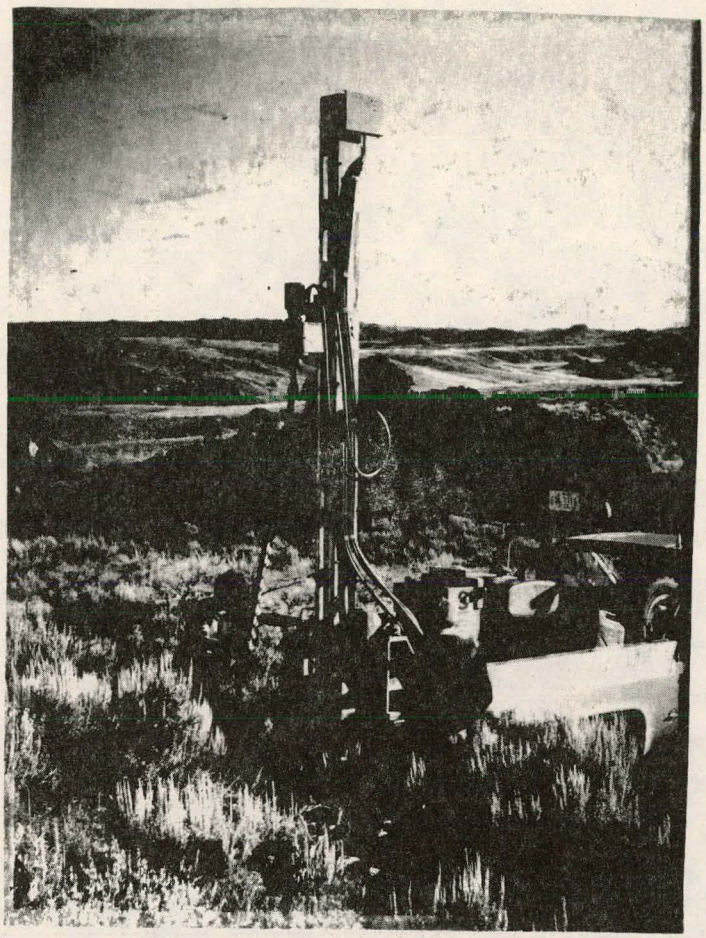


Figure A.3-12a

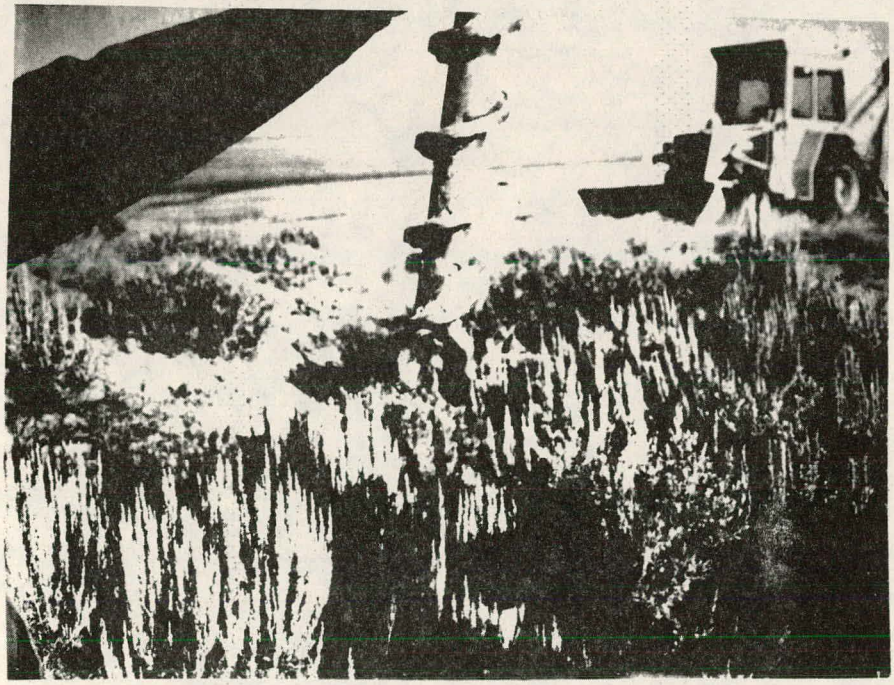


Figure A.3-12b

Figure A.3-12. Soil Augering Drilling

A.3.3.2 Drilling Data

A.3.3.2.1 Core/Hydro Observation Holes

The data obtained from the hydrologic observation well drilling program consisted of the core and cutting samples and descriptive summary data. Included in the summary data are the Master Drilling Plan Map (See Figure B-46 in Appendix B) which illustrates the locations of the core, hydrologic observation, and anchor bolt holes; the Master Drilling Schedule Table (See Table B-1 in Appendix) which indicates when the drilling activities occurred, the core recovery data (Tables A.3-1 and 2), and sets of descriptive drilling/completion/lithologic/geophysical data for each of the 12 hydrologic observation wells. The data package for each well includes:

1. A well location map.
2. A summary drilling schedule table which indicates when the drilling activities for each well occurred.
3. A core/cutting handling description which indicates the kind and type of sample collected, when the sample was packaged, where the samples are stored, and what samples were shipped from the site for chemical analysis.
4. A geologic description of the cores and cuttings.
5. A graphic lithologic log at a vertical scale of 1 in = 27.5 ft.
6. Geophysical logs which include caliper, gamma ray, gamma-gamma density, resistivity and temperature logs.
7. Drift survey data. This includes the raw drift data, the converted data, and a seam view map of the hole.
8. A summary table of the well completion statistics.
9. A well completion diagram illustrating where the hydrologic observation zone was installed.
10. Drilling rate data including the geolograph and a drilling rate graph.

Most of this data are presented for Core Holes 3 and 4 in Appendix B as B-48 and B-49.

WELL NUMBER: CORE HOLE 3

1. Samples collected at intervals of:

DAY	RUN	INTERVAL	BOX NO.'S	TOTAL DRILLED	CORE RECOVERED
8-02	1	36-50.0	1-4	14.5	12.0
	2	-62.0	5-8	12.0	12.0
8-03	1	-90.0		28.0	28.0
	2	-110.0	28-31	21.0	21.0
8-04	1	-131.0	32-40	20.0	20.0
	2	-160.0	41-53	29.0	29.0
8-05	1	-183.0	54-63	23.0	21.0
	2	-211.0	64-73	28.0	28.0
	3	-239.0	74-82	20.0	20.0
8-07	1	-256.0	83---	17.0	8.0
	2	-278.0	---94	22.0	21.5
	3	-308.0	95-102	30.0	30.0
	4	-331.0	103-109	23.0	22.5
8-08	1	-361.0	110-120	30.0	30.0
	2	-391.0	121-126	30.0	22.0
	3	-403.0	127	12.0	3.0
8-09	1	-421.0	128----132	19.0	13.0
	2	-425.0	133	3.0	3.0
8-10	1	-453.0	134-143	28.0	28.0
8-11	1	-475.0	144-151	23.0	23.0
	2	-494.0	152-157	18.0	18.0
8-12	1	-513.0	158-163	19.0	19.0
	2	-543.0	164-173	30.0	28.0
8-13	1	-573.0	174-185	30.0	30.0
				529.5	490.0

Core Recovery Percent = 92.5%

Table A.3-2

WELL NUMBER: CORE HOLE 4

1. Samples collected at intervals of:

DAY	RUN	INTERVAL	BOX NO.'S	TOTAL DRILLED	CORE RECOVERED
8-19	1	36-61.0	1-08	25.0	22.0
	2	-89.0	9-19	28.0	27.0
	3	-113.0	20-23	24.0	12.0
8-20	1	-136.0	24-27	23.0	11.5
	2	-148.0	28-31	12.0	10.5
8-21	1	-165.0	32-36	17.0	12.0
	2	-195.0	37-46	30.0	28.0
	3	-202.5	47-49	7.5	6.0
	4	-228.0	50-57	25.5	21.5
8-22	1	-258.0	58-64	30.0	22.5
	2	-288.0	65-75	30.0	30.0
	3	-316.0	76-85	28.0	27.0
8-23	1	-346.0	86-95	30.0	28.5
	2	-374.0	96-106	30.0	27.0
	3	-390.0	107-111	16.0	13.5
8-24	1	-420.0	112-122	30.0	30.0
	2	-449.0	123-133	29.0	29.0
	3	-467.0	134-140	18.0	18.0
8-25	1	-497.0	141-151	30.0	30.0
	2	-516.0	152-158	19.0	18.0
	3	-536.0	159-165	20.0	19.0
8-26	1	-566.0	166-176	30.0	30.0
	2	-596.0	177-187	30.0	30.0
				562.0	503.0

Core Recovery Percent = 89.5%

A.3.3.2.2 Exploration Holes (E_1-E_{27})

Data obtained from the exploration hole drilling program consisted of a Master Drilling Plan Map which illustrates the location of the holes (Figure B-46 in Appendix B), drill cutting descriptions for each of the holes, and gamma ray and resistivity logs for most of the holes. Cuttings samples were packaged or stored for later analysis.

A.3.3.2.3 Soil Augering Holes

The data obtained from the soil augering program consisted of a soil drilling record and geophysical logs for three of the holes. None of these samples were packaged or stored for later analysis.

A.3.4 GEOPHYSICAL LOGGING

A suite of six geophysical logs each run in each drill hole. These were:

1. Gamma ray log - indicates the natural radioactivity of rocks and provides lithologic information about the drilled section of rock.
2. Gamma-gamma density log - indicates the porosity of the formation and is used for the lithologic interpretation with the gamma ray and resistivity log.
3. Resistance log - indicates the presence of fluids in the rock formation and further validates the lithologic interpretation of the gamma ray and gamma-gamma density logs.
4. Temperature Log -
5. Drift Survey log - indicates vertical deviations in the borehole so that the location of the hole can be accurately located in the subsurface.
6. Caliper log - indicates the diameter of the boreholes and helps identify large cavities and washouts in the drill hole.

A.3.4.1 Procedures

Logs were run in the hydrologic observation holes by Nuclear Logging Services. At approximately one-half projected total depth, a drift survey log, a gamma-ray log and a resistance log were taken. Immediately after reaching total depth, logs were run as follows:

Run	Log
1 - down	None
1 - up	Caliper
2 - down	Gamma ray
2 - up	Resistance
3 - up	Gamma-Gamma density
4 - down	Drift Survey
4 - up	None

One week after the well was completed, temperature and gamma-gamma density logs were run.

After the exploration and soil augering holes were drilled, gamma ray and resistance logs were run.

The logging equipment was mounted in a panel truck and consisted of a winch, 3/16-inch armored conductor cable, electronic processing modules, a strip-chart recorder, and the probes. Descriptive data for the probes included:

Probe	Characteristics
Caliper	Hole variations from 3 to 16 inches on diameter; log run at 10 ft/min; log scale set at 10 in (1 in = 1.4 in).
Gamma ray	Standard gamma scintillation counter log run at 20 ft/min; log scale set at 5 in with 150 counts/sec/in and at a time constant of 4.
Resistance	Single point resistance; log run at 10 ft/min, log scale set at 1 in = 50.
Gamma-gamma density	Log-spaced (16 in) density tool with a Ce-137 radioactive source; log run at 5 in with 1K-.373 counts/sec. and 2 times constant of 2 while in water, and with 10K-.757 counts/sec. and a time constant of 2 while in air.

Temperature	Thermistor sensor; log run at 10 ft/min log scale set at 1 in = 2°F.
Drift	Digital drift tool attached to a computer Capable of providing a continuous read-out; tangential method of drift analysis used; readings taken at 50 ft intervals.

The logging equipment was serviced and operated by a single operator (Figure A.3-13).

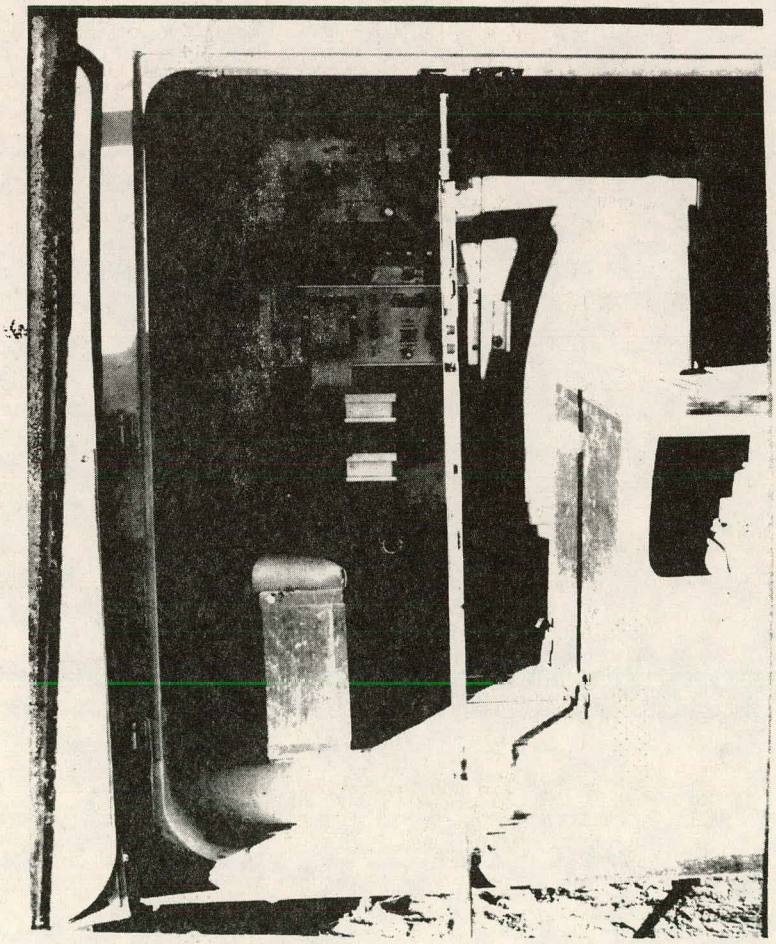


Figure A.3-13a

Logging Equipment

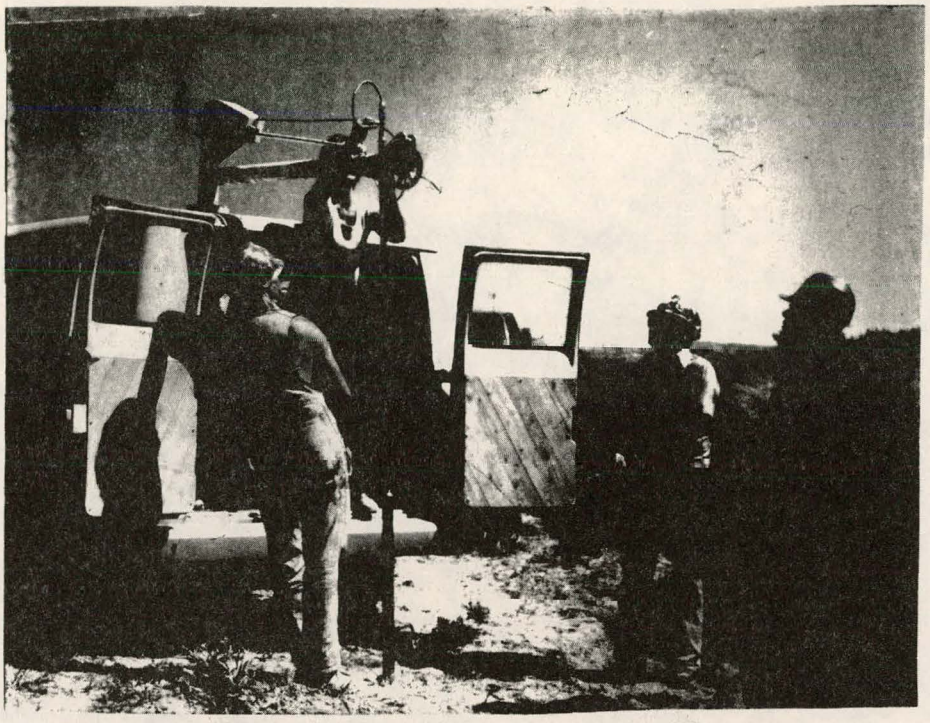


Figure A.3-13b

Figure A.3-13. Logging Equipment

For each set of runs, the logs were plotted on standard 10-inch wide strip-chart graph paper as follows:

Graph Number	Types of Logs
1	Caliper
2	Gamma ray, gamma-gamma Density, resistance
3	Temperature

Vertical scale for the logs was 1 in = 10 ft and the horizontal scale varied depending on the log being run.

The drift data was printed on a standard 3-inch wide paper roll.

A.3.4.2 Data

The data from the geophysical logging activities consisted of the sets of paper logs run in each of the holes. These data are included for Core Holes 3 and 4 in Section B-48 and 49 of Appendix B.

A.3.5 WELL COMPLETION

The well completion design required allowing a hydrologic communication with an interval of the drill hole, while sealing off the rest of the hole and maintaining a communication between the open horizon and surface through a casing pipe. The completed wells were used to determine the permeability of the rock formation in hydrologic tests and for collecting water samples from specified horizons in the drill holes. The hydrologic observation zones were designed as follows:

Well	Zone Installed In
H7, H8, H9, H12, H15, P-1	G coal (G_{mc})
H11	Aquifer above G coal
H13	Aquifer below G coal

A.3.5.1 PROCEDURES

Well completion procedures consisted of the following steps:

1. Drill hole to total depth. Total depth was always a minimum of 25 feet below the bottom of the G coal seam.
2. Circulate water for 15-20 minutes.
3. Remove the drill pipe from the open hole.
4. Run the suite of geophysical logs in the open hole.
5. Set the lower cement plug. This was done by:

    - Determining the location of the top of the lower cement plug on the gamma ray/gamma-gamma density/resistance log. This depth was generally 20 feet below the middle unit of the middle G coal bench.

- Calculating the volume of cement that would be needed for the lower cement plug from the caliper log. A 20-50% excess was usually added.
- Lowering the drill pipe into the hole to toal depth and then lifting up 2 to 5 feet.
- Injecting the cement through the drill stem. The cement was mixed and pumped into the well by Haliburton and it was a light-weight (13.6 lb) cement loaded with bentonite to increase its filler capacity.
- Lifting the drill stem to approximately 5 feet above the design depth of the lower cement plug and circulating 10-20 barrels of clean water. This was done to wash the observation zone.
- Remove the drill stem from the hole.

6. Construct the production assembly. The production assembly consisted of:

- A Johnson stainless steel well screen (Figure A.3-14). The well screen characteristics were:
  - length - 6 feet for all wells; except P-1 which had a 30-foot screen.
  - diameter - 3 inches for H-15, CH-1, CH-2, CH-3, CH-4; 4 inches for H-7, H-8, H-9, H-11, H-12, H-13, and P-1.
  - slot size = 0.026 inch at 0.04-inch intervals.
- A solid aluminum disc (either 3 or 4-inches in diameter), 1-inch thick, and fitted with a 1/8-inch rubber O-ring.
- A 2-foot steel cementing sub. The sub was either 3 or 4-inches in diameter and it had four 1-inch holes drilled on 8-inch centers staggered at 180°.
- A (Weatherford-Lamb steel cement basket) cement basket attached to the bottom of the cementing sub; H-15 and H-12, utilized a Haliburton canvas cement basket (Figure A.3-15).

- An aluminum disc with a 1-inch hole drilled in its center. The disc was either 3 or 4 inches in diameter and 1 inch thick.
- 3 or 4 inch I.D. steel casing from the top of the cementing sub to the surface. The casing lengths were approximately 30 feet.
- 4-1/2 inches long drill collars at each joint.
- Steel bow-spring centralizers. The first centralizer was set just above the cement sub on the first casing length and one was added on every third casing length. The well screen, cementing sub, cement basket, and the first centralizer were welded to the connecting drill collars (Figure A.3-16). However, no welding was done on other connecting joints or centralizers.

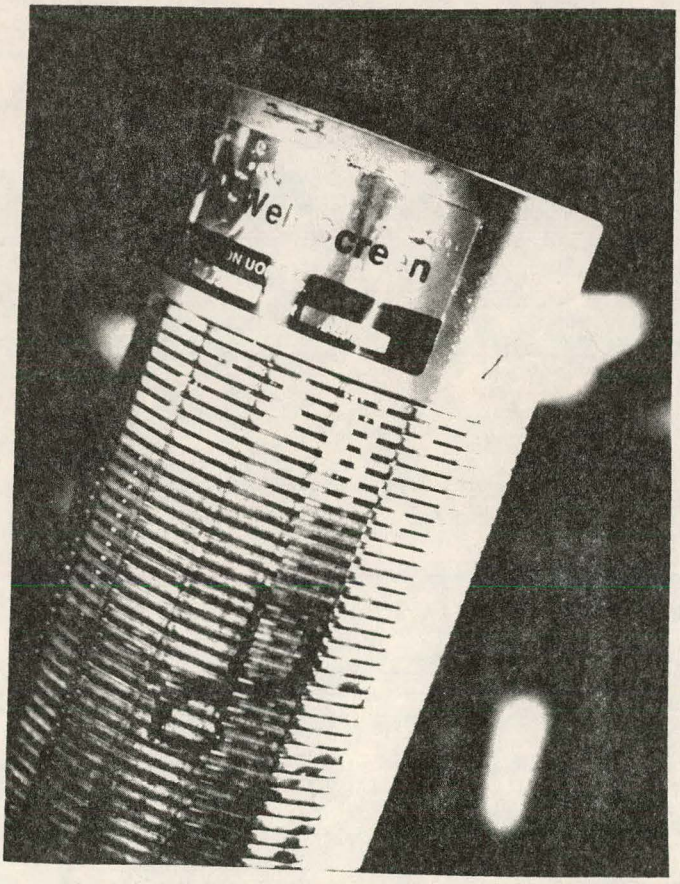


Figure A.3-14. Johnson Well Screen

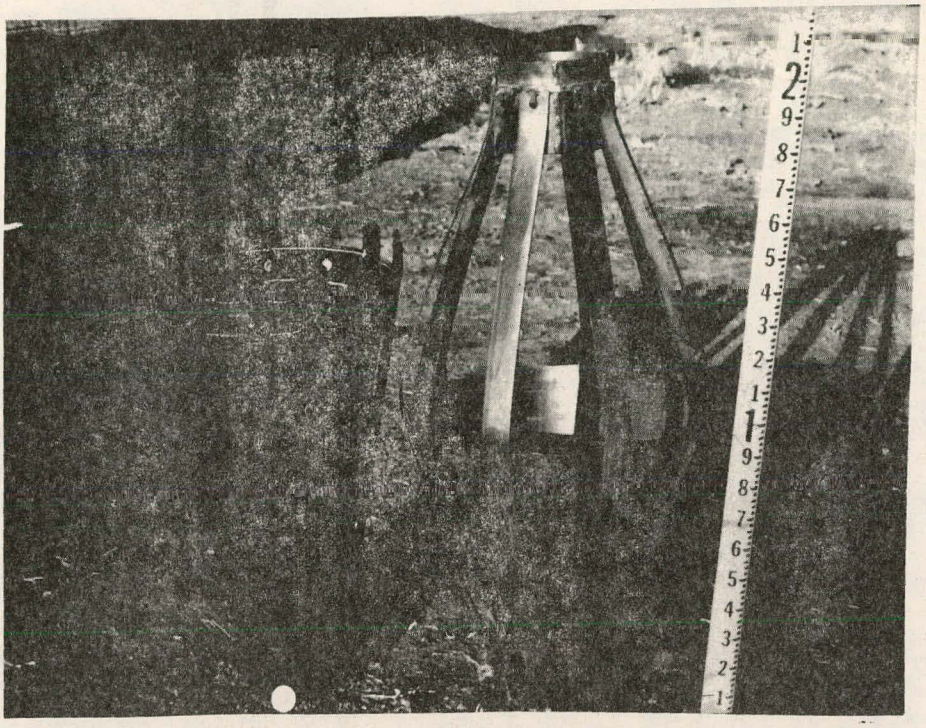


Figure A.3-15. Cement Basket

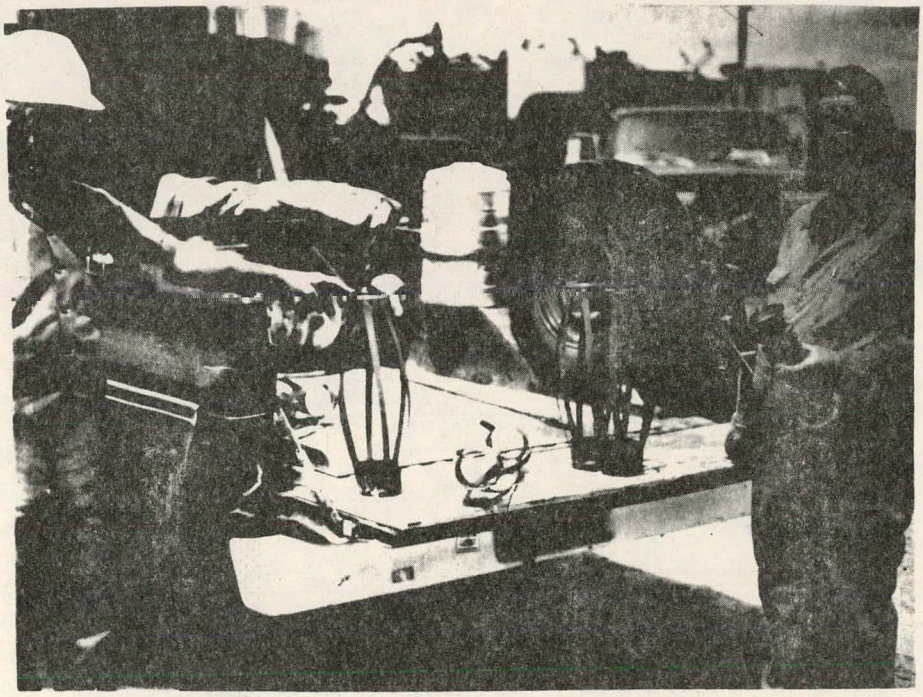


Figure A.3-16. Centralizers

7. Set the production assembly. The production assembly was lowered into the hole by making up a casing length at one time. The bottom of the well screen was set at a depth of 5 feet above the design depth of the top of the lower cement plug (Figure A.3-17).

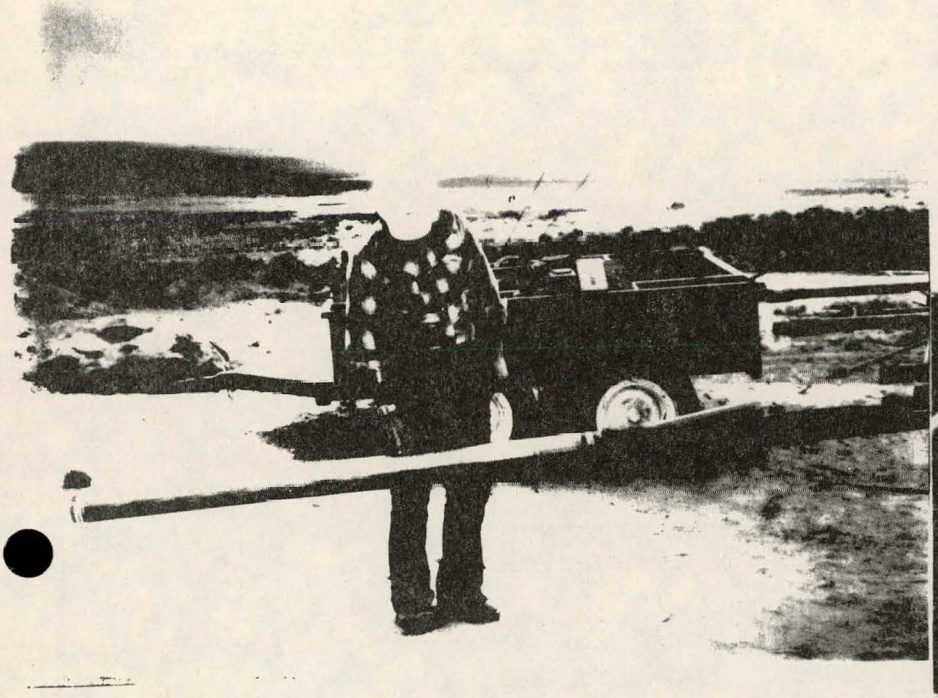


Figure A.3-17a

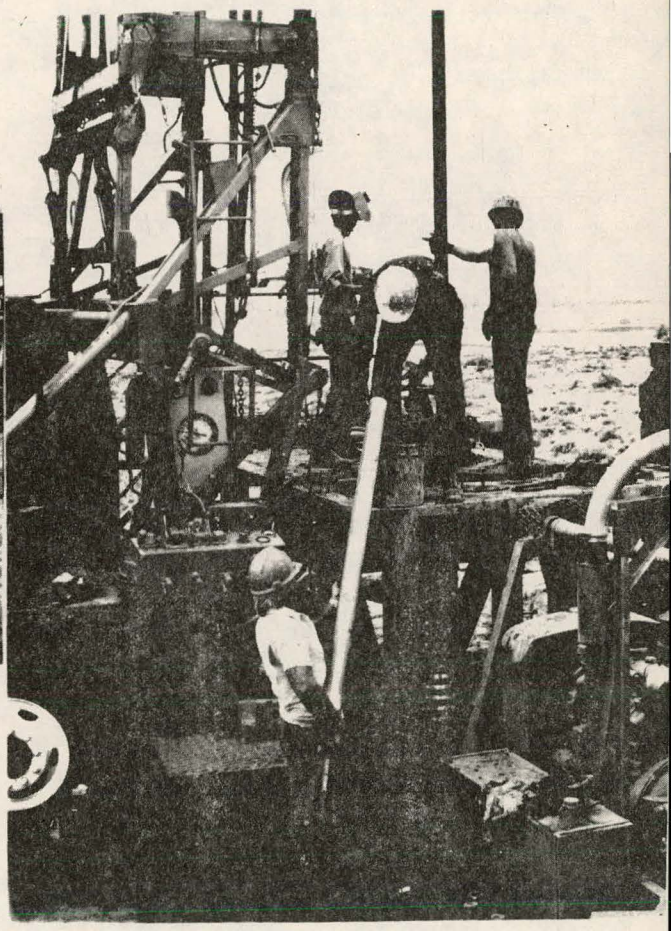


Figure A.3-17b

Figure A.3-17. Lowering the Production Assembly

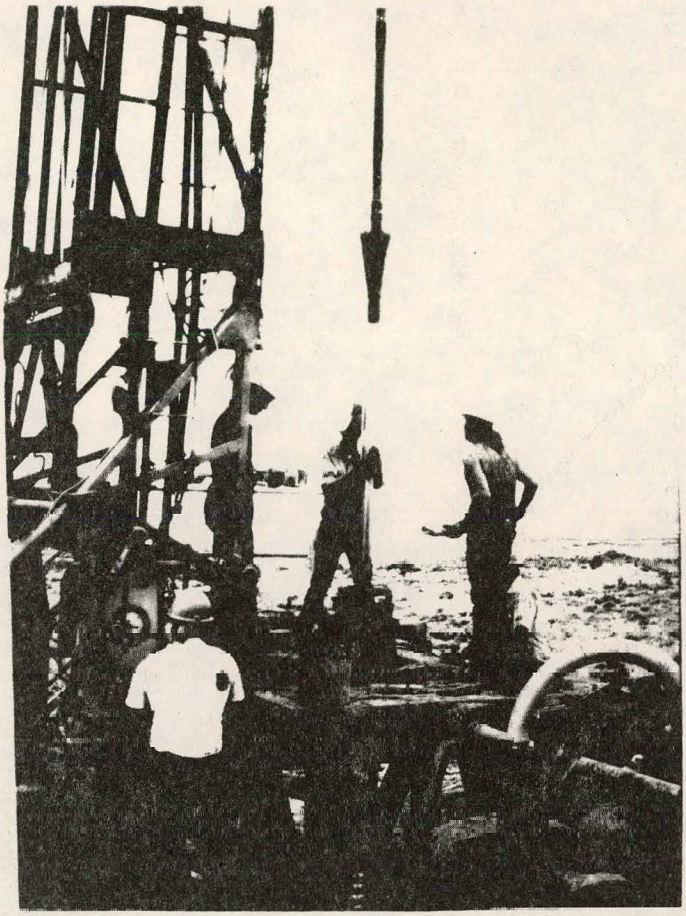


Figure A.3-17c

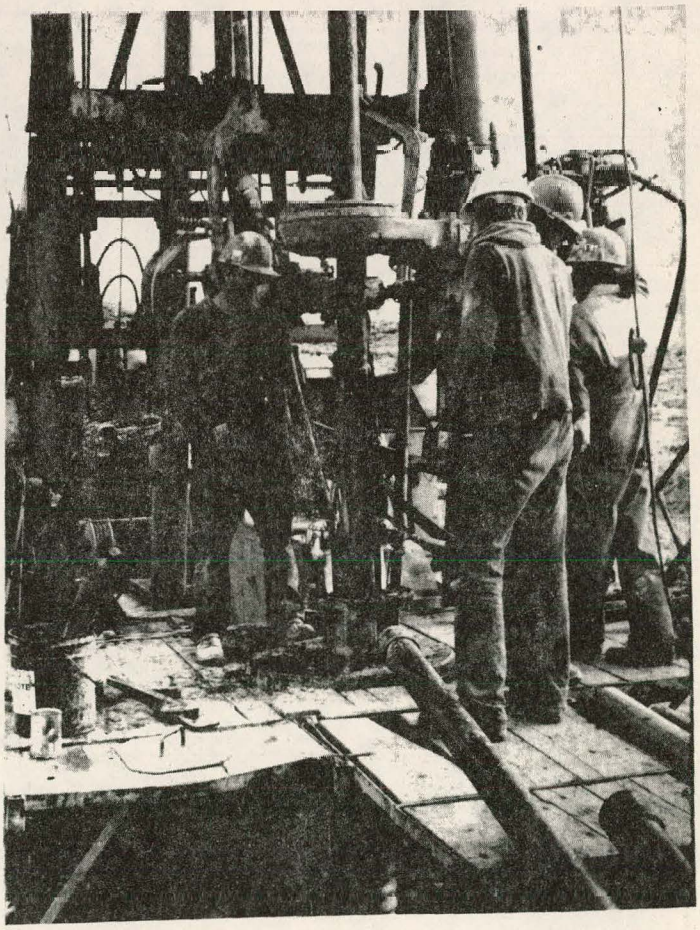


Figure A.3-17d

Figure A.3-17. Lowering the Production Assembly (cont'd.)

8. Set the upper cement plug. The upper cement plug was set by:

- Calculating the volume of cement that would be needed to fill the hole annulus using the caliper log. A 20-50% excess was used.
- Injecting the cement through the production assembly. The cement was mixed and pumped into the well by Haliburton. The same light weight (13.6 lb) cement was used (Figure A.3-18).
- Displace the cement to the surface. After all of the cement was pumped into the casing, a rubber cement plug was placed in the top of the casing string and water was pumped into the casing to displace the rubber cement plug and cement. The rubber plug was used in completing the first five wells. In the last nine wells only water was used to displace the cement in the casing. In these holes, the aluminum disc with the 1-inch hole was also removed from the production assembly.

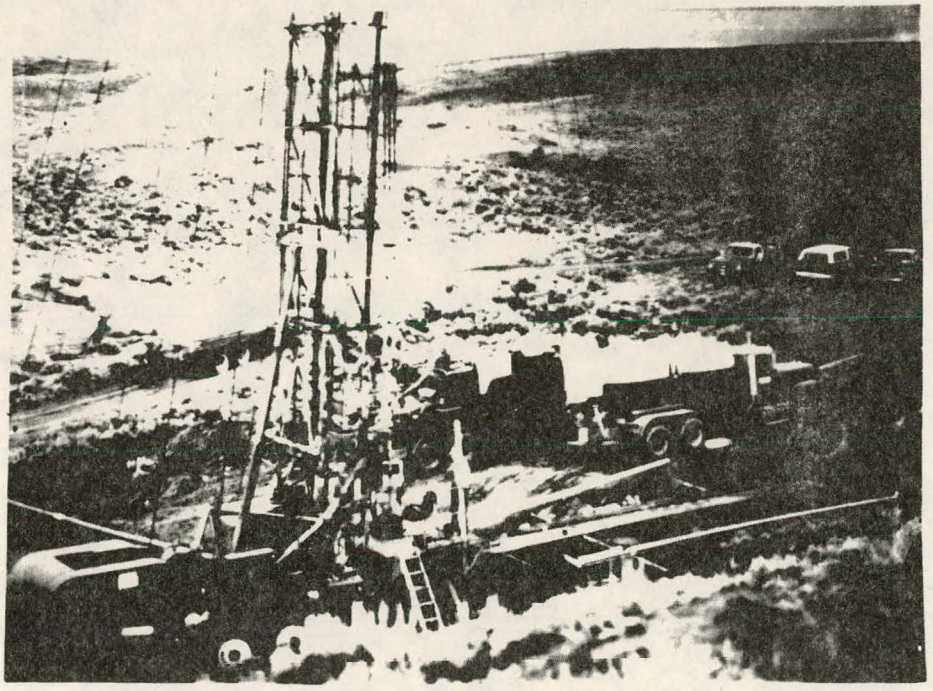


Figure A.3-18a
Injecting Cement

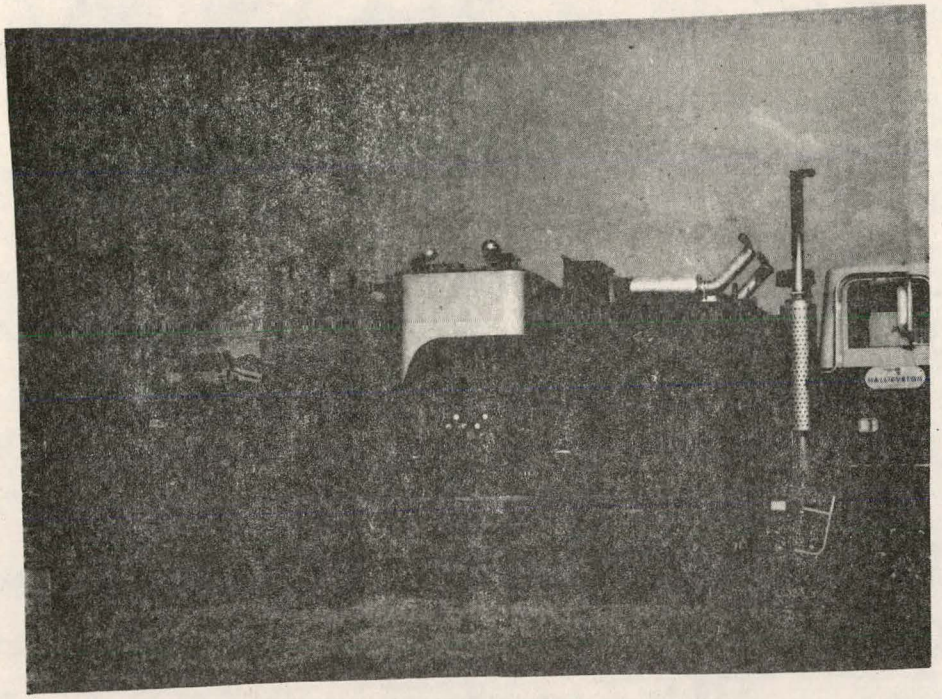


Figure A.3-18b

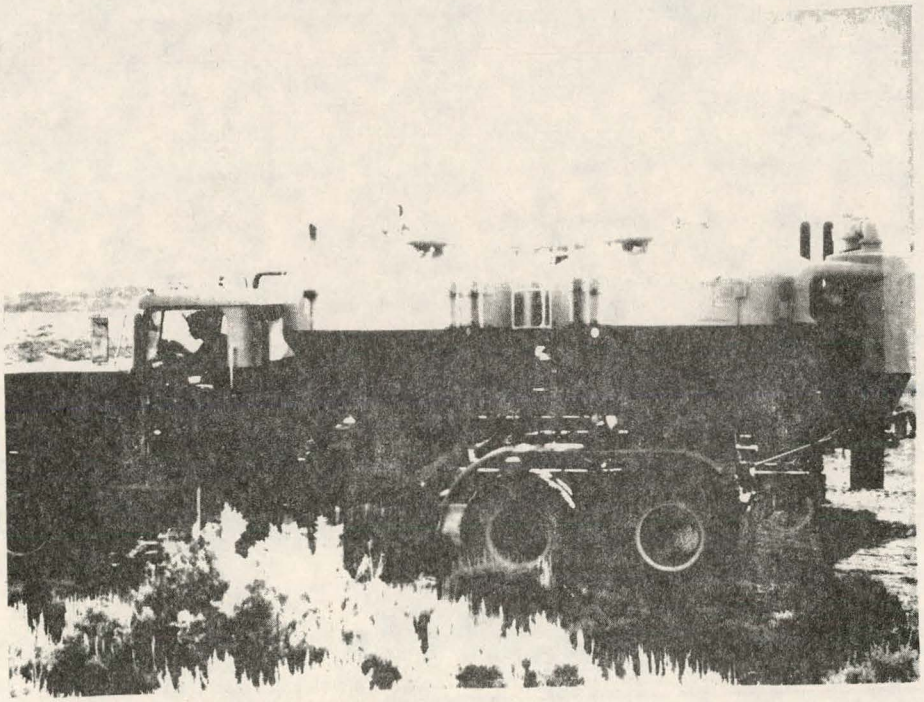


Figure A.3-18c

Figure A.3-18. Injecting Cement

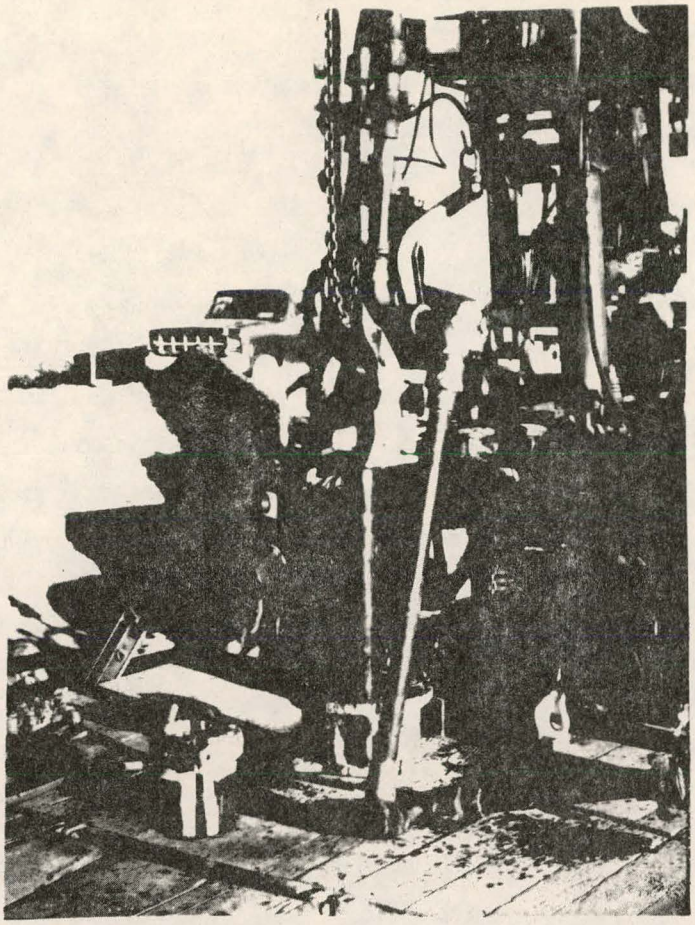


Figure A.3-18d

Figure A.3-18. Injecting Cement

9. Wait for the cement to set. A 24 hr time period was allowed for the cement in the lower and upper cement plugs to set. Minimal setting time was allowed between installing the lower cement plug and production assembly and upper cement plug.
10. Drill out the cement wiper plug and aluminum discs. A 2 7/8 or 3 7/8-inch carbide drag bit and 1 1/2-inch and 2-inch drill tubing were used to drill out both the rubber plug and aluminum discs. Because of the difficulty in drilling out the rubber cement plugs, it was not used to complete the last nine wells. This difficulty arose from either the plug spinning in the hole as the bit rotated on it, or not being able to cut the plug since weight could not be added to the drill stem due to the shallow completion depth.

11. Circulate water in the hole. The drill bit was lowered until it touched the bottom of the well screen and clean water was circulated for 15-20 min.
12. Remove the drill stem from the hole.
13. Install the surface well head. Installation procedures consisted of:
    - cutting off the conductor pipe even with the ground.
    - filling up conductor pipe with cement to the ground surface.
    - cutting off the casing 18 inches above the ground.
    - threading the end of the casing.
    - placing a cap on the casing. The cap was a drill collar with a steel plate welded on one end.
    - welding pieces of chain to the casing and cap.
    - placing a lock on the well head.
    - painting the well head florescent orange (Figure A.3-19).

The well completion procedure was successful for all wells except H-12. When drilling out H-12, the drill bit did not drop to the bottom of the well screen after it drilled through the solid aluminum disc. After penetrating the disc, solid cement was encountered in the wellscreen; therefore, it was assumed that the canvas cement basket had failed and allowed cement to surround and infill the well screen. In order to salvage H-12, the following steps were taken:

1. the cement in the well screen was drilled out.
2. the hole was perforated with a 4-foot long, 3 1/8-inch diameter 24-shot, gun perforator. This service was provided by Wellex (Figure A.3-20).

A.3.5.2 Well Completion Data

Data generated for the well completion program included:

1. well completion tables for each well.
2. well completion diagrams (For example see B-48 and 49, Core Holes 3 and 4 Data Packages in Appendix B).

Figure A.3-19. Well Head

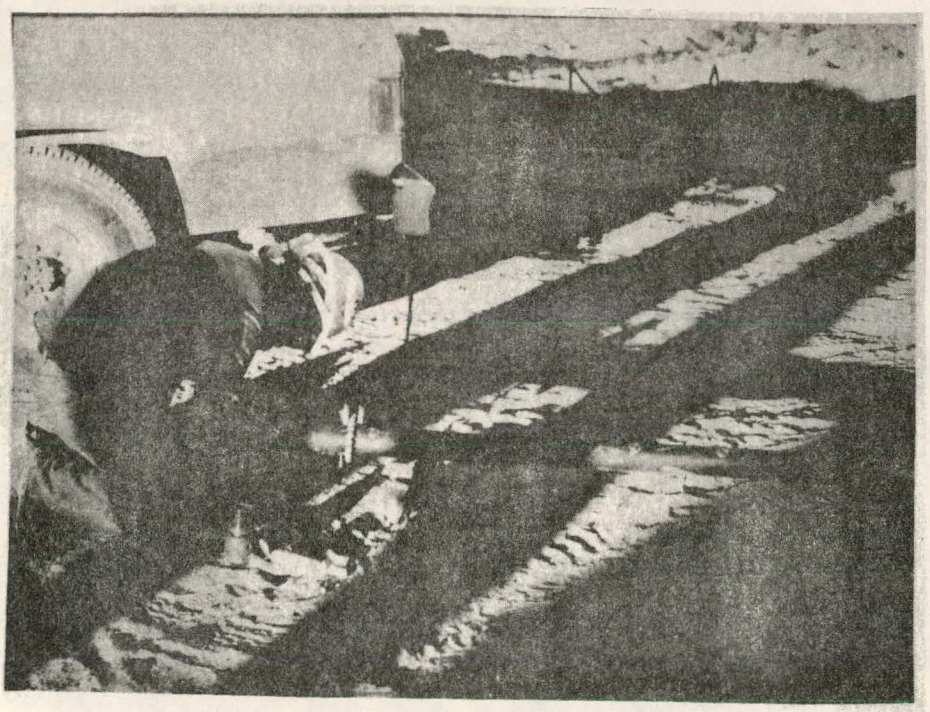


Figure A.3.20a. Perforating the Well

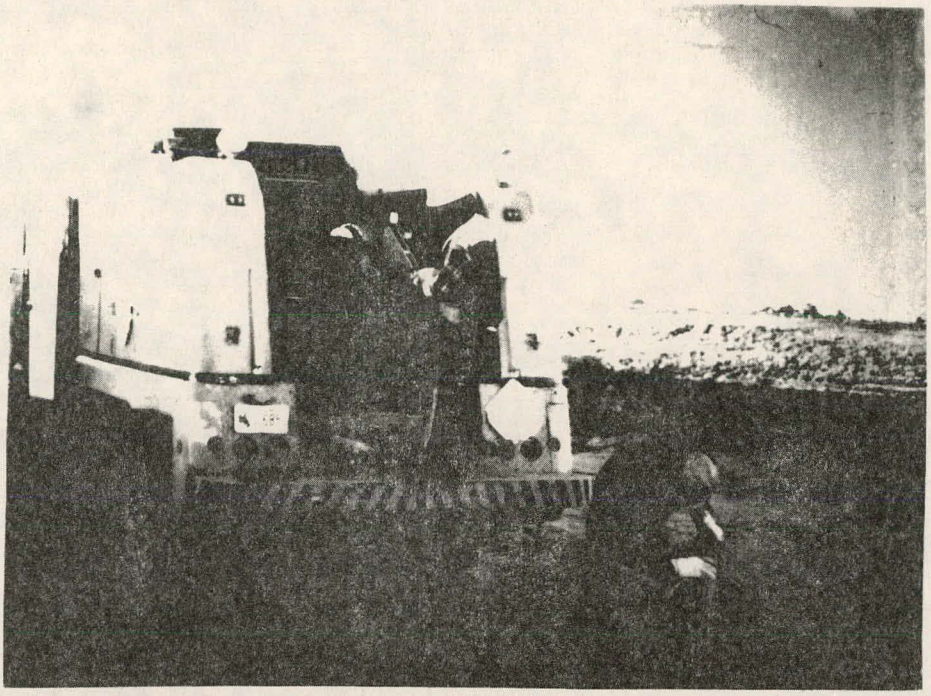


Figure A.3-20b. Perforating the Well

A.3.6 WELL DEVELOPMENT

After the wells had been completed, they stood idle for periods of 30 to 120 days. During this time, periodic water-level measurements were taken in the wells to establish the steady state natural potentiometric surface representative of the ground water in the G coal seam. After review of this data, it was concluded that the data did not accurately represent the true potentiometric surface in the coal seam. This may have been a result of:

- "Mudding up" the formation during drilling and cementing.
- Density stratification of the water in the drill hole. This could have resulted from having brine water, drill cuttings, or cement slurry influxing into the bottom of the casing from the formation. In all cases, the lower density fresh water in the

formation would not displace any water, sediment or brine in the casing.

- Poor completion methods.

To resolve this problem and insure that representative water samples would be collected for baseline monitoring, it was decided that development activities should be undertaken for all wells. These activities consisted of determining the pre-development water level in the wells, cleaning out the wells, and restoring the water levels to their pre-development levels.

A.3.6.1 Procedures

All water level reading in the wells were measured manually with a hand-held, battery-operated, water level indicator with a probe and a 500-foot cable. All measurements were taken from the tops of the casing wellheads, and the water level depths were recorded to the nearest 0.1 foot. A steel tape measure was used to measure distances on the probe cable between the 5-foot markers. The water level depth readings were later converted to elevations of the pressure surface.

The development plan for cleaning the wells initially was to:

1. Measure the water level in the well.
2. Lower a submersible REDA pump to within 2-5 feet of the bottom of the well screen.
3. Pump out the casing water.
4. Wait for a recharge to occur.
5. Pump out the casing water.
6. Refill the well with water to the pre-development level.
7. Monitor the water level and refill (or blow-out) as necessary until the well maintained the pre-development level.

Steps 1 and 2 of this procedure were implemented on H-13, CH-1, and CH-3. In all three wells, the casing water near the bottom of the well screen had an extremely high amount of fine-grained suspended solids and the high

concentration of this material inhibited the proper operation of the REDA pump. Consequently, the procedure had to be modified to:

1. Measure the water level in the well.
2. Lowering an open ended drill pipe (2 to 2 1/2-inch O.D.) to within 2-5 feet of the bottom of the well screen.
3. Flushing out the casing with clean water. This consisted of pumping 10-15 barrels of clean water down the pipe to displace the casing water to the surface and waiting 15-20 min. This procedure was repeated two more times. Thus, a total of 30-50 barrels of clean water were flushed through the casing and well screen.
4. Remove the drill pipe from the well.
5. Monitor the water level in the well.
6. Restore the water level to its pre-development level. If the post-flushing level was above the initial level, water would be blown out of the well, if it was below the initial level water would be added to the well.
7. Monitor the water level and adjust it until it maintained the pre-development level.

Because of scheduling constraints, this procedure was performed by two contractors; Ford's Water Well Service, Inc., and the Red Desert Drilling Company.

The equipment used by Ford's Water Well Service included:

- A Smeal truck to run the pipe in and out of the well.
- A 2-inch I.D. steel line pipe.
- A Halliburton pumper truck to pump the water into the casing.
- A 150-barrel water truck to supply water for the flushing.

The equipment used by the Red Desert Drilling Company included:

- A Mayhew/1000 drill rig to run the pipe in and out of the well.

- A 2 7/8-inch O.D. pipe.
- A 150-barrel water truck to supply water for the flushing.

The flushing work was performed by Ford's Water Well Services, Inc. on H-7, H-11, H-12, H-13 and P-1; the Red Desert Drilling Company flushed H-8, H-9, CH-1, CH-2, CH-3 and CH-4. Well H-15 was not flushed by this procedure. In all wells, a relatively clean return water was observed coming from the casing after pumping the first 10-15 barrels.

Well H-15 was flushed by lowering a 1/2 inch O.D. copper tubing to within 2-5 feet of the bottom of the well screen, installing a cap with an inject and a discharge valve on the well head, and injecting nitrogen through the cap and down the annulus between the casing and the copper tubing. Halliburton Services supplied the nitrogen for flushing this well.

A.3.6.2 WELL DEVELOPMENT DATA

The data collected during the development work consisted of the pre- and post-development water levels in the wells and a field log of activities associated with the development work. Only the pre- and post-development water level readings are included in this report and they are presented in the Hydrology section of this Appendix, A.6.

A.3.7 SITE RESTORATION

Site restoration activities were undertaken to restore the drilling sites to their original conditions. To complete this task, the following steps were taken:

1. All drilling equipment was removed from the site.
2. The mud pits and drill pads were recontoured (by Withrow Construction with a D6 bulldozer).
3. The exploration trenches were refilled.
4. All miscellaneous debris was picked up and removed from the site.

The anchor bolts were left installed in the ground, and the exploration and soil auger holes were left open. These holes will be cemented.

Access roads to the wells will be recontoured when all hydrologic testing is complete. No revegetation activities were begun at this time but they will be undertaken at the termination of this project.

A.3.8 SUMMARY/CONCLUSIONS

The following activities were accomplished in the drilling phase of this project:

1. Subsurface samples (drill cuttings, drill core, and geophysical logs) of the rock strata on the facility were obtained for analysis.
2. Hydrologic observation holes (12 total) exploration holes (27 total), and soil augering (7 total) holes were drilled on the facilty.
3. Operational drilling information was obtained for the penetrated formations.
4. Hydrologic observation zones were installed in the G coal seam and in aquifers adjacent to the coal.
5. Well development activities removed drilling debris and brine solutions from the observation wells.
6. Drilling sites were constructed and recontoured.

Conclusions of the well installation activities are as follows:

1. Adequate samples were obtained from the facility for defining its subsurface geology, and for conducting chemical analysis and physical property testing.
2. Core recovery rates were in excess of 90%.
3. The use of the PVC liner during coring increased the core handling efficiency.
4. Excessive sample deterioration did not occur as a result of the surface handling procedures used to process the samples.

5. Good lithologic definition was observable on the geophysical logs.
6. Lithologic correlation was possible between the drilling, sample and geophysical logs.
7. The hole deviation surveys adequately located the drill hole path in the subsurface.

A.3.8.1 Drilling Operations

1. The rotary equipment and methodologies used were adequate for the program needs.
2. Percussion equipment and methodologies probably would not have been as efficient due to the "soft" character of the formations; and due to the presence of wet formations.
3. Drilling rates varied significantly from a low of 8 ft/hr during coring to a high of 60 ft/hr.
4. The best non-coring drilling rates were obtained using:
   a.) A Hugh's J-2 bit with 10/32" nozzles
   b.) A pumping rate of 135 gpm
   c.) An average drilling speed of 120-160 rpm
   d.) 8 drill collars (total weight of 12 000 lb)
5. Hole deviations ranged from 5-55 ft at total depth.
6. Hole deviations were generally oriented to the northeast ("updip"). The drift direction is probably a function of lithology, dip direction, bedding orientation in the formations, and bit rotation direction.
7. The exploration/water well drill/rig (with mechanical pulldown and drill collars) should be used when the bottom hole placement of drill holes is not critical.
8. Except for one section of H-15, excessive water loss to the formations during drilling was not a problem.
9. Air was successfully used as a circulating fluid for most of the exploration drilling program. Air could not be used when clinker material or "wet formations" were being drilled.

10. Foam was unsuccessfully used as a circulating fluid while attempting to drill through the clinker material.
11. Soil thickness data should be obtained using a small exploration/ water well drilling rig.

A.3.8.2 Well Completion

1. The well completion procedures adequately isolated hydrologic observation zones in the wells.
2. Steel cement baskets (not canvas) should be used for the production assembly.
3. Standard rubber, cement wiper plugs should not be used to displace cement in shallow holes. Sufficient weight cannot be added to the drill string to drill out the plug.
4. Cement volumes could be calculated from the caliper logs and an accurate measurement of the casing thickness.
5. The cement basket should not be located downhole in an area of expanded hole.
6. When welding around canvas cement baskets caution must be taken that the canvas is not burned in the process.

A.3.8.3 Well Development

1. The well development procedures successfully "cleaned up" the wells; they removed excessive quantities of suspended solids and diluted brine concentrations in the wells.
2. Well development activities should take place immediately after the cement plug is drilled out, and before the drill rig moves off the well. This eliminates having to bring additional drilling equipment on-site at a later date.
3. Drilling activities should be scheduled (if possible) such that air temperatures are above freezing so brine solutions do not have to be used for circulating fluids. This is particularly important for holes which will be later used for water sampling.

4. Clean water and de-silting equipment should be used when drilling through and below the designated hydrologic observation zone.

A.3.8.4 Site Preparation/Restoration

1. The surface topography, geology and vegetation did not inhibit the site preparation or restoration activities.
2. All site work was completed with a D6 or D8 bulldozer and no blasting was necessary.
3. Surface conductor pipes should be installed for each hole prior to "spudding in".

A.4 GEOLOGY

A.4.1 INTRODUCTION

The North Knobs geology program was designed to obtain surface and subsurface data to aid in:

1. Characterizing the stratigraphy and structure of the rock strata on the facility.
2. Defining the slant-hole drilling methods which would be used to drill the process wells.
3. Locating the subsurface burn site and the surface components of the facility.
4. Completing required permit applications.

The geology program consisted of collecting regional and local (site) geologic field data, and using the data to construct geologic maps, cross-sections, columns and correlation diagrams. In addition, an estimate of the coal tonnage in-place on the site was calculated and a 3-D model of the site geology was constructed.

The field work was conducted during the summer and fall of 1978, and the data processing took place during the winter of 1978-1979.

A.4.2 REGIONAL GEOLOGY

A.4.2.1 Procedures

The following activities were completed to obtain the regional geologic data:

1. Describing the stratigraphic and structural characteristics of rock outcrops in the study area.

2. Observing the study area's aerial photographs and mapping the stratigraphy and structure.
3. Drilling exploration holes on the site and describing the characteristics of the rock samples obtained.
4. Constructing trenches and access roads on the site and describing their exposed geologic characteristics.
5. Constructing maps, cross-sections, columns, correlation diagrams and models to interpret and illustrate the data.
6. Calculating the in-place coal reserves for the three coal seams on the site.
7. Constructing a 3-D model of the site geology.

A.4.2.2 Data

The following data were obtained from the regional geologic mapping program:

Regional Data

1. Description of the study area stratigraphy and structure geology
   a. One regional geologic map
      Area - Section 11 and 8 adjacent sections
   b. One regional geologic cross-section
      location - see regional geologic map
      horizontal scale - 1 inch = 500 feet
      vertical scale - 1 inch = 500 feet
      depth of projection - to 3000 ft below sea level
   c. One regional geologic column
      vertical scale - 1 inch = 50 feet

A.4.3 SITE GEOLOGY

A.4.3.1 Procedures

The following activities were completed to obtain the geologic data for the site:

1. The stratigraphic and structural characteristics of rock outcrops in the study area were described.
2. Observing the study area's aerial photographs and mapping the stratigraphy and structure.
3. Drilling exploration holes on the site and describing the characteristics of the rock samples obtained.
4. Constructing trenches and access roads on the site and describing their exposed geologic characteristics.
5. Constructing maps, cross-sections, columns, correlation diagrams and models to interpret and illustrate the data.
6. Calculating the in-place coal reserves for the three coal seams on the site.
7. Constructing a 3-D model of the site geology.

A.4.3.2 Data

The site geologic data included:

1. A description of the facilities stratigraphy and structure geology.
   a.) One facility geologic map
      Area - UCG site as defined in June, 1978
      Horizontal scale - 1 in = 50 ft
   b.) Two site geologic cross-sections
      Location = on 5 + 00 and 11 + 00 ft radial lines
      Horizontal scale = 1 in = 50 ft
      Vertical scale = 1 in = 50 ft
      Depth of Projection = To 6000 ft above sea level

c.) One site geologic column

Vertical scale = 1 in = 10 ft

d.) One enlarged facility aerial photography with surface geology

Horizontal scale = 1 in = approximately 50 ft

e.) A summary table of depths at which marker formations were penetrated in the drillholes. (Marker formations are rock formations which are recognizable in outcrop across the facility). (Refer to Table 5.1-1 in the main text.)

2. A description of the jointing (rock fracturing) on the site.
   a.) An overlay for the enlarged site aerial photography illustrating the orientation and density of fracture traces (fractures which can be observed or aerial photographs).
   b.) Orientation diagrams for joints and cleats on the site.
   c.) Graphs for predicting the attitude of dominant joint sets and cleats from bedding attitudes on the site.
   d.) A diagram illustrating the relationship between the geometry of joint sets and the estimated path of gas migration on the site.

3. A description of the detailed geology of the G coal seam.
   a.) A diagram defining the stratigraphy of the G coal seam.
   b.) Maps illustrating the character of the G seam subcrop and soil/overburden cover on radial lines 5 + 00, 7 + 60, 11 + 70, and 12 + 30 (The burn process well locations).
   c.) The thickness and depth data for the G coal seam on the facility. These data are corrected for drill hole deviation.

4. An estimate of the in-place coal reserves on the site.
   a.) Reserves for the I seam.
   b.) Reserves for the G seam.
   c.) Reserves for the Wally seam.

5. A 3-D Model of the site.

A.5 CORE TESTING

A.5.1 Boundary Strata

A.5.1.1 Procedures

A.5.1.1.1 Rock Quality Designation

The indirect engineering evaluation of the rock mass is completed by observing each core run to obtain the cumulative length of pieces of core which are greater than four inches in length. This value is then divided by the total length of the core run to obtain a rock quality designation (RQD). The calculated value is compared to a set of standards thereby obtaining a descriptive classifier for the core. Core runs with high RQD values have not been extremely fractured or altered naturally in the drilling process; therefore, the penetrated rock should have relatively good mechanical and strength properties relating to rock stability during and after gasification experiments. Figure A.5.1-1 presents an example of the application of this method.

A.5.1.1.2 Laboratory Testing

Laboratory testing of the core was undertaken to determine the mechanical properties and strength parameters of the selected rock strata located above the G coal seam. The testing included:

Test	Parameter Obtained
Uniaxial compression	Compressive strength, Young's modulus and Poisson's Ratio
Triaxial compression	Compressive strength at various confining pressures
Brazilian	Tensile strength

All of the testing was completed on samples from core hole 4; Table A.5.1-1 and Figure 5.4-3 in the main text present respectively the lithologic depth of the samples and characteristics. The samples of core selected for testing were at

(a)

Core Recovery	Modified Core Recovery
10"	10"
2"	
2"	
3"	
4"	4"
5"	5"
3"	
4"	4"
6"	6"
4"	
2"	
5"	5"
50"	34"

Core Run = 60"

Core Recov. = 50/60 = 83%

RQD = 34/60 = 57%

(b)

RQD (Rock Quality Designation)	Description of Rock Quality
0 – 25	v. poor
25 – 50	poor
50 – 75	fair
75 – 90	good
90 – 100	excellent

Ref: Deere, D.U., A.J.Hendron, F.D.Patton, and E.J.Cording, "Design of Surface and Near-Surface Construction in Rock", Eighth Symposium on Rock Mechanics, Minneapolis, 1966

FIGURE A.5.1-1
MODIFIED CORE RECOVERY AS AN INDEX OF ROCK QUALITY

Table A.5.1-1

Characteristics of Samples Collected for
Laboratory Boundary Strata Analysis

Depth (ft)	Lithology		Number of Samples	Average Sample Length
78-81	Sandstone	Coarse grained	1	3 ft
81-83.1	"		1	2.1 ft
183-186	Sandstone	Fine grained	1	3 ft
362-365	Sandstone	Fine grained	1	3 ft
387-390	Sandstone	Fine grained	1	3 ft
391.3-394.3	Sandstone	Fine grained	1	3 ft
410-413	Sandstone	Fine grained	1	3 ft
499-502	Siltstone	Carbonaceous	1	3 ft
560-563	Siltstone	Carbonaceous	1	3 ft
507-510	Shale	Carbonaceous	1	3 ft
"				
511.9-514.9	Shale	Carbonaceous	1	3 ft
522.8-523.2	Coal	G seam	1	5 in
534.8-535.2	Coal	G seam	1	5 in

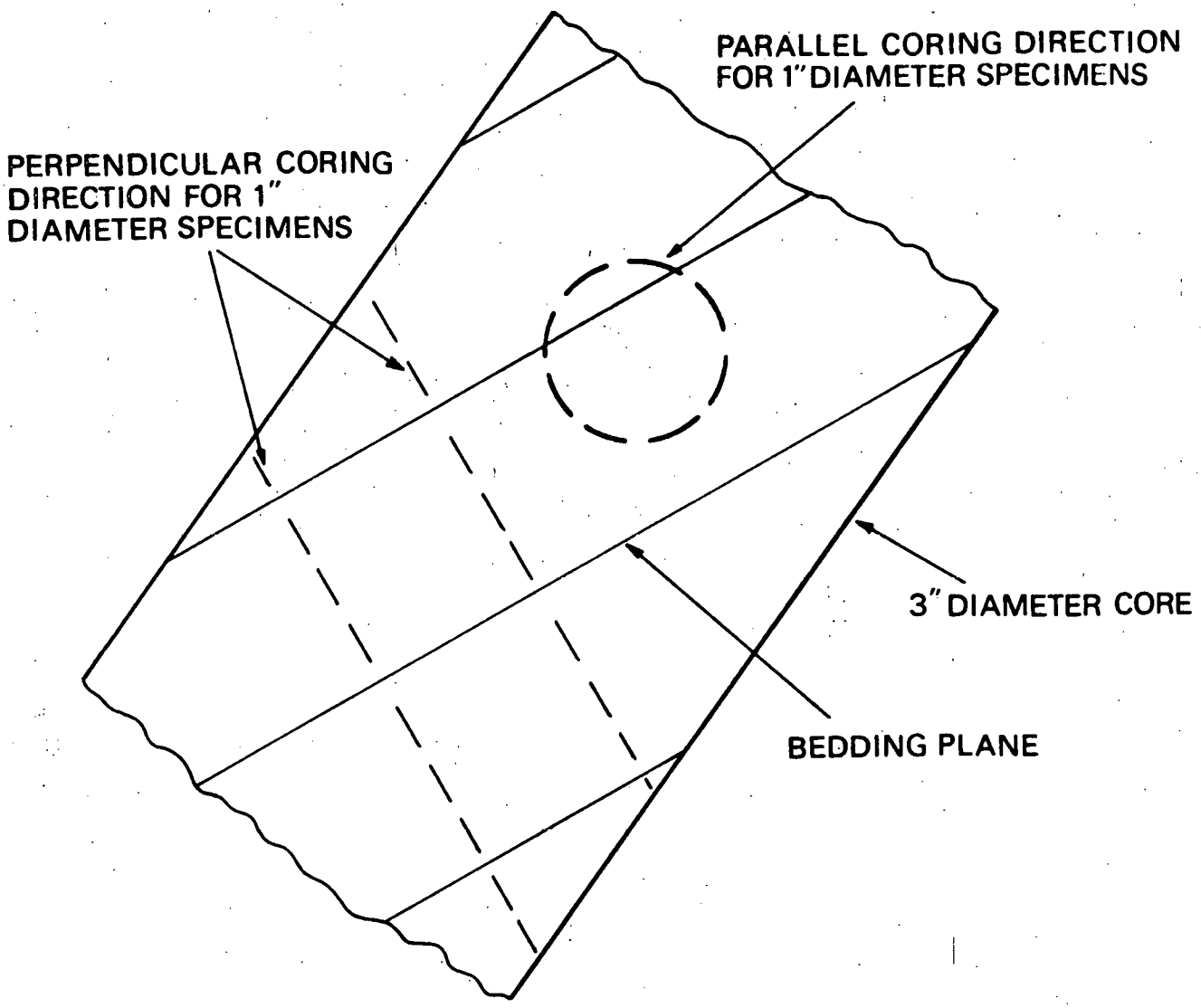
least 6 inches long, and they were generally free of fractures and altered zones.

Test	Sample Preparation
Uniaxial compression tests	1. Drill sets of 1-inch diameter by 3-inch long specimens from each field sample--each specimen set contains a specimen which was drilled parallel and perpendicular to the bedding planes of the field samples (Figure A.5.1-2). 2. Dry the specimens to remove internal moisture.
Triaxial compression test	1. Drill sets of 1-inch diameter by 3-inch long specimens from each field sample--each specimen set contains a specimen which was drilled parallel and perpendicular to the bedding planes of the field samples (Figure A.5.1-2). 2. Dry the specimens to remove internal moisture.
Brazilian test	1. Drill sets of 1.575-inch diameter cores parallel and perpendicular to the bedding planes of the field samples. 2. Cut the 1.575-inch cores to a length of 0.5 inches. 3. Dry the discs to remove internal moisture.

Specimens were drilled perpendicular and parallel to bedding so that the rock anisotropy could be assessed. After the specimens were prepared, the following testing was conducted:

Uniaxial Compression Testing which consisted of:

1. Mounting strain gauges parallel and perpendicular to the longitudinal axis of the test specimens. The gauges would measure respectively axial and lateral deformations.



MODE OF SPECIMEN PREPARATION FOR UNIAXIAL COMPRESSION TEST

Figure A.5.1-2

2. Applying an axial load gradually to the specimen until it failed (Figure A.5.1-3).

3. Recording the applied load and observed deformation continuously through specimen failure.

4. Calculating the Young's modulus and Poisson's ratio from the observed data.

5. Repeating the testing on duplicate specimen sets (see Figure A.5.1-3).

Triaxial Compression Testing which consisted of:

1. Jacketing the specimens in a triaxial cell.

2. Applying a confining pressure of 100 psi to the specimen.

3. Applying an axial load to the specimen and gradually increasing the load until failure occurred. (Figure A.5.1-4)

4. Recording the applied load and observed deformation continuously through specimen failure.

5. Repeating the above on specimen sets from the same lithology, at confining pressures of 200, 400, and 600 psi. Because of the size of the field core sample, all confining pressures could not be completed for each lithology.

Brazilian Testing which consisted of:

1. Applying a diametrical load gradually to each disc until failure occurred. (Figure A.5.1-5)

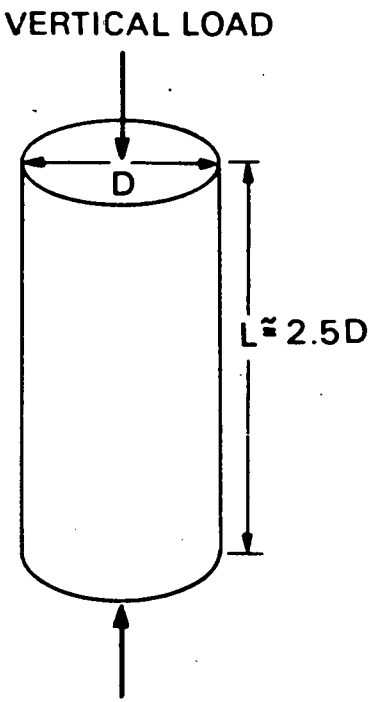
2. Recording the applied load continuously through specimen failure.

3. Calculating the tensile strength.

4. Repeating the testing on disc sets which were cut perpendicular to bedding so that the bedding plane was oriented at directions of 0°, 22.5°, 45°, 67.5°, and 90° with respect to the loading axis.

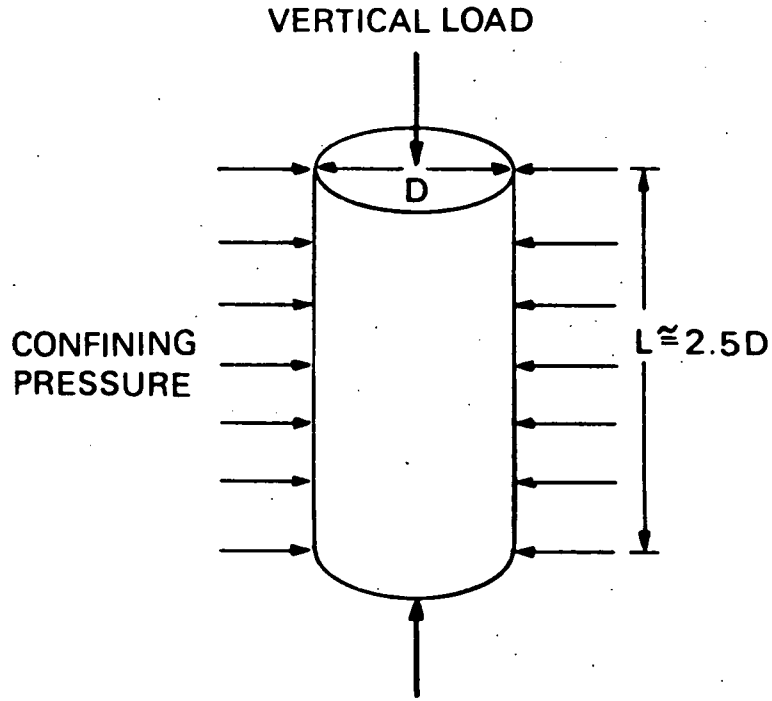
A.5.1.2 Data

The following data were obtained from the boundary strata analysis program:



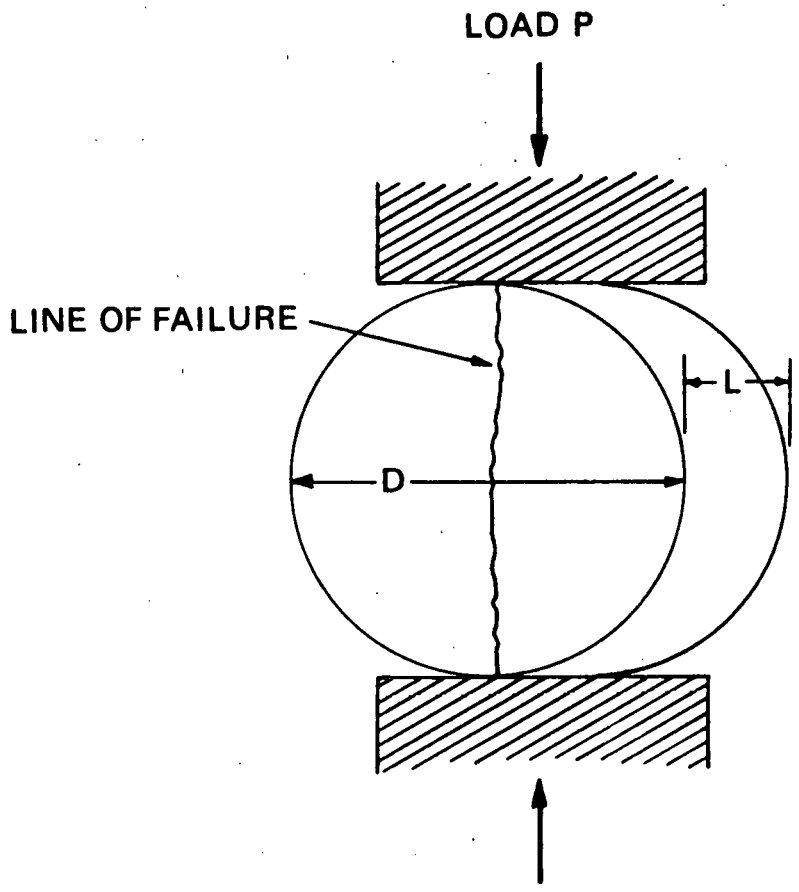
A ROCK SPECIMAN IN UNIAXIAL COMPRESSION TEST

Figure A.5.1-3



A ROCK SPECIMEN IN TRIAXIAL COMPRESSION TEST

Figure A.5.1-4



A ROCK SPECIMEN IN BRAZILIAN TEST

Figure A.5.1-5

Rock Quality Distination Analysis

1. RQD values for each of the major lithological units penetrated in core hole 4.

2. An average - RQD value of 66.1% (fair quality) was obtained for the entire rock sequence penetrated by core hole 4.

Laboratory Testing

1. The laboratory records and data plots. These data, because of its volume, is not included in this report. For those interested in obtaining the data, refer to UCG file report, "Laboratory Analysis from Boundary Strata Analysis" by Core Laboratories, Inc.

2. Summary tables of the data from the Uniaxial Compression Testing the Triaxial Compression Testing, and the Brazilian Testing.

FROM J. M. Avasthi AT Denver DATE 11-20-78

TO G. E. Jones AT Harmarville REFERENCE 6240FT40

SUBJECT SUBSIDENCE PREDICTION FOR UCG USING EMPIRICAL APPROACH

To predict subsidence due to UCG at the North Knobs site, it seemed appropriate to consider the empirical approach as a first step. The following information regarding the cavity created by UCG was obtained from the UCG group.

BURN I

Depth	- 390 feet
Amount of Coal to be Consumed	- 470 tons
Volume of Coal to be Consumed	- 10,500 cubic feet
Approximate size of the cavity (L x W x H)	- 52.5 x 10 x 20 feet 26 x 20 x 20 feet 18 x 30 x 20 feet

BURN II

Depth	- 550 feet
Amount of Coal to be Consumed	- 2,780 tons
Volume of Coal to be Consumed	- 61,800 cubic feet
Approximate size of the cavity (L x W x H)	- 309 x 10 x 20 feet 155 x 20 x 20 feet 103 x 30 x 20 feet

BURN III

Depth	- 550 feet
Amount of Coal to be Consumed	- 6,340 tons
Volume of Coal to be Consumed	- 140,800 cubic feet
Approximate size of the cavity	- 78 x 90 x 20 feet

The cavity sizes are based on the assumption that the burn will occur along the full thickness of the coal seam, and cavity will extend along the dip of the coal seam.

After a review of the literature on subsidence, it was determined that NCB* procedures were best suited for this purpose. For the approximated cavity sizes for Burn I and Burn II, the dimensions of the cavities were found to be too small for the NCB procedure to be used for the subsidence prediction. For Burn III, the following calculation was made:

Depth = 165 m, Width = 27 m, Advance = 24 m, seam thickness = 6 m

From the graph* maximum subsidence/seam thickness = 0.05

$\therefore$ Maximum Subsidence = 0.05 x 6 = 03 m

This is maximum subsidence for extraction length = 1.4 x depth
= 1.4 x 165
= 231 m

Therefore, the correction for the limited face advance is:

$$\frac{\text{Advance}}{\text{Depth}} = \frac{24}{165} = 0.145$$

Correction in $\frac{\text{Advance}}{\text{Depth}}$ for the extraction in a virgin area = 0.145 x 0.9 = 0.13

From graph* s/S for 0.13 at 165m depth = 0
which results in a maximum subsidence of zero.

Since the calculated subsidence resulted in zero, further calculation for seam inclination was not carried out. And once again, the cavity size is too small to cause any significant subsidence.

It should be kept in mind, however, that NCB predictions apply only under conditions similar to those of the original observations. The prediction procedures of NCB are based almost entirely on surface data and are purely geometric in nature. The geology, topography, material properties of the subsiding rock mass or method of mining (other than longwall) are not considered. All these factors influence subsidence development. Moreover, the NCB empirical procedures are restricted to conditions where trough subsidence predominates.

* - National Coal Board - Subsidence Engineers Handbook, National Coal Board Production Department, England, 1973.

They may be applied elsewhere, but there is no guarantee, although NCB represents the largest systematic study of its kind.

Another empirical formulation* for the prediction of subsidence, simply based on the seam thickness, excavation depth and the angle of dip is given as follows:

$$S_{max} = \frac{25m}{25 + \sqrt{h}} \cos\alpha$$

where S_{max} = maximum subsidence at the surface
m = thickness of the seam
h = depth of excavation
α = angle of dip

On the basis of the above formulation, the maximum subsidence at the surface for the three burns are as follows:

Burn I - 4.7 feet
Burn II - 4.34 feet
Burn III- 4.34 feet

These figures do not seem to be realistic because too many variables have been neglected in this calculation.

Based on the results from NCB calculations, it can not be implied that there will be no surface subsidence due to UCG at the North Knobs site. The NCB calculations are based entirely on the factors related to the longwall mining and a number of different factors are involved in UCG. This strengthens the view that a simulation approach needs to be followed, which could take into account the appropriate variables, and would provide more realistic results.

J. M. Avasthi

JMA:mah
cc: RHG
JMD
BED
GJH

* - Brauner, G. - Subsidence Due to Underground Mining, Bureau of Mines Information Circular 8571, 1973.

A.5.2 Coal Core Analysis

Table A.5.2-1 lists the tests performed on the coal core, along with the laboratory responsible and the on-site coal core handling procedures.

The tests performed by Hazen Research, Inc. are standard ASTM coal analysis tests.

The laboratory gasifier studies are scheduled for this spring at GR&DC. Gasifier performance of the North Knobs coal will be compared to Bighorn subbituminous coal and with potential UCG coals.

In "The Measurements of the Flow Properties of Coal for In Situ Gasification," by A. A. Reznick, P. F. Fulton, and C. L. Lien published January 1979 under contract #ET-78-5-02-4639, the techniques used for permeability and porosity testing are described.

Penn State University's Coal Research Laboratory completed the petrographic study of the G seam by characterizing the maceral content. Macerals are determined microscopically by the amount of light normally reflected from a polished coal surface with an oil immersion lens.

Core Laboratories, Inc. tested coal samples for physical properties. Description of the strength tests can be found in Section A.5.1.

The data from these coal core tests is assembled as follows:

Table	Title
A.5.2-2	Proximate Analysis of G Seam Drill Cuttings from Core Hole 2
A.5.2-3	Proximate Analysis of G Coal Core from Core Hole 3
A.5.2-4	Proximate Analysis of I Coal Seam from Core Hole 3
A.5.2-5	Proximate Analysis of G Coal Seam from Core Hole 4
A.5.2-6	"As Received" Ultimate G Seam
A.5.2-7	MAF Ultimates - G Seam
A.5.2-8	Fusion Temperature of Ash From G and I Coal Core From Core Hole 3

A.5.2-9	Fusion Temperature of Ash From G Coal Core from Core Hole 4
A.5.2-10	Elemental Ash Analyses for G and I Seam Ash from Core Hole 3
A.5.2-11	Elemental Ash Analyses for G Seam Ash from Core Hole 4
A.5.2-12	Physical Property Data for the Main Part of the G Coal Seam
A.5.2-13	Maceral Composition of 10 Samples from GR&DC Coal Near Rawlins Wyoming
A.5.2-14	Summary of Laboratory Porosity and Permeability Testing on the G_{mc} Coal

Figure	Title
A.5.2-1 to 5	Effective Permeability to Gas in md at Simulated Overburden Pressure of 200 psig
A.5.2-6 to 9	Effective Permeability to Gas in md at Simulated Overburden Pressure of 550 psig
A.5.2-10 to 14	Relative Permeability to Gas at 200 psig
A.5.2-15 to 18	Relative Permeability to Gas at 550 psig
A.5.2-19 to 22	Average Relative Permeabilities

Table A.5.2-1

Summary of Core Analysis Subcontractors,
Tests and Handling Procedures

Analytical Laboratory	Tests Performed	Coal Core Handling On-Site
Hazen Research, Inc.	1. Proximate Analysis 2. Ultimate Analysis 3. Ash Fusion 4. Elemental Ash Analysis 5. Bulk Density	1. Separate core into samples 1.5 ft long. 2. Split samples longitudinally. 3. Place 1/2 of split sample into a 2 ft long piece of 6 ml polyethylene tubing. 4. Seal the tubing with packaging tape. 5. Lable each sample. 6. Package and ship the samples.
GR&DC	1. Bulk Coal Studies (Lab Gasifier)	1. Separate core into samples 1.5 ft long. 2. Split samples longitudinally. 3. Place 1/2 of split sample into a 2 ft long piece of 6 ml polyethylene tubing. 4. Add water to the sample. 5. Seal the tubing with packaging tape. 6. Label each sample. 7. Package and ship the samples.
University of Pittsburgh	1. Absolute Porosity 2. Absolute and Relative Permeabilities 3. Shrinkage Valve	1. Select a 4.5 ft long piece of unbroken core. 2. Saturate the core. 3. Seal the sample in the polyethylene tubing. 4. Package and ship the samples.
Pennsylvania State University	1. Masceral Composition	1. Select 10 1-2 in long pieces of the coal core. 2. Saturate the samples. 3. Seal the samples in polyethylene tubing. 4. Label samples. 5. Package and ship the samples.
Core Laboratories, Inc.	1. Modified Fischer Assay 2. Electrical Conductivity 3. Bulk Density 4. Uniaxial Compressive Strength 5. Triaxial Compressive Strength	1. Select 2 6-in long pieces of unbroken core. 2. Seal the sample in polyethylene tubing. 3. Lable the samples. 4. Package and ship the samples.

Table A.5.2-2 Proximate Analysis of G Seam Drill Cuttings From Core Hole 2

		As Received						Dry						
	Interval (feet)	Moisture (%)	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	Calorific Value (Btu/lb)	Sulfur (%)	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	Calorific Value (Btu/lb)	Sulfur (%)	Mineral Matter Free (Btu/lb)	Air Dry Loss (%)
Coal Seam G	480-490	32.64	7.55	26.79	33.02	7,558	0.19	11.20	39.77	49.03	11,220	0.29	12,770	29.43
Coal Seam G	490-500	27.85	15.51	25.98	30.66	7,118	0.21	21.49	36.01	42.50	9,864	0.29	12,854	25.19
Coal Seam G	500-510	25.55	7.95	28.49	38.01	8,309	0.12	10.68	38.28	51.04	11,161	0.16	12,620	19.24
Coal Seam G	510-520	30.81	12.03	27.21	29.95	7,230	0.45	17.38	39.32	43.30	10,449	0.65	12,981	25.35
Coal Seam G	520-530	34.16	17.43	22.48	25.93	6,197	0.96	26.48	34.15	39.37	9,412	1.46	13,227	31.18
Coal Seam G	530-540	24.87	41.33	19.41	14.39	2,835	0.65	55.02	25.84	19.14	3,774	0.87	9,302	22.27

Table A.5.2-3 Proximate Analysis of G Coal Core From Core Hole 3

			As Received						Dry						
Hole No.	Sample No.	Interval (feet)	Moisture (%)	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	Calorific Value (Btu/lb)	Sulfur (%)	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	Calorific Value (Btu/lb)	Sulfur (%)	Mineral Matter Free (Btu/lb)	Air Dry Loss (%)
CH-3	G-1	47.0-48.5	11.84	50.75	21.90	15.51	4,282	0.64	57.57	24.85	17.58	4,857	0.73	12,881	8.37
CH-3	G-2	48.5-50.0	11.53	41.21	23.70	23.56	5,675	0.52	46.58	26.79	26.63	6,414	0.59	12,932	7.11
CH-3	G-3	50.0-51.5	12.83	19.86	31.45	35.86	8,382	0.56	22.78	36.08	41.14	9,616	0.64	12,771	8.05
CH-3	G-4	51.5-52.0	6.87	65.25	13.71	14.17	2,986	0.25	70.07	14.72	15.21	3,207	0.27	13,205	4.87
CH-3	G-5	59.0-60.5	13.69	10.11	33.60	42.60	9,446	0.59	11.71	38.93	49.36	10,945	0.69	12,544	8.61
CH-3	G-6	60.5-62.0	16.42	4.72	35.56	43.30	9,783	0.24	5.65	42.55	51.80	11,706	0.28	12,472	9.75
CH-3	G-7	62.0-63.5	15.28	4.25	34.80	45.67	9,970	0.22	5.02	41.08	53.90	11,769	0.26	12,449	8.42
CH-3	G-8	63.5-65.0	15.22	3.57	35.02	46.19	10,065	0.19	4.22	41.31	54.47	11,872	0.22	12,443	7.73
CH-3	G-9	65.0-66.5	15.97	3.09	35.79	45.15	9,934	0.16	3.68	42.59	53.73	11,821	0.19	12,314	10.55
CH-3	G-10	66.5-68.0	15.86	3.32	35.34	45.48	10,041	0.14	3.95	42.00	54.05	11,934	0.16	12,468	8.26
CH-3	G-11	68.0-69.5	16.02	4.62	35.15	44.21	9,797	0.19	5.50	41.85	52.65	11,666	0.22	12,408	10.66
CH-3	G-12	69.5-71.0	16.29	3.50	34.95	45.26	9,853	0.15	4.19	41.75	54.06	11,771	0.18	12,331	9.52
CH-3	G-13	71.0-72.3	15.82	3.57	36.03	44.58	9,910	0.15	4.24	42.80	52.96	11,773	0.18	12,341	8.60
CH-3	G-14	74.0-75.5	14.21	8.16	35.83	41.80	9,564	0.16	9.51	41.77	48.72	11,148	0.19	12,428	7.57
CH-3	G-15	75.5-77.0	17.48	4.38	34.48	43.66	9,600	0.13	5.31	41.79	52.90	11,633	0.16	12,344	10.00
CH-3	G-16	77.0-78.5	14.82	4.81	37.11	43.26	9,862	0.14	5.65	43.57	50.78	11,578	0.17	12,333	8.54
CH-3	G-17	78.5-80.0	14.77	5.58	38.48	41.17	9,856	0.18	6.55	45.15	48.30	11,563	0.21	12,447	9.38
CH-3	G-18	80.0-81.5	13.64	16.89	31.87	37.60	8,510	0.23	19.56	36.91	43.53	9,854	0.27	12,499	8.50
CH-3	G-19	81.5-83.0	14.64	5.40	35.77	44.19	9,847	0.23	6.32	41.91	51.77	11,536	0.27	12,367	7.66
CH-3	G-20	83.0-84.5	14.85	5.77	33.86	45.52	9,732	0.14	6.78	39.76	53.46	11,429	0.17	12,334	7.36
CH-3	G-21	84.5-86.0	15.80	5.27	33.21	45.72	9,534	0.12	6.26	39.45	54.29	11,324	0.14	12,148	10.28
CH-3	G-22	86.0-87.5	15.36	4.27	34.10	46.27	9,877	0.10	5.04	40.29	54.67	11,669	0.12	12,344	9.39
CH-3	G-23	87.5-89.0	17.03	3.71	32.07	47.19	9,641	0.08	4.48	38.65	56.87	11,620	0.10	12,212	11.90
CH-3	G-24	89.0-90.0	16.58	3.75	32.58	47.09	9,781	0.10	4.49	39.06	56.45	11,726	0.12	12,326	4.53
CH-3	G-25	90.0-91.5	16.89	3.85	32.10	47.16	9,751	0.10	4.64	38.63	56.73	11,733	0.12	12,354	10.21
CH-3	G-26	91.5-93.0	16.58	4.20	35.00	44.22	9,835	0.14	5.04	41.95	53.01	11,791	0.17	12,473	8.52
CH-3	G-27	93.0-94.5	17.57	3.55	32.89	45.99	9,856	0.11	4.31	39.90	55.79	11,957	0.14	12,543	11.02
CH-3	G-28	94.5-96.0	16.01	3.21	35.48	45.30	10,146	0.14	3.82	42.25	53.93	12,080	0.16	12,602	9.55
CH-3	G-29	96.0-97.5	17.28	3.31	34.71	44.70	9,998	0.15	4.00	41.96	54.04	12,086	0.19	12,636	11.21
CH-3	G-30	97.5-99.0	16.66	3.29	35.00	44.85	10,021	0.19	3.96	42.10	53.94	12,054	0.23	12,596	10.30
CH-3	G-31	99.0-100.5	15.94	4.37	36.31	43.38	9,977	0.25	5.20	43.20	51.60	11,869	0.29	12,582	7.83
CH-3	G-32	100.5-102.0	14.81	6.27	36.96	41.96	10,026	0.44	7.36	43.39	49.25	11,769	0.52	12,797	7.98
CH-3	G-33	102.0-103.0	15.10	14.12	33.82	36.96	8,835	0.71	16.63	39.83	43.54	10,407	0.83	12,705	8.46
CH-3	G-34	117.0-118.5	15.24	7.32	34.44	43.00	9,644	0.73	8.64	40.63	50.73	11,378	0.86	12,568	8.62
CH-3	G-35	118.5-120.0	16.77	5.52	36.33	41.38	9,744	0.51	6.64	43.65	49.71	11,708	0.62	12,625	9.66
CH-3	G-36	120.0-121.5	17.02	5.17	35.65	42.16	9,780	0.49	6.23	42.96	50.81	11,786	0.59	12,648	9.90
CH-3	G-37	126.0-127.5	16.36	7.10	34.43	42.11	9,536	0.56	8.49	41.16	50.35	11,402	0.67	12,567	8.49
CH-3	G-38	127.5-128.0	13.86	10.77	34.32	41.05	9,469	1.03	12.50	39.85	47.65	10,992	1.20	12,736	6.09

Table A.5.2-4 Proximate Analysis of I Coal Seam From Core Hole 3

Hole No.	Sample No.	Interval (feet)	As Received						Dry						Air Dry Loss (%)
			Moisture (%)	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	Calorific Value (Btu/lb)	Sulfur (%)	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	Calorific Value (Btu/lb)	Sulfur (%)	Mineral Matter Free (Btu/lb)	
CH-3	I-1	479.5-481.0	15.16	3.63	35.04	46.17	10,269	0.27	4.28	41.30	54.42	12,105	0.32	12,697	8.18
CH-3	I-2	481.0-482.5	15.66	3.40	35.10	45.84	10,279	0.25	4.03	41.62	54.35	12,188	0.30	12,749	9.47
CH-3	I-3	482.5-484.0	16.19	3.37	32.65	47.79	10,134	0.18	4.03	38.96	57.01	12,091	0.22	12,645	10.06
CH-3	I-4	484.0-485.5	14.12	9.94	33.43	42.51	9,540	0.20	11.57	38.93	49.50	11,109	0.23	12,701	8.05
CH-3	I-5	485.5-487.0	15.38	7.08	32.65	44.89	9,734	0.18	8.37	38.58	53.05	11,502	0.21	12,650	7.53
CH-3	I-6	487.0-488.5	16.25	4.96	32.81	45.98	9,837	0.14	5.92	39.17	54.91	11,746	0.17	12,551	8.51
CH-3	I-7	488.5-490.0	16.32	5.08	33.76	44.84	9,798	0.13	6.07	40.34	53.59	11,709	0.15	12,533	9.15
CH-3	I-8	490.0-491.5	16.42	5.03	31.29	47.26	9,824	0.11	6.02	37.44	56.54	11,754	0.13	12,574	9.66
CH-3	I-9	491.5-493.0	16.89	6.14	31.92	45.05	9,523	0.12	7.38	38.41	54.21	11,458	0.14	12,454	9.84
CH-3	I-10	493.0-494.5	17.40	15.13	29.89	37.58	8,346	0.20	18.32	36.19	45.49	10,104	0.25	12,602	10.99
CH-3	I-11	494.5-496.0	14.30	5.37	37.95	42.38	10,116	0.28	6.27	44.27	49.46	11,804	0.32	12,668	4.81
CH-3	I-12	496.0-497.5	13.69	6.87	37.28	42.16	10,061	0.44	7.95	43.20	48.85	11,657	0.50	12,763	3.78
CH-3	I-13	497.5-499.0	12.75	14.25	34.66	38.34	9,225	0.71	16.33	39.72	43.95	10,573	0.81	12,857	4.32
CH-3	I-14	499.0-500.5	11.26	27.71	30.34	30.69	7,405	0.48	31.22	34.19	34.59	8,345	0.54	12,607	3.38
CH-3	I-15	500.5-502.0	12.40	18.89	32.48	36.23	8,468	0.57	21.57	37.08	41.35	9,667	0.65	12,619	4.59
CH-3	I-16	502.0-503.5	13.11	13.44	32.34	41.11	9,249	0.49	15.47	37.22	47.31	10,644	0.56	12,793	4.37
CH-3	I-17	503.5-505.0	14.95	8.60	32.04	44.41	9,208	0.18	10.11	37.67	52.22	10,827	0.21	12,159	5.45
CH-3	I-18	505.0-506.5	15.31	6.01	31.96	46.72	9,731	0.15	7.09	37.74	55.17	11,490	0.18	12,447	4.95
CH-3	I-19	506.5-508.0	14.51	5.77	35.11	44.61	9,924	0.16	6.75	41.08	52.17	11,609	0.19	12,526	4.52
CH-3	I-20	508.0-509.5	14.57	4.57	35.97	44.89	10,371	0.22	5.34	42.10	52.56	12,140	0.26	12,889	4.26
CH-3	I-21	509.5-511.0	11.69	26.23	28.75	33.33	7,765	0.56	29.70	32.56	37.74	8,792	0.63	12,965	3.54
CH-3	I-22	511.0-512.0	12.09	26.51	29.21	32.19	7,758	0.62	30.15	33.23	36.62	8,825	0.71	13,109	3.83

Table A.5.2-5 Proximate Analysis of G Coal Seam From Core Hole 4

Hole No.	Sample No.	Interval (feet)	As Received						Dry						Air Dry Loss (%)
			Moisture (%)	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	Calorific Value (Btu/lb)	Sulfur (%)	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	Calorific Value (Btu/lb)	Sulfur (%)	Mineral Matter Free (Btu/lb)	
CH-4	G-1	517-518.5	14.35	4.81	36.28	44.56	10,218	0.22	5.62	42.36	52.02	11,930	0.26	12,706	7.76
CH-4	G-2	518.5-520	15.39	3.27	35.49	45.85	10,448	0.20	3.87	41.94	54.19	12,349	0.24	12,893	10.19
CH-4	G-3	520-521.5	14.91	3.10	35.16	46.83	10,508	0.16	3.64	41.32	55.04	12,350	0.19	12,960	9.17
CH-4	G-4	521.5-523	15.22	4.12	36.33	44.33	10,266	0.15	4.86	42.85	52.29	12,109	0.17	12,793	10.86
CH-4	G-5	523-524.5	16.35	4.02	36.96	42.67	10,058	0.13	4.81	44.18	51.01	12,024	0.16	12,686	11.32
CH-4	G-6	524.5-526	15.95	3.17	35.94	44.94	10,326	0.13	3.77	42.76	53.47	12,286	0.15	12,811	11.32
CH-4	G-7	526-527.5	14.24	4.73	36.68	44.35	10,248	0.14	5.52	42.77	51.71	11,950	0.16	12,711	9.14
CH-4	G-8	527.5-529	14.48	7.64	34.93	42.95	9,869	0.13	8.93	40.84	50.23	11,540	0.15	12,776	9.52
CH-4	G-9	529-530.5	14.07	4.73	36.48	44.72	10,264	0.11	5.50	42.46	52.04	11,968	0.13	12,727	9.41
CH-4	G-10	530.5-532	13.32	5.58	36.41	44.69	10,229	0.15	6.43	42.00	51.47	11,801	0.17	12,685	9.50
CH-4	G-11	532-533.5	13.30	14.96	32.47	39.27	9,233	0.15	17.26	37.45	45.29	10,649	0.17	13,093	8.87
CH-4	G-12	533.5-535	12.73	10.28	36.91	40.09	9,684	0.27	11.78	42.29	45.93	11,096	0.31	12,720	8.55
CH-4	G-13	535-536.5	14.27	5.63	33.88	46.22	9,937	0.18	6.56	39.52	53.92	11,661	0.21	12,556	8.60
CH-4	G-14	536.5-538	14.40	4.58	35.18	45.84	10,175	0.13	5.35	41.09	53.56	11,886	0.16	12,618	8.86
CH-4	G-15	538-539.5	15.38	5.06	33.52	46.04	9,705	0.11	5.98	39.61	54.41	11,469	0.12	12,264	10.87
CH-4	G-16	539.5-541	15.83	3.97	34.02	46.18	10,130	0.11	4.71	40.41	54.88	12,035	0.13	12,683	11.73
CH-4	G-17	541-542.5	15.37	3.81	34.84	45.98	10,203	0.11	4.50	41.18	54.32	12,057	0.13	12,675	11.06
CH-4	G-18	542.5-544	16.06	3.39	32.45	48.10	10,096	0.08	4.03	38.66	57.31	12,028	0.10	12,579	11.56
CH-4	G-19	544-545	16.32	3.30	31.75	48.63	10,057	0.09	3.94	37.94	58.12	12,065	0.10	12,605	11.50
CH-4	G-20	549-549.5	14.69	3.16	34.97	46.98	10,342	0.11	3.71	41.09	55.20	12,151	0.13	12,661	9.83
CH-4	G-21	549.5-551	14.45	4.16	34.96	46.43	10,202	0.12	4.87	40.86	54.27	11,924	0.14	12,589	9.75
CH-4	G-22	551-552.5	14.73	3.31	36.38	45.58	10,407	0.13	3.88	42.67	53.45	12,205	0.16	12,741	10.18
CH-4	G-23	552.5-554	14.16	3.26	37.47	45.11	10,597	0.17	3.80	43.66	52.54	12,346	0.20	12,879	9.13
CH-4	G-24	554-555.5	14.38	4.07	37.44	44.11	10,481	0.18	4.76	43.73	51.51	12,242	0.21	12,909	9.52
CH-4	G-25	555.5-557	13.84	7.13	38.07	40.96	9,869	0.26	8.27	44.19	47.54	11,454	0.30	12,584	9.01
CH-4	G-26	557-558.5	13.43	7.39	36.14	43.04	10,151	0.53	8.54	41.74	49.72	11,726	0.61	12,932	7.66
CH-4	G-27	558.5-560	12.94	11.37	34.87	40.82	9,688	0.64	13.06	40.05	46.89	11,128	0.73	12,974	8.37
CH-4	G-28	563-564.5	10.33	43.32	25.19	21.16	5,459	1.46	48.31	28.09	23.60	6,057	1.62	12,759	6.76
CH-4	G-29	564.5-566	9.28	46.48	24.35	19.89	5,170	1.70	51.23	26.85	21.92	5,693	1.87	12,797	6.16
CH-4	G-30	566-567.5	9.72	29.45	31.02	29.81	7,769	1.69	32.62	34.36	33.02	8,605	1.87	13,355	5.88
CH-4	G-31	567.5-569	12.15	16.23	33.67	37.95	8,960	0.80	18.48	38.32	43.20	10,199	0.91	12,764	8.41
CH-4	G-32	569-570.5	12.63	16.42	32.90	38.05	8,908	1.09	18.79	37.66	43.55	10,196	1.24	12,825	7.83
CH-4	G-33	570.5-572	13.73	9.91	33.43	42.93	9,621	0.83	11.49	38.75	49.76	11,152	0.96	12,754	9.35
CH-4	G-34	572-573.5	11.50	16.55	35.16	36.79	9,289	1.13	18.70	39.73	41.57	10,496	1.27	13,189	6.94
CH-4	G-35	573.5-575	11.18	23.63	31.36	33.83	8,228	0.82	26.61	35.31	38.08	9,283	0.93	13,027	7.17
CH-4	G-36	575-576.5	13.45	6.60	38.16	41.79	10,050	0.47	7.62	44.09	48.29	11,611	0.54	12,664	8.42
CH-4	G-37	576.5-578	13.83	4.69	37.44	44.04	10,230	0.50	5.44	43.45	51.11	11,985	0.57	12,748	9.69
CH-4	G-38	578-579.5	13.25	8.56	36.07	42.12	10,067	0.76	9.87	41.58	48.55	11,604	0.87	13,010	7.77
CH-4	G-39	579.5-581	7.36	63.44	17.13	12.07	3,084	0.43	68.48	18.49	13.03	3,329	0.46	12,807	5.74

Table A.5.2-6
"As-Received" Ultimates - G Seam

	Interval	Moisture	Carbon	Hydrogen	Nitrogen	Sulfur	Ash	Oxygen*
	63.5-65.0	15.22	59.85	4.28	0.70	0.19	3.57	16.19
	69.5-71.0	16.29	59.15	4.26	0.75	0.15	3.50	15.90
	77.0-78.5	14.82	58.99	4.25	0.81	0.14	4.81	16.18
Core	83.0-84.5	14.85	58.74	3.60	0.64	0.14	5.77	16.26
Hole	89.0-90.0	16.58	59.13	3.77	0.61	0.10	3.75	16.06
CH-3	94.5-96.0	16.01	59.62	3.94	0.69	0.14	3.21	16.39
	100.5-102.0	14.81	58.64	4.30	0.68	0.44	6.27	14.86
	Core Hole CH-3 Average	15.51	59.16	4.05	0.70	0.19	3.98	15.97
	521.5-523	15.22	60.06	4.22	1.05	0.15	4.12	15.18
	527.5-529	14.48	58.18	3.91	0.68	0.13	7.64	14.98
Core	533.5-535	12.73	56.76	4.07	0.64	0.27	10.28	15.25
Hole	539.5-541	15.83	59.65	3.96	0.62	0.11	3.97	15.86
CH-4	548-549.5	14.89	61.37	4.15	0.60	0.11	3.16	15.72
	554-555.5	14.38	60.60	4.34	0.76	0.18	4.07	15.67
	Core Hole 4 Average	14.59	59.44	4.11	0.73	0.17	5.54	15.44
	GRAND AVERAGE	15.05	59.30	4.08	0.72	0.18	4.76	15.91*

*By Difference.

Table A.5.2-7

MAF Ultimates - G Seam

Sample	Interval	C	H	N	S	O
3G-8	63.5-65.0	73.71	5.27	0.87	0.23	19.92
3G-12	69.5-71.0	73.75	5.30	0.94	0.19	19.82
3G-16	77.0-78.5	73.40	5.28	1.02	0.18	20.13
3G-20	83.0-84.5	74.01	4.54	0.80	0.18	20.47
3G-24	89.0-90.0	74.22	4.74	0.76	0.13	20.14
3G-28	94.5-96.0	73.80	4.89	0.85	0.17	20.30
3G-32	100.5-102.0	74.31	5.44	0.86	0.56	18.83
Average CH-3		73.89	5.07	0.87	0.23	19.94
4G-4	521.5-523	74.46	5.23	1.30	0.18	18.82
4G-8	527.5-529	74.70	5.02	0.87	0.16	19.25
4G-12	533.5-535	73.71	5.28	0.83	0.35	19.83
4G-16	539.5-541	74.36	4.93	0.77	0.14	19.80
4G-20	548-549.5	74.89	5.06	0.74	0.14	19.17
4G-24	554-555.5	74.31	5.32	0.93	0.22	19.20
Average CH-4		74.41	5.14	0.91	0.20	19.35
Grand Average (CH-3 and CH-4)		74.15	5.11	0.89	0.22	19.65

Table A.5.2-8 Fusion Temperature of Ash From G & I Coal Core From Core Hole 3

	Hole No.	Sample No.	Interval (')	Reducing °F Initial Deformation	°F Softening	°F Hemispherical	°F Fluid
G Coal Seam	CH-3	G-2	48.5-50.0	2350	2520	2640	2690
	CH-3	G-4	51.5-52.0	+2700	+2700	+2700	+2700
	CH-3	G-6	60.5-62.0	2430	2440	2450	2460
	CH-3	G-8	63.5-65.0	2370	2430	2460	2590
	CH-3	G-10	66.5-68.0	2370	2380	2390	2400
	CH-3	G-12	69.5-71.0	2390	2400	2410	2460
	CH-3	G-14	74.0-75.5	2200	2210	2220	2250
	CH-3	G-16	77.0-78.5	2510	2530	2540	2600
	CH-3	G-18	80.0-81.5	2170	2300	2350	2620
	CH-3	G-20	83.0-84.5	2350	2450	2460	2480
	CH-3	G-22	86.0-87.5	2390	2400	2410	2420
	CH-3	G-24	89.0-90.0	2370	2390	2540	2570
	CH-3	G-26	91.5-93.0	2420	2430	2440	2450
	CH-3	G-28	94.5-96.0	2410	2420	2430	2500
	CH-3	G-30	97.5-99.0	2400	2420	2430	2500
	CH-3	G-32	100.5-102.0	2240	2300	2340	2430
	CH-3	G-34	117.0-118.5	2490	2530	2560	2620
	CH-3	G-36	120.0-121.5	2560	2640	2650	2670
	CH-3	G-38	127.5-128.0	2290	2350	2380	2520
	CH-3	I-2	481.0-482.5	2260	2330	2350	2380
I Coal Seam	CH-3	I-4	484.0-485.5	2140	2190	2240	2340
	CH-3	I-6	487.0-488.5	2260	2320	2340	2350
	CH-3	I-8	490.0-491.5	2440	2460	2470	2480
	CH-3	I-10	493.0-494.5	2110	2180	2210	2460
	CH-3	I-12	496.0-497.5	2300	2310	2320	2330
	CH-3	I-14	499.0-500.5	2290	2490	2520	2690
	CH-3	I-16	502.0-503.5	2100	2180	2200	2450
	CH-3	I-18	505.0-506.5	2420	2430	2440	2450
	CH-3	I-20	508.0-509.5	2320	2490	2530	2580
	CH-3	I-22	511.0-512.0	2320	2510	2560	+2700

Table A.5.2-9 Fusion Temperature of Ash From G Coal Core From Core Hole 4

Hole No.	Sample No.	Interval (')	Reducing			
			°F Initial Deformation	°F Softening	°F Hemispherical	°F Fluid
CH-4	G-2	518.5-520	2280	2310	2320	2350
CH-4	G-4	521.5-523	2360	2380	2390	2400
CH-4	G-6	524.5-526	2350	2380	2390	2400
CH-4	G-8	527.5-529	2180	2200	2210	2240
CH-4	G-10	530.5-532	2300	2310	2320	2330
CH-4	G-12	533.5-535	2200	2210	2220	2230
CH-4	G-14	536.5-538	2280	2290	2300	2310
CH-4	G-16	539.5-541	2330	2340	2350	2360
CH-4	G-18	542.5-544	2380	2390	2400	2420
CH-4	G-20	548-549.5	2360	2410	2420	2430
CH-4	G-22	551-552.5	2370	2420	2450	2460
CH-4	G-24	554-555.5	2350	2370	2410	2440
CH-4	G-26	557-558.5	2190	2210	2220	2400

Table A.5.2-10

Elemental Ash Analysis for G&I Seam Ash
From Core Hole 3

	G Seam						
Sample No.	G2	G4	G6	G8	G10	G12	G14
Interval	48.5-50.0	51.5-52.0	60.5-62.0	63.5-65.0	66.5-68.0	69.5-71.0	74.0-75.5
Oxide							
SiO_2	68.71	82.86	20.62	9.49	9.14	8.57	47.70
Al_2O_3	16.94	12.74	13.27	12.40	11.43	12.16	13.74
TiO_2	1.14	0.95	0.51	0.36	0.42	0.33	1.43
Fe_2O_3	3.38	0.96	10.76	15.19	16.18	14.62	6.64
CaO	2.60	0.98	33.29	37.89	40.39	42.69	20.87
MgO	1.79	0.50	7.74	8.08	8.15	8.36	4.10
Na_2O	0.13	0.02	0.89	1.62	1.52	1.76	0.89
K_2O	2.41	1.35	0.37	0.21	0.21	0.27	0.10
P_2O_5	0.24	0.05	0.29	0.58	0.25	0.23	0.25
SO_3	2.05	0.77	11.21	12.63	11.32	9.12	4.48
Ash Viscosity Calculations							
Base Content (PCT)	10.62	3.80	60.67	73.90	76.00	76.19	34.15
Acid Content (PCT)	89.39	96.21	39.34	26.11	24.01	23.82	65.86
Dolomite Content (PCT)	42.59	38.85	77.35	72.98	73.05	75.41	76.60
Base to Acid Ratio	0.12	0.04	1.55	2.84	3.17	3.20	0.52
Silica to Aluminum Ratio	4.06	6.50	1.55	0.70	0.80	0.70	3.47
Temp in °F for 250 poise	>2800	>2800	2457	>2529	>2530	>2551	2299
Equivalent Silica Content	89.85	97.14	28.48	13.44	12.38	11.55	60.15
Viscosity from Equivalent Silica (Poise)	5166.3	>9999.9	0.9	0.2	0.2	0.2	34.0

Table A.5.2-10 (cont.)

Elemental Ash Analysis for G&I Seam Ash from Core Hole 3

	G Seam						
Sample No.	G16	G18	G20	G22	G24	G26	G28
Interval	77.0-78.5	80.0-81.5	83.0-84.5	86.0-87.5	89.0-90.0	91.5-93.0	94.5-96.0
Oxide							
SiO_2	12.38	62.93	19.62	9.20	14.47	8.81	9.15
Al_2O_3	18.30	14.80	15.67	10.37	9.42	5.83	9.04
TiO_2	0.38	2.20	0.61	0.11	0.13	0.13	0.15
Fe_2O_3	11.01	383	10.20	18.29	14.39	19.00	15.40
CaO	41.61	10.17	38.69	46.50	41.81	47.15	42.44
MgO	5.48	1.96	4.98	6.37	7.28	6.04	7.03
Na_2O	1.75	0.78	2.38	1.58	3.17	3.37	4.01
K_2O	0.21	0.54	0.12	0.06	0.24	0.12	0.06
P_2O_5	0.29	0.25	0.68	0.04	0.06	0.08	0.05
SO_3	6.11	2.97	5.81	5.57	5.80	6.05	8.94
Ash Viscoisty Calculations							
Base Content (PCT)	65.92	17.78	61.10	78.72	73.58	83.68	78.99
Acid Content (PCT)	34.09	82.23	38.91	21.29	26.43	16.33	21.02
Dolomite Content (PCT)	78.41	70.20	77.48	72.63	73.39	70.29	71.76
Base to Acid Ratio	1.94	0.22	1.58	3.70	2.79	5.13	3.76
Silica to Aluminum Ratio	0.68	4.25	1.25	0.89	1.54	1.51	1.01
Temp in °F for 250 poise	2522	2757	2462	>2526	>2533	>2505	>2518
Equivalent Silica Content	17.57	79.77	26.70	11.45	18.57	10.88	12.37
Viscosity From Equivalent Silica (Poise)	0.3	795.6	0.7	0.2	0.3	0.2	0.2

Table A.5.2-10 (cont.)

Elemental Ash Analysis for G&I Seam Ash from Core Hole 3

	G Seam					I Seam	
Sample No.	G30	G32	G34	G36	G38	I2	I4
Interval	97.5-99.0	100.5-102.0	117.0-118.5	120.0-121.5	127.5-128.0	481.0-428.5	484.0-485.5
Oxide							
SiO_2	9.88	26.63	17.51	9.72	38.49	9.48	47.20
Al_2O_3	9.70	16.19	17.65	19.38	18.02	8.24	19.72
TiO_2	0.24	0.45	0.14	0.23	1.08	0.35	1.43
Fe_2O_3	14.48	9.73	7.74	9.10	5.39	12.84	5.67
CaO	40.60	24.38	31.66	26.66	11.69	36.72	15.65
MgO	7.06	3.62	2.69	5.75	8.41	5.67	2.24
Na_2O	4.08	2.46	2.58	2.94	1.76	3.65	1.71
K_2O	0.06	0.11	0.13	0.08	0.55	0.23	0.14
P_2O_5	0.05	0.83	0.28	2.27	0.28	0.18	0.25
SO_3	11.10	13.24	16.11	19.45	14.91	16.77	4.47
Ash Viscosity Calculations							
Base Content (PCT)	76.99	48.23	55.94	60.29	32.56	76.59	27.11
Acid Content (PCT)	23.02	51.78	44.07	39.72	67.45	23.42	72.90
Dolomite Content (PCT)	71.91	69.48	76.68	72.79	72.31	71.72	70.41
Base to Acid Ratio	3.35	0.94	1.27	1.52	0.49	3.28	0.38
Silica to Aluminum Ratio	1.02	1.64	0.99	0.50	2.14	1.15	2.39
Temp in °F for 250 poise	>2520	2177	2393	2408	2324	>2518	2443
Equivalent Silica Content	13.72	41.38	29.38	18.98	60.16	14.65	66.71
Viscosity from Equivalent Silica (Poise)	0.2	3.2	0.9	0.3	34.1	0.2	89.0

Table A.5.2-10 (cont.)

Elemental Ash Analysis for G&I Seam Ash from Core Hole 3

	I Seam						
Sample No.	I-6	I-8	I-10	I-12	I-14	I-16	I-18
Interval	487.0-488.5	490.0-491.5	493.0-494.5	496.0-497.5	499.0-500.5	502.0-503.5	505.0-506.5
Oxide							
SiO_2	15.15	12.13	52.15	14.20	54.70	45.42	8.26
Al_2O_3	14.07	8.11	18.18	13.17	23.91	17.05	7.45
TiO_2	0.22	0.33	0.60	0.42	0.74	0.86	0.28
Fe_2O_3	14.37	14.64	7.08	13.27	5.38	10.94	12.03
CaO	38.41	47.63	12.41	34.43	6.39	13.34	53.72
MgO	4.56	6.34	2.33	4.83	1.20	2.24	5.44
Na_2O	2.87	2.92	1.11	1.61	0.53	0.92	1.69
K_2O	0.14	0.12	0.98	0.12	0.57	0.23	0.20
P_2O_5	0.27	0.43	0.41	0.97	0.19	0.20	0.34
SO_3	7.18	5.77	3.19	14.06	3.66	7.72	8.22
Ash Viscosity Calculations							
Base Content (PCT)	67.22	77.70	25.22	66.14	15.07	30.41	82.05
Acid Content (PCT)	32.79	22.31	74.79	33.87	84.94	69.60	17.96
Dolomite Content (PCT)	71.21	75.33	61.65	72.36	53.95	56.31	80.96
Base to Acid Ratio	2.05	3.49	0.34	1.96	0.18	0.44	4.58
Silica to Aluminum Ratio	1.08	1.50	2.87	1.08	2.29	2.66	1.11
Temp in °F for 250 poise	2465	>2551	2487	2466	2785	2365	>2599
Equivalent Silica Content	20.90	15.03	70.51	21.28	80.84	63.14	10.40
Viscosity from Equivalent Silica (Poise)	0.4	0.2	163.2	0.4	969.5	52.8	0.1

Table A.5.2-10 (cont.)

Elemental Ash Analysis for
G&I Seam Ash from Core Hole 3

	I Seam	
Sample No.	I-20	I-22
Interval	508.0-509.5	11.0-512.0
Oxide		
SiO_2	10.44	61.06
Al_2O_3	13.90	21.29
TiO_2	0.30	0.76
Fe_2O_3	16.19	4.11
CaO	38.23	5.32
MgO	4.01	0.88
Na_2O	1.81	0.48
K_2O	0.05	0.93
P_2O_5	0.42	0.10
SO_3	11.66	2.81
Ash Viscosity Calculations		
Base Content (PCT)	70.99	12.36
Acid Content (PCT)	29.02	87.65
Dolomite Content (PCT)	70.07	52.91
Base to Acid Ratio	2.45	0.15
Silica to Aluminum Ratio	0.75	2.87
Temp in °F for 250 poise	2490	>2800
Equivalent Silica Content	15.16	85.56
Viscosity from Equivalent Silica (Poise)	0.2	2330.2

Table A.5.2-11

Elemental Ash Analysis for G Seam Ash from
Core Hole 4

Sample No.	G2	G4	G6	G8	G10	G12	G14
Interval	518.5-520.0	521.5-523.0	524.5-526.0	527.5-529.0	536.5-538.0	533.5-535.0	530.5-53
Oxide %							
SiO_2	11.75	25.29	6.17	44.84	14.48	39.56	9.98
Al_2O_3	12.23	11.14	14.31	13.10	21.84	18.02	16.62
TiO_2	0.34	0.48	0.28	0.74	0.24	0.96	0.02
Fe_2O_3	12.52	9.78	13.56	12.53	10.98	5.98	14.65
CaO	34.72	31.71	42.22	20.10	35.89	21.95	39.91
MgO	8.51	7.71	8.80	3.85	5.19	2.87	5.29
Na_2O	5.15	3.69	1.71	1.29	1.80	1.07	1.66
K_2O	0.29	0.20	0.14	0.08	0.08	0.68	0.19
P_2O_5	0.15	0.08	0.09	0.27	0.41	0.13	0.51
SO_3	12.63	9.12	9.89	4.54	6.39	6.14	7.19
Ash Viscosity Calculations							
Base Content (PCT)	71.56	58.9	76.19	39.22	59.61	35.74	69.86
Acid Content (PCT)	28.45	41.02	23.82	69.79	40.40	64.27	30.15
Dolomite Content (PCT)	70.65	74.26	76.81	63.28	76.16	76.26	73.26
Base to Acid Ratio	2.52	1.44	3.20	0.65	1.48	0.56	2.32
Silica to Aluminum Ratio	0.96	2.27	0.43	3.42	0.66	2.20	0.60
Temp in °F for 250 poise	2500	2408	>2563	>2234	2434	2277	2512
Equivalent Silica Content	17.41	33.96	8.73	55.15	21.77	56.23	14.30
Viscosity from Equivalent Silica (Poise)	0.3	1.5	0.1	16.7	0.4	19.3	0.2

Table A.5.2-11 (cont.)

Elemental Ash Analysis for G Seam Ash
from Core Hole 4

Sample No. Interval	G16 539.5-546.0	G18 542.5-544.0	G20 548.0-549.5	G22 551.0-552.5	G24 554.0-555.5	G26 557.0-558.5
Oxide						
SiO_2	8.81	11.07	7.12	9.92	12.56	31.21
Al_2O_3	13.66	10.96	7.10	10.34	10.49	18.41
TiO_2	0.24	0.32	0.21	0.38	0.96	1.55
Fe_2O_3	9.56	12.37	16.40	13.45	17.88	7.33
CaO	48.82	48.03	44.45	43.35	43.05	20.43
MgO	6.44	8.52	6.84	8.31	6.99	3.53
Na_2O	1.68	2.60	2.46	2.60	2.17	1.67
K_2O	0.17	0.22	0.26	0.20	0.14	0.46
P_2O_5	0.14	0.09	0.10	0.05	0.01	0.99
SO_3	7.29	7.03	11.83	9.64	7.38	11.95
Ash Viscosity Calculations						
Base Content (PCT)	74.60	76.25	83.00	76.70	74.53	39.51
Acid Content (PCT)	25.41	23.76	17.01	23.31	25.48	60.50
Dolomite Content (PCT)	82.89	78.83	72.85	76.08	71.26	71.70
Base to Acid Ratio	2.94	3.21	4.88	3.30	2.93	0.66
Silica to Aluminum Ratio	0.64	1.01	1.00	0.96	1.20	1.70
Temp in °F for 250 poise	>2615	>2581	>2528	>2557	>2514	2231
Equivalent Silica Content	11.97	13.84	9.52	13.23	15.61	49.94
Viscosity from Equivalent Silica (Poise)	0.2	0.2	0.1	0.2	0.2	8.5

Table A.5.2-12 Physical Property Data for the Main Part of the G Coal Seam

1. Modified Fischer Assay Data

	G_{MC}-Core Hole 4*
Oil (gal oil/ton coal)	12.2
Wt %	5.1
Water (gal H_2O/ton coal)	44.6
Wt%	18.6
Oil Gravity	0.997
Solids (wt%)	69.6
Gas + Loss Wt%	6.8
Tendency to coke	0.0

*Sample Interval = 522.8 to 523.2 and 534.8 to 535.2

2. Specific gravity of the G_{MC} coal from core hole 3*

	As Received	Dry	Moisture/ Ash Free
Specific Gravity	1.36	1.42	1.32

*Sample Interval = 63.5-65.0; 74.0-75.5; 100.5-102.0

3. Specific gravity of the G_{MC} coal ash from core hole 3* = 2.83

*Sample Interval = 47.0-128.0

4. Electrical conductivity = <15 microhm/meter

5. Uniaxial compressive strength = 762 psi

6. Triaxial compressive strength at 600 psi
Confining pressure = 2678, 3191, 3574 psi

Table A.5.2-13 Maceral Composition of Core Samples from Core Hole 4 "G" Coal Seam

Depth in Feet	Vitrinite	Pseudo-vitrinite	Fusinite	Semi-Fusinite	Massive Micrinite	Granular Micrinite	Exinite	Resinite	Sclerotinite
521	85.4	1.2	1.4	7.9	0.9	1.2	1.5	0.4	0.1
526.5	59.9	0.7	5.6	23.3	2.6	5.0	2.9	0.0	
532	87.7	2.6	3.7	4.5	0.2	0.5	0.5	0.3	
539.5	54.6	0.3	7.6	32.7	1.4	2.8	0.6	0.0	
550.5	86.5	0.0	1.4	8.9	0.5	2.0	0.6	0.1	
558	90.8	0.0	1.6	4.6	0.4	0.4	2.1	0.1	
564	96.6	0.0	0.2	0.7	0.3	1.5	0.6	0.1	
577	92.7	1.7	1.4	2.9	0.1	0.5	0.6	0.1	
583	88.9	2.2	2.2	5.2	0.3	0.2	1.0	0.0	
586	91.5	2.7	0.3	2.0	0.1	1.1	2.2	0.1	

Table A.5.2-14

Summary of Laboratory Porosity and Permeability Testing on the G_{mc} Coal

1. Average Static Properties

Sample	Porosity by Water Saturation (% B.V.)	Shrinkage (% Original B.V.)	Absolute Permeability*+(md) at: P_{ov} = 200 psig	P_{ov} = 400 psig	Pov As Indicated
WRG-1	20.8	7.0	2200 (N_2)		
WRG-2	21.6	8.8	2200 (N_2)		
WRG-3	18.9	4.5	2010 (N_2)		
WRG-4	21.3	6.7	1830 (N_2)		
WRG-5	19.4	5.0	6840 (N_2)		
WRG-6	19.3	8.0	419 (N_2)		166 (N_2) @P_{ov}=550 psig
WRG-7	20.3	7.6	736 (N_2)		405 (N_2) @ P_{ov}=550 psig
WRG-8	17.5	9.5	2721 (N_2)		1846 (N_2) @ P_{ov}=550 psig
WRG-9	19.1	8.6	722 (N_2)		P_{ov}=550 psig
Average	19.8	7.3	2186		673.5

*100% saturation with gas indicated in brackets.

+Direction of flow parallel to the bedding plane, Cleat orientation unknown.

B.V. = bulk volume (cc)

P_{ov} = simulated overburden pressure in psig = twice the Hassler-type sleeve pressure of the core holder

2. Average Critical Gas Saturation (percent of pore volume)

N_2(P_{ov} = 200 psig)	CO_2 (P_{ov} = 200 psig)	CO_2(P_{ov} = 400 psig)	N_2(P_{ov} as indicated)
12.5 (5)	--	--	31.7 (4) (@ P_{ov}=550 psig)

Figures A.5.2-1 to A.5.2-5 Effective Permeability to Gas in md at Simulated Overburden Pressure of 200 psig

k_g = the effective permeability to gas in md

S_w = water saturation as fraction of pore volume

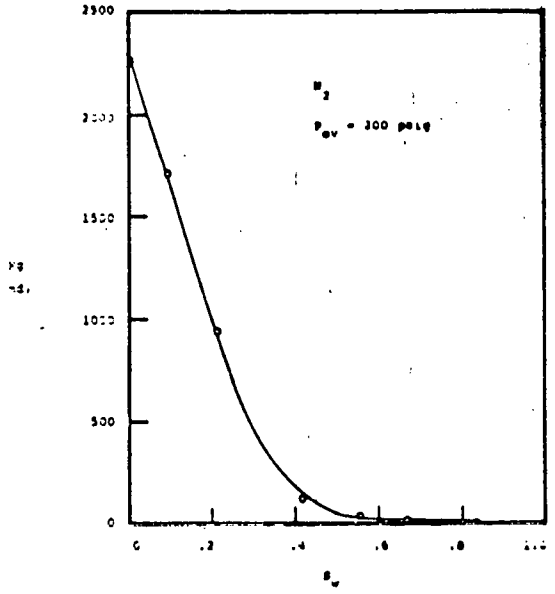


Figure A.5.2-1 [illegible]

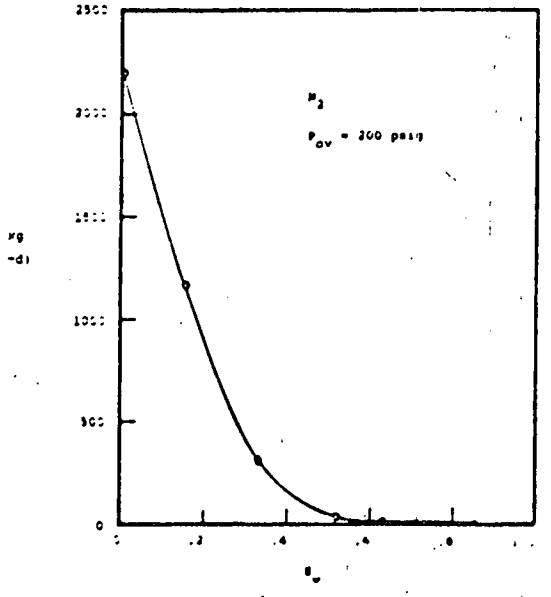


Figure A.5.2-1 [illegible]

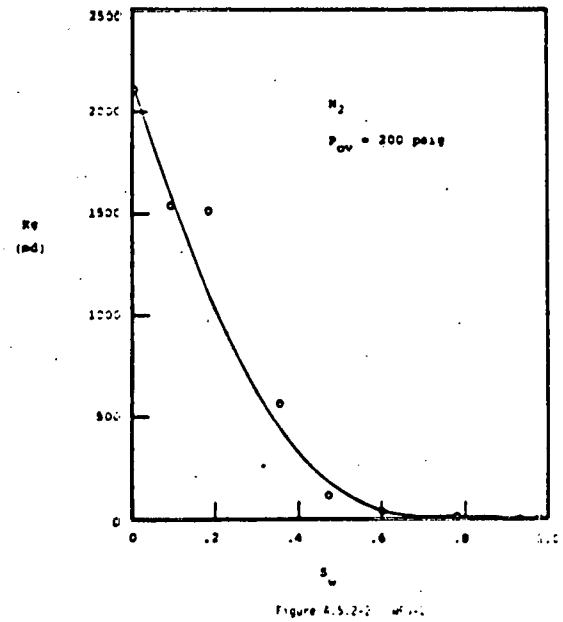


Figure A.5.2-2 [illegible]

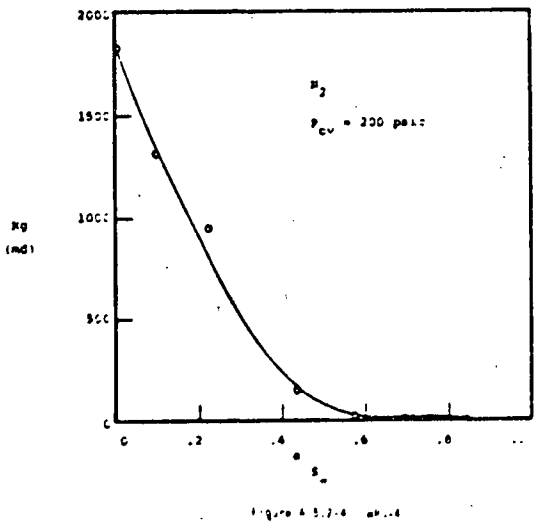


Figure A.5.2-4 [illegible]

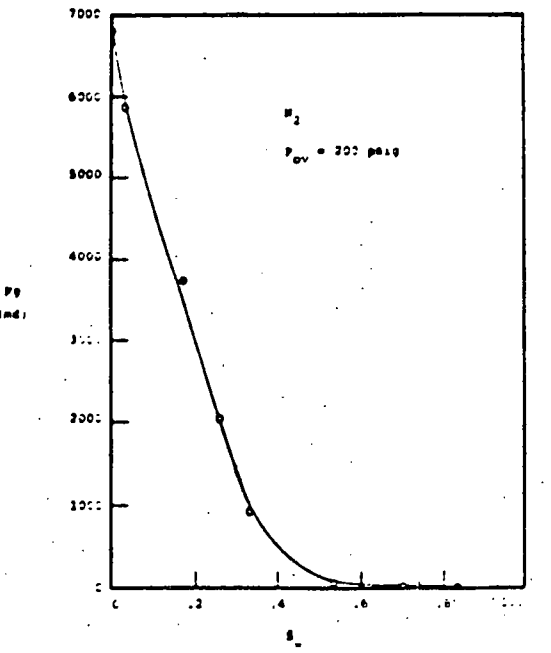
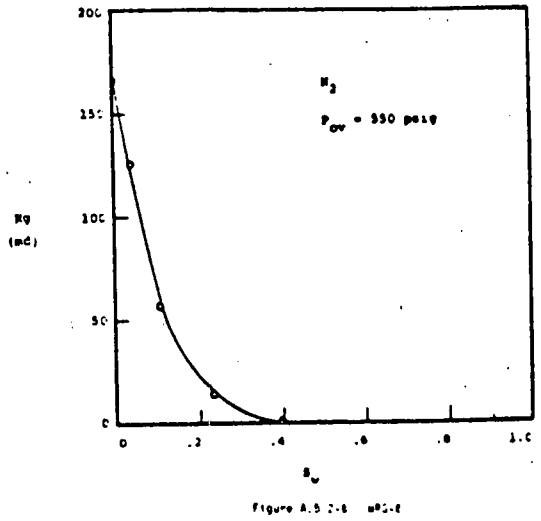
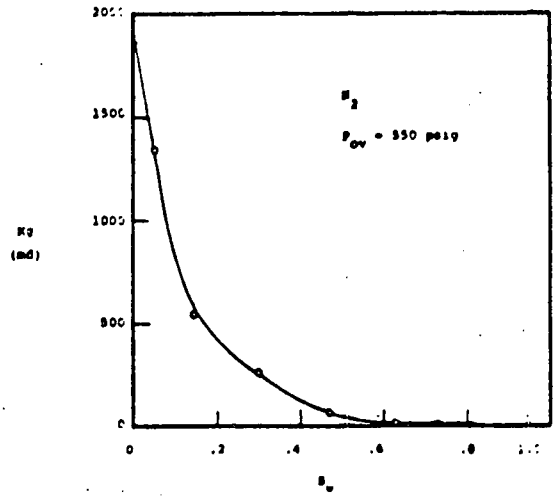
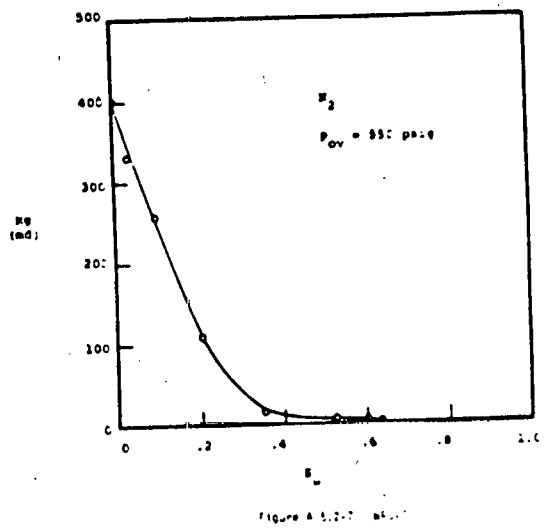
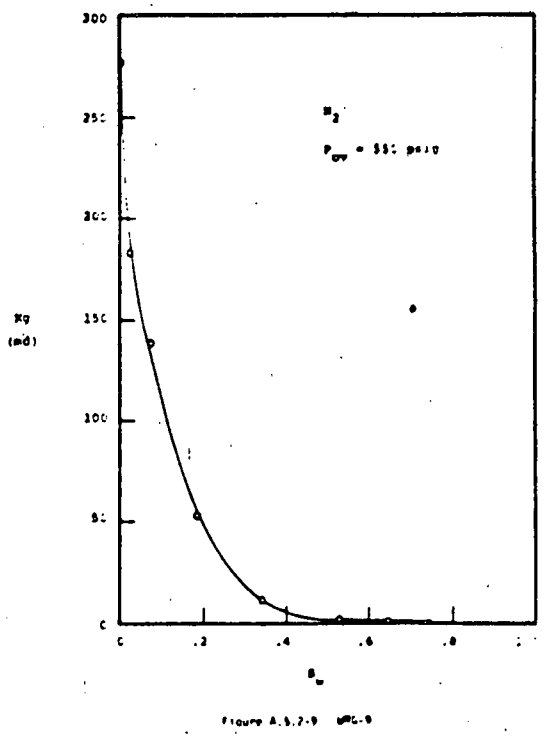


Figure A.5.2-5 [illegible]

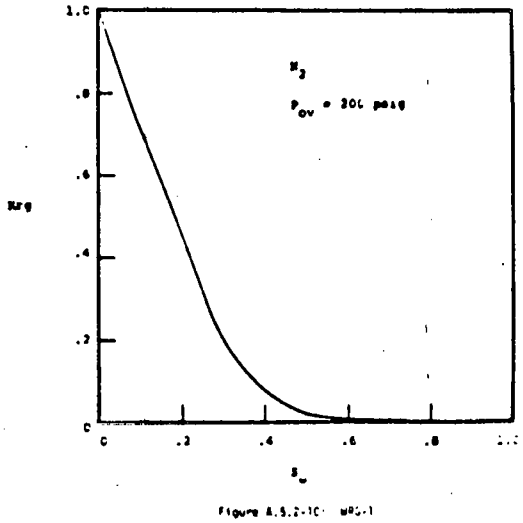


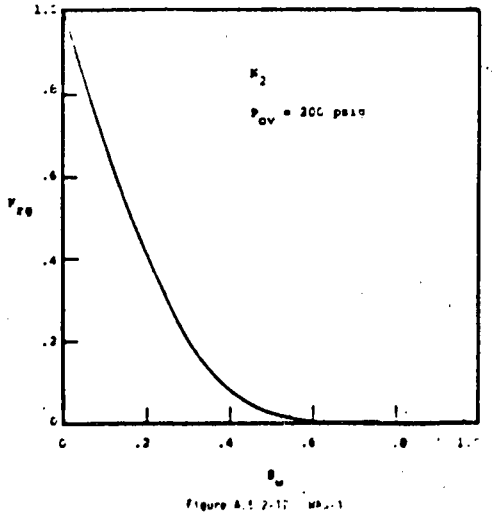


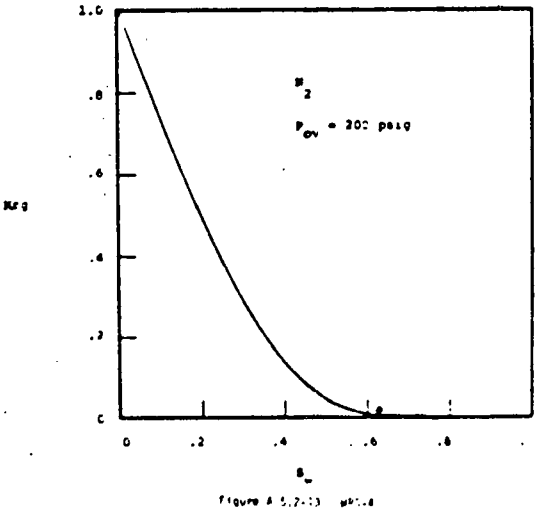


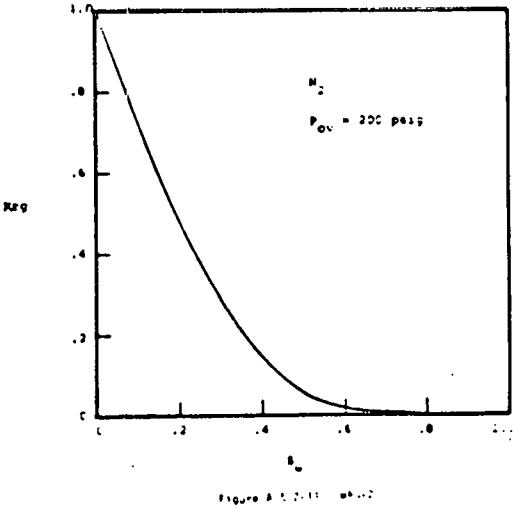


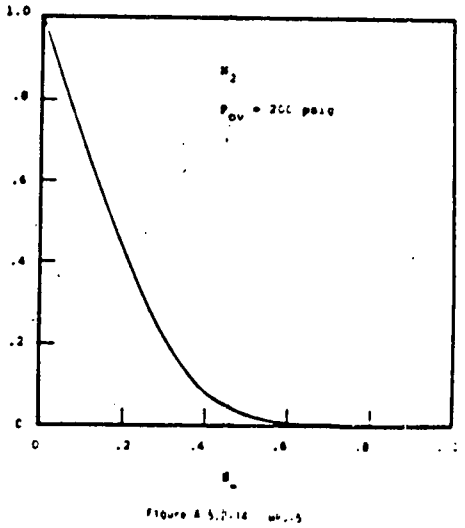
Figures A.5.2-6 to A.5.2-9 Effective Permeability to Gas in md at Simulated Overburden Pressure of 550 psig











Figures A.5.2-10 to A.5.2-14 Relative Permeability to Gas at 200 psig

Krg= the relative permeability to gas =

k_g/k_g @ $S_W = 0$

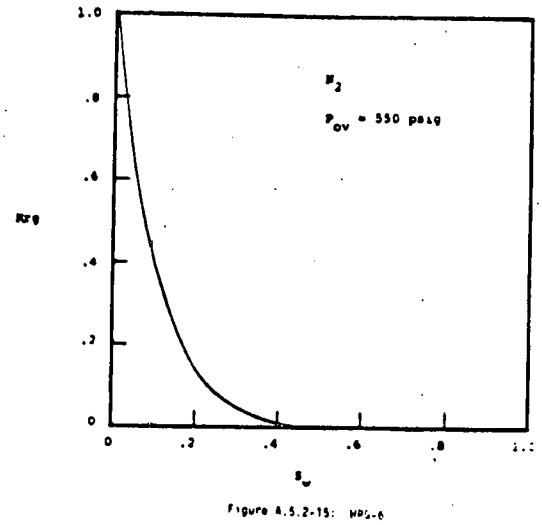


Figure A.5.2-15: MRG-6

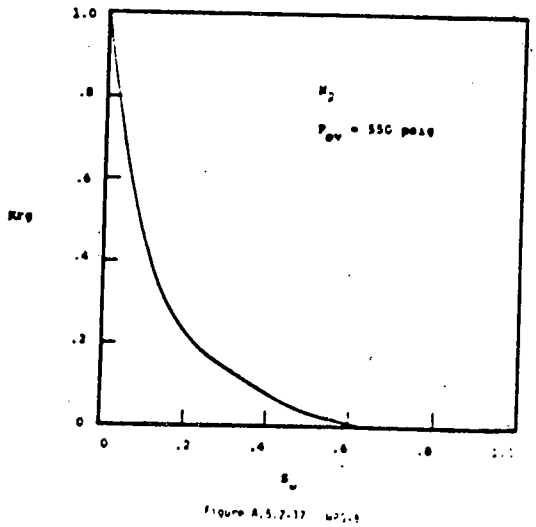


Figure A.5.2-17 MRG-8

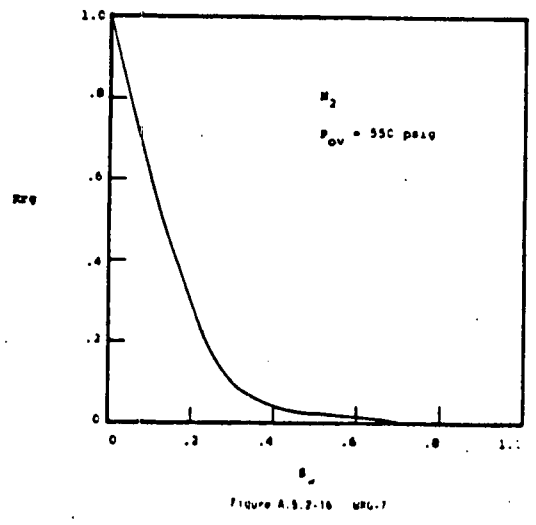


Figure A.5.2-16 MRG-7

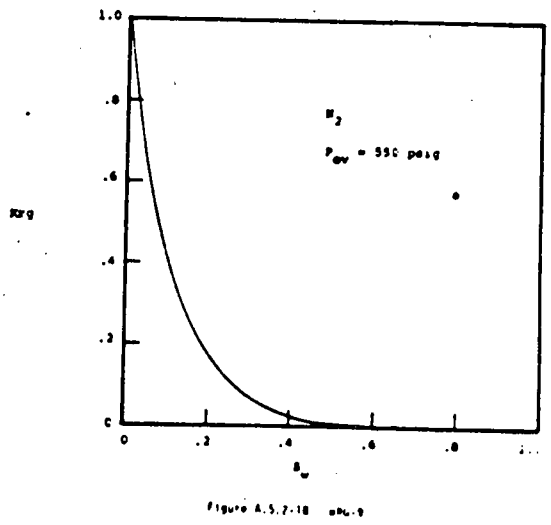


Figure A.5.2-18 MRG-9

Figures A.5.2-15 to A.5.2-18 Relative Permeabilities to Gas at 550 psig

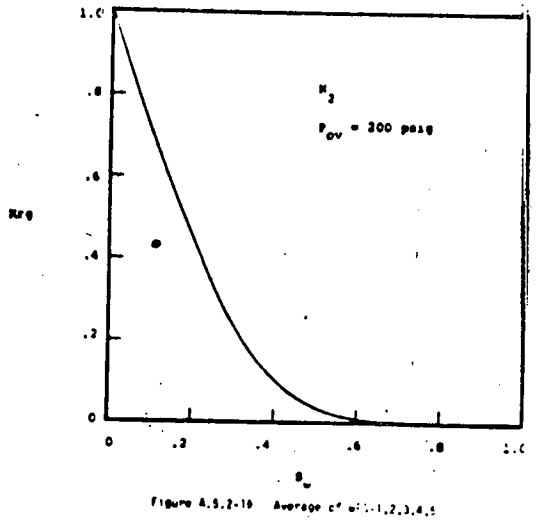


Figure A.5.2-19 Average c[illegible]

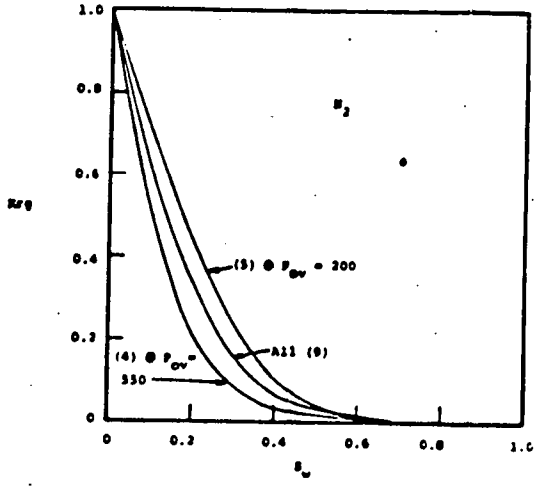


Figure A.5.2-21: Average Permeability to Gas of Rawlins Coal

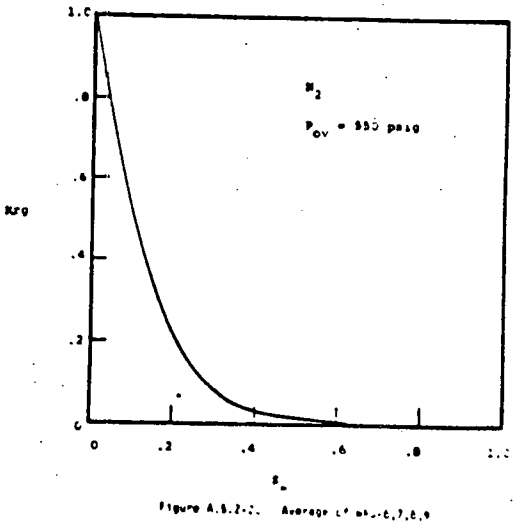


Figure A.5.2-[illegible] Average c[illegible]

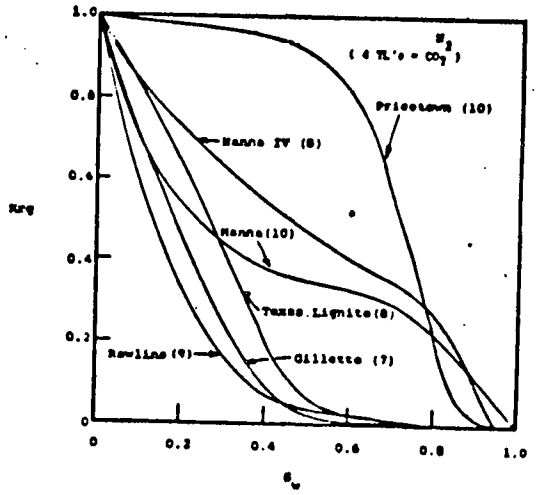


Figure A.5.2-22: Average Relative Permeability to Gas of Six Coals

Figures A.5.2-19 to A.5.2-22 Average Relative Permeabilities

A.6 HYDROLOGY

A.6.1 WATER SAMPLING PROGRAM

A.6.1.1 Introduction

A water sampling plan was developed to monitor the pre-gasification chemistry of the ground water in the G coal seam, and in the aquifers immediately above the coal. The plan consisted of:

1. Collecting water samples from 6 of the completed wells on a 3-month sampling interval so that seasonal variations in water quality could be assessed. The designated water monitoring wells are:

Well Number	Hydrologic Observation Zone
CH-2	G Coal
CH-4	G Coal
H-11	Aquifer Above G Coal
H-13	Aquifer Below G Coal
H-15	G Coal
P-1	G Coal

2. Determining the physical properties (temperature, pH, and conductivity) of the samples on-site.
3. Preserving the samples on-site in accordance with EPA-recommended procedures (EPA methods for chemical analysis of water and wastes, Section 4, pages 81-83, 197) and shipping the samples to water analysis laboratories.
4. Analyzing the water samples for inorganic metals, inorganic non-metals, organics and radioactivity. These are Al, As, Ba, B, Cd, Cu, Fe, Pb, Li, Mg, Hg, Mo, Total N_2, organic N_2, NO_3, NO_2, Ni, pH, K, Se, SiO_2, Na, SO_4, S, U, V, Zn, COD, oil, grease, phenols, total oxygen demand, and radioactivity.

A.6.1.2 Procedures

A 2-5 gal water sample was collected from each of six monitoring wells on the following dates:

Well Number	Date of Sampling
H-15	9/1/78
	9/15/78
	10/30/78
H-13	10/31/78
P-1	11/1/78
H-11	11/1/78
CH-4	11/2/78
CH-2	11/2/78

Water samples were obtained from the wells by the following procedures:

1. Well H-15 (on 9/1/78)

- measure the water level in the well.
- calculate the volume of water in the casing.
- install a cap with two pieces of copper tubing (1/2-inch O.D.) on the casing.
- lower a copper tubing line (1/2-inch O.D.) to within 2-5 foot of the bottom of the well screen and attach the tubing string to one of the pieces of tubing running through the casing cap.
- attach a 125 psi compressor to the well-head and pump air down the annulus between the casing and copper tubing. It was found that the compressed air could only displace approximately 1/2 of the water in the casing; therefore, nitrogen was substituted for the displacing fluid.
- inject nitrogen (supplied by Haliburton) into the annulus between the casing and copper tubing until all water was removed from the casing.
- allow the casing to recharge for 30 minutes.
- re-pressurize the casing with nitrogen.
- collect a two gal water sample and determine its physical characteristics.
- preserve the sample and ship it to the laboratory for analysis.
- measure the water level in the well.
- allow the well to recharge.
- measure the water level in the well.

2. Well H-15 (on 9/15/78 and 10/30/78):

- allow the water level in the well to recharge.
- measure the water level in the well.
- calculate the volume of water in the casing.
- displace the water standing in the copper tubing above the coal seam with compressed air.
- collect a two-gal water sample and determine its physical characteristics.
- preserve the sample and ship it to the laboratory for analysis.
- measure the water level in the well.

- refill the well with clean water to its pre-sampling level.
- measure the water level in the well.

3. Wells H-13, P-1, H-11, CH-3, CH-2 (on 10/31/78 to 11/2/78):

- allow wells to recharge after development work.
- measure the water level in the well.
- calculate the volume of water in the casing.
- install a submersible REDA pump in the well. Lower the pump into the casing to approximately 2-5 foot above the bottom of the well screen.
- calculate the volume of the casing taken up by the pump and connecting pipe and calculate the displaced water level in the casing.
- measure the water level in the casing and compare it to the calculated value.
- calculate the volume of water standing above the pump in the casing and pump the calculated volume out of the casing.
- measure the quantity of water pumped from the well at the surface.
- pump an additional 3-5 gal of water from the well for the water sample.
- determine the physical properties of the sample.
- preserve the sample and ship it to the laboratory for analysis.
- remove the pump from the casing.
- measure the water level in the well.
- calculate the volume of water needed to refill the casing to its pre-sampling level.
- refill the well with the pumped water to its pre-sampling level.
- measure the water level in the well.

A.6.1.3 Data

The data obtained from the water sampling program included the following:

- water analysis data for each sampled well (Table 5.5-1 in main report).
- physical property data for the water samples from each well (Table 5.5-2 in main report.)

A.6.2 Water Table Depth

Depth to water level measurements were taken in all wells shortly after their completion, prior to and after conducting well development and

water sampling activities, prior to and during the drawdown testing, and at frequent intervals between these activities. The depth measurements were converted to water table elevation and graphically illustrated. This work was completed by GR&DC hydrologic field personnel and subcontracted hydrologic consultants (Resource Consultants, Inc.).

All water level elevation measurements were made with a hand-held battery powered, electric sounder (Figure A.6-1A and B). All measurements were taken from the tops of the casing well head and were recorded to the nearest 0.01 foot. (The elevations of the casing wellhead were obtained by surveying techniques). The measured depths were converted to water-table elevations by subtracting the barometrically corrected depth from the elevation of the measuring point (top of the casing well head). An average water level for each well was calculated, and the potentiometric surface was defined by regression analysis. The water level measurement history for each well is shown in Tables A.6-1 to A.6-12. The graphic plots of the water levels are shown in Figures A.6-2 to A.6-13).

A.6.2.1 Data

The following data were obtained from the water level measurements:

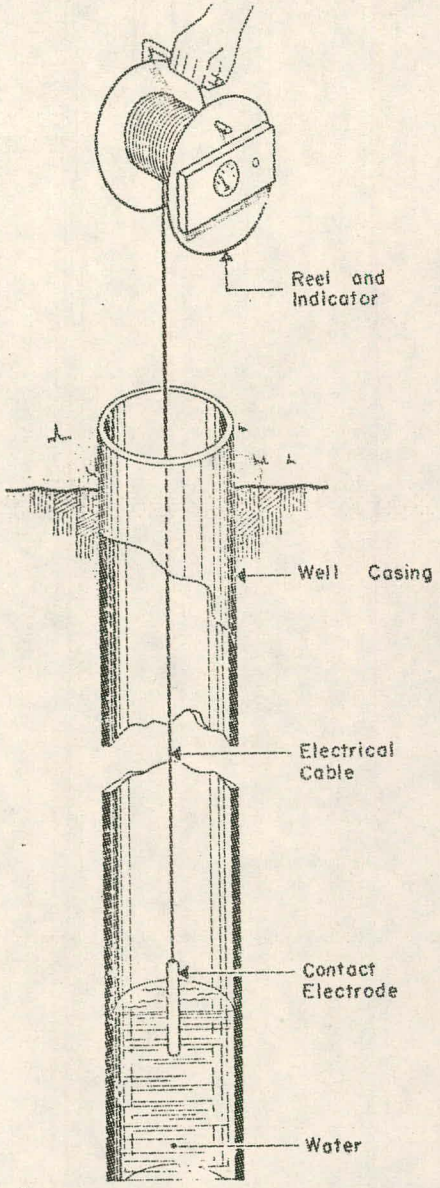
1. The water level measurement history for each well (Tables A.6-1 to A.6-12).
2. The graphic plots of the water level measurements for each well (Figures A.6-2 to A.6-13).

A.6.3 Drawdown Testing

A.6.3.1 Pump Installation

A pump was needed for the drawdown/recovery testing, which would meet the following criteria:

1. operate at varying, low-volume discharge rates (1-2 gpm).



A. Electric sounder for measuring depth to water consists of electrode, two-wire cable and ammeter which indicates a closed circuit when electrode touches water.

B. Water level measurements being taken

(Johnson Division, UOP Inc., Ground Water and Wells, Edward E. Johnson, Inc., Saint Paul, Minn. 1975, p. 89)

FIGURE A.6-1A and B

INSTRUMENTATION USED FOR WATER LEVEL MEASUREMENT

Table A.6-1

Water Level Elevation Measurements - Core Hole 1

Observation hole designation CH-1 Measuring point elevation (ft above MSL*) 6926.50

Observation Zone - GMC

Date	Time (hr:min)	Depth below measuring point (ft)	Water-table elevation (ft)	Activity
9/5/78	10:45			Well completed
9/13/78	No Data	92.50	6834.00	
9/22/78	No Data	91.50	6835.00	
10/12/78	No Data	92.00	6834.50	
10/19/78	No Data	91.42	6835.08	
10/30/78	No Data	99.50	6827.00	Well Development
10/31/78	11:00	93.75	6832.75	
11/01/78	a.m.	92.00	6834.50	
11/01/78	16:30	92.00	6834.50	
11/02/78	9:00	91.75	6834.75	
11/04/78	10:00	91.50	6835.00	
11/06/78	10:00	91.50	6835.00	
11/06/78	16:30-17:30	91.50	6835.00	
11/07/78	8:30-9:30	91.67	6834.83	
11/07/78	16:30-17:30	91.50	6835.00	
11/08/78	8:30-9:30	91.50	6835.00	
11/08/78	16:30-17:30	91.42	6835.08	
11/09/78	8:30-9:30	91.42	6835.08	
11/09/78	16:30-17:30	91.42	6835.08	
11/10/78	8:30-9:30	91.33	6835.17	
11/13/78	8:30	91.58	6834.92	
11/14/78	8:30-9:30	91.50	6835.00	
11/15/78	9:00-10:00	91.75	6834.75	
11/16/78	11:45-13:15	91.25	6835.25	
11/17/78	12:00-13:30	91.50	6835.00	
11/20/78	10:00-11:00	91.25	6835.25	
11/21/78	9:00-10:00	91.42	6835.08	
11/22/78	8:39-9:30	91.25	6835.25	
11/27/78	12:09	91.21	6835.29	
11/28/78	8:00			↑
11/29/78	11:55	91.25	6835.25	
11/30/78	10:35	91.30	6835.20	
12/01/78	17:02	91.30	6835.20	
12/02/78	15:23	91.28	6835.22	
12/03/78	15:09	91.30	6835.20	
12/04/78	11:56	91.30	6835.20	Drawdown testing
12/15/78	13:47	91.18	6835.32	
12/18/78	9:30	91.50	6835.00	
12/19/78	9:30	91.50	6835.00	
1/17/79	11:00	91.75	6834.75	
2/8/79	11:00	91.80	6834.70	
2/13/79	3:00	91.50	6835.00	↓

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*MSL = mean sea level

Table A.6-2

Water-Level Elevation Measurements - Core Hole 2

Observation hole designation Ch-2 Measuring point elevation (ft above MSL*) 6910.60

Observation Zone - GMC

Date	Time	Depth below measuring point (ft)	Water-table elevation (ft)	Activity
9/11/78	10:50			Well completed
9/13/78	No Data	64.60	6846.00	
9/22/78	No Data	69.60	6841.00	
10/12/78	No Data	73.50	6837.10	
10/19/78	No Data	73.33	6837.27	
10/30/78	No Data	99.83	6810.77	Well Development
10/31/78	11:00	99.75	6810.85	
11/01/78	a.m.	99.75	6810.85	
11/01/78	16:30	99.75	6810.85	
11/02/78	9:00	99.75	6810.85	
11/04/78	10:00	159.00	6751.60	↑
11/06/78	10:00	158.83	6745.77	
11/06/78	16:30-17:30	158.58	6752.02	
11/07/78	8:30-9:30	158.58	6752.02	
11/07/78	16:30-17:30	158.50	6752.10	
11/08/78	8:30-9:30	158.42	6752.18	Water sampling
11/08/78	16:30-17:30	158.50	6752.10	
11/09/78	8:30-9:30	158.17	6752.43	
11/09/78	16:30-17:30	158.00	6752.60	
11/10/78	8:30-9:30	157.83	6752.77	
11/13/78	8:30	157.17	6753.43	↓
11/13/78		104.58	6806.02	
11/14/78	8:30-9:30	103.50	6807.10	
11/15/78	9:00-10:00	104.00	6806.60	
11/16/78	11:45-13:15	103.42	6807.18	
11/17/78	12:00-13:30	103.67	6806.93	
11/20/78	10:00-11:00	103.50	6807.10	
11/21/78	9:00-10:00	103.25	6807.35	
11/22/78	8:30-9:30	103.58	6807.02	
11/27/78	12:02	103.30	6807.30	
11/28/78	8:00			↑
11/29/78	11:59	103.35	6807.25	
11/30/78	10:46	103.30	6807.30	
12/01/78	16:52	103.25	6807.35	
12/02/78	15:16	103.28	6807.32	
12/03/78	15:04	103.30	6807.30	Drawdown testing
12/04/78	11:52	103.23	6807.37	
12/15/78	13:43	103.03	6807.57	
12/18/78	9:45	102.10	6807.50	
12/19/78	9:45	102.00	6808.60	
1/17/79	11:10	103.16	6807.44	↓
2/8/79	11:10	102.80	6807.80	
2/13/79	3:10	102.50	6808.10	

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*MSL = mean sea level

Table A.6-3

Water-Level Elevation Measurements - Core Hole 3

Observation hole designation CH 3 Measuring point elevation (ft above MSL*) 6862.4

Observation Zone - GMC

Date	Time	Depth below measuring point (ft)	Water-table elevation (ft)	Activity
8/16/78	16:30			Well completed
8/25/78	No Data	52.90	6809.50	
9/06/78	No Data	58.70	6803.70	
9/13/78	No Data	62.90	6799.50	
9/22/78	No Data	63.40	6799.00	
10/12/78	No Data	66.50	6795.90	
10/19/78	No Data	66.42	6795.98	
10/25/78	10:40	66.70	6795.70	
10/25/78	17:10	83.40	6779.00	↑
10/26/78	9:55	81.80	6780.60	Well Development
10/30/78	No Data	81.25	6781.15	↓
10/30/78	No Data	65.00	6997.40	
10/31/78	11:00	65.00	6797.40	
11/01/78	a.m.	65.17	6797.23	
11/01/78	16:30	65.25	6797.15	
11/02/78	9:00	65.00	6797.40	
11/04/78	10:00	65.58	6796.82	
11/06/78	10:00	65.67	6796.73	
11/06/78	16:30-17:30	65.50	6796.90	
11/07/78	8:30-9:30	65.83	6796.57	
11/07/78	16:30-17:30	65.67	6796.73	
11/08/78	8:30-9:30	65.67	6796.73	
11/08/78	16:30-17:30	65.75	6796.65	
11/09/78	8:30-9:30	65.75	6796.65	
11/09/78	16:30-17:30	65.83	6796.57	
11/10/78	8:30-9:30	65.67	6796.73	
11/13/78	8:30	66.58	6796.82	
11/14/78	8:30-9:30	66.83	6795.57	
11/15/78	9:00-10:00	66.50	6795.90	
11/16/78	11:45-13:15	66.33	6796.07	
11/17/78	12:00-13:30	66.58	6995.82	
11/20/78	10:00-11:00	66.58	6795.82	
11/21/78	9:00-10:00	66.67	6795.73	
11/22/78	8:30-9:30	66.58	6795.82	
11/27/78	11:52	66.96	6795.44	
11/28/78	8:00			
11/29/78	11:42	67.05	6795.35	↑
11/30/78	10:26	67.00	6795.40	
12/01/78	17:07	67.10	6795.30	
12/02/78	15:38	67.05	6795.35	
12/03/78	15:19	67.15	6795.25	Drawdown testing
12/04/78	12:04	67.15	6795.25	
12/15/78	13:55	67.48	6794.92	
12/18/78	9:55	67.75	6794.65	
12/19/78	9:55	67.75	6794.65	
1/17/79	11:20	68.33	6794.07	
2/8/79	11:20	68.33	6794.07	
2/13/79	3:20	68.25	6794.15	↓

*MSL= mean sea level

Table A.6-4

Water-Level Elevation Measurements - Core Hole 4

Observation hole designation Ch-4 Measuring point elevation (ft. above MSL*) 6880.20

Observation Zone - GMC

Date	Time	Depth below measuring point (ft)	Water-table elevation (ft)	Activity
8/30/78	14:00			Well Completed
9/06/78	No Data	76.20	6804.0	
9/13/78	No Data	81.20	6799.0	
9/22/78	No Data	81.20	6799.0	
10/12/78	No Data	85.00	6795.20	
10/19/78	No Data	84.00	6796.20	
10/30/78	No Data	105.08	6775.12	Development
10/31/78	11:00	105.00	6775.0	
11/01/78	No Data	105.00	6775.0	
11/01/78	16:30	102.08	6778.12	
11/02/78	9:00	103.58	6776.62	
11/04/78	10:00	174.42	6705.78	
11/06/78	10:00	172.00	6708.20	
11/06/78	16:30-17:30	172.00	6708.20	
11/07/78	8:30-9:30	171.25	6708.95	
11/07/78	16:30-17:30	171.00	6709.20	
11/08/78	8:30-9:30	170.42	6709.78	Water sampling
11/08/78	16:30-17:30	169.83	6710.37	
11/09/78	8:30-9:30	169.33	6710.87	
11/09/78	16:30-17:30	169.67	6710.53	
11/10/78	8:30-9:30	169.33	6710.87	
11/13/78	No Data	167.25	6712.95	
11/13/78	No Data	102.50	6777.70	
11/14/78	8:30-9:30	101.67	6778.53	
11/15/78	9:00-10:00	102.17	6778.03	
11/16/78	11:45-13:15	101.67	6778.53	
11/17/78	12:00-13:30	102.00	6778.20	
11/20/78	10:00-11:00	101.83	6778.37	
11/21/78	9:00-10:00	101.83	6778.37	
11/27/78	11:48	101.71	6778.49	
11/28/78	8:00			
11/29/78	11:37	101.63	6778.57	
11/30/78	10:17	101.60	6778.60	
12/01/78	16:44	101.53	6778.67	
12/02/78	15:02	101.55	6778.65	
12/03/78	14:51	101.50	6778.70	Drawdown testing
12/04/78	11:41	101.38	6778.82	
12/15/78	13:30	100.03	6779.17	
12/18/78	10:00	100.08	6780.12	
12/19/78	10:00	100.16	6780.04	
2/17/79	11:30	100.16	6780.04	
2/08/79	11:30	99.80	6780.40	
2/13/79	3:30	99.75	6780.45	

*MSL = mean sea level

Table A.6-5

Water-Level Elevation Measurements - H-7

Observation hole designation H-7 Measuring point elevation (ft above MSL*) 6893.73

Observation Zone - GMC

Date	Time	Depth below measuring point (ft)	Water-table elevation (ft)	Activity
10/05/78	14:51			Well completed
10/12/78	No Data	55.00	6838.73	
10/19/78	No Data	52.50	6841.23	
10/30/78	No Data	56.42	6837.31	Well Development
10/31/78	11:00	53.42	6840.31	
11/01/78	a.m.	53.58	6840.15	
11/01/78	16:30	53.42	6840.31	
11/02/78	9:00	53.33	6840.40	
11/04/78	10:00	53.00	6840.73	
11/06/78	10:00	50.67	6843.06	
11/06/78	16:30-17:30	53.25	6840.48	
11/07/78	8:30-9:30	53.00	6840.73	
11/07/78	16:30-17:30	53.00	6840.73	
11/08/78	8:30-9:30	53.00	6840.73	
11/08/78	16:30-17:30	52.67	6841.06	
11/09/78	8:30-9:30	52.50	6841.23	
11/09/78	16:30-17:30	52.42	6840.31	
11/10/78	8:30-9:30	52.00	6841.73	
11/13/78	No Data	54.08	6839.65	
11/14/78	8:30-9:30	54.50	6839.23	
11/15/78	9:00-10:00	54.50	6839.23	
11/16/78	11:45-13:15	54.25	6839.48	
11/17/78	12:00-13:30	54.25	6839.48	
11/20/78	10:00-11:00	54.54	6839.23	
11/21/78	9:00-10:00	54	6839.15	
11/27/78	11:19	54.77	6838.96	
11/28/78	9:03	54.80	6838.93	↑
11/29/78	11:27	54.85	6838.88	
11/30/78	10:11	54.86	6838.87	
12/01/78	9:00	54.85	6838.88	
12/01/78	16:28	54.90	6838.83	
12/02/78	7:44	55.24	6838.49	
12/02/78	14:40	55.00	6838.73	Drawdown testing
12/03/78	7:56	55.00	6838.73	
12/04/78	10:37	55.00	6838.73	
12/05/78	13:31	55.00	6838.73	
12/06/78	9:04	55.15	6838.58	
12/15/78	9:00+	55.29	6838.44	
12/18/78	10:10	55.08	6838.65	
12/19/78	10:10	55.16	6838.49	
1/17/79	11:45	56.92	6836.81	
2/8/79	11:45	57.33	6836.40	
2/13/79	3:40	56.80	6836.93	↓

*MSL = mean sea level

Table A.6-6

Water-Level Elevation Measurements - H-8

Observation designation H-8 Measuring point elevation (ft above MSL*) 6888.86

Observation Zone - GMC

Date	Time	Depth below measuring point (ft)	Water-table elevation (ft)	
9/26/78	15:00			Well completed
10/12/78	No Data	63.50	6825.36	
10/19/78	No Data	61.83	6827.03	
10/30/78	No Data	63.58	6825.28	Well development
10/31/78	11:00	92.33	6796.53	
11/01/78	a.m.	91.25	6797.61	
11/01/78	16:30	91.33	6797.53	
11/02/78	9:00	91.17	6797.69	
11/04/78	10:00	91.00	6797.86	
11/06/78	10:00	90.92	6997.94	
11/06/78	16:30-17:30	90.83	6798.03	
11/07/78	8:30-9:30	89;83	6799.03	
11/07/78	16:30-17:30	90.58	6798.28	
11/08/78	8:30-9:30	90.83	6998.03	
11/08/78	16:30-17:30	89.83	6799.03	
11/09/78	8:30-9:30	91.00	6797.86	
11/09/78	16:30-17:30	90.75	6798.11	
11/10/78	8:30-9:30	90.58	6798.28	
11/13/78	8:30	90.42	6998.44	
11/14/78	8:30-9:30	90.42	6798.44	
11/15/78	9:00-10:00	90.33	6998.53	
11/16/78	11:45-13:15	90.00	6998.86	
11/17/78	12:00 13:00	90.00	6798.86	
11/20/78	10:00-11:00	90.08	6798.78	
11/21/78	9:00-10:00	89.92	6798.94	
11/27/78	11:21	89.75	6799.11	
11/28/78	8:57	89.65	6799.21	
11/29/78	11:10	89.55	6999.31	
11/30/78	9:55	89.55	6799.31	
12/01/78	8:57	89.50	6799.36	
12/01/78	16:22	89.60	6799.26	
12/02/78	7:38	89.40	6799.46	
12/02/78	14:36	89.55	6799.31	
12/03/78	7:46	89.51	6799.35	Drawdown testing
12/04/78	11:12	89.52	6799.34	
12/05/78	13:27	89.40	6799.46	
12/06/78	9:23	89.35	6799.51	
12/15/78	9:00	89.69	6799.17	
12/18/78	10:15	89.00	6799.86	
12/19/78	10:15	89.08	6799.78	
1/17/79	12:00	89.92	6798.94	
2/8/79	12:00	90.50	6708.36	
2/13/79	3:55	90.25	6798.75	

*MSL = mean sea level

Table A.6-7

Water-Level Elevation Measurements H-9

Observation hole designation H-9 Measuring point elevation (ft above MSL*) 6884.49

Observation Zone - GMC

Date	Time	Depth below measuring point (ft)	Water-table elevation (ft)	Activity
10/17/78	9:55			Well completed
10/30/78	No Data	122.00	6762.49	Well development
10/31/78	11:00	124.00	6760.49	
11/01/78	No Data	123.58	6760.91	
11/01/78	16:30	123.67	6760.82	
11/02/78	9:00	123.17	6761.32	
11/04/78	10:00	123.42	6761.07	
11/06/78	10:00	122.83	6761.66	
11/06/78	16:30-17:30	123.25	6761.24	
11/07/78	8:30-9:30	123.00	6761.49	
11/07/78	16:30-17:30	122.67	6761.82	
11/08/78	8:30-9:30	122.75	6761.74	
11/08/78	16:30-17:30	122.42	6762.07	
11/09/78	8:30-9:30	121.75	6762.74	
11/09/78	16:30-17:30	122.50	6761.99	
11/10/78	8:30-9:30	122.67	6761.82	
11/13/78	8:30	122.58	6761.91	
11/14/78	8:30-9:30	121.75	6762.74	
11/15/78	9:00-10:00	121.83	6762.66	
11/16/78	11:45-13:15	121.33	6762.16	
11/17/78	12:00-13:30	121.50	6762.99	
11/20/78	10:00-11:00	121.17	6763.32	
11/21/78	9:00-10:00	121.00	6763.49	
11/27/78	11:24	121.03	6763.46	
11/28/78	8:55	120.72	6763.77	
11/29/78	11:04	120.55	6763.94	
11/30/78	9:50	120.55	6763.94	
12/01/78	8:53	120.58	6763.91	
12/01/78	16:20	120.50	6763.99	
12/02/78	7:25	120.41	6764.08	
12/02/78	14:32	120.42	6764.07	
12/03/78	7:42	120.24	6764.25	
12/04/78	11:07	120.28	6764.21	Drawdown testing
12/05/78	13:25	120.25	6764.24	
12/06/78	9:18	120.18	6764.31	
12/15/78	9:00+	119.96	6764.53	
12/18/78	10:20	119.75	6764.83	
1/17/79	12:15	119.16	6764.33	
2/08/79	12:15	118.56	6764.93	
2/13/79	4:05	118.33	6765.16	

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*MSL = mean sea level

Table A.6-8

Water-Level Elevation Measurements - H-11

Observation hole designation H-11 Measuring point elevation (ft above MSL*) 6893.90

Observation Zone - Aquifer Below G Coal

Date	Time	Depth below measuring point (ft)	Water-table elevation (ft)	Activity
10/02/78	8:30			Well completed
12/12/78	No Data	78.00	6815.90	
10/19/78	No Data	66.83	6827.07	
10/30/78	No Data	88.25	6805.65	Well development
10/31/78	11:00	86.92	6806.98	
11/01/78	a.m.	86.83	6807.07	
11/01/78	16:30	135.83	6758.07	
11/02/78	9:00	133.67	6760.23	
11/04/78	10:00	129.75	6764.15	
11/06/78	10:00	125.83	6768.07	
11/06/78	16:30-17:30	125.00	6768.90	
11/07/78	8:30-9:30	124.08	6769.83	
11/07/78	16:30-17:30	123.50	6770.40	Water sampling
11/08/78	8:30-9:30	122.25	6771.65	
11/08/78	16:30-17:30	121.75	6772.15	
11/09/78	8:30-9:30	120.50	6773.40	
11/09/78	16:30-17:30	120.25	6773.65	
11/10/78	8:30-9:30	119 00	6774.90	
11/13/78	8:30	114.83	6779.07	
11/13/78	No Data	87.75	6806.15	
11/14/78	8:30-9:30	87.33	6806.57	
11/15/78	9:00-10:00	87.75	6806.15	
11/16/78	11:45-13:15	87.17	6806.73	
11/17/78	12:00-13:30	87.50	6806.40	
11/20/78	10:00-11:00	87.42	6806.48	
11/21/78	9:00-10:00	87.50	6806.40	
11/27/78	11:17	87.95	6805.95	
11/28/78	9:05	87.79	6806.11	
11/29/78	11:21	87.95	6805.95	
11/30/78	10:05	87.90	6806.00	
12/01/78	9:03	87.95	6805.95	
12/01/78	16:27	88.00	6805.90	
12/02/78	14:46	87.95	6805.95	
12/03/78	7:53	87.93	6805.97	
12/04/78	11:23	87.90	6806.00	
12/05/78	13:34	87.96	6805.94	Drawdown testing
12/06/78	9:09	88.02	6805.88	
12/15/78	9:00+	88.54	6805.36	
12/18/78	10:25	88.66	6805.24	
12/19/78	10:25	88.08	6805.82	
1/17/79	12:30	88.92	6804.98	
2/08/79	12:40	88.75	6805.15	
2/13/79	4:10	88.56	6805.34	

*MSL = mean seal level

Table A.6-9

Water-Level Elevation Measurements - H-12

Observation hole designation H-12 Measuring point elevation (ft. above MSL*) 6887.50

Observation Zone - GMC

Date	Time	Depth below measuring point (ft)	Water-table elevation (ft)	
9/16/78	8:30			Well completion
10/12/78	No Data	61.00	6826.50	
10/19/78	No Data	59.08	6828.42	
10/30/78	No Data	63.67	6823.83	Well development
10/31/78	11:00	64.50	6823.00	
11/01/78	No Data	64.75	6822.75	
11/01/78	16:30	64.67	6822.83	
11/02/78	9:00	64.50	6823.00	
11/04/78	10:00	65.00	6822.50	
11/06/78	10:00	65.00	6822.50	
11/06/78	16:30-17:30	64.83	6822.67	
11/07/78	8:30-9:30	64.83	6822.67	
11/07/78	16:30-1730	64.83	6822.67	
11/08/78	8:30-9:30	64.83	6822.67	
11/08 78	16:30-17:30	64.83	6822.67	
11/09/78	8:30-9:30	64.83	6822.67	
11/09/78	16:30-17:30	65.17	6822.33	
11/10/78	8:30-9:30	64.83	6822.67	
11/13/78	No Data	65.00	6822.50	
11/14/78	8:30-9:30	64.92	6822.58	
11/15/78	9:00-10:00	65.08	6822.42	
11/16/78	11:45-13:15	64.92	6822.58	
11/17/78	12:00-13:30	65.00	6822.50	
11/20/78	10:00-11:00	65.00	6822.50	
11/21/78	9:00-10:00	65.08	6822.42	
11/22/78	8:30-9:30	65.00	6822.50	
11/27/78	11:31	65.25	6822.25	
11/28/78	8:50	65.30	6822.20	
11/29/78	11:16	65.25	6822.25	
11/30/78	9:59	65.23	6822.27	
12/01/78	9:06	65.35	6822.15	
12/01/78	16:25	65.43	6822.07	
12/02/78	7:34	65.24	6822.26	
12/02/78	14:52	65.36	6822.14	
12/03/78	7:50	65.15	6822.35	
12/04/78	11:33	65.32	6822.18	Drawdown testing
12/05/78	13:35	65.33	6822.17	
12/06/78	9:29	65.37	6822.13	
12/15/78	9:00+	65.65	6821.85	
12/18/78	10:30	65.80	6821.70	
12/19/78	10:30	65.75	6821.75	
1/17/79	12:40	66.40	6822.10	
2/08/79	12:45	66.66	6821.84	
2/13/79	4:15	67.16	6822.34	

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*MSL - mean sea level

Table A.6-10

Water-Level Elevation Measurements - H 13

Observation hole designation H-13 Measuring point elevation (ft above MSL*) 6884.49

Observation Zone - Aquifer Above G Coal

Date	Time	Depth below measuring point (ft)	Water-table elevation (ft)	Activity
10/12/78	9:40			Well completed
10/27/78	No Data	109.00	6775.49	
10/30/78	No Data	72.67	6811.82	Well Development
10/31/78	11:00	73.08	6811.41	
10/31/78	No Data	135.42	6749.07	
11/01/78	No Data	135.00	6749.49	
11/01/78	16:30	200.02	6683.57	
11/02/78	9:00	200.00	6684.49	
11/04/78	10:00	197.25	6687.24	
11/06/78	10:00			
11/06/78	16:30-17:30	195.83	6688.66	Water sampling
11/07/78	8:30-9:30	195.00	6689.49	
11/07/78	16:30-17:30	194.50	6889.99	
11/08/78	8:30-9:30	193.83	6690.66	
11/08/78	16:30-17:30	190.67	6693.83	
11/09/78	8:30-9:30	189.75	6694.74	
11/09/78	16:30-17:30	189.58	6694.91	
11/10/78	8:30-9:30	192.50	6691.99	
11/13/78	8:30	190.50	6693.99	
11/13/78	No Data	122.75	6761.74	
11/14/78	8:30-9:30	122.17	6762.32	
11/15/78	9:00-10:00	122.33	6762.16	
11/16/78	11:45-13:15	121.58	6762.91	
11/17/78	12:00-13:00	121.67	6762.82	
11/20/78	10:00-11:00	121.17	6763.32	
11/21/78	9:00-10:00	121.00	6763.49	
11/22/78	8:30-9:30	120.83	6763.66	
11/27/78	11:28	120.15	6764.34	
11/28/78	8:53	119.90	6764.59	
11/29/78	11:01	119.85	6764.64	
11/30/78	9:31	119.70	6764.79	
12/01/78	8:48	119.55	6764.94	
12/01/78	16:16	119.55	6764.94	
12/02/78	7:30	119.58	6764.91	
12/02/78	14:28	119.50	6764.99	
12/03/78	7:39	119.53	6764.96	
12/04/78	11:02	119.25	6765.24	Drawdown testing
12/05/79	13:23	119.18	6765.31	
12/06/78	9:14	118.98	6765.51	
12/15/78	9:00+	118.42	6766.07	
12/18/78	10:35	118.53	6784.83	
12/19/78	10:35	118.08	6766.41	
1/17/79	12:45	116.75	6767.74	
2/08/79	12:55	115.56	6768.93	
2/13/78	4:20	115.25	6769.24	

*MSL = mean sea level

Table A.6-11

Water-Level Elevation Measurements - H-15

Observation hole designation H-15 Measuring point elevation (ft above MSL*) 6860.6

Observation Zone - GMC

Date	Time	Depth below measuring point (ft)	Water-table elevation (ft)	Activity
8/1/78	12:30			Well completed
8/17/78	No Data	89.60	6771.000	
8/25/78	No Data	89.60	6771.00	
9/01/78	No Data			Well Development & sampling
9/05/78	No Data			Water sampling
9/06/78	10:00	132.00	6728.40	
9/07/78	15:00	130.60	6730.00	
9/08/78	15:15	128.10	6732.50	
9/09/78	14:45	125.60	6735.00	
9/10/78	15:20	123.90	6736.70	
9/13/78	15:30	119.10	6741.50	
9/22/78	No Data	116.10	6744.50	
10/12/78	No Data	100.00	6860.60	
10/19/78	No Data	97.42	6763.18	
10/30/78	No Data	97.08	6763.52	Water sampling
11/01/78	No Data	115.50	6745.10	
11/02/78	9:00	113.50	6747.10	
11/04/78	10: 00	110.67	6749.93	
11/06/78	10:00	108.33	6752.27	
11/07/78	8:30-9:30	107.67	6752.93	
11/08/78	8:30-9:30	106.25	6754.35	
11/09/78	8:30-9:30	106.08	6754.52	
11/10/78	8:30-9:30	106.00	6754.60	
11/13/78	8:30	102.33	6758.27	
11/14/78	8:30-9:30	102.00	6758.60	
11/15/78	9:00-10:00	101.33	6759.27	
11/16/78	11:45-13:15	100.67	6759.93	
11/17/78	12:00-13:30	100.50	6760.10	
11/20/78	10:00-11:00	99.83	6760.77	
11/21/78	9:00-10:00	99.50	6861.10	
11/22/78	8:30-9:30	99.42	6761.18	
11/28/78	8:00			
12/03/78	15:28	96.08	6764.52	↑
12/04/78	12:12	95.85	6764.75	
12/05/78	15:48	95.65	6764.95	
12/15/78	14:02	9554	6766.06	Drawdown testing
12/18/78	10:45	94.50	6766.10	
12/19/78	10:45	94.50	6766.10	
2/13/79				↓

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*MSL = mean sea level

Table A.6-12

Water-Level Elevation Measurements - P-1

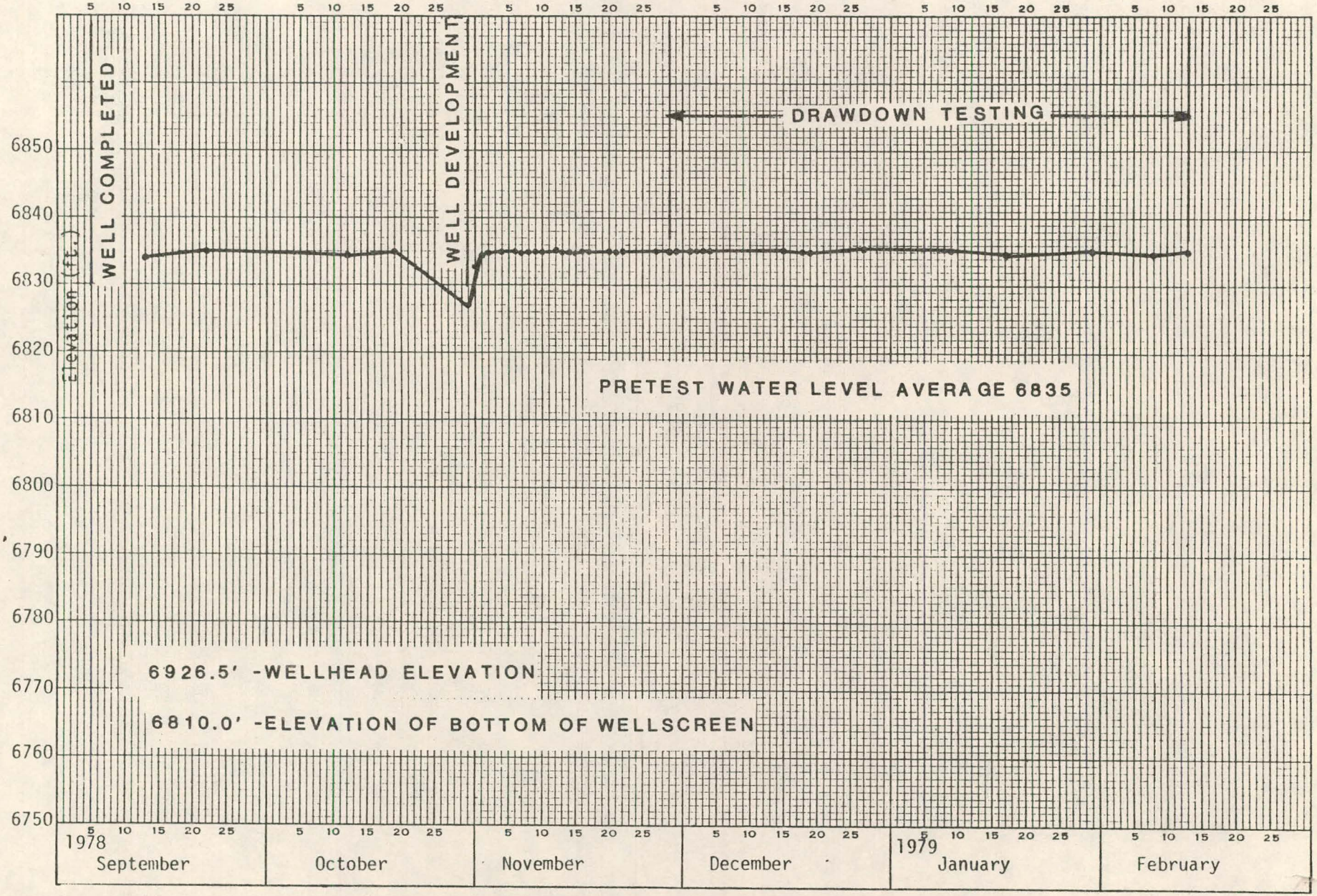
Observation hole designation P-1 Measuring point elevation (ft above MSL*) 6888.76

Observation Zone - GMC

Date	Time	Depth below measuring point (ft)	Water-table elevation (ft)	Activity
9/22/78	11:05			Well completed
10/12/78	No Data		6810.76	
10/19/78	No Data		6810.68	
10/30/78	No Data	98.08	6790.68	Well development
10/31/78	11:00	97.50	6791.26	
11/01/78	No Data	97.17	6791.59	
11/01/78	13:00	97.00	6791.76	
11/01/78	16:30	204.58	6684.18	
11/02/78	9:00	201.25	6687.51	
11/04/78	10:00	199.50	6689.26	
11/06/78	10:00	194.33	6694.43	
11/06/78	16:30-17:30	195.25	6693.51	
11/07/78	8:30-9:30	194.58	6694.18	
11/07/78	16:30-17:30	194.25	6694.51	Water sampling
11/08/78	8:30-9:30	193.58	6695.25	
11/08/78	16:30-17:30	191.17	6697.59	
11/09/78	8:30-9:30	189.50	6699.26	
11/09/78	16:30-17:30	215.83	6672.93	
11/10/78	8:30-9:30	217.50	6671.26	
11/13/78	8:30	213.67	6675.09	
11/13/78	No Data	92.92	6795.84	
11/14/78	8:30-9:30	93.50	6795.26	
11/15/78	9:00-10:00	94.17	6794.59	
11/16/78	11:45-13:15	94.33	6794.43	
11/17/78	12:00-13:30	94.50	6794.26	
11/21/78	9:00-10:00	94.67	6794.09	
11/22/78	8:30-9:30	94.83	6793.93	
11/27/78	11:12	94.70	6794.06	
11/28/78	8:48	95.10	6793.66	
11/28/78	15:00	104.00	6784.76	
11/29/78	10:50	102.92	6785.84	
11/30/78	9:26	103.65	6785.11	
11/30/78	18:45	333.90	6554.86	
12/01/78	8:37	330.65	6558.11	
12/01/78	16:05	455.27	6433.49	
12/02/78	8:32	455.35	6433.41	
12/03/78	7:50	451.45	6437.31	
12/03/78	15:56	450.65	6483.11	
12/04/78	10:37	448.32	6444.44	
12/05/78	13:10	444.40	6444.36	
12/05/78	15:28	456.13	6432.63	Drawdown testing
12/05/78	16:09	455.87	6432.89	
12/06/78	8:51	453.35	6435.41	
12/15/78	No Data	could not measure	6435.41	
12/18/78	10:40	413.50	6475.26	
12/19/78	10:40	413.50	6475.26	
1/17/79	1:00	469.00	6419.76	
2/8/79	1:30	443.00	6445.76	
2/13/79	5:00	436.00	6452.76	

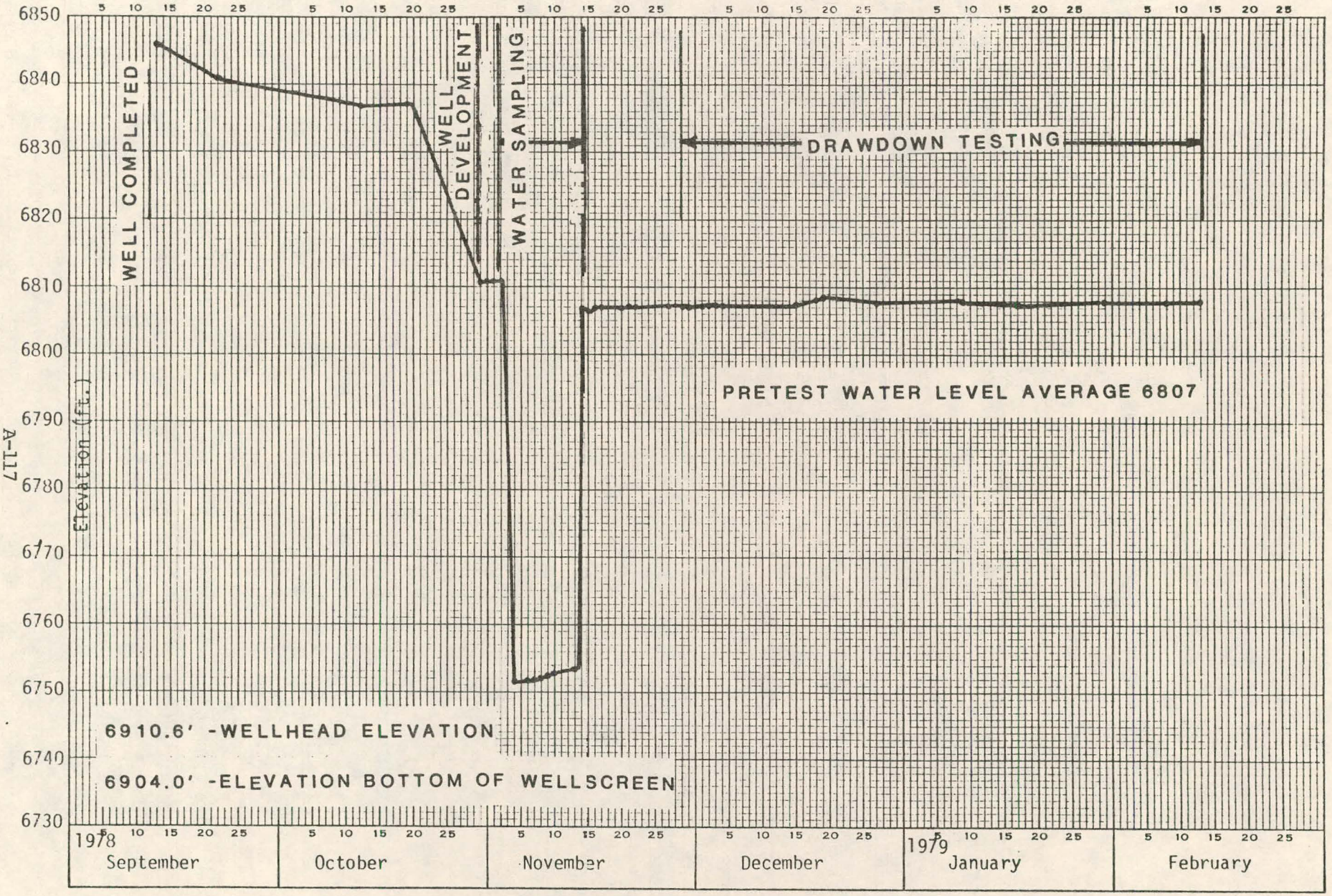
*MSL = mean sea level

Figure A.6-2



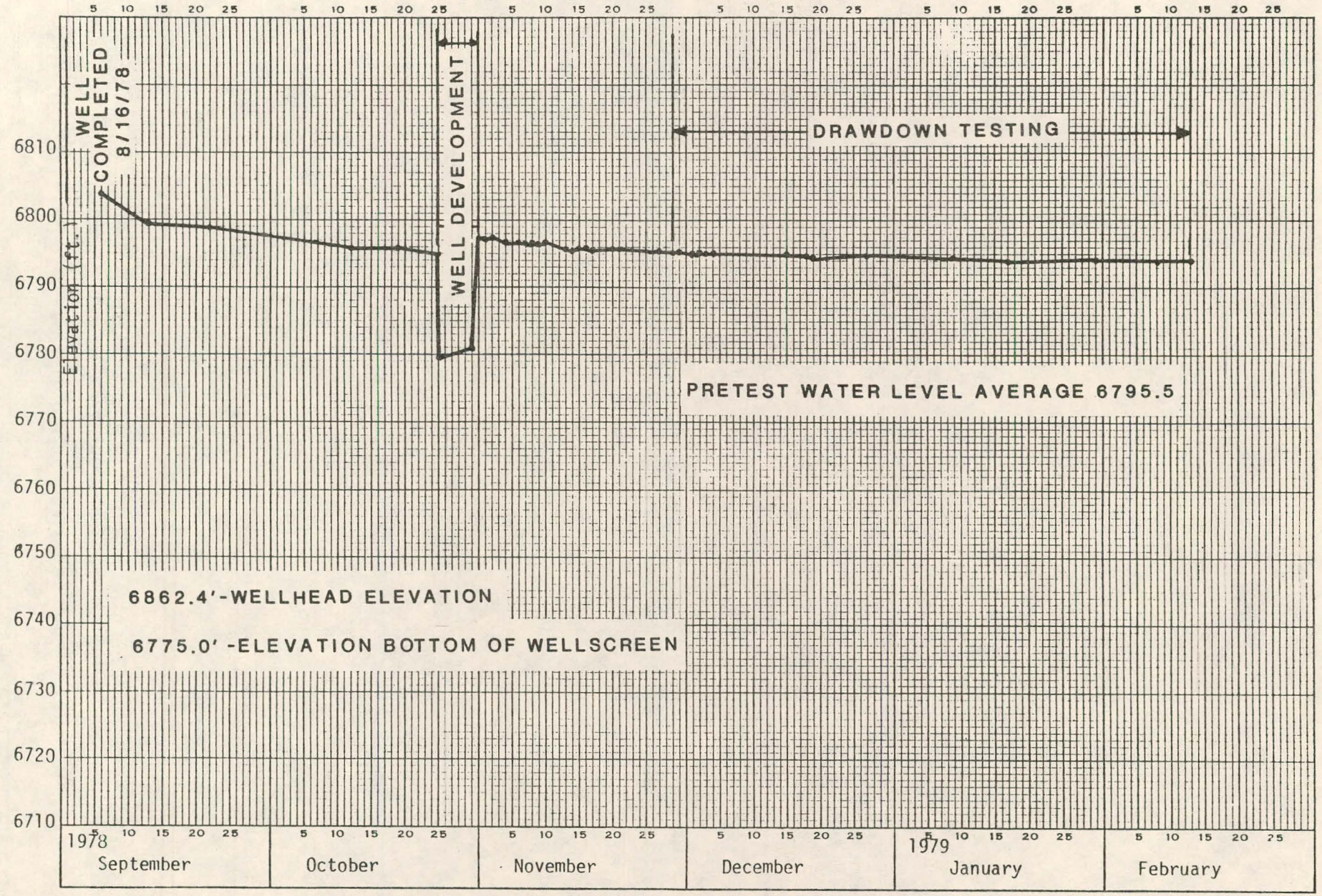
WATER LEVEL ELEVATIONS IN CORE HOLE 1

Figure A.6-3



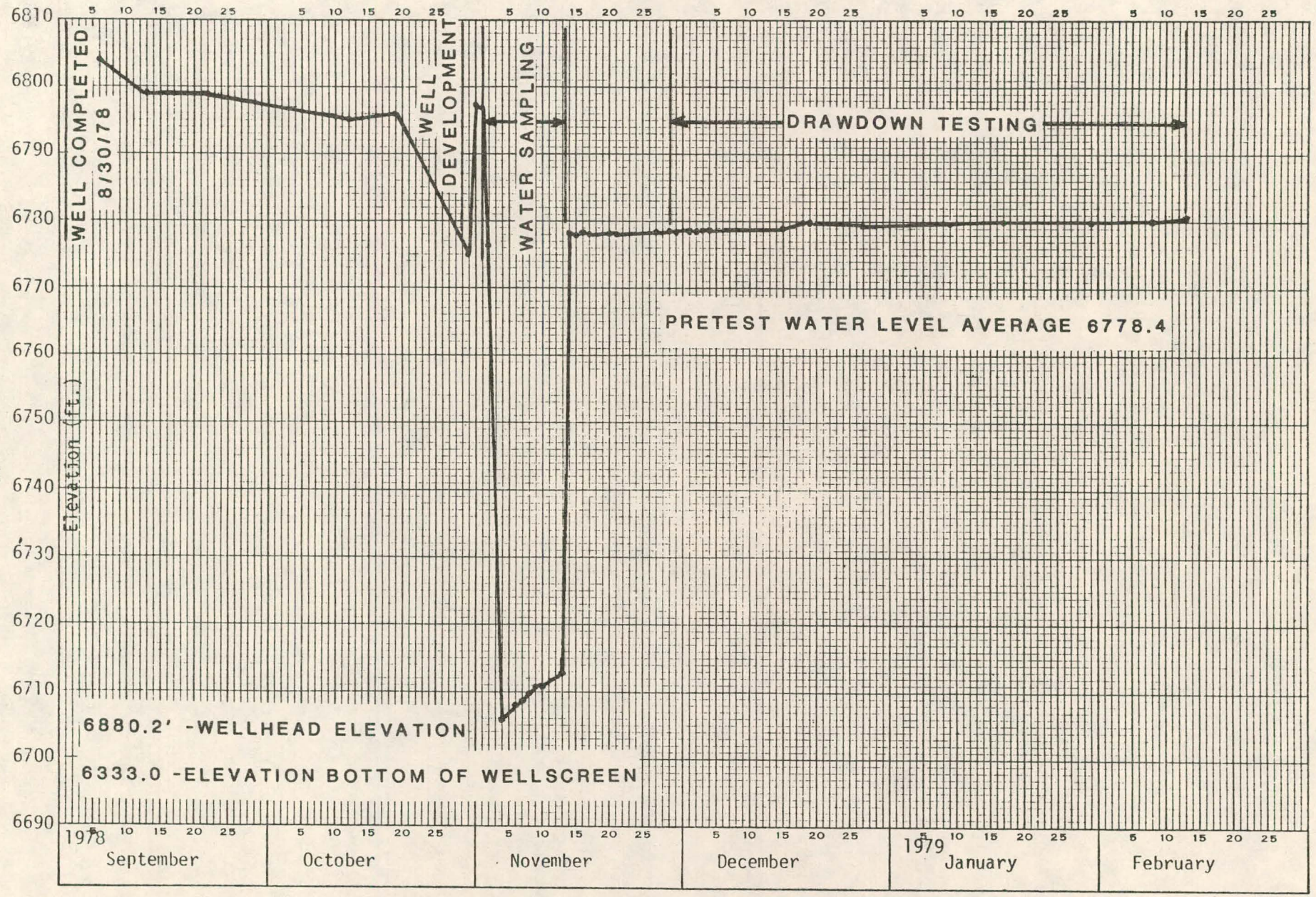
WATER LEVEL ELEVATIONS IN CORE HOLE 2

Figure A.6-4



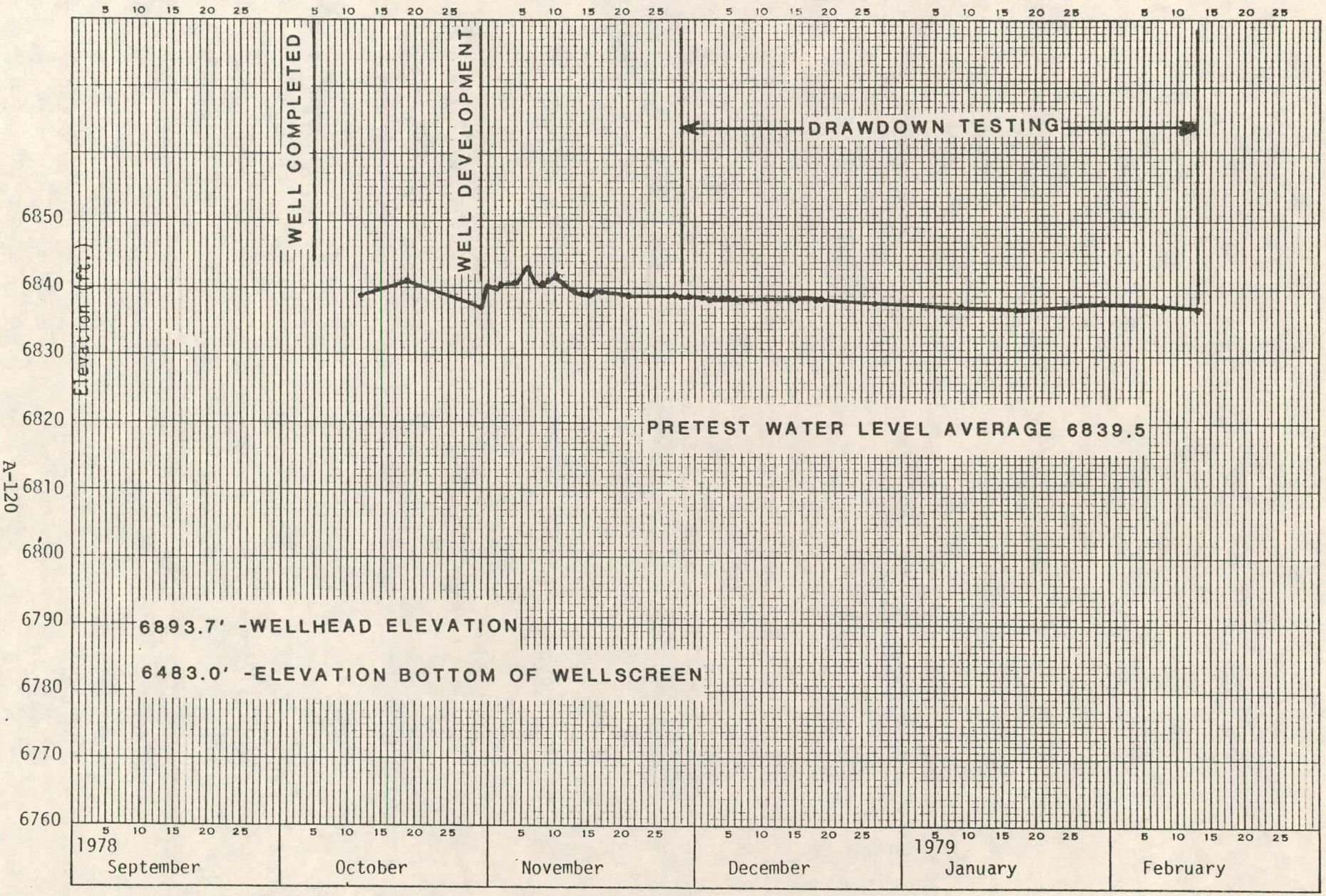
WATER LEVEL ELEVATIONS IN CORE HOLE 3

Figure A.6-5



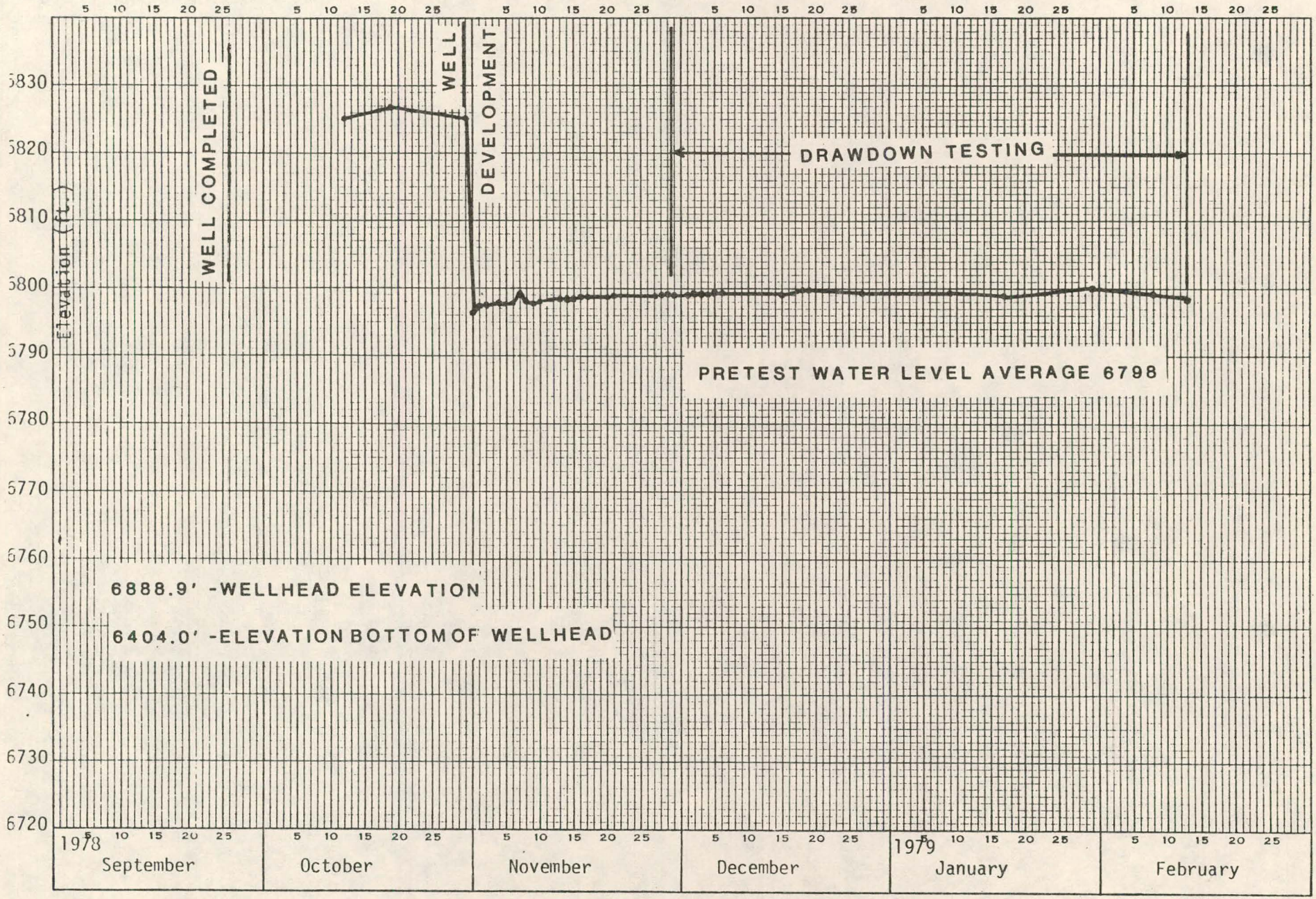
WATER LEVEL ELEVATIONS IN CORE HOLE 4

Figure A.6-6



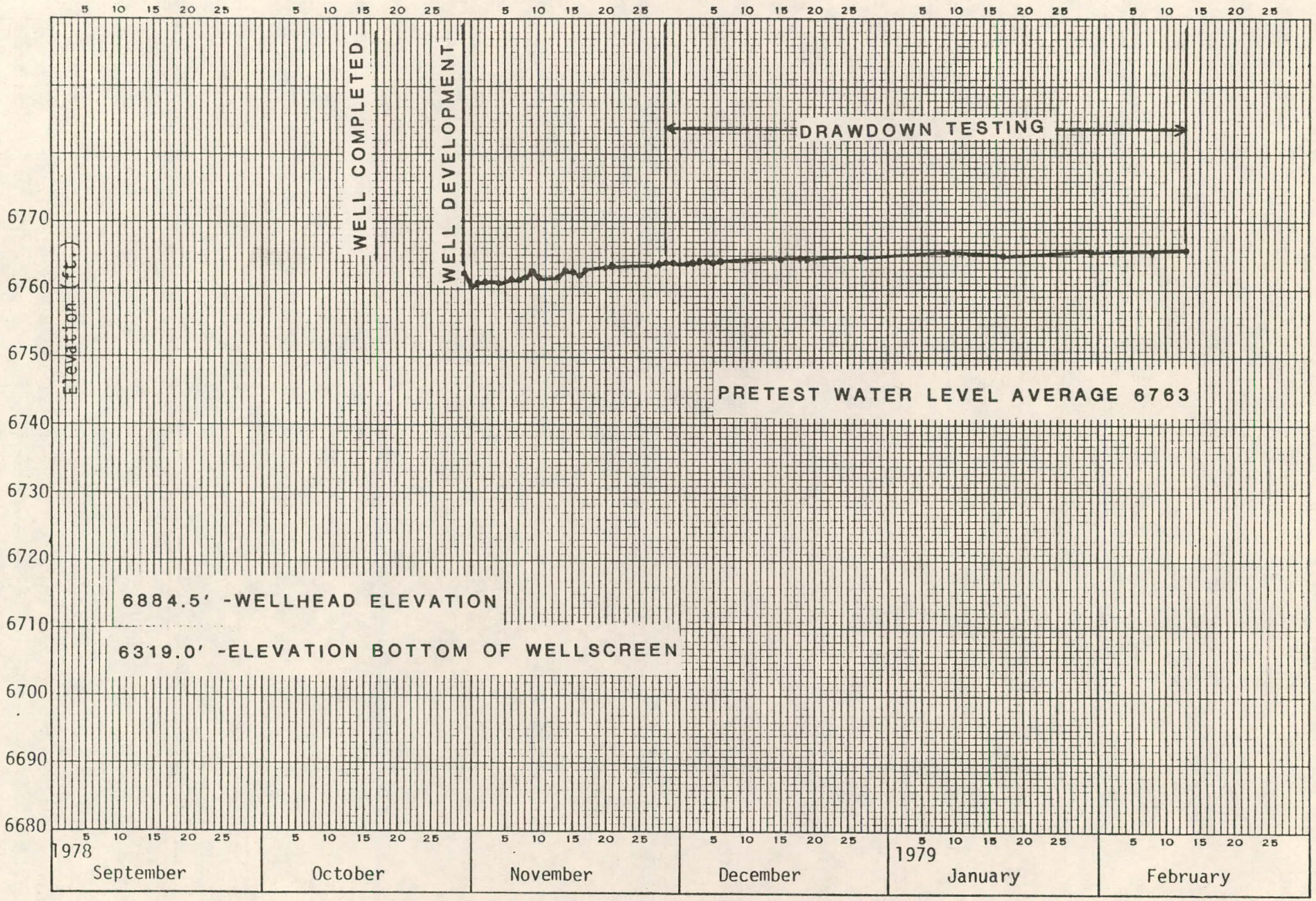
WATER LEVEL ELEVATIONS IN H-7

Figure A.6-7



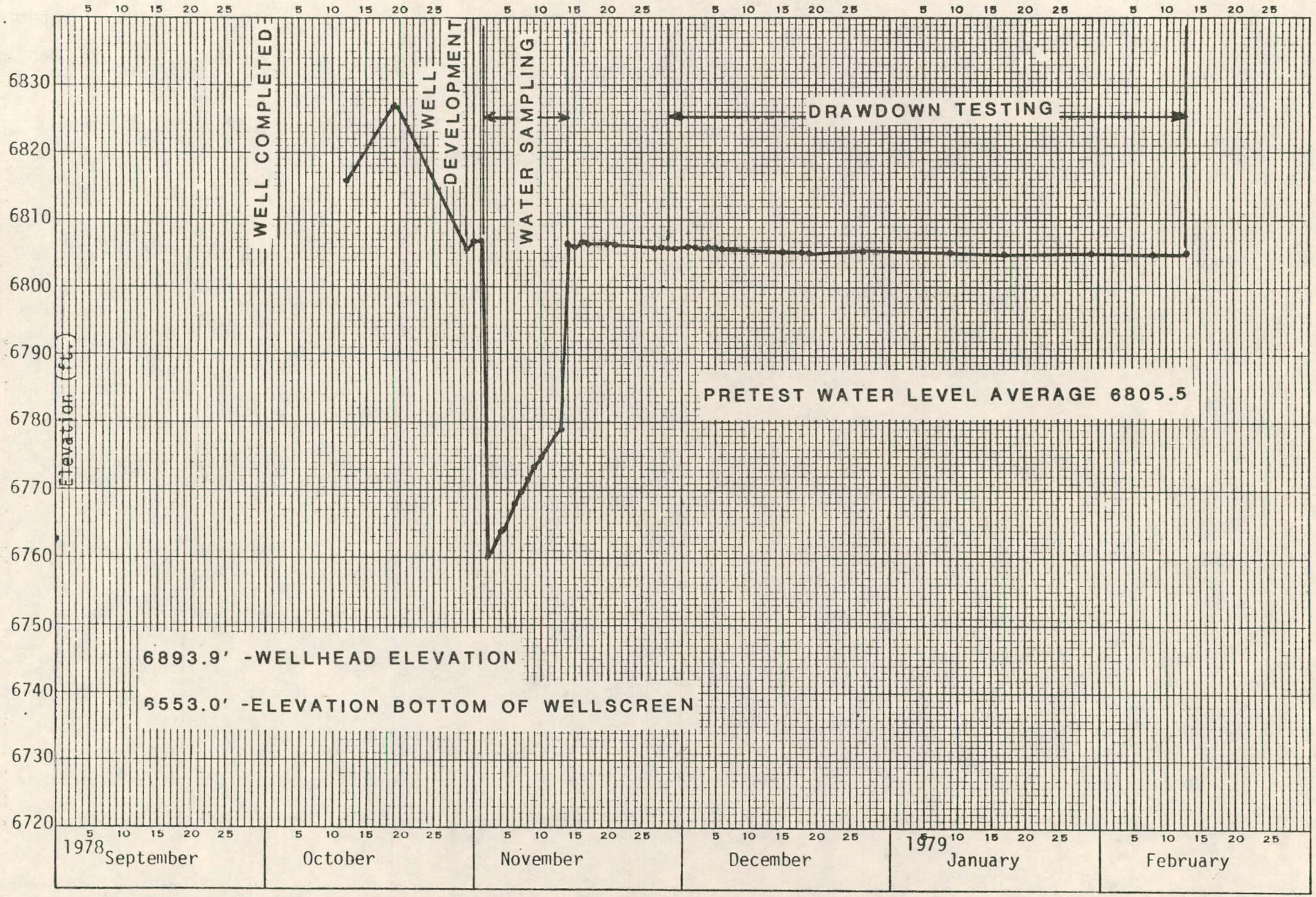
WATER LEVEL ELEVATIONS IN H-8

Figure A.6-8



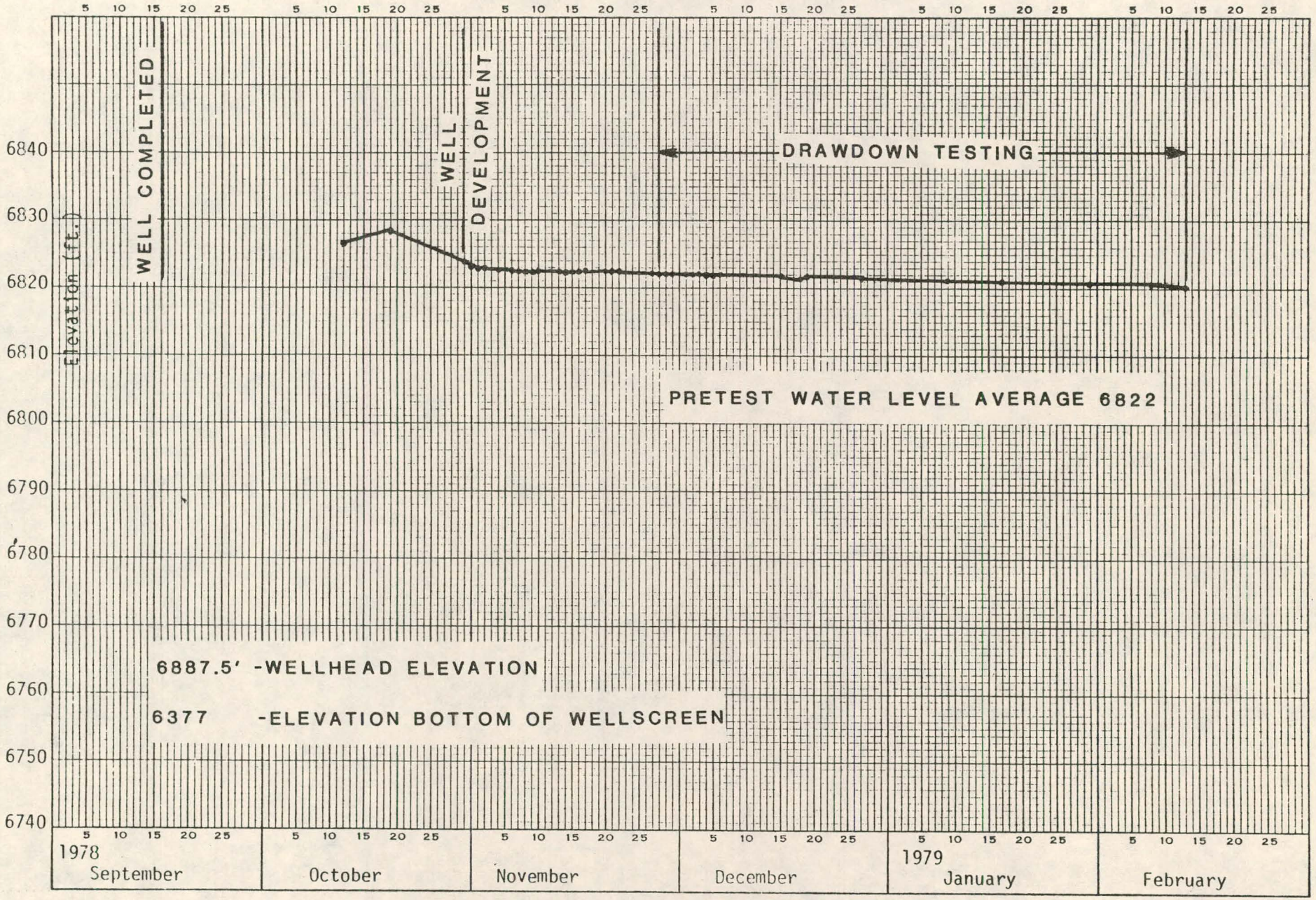
WATER LEVEL ELEVATIONS IN H-9

Figure A.6-9



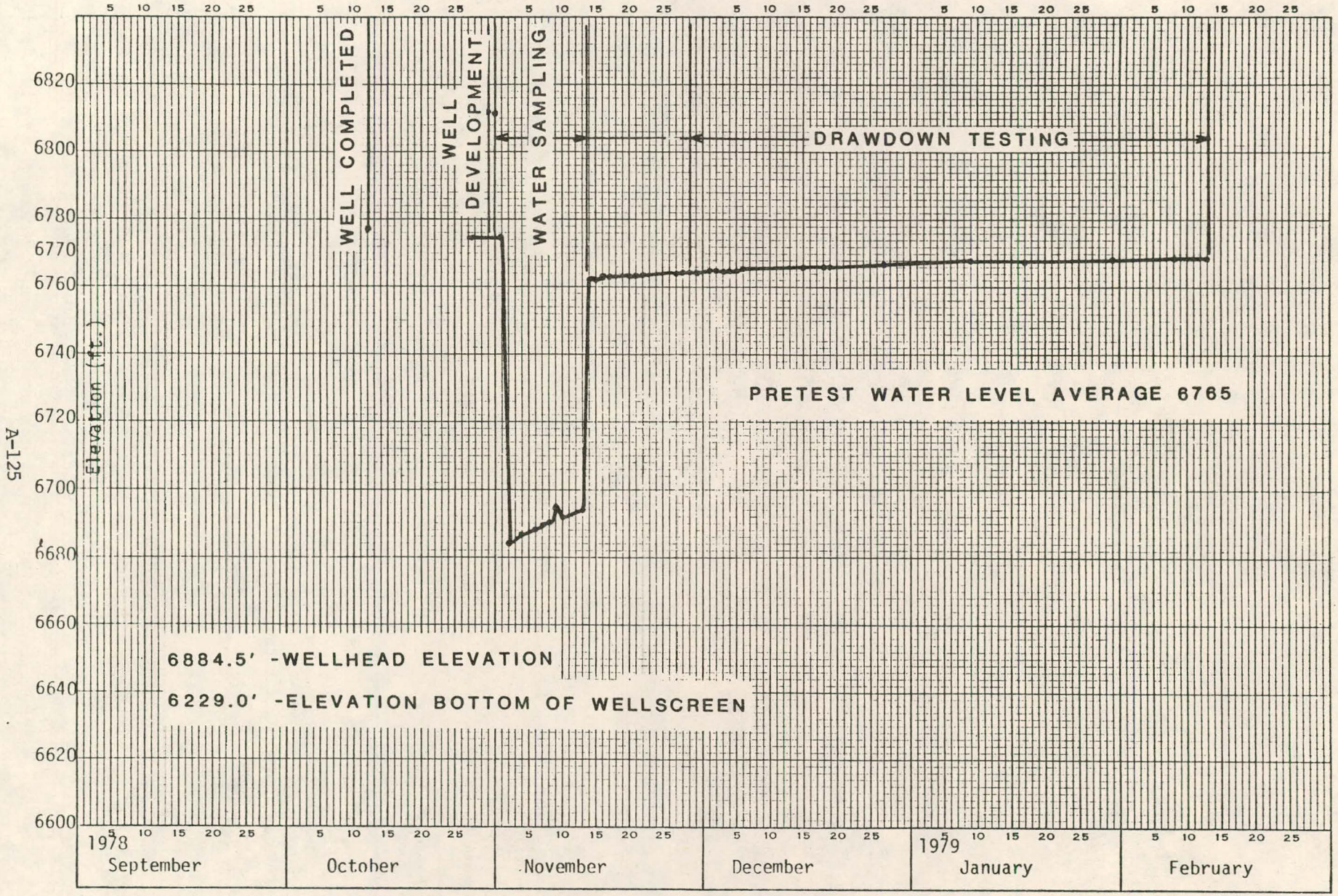
WATER LEVEL ELEVATIONS IN H-11

Figure A.6-10



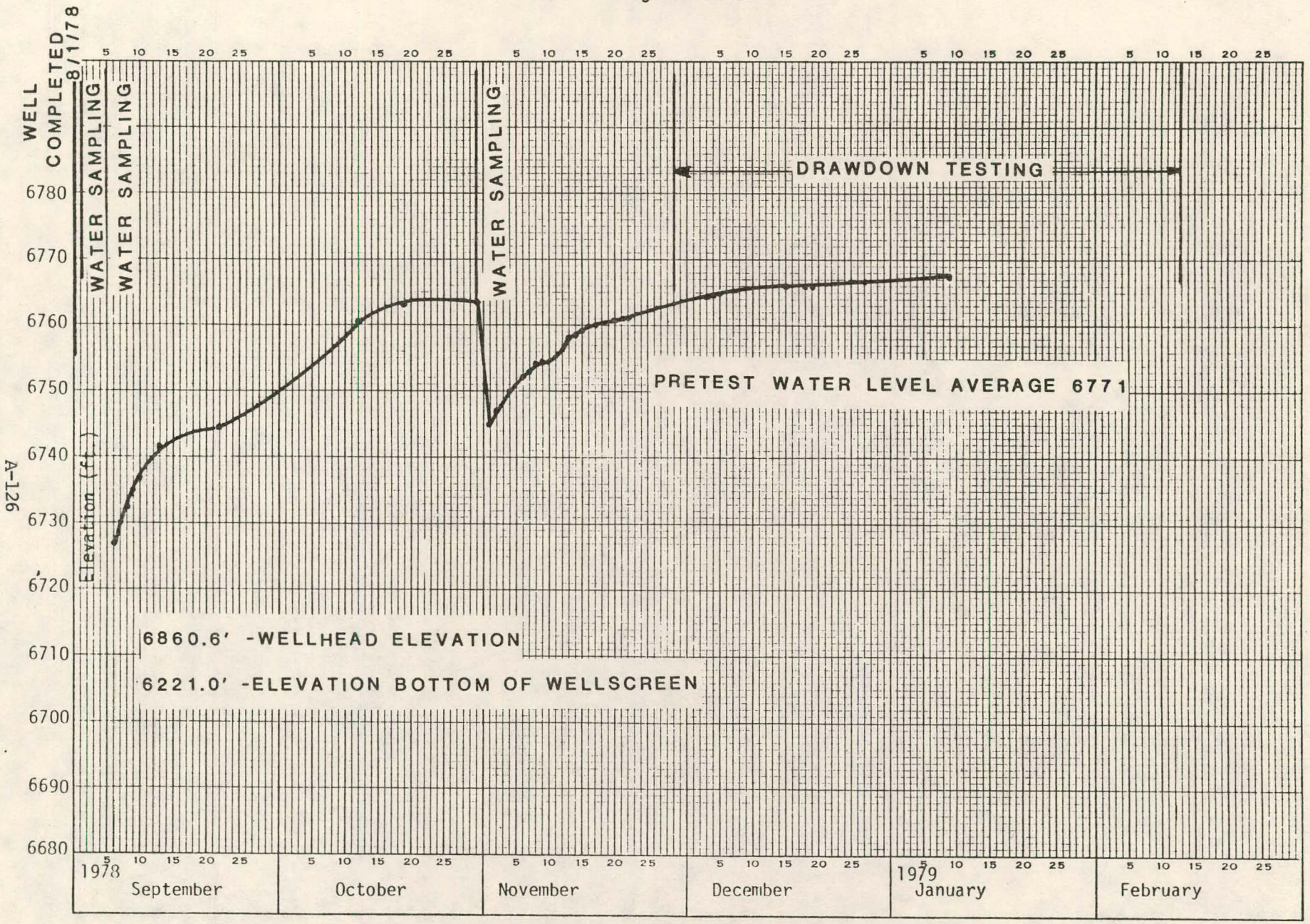
WATER LEVEL ELEVATIONS IN H-12

Figure A.6-11



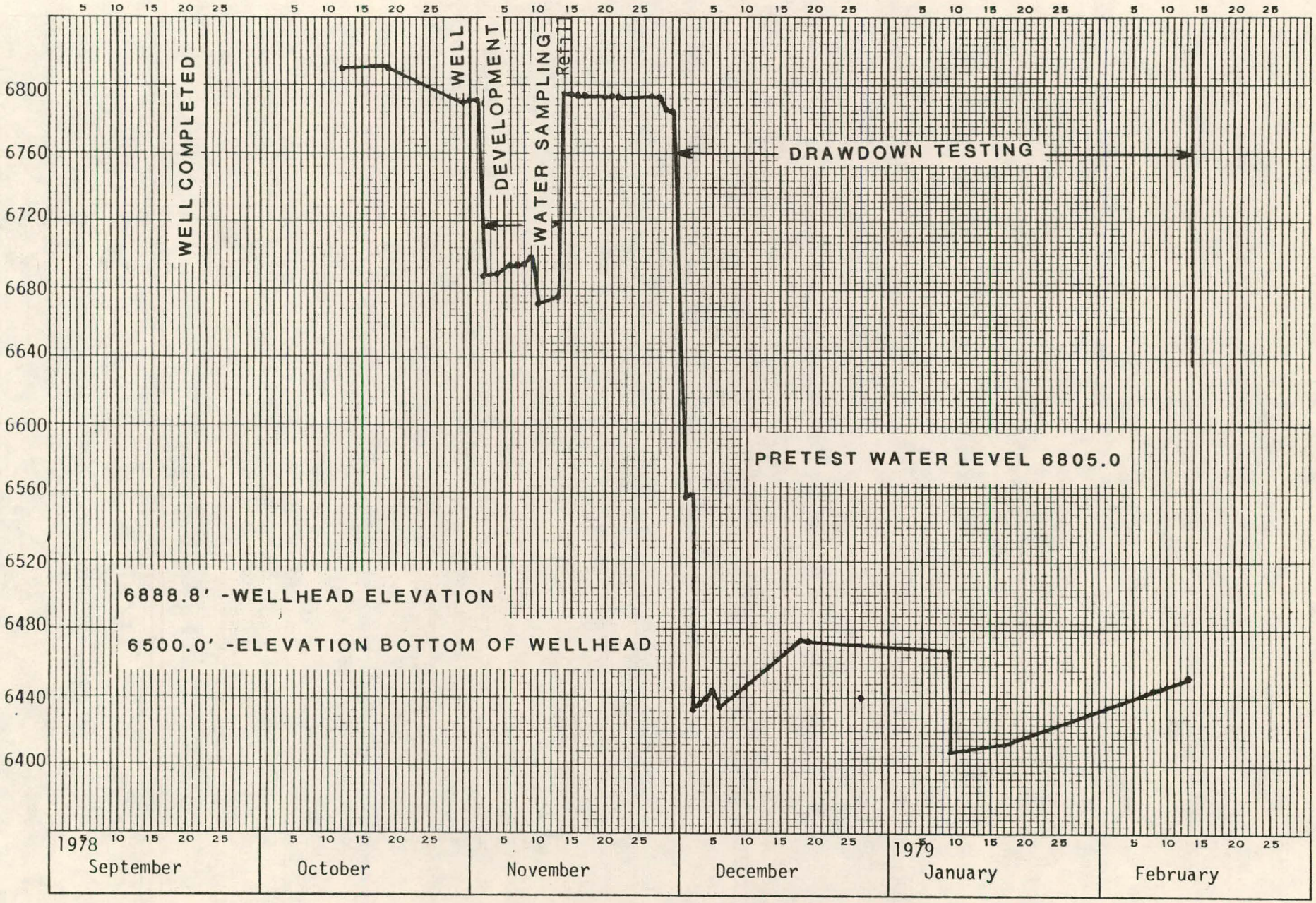
WATER LEVEL ELEVATIONS IN H-13

Figure A.6-12



WATER LEVEL ELEVATIONS IN H-15

Figure A.6-13



WATER LEVEL ELEVATIONS IN P-1

2. fit inside of the casing and well screen and still allow the measurement of the water level in the casing (pump assembly had to be less than 2-inch O.D.).
3. pump from depths of 700 foot (hydrostatic head of 300 foot).
4. pump water which might contain some solids.

After reviewing the specifications for pumps manufactured by several companies, it was found that Jensen Brothers manufactured a pump which would meet the above criteria. The pump selected was a Jensen Model 19W7 positive displacement pump which:

1. had a downhole, positive displacement pump cyclinder (1 3/8-inch O.D.), a 7-inch stroke, and could displace up to 1.7 gal/min.
2. used steel line pipe (1 1/2-inch I.D.) and hollow steel sucker rods (5/8-inch O.D.) to transport the water to the surface.
3. used a surface activator consisting of a 1/2 hp motor connected to an eccentric drive which powered the sucker rod by means of a walking arm/counterweight assembly.

Figure A.6-14 illustrates the pumping assembly components used at the North Knobs facility.

A.6.3.1.1 Procedures

Installation of the pump consisted of the following:

1. measuring the water level in the casing.
2. constructing a 48x48x6 inch concrete pad on the ground adjacent to the P-1 casing.
3. attaching the pump cyclinder (without the traveling valve) to the steel line pipe, and adding line pipe to lower the cyclinder to within 2-feet of the bottom of the P-1 wellscreen. A Smeal truck (Ford's Water Well Service, Inc.) placed the cylinder and pipe in the well.

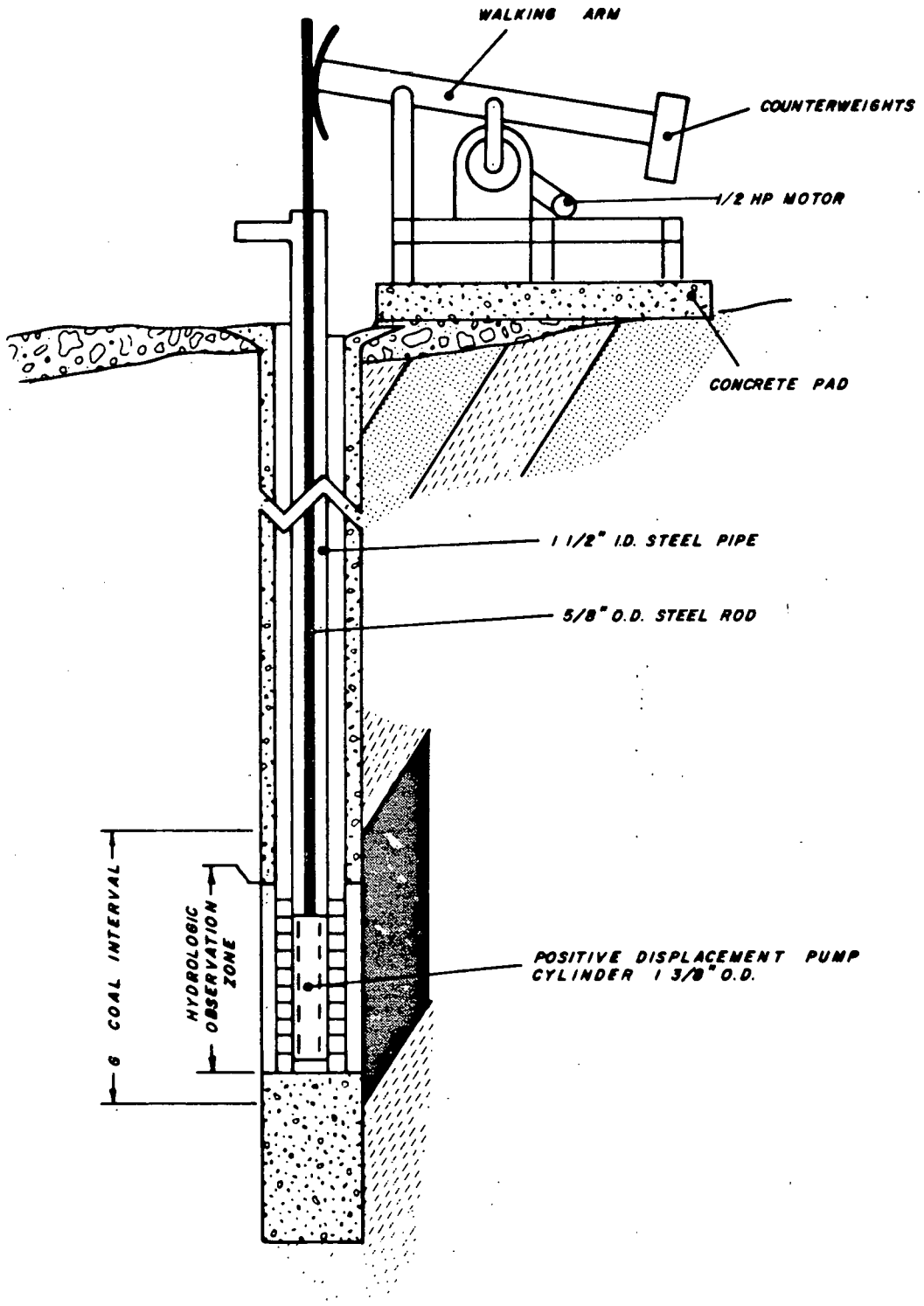


Figure A.6-14 **WELL DESIGN FOR DRAWDOWN TESTING**

4. connecting the line pipe to the wellhead cap, and attaching a discharge "T" fitting to the top of the cap.
5. dropping the check valve (steel ball) into the line pipe.
6. connecting the hollow sucker rod to the traveling valve (piston) and lowering the valve and rod into the line pipe with the Smeal truck. To make certain that the check valve was properly seated, it was "tagged" with the traveling piston.
7. connecting a solid steel rod to the sucker rod as its last joint, and passing the solid rod through a brass sleeve and stuffing box.
8. connecting the brass sleeve and stuffing box to the steel line pipe.
9. assembling the pump activator assembly, and attaching it to the concrete pad.
10. connecting the traveling arm of the pump activator to the sucker rod assembly with a steel cable (1/8-inch diameter).
11. placing counterweights (as calculated) on the walking arm of the pump activator.
12. installing a nipple (1/2 inch I.D.) to the well head cap so that the water level in the casing could be monitored.
13. measuring the water level in the casing.

These activities took place on the following dates:

Activity	Date
Concrete Pad Installed	10/31/78
Pump Installed	11/7/78
Electricity Installed	11/23 to 27 1978

The installation work was completed by GR&DC field and Ford's Water Well Service, Inc.

A.6.3.2 Drawdown Testing

The plan for the drawdown testing consisted of:

1. Measuring the water levels in all wells.
2. Pumping water from well P-1 at a rate of 1-2 gal/min continuously for a test period of 14-21 days. At this discharge rate, the water level

in the casing of P-1 was expected to fall to within 10-50 foot above the top of the coal seam, and remain at that level throughout the test.

3. Monitoring the water levels in the surrounding wells twice daily to record changes, and graphically illustrating the data. It was expected that the observation wells closest to P-1 would exhibit observable and normal drawdown responses over the 14-21 day test period, i.e., the drawdown response graphs would begin to flatten out indicating equilibrium.
4. Monitor the rate of recovery in P-1, and graphically illustrate the data.

The test was scheduled to start after the pump was installed in well P-1, and testing was conducted by GR&DC field and subcontracted (Resource Consultants, Inc.) hydrologic personnel. The pumping history for P-1 is shown in Table A.6-13.

A.6.3.3 Data

The descriptive hydrologic parameters for the North Knobs UCG facility are summarized and presented in Table 5.5-3 in the main report.

A.6.4 SUMMARY/CONCLUSIONS

The North Knobs hydrology program provided the following information:

1. Water quality data from the baseline environmental monitoring wells.
2. Definition of the pre-test potentiometric surface for the ground water in the G coal seam.
3. Drawdown test data from the facility well field.
4. A set of descriptive hydrologic parameters for the G coal seam.

From this data, the following can be concluded:

Table A.6-13 Pumping History for P-1 During Drawdown Testing

Date	Time	Water Level	Time of W.L. Reading	Pump Activity	Quantity Pumped
11/28/78	8:48	95.10	Before		
	10:15			On	
	11:00			Off	7.1 gal
	11:15	104.00	After		
	11:30			On	
	11:45			Off	0 gal
	14:45				
	15:00	104.00	After		
11/29/78	10:50	102.92			
11/30/78	8:30	100.00	Before		
	9:26	103.65		On--Pump not operational.	
	14:45	126.55		Remove pump from hole.	
				18.3 gal water removed.	
				Pump repaired and reinstalled.	
	15:30	123.00	Before		
	15:45			On	
	18:30			Off	168.7 gal
	18:45	333.90			
12/1/78	8:37	330.65	Before		
	8:50			On	
	13:30			Off	99.7 gal
	16:05	455.27	After		
12/2/78	8:32	455.35			
12/3/78	7:50	451.45			
	15:56	450.65			
12/4/78	10:37	448.32			
12/5/78	13:10	444.40	Before		
	14:17	444.00	Before	On	
	14:31	450.50	After	Off	5.28 gal

Table A.6-13 Pumping History for P-1 During Drawdown Testing (Cont'd.)

Date	Time	Water Level	Time of W.L. Reading	Pump Activity	Quantity Pumped
	15:00	450.00	Before	On	
	15:28	456.13	After	Off	4.9 gal
	16:09	455.87			
12/6/78	8:51	453.35			
12/15/78	14:00	429.35	Before		
	14:15			On	
	14:35			Off	22.66 gal
	14:45	457.67	After		
12/18/78	9:30	443.67			
	10:00	440.17			
1/9/79	13:00	420.47	Before		
	13:15			On	
	15:00			Off	47.6 gal
	15:15	480.00	After		
1/17/79	11:00	468.00			
2/8/79	11:30	443.00			
2/13/79	15:00	436.00			
**2/13/79	17:00	- Drawdown Testing Terminated.			

A.6.4.1 Water Sampling/Analysis

1. Since the water samples were collected soon after development work occurred, and since relatively low recharge rates from the formations were encountered, it is thought that the water analysis data are not truly representative of the ground water in the G coal seam and adjacent aquifers.
2. Water analysis data from wells H-11, H-13 and P-1 appear to be contaminated by the brine water which was used as a drilling fluid to drill the wells.
3. Representative ground water analysis data should be available from the facility wellfield before ignition of Burn 1 in October, 1979.

The hydrologic data indicate that the quantity of ground water in the G coal seam and the ground water flow rate through the G coal seam are much lower than expected. Consequently,

1. The G coal seam can probably be defined as an aquaclude - not an aquifer.
2. The G coal seam and the adjacent aquifers can be expected to yield very low quantities of ground water to the gasification process in the burn chamber (overburden fracturing due to subsidence or thermal alteration could modify this condition).
3. The ground water environmental monitoring wells should be located relatively close to, and at increasing depths down hydraulic dip from the burn chamber.
4. The post burn environmental monitoring should include using the process wells for monitoring and sampling the burn chamber itself.

A.6.4.2 G Seam Potentiometric Surface

1. The G coal seam (and the boundary strata) on the facility appear to be saturated with ground water below a vertical depth of 90-100 foot.

2. The G seam potentiometric surface was found to have a hydraulic slope of 5° and a hydraulic slope orientation of S84°W on the facility.

A.6.4.3 Drawdown Pump

1. The Jensen pump was able to place and maintain a hydraulic stress on the G coal seam.
2. As a result of drilling a non-vertical hole, a frictional drag resulted downhole between the sucker rod and the line pipe. Consequently, the walking arm of the pump had to be manually assisted. This could probably be corrected by installing a larger motor (3/4 hp) on the pump activator.

A.6.4.4 Drawdown Testing

1. The drawdown testing placed and maintained a hydraulic stress on the G coal seam.
2. As a result of the horizontal spacing (or intraformation spacing) of the wells and the G coals' low permeability, expected water level responses were not seen in the surrounding G seam observation wells or adjacent aquifer observation wells during the drawdown testing.

A.6.4.5 Hydrologic Parameters

1. Relatively low quantities of ground water were found to be present in the G coal seam on the facility.
2. Relatively low flow rates were found for the ground water in the G coal seam.
3. The G coal seam has relatively low formational and fracture permeability.
4. The aquifers adjacent to the G coal seam appear to have hydrologic parameters which are similar to those of the coal.

APPENDIX B

APPENDIX B

List of Figures

B-1	Regional Cross Section A-A'
B-2	Regional Geologic Column
B-3	Facility Geologic Column
B-4	Facility Geologic Map
B-5	Facility Photogeologic Map
B-6	Facility Cross Section Line 5 + 00
B-7	Facility Cross Section Line 11 + 00
B-8	Aerial Photograph No. 258
B-9 to 38	Orientation of Joint Surfaces Relative to Bedding
B-39 to 44	Cleat Orientation Relative to Bedding
B-45	Description and Correlation of Units Exposed in Trenches
B-46	Master Drilling Plan Map
B-47	Topographic Map of the North Knobs Outcrop Belt (3 sheets)
B-48	Core Hole 3 Data Package
B-49	Core Hole 4 Data Package
B-50	Lithologic Columns of Wells Drilled

TABLES

B-1	Master Drilling Schedule Table

A

A'

8000

6000

4000

2000

SEA LEVEL

-2000

FORT UNION FORMATION

MEDICINE BOW FORMATION

UPPER MEMBER

MIDDLE MEMBER

LOWER MEMBER

SEPARATION FLATS

66

71

68

76

75

71

63

67

67

62

WEST LINE SEC. 11

EAST LINE SEC. 11, WEST LINE SEC. 12

EAST LINE SEC. 12

LEWIS SHALE

MESAVERDE FM.

STEELE FM.

EXPLANATION

SOIL COVERED AREA

CONGLOMERATE AND VERY COARSE GRAINED SANDSTONE

SANDSTONES

SANDSTONES, SILTY

ALTERNATING SILTY SHALES AND SANDSTONES

SHALES
(INCLUDES MINOR CARBONACEOUS SHALES AND COAL STRINGERS)

CARBONACEOUS SHALES
(INCLUDES MINOR COAL STRINGERS)

SILTY SANDSTONES AND SHALES ALTERNATING WITH CARBONACEOUS SHALE AND COAL

COAL

75

APPARENT DIP OF BEDS ON SECTION

ROBERT Mc CURDY
CONSULTING COAL GEOLOGIST

FOR

GULF RESEARCH AND DEVELOPMENT COMPANY

GEOLOGIC CROSS SECTION A-A'
NORTH KNOBS PROJECT
CARBON COUNTY, WYOMING

REVISION			
DATE	BY		
		GEOLOGY BY ROBERT Mc CURDY & DON SCHOFIELD	12/1978
		ENGINEERING BY	
		SURVEYED BY	
		PREPARED BY GEO-ILLUSTRATED--DENVER	12/1978
		APPROVED BY	
		SCALE 0 500 1000 FT.	SHEET ___ OF ___
			DWG. No. 1

Figure B-1

Regional Cross Section, A-A'

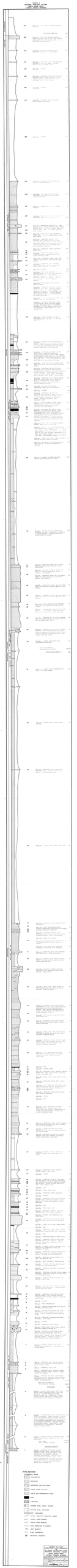

SCALE 1"
APPROXIMATELY 100 FEET
SURFACE GEOLOGY
LOWER CLEARWATER RIVER
Qal
Qt
Qls
Qmw
Qmw
Qmw

Figure B-2

Regional Geologic Column

TOWN DOCK MEMBER
Lower Member

Thick

Unit M1
Chalk, soft to very soft, thin stylolitic nodularity. 5.77

Unit M2
Chalk, varying between CH CM CMV, thick, thin stylolitic nodularity. 5.77

Unit M3
Chalk, very thin CMV, soft, nodularity. 5.77

Unit M4
Chalk, mainly stylolitic nodularity CH CM CMV, thick. 136.67

Measured thickness
(Lower Member)
(Town Dock Member) 142.44

TOWN DOCK MEMBER
Upper Member

Unit M5
Chalk, mainly hard but 0.5 very hard CMV, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 16.35

Unit M6
Chalk, very hard, very calcareous brown CH CM CMV, thick. 17.45

Unit M7
Chalk, mainly hard CMV, stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M8
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 9.27

Unit M9
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 13.07

Unit M10
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 13.07

Unit M11
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M12
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M13
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M14
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M15
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M16
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M17
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M18
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M19
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M20
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M21
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M22
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M23
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M24
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M25
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M26
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M27
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M28
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M29
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M30
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M31
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M32
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M33
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M34
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M35
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M36
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M37
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M38
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M39
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M40
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M41
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M42
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M43
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M44
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M45
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M46
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M47
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M48
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M49
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M50
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M51
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M52
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M53
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M54
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M55
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M56
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M57
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M58
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M59
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M60
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M61
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M62
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M63
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M64
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M65
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M66
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M67
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M68
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M69
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M70
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M71
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M72
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M73
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M74
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M75
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M76
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M77
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M78
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M79
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M80
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M81
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M82
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M83
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M84
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M85
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M86
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M87
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M88
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M89
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M90
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M91
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M92
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M93
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M94
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M95
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M96
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M97
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M98
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M99
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M100
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M101
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M102
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M103
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M104
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M105
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M106
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M107
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M108
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M109
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M110
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by replacement, fossil preservation by infilling, fossil preservation by recrystallisation. 3.45

Unit M111
Chalk, mainly hard, thin stylolitic nodularity, thin grey marly seams, abundant shells, shell debris, shells crushed, fragments, bioturbated, thin flint bands, thin flint nodules, flint fragments, flint replacement fossils, fossils preserved by dissolution, fossil preservation by

Figure B-3

Facility Geologic Column

EAST LINE SECTION 11 & FACILITY BOUNDARY

BASELINE

PROJECTED OUTCROP B

K1 ZONE

K2

K3 ZONE

K4A

K4B

K5

K5R

K6

K7

K8A

K8B

K8

K9

K10

K11

Σ BED

WALLY BED

EDC 232

EDC 230

EDC 233

EDC 231

EDC 260

EXPLANATION

OUTCROP

OUTCROP MEASUREMENTS

DRILL HOLE LOCATION

APPARENT DIP OF BEDS

TRENCH LOCATION

ROBERT Mc CURDY
CONSULTING COAL GEOLOGIST
FOR
GULF RESEARCH & DEVELOPMENT COMPANY
GEOLOGIC MAP
NORTH KNOBS U. C. G. FACILITY
CARBON COUNTY, WYOMING

REVISION	GEOLOGY BY ROBERT Mc CURDY & DON SCHOFIELD	12/1978
DATE BY	ENGINEERING BY	
	SURVEYED BY	
	PREPARED BY GSC	ILLUSTRATED--DENVER 12/1978
	APPROVED BY	

SCALE 0 50 100 FT. SHEET OF DWG. No. 4

Figure B-4

Facility Geologic Map

ROBERT Mc CURDY
CONSULTING COAL GEOLOGIST

FOR

GULF RESEARCH AND DEVELOPMENT COMPANY

PHOTOGEOLOGIC MAP
NORTH KNOBS U.C.G. FACILITY
CARBON COUNTY, WYOMING

REVISION		GEOLOGY BY R. McCURDY, D. SCHOFIELD	12/1978
DATE	BY	ENGINEERING BY	
		SURVEYED BY	
		PREPARED BY GEO-ILLUSTRATED--DENVER	11/1979
		APPROVED BY	

SCALE 0 50 100 FT.

SHEET OF

DWG. No. 5

EXPLANATION

K2 — FORMATION CONTACT, DASHED WHERE COVERED

SOIL COVER BOUNDARY, APPROXIMATELY LOCATED

STRIKE AND DIP OF BEDS

APPARENT DIP OF BEDS

DRILL HOLE LOCATION

K1 ZONE

K2

PROJECTED OUTCROP - BASE OF K2

NORTH KNOBS BASELINE

K3 ZONE

K4A

K4B

K5

K5R

K6

K7

K8

K8A

K8B

K9

K10

BASE

TOP

Figure B-5

Facility Photogeologic Map