PROCEEDINGS

UNCONVENTIONAL GAS RECOVERY PROJECT REVIEW

a. EASTERN GAS SHALES PROJECT

b. METHANE RECOVERY FROM COALBEDS PROJECT

c. WESTERN GAS SANDS PROJECT

March 11-12, 1980

Incorporating Martin Adams' Notes

VOLUME II--March 12

b. Methane Recovery from Coalbeds Project

c. Western Gas Sands Project

DEPARTMENT OF ENERGY
Morgantown Energy Technology Center
Morgantown, WV

Vol. II of II

March 11-12, 1980

UNCONVENTIONAL GAS RECOVERY
PROJECT REVIEW

Tuesday, March 11

8:30 a.m.	WELCOME	Augie Pitrolo
8:45	OPENING REMARKS	Martin Adams
9:00	UGR - STRATEGY	Paul Wieber
9:15	UGR - OVERVIEW	Arlen Hunt
9:30	PROJECT OVERVIEWS	
	. Eastern Gas Shales	Chuck Komar
	. Methane Recovery from Coalbeds	John Duda
	. Western Gas Sands	Harry Johnson/Alex Crawley
11:00	DISCUSSION	
11:15	Eastern Gas Shales Project	(Chuck Komar)
	RESOURCE CHARACTERIZATION	
	. Core and Log Acquisition	Charlie Byrer
	Gruy Federal	
	Cliffs Minerals	
11:35	. Structural/Stratigraphic	Yonnie Williams
	State Surveys (PA, OH, NY, WV, IN, IL, KY)	
	Tetra Tech - Prospect Sites	
12:00	. Exploration R&D	Claude Dean
	ERIM	
	WVU (Geochem)	
	WVU (Structural Discontinuity)	
	Tennessee G. S.	
12:20	. Outgassing/Geochem Characterization	Ron Zielinski, Mound Lab
12:40	DISCUSSION	
1:00	LUNCH	
2:00	. Resource Assessment	
	Appalachian Basin	Wally de Witt, USGS
2:20	Illinois & Michigan Basins	Bill Gwilliam
2:40	. Geologic Data Base Integration	Stephanie Bialobok
3:00	EXTRACTION TECHNOLOGY R&D	
	. Fracture Mechanics	Chuck Komar
	Ohio State	
	SRI (Model Development)	
	University of Maryland	
	SAI	
	DuPont	
	SRI (Proppant Research)	
	Terra Tek (Fluid/Shale)	
	Terra Tek (Stress Tool)	
3:30	Proposed Mineback Project	Jim White
3:40	Technical Support-NTS	Dave Northrop, Sandia

Tuesday, March 11 (Cont.)

4:00	. Production Enhancement Tetra Tech (Dual Completion) Waggoner (Recompletion) Mitchell	Karl Frohne
	. Reservoir Performance Gruy (Well Test Analysis) Gruy & SAI (Offset Well)	Karl Frohne
4:30	TECHNOLOGY TESTING & VERIFICATION	
	. Exploration/Reservoir Mitchell Energy Donohue (OH) Donohue (NY)	Al Yost
	. Exploitation/Production Verification Tests Columbia Gas Weed/Henry Houghton College	Al Yost
5:00	DISCUSSION	
7:00 - 9:00	UGR FY 81 REVIEW AND REPORTING	

Wednesday, March 12

8:30 a.m.	Methane Recovery from Coalbeds Project	(Duda)
	RESOURCE CHARACTERIZATION	Harold Shoemaker
	. Resource Engineering	
	. Resource Assessment	
	. Resource Evaluation TRW	
	TECHNOLOGY TEST Waynesburg Occidental	
	PROJECT INTEGRATION	
	RESEARCH & DEVELOPMENT (Overview)	Harold Shoemaker
	. Fracture Mechanics Physics International WVU	
	. Drilling Sandia Maurer	
	. Production Enhancement University of Pittsburgh	

Wednesday, March 12 (Cont.)

9:10	TECHNOLOGY TESTING & VERIFICATION	
	. Mined Coalbeds	
	Westinghouse (Power Generation)	Jerry Rennick
9:20	U.S. Steel	Steve Lambert
9:30	Clinchfield	Mike Trevits
9:40	Emerald Mine	Pat Diamond
9:50	. Unmined Coalbeds	
	Mt. Fuel	Harold Shoemaker
10:00	Intercomp/Coseka	Harold Shoemaker
10:10	Westinghouse (Space Heating)	Jerry Rennick
10:20	DISCUSSION	
10:30	GAS HYDRATES	Bill Overbey
11:00	DISCUSSION	
11:15	Western Gas Sands Project	(Alex Crawley)
	RESOURCE CHARACTERIZATION	Charles Spencer
12:00	LUNCH	
1:00	PRODUCTION TECHNOLOGY DEVELOPMENT	Charles Atkinson
	. Cost-Shared Field Test	
1:20	RESEARCH, INSTRUMENTATION & MODELING	
	. Fracture Performance Research	Herb Carroll
	. Mine-Back Experiments	Dave Northrop
	. Fracture Modeling	Merle Hanson
	. Fracture Instrumentation	Carl Schuster
	. Reservoir Diagnostic Research	Herb Carroll
	. Reservoir Diagnostic Instrumentation	Carl Schuster
3:30	PRODUCTION TECHNOLOGY DEVELOPMENT	
	. Field Laboratory	Dave Northrop
4:00	DISCUSSION	
7:00 - 9:00	UGR FY 81 BUDGET REVIEW	

ATTENDEES LIST

UNCONVENTIONAL GAS RECOVERY REVIEW

March 11-12, 1980

Martin Adams
DOE HQ
MS D-107
Washington, DC 20545
FTS: 233-2703

Gordon Anderson
Lawrence Livermore Lab
P.O. Box 808
Livermore, CA 94550
Tel: 415/422-3950

Charles Atkinson
US DOE/BETC
Las Vegas, NV 89101
Tel: 710/734-3424

Stephanie J. Bialobok
US DOE/METC
P.O. Box 880
Morgantown, WV 26505
FTS: 923-7305

Boyce D. Burts
US DOE/METC
P.O. Box 880
Morgantown, WV 26505
FTS: 923-7366

Charlie Byrer
US DOE/METC
P.O. Box 880
Morgantown, WV 26505
FTS: 923-7305

Herb Carroll
US DOE/BETC
P.O. Box 1398
Bartlesville, OK 74003
FTS: 735-4297

W. J. Carter
LASL
Los Alamos, NM
FTS: 843-6651

Alex Crawley
US DOE/BETC
P.O. Box 1398
Bartlesville, OK 74003
FTS: 735-4364

Claude Dean
US DOE/METC
P.O. Box 880
Morgantown, WV 26505
FTS: 923-7211

Wallace de Witt, Jr.
USGS
Reston, VA 22092
FTS: 923-6634

John R. Duda
US DOE/METC
P.O. Box 880
Morgantown, WV 26505
FTS: 923-7325

K-H. Frohne
US DOE/METC
P.O. Box 880
Morgantown, WV 26505
FTS: 923-7412

Bill Gwilliam
US DOE/METC
P.O. Box 880
Morgantown, WV 26505
FTS: 923-7166

Merle Hanson
Lawrence Livermore Lab
P.O. Box 808
Livermore, CA 94550
Tel: 415/422-3939

Arlen Hunt
US DOE/METC
P.O. Box 880
Morgantown, WV 26505
FTS: 923-7265

Harry Johnson
US DOE/BETC
P.O. Box 1398
Bartlesville, OK 74003
FTS: 735-4200

Chuck Komar
US DOE/METC
P.O. Box 880
Morgantown, WV 26505
FTS: 923-7107

James C. Mercer
US DOE/METC
P.O. Box 880
Morgantown, WV 26505
FTS: 923-7509

Dave Northrop
Sandia
Div 4732
Albuquerque, NM 87185
Tel: 505/844-8735

Bill Overbey
US DOE/METC
P.O. Box 880
Morgantown, WV 26505
FTS: 923-7726

Augie Pitrolo
US DOE/METC
P.O. Box 880
Morgantown, WV 26505
FTS: 923-7511

G. E. Rennick
US DOE/METC
P.O. Box 880
Morgantown, WV 26505
FTS: 923-7217

ATTENDEES LIST (Cont.)

Leo Schrider
US DOE/METC
P.O. Box 880
Morgantown, WV 26505
FTS: 923-7492

Carl L. Schuster
Sandia
P.O. Box 5800
Albuquerque, NM 87185
Tel: 505/844-9142

Harold D. Shoemaker
US DOE/METC
P.O. Box 880
Morgantown, WV 26505
FTS: 923-7715

L. Z. Shuck
US DOE/METC
P.O. Box 880
Morgantown, WV 26505
Tel: 304/293-4821

Jeff Smith
DOE HQ
MS D-107
Washington, DC 20545
FTS: 233-2731

Charles W. Spencer
USGS
Denver, CO 80202
FTS: 234-3893

Hap Stoller
Sandia
P.O. Box 5800
Albuquerque, NM 87185
Tel: 505/844-8735

Jim R. White
US DOE/METC
P.O. Box 880
Morgantown, WV 26505
FTS: 923-7217

Paul R. Wieber
DOE HQ
MS D-107
Washington, DC 20545
FTS: 233-2729

Yonnie Williams
US DOE/METC
P.O. Box 880
Morgantown, WV 26505
FTS: 923-7108

Bob Wise
US DOE/METC
P.O. Box 880
Morgantown, WV 26505
FTS: 923-7492

Albert B. Yost, II
US DOE/METC
P.O. Box 880
Morgantown, WV 26505
FTS: 923-7479

Ron Zielinski
Mound Lab
Monsanto Research Corp.
P.O. Box 32
Miamisburg, OH 45342
FTS: 774-3607

ADDITIONAL REGISTRANTS

Michael A. Trevits
US Bureau of Mines
4800 Forbes Avenue
Pittsburgh, PA

William P. Diamond
US Bureau of Mines
4800 Forbes Avenue
Pittsburgh, PA

METHANE FROM COALBEDS

STATE-OF-THE-ART

RESOURCE ENGINEERING

- METHANE CONTENT OF LARGE PROPORTION OF THE COALBEDS OF THE U.S. IS UNKNOWN
- PRODUCIBILITY OF THE RESOURCE IS NOT WELL UNDERSTOOD
  - — RESERVOIR CHARACTERISTICS
  - — RESERVOIR PREDICTION
- EXPLORATION METHODS FOR EXAMINING AND GEOLOGICAL FACTORS GOVERNING THE RESOURCE AREAS ARE NOT WELL UNDERSTOOD

PROJECT OBJECTIVES

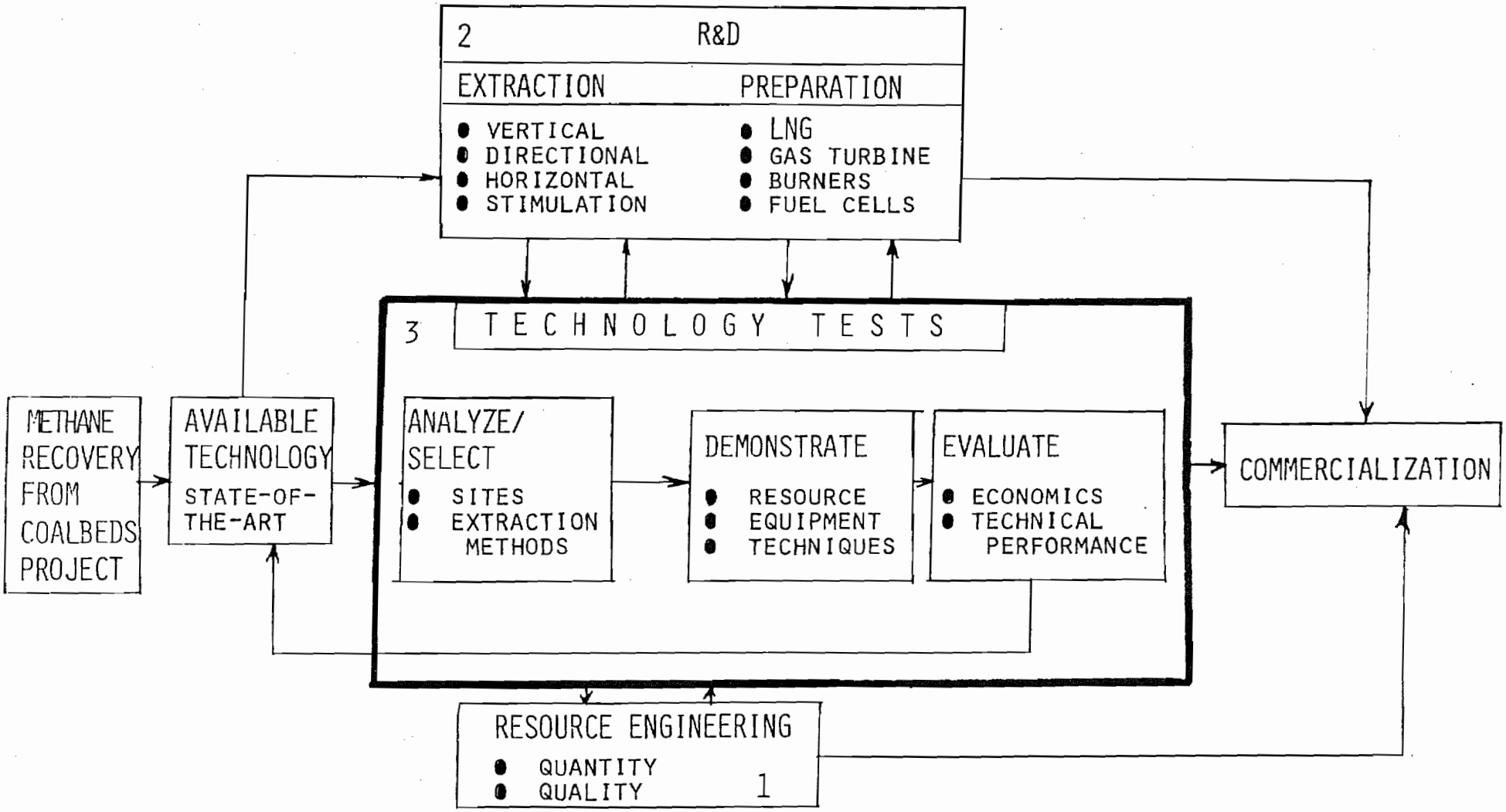
- RESOURCE VERIFICATION
- RESERVOIR EVALUATION
- PRODUCTION ENHANCEMENT
- PRODUCT PREPARATION

PROJECT OBJECTIVES

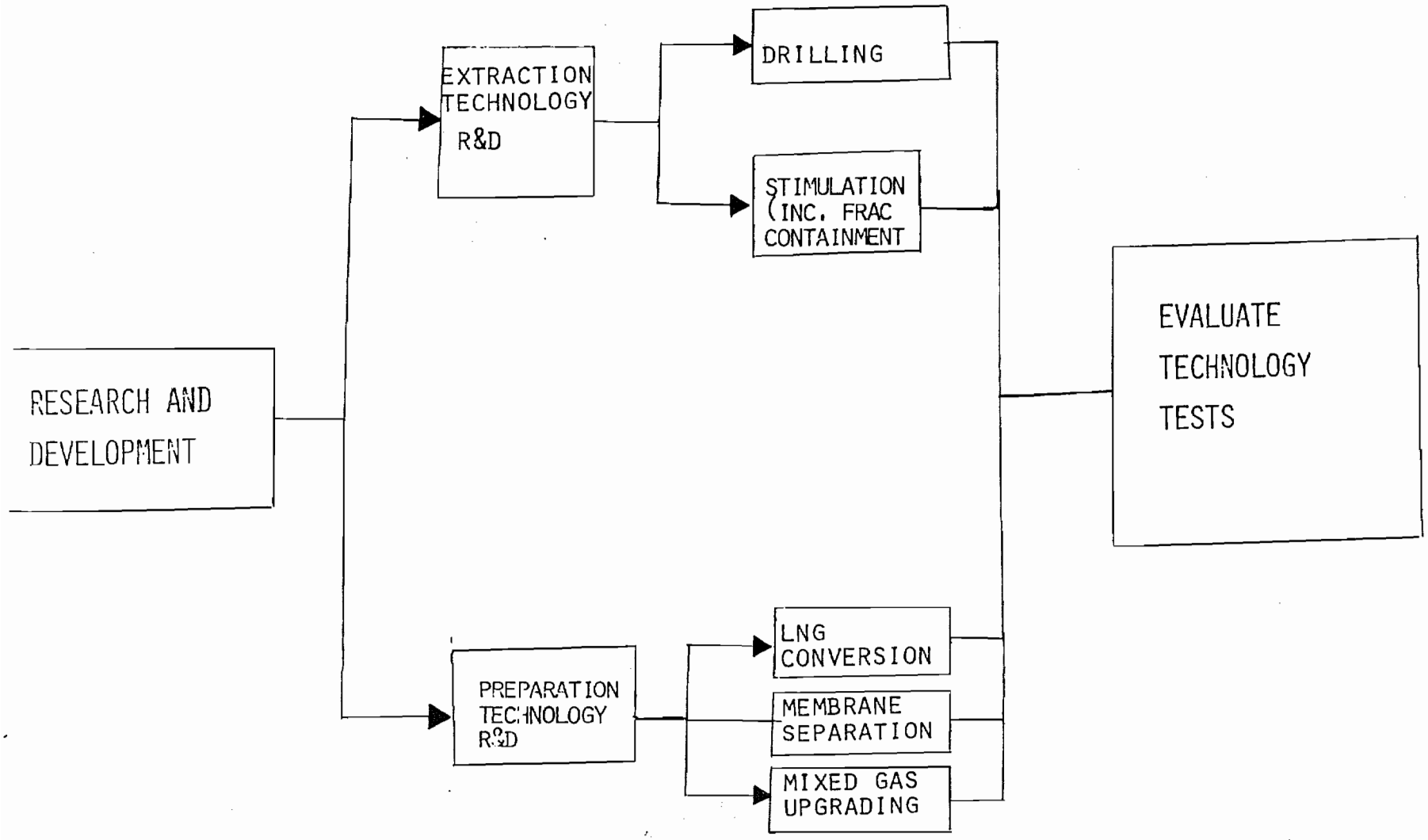
- RESOURCE VERIFICATION
- RESERVOIR EVALUATION
- PRODUCTION ENHANCEMENT
- PRODUCT PREPARATION

KEY ISSUES

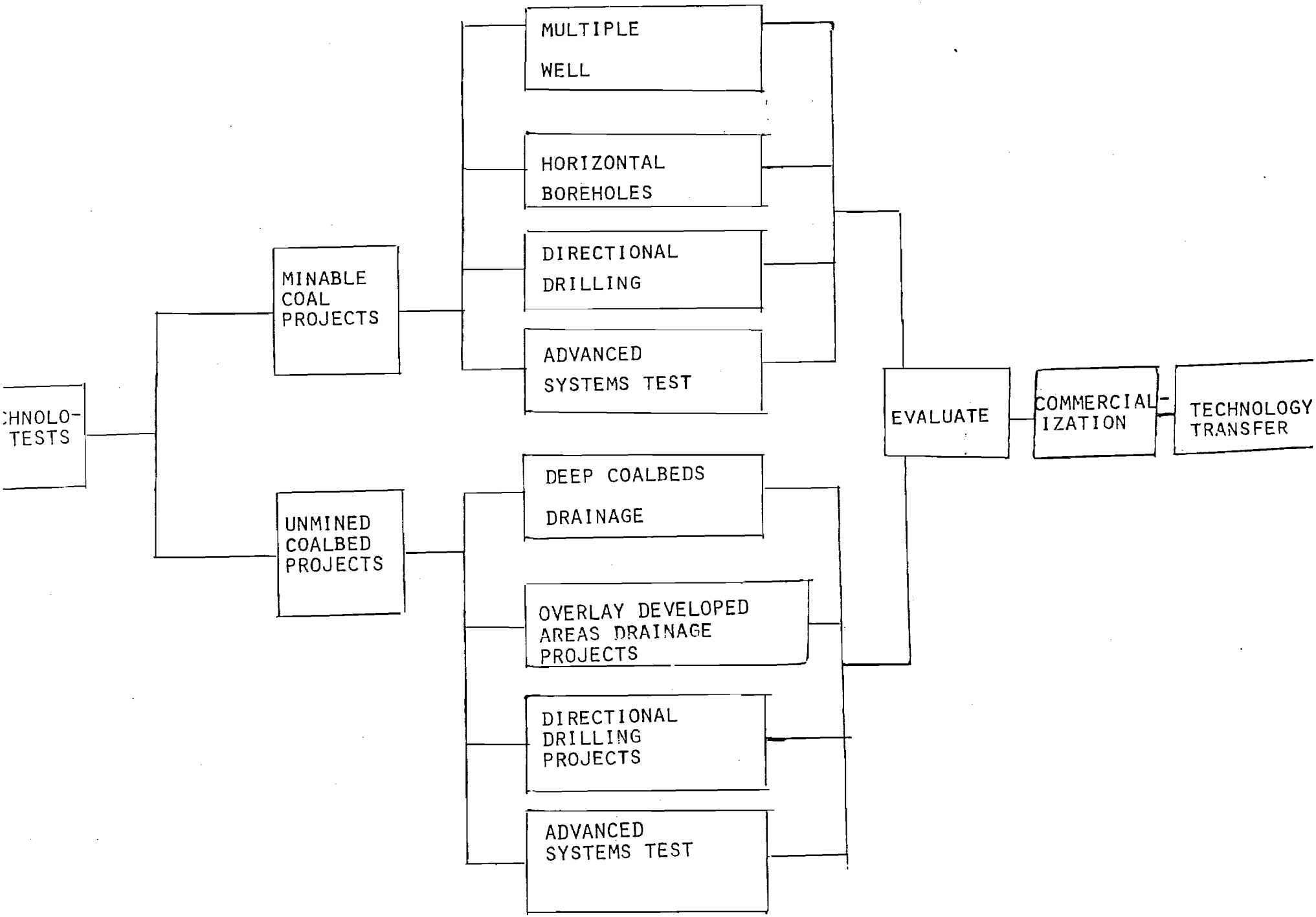
- TECHNOLOGY
  - — GAS PRODUCTION MECHANISM
  - — FRACTURE CONTAINMENT
  - — DRAINAGE CONFIGURATIONS
  - — END USE ALTERNATIVES
  - — RESOURCE VERIFICATION
- INSTITUTIONAL
- REGULATORY



PROJECT DESCRIPTION / ACTIVITY FLOW OVERVIEW-METHANE RECOVERY FROM COALBEDS PROJECT



2) RESEARCH AND DEVELOPMENT ACTIVITY FLOW



3) TECHNOLOGY TESTS ACTIVITY FLOW

METHANE FROM COALBEDS PROJECT

PROJECT FUNDING PROFILE (MILLIONS $)

PAST				CURRENT	FUTURE					
PRIOR YR FUNDING	FY 77	FY 78	FY 79	FY 80	FY 81	FY 82	FY 83	FY 84	FY 85	FY 86
BASIC:										
	.4/4.5/6.0			5.0	5.0	5.0	5.0	5.0	5.0	5.0
MINIMUM OVERTARGET:					8.7	9.0	10.0	10.0	9.4	9.1
OVERTARGET:					13.9	18.1	19.2	18.5	11.5	9.7

METHANE FROM COALBEDS PROJECT

FY 80 BUDGET SUMMARY (THOUSANDS $)

FUNDING AREA	NUMBER OF CONTRACTS	FY 80
INHOUSE	--	456
TECHNICAL SUPPORT 1/	2	1,013
NATIONAL LABS	1	120
UNIVERSITIES 2/	5	330
INDUSTRY CONTRACTS 1/	9	3,081
T O T A L S	17	5,000,000

1/ DOES NOT INCLUDE USBM AND DOE - FUNDED MINING CONTRACTS NOW BEING ADMINISTRATED BY MRCP.

2/ INCLUDES TWO @ PRIME CONTRACT LEVEL AND THREE @ SUBCONTRACT LEVEL.

METHANE FROM COALBEDS PROJECT

CRITICAL ISSUES

- MULTI - WELL MINE DEGASIFICATION PROJECT IN ALABAMA REQUIRES ADDITIONAL FUNDS OF $1 MILLION FOR UTILIZATION

- UTILIZATION OF METHANE PROJECT AT WALTZ MILL REQUIRES ADDITIONAL FUNDS OF $2.83 MILLION FOR FIELD DEVELOPMENT, TESTING OF GOB GAS UPGRADER, AND FUEL CELLS.

- CONCERN FOR MINE DAMAGE RESULTING FROM METHANE RECOVERY ACTIVITIES

- UNCERTAINTY OF COALBED GAS OWNERSHIP RIGHTS

METHANE FROM COALBEDS PROJECT

EXPECTED ACCOMPLISHMENTS IN FY 81

- CORE 8 ADDITIONAL WELLS
- PREPARE 4 PRELIMINARY BASIN REPORTS AND UPDATE 4 OTHERS
- INITIATE A COMPLETE WATER JET DRILLING SYSTEM FIELD TEST
- DEVELOP UTILIZATION SYSTEM FOR THE DIRECTIONAL DRILLING PROJECT
- COMPLETE THE IN - MINE LONG HORIZONTAL HOLE PROJECT INCLUDING UTILIZATION
- INITIATE PRODUCTION TESTING OF THE DEEP UNMINED COALBED PROJECT

METHANE FROM COALBEDS PROJECT

EXPECTED ACCOMPLISHMENTS IN FY 80

- CORE 8 ADDITIONAL WELLS
- ANALYZE DATA FOR 32 WELLS
- PREPARE 4 PRELIMINARY BASIN REPORTS AND UPDATE 6 OTHERS
- COMPLETE TESTING OF TURBODRILL
- COMPLETE DEVELOPMENT OF WALTZ MILL SITE
- TEST IN-MINE HORIZONTAL HOLES WITH PRODUCTION UTILIZATION
- COMPLETE THE POWER GENERATION PROJECT
- DRILL AND COMPLETE 10 WELLS AS RELATED TO NEAR-MINE METHANE CONTROL ACTIVITIES

METHANE FROM COALBEDS PROJECT

ACCOMPLISHMENTS TO DATE

- DEMONSTRATED A 50 PERCENT IN-MINE REDUCTION OF METHANE.
- DEMONSTRATED THE ABILITY TO DRILL HORIZONTALLY IN-SEAM THROUGH A SURFACE-SLANTED WELLBORE.
- DEMONSTRATED THE ABILITY TO DRILL LONG HORIZONTAL HOLES FROM WITHIN A MINE FOR DEGASIFICATION AND PRODUCTION.
- 6 BASIN REPORTS.
- 27 CORING COOPERATIVE WELLS
- SPACE HEATING

METHANE FROM COALBEDS PROJECT

ACTIVE CONTRACTS AND ESTIMATED FY80 CONTRACT FUNDING

CONTRACTOR	ESTIMATED FUNDING FY80, $
•RESEARCH CHARACTERIZATION:	
TRW	3,000,000 1/
INTERCOMP	50,000
COLORADO GEOLOGICAL SURVEY	60,000
UTAH GEOLOGICAL SURVEY	52,000
•RESEARCH & DEVELOPMENT:	
PHYSICS INTERNATIONAL	------2/
SANDIA	120,000
UNIVERSITY OF PITTSBURGH	65,000
MAURER ENGINEERING	11,000
WEST VIRGINIA UNIVERSITY	14,000
GEO CHEM	100,000
•TECHNOLOGY TESTING:	
U.S. STEEL--VERT. DEGAS.	------3/
U.S. STEEL--DYN. RES. COND.	------3/
WESTINGHOUSE--SPACE HEATING	------2/
WESTINGHOUSE--POWER GENERATION	200,000
EMERALD MINE	100,000
CLINCHFIELD	------3/
MOUNTAIN FUEL	600,000
INTERCOMP / COSEKA	------2/
NEAR-MINE STIMULATION	------3/
•SUPPORT:	
HARRIS & ASSOCIATES	172,000
USBM SUPPORT	------3/
INHOUSE	456,000
T O T A L	5,000,000

1/ INCLUDES RESOURCE DELINEATION, TECHNOLOGY TESTING, INSTRUMENTATION (MODELING), AND SUPPORT.

2/ ONGOING WORK FUNDED FROM PREVIOUS YEAR.

3/ PREVIOUSLY FUNDED, BROUGHT OVER FROM USBM AND DOE MINING.

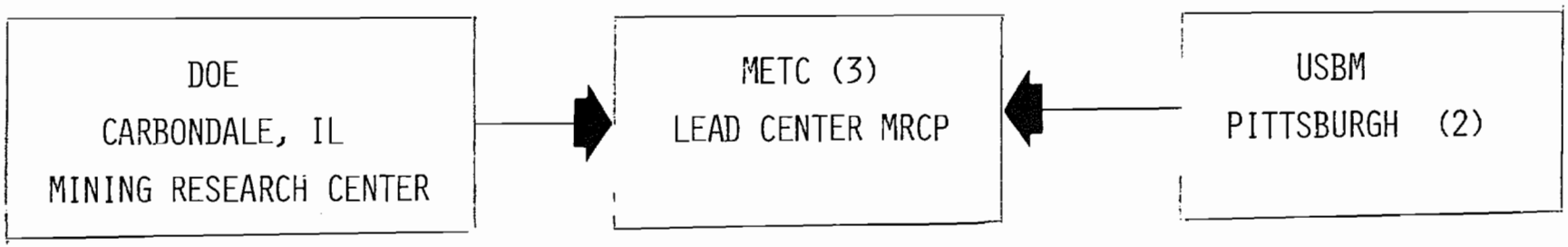
METHANE FROM COALBEDS PROJECT

TECHNICAL OBJECTIVES

- LOCATION & DELINEATION OF COALBED METHANE RESOURCES
- DEVELOPMENT OF METHANE RECOVERY PREDICTION AND PRODUCTION TECHNIQUES (MODELS FOR WELL PRODUCTIVITY)
- DEVELOPMENT OF IMPROVED, COST-EFFECTIVE METHANE RECOVERY & UTILIZATION TECHNOLOGY
- FIELD TEST OF METHANE EXTRACTION / PREPARATION / UTILIZATION TECHNOLOGY SYSTEMS
- IDENTIFICATION OF LEGAL, REGULATORY, AND ENVIRONMENTAL BARRIERS TO COMMERCIALIZATION
- DEVELOPMENT OF SYSTEMS & TECHNIQUES FOR USE IN MINE PLANNING

METHANE FROM COALBEDS PROJECT

GOVERNMENT "IN HOUSE" MANAGEMENT SUPPORT
(MAN YEARS / YEAR)



- U.S. STEEL, AL
  VERT. DEGAS
  DYN. RES. COND.

- EVERYTHING ELSE

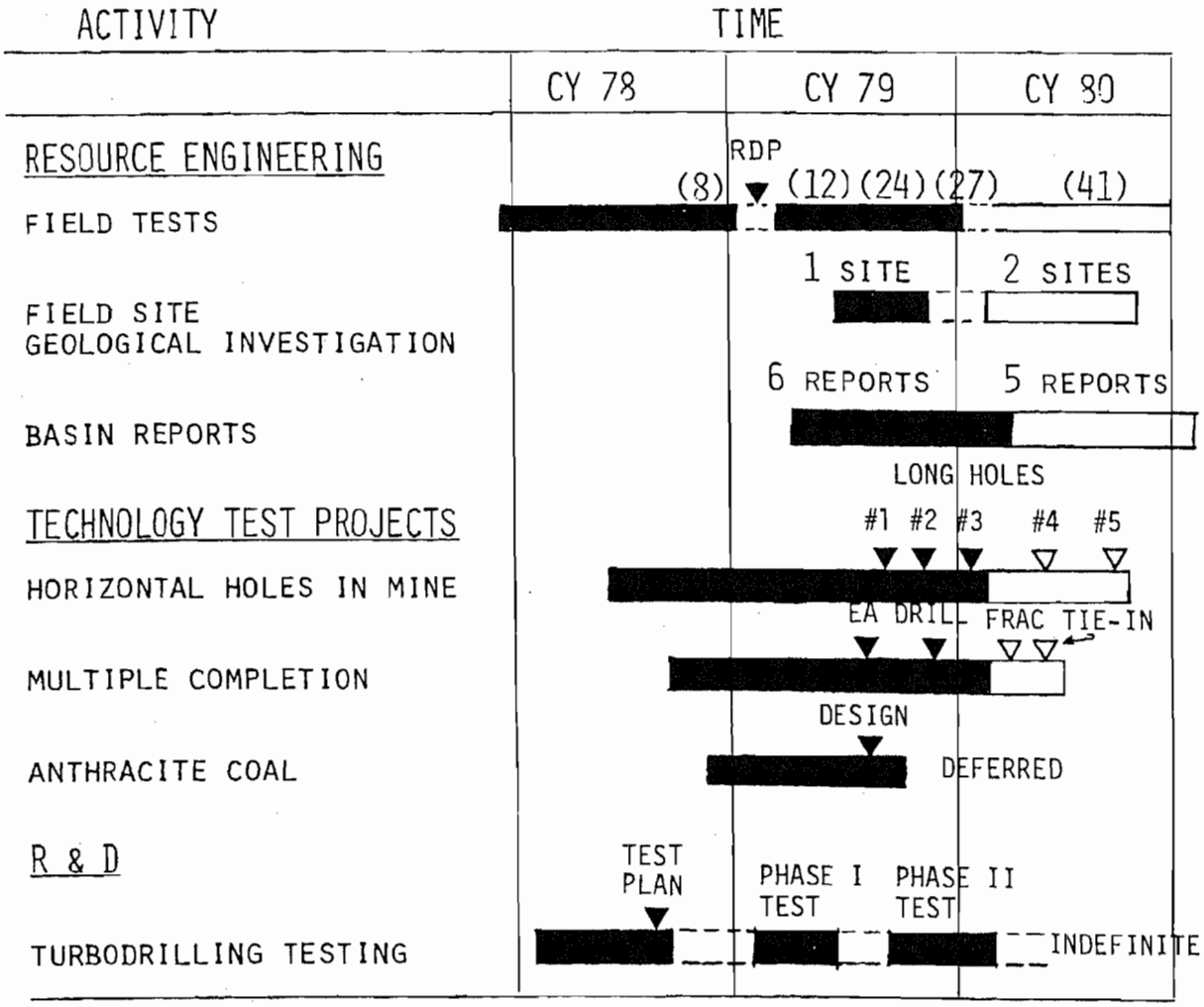
- EMERALD MINE, PA
- CLINCHFIELD, VA
- DESORPTION ANALYSIS
- NEAR MINE STIMULATION

PROJECT OBJECTIVES

- RESOURCE VERIFICATION
- RESERVOIR EVALUATION
- PRODUCTION ENHANCEMENT
- PRODUCT PREPARATION

- CONTRACT: TRW ENERGY SYSTEMS
  DE-AC21-78MC08089
- CONTRACT DATE: DECEMBER 12, 1977
- ANTICIPATED COMPLETION DATE: FEBRUARY 12, 1981
- TOTAL COST: $10,065,000
- DOE COST: $10,065,000
- OBJECTIVES:
  - RESOURCE ENGINEERING
    TO PROVIDE TECHNICAL ASSISTANCE AND SUBCONTRACTING SUPPORT FOR RESOURCE DELINEATION ACTIVITIES
  - TECHNOLOGY TEST PROJECT
    TO PROVIDE DESIGN/DEVELOPMENT ANALYSES, IMPLEMENTATION, AND EVALUATION OF TECHNOLOGY TEST PROJECTS
  - ENGINEERING ASSISTANCE
    TO PROVIDE TECHNICAL ASSISTANCE TO THE METHANE FROM COALBEDS PROJECT

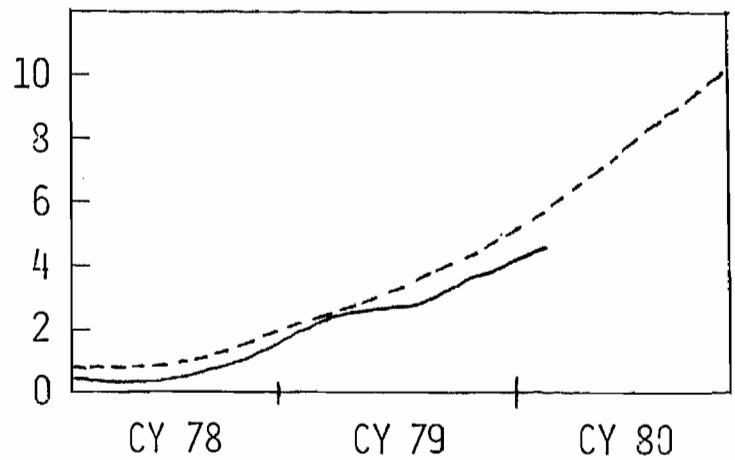
- MAJOR ACTIVITIES:



( ) NUMBER OF TESTS, CUMULATIVE

RDP RESOURCE DELINEATION PLAN

- FUNDING PROFILE:



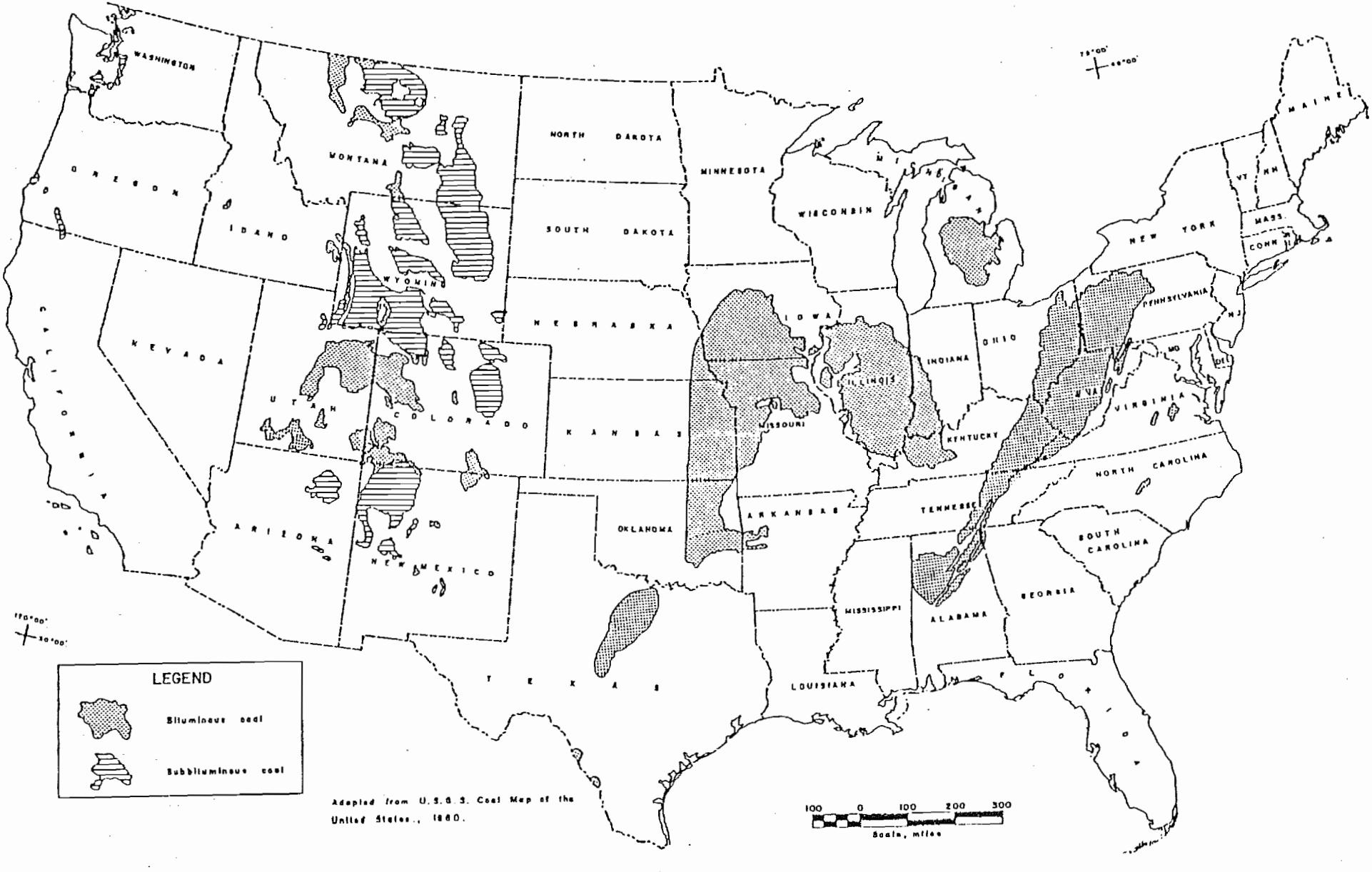
PLANNED _ _ _ _ _

ACTUAL ————

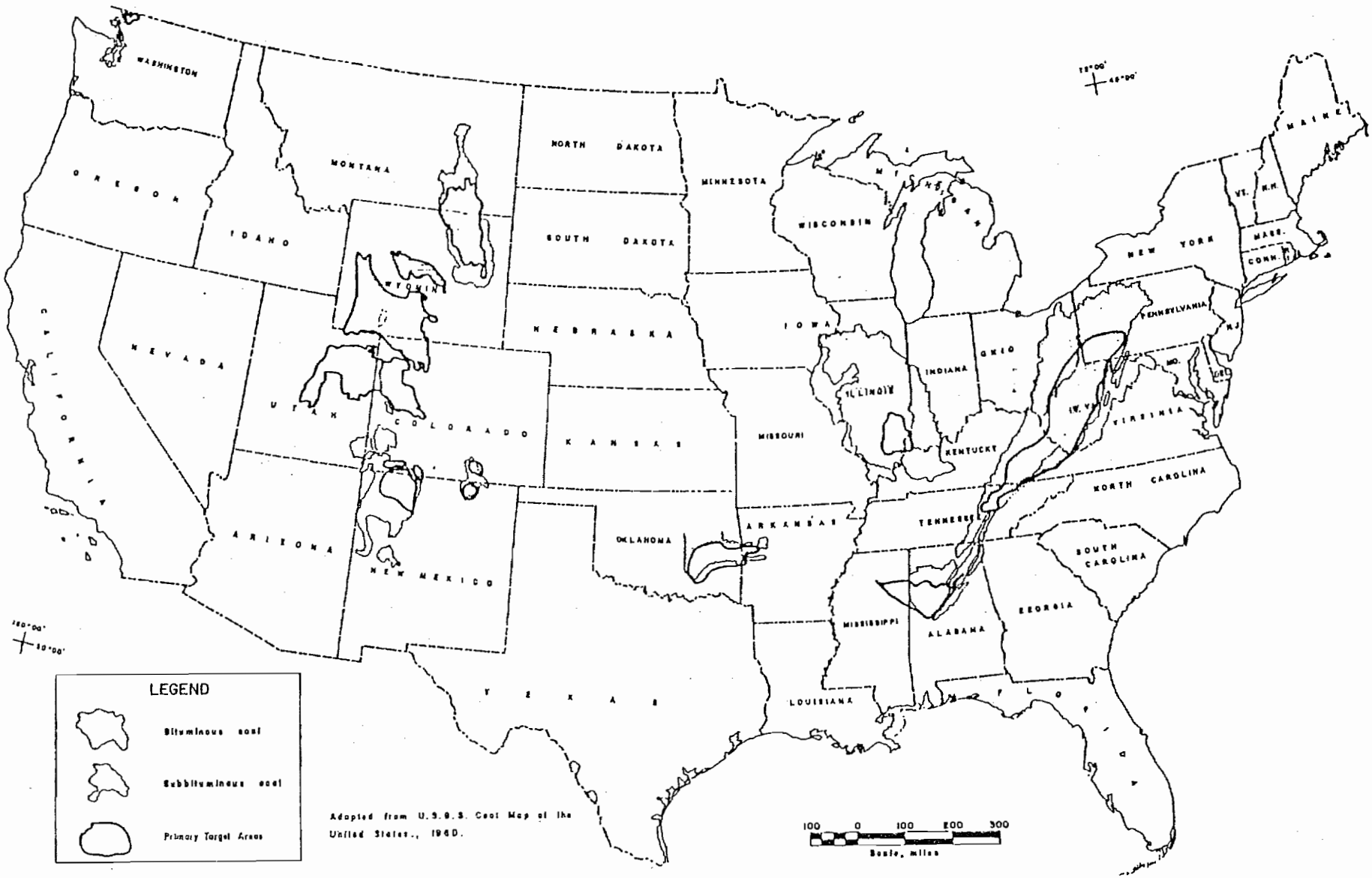
PROJECT ELEMENTS

- RESOURCE ENGINEERING
- RESEARCH AND DEVELOPMENT
- TECHNOLOGY SYSTEMS TESTS
- PROJECT INTEGRATION

METHANE FROM COALBEDS



METHANE FROM COALBEDS



METHANE FROM COALBEDS

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COALBED METHANE - RESOURCE ENGINEERING

OBJECTIVE: DEFINE THE RESOURCE BY DEVELOPING -

- METHANE CONTENT (TYPE I TEST - OIL OR GAS WELL AVAILABLE FOR SHORT COOP TESTING FOR COAL GAS CONTENT)
- METHANE PRODUCIBILITY (TYPE II & III - OIL OR GAS WELL - ABANDONED OR READY FOR COAL GAS PRODUCTION EFFORTS)
- TARGET SELECTION/EXPLORATION METHOD SELECTION (BASIN REPORTS - DETAILED SITE INVESTIGATION)

SCOPE:

- 380,000 SQUARE MILES OF COAL-BEARING ROCK IN THE U. S. 80,000 SQUARE MILES IN 12 MAJOR AREAS SELECTED FOR "FAST TRACK" COMMERCIALIZATION EFFORT.

COALBED METHANE - RESOURCE ENGINEERING

WELL TYPES

TYPE I: CONVENTIONAL OIL OR GAS WELL BEING DRILLED IN POTENTIAL RESERVOIRS BELOW THE COAL. ACTIVITIES LIMITED TO SHORT PERIODS. THE TESTING MAY INCLUDE CONVENTIONAL AND SIDEWALL CORES AND DRILL STEM TESTS (DST).

TYPE II: WELL DRILLED FOR OTHER PURPOSES AND READY FOR ABANDONMENT. ALL ACTIVITIES WITH TYPE II WELLS ASSUME COAL IS CASED WITH GOOD CEMENT OVER THE COAL ZONE. THE TESTING WOULD THEN INVOLVE PERFORATING THE CASING IN THE AREA OF THE COAL WHERE INFORMATION IS DESIRED, CONDUCTING A DST AND PERHAPS FLUID/ACID INJECTION TEST. IF THESE TESTS ARE FAVORABLE THEN PERHAPS CONDUCT A HYDRAULIC FRACTURE OF THE COAL SEAM AND POST-TEST INJECTION TESTS.

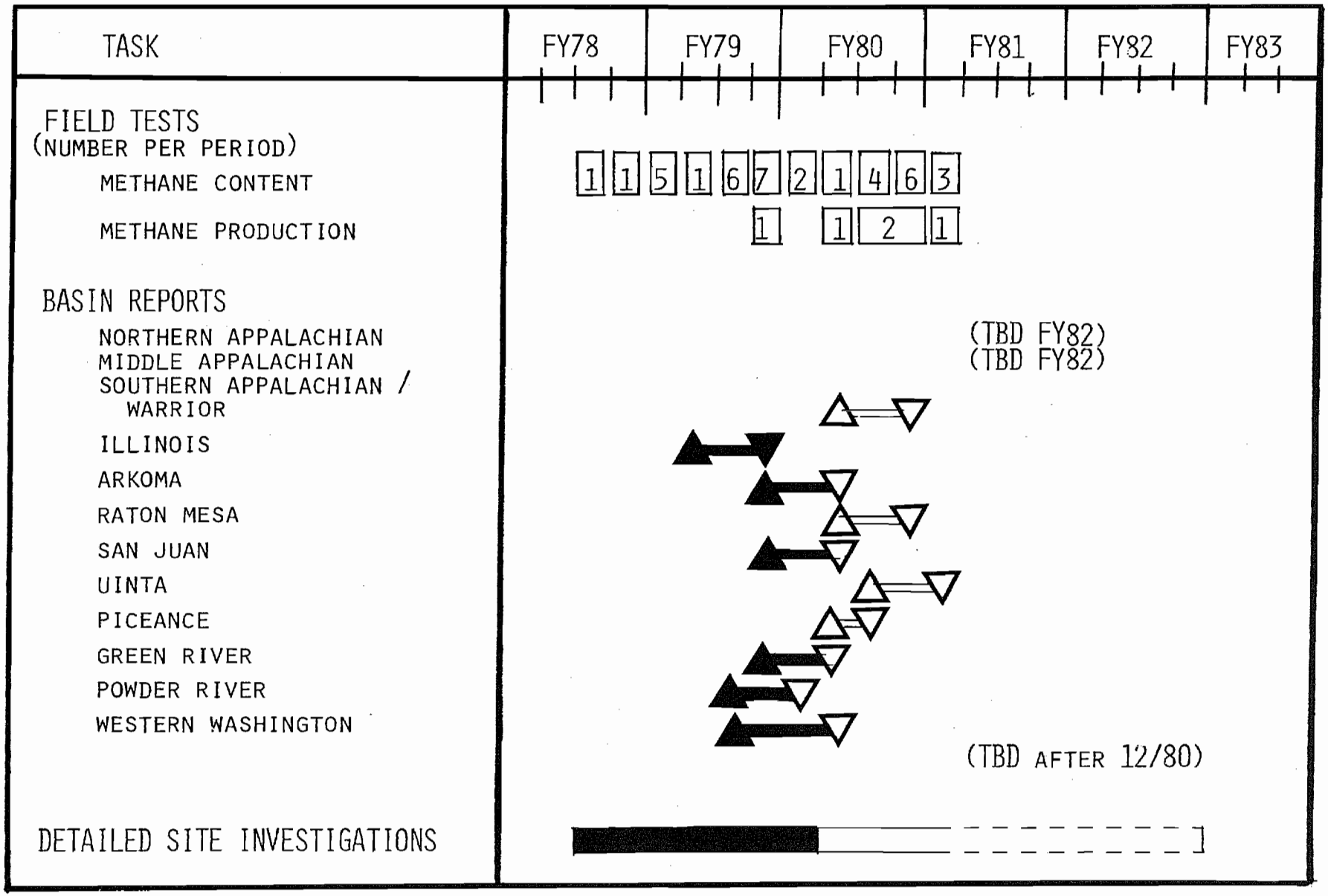
TYPE III: A NEW WELL DRILLED PRIMARILY FOR COMPLETION AS A PRODUCTION WELL FROM COALBEDS AND CAN BE USED FOR ENTIRE SUITE OF TESTS. THE TESTING MAY INCLUDE CONVENTIONAL AND SIDEWALL CORES, DST, PRE- AND POST-FRACTURE INJECTION TESTS, HYDRAULIC FRACTURING AND FLOW TESTS.

COALBED METHANE - RESOURCE ENGINEERING

MAJOR COAL-BEARING REGIONS

Region	Area Underlain by Coal-Bearing Rocks (sq mi)	Initial Primary Target Area (sq mi)
Northern Appalachian	47,900	19,600
Middle Appalachian	18,300	5,500
Southern Appalachian (Warrior Basin)	14,400	6,800
Eastern (Illinois Basin)	39,000	9,100
Western (Arkoma Basin)	5,300	5,300
San Juan	19,000	4,900
Raton Mesa	2,400	1,600
Unita	19,300	19,300
Green River	21,200	21,200
Wind River	3,800	3,800
Powder River	22,700	12,800
Western Washington	7,500	400

COALBED METHANE - RESOURCE ENGINEERING MASTER SCHEDULE



COALBED METHANE - RESOURCE ENGINEERING

OBJECTIVE: TO ESTIMATE MORE RELIABLY THE AMOUNT OF METHANE IN COALBEDS OF THE UNITED STATES

ACCOMPLISHMENTS:

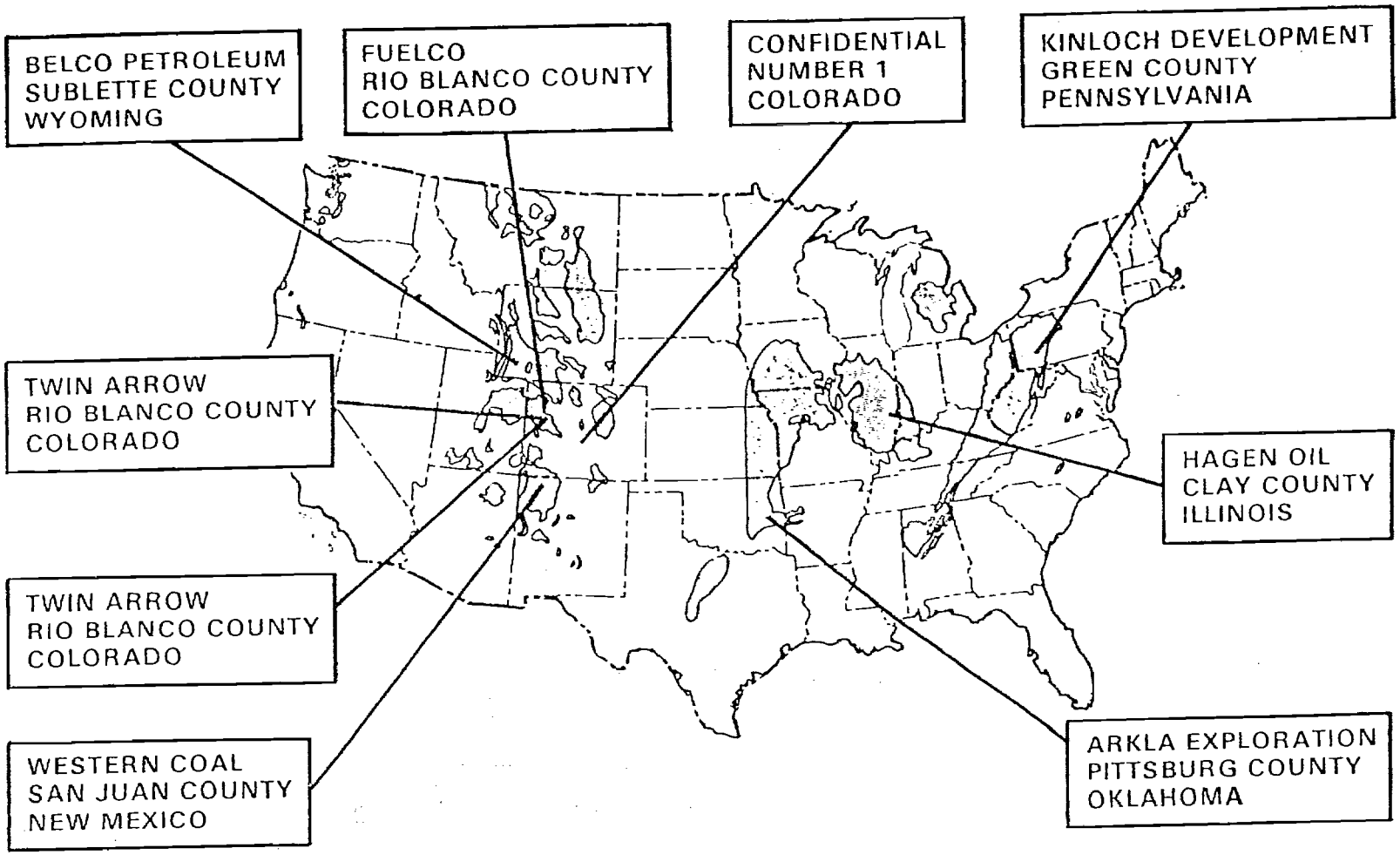
- CONDUCTED 27 TYPE I TESTS IN 9 GEOLOGIC AREAS
- GAS CONTENT ANALYSES FROM 131 COAL SAMPLES AND 21 ROOF AND FLOOR ROCK SAMPLES
- GAS CONTENTS OBSERVED RANGE FROM 1 - 540 CF/T

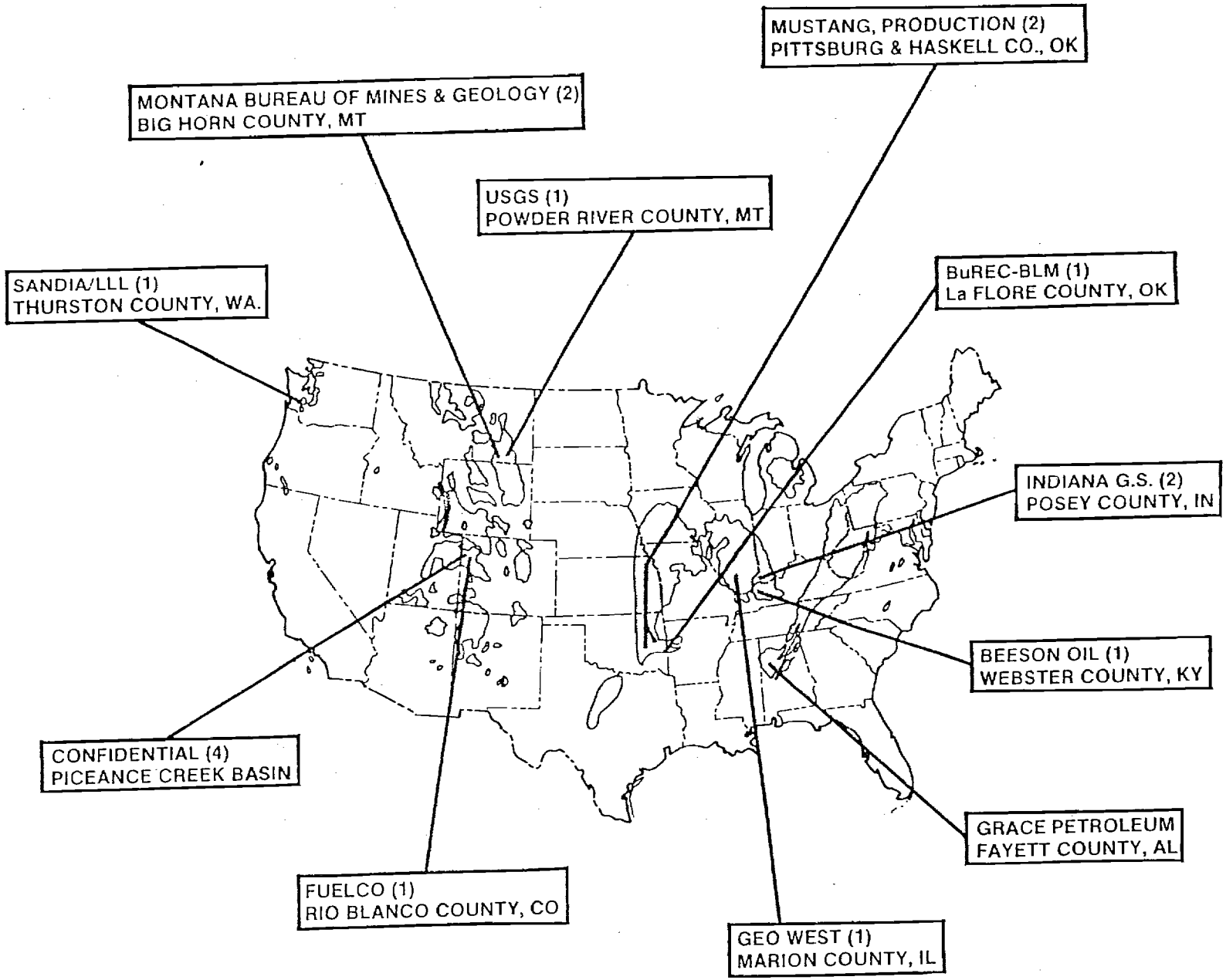
CRITICAL ITEMS:

- ADDITIONAL GAS CONTENT ANALYSES IN REDEFINED TARGET AREAS
- DETERMINE WHICH GEOLOGICAL PARAMETERS MOST STRONGLY INFLUENCE METHANE CONTENT AND DISTRIBUTION

RECOMMENDATIONS:

- CONDUCT TYPE I TESTS IN REDEFINED TARGET AREAS
- EVALUATE METHANE CONTENT AND DISTRIBUTION RELATIVE TO ENVIRONMENT OF DEPOSITION OF COALBEDS


BELCO PETROLEUM
SUBLETTE COUNTY
WYOMING
FUELCO
RIO BLANCO COUNTY
COLORADO
CONFIDENTIAL
NUMBER 1
COLORADO
KINLOCH DEVELOPMENT
GREEN COUNTY
PENNSYLVANIA
TWIN ARROW
RIO BLANCO COUNTY
COLORADO
HAGEN OIL
CLAY COUNTY
ILLINOIS
TWIN ARROW
RIO BLANCO COUNTY
COLORADO
WESTERN COAL
SAN JUAN COUNTY
NEW MEXICO
ARKLA EXPLORATION
PITTSBURG COUNTY
OKLAHOMA


MUSTANG, PRODUCTION (2)
PITTSBURG & HASKELL CO., OK
MONTANA BUREAU OF MINES & GEOLOGY (2)
BIG HORN COUNTY, MT
USGS (1)
POWDER RIVER COUNTY, MT
SANDIA/LLL (1)
THURSTON COUNTY, WA.
BuREC-BLM (1)
La FLORE COUNTY, OK
INDIANA G.S. (2)
POSEY COUNTY, IN
BEESON OIL (1)
WEBSTER COUNTY, KY
CONFIDENTIAL (4)
PICEANCE CREEK BASIN
GRACE PETROLEUM
FAYETT COUNTY, AL
FUELCO (1)
RIO BLANCO COUNTY, CO
GEO WEST (1)
MARION COUNTY, IL

COALBED METHANE - RESOURCE ENGINEERING

RANGE OF GAS CONTENTS TO DATE

BASIN	GAS CONTENT (FT^3/TON)
ILLINOIS	23 - 48
ARKOMA	73 - 268
PICEANCE	10 - 339
WARRIOR	17 - 104
POWDER RIVER	1 - 13
GREEN RIVER	133 - 540
SAN JUAN	16 - 73
NORTHERN APPALACHIANS	33 - 425
WESTERN WASHINGTON	34 - 93 *

* ANALYSIS IN PROGRESS

COALBED METHANE - RESOURCE ENGINEERING

METHANE PRODUCTION TESTS

OBJECTIVE: TO DETERMINE THE PRODUCIBILITY OF THE METHANE RESOURCE

ACCOMPLISHMENTS:

- CONDUCTED ONE TYPE III TEST IN GREEN RIVER BASIN
  - PRE-FRAC TESTING COMPLETED
  - FRAC TREATMENT COMPLETED
  - POST-FRAC TESTING IN PROGRESS WITH WATER AND GAS FLOW MONITORED -- MINIMAL FLOW
- CONTRACT FOR ONE TYPE III TEST IN ARKOMA BASIN IN PLACE; OPERATIONS SCHEDULED FOR EARLY 1980

CRITICAL ITEMS:

- RESOLUTION OF PERMITTING PROBLEMS FOR FRAC TESTING COALS ON FEDERAL LANDS
- DOCUMENTED METHANE PRODUCTION AT HIGH LEVELS FROM COALBEDS

RECOMMENDATIONS:

- CONDUCT PRODUCTION TESTS IN AREAS WITH MAXIMUM POTENTIAL FOR PRODUCING COMMERCIAL QUANTITIES OF GAS TO A READY MARKET
- DETERMINE WHICH GEOLOGIC AND RESERVOIR CHARACTERISTICS MOST STRONGLY INFLUENCE METHANE PRODUCTION

COALBED METHANE - RESOURCE ENGINEERING

TARGET SELECTION

OBJECTIVES:

- ASSIMILATE COAL-RELATED REGIONAL GEOLOGIC INFORMATION ON A BASIN-BY-BASIN BASIS
- REDEFINE MRCP GAS TARGET AREAS
- PROVIDE GEOLOGIC FRAMEWORK ON WHICH TO PREDICT METHANE DISTRIBUTION

ACCOMPLISHMENTS:

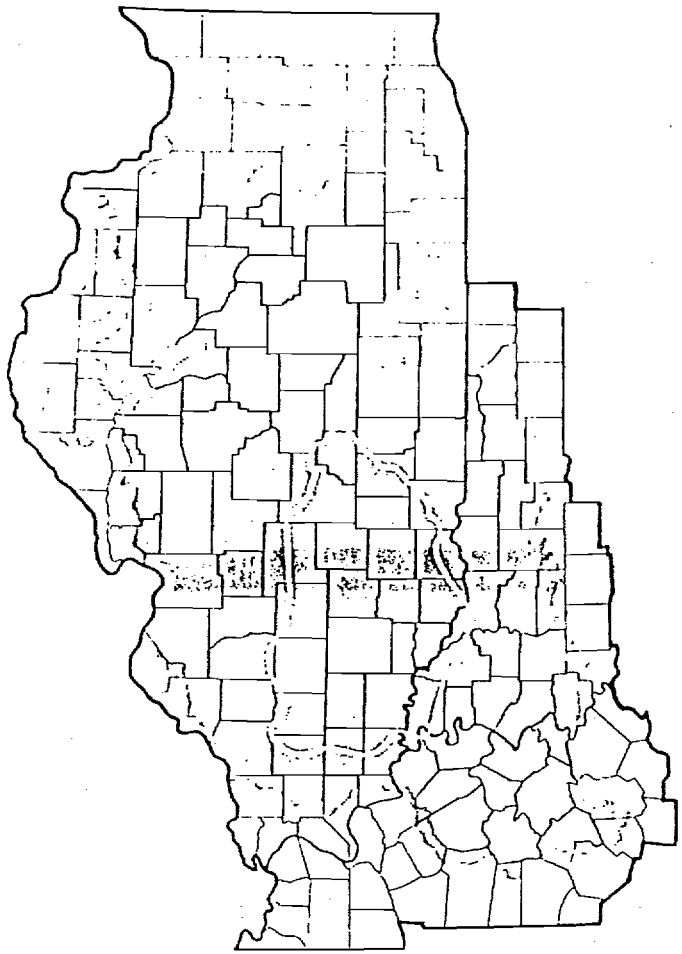
- GENERATED GAS-IN-PLACE ESTIMATES FOR 6 BASINS
- GENERATED 6 BASIN REPORTS THAT REDEFINE TARGET AREAS

CRITICAL ITEMS:

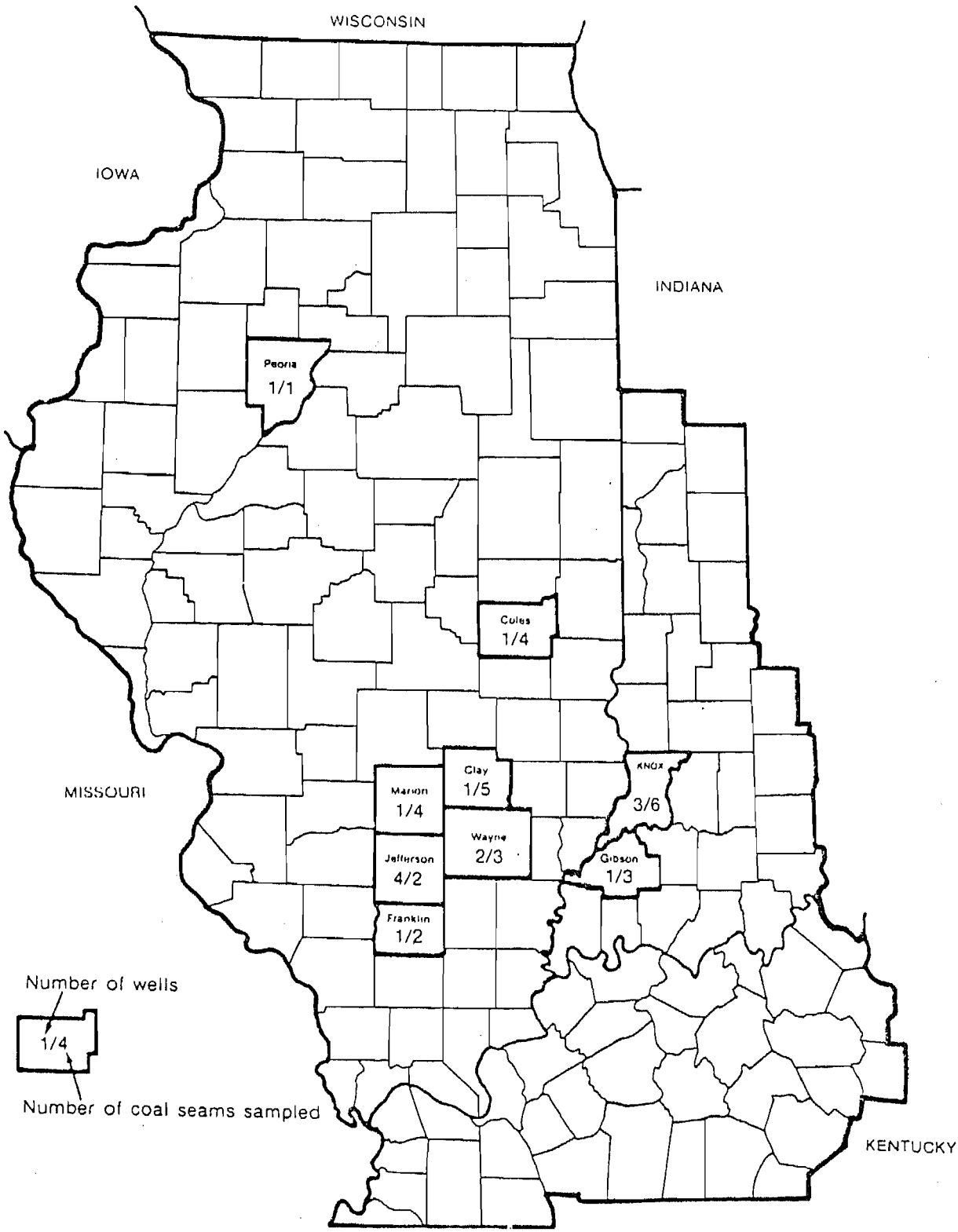
- GENERATION OF ADDITIONAL BASIN REPORTS FOR REMAINING MAJOR COAL-BEARING BASINS
- UPDATE EXISTING RESOURCE ESTIMATES ON THE BASIS OF NEW DATA

RECOMMENDATIONS:

- MAINTAIN CLOSE CONTACT WITH STATE GEOLOGICAL SURVEYS TO PROVIDE INPUTS OF NEW INFORMATION
- PROVIDE FOR CONTINUOUS UPDATING OF DATA BASE TO REDEFINE POTENTIAL METHANE TARGETS

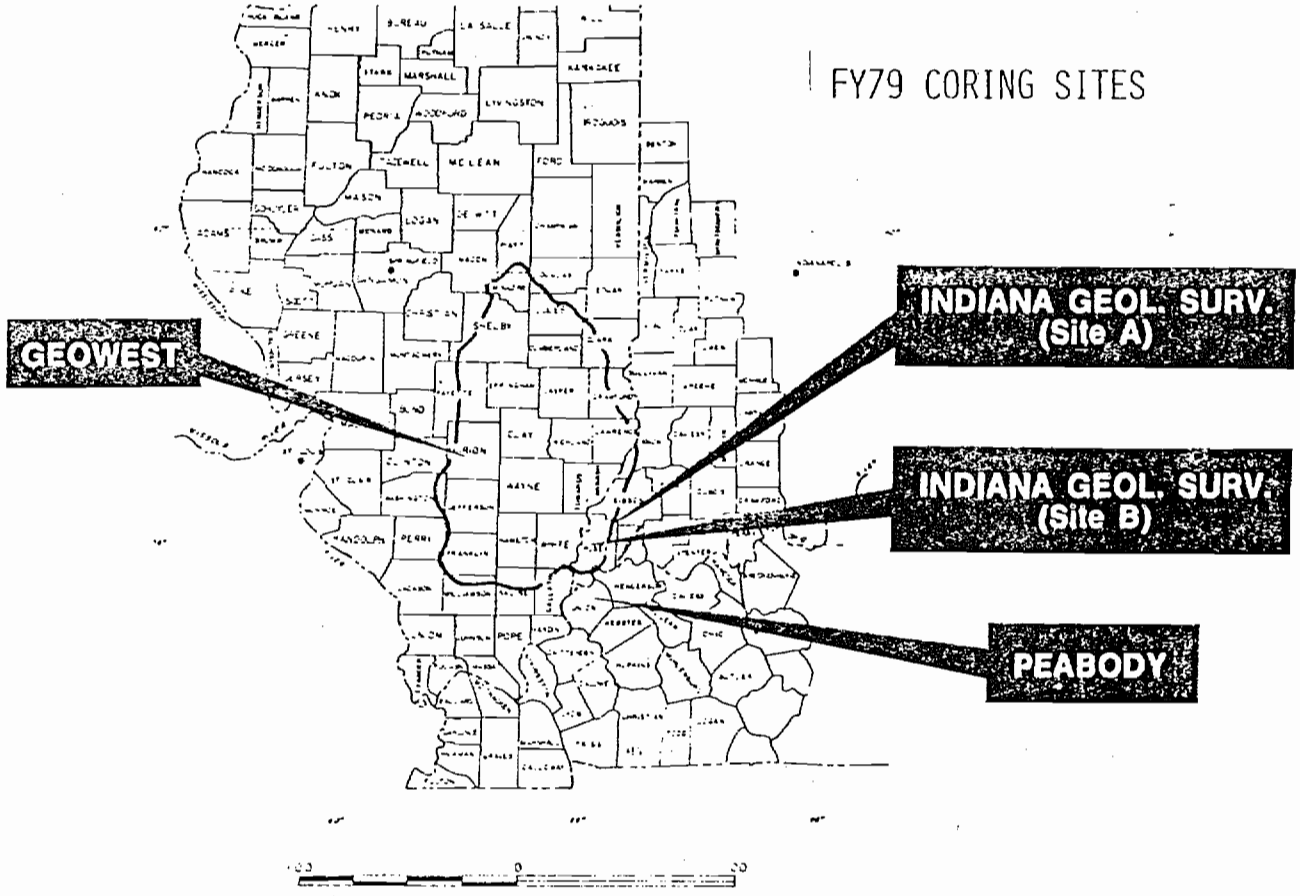


ILLINOIS BASIN SHOWING INITIAL PRIMARY TARGET AREA



Illinois basin map locating counties in which methane desorption data are available

FY79 CORING SITES

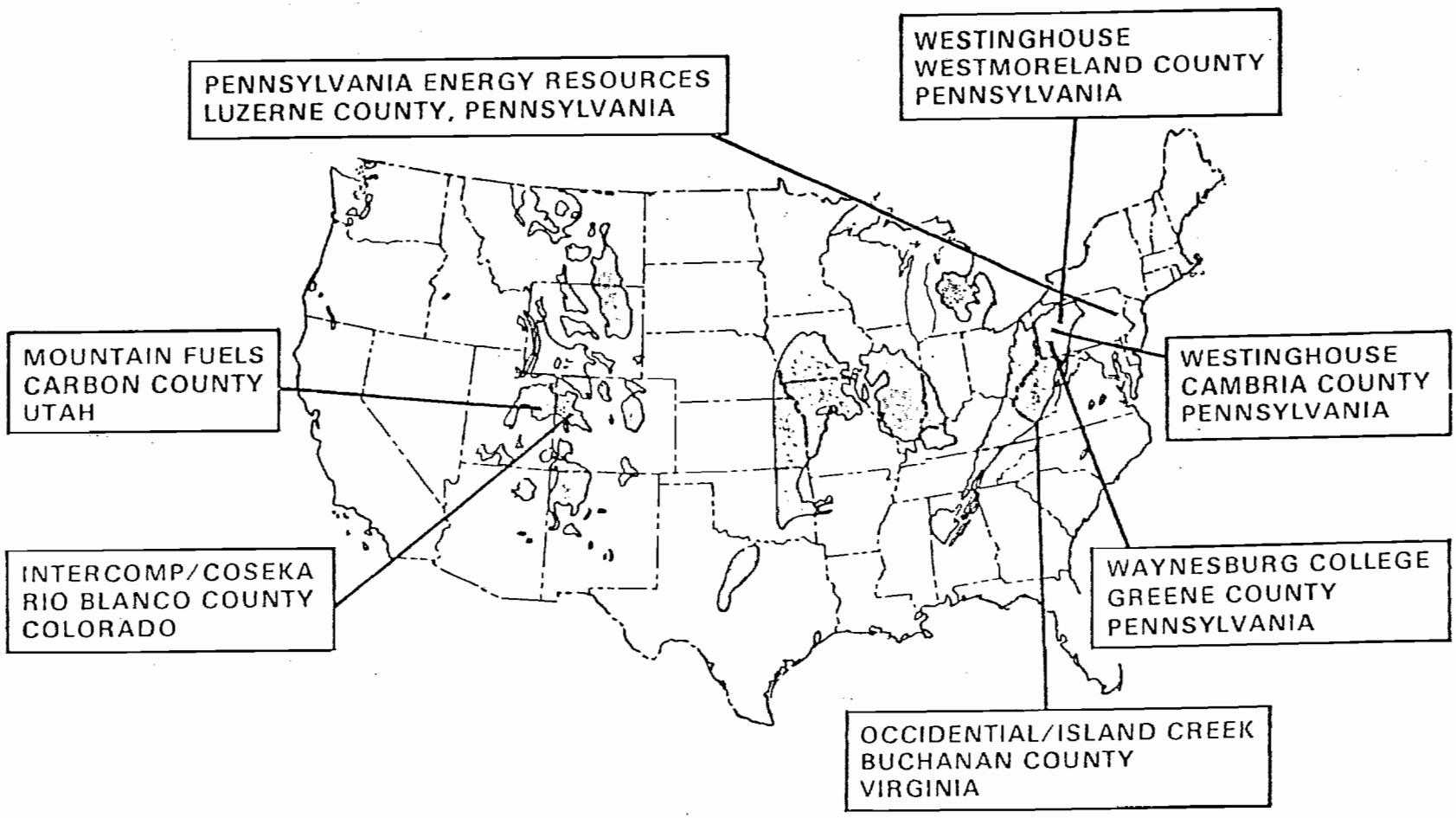


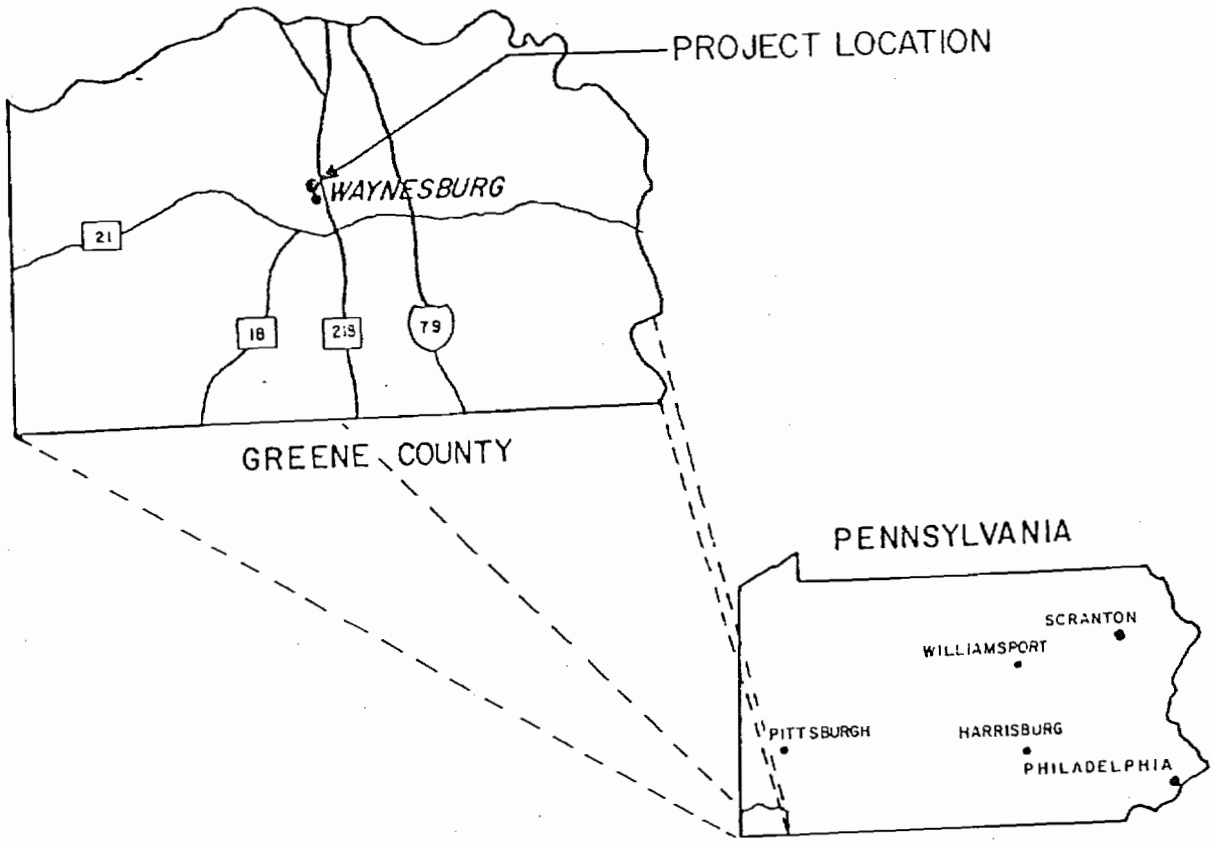
Redefined Illinois Basin Coalbed Methane Target Areas

COALBED METHANE - RESOURCE ENGINEERING

BASIN REPORTS

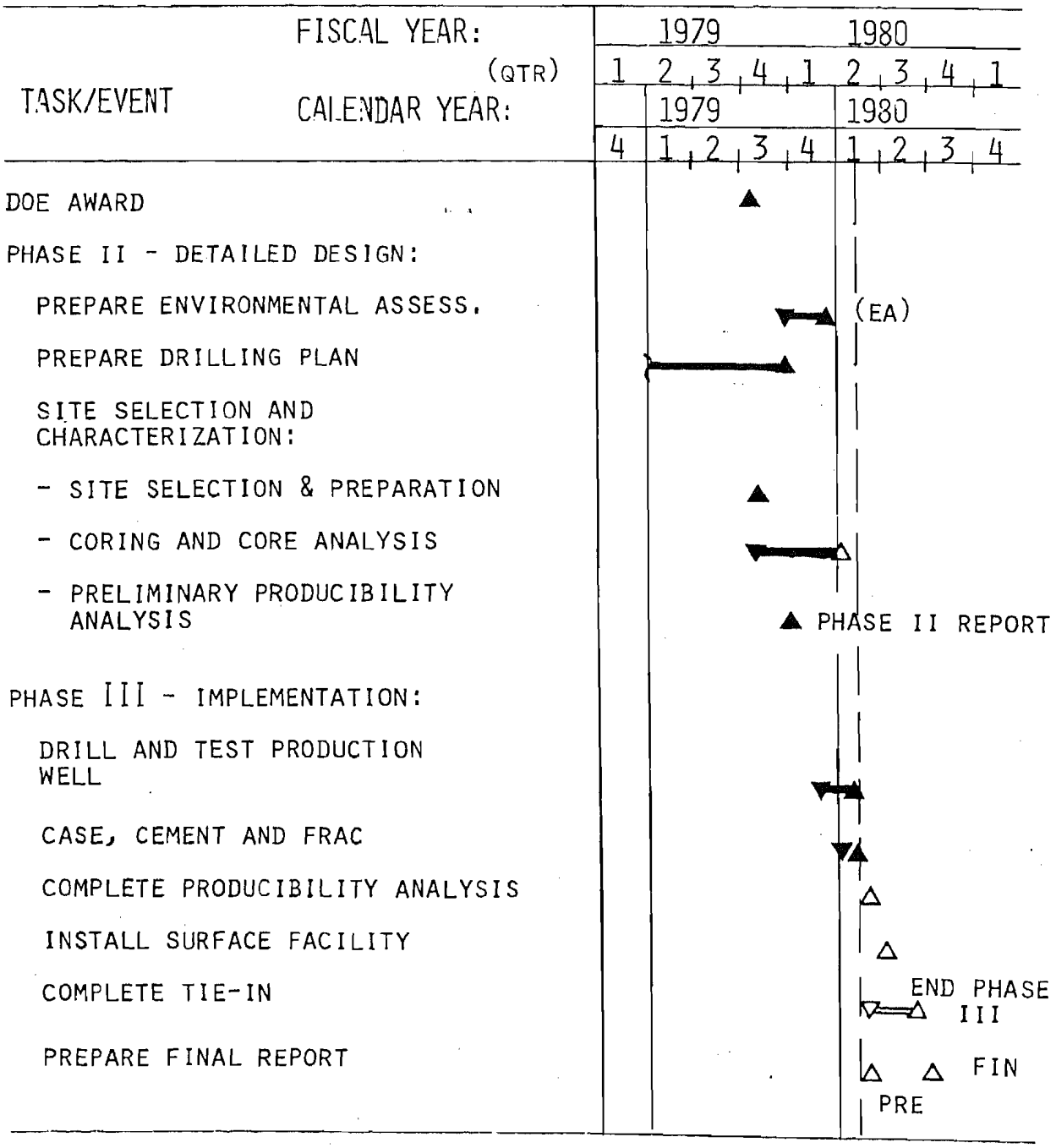
BASIN	AREA UNDERLAIN BY COAL-BEARING ROCKS (SQ MI)	INITIAL PRIMARY TARGET AREA (SQ MI)	REDEFINED TARGET AREA (SQ MI)
ILLINOIS	39,000	9,100	4,300
POWDER RIVER	22,700	12,800	6,750
ARKOMA	5,300	5,300	3,000
SAN JUAN	19,000	4,900	1,400
GREEN RIVER	21,200	21,200	5,000
WESTERN WASHINGTON	~ 7,500	400	1,800


PENNSYLVANIA ENERGY RESOURCES
LUZERNE COUNTY, PENNSYLVANIA
WESTINGHOUSE
WESTMORELAND COUNTY
PENNSYLVANIA
MOUNTAIN FUELS
CARBON COUNTY
UTAH
WESTINGHOUSE
CAMBRIA COUNTY
PENNSYLVANIA
INTERCOMP/COSEKA
RIO BLANCO COUNTY
COLORADO
WAYNESBURG COLLEGE
GREENE COUNTY
PENNSYLVANIA
OCCIDENTIAL/ISLAND CREEK
BUCHANAN COUNTY
VIRGINIA

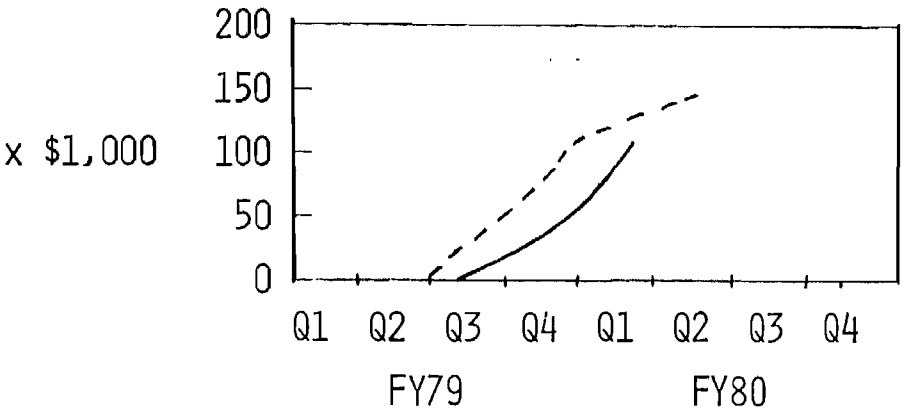

PROJECT LOCATION
WAYNESBURG
21
18
218
79
GREENE COUNTY
PENNSYLVANIA
SCRANTON
WILLIAMSPORT
PITTSBURGH
HARRISBURG
PHILADELPHIA

- CONTRACT: MULTIPLE COMPLETION DEVELOPMENT TEST
  GREENE COUNTY, PENNSYLVANIA
  WAYNESBURG COLLEGE
  DE-AC21-78MC08089
- CONTRACT DATE: JULY 1979
- ANTICIPATED COMPLETION DATE: JUNE 1980
- TOTAL COST: $262,100
- DOE COST: $150,000
- OBJECTIVE: TO DEVELOP AND DEMONSTRATE A MULTIPLE COMPLETION TECHNIQUE SYSTEM CONSIDERING A VARIABLE NEED FOR DEWATERING EACH ZONE AND UTILIZING THE RECOVERED METHANE IN A LOCAL DISTRIBUTION PIPELINE.

- TASKS:


FISCAL YEAR:
1979
1980
(QTR)
1 2 3 4 1 2 3 4 1
TASK/EVENT
CALENDAR YEAR:
1979
1980
4 1 2 3 4 1 2 3 4
DOE AWARD
PHASE II - DETAILED DESIGN:
PREPARE ENVIRONMENTAL ASSESS.
(EA)
PREPARE DRILLING PLAN
SITE SELECTION AND CHARACTERIZATION:
- SITE SELECTION & PREPARATION
- CORING AND CORE ANALYSIS
- PRELIMINARY PRODUCIBILITY ANALYSIS
PHASE II REPORT
PHASE III - IMPLEMENTATION:
DRILL AND TEST PRODUCTION WELL
CASE, CEMENT AND FRAC
COMPLETE PRODUCIBILITY ANALYSIS
INSTALL SURFACE FACILITY
COMPLETE TIE-IN
END PHASE III
PREPARE FINAL REPORT
FIN
PRE

- FUNDING PROFILE:



PLANNED - - - - -

ACTUAL ———

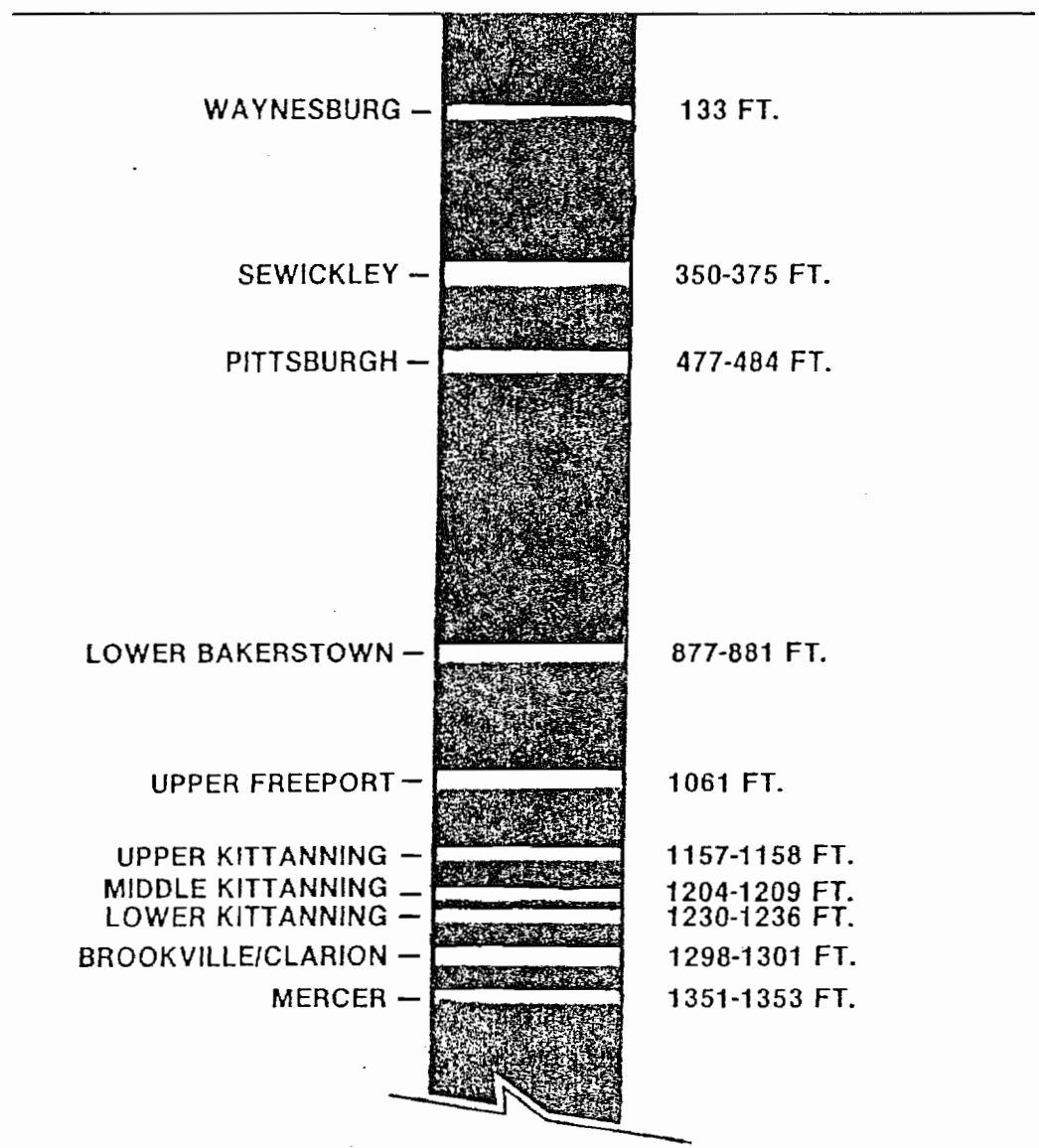
- SUMMARY OF PROGRESS:
  - ENVIRONMENTAL ASSESSMENT COMPLETED
  - DRILLING PLAN COMPLETED
  - SITE SELECTED AND CHARACTERIZED
  - CORING COMPLETED
  - CORE DESORBED
  - PRODUCTION WELL DRILLED, CASED, CEMENTED
  - FRACTURE TREATMENT IN PROGRESS

- CRITICAL ITEMS:
  - GAS QUALITY AND QUANTITY

- RECOMMENDATIONS: NONE

WAYNESBURG COLLEGE METHANE WELL

EXPECTED COAL HORIZONS



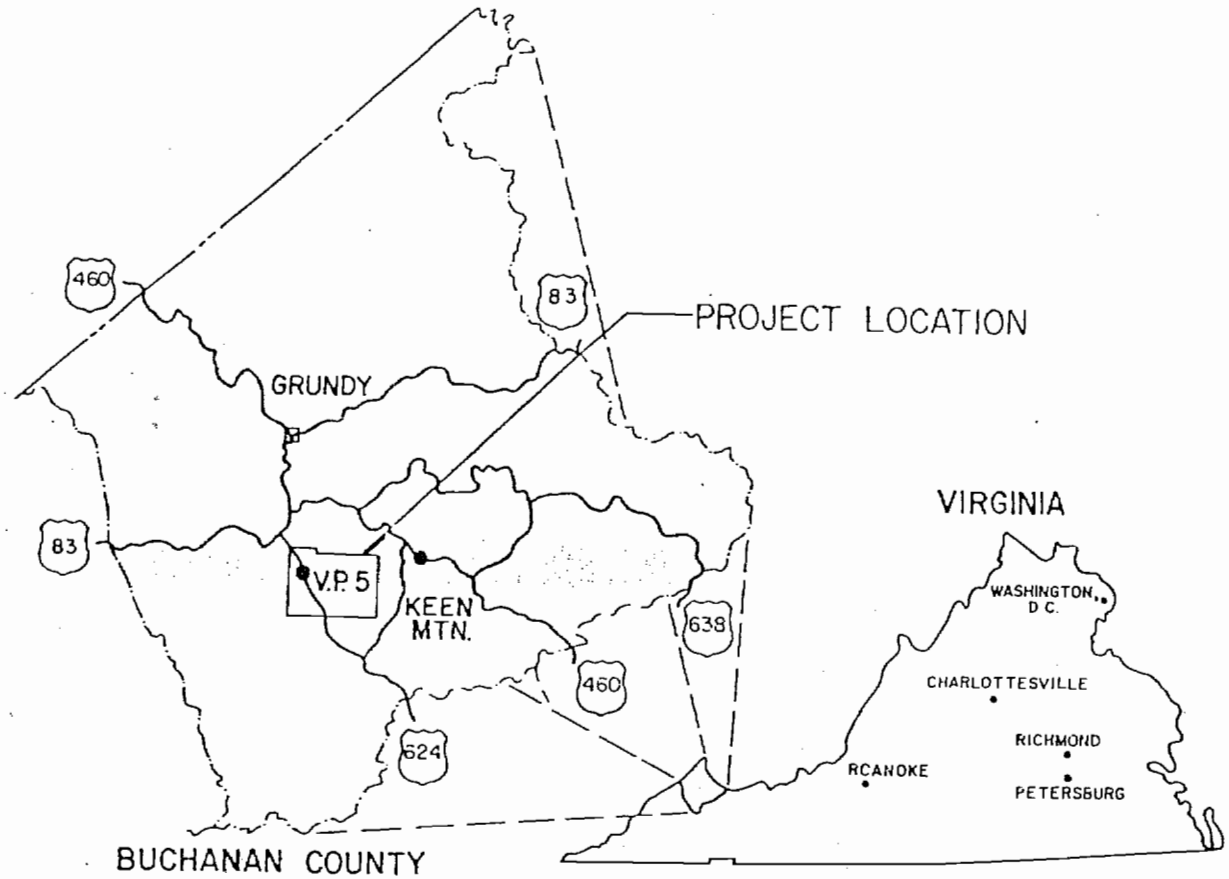
NOT TO SCALE

WAYNESBURG WELL

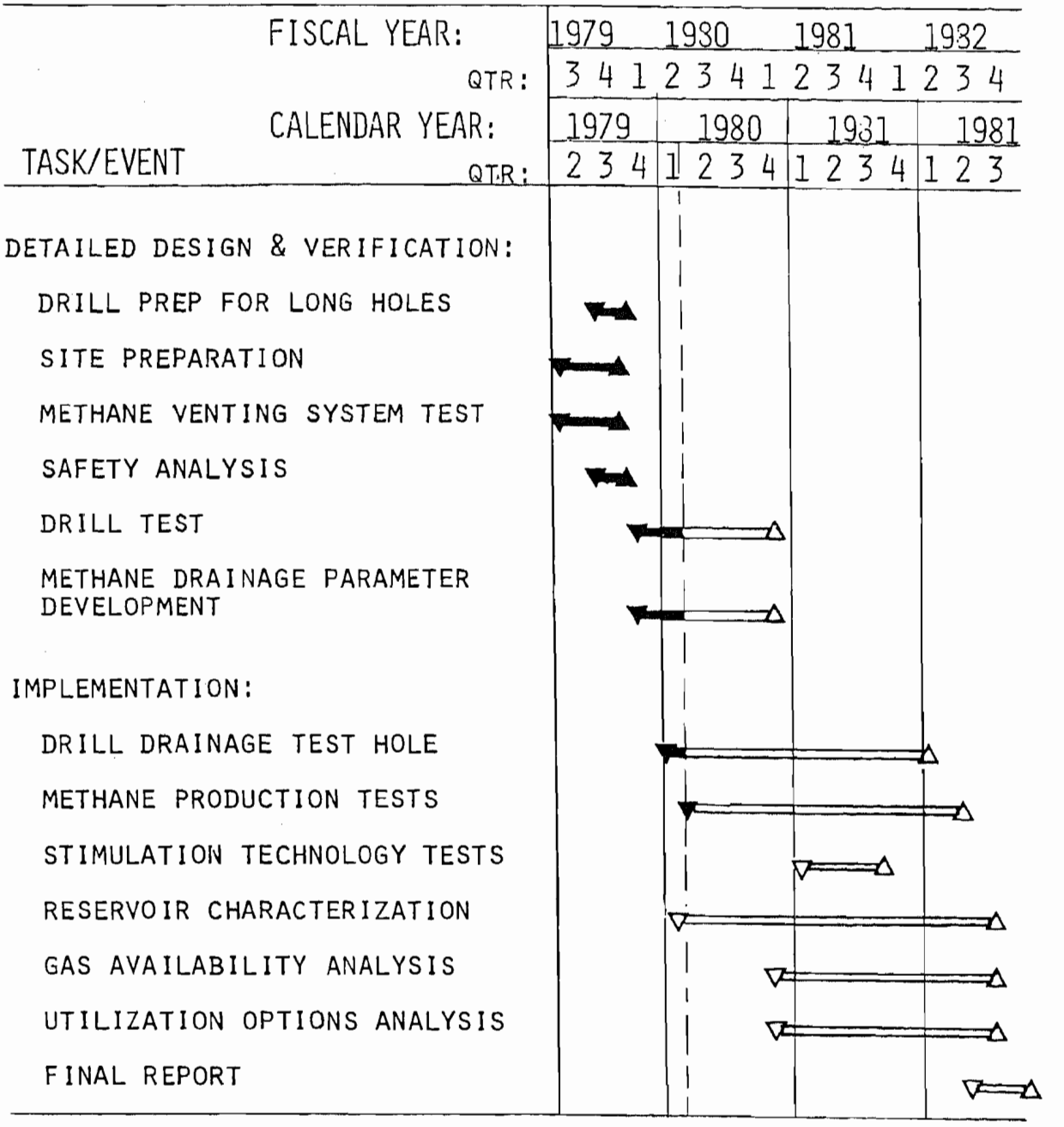
	CF/TON*
WAYNESBURG COALBED	44
SEWICKLEY COALBED	87
PITTSBURGH COALBED	80
BAKERSTOWN COALBED	83
UPPER FREEPORT COALBED	47
UPPER KITTANNING COALBED	116
MIDDLE KITTANNING COALBED	77
CLARION COALBED	94

*DOES NOT INCLUDE RESIDUAL GAS (MINIMUM VALUES)

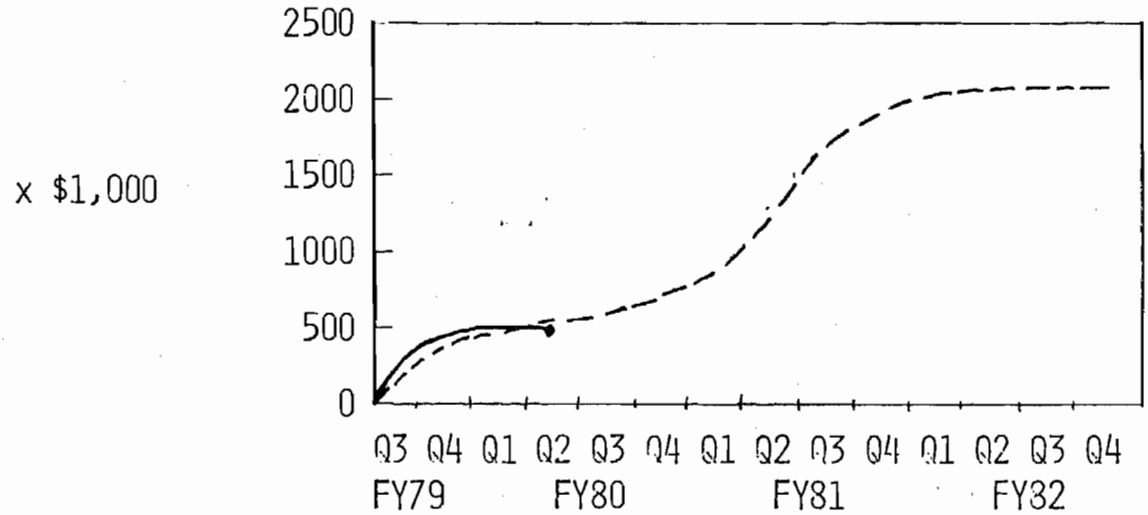
- CONTRACT: LONG HORIZONTAL HOLES, ACTIVE MINE TEST
  BUCHANAN COUNTY, VIRGINIA
  OCCIDENTAL RESEARCH CORP.
  DE-AC21-78MC08089
- CONTRACT DATE: APRIL 1979
- ANTICIPATED COMPLETION DATE: JULY 1981
- TOTAL COST: $2,982,300
- DOE COST: $1,988,200
- OBJECTIVE: TO DEVELOP A TECHNIQUE FOR RECOVERY OF METHANE FROM LONG HORIZONTAL HOLES DRILLED FROM WITHIN THE MINE AND USE THE GAS TO PRODUCE LNG; OR A SIMILAR APPLICATION


460
83
PROJECT LOCATION
GRUNDY
83
V.P. 5
KEEN
MTN.
638
460
624
BUCHANAN COUNTY
VIRGINIA
WASHINGTON,
D.C.
CHARLOTTESVILLE
RICHMOND
ROANOKE
PETERSBURG

- TASKS:


FISCAL YEAR:
1979
1980
1981
1982
QTR:
3 4 1 2 3 4 1 2 3 4 1 2 3 4
CALENDAR YEAR:
1979
1980
1981
1981
TASK/EVENT
QTR:
2 3 4 1 2 3 4 1 2 3 4 1 2 3
DETAILED DESIGN & VERIFICATION:
DRILL PREP FOR LONG HOLES
SITE PREPARATION
METHANE VENTING SYSTEM TEST
SAFETY ANALYSIS
DRILL TEST
METHANE DRAINAGE PARAMETER DEVELOPMENT
IMPLEMENTATION:
DRILL DRAINAGE TEST HOLE
METHANE PRODUCTION TESTS
STIMULATION TECHNOLOGY TESTS
RESERVOIR CHARACTERIZATION
GAS AVAILABILITY ANALYSIS
UTILIZATION OPTIONS ANALYSIS
FINAL REPORT

- FUNDING PROFILE:



PLANNED - - - - -

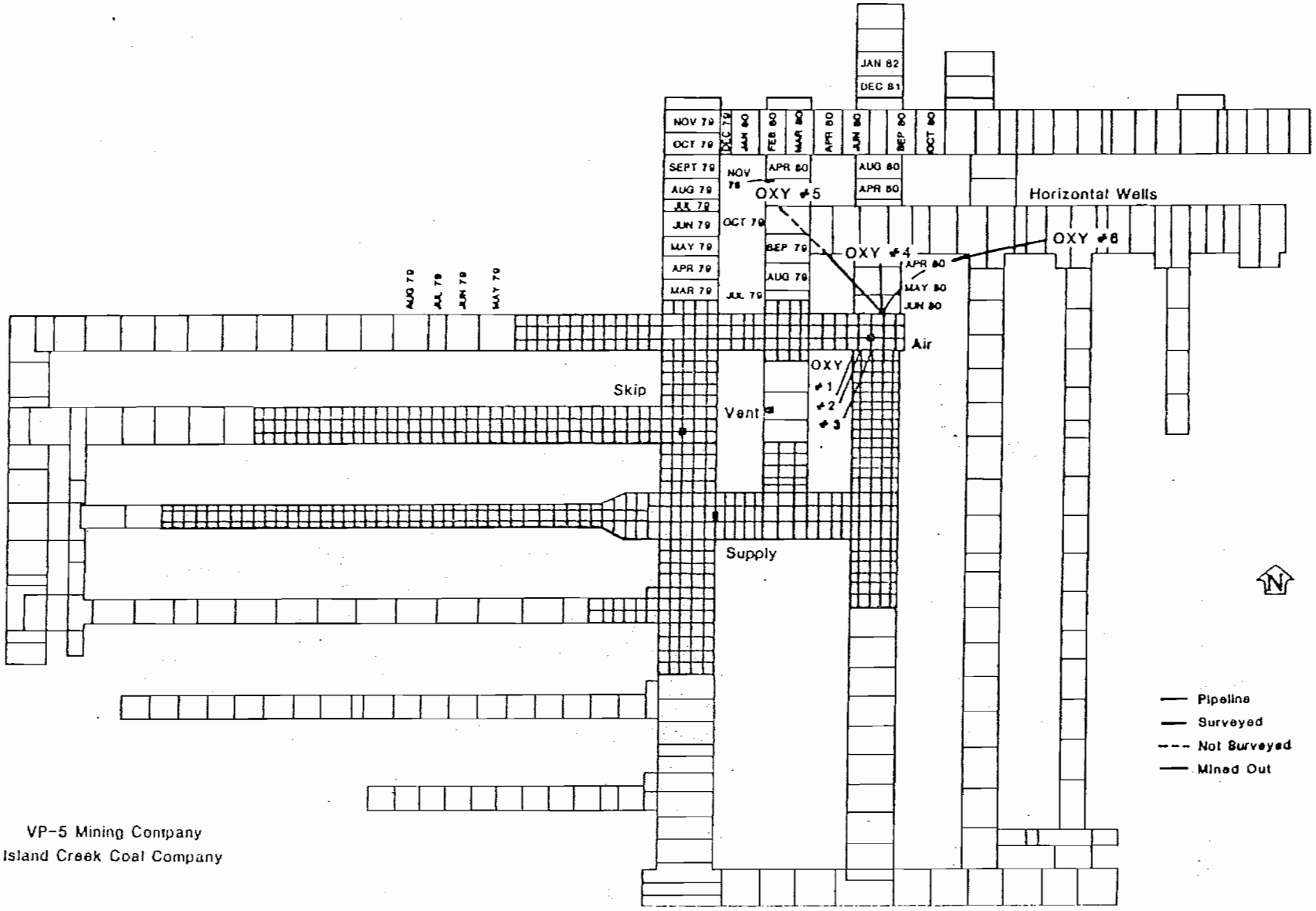
ACTUAL ————

- SUMMARY OF PROGRESS:
  - BASIC TECHNIQUES FOR DRILLING LONG AND SHORT HORIZONTAL BOREHOLES TESTED
  - DRILLING OF VALIDATION LONG HOLE COMPLETED
  - IN-MINE PIPING FOR METHANE VENTING TEST INSTALLED
  - DRILLING OF METHANE PRODUCTION HOLE INITIATED

- CRITICAL ITEMS: NONE

- RECOMMENDATIONS: NONE

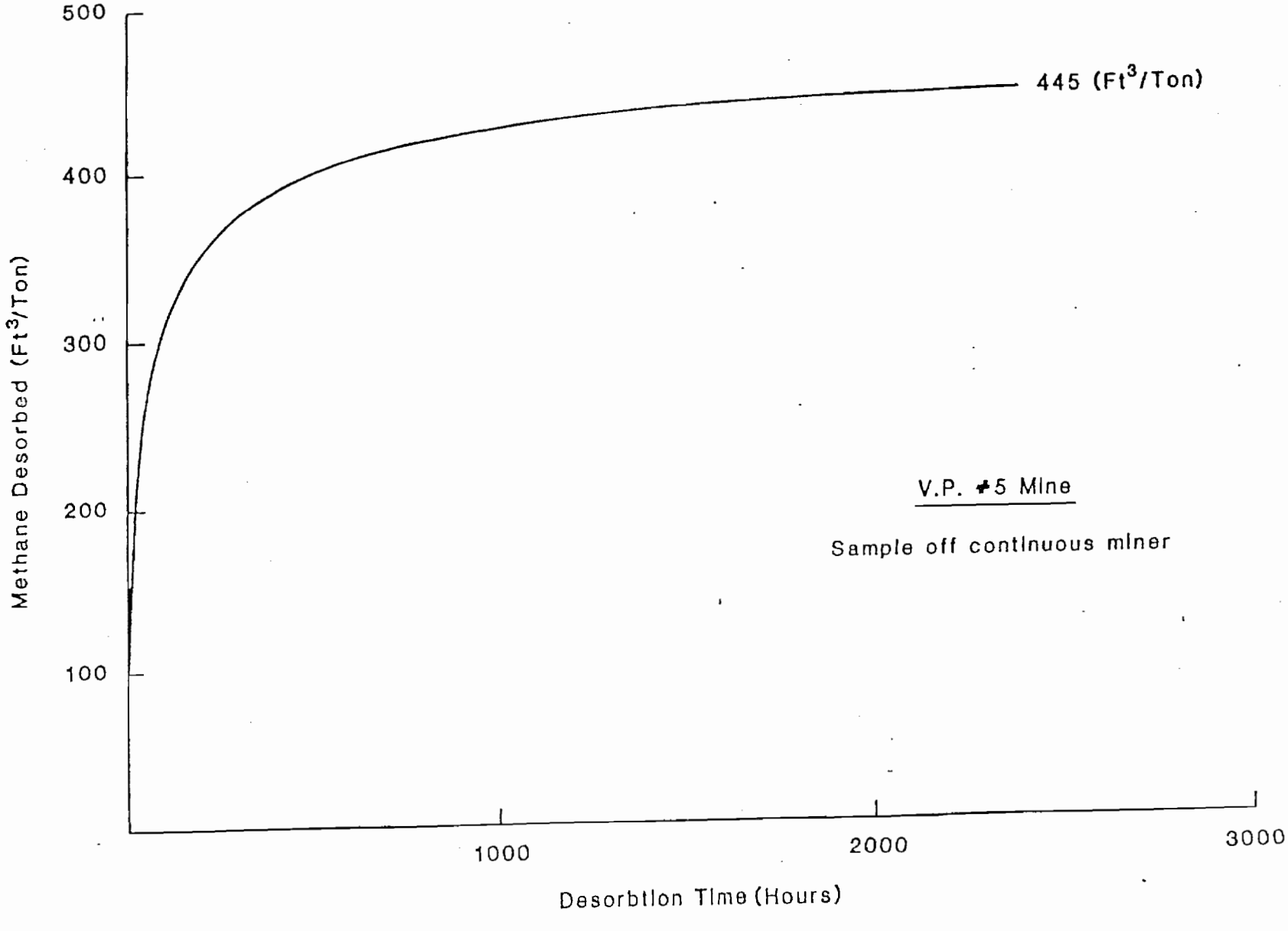
Mining Plan and Current Works



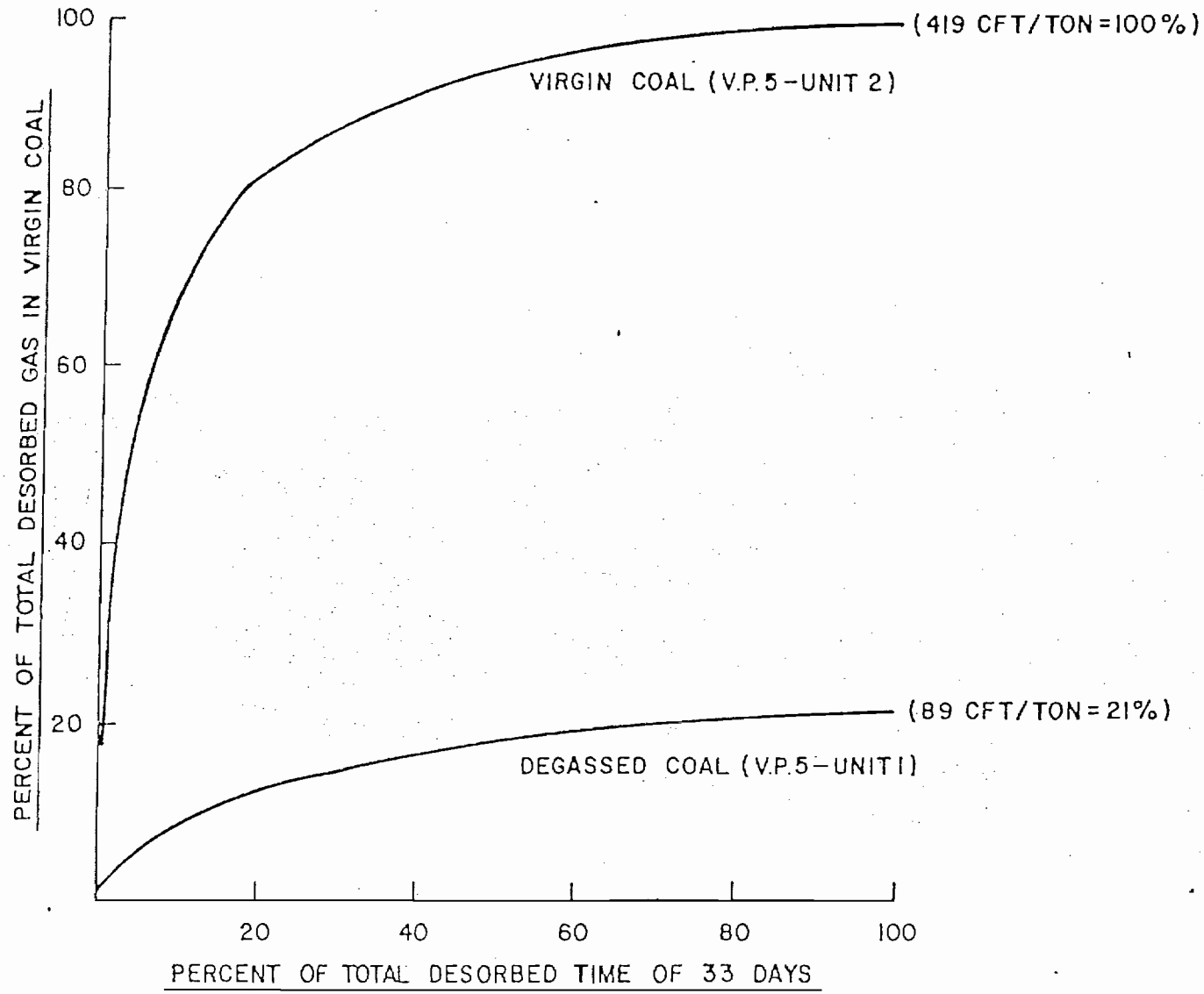
VP-5 Mining Company
Island Creek Coal Company

Methane Content

Pocahontas No. 3 Coal Bed

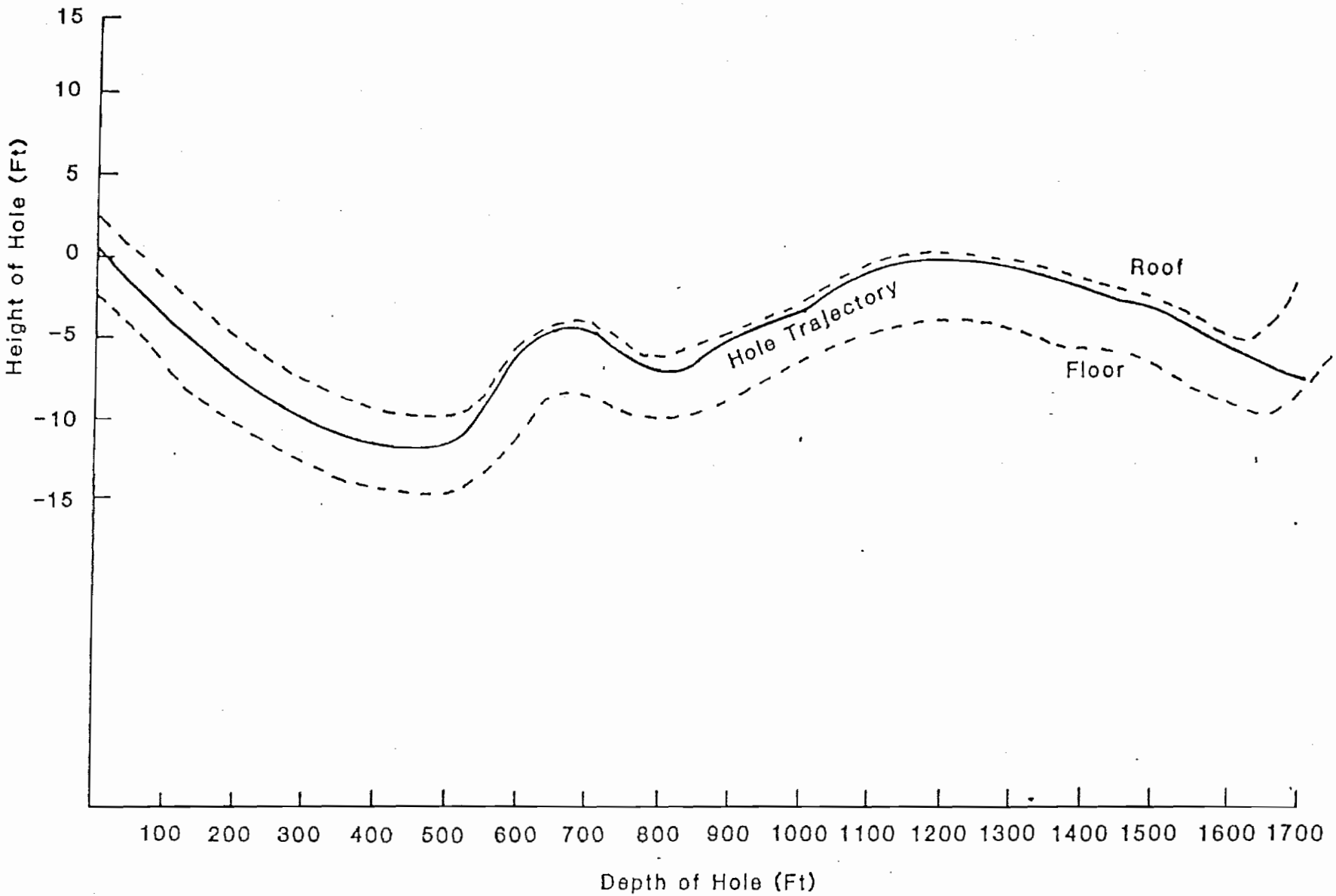


DESORBTION CURVES FOR VIRGIN AND DEGASSED COAL SAMPLES

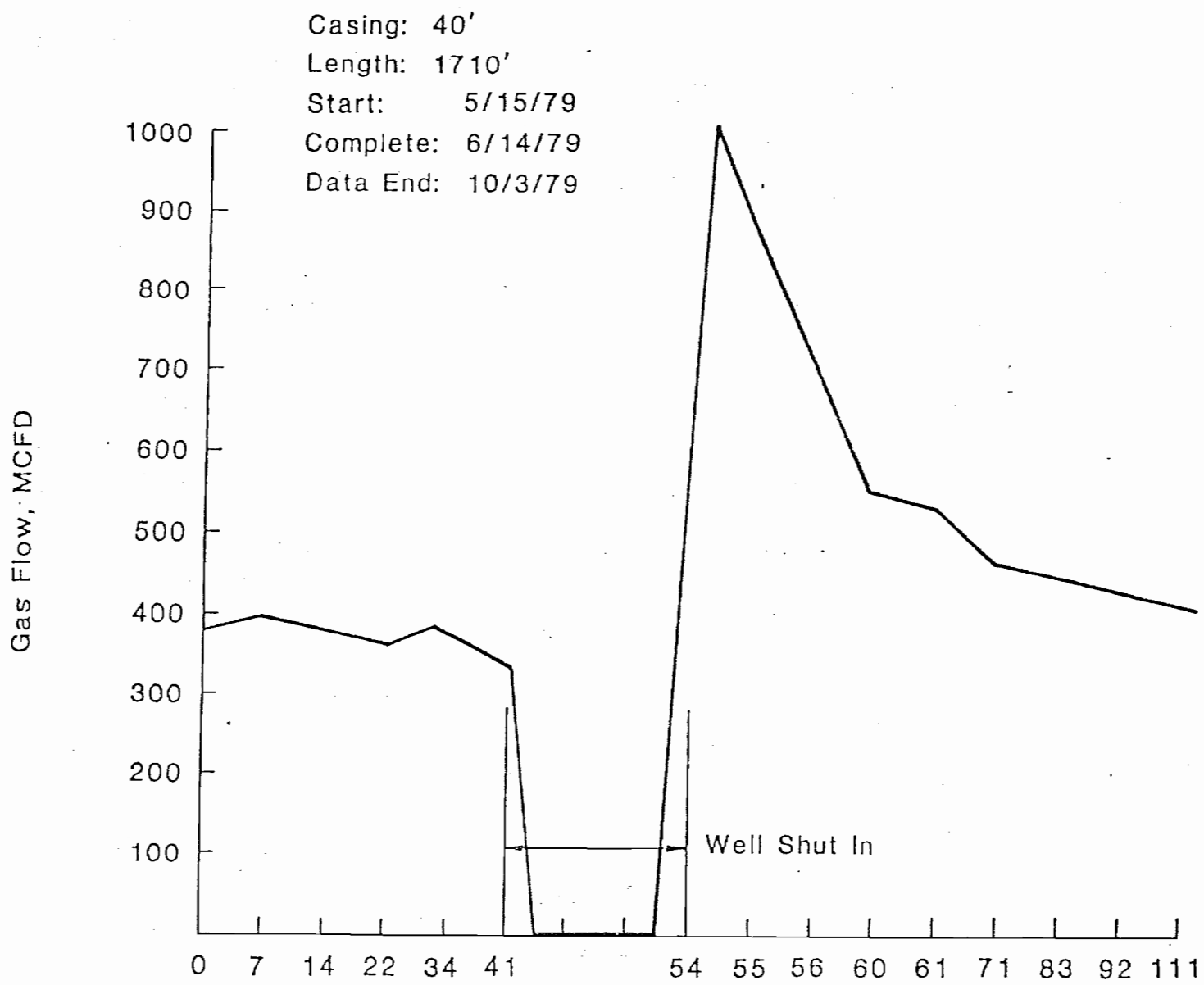


Trajectory

OXY Hole #6



Oxy Hole #6


Casing: 40'
Length: 1710'
Start: 5/15/79
Complete: 6/14/79
Data End: 10/3/79
Gas Flow, MCFD
1000
900
800
700
600
500
400
300
200
100
Well Shut In
0
7
14
22
34
41
54
55
56
60
61
71
83
92
111

UTILIZATION ANALYSIS

(AVAILS VS USE)

GAS AVAILS, END 1980	CFD
OXY 4, 5, 6	650,000
OXY 7*, 8, 9, 10, 11	1,000,000
	1,650,000

* SLANT HOLE

GAS UTILIZATIONS	CFD
COAL DRYER	670,000
MINE FANS (2)	320,000
LNG UNIT (1)	300,000
PIPELINE	UNCERTAIN

COALBED METHANE - RESEARCH AND DEVELOPMENT

FRACTURE MECHANICS / PRODUCTION ENHANCEMENT

THE PENNSYLVANIA STATE UNIVERSITY

- OBJECTIVE: DETERMINE TECHNICAL AND ECONOMIC EFFECTS OF VERTICAL WELL STIMULATION ON ASSOCIATED STRATA IN ACTIVE COAL MINE WORKINGS

- ACCOMPLISHMENTS:
  - DATA BASE ON METHANE RECOVERY PARAMETERS BEING ASSEMBLED
  - VENTILATING AIR SIMULATION MODEL CODED
  - EVALUATION OF DEGASIFICATION IMPACT ON MINE VENTILATION COSTS IN PROGRESS

COALBED METHANE - RESEARCH AND DEVELOPMENT

FRACTURE MECHANICS / PRODUCTION ENHANCEMENT

COLORADO SCHOOL OF MINES

- OBJECTIVE: DETERMINE EFFECTS OF PRE-MINING METHANE DRAINAGE ON UNDERGROUND COAL MINING OPERATIONS

- ACCOMPLISHMENTS:
  - DATA BASE ON PRE-MINING METHANE RECOVERY BEING ASSEMBLED
  - LABORATORY EXPERIMENTS ON FRACTURING IN PROGRESS

COALBED METHANE - PROJECT INTEGRATION

OBJECTIVE: PROVIDE OVERALL SUPPORT, REPORTING, PLANNING, AND COORDINATION OF ALL ACTIVITY

ACCOMPLISHMENTS:

- PROJECT DOCUMENTATION
- INFORMATION MANAGEMENT PLAN BEING DEVELOPED
- TECHNOLOGY TRANSFER PLAN BEING DEVELOPED
- INTEGRATION OF ACTIVITIES ASSOCIATED WITH RESOURCE ENGINEERING, RESEARCH AND DEVELOPMENT, AND FIELD VERIFICATION

COALBEDS METHANE - RESOURCE ENGINEERING

UNIVERSITY AND GEOLOGICAL SURVEYS

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

OBJECTIVE: DETERMINE THE METHANE CONTENT OF UNMINEABLE COALBEDS IN SOUTHEASTERN UNITED STATES

ACCOMPLISHMENTS:

- REPORT ON GEOLOGY OF THE RICHMOND BASIN HAS BEEN COMPLETED AND IS BEING ASSIMILATED INTO A REPORT ON THE METHANE PRODUCTION POTENTIAL FOR THE AREA

COLORADO GEOLOGICAL SURVEY

OBJECTIVE: PROVIDE FOR THE CHARACTERIZATION OF UNMINED / UNMINEABLE COALBEDS PRIMARILY IN THE STATE OF COLORADO

ACCOMPLISHMENTS:

- 166 COAL, SHALE, AND SILTSTONE SAMPLES DESORBED
- 149 ULTIMATE, PROXIMATE, AND TRACE ELEMENT ANALYSES RUN
- 15 PETROGRAPHIC ANALYSES RUN
- 22 GAS SAMPLES ANALYZED
- 3 BASINS BEING MAPPED

UTAH GEOLOGICAL AND MINERAL SURVEY

OBJECTIVE: PROVIDE FOR THE CHARACTERIZATION OF UNMINED / UNMINEABLE COALBEDS PRIMARILY IN THE STATE OF UTAH

ACCOMPLISHMENTS:

- 84 COAL SAMPLES DESORBED
- 100 ULTIMATE AND PROXIMATE ANALYSES RUN

KEY ISSUES

- TECHNOLOGY
  - — GAS PRODUCTION MECHANISM
  - — FRACTURE CONTAINMENT
  - — DRAINAGE CONFIGURATIONS
  - — END USE ALTERNATIVES
  - — RESOURCE VERIFICATION
- INSTITUTIONAL
- REGULATORY

DRILLING TECHNOLOGY

CURRENT ACTIVITIES:

- A PROTOTYPE WATER JET DRILL
- A SENSOR/GUIDANCE SYSTEM FOR REAL-TIME DOWNHOLE DIRECTION CONTROL
- REFURBISHMENT OF THE HYCALOG #1 ANGLE RIG
- DIRECTIONAL DRILLING TRAINING NEEDS
- DEMO OF TECHNOLOGY FOR HORIZONTAL DRILLING
- STATE-OF-THE-ART ASSESSMENT OF DIRECTIONAL DRILLING AND THRUSTOR/RETRACTOR SYSTEMS FOR DRILL MOTORS

- CONTRACT: DRILLING TECHNOLOGY - R & D
  WATER JET DRILL

  SANDIA LABORATORIES
  MR-11098

- CONTRACT DATE: APRIL 1, 1979

- ANTICIPATED COMPLETION DATE: DECEMBER 31, 1981

- TOTAL COST: $1,300,000

- DOE COST: $1,300,000

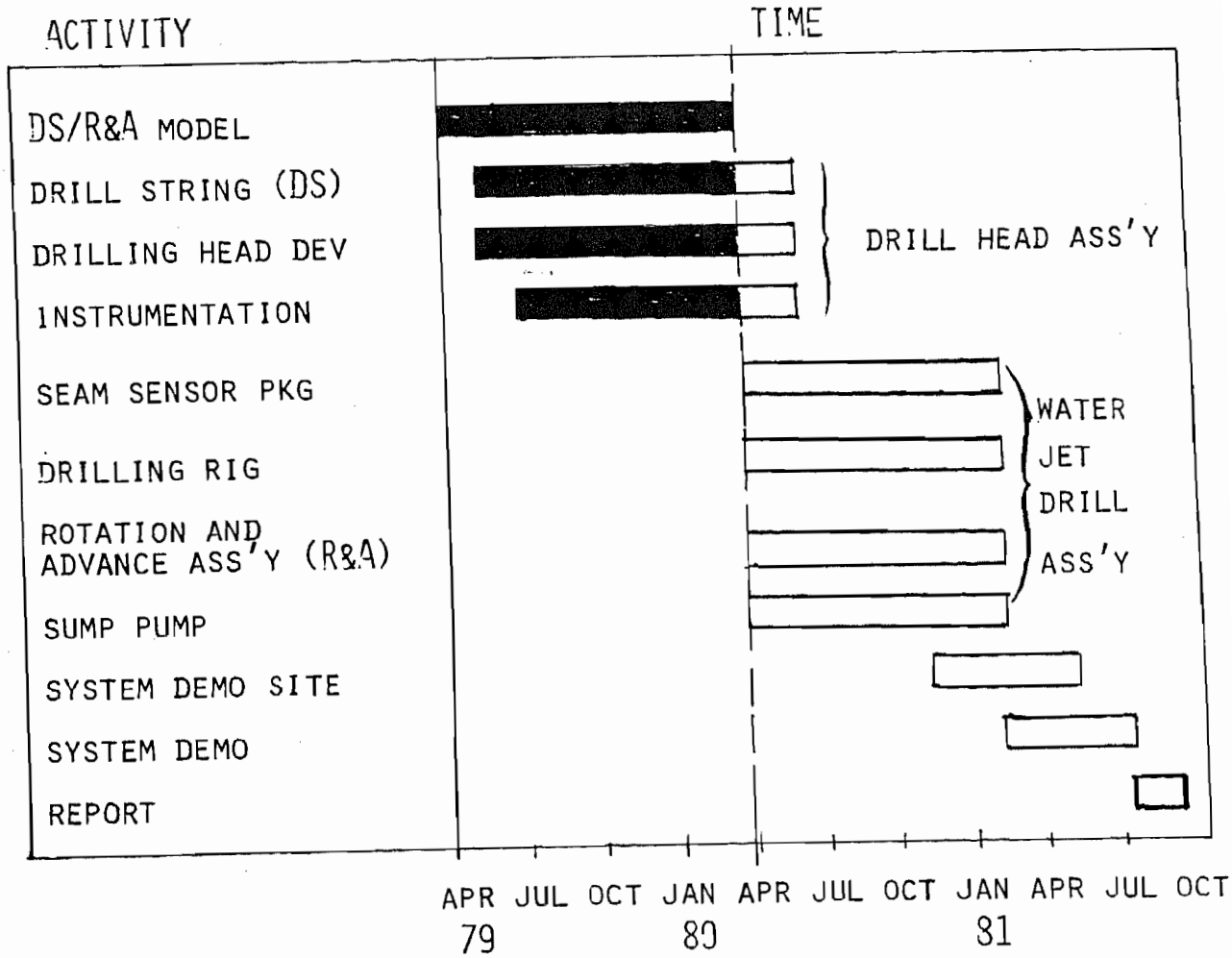
- OBJECTIVE: TO DEVELOP REQUIRED TECHNOLOGY FOR DEEP HORIZONTAL PENETRATION OF COAL SEAMS USING WATER JET DRILLING TECHNIQUES

- ACCOMPLISHMENTS:
  - DEVELOPMENT OF THREE DRILLING HEADS
  - DEVELOPED AND DEMONSTRATED 1/4-SCALE MODEL OF THE DRILL STRING AND ROTATION AND ADVANCE ASSEMBLY
  - EXPECT IN FY80 TO DRILL 300 FEET HORIZONTALLY INTO A COAL SEAM

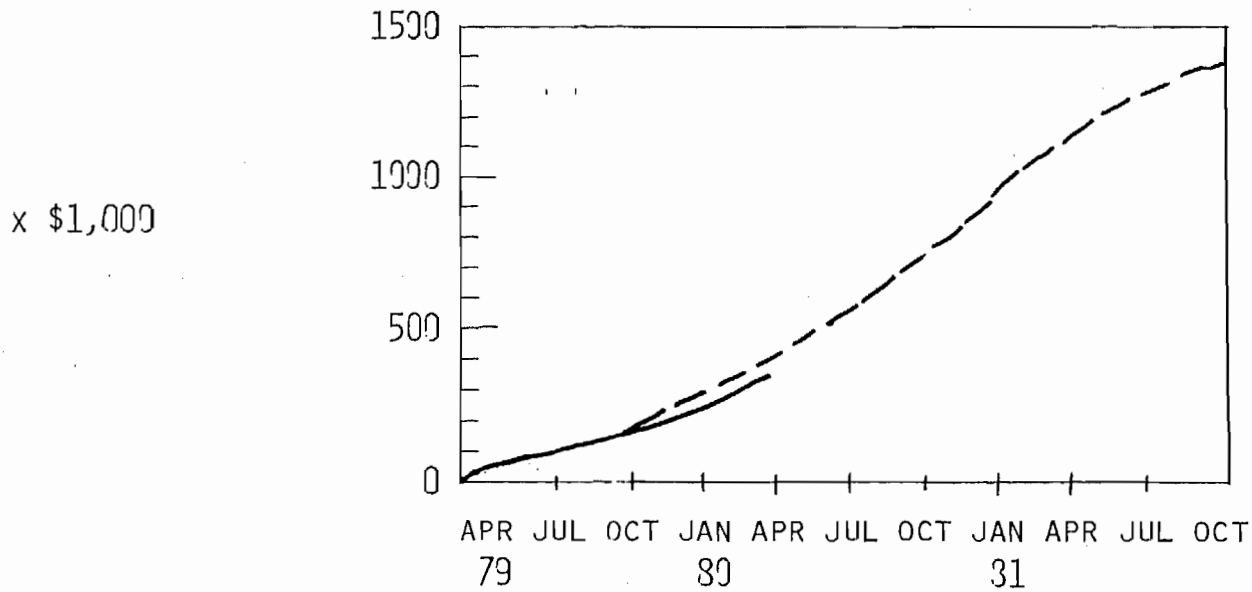
- CRITICAL ITEMS: MATERIALS AND NOISE LEVELS

- RECOMMENDATIONS: NONE

- MAJOR ACTIVITIES:

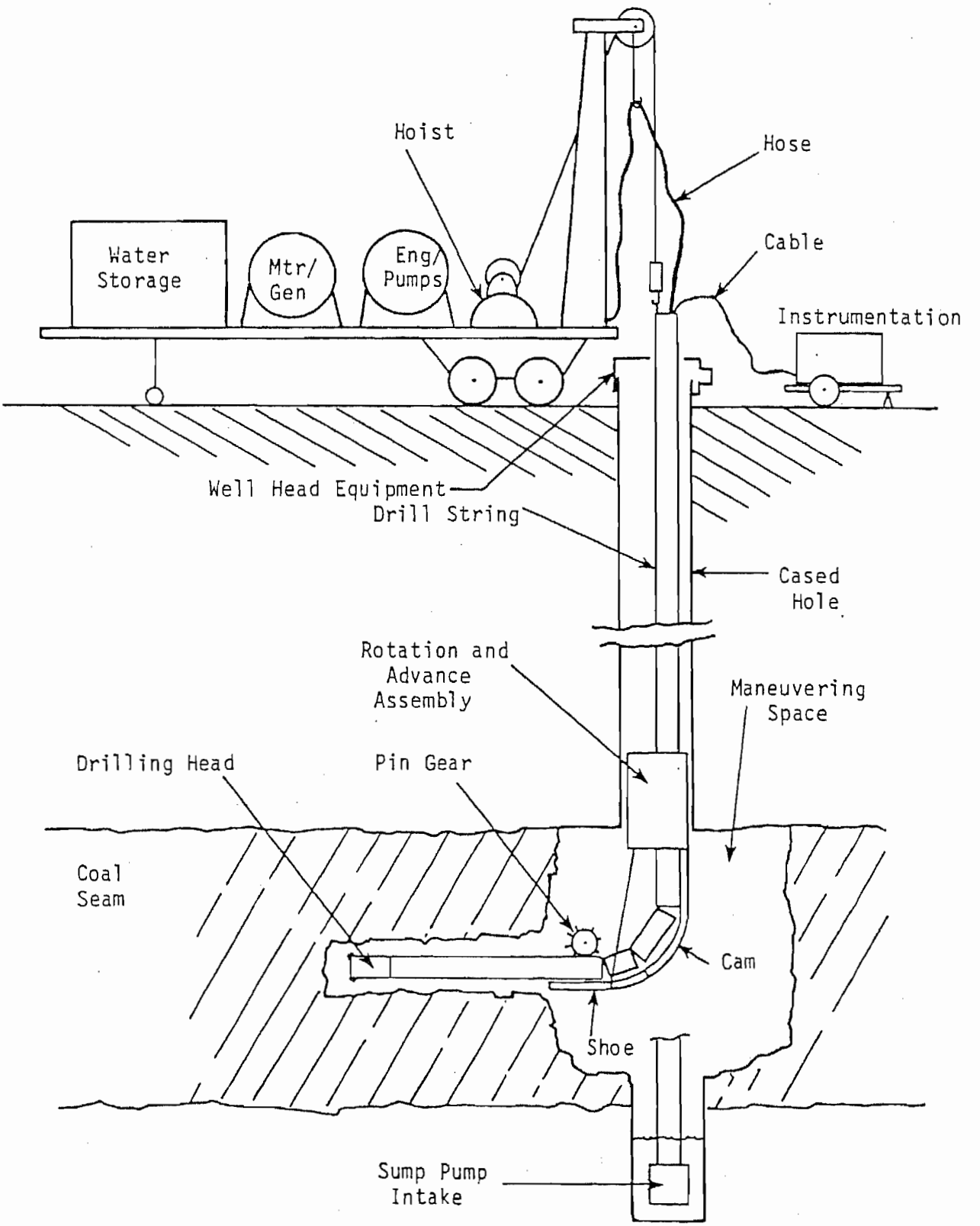


- FUNDING PROFILE:



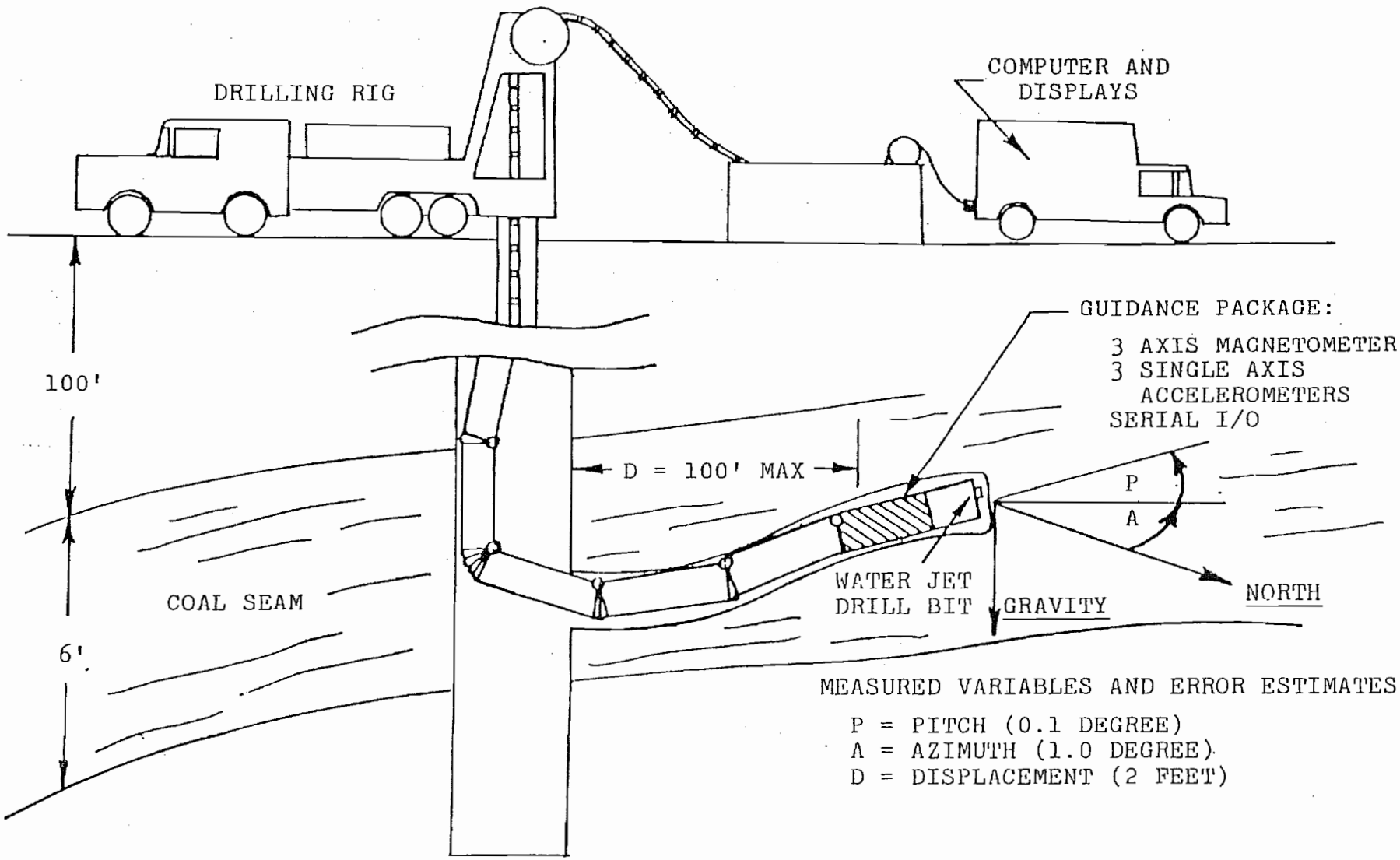
PLANNED - - - - -

ACTUAL ————

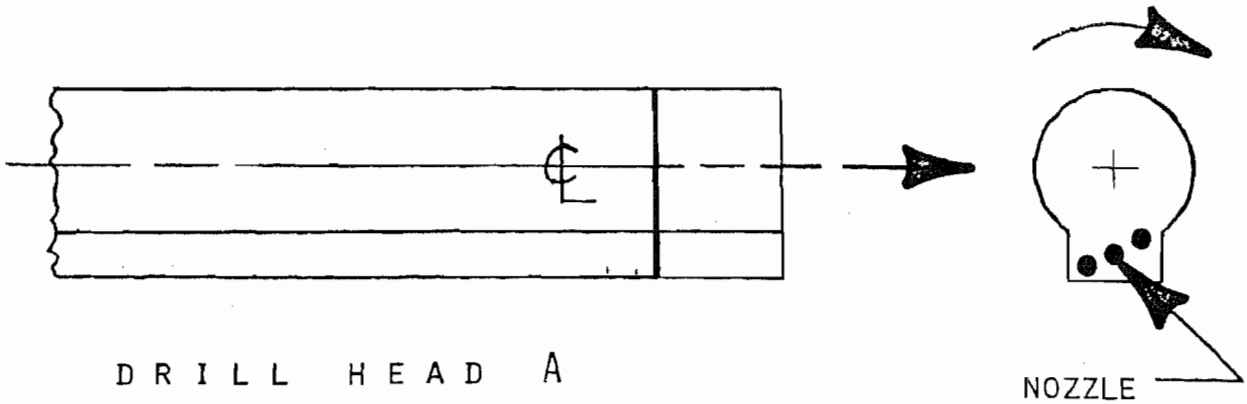


WATER JET DRILLING SYSTEM LAYOUT

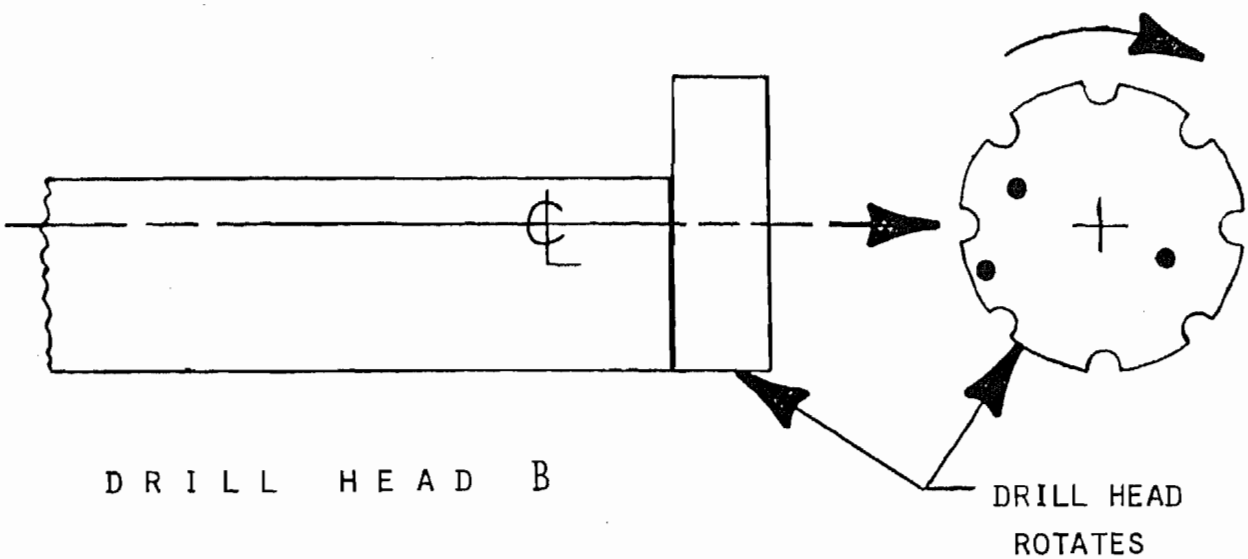
GUIDANCE INSTRUMENTATION FOR COAL SEAM DRILLING SYSTEM



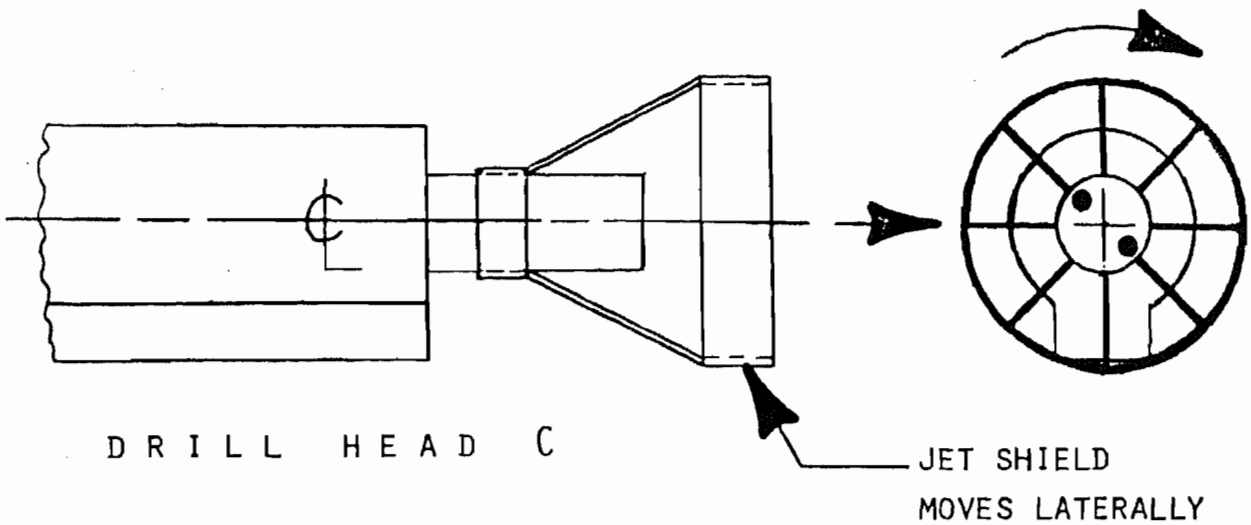
WATER JET DRILL HEADS



DRILL HEAD A



DRILL HEAD B



DRILL HEAD C

WATER JET DRILL HEADS

DRILLING PERFORMANCE IN COAL

DRILL HEAD A:

- DRILLED 8-INCH ROUND HOLE 34 FEET LONG*
- DRILLING RATE, APPROXIMATELY 1 FPM

DRILL HEAD B:

- DRILLED 10-12-INCH OVAL HOLE 5 FEET LONG
- DRILLING RATE, APPROXIMATELY 1 FPM

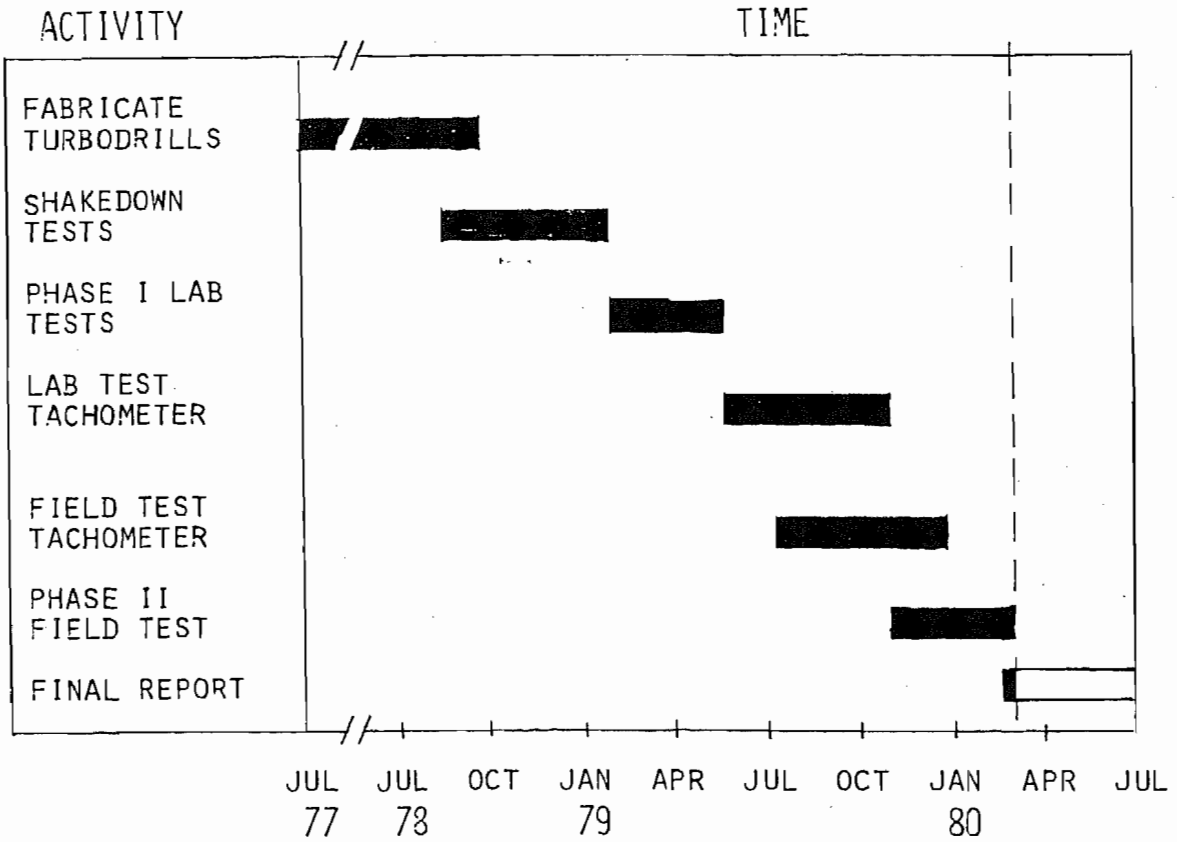
DRILL HEAD C:

- DRILLED 8-INCH ROUND HOLE 35 FEET LONG
- DRILLING RATE, APPROXIMATELY 2 FPM

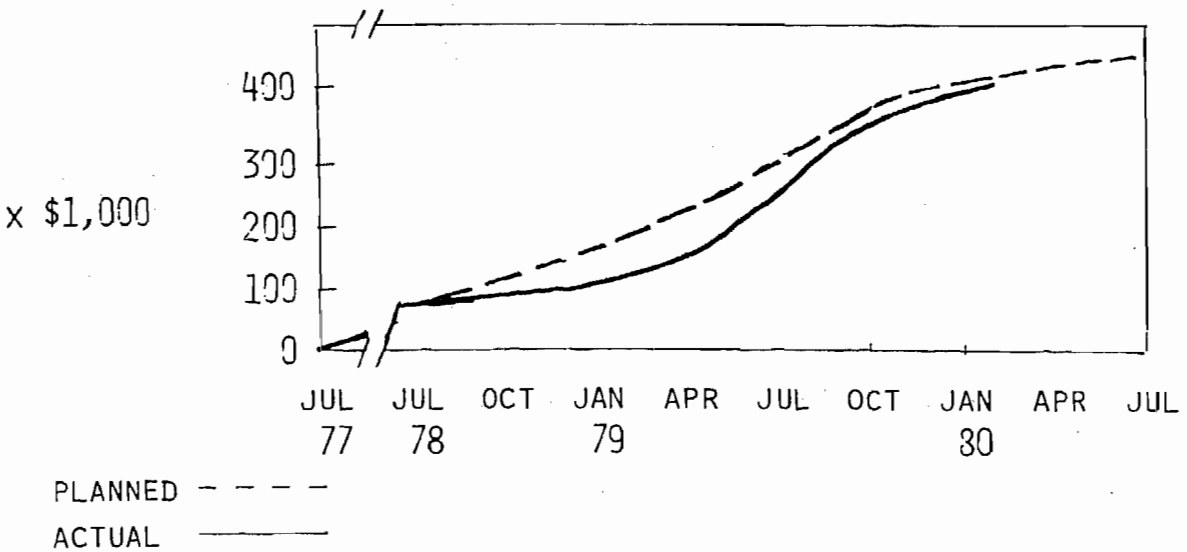
* CUTTINGS REMOVAL WAS AIDED BY A SUPPLEMENTARY 32 GPM WATER SUPPLY DELIVERED AT THE DRILL HEAD VIA AN ADDITIONAL PIPE (8-10 GPM AT 8 KSI ARE UTILIZED BY THE JETS). HAVING NO GUIDANCE CAPABILITY, THE "A" AND "C" HEADS APPARENTLY DRILLED OUT THROUGH THE FLOOR OF THE COAL SEAM AT APPROXIMATELY 35 FEET.

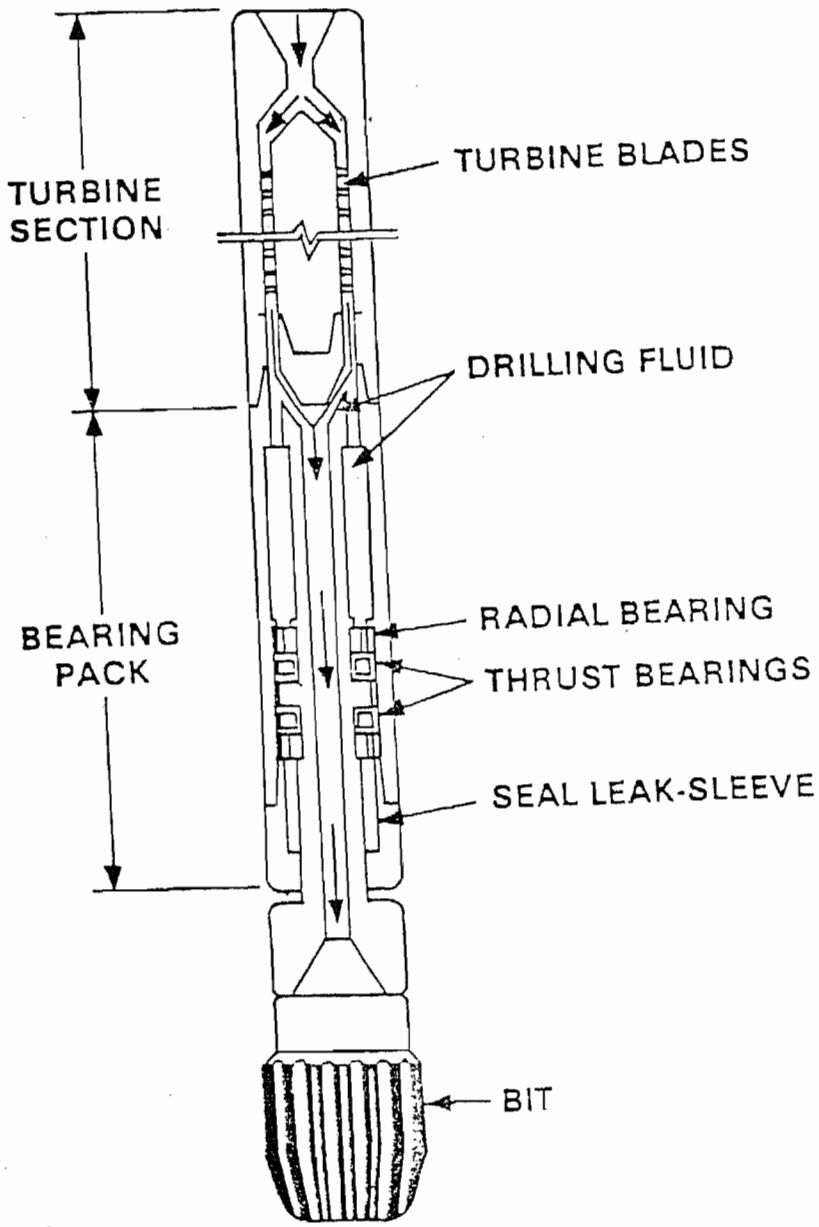
- CONTRACT: DRILLING TECHNOLOGY - R & D
  TURBODRILL AND TECHOMETER
  MAURER ENGINEERING, INC.
  DE-AC21-78MC08380 & DE-AC21-79MC11251
- CONTRACT DATE: JUNE 14, 1977
- ANTICIPATED COMPLETION DATE: APRIL 30, 1980
- TOTAL COST: $398,800
- DOE COST: $398,800
- OBJECTIVE: TO DEVELOP AND TEST A TURBODRILL DOWNHOLE MOTOR FOR USE IN DIRECTIONAL DRILLING APPLICATIONS IN THE EXTRACTION OF METHANE FROM COAL SEAMS.
- ACCOMPLISHMENTS:
  - SHAKEDOWN TESTING COMPLETED
  - PHASE I TESTING COMPLETED
  - PHASE II TESTING COMPLETED FY80
  - SUCCESSFUL TEST OF TACHOMETER
- CRITICAL ITEMS:
  - MUD FLOW THROUGH BEARING PACKAGE DESIGN
  - SEALED BEARING PACKAGE DESIGN & MATERIALS
- RECOMMENDATIONS: FURTHER BEARING PACKAGE DESIGN

- MAJOR ACTIVITIES:

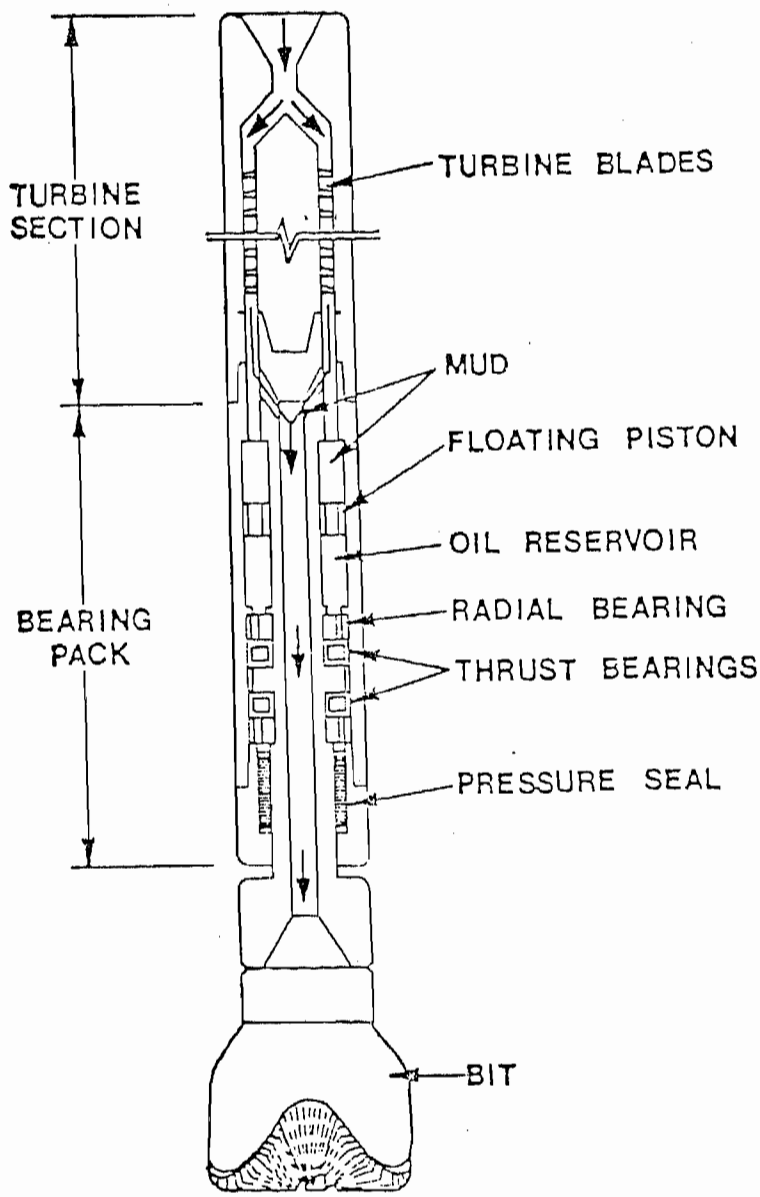


- FUNDING PROFILE:



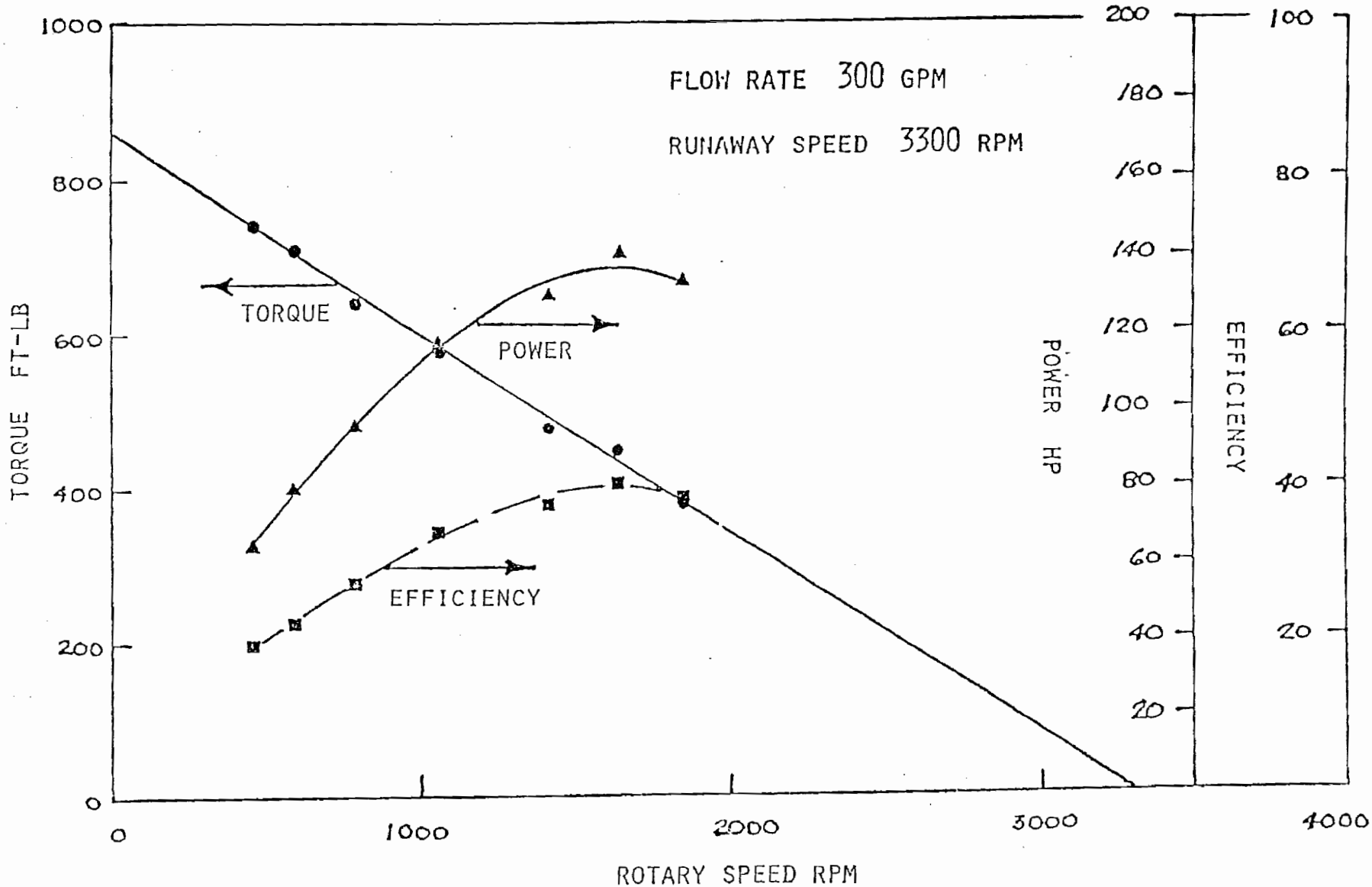


TURBODRILL - FLOW-THROUGH BEARING PACKAGE



TURBODRILL - OILFIELD MODEL

PERFORMANCE IN SHAKEDOWN TEST NO. 2



COALBED METHANE - RESEARCH AND DEVELOPMENT

FRACTURE MECHANICS / PRODUCTION ENHANCEMENT

PHYSICS INTERNATIONAL COMPANY

- OBJECTIVE: TO EVALUATE THE FEASIBILITY OF INCREASING THE PERMEABILITY OF COAL BY THE IGNITION OF AN EXPLOSIVE GAS MIXTURE THAT IS INJECTED INTO A FRACTURE SYSTEM OF THE COAL
- ACCOMPLISHMENTS: 10-15 DETONATION TESTS RESULTING IN A DECREASE IN SAMPLE PERMEABILITY

COALBED METHANE - RESEARCH AND DEVELOPMENT

FRACTURE MECHANICS / PRODUCTION ENHANCEMENT

WEST VIRGINIA UNIVERSITY

- OBJECTIVE: TO ACQUIRE FUNDAMENTAL KNOWLEDGE OF THE MECHANISMS CONTROLLING FRACTURE INITIATION AND GROWTH IN COAL

- ACCOMPLISHMENTS:
  - PERFORM FRACTURE TOUGHNESS TESTS
  - PERFORM COAL FRACTURE TESTS UNDER SIMULATED IN SITU CONDITIONS

COALBED METHANE - RESEARCH AND DEVELOPMENT

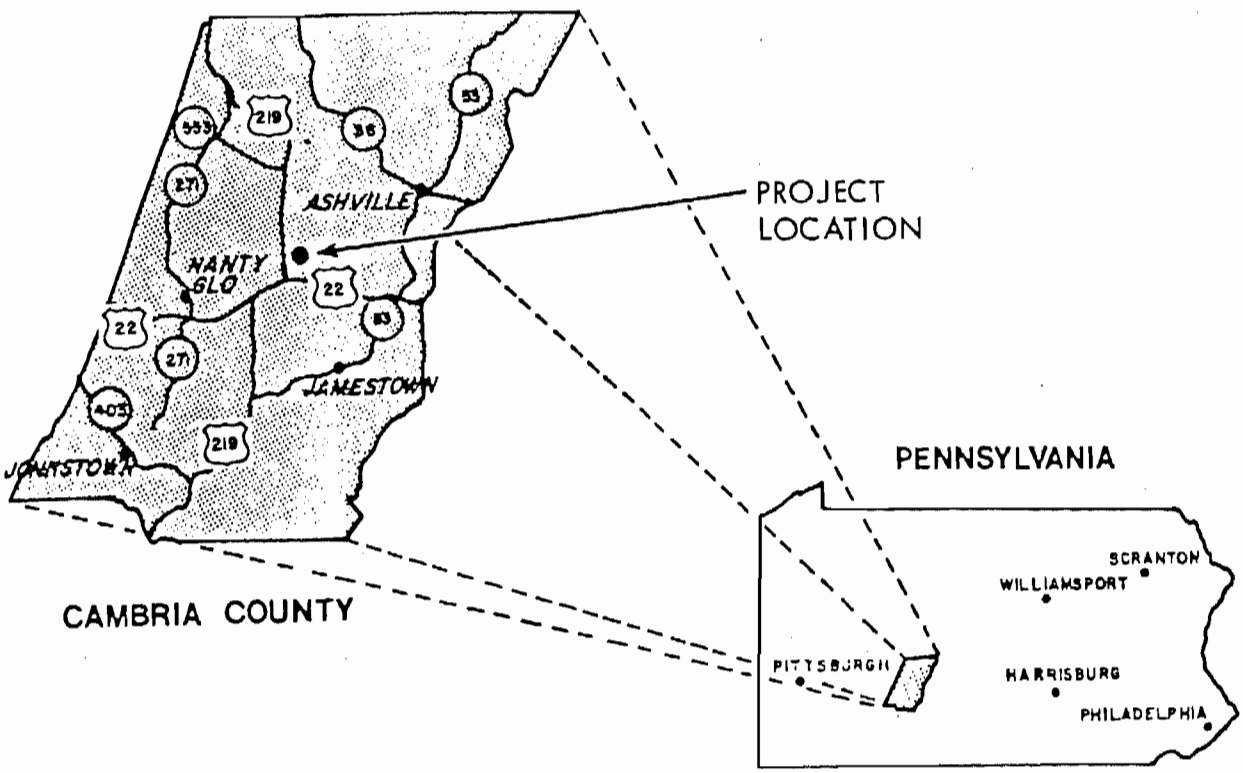
FRACTURE MECHANICS / PRODUCTION ENHANCEMENT

UNIVERSITY OF PITTSBURGH

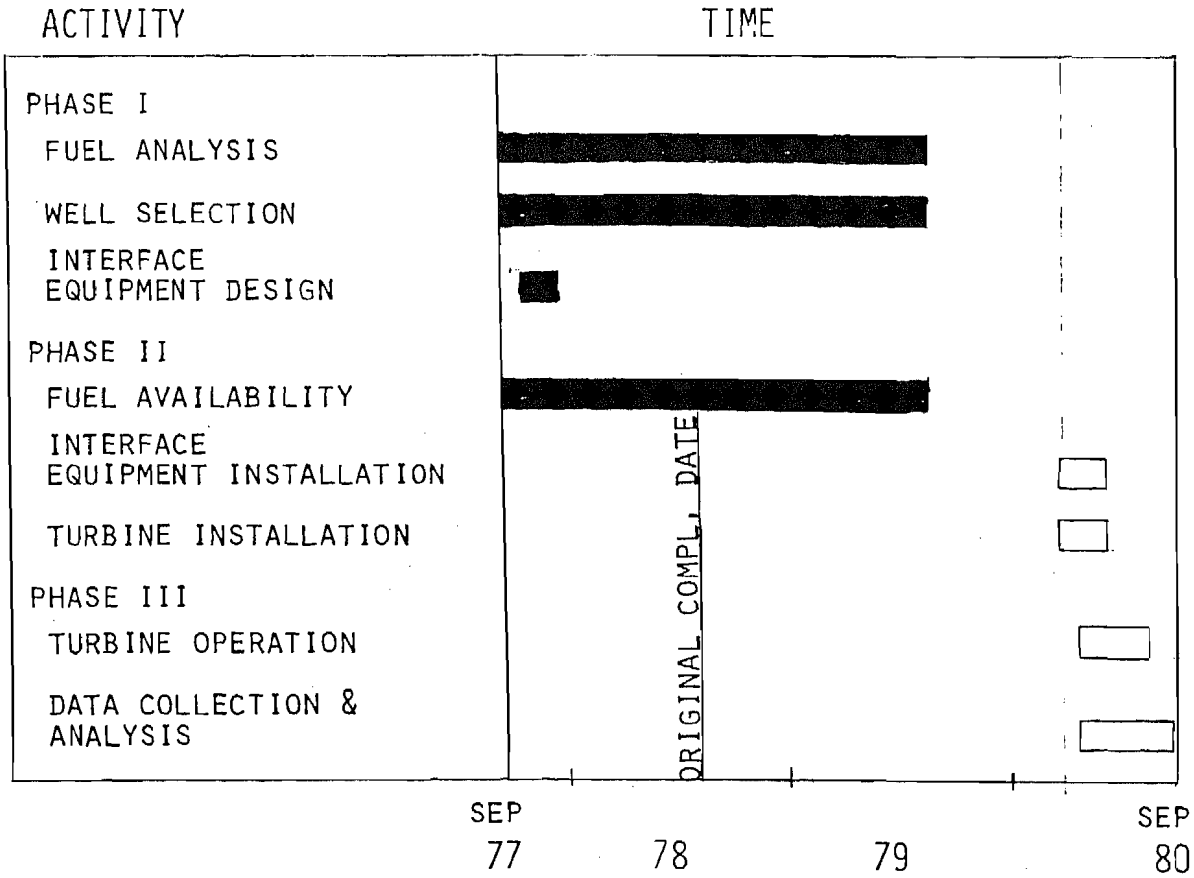
- OBJECTIVE: ENHANCING THE PRODUCTION OF IN SITU METHANE FROM COAL SEAMS BY CARBON DIOXIDE INJECTION

- ACCOMPLISHMENTS:
  - LAB TESTS TO DETERMINE THE EFFECTIVENESS OF COMPETITIVE ADSORPTION - DESORPTION OF METHANE BY CARBON DIOXIDE
  - CARBON DIOXIDE INJECTION RESULTED IN AN INCREASED RATE OF METHANE DESORPTION OF APPROXIMATELY 30 PERCENT

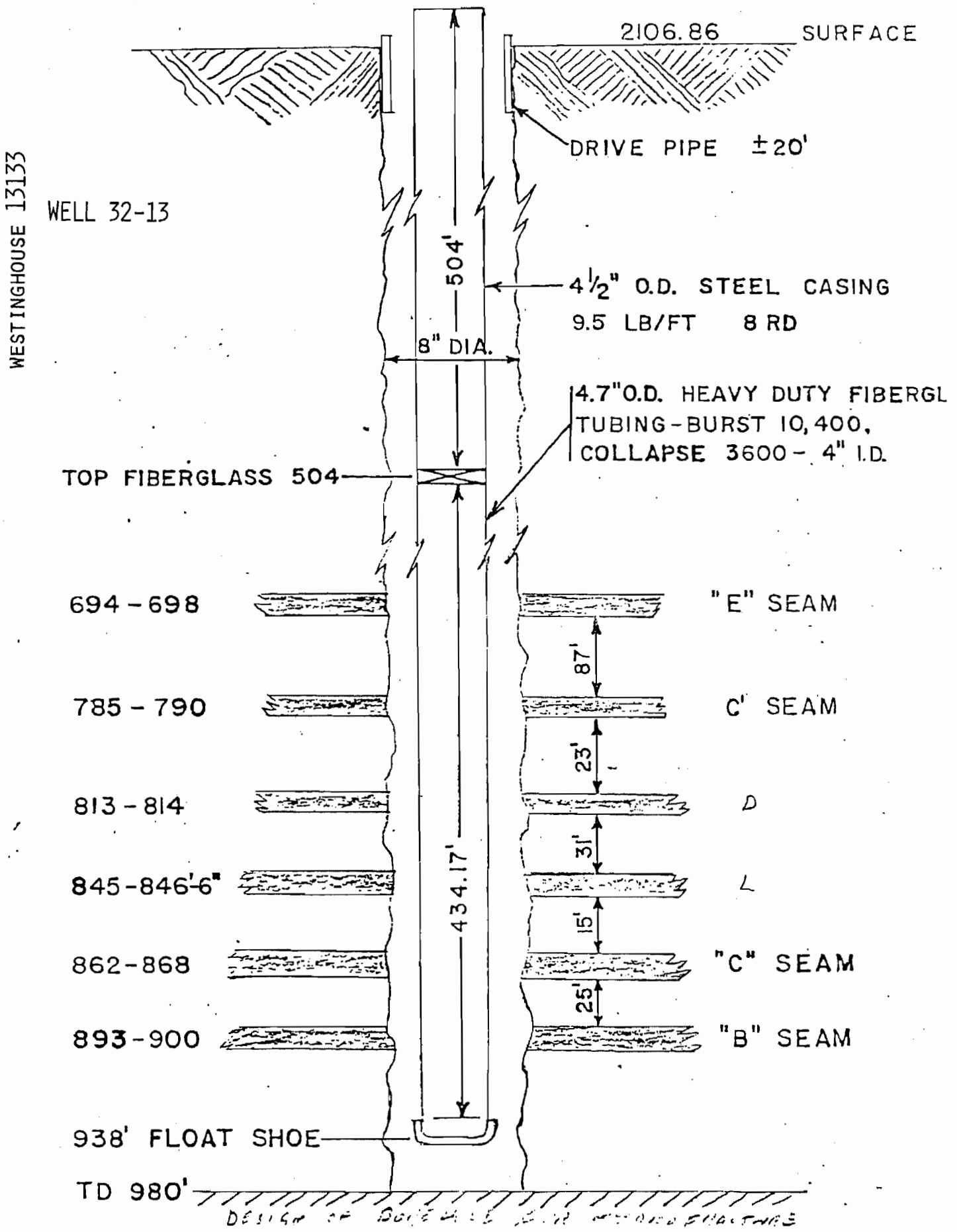
- CONTRACT: WESTINGHOUSE ELECTRIC CORPORATION
  DE-AC05-77ET13133
- CONTRACT DATE: SEPTEMBER 1, 1977
- ANTICIPATED COMPLETION DATE: MARCH 1, 1980
- TOTAL COST: $1,003,051
- DOE COST: $934,051
- COMMONWEALTH OF PA COST: $69,000
- OBJECTIVE: TO DEVELOP CAPABILITY FOR USING COALBED GAS FOR POWER GENERATION.
- LOCATION MAP:



- MAJOR ACTIVITIES:



BETHLEHEM MINES CORPORATION



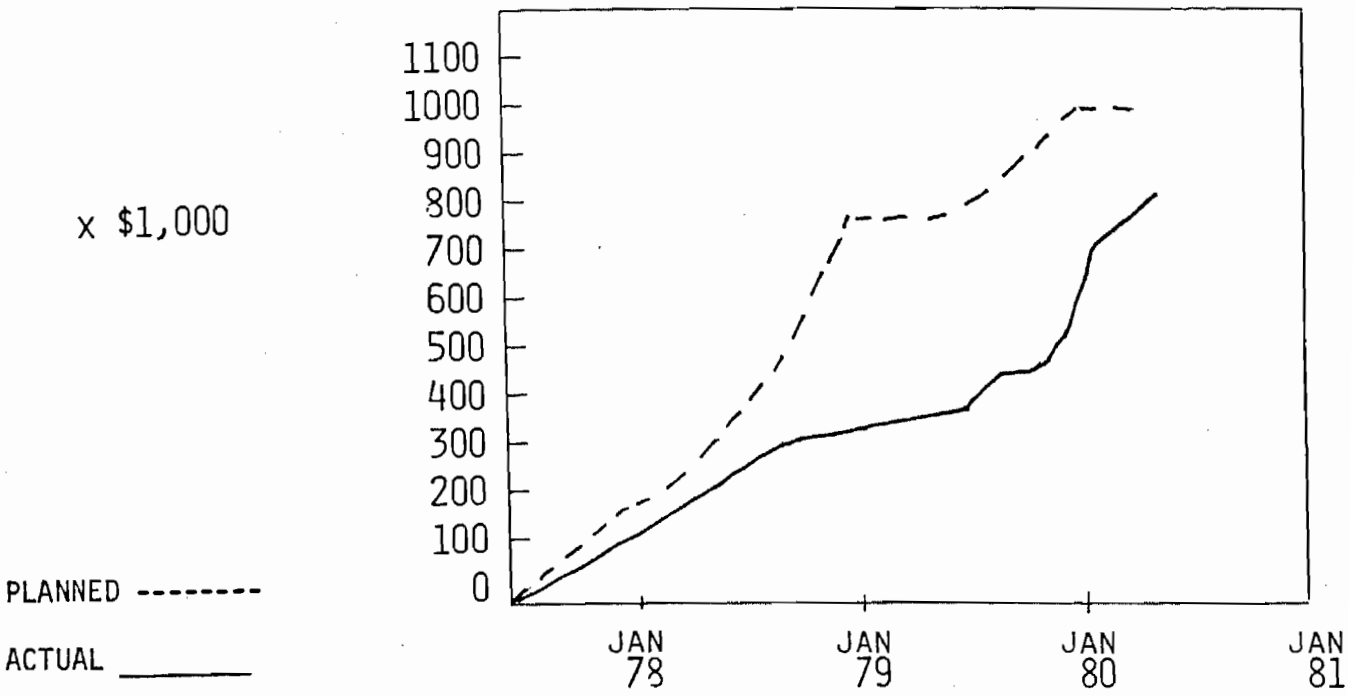
WESTINGHOUSE DE-AC05-77ET13133

SUMMARY OF STIMULATION TREATMENTS

BETHLEHEM 32-13

SEAM	ZONE FT.	FLUID VOLUME GAL.	SAND LB.	INJECTION RATE, BPM	INJECTION PRESS. PSIG
B	892-900	59,000	20,000	18	1,800
C	863-868	60,000	24,000	18	2,200
C'	784-790	54,000	23,800	20	1,800
E	694-698	51,000	17,000	18	2,600

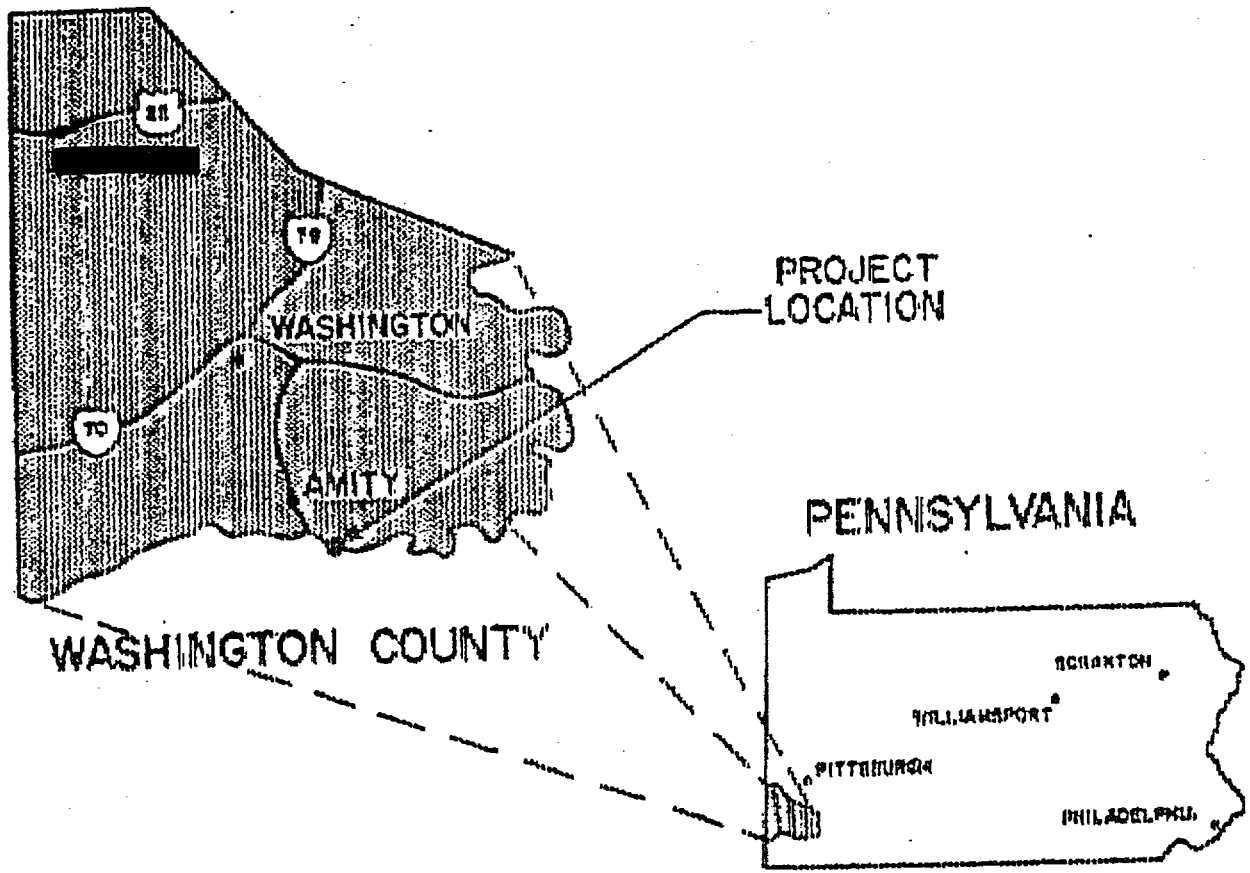
- FUNDING PROFILE:



BETHLEHEM MINES CORPORATION
ELLSWORTH DIVISION
WAYCHOFF BOREHOLE FLOW CHARACTERISTICS

COAL SEAM BACK PRESSURE AT FACE	TOTAL FLOW, SCFD	HORIZONTAL BOREHOLE			
		#1 1070′	#2 2505′	#3 1238′	#4 980′
± 1/2″ H_2O	240,000	53,199	103,578	57,366	25,655
1/2 PSIG	192,484	49,348	79,074	50,010	14,052
1 PSIG	138,583	38,512	63,866	28,344	7,861
2 PSIG	105,667	32,286	49,317	24,064	0

ABOVE MEASUREMENTS PERFORMED BY U. S. BUREAU OF MINES ON SEPTEMBER 18, 1979

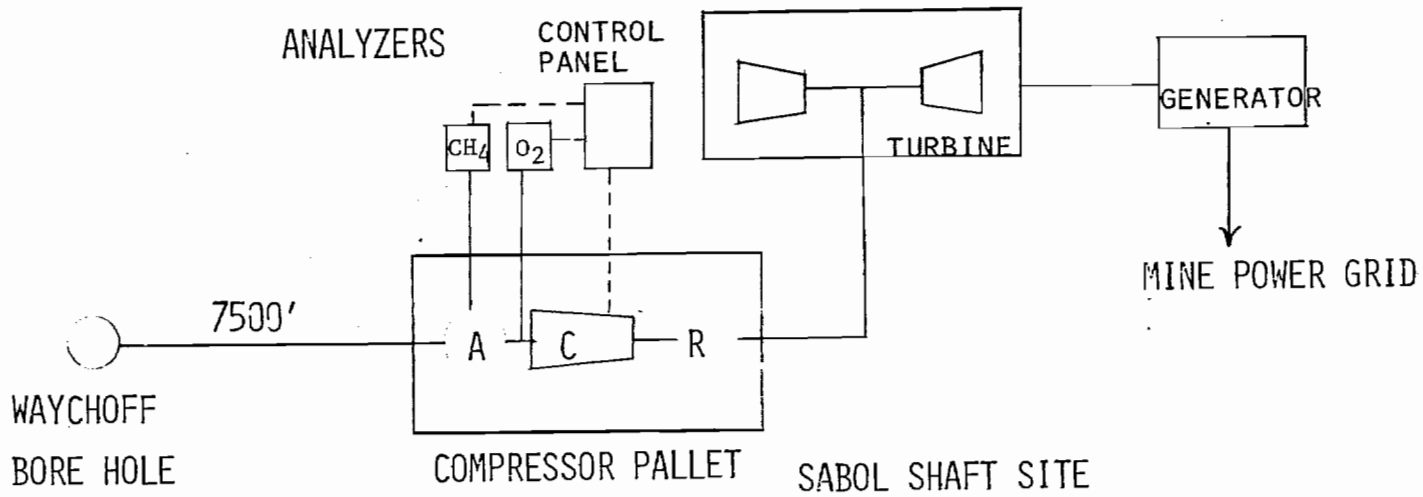


WESTINGHOUSE ELECTRIC CORPORATION POWER GENERATION

PROPOSED SITE

DE-AC05-77ET13133

WESTINGHOUSE DE-AC05-77ET13133



MARIANNA NO. 58 MINE

WESTINGHOUSE ELEC CORP.
DE-AC05-77ET13133

- SUMMARY OF PROGRESS:
  - INTERFACE EQUIPMENT DESIGN
  - REVLOC #32-13 DRILLED, FRACTURED AND TESTED
  - OBTAINED 750-KW TURBOGENERATOR FROM U.S. ARMY
  - LOCATED WELL NEAR ELLSWORTH, PA.

- CRITICAL ITEMS:
  - LEASE OF U.S. ARMY TURBOGENERATOR EXPIRES SEPTEMBER 1980

PROJECT COSTS

DEPT. OF ENERGY	1,232,000
US STEEL	1,125,000
TOTAL	$ 2,357,000

Title of Project: Demonstration of Degasification of a Portion of the Mary Lee Coal Group

Contractor: U.S. Steel Corporation/DOE cost-sharing

Location: Oak Grove, Alabama

Contract No. ET-75-C-01-9027

	Original	Ext. 1	Ext. 2	Ext. 3	Ext. 4	Total
Starting Date:	06-30-75	06-29-78	08-29-79			06-30-75
Completion Date:	06-29-78	06-29-79	08-31-80			08-31-80
Funding:	500,000 (FY 76)	332,000 (FY 78)	400,000 (FY 79)			1,232,000

DOE Monitor: Stephen W. Lambert Phone Number: (618)985-3771

USS Principle Investigator: James Mahoney Phone Number: (412)351-3100

OBJECTIVE

TO DEVELOP THE CAPABILITY OF REMOVING COALBED GAS USING A PATTERN OF VERTICAL BOREHOLES AND TO DEMONSTRATE THIS METHOD'S COMPATABILITY WITH THE PROCESS OF MINING COAL.

SUMMARY OF PROGRESS

* 23 WELLS COMPLETED
  - 5 NEAR - MINE
  - 17 GRID PATTERN

* APPROX 9000 DAYS OF WELL OPERATION MONITORED 1/
  - 8000 GRID PATTERN
  - 1000 NEAR - MINE

* CONCEPTUAL RESERVOIR MODEL DEVELOPED
  - UNLIMITED RESERVOIR (SINGLE TEST WELL)
  - LIMITED RESERVOIR (PATTERN OR NEAR - MINE)
  - DOE RI-PMTC-3(79)

1/ Total Gas Removed as of March 4, 1980:

529,953,526 cubic feet

Average Daily Rate from 17 Well Pattern:

1,200,000 cubic feet

Current Gas Depletion Rate:

20.6% per year - approximately 25% of the gas in-place has been removed since August, 1977

SUMMARY OF PROGRESS

* SHORT-TERM EFFECTS ON MINING IDENTIFIED
    - MINE ROOF AND FLOOR STABILITY[2/]
    - VENTILATION
    - USBM RI 8295
    - DOE RI - PMTC - 3(79)

* WELL OPERATIONAL REQUIREMENTS IDENTIFIED AND SYSTEM REFINED
    - MAINTENANCE SCHEDULES
    - MONITORING TECHNIQUES
    - DOWNHOLE PUMP REQUIREMENTS
    - USBM RI 8309

2/ Stimulation has not been an obvious detriment to mining even though induced fractures have entered roof rock at three out of five underground well sites. The word "damage" when used by US Steel to describe stimulation's effects, simply means fractures entered roof or floor rock. Experience at Oak Grove and other areas indicate very little can be done at the surface to keep a fracture precisely "in zone". Therefore, much more emphasis should be given toward developing safe and efficient engineering procedures of mining through stimulated zones (regardless of roof penetration) in both developmental mining and retreat mining.

SUMMARY OF PROGRESS

* WELL DRILLING, COMPLETION, AND PRODUCTION PROBLEMS IDENTIFIED AND SYSTEM REFINED

  - FORMATION "DAMAGE"
  - UNLOADING
  - FRAC SAND INFLUX
  - PUMP "GAS LOCK"
  - DOE RI (IN TECHNICAL FIELD REVIEW)

* PLAN FORMALLY PROPOSED BY USS TO COMMERCIALLY PIPELINE COALBED GAS[3/]

  - 50/50 COST - SHARING
  - USS PAY BACK (FOR UTILIZATION) IN 12 MONTHS
  - DOE PAY BACK (FOR UTILIZATION) IN 36 MONTHS

3/ A gas collection system is described in the 1975 agreement with U.S. Steel. The actual development of such a system hinges on economic feasibility as determined by the contractor and Government concurrence with U.S. Steel's results.

The global lack of pertinent long-term production data and "reserve dedication clauses" contained in previous laws governing the use of natural gas prohibited U.S. Steel from developing their coalbed gas resource even on a small scale before this time. Therefore, the fact that U.S. Steel presently wishes to accept the "economic risk" of utilization is . . testimony to the innate results of the project (in terms of production) and to the success of newly written natural gas laws.

The real "progress" toward development of industry-wide recovery of coalbed gas is expected to be dramatic, simply because "if U.S. Steel thinks it is feasible, then it must be".

CRITICAL ITEMS

* MEASURE LONG-TERM WELL PERFORMANCE AND SUBSEQUENT IMPACT TO MINING
    - PRODUCTION
    - VENTILATION
    - DEGREE OF PHYSICAL COMPATABILITY

* QUANTIFY RESERVOIR PARAMETERS
    - ANALYZE EXISTING DATA
    - FORMULATE METHODS TO PREDICT FUTURE RESULTS
    - VERIFY PREDICTIONS
    - ESTABLISH PREDICTIVE CAPABILITY

CRITICAL ITEMS

* RESOLVE MAJOR DOWN-HOLE PROBLEMS
  - FRAC SAND INFLUX[4/]
  - GAS FLOW STABILIZATION

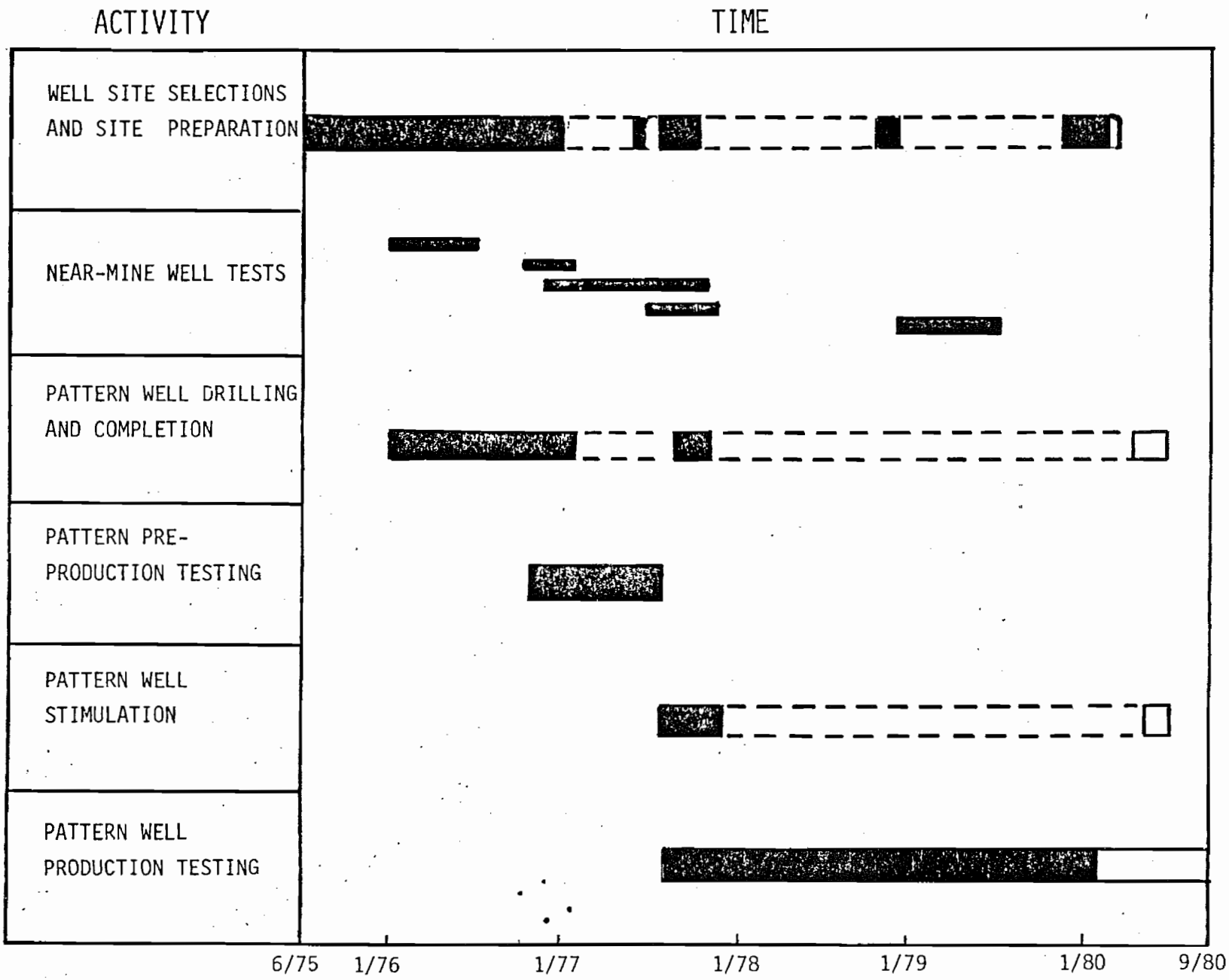
* IDENTIFY UTILIZATION SYSTEM REQUIREMENTS**[5/]
  - SURFACE PLANT INSTALLATION
  - PIPELINE CONSUMPTION REQUIREMENTS AND LIMITATION
  - OPERATING COSTS
  - INSTITUTIONAL LIMITATIONS

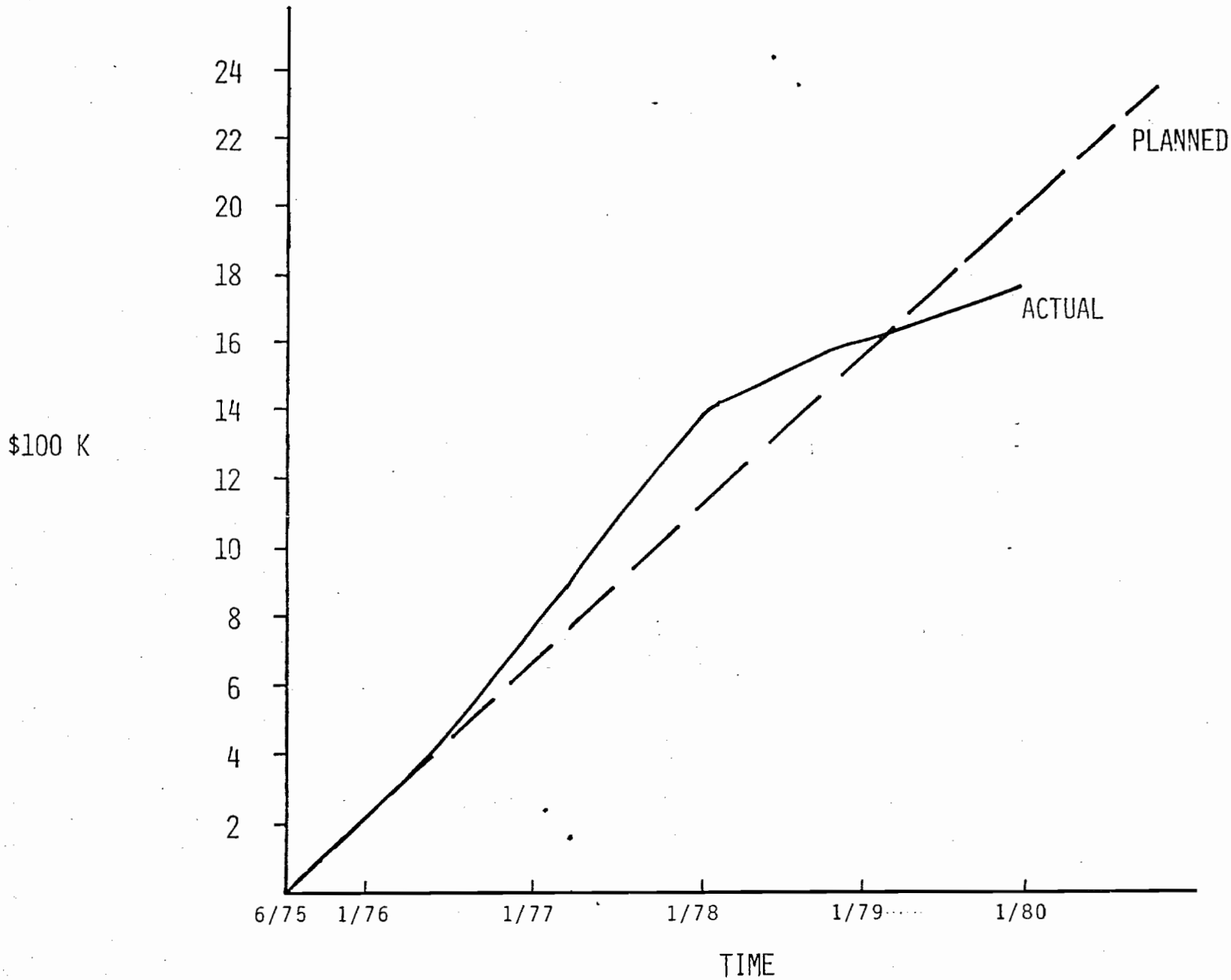
* DETERMINE ECONOMIC VIABILITY OF GAS DRAINAGE**
  - BENEFITS VERSUS COSTS

** EFFORTS NOT ENTIRELY PROVIDED FOR UNDER THE PRESENT CONTRACT.

4/ Six additional wells will be completed, increasing the number of wells on the pattern from 17 to 23. These six tests are designed to establish one or more stimulation techniques which will minimize, or altogether eliminate, the Frac Sand influx problem.

5/ With the integration of a utilization program, this project becomes a totally comprehensive effort, covering every aspect of coalbed methane drainage from site selection to underground interception.


ACTIVITY
TIME
WELL SITE SELECTIONS AND SITE PREPARATION
NEAR-MINE WELL TESTS
PATTERN WELL DRILLING AND COMPLETION
PATTERN PRE-PRODUCTION TESTING
PATTERN WELL STIMULATION
PATTERN WELL PRODUCTION TESTING
6/75
1/76
1/77
1/78
1/79
1/80
9/80

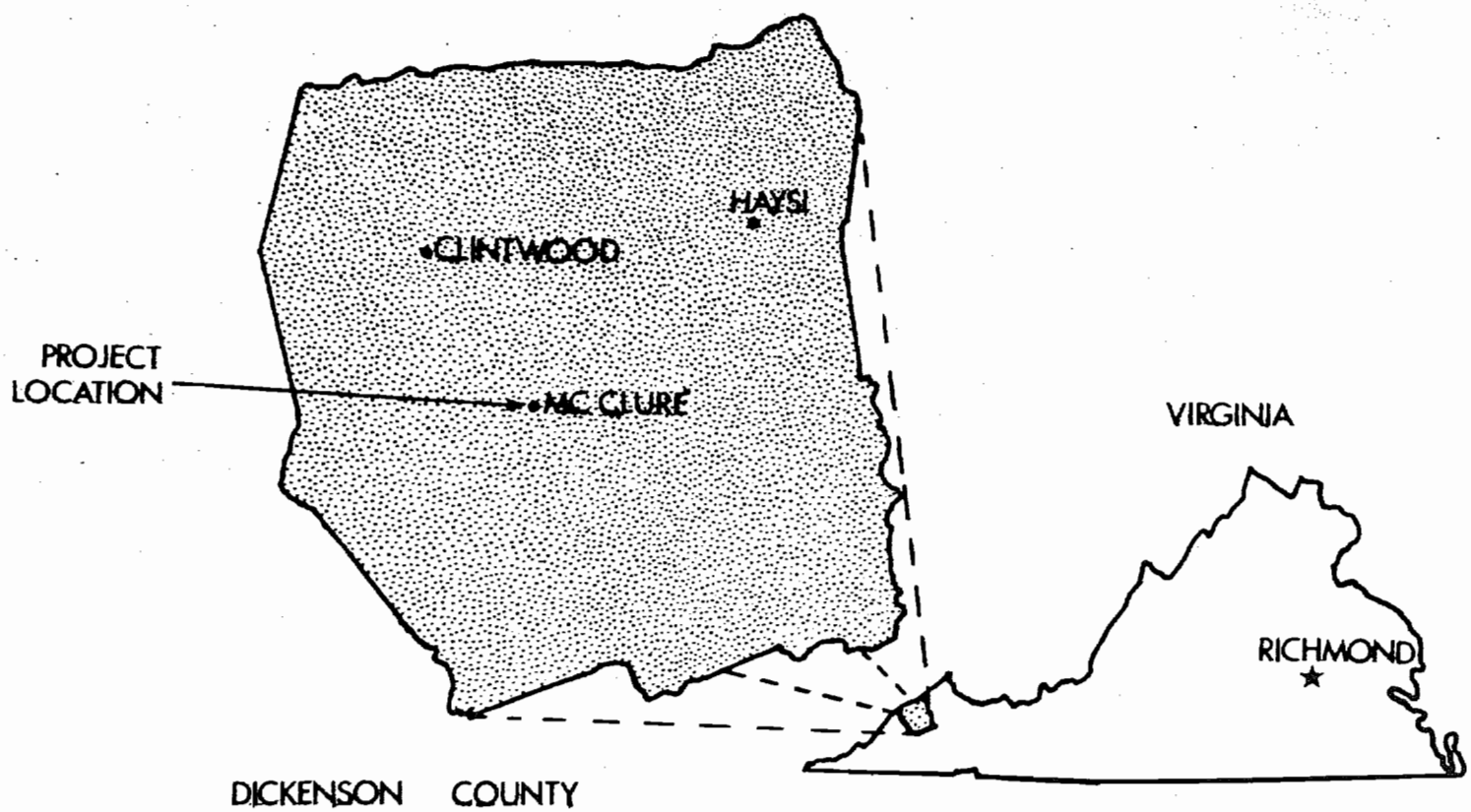

24
22
20
18
16
14
$100 K
12
10
8
6
4
2
PLANNED
ACTUAL
6/75
1/76
1/77
1/78
1/79
1/80
TIME

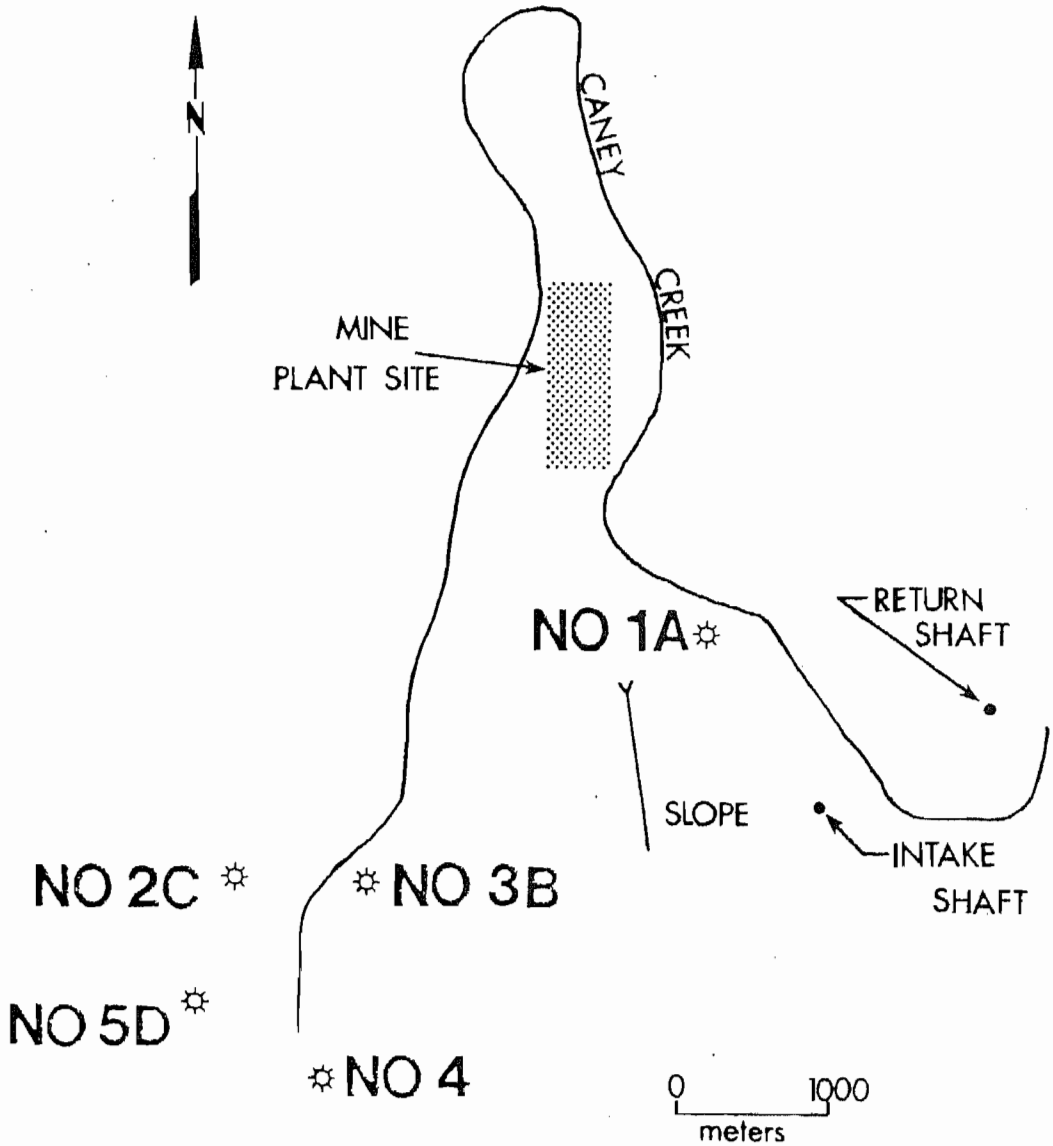
BUREAU OF MINES TECHNICAL FACT SHEET

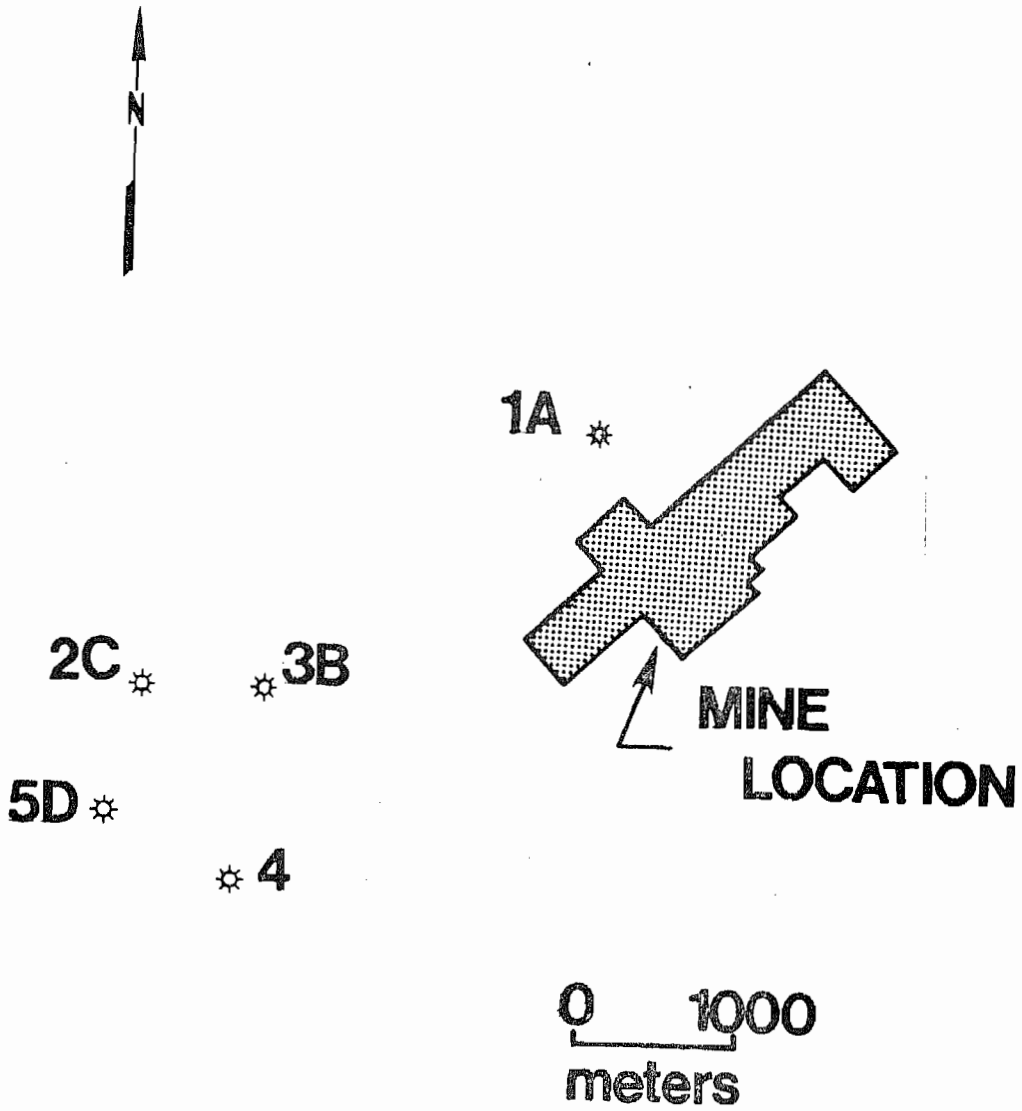
VERTICAL DRILLING TO DEGASIFY THE JAWBONE COALBED DICKENSON COUNTY, VA CONTRACT NO. ET-77-C-01-9151

VERTICAL DRILLING TO DEGASIFY THE JAWBONE COALBED, DICKENSON, CO., VIRGINIA

CONTRACT NO.	ET-77-C-01-9151
CONTRACTOR:	CLINCHFIELD COAL CO.
CONTRACT DATE:	SEPTEMBER 28, 1977
COMPLETION DATE:	SEPTEMBER 28, 1982
CONTRACT VALUE:	$ 390 K
DOE SHARE:	$ 195 K
CONTRACTOR SHARE:	$ 195 K
USBM TPO:	MICHAEL A. TREVITS


HAYSI
CLINTWOOD
PROJECT
LOCATION
MC CLURE
VIRGINIA
RICHMOND
DICKENSON COUNTY


N
CANEY
CREEK
MINE
PLANT SITE
NO 1A
RETURN
SHAFT
SLOPE
INTAKE
SHAFT
NO 2C
NO 3B
NO 5D
NO 4
0
1000
meters


N
1A
2C
3B
5D
4
MINE
LOCATION
0
1000
meters

SUMMARY OF PROGRESS

1. Drilling and stimulation of initial well.

2. Production monitoring.

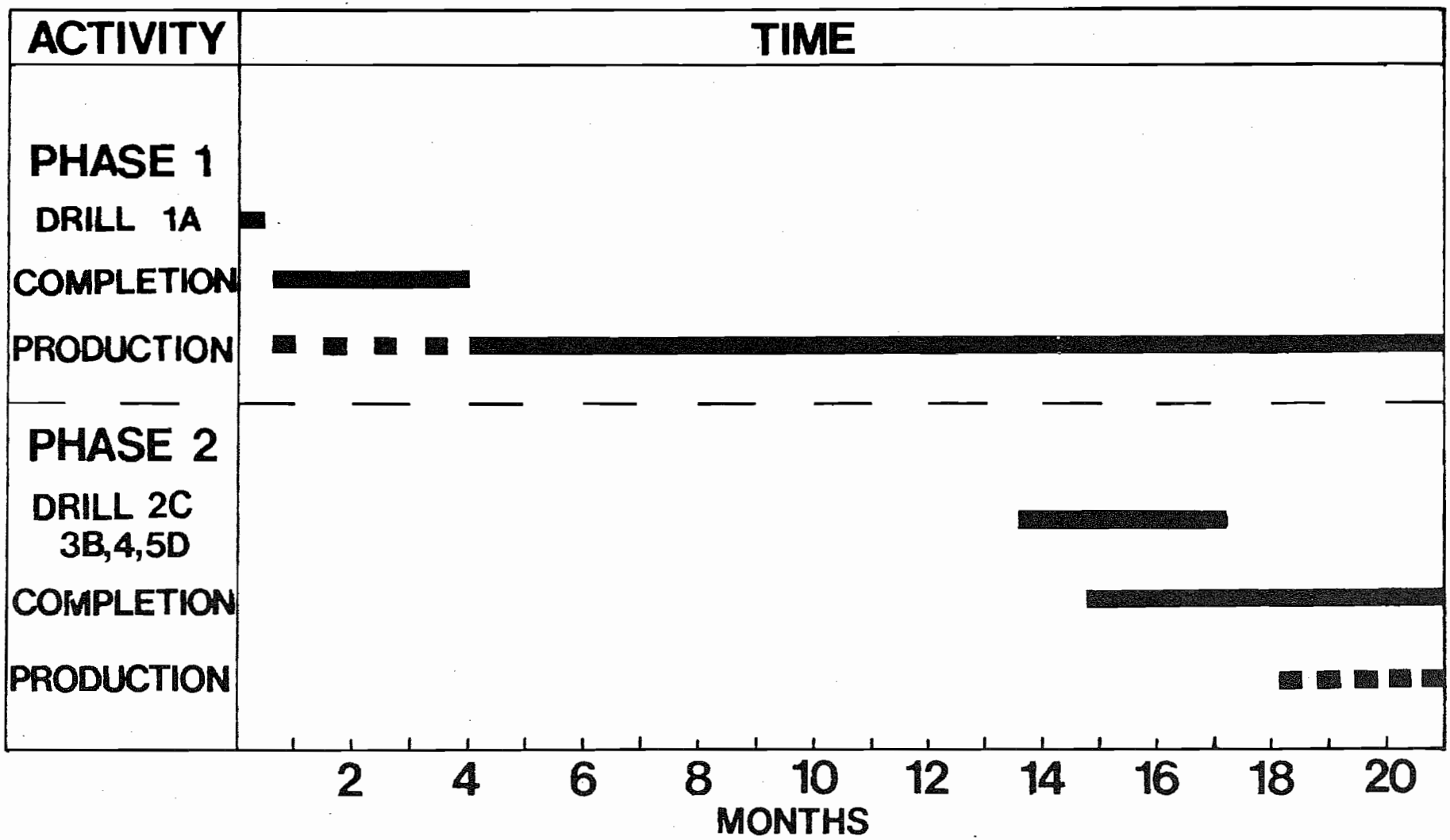
3. Drilling and stimulation of four additional wells.

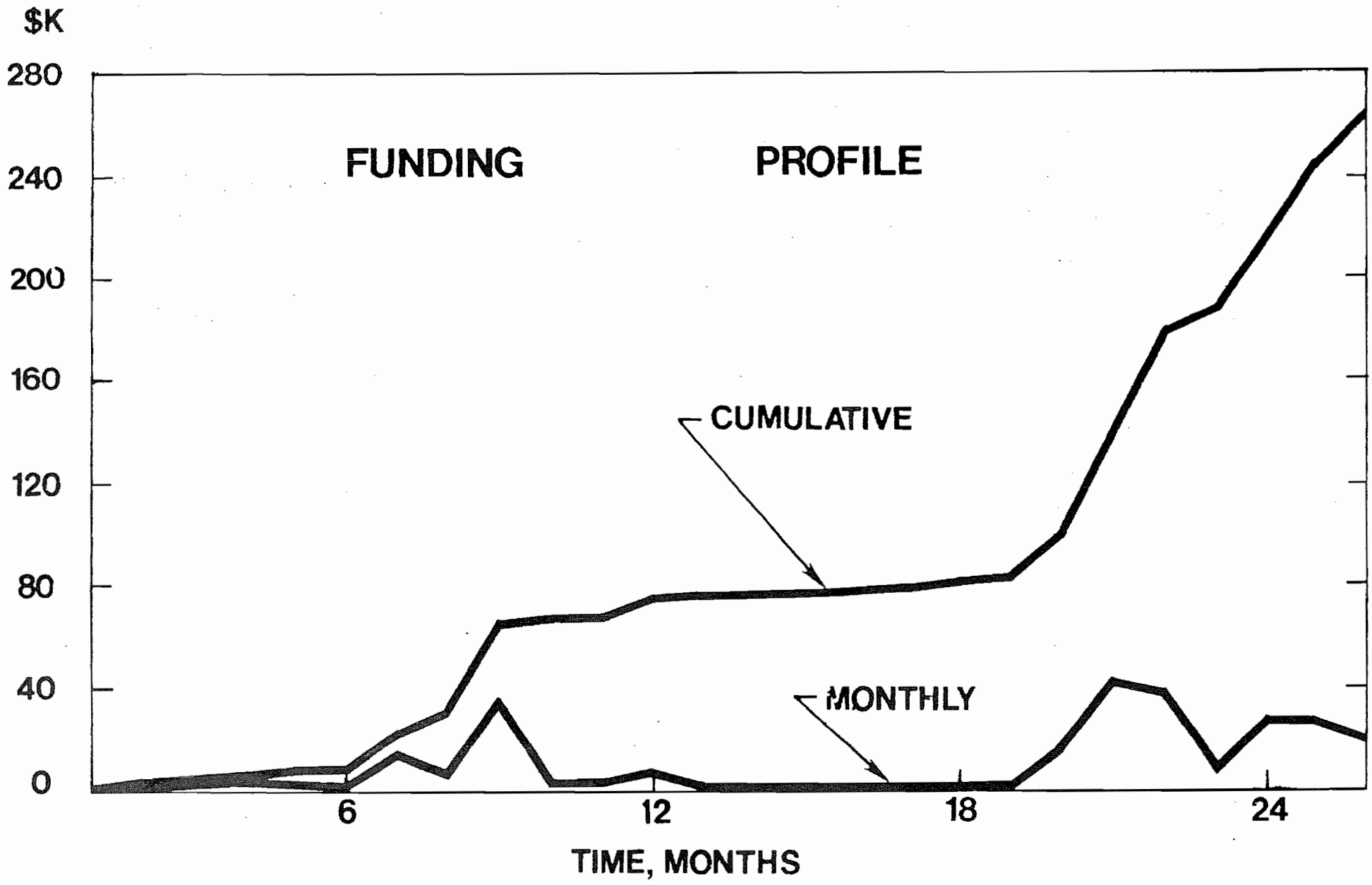
4. Production monitoring.

5. Preparation for underground investigation.

CRITICAL ITEMS

1. Uninterrupted production of gas drainage wells.


ACTIVITY
TIME
PHASE 1
DRILL 1A
COMPLETION
PRODUCTION
PHASE 2
DRILL 2C
3B,4,5D
COMPLETION
PRODUCTION
2
4
6
8
10
12
14
16
18
20
MONTHS


$K
280
240
200
160
120
80
40
0
FUNDING PROFILE
CUMULATIVE
MONTHLY
6
12
18
24
TIME, MONTHS

TECHNICAL FACT SHEET

Vertical Drilling to Degasify Jawbone Coalbed, Dickenson County, Va.

DOE Contract No. ET-77-C-01-9151.

Key Personnel

Michael A. Trevits, Geologist
U.S. Bureau of Mines
4800 Forbes Avenue
Pittsburgh, Pennsylvania 15213
412/675-6556

Clinchfield Coal Company
Timothy Wallace, Project Engineer
Dante, Virginia 24237
703/495-8700

Total Contract Amount

$390,767.00

Date of Contract Awards

September 29, 1977

Date of Contract Expiration

September 28, 1982

Project Objective

To determine the feasibility of using vertical boreholes to drain methane gas from the Jawbone coalbed and to evaluate the relationship of borehole spacing on gas drainage rates.

Summary of Events

May 30, 1978	Drilling began on first degasification hole, DG-1A.
June 6, 1978	Two core samples of the Jawbone coalbed were obtained and desorbed using Bureau of Mines direct method test. Estimated in place gas content 280 ft^3/ton.
June 26, 1978	Stimulation treatment using 30,000 gal of foam and 27,000 lb of 20-40 mesh sand completed on DG-1A.
Sept 8, 1978	Pump was installed on DG-1A, but problems prevented steady production.

Oct 1, 1978	The pump was reset and started producing water at 103 bpd and gas at 11,800 cfd.
Oct 20, 1978	The pump was down after producing water for 20 days at an average rate of 28 bpd and gas at 24,400 cfd.
Dec 12, 1978	The pump was reset and produced water at 103 bpd.
Dec 18, 1978	The highest gas production was recorded, 43,500 cfd and 34 bpd water.
May 31, 1979	Agreements were signed with the Philadelphia Oil Co. and the Brown Family Trust to give Clinchfield Coal Co. rights to drill wells DG-2C and DG-5D. Cumulative production from well DG-1A was 5,500,000 cf.
July 10, 1979	Well DG-3B was drilled to 481 feet.
Aug 20, 1979	Well DG-3B was stimulated with 30,000 gal of foam and 15,600 lb of 20-40 mesh prop sand.
Aug 29, 1979	Well DG-4 was drilled to its total depth of 465 feet.
Sept 27, 1979	Well DG-4 was stimulated with 30,000 gal of foam and 15,800 lb of 20-40 mesh sand.
Nov 6, 1979	Well DG-2C drilled to 676 feet.
Nov 8, 1979	Well DG-5D drilled to 673 feet.
Nov 30, 1979	Methane powered motors were installed on wells DG-3B and DG-4 to operate the pump jacks. Water production initiated from well DG-3B.
Dec 12, 1979	No proppant stimulation treatment performed at DG-2C. Fluid volume used 26,300 gal of foam. Stimulation of well DG-5D with 24,400 gal of foam and 14,200 lb of 20-40 mesh sand.
Jan 1, 1980	Well DG-1A was producing 20,900 cfd and cumulative production from DG-1A was 10,500,000 cf; water production declined to 1 bpd.
Jan 9, 1980	After slight water production DG-4 began "unloading" and producing 14,000 cfd.
Jan 17, 1980	Well DG-2C was equipped with a pump and methane powered motor and produced water.
Jan 21, 1980	Intermittent production from well DG-2C was 9,600 cfd gas and 103 bpd water. Intermittent production from well DG-4 was 10,000 cfd gas and 103 bpd water.

Jan 23, 1980 Cumulative gas production from well DG-1A was 11,000,000 cu. ft.

Feb 29, 1980 Production from DG-1A was 16,600 cfd gas and 0.7 bpd water total gas produced to date 11,689,000 cu. ft.

BUREAU OF MINES TECHNICAL FACT SHEET

DIRECTIONAL DRILLING FOR DEGASIFICATION OF THE PITTSBURGH COALBED GREENE COUNTY, PA CONTRACT NO. ET-77-C-01-8891

DIRECTIONAL DRILLING FOR DEGASIFICATION OF THE PITTSBURGH COALBED, GREENE CO., PA

CONTRACT NO.:	ET-77-C-01-8891
CONTRACTOR:	Harold F. Scott
CONTRACT DATE:	September 27, 1977
CURRENT COMPLETION DATE:	May 26, 1980
ANTICIPATED COMPLETION DATE:	May 26, 1983
CURRENT CONTRACT VALUE:	1843 K
DOE SHARE:	1843 K
ADDITIONAL FUNDING REQUIREMENTS:	300 K @ 100 K/year
USBM TECHNICAL PROJECT OFFICER:	W. Patrick Diamond

OBJECTIVE: To demonstrate the capability of using directional drilling techniques to drill long, horizontal methane drainage holes in coalbeds to reduce the explosion hazard of methane/air mixtures and utilize the recovered methane.

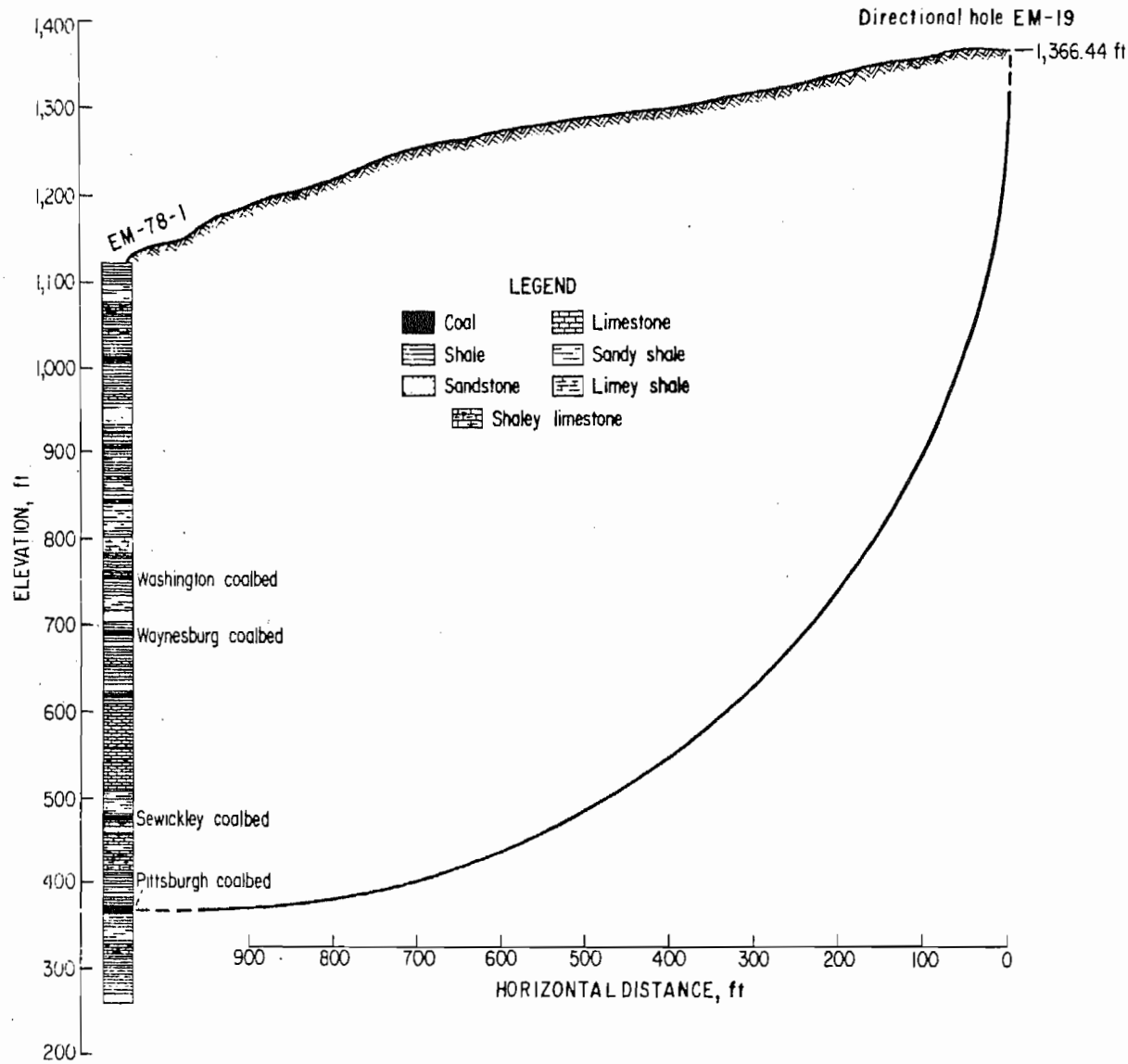
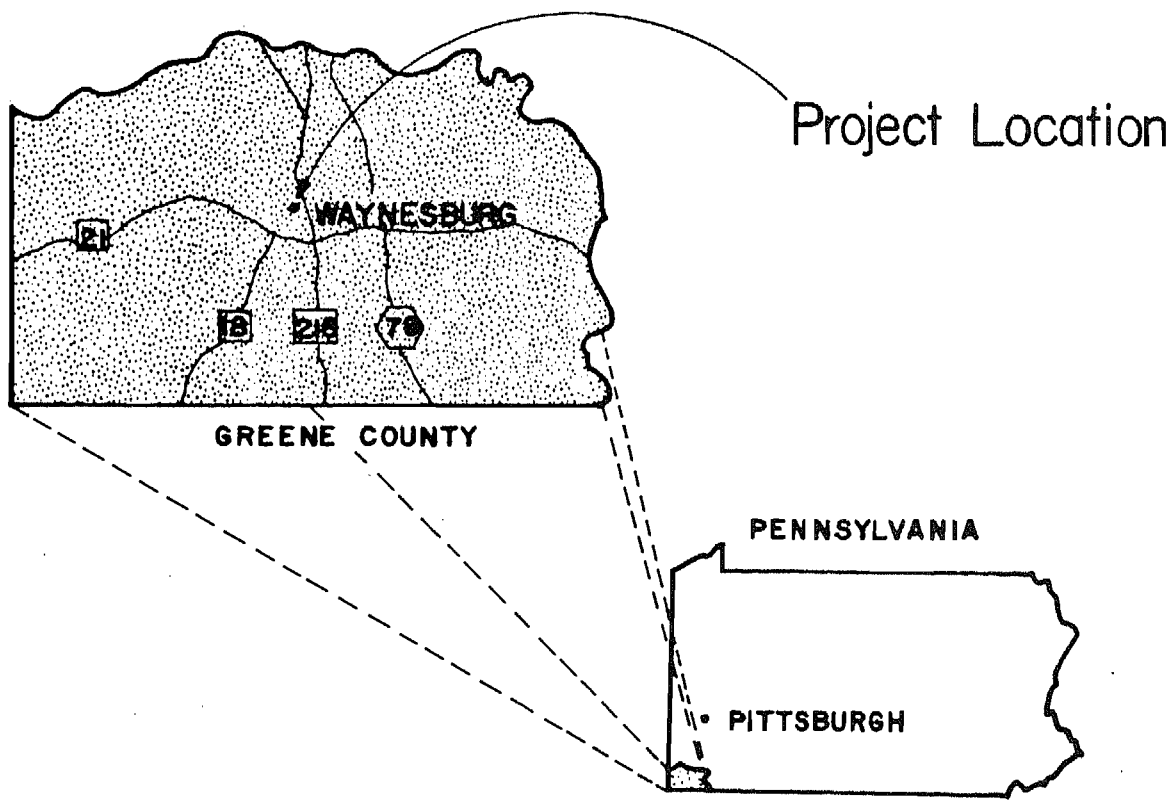


FIGURE 1. - Section view of slant-hole well path with geologic column.

LOCATION MAP



SUMMARY OF PROGRESS

1. Drilling of core hole, dewatering hole, and seven vertical monitoring holes completed.

2. 10,882 feet of horizontal drilling completed including:

H1 - 1767 feet	62%	in coal
H2 - 3207 feet	84%	in coal
H3 - 2993 feet	92%	in coal
H4 - 870 feet	62%	in coal
H5 - 707 feet	85%	in coal

3. Improvements in drilling rates from 80 ft/day to 213 ft/day achieved.

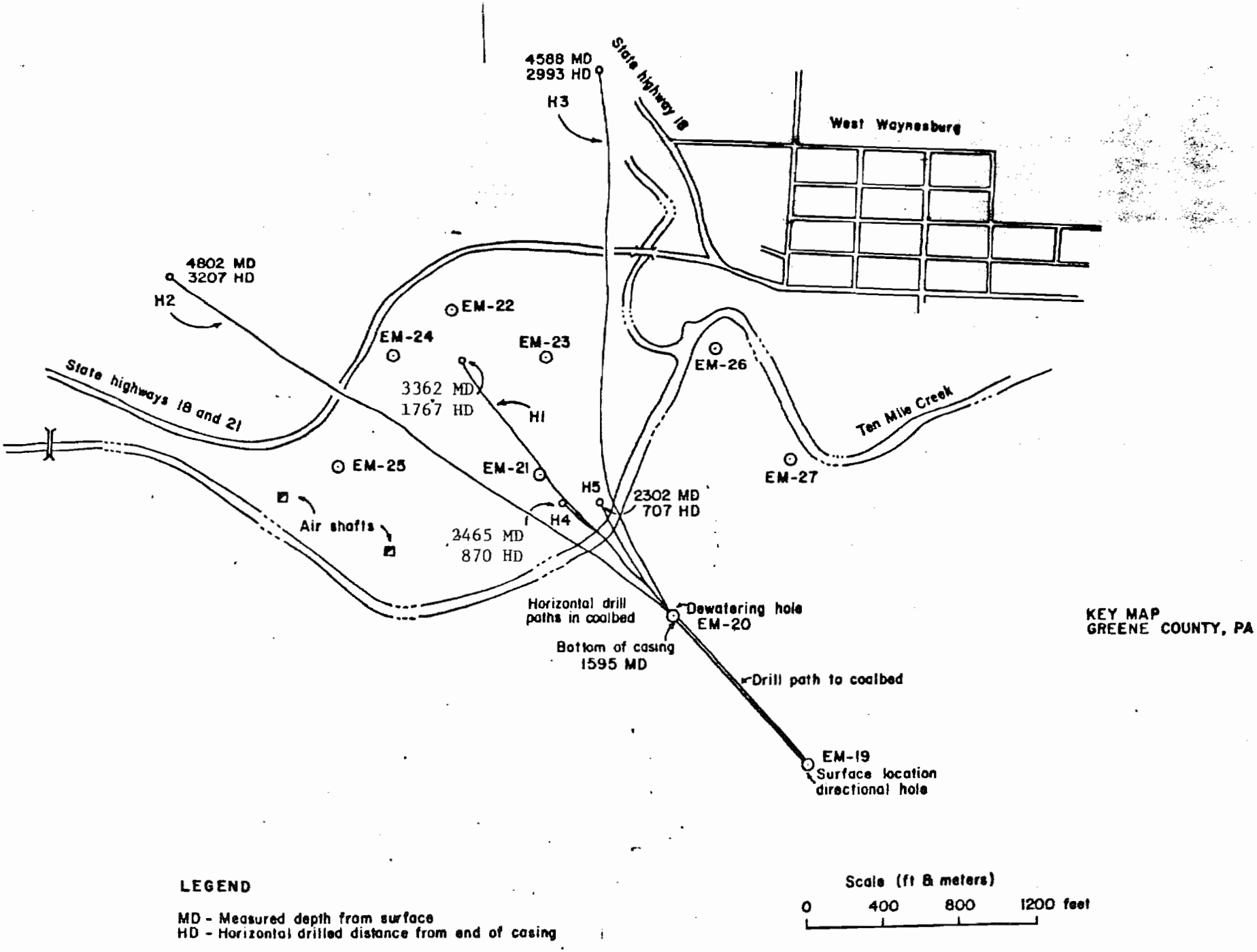
4. System prepared for water and gas production and monitoring.

5. Dewatering begun.

CRITICAL ITEMS

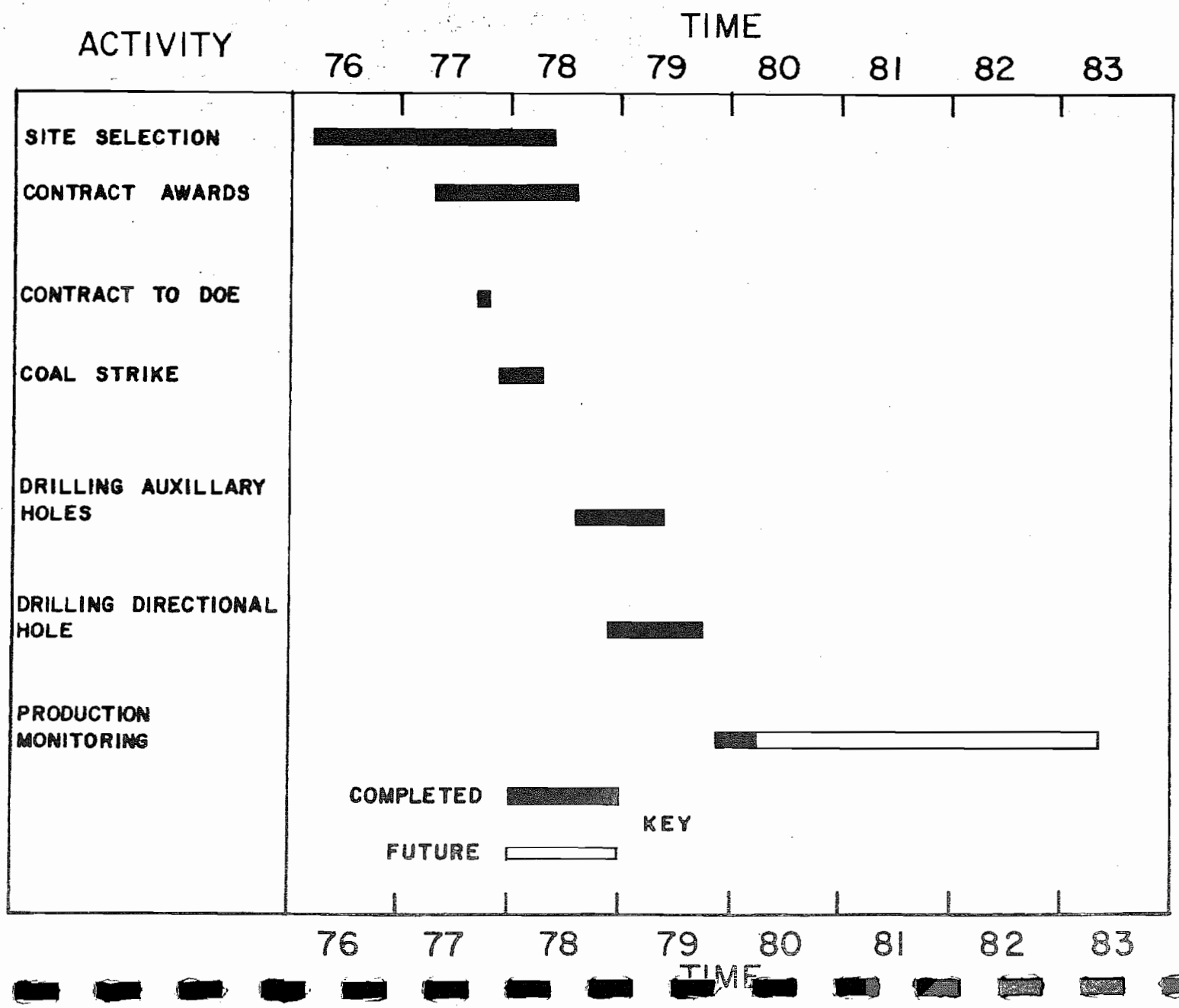
1. Approval of 1 year contract extension for maintenance and servicing of system.

2. Efficient dewatering of coalbed.

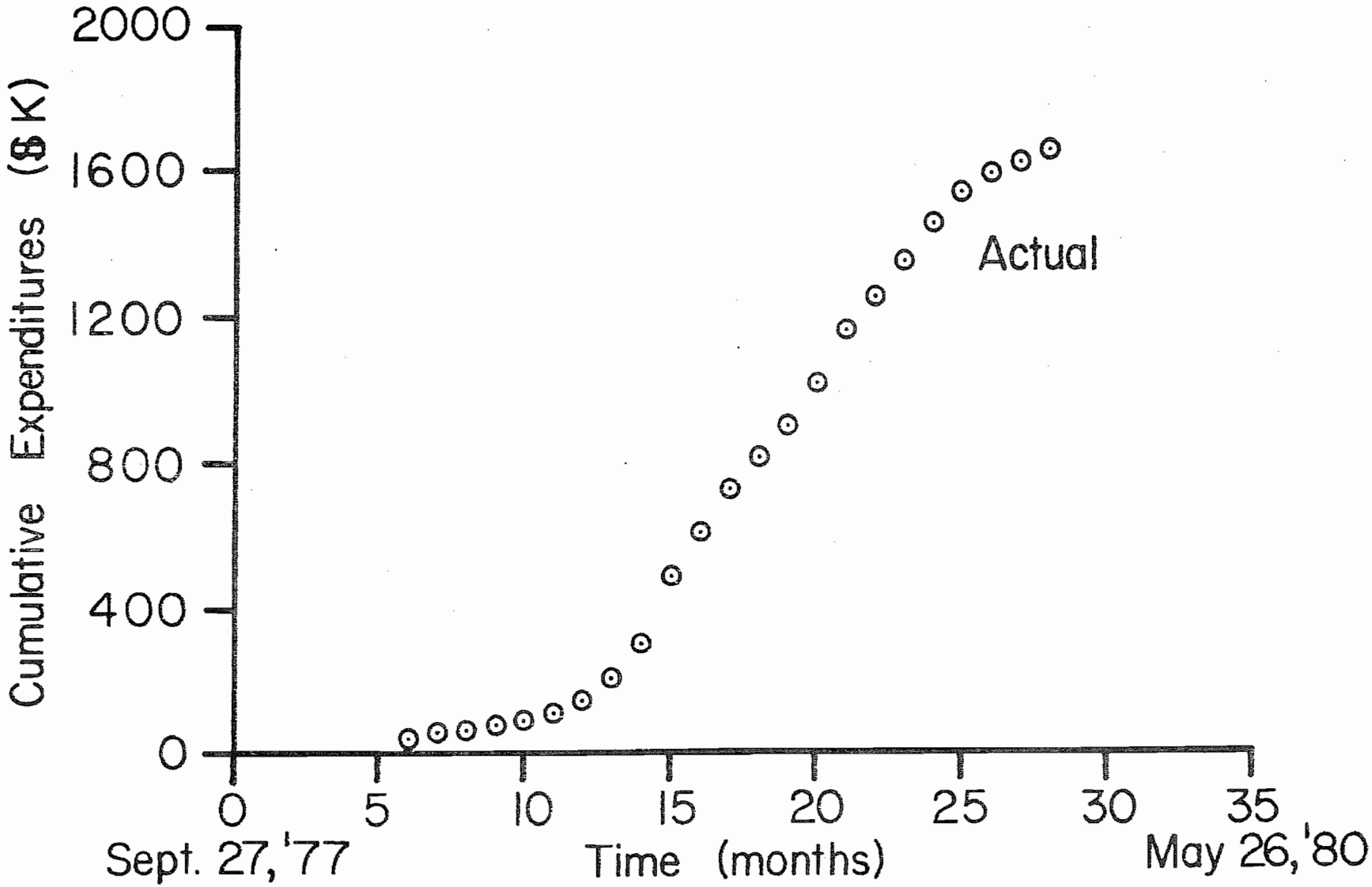


Plan view of drill sites and actual well path.

TIME TASK CHART--MAJOR ACTIVITIES



FUNDING PROFILE



FACT SHEET

Directional Drilling for Degasification of the Pittsburgh Coalbed
Greene County, Pa. DOE Contract No. ET-77-C-01-8891.

Key Personnel

Harold F. Scott, Contractor
P.O. Box 419
Bridgeville, PA 15017
412/221-4141

William P. Diamond, TPO
Supervisory Geologist
U.S. Bureau of Mines
4800 Forbes Avenue
Pittsburgh, PA 15213
412/675-6523 FTS 723-6523

Emerald Mine Corp. (J&L), Cooperating Coal Co.
Gordon H. Walrod, Company Contract
Director Coal Development Engineering
Jones and Laughlin Research Center
900 Agnew Road
Pittsburgh, PA 15227
412/884-1000 Ext. 264

Total Contract Value

$1,843,668.32

Important Contract Dates

Original contract signed - Sept. 27, 1977
Notice to proceed - July 10, 1978
Expiration of present contract - May 26, 1980

Major Accomplishments as of Dec. 21, 1979

1. Core hole completed.
2. Dewater hole drilled, cored, cemented, slotted, and stimulated.
3. Seven vertical monitoring holes drilled, cased and cemented, and cores taken of the Pittsburgh coalbed for gas content determinations.
4. 3-inch diameter directional pilot hole completed to the Pittsburgh coalbed.
5. Reaming of 3-inch pilot hole to 8-3/4 inches completed to depth of 1,612 feet, 5-1/2 inch production casing installed to depth of 1,595 feet.
6. First horizontal hole (center) completed to 1,767 feet beyond bottom of casing.
7. Second horizontal hole (left) completed to 3,207 feet beyond bottom of casing.

8. Third horizontal hole (right) completed to 2,993 feet beyond bottom of casing.
9. Two short holes (707 feet and 870 feet beyond bottom of casing) completed between center and right holes.
10. Downhole pump installed on dewatering hole and production monitoring begun.

Chronology of Events

January 1976	Began search for new drilling site after termination of Mather directional drilling project.
March 16, 1977	Drilling and Directional Control RFP out for bid.
Sept. 6, 1977	Cooperative agreement signed with Emerald Mine Corp.
Sept. 27, 1977	Drilling contract signed with Harold F. Scott, Contractor. Original site at Emerald Mine fell through becasuse of problem with gas rights.
Oct. 1, 1977	Contract transferred to DOE with project management remaining with USBM.
Oct. 27, 1977	Modification to contract signed to delay notice to proceed for approximately 90 days due to the Emerald Mines difficulty in finding a new site.
Dec. 1977-March 1978	Coal Strike precluded start of drilling operations because of requirement to use UMWA labor.
Jan. 25, 1978	All responses to Directional Control RFP declared unacceptable.
Feb. 21, 1978	Proposed modification to contract of Harold F. Scott to drill core hole, dewater hole, and subcontract directional control work submitted to DOE Washington Office Staff Engineer.
April 7, 1978	Proposed modification to contract of Harold F. Scott to drill 7 vertical monitoring holes submitted to DOE Washington Office Staff Engineer.
May 1978	Emerald Mines Corp. secured acceptable drilling site.
June 1978	Emerald Mine Corp. began preparation of drill site.
July 10, 1978	Notice to proceed on original drilling specifications received by Harold F. Scott. Actual drilling operations could not proceed pending approval of contract modifications submitted to the DOE, Feb. 21, 1978, and April 7, 1978.
August 15, 1978	Contractor began mobilization of equipment to drill site.

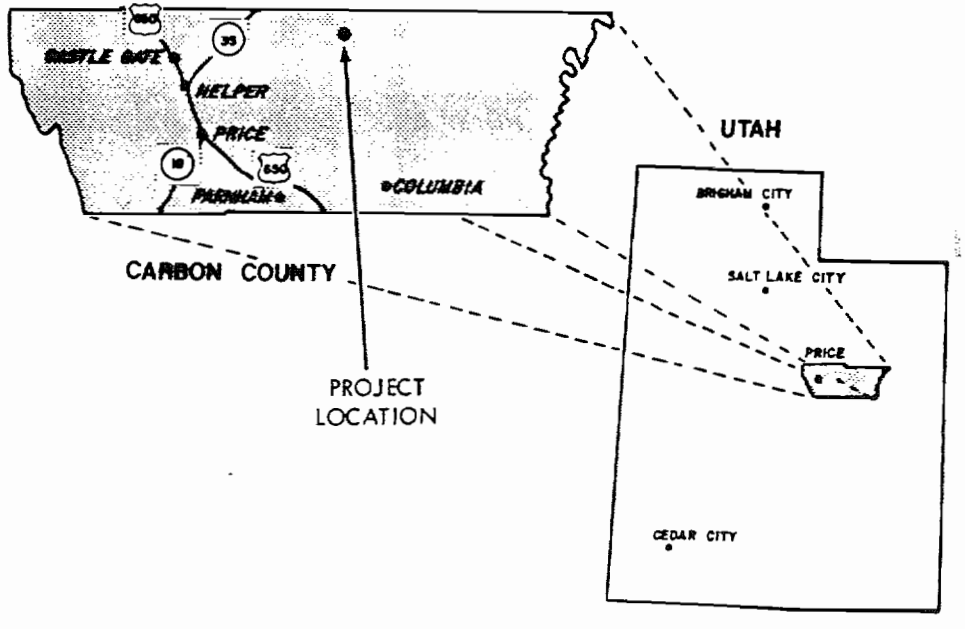
August 22, 1978	Contract of Harold F. Scott modified to include drilling a core hole, dewater hole and subcontract directional control services, $385,498.37. (Time required for approval of contract modification-6 months.)
Sept. 7, 1978	Contractor began drilling core hole at anticipated intercept of the Pittsburgh coalbed by the directional hole.
Sept. 21, 1978	Core hole completed to a depth of 759 feet.
Sept. 26, 1978	Contractor began drilling dewater hole with Government-owned drill rig near anticipated intercept of the Pittsburgh coalbed.
Sept. 28, 1978	Contract to Harold F. Scott modified to include the drilling of 7 vertical holes, $443,196.35. (Time required for approval of contract modification-5-1/2 months.
Oct. 11, 1978	Emerald Mines Corp. began site preparation for vertical monitoring holes.
Oct. 18, 1978	Began drilling first vertical monitoring hole.
Oct. 24, 1978	Dewater hole completed to depth of 900 feet, 7-inch OD casing run and cemented.
Nov. 1, 1978	Government-owned rig moved and set up on directional drilling site.
Nov. 2, 1978	Drilling operations on directional hole began.
Nov. 21, 1978	Casing jet slotted adjacent to Pittsburgh coalbed in dewater hole.
Dec. 19, 1978	3-inch pilot hole to Pittsburgh coalbed completed to total measured depth of 1,649 feet (999 True Vertical Depth).
Dec. 23, 1978- Jan. 2, 1979	Project shut-down for Christmas holiday.
Jan. 8, 1979	Began over-reaming directional hole from 3-inches to 8-3/4-inches diameter.
Jan. 9, 1979	Directional hole reamed to 191 feet, severe lost circulation problems.
Jan. 15, 1979	Began reaming directional hole to 9-7/8-inches from surface to 110 feet for installation of 9-5/8-inch intermediate casing for control of lost circulation.
Jan. 23, 1979	Intermediate casing string parted while running to bottom, leaving 30 feet stuck in hole.
Jan. 24, 1979	Began recovery operations for 30 feet of stuck casing.

Jan. 26, 1979	Drilling and casing of 7 vertical monitoring holes completed.
Jan. 30, 1979	Retrieved 30 feet of stuck 9-5/8-inch casing. Ran 112 feet of new 9-5/8-inch casing in directional hole.
Feb. 1, 1979	Pulled worn Strata-Pax bit at 273 feet, switched to diamond bit.
Feb. 9, 1979	"Backed off" BQ drill rod while running lost circulation material, began fishing operations to retrieve BQ drill rod.
Feb. 13, 1979	Fished 130 feet of BQ drill rod from directional hole. Obtained core of Pittsburgh coalbed from vertical monitoring hole EM-21.
Feb. 20, 1979	Obtained core of Pittsburgh coalbed from vertical monitoring hole EM-22.
Feb. 21, 1979	Changed to flat-faced Strata-Pax bit at depth of 612 feet. Bit crown separated from shank at 620 feet, began fishing operations.
Feb. 23, 1979	Ran mill to grind-up bit crown, mill cut 1-inch pipe at about 120 feet, began fishing operations for 1-inch pipe and BQ drill rod.
March 13, 1979	Ran down-hole TV camera, removed main string of 1-inch pipe and BQ drill rod.
March 30, 1979	Bit crown speared and retrieved.
April 4, 1979	Resumed reaming operations with third Strata-Pax bit, using stinger to guide down 3-inch pilot hole.
April 17, 1979	Strata-Pax bit removed at 842 feet due to wear. Second diamond bit run.
April 25, 1979	Obtained core of Pittsburgh coalbed from vertical monitoring hole EM-24.
May 4, 1979	Obtained core of Pittsburgh coalbed from vertical monitoring hole EM-25.
May 9, 1979	Reaming of directional hole completed at 1,612 feet.
May 10, 1979	Ran 1,595 feet of 5-1/2-inch casing in directional hole. Obtained core of Pittsburgh coalbed from vertical monitoring hole EM-23.
May 11, 1979	Casing cemented in directional hole.
May 14, 1979	Casing plug drilled out.

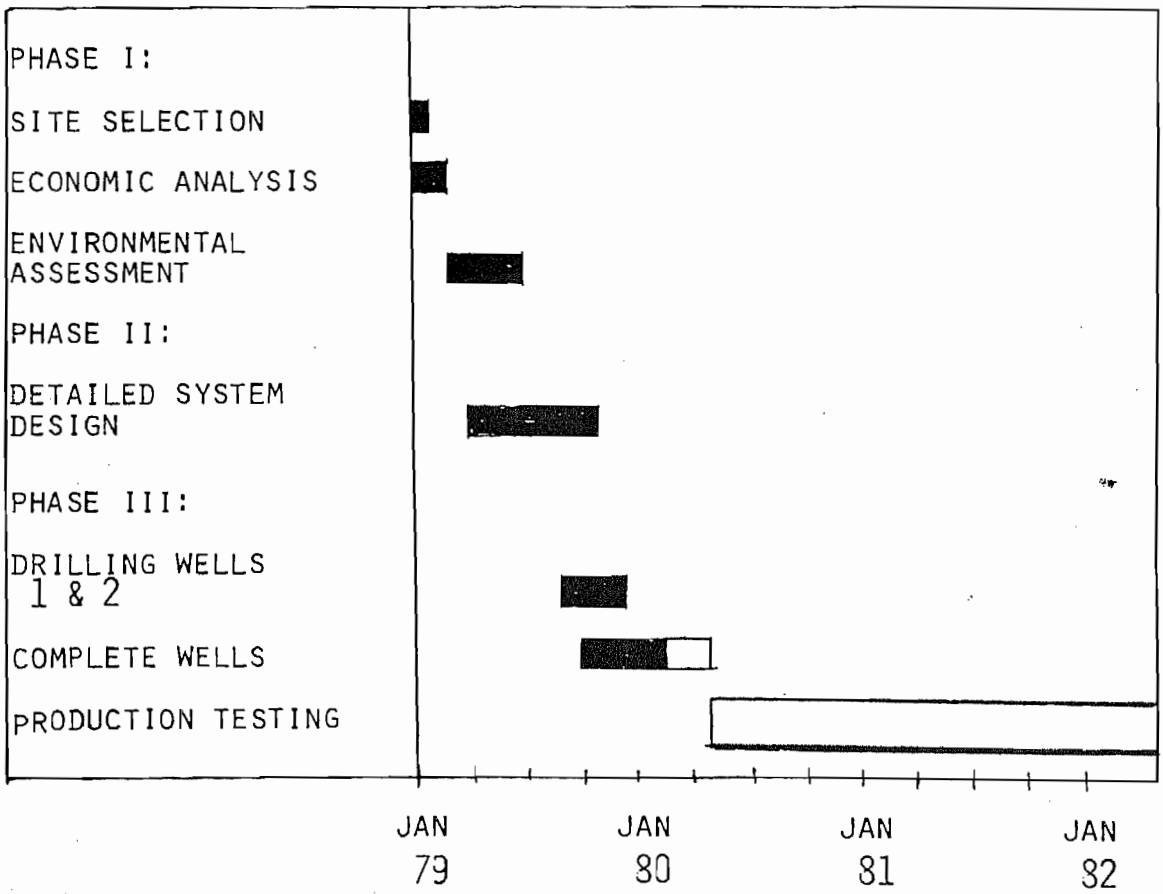
May 18, 1979	Drilled 90 feet of 3-inch horizontal hole in preparation for hydraulic stimulation of EM-20.
May 24, 1979	EM-20 hydraulically stimulated using 21,000 gallon foam treatment.
May 28, 1979	Began drilling of horizontal hole H1.
June 6-8, 1979	Shut down while replacing rig clutch, H1 at 2,351 feet (md).
June 14, 1979	Drilled to 2,631 feet (md). Pulled back to 2,212 (md) to sidetrack.
June 20, 1979	Drilled to 2,652 feet (md).
June 26, 1979	Proposed modification to contract of Harold F. Scott to recover funds expended during unanticipated fishing operations and lost circulation treatments submitted to DOE Washington Office Staff Engineer.
June 29, 1979	H1 at 2,988 feet (md).
June 30, 1979-July 8, 1979	Shut down for July 4 holiday.
July 11, 1979	H1 reaches maximum depth of 3,362 feet (md). After pulling tools to change Dyna-drill, could not get back into H1.
July 13, 1979	Begin H2 at 1,612 feet (md).
July 19, 1979	H2 drilled to 2,302 feet (md). Pulled Dyna-drill and could not get back into H2.
July 20, 1979	Began sidetrack of H2 at 1,982 feet (md).
July 24, 1979	H2 at 2,366 feet (md). Dyna-drill failed and tools pulled. Bit and rotating sub left in the hole.
July 25-26, 1979	Fishing for bit. Bit left in the hole at 2,109 feet in H-2-2 (md).
July 30, 1979	Begin sidetrack H-2-3 at 1,942 feet (md).
August 2, 1979	H2 passes 2,300 feet (md).
August 9, 1979	Began cleaning the hole with Con-Det and Torque-Trim.
August 14, 1979	H2 drilled to 3,382 feet (md). Pulled tools when Dyna-drill would not start.
August 15, 1979	Could not get tools past 1,682 feet (md)

August 16, 1979	Washed drill string into H2.
August 31, 1979	TD hole H2 at 4,802 feet (md). 3,207 feet of horizontal hole.
Sept. 4, 1979	Begin sidetracking H3 at 1,632 feet (md).
Sept. 12, 1979	H3 at 3,042+ feet (md).
Sept. 18, 1979	Contract of Harold F. Scott modified to recover funds expended during unanticipated fishing operations and lost circulation treatments, $244,764,26. (Time required for approval of contract modification-2-3/4 months.)
Sept. 21, 1979	H3 at toal depth of 4,588 feet (md).
Sept. 26, 1979	H4 started at 1,602 feet (md).
Oct. 1, 1979	H4 terminated at 2,462 feet (md). H5 started at 1,602 feet (md).
Oct. 5, 1979	H5 terminated at 2,302 feet (md).
Oct. 8-9, 1979	EM-19 opened from 3 inches to 8-1/2 inches from 1,595 to 1,742 feet (md). In coal at 1,712 feet (md).
Oct. 10, 1979	Proposed modification to contract of Harold F. Scott for a no cost time extension to May 26, 1980 submitted to DOE Methane from Coalbeds Project Manager, Morgantown, W.Va.
Oct. 15-20, 1979	Cleaned out EM-20 and bailed water.
Oct. 22-26, 1979	Bailed and swabbed EM-20.
Oct. 26, 1979	Contract of Harold F. Scott modified for a no cost time extension to May 26, 1980. (Time required for approval of contract modification-16 days.)
Nov. 5, 1979	Ran tubing and rods in EM-20.
Nov. 6-7, 1979	Pumped EM-20 with spudding rig. Installed EM-19 wellhead.
Nov. 9, 1979	Set pumping unit on EM-20.
Nov. 15, 1979	Mine hooked up power lines to EM-20. Begin pumping water at 128 bbl/day.
Dec. 4-7, 1979	Attempted to circulate water in EM-19 to clean up well and increase water production at EM-20.
Dec. 17 and 19, 1979	Pumped into EM-20 at up to 1,285 psi and 1-2 bbl/min in attempt to fracture coal and move cuttings to EM-19. Circulate water at EM-19 to remove cuttings.
Dec. 20-21, 1979	Use compressed air lift to dewater EM-19 (EM-20's sucker rod pump also pumping.

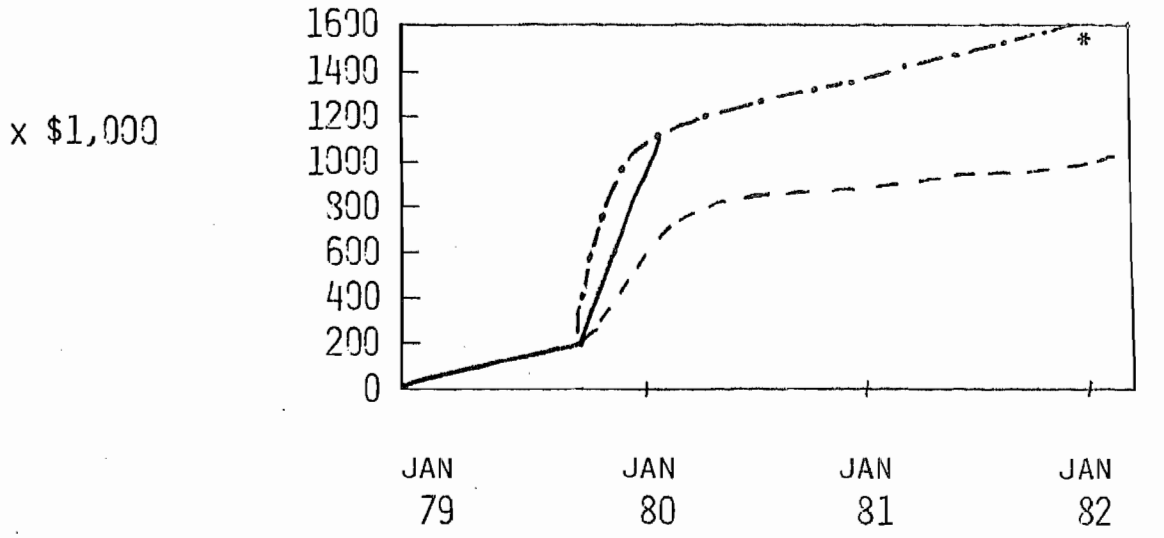
- CONTRACT: BOOK CLIFFS COALFIELD PRODUCTION TEST
  MOUNTAIN FUEL SUPPLY COMPANY
  DE-AC21-78MC10734
- CONTRACT DATE: JANUARY 11, 1979
- ANTICIPATED COMPLETION DATE: APRIL 11, 1982
- TOTAL COST: $1,590,000
- DOE COST: $850,000
- OBJECTIVE: TO DETERMINE EFFECTIVE EXTRACTION TECHNIQUES FOR ULTIMATE RECOVERY AND UTILIZATION OF COALBED METHANE FROM DEEP HORIZONS


HELPER
PRICE
COLUMBIA
CARBON COUNTY
PROJECT
LOCATION
UTAH
BRIGHAM CITY
SALT LAKE CITY
PRICE
CEDAR CITY

- TASKS:


PHASE I:
SITE SELECTION
ECONOMIC ANALYSIS
ENVIRONMENTAL ASSESSMENT
PHASE II:
DETAILED SYSTEM DESIGN
PHASE III:
DRILLING WELLS 1 & 2
COMPLETE WELLS
PRODUCTION TESTING
JAN 79
JAN 80
JAN 81
JAN 82

- FUNDING PROFILE:



INITIAL PLAN - - - - - -

UPDATED PLAN - · - · - · -

ACTUAL ————————

* DUE TO INCREASED DRILLING COSTS (HAD TO RESORT TO MUD DRILLING RATHER THAN AIR)

- ACCOMPLISHMENTS:
  - DRILLED AND CORED (IN COAL SEAMS) WELLS 1 & 2
  - ENVIRONMENTAL ASSESSMENTS COMPLETED
  - OBTAINED DRILLING PERMITS FOR TWO WELLS
  - APPLIED FOR PERMIT ON THIRD WELL, ON BLM LAND
  - COMPLETED ECONOMICAL ANALYSIS

- CRITICAL ITEMS:
  - DRILLING PERMIT ON THIRD WELL DENIED DUE TO (A) COAL OWNERSHIP AND (B) MINEABILITY OF THE COAL AT SITE OF CASTLE GATE WELL.

- RECOMMENDATIONS:
  - RESOLVE PERMIT PROBLEM EITHER BY OBTAINING APPROVAL FOR DRILLING AT PRESENT SITE, OR SELECT ANOTHER SITE.

MOUNTAIN FUEL - TECHNOLOGY TEST PROJECT

- DESORPTION DATA (GILSON SEAM)
  - ONE SAMPLE YIELDED 372 CF/T
  - CUMULATIVE AVERAGE WAS 300 CF/T
  - GAS ANALYSIS WAS 97 - 98 PERCENT CH_4
- PRELIMINARY TESTING OF WELLS 1 AND 2
  - PERMEABILITY IS $\sim$2 MD

- CONTRACT: PICEANCE BASIN PRODUCTION TEST

  INTERCOMP, INC.
  DE-AC21-78MC08384

- CONTRACT DATE: SEPTEMBER 29, 1978

- ANTICIPATED COMPLETION DATE: DECEMBER 31, 1980

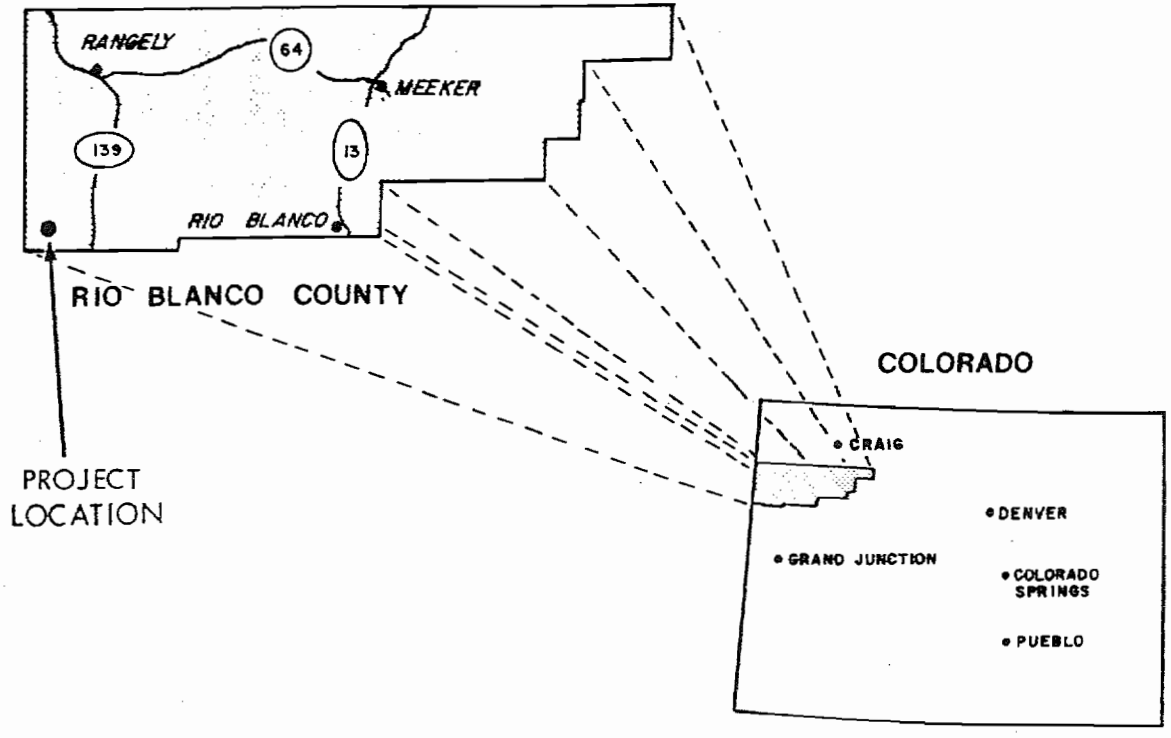
- TOTAL COST: $275,000

- DOE COST: $221,500

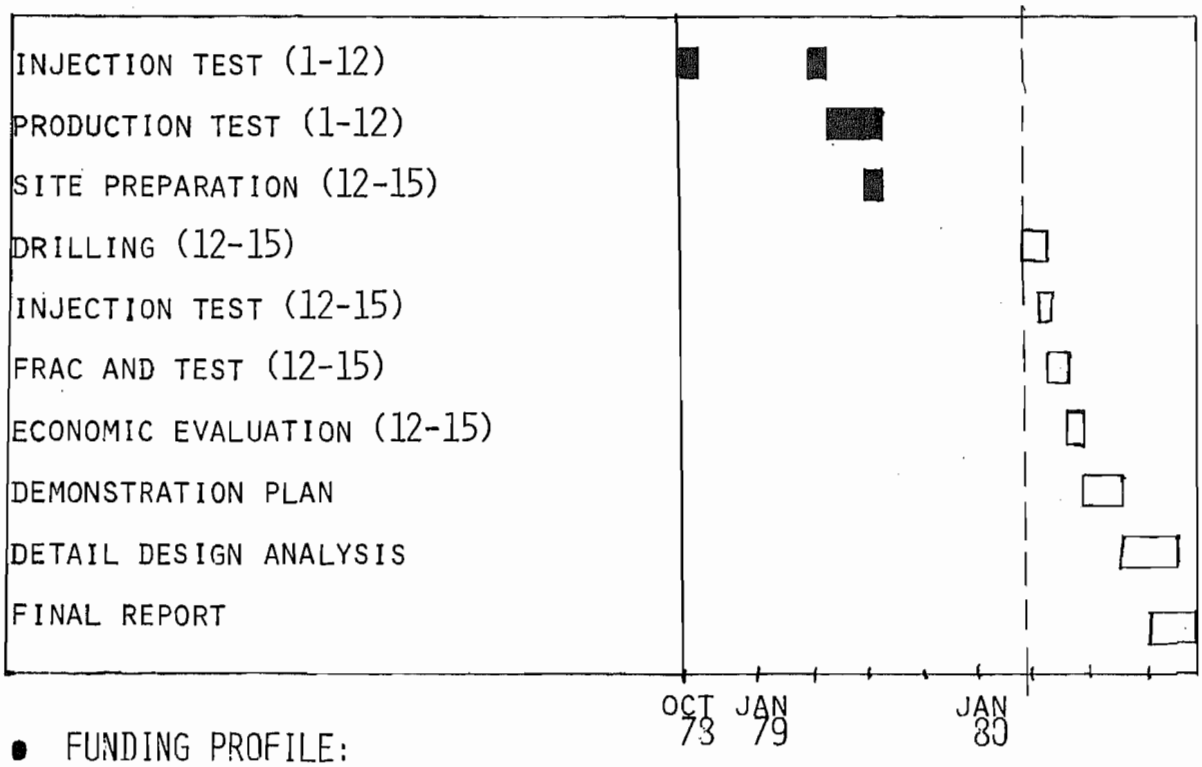
- OBJECTIVE: TO DEMONSTRATE EFFECTIVE EXTRACTION TECHNOLOGY FOR ULTIMATE RECOVERY AND UTILIZATION OF METHANE FROM COALBEDS LOCATED IN RIO BLANCO COUNTY, COLORADO

INTERCOMP/COSEKA TECHNOLOGY TEST PROJECT

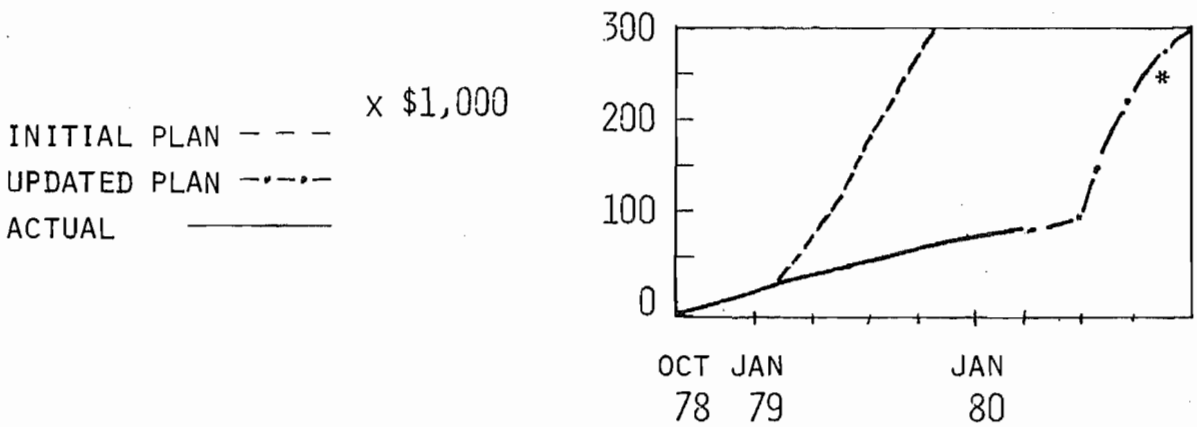
METHANE RECOVERY FROM UNMINABLE COAL



- TASKS:



- FUNDING PROFILE:



* REDEFINED PLAN OF EXPENDITURES IF DOE/USGS PERMITS WELL 12-15

- ACCOMPLISHMENTS:
  - ENVIRONMENTAL ASSESSMENT COMPLETED
  - COMPLETED INITIAL PRODUCTION ANALYSES OF WELL 1-12
  - DRILLING PLANS PREPARED FOR PRODUCTION WELL
  - FRACTURE TREATMENT PLAN IN PREPARATION
- CRITICAL ITEMS:
  - DRILLING PERMIT ON THE SECOND WELL (12-15) DENIED DUE TO MINEABILITY OF THE COAL AT THE WELL SITE
- RECOMMENDATIONS:
  - RESOLVE PERMIT PROBLEM ON THE BASIS OF AN R & D PROJECT

FIGURE 1
DATA FROM FEDERAL 1-16

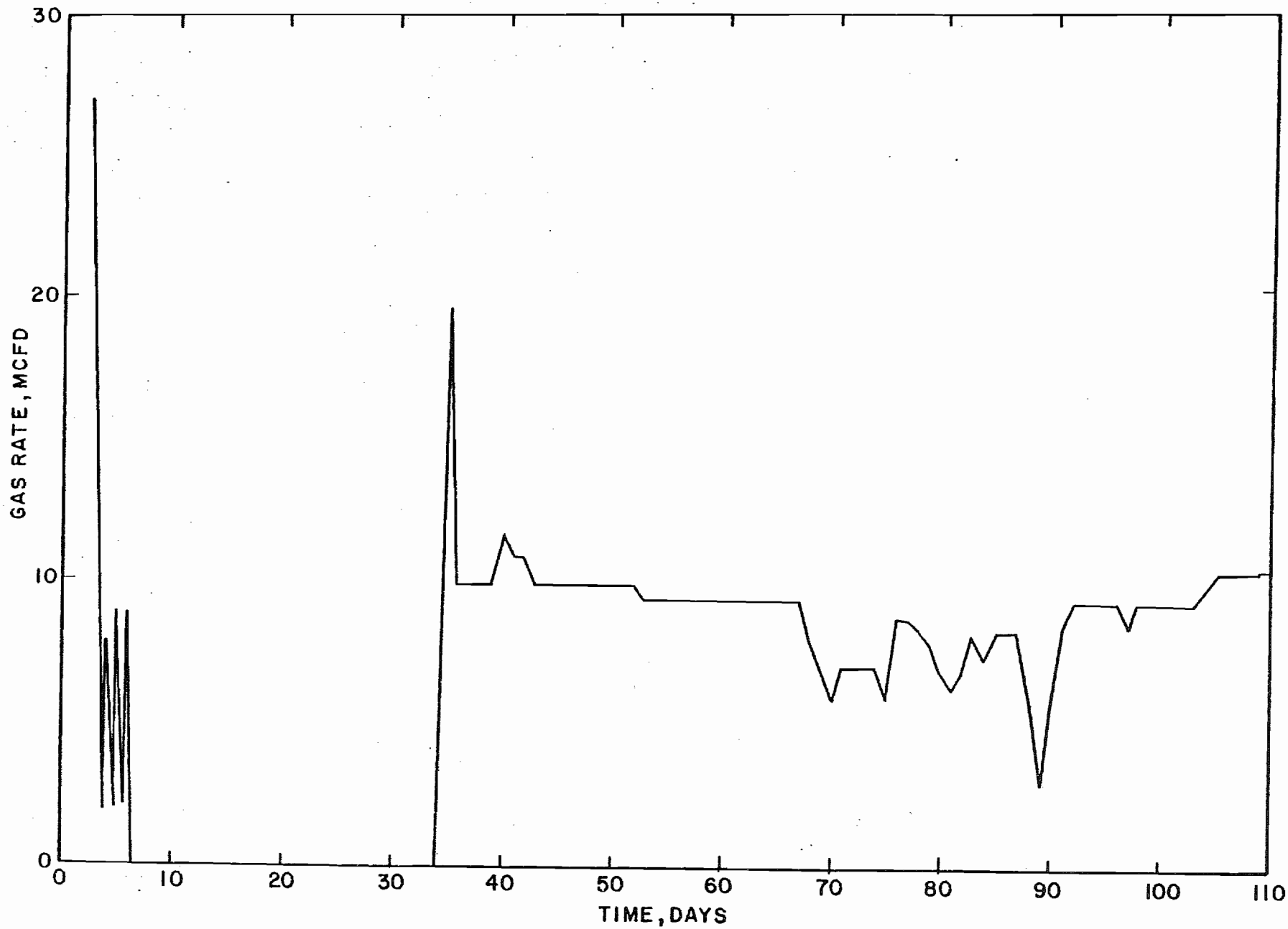
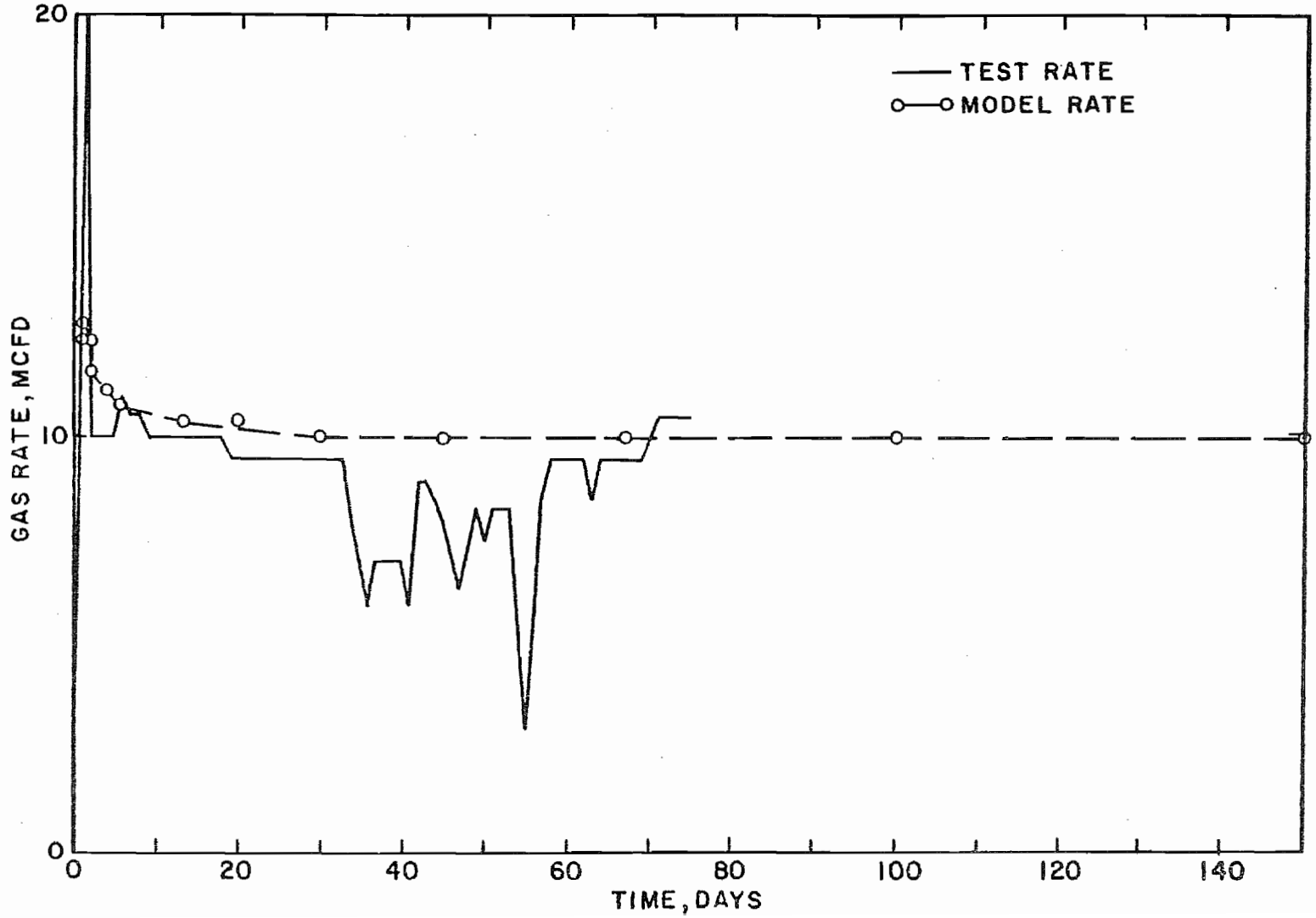
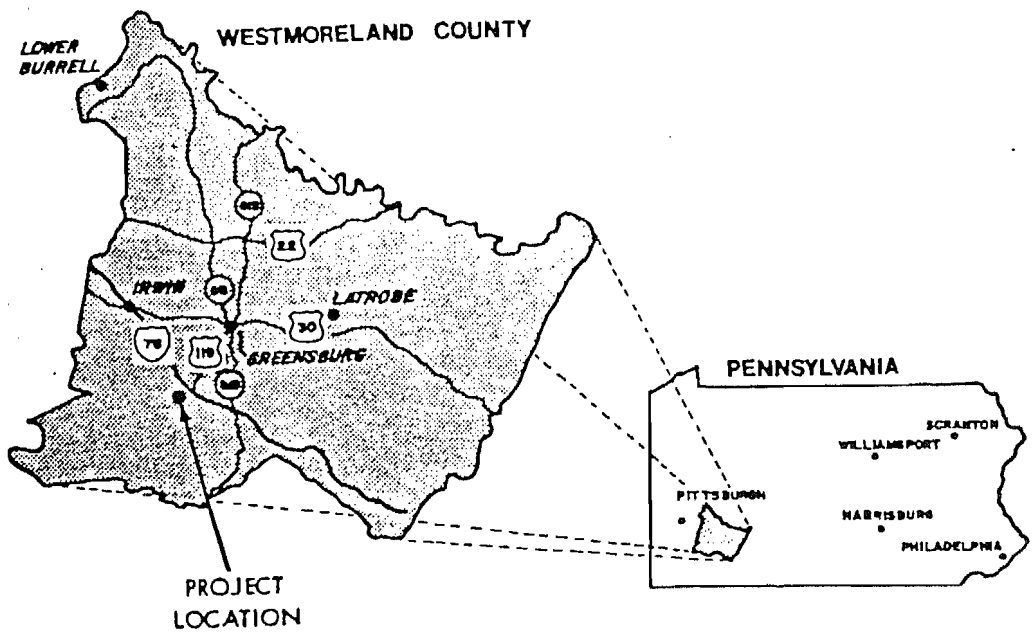


FIGURE 2

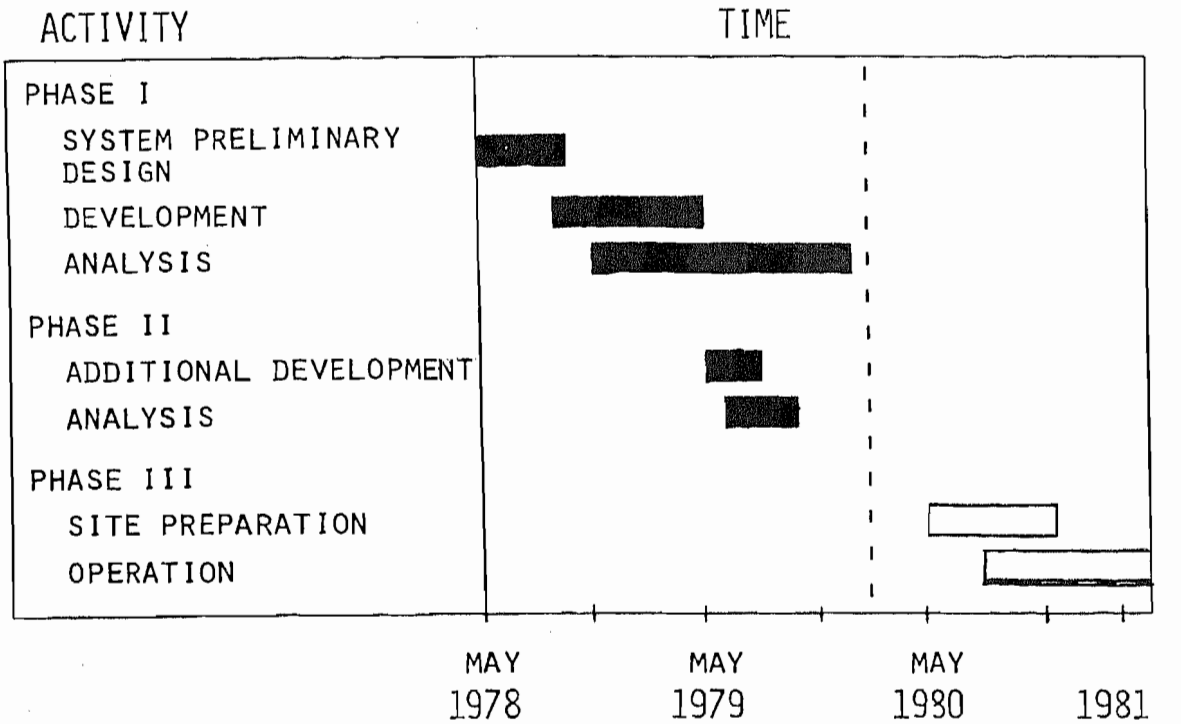
COMPARISON OF TEST DATA TO MODEL SIMULATION FOR FEDERAL I-16



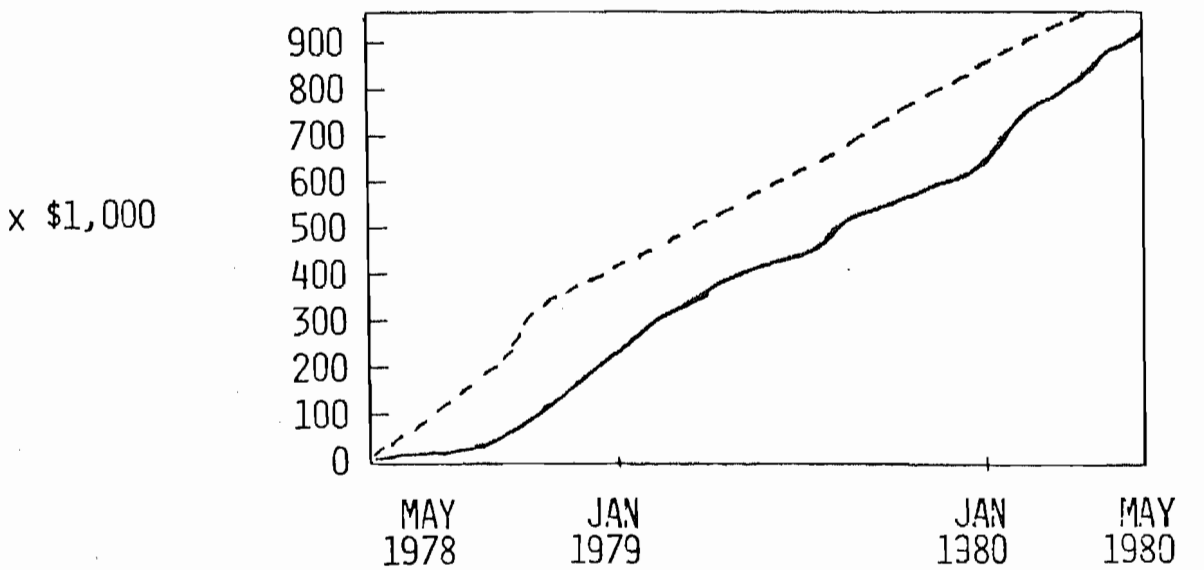
- CONTRACT: WESTINGHOUSE ELECTRIC CORPORATION
  DE-AC21-78MC08332
- CONTRACT DATE: MAY 12, 1978
- ANTICIPATED COMPLETION DATE: JULY 12, 1981
- TOTAL COST: $861,059
- DOE COST: $836,759
- WESTINGHOUSE COST: $24,300
- OBJECTIVE: TO DEVELOP TECHNIQUES FOR EXTRACTION OF METHANE FROM COALBEDS AND TO DETERMINE THE SUITABILITY OF THE GAS FOR PROCESS HEAT GENERATION.
- LOCATION MAP:



- MAJOR ACTIVITIES:

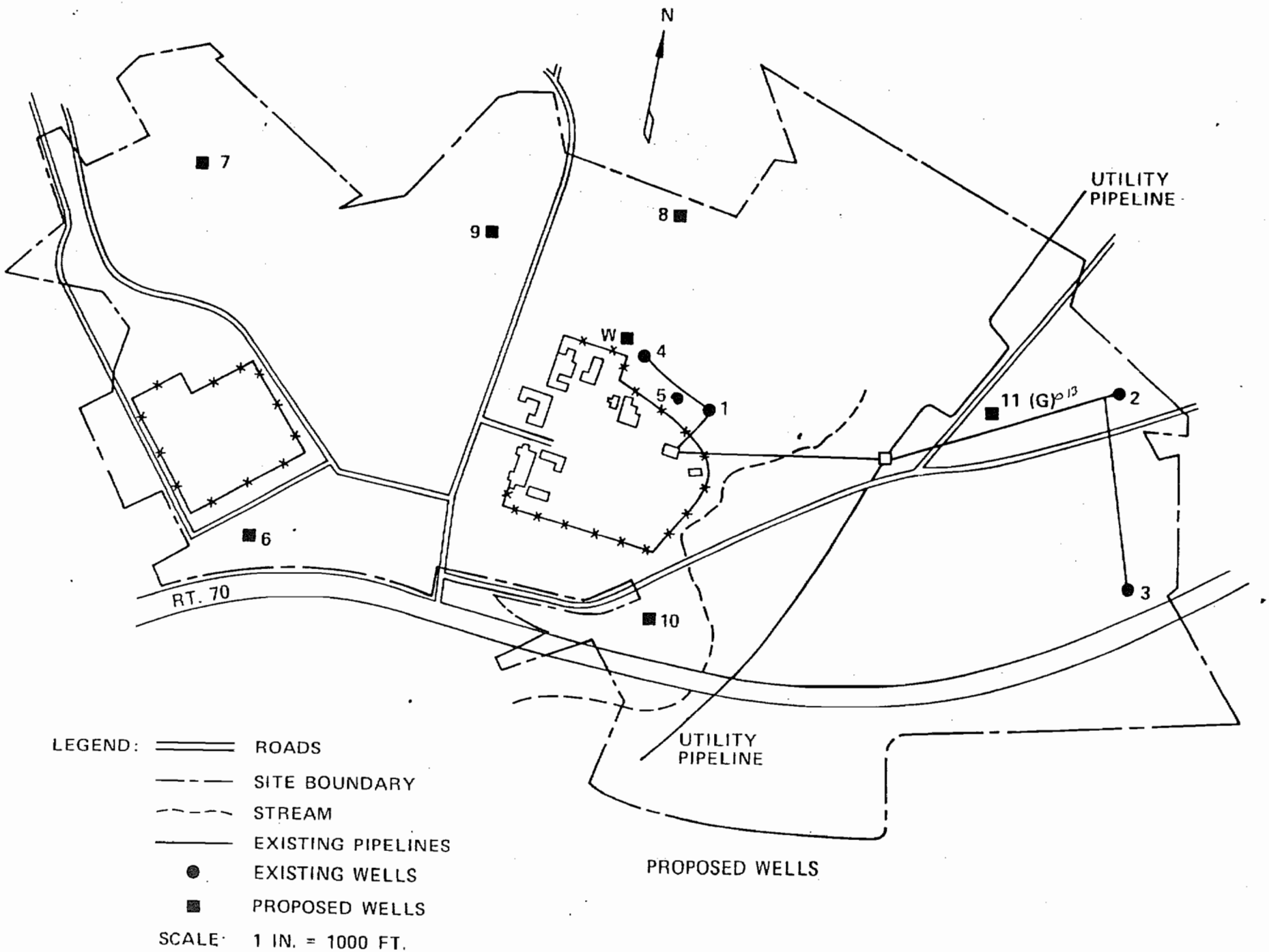


- FUNDING PROFILE:



PLANNED- - - - - -

ACTUAL ————


N
7
9
8
W
4
5
1
11 (G)
2
3
6
10
RT. 70
UTILITY PIPELINE
UTILITY PIPELINE
PROPOSED WELLS
LEGEND:
ROADS
SITE BOUNDARY
STREAM
EXISTING PIPELINES
EXISTING WELLS
PROPOSED WELLS
SCALE: 1 IN. = 1000 FT.

CORE DATA SUMMARY

COAL SEAM	SEAM DEPTH FEET	SEAM THICKNESS INCHES	GAS CONTENT cc/g
UPPER FREEPORT	187-189.3	28	.376
LOWER FREEPORT	237-243	74	(.458) (.648) (.821)
UPPER KITTANNING	324-326	25	.807
LOWER KITTANNING	384-389	62	(1.669) (1.628)
CLARION	432-435.5	46	.723
BROOKVILLE	458-459.5	18	.878
UPPER MERCER	477.5-479	15	1.978
MIDDLE MERCER	517-518	14	.966
LOWER MERCER	552-554	24	1.482
QUAKERTOWN	589	5	1.441
UPPER SHARON	618	4	1.846
LOWER SHARON	628.5	8	3.245

WELL NO. 5

STIMULATION SUMMARY

ZONE/STAGES	PERFORATIONS DEPTH	NUMBER OF HOLES	SAND LB	VOLUME PUMPED BBL	RATE BPM	PRESSURE PSIG
1/1	657-58	2	0	145	8	3800
	652-53	2				
	645-47	3				
	614-16	5				
2/5	570-72	4	26000	2105	26	2100
	530-32	4				
	490-92	4				
3/5	449-52	6	26000	2145	30	2700-1000
	385-88	6				
4/5	333-35	4	24000	2080	32	1200
	256-58	4				
	193-95	4				
TOTAL		48	76000	6475		

WELL NO. 4

INITIAL ECONOMICS
(12 YEAR LIFE CYCLE)

COST ELEMENT	$/10^6 BTU
WELLS	0.76
WELLHEAD EQUIPMENT	0.06
COLLECTION SYSTEM (3 MILES OF PIPELINE)	0.05
WASTE WATER HANDLING SYSTEM	0.18
SUB-TOTAL	1.05
O&M COSTS	0.20
TOTAL	1.25

ECONOMIC PROJECTION

SYSTEM PAYOUT - 5 YEARS

EARNINGS - 15%

AVERAGE PRESENT WORTH - $29 K/YEAR CASH INCOME

PRELIMINARY PLAN FOR PHASE III

- COMPLETE WELLS AT SITES 6, 7, AND 8
- DEVELOP WELLS AT SITES 9 AND 10
- DEVELOP GOB SITE 11
- PROCURE AND INSTALL STANDARD EQUIPMENT FOR WELLS
- PROCURE AND INSTALL GOB GAS/METHANE UPGRADER
- PROCURE AND INSTALL FUEL CELL WITH ASSOCIATED EQUIPMENT
- DEVELOP DEEP WELL DISPOSAL SYSTEM
- OPERATE SYSTEM

WESTINGHOUSE ELEC CORP.
DE-AC21-78MC08332

- SUMMARY OF PROGRESS:

  - CORED WELL NO. 5
  - DRILLED, COMPLETED, AND FRACTURED WELL NO. 4.
  - WELL NO. 4 TIED INTO PLANT GAS PIPELINE SYSTEM
  - DRILLED AND CORED WELLS NO. 6, 7, AND 8.

CRITICAL ITEMS: ADDITIONAL FUNDS NEEDED TO CONDUCT PHASE III

NATURAL GAS HYDRATES

RESOURCE DEVELOPMENT

- DISCOVERY
- CHARACTERIZATION
- APPRAISAL
- EXPLORATION
- EXPLOITATION
- PRESENT STATUS OF RESEARCH
- POSSIBLE DOE ROLE
- PROPOSED INITIAL R&D WORK
- PROPOSED BUDGET

DISCOVERY OF NATURAL GAS HYDRATES

- SIR HUMPHREY DAVEY DISCOVERED THE FIRST CLATHRATE HYDRATE OF CHLORINE GAS IN 1810.

- METHANE HYDRATE (A CLATHRATE HYDRATE WHICH IS A CRYSTAL LATTICE WITH VOIDS THAT CAN BE FILLED BY GASES WITH A MOLECULAR SIZE SMALLER THAN 6.7A^{o}) WAS FIRST REPORTED BY HAMMERSCHMIDT, 1931 AS GAS HYDRATES IN PIPELINES. (ARTIFICIAL HYDRATES)

- STACKLEBURG AND CO-WORKERS (1949-1954) DETERMINED THE TWO TYPES OF STRUCTURES OF GAS HYDRATES BY X-RAY DIFFRACTION.

- MILLER IN 1969 REPORTED FIRST OCCURRENCE OF A NATURAL HYDRATE OF AIR IN AN ANTARCTIC ICE CORE.

- RUSSIANS REPORT OCCURRENCE OF NATURAL GAS HYDRATES IN SIBERIA IN 1971 (MAKAGON, ET. AL.).

- BILY AND DICK IN 1973 REPORT OCCURRENCE OF NATURAL GAS HYDRATES IN MACKENZIE DELTA AND ARCTIC ISLANDS OF CANADA.

- KATZ, 1971, POSTULATED POSSIBLE PRESENCE OF HYDRATES IN PRUDHOE BAY AT DEPTHS OF 600 TO 1035 M.

- STOLL, 1971, POSTULATED PRESENCE OF HYDRATES IN MARINE SEDIMENTS.

CHARACTERIZATION OF HYDRATES

- SOLID ICE-LIKE CYRSTALLINE LATTICES OF WATER MOLECULES WHICH FORM CAGES AROUND GAS MOLECULES.

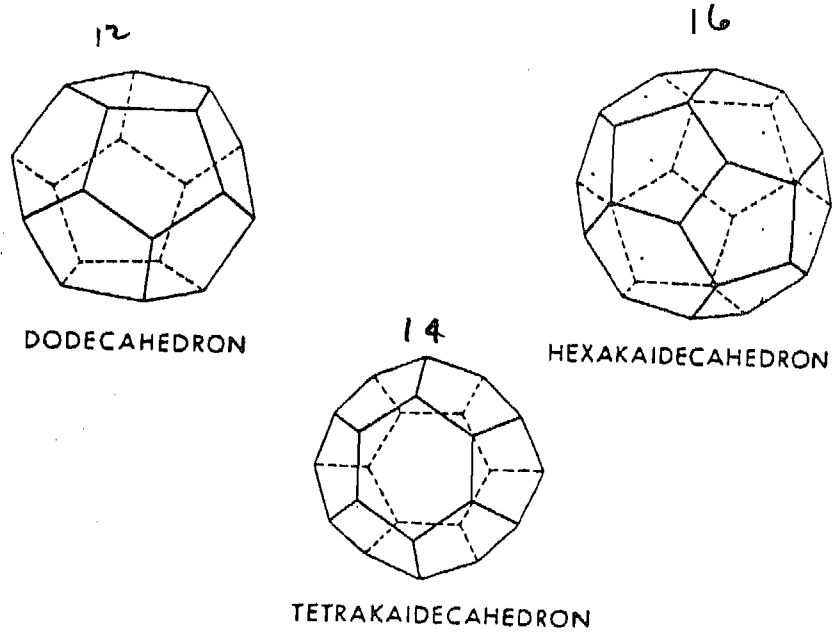
- GAS MUST BE IN SOLUTION IN THE WATER WHEN WATER IS LOWERED BELOW FREEZING POINT TO ALLOW HYDRATES TO FORM. PRESSURE IS REQUIRED TO KEEP GAS IN SOLUTION.

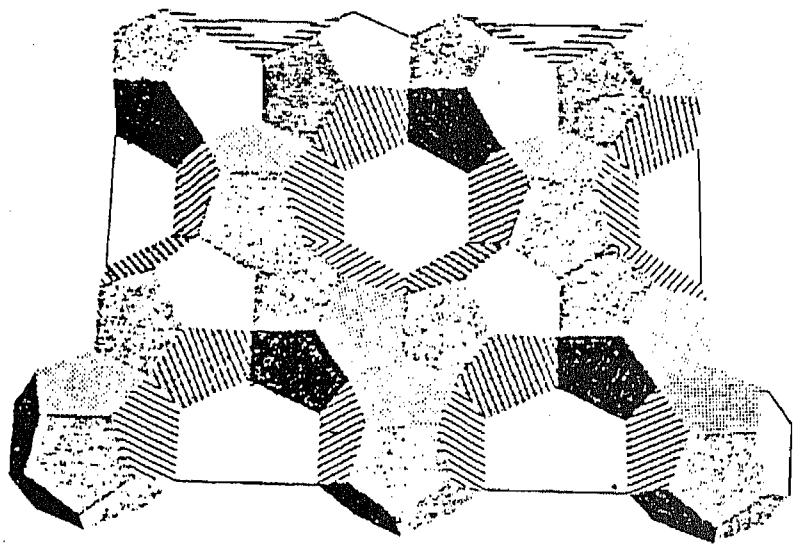
- MOST CHARACTERIZATION WORK TO DETERMINE PRESSURE TEMPERATURE RELATIONS WITH VARIOUS GASES HAVE BEEN WITH PURE MATERIALS (WATER AND GAS).

- NATURAL GAS HYDRATES COULD EXIST AS THIN LAYERS OF PURE HYDRATES OR AS CRYSTALS IN SEDIMENTS AT THE BOTTOM OF THE OCEAN.

- THEY COULD EXIST AS CEMENTING MATERIAL FOR MUDDY ORGANIC RICH BOTTOM SEDIMENTS.

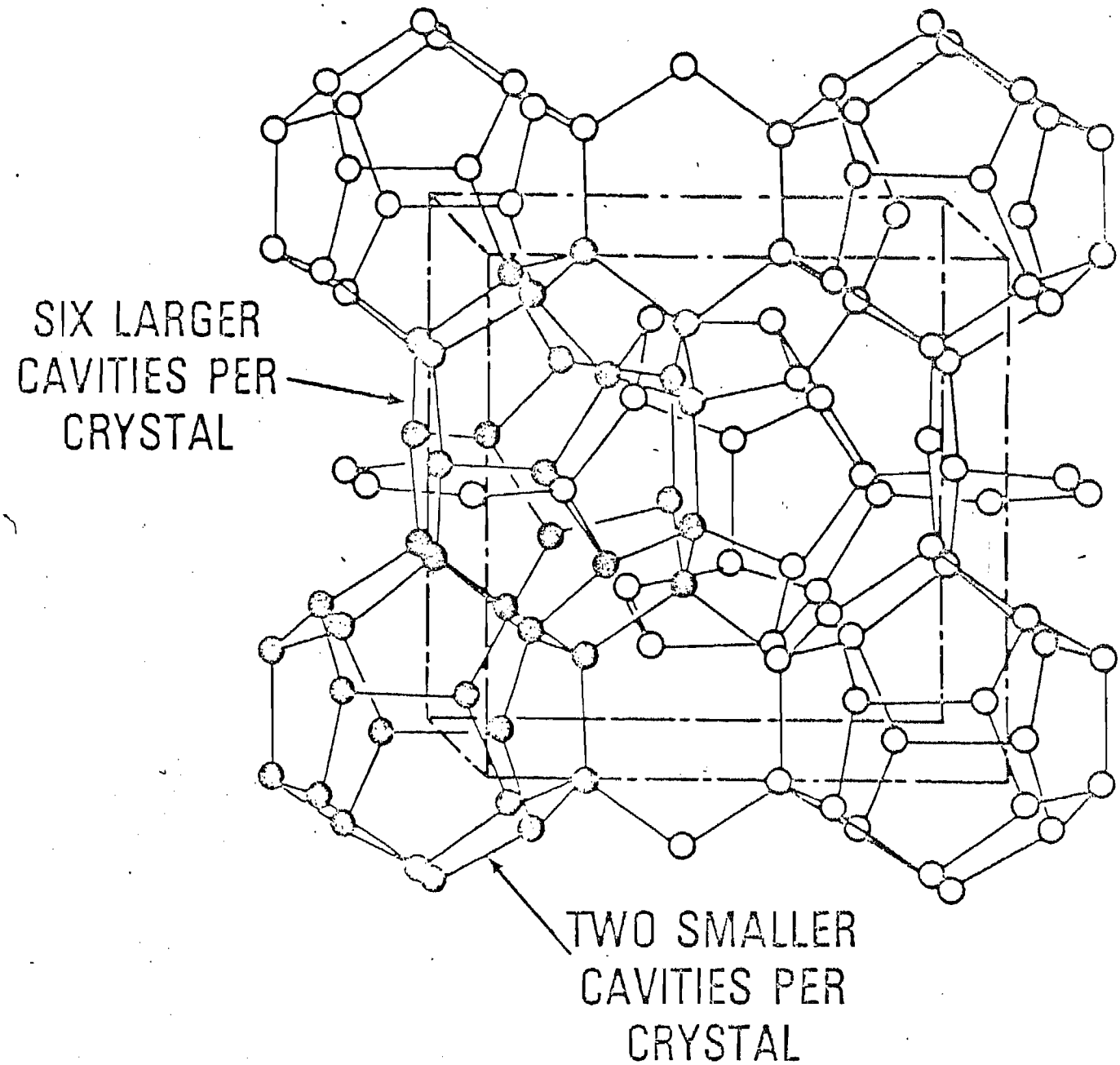
- THEY COULD EXIST AS CRYSTALS FILLING POROSITY IN CONSOLIDATED OR UNCONSOLIDATED SANDSTONES.





BRIAN HITCHON

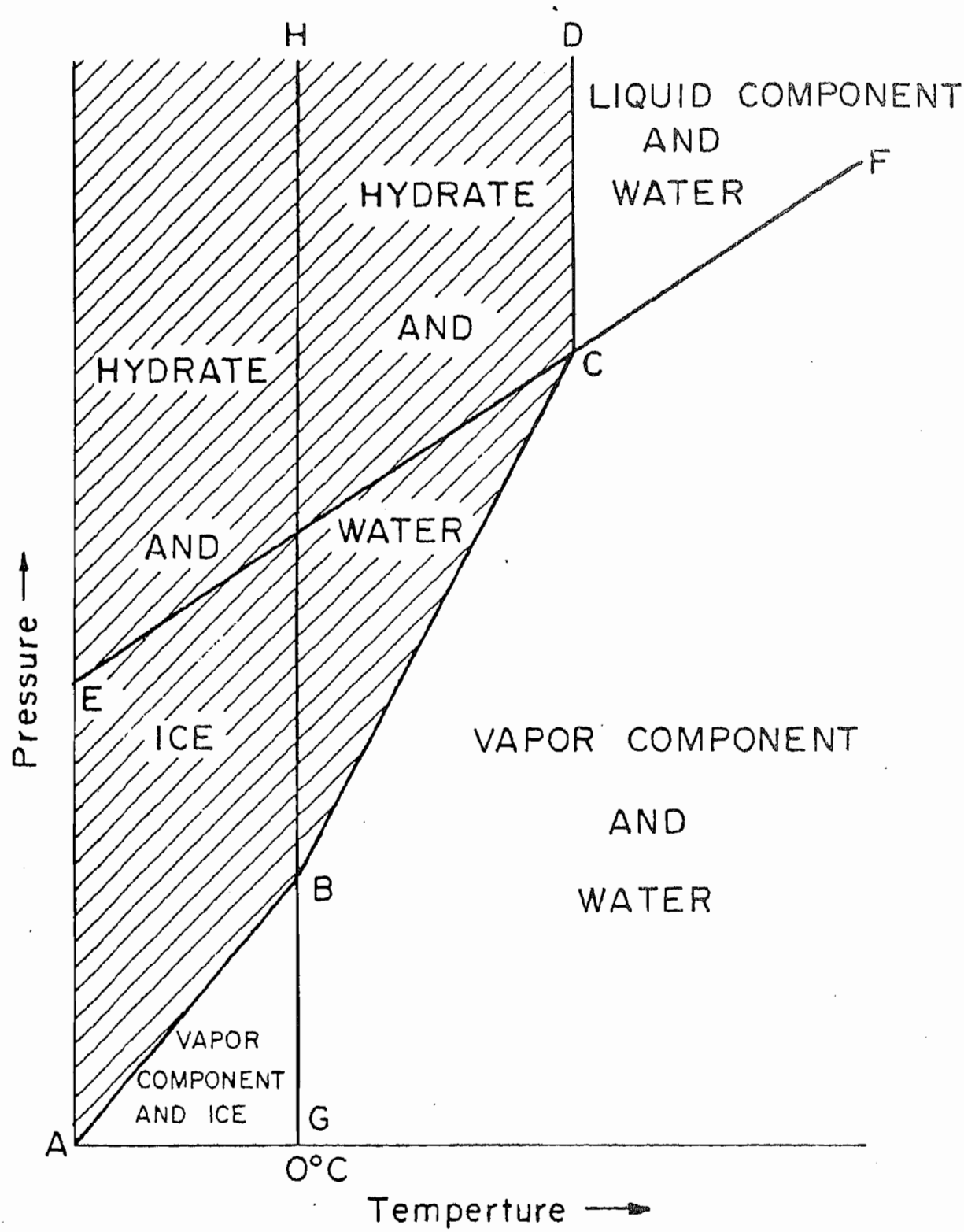
GAS HYDRATES ARE SOLID, ICE-LIKE CRYSTALLINE LATTICES OF WATER MOLECULES WITHIN WHICH GAS MOLECULES ARE PHYSICALLY TRAPPED.



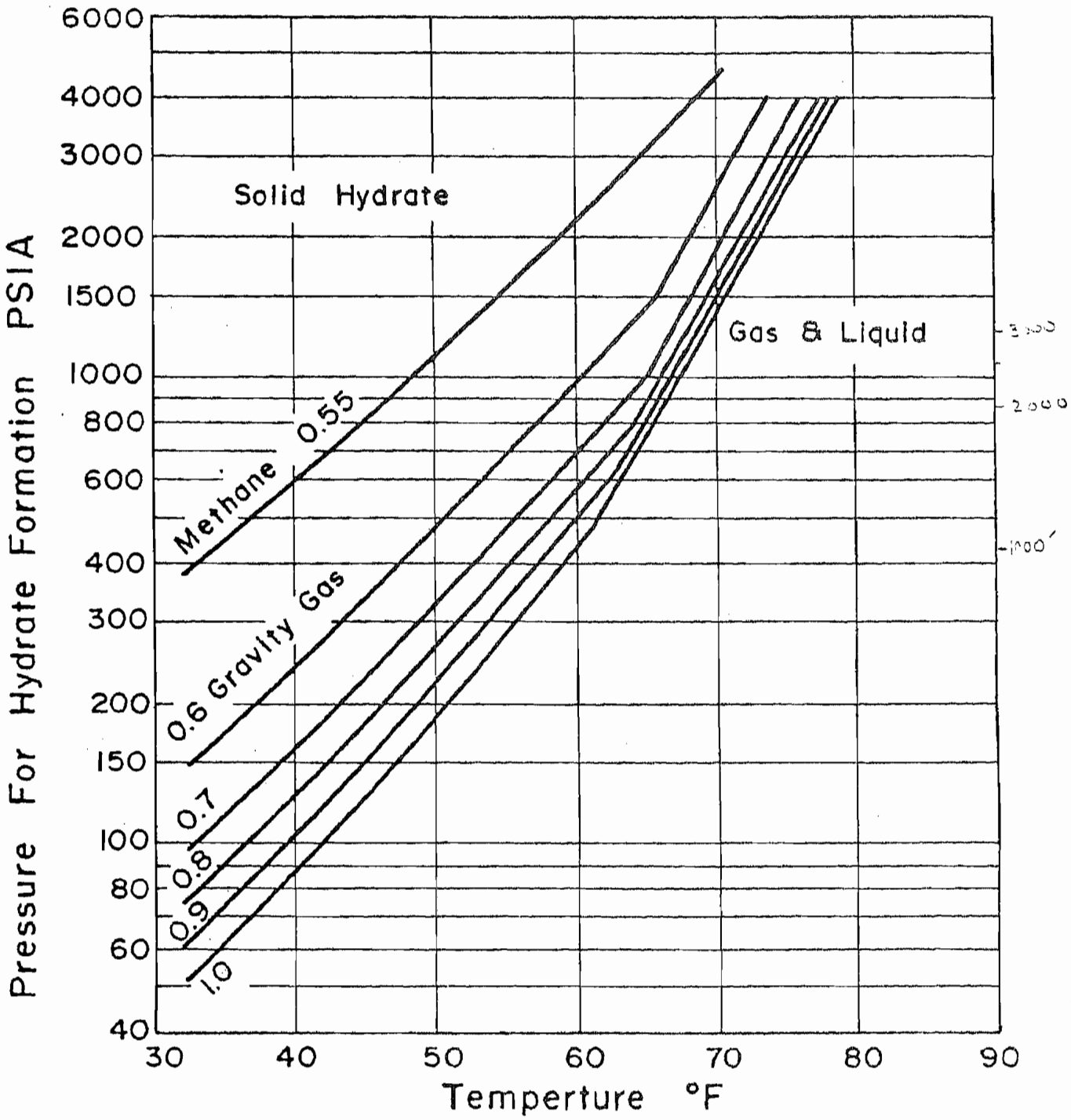
FROM G. R. HOLDER, 1

CONDITIONS REQUIRED FOR HYDRATE FORMATION

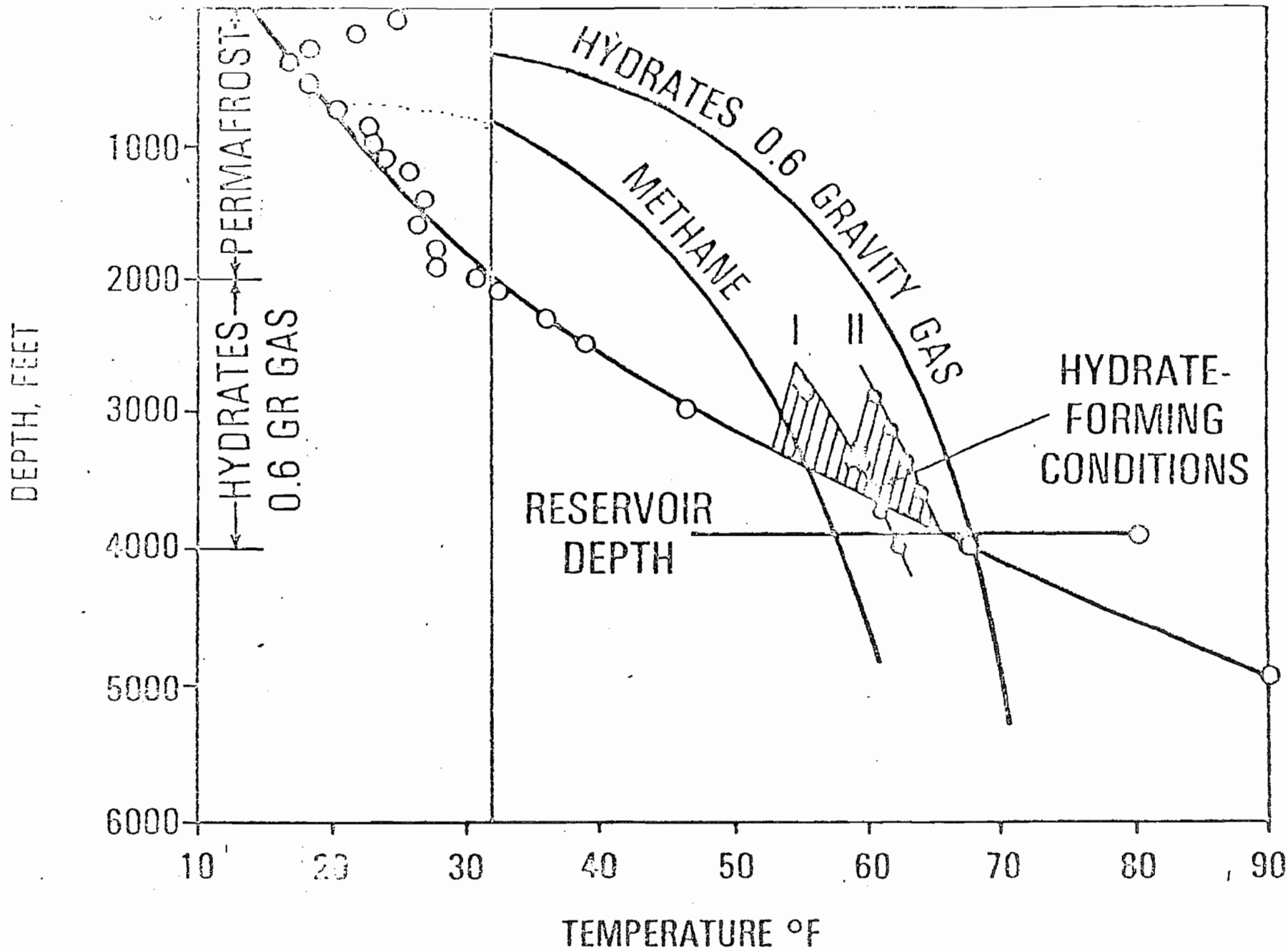
- LOW TEMPERATURES
- HIGH PRESSURES
- WATER
- LIGHT NON-POLAR GAS(ES)



FIELDS OF HYDRATE FORMATION
(WILCOX et. al., 1941)



GAS HYDRATE FORMATION CONDITIONS



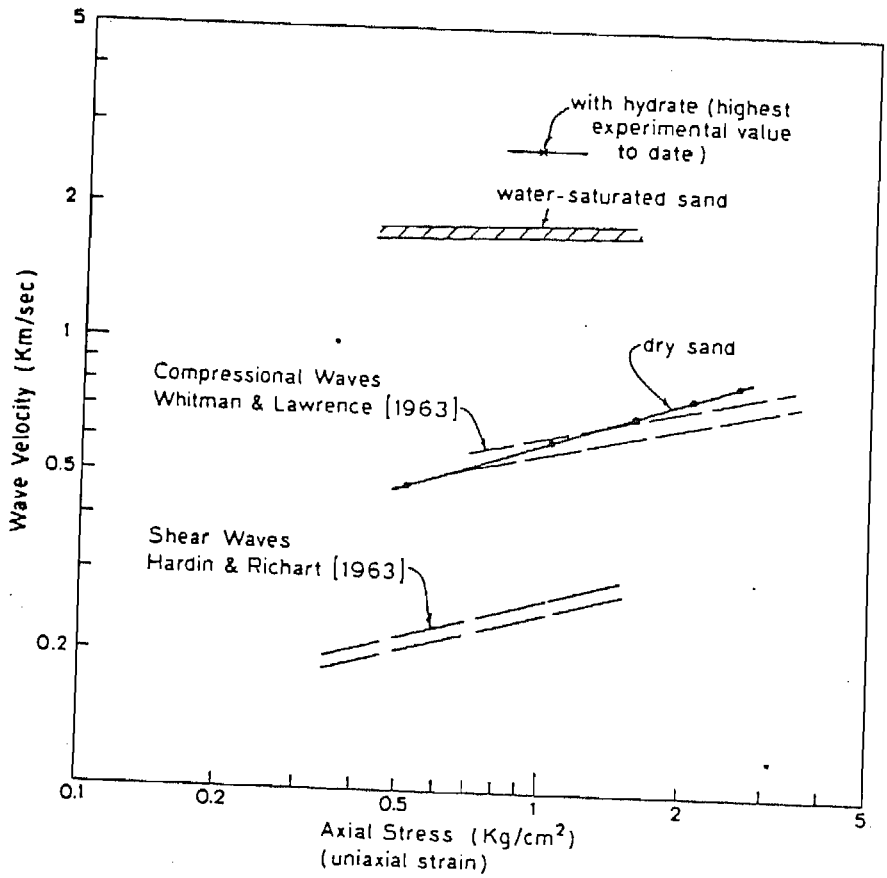
FROM G.R. HOLDER, 1979

CHARACTERIZATION OF HYDRATES

- HYDRATES EXHIBIT HIGH WAVE VELOCITIES COMPARED TO DRY OR WET SAND.

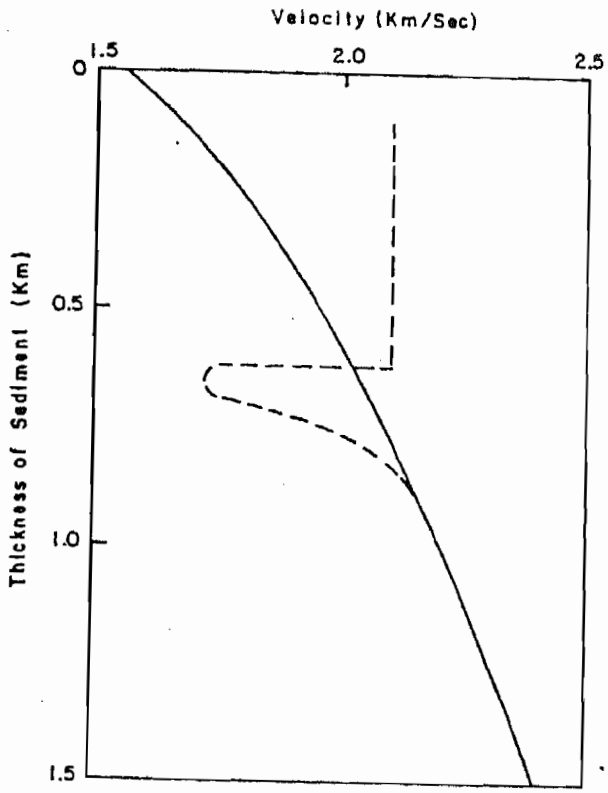
- APPARENT LOG RESPONSES (BILY AND DICK) ARE RELATIVELY HIGH RESISTIVITY AND LOW SP WITH CYCLE SKIPPING ON SONIC LOG. MUD LOG HAS HIGHGAS CUT -- ALL ARE INDIRECT INDICATIONS OF HYDRATES.

EFFECTS OF GAS HYDRATES IN SEDIMENTS



Wave velocity in sediment for various conditions

GEORGE M. BRYAN



Typical velocity profile (solid line) and hypothetical modification of it (dashed line) by the presence of hydrate in the upper 600 meters and accumulation of gas at 600 meters.

APPRAISAL OF HYDRATES

- PURE METHANE HYDRATES COULD HAVE AS MUCH AS 170 FT^3 OF CH_4/FT^3 OF HYDRATE.

- SINCE MOST CONNATE WATER CONTAINS NACL AND CACL, THE CH_4 SATURATION WILL BE REDUCED AND TOTAL GAS CONTENT REDUCED ACCORDINGLY.

- IT IS LIKELY THAT MOST HYDRATES IN THE ARCTIC SLOPE REGIONS OF ALASKA AND CANADA WILL BE IN UNCONSOLIDATED SANDSTONES OF 20 TO 30% POROSITY -- MEANING A FURTHER REDUCTION IN CH_4/FT^3 OF RESERVOIR ROCK.

- HYDRATE ZONES WITH THICKNESSES OF 400 TO 600 M ARE POSSIBLE NEAR PRUDHOE BAY ACCORDING TO KATZ (1971).

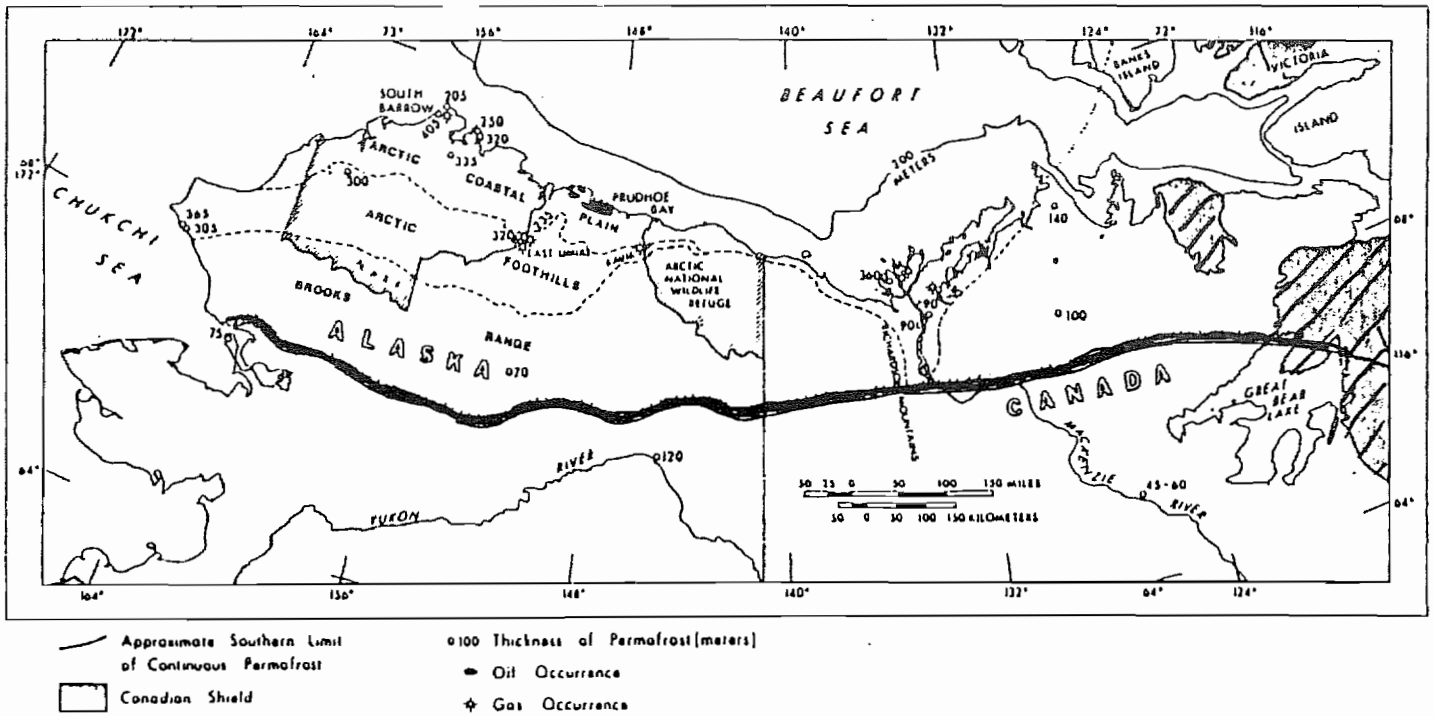
- IF PERMAFROST IS A REQUIREMENT FOR THE DEVELOPMENT OF NATURAL GAS HYDRATES, ALASKA HAS 1.5×10^6 KM^2 (APPROXIMATELY 580,000 SQUARE MILES) WHERE HYDRATES MIGHT BE DEVELOPED.

- ARCO-WEST SAK RIVER FIELD WHERE RESERVOIR PRESSURE IS SO LOW 18° API OIL WILL NOT FLOW TO SURFACE IS BELIEVED TO BE RESULT OF DEPLETION OF GAS CAP THROUGH HYDRATE FORMATION.

APPRAISAL CONT.

- PROPER APPRAISAL CANNOT BE MADE UNTIL THE HYDRATES ARE CHARACTERIZED AS TO TYPE, THICKNESS, LOG-CORE CORRELATED RESPONSES FOR EVALUATION.

- MAPPING OF THERMAL GRADIENTS, PERMAFROST REGIONS, ORGANIC SOURCE MATERIAL IN SEDIMENTARY BASINS WILL BE REQUIRED TO MAKE AN ESTIMATE OF THE POTENTIAL OF HYDRATE RESOURCE.



Oil and gas discoveries in the Arctic slope petroleum province of Alaska and the Mackenzie Delta, Canada.

EXPLORATION

- RESERVOIR MODELS IN CONJUNCTION WITH SEDIMENTATION MODELS WILL BE REQUIRED TO ADEQUATELY DEFINE EXPLORATION RATIONALES FOR LOCATION OF HYDRATE DEPOSITS.

- MAPPING OF BASE OF PERMAFROST REGIONS ON SHORE AND BSR'S OFFSHORE WILL PROVIDE CLUES WHERE HYDRATES MIGHT EXIST IN CONJUNCTION WITH PRESENCE OF RESERVOIR AND SOURCE MATERIALS.

- EVALUATION OF DRILLING DATA, PARTICULARLY MUD LOGS FOR GAS CUT ZONES AND HISTORIES OF BLOW OUTS WILL PROVIDE CLUES ABOUT POTENTIAL HYDRATE DEPOSITS.

- LARGE FIELDS MAY BE FOUND DETAILED EXAMINATION OF SEISMIC DATA FOR VELOCITY AND AMPLITUDE ANOMALIES.

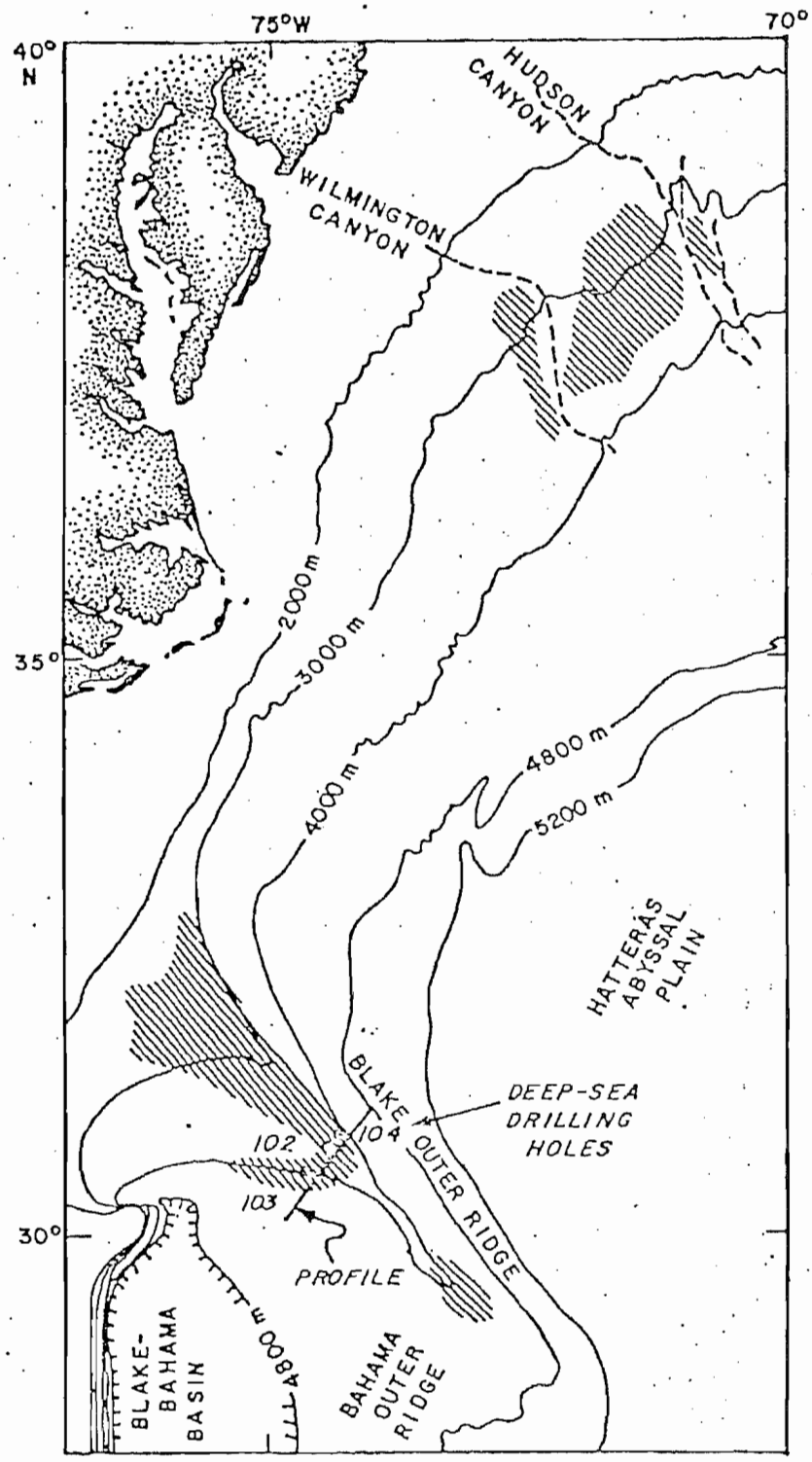


Figure 3 - Distribution of BSRs (shaded) that presumably represent gas-hydrate concentrations off the eastern U.S. Adapted from Tucholke, et (1977).

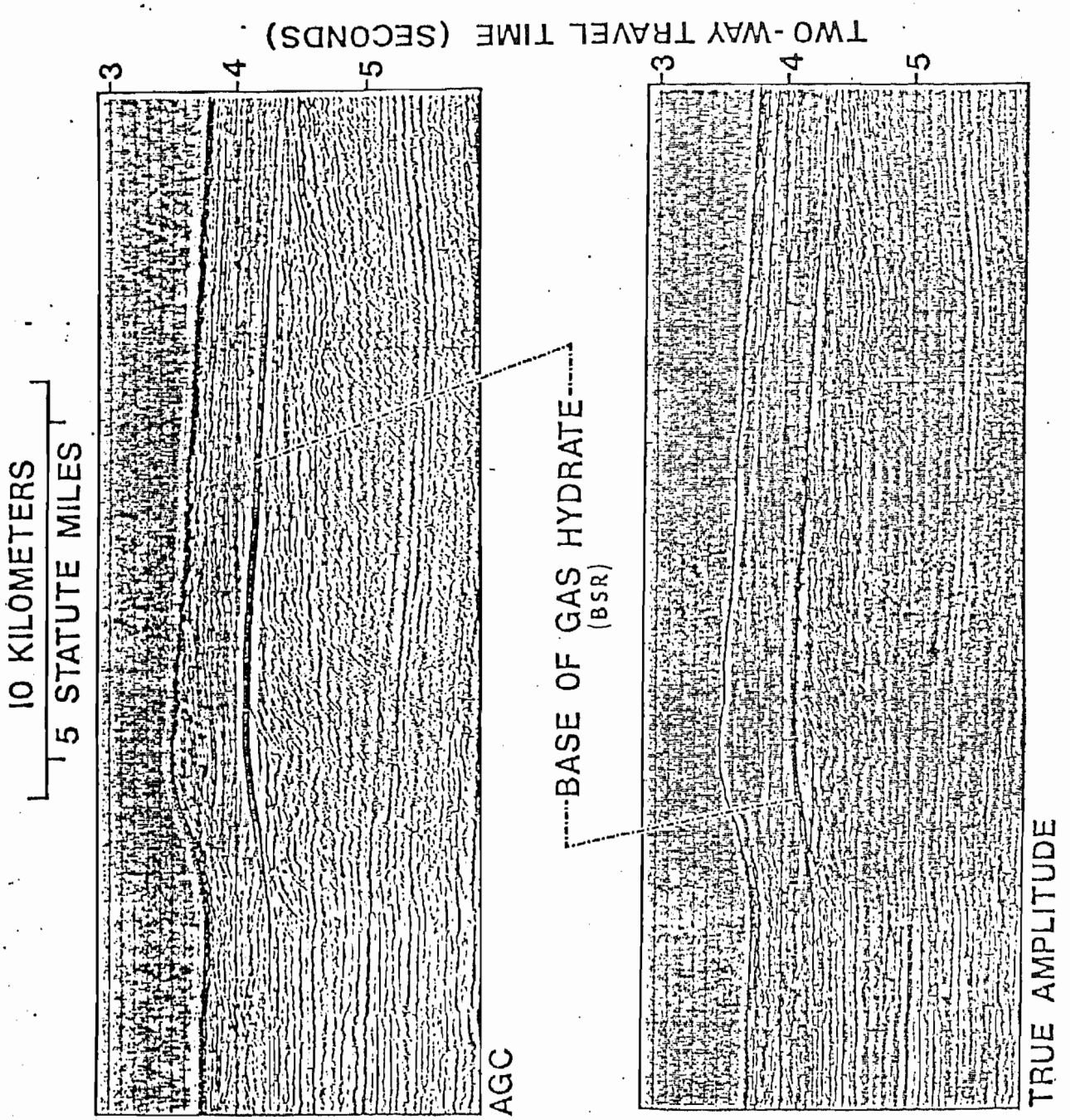
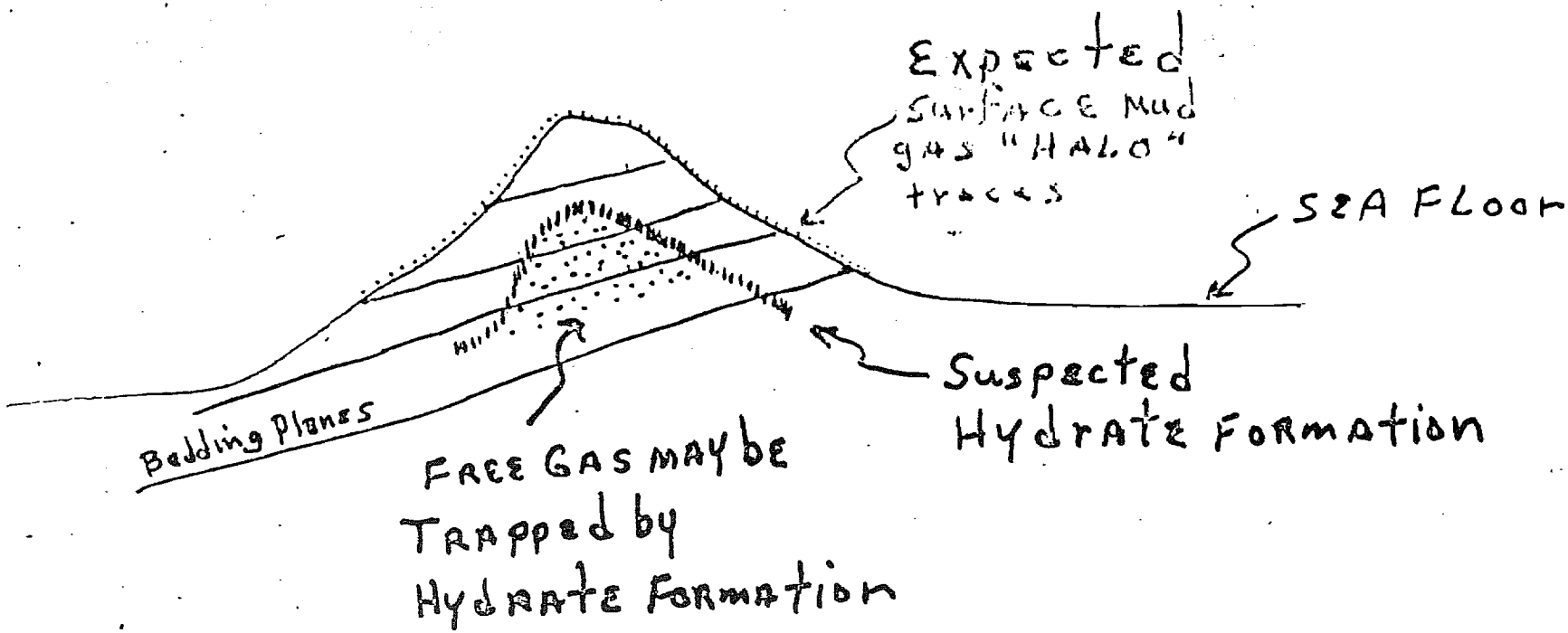


Figure 6 - Part of 36-channel seismic reflection profile along the crest of the Blake Ridge (location in Figure 5). Both sections are the same, with automatic gain control (AGC) in the recording electronics above. Note the BSR, paralleling seafloor and intersecting sedimentary reflectors. Gas hydrate formation apparently reduces amplitude of reflections above the BSR as compared to below.


Expected
Surface Mud
gas "HALO"
traces
SEA FLOOR
Suspected
Hydrate Formation
Bedding Planes
FREE GAS MAY BE
TRAPPED by
Hydrate Formation

EXPLOITATION

- RECOVERY PROBLEMS

  -- LOWERING OF TEMPERATURE DUE TO EXPANSION AND FLOW OF GAS

  -- DISSOCIATION OF HYDRATE LEAVES WATER TO BLOCK FLOW OF GAS OR FORM ICE

  -- RESERVOIR PROPERTIES UNKNOWN

  -- ENVIRONMENTAL AND SAFETY PROBLEMS NOT DEFINED

- POTENTIAL METHODS OF RECOVERY

  -- STEAM TO PRODUCE DISSOCIATION AND PROVIDE HEAT TO MAINTAIN FLOWRATES

  -- CIRCULATION OF $CACL_2$ (30%) -- METHANOL (10%) SOLUTIONS TO MELT AND DISSOLVE GAS

  -- AERIATED DIESEL FUELS OR PETROLEUM FLUIDS

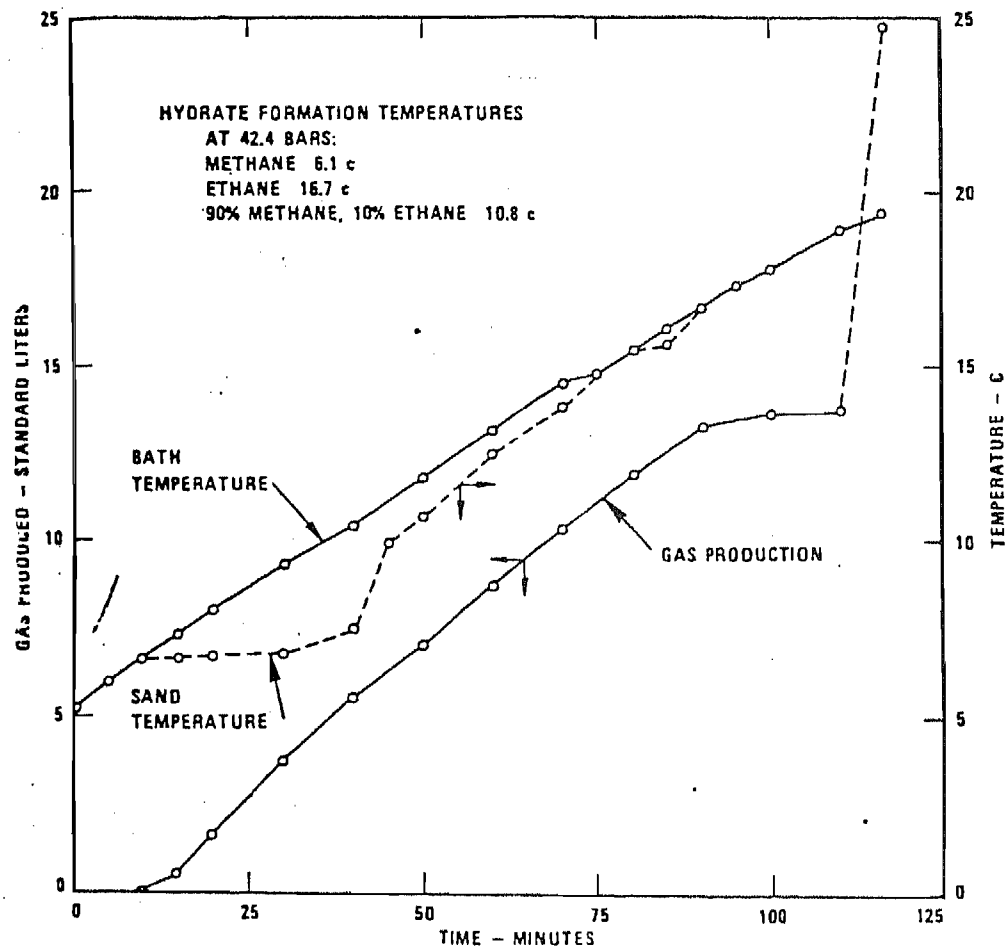
  -- BRINE-ETHANOL SOLUTIONS

  -- PRESSURE REDUCTION BELOW 380 PSI

THERMODYNAMIC REQUIREMENTS

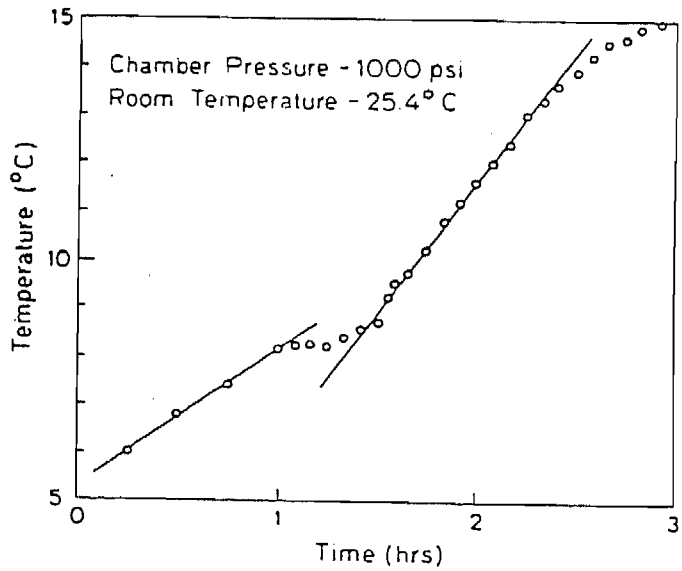
HEAT OF COMBUSTION OF THE GAS RELEASED FROM THE HYDRATES	200-230 KCAL/MOLE
LATENT HEAT REQUIRED TO PRODUCE GAS THROUGH HYDRATE DISSOCIATION	15-30 KCAL/MOLE
NET THERMODYNAMIC ENERGY GAIN	170-215 KCAL/MOLE

EXPERIMENTS ON HYDROCARBON GAS HYDRATES



Gas production from gas hydrate in unconsolidated sand by temperature increase at constant pressure.

ROBERT D. STOLL



Warming curve showing dissociation.

PRESENT STATUS OF GAS HYDRATE RESEARCH

PROGRAMMATIC

- NO CLEAR FOCUS ON R&D GOALS AND OBJECTIVES FROM A NATIONAL STANDPOINT.

- TWO WORKSHOPS IN 1979 BY GRI AND LASL INDICATE SIMILAR OBJECTIVES.

- GRI PRESENTLY LEADING EFFORT TO FOCUS ON R&D NEEDS -- DATA EVALUATION -- 20 YEAR PLAN.

- INUDSTRY INTERESTED IN SEEING R&D MOVE AHEAD.

- GRI FEELS THERE IS NO STRONG PRESSURE FOR A MAJOR PROGRAM BECAUSE THERE IS NO ALASKA PIPELINE AND NO NEED TO DEVELOP MORE GAS RESERVES IN NORTH SLOPE REGION.

- DOE HAS NO OFFICIAL POSITION BUT INTEREST IN PURSUING R&D TO DEFINE RESOURCE BASE (METC-LEAD LAB POSITION).

R&D PROGRAMS RECOMMENDED BY GRI WORKSHOPS

- DETERMINE EFFECTS OF COMPONENTS, PHASES AND IMPURITIES ON EQUILIBRIUM, PROPERTIES, KINETICS OF FORMATION, AND DECOMPOSITION (AS A FUNCTION OF PVT).

- MAKE UNAMBIGUOUS IDENTIFICATION OF HYDRATES IN PERMAFROST AND MARINE ENVIRONMENTS.

- ESTIMATE HYDRATE RESERVES FROM THE PHYSICAL ENVIRONMENT AND CONDITIONS.

- CONDUCT THEORETICAL AND COMPUTATIONAL EVALUATION OF POTENTIAL RECOVERY TECHNIQUES WITH SOME TESTING OF MORE PROMISING TECHNIQUES.

- DEMONSTRATE RECOVERY METHODS-- BENCH SCALE EXPERIMENTAL INVESTIGATIONS OF MOST PROMISING RECOVERY METHODS FOLLOWED BY PILOT SCALE TESTS.

SUGGESTED DOE ROLE

- LEAD LAB FOR UNCONVENTIONAL GAS (METC) SHOULD BECOME FOCUS FOR DEVELOPING FOSSIL ENERGY POSTURE AND STRATEGY RECOMMENDATIONS TO FOSSIL ENERGY HEADQUARTERS ON NATURAL GAS HYDRATES.

- IN COOPERATION WITH OTHER AGENCIES, DEVELOP A STRATEGY TO EVALUATE POTENTIAL OF NATURAL GAS HYDRATES AS A NATIONAL ENERGY SOURCE.

- SERVE AS INTEGRATOR-MANAGER-CATALYST THAT WOULD LEAD TO DEVELOPMENT OF A RESOURCE CHARACTERIZATION AND ASSESSMENT PLAN.

- INITIATE AND CONDUCT IN-HOUSE R&D PROJECTS ON NATURAL HYDRATE PROPERTIES VIA EXAMINATION OF HYDRATE DEVELOPMENT PROCESSES.

- UTILIZE LASL AND OTHER NATIONAL LABS TO ASSIST IN PROGRAM DEVELOPMENT AND CONDUCTING FEASIBILITY STUDIES ON OBTAINING CORES FROM THE PERMAFROST REGION.

- DEVELOP A NEAR TERM R&D PROGRAM PLAN WITH A FAST AND SLOW TRACK THAT CAN BE FOLLOWED ACCORDING TO NATIONAL NEEDS.

PROPOSED WORK BY LOS ALAMOS

OBJECTIVE: CONDUCT LABORATORY AND FIELD STUDIES TO VERIFY THE EXISTENCE OF NATURAL GAS HYDRATES IN THE PERMAFROST ENVIRONMENT AND DETERMINE PHYSICAL, CHEMICAL, AND THERMODYNAMIC PROPERTIES OF THE DEPOSIT FOR RESOURCE CHARACTERIZATION AND ASSESSMENT APPLICATIONS.

JUSTIFICATION: CONFIRMATION OF HYDRATES IN THE MOST LIKELY NATURAL ENVIRONMENT WILL ALLOW DEVELOPMENT OF METHODS OF EXPLORING FOR ECONOMIC DEPOSITS USING S-O-A TECHNOLOGY.

DEVELOPMENT OF A SOUND UNIMPEACHABLE DATA BASE RELATIVE TO POTENTIAL SIZE OF RESOURCE IS REQUIRED FOR SOUND, PROGRAMMATIC PLANNING PURPOSES.

TASK 1. CONDUCT A FEASIBILITY STUDY TO EXAMINE THE SAFETY, ENVIRONMENTAL, AND LOGISTICAL PROBLEMS WITH OBTAINING A PRESSURIZED CORE OF NATURAL GAS HYDRATES FROM THE PERMAFROST REGION OF ALASKA.

TASK 2. CONDUCT DESIGN STUDIES OF EXPERIMENTS TO BE PERFORMED ON NATURAL GAS HYDRATE CORE MATERIALS SUCH AS:

- PRESSURE, VOLUME, TEMPERATURE (PVT) RELATIONS OF THE HYDRATES, THEIR PHYSICAL PROPERTIES, SUCH AS RESISTIVITY, SONIC VELOCITY, NATURAL GAMMA RADIATION, DENSITY, STABILITY, AND RATE OF SUBLIMATION AT VARIOUS TEMPERATURES, BOTH IN THE FIELD AND IN THE LABORATORY.

TASK 4. CONDUCT SPECIAL LABORATORY TESTS ON CORE MATERIAL TO DETERMINE THE VARIOUS TYPES OF HYDRATE RESERVOIRS THAT EXIST AND TO INVESTIGATE THEIR BASIC CHEMISTRY AND PHYSICS. DATA COLLECTED SHOULD BE DIRECTED TOWARDS UNDERSTANDING THE NATURAL GAS-SEDIMENT-GROUNDWATER/SEAWATER SYSTEMS WHICH RESULTED IN THE FORMATION OF THE HYDRATE DEPOSITS. INVESTIGATE HEAT AND MASS TRANSFER DURING THE DECOMPOSITION OF THE HYDRATES FOR USE IN DESIGNING POTENTIAL RECOVERY SYSTEMS.

TASK 5. CONDUCT LABORATORY STUDIES FOR POROSITY AND PERMEABILITY MEASUREMENTS OF HYDRATES AND THEIR POTENTIAL APPLICATION TO FIELD RESERVOIR ANALYSIS TECHNIQUES.

TASK 6. INITIATE STUDIES THAT WOULD TEST IDEAS ON RESOURCE CHARACTERIZATION AND APPRAISAL EFFORTS. WITH DOE-METC, USGS, GRI, AND INDUSTRY, INITIATE A DETAILED EVALUATION OF THE HYDRATE RESOURCE POTENTIAL IN THE PERMAFROST REGIONS OF ALASKA.

LOS ALAMOS (CONT.)

TASK 7. CONDUCT STUDIES THAT WOULD ALLOW DOE TO USE DATA GENERATED IN PERMAFROST REGIONS TO BEGIN SYSTEMATIC INVESTIGATION OF MARINE HYDRATE DEPOSITS. SUCH STUDIES WOULD INCLUDE SAFETY, ENVIRONMENTAL, AND LOGISTICAL PROBLEMS THAT MIGHT BE ENCOUNTERED IN OBTAINING CORES FROM AREAS SUCH AS THE BLAKE OUTER RIDGE SUSPECTED DEPOSIT.

USGS -- WOODSHOLE OCEANIC INSTITUTE PROPOSAL

OBJECTIVE: CONDUCT A GEOLOGICAL/GEOPHYSICAL FIELD AND LABORATORY PROGRAM TO OBTAIN ADDITIONAL AND UNIQUE EVIDENCE TO VERIFY THE EXISTENCE OF GAS HYDRATES AND THEIR DISTRIBUTION BENEATH THE BLAKE OUTER RIDGE OFF THE U.S. EAST COAST MARGIN.

JUSTIFICATION: CONFIRMATION OF HYDRATES WILL PROVE THE UTILITY OF THE BSR SEISMIC PHENOMENA AS A METHOD OF EXPLORING FOR HYDRATES AND/OR FREE GAS FIELDS THAT MAY BE TRAPPED BY THE HYDRATES IN MARINE ENVIRONMENTS.

GAS HYDRATES CAN BE CONSIDERED ECONOMIC SOURCES OF GAS BECAUSE ENERGY REQUIRED FOR RECOVERY IS ONLY 5 TO 30% OF TOTAL ENERGY PRESENT. (G. HOLDER, 1979)

TASK 1. DETERMINE THE RELATION OF HEAT FLOW TO STRUCTURAL CONFIGURATION AND DISTRIBUTION OF THE BSR (BOTTOM SIMULATING REFLECTOR).

TASK 2. OBTAIN GEOCHEMICAL EVIDENCE FOR THE DISTRIBUTION OF GASEOUS HYDROCARBONS IN THE SEDIMENTS (LOOK FOR "HALO" EFFECT).

USGS -- WOODSHOLE OCEANIC INSTITUTE PROPOSAL (CONT.)

TASK 3. INVESTIGATE THE RELATIONSHIP OF SEISMIC VELOCITIES, AND WAVE AMPLITUDES TO THE INFERRED STRUCTURE TO DETERMINE THE THICKNESS OF THE HYDRATE LAYERS.

TASK 4. INVESTIGATE THE STRUCTURAL RELATIONS BETWEEN THE BSR (HYDRATE/GAS PHASE BOUNDARY) AND NORMAL BEDDING PLANES.

PRESENT STATUS OF GAS HYDRATE RESEARCH

FUNDING

	FY 80	FY 81	FY 82
GRI			
KINETIC STUDIES	75	75	--
DATA COLLECTION AND PLANNING	100	100	--
	175	175	
NSF	150	150	?
USGS	0	0	0
INDUSTRY	?	?	?
UNIVERSITIES	100?	100?	?
DOE			
OER	0	0	0
FE	(220)	( )	( )

PROPOSED BASE CASE OR MINIMAL BUDGET OUTLAY TO
SUPPORT METHANE HYDRATES

ACTIVITY	CURRENT FUNDING FY80	FUTURE FUNDING FY81	FY82	Outyears
Phase I Studies Methane Hydrate Evaluation*	220 K	1,300 K	2,000 K	300
Phase II Resource Characterization and Assessment Studies**	---	200 K	400	800
Phase III Extraction Technology Development***	---	---	100	2,000
TOTAL	220	1,500	2,500	3,100

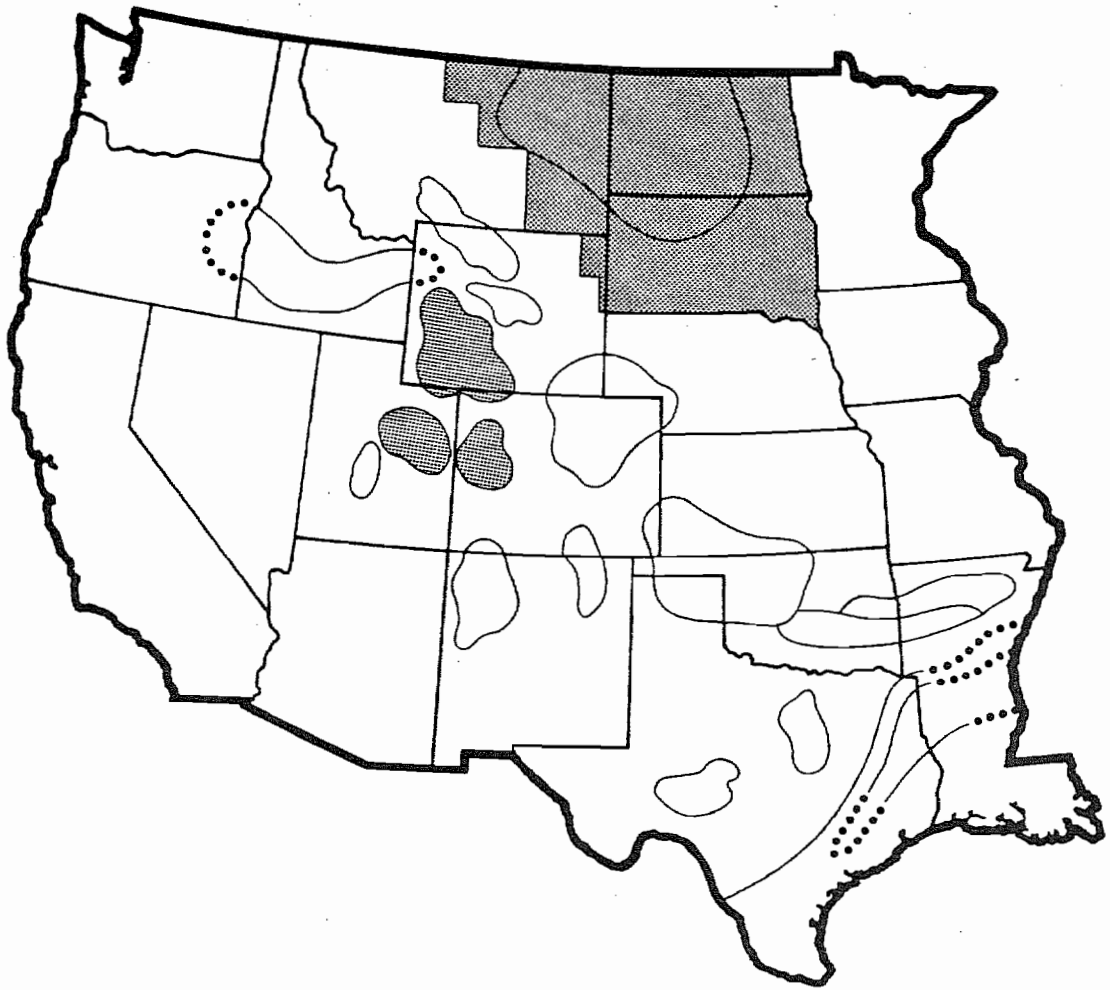
*High Phase I costs in FY81 and FY82 are for obtaining expensive pressurized cores under adverse conditions -- permafrost and marine-offshore environments.

**Phase II costs are projected as minimal based on evaluation of core material from Phase I. If additional cores are required, Phase II costs would have to be altered accordingly in FY82 and outyears.

***Phase III costs are projected based on examination of only 1 prime extraction technology approach (such as steam) in a series of laboratory studies.

Alex Crowley

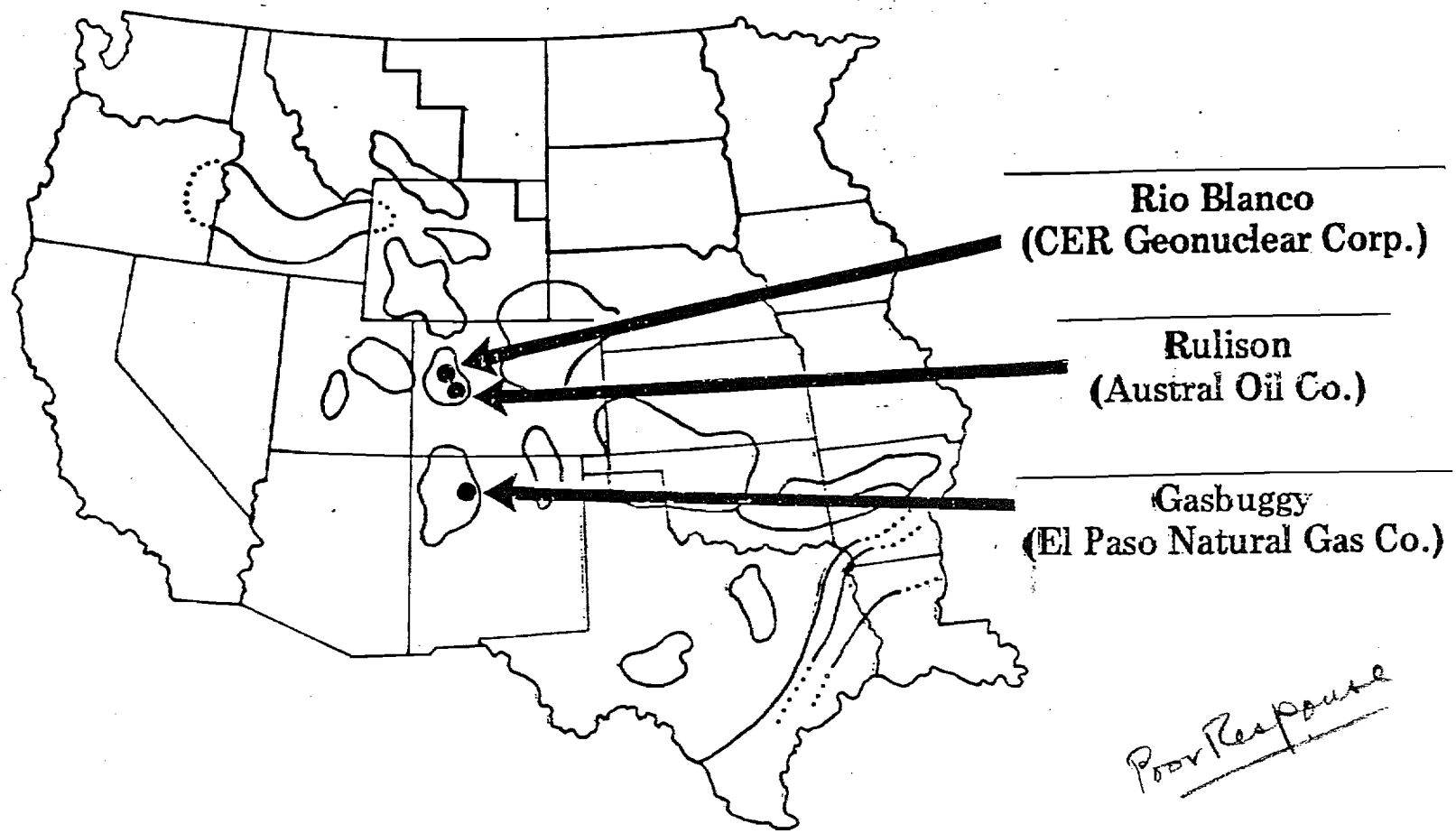
WESTERN GAS SANDS PROJECT



TIGHT GAS SAND RESERVE ESTIMATES

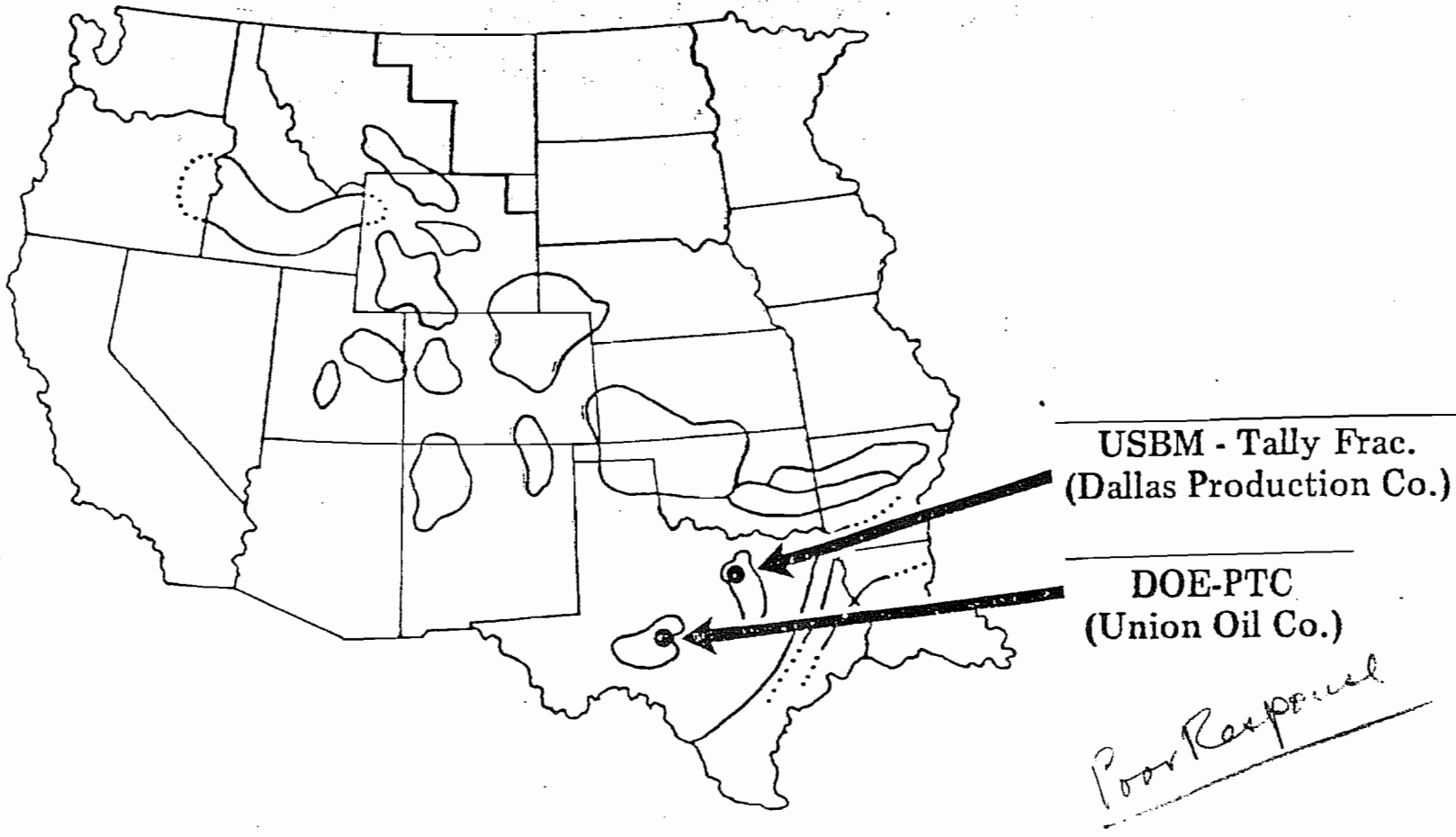
PICEANCE, UINTA, GREATER GREEN RIVER

SOURCE	GAS-IN-PLACE (TCF)	RECOVERABLE (TCF)
FPC, Nat'l Gas Survey (1976)	790	—
Lewin & Assoc. (1978)	410	210
DOE Working Group (1978)	700-1110	170-560
GRI (1979)	50-600	25-300
National Energy Plan II *(1979)*	50-420	—



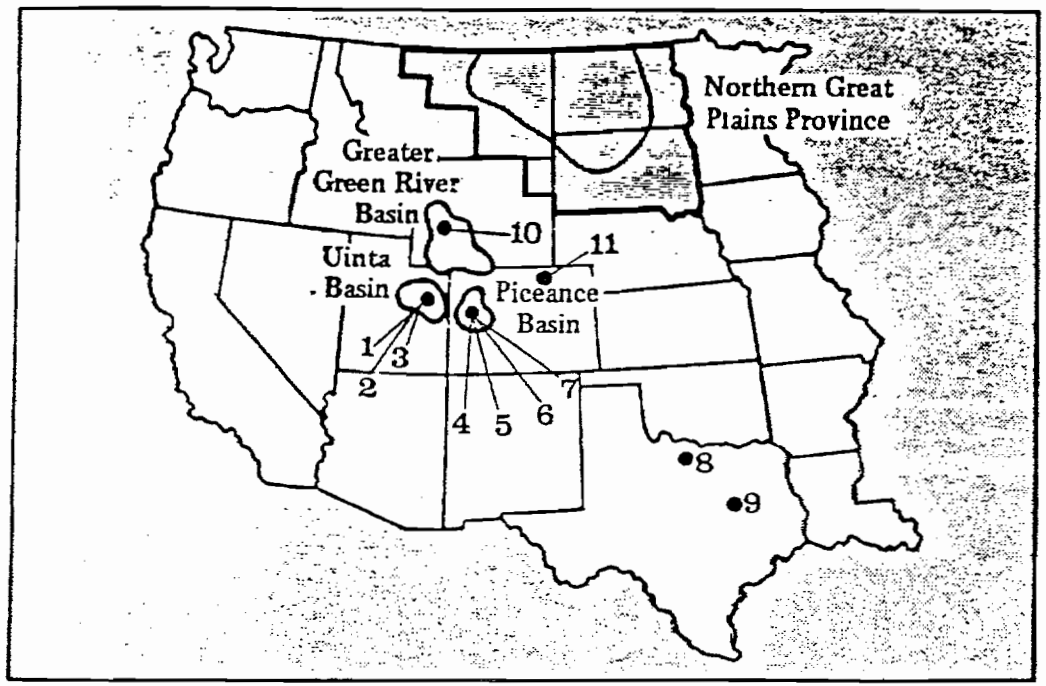
Poor Response

Tight Gas Sands, Nuclear Explosive Projects



Tight Gas Sands, Chemical Explosive Projects

MHF is best approach



Hydraulic Fracturing

1. Gas Producing Enterprises, Inc.
2. Pacific Transmission Supply Co.
3. Western Oil Shale Corporation
4. CER Corporation MHF-3
5. Rio Blanco Natural Gas Company
6. Austral Oil Company
7. Mobil Oil Company
8. Dallas Production, Inc.
9. Mitchell Energy Corporation
10. El Paso Natural Gas

Dry Gas Injection

11. Colorado Interstate Gas

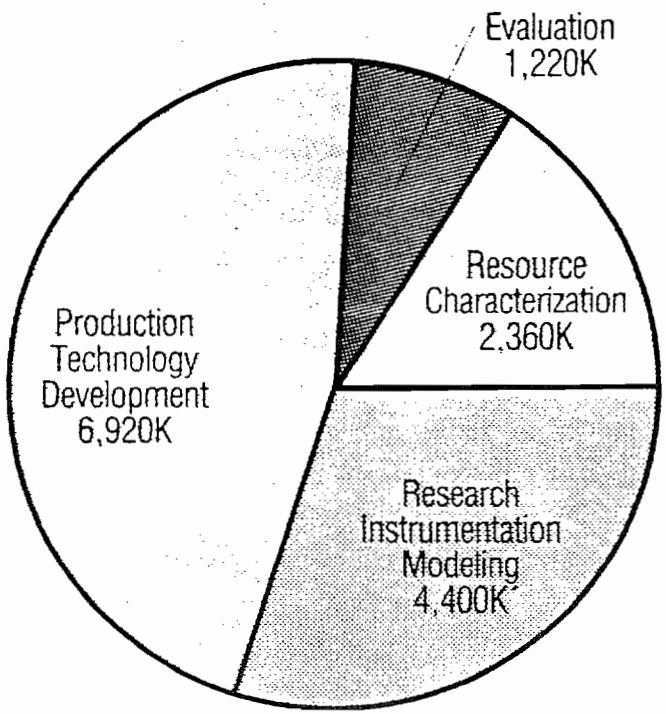
Locations of DOE/Industry Cost-Shared Single-Well Tests

OBJECTIVES

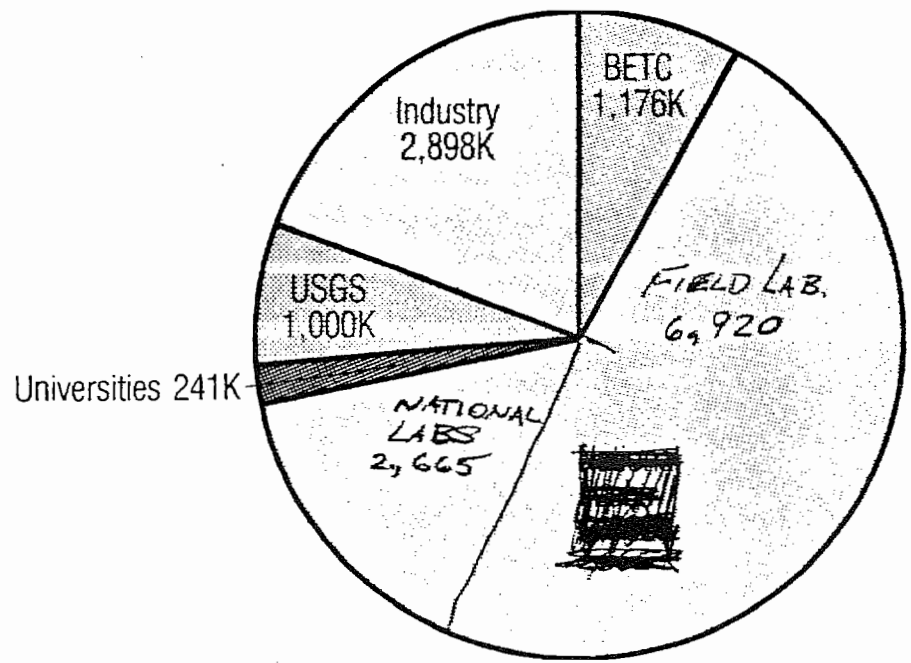
I. REDUCE THE UNCERTAINTY IN THE MAGNITUDE OF THE PRODUCIBLE RESOURCE ESTIMATE.

II. IMPROVE THE PREDICTIBILITY OF THE EXTRACTION PROCESS SUFFICIENT FOR COMMERCIAL DEVELOPMENT.

FY-80 BUDGET ALLOCATIONS



PROGRAM SEGMENT



PERFORMER TYPE

RESOURCE CHARACTERIZATION

PROBLEM:

- LITTLE DATA AND LESS CORE SAMPLES TO WORK WITH.
- THE RESERVOIRS WHERE A LARGE PERCENT OF THE GAS IS FOUND IS NOT A BLANKET TYPE THAT CAN BE CORRELATED ACROSS LARGE AREAS.

PROGRAM FY-80

° CER	CORE ACQUISITION	$500K
° CK GEOENERGY	OUT-CROP STUDIES	$200K
° USGS	RESOURCE & RESERVOIR CHARACTERIZATION	$1,000K
° OTHERS INCLUDING CONTRACTS IN PROGRESS		$660K
	TOTAL	$2,360K

ACCOMPLISHMENTS

- ELEVEN WELLS CORED TO DATE
- FIVE WELLS PER YEAR TO BE CORED
- 67 REPORTS ON GEOLOGY OF PRIORITY BASINS (PICEANCE, UINTA, GREEN RIVER AND NORTHERN GREAT PLAINS)
- OUT CROP STUDIES COMPLETED IN GREEN & WIND RIVER BASINS.

RESEARCH, INSTRUMENTATION & MODELING

FRACTURE DYNAMICS

PROBLEMS:

- PREDICTIVE CAPABILITY INADEQUATE
- FRACTURE DYNAMICS NOT UNDERSTOOD
- NO INSTRUMENTATION FOR GATHERING DATA TO PREDICT NOR ANALIZE FRACTURES

PROGRAM FY-80

°	BETC	FRACTURE CONDUCTIVITY STUDIES	$250K	
°	SANDIA	MINE-BACK EXPERIMENTS	$500K	1,000
		INSTRUMENTATION DEVELOPMENT	$615K	1,000
°	LLL	MODELS & INSTRUMENTATION	$400K	800
°	U. TULSA	PROPPANT TRANSPORT MODEL	$ 40K	
°	TERRA TEK	PROPPANT DESIGN R&D	$100K	

ACCOMPLISHMENTS

- PRIMARY PARAMETERS AFFECTING FRACTURE PROPAGATION DEFINED
- INSTRUMENTATION FOR FRACTURE ORIENTATION & LENGTH DEVELOPED
- STRESS TOOL FEASIBILITY ESTABLISHED & DESIGN INITIATED
- EFFECTIVENESS OF SEVERAL PROPPANTS INVESTIGATED

RESEARCH, INSTRUMENTATION & MODELING

RESERVOIR EVALUATION

PROBLEMS:

- EXISTING TOOLS AND INTERPRETIVE TECHNIQUES FOR POROSITY, PERMEABILITY AND WATER SATURATION NOT APPLICABLE TO THE TIGHT RESERVOIRS.

PROGRAM FY-80

° BETC	IMPROVED LOG INTERPRETATION	$ 50K
° SANDIA	LOG TOOL DEVELOPMENT	$700K
° LANSL	NMR LOG TOOL DEVELOPMENT	$400K
° TEXAS A&M	IMPROVED LOG INTERPRETATION	$ 40K
° IGT	IN SITU PERMEABILITY	$250K
° LLL	IN SITU PERMEABILITY	$ 50K
° OTHERS INCLUDING CONTRACTS IN PROGRESS		$1,005K
	TOTAL	$4,400K

ACCOMPLISHMENTS

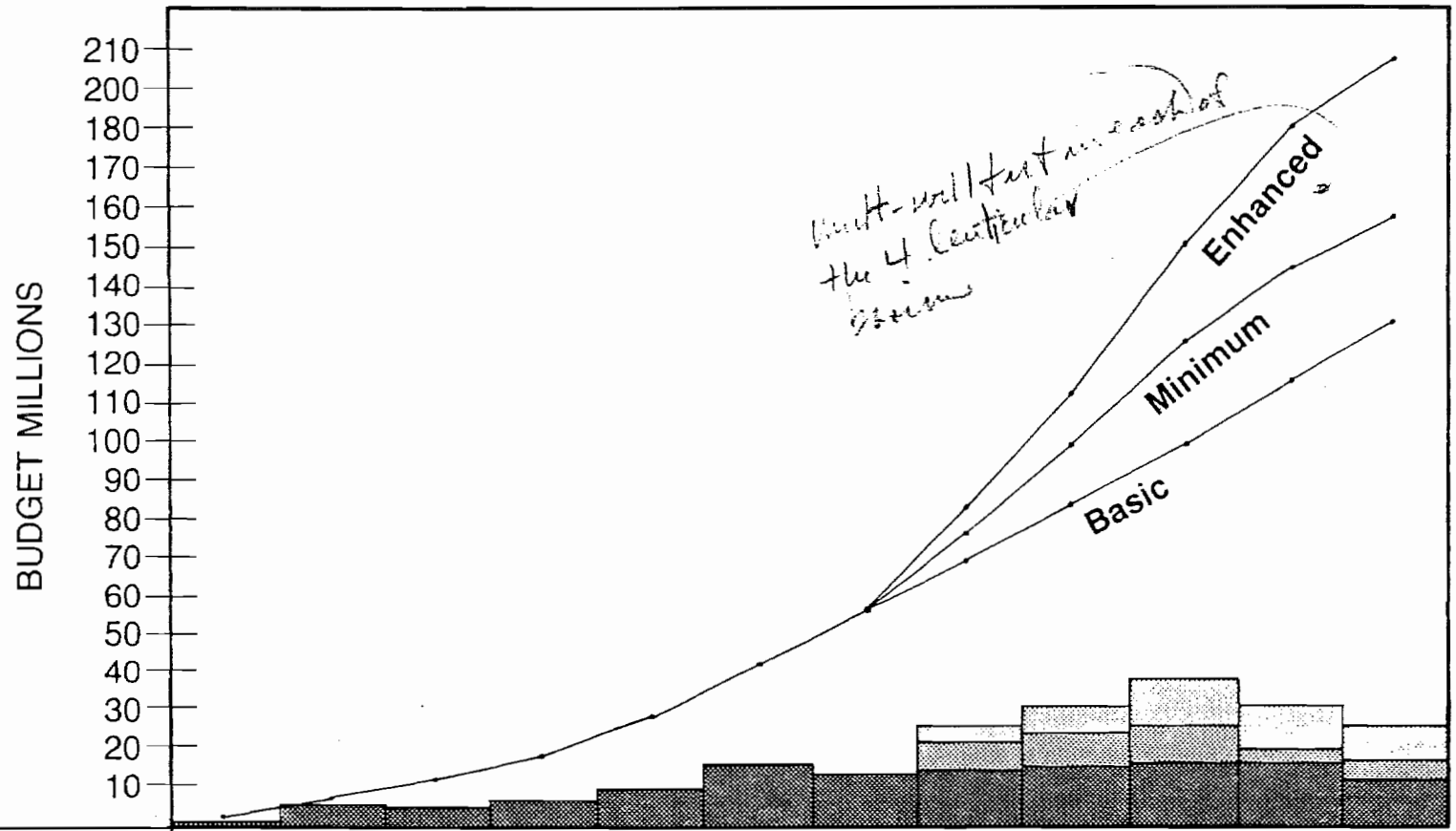
- THEORY AND FEASIBILITY SHOULD BE ESTABLISHED FOR NEW LOGGING TECHNIQUES BY FY-81.

PRODUCTION TECHNOLOGY DEVELOPMENT

- A FIELD LABORATORY WHERE INSIGHTS AND DATA PERTAINING TO ALL THE ABOVE PROBLEMS WILL BE GAINED.

- FIVE YEAR $20M EFFORT
- IMPLEMENTED BY SANDIA
- FY-80 BUDGET $6,920K
- ACCOMPLISHMENTS
  - -DETAILED PROGRAM PLAN ESTABLISHED
  - -ADVISORY GROUP FORMED
  - -IMPLEMENTATION CONTRACTS PLACED
  - -THREE SITES INVESTIGATED
- PROBLEM
  - -DELAYS IN SITE SELECTION

FUNDING PROFILE



YEAR	75	76	77	78	79	80	81	82	83	84	85	86
Actual & Basic	1.0	5.1	4.9	7.3	9.8	14.9	12.4	13.6	14.1	15.5	15.5	16.5
Minimum								20.7	23.7	26.6	18.6	12.0
Enhanced								26.6	30.6	37.9	31.0	26.6

CONCLUSIONS

- WESTERN TIGHT GAS SANDS ARE A SIGNIFICANT RESOURCE
- PROBLEMS REQUIRING R&D HAVE BEEN IDENTIFIED
- A RESEARCH PROGRAM ADDRESSING THESE TECHNOLOGIC NEEDS HAS BEEN DEVELOPED AND IS IN PROGRESS.

1 TCF now, mainly from blanket
< 3 TCF by 1990 @ $2.50/MCF
5-10 TCF by 1990 @ $5.00/MCF

Price won't bring on the production from the lenticular formations, but from blankets.
Largest part of the resource is in lenticular formations.
[illegible] in place is in lenticulars.

ADAMS

USGS WESTERN TIGHT GAS SANDS PROGRAM

RESERVOIR CHARACTERIZATION AND RESOURCE ANALYSIS

PROGRAM CHIEF: C. W. SPENCER

PROJECTS

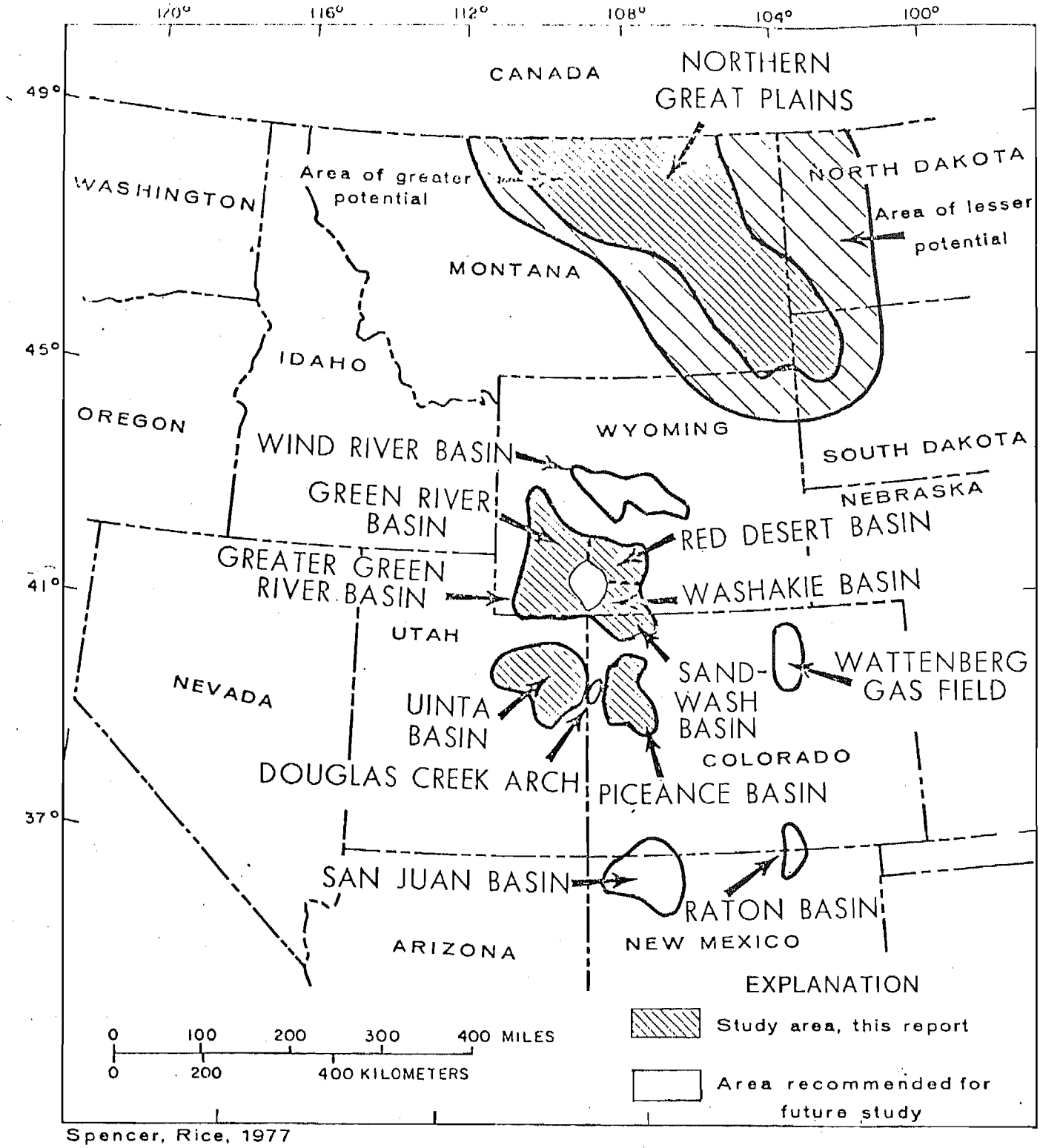
NORTHERN GREAT PLAINS: D. D. RICE

GREATER GREEN RIVER BASIN: B. E. LAW

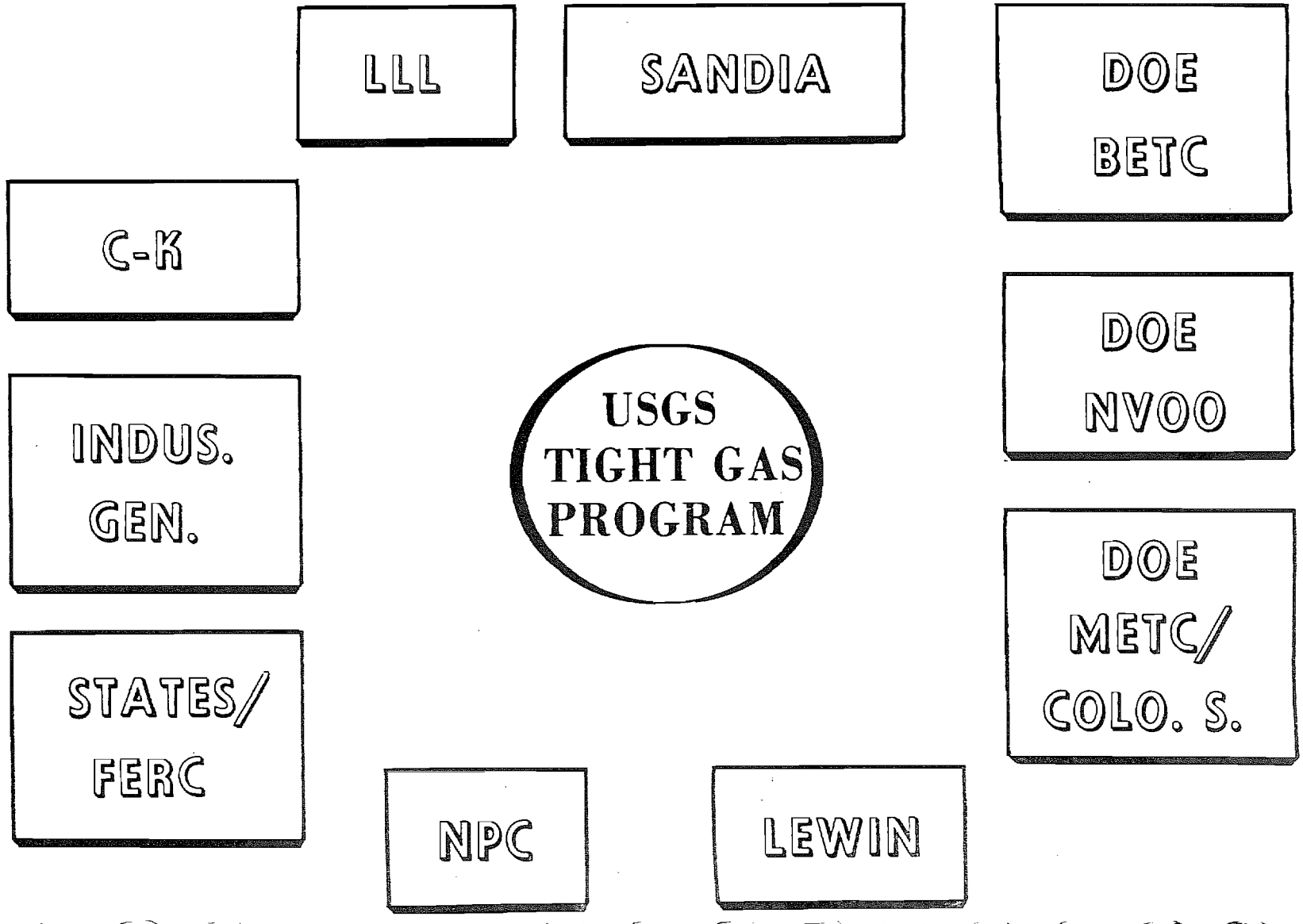
UINTA - PICEANCE BASINS: T. D. FOUCH

Bottom lines: There is more gas there by a large amount than was previously thought to be there by Lewin and others.

Porosity and Permeability dont go together in the tight gas formations. They do elsewhere!



Spencer, C. W., Fouch, T. D., and Rice, D. D., 1977, 3rd ERDA Symposium on Enhanced Oil and Gas Recovery and Improved Drilling Methods, v. 2, p. E1-E15.


LLL
SANDIA
DOE BETC
C-K
DOE NVOO
INDUS. GEN.
USGS TIGHT GAS PROGRAM
DOE METC/ COLO. S.
STATES/ FERC
NPC
LEWIN

STUDY AREAS

1) NORTHERN GREAT PLAINS
2) GREATER GREEN RIVER BASIN
3) PICEANCE AND UINTA BASINS

SCOPE OF WORK

1) STRATIGRAPHIC AND STRUCTURAL STUDIES
2) GEOCHEMICAL STUDIES
3) RESERVOIR PROPERTIES
4) CLAY MINERAL STUDIES
5) CORING PROGRAM
6) DATA ACQUISITION AND PROCESSING
7) BOREHOLE GRAVITY SURVEYS
8) RESOURCE APPRAISAL

1

STRATIGRAPHIC AND STRUCTURAL STUDIES

1) DISTRIBUTION, GEOMETRY, THICKNESS, STRAT. RELATIONS
2) STRUCTURAL FRAMEWORK RELATION TO GAS
3) PALEOGEOGRAPHY, SEDIMENTARY HISTORY, DEPOSITIONAL ENVIRONMENTS. LATERAL AND VERTICAL EXTENT OF RESERVOIRS
4) TRAPPING MECHANISMS (STRAT. AND STRUCT.) AND POSSIBLE HYDRODYNAMICS

2

GEOCHEMICAL STUDIES

1) ORIGIN(S) OF GASES
2) TIME OF GAS GENERATION AND AREA AND DEPTHS OF MAXIMUM GENERATION
3) IDENTIFY AND QUANTIFY POTENTIAL SOURCE BEDS TO ESTIMATE AMOUNT OF GAS THAT SHOULD HAVE BEEN GENERATED
4) MAP PALEOMIGRATION PATHWAYS TO IDENTIFY REGIONAL AREAS OF GAS ENTRAPMENT

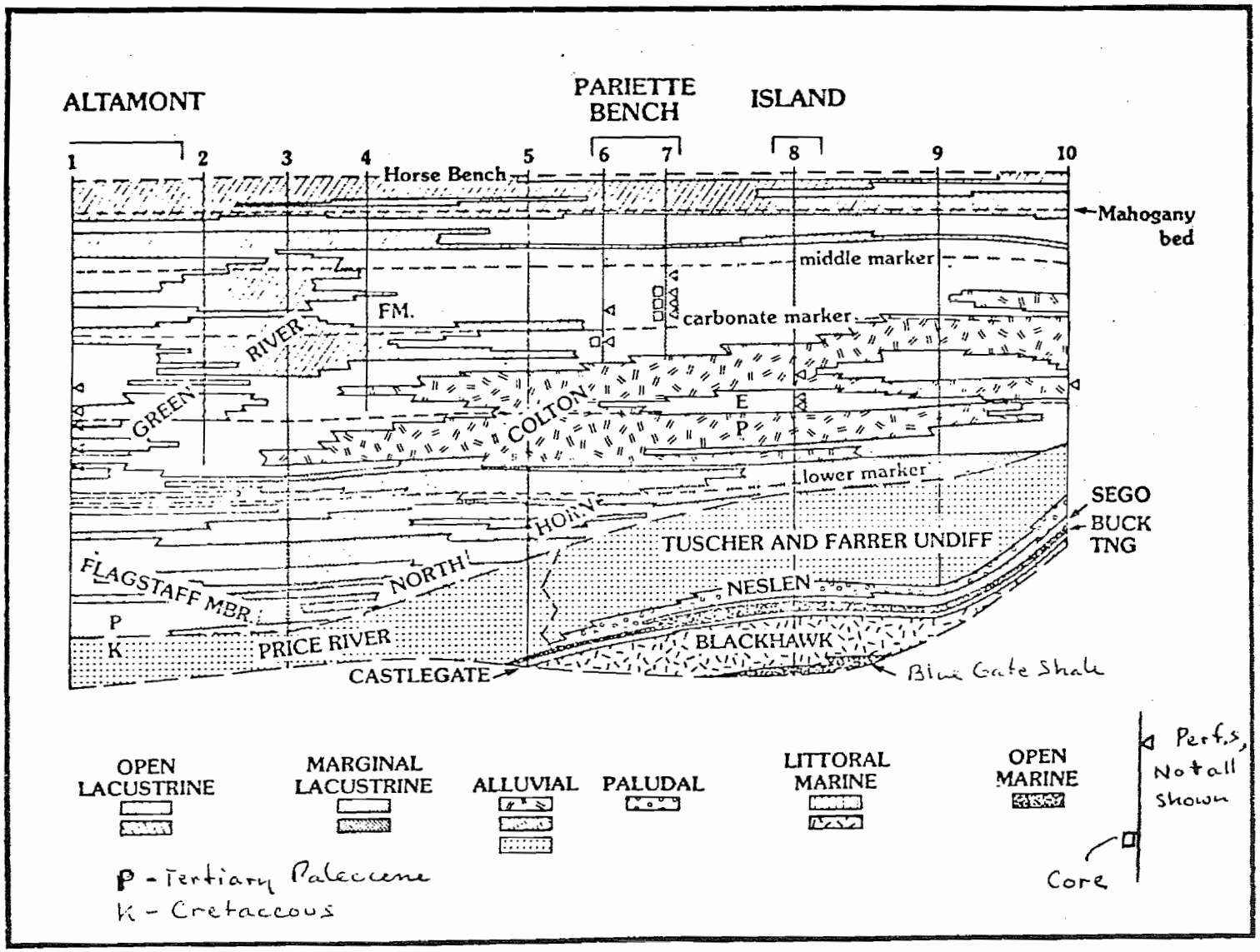


FIGURE 3-1 STRATIGRAPHIC CROSS SECTION

Reference: Fouch, T.D., Cashion, W.B., and Pitman, J.K., 1978, Western Gas Sands Project Status Report May 1, 1978, p. 8.

Interval 4. — The distribution of facies in the Niobrara, Telegraph Creek, Eagle, and equivalent units is shown in figure 12. Parallel, north-south-trending bands of nonmarine rocks and coastal sandstones in the western part of the study area reflect the proximity of the western source terrane for the Eagle Sandstone. Underlying these facies are shelf sandstones in the Telegraph Creek Formation. Shelf sandstones developed in the Eagle interval form an irregular pattern seaward of the coastal sandstones. These shelf sandstones project a considerable distance to the east in the southern part of the study area where they are equivalent to the Shannon Sandstone Member of the Steele Shale of the Powder River Basin and the Groat Sandstone Bed of the Gammon Member of the Pierre Shale of the Black Hills. Natural gas was recently discovered in South Dakota near the Montana border (McCaslin, 1978) entrapped in shelf sandstones equivalent to the Shannon. The chalk facies in the eastern study area marks the western extent of the lowest chalk tongue developed in the Niobrara Formation. Younger chalk tongues are developed to the east.

Interval 5. — Facies in the Claggett Shale, Judith River Formation, and equivalent units are distributed as shown on the map in figure 13. The facies distribution of nonmarine rocks and coastal sandstones indicates a western source area for both the Judith River Formation and Eagle Sandstone. The extent of nonmarine rocks indicates that the Judith River regression was widespread and surpassed only by the complete withdrawal of the seas during the Fox Hills regression. The eastward projections in the boundaries between facies I, II, and III suggest that deltaic sedimentation controlled their distribution, even in the shelf environment. The different pattern for coastal sandstones centralized over the Cedar Creek anticline in eastern Montana emphasizes an area of better development. The region may have existed as a submarine shoal that resulted in the winnowing of sands during Judith River deposition. Impure chalks correlative with the Judith River Formation are developed east of the study area.

WESTERN CANADA ANALOG

Shallow, tight reservoirs of Cretaceous age have been known to be gas-bearing in western Canada since the 1880's when a well being drilled for water in Alberta encountered natural gas in the Milk River Formation. The well-known Medicine Hat field, which straddles the Alberta-Saskatchewan border and lies about 75 mi (120

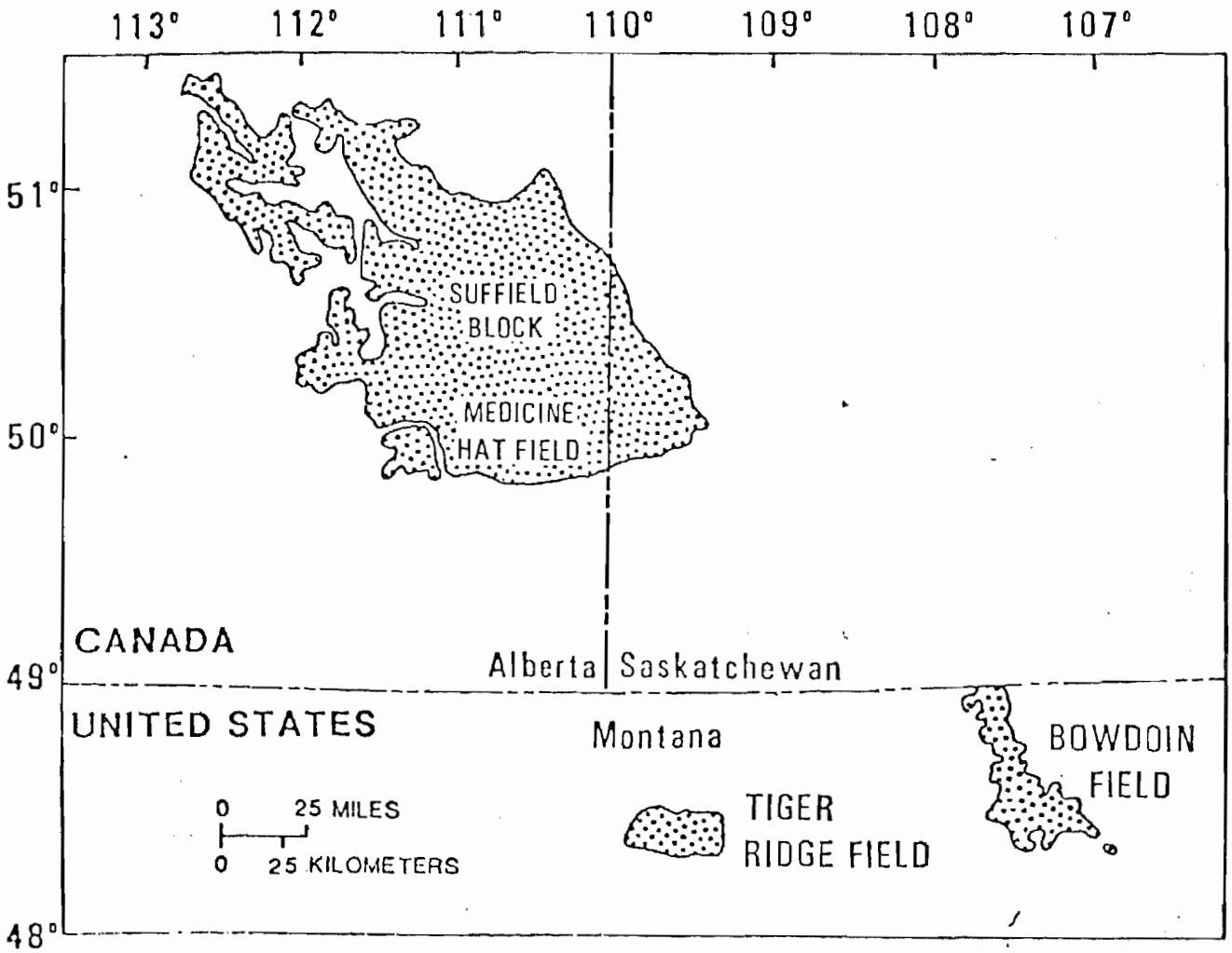


FIGURE 14

Map showing distribution of shallow gas fields (stipple) in north-central Montana, southeastern Alberta, and southwestern Saskatchewan. Bowdoin field and large area in Canada produce from low-permeability reservoirs. Tiger Ridge field produces from structural traps of conventional reservoirs.

Reference: Rice, D.D. and Shurr, G.W., 1978, Potential for major natural gas resources in shallow, low-permeability reservoirs of the northern Great Plains: Montana Geol. Soc. Guidebook 24th Ann. Conf. Williston Basin Symposium, p. 267-271.

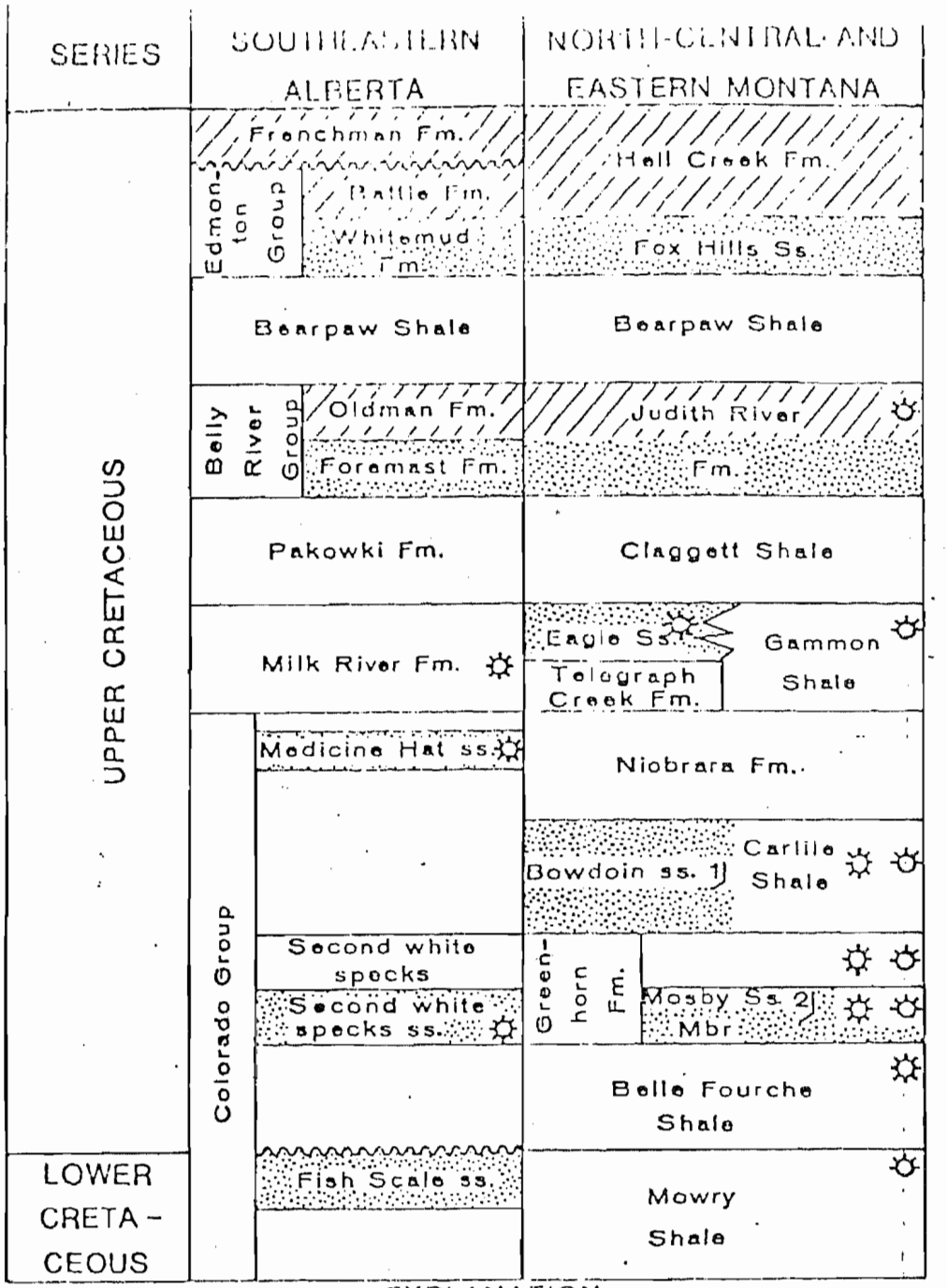


Figure 2.--Stratigraphic chart showing correlation of selected Upper and Lower Cretaceous rocks currently producing natural gas, and intervals with potential for gas production from tight reservoirs in the northern Great Plains.

Reference: Spencer, C. W., Fouch, T. D., and Rice, D. D., 1977, 3rd ERDA Symposium on Enhanced Oil and Gas Recovery and Improved Drilling Methods, v. 2, p. E1-E15.

below this cutoff. Second, resistivity determinations are good only for a small area where the uniformity of logs can be maintained and the results can be calibrated to core and production test data. Finally, the resistivity values can only be used to calculate "relative" net pay because many of the beds are less than 1 ft. (305 mm) thick and are averaged out over a 5 ft. (2 m) interval.

Based on resistivity mapping and indicated production from 77 widely spaced wells, gas reserves in the Suffield Block were assigned to each of the productive Upper Cretaceous units — Second white specks, Medicine Hat, and Milk River. The Lower Cretaceous Bow Island Formation and Glauconitic Sandstone of the Manville Group were also evaluated, but they contain conventional reservoirs. The Suffield Block was assigned a gas-in-place reserve figure of 3,533 billion cubic feet (Bcf) for the three Upper Cretaceous units and a recoverable sales gas figure of 2,555 Bcf (Suffield Evaluation Committee, 1974). The breakdown of reserves for individual units is shown on table 1. Over the entire productive area of Alberta and Saskatchewan, recoverable reserves average as much as 2 Bcf per sq. mi. This figure is lower than that existing for the Suffield Block because of the various states of technology and gas prices which existed when the gas was developed. Using these reserve data as an analog, the northern Great Plains study area could contain resources of natural gas in excess of 100 trillion cubic feet. The volume of recoverable gas will be dependent on the development of recovery technology and on the increase of gas prices.

The closest production from similar, low-permeability reservoirs in the northern Great Plains study area comes from the Bowdoin field in north-central Montana, located more than 110 mi. (180 km) southeast of the Suffield Block (fig. 14). Natural gas was originally discovered in 1913 when shallow water wells were drilled (Perry, 1960). Development drilling, which took place through the 1950's,

TABLE 1
Gas reserves of the Suffield Block, Alberta (in Bcf)
Data from Suffield Evaluation Committee (1974)

	Sales Gas	In Place
Milk River equivalent	1,993	2,790
Medicine Hat Sandstone	405	501
Second white specks sandstone	157	242
Total	2,550	3,533

was centralized over the main part of the structure. The field, at that time, covered an area of 200 sq. mi. (520 sq. km), and most of the wells were natural, open-hole completions at depths ranging between 800 and 1,000 ft. (240-300 m). With the advent of improved production technology in the 1970's, the field was extended north to the Canadian border and was expanded in size to as much as 600 sq. mi. (1,600 sq. km). The reservoirs in this expanded area are lower in permeability and occur at depths ranging between 1,200 and 1,800 ft. (110-550 m). Details of this recent development and production are given in Rounds (1977).

The productive intervals in the Bowdoin field are shelf sandstones developed in the upper Belle Fourche Shale and Mosby Sandstone Member of the Greenhorn Formation (the Phillips sandstone of subsurface usage) and in the Carlile Shale (the Bowdoin sandstone of subsurface usage) (fig. 15). A thin chalk facies in the upper Greenhorn Formation also produces natural gas. The Martin sandy zone, which occurs in the Niobrara Formation, tested gas on the original discovery well, but did not yield commercial quantities of gas. The correlation of units and production data for typical wells in the Bowdoin field area are illustrated on figure 17. Two items are worth noting on this cross section. First, intervals similar to the productive units are present throughout the Mowry through Gammon sequence. Second, some of the wells are dry holes be-

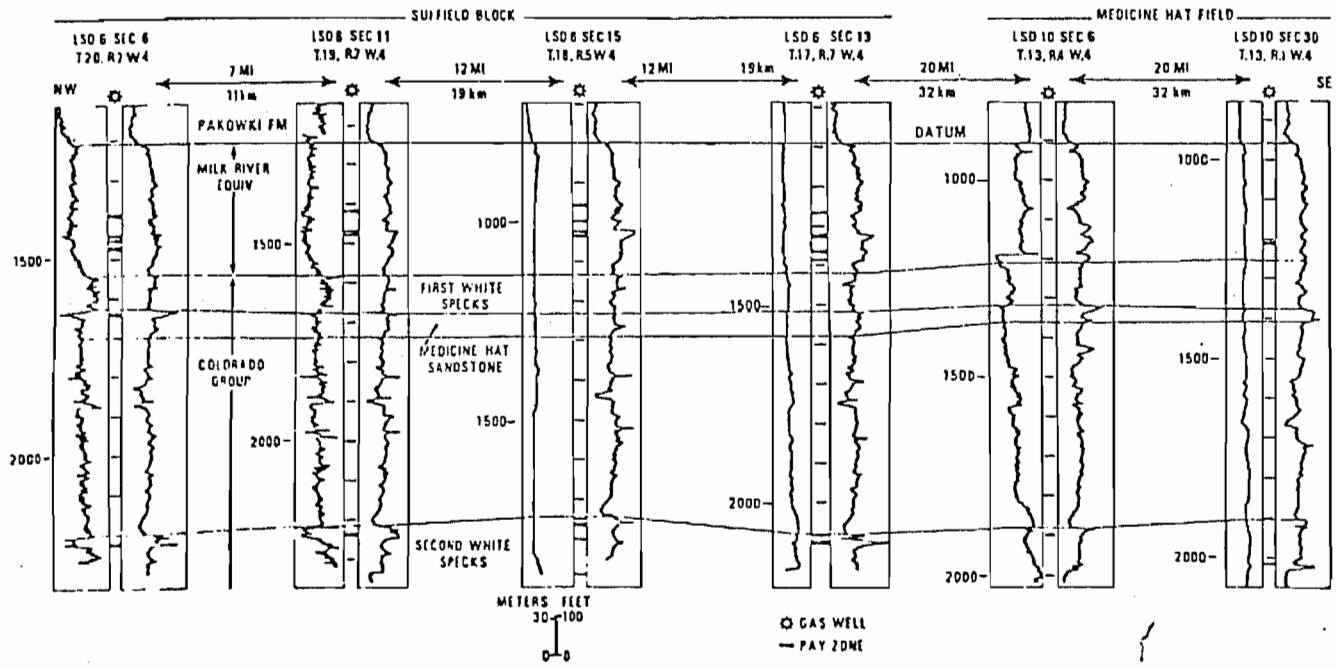


FIGURE 16

Gamma ray and electric log cross section through Suffield Block and Medicine Hat field in southeastern Alberta showing correlation of lower Upper Cretaceous rocks and pay zones. Scale for all resistivity logs is 0-20 ohms m²/m. Datum is top of Milk River equivalent. Depths shown as feet below Kelly bushing.

Reference: Rice, D.D. and Shurr, G.W., 1978, Potential for major natural gas resources in shallow, low-permeability reservoirs of the northern Great Plains: Montana Geol. Soc. Guidebook 24th Ann. Conf. Williston Basin Symposium, p. 267-271.

because the operators were not experienced in completing gas wells in tight reservoirs and because some of the wells were drilled when gas prices were much lower and, therefore, were noncommercial.

SUMMARY AND CONCLUSIONS

Potential major resources of natural gas are entrapped in tight reservoirs of Cretaceous age at depths less than [illegible] ft. (1,200 m) in the northern Great Plains. The study area, as restricted for this report, is situated in eastern Montana, western North and South Dakota, and northeastern Wyoming and covers an area of approximately 120,000 sq. mi. (310,000 sq. km). Because the reservoirs are low in permeability and pressure, the resulting natural gas production will be at low daily rates on an individual well basis. Owing to the widespread distribution of the reservoirs, the development of this type of resource should result in significant additions to natural gas reserves providing that improvements in recovery technology and increases in gas prices occur. The following points are considered particularly relevant:

1. Prospective low-permeability gas reservoirs range in age from late Early Cretaceous to Late Cretaceous and include most of the section from the base of the Mowry Shale to the top of the Judith River Formation and equivalents.
2. Six facies, each of which has distinctive reservoirs, can be distinguished throughout the study area. Tight reservoirs in the shelf sandstone, siltstone, and chalk facies have the best potential for gas production. The siltstone and shale facies are considered together at this time because conventional logs can not differentiate the two rock types. When facies maps for the five study intervals are combined, facies with potential tight reservoirs occur throughout most of the study area.
3. Natural fracturing may play an important role in the economic development of the low-permeability reservoirs, particularly in the shale facies. The shale facies is the major source rock for the natural gas in the study area, and also may be a reservoir if commercial flows of gas can be attained. Paleomovement along lineaments may be a mechanism for the development of fractures concentrated in zones along the lineaments. Lineaments may have the additional effect of partially controlling the distribution of facies, particularly in the shelf environment.
4. Shallow gas, which consists chiefly of methane, is generated by biological processes at shallow depths in accumulating sediments and is referred to as biogenic gas. This type of gas is widespread and accumulated in significant quantities.
5. The development of an extensive shallow gas accumulation from tight Upper Cretaceous reservoirs in western Canada serves as a model for understanding and developing the natural gas resources in the U.S. portion of the northern Great Plains. Using western Canada as an analog, the study area may contain resources in excess of 100 Tcf of natural gas.

In conclusion, the geological characterization of low-permeability gas-bearing reservoirs is essential for the development of potential major natural gas resources in the northern Great Plains. Research on petrography, clay mineralogy, organic geochemistry, detailed subsurface mapping, paleoenvironmental interpretation, and lineament analysis will assist in characterizing the reservoirs, improving the recovery technology, and refining the estimates of natural gas resources.

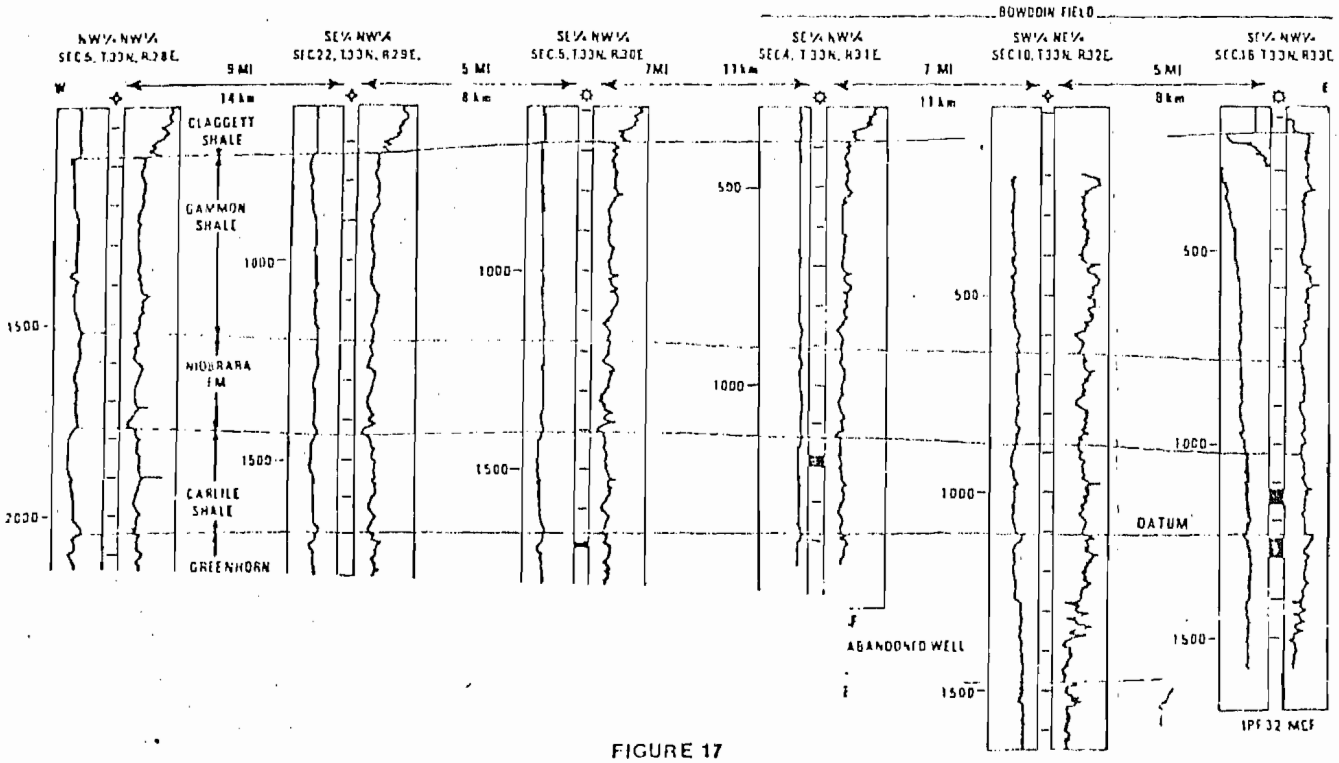


FIGURE 17

Electric log cross section through Bowdoin field area in north-central Montana showing correlation of selected Lower and Upper Cretaceous units and pay zones. Scale of resistivity log for second well from right is 0-50 ohms m²/m. All other resistivity logs are at scale of 0-20 ohms m²/m. Datum is top of Greenhorn Formation. Depths shown as feet below Kelly bushing.

Reference: Rice, D.D. and Shurr, G.W., 1978, Potential for major natural gas resources in shallow, low-permeability reservoirs of the northern Great Plains: Montana Geol. Soc. Guidebook 24th Ann. Conf. Williston Basin Symposium, p. 267-271.

3

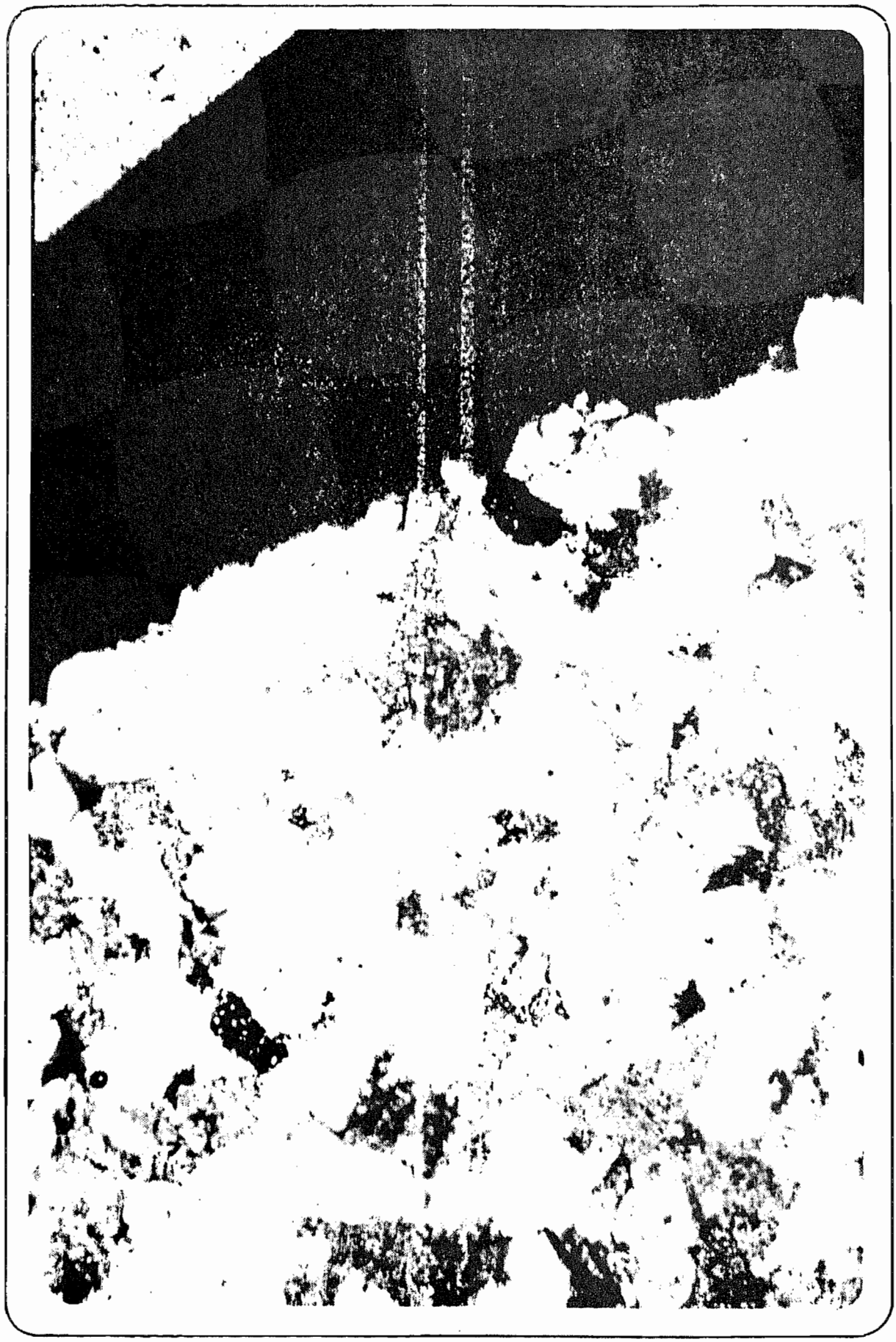
RESERVOIR PROPERTIES

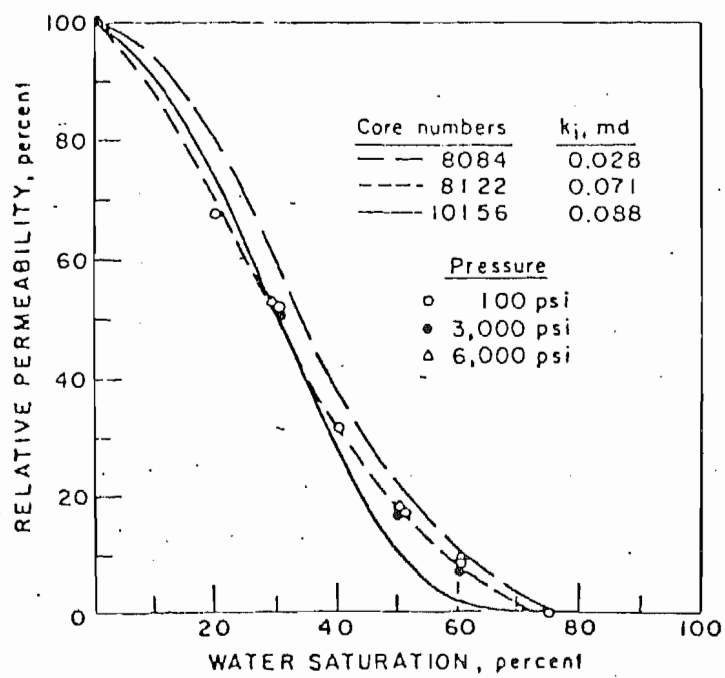
1) PETROGRAPHY TIGHT GAS SANDS. PORE THROATS, CLAYS, THIN SECTIONS
2) EFFECTS OF DEPTH AND TEMPERATURE ON POROSITY-PERM.
3) REGIONAL PRESSURE DATA FOR SELECTED FORMATIONS FROM PI AND DST DATA
4) EFFECTS OF POROSITY TYPES AND CLAYS ON LOG ANALYSIS AND RECOVERY TECHNOLOGY
5) DEFINE AREAS AND DEPTHS WITH MAXIMUM RESOURCE POTENTIAL

4

CLAY MINERALOGY

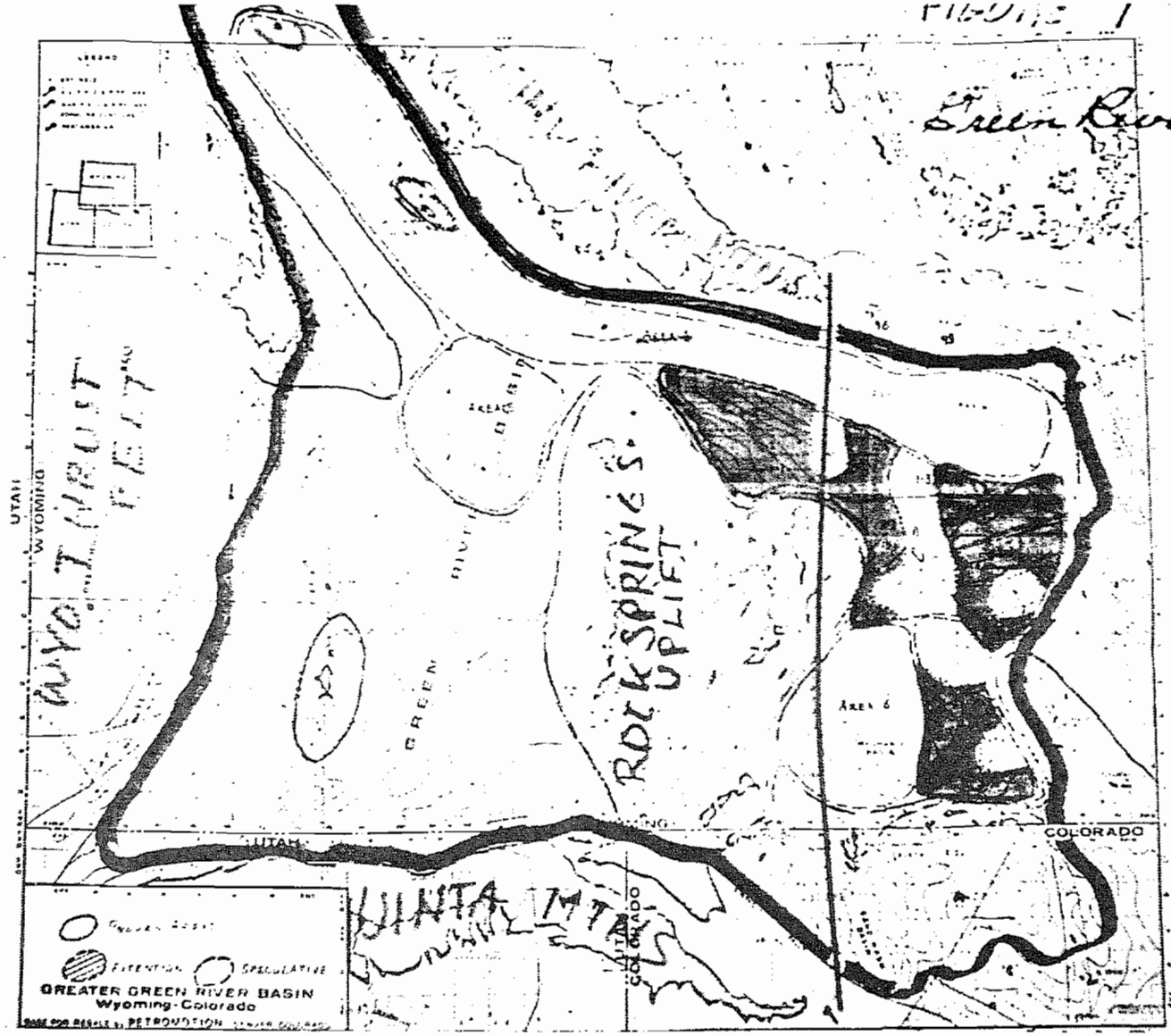
1) TYPES AND PERCENT
2) ORIGIN OF CLAYS AND DISTRIBUTION
3) RELATION OF CLAY TYPES TO GAS OCCURRENCE
4) CHARACTER OF CLAYS IN PORE THROATS, SEM AND ELECTRON PROBE
5) EFFECTS OF CLAYS ON RECOVERY TECHNOLOGY

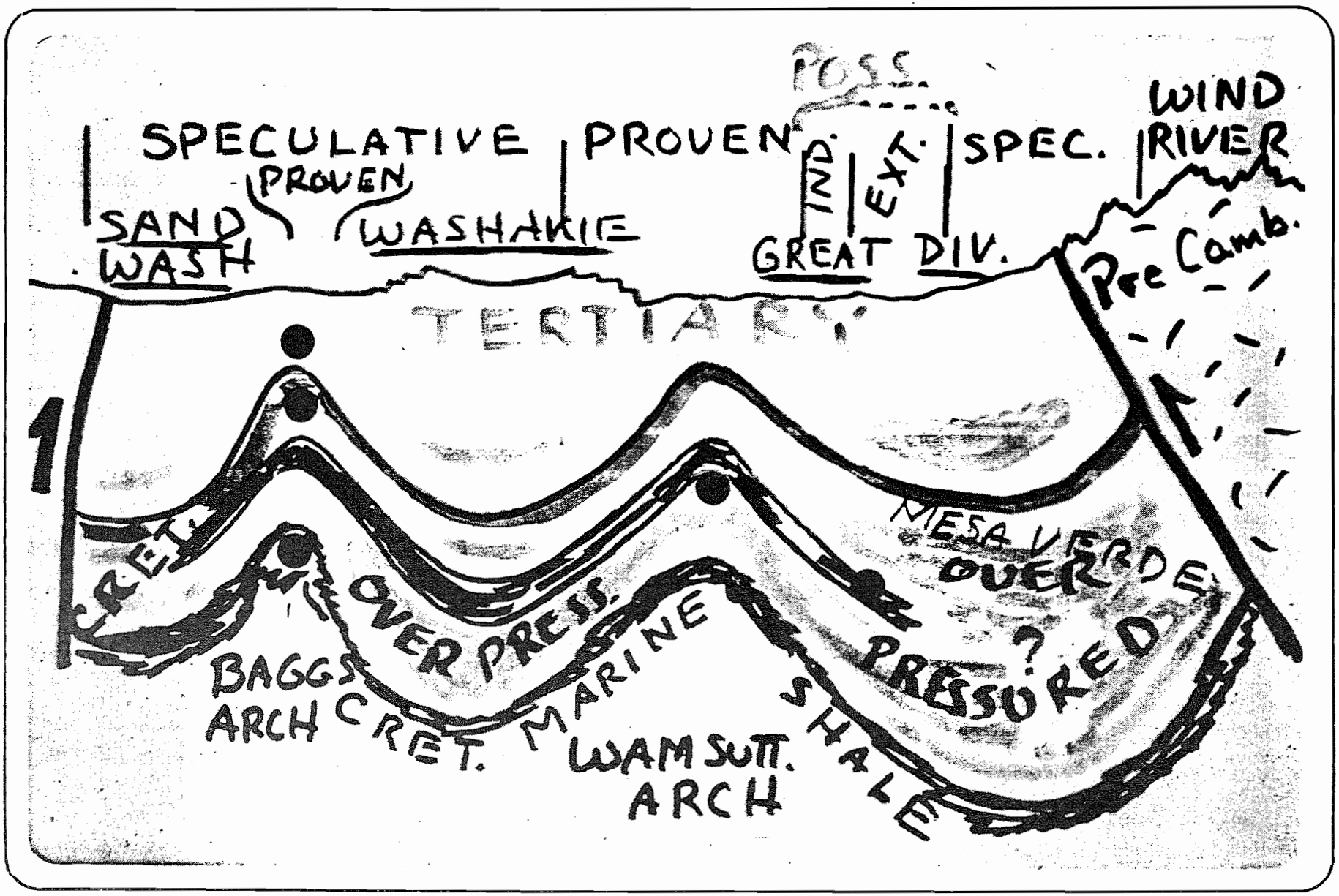




Source: Thomas and Ward (1972)

FIGURE 1


Green River
WYOMING
UTAH
WYOMING
ROCK SPRINGS UPLIFT
GREEN
UTAH
COLORADO
UINTA MTS
COLORADO
EXTENTION
SPECULATIVE
GREATER GREEN RIVER BASIN
Wyoming-Colorado


POSS.
SPECULATIVE
PROVEN
SPEC.
WIND RIVER
PROVEN
SAND WASH
WASHAKIE
IND.
EXT.
GREAT DIV.
Pre Camb.
TERTIARY
1
CRET.
MESA VERDE
OVER PRESS.
OVERPRESSURED ?
BAGGS ARCH
CRET. MARINE
WAMSUTT. ARCH
SHALE

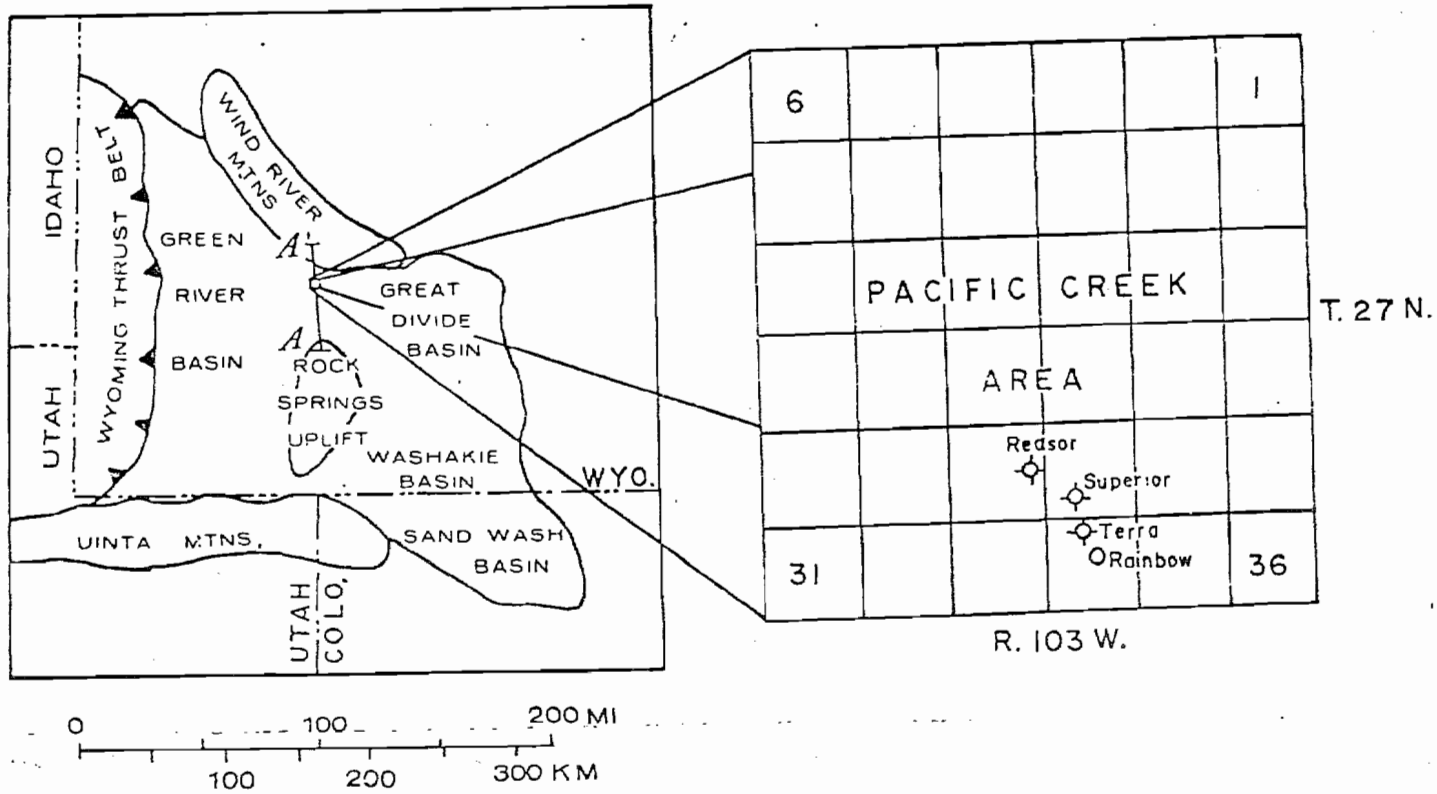


Figure 1. Index map of the Greater Green River Basin, southwestern Wyoming and northwestern Colorado, showing location of Pacific Creek area and cross section *A-A'*.

Reference: Law, B.E., Spencer, C.W., and Bostick, N.H., 1979, 5th DOE Symposium on Enhanced Oil and Gas Recovery and Improved Drilling Technology, v. 3, p. K2/1-K2/13.

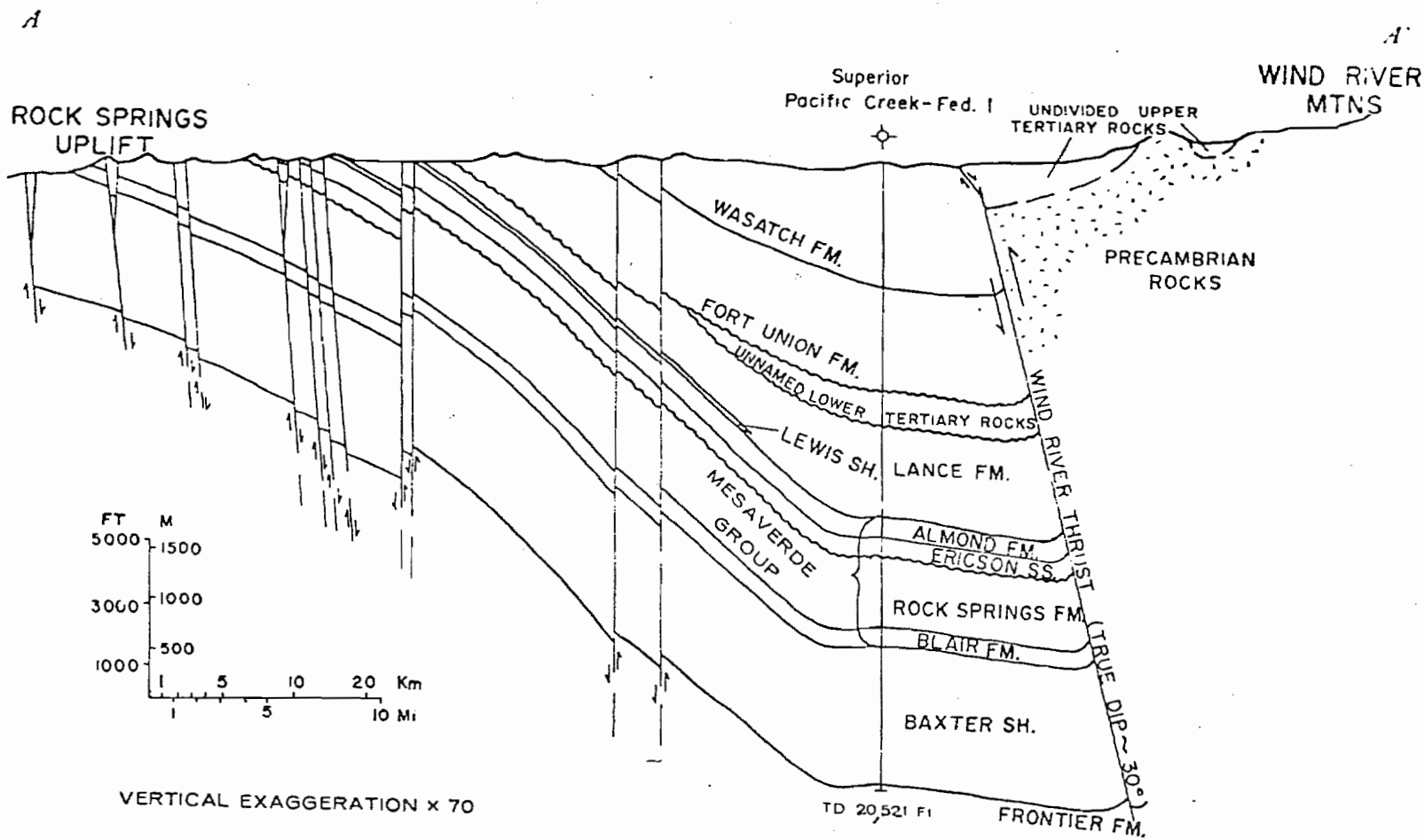


Figure 2. Generalized cross section A-A' drawn through the Pacific Creek area from the north end of the Rock Springs Uplift to the Wind River Mountains. Location of cross section shown on figure 1.

Reference: Law, B.E., Spencer, C.W., and Bostick, N.H., 1979, 5th DOE Symposium on Enhanced Oil and Gas Recovery and Improved Drilling Technology, v. 3, p. K2/1-K2/13.

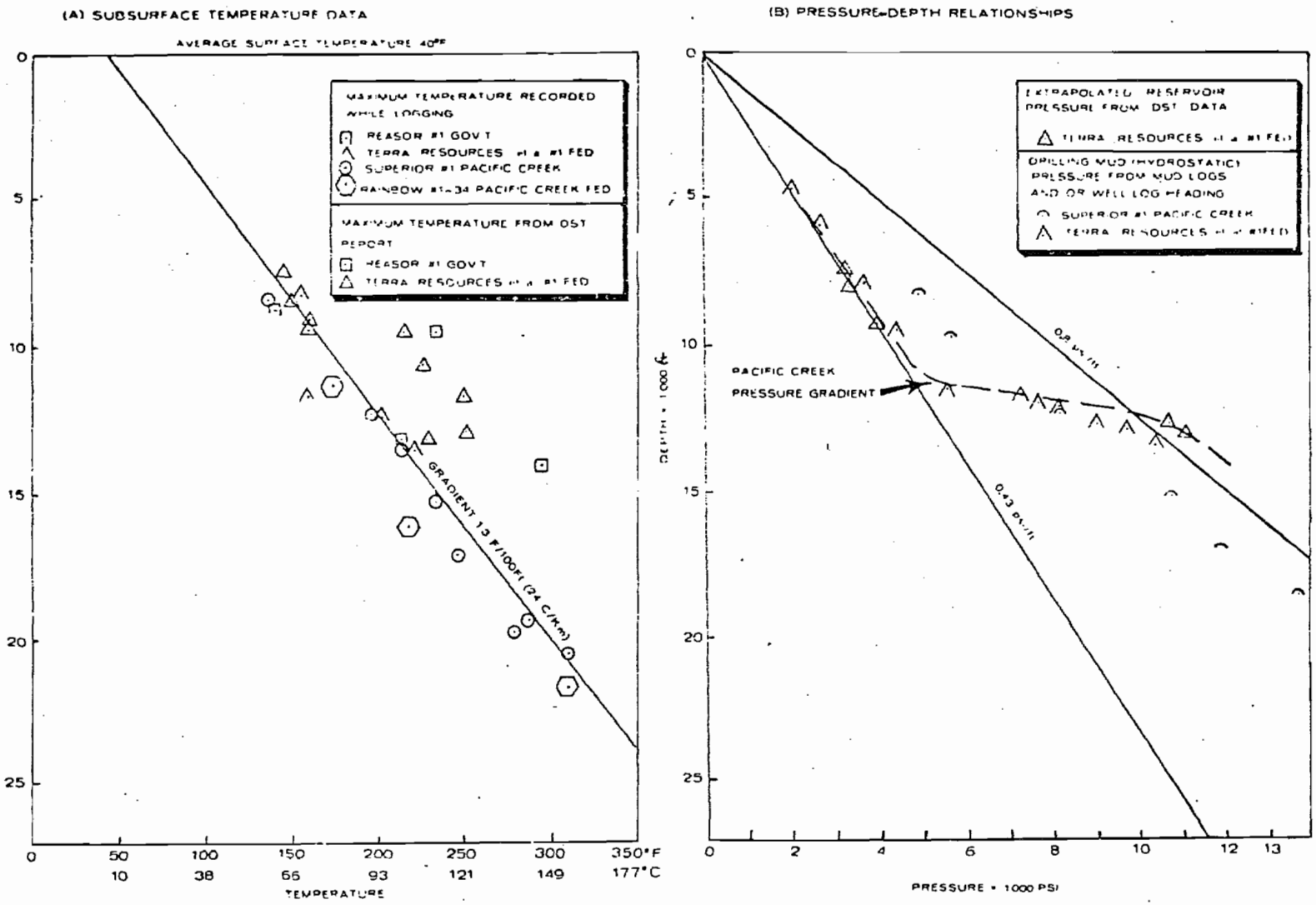


Figure 5. Temperature (A) and pressure (B) data from all wells drilled in the Pacific Creek area, Sublette County, Wyoming.

Reference: Law, B.E., Spencer, C.W., and Bostick, N.H., 1979, 5th DOE Symposium on Enhanced Oil and Gas Recovery and Improved Drilling Technology, v. 3, p. K2/1-K2/13.

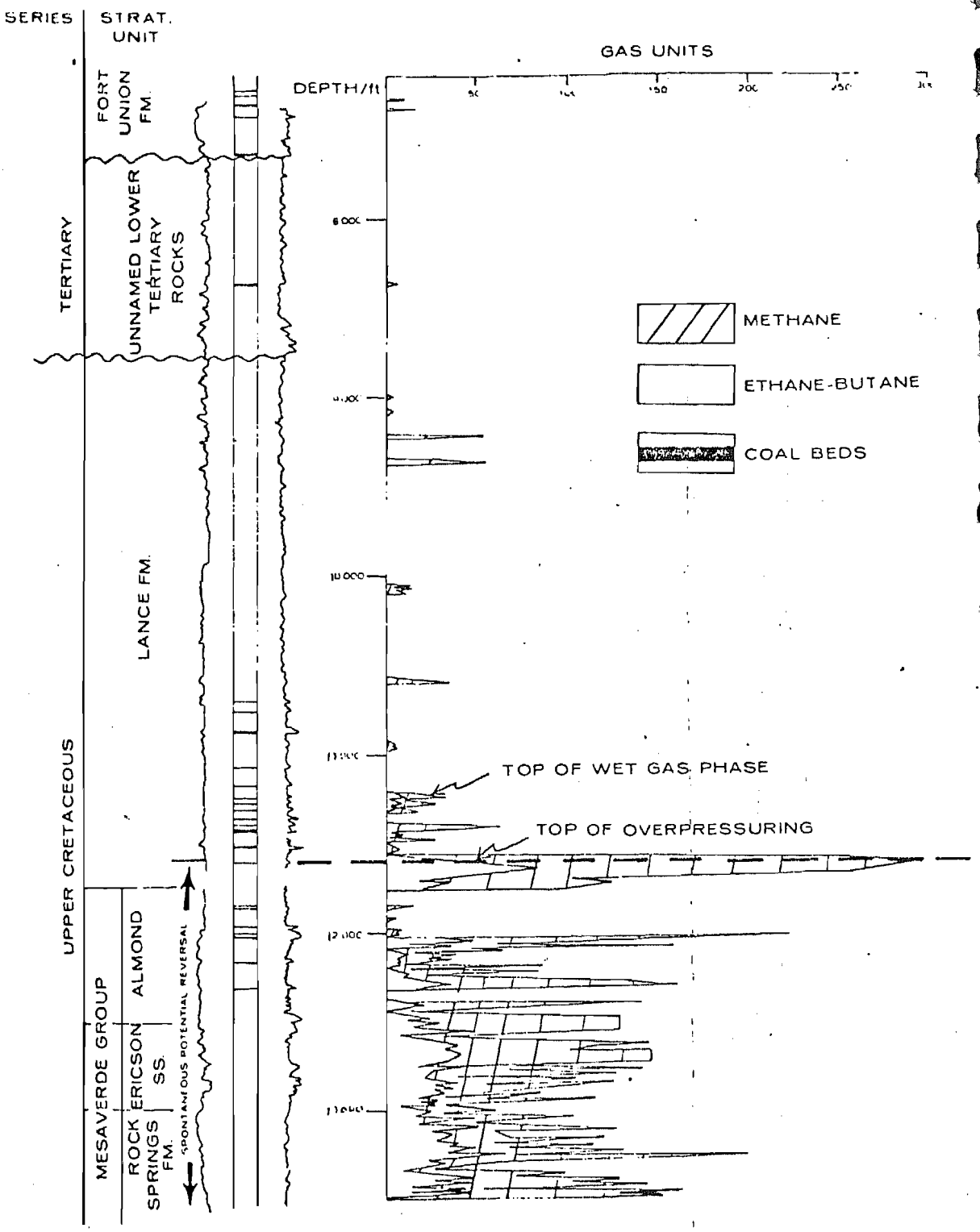


Figure 3. Electric log and gas mud log from the Terra Resources, et al #1 Fed. well showing relationships of wet gas phase, overpressuring, and spontaneous potential reversal. Note large number of coals in or near top of wet gas phase.

Reference: Law, B.E., Spencer, C.W., and Bostick, N.H., 1979, 5th DOE Symposium on Enhanced Oil and Gas Recovery and Improved Drilling Technology, v. 3, p. K2/1-K2/13.

USGS RECOMMENDATIONS FOR FUTURE TIGHT GAS RESEARCH

USGS geologic and engineering research to date indicates the following needs in addition to present research effort:

1) DOE support coring, logging, and testing of five or more widely-spaced wells in the Shallow Northern Great Plains area. This work would better define USGS (Rice) preliminary resource estimates and stimulate early commercialization of resource over a broad area. Air or gas drilling should be considered.

2) DOE support deep (+ 15,000 ft) drilling, coring, and logging in the relatively unevaluated, deep, overpressured parts of the Uinta and Greater Green River Basins. Minimum of four wells in Greater Green River, two in Uinta. Experience in WGSP could be extended to other deep basins.

3) Development of techniques to restore water-damaged wells to production (e.g. dry-gas cycling, alcohol-gas overflush, etc.)

4) Improvement of proppant carriers to reduce amount of solids left in reservoirs, assure complete "breaking," and increase high-temperature stability.

5) Support frac experiments using little or no water to minimize formation damage (e.g. gas fracs, foam fracs, gelled-alcohol-gas fracs, etc.)

6) Conduct experiments to gas drill into pay zones to minimize formation damage. If get good gas flows, hang slotted liners, if not, cement casing and frac with low-water fluids.

7) Undertake hydrofluoric-acid stimulation of secondary porosity in deep reservoirs where proppant crushing is a problem (+10,000 ft). Acid will have to contain additives to prevent precipitation of residues in formation. May be desirable to gas overflush.

8) Contract for development of a continuously recording grain-density log to "compensate" conventional density logs for variations in grain density. Lab studies of grain density and USGS petrographic work demonstrate wide variations in grain densities in tight gas sands. Conventional reservoirs usually have consistent grain densities.

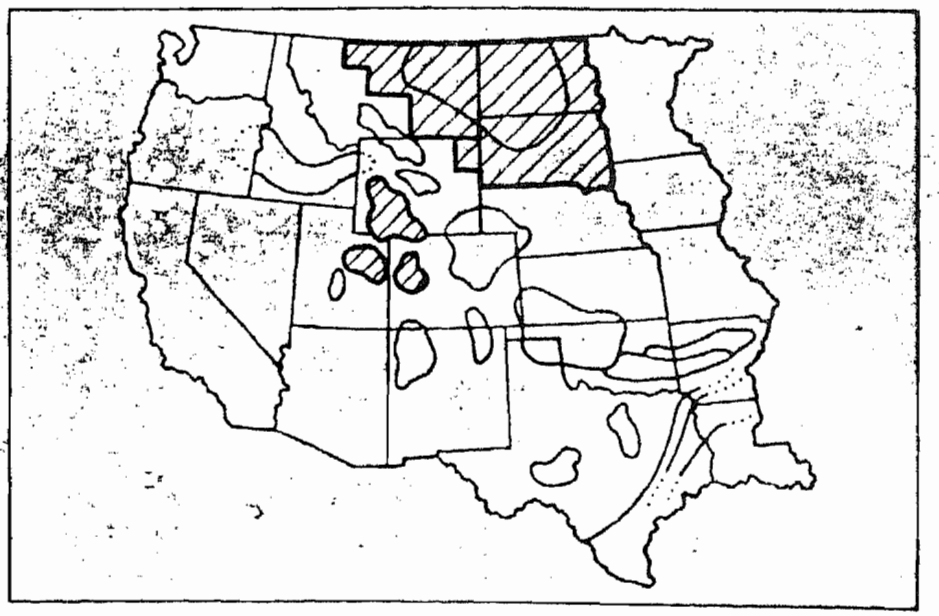
C.W.Spencer 3/6/80.

Western Gas Sands Project

MHF FIELD TEST SUMMARY

UGR Briefing for Dep. Asst. Sec.

Morgantown WV



March 12, 1980

Prepared for
U.S. Department of Energy
Bartlesville Energy Technology Center
Las Vegas Field Office
C. H. Atkinson

Compiled by CER Corporation
Las Vegas, Nevada

Contract DE-AC08-79BC10003

Cost-Shared Single-Well Field Testing

FUNCTION: TEST EFFECTS OF STIMULATION ON GAS PRODUCTION FROM TIGHT SAND RESERVOIRS

COST:
- SHARED WITH INDUSTRY
- DOE COST - VARIABLE

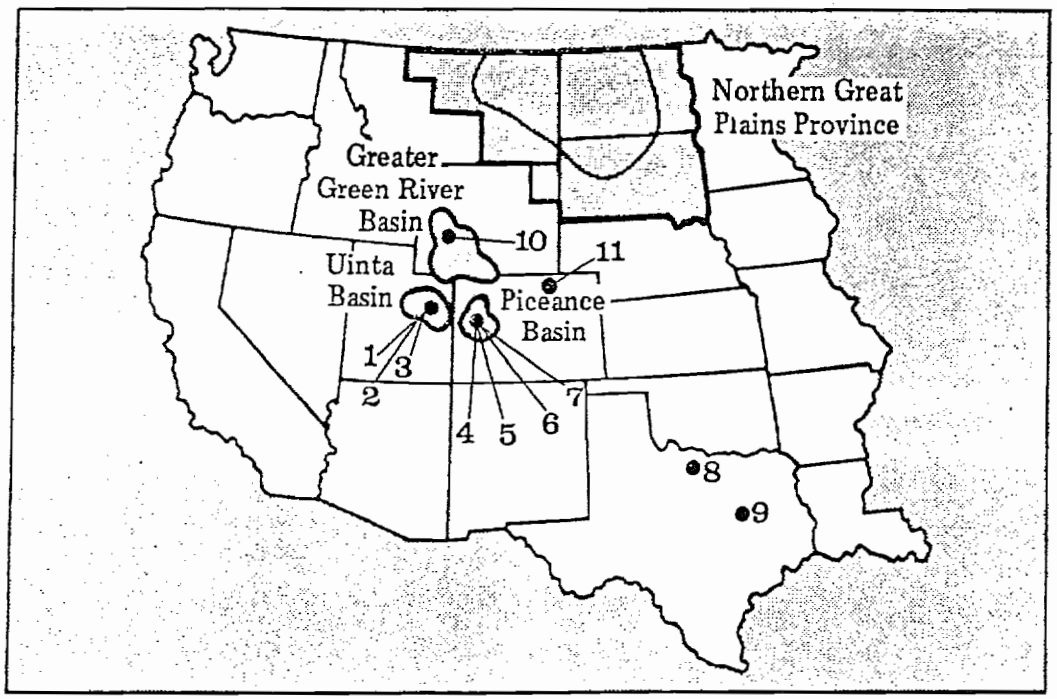
OBJECTIVES: PERFORM STIMULATION & TEST OPERATIONS IN INDUSTRY WELLS TO
- VERIFY LAB & MODEL RESULTS
- CONFIRM RESOURCE & TECHNOLOGY UNDERSTANDING
- PROVIDE ECONOMIC EVALUATION DATA
- DETERMINE COMMERCIAL VIABILITY OF RESOURCES

PROGRESS:
- 28 MHF TESTS PERFORMED - 16 SITES - 9 OPERATORS
  - FOUR OPERATIONS STILL ACTIVE
- DRY GAS INJECTION TEST NOW ACTIVE
- TWO ADDITIONAL TESTS PLANNED WITH FY 1980 ADD-ON

Cost-Shared Single-Well Field Testing (continued)

RESULTS:

- MHF IN BLANKET RESERVOIRS SHOWS SUCCESS
  - WATTENBERG MUDDY J
  - COTTON VALLEY TREND
- MHF IN LENTICULAR RESERVOIRS LESS SUCCESSFUL
  - PICEANCE MESAVERDE
  - GREEN RIVER MESAVERDE



Hydraulic Fracturing

1. Gas Producing Enterprises, Inc.
2. Pacific Transmission Supply Co.
3. Western Oil Shale Corporation
4. CER Corporation MHF-3
5. Rio Blanco Natural Gas Company
6. Austral Oil Company
7. Mobil Oil Company
8. Dallas Production, Inc.
9. Mitchell Energy Corporation
10. El Paso Natural Gas

Dry Gas Injection

11. Colorado Interstate Gas

Locations of DOE/Industry Cost-Shared Single-Well Tests

Rio Blanco MHF Experiment (MHF-3)-Project 4

CONTRACT NO: EY-76-C-08-0623

COST SHARED WITH INDUSTRY CONSORTIUM MANAGED BY CER CORPORATION

COST:	INDUSTRY -	$1,630,000
	DOE -	1,975,000
	TOTAL	$3,605,000

CONTRACT START: JUNE, 1974

CONTRACT COMPLETE: NOVEMBER, 1979

OBJECTIVES:

- TEST ADVANCED HYDRAULIC FRACTURING TECHNOLOGY IN MASSIVE GAS-BEARING SANDS THAT DO NOT PRODUCE AT COMMERCIAL RATES
- COMPARE EFFECTIVENESS OF MHF & NEF. THIS WELL IS LOCATED ONE MILE FROM RIO BLANCO NUCLEAR SITE

Industrial Consortium Members: MHF-3

FRACTURE AND WELL DESIGN GROUP

AMOCO PRODUCTION COMPANY
ATLANTIC RICHFIELD COMPANY
CER GEONUCLEAR CORPORATION (now CER CORPORATION)
CONTINENTAL OIL COMPANY
DOWELL DIVISION OF DOW CHEMICAL COMPANY
EL PASO NATURAL GAS COMPANY
EQUITY OIL COMPANY
EXXON PRODUCTION RESEARCH COMPANY
HALLIBURTON SERVICES
LAWRENCE LIVERMORE LABORATORY
MOBIL OIL CORPORATION
BARTLESVILLE ENERGY TECHNOLOGY CENTER (now DOE-BETC)
MORGANTOWN ENERGY RESEARCH CENTER (withdrew)

Later joined by:

SHELL OIL COMPANY
MICHIGAN-WISCONSIN PIPE LINE COMPANY
CHAMPLIN OIL COMPANY
COLUMBIA GAS PIPE LINE COMPANY

Industrial Consortium Members: MHF-3 (continued)

ANALYSIS DESIGN GROUP

AMOCO PRODUCTION COMPANY
ATLANTIC RICHFIELD COMPANY
CER GEONUCLEAR CORPORATION (now CER CORPORATION)
CONTINENTAL OIL COMPANY
DOWELL DIVISION OF DOW CHEMICAL COMPANY
EL PASO NATURAL GAS COMPANY
EQUITY OIL COMPANY
EXXON PRODUCTION RESEARCH COMPANY
HALLIBURTON SERVICES (a diviison of the Halliburton Co.)
LAWRENCE LIVERMORE LABORATORY
LOS ALAMOS SCIENTIFIC LABORATORY (withdrew)
MOBIL OIL CORPORATION
MORGANTOWN ENERGY RESEARCH CENTER (withdrew)
BARTLESVILLE ENERGY TECHNOLOGY CENTER (now DOE-BETC)
SANDIA LABORATORIES

Later joined by:

SHELL OIL COMPANY
MICHIGAN-WISCONSIN PIPE LINE COMPANY
CHAMPLIN OIL COMPANY
COLUMBIA GAS PIPE LINE COMPANY

Characteristics & Results of Each Fracture Treatment: MHF-3

TREATMENT & RESULTS:

Basin & Formation	Location T/R/Sec	Well	Interval Fractured ft	Fracture Date	Fracture Treatment Lb of Sand	Injected Fluid 10^3 Gal	Production Rates MCFD Before	After	Ratio
Piceance, Mesaverde	3S/98W/Sec 11 Rio Blanco Cty, Colorado	RB-MHF-3	8,048-8,078	10-23-74	400,000	117	60	61	1.02
Mesaverde			7,760-7,864	05-02-75	880,000	285	57	137	2.40
Ft. Union			5,925-6,026	05-04-76	815,000	400	42	160	3.81
Ft. Union			5,851-5,869	11-03-76	448,000	228	56	69	1.23

Pinedale Unit, Wyoming MHF Experiment - Project 10

CONTRACT NO: E(34-1)-0033

COST SHARED WITH EL PASO NATURAL GAS COMPANY

ERDA COST: $585,000

CONTRACT START: SEPTEMBER, 1975

CONTRACT COMPLETE: OCTOBER, 1976

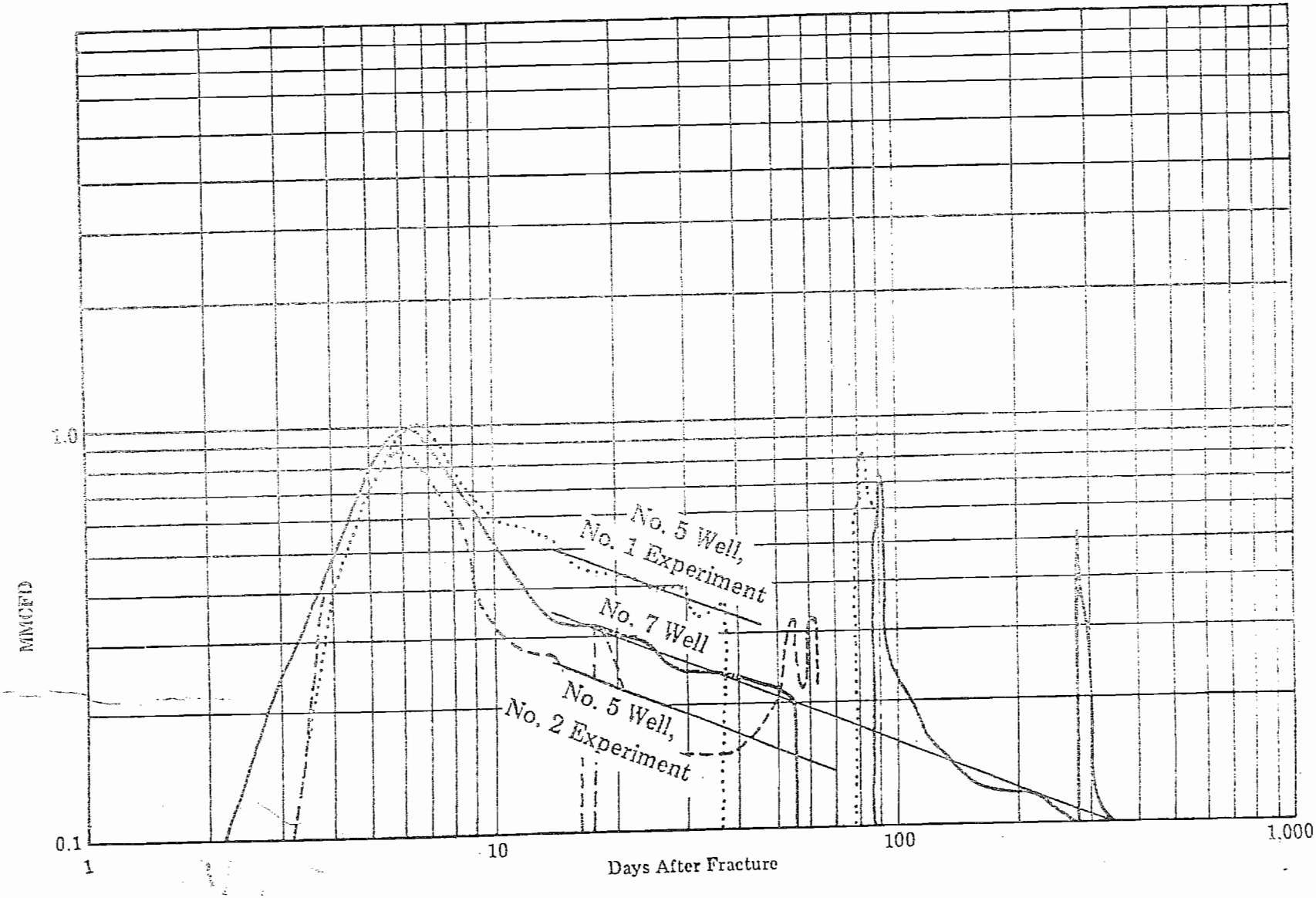
OBJECTIVE: EVALUATE MHF EFFECTIVENESS IN STIMULATING GAS PRODUCTION FROM THICK, DEEP SAND RESERVOIRS HAVING LOW PERMEABILITY

Pinedale Unit, Wyoming MHF Experiment (continued)

TREATMENT & RESULTS

Basin & Formation	Location T/R/Sec	Well	Interval Fractured ft	Fracture Date	Fracture Treatment Lb of Sand	Injected Fluid 10^3 Gal	Production Rates MCFD Before	After	Ratio
Northern Green River, Fort Union	30N/108W/Sec 5 Sublette Cty, Wyoming	Pinedale Unit No. 5	10,950-11,180	07-02-75	518,000	183 Emul 8 Gel	150	340	2.3
			10,120-10,790	10-20-75	1,422,000	459 Gel	--	150	--

- POOR RESULTS INDICATED BY EXCESSIVE WATER PRODUCTION & LOW GAS PRODUCTION



Observed Production from the 3 Pinedale MHF Experiments

Natural Buttes Unit, Utah MHF Demonstration - Project 1

CONTRACT NO: DE-AC08-76ET-12060

COST SHARED WITH GAS PRODUCING ENTERPRISES, HOUSTON

COST:	GPE (PRIOR)	-	$1,881,000
	GPE (NEW)	-	3,051,000
	DOE	-	1,973,000
	TOTAL		$6,905,000

CONTRACT START: JULY, 1976

ANTICIPATED COMPLETION: MARCH, 1980

OBJECTIVE: EVALUATE MHF EFFECTIVENESS IN STIMULATING GAS PRODUCTION FROM DEEP, THICK SAND RESERVOIRS HAVING LOW PERMEABILITY.

Natural Buttes Unit, Utah MHF Demonstration (continued)

TREATMENT & RESULTS:

Basin & Formation	Location T/R/Sec	Well	Interval Fractured ft	Fracture Date	Fracture Treatment Lb of Sand	Injected Fluid 10^3 Gal	Production Rates MCFD Before	After	Ratio
Uinta, Wasatch and Mesa-verde	10S/22E/Sec 10 Uintah Cty, Utah	Natural Buttes No. 18	6,490-8,952	09-22-76	1,480,000	745 Gel	--	1,400	--
	10S/21E/Sec 21 Uintah Cty, Utah	Natural Buttes No. 19	8,909-9,664 7,224-8,676	09-21-76 09-28-76	424,000 784,000	280 Gel 364 Gel	--	166	--
	9S/21E/Sec 22 Uintah Cty, Utah	Natural Buttes No. 14	6,646-8,004	03-15-77	1,093,000	544 Gel	38	800	21.0
	9S/21E/Sec 28 Uintah Cty, Utah	Natural Buttes No. 20	8,498-9,476	06-22-77	826,000	322 Gel	75	1,200	16.0

Natural Buttes Unit, Utah MHF Demonstration (continued)

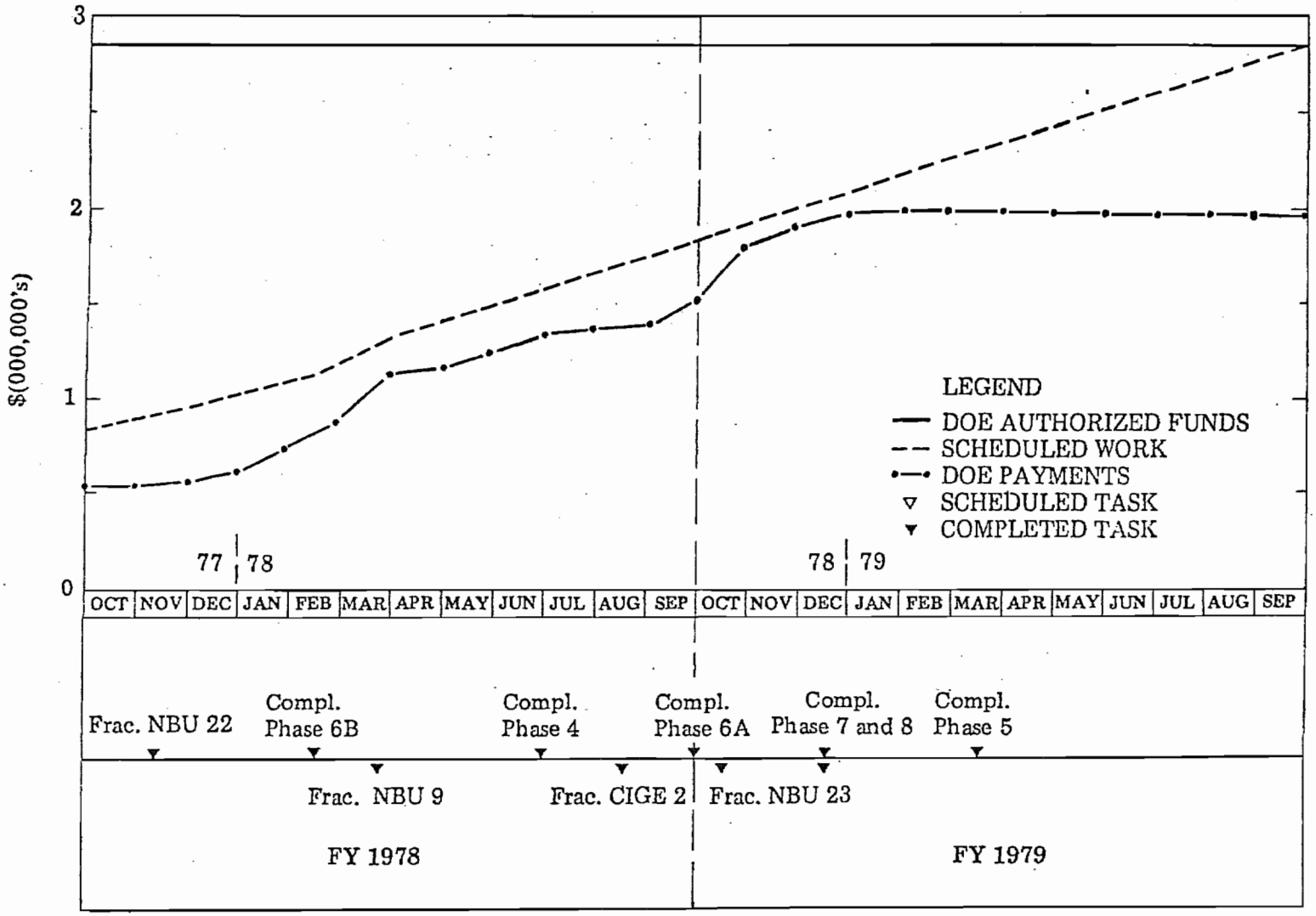
TREATMENT & RESULTS (Continued)

Basin & Formation	Location T/R/Sec	Well	Interval Fractured ft	Fracture Date	Fracture Treatment Lb of Sand	Injected Fluid 10^3 Gal	Production Rates MCFD Before	After	Ratio
Uinta, Wasatch and Mesa-verde	10S/22E/Sec 18 Uintah Cty, Utah	Natural Buttes No. 22	6,838-8,550	11-21-77	1,151,000	499 Gel	--	700	--
	9S/22E/Sec 19 Uintah Cty, Utah	Natural Buttes No. 9	5,661-8,934	03-27-78	554,000	349 Gel	140	540	3.9
	10S/21E/Sec 29 Uintah Cty, Utah	CIGE No. 2	9,237-9,653	06-22-78	170,500	203 Gel	--	Water	--
			7,251-8,774	08-08-78	1,965,000	722 Gel	--	Water	--
	10S/22E/Sec 7 Uintah Cty, Utah	Natural Buttes No. 23	5,080-6,294	10-04-78	470,000	240 Gel	--	800	--

Natural Buttes Unit, Utah MHF Demonstration (continued)

TREATMENT & RESULTS (Continued)

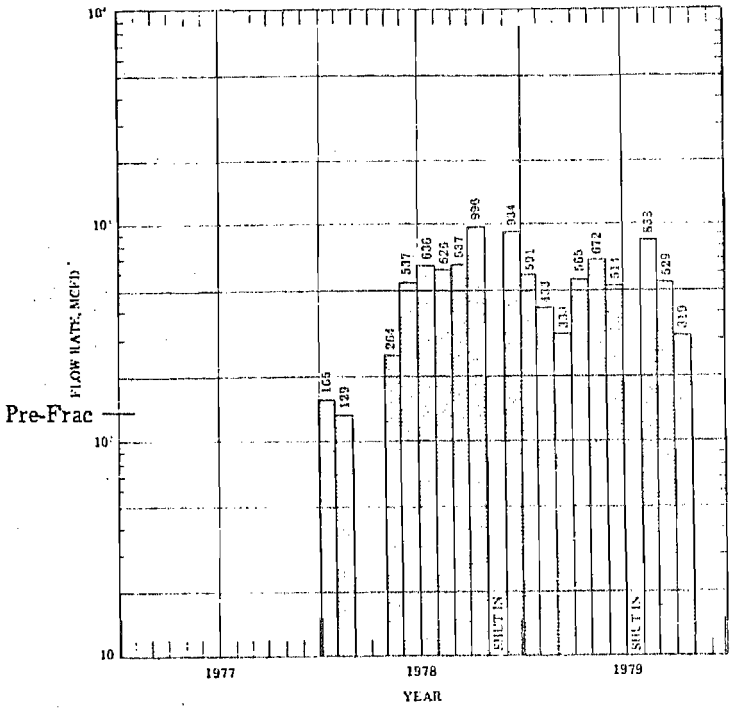
- MULTIPLE TREATMENTS USED VARIATIONS IN GEL VISCOSITY & VOLUME, SAND SIZE, ZONE POROSITY & FRAC DESIGN
- RESERVOIR PROPERTY VARIATIONS MASKED FRAC EFFICIENCY DIFFERENCES RESULTING FROM ABOVE VARIATIONS
- N.B.U. NO. 21 WAS CORED & TESTED BUT STIMULATION WAS NOT WARRANTED

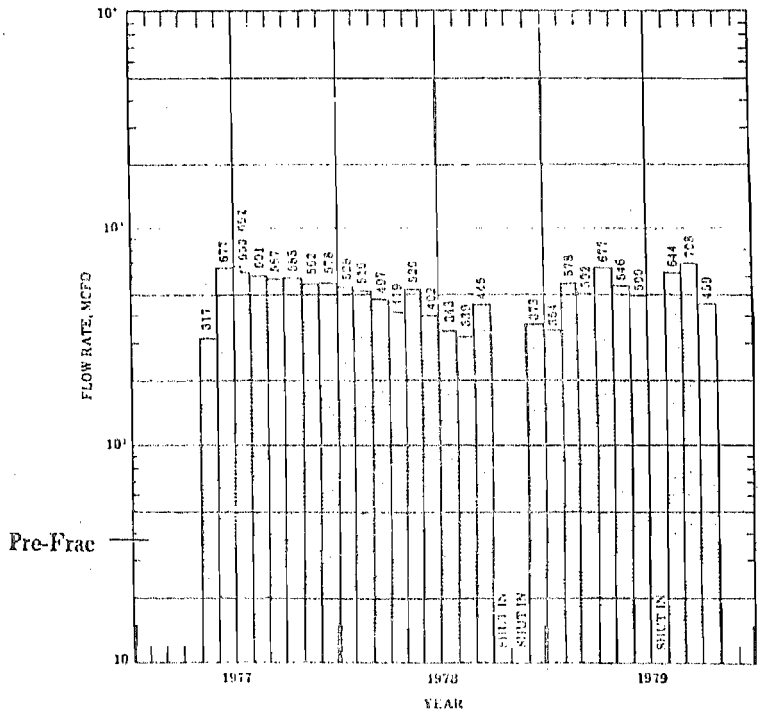


Gas Producing Enterprises FY 78 and FY 79

Costs & Work Schedule

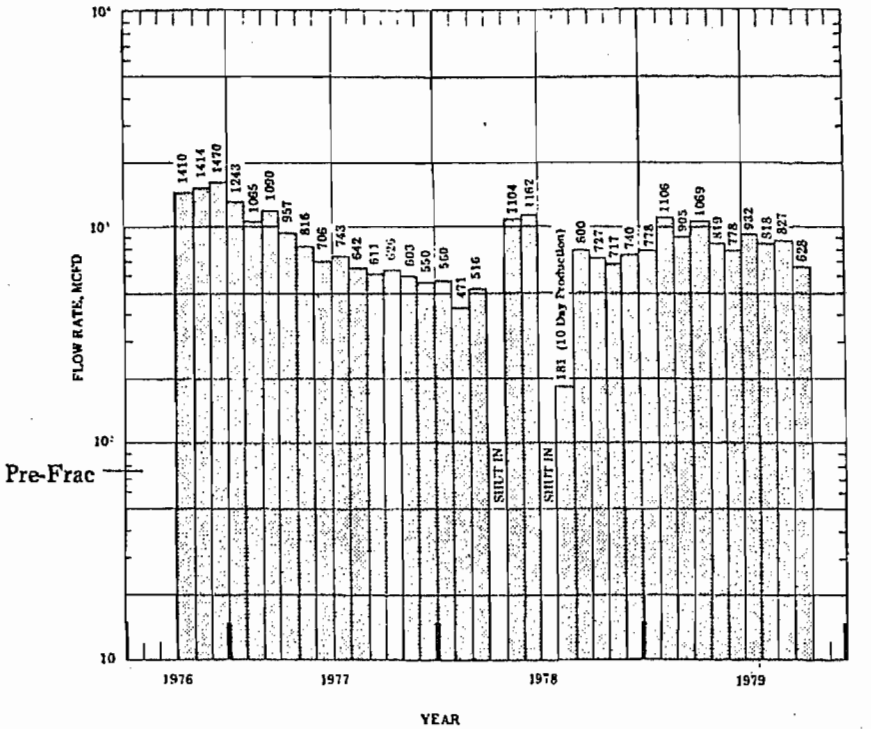
Flow Rate Performance of Natural Buttes No. 9 Well

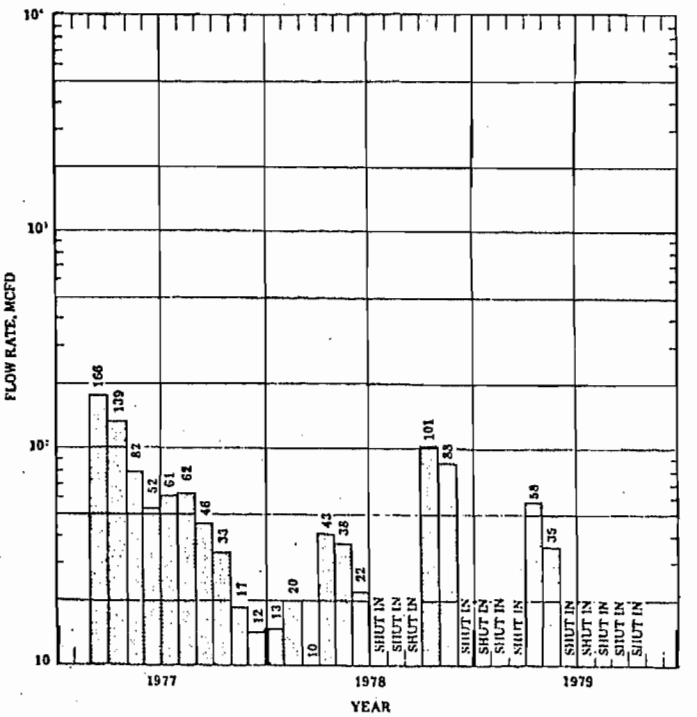




Flow Rate Performance of Natural Buttes No. 14 Well

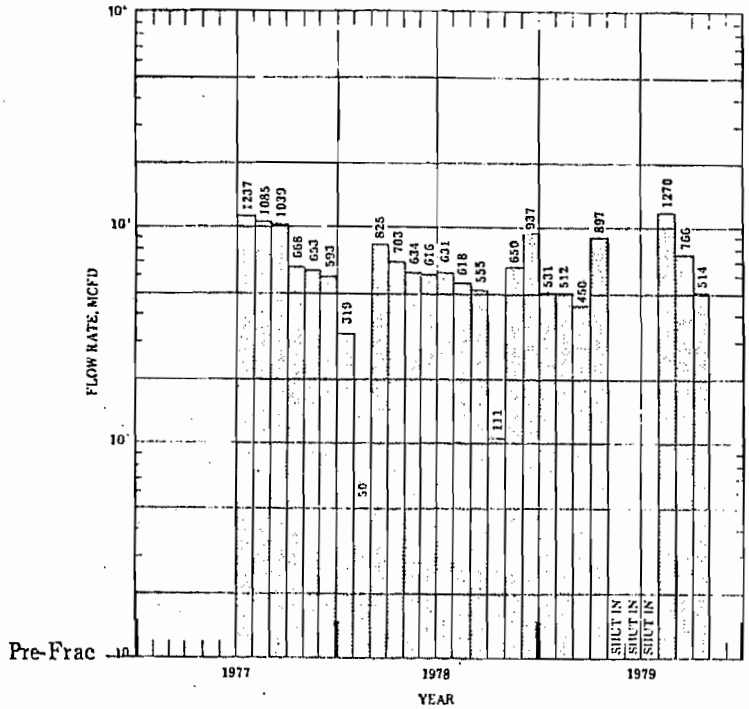
Flow Rate Performance of Natural Buttes No. 18 Well

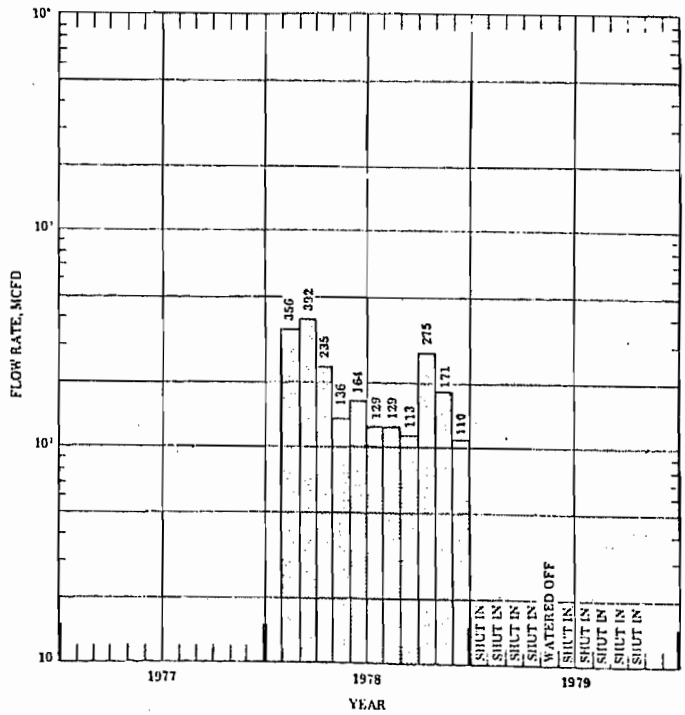




Flow Rate Performance of Natural Buttes No. 19 Well

Flow Rate Performance of Natural Buttes No. 20 Well





Flow Rate Performance of Natural Buttes No. 22 Well

Rulison Field, Colorado MHF Demonstration - Project 6

CONTRACT NO: EY-76-C-08-0679

COST SHARED WITH AUSTRAL OIL COMPANY, HOUSTON

COST:	AUSTRAL (PRIOR)	-	$545,000
	AUSTRAL (NEW)	-	54,000
	DOE	-	334,000
	TOTAL		$933,000

CONTRACT START: JUNE, 1976

CONTRACT COMPLETE: DECEMBER, 1977

OBJECTIVE: EVALUATE MHF EFFECTIVENESS IN STIMULATING GAS PRODUCTION FROM THICK, DEEP SAND RESERVOIRS HAVING EXTREMELY LOW PERMEABILITY

Rulison Field, Colorado MHF Demonstration (continued)

TREATMENT & RESULTS

Basin & Formation	Location T/R/Sec	Well	Interval Fractured ft	Fracture Date	Fracture Treatment Lb of Sand	Injected Fluid 10^3 Gal	Production Rates MCFD Before	After	Ratio
Piceance,	7S/94W/Sec 3	Federal	6,198-6,333	08-13-76	420,000	225 Gel	35	62	1.8
Mesaverde	Garfield Cty, Colorado	3-94	5,170-5,630	08-25-76	720,000	316 Gel			

- POOR RESULTS ATTRIBUTED TO LOW FORMATION PERMEABILITY & RESTRICTED (LENTICULAR) RESERVOIR

Application of MHF Technology to a Tight Gas Sand in the Fort Worth Basin - Project 8

CONTRACT NO: EY-76-C-08-0684

COST SHARED WITH DALLAS PRODUCTION, INC.

COST:	DALLAS PROD.	-	$178,000
	DOE	-	150,000
	TOTAL		$328,000

CONTRACT START: AUGUST, 1976

CONTRACT COMPLETE: JUNE, 1977

OBJECTIVE: EVALUATE MHF EFFECTIVENESS IN STIMULATING GAS PRODUCTION FROM MARGINAL, LOW PERMEABILITY RESERVOIRS AT MODERATE DEPTHS & HAVING LARGE AREAL EXTENTS

Application of MHF Technology to a Tight Gas Sand in the Fort Worth Basin (continued)

TREATMENT & RESULTS:

Basin & Formation	Location T/R/Sec	Well	Interval Fractured ft	Fracture Date	Fracture Treatment Lb of Sand	Injected Fluid 10^3 Gal	Production Rates MCFD Before	After
Fort Worth, Bend Cong.	Ben D. Smith Survey A-779 Wise Cty, Texas	Ferguson A-1	5,957-6,794	09-16-76	506,000	139 Foam 198 Emul	40	15

- WELL INITIALLY COMPLETED IN 1973 WITH MEDIUM-SIZE FRAC:
  - FIVE ZONES - EACH FRACED WITH 10,000 GAL KCl WATER GEL & 20,000 LB 20/40 SAND
- CASING RUPTURED DURING MHF AFTER PLACING 87,000 GAL FOAM; 52,000 GAL EMULSION; 151,000 LB 10/20 SAND & 67,000 LB 100 SAND

Application of MHF Technology to a Tight Gas Sand in the Fort Worth Basin (continued)

- AFTER TWO-DAY REPAIR, MHF CONTINUED WITH 51,800 GAL FOAM; 146,000 GAL EMULSION; 250,000 LB 20/20 SAND & 38,000 LB 100 SAND

- INTERRUPTION IN MHF MAY BE FACTOR IN STIMULATION FAILURE

Rio Blanco County, Colorado MHF Demonstration - Project 5

CONTRACT NO: EY-76-C-08-0677

COST SHARED WITH RIO BLANCO NATURAL GAS CO. - DENVER

COST:	RIO BLANCO -	$ 593,000
	DOE -	410,000
	TOTAL	$1,003,000

CONTRACT START: AUGUST, 1976

CONTRACT COMPLETE: DECEMBER, 1979

OBJECTIVE: EVALUATE MHF EFFECTIVENESS IN STIMULATING GAS PRODUCTION FROM THICK, DEEP SAND RESERVOIRS HAVING EXTREMELY LOW PERMEABILITY

Rio Blanco County, Colorado MHF Demonstration (continued)

TREATMENT & RESULTS:

Basin & Formation	Location T/R/Sec	Well	Interval Fractured ft	Fracture Date	Fracture Treatment Lb of Sand	Injected Fluid 10^3 Gal	Production Rates MCFD Before	After	Ratio
Rio Blanco	4S/98W/Sec 4	Federal	6,150-6,312	10-22-76	766,000	276 Gel	57	130	2.3
Natural Gas	Rio Blanco	498-4-1	5,376-5,690	11-30-77	243,000+	164 Gel	80	350	4.4
Piceance,	Cty, Colorado				22,600 Beads				
Mesaverde									

- MODERATELY SUCCESSFUL STIMULATION

No. 1 Home Federal Well, Utah MHF Experiment - Project 3

CONTRACT NO: EY-76-C-08-0683

COST SHARED WITH WESTERN OIL SHALE CORPORATION, LAS VEGAS

COST:	WOSCO (PRIOR)	-	$ 566,000
	WOSCO (NEW)	-	393,000
	DOE	-	65,000
	TOTAL		$1,024,000

CONTRACT START: JULY, 1976

CONTRACT COMPLETE: SEPTEMBER, 1977

OBJECTIVE: EVALUATE MHF EFFECTIVENESS IN STIMULATING GAS PRODUCTION FROM THICK, DEEP LOW PERMEABILITY RESERVOIRS

No.1 Home Federal Well, Utah MHF Experiment (continued)

TREATMENT & RESULTS:

Basin & Formation	Location T/R/Sec	Well	Interval Fractured ft	Fracture Date	Fracture Treatment Lb of Sand	Injected Fluid 10^3 Gal	Production Rates MCFD Before	After	Ratio
WESTCO	10S/19E/Sec 34	Home Fed.	10,014-10,202	12-21-76	500,000	248 Gel	33	155	4.7
Uinta, Mesaverde	Uintah Cnty, Utah	No. 1	7,826-9,437	10-01-76	600,000	412 Gel	40	Water	--

Piceance Creek Field, Colorado MHF Demonstration - Project 7

CONTRACT NO: EY-76-C-08-0678

COST SHARED WITH MOBIL R&D CORPORATION

COST:	MOBIL (PRIOR)	-	$2,376,000
	MOBIL (NEW)	-	1,591,000
	DOE	-	2,510,000
	TOTAL		$6,477,000

CONTRACT START: JULY, 1976

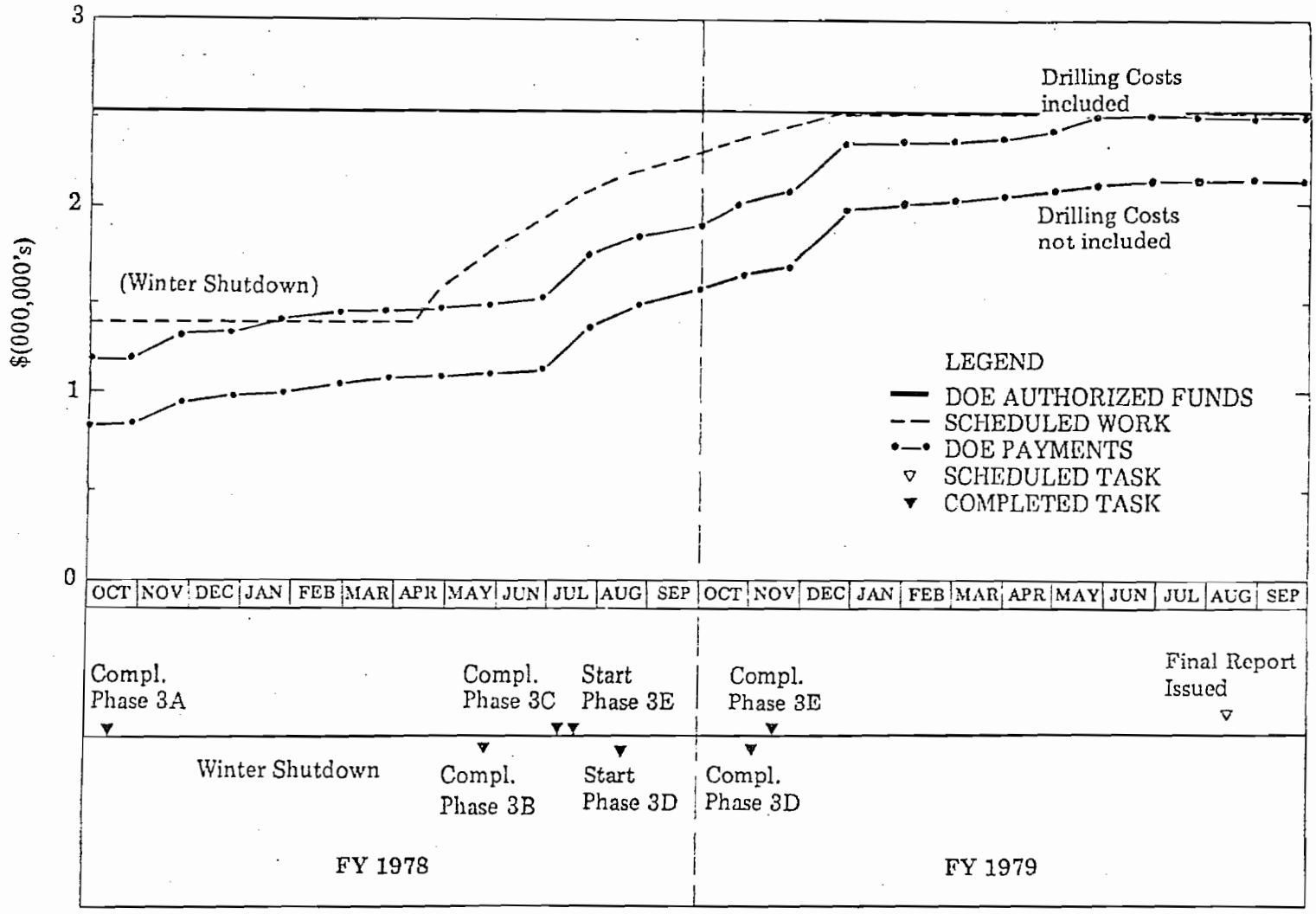
CONTRACT COMPLETE: FEBRUARY, 1980

OBJECTIVE: EVALUATE MHF EFFECTIVENESS IN STIMULATING GAS PRODUCTION FROM THICK, DEEP SAND RESERVOIRS HAVING EXTREMELY LOW PERMEABILITY

Piceance Creek Field, Colorado MHF Demonstration (continued)

TREATMENT & RESULTS:

Basin & Formation	Location T/R/Sec	Well	Interval Fractured ft	Fracture Date	Fracture Treatment Lb of Sand	Injected Fluid 10^3 Gal	Production Rates MCFD Before	After	Ratio
Piceance,	2S/97W/Sec 13	F31-13G	10,549-10,680	06-22-77	580,000	316 Gel	300	800	2.7
Mesaverde	Rio Blanco Cty,		9,392-9,533	08-24-77	600,000	260 Gel	700	2,600	3.7
	Colorado		8,765-8,792	05-10-78	388,000	150 Gel	479	430	--
			8,163-8,650	07-06-78	660,000	288 Gel	--	360	--
			7,704-7,794	09-07-78	218,000	120 Gel	--	180	--
			7,324-7,476	11-15-78	700,000	365 Gel	1,000	2,000	2.0



Mobil Research & Development FY 78 and FY 79 Costs & Work Schedule

Summary of Results from Pre-Frac PBU Tests

pressure buildup

ZONE	APPROX. NET FT.	KH FROM PRE-FRAC PBU (FINAL SLOPE)* md-ft	K	EST. RESERVOIR PRESS., PSI
1	60	0.3	.005	4800
2	30	0.3 (est.)	.01	4650
3	50	1.0	.02	4200
4A	50	.07	.0014	4000
4B	30	.03	.001	4000
5	60	0.2	.0033	3815
6	70	0.14	.002	3680
7	50	0.22	.0044	3200
Total (Mesaverde Only)	400	2.26	.00565 (avg)	
8	40	0.5	.0125	3000
9	125	2.0	.016	2865

*Final slope - last measured pressure value connected to est. value for reservoir pressure.

Reservoir Characteristics used in Economic Evaluation

(Mesaverde)

Item	Value
Net thickness	400 feet
Gross thickness	600 feet
Porosity	.09 fraction
Water saturation	.60 fraction
Initial reservoir pressure	4000 psi
Flowing well pressure	500 psi
Average lens size	$(1500)^2$ $(ft)^2$
Effective fracture length	200 feet (wellbore to tip)
Gas Permeability	.005 md
Maximum permissible flow rate	3000 MSCFPD

Reservoir Characteristics used in Economic Evaluation

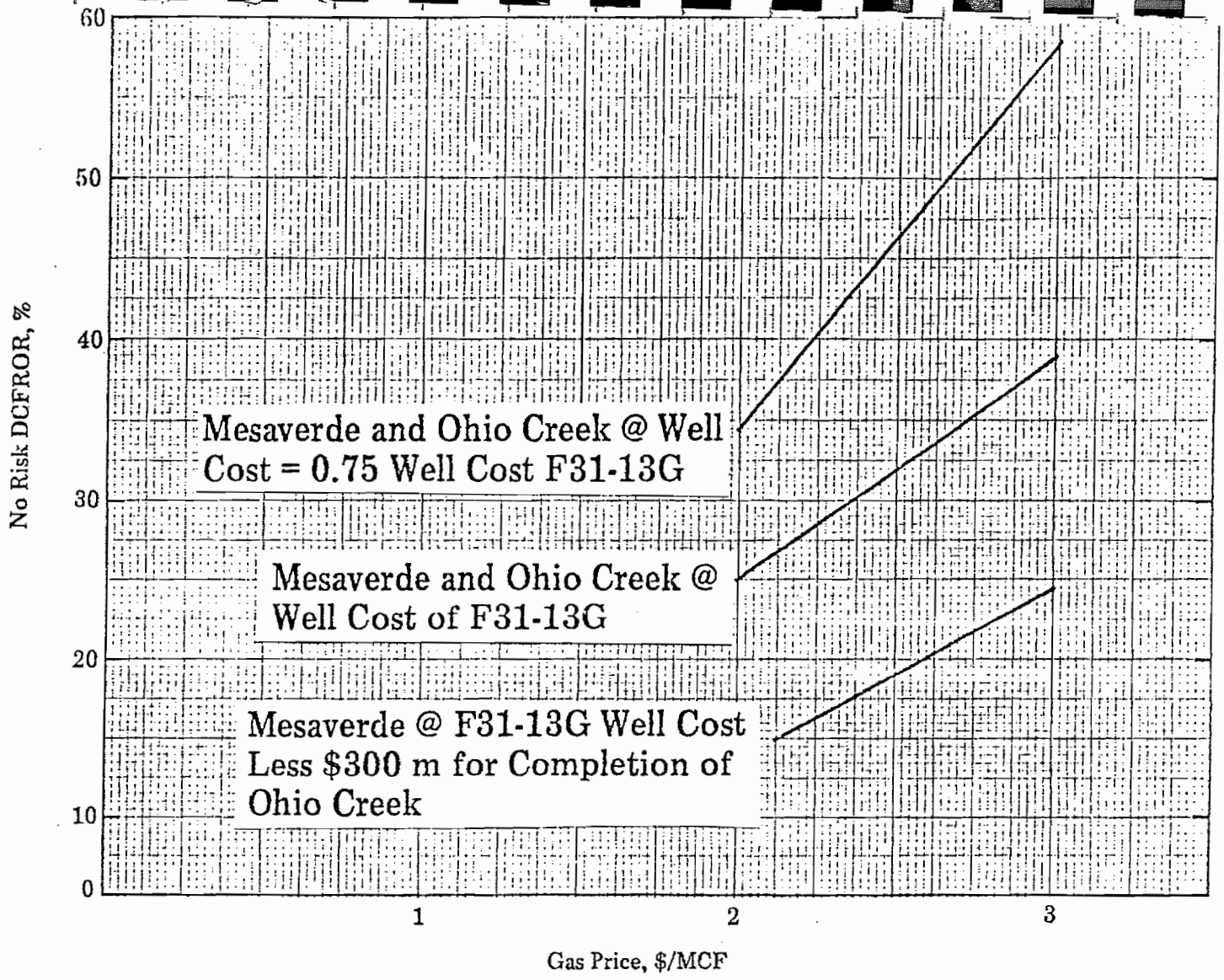
(Ohio Creek)

Item	Value
Net thickness	125 feet
Gross thickness	150 feet
Porosity	.09 fraction
Water saturation	.60 fraction
Initial reservoir pressure	3000 psi
Flowing well pressure (BHP)	500 psi
Well spacing	160 acres
Effective fracture length	525 feet
Gas permeability	.012 md
Maximum permissible flow rate	2500 MSCFPD

Economic Parameters

Item	Value
Total well cost	$3900 M*
Intangible costs (expense)	$3400 M*
Tangible costs (capital)	$ 500 M
Working interest	.875 fraction
Severence and ad-valorem tax	6.8% of wellhead price
State tax	6%
Federal tax	48%
Investment	Beginning of year discounting
Cash flow	Mid-year discounting
Gas sales price	Variable

*Add $300 M when Ohio Creek Zone is included.



Economic Potential of Piceance Basin,

Tight Gas Sands as Indicated by Mobil F31-13G Well

Fallon - North Personville, Texas MHF Demonstration - Project 9

Blanket Sand

CONTRACT NO: EF-78-C-08-1547

COST SHARED WITH MITCHELL ENERGY CORP, HOUSTON

COST:	MITCHELL -	$1,075,000
	DOE -	554,000
	TOTAL	$1,629,000

CONTRACT START: MARCH, 1978

NOW COMPLETE PENDING FINAL REPORT

OBJECTIVE: EVALUATE MHF EFFECTIVENESS IN COTTON VALLEY LIMESTONE FORMATION

Fallon - North Personville, Texas MHF Demonstration (continued)

TREATMENT & RESULTS

Basin & Formation	Location	Well	Interval Fractured ft	Fracture Date	Fracture Treatment Lb of Sand	Injected Fluid 10^3 Gal	Production Rates MCFD Before	After	Ratio
Cotton Valley, Limestone	Limestone Cty, Texas	Muse-Duke No. 1	11,235-11,418	11-15-78	2,800,000	891 Gel	2,000	6,600	3.3

- PRODUCTION DECREASED TO 3,000 MCFD BY MID-1979
- RESULTS:
  - LONG FRACTURE (~ 2,500 ft) HAVING HIGH FLOW CAPACITY WAS CREATED.
  - ECONOMICS BASED ON TOTAL COST OF $2,360,000. EST. RESERVE OF 3.25 BCF, $2.24/MCF PLUS 6%/YEAR FOR 10 YEARS INDICATE INTERNAL RATE OF RETURN = 33%
- WELLS IN TREND STIMULATED PREVIOUSLY
  - < 50,000 GAL ACID OR SAND-WATER FRAC
  - INITIAL PRODUCTION: 1-4 MMCFD
  - 200-500 MCFD IN LESS THAN TWO YEARS

Uinta Basin, Utah, MHF Demonstration - Project 2

CONTRACT NO: EY-76-C-08-0680

COST SHARED WITH PACIFIC TRANSMISSION SUPPLY COMPANY

COST:	PTS CO. -	$ 557,811
	DOE -	1,098,775
	TOTAL	$1,656,586

CONTRACT START: SEPTEMBER, 1976

CONTRACT COMPLETED: SEPTEMBER, 1978

OBJECTIVE: EVALUATE MHF EFFECTIVENESS IN DEEP FORMATIONS IN UINTA BASIN, UTAH
NO MHF PERFORMED. DRY HOLE.

Wattenberg Field Dry Gas Cycling Experiment - Project 11

CONTRACT NO: EY-77-C-08-1514

COST SHARED WITH COLORADO INTERSTATE GAS CO.

COST:	CIG -	$ 99,000
	DOE -	75,000
	TOTAL	$174,000

CONTRACT START: SEPTEMBER, 1977

ANTICIPATED COMPLETION: MARCH, 1981

OBJECTIVE: EVALUATE EFFECTIVENESS OF CYCLIC INJECTION OF DRY GAS IN STIMULATING PRODUCTION FROM LOW PERMEABILITY SANDS

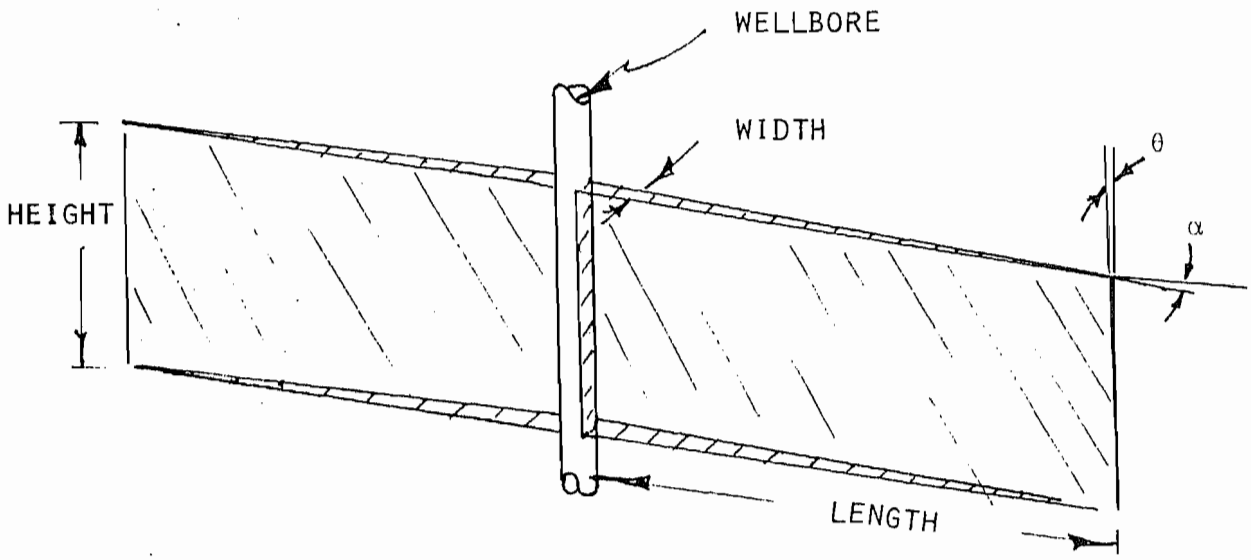
Herb Carroll
Draft + Presentation!

RESEARCH EFFORT IN W.G.S.P.

- STARTED DUE TO ANOMALOUS FIELD RESULTS
  - HIGH SW IN SAND LENS NOT PREDICTED WITH PRESENT LOGGING TECHNIQUES
  - LOW PRODUCTIVITY RATIO FROM PRODUCTION BEFORE AND AFTER STIMULATION

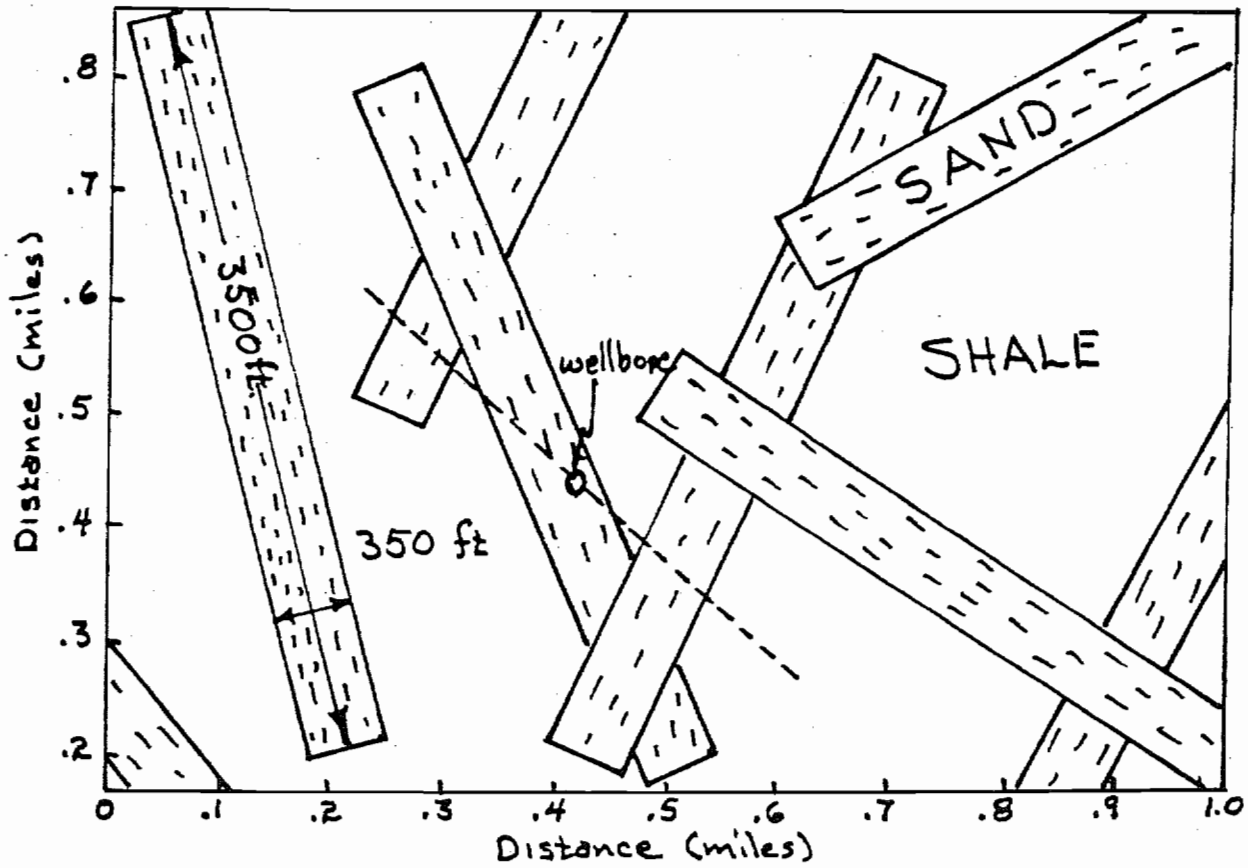
FRACTURE TECHNOLOGY RESEARCH

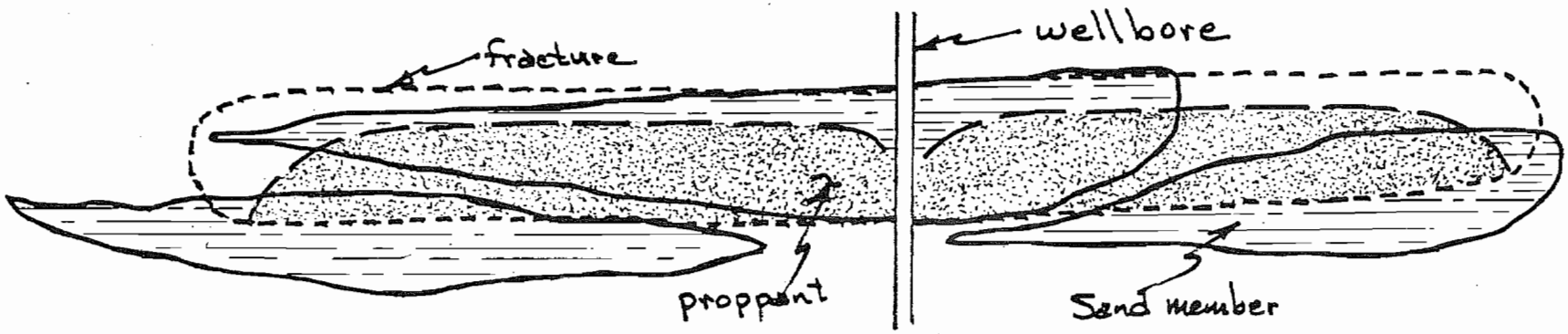
- FRACTURE DIRECTION, ORIENTATION AND DIMENSIONS



- FRACTURE CONTAINMENT

- FRACTURE CONDUCTIVITY


SAND
SHALE
wellbore
3500 ft
350 ft
Distance (miles)
Distance (miles)
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0


fracture
wellbore
proppant
Sand member

CRITICAL ISSUES

- DIAGNOSTIC TOOLS AND INTERPRETATION TECHNIQUES ARE INADEQUATE FOR RESERVOIR EVALUATION AND FRAC DESIGN.

  - DEVELOP AND IMPROVE LOGGING TOOLS FOR MEASURING OF FLUID SATURATIONS, POROSITY, PERMEABILITY (IN SITU), MECHANICAL AND CHEMICAL PROPERTIES OF ROCK IN GAS ZONES.

  - IMPROVE CALIBRATION OF LOGGING AND CORING TECHNIQUES.

  - DEVELOP CAPABILITY TO DETERMINE GEOMETRY, DOMINANT ORIENTATION AND DISTRIBUTIONS OF GAS BEARING LENSES, INCLUDING THOSE REMOTE FROM WELLBORE.

  - IMPROVE CAPABILITY TO MEASURE INDUCED FRACTURE GEOMETRY (FRACTURE GROWTH VERTICALLY AWAY FROM THE WELLBORE, WIDTH, LENGTH).

  - NEED CAPABILITY TO MEASURE (POST FRAC) FRACTURE CONDUCTIVITY AND FORMATION DAMAGE.

  - IMPROVE CAPABILITY TO MEASURE REGIONAL STRESS FIELD (WHICH DETERMINES FRACTURE ORIENTATION).

PARTICLE DATA FROM FLUIDS AND PROPPANTS USED IN

UINTA COUNTY, UTAH, MHF EXPERIMENT

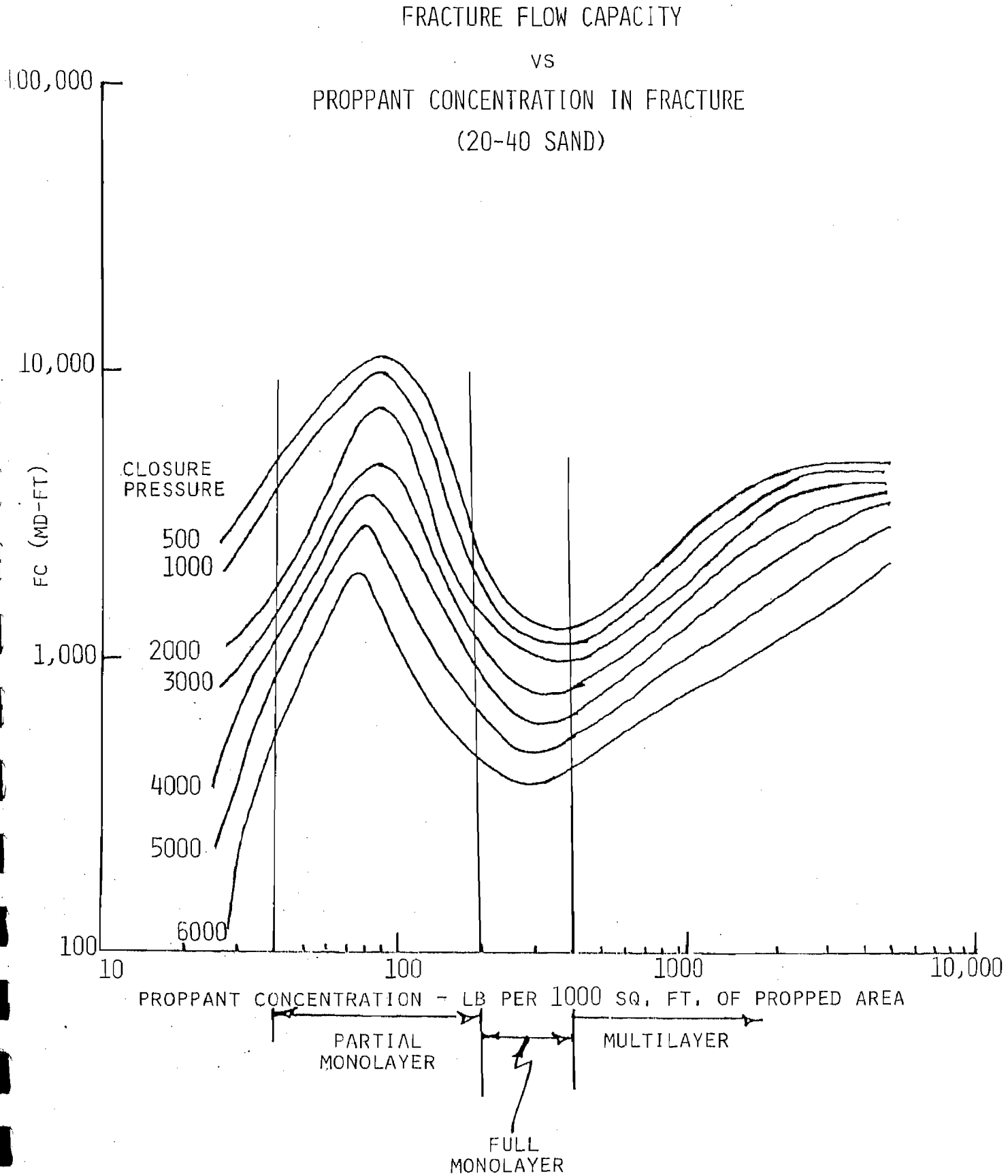
(corrected for background)

Sample Number	Sample source	Mean (microns)	Mode (microns)	Concentration particles/ml	Range (microns)
1	Green River	2.74	2.74	77,000	1.54- 5.60
	Water	2.94	3.08	78,000	1.54- 6.15
2	Fines from 20/40 mesh sand	2.87	2.81	84,000*	1.54- 6.60
3	Fines from 40/60 mesh sand	2.39	1.81	62,000*	1.54- 5.35
4	Broken 40 Pound (18.41 Kg) gelled	3.62	2.87	285,000	1.54-20.4
	2 percent KCl water	3.62	2.87	284,000	1.54-21.3
5	Fluid produced back	9.97	10.93	435,000	1.77-39.80
	on clean-up	10.20	10.93	414,000	1.81-37.91

* Fines washed from 120 grams of sand with 300 cc of 2 percent KCl solution.

FACTORS EFFECTING FRACTURE CONDUCTIVITY AND PERFORMANCE

- PROPPANT TRANSPORT AND PLACEMENT
  - FLUID VISCOSITY
  - PROPPANT CLUSTERING AND SETTLING RATE
  - PROPPING AGENT TYPE, SIZE AND CONCENTRATION
- DAMAGE IN THE FRACTURE
  - CRUSHING OF THE PROPPING AGENT
  - EMBEDMENT OF THE PROPPING AGENT
  - PLUGGING OF THE FRACTURE PORE SPACE BY FORMATION FINES, FLUID LOSS ADDITIVES, FRAC-FLUID RESIDUES AND ETC.
- DAMAGE TO THE FORMATION
  - SWELLING CLAYS
  - MOVEMENTS OF FINES AND PRECIPITATES
  - UNBROKEN GEL
  - PHYSICAL OR CHEMICAL REACTIONS BETWEEN THE INJECTED MATERIALS AND THE IN SITU MATERIALS


FRACTURE FLOW CAPACITY
VS
PROPPANT CONCENTRATION IN FRACTURE
(20-40 SAND)
100,000
10,000
1,000
100
FC (MD-FT)
CLOSURE PRESSURE
500
1000
2000
3000
4000
5000
6000
10
100
1000
10,000
PROPPANT CONCENTRATION - LB PER 1000 SQ. FT. OF PROPPED AREA
PARTIAL MONOLAYER
MULTILAYER
FULL MONOLAYER

ESTIMATED PORE SIZE IN THE FRACTURE

40/60-MESH SAND SHOWED A HIGH ROUNDNESS NO.

420 MICRON PARTICLES AS PRIMARY MATERIAL

250 MICRON PARTICLES AS SECONDARY

TERTIARY PORE SIZE GIVEN BY:

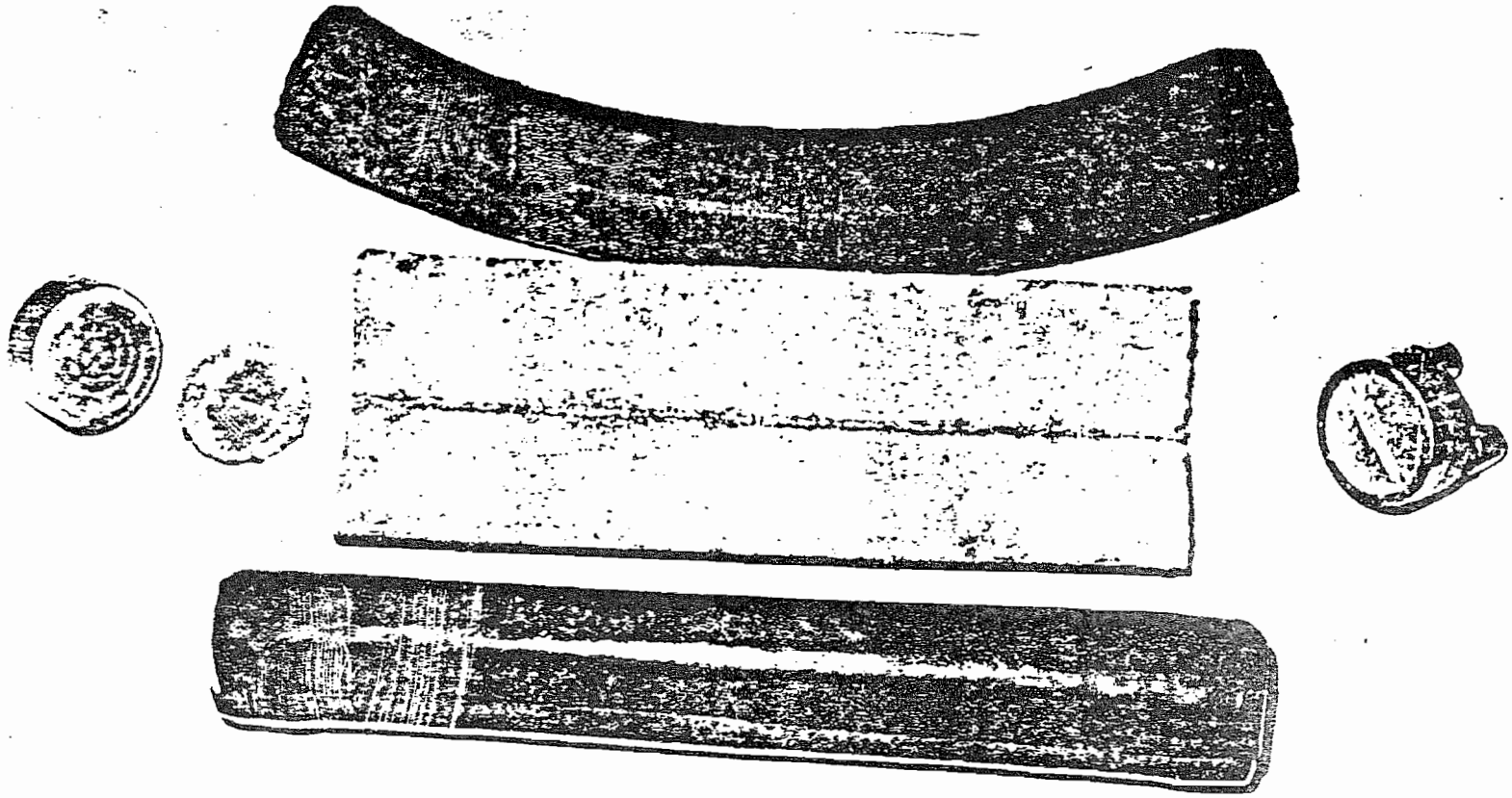
DIA. PORE = 0.225 x DIA. PARTICLE (1)

MAXIMUM DIAMETER = 95 MICRONS

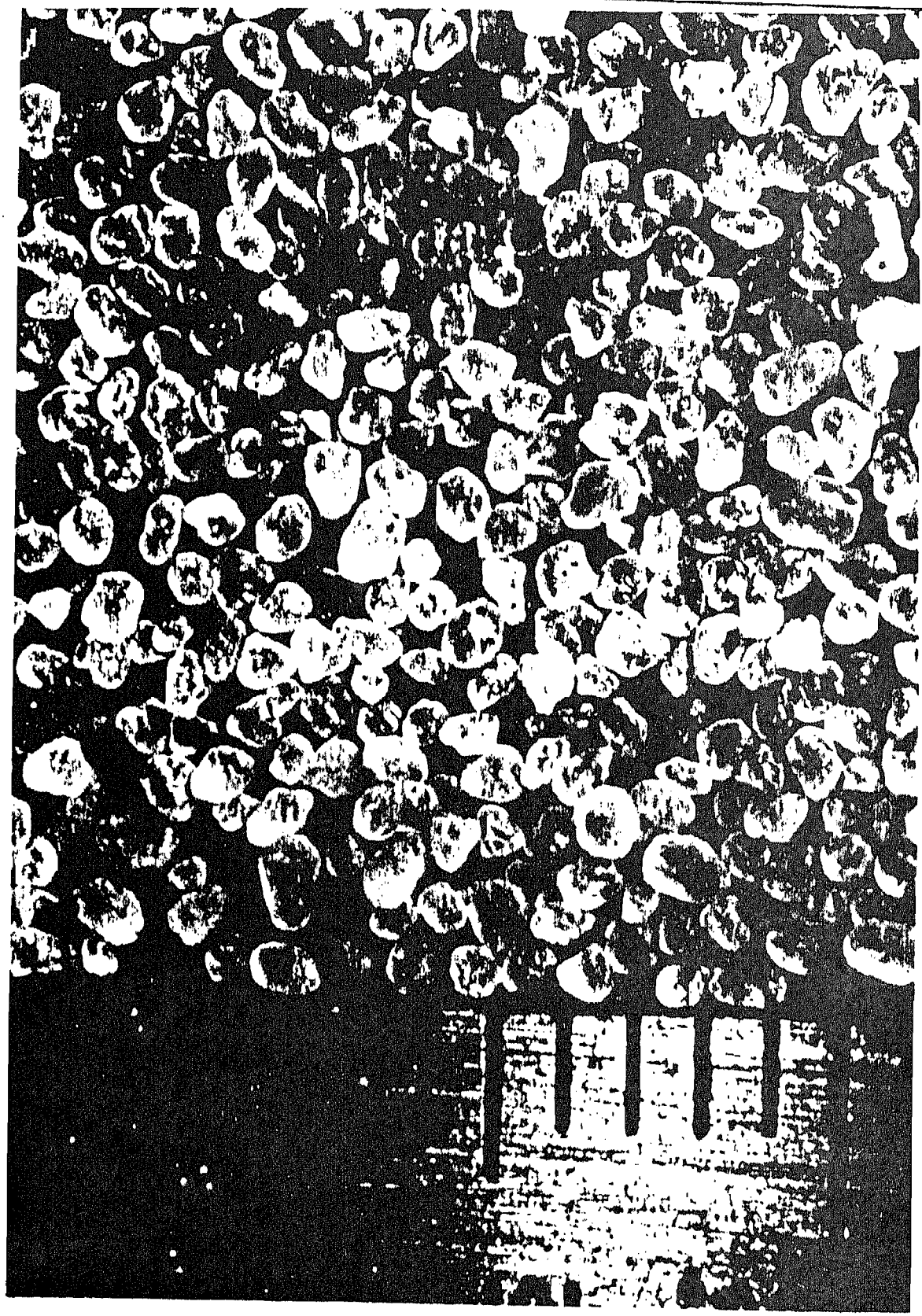
MINIMUM DIAMETER = 56 MICRONS

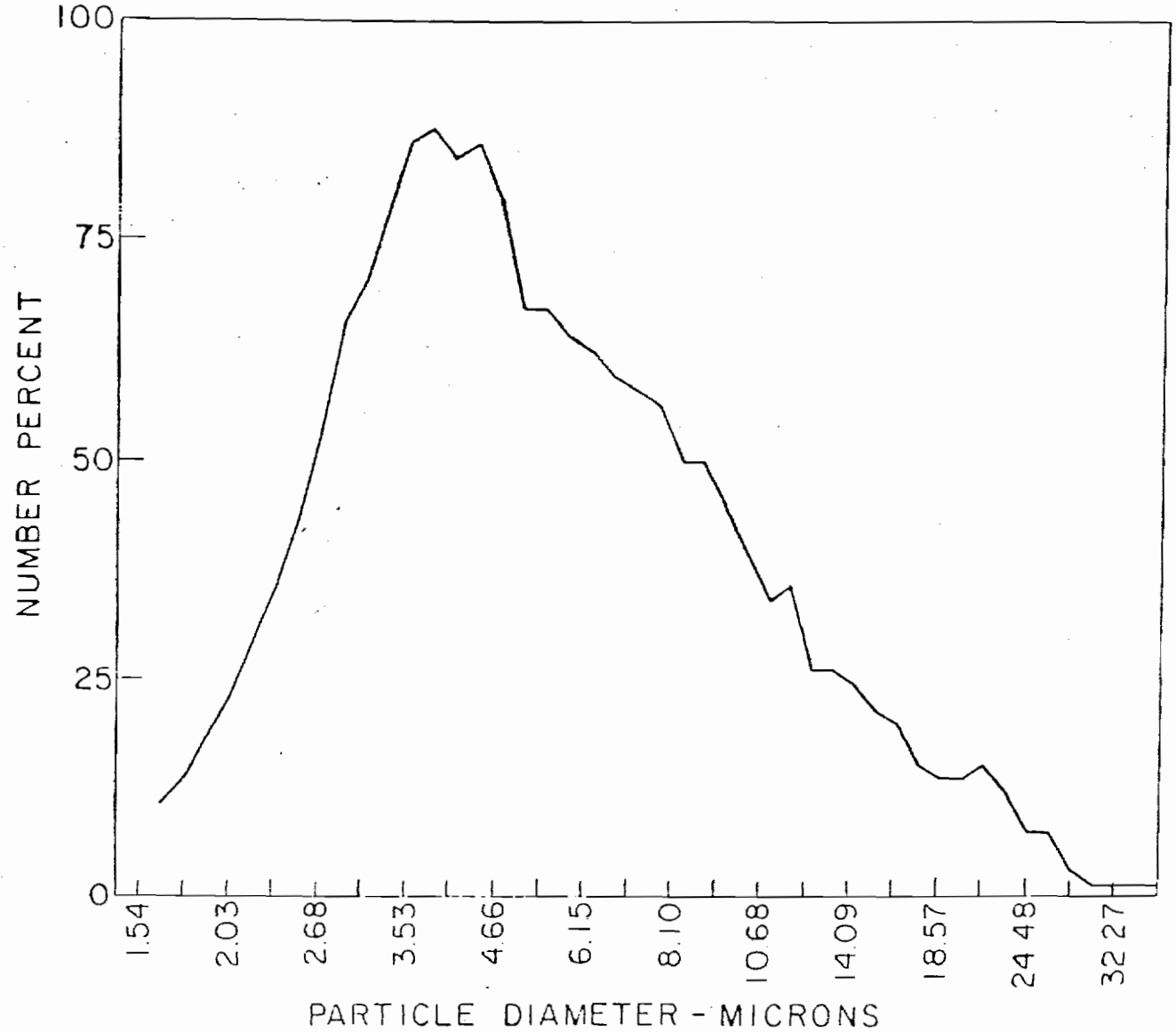
THEREFORE INTERCONNECTING CHANNELS $\leq$ 95 MICRONS
REDUCED BY PRESSURE AND SOLIDS

(1) MICROMERITICS, J. M. DALLAVALLE, 2ND EDITION, PITMAN PUBLISHING CORP., NEW YORK, 1948.

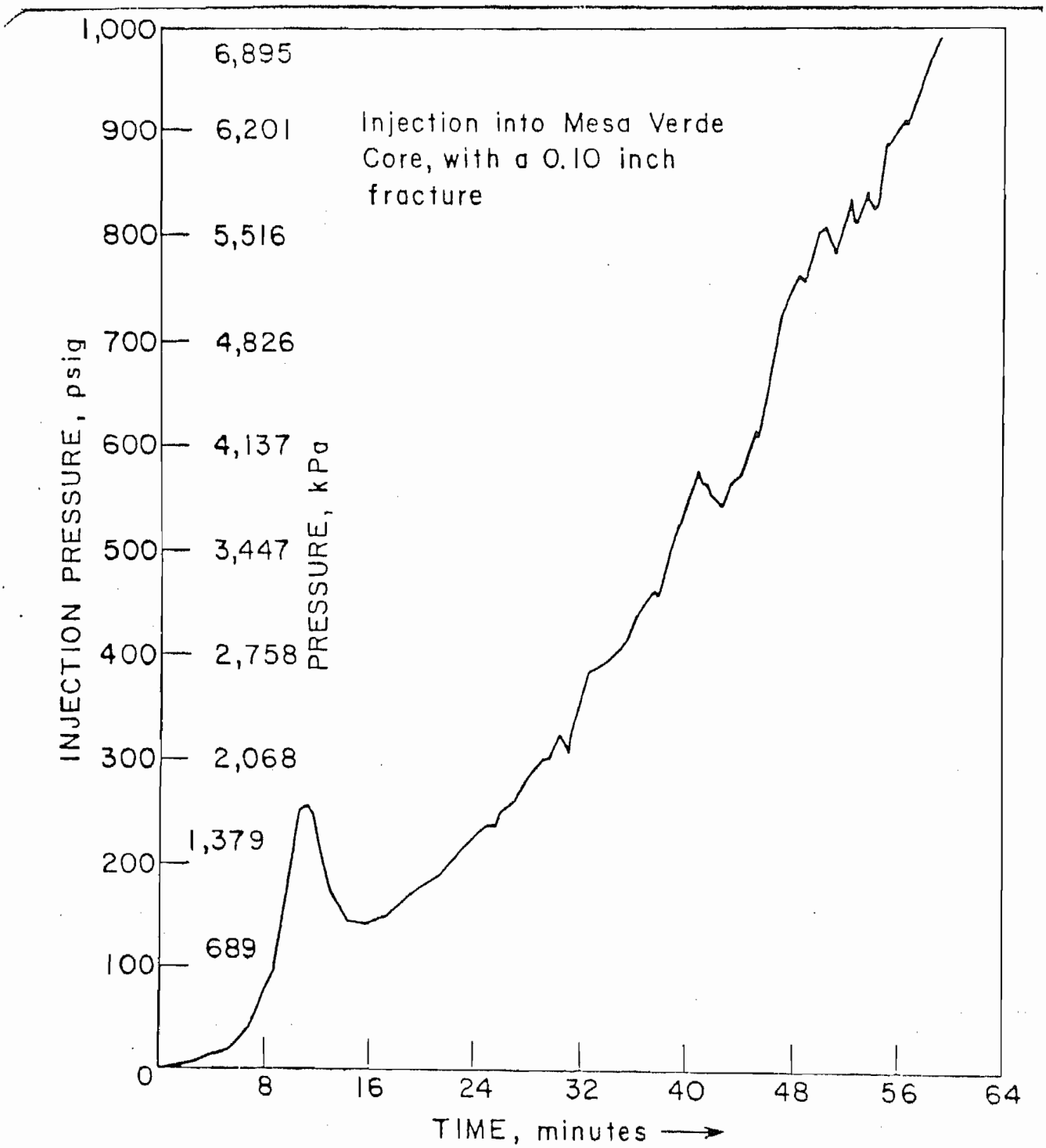


Disassembled core showing; a) rubber tubing, b) heat shrinkable tubing, c) split core with sand, d) inlet end piece, and e) outlet end piece.

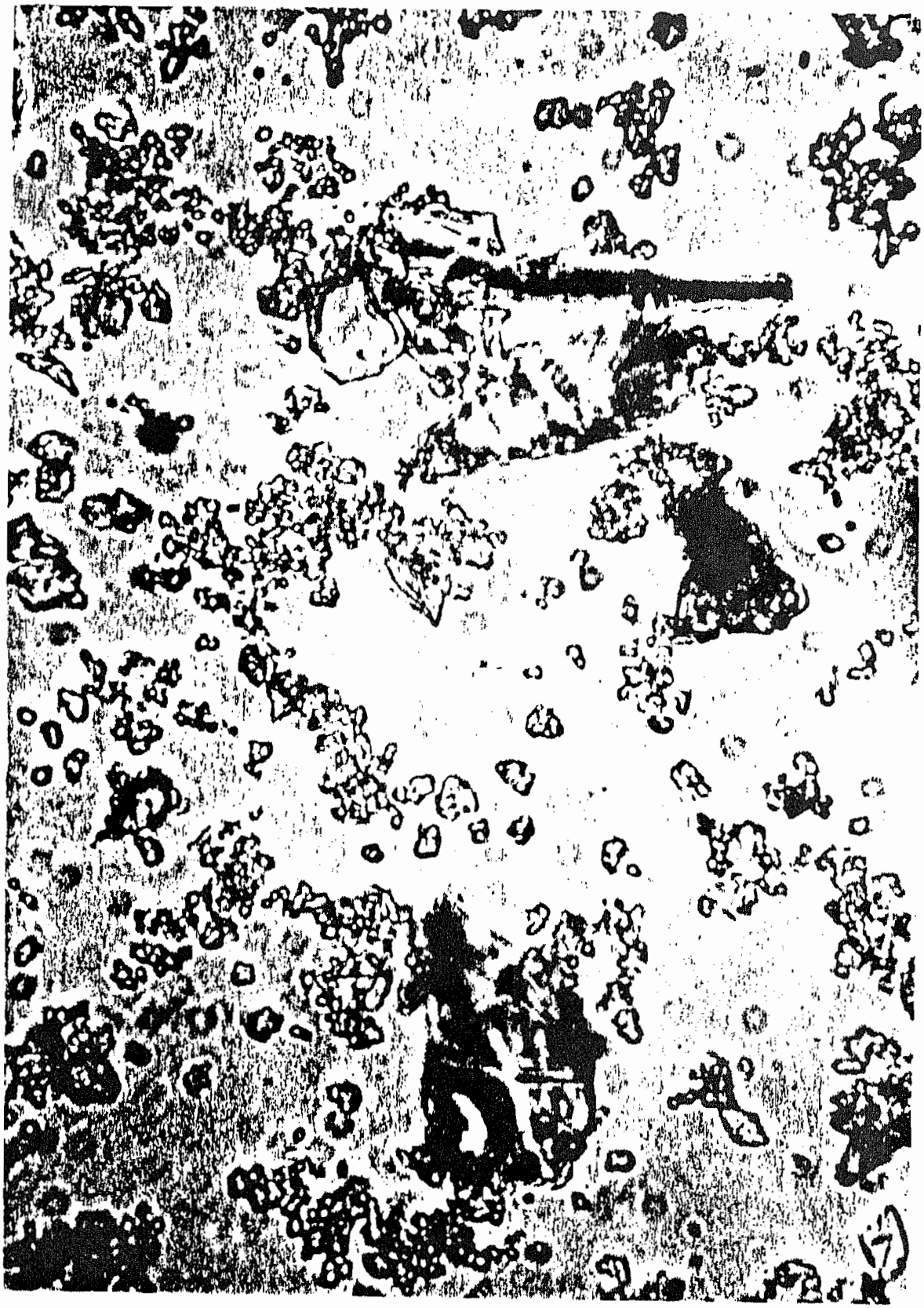


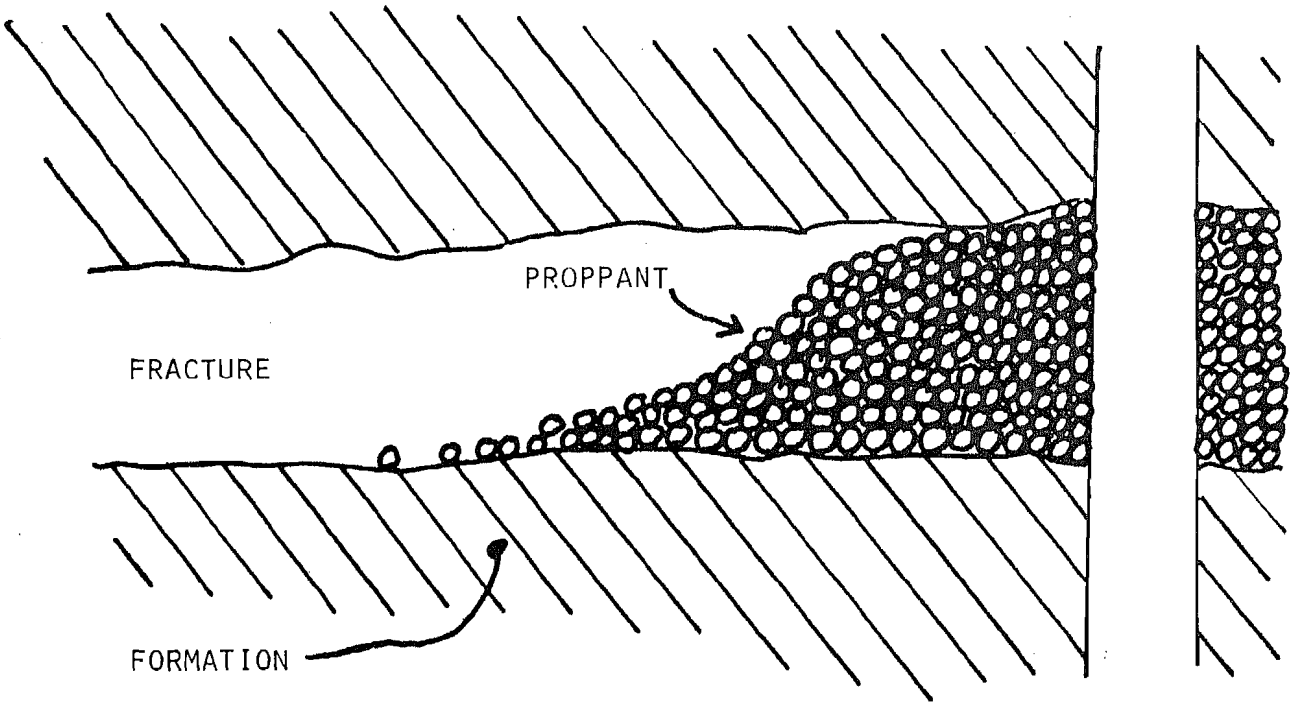


Particle size distribution in the broken frac-fluid with a low sand concentration.



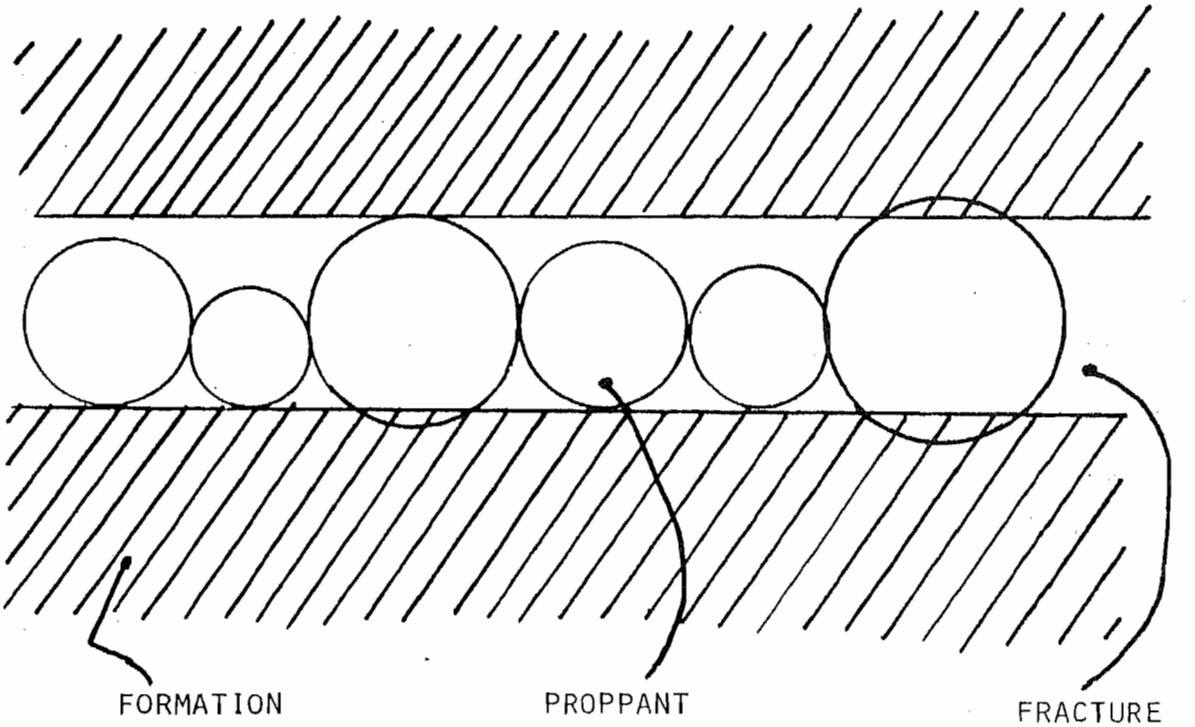
Pressure profile from injection of broken frac-fluid with sand into the propped fracture in the Mesaverde core.



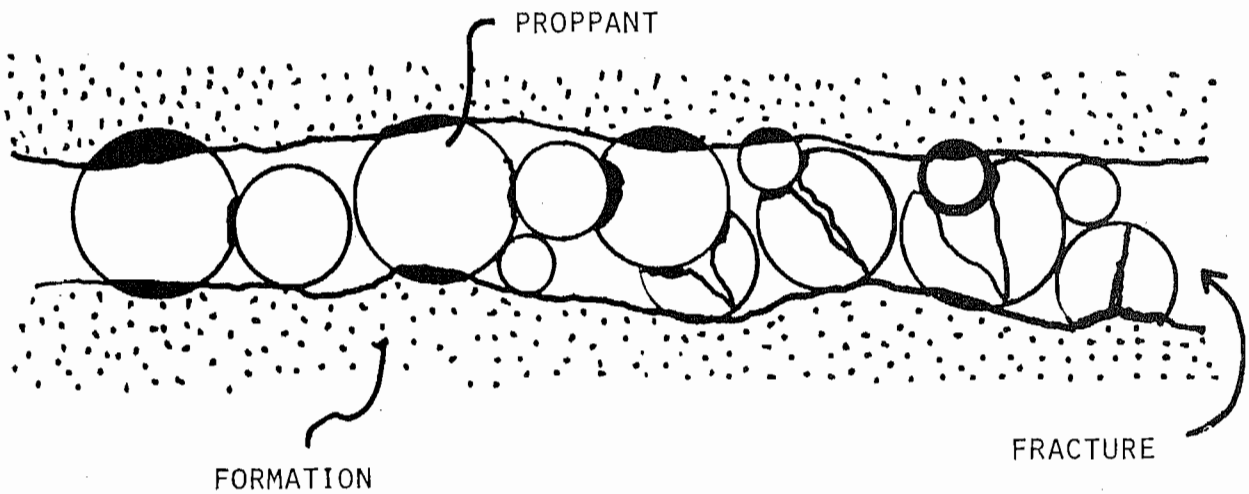


PROPPANT SUSPENDED IN FRACTURING FLUID CAN PREMATURELY SETTLE OUT IF GEL VISCOSITY DECREASES TOO SOON. FACTORS THAT CAN CAUSE EARLY VISCOSITY DROP ARE:

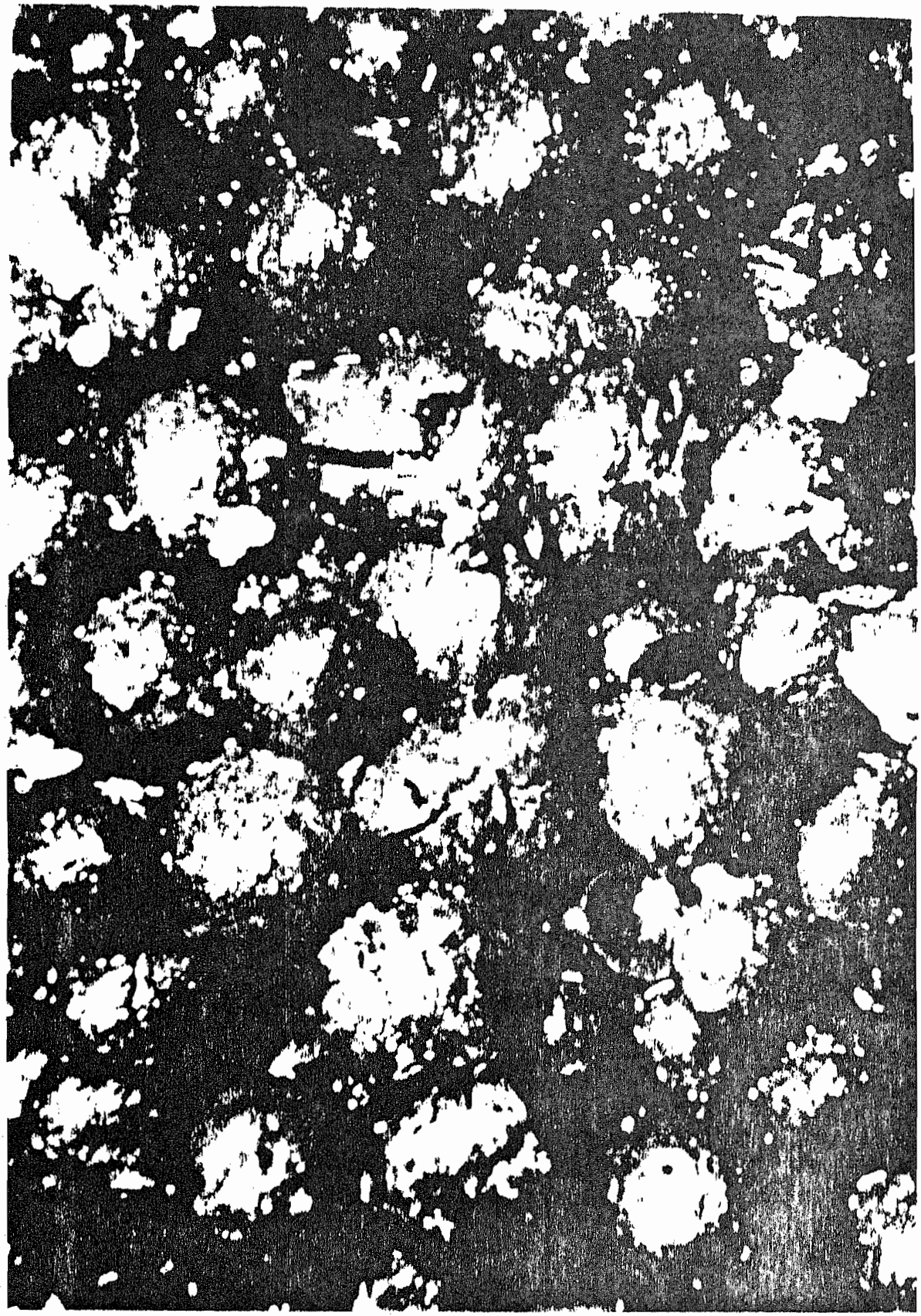
- INCREASE IN FRACTURE FLUID TEMPERATURE AS IT MOVES INTO FRACTURE
- TRACE METAL IONS IN FORMATION WATER
- POOR PH CONTROL
- HIGH SHEARING OF FRACTURING PROCESS

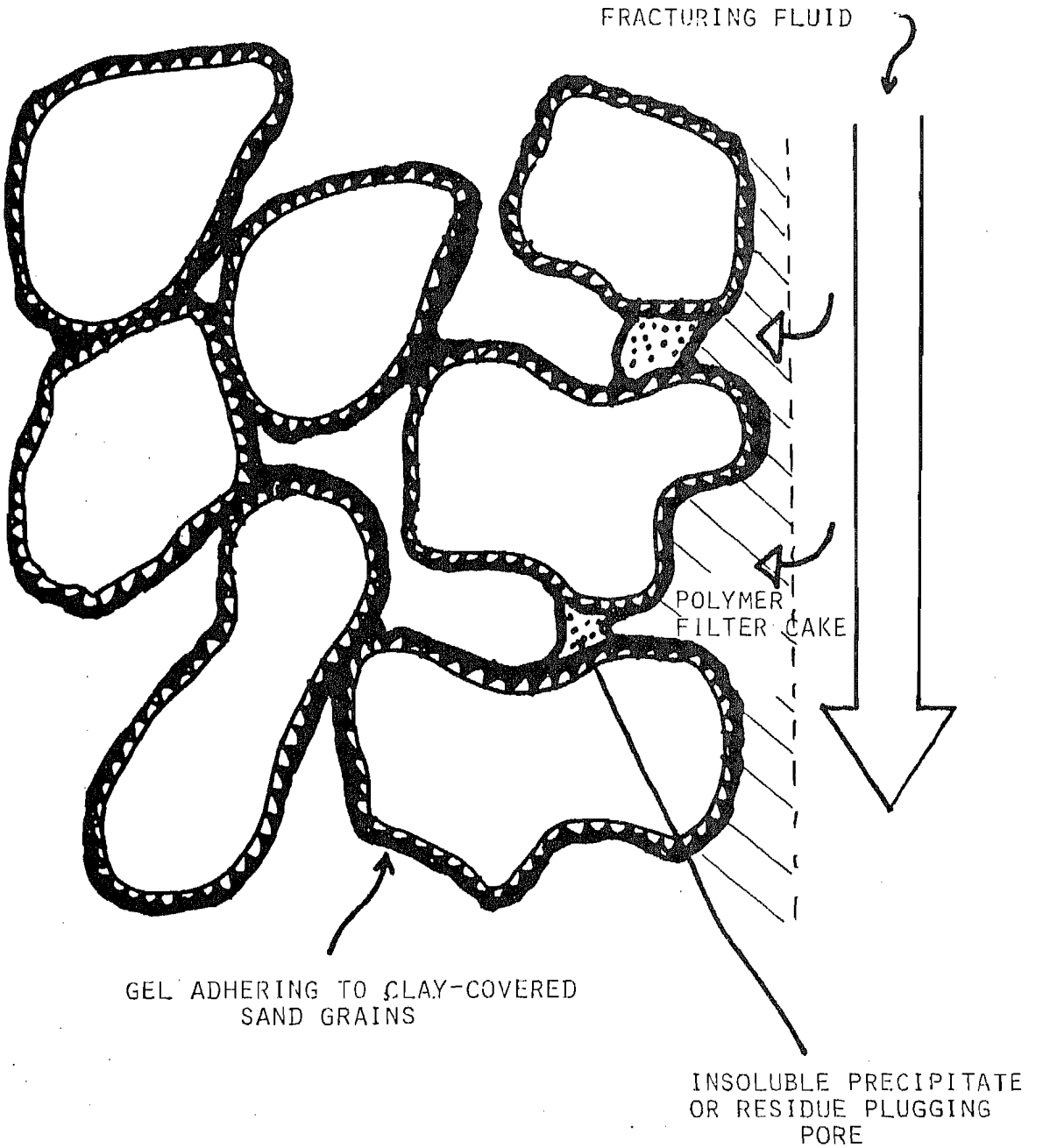


WIDE RANGE OF PROPPANT SIZE MEANS ONLY SMALL PERCENTAGE OF PROPPANT SUPPORTING FRACTURE

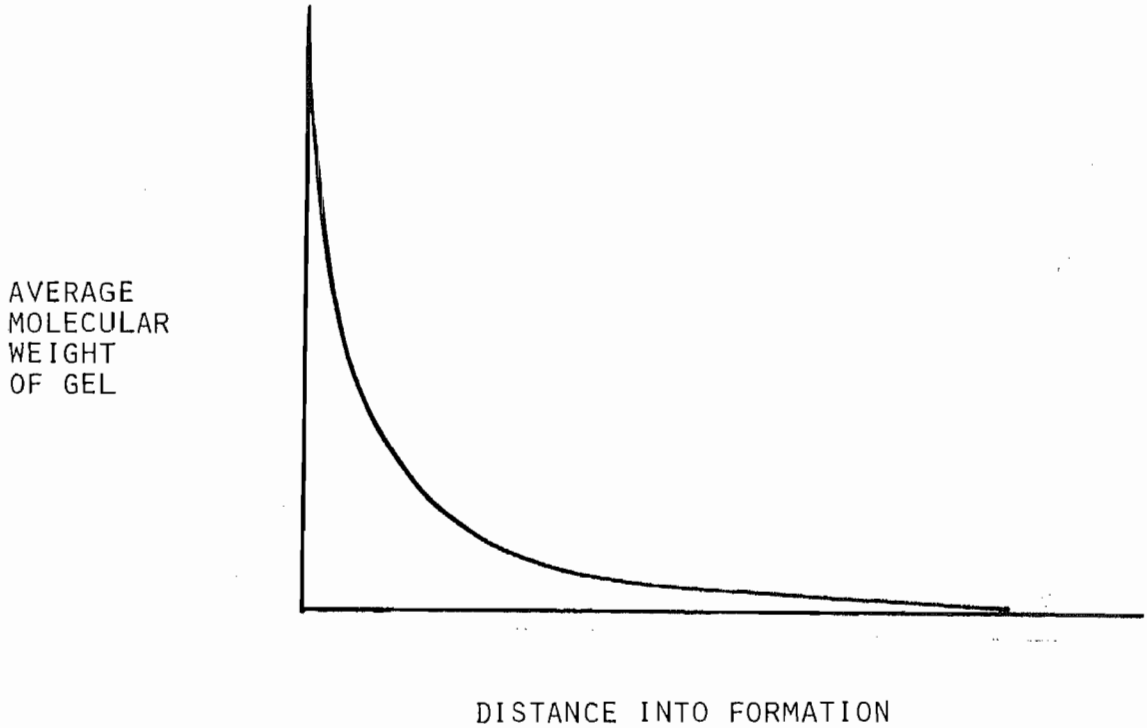


PROPPANT CRUSHING CAN BE CAUSED BY THE FORMATION OR OTHER PROPPANT. SINTERED BAUXITE TENDS TO MASH AND SPLIT RATHER THAN SHATTER LIKE SAND PROPPANT.

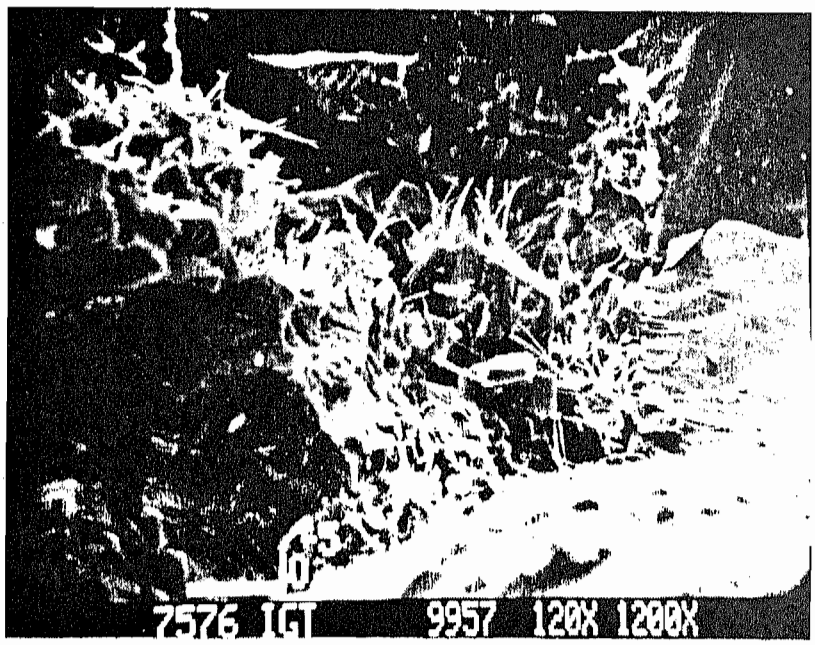




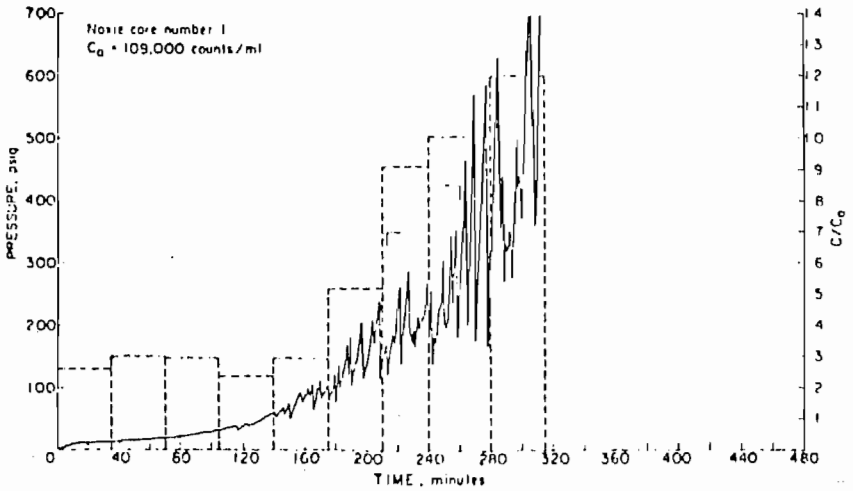
FORMATION DAMAGE BY FRACTURING FLUIDS



GEL BUILDS UP ON FORMATION SURFACE AS FRACTURE FLUID IS FORCED INTO THE FORMATION. THIS LIMITS THE AMOUNT OF VERY HIGH MOLECULAR WEIGHT GEL PASSING INTO THE FORMATION. THE AVERAGE MOLECULAR WEIGHT WILL DECREASE RAPIDLY AS THE FLUID MOVES DEEPER INTO THE FORMATION. EVEN WHEN BROKEN, THE DEGRADED GEL HAS A HIGH PERCENTAGE OF MATERIAL WITH MOLECULAR WEIGHT GREATER THAN 10^6 (40-80%).



SEM PHOTOGRAPH OF CORE CONTAINING ILLITE
CLAYS LINING PORES AND OBSTRUCTING CAPILLARIES



Pressure and effluent particle concentration versus time

PROPPANT EMBEDMENT INTO SHALES

- SHALES HIGH IN KAOLINITE OR CHLORITE (20-40%) ARE COMPATIBLE WITH POTASSIUM BRINE AND CAN BE PROPPED ABOUT AS WELL AS THE NEARBY SANDSTONES (UNITA AND PICEANCE BASINS).

- SHALES HIGH IN MONTMORILLONITE OR MIXED LAYER MONTMORILLONITE-ILLITE (10-40%) SWELL WHEN CONTACTED BY WATER. THESE SHALES FALL APART EVEN IN POTASSIUM BRINE AND CANNOT BE EASILY PROPPED (NORTHERN GREAT PLAINS PROVINCE).

RESEARCH CONTRACTS TO ACCOMPLISH TASKS

1.) PROPPANT TRANSPORT IN M.H.F.

UNIVERSITY OF TULSA - TULSA, OKLAHOMA

2.) HIGH STRENGTH, LOW DENSITY PROPPANT STUDY.

TERRA TEK, INC. - SALT LAKE CITY, UTAH

3.) ANALYSIS OF MHF TESTS; AN ENGINEERING STUDY.

INTERCOMP, INC.

4.) MINEBACK RESEARCH.

SANDIA LABORATORIES

5.) FRACTURE AND PROPPANT TRANSPORT MODELING.

LAWRENCE LIVERMORE LABORATORY

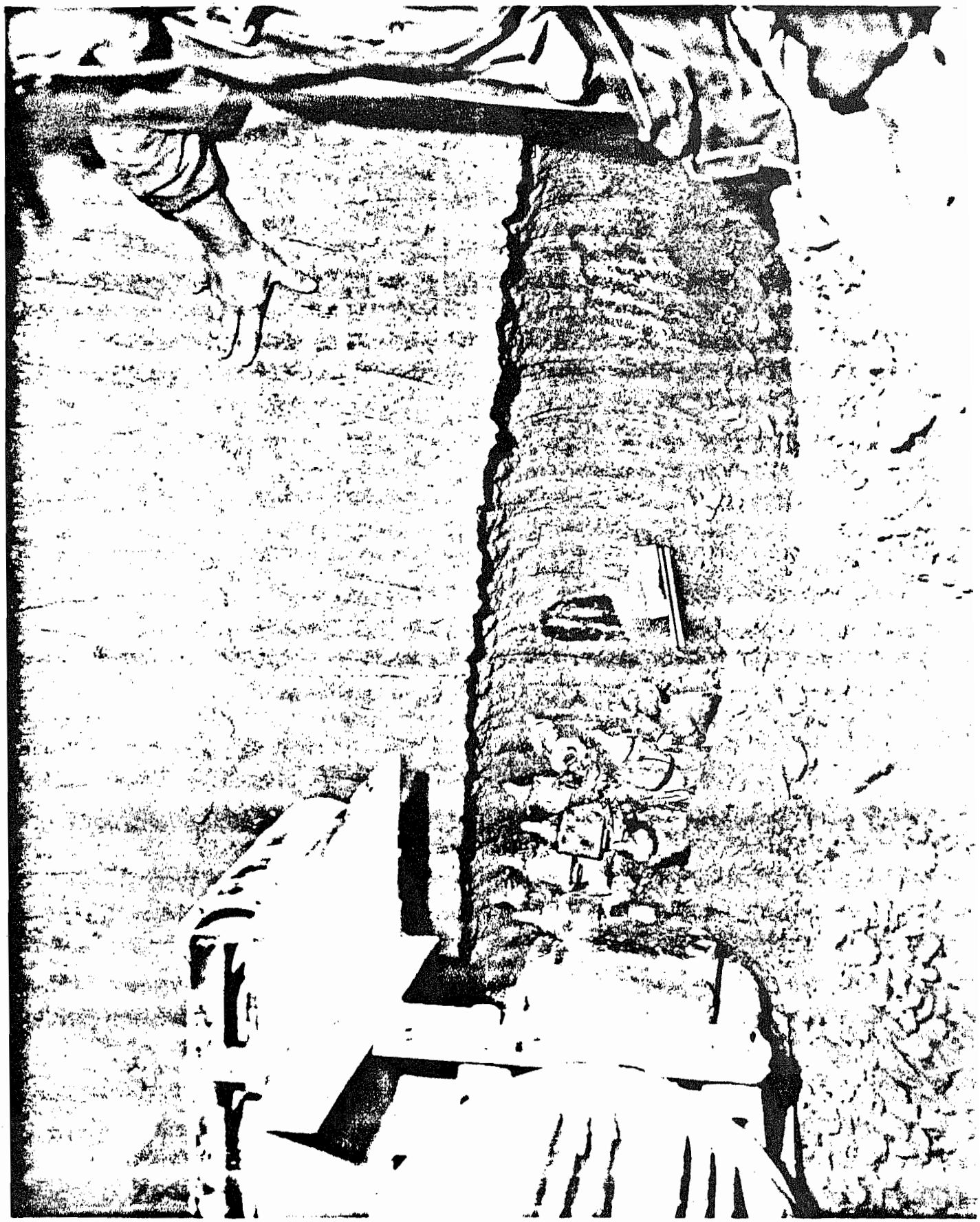
6.) FRACTURE MAPPING PROGRAM.

SANDIA LABORATORIES

NTS MINEBACK PROJECT

PHYSICALLY OBSERVING STIMULATION TECHNIQUES TO DEFINE THEIR DEFICIENCIES AND IMPROVE THEM

Sandia Laboratories



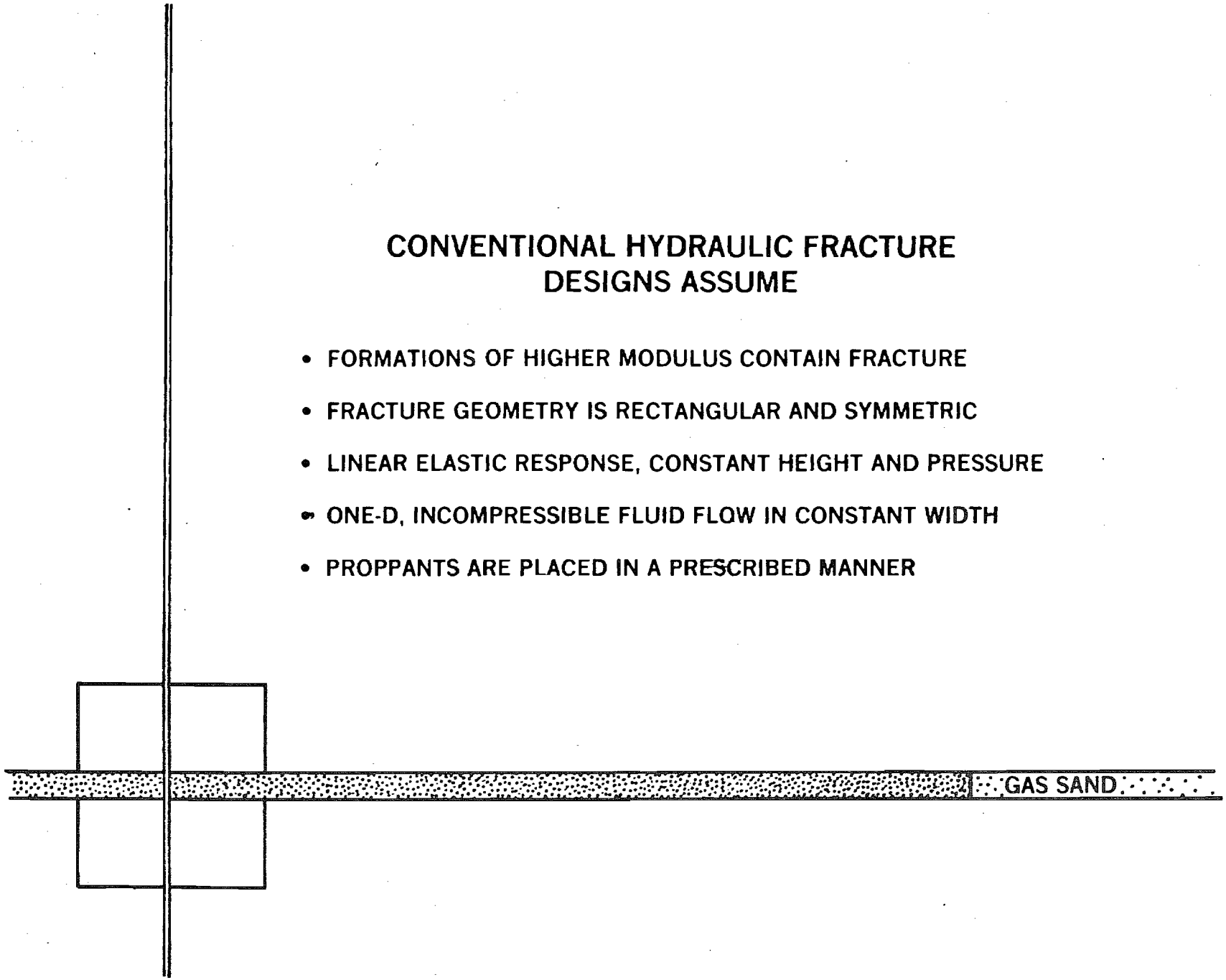
Bag

PROJECT TASKS

- MINEBACK EXPERIMENTS
- ROCK MECHANICS, FLUID MECHANICS, GEOLOGY AND GEO-CHEMISTRY STUDIES FOR EGR
- INVESTIGATION OF INNOVATIVE STIMULATION TECHNIQUES
- CALIBRATION OF INSTRUMENTATION TECHNIQUES

CONVENTIONAL HYDRAULIC FRACTURE DESIGNS ASSUME

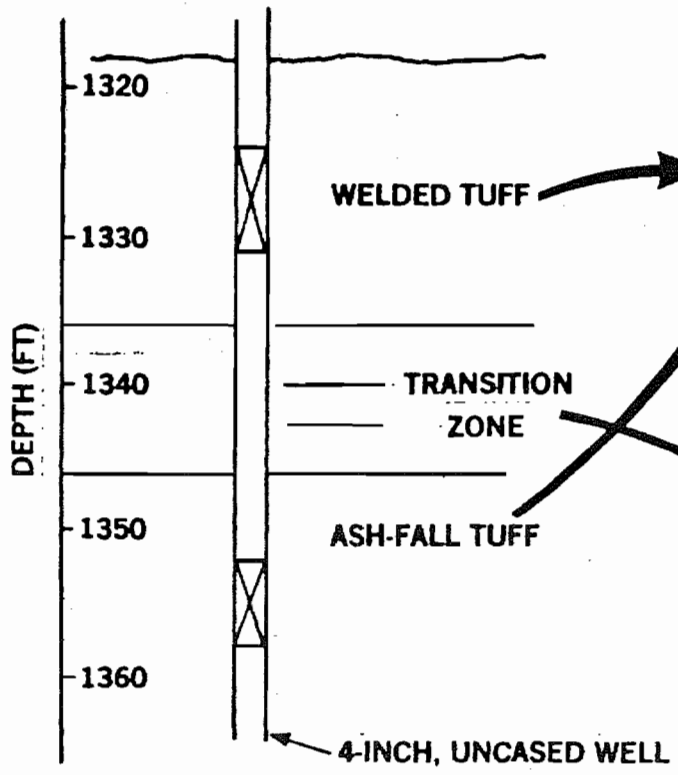
- FORMATIONS OF HIGHER MODULUS CONTAIN FRACTURE
- FRACTURE GEOMETRY IS RECTANGULAR AND SYMMETRIC
- LINEAR ELASTIC RESPONSE, CONSTANT HEIGHT AND PRESSURE
- ONE-D, INCOMPRESSIBLE FLUID FLOW IN CONSTANT WIDTH
- PROPPANTS ARE PLACED IN A PRESCRIBED MANNER



HOLE 6 - FORMATION INTERFACE EXPERIMENT

EXPERIMENT DESIGN

CREATE 50 FT HIGH, 600 FT TOTAL LENGTH FRACTURES FROM OPEN HOLE INTERVALS SHOWN



	DENSITY (g/cm^3)	POROSITY (%)	MODULUS (10^6 psi)	POISSON'S RATIO
WELDED TUFF	2.4	13	3.8	0.238
ASH-FALL TUFF	1.8	45	0.24	0.312

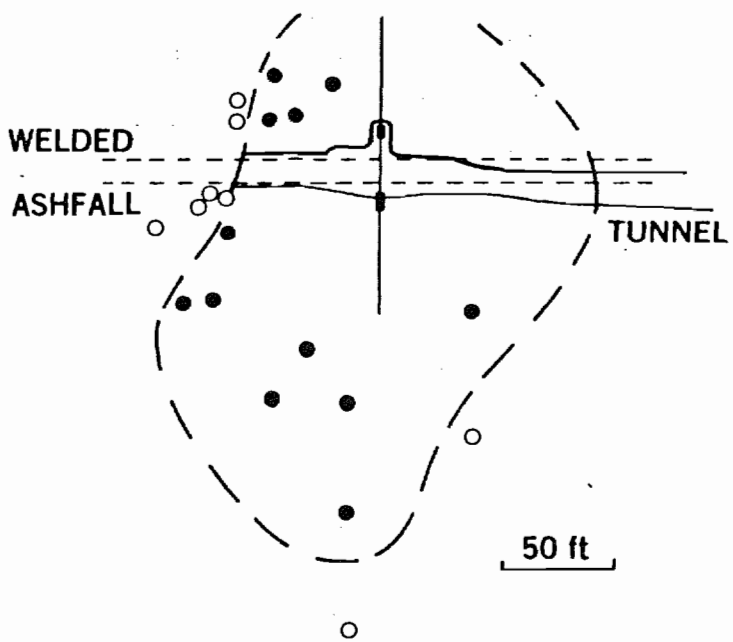
TRANSITION ZONE:

- SOFT ORANGE MATRIX WITH ABUNDANT HARD LITHICS
- GREEN-BROWN, VITRIC, HARD ASH FLOW
- YELLOWISH-BROWN, ASH FLOW, MEDIUM-SOFT

THICKNESS VARIABLE

PROPERTIES TO BE DETERMINED

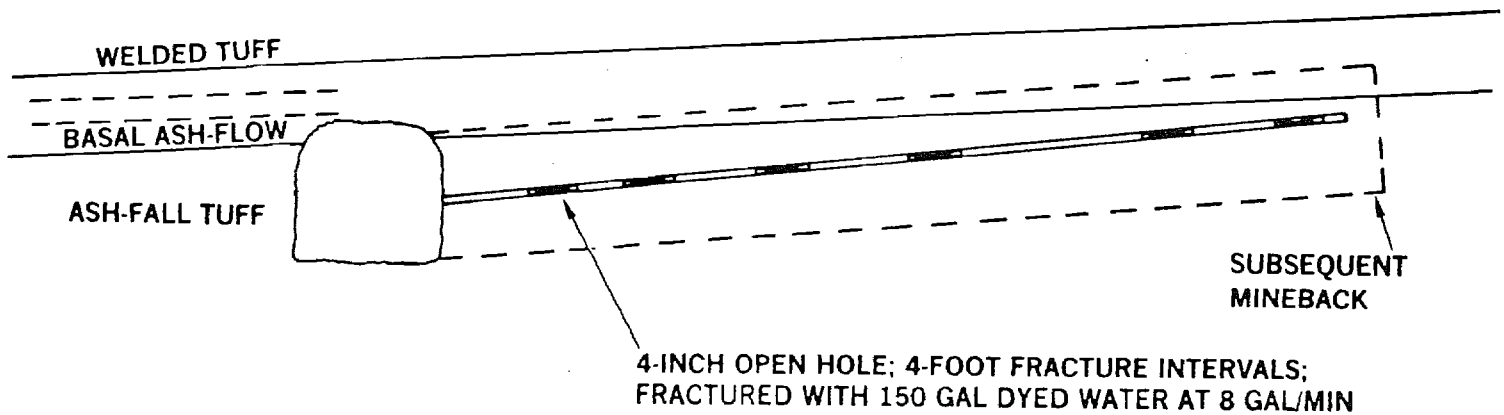
HOLE 6 - FORMATION INTERFACE EXPERIMENT



RESULTS

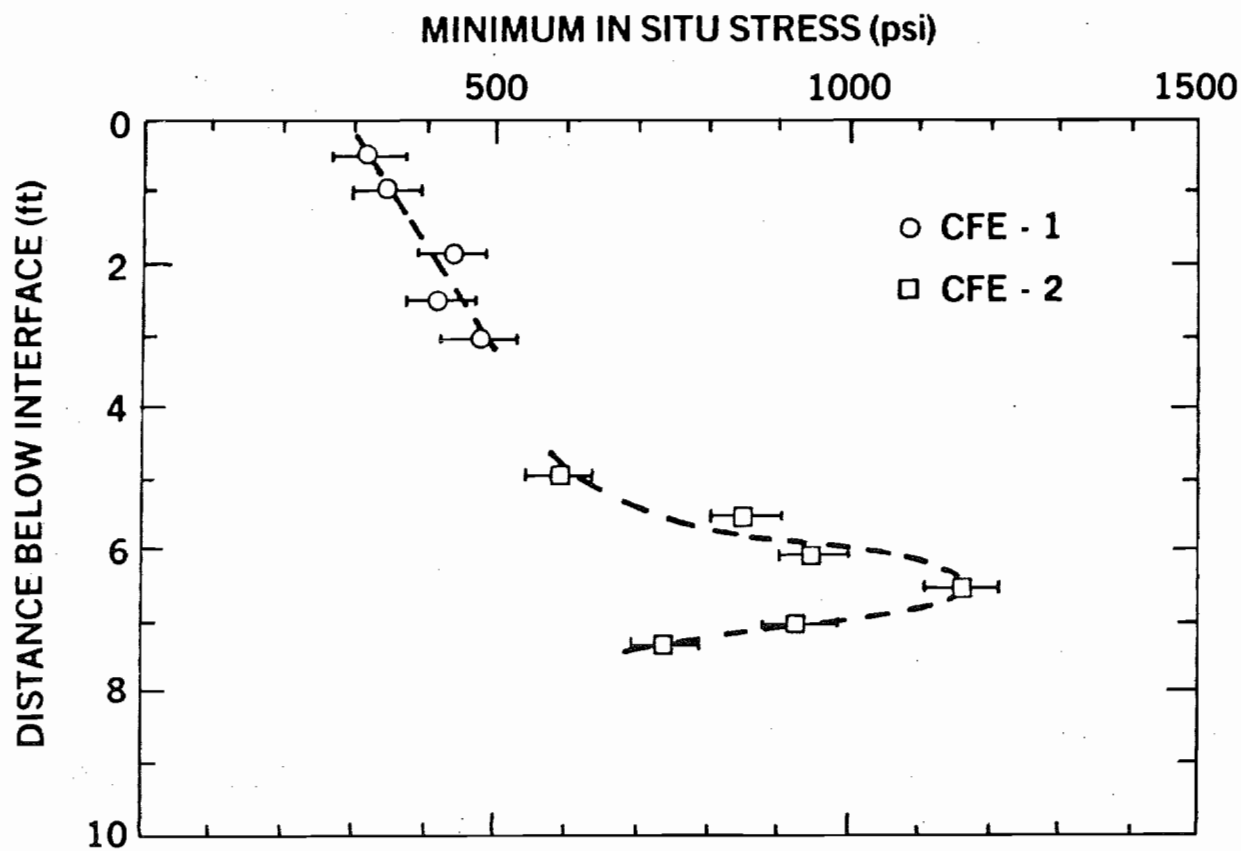
- NO APPARENT EFFECT ON CONTAINMENT
- GROWTH PREDOMINANTLY VERTICAL
- FRACTURE WIDTHS CONSISTENT WITH DESIGN
- NATURAL FRACTURES IN WELDED TUFF
- ~45% OF GROUT "OBSERVED"

INTERFACE TEST SERIES

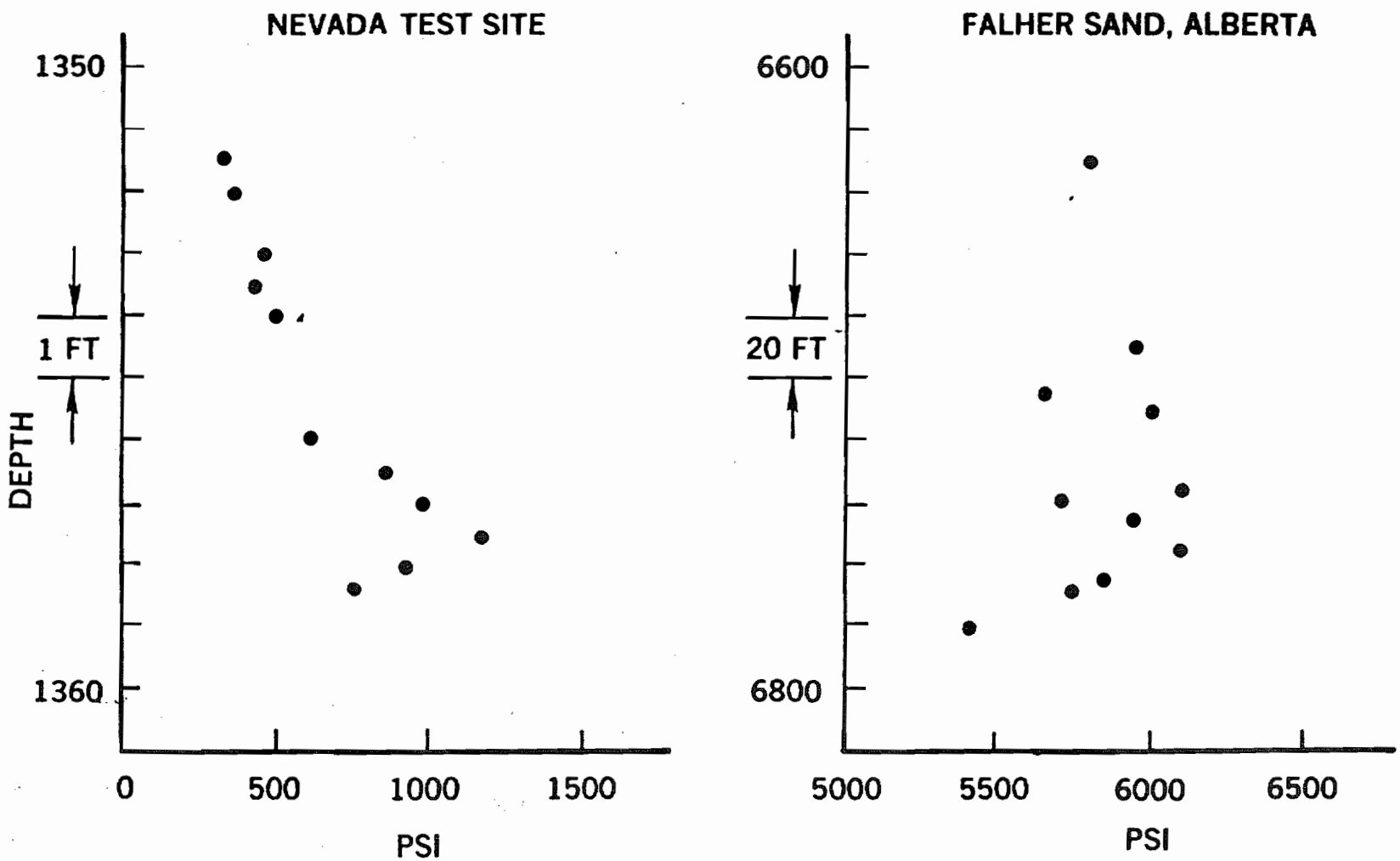


PROPERTIES	DENSITY (g/cm^3)	POROSITY (%)	MODULUS (10^6 psi)	PERMEABILITY (md @ 500 psi)
BASAL ASH-FLOW	2.1	22	1.25	0.005
ASH-FALL	1.7	45	0.25	0.200

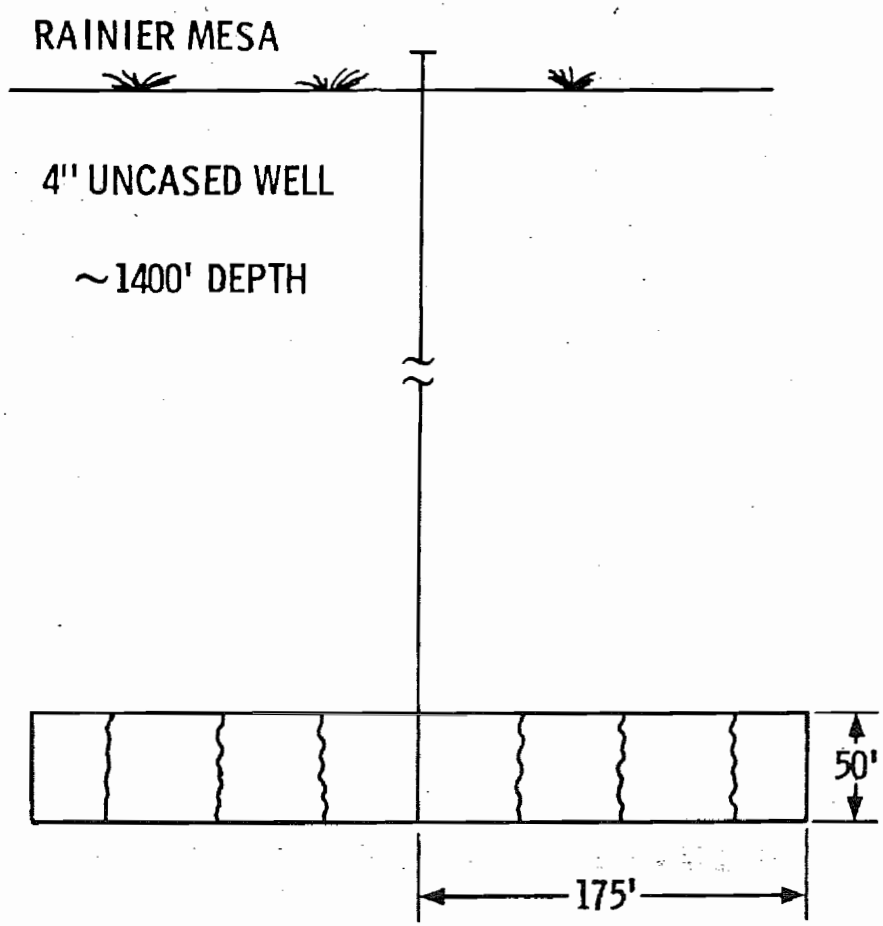
INTERFACE TEST SERIES



VERTICAL IN SITU STRESS DISTRIBUTIONS



HOLE 5 - PROPPANT DISTRIBUTION EXPERIMENT



FRACTURE DESIGN

FLUID: PWG/FR26L, μ = 79 cps

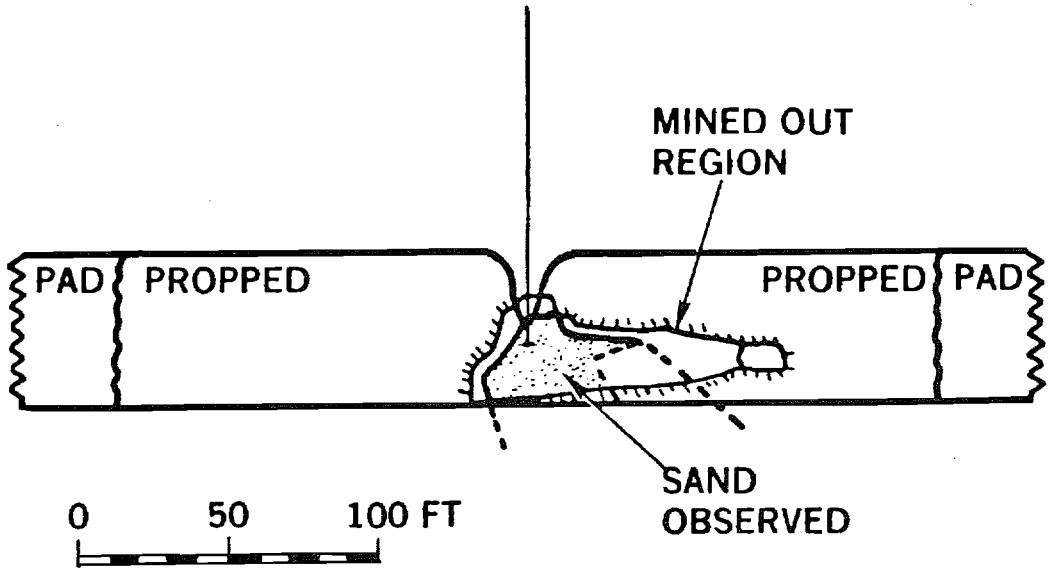
INJECTION RATE: 4 bbls/min

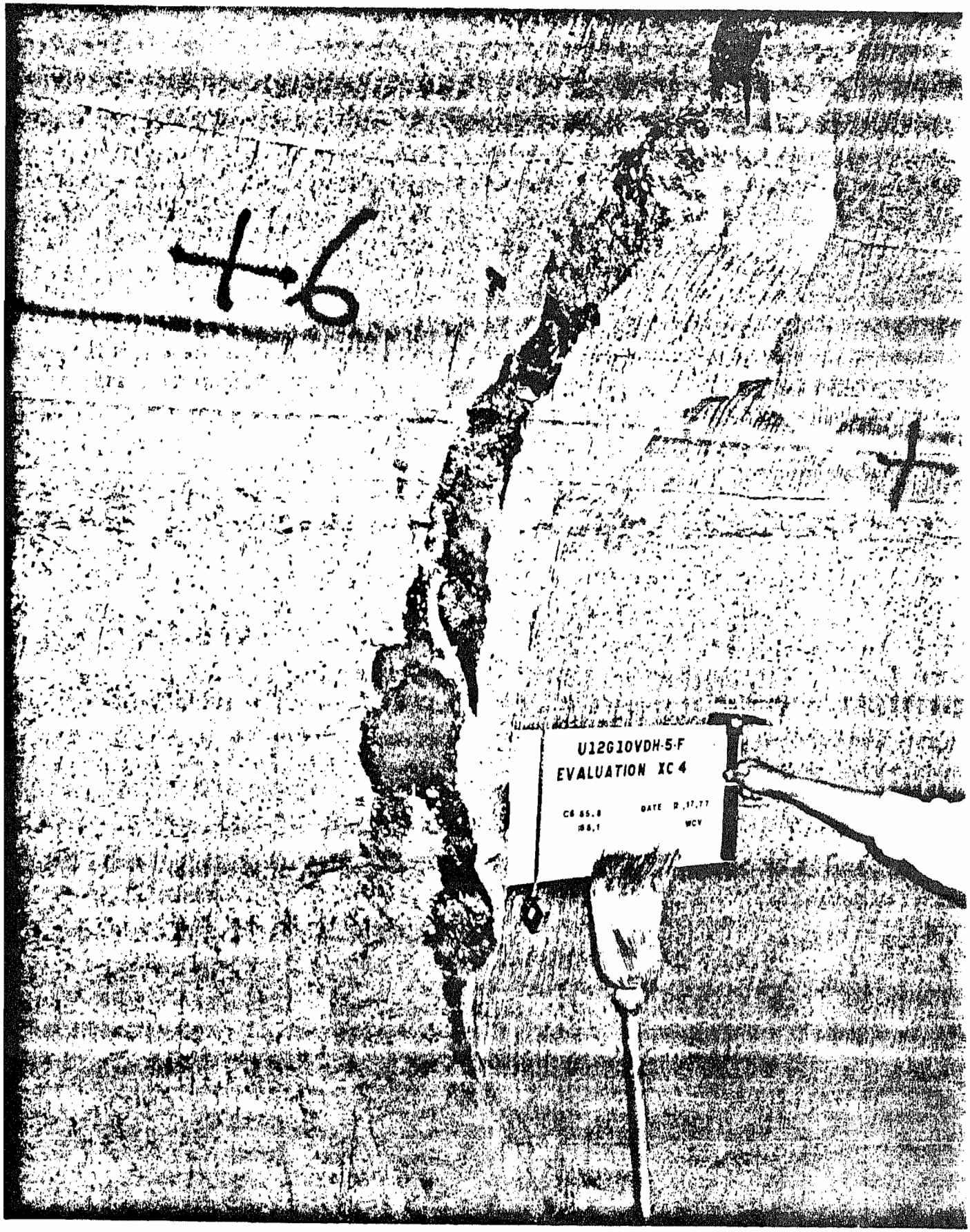
VOLUME	CONCENTRATION	20-40 SAND
350 gal	PAD	-
450	1 lb/gal	BLACK
400	2	RED
400	3	BLUE

FRACTURE THICKNESS: 0.15"

HOLE 5 - STAGED PROPPANT DISTRIBUTION EXPERIMENT

- OBSERVED BEHAVIOR DIFFERED SIGNIFICANTLY FROM DESIGN




U12G10VDH-5-F
EVALUATION XC 4
C6 55.8
B6.1
DATE 12.17.77
WCV

OBSERVED FIELD RESULTS OF HYDRAULIC FRACTURING TECHNOLOGY ARE INCONSISTANT WITH CONVENTIONAL DESIGN PRACTICE

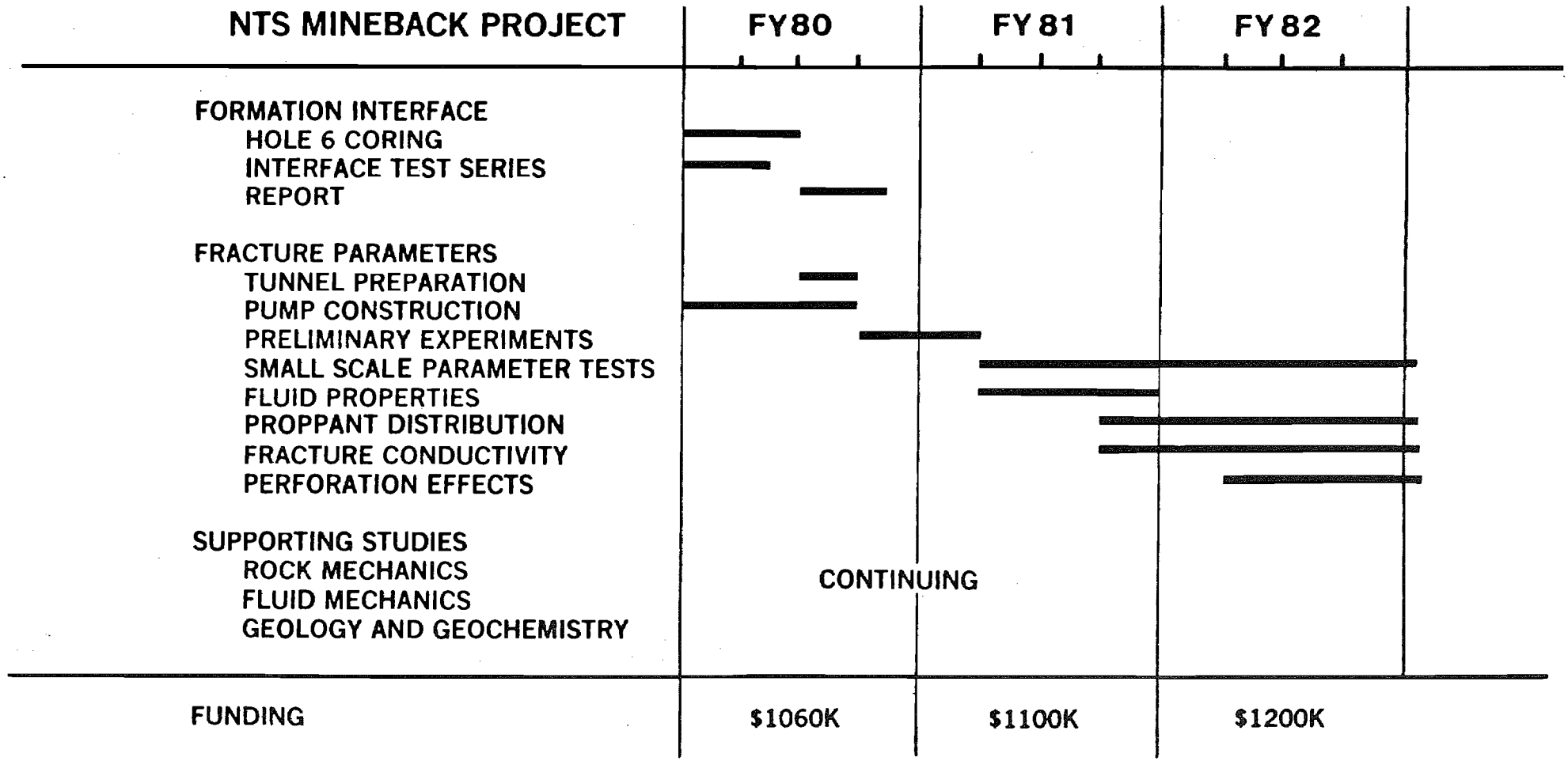
- FORMATIONS OF HIGHER MODULUS DO NOT CONTAIN HYDRAULIC FRACTURE - IN SITU STRESSES DO
- FRACTURE GEOMETRY IS NOT RECTANGULAR AND SYMMETRIC
- PROPPANTS ARE NOT PLACED IN A PRESCRIBED MANNER.

FUTURE EXPERIMENTS TO EXAMINE FRACTURE PARAMETERS

- FRACTURE WIDTH MEASUREMENTS DURING FRACTURING
- FLUID/PROPPANT EFFECTS
- IN SITU FRACTURE CONDUCTIVITY
- MINEBACK FOR GEOMETRY AND PROPPANT DISTRIBUTION

IMPROVED FRACTURE DESIGN

IMPROVED WELL TEST INTERPRETATION



Sandia Laboratories

Merrill Hanson

THEORETICAL AND EXPERIMENTAL MODELING

LAWRENCE LIVERMORE LABORATORY

OUTLINE:

- HISTORY AND EXPERIENCE OF HYDRAULIC FRACTURING AND MHF FOR STIMULATING GAS PRODUCTION
- OUR LITERATURE AND INDUSTRY HYDRAULIC FRACTURING SURVEY
- LLL PROGRAM
- OUR APPROACH
- SELECTED THEORETICAL AND EXPERIMENTAL RESULTS.
- SUMMARY

HISTORY

- HYDRAULIC FRACTURING INTRODUCED TO INDUSTRY IN 1949 BY CLARK
- MORE THAN 3/4 MILLION APPLICATIONS
- CURRENT THEORETICAL AND DESIGN WORK BASED ON EARLY PERKINS AND KERN'S STUDIES SUMMARIZED BY R. FAST IN SPE MONOGRAPH.
- MHF USED EARLY BY AMOCO TO STIMULATE TIGHT RESERVOIRS -

  SUCCESS IN WATTENBURG FIELD NEAR DENVER.

EXPERIENCE

- APPLICATION OF MHF HAS BEEN DISAPPOINTING IN MANY CASES, EXAMPLES
  - CER-INDUSTRY-GOVERNMENT TEST IN PICEANCE BASIN.
  - EL PASO GAS TEST NEAR PINEDALE, WY

- SUCCESSFUL IN BLANKET-MARINE SANDS IN WATTENBURG BY AMOCO.

- COSTS RANGE FROM 100K TO MORE THAN 600K

- ACTUAL FRACTURE LENGTHS MUCH SHORTER THAN DESIGN LENGTHS IN LENTICULAR RESERVOIRS, E.G., MOBILE'S PICEANCE WELL.

OUR SURVEY

WE CONDUCTED LITERATURE AND INDUSTRY SURVEYS PRIOR TO PROPOSING A PROGRAM TO DOE

- SEVERAL PROBLEM AREAS NEEDED RESOLUTION BEFORE MHF CAN, IN GENERAL, BE SUCCESSFUL. THESE INCLUDED:
  - WHAT CONTROLS FRACTURE GEOMETRY?
  - HOW IS PROPPANT DEPOSITED IN THE FRACTURE?
  - CAN WE CONTROL THE DAMAGE TO THE RESERVOIR - TAILOR THE FRAC FLUIDS?
  - CAN WE CONTROL THE FRACTURE GEOMETRY?
- CURRENT THEORETICAL AND DESIGN TECHNIQUES INDICATED THAT THEY ARE BASED ON CONSERVATION OF MASS PROVIDING LITTLE KNOWLEDGE OF WHAT CONTROLS FRACTURE GEOMETRY.
- A SIGNIFICANT FACT WAS THAT WE HAVE TO DEFINE THE GEOMETRY TO APPLY THE DESIGN TECHNIQUES.

GENERALLY - WE KNOW EVERYTHING ABOUT HYDRAULIC FRACTURING EXCEPT HOW HIGH IT IS, HOW LONG IT IS, AND WHERE IT GOES.

CONCLUSIONS DRAWN FROM BACKGROUND MATERIAL

- THE TECHNOLOGY HAD NOT BEEN DEVELOPED TO UNDERSTAND WHAT RESERVOIR PARAMETERS CONTROL FRACTURE GEOMETRY.

- COST WOULD PRECLUDE FIELD DEVELOPMENT OF THE PROCESS IN GENERAL, IF THAT IS POSSIBLE AT ALL.

- FRACTURES IN GENERAL DID NOT HAVE THE NICE DEFINED RECTANGULAR SHAPE PREDICTED BY THE DESIGNS.

- RESERVOIR ANALYSIS INDICATED FRACTURES MUCH SHORTER THAN DESIGN LENGTHS IN DISCONTINUOUS RESERVOIRS.

- RESULTS INDICATED SUCCESS IN SOME RESERVOIRS.

- STRONG NEED TO RESEARCH SOME OF THESE PROBLEMS.

LLL PROGRAM

1. THEORETICAL MODEL DEVELOPMENT AND APPLICATIONS.
2. LABORATORY EXPERIMENTS.
3. RESERVOIR ANALYSIS.
4. ROCK PROPERTIES MEASUREMENTS.
5. GEOLOGY/GEOPHYSICS OF TIGHT GAS RESERVOIRS.
6. LOG DEVELOPMENT AND LOG INTERPRETATION.
7. ENVIRONMENTAL REPORTS IN SUPPORT OF DOE RELATED PROGRAMS.
8. ANALYSIS OF OTHER STIMULATION TECHNIQUES.

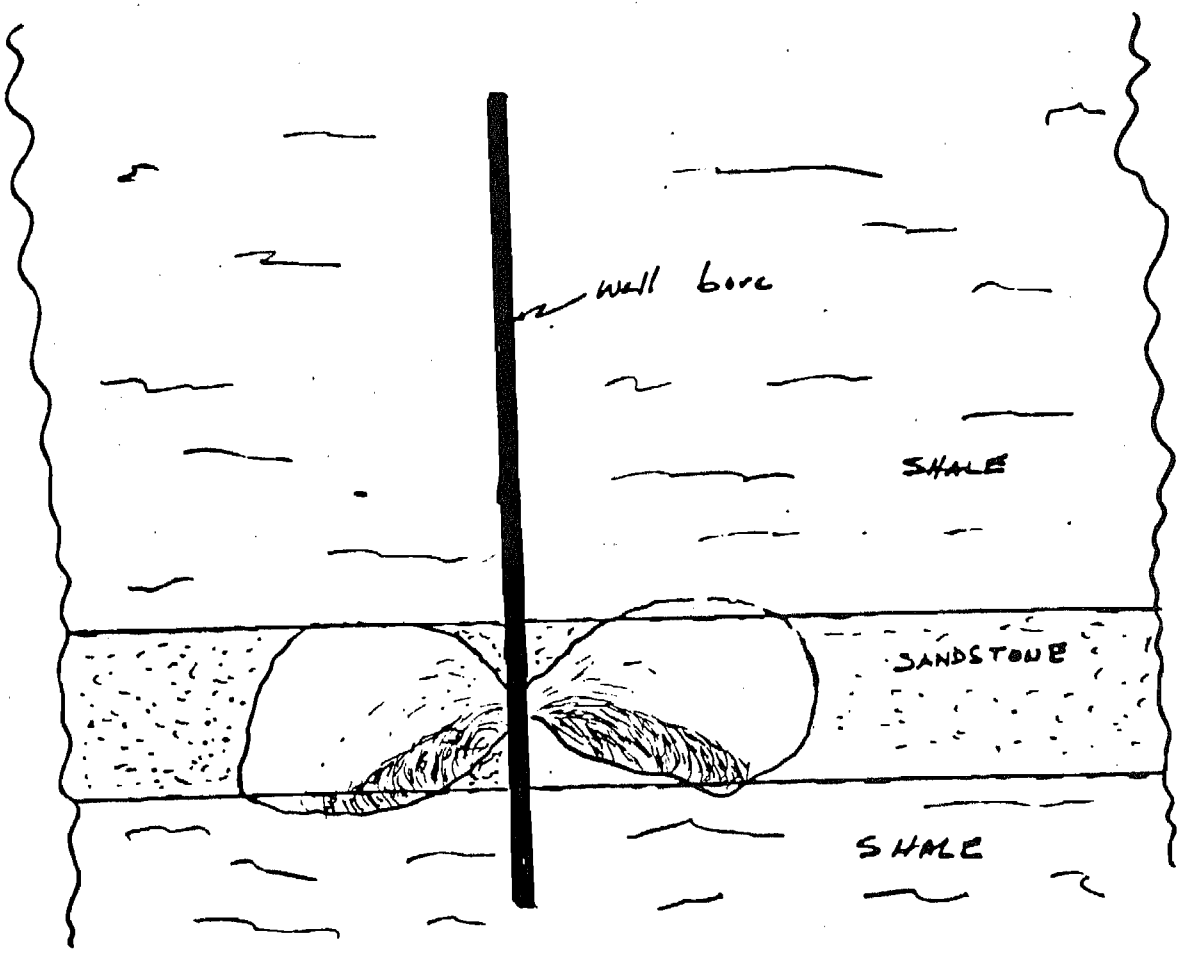
RELATED LLL UGR PROGRAMS

- MEASUREMENT OF LOW PERMEABILITY RESERVOIR MATERIAL.
- ULTRASONIC TECHNIQUES FOR IN-SITU STRESS MEASUREMENT.

APPROACH

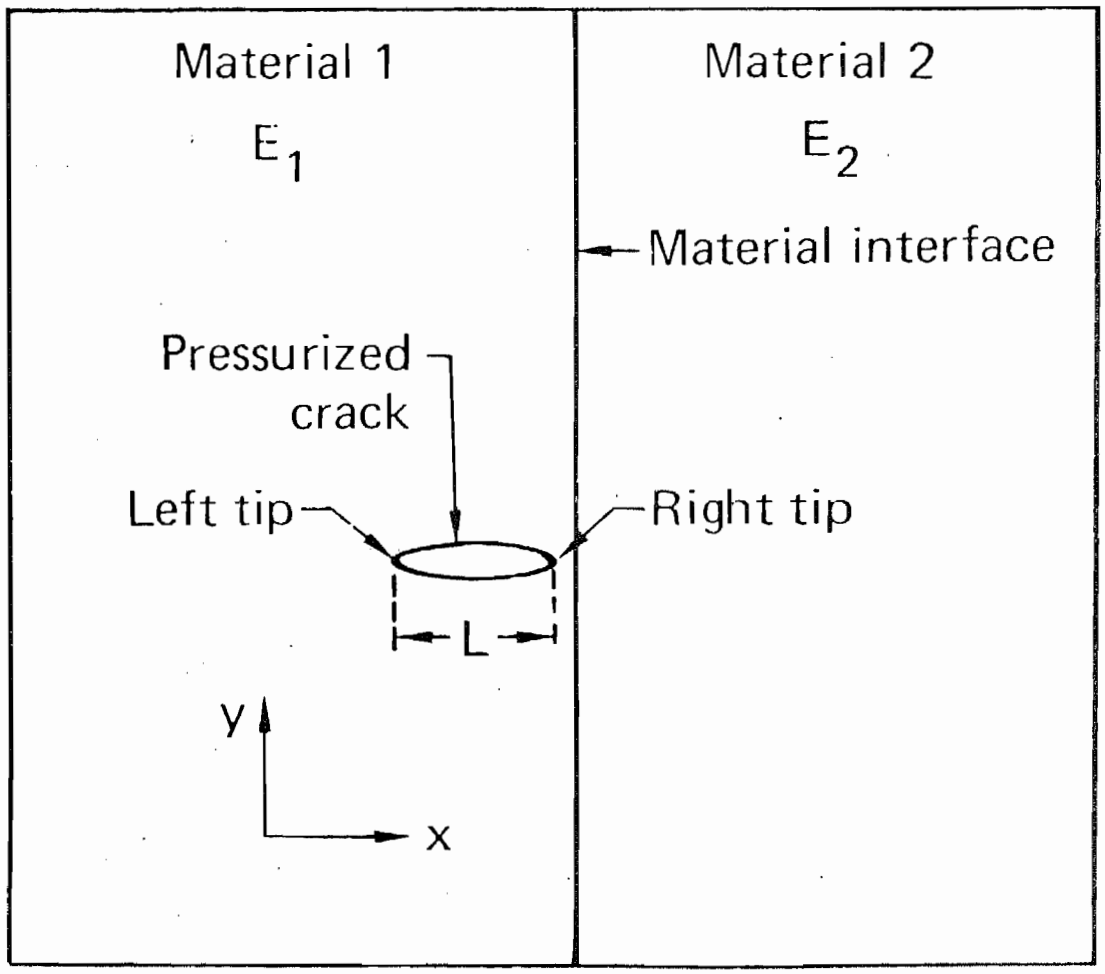
- PURSUING A PROGRAM DIRECTED TOWARD UNDERSTANDING THOSE RESERVOIR PARAMETERS WHICH CONTROL FRACTURE GEOMETRY.
- CONDUCTING A THEORETICAL-EXPERIMENTAL PROGRAM WHERE THEORY AND EXPERIMENT COMPLEMENT EACH OTHER.
- USING FIELD OR OTHER DATA WHEN AND FROM WHATEVER SOURCE AVAILABLE.
- USING RESERVOIR ANALYSES TECHNIQUES TO EVALUATE SIZE OF FRACTURE CONTACTING PRODUCTIVE RESERVOIR.
- AIMING AT DEVELOPING SIMPLIFIED DESIGN TOOLS INCORPORATING OUR FINDINGS AND UNDERSTANDING DEVELOPED THROUGH THIS RESEARCH.
- WORKING WITH MIT AND UNIVERSITY OF WISCONSIN.

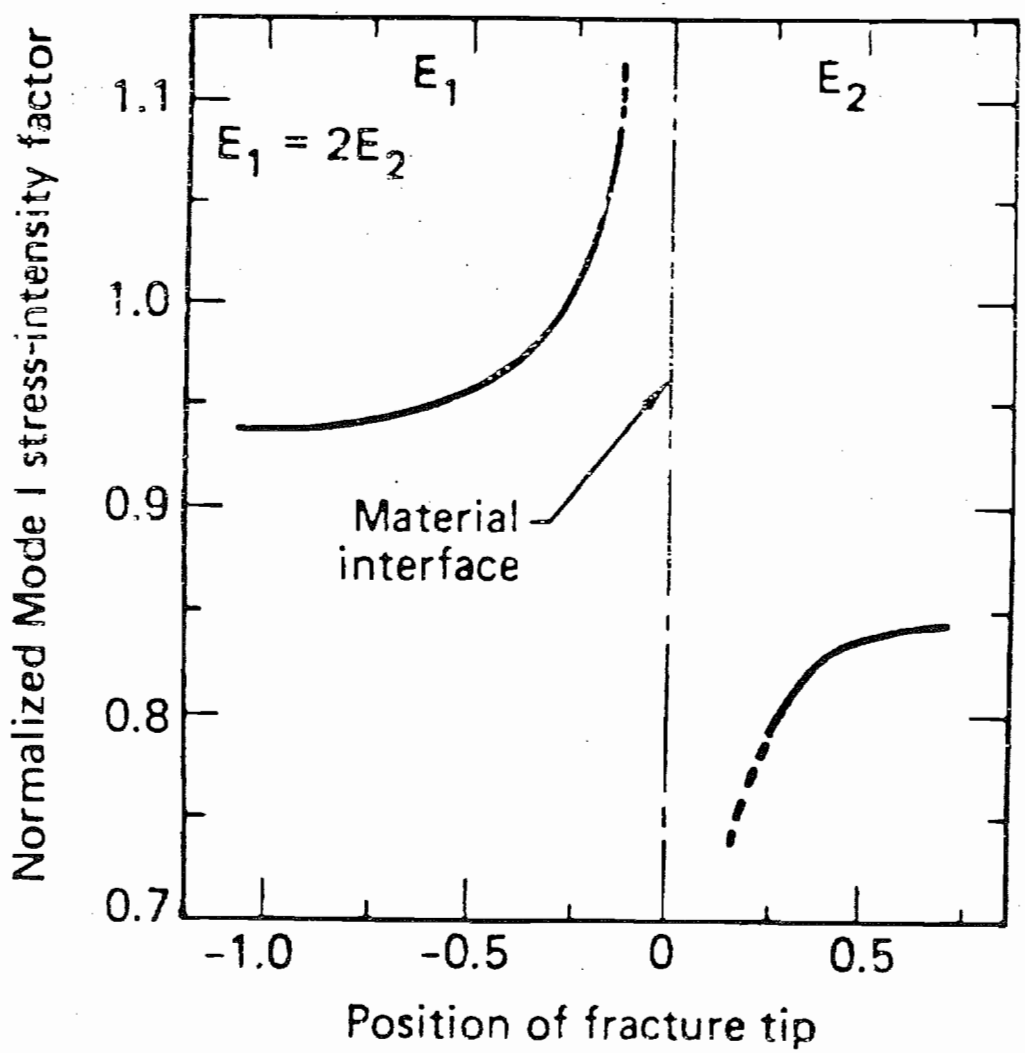
WHAT CONTROLS FRACTURE GROWTH (GEOMETRY)?

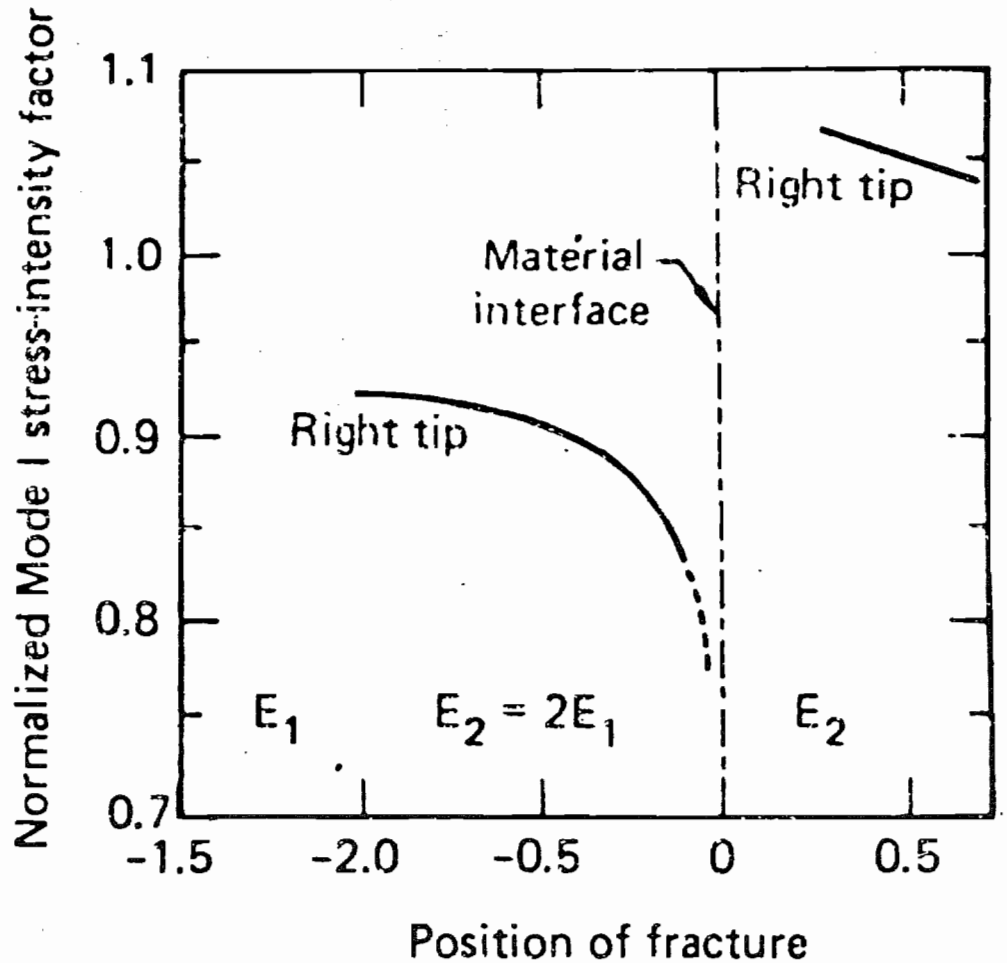


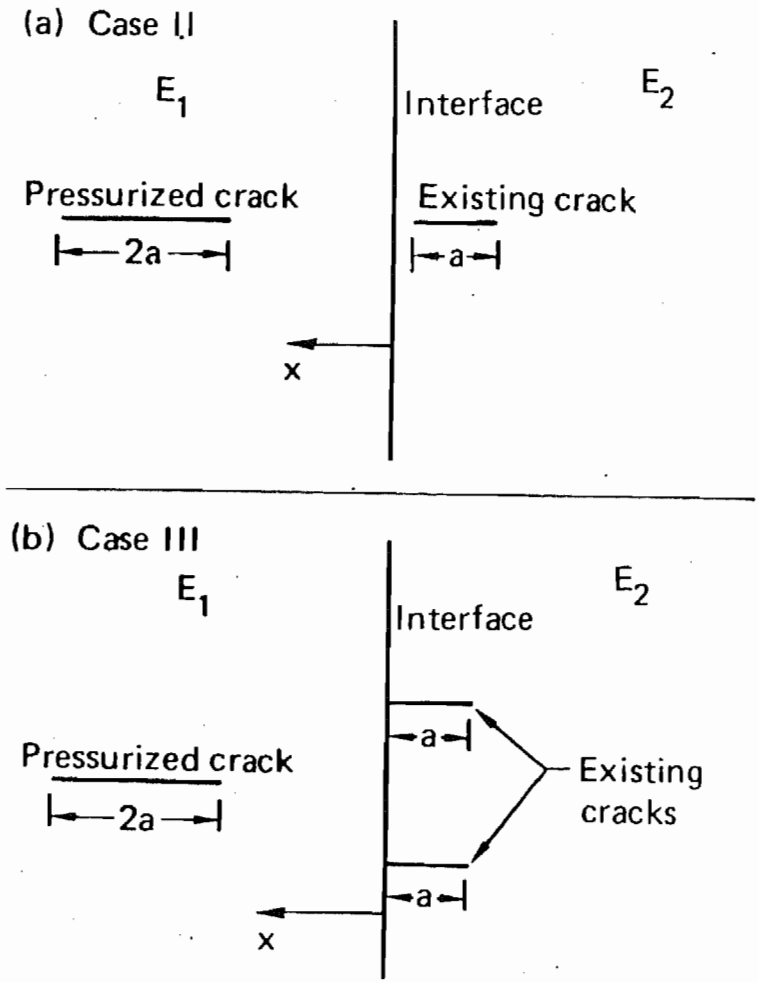
SELECTED THEORETICAL AND EXPERIMENTAL RESULTS

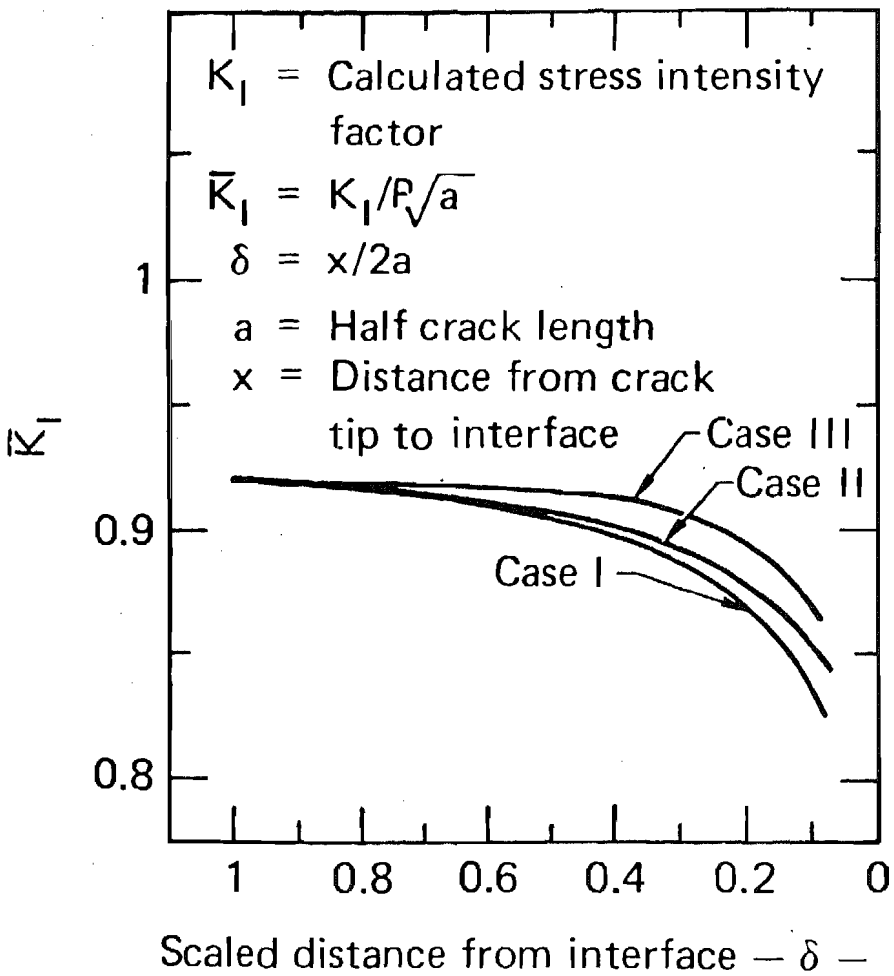
- FRACTURING NEAR AND PENETRATION OF INTERFACES.
- SOME FRICTIONAL EFFECTS, RESULTS AND MEASUREMENTS
- FLUID FLOW IN FRACTURE
- EFFECT OF STRESS MAGNITUDES ON FRACTURE ORIENTATION.

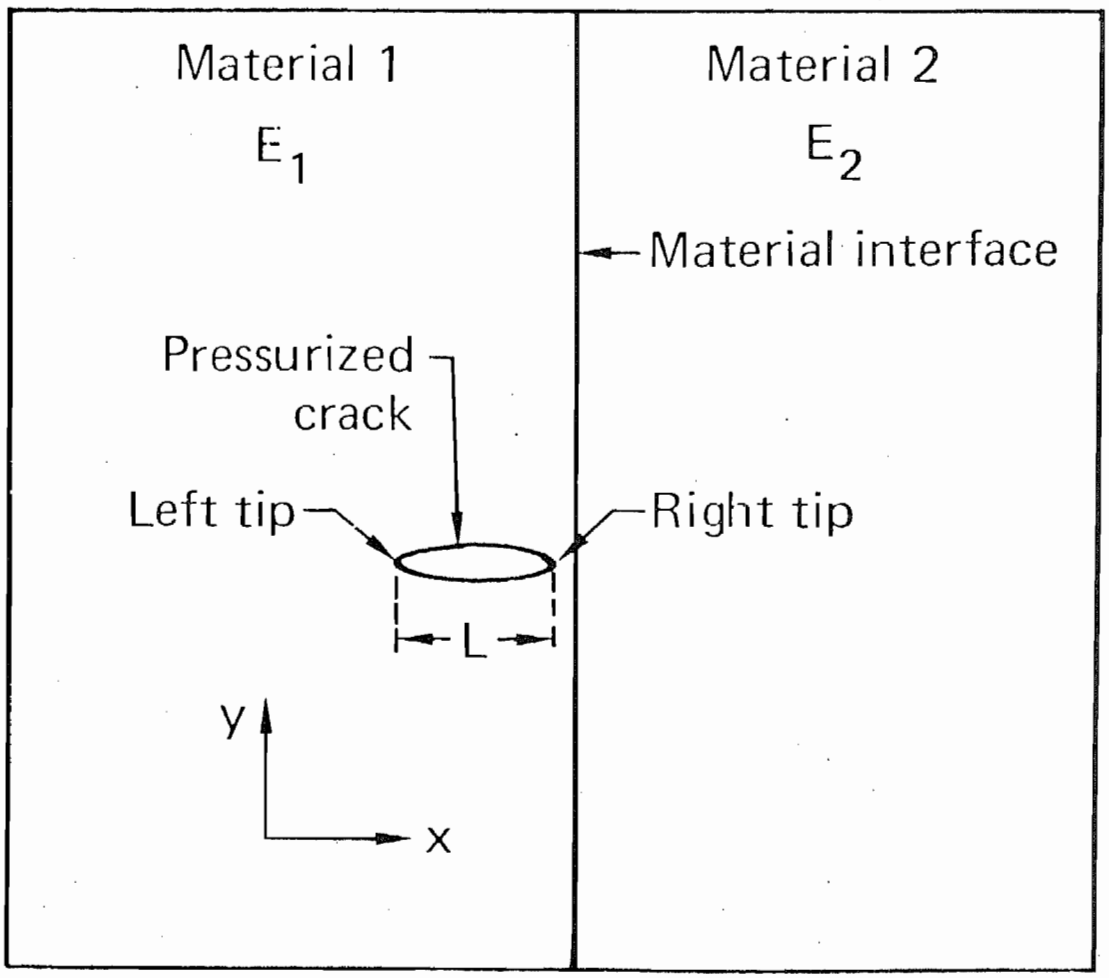

Material 1
E_1
Material 2
E_2
Material interface
Pressurized crack
Left tip
Right tip
L
y
x

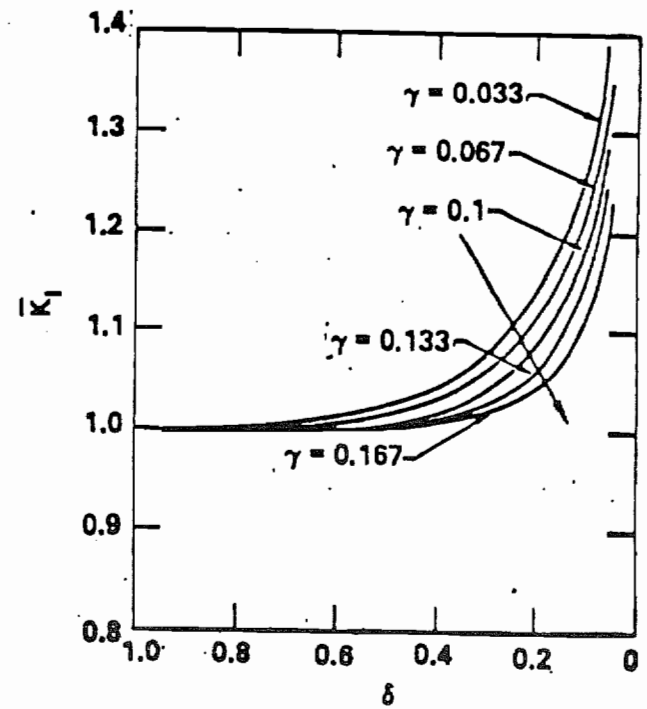

Normalized Mode I stress-intensity factor
1.1
1.0
0.9
0.8
0.7
E_1
E_2
$E_1 = 2E_2$
Material interface
-1.0
-0.5
0
0.5
Position of fracture tip

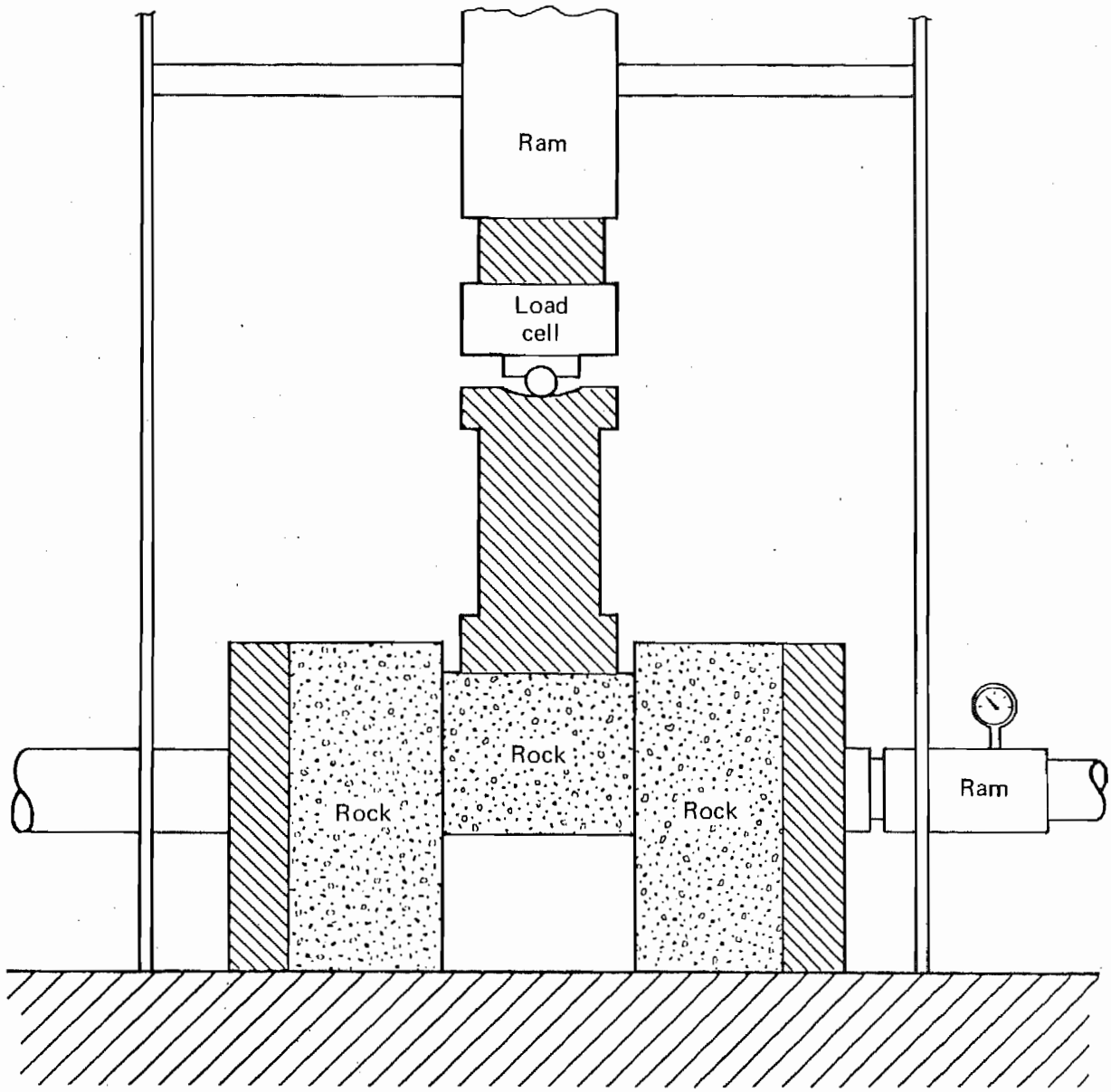

Normalized Mode I stress-intensity factor
1.1
1.0
0.9
0.8
0.7
-1.5
-2.0
-0.5
0
0.5
Position of fracture
Right tip
Material interface
Right tip
E_1
$E_2 = 2E_1$
E_2


(a) Case II
E1
Interface
E2
Pressurized crack
2a
Existing crack
a
x
(b) Case III
E1
Interface
E2
Pressurized crack
2a
a
Existing cracks
a
x

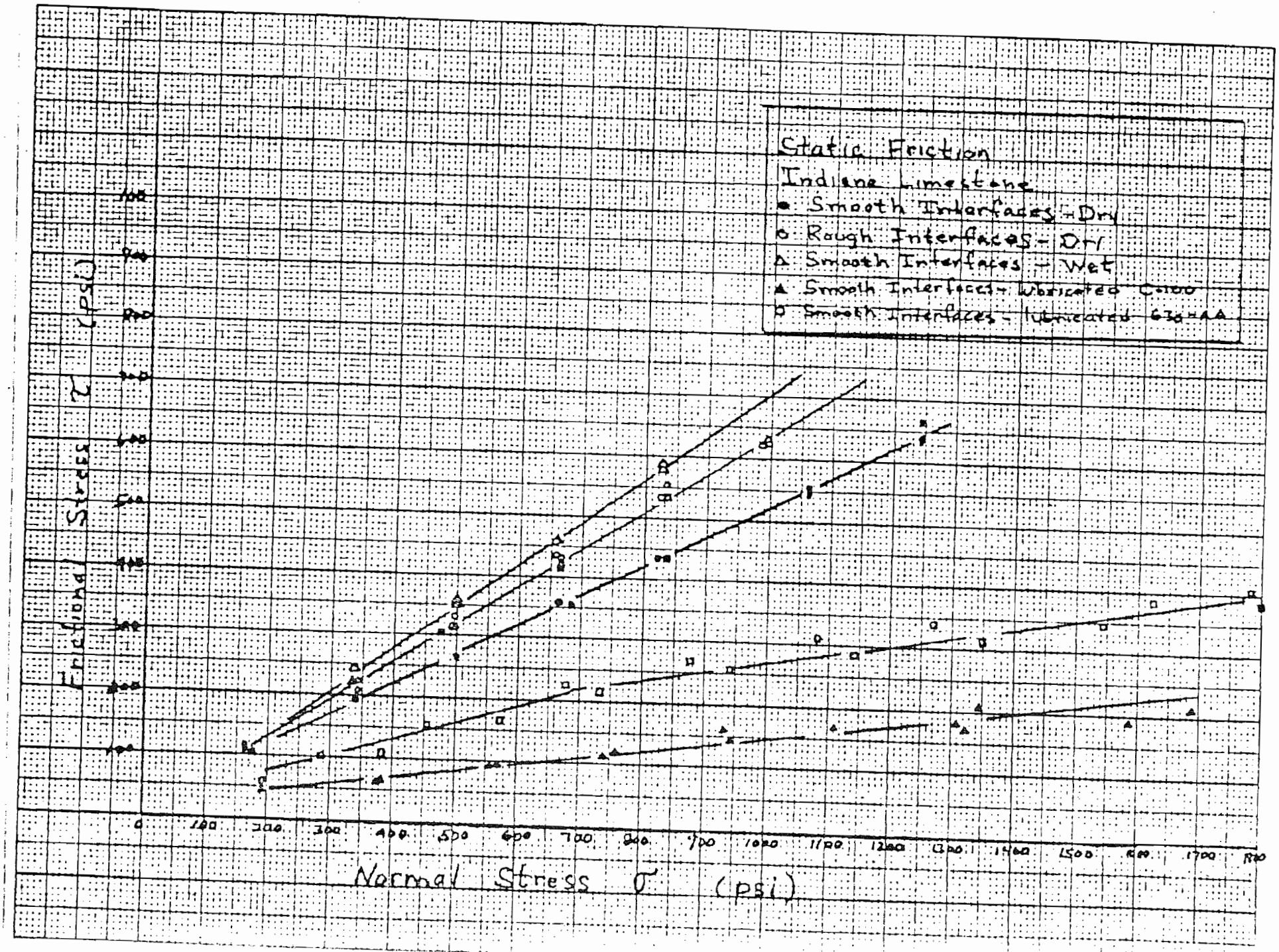

K_I = Calculated stress intensity factor
$\bar{K}_I = K_I/P\sqrt{a}$
$\delta = x/2a$
a = Half crack length
x = Distance from crack tip to interface
Case III
Case II
Case I
$\bar{K}$
1
0.9
0.8
1
0.8
0.6
0.4
0.2
0
Scaled distance from interface — δ —

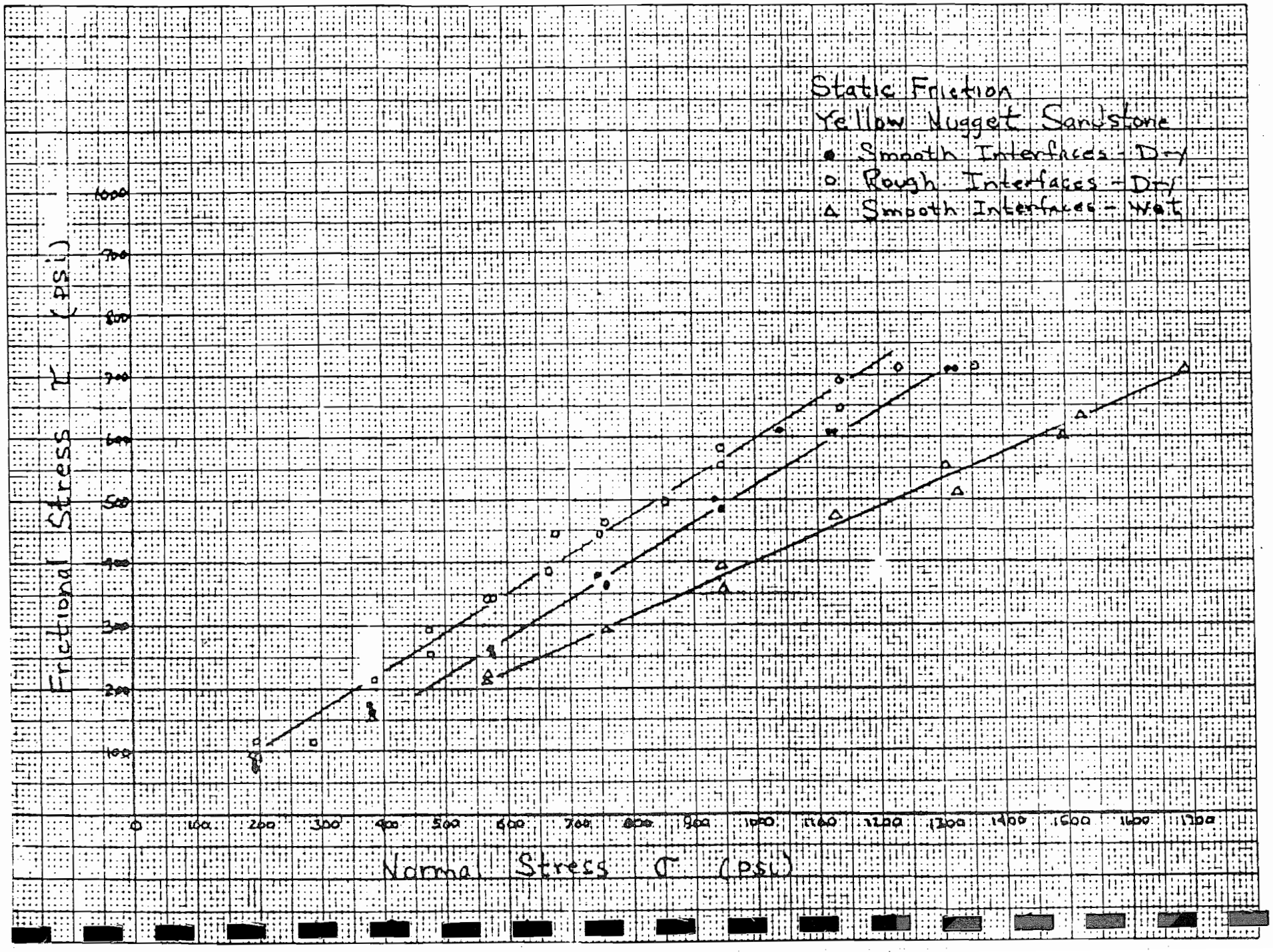

Material 1
E_1
Material 2
E_2
Material interface
Pressurized crack
Left tip
Right tip
L
y
x


1.4
1.3
1.2
1.1
1.0
0.9
0.8
$|\bar{K}|$
1.0
0.8
0.6
0.4
0.2
0
δ
$\gamma = 0.033$
$\gamma = 0.067$
$\gamma = 0.1$
$\gamma = 0.133$
$\gamma = 0.167$


Ram
Load
cell
Rock
Rock
Rock
Ram

GRAPH PAPER GRAPHIC CONTROLS CORPORATION Buffalo New York
Printed in U.S.A.




Static Friction
Yellow Nugget Sandstone
Smooth Interfaces - Dry
Rough Interfaces - Dry
Smooth Interfaces - Wet
Frictional Stress τ (PSI)
Normal Stress σ (PSI)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700

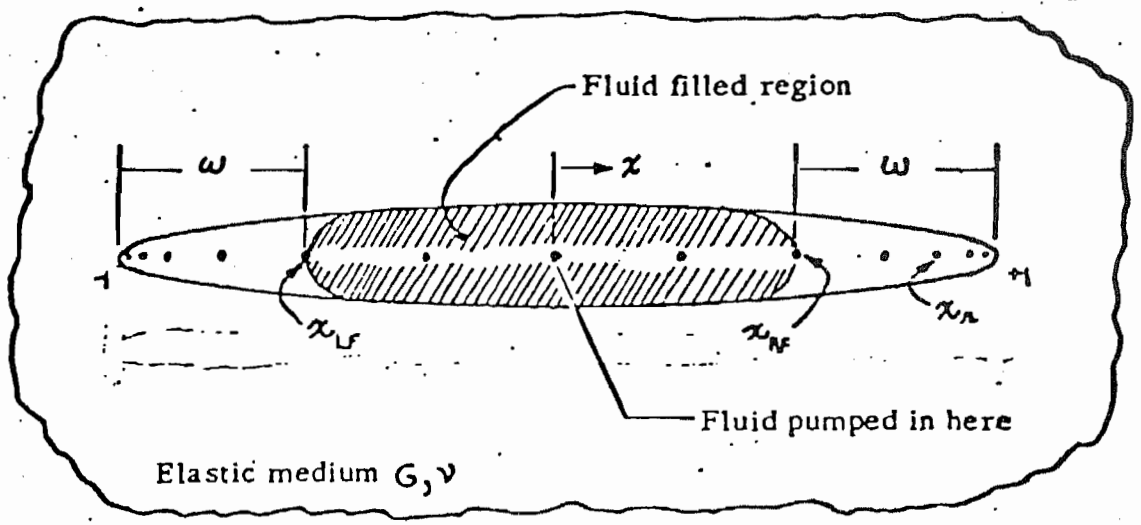
MODELING FLUID FLOW IN AN EXPANDING CRACK

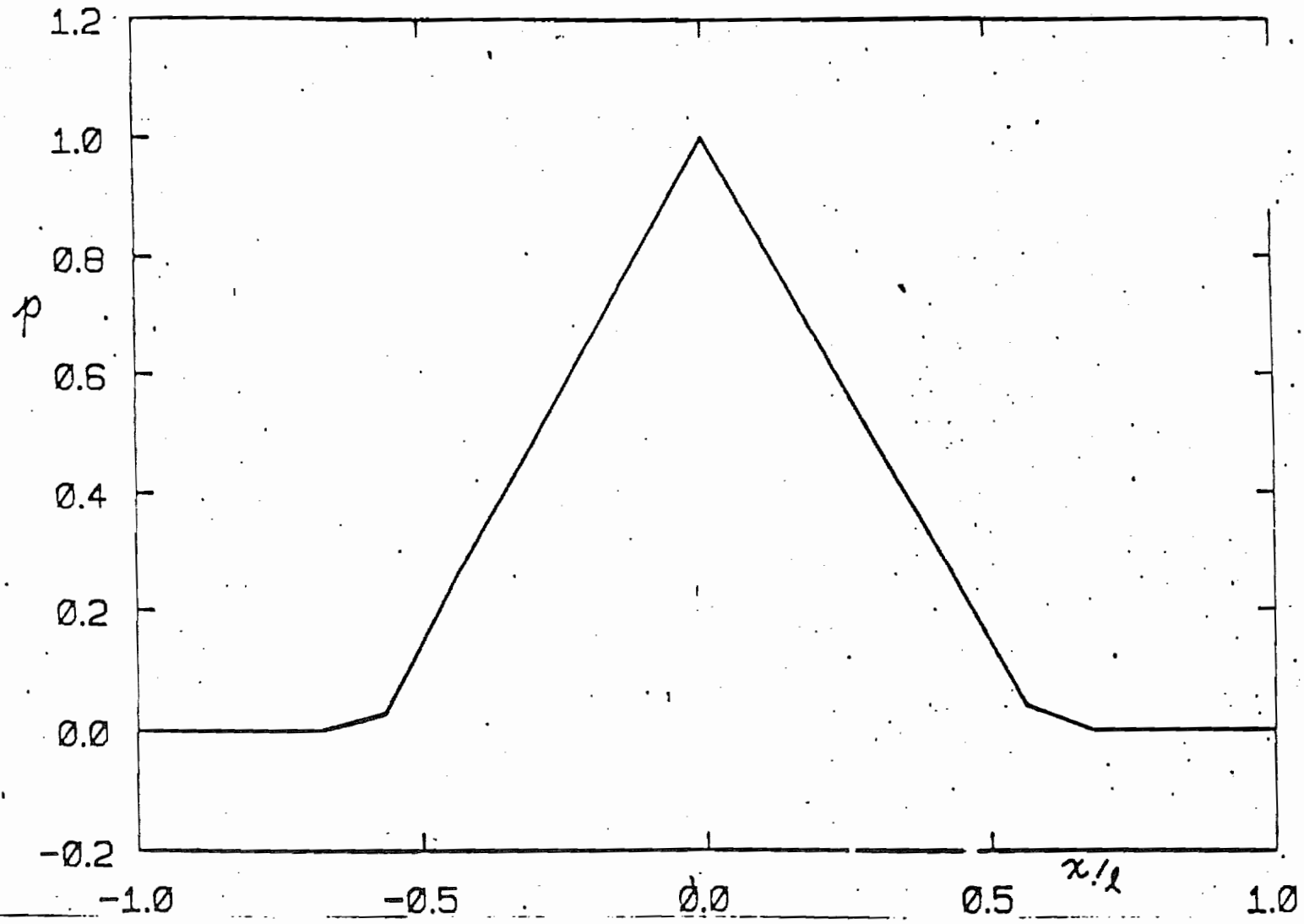
- GOAL -- A BETTER UNDERSTANDING OF FLOW AND PRESSURE EVOLUTION IN A CRACK AND HOW IT EFFECTS CRACK PROPAGATION.

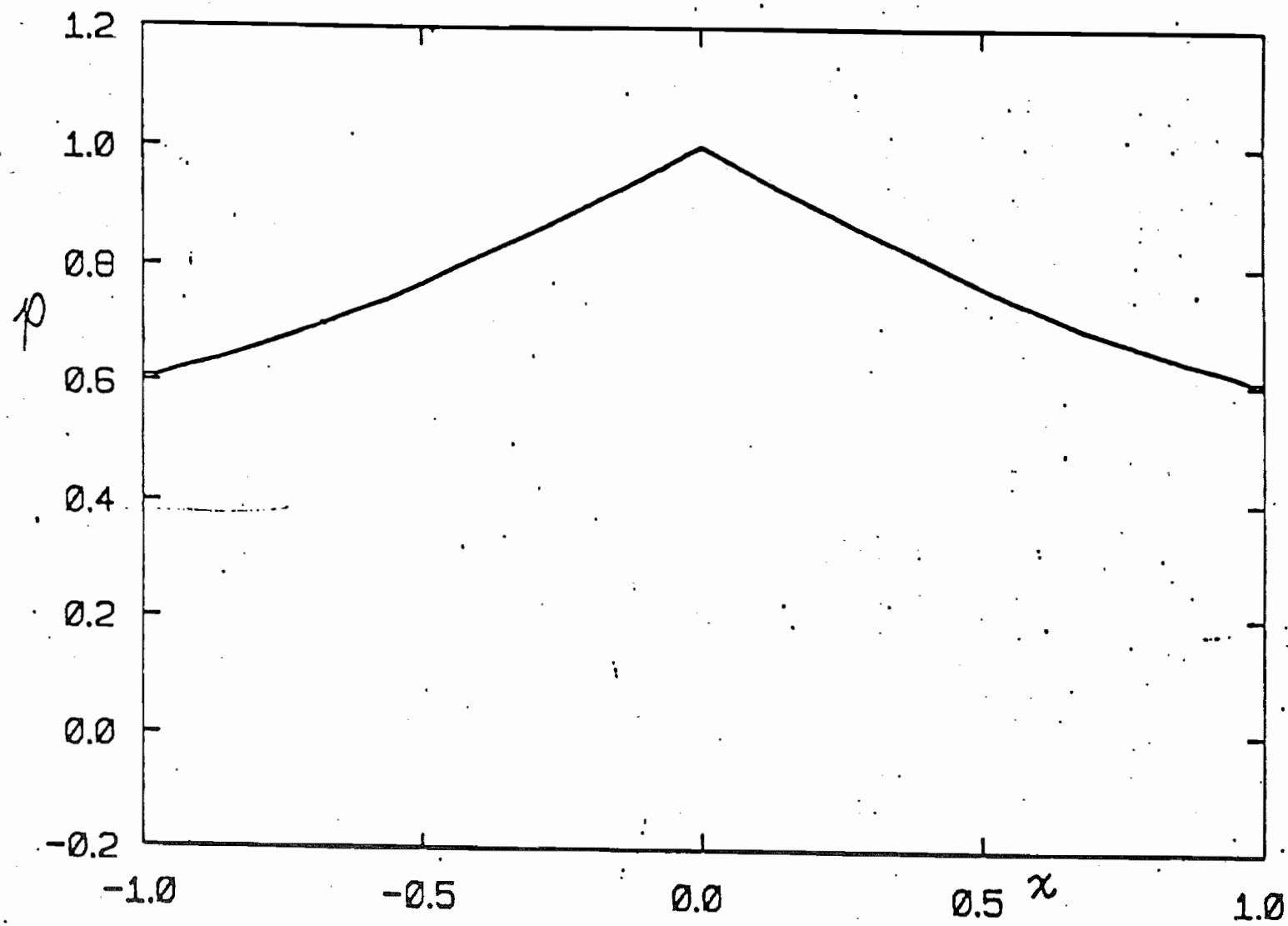
- APPROACH -

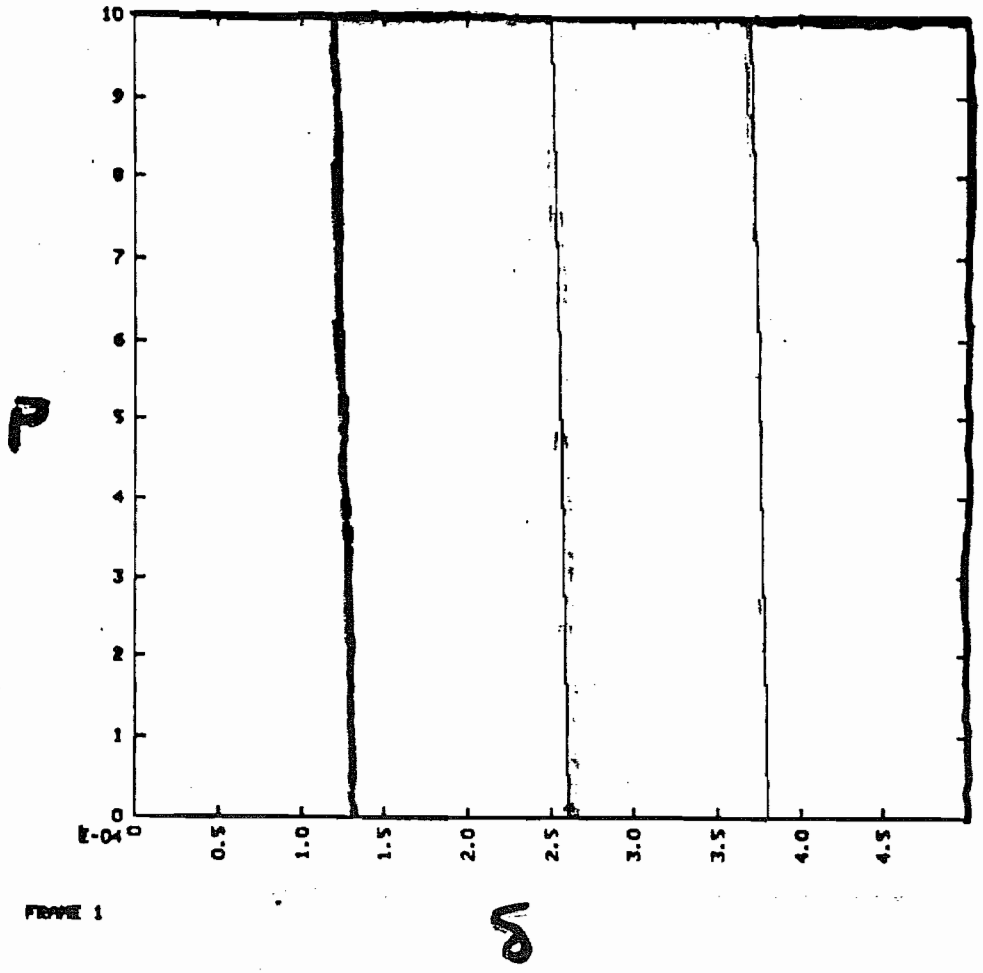
  I) AVERAGED FLUID PROPERTIES

  II) DETAILED FLUID PROPERTIES.


Fluid filled region
ω
x
ω
-1
+1
x_{LF}
x_{RF}
x_R
Fluid pumped in here
Elastic medium G, ν


1.2
1.0
0.8
p
0.6
0.4
0.2
0.0
-0.2
-1.0
-0.5
0.0
0.5
1.0
x/l


1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
p
-1.0
-0.5
0.0
0.5
1.0
x

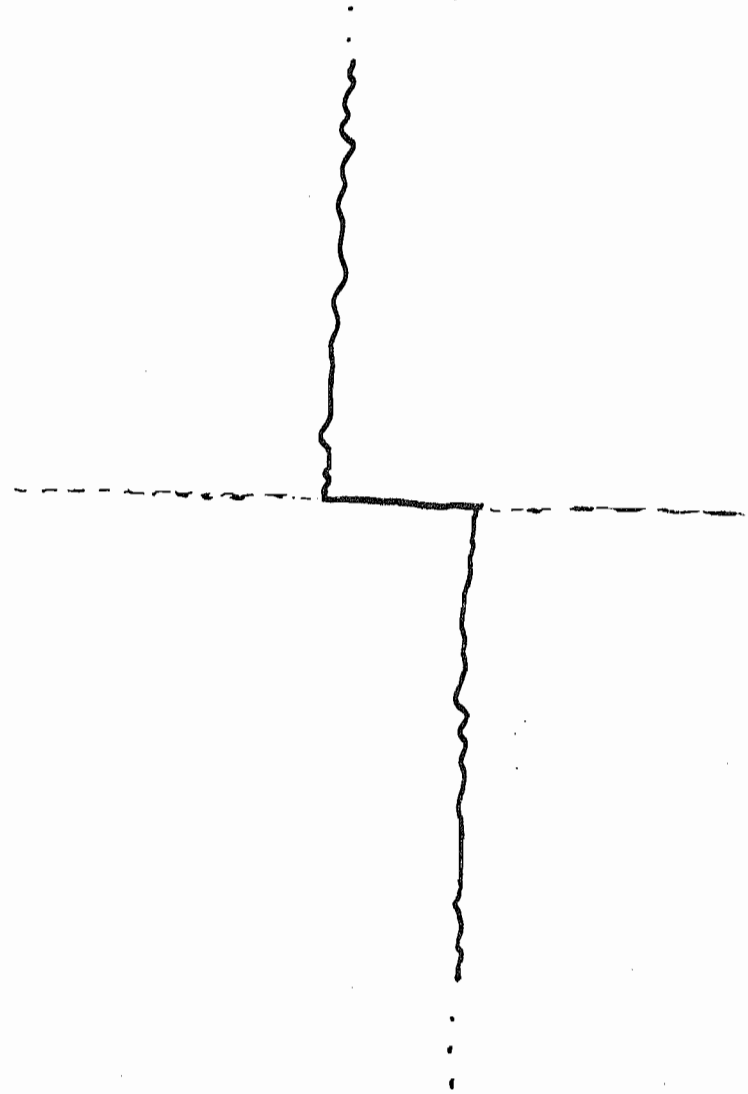


FRAME 1

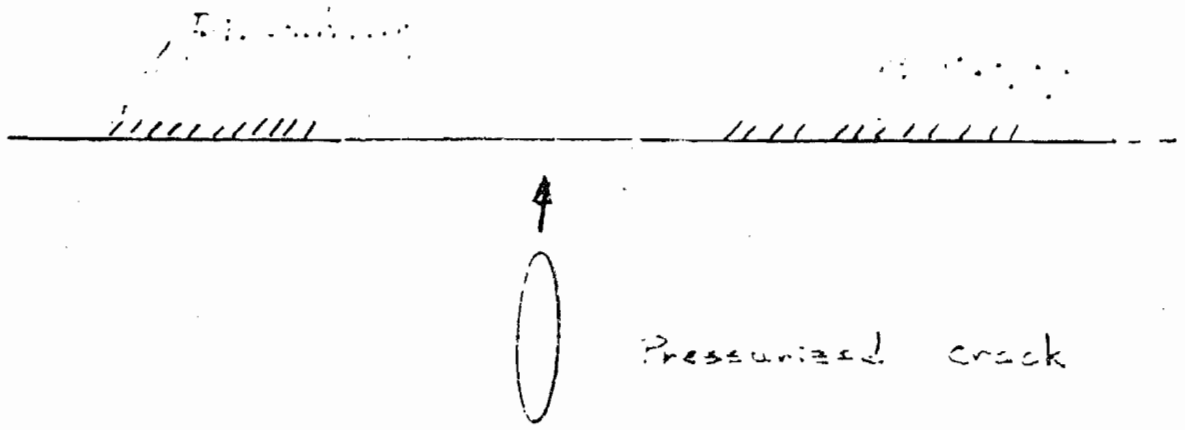
FIGURE 2
E-03
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
0
1
2
3
4
5
6
7
8
9
η_y
ξ

(a)

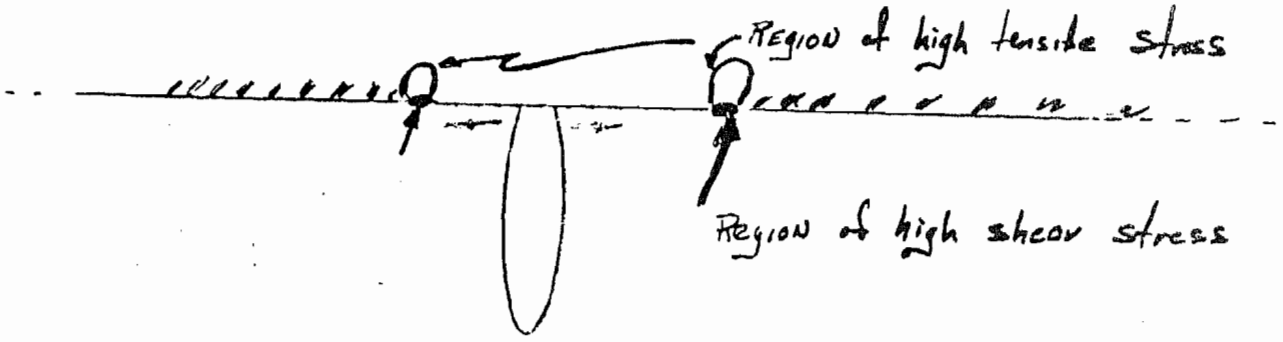
(b)

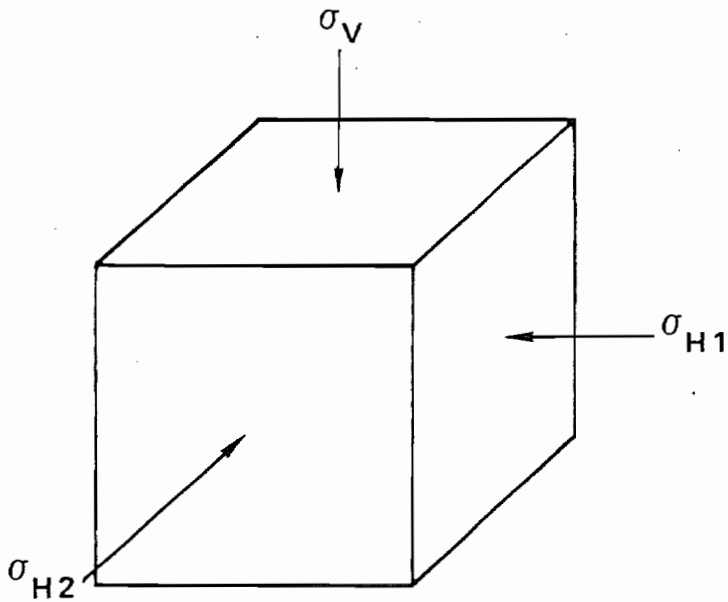


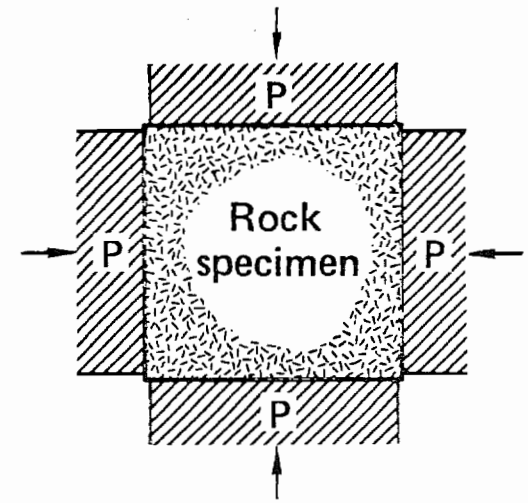
a)


Pressurized crack

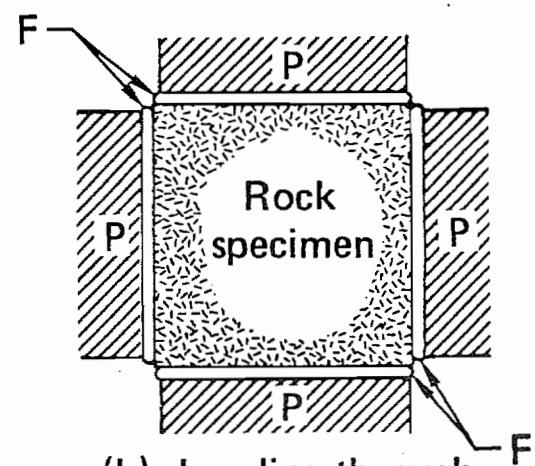
b)


Region of high tensile stress
Region of high shear stress



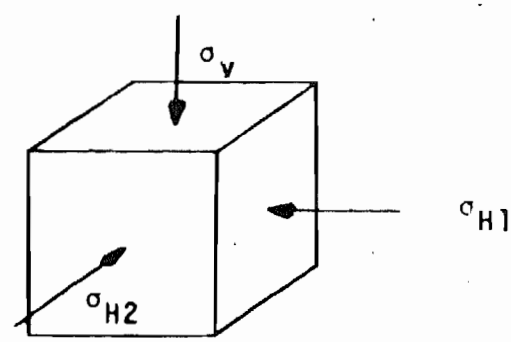


(a) Direct piston (P) loading



(b) Loading through pressurized flat jacks (F)

EFFECT OF STRESS MAGNITUDE ON FRACTURE ORIENTATION



1. VARIATION IN σ_V FROM σ_V = 500 psi TO σ_{HMIN}

   - 23 tests
   - 50% tests started vertical then turned horizontal with predominance of vertical as $\sigma_V \rightarrow \sigma_{HMIN}$

2. $\sigma_V > \sigma_{H1} > \sigma_{H2}$

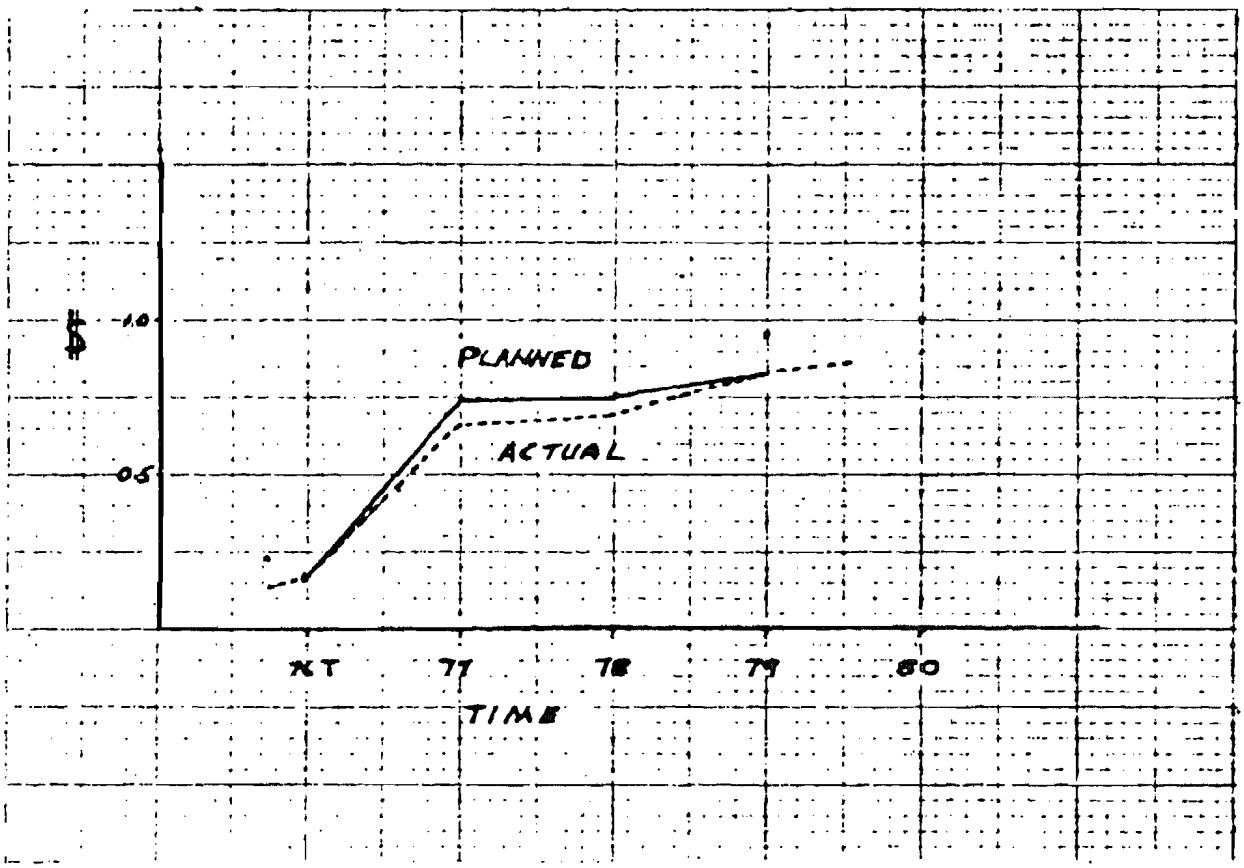
   - fracture perpendicular to σ_{HMIN}

     for $\sigma_{H1} - \sigma_{H2} > 75$ psi

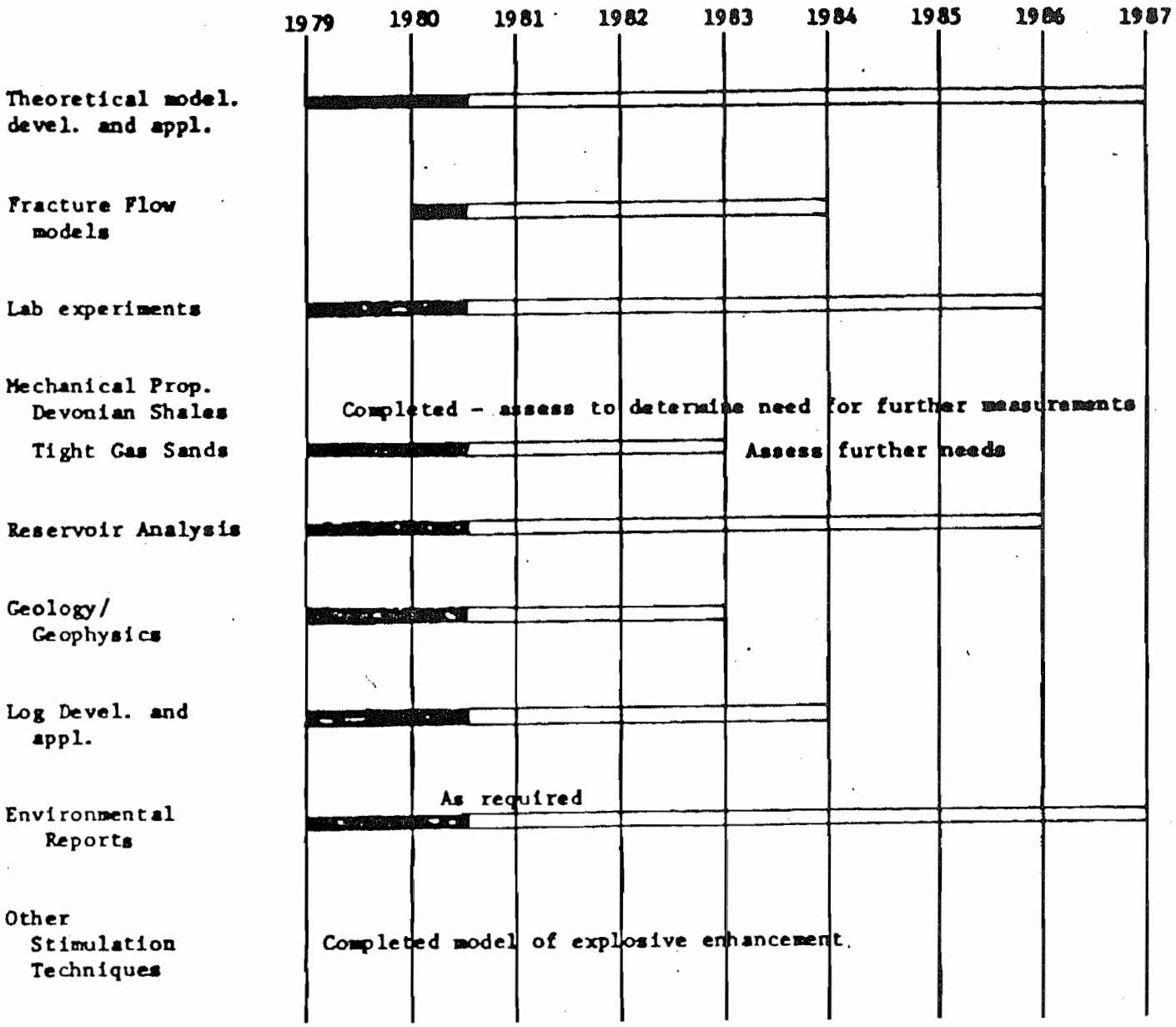
SOME CONCLUSIONS FROM OUR WORK

- IN-SITU STRESS FIELD STRONGLY INFLUENCES FRACTURE GEOMETRY.
- FRICTIONAL INTERFACES IMPORTANT, ESPECIALLY IN THE SHALLOWER RESERVOIRS.
- PROBABLE BLUNTING EFFECT WHEN FRACTURING FROM STIFFER TO LESS STIFF MATERIAL ACROSS INTERFACE.
- LEADS TO THE PROBLEMS IN IDENTIFYING THESE PARAMETERS IN THE RESERVOIRS.

o FUNDING PROFILE (TOTAL PROGRAM, INCLUDING EAST AND WEST)



TIME TASK CHART



Progress and funding on schedule.

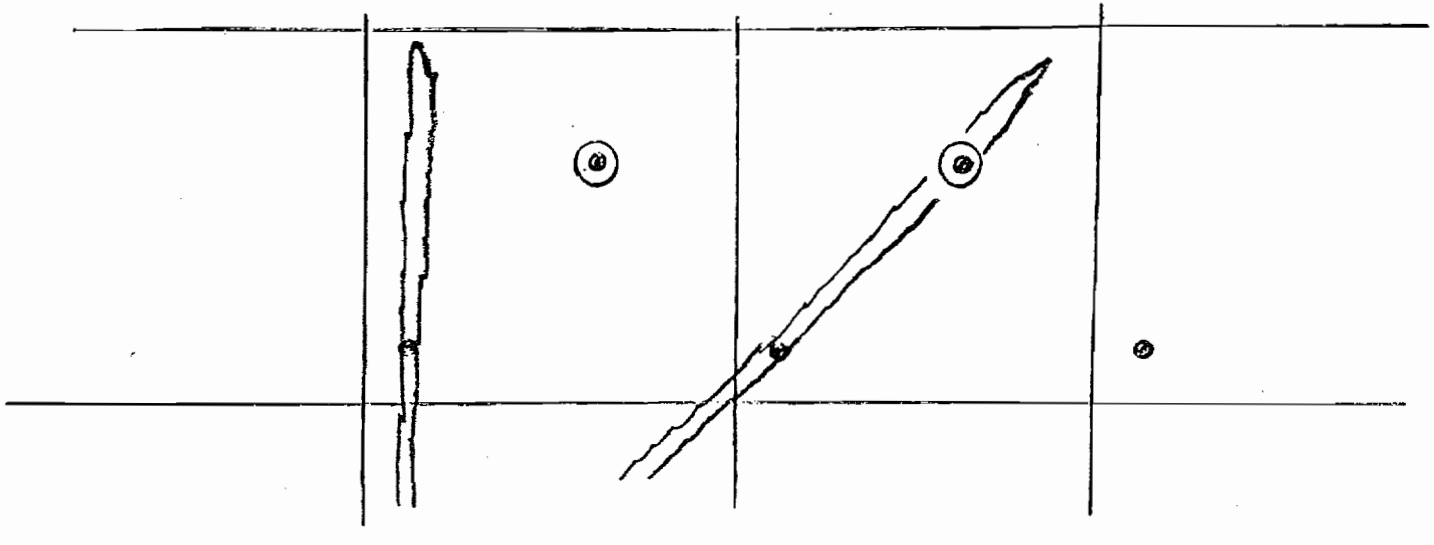
STIMULATION TECHNOLOGY REQUIRES DIAGNOSTIC INSTRUMENTATION FOR UNDERSTANDING AND EVALUATION

DOE

UNCONVENTIONAL GAS RECOVERY

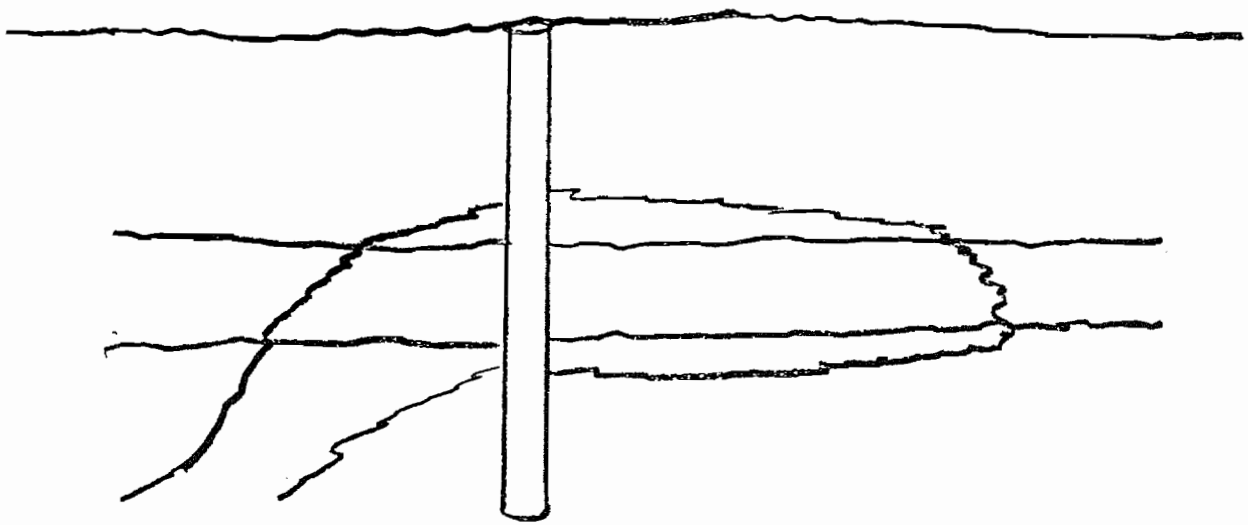
PROJECT REVIEW

WHY IS FRACTURE ORIENTATION IMPORTANT FOR GAS PRODUCTION?



1) MHF FRACTURE LENGTHS MAY EXCEED PLANNED WELL SPACINGS
2) DRAINAGE PATTERNS MAY BE OPTIMIZED FOR IN-FIELD DRILLING PROGRAMS

WHY IS FRACTURE GEOMETRY IMPORTANT TO GAS PRODUCTION?



1) STIMULATION MUST STAY WITHIN ZONE FOR MAXIMUM PRODUCTION
2) VERTICAL GROWTH INTO CONTAINMENT STRATA MUST BE LIMITED

BOTH SURFACE AND BOREHOLE INSTRUMENTATION SYSTEMS ARE BEING DEVELOPED TO CHARACTERIZE FRACTURING BEHAVIORS

1) SURFACE ELECTRICAL POTENTIAL SYSTEM

2) SURFACE TILTMETER ARRAY

3) BOREHOLE SEISMIC SYSTEM

4) BOREHOLE MULTIPLE HYDROPHONE SYSTEM

5) IN-SITU STRESS MEASUREMENT

6) OTHER: CORE, LINEAMENT, TELEVISION, TELEVIEWERS, IMPRESSION PACKERS

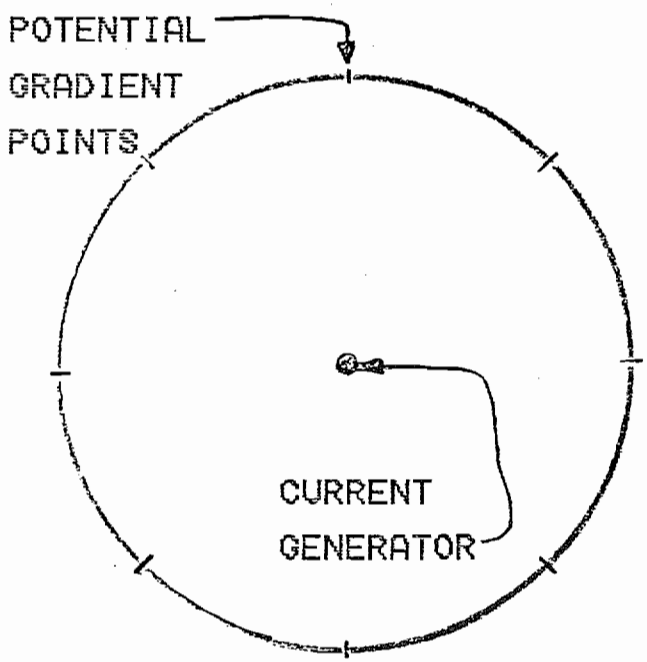
SURFACE ELECTRICAL POTENTIAL SYSTEM HAS MEASURED FRACTURE ORIENTATIONS AND ASYMMETRIES

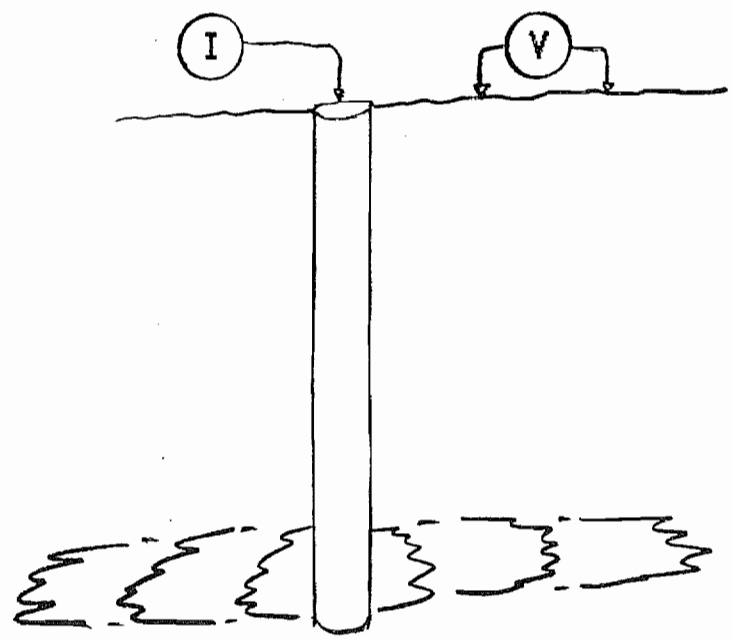
1) ADAPTATION OF FOUR TERMINAL RESISTIVITY SURVEYING TECHNIQUE

2) INJECT ELECTRICAL CURRENT INTO EARTH THRU FRAC WELL AND FLUID

3) MEASURES RESULTING ELECTRIC FIELD CHANGES DURING FRACTURING

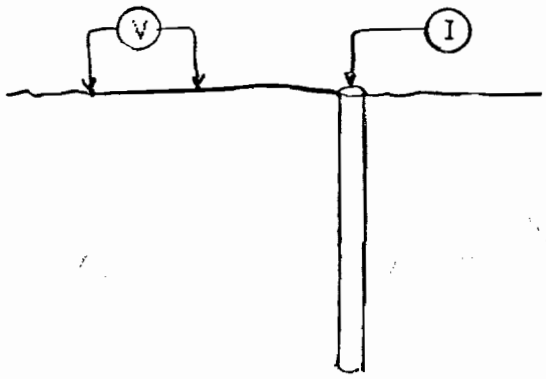
CHANGING CURRENT ELECTRODE GEOMETRY
CHANGES ELECTRICAL POTENTIAL FIELD



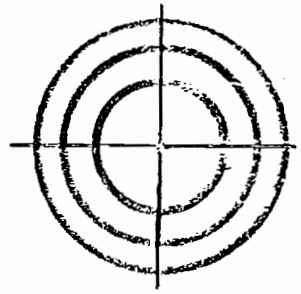


SURFACE POTENTIAL MAPPING TECHNIQUE

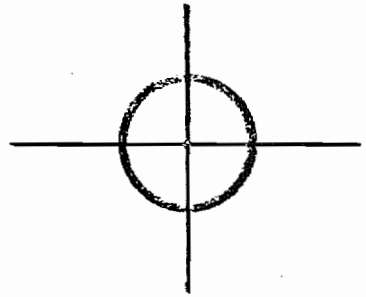
1) FRACTURE WELL AS CURRENT SOURCE



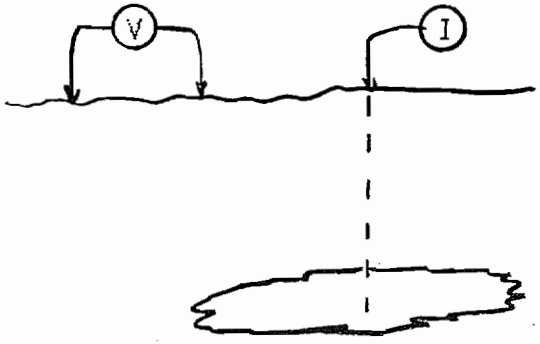
RESULTANT POTENTIAL LINES

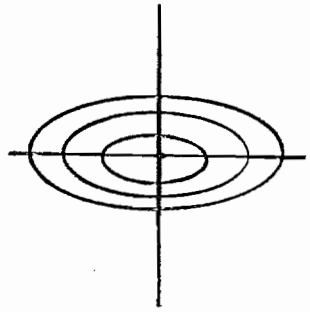


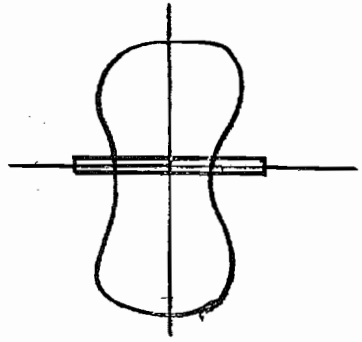
POTENTIAL GRADIENT



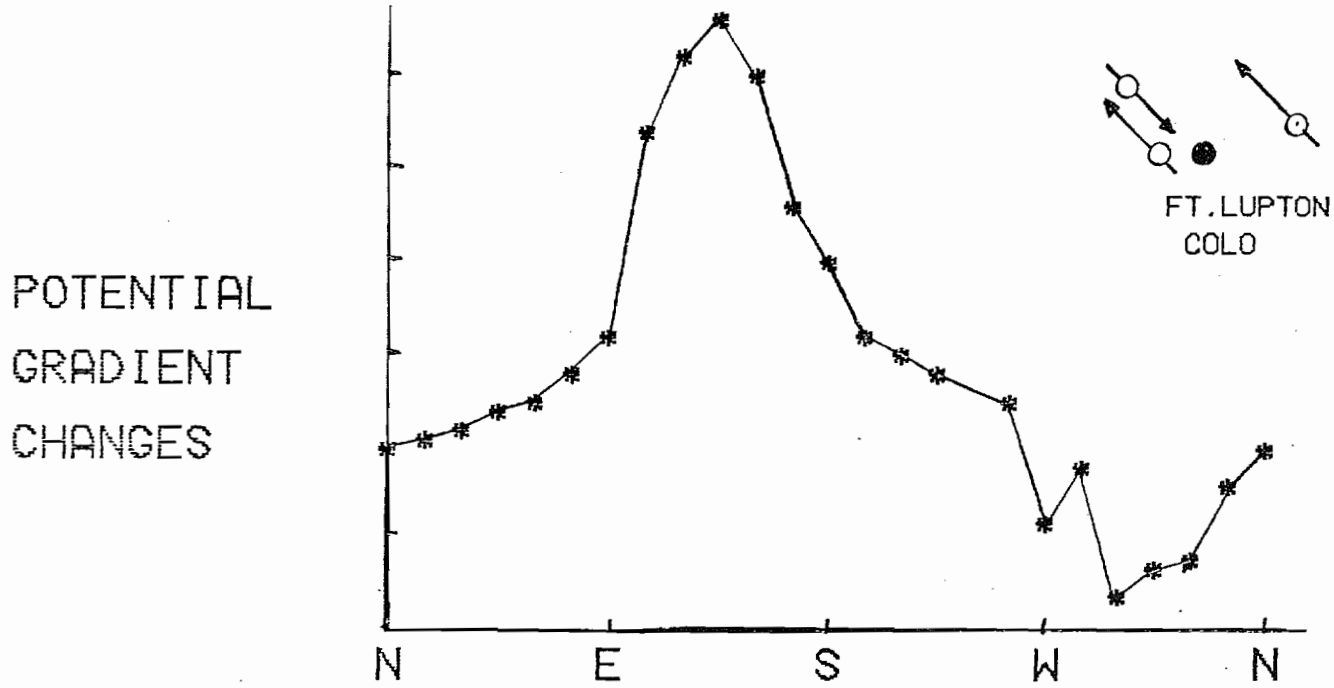
2) HYDRAULIC FRACTURE AS CURRENT SOURCE







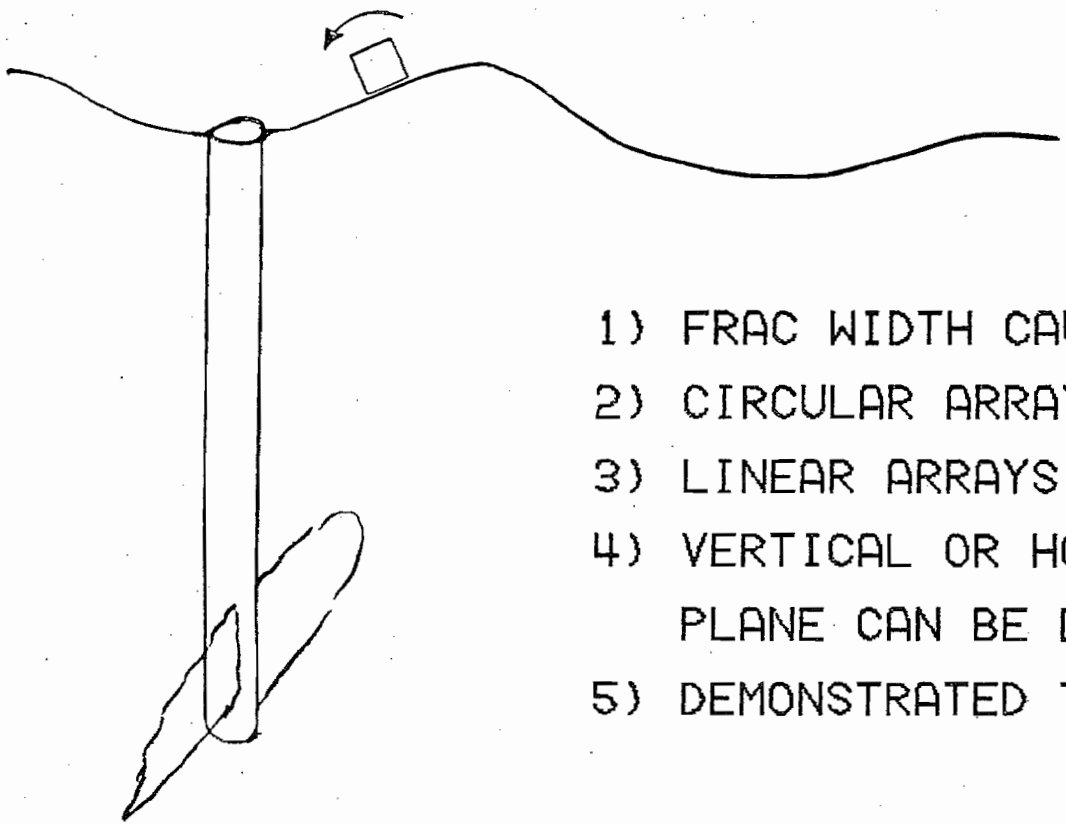
ELECTRICAL POTENTIAL DATA
WATTENBERG FIELD AT 8000 FT



1) FRACTURE ORIENTATION N45W TO S45E

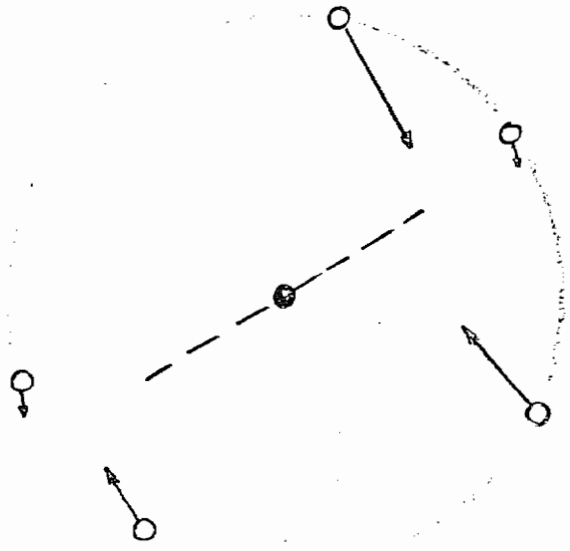
2) ASYMMETRY: LONG SIDE TO N45W

USE OF SURFACE TILTMETER ARRAYS FOR FRACTURE RESEARCH ORIGINATED BY USGS & COMMERCIALIZED BY M D WOOD



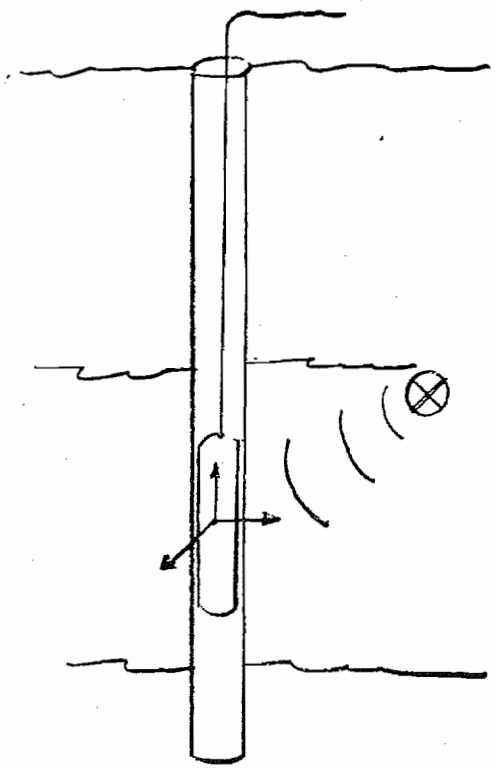
1) FRAC WIDTH CAUSES SURFACE UPLIFT
2) CIRCULAR ARRAYS MAP ORIENTATIONS
3) LINEAR ARRAYS MEASURE LENGTHS
4) VERTICAL OR HORIZONTAL FRACTURE PLANE CAN BE DETERMINED
5) DEMONSTRATED TO 10,000 FEET

THURLOW WEED & ASSOCIATES
NITROGEN GAS STIMULATION EXPERIMENT
DEVONIAN SHALE-MT VERNON, OHIO
TILTMETER DATA



1) EARLY PHASE PUMPING CREATED VERTICAL FRACTURE N62E
2) FRAC BECAME HORIZONTAL
3) AFTER SHUT IN FRAC GROWTH CONTINUED FOR 6 MINUTES

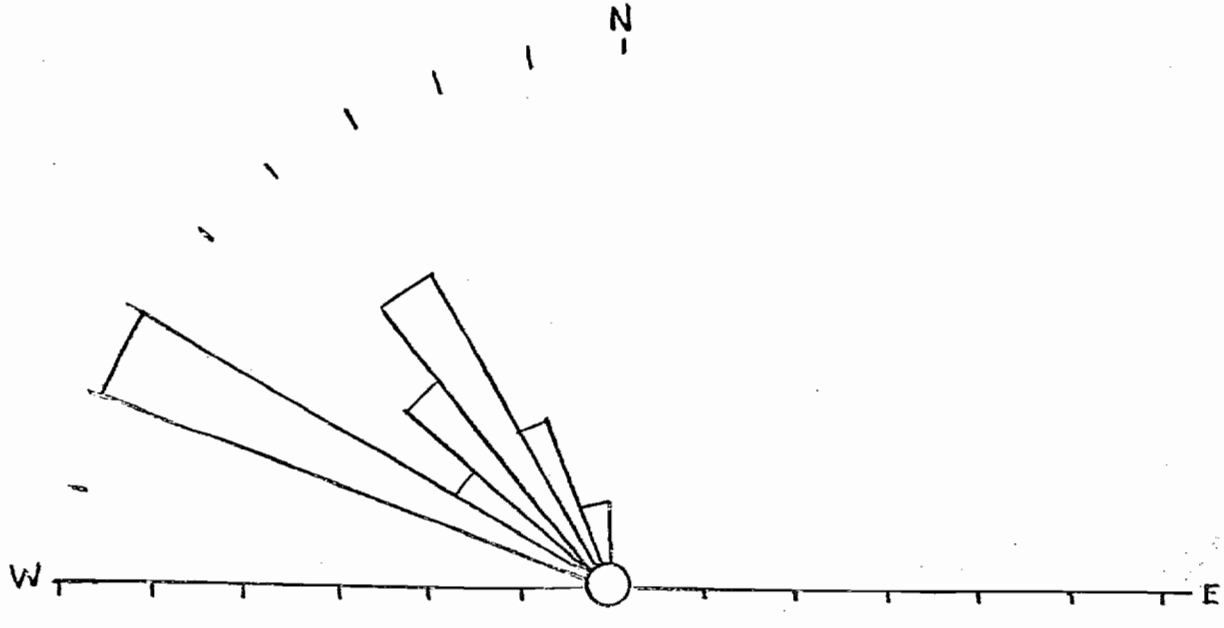
BOREHOLE SEISMIC SYSTEM FOR DETERMINING FRACTURE AZIMUTH



1) SINGLE CONDUCTOR WIRE LINE SYSTEM
2) THREE ORTHOGONAL GEOPHONES
3) LOWERED AND CLAMPED TO SIDEWALL
4) RECORDS DATA AT FRAC DEPTH DURING SHUT IN PERIODS WITH NO FLOW
5) ON BOARD COMPASS UNIT OR SURFACE EXPLOSIVE SHOTS ORIENT SYSTEM

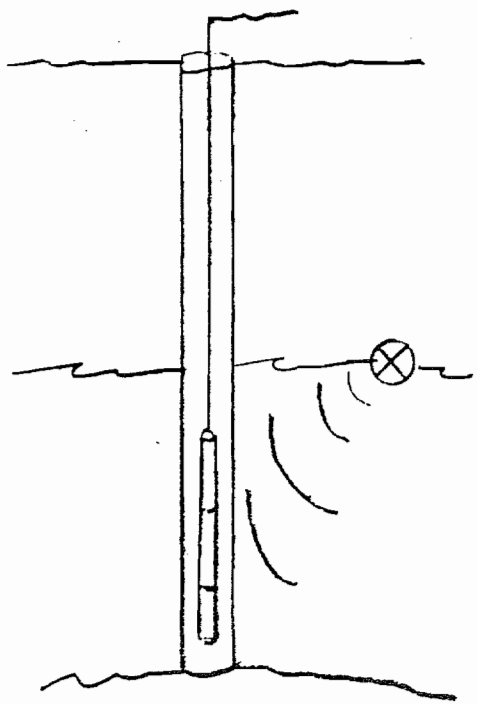
BOREHOLE SEISMIC SYSTEM DATA

COTTON VALLEY-9,600 FT DEEP



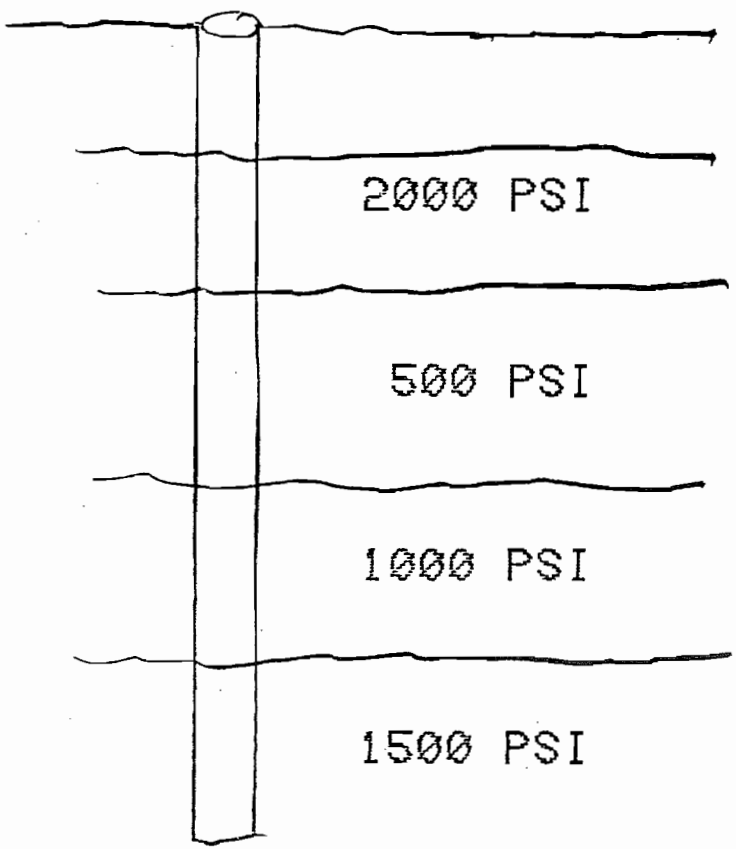
NUMBER OF EVENTS

BOREHOLE MULTIPLE HYDROPHONE TOOL UNDER DEVELOPMENT FOR DETERMINING FRACTURE HEIGHTS AWAY FROM WELLBORE



1) FOUR PRESSURE SENSITIVE HYDROPHONES 10 FT SPACING
2) VERTICAL LOCATION OF SEISMIC SOURCES
3) SMALL DIAMETER TOOL FOR USE IN TUBING AFTER MAIN FRACTURES
4) PROTOTYPE UNDERGOING TESTING

IN-SITU STRESS CONTROLS FRACTURE GROWTH INTO CONTAINMENT STRATA



1) FORMATION BREAK DOWN AND SHUT IN PRESSURES
2) LLL-SONIC VELOCITY WIRE LINE TECHNIQUE
3) SNL-WIRE LINE STRAIN RELIEF TOOL

PROGRESS IS BEING MADE IN THE UNDERSTANDING OF STIMULATION TECHNIQUES BY SURFACE AND BOREHOLE DIAGNOSTICS

1) ORIENTATION-DEMONSTRATED TECHNOLOGY

2) ASYMMETRY & LENGTH-IN DEVELOPMENT

3) HEIGHT AND CONTAINMENT-NEW TECHNOLOGY

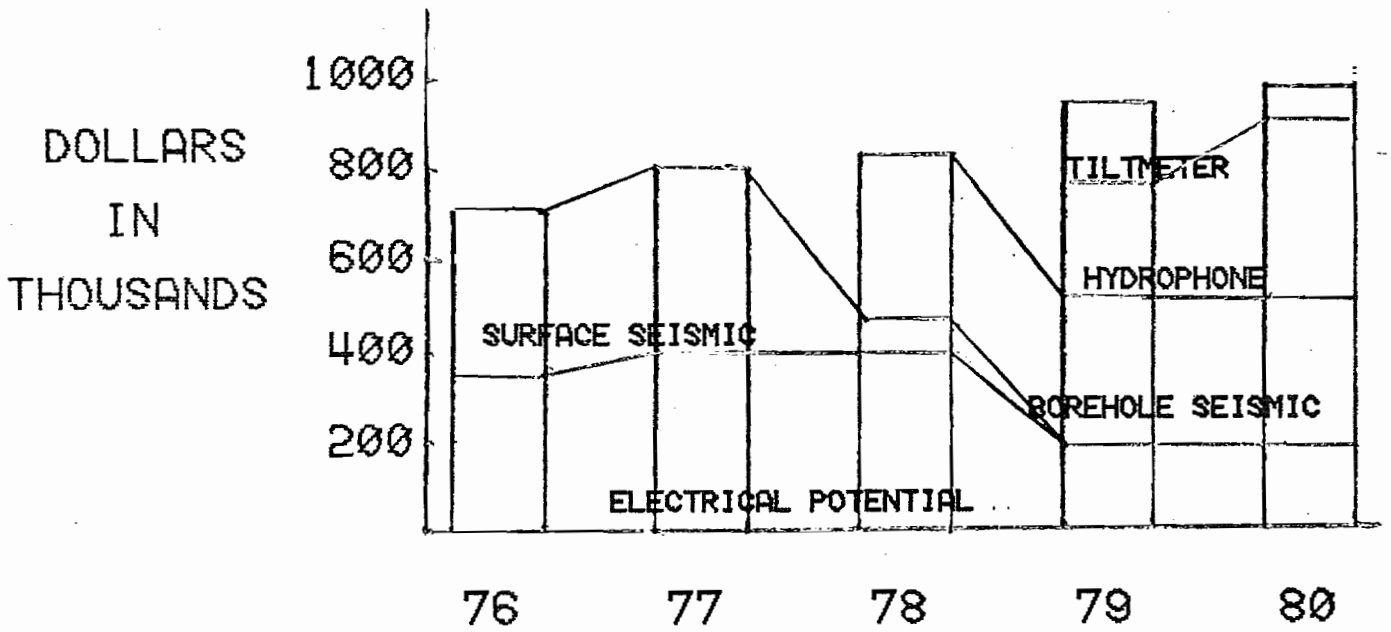
JOINT EXPERIMENTS HAVE ASSISTED IN INSTRUMENTATION DEVELOPMENT AND TECHNOLOGY TRANSFER

JOINT FIELD EXPERIMENTS ALLOW FOR DIRECT TECHNOLOGY DEVELOPMENT AND TRANSFER

E.P.N.G.	TIGHT GAS SANDS
AMOCO	BLANKET
SHELL	LENTICULAR
CONOCO	DEVONIAN SHALE
G.P.E.	TAR SAND
NUMAC	EOR-WATER FLOOD
COLUMBIA	OIL SHALE
T. WEED & ASSOC.	
P.T.C.	

DIAGNOSTIC INSTRUMENTATION

FUNDING LEVELS



INTERVALS SELECTED FOR STIMULATION MUST HAVE THE POTENTIAL FOR ECONOMICAL GAS PRODUCTION

DOE

UNCONVENTIONAL GAS RECOVERY

PROGRAM REVIEW

SEVERAL FORMATION PARAMETERS

CONTROL THE GAS PRODUCIBILITY

1) S_W (WATER SATURATION) OR CONVERSELY GAS SATURATION MOST IMPORTANT

2) ϕ (POROSITY) ALLOWS CALCULATION OF GAS PER UNIT VOLUME OF ROCK

3) K (PERMEABILITY) HOW EASY CAN GAS FLOW THRU FORMATION

4) LENS DIMENSIONS-TOTAL GAS IN PLACE

COMMERCIALLY AVAILABLE LOGGING TOOLS AND GEOPHYSICAL INTERPRETATIONS DEVELOPED FOR GULF COAST-TEXAS-OKL RESERVOIRS CHARACTERIZED BY:

1) HIGH POROSITIES

2) HIGH PERMEABILITIES

3) LOW WATER SATURATIONS

4) HIGH PRODUCTION RATES

MARGINAL RESERVOIRS HOLD LITTLE ECONOMIC STIMULUS FOR DEVELOPMENT OF NEW LOGGING TOOLS

HOW ARE THE MEASURABLE ROCK PROPERTIES RELATED TO THE HYDROCARBON PRODUCTION PARAMETERS

1) ELECTROMAGNETIC IMPEDANCE

2) BOREHOLE RESISTIVITY SURVEY

3) NUCLEAR MAGNETIC RESONANCE

4) VELOCITY PROFILING

5) HIGH RESOLUTION SEISMIC SURVEY

6) BOREHOLE TRANSCEIVER SYSTEMS

ELECTROMAGNETIC IMPEDANCE LOGGING RESEARCH PROGRAM

(K, ϕ, AND S_W)

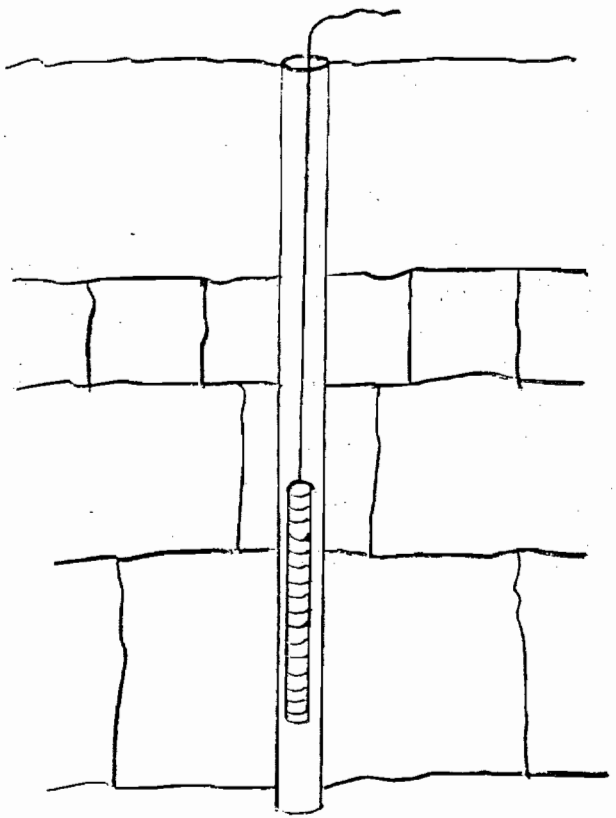
1) EXACT SOLUTION TO MAXWELL'S EQUATION FOR LAYERED/CYLINDRICAL GEOMETRIES

2) FREQUENCY DEPENDENT DIELECTRIC STRENGTH RELATED TO PORE SHAPES

3) STATISTICAL MODELING OF ROCK PROPERTIES AND THEIR RELATIONSHIP TO THE ELECTRICAL PARAMETERS

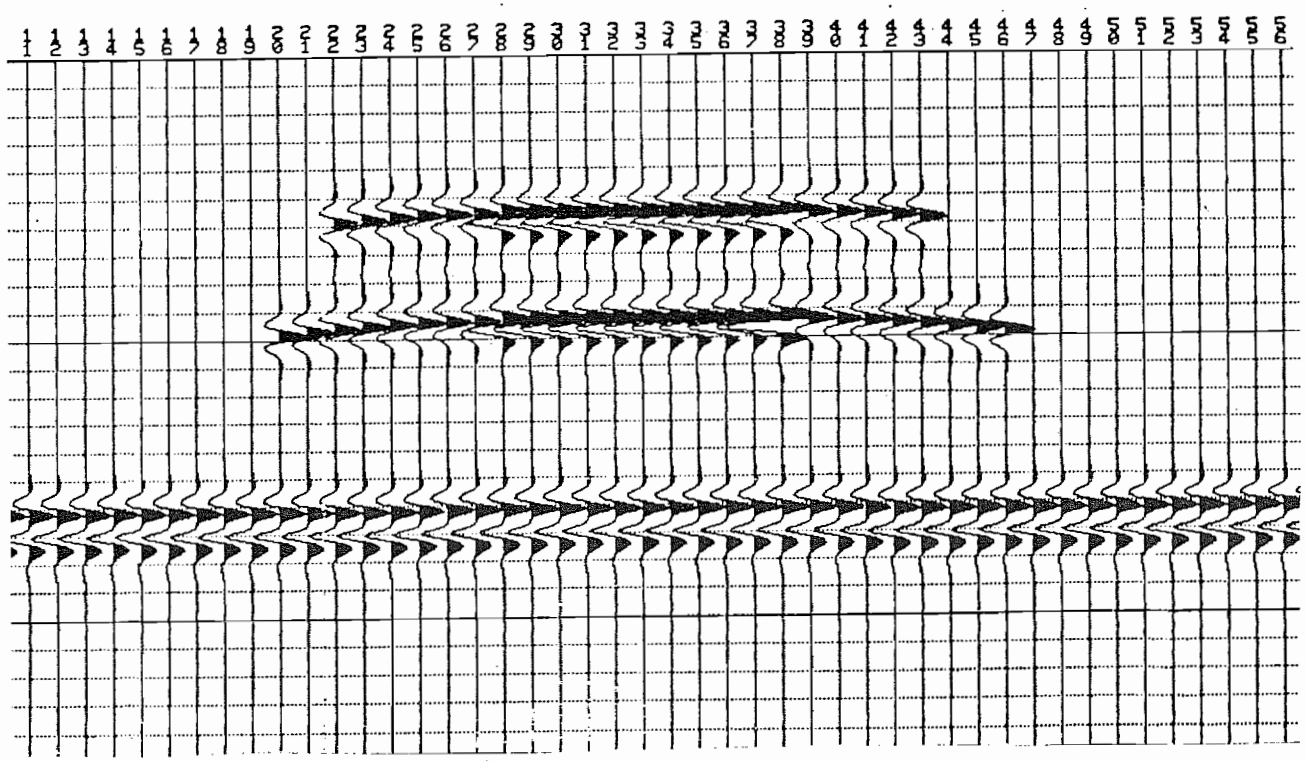
4) PROGRAM GOALS HAVE BEEN REVIEWED BY PRODUCERS AND LOGGING CO.

BOREHOLE RESISTIVITY SURVEY WILL MEASURE DEPTH OF INVADED ZONE (K) AND FORMATION RESISTIVITY (S_W)

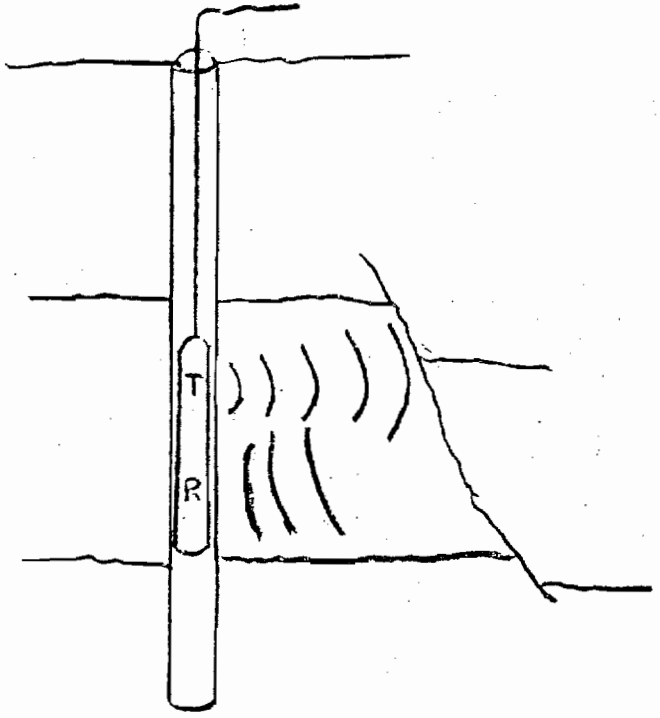


1) LARGE DATA BASE OF ELECTRICAL POTENTIALS
2) INVERSE SOLUTION TO THE ELECTRIC FIELD EQUATIONS
3) CALCULATE RESISTIVITY, RADIUS, AND THICKNESS EACH LOCATION
4) NESTING ALL SOLUTIONS
5) K-DEPTH OF INVADED ZONE
6) R_T-WATER SATURATION

HIGH RESOLUTION 3-D SURFACE SEISMIC SURVEYS MAY BE CAPABLE OF DEFINING LENS DIMENSIONS



BOREHOLE TRANSCEIVER TECHNIQUES NEED TO BE EVALUATED FOR DETERMINING LENS BOUNDARIES



1) DOWNHOLE ACTIVE TRANSMITTERS EITHER RF OR SONIC
2) RECEIVER ARRAYS FOR COHERENT DETECTION
3) PROGRAM PLANS NEED TO BE FORMULATED

UNCONVENTIONAL GAS FORMATIONS WILL REQUIRE NEW LOGGING AND GEOPHYSICAL INTERPRETATION TECHNIQUES FOR DETERMINING PRODUCTION PARAMETERS

1) ELECTROMAGNETIC: K AND ϕ

2) RESISTIVITY: K, R_T, AND S_W

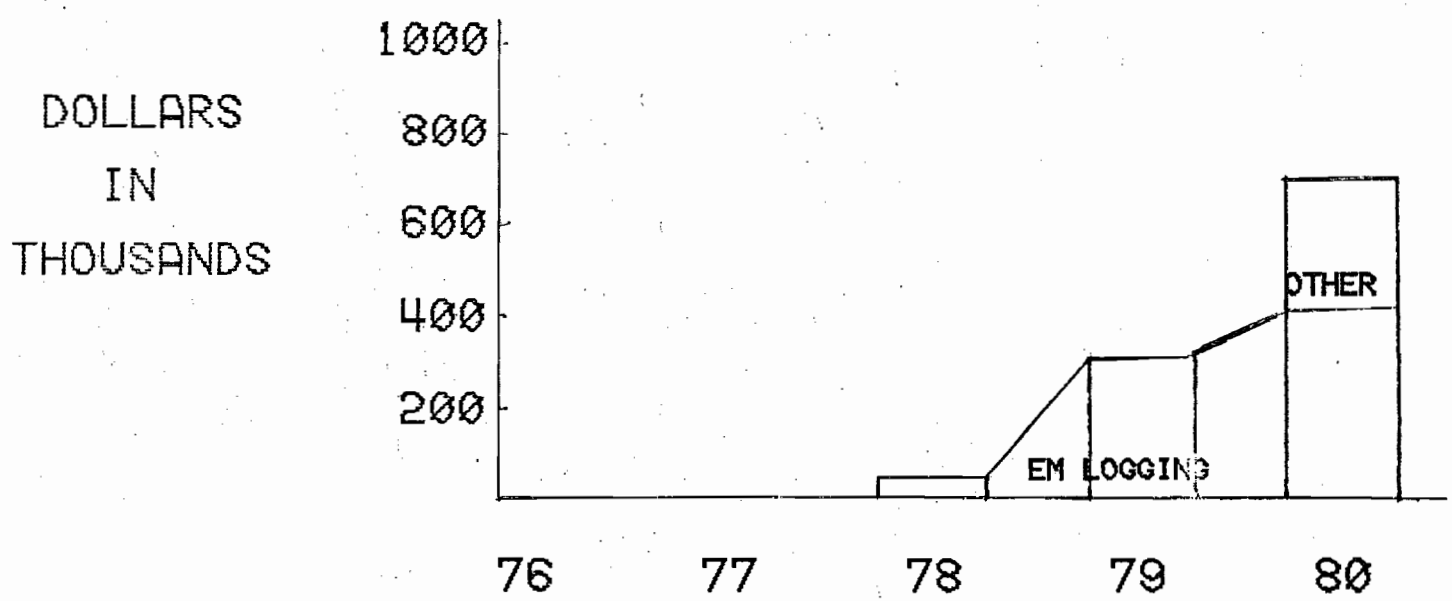
3) NUCLEAR MAGNETIC RESONANCE: K AND ϕ

4) BOREHOLE HYDROPHONE: S_W OR S_G

5) SEISMIC SURVEYS: LENS VOLUME

6) TRANSCEIVER SYSTEMS: LENS BOUNDARIES

FORMATION EVALUATION
FUNDING LEVELS



CHARACTERISTICS OF RESERVOIRS IN THE W.G.S.P.

- HIGH WATER SATURATION IN SANDS
- LOW PERMEABILITY AND POROSITY
- HIGH CLAY CONTENT

RESERVOIR PROPERTIES NEEDED TO CHOOSE GAS ZONES AND MODEL PERFORMANCE

- LOG DERIVED PARAMETERS TO CALCULATE S_w

  POROSITY
  WATER RESISTIVITY
  FORMATION RESISTIVITY
  CEMENTATION FACTOR
  SATURATION EXPONENT

- SHALY CORRECTIONS AND MODIFICATIONS ADD

  CLAY CONTENT
  CATION EXCHANGE CAPACITY
  SURFACE AREA

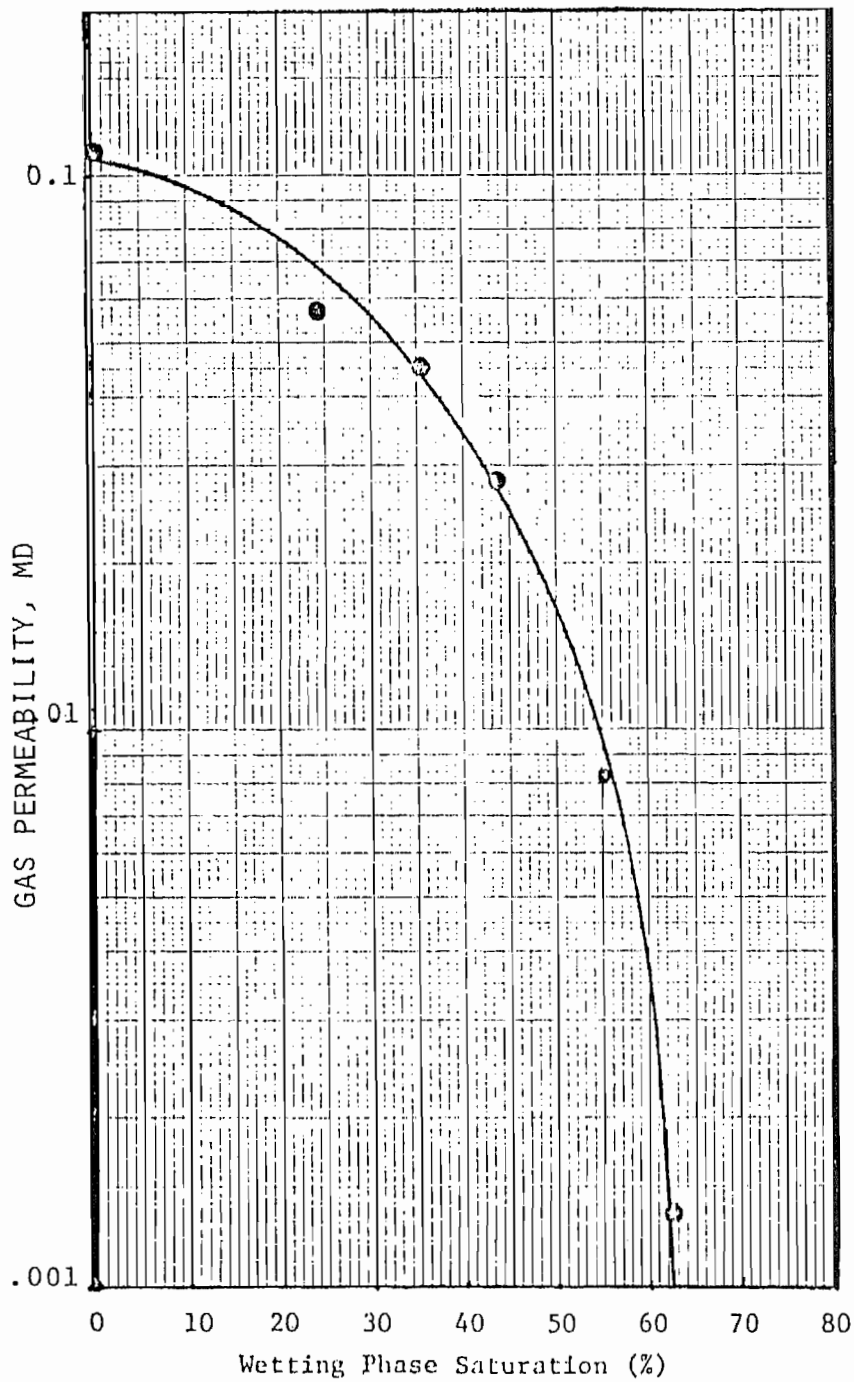
- ROCK PARAMETERS NEEDED FOR RESERVOIR SIMULATORS

  POROSITY
  PERMEABILITY v.s. OVERBURDEN
  PERMEABILITY v.s. WATER SATURATION

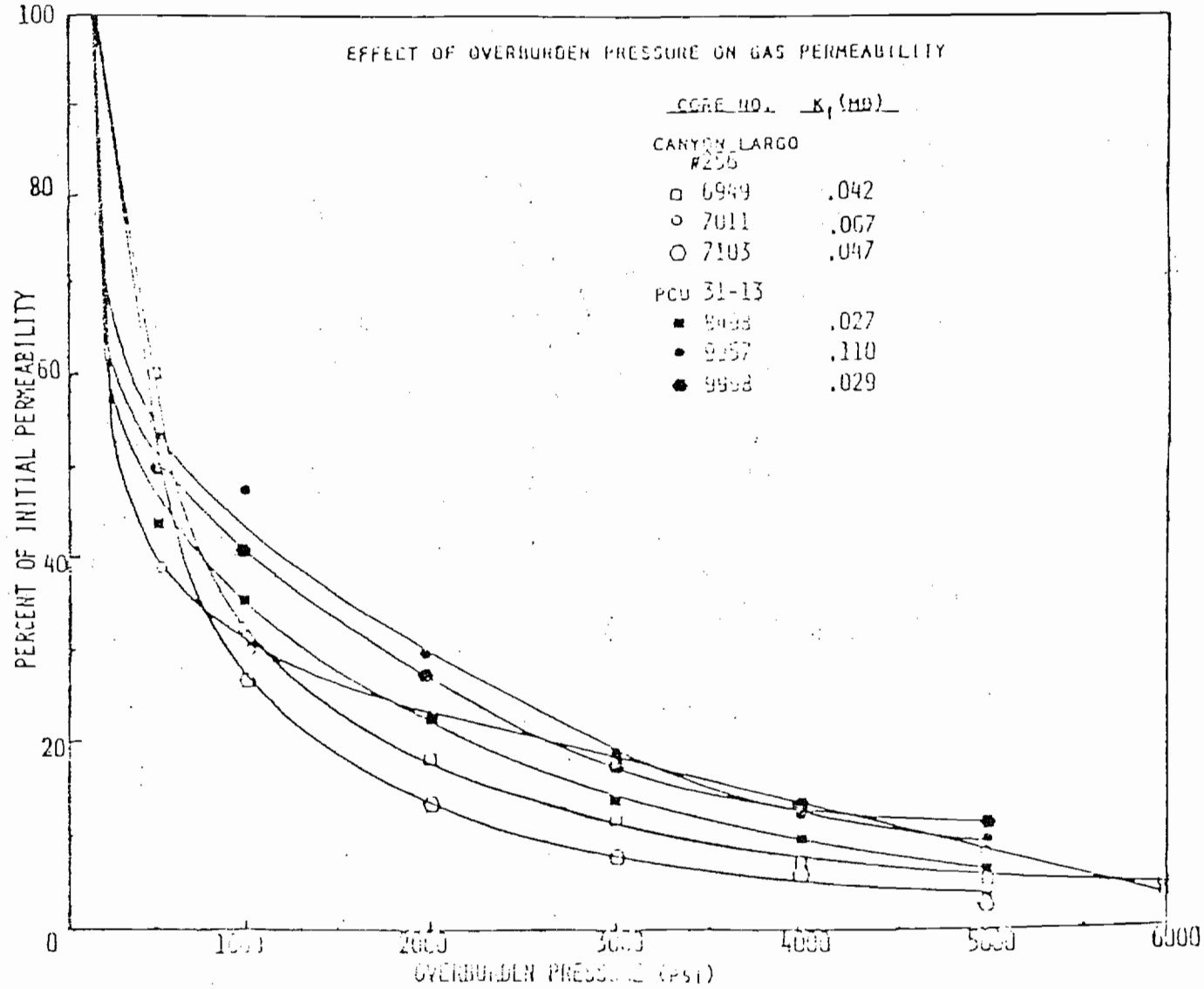
RESERVOIR PROPERTIES DIFFICULT TO PREDICT

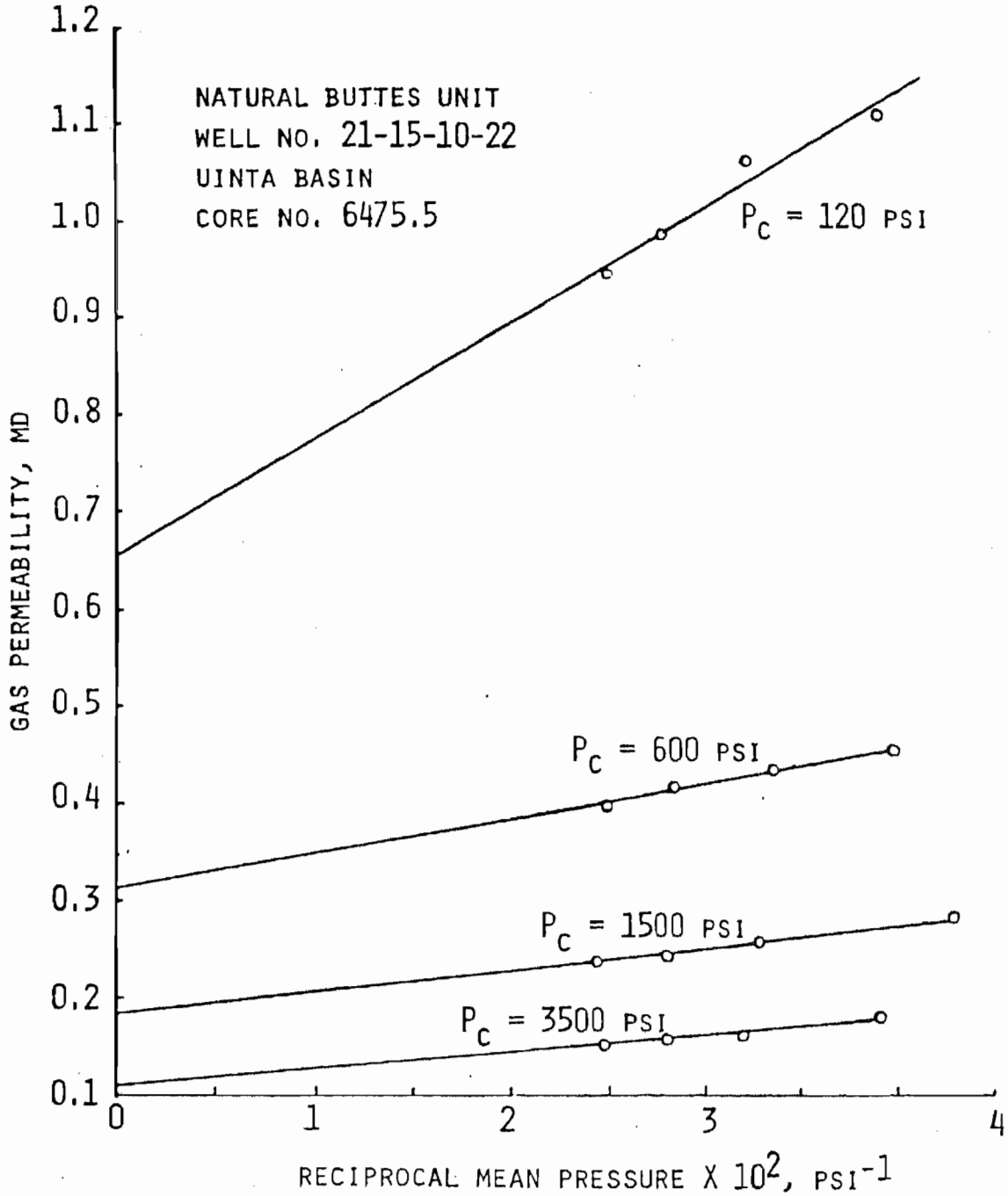
- MEASURED QUANTITIES HIGHLY SENSITIVE TO SAMPLING PROCEDURES
- STANDARD CORE ANALYSIS TECHNIQUES NOT PRECISE ENOUGH
- LOG INTERPRETATION TECHNIQUES NEED REFINEMENT
- STANDARD LOGGING TOOLS LIMITED BY LOW PERMEABILITY, POROSITY, HIGH CLAY CONTENT AND RELATIVELY FRESH WATER

SEM PHOTOGRAPH OF CORE CONTAINING ILLITE
CLAYS LINING PORES AND OBSTRUCTING CAPILLARIES



MOBILE F31-13G 9957 CORE PICEANCE BASIN EFFECT
OF WATER SATURATION ON PERMEABILITY


EFFECT OF OVERBURDEN PRESSURE ON GAS PERMEABILITY
CORE NO.
K_i (MD)
CANYON LARGO
#255
6949 .042
7011 .067
7103 .047
PCU 31-13
.027
.110
.029
PERCENT OF INITIAL PERMEABILITY
100
80
60
40
20
0
1000
2000
3000
4000
5000
6000
OVERBURDEN PRESSURE (PSI)



EFFECT OF OVERBURDEN AND GAS PRESSURE ON PERMEABILITY

IMPORTANCE OF THE CATION EXCHANGE CAPACITY

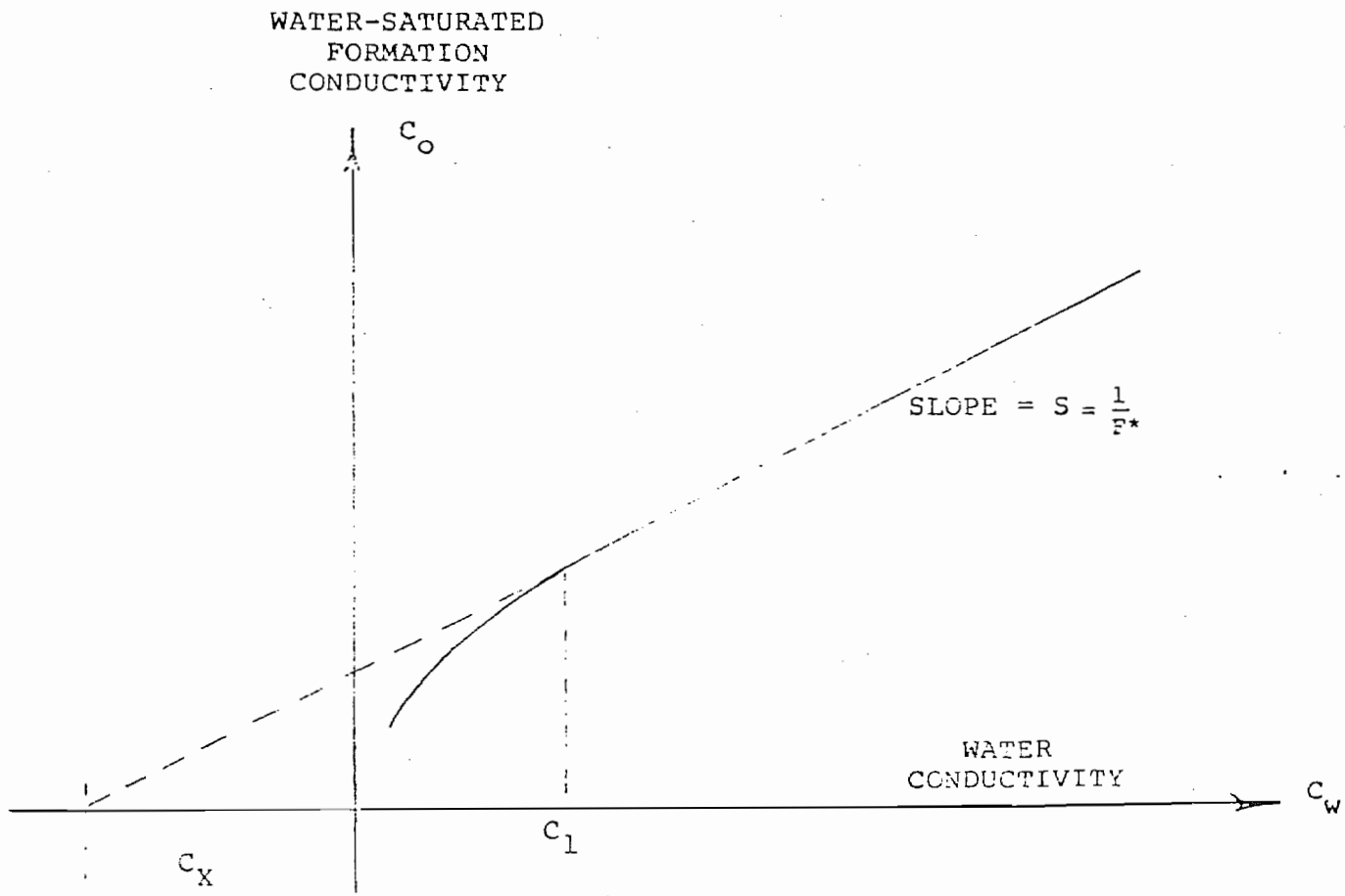
- ADSORBED IONS ON CLAYS INCREASE ELECTRICAL CONDUCTIVITY OF FORMATIONS MAKING ELECTRIC LOG INTERPRETATION DIFFICULT.

- THE CATION EXCHANGE CAPACITY IS AN INTEGRAL PART OF SOME OF THE SHALY SANDS MODELS.

- SOME CLAYS ARE WATER SENSITIVE, SWELLING WHEN CONTACTED BY WATER WHICH LEADS TO DRILLING PROBLEMS AND FORMATION DAMAGE THROUGH RELEASED FINES.

- CLAYS CAN ADSORB ADDITIVES IN FRACTURE FLUID, INCREASING THE EXPENSE AND DECREASING THE EFFECTIVENESS OF THE ADDITIVE.

- CLAYS CAN INTERACT WITH GELS OF THE FRACTURE FLUID (ADSORPTION, CHEMICAL REACTION) TO INCREASE CHANCES OF FORMATION DAMAGE VIA PORE PLUGGING.



A SCHEMATIC SHOWING CONDUCTIVITY, C_o, OF A WATER-SATURATED SHALY FORMATION AS A FUNCTION OF FORMATION-WATER CONDUCTIVITY, C_w.

SHALY SANDS RELATIONS - II

WAXMAN-SMITS

$$\frac{1}{R_t} = \frac{S_w^{\,n}}{F^*}\left(\frac{1}{R_w} + \frac{B \cdot Q_v}{S_w}\right)$$

DUAL-WATER

$$\frac{1}{R_t} = \frac{S_w^{\,n}(1-\alpha \cdot V_Q \cdot Q_v)}{F_o}\left[\frac{1}{R_w} + \frac{\beta \cdot Q_v}{S_w(1-\alpha \cdot V_Q \cdot Q_v)}\right]$$

Q_v IS THE CONCENTRATION OF THE COUNTERIONS ADSORBED ONTO THE CLAY COATING THE SAND GRAINS.

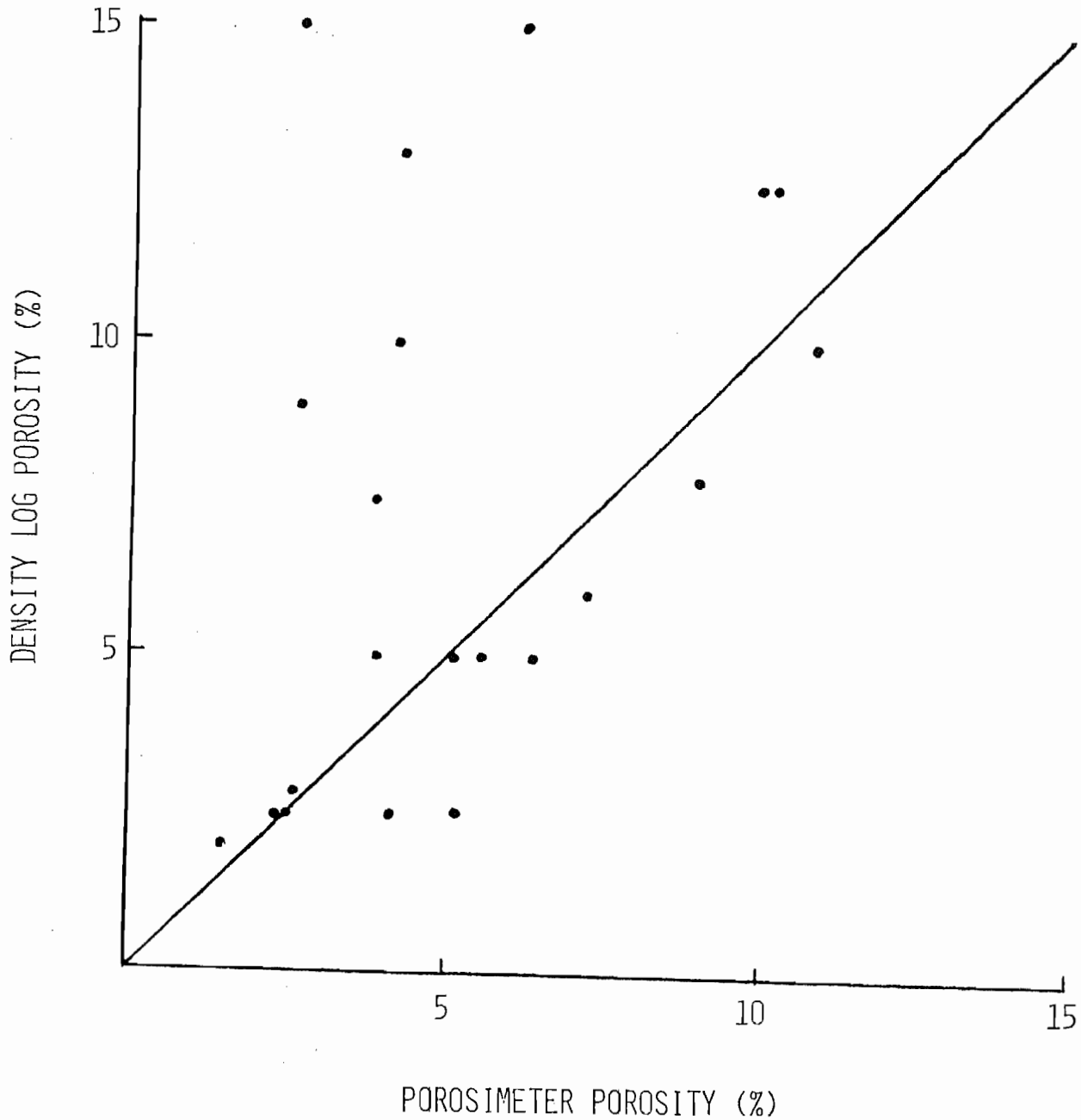
B, OR β, IS THE EQUIVALENT CONDUCTANCE OF THE COUNTER IONS.

$\alpha = 1$ FOR HIGH SALINITY ($\geq$ 1.5% FOR NACL) AND BECOMES LARGER AS THE FORMATION WATER SALINITY DECREASES ($\alpha = 2.6$ FOR 0.2% NACL).

V_Q IS THE PRODUCT OF THE DISTANCE FROM THE COUNTER IONS TO THE CLAY SURFACE, AND THE SPECIFIC CLAY AREA COEFFICIENT.

NATURAL BUTTES #21

DENSITY LOG BASED ON SANDSTONE DENSITY



MULTI-WELL EXPERIMENT — A RESEARCH-ORIENTED FIELD LABORATORY TO CHARACTERIZE LENTICULAR GAS SENDS AND EVALUATE TECHNOLOGY FOR THEIR PRODUCTION

- CLOSE-SPACED WELLS WITH FULL MESAVERDE CORE
- COMPREHENSIVE CORE ANALYSIS, LOGGING, AND FORMATION TESTING PROGRAMS
- VARIED STIMULATION EXPERIMENTS
- GEOPHYSICAL, FRACTURE DIAGNOSTIC, AND IN SITU STRESS MEASUREMENTS
- ANALYSIS AND EVALUATION

ADVANTAGES:

LESS SENSITIVE TO VARIATIONS IN WATER RESISTIVITY THAN STANDARD RESISTIVITY LOGS.

MORE ACCURATE THAN RESISTIVITY LOGS IN FRESH FORMATION WATERS.

DISADVANTAGES:

HIGH LEVEL OF PRECISION REQUIRED.

ADDITIONAL PARAMETERS REQUIRED FOR ACCURATE RESULTS.

PROJECTS AND THEIR MAJOR THRUST:

SANDIA - OPTIMUM TOOL DESIGN, RELATIONSHIP TO PORE GEOMETRY, AND LAB MEASUREMENTS 50KHz TO 100 MHz.

COLORADO SCHOOL OF MINES - TEMPERATURE EFFECTS AND LAB METHODS 1 MHz TO 1000 MHz.

BETC - WATER SALINITY, CLASSICAL COMPONENT MODELS AND LAB METHODS 500 KHz TO 30 MHz.

FIELD DIAGNOSTICS

- HIGH-RESOLUTION SEISMIC REFLECTION; 3D ANALYSIS
- SURFACE-WELL AND WELL-TO-WELL SEISMIC STUDIES
- FRACTURE AZIMUTH AND GEOMETRY; SURFACE, WELLBORE
- PRESSURE MEASUREMENTS
- VERTICAL IN SITU STRESS DISTRIBUTION

RESEARCH DEVELOPING IMPROVED INSTRUMENTS

- ELECTROMAGNETIC LOG
- N.M.R. LOG
- IN - SITU STRESS LOG

PRODUCTION TESTING

- DRILL STEM TESTS
- INTERFERENCE AND PULSE TESTS BETWEEN WELLS
- PRE- AND POST-STIMULATION TESTS
- DOWNHOLE SHUT-OFF TECHNIQUE DEVELOPMENT
- LONG-TERM PRODUCTION DATA

AS RESULT OF WGSP FIELD EXPERIMENTS

(contrary)

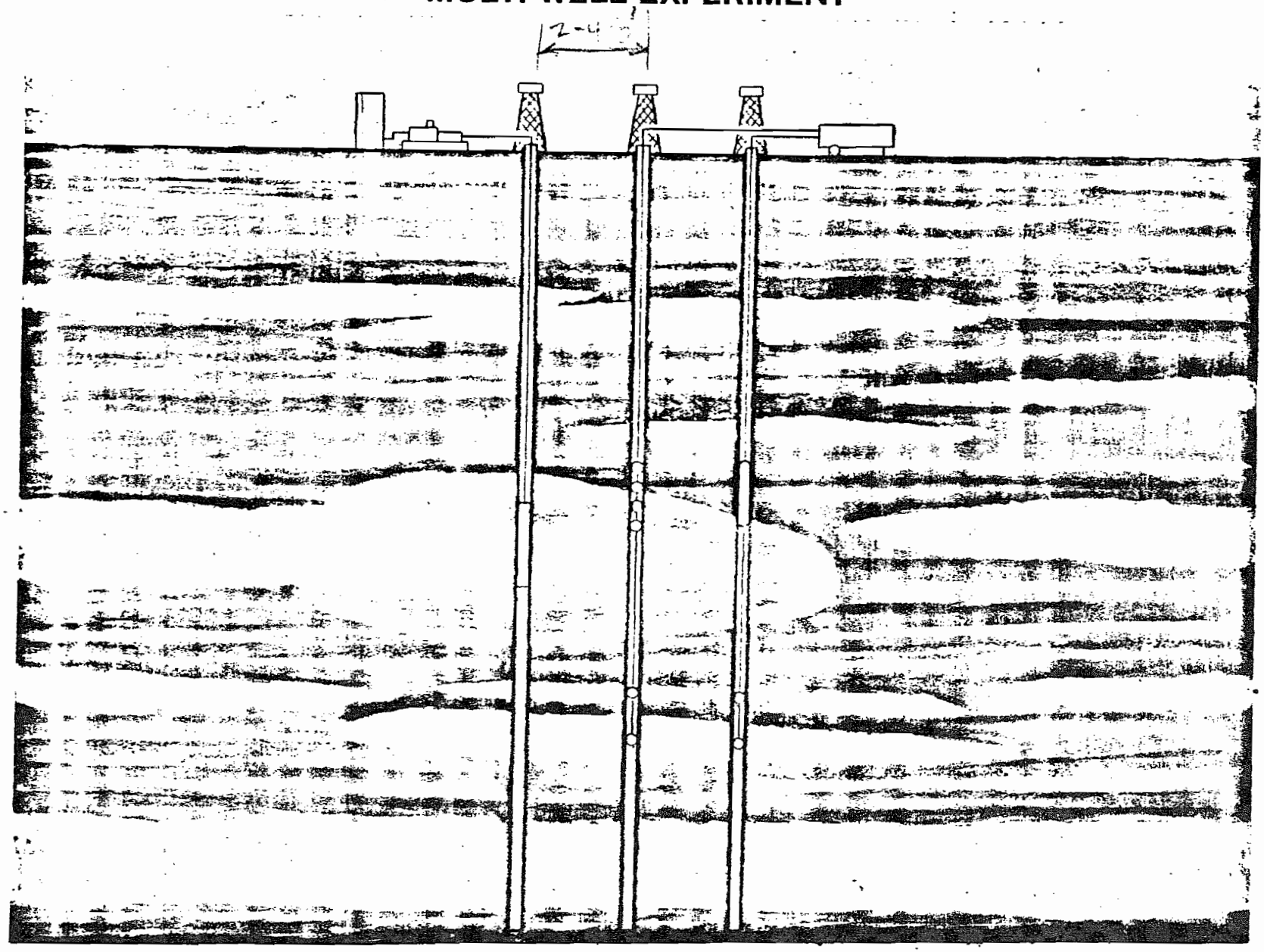
- INDUSTRY IS NOT ACTIVE IN THIS RESOURCE
- NEED FOR RESEARCH EMPHASIZED
- STRONG INDUSTRY INTEREST IN RESEARCH-ORIENTED, DOE-SPONSORED TEST

The argument is
almost circular.
How can [illegible] this?

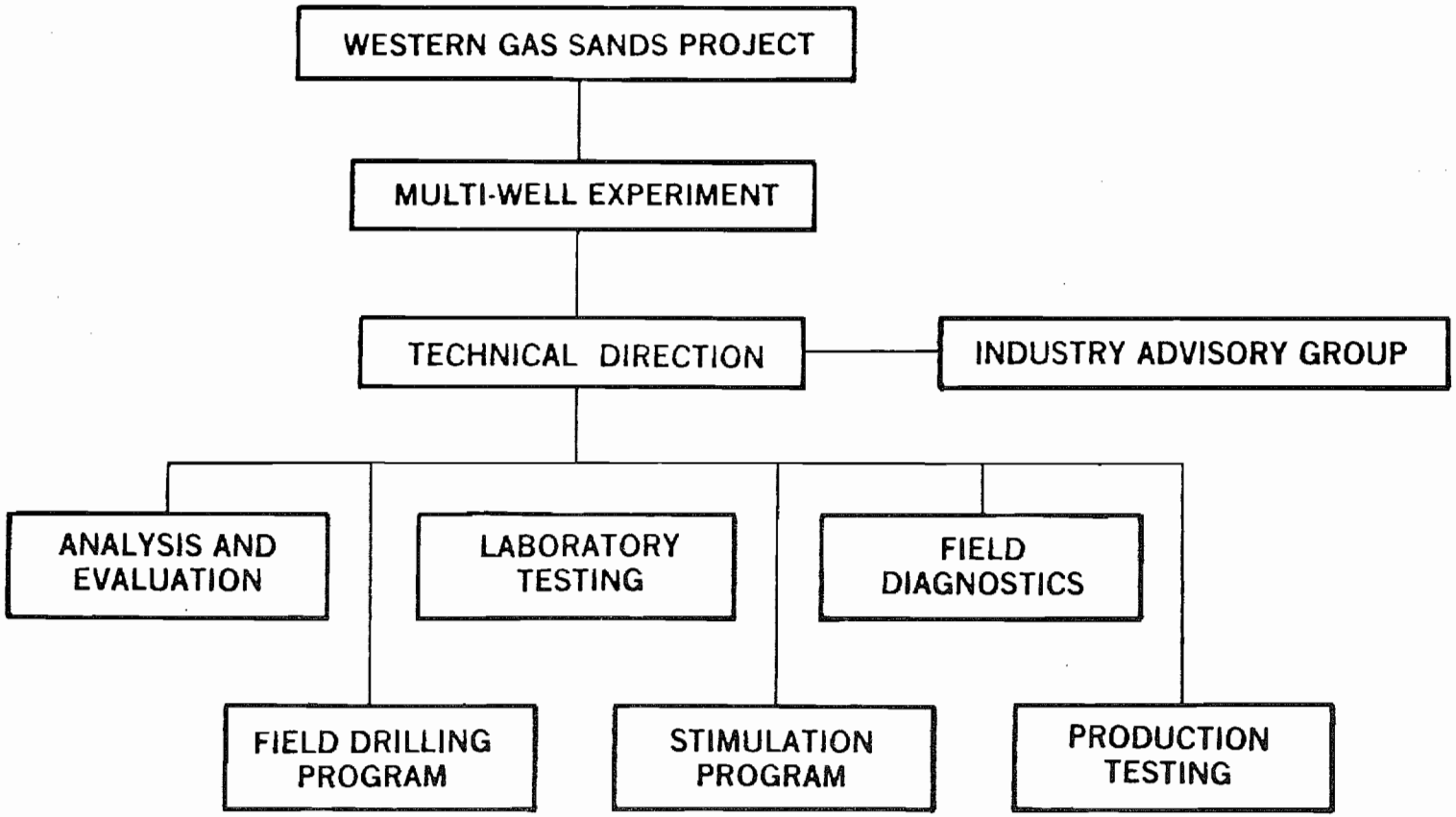
FIELD DRILLING PROGRAM

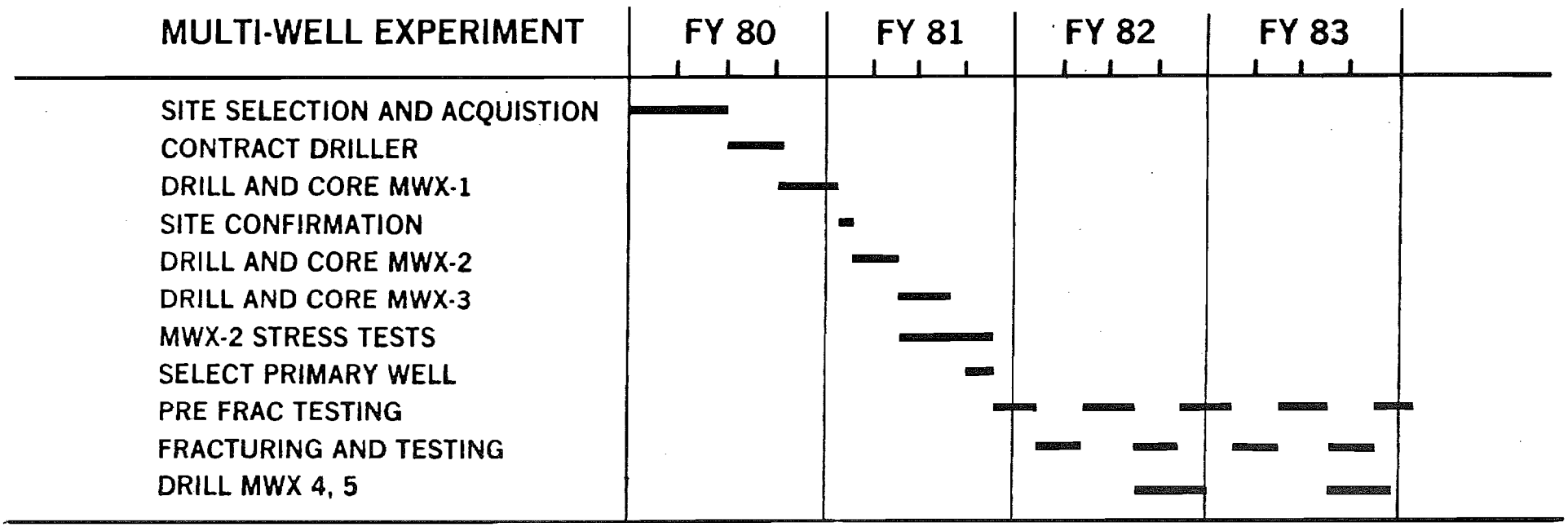
- SITE CONSTRUCTION AND MAINTENANCE
- DRILLING PROGRAM
- CORE PROGRAM: CONVENTIONAL
  STRATAPAX BITS
  IMPROVED PRESSURE CORING
- LOGGING PROGRAM: CONVENTIONAL AND EXPERIMENTAL

MULTI-WELL EXPERIMENT



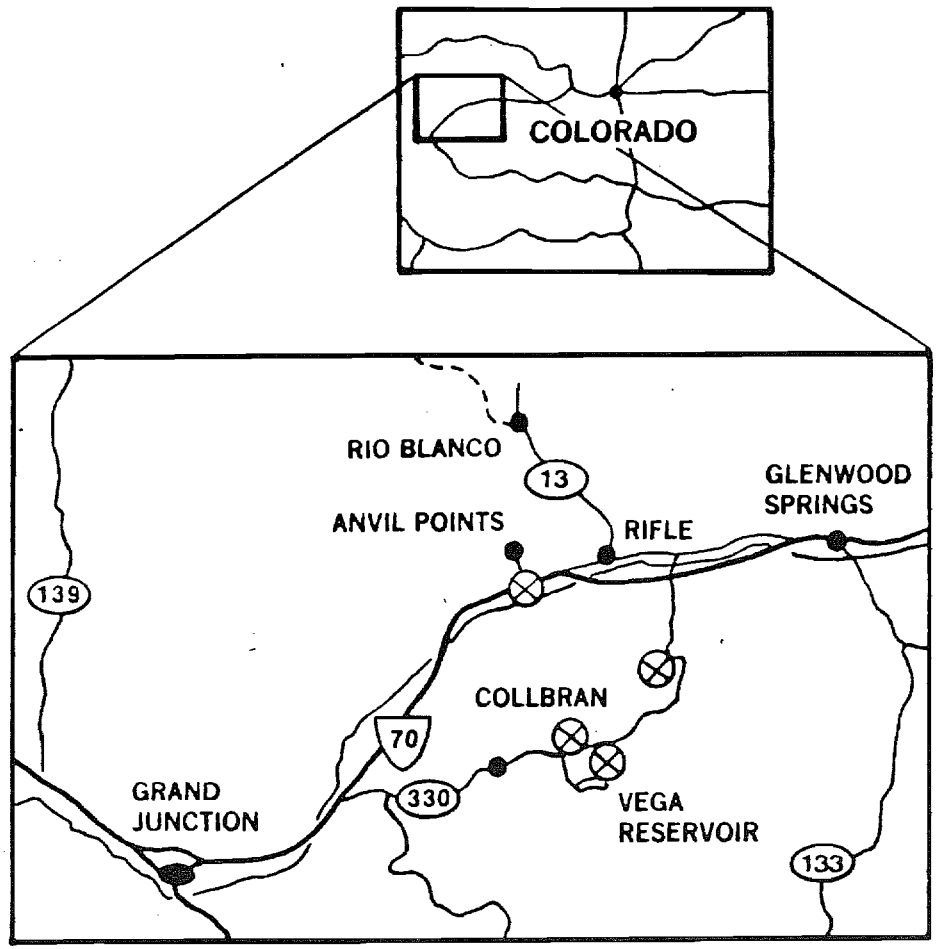
8500' total depth


WESTERN GAS SANDS PROJECT
MULTI-WELL EXPERIMENT
TECHNICAL DIRECTION
INDUSTRY ADVISORY GROUP
ANALYSIS AND EVALUATION
LABORATORY TESTING
FIELD DIAGNOSTICS
FIELD DRILLING PROGRAM
STIMULATION PROGRAM
PRODUCTION TESTING


MULTI-WELL EXPERIMENT
FY 80
FY 81
FY 82
FY 83
SITE SELECTION AND ACQUISTION
CONTRACT DRILLER
DRILL AND CORE MWX-1
SITE CONFIRMATION
DRILL AND CORE MWX-2
DRILL AND CORE MWX-3
MWX-2 STRESS TESTS
SELECT PRIMARY WELL
PRE FRAC TESTING
FRACTURING AND TESTING
DRILL MWX 4, 5

STATUS

- FUNDING INITIATED
- INDUSTRY ADVISORY GROUP FORMED, 4 MEETINGS
- PLANNING UNDERWAY
  - PRELIMINARY
  - NETWORK PLAN
  - MWX DOCUMENT
  - SUBCOMMITTEES ACTIVE
- SUPPORT CONTRACT COMPLETE
- SITE ACQUIRED (ALMOST)



INDUSTRY ADVISORY GROUP; MULTI-WELL EXPERIMENT

LINCOLN F. ELKINS	SOHIO PETROLEUM CO.
JOHN L. FITCH	MOBIL RESEARCH & DEVELOPMENT CO.
TOM W. MUECKE	EXXON PRODUCTION RESEARCH CO.
RANDY J. SAUCIER	SHELL DEVELOPMENT CO.
RALPH W. VEATCH	AMOCO PRODUCTION CO.

$20 million over 5 yr
zero cost sharing

MULTI-WELL EXPERIMENT OBJECTIVES

- TO OBTAIN A COMPREHENSIVE GEOLOGIC CHARACTERIZATION OF THE LOW PERMEABILITY, LENTICULAR GAS SANDS OF THE WESTERN UNITED STATES
- TO EVALUATE STATE-OF-THE-ART AND DEVELOPING TECHNOLOGY FOR THE PRODUCTION OF THESE RESERVOIRS

LABORATORY TESTING

- COMPREHENSIVE CORE ANALYSIS PROGRAM
- GAS AND FLUID ANALYSES
- FRACTURE FLUID - FORMATION INTERACTIONS
- PROPPANT STUDIES

CHARACTERISTICS OF PAST FIELD EXPERIMENTS

- PRODUCTION-ORIENTED PLANS, SCHEDULES, AND BUDGET
- NO CORE EXISTS FOR ANY FRACTURED INTERVAL
- GAS PRODUCTION (AND LOGS) ONLY DATA FOR ANALYSIS
- WELL SPACING $\geqslant$ 1 MILE, $\gg$ LENS DIMENSIONS
- LIMITED, IF ANY, DIAGNOSTICS
- NO CONCERTED, COORDINATED ANALYSIS

STIMULATION PROGRAM

- 2-3 FRACTURE EXPERIMENTS PER YEAR
- UNLIMITED POSSIBILITIES:

  DIRECT COMPARISONS IN DIFFERENT LENSES
  PROPPANT AND FLUID EFFECTS
  INCREMENTAL FRACS

- OBTAIN COMPLETE DIAGNOSTIC AND STIMULATION DATA

RESEARCH DEVELOPING IMPROVED ANALYSIS

- METHODS OF MEASURING PERMEABILITY
  - VARIATION WITH CONFINING PRESSURE
  - VARIATION WITH WATER SATURATION
  - EFFECTS FROM FORMATION DAMAGE
- PERMEABILITY MODEL RELATING
  - ROCK STRENGTH
  - CONFINING PRESSURE
  - GRAIN SIZE
- CORRECTIONS TO STANDARD LOGGING INTERPRETATIONS
  - C.E.C. FROM LOGS OR LABORATORY
    - GAMMA LOG CORRELATION
    - X-RAY ANALYSIS OF CLAY CONTENT
    - SURFACE AREA MEASUREMENTS
  - MODIFICATIONS TO POROSITY LOGS

ANALYSIS AND EVALUATION

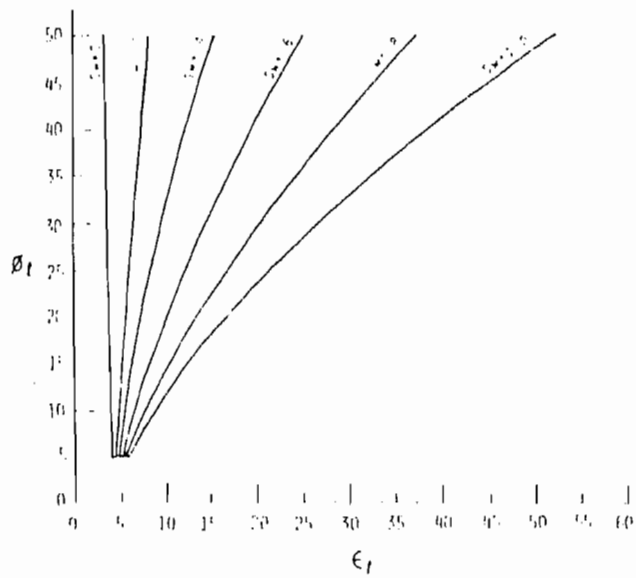
- GEOLOGIC CHARACTERIZATION OF LENTICULAR RESERVOIR
- RESERVOIR (GAS PRODUCTION) MODEL
- FRACTURE GEOMETRY AND STIMULATION MODEL
- LOG-CORE-PROPERTY CORRELATIONS
- TECHNOLOGY ASSESSMENT AND EVALUATIONS:

  ECONOMICS
  RECOMMENDATIONS

FORMATION EVALUATION USING DIELECTRIC CONSTANT MEASUREMENTS

DIELECTRIC CONSTANT - MEASURE OF A MATERIAL'S ABILITY TO STORE ENERGY IN AN ELECTRIC FIELD.

HIGH CORRELATION WITH WATER SATURATION SW.



Crossplot of relative dielectric constant versus total porosity for S_w.