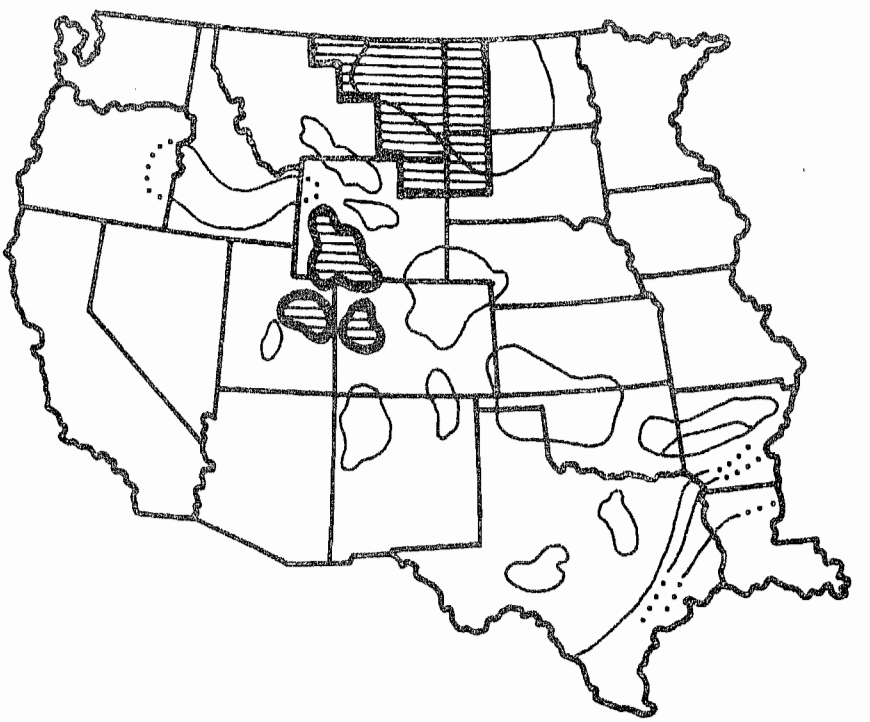
Western Gas Sands Project

Project Plan Document FY 1978



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Prepared for
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1. SUMMARY

The Department of Energy (DOE) has embarked on a program to accelerate the development of domestic energy resources. One project under this program is the Western Gas Sands Project (WGSP) which is directed toward development of new or improved techniques for recovering natural gas from low permeability reservoirs currently not economic. The principal activities that comprise this project are:

Project Management

Resource Assessment

Research and Development by Energy Research Centers and National Laboratories

Field Tests and Demonstrations

Project Management assures coordination between the various activities and furnishes technical and financial monitoring of the various projects. An economic analysis will be prepared on each area utilizing available field data, but since this is an ongoing evaluation throughout the project's duration, all such analyses will be interim. Environmental assessments prepared for field projects will be reviewed and analyzed. Periodic progress reports will be prepared to summarize project activities and an information management system will assure timely dissemination of useful data to the public.

Resource Assessment includes geological and geophysical studies performed mainly by the U.S. Geological Survey (USGS). Efforts will continue to upgrade logging tools and interpretation techniques with emphasis being placed on field testing of the new gravimeter under development. Core samples from specific areas will be taken and a routine core analysis will be performed by a commercial laboratory. Special analyses will be performed by the USGS, Bartlesville Energy Research Center (BERC), Lawrence Livermore Laboratory (LLL), and others.

CER Corporation will continuously monitor the drilling and exploratory activities in the Uinta, Piceance, Greater Green River Basin and the Northern Great Plains Province.

Intercomp Resource Development and Engineering, Inc. will perform a reservoir engineering evaluation of the previous massive hydraulic fracture (MHF) tests using numerical simulation techniques.

Research and development activities funded by DOE have been directed toward new tools and instrumentation systems, rock mechanics, modeling and data analysis. The activities are performed primarily by DOE's

Energy Research Centers, National Laboratories and the USGS. BERC is monitoring a contract with Sandia Laboratories which involves the development of an improved pressure coring tool. BERC is also involved in a research effort to define MHF design parameters. This includes evaluation of potential productivity of low permeability and low porosity formations by applying new or innovative logging techniques and interpretations. The amount of formation damage due to invasion of hydraulic fracturing fluids is also being investigated. Lawrence Livermore Laboratory has a research program aimed at understanding stimulation processes. Sandia Laboratories, through their mineback procedures at the DOE's Nevada Test Site, is offered direct observation and evaluation for determining in situ stress distributions, fracture orientation and geometry and other fracturing results, such as proppant distribution. Sandia also has developed the surface electrical potential system for fracture orientation determination. The development of a down-hole seismic sensor may offer a better opportunity to measure fracture height and orientation and may shift the emphasis from surface detection of fracture related signals to a down-hole system.

Field tests and demonstrations comprise an essential part of the WGSP. In the field, application of new skills and techniques are implemented for final evaluation and assessment. Four field projects will carry over into FY 78. These are:

Gas Producing Enterprises Incorporated, Uinta Basin, UT

Mobil Research and Development Corporation, Piceance Basin, CO

Rio Blanco Natural Gas Corporation, Piceance Basin, CO

A consortium of industry companies managed by CER Corporation, Piceance Basin, CO

One additional contract has been let for a joint DOE/Industry stimulation project with Colorado Interstate Gas Corporation, northeast of Denver.

All of the MHF wells, with the exception of one, have been fractured in the planned formations with the Mobil and GPE No. 14, 18 and 20 wells showing significant improvement as compared to original flow rates.

2. INTRODUCTION

2.1 Background

The Department of Energy (DOE) has embarked on a program to accelerate the development of domestic energy resources. One of the projects under this program is the Western Gas Sands Project. It is directed toward the development of new or improved techniques for recovering natural gas from low permeability reservoirs that currently cannot be economically produced.

Geologic studies have indicated that an immense resource of natural gas exists in these reservoirs in a number of geologic basins scattered throughout the western states (Figure 2-1).

The low permeability gas sands are interbedded with shale throughout intervals thousands of feet thick. Potentially productive sands within these intervals might number a hundred or more and may range in thickness from a few feet to more than 100 feet and may either be "blanket" having large areal extent, or lenticular of unknown size.

As identified by the Federal Power Commission (FPC) study in 1973 and supplemented by the United States Geological Survey (USGS), four of these areas are large in areal extent, contain a large fraction of known low permeability reservoirs and have a sizable existing data base (Table 2-1).

The project, as currently conceived, spans eight years and the Federal Government's contribution has been estimated at $150 million. The rate of technological development depends upon the yearly budget levels.

2.2 Project Objectives and Strategy

The purpose of the project is to encourage and supplement industrial efforts in developing technology and demonstrating the economic feasibility of producing natural gas from these reservoirs.

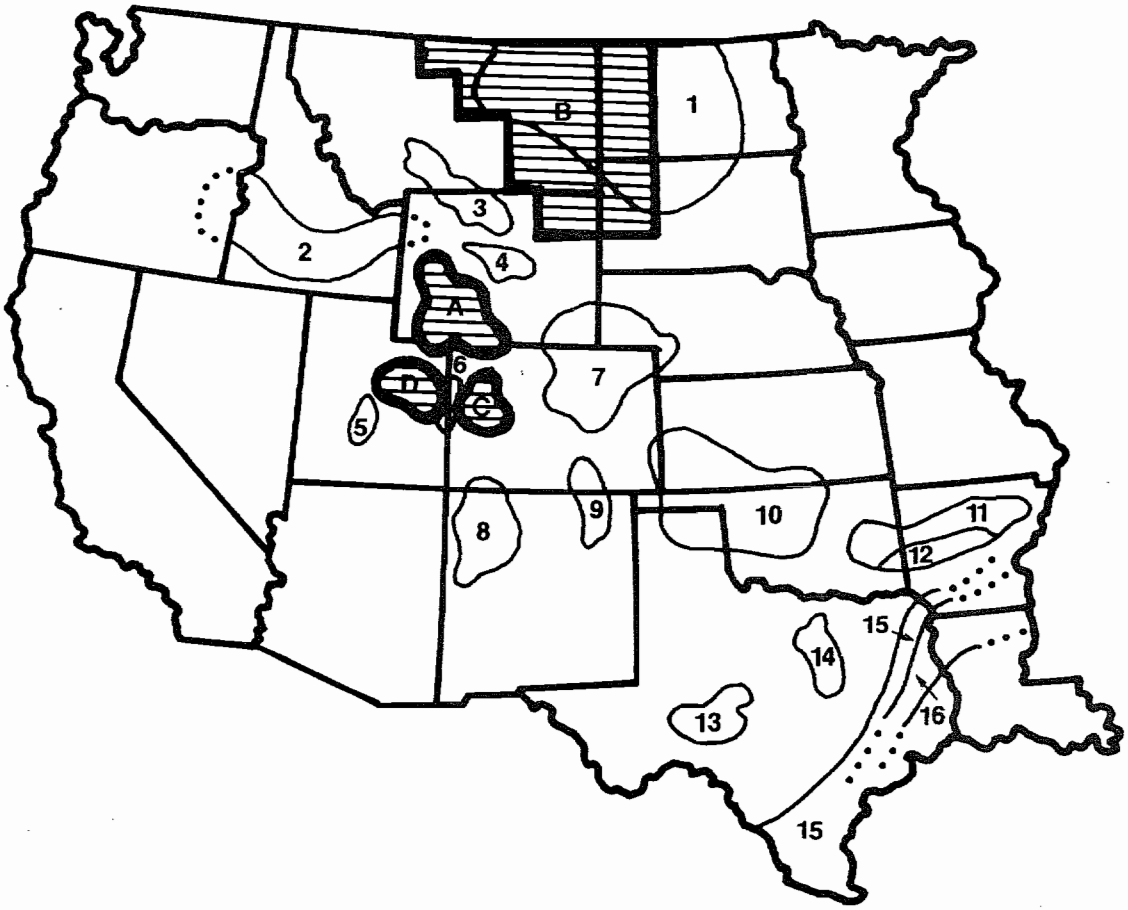
The project objectives are:

a. To more accurately define the resource base.

b. To determine physical and chemical properties of the reservoirs.

c. To determine appropriate stimulation technology.

d. To assess potential gas reserves and demonstrate economic productivity to encourage industrial development of the resource.



PRIMARY STUDY AREAS

A. GREATER GREEN RIVER BASIN
B. NORTHERN GREAT PLAINS PROVINCE
C. PICEANCE BASIN
D. UINTA BASIN

ADDITIONAL LOW PERMEABILITY SANDSTONE AREAS

1. WILLISTON BASIN
2. SNAKE RIVER DOWNWARP
3. BIG HORN BASIN
4. WIND RIVER BASIN
5. WASATCH PLATEAU
6. DOUGLAS CREEK RANCH
7. DENVER BASIN
8. SAN JUAN BASIN
9. RATON BASIN
10. ANADARKO BASIN
11. ARKOMA BASIN
12. OUACHITA MOUNTAINS PROVINCE
13. SONORA BASIN
14. FORT WORTH BASIN
15. WESTERN GULF BASIN
16. COTTON VALLEY TREND

FIGURE 2-1 LOW PERMEABILITY REGIONS

Table 2-1 Principal Study Areas and Resource Base Estimates

AREA	STATE	ESTIMATED RESOURCE (TCF)*
Greater Green River Basin	WY	240
Northern Great Plains Province	MT	130
Piceance Basin	CO	210
Uinta Basin	UT	150
TOTAL		730

*Trillion Cubic Feet, based on FPC and USGS estimates

Achieving these objectives will require:

a. activating the Petroleum Information Well Data Bank Program by the USGS and utilizing new and revised geological information to determine optimum drilling sites for resource confirmation and production research activities.

b. cost-sharing field tests with industry to characterize the reservoirs and to test and refine production stimulation technologies, particularly massive hydraulic fracturing.

c. maintaining an effective research program in government, industry and academic institution laboratories for enhanced gas recovery from low permeability reservoirs.

d. incorporating and building upon industry R&D results.

e. economic analyses and technology transfer.

2.3 General Project Activities

The base funding level for FY 78 (approximately $5,000,000) is significantly smaller than anticipated in the general project plan. Consequently, the bulk of the FY 78 effort will be in resource assessment, continuation of current field projects, analysis of results from completed field tests, geophysical logging and coring tool development and detailed planning and analysis in preparation for FY 79. Anticipating substantially increased FY 79 funding, plans will be made for the initiation of new laboratory R&D activities, and additional joint government/industry field projects.

Figure 2-2 shows a breakdown of the project by elements. Figure 2-3 identifies activities that will be accomplished both concurrently and sequentially. Some field tests are dependent upon the outcome of resource assessment as well as laboratory evaluations, while others can be conducted immediately.

2.3.1 Project Management

The Western Gas Sands Project is a complex multi-year effort involving Federal agencies, State organizations, universities and industry. The Project will be managed through a project office consisting of a project manager, his staff and selected consultants with contractual support from an appropriate DOE office.

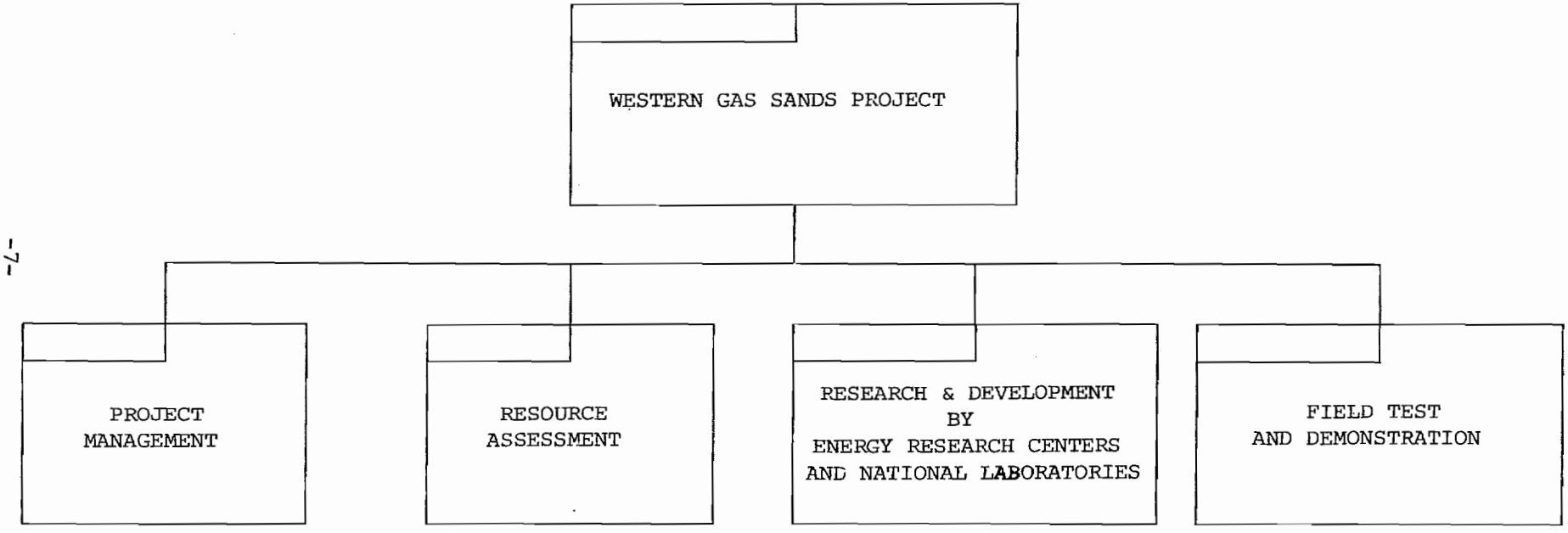


Figure 2-2 Elements of Western Gas Sands Project

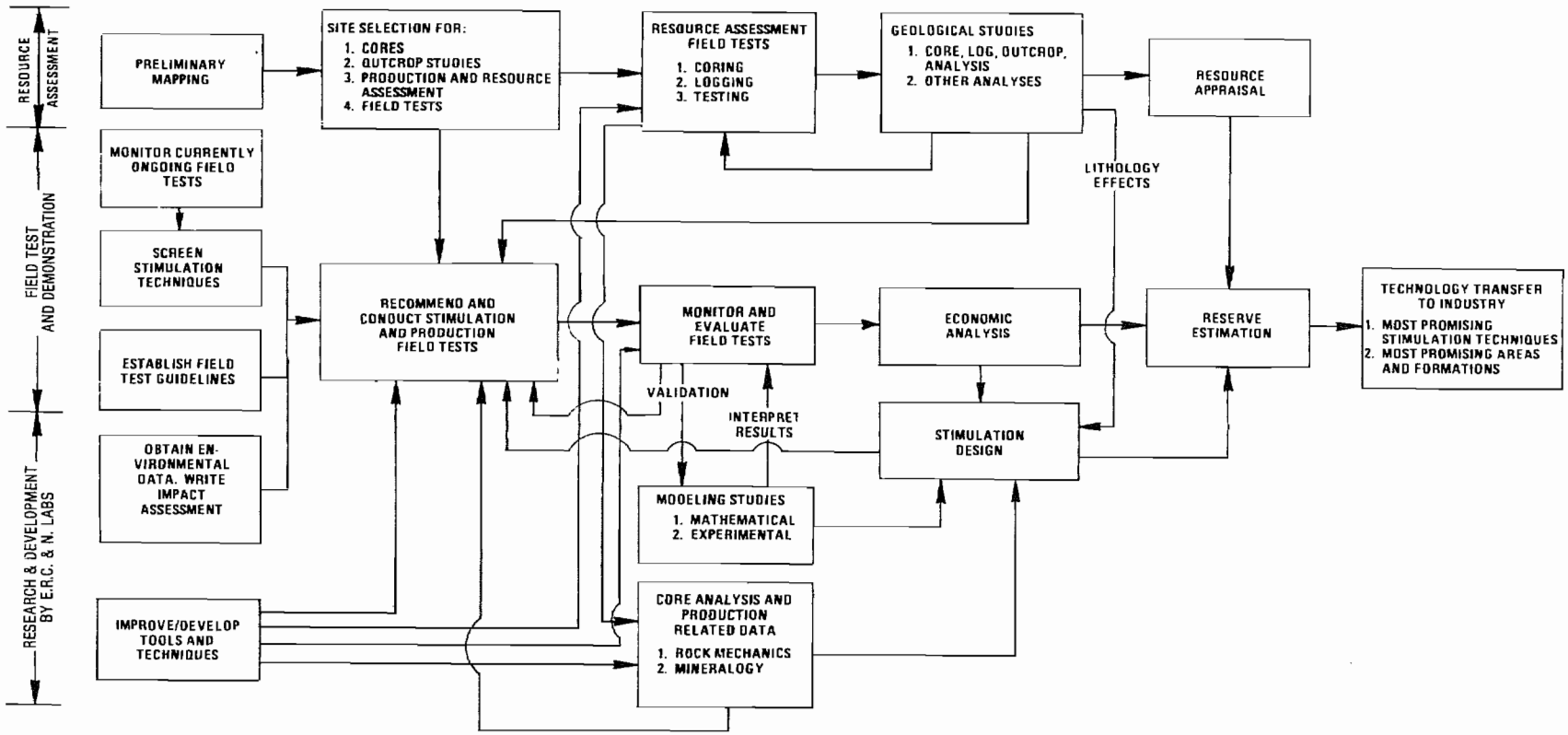


Figure 2-3 Principal Project Activities and Their Interrelationships

The roles and responsibilities of the project participants are summarized in Table 2-2. The roles and responsibilities are traditional with the exception of the project office, which must operate as the interface between DOE and contractors. During the year the project office will monitor project activities and perform reviews on technical adequacy, technique and results.

Routine performance reports as detailed in Section 6 will be required from all participants and will be summarized by the project manager and submitted to the appropriate DOE offices and participants. The reports will summarize progress on all activities and plans for the following month. In addition, cost data and activity schedule information will be reported.

Reports issued will be available from the National Technical Information Service and in open files at various locations. In addition, use of technical forums, symposiums and workshops, publications in technical journals., and other means of disseminating information will ensure technology transfer to industry.

As cost and production data become available, the economic viability of commercial development can be estimated, based on both prevailing and projected price structures.

2.3.2 Resource Assessment

Resource assessment includes geological and geophysical studies to better understand the target resource base. One of the tasks will be to continue the gathering and synthesis of available well data taken from an existing computerized data bank along with other available information. Continued effort in general and detailed mapping are needed to improve the understanding of the gas bearing formations and trapping mechanisms. This work will lead to selection of sites where new subsurface information is needed from cores, geophysical logs, and gas-production tests. Some of these sites will likely become the locations for field R&D activities; and when sufficient information is accumulated, accurate resource estimates will be possible. The appraisals will delineate and characterize the reservoirs of each area that are the most promising for economic development.

2.3.3 Research and Development by Energy Research Centers and National Laboratories.

Research and development effort will continue in conjunction with field studies with the principal effort directed toward developing equipment and techniques required for accurate resource and stimulation evaluation. This will include development and refinement of techniques for recovering cores at reservoir conditions, improving logging instrumentation and

Table 2-2 Roles and Responsibilities of Western Gas Sands Project Participants

HEADQUARTERS	DEVELOPS AND DEFINES DIVISION BUDGET REQUESTS FORMULATES POLICIES ENCOMPASSING PROJECT CONTENT, GOALS AND OBJECTIVES APPROVES PROJECT PLANS MONITORS PROJECT PROGRESS, EVALUATES RESULTS, INITIATES PROJECT REVIEWS AND MODIFIES PROJECT DIRECTION AS APPROPRIATE
BARTLESVILLE ENERGY RESEARCH CENTER	PROVIDES PROJECT MANAGER (RESIDENT AT NV) TO STAFF PROJECT OFFICE AND SUPPORTS THE PROJECT WITH IN-HOUSE AND CONTRACTED R&D
PROJECT OFFICE	EXECUTES TECHNICAL DIRECTION OF CONTRACTORS AND AGENCIES PARTICIPATING IN THE PROJECT WITHIN THE GUIDANCE ORIGINATED BY HEADQUARTERS PARTICIPATES IN THE PLANNING, REVIEW, EVALUATION AND OVERALL GUIDANCE OF THE PROJECT ASSISTS IN CONTRACT WORK STATEMENT PREPARATION, PROPOSAL EVALUATIONS AND TECHNICAL NEGOTIATIONS IS RESPONSIBLE FOR CONTRACT TECHNICAL PERFORMANCE CERTIFIES CONTRACTOR EXPENSE VOUCHERS FOR NV PAYMENT
NEVADA OPERATIONS OFFICE (NV)	PREPARES AND NEGOTIATES CONTRACTS, PERFORMS RELATED CONTRACTUAL ADMINISTRATIVE ACTIVITIES, AND MAKES NECESSARY PAYMENT TO CONTRACTORS FORWARDS FINANCIAL PLAN DOCUMENTS ORIGINATED BY HEADQUARTERS TO PROJECT OFFICE
CONTRACTORS AND AGENCIES	EXECUTE CONTRACT WORK MAINTAIN PROPER INTERFACE WITH PROJECT OFFICE AND ITS REPRESENTATIVES ON TECHNICAL MATTERS INTERFACE WITH NV ON FINANCIAL, LEGAL AND CONTRACT ADMINISTRATION MATTERS
ENERGY RESEARCH CENTERS AND NATIONAL LABORATORIES	PERFORM AND DIRECT RESEARCH AND DEVELOPMENT IN VARIOUS AREAS OF EXPERTISE

interpretation, and improving production testing techniques. Equipment and techniques will be developed to better estimate induced fracture geometry and orientation. Other laboratory support will include reservoir simulation and computer use to provide a basis for conducting statistical, parametric and prediction analyses. Test data will be used to validate the models, which in turn, may be used in the interpretation of subsequent test results.

Innovative stimulation technology will be considered. Core samples will be analyzed to obtain rock mechanics data and other formation properties to improve stimulation technology.

The major energy research centers and national laboratories actively participating in FY 78 are Bartlesville Energy Research Center, Lawrence Livermore Laboratory, and Sandia Laboratories. Morgantown Energy Research Center is handling the Eastern Gas Shales Project which is similar in structure to the Western Gas Sands Project and many of their activities may be applicable. Los Alamos Scientific Laboratory is also involved in fracturing research activities which could be helpful.

Bartlesville Energy Research Center will handle R&D tasks associated with logging research, rock-fluid interactions, instrument development (such as new coring and logging tools) and will provide various other support as the project develops. Lawrence Livermore Laboratory primarily is pursuing modeling and computer applications associated with fracturing processes. Sandia is developing instrumentation systems to determine fracture orientation and geometry, to collect production test data in the field and to obtain pressurized cores. They also are evaluating fracturing by mining through induced fractures in formations at the Nevada Test Site.

2.3.4 Field Tests and Demonstrations

Some field tests begun in FY 77 will be continued and one or two new tests may be initiated. The selection of future test sites and promising technical approaches will utilize information obtained from these and earlier tests. There will be continuing effort in improving the effectiveness of stimulation treatments. Data will be taken before and during field tests for analysis of the potential environmental impact of large-scale commercial development.

3. PROJECT MANAGEMENT

The Western Gas Sands Project is in the management structure of the Division of Oil, Gas, Shale and In Situ Technology at DOE Headquarters which will provide overall program guidance. A project office has been established consisting of a Project Manager provided by DOE's Bartlesville Energy Research Center (BERC), his staff and project consultants. DOE's Nevada Operations Office will handle the major procurement actions and contract administration. Because of the desirability to maintain close liaison between the project office and the contract and procurement functions, the project manager is housed at the Nevada Operations Office in Las Vegas. A breakdown of the various elements involved in the project management function is shown in Figure 3-1.

Technical and financial monitoring of the various projects, both laboratory and field, will be an ongoing function. Coordination between the various activities will be emphasized. An accurate and comprehensive reservoir data collection, analysis and interpretation program will be initiated early in the year. An economic analysis will be done on each area utilizing available field data. Since this is an ongoing evaluation through the project's lifetime, all such analyses will be interim. Environmental assessments prepared for field projects will be reviewed and analyzed to estimate the regional effects of potential large-scale commercial applications. Preparation of periodic progress reports will summarize project activities. An information management system will be established to effect timely dissemination of useful data.

Several procurement items will be initiated; some of which will be add-ons to industry activities, such as obtaining cores in areas of interest. Technical details for future RFP's will be developed as will evaluation of proposals. The funds allocated to the Western Gas Sands Project in FY 78 are $5,000,000, distributed as shown in Table 3-1. This does not include funds previously committed but as yet not costed. The total funds available at the beginning of the fiscal year, both committed and non-committed, are approximately $5,745,000. The current funding does not allow for the establishment of any significant new field projects although there are adequate funds to perform the preparatory work needed to initiate a substantial field program in FY 79.

3.1 Technical and Administrative Support

CER Corporation is under contract to DOE to provide technical and administrative support services. The programatic support to the Project Manager is in the following areas:

a. Provide technical summaries of significant developments related to the WGSP. Prepare monthly status reports and other documents which might be requested. Provide technical information requested for the development of RFP's.

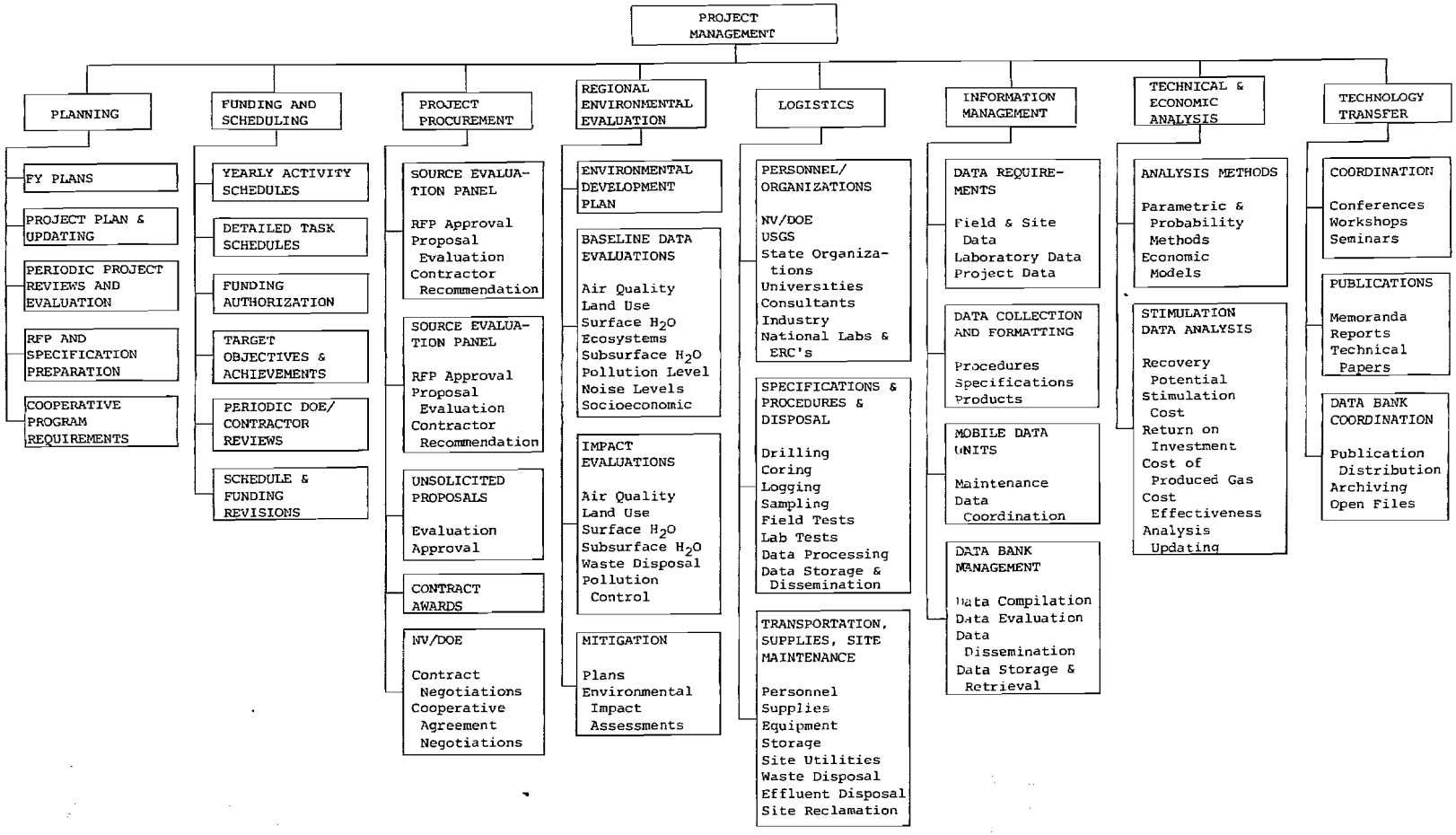


Figure 3-1 Project Management

Table 3-1 Western Gas Sands Project—FY 78 Funding *

PROJECT TECHNICAL AND ADMINISTRATIVE SUPPORT FOR PROJECT MANAGER	$ 700,000
NV CONTRACT MODIFICATION FUND	490,000
BARTLESVILLE ENERGY RESEARCH CENTER (Laboratory R & D)	500,000
LAWRENCE LIVERMORE LABORATORY	360,000
SANDIA LABORATORIES	590,000
USGS INDUSTRIAL CORES	800,000 300,000
ONGOING FIELD WORK: (GPE MHF TESTS) (MOBIL FIELD TEST)	560,000 700,000
SUBTOTAL	$5,000,000
TENTATIVE TEST IN TEXAS (MITCHELL ENERGY COMPANY)	520,000
FIELD TEST IN COLORADO (CIG)	75,000
ADDITIONAL MHF IN COLORADO (RBNG)	150,000
TOTAL	$5,745,000

*Complementary activities proposed to be funded outside the WGSP budget not listed are: (1) USGS/Menlo Park $ 213,000
(2) Intercomp (tentative) 190,000

b. Maintain liaison with industry and remain current on stimulation technology on various projects which are conducted outside the DOE programs to the extent possible and identify any innovations for investigation and possible inclusion into the DOE programs.

c. Conduct routine visits to State and Federal offices to obtain drilling and completion information to monitor work currently being performed in low permeability gas sand areas in the western United States.

d. Recommend key wells being drilled by industry for coring contracts.

e. Monitor specific field activities as requested and assist in developing criteria and specifications in such areas as production testing.

f. Update the Project Plan Document FY 78 for FY 79 to include detailed tasks, schedules and cost estimates.

g. Evaluate solicited and unsolicited proposals as requested and provide recommendations.

h. As information becomes available, prepare preliminary estimates of the potential economics associated with gas production from the low permeability sands.

i. Provide initial analysis of field test data from ongoing DOE/Industry field demonstrations and coordinate with Intercomp for in-depth analysis using Intercomp's computer simulation models of reservoir performance. Develop analysis programs with Intercomp and Lawrence Livermore Laboratory for investigation of key properties and problem areas in current reservoir evaluation techniques. This would include parametric studies on such things as fracture conductivities, fluid loss damage, dynamic estimates, evaluation of effects of sand lenticularity, etc.

j. Develop a program to investigate log interpretation techniques including plans for specific experiments. This would include logging techniques for multi-well experiments as described in the WGSP.

3.2 Planning

Emphasis will be placed on planning in FY 78 in anticipation of a major field effort commencing in FY 79. These planning activities will consider modification to current and new laboratory and field R&D programs,

and will include project review meetings plus routine liaison and coordination with DOE Headquarters, the energy research centers, the national laboratories, and the USGS. The areas of laboratory R&D conducted this year will support and complement future field projects. Specific technical goals and requirements for future field projects will be identified as well as regional locations for their performance in anticipation of the development of RFP's for FY 79. In some cases, specific limited areas, dependent on the technical goals and geologic resources will be identified.

Where additional resource assessment or other desired information can be gained, add-on experiments will be recommended. In addition, new requirements for cores will be developed and specific areas identified, as has been done for FY 78. A detailed schedule of all activities and project schedule of future activities will be maintained along with the associated funding requirements.

3.3 Monitoring and Evaluation

Each task will be monitored and evaluated. The responsibility for the monitoring and reporting of currently identified tasks has been established, such as a multiplicity of laboratory R&D tasks being handled by BERC. The project manager will assess the relevance and desirability of any new proposed tasks under general guidance provided by DOE Headquarters. In addition to the monitoring of ongoing activities, the project manager will evaluate RFP responses and unsolicited proposals and recommend appropriate action. As a part of the technical evaluation, a reservoir analysis program will be initiated which will review production test information collected on past projects and those conducted during FY 78. This analysis will utilize existing techniques with the bulk of the processing being done by Intercomp. CER will provide input to Intercomp and coordinate activities with LLL.

For flow test analysis and design, Intercomp will use the conventional analytical techniques as a supplement to the numerical simulation studies. For single-well flow tests, conventional pressure transient analysis techniques will provide estimates of reservoir kh, damaged/improved zones as characterized by skin and/or fracture half-lengths, radius of drainage, and other factors such as fault boundaries and reservoir layering. Reservoir parameters calculated from the pressure transient data using these techniques will provide useful estimates for history matching specific flow tests with models and for generating values around which a parametric investigation may be performed. Two of Intercomp's existing reservoir simulators will be used as required:

1) a single-well, single-phase model in three dimensions
2) a single-well, two-phase model in three dimensions.

In cases where water movement is not a prime consideration the first model will be used and in cases where water plays a primary role, the second model will be used. The principal objective of the parametric studies is to isolate the system (reservoir/fracture) variables which are the most critical to the success of a massive hydraulic fracture (MHF) project from a reservoir engineering standpoint. The initial paper study of parametric sensitivity using the reservoir simulation models will consider the following for systematic adjustment: porosity, thickness, water saturation, permeability, relative permeability, permeability sensitivity to overburden pressure differential, turbulence factor, radius of drainage, and lenticularity or shape. Various combinations of these properties in layers will also be considered. In addition to these reservoir properties are the properties of the fracture including half-length, damage to fracture face, fracture healing, fracture conductivity, and turbulence factor within the fracture. A resulting output from this study will be the formulation of guidelines for flow times and build-up times for field tests, which will result in better determination of reservoir characteristics.

3.4 Information Management

A WGSP monthly report will be prepared having two main features; one will be reporting on technical progress, and the other on costs. A combined report of both sections will receive limited distribution; primarily to DOE Headquarters, DOE Nevada Operations Office (NV) and Bartlesville Energy Research Center, while the technical portion of the monthly report will receive wide distribution. The types and numbers of reports and reporting schedules for individual tasks or field projects are dependent on the nature of the activity. For instance, during peak field activity, a daily report is generally provided and, likewise, during periods of little or no activity, no reporting is done. Final reports will conform to the DOE requirements and will receive wide distribution. From time to time, special study groups and reports may arise which require support such as the one on enhanced gas recovery performed by Lewin & Associates. As a result of the planning activities, the Project Plan Document FY 79 will also be prepared. Other special reports such as the preliminary regional environmental report, if sufficient data becomes available, a reservoir evaluation report, and economic analysis reports will be prepared.

A master project file containing the available project information including such items as raw data and logs will be established and maintained by CER. It will be available for inspection in their office at 4220 South Maryland Parkway, Las Vegas, Nevada. Those reports available through the National Technical Information Service (NTIS) will be identified. If information is unavailable through NTIS, all reasonable requests for copies will be fulfilled by CER. Most of the information is also available at BERC and the Project Office at NV. (For example, electrical logs may not be found at all locations).

4. RESOURCE ASSESSMENT

The majority of the resource assessment work will be performed by the USGS. There will be other activities which will provide input data and support to their work, primarily in the area of field tests, obtaining core samples and special core tests. A breakdown of the various items is contained in Figure 4-1.

4.1 United States Geological Survey

USGS studies in support of DOE's Western Gas Sands Project will continue in FY 78. Maps and data for cross sections will be acquired for an information service company's computer files for the Rocky Mountain region. Preliminary cross sections will be in open file form with approximately ten additional completed cross sections, not yet in open file form. Both core distribution and drill stem test (DST) maps, by geologic age, will be compiled along with a series of gas show maps. Work will commence on paleographic maps with completion anticipated sometime in FY 79.

During FY 78, study of clay mineralogy will continue with more than 400 clay samples being subjected to X-ray diffraction and fluorescence studies. In addition, about 100 samples will be studied with the scanning electron microscope and 200 thin sections made.

To aid in understanding the origin and distribution of the gas, organic chemical analysis will be performed on approximately 100 samples.

Efforts will continue to upgrade logging tools and interpretation techniques with emphasis being placed on field testing and interpretation of a new gravimeter under development by the USGS. At least two wells will be logged with a new small tool designed for higher temperature environments.

Early in FY 78, new outcrop sections from Debeque Canyon, Colorado, to Book Cliffs, Colorado in the Uinta Basin tertiary section to the top of the Cretaceous will be completed with the Upper Cretaceous section being completed by the end of FY 78.

My mid-FY 78 the USGS will have developed a format for computer input of data which will include parameters such as X-ray data, paleontology and geochemistry.

The following are to be released as open-file reports.

> Well penetration maps of the Green River Basin which will show the outcrop limit of base of Tertiary and base of Upper Cretaceous Mesaverde Group.

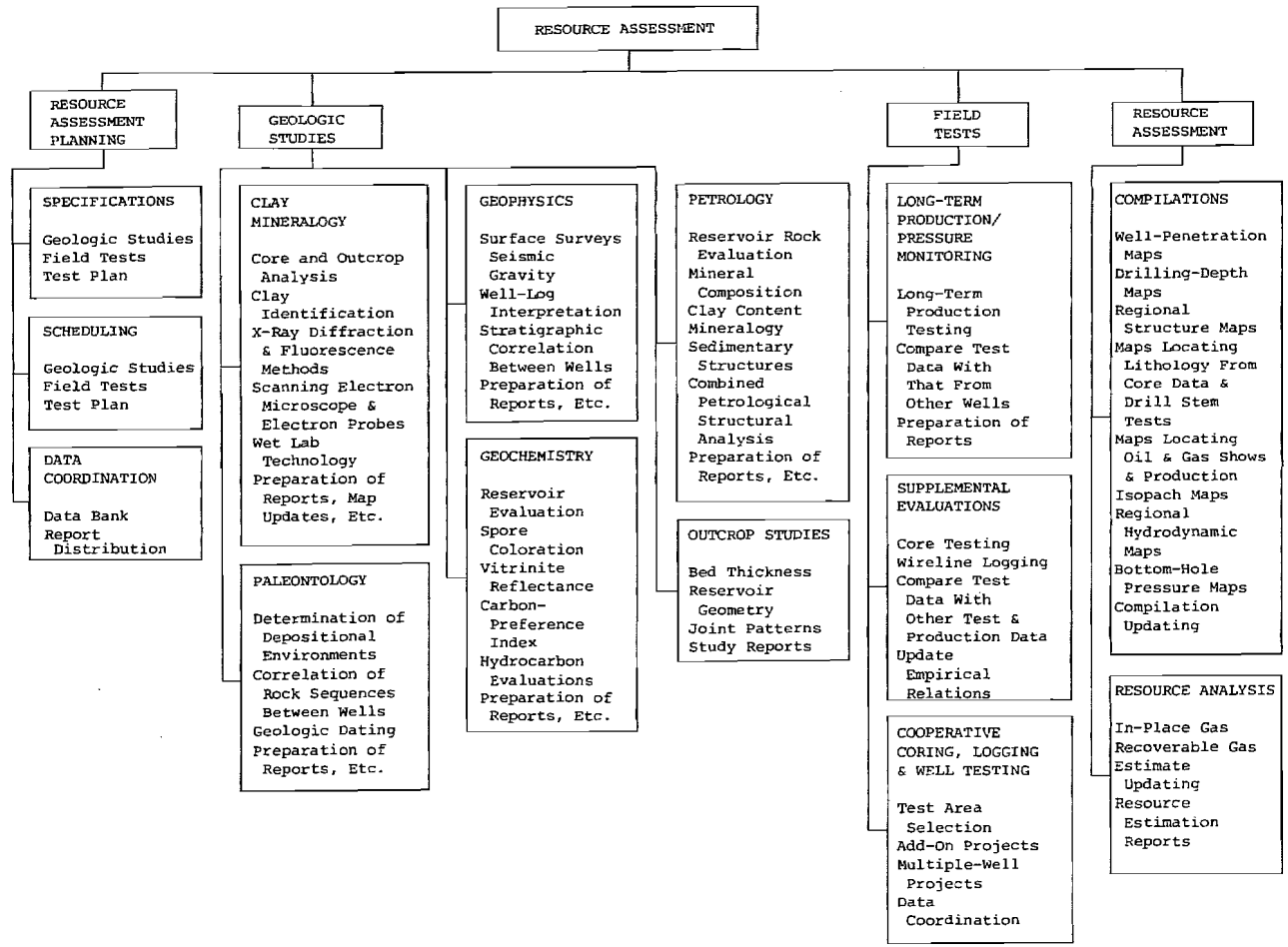


Figure 4-1 Resource Assessment

Preliminary pressure gradient maps for the Green River Basin which were generated from shut-in pressures of drill stem tests.

Several cross sections through low permeability reservoirs in the Washakie, Uinta, and Piceance Basins.

A report on the distribution of potential low permeability gas reservoir facies in the Northern Great Plains Province will be published.

Figure 4-2 is a milestone chart for the USGS FY 78 activities.

4.2 United States Geological Survey (Menlo Park)

USGS/Menlo Park in support of DOE's Western Gas Sands Project will continue to develop and apply a surface tilt monitoring technique to determine the spatial geometry and growth rate of fracturing processes originating to depths of at least 2 km.

During the past year, computer model studies were conducted to determine the feasibility of detecting seismically and nonseismically induced fractures with surface tiltmeters. Relationships between azimuth and amplitudes of surface tilt response to azimuth and extent of a propagating fracture were studied. Other computer studies were made of how to best separate the effects of surface noise contaminents such as rainfall and temperature from the response to the seismic or nonseismic (hydraulic) sources of fracturing. Techniques for more efficient instrument emplacement, array maintenance and signal recording were initiated. Field investigations were continued to extend previous studies of the surface tilt response due to massive hydraulic fractures and explosively generated fractures.

The cumulative number of tiltmeters deployed during the period of this project exceeds any comparable effort in the world. These experiences have stimulated the development of new and improved instrument emplacement techniques. The idea that an array of sensitive tiltmeters can produce coherent results at high gain shortly after development has been demonstrated. Signals associated with induced fractures at 2 km depths in the tidal level have been obtained in a variety of surface noise environments. The spatial geometry of these induced fractures has been found in good agreement with other geophysical measurements (i.e., resistivity) for fractures ranging over several orders of magnitude in depth and dimension. A previously developed dislocation model has been extended to simulate a growing fracture. A more recent application of a model developed by Pollard (Proj # 9960-01489) has provided a means to relate pressure variations during fracturing to tilt response at the surface. Tilt response due to more than one input has been separated

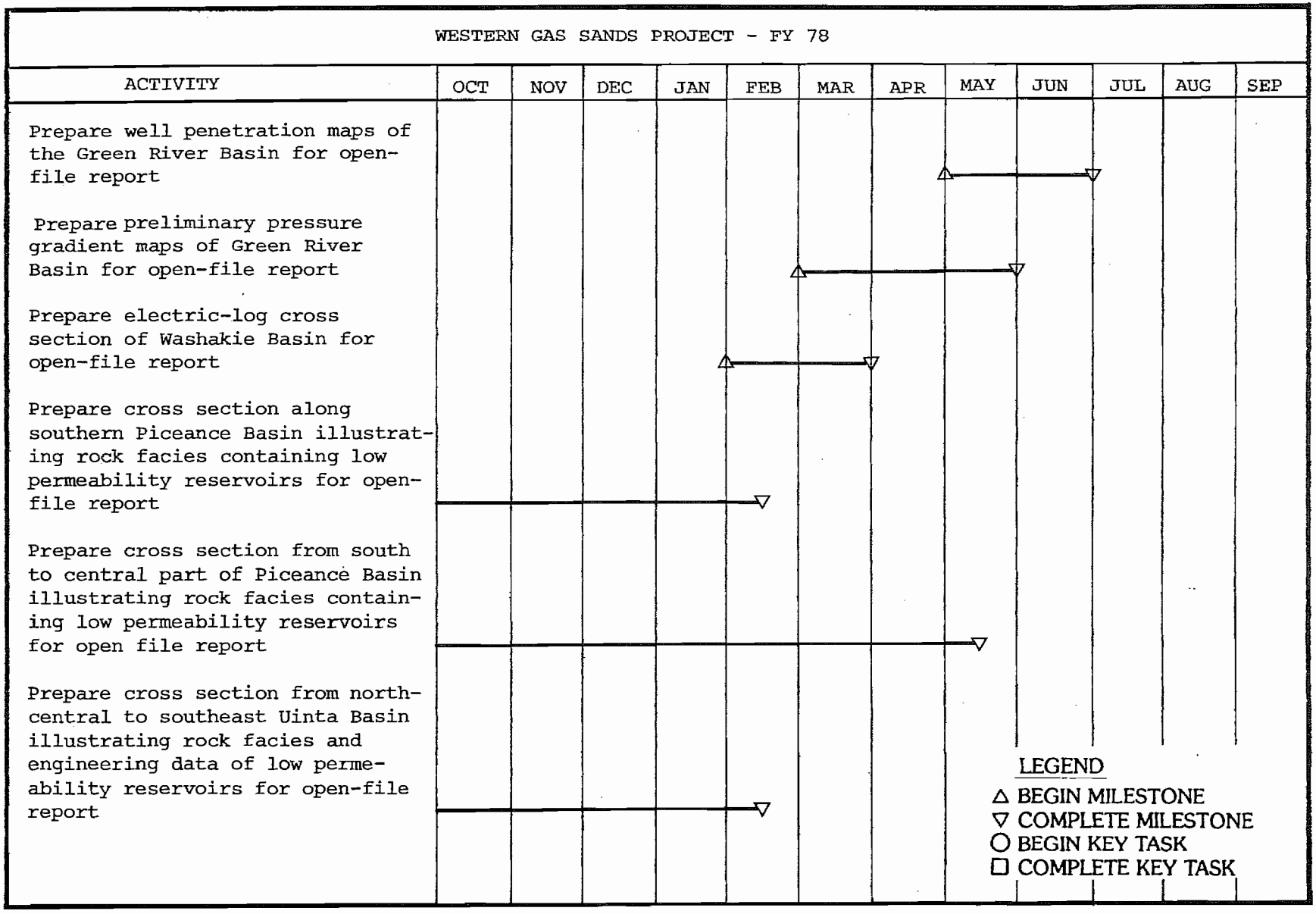


Figure 4-2 Milestone Chart (USGS)

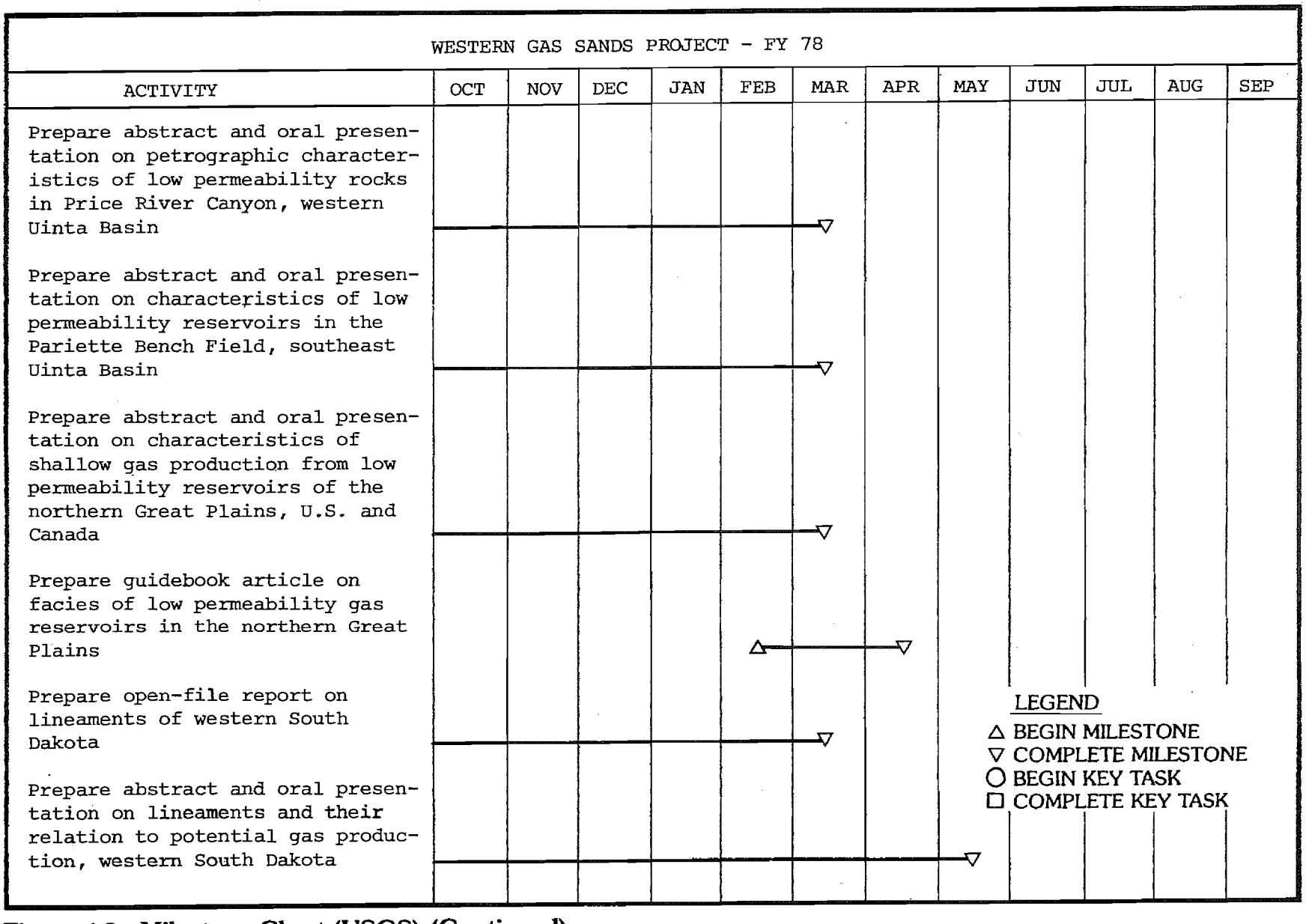


Figure 4-2 Milestone Chart (USGS) (Continued)

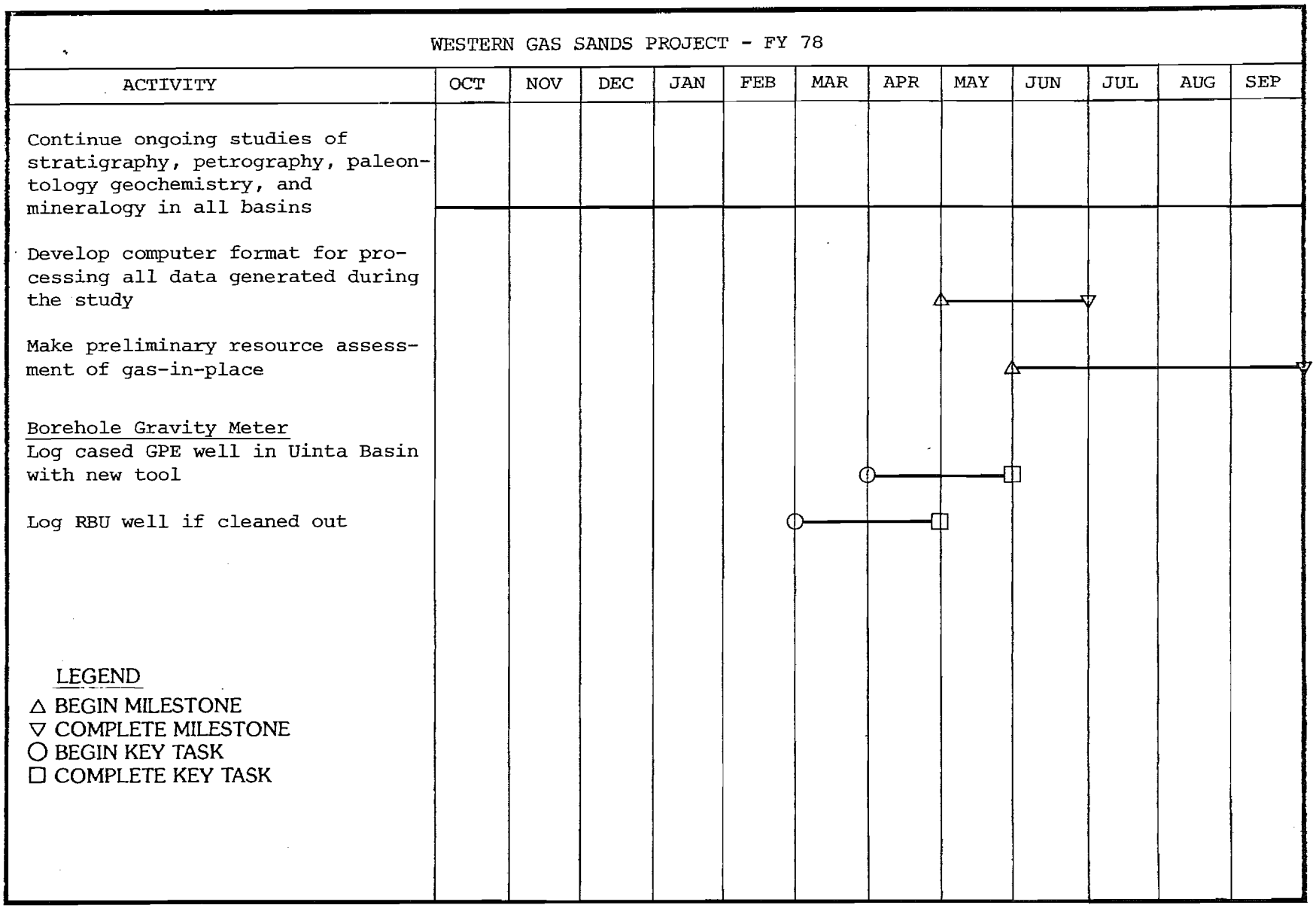


Figure 4-2 Milestone Chart (USGS) (Continued)

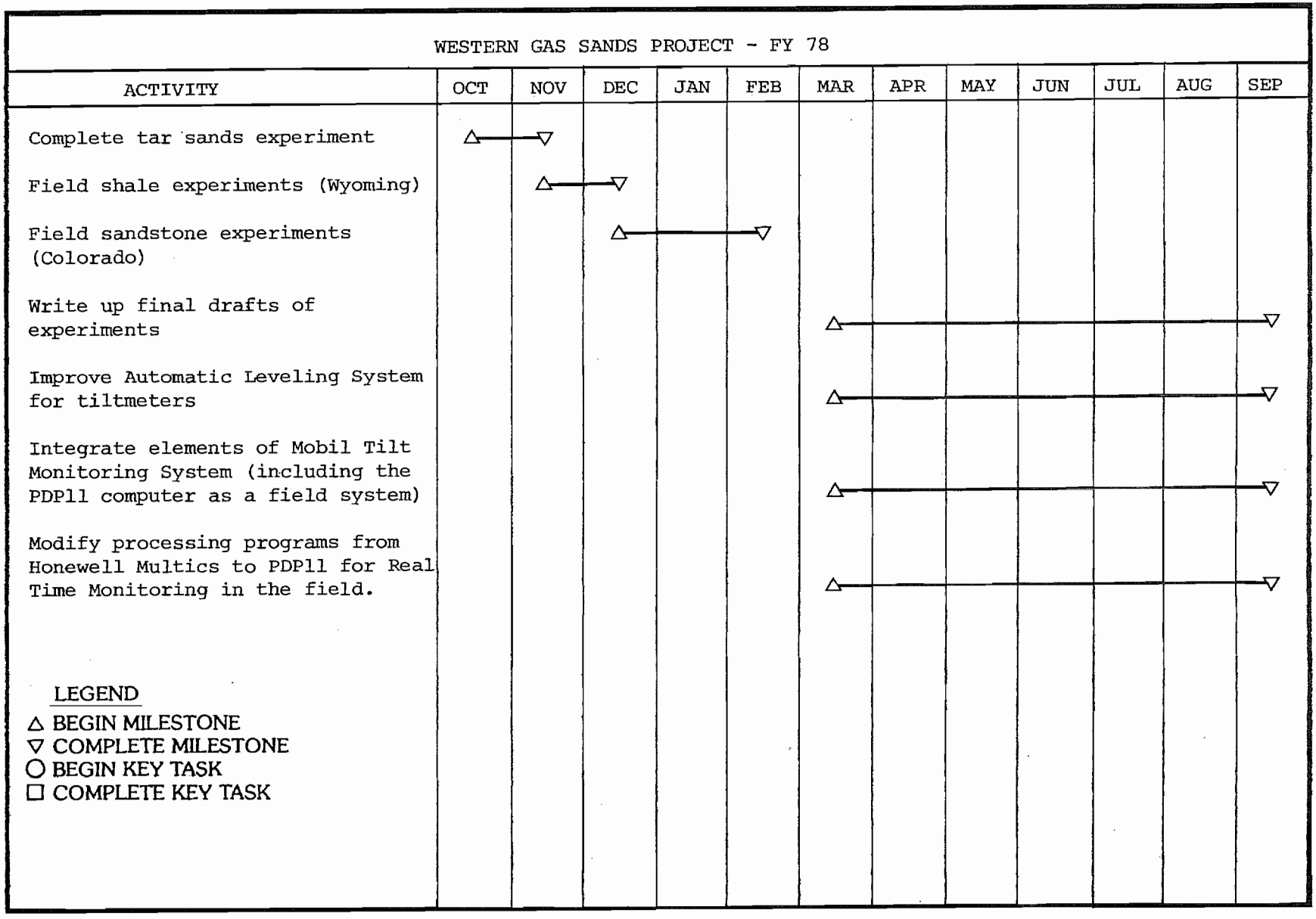


Figure 4-3 Milestone Chart (USGS Menlo Park)

with an improved version of a least squares Wiener prediction and shaping filter. These numerical techniques have enabled researchers to effectively work with extremely poor signal to noise data, to simulate fracturing as a kinematic and a dynamic process, to provide the basis for real time mapping of induced fractures and a means to interact and modify the fracturing process in real time.

Field investigations were conducted on sites in Lincoln County near Huntington, West Virginia, a site on the Mexican border near Laredo, Texas, three experiments at the Laramie Energy Research Center test site near Rock Springs, Wyoming, and two experiments in the Athabascan Tar Sands area near Ft. McMurray, Alberta, Canada.

Project plans for FY 78 include final analysis of data and reports made on (1) explosive fracturing experiments in shale at shallow depths in Wyoming, (2) MHF experiments at depth (9,000 ft) in Colorado, (3) MHF experiment in sandstone at depth on the Mexican border near Laredo, Texas, (4) MHF experiments in Devonian shale of West Virginia, and (5) tar sands experiments in Alberta, Canada. Improvements to the automatic leveling system will be continued and a remote clamping mechanism will be tested for deeper deployment of the system. Primary processing programs will be modified and moved from the large core Honeywell Multics system to a field worthy minicomputer. Elements of the Mobile Tilt Monitoring System will be integrated as a field system for Real Time Monitoring of fracture growth. Figure 4-3 is a milestone chart for USGS/Menlo Park FY 78 activities.

4.3 Core Program

The USGS has advised the DOE of the need to obtain core samples from critical areas and will provide personnel and facilities for processing and storing of the cores. Where needed, special core analysis will be performed by the USGS. Routine core analysis will be done at a commercial laboratory. Four tentative areas have already been selected in the Northern Great Plains Province. They are listed below by county, township and range with potential reservoir intervals and footages.

a. Powder River County, Montana
   T5S, R52E and 53E
   Judith River 200 ft
   Eagle 400 ft
   Niobrara (chalk) 200 ft

b. Custer and Prairie Counties, Montana
   T10 and 11N, R48 and 49E
   Judith River 200 ft
   Eagle 400 ft.

c. Valley County, Montana (fractured reservoir)
T29N, R35 and 36E
T30N, R36 and 37E
Eagle through Upper Mowry 1,450 ft

d. Phillips County, Montana
T29 and 30N, R25 and 27E
Eagle through Upper Mowry 1,400 ft

Sites as large as two to four townships have been chosen for several reasons: (1) all are separated from productive areas and thus can provide data on the sands in unevaluated areas; (2) all sites would test at least two potential reservoir intervals in addition to adjacent source rocks; (3) the combination of these sites would test several different reservoir types (which the USGS had identified in each potential productive unit) i.e., Eagle and Judith River Formations; (4) a potential reservoir type, chalk, would be cored in the Niobrara Formation at Site a. These fine grained carbonate chalks can have up to 40% porosity but permeabilities in the microdarcy range; and (5) Site c, situated along a lineament zone southeast of the currently productive Bowdoin Dome, will provide the opportunity to evaluate fractured reservoirs, particularly in shale intervals.

These sites will provide valuable data on stratigraphic relationships and reservoir properties and will be a good first step toward evaluating the tight gas resources of the Northern Great Plains Province.

The DOE support for coring will require a comprehensive logging program by the operators since only minimal logs are now being run due to current unfavorable economics. Production tests also will be run when possible.

4.4 Basin Activities

CER Corporation, through review of the Petroleum Information Corporation's Rocky Mountain Reports and other sources of information is continuously monitoring drilling and exploratory activities in the four study basins.

Each status report will contain a brief summary of basin activities, and a quarterly basin activities report will be issued documenting the number of wells being drilled and the active drilling operators involved. Well locations, key formation tops, formation tests, perforation intervals, fracture treatments and results will be categorized in the quarterly report. This activity will continue during FY 78 with emphasis being placed on those areas that show increased possibilities of successful MHF treatment demonstrations.

4.5 Log Analysis

A reservoir engineering evaluation of the previous MHF tests will be conducted using numerical simulation techniques. Pressure transient analysis, coupled with history matching techniques, will be used to interpret specific flow tests. Additional parts of the program include the formulation of improved log analysis techniques, and both single and multi-well test design.

The effort will be concentrated in four main areas:

Analytical Techniques

Petrophysical Studies

Numerical Simulation Studies

Data Base

In order to achieve a comprehensive understanding of the MHF program in general, and certain experiments specifically, a data base is required in the following areas:

Logging Suites

Flow and Pressure Data

Frac Fluid Data

Rock/Formation Fluid Data

The data and programs developed will be available for use by BERC and by CER.

5. RESEARCH AND DEVELOPMENT BY ENERGY RESEARCH CENTERS AND NATIONAL LABORATORIES

Laboratory R&D activities funded by DOE have been directed toward new tools and instrumentation systems, rock mechanics experiments, mathematical modeling and data analysis. These activities to date have primarily been performed by DOE's Energy Research Centers, the National Laboratories, and USGS. Some items are arbitrarily reported in this category even though they require considerable field experimentation. A breakdown is given in Figure 5-1.

The positive results of system development and data analysis techniques by Sandia and USGS/Menlo Park, in determining fracture orientation have been very encouraging and these techniques will be evaluated further in FY 78, as funds permit.

5.1 Bartlesville Energy Research Center

5.1.1 Improved Coring Methods

During the first quarter of FY 78, a contract with Sandia will be monitored which involves the development of an improved pressure coring system which begins with design analysis for the core barrel and a literature review for evaluation of coring fluids. This activity is expanded under Section 5.3.4, "Improved Coring Tool."

Also during the first quarter, a contract may be negotiated with Terra Tek to perform special core analysis on a series of cores to be recovered during FY 78. If available, one of the first cores recovered will be tested.

Terra Tek's evaluation of results from core no. 1 will be made during the second quarter and plans formulated for the testing of core no. 2. Tests on core no. 2 will be performed during the third quarter. The results of Terra Tek's tests on core no. 2 will be evaluated during the fourth quarter and a plan made for future tests. Figure 5-2 is a milestone chart.

5.1.2 Production Stimulation by Fracturing

The general objective of this research effort is to define important experimental parameters for design of MHF in the Western Gas Sands Project. The objectives include the evaluation of potential productivity of low permeability and low porosity formations by applying new or

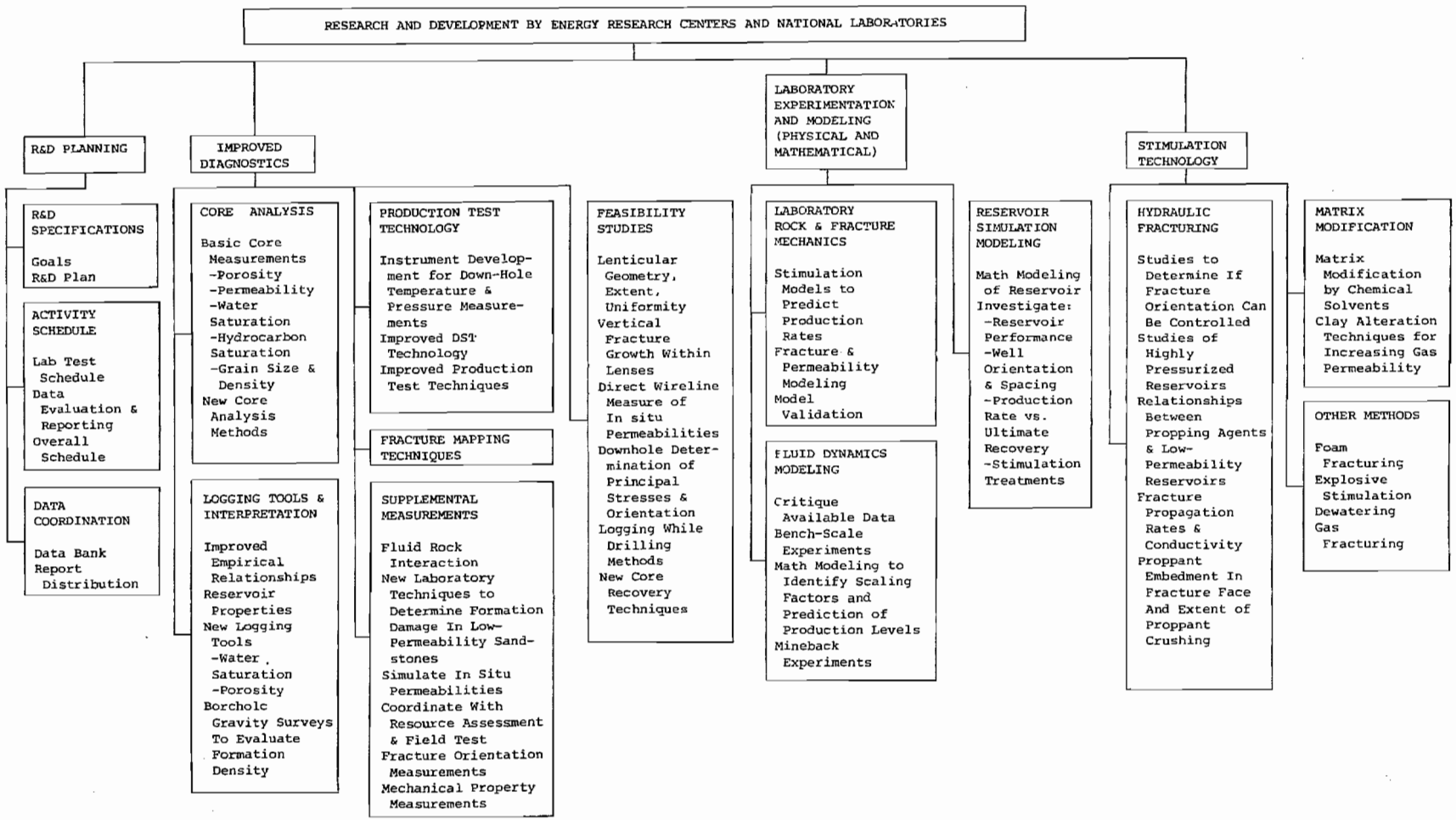


Figure 5-1 Research and Development by Energy Research Centers and National Laboratories

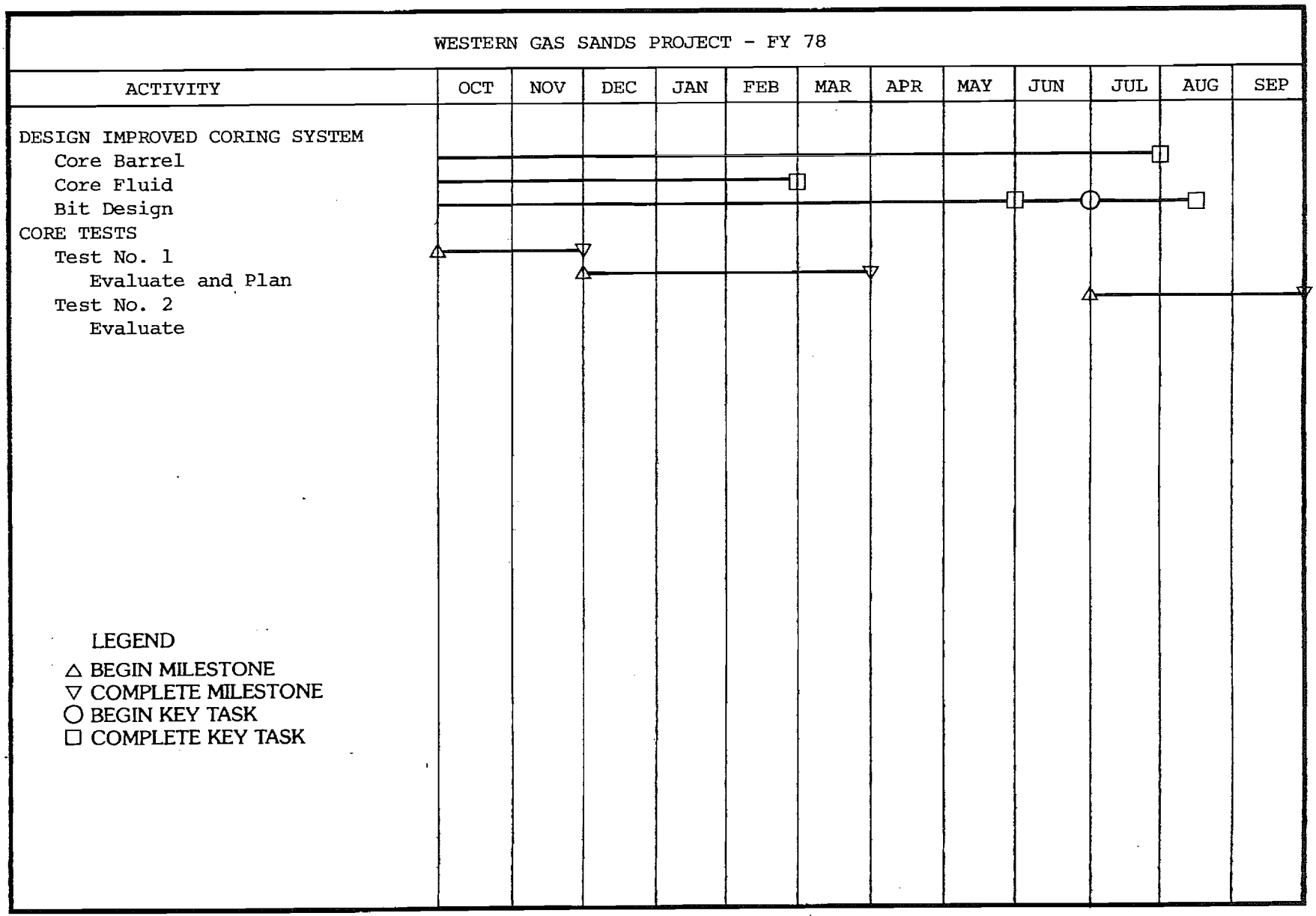


Figure 5-2 Milestone Chart (Coring Systems and Core Analysis—Sandia and Terra Tek)

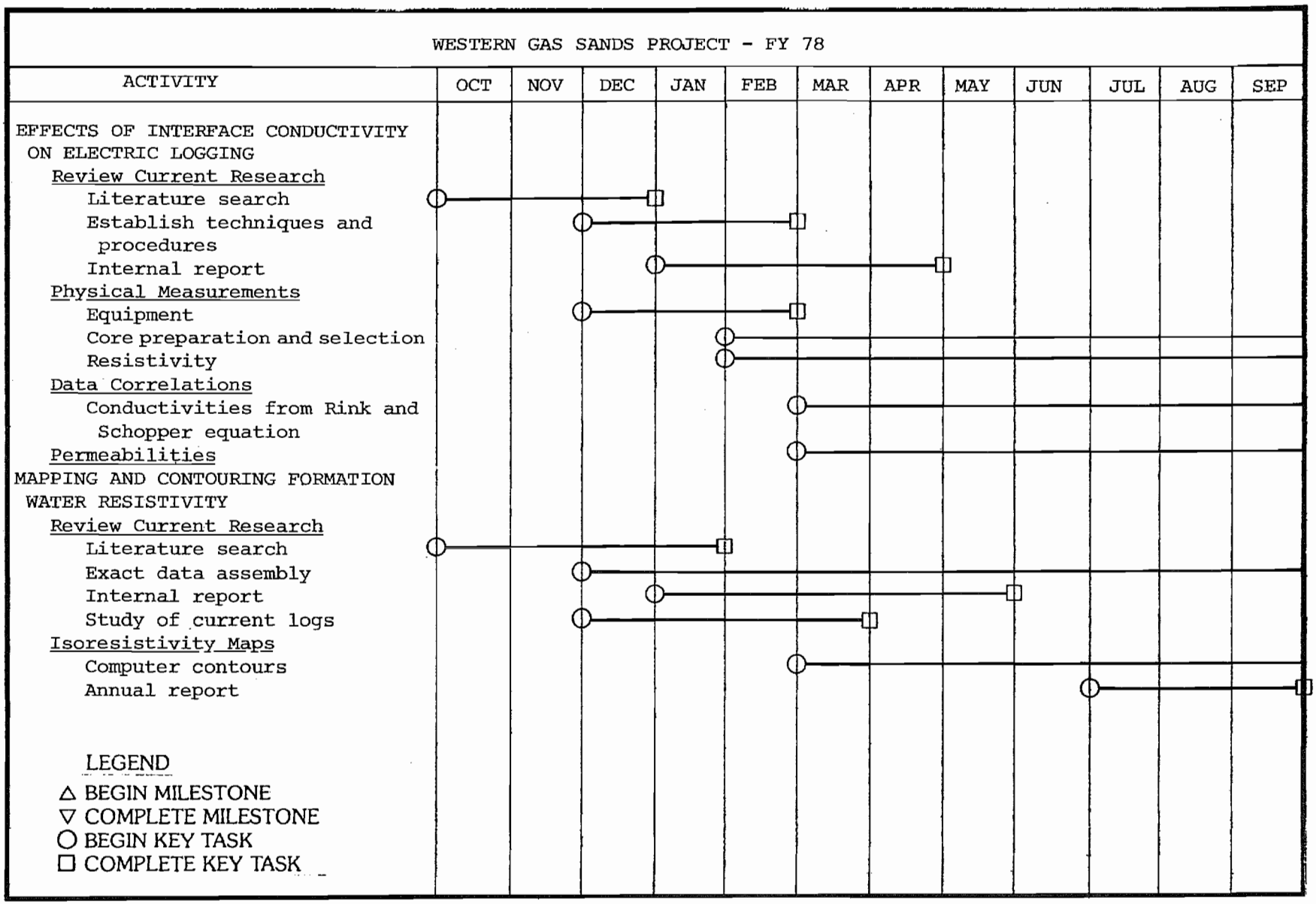


Figure 5-3 Milestone Chart (Schedule of Production Stimulation by Fracturing-BERC)

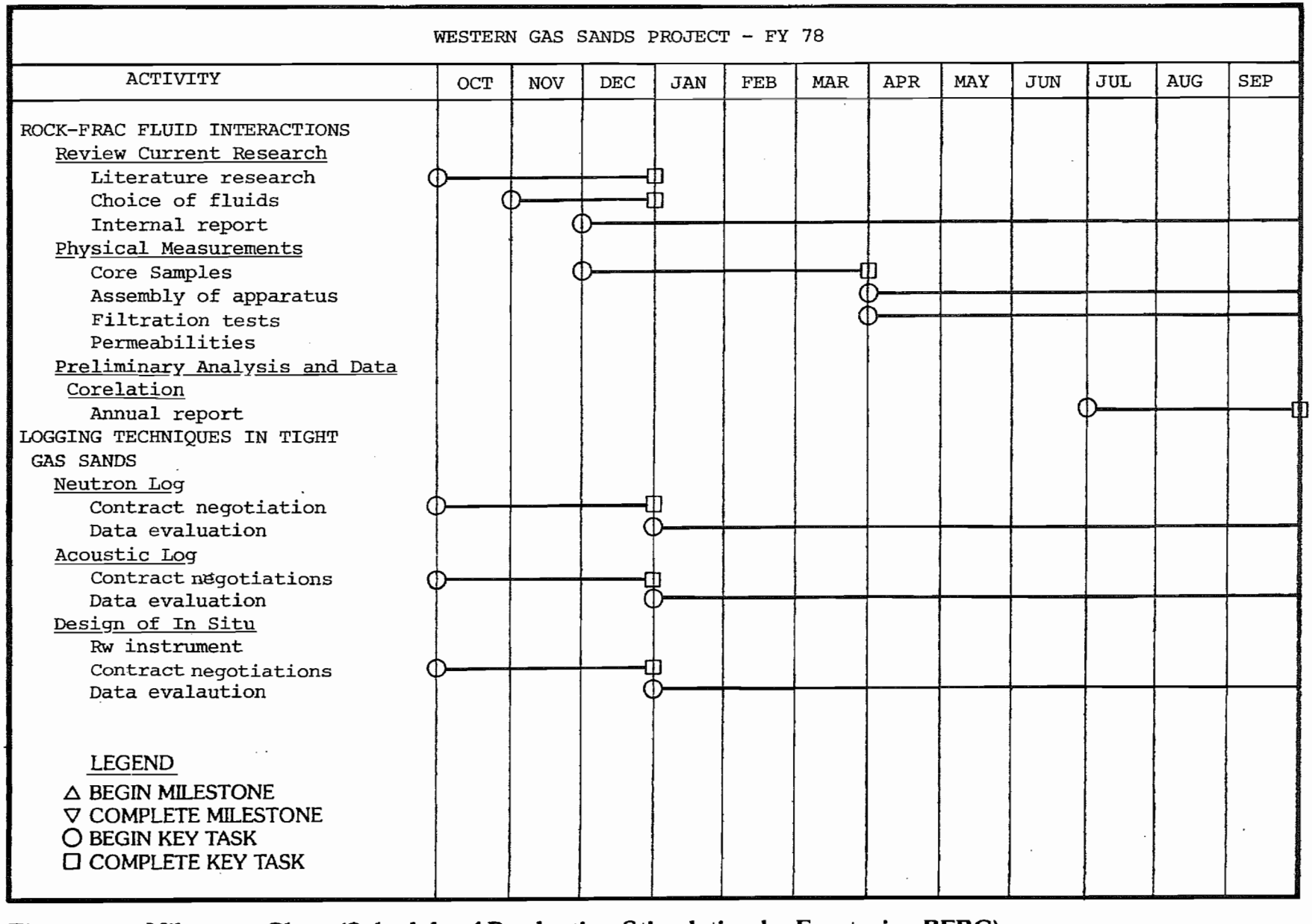


Figure 5-4 Milestone Chart (Schedule of Production Stimulation by Fracturing-BERC)

innovative logging techniques and interpretations, and also to examine the degree of formation damage due to the invasion of hydraulic fracturing fluids.

Initiation of these tasks in the first quarter of FY 78 will require that primary emphasis be upon the review of current research in interpretation of electric, neutron and acoustic logs of gas wells in low permeability and porosity sands. Initial laboratory techniques will be established to prepare cores for measuring interface conductivity caused by fluid-matrix interactions in the formations. Design and assembly of laboratory equipment will begin during the later part of the quarter. Figures 5-3 and 5-4 are milestone charts showing these activities.

A conference with the project manager to determine the type and number of frac fluids most likely applied to MHF in the western tight gas sands will establish the fluid and additives to study for interaction with rock. This choice will be based upon frequency of use, economics and environmental assessments. Equipment will be assembled during the quarter. Existing data for formation water resistivity (R_w) from logs and current literature in the western tight gas sands will be studied for anomalies from one location to another in a given formation. Assembling an internal report on the literature survey will be initiated in the later part of the quarter.

During the second quarter, assembly of the necessary apparatus and procedures for measuring interface conductivity will be completed. Core samples from various porous formations of interest will be selected during the later part of the quarter.

The efficiency determination of thermal degradation and/or "breaker" chemicals on polymer additives in frac fluids will begin. The design and assembly of equipment with tests on operating procedures will continue.

The literature survey of lateral variations in formation water resistivities (R_w) during the first part of the second quarter will be completed. Assembly and arrangement of the data in proper form for computer input will be finished. Logs or log data from current work in western tight gas sand formations that display seemingly lateral R_w anomalies will be acquired.

Permeabilities, porosity, specific internal surface area and resistivity measurements will be made on the saturated cores during the third quarter. Preliminary interpretation of the correlation between the variables to verify the proposed modified form of Archie's equation will begin.

Measurements will begin of how much polymer residue or frac fluid additives are excluded from rocks when the fluid filters through the face of the rock. Measurements of change in permeabilities due to infiltration of fluid-loss additives will be made.

The internal report on the literature survey of lateral variation of R_w in tight gas sands will be completed. The drawing of isoresistivity maps as an overlay to the formation examined will commence.

During the fourth quarter, correlation will be made between the rock conductivity and fluid conductivity to obtain the interface conductivity and formation factor. The relationship between conductivity and internal surface area as a means of determining permeability will be evaluated.

Experimental measurements of polymer and fluid-loss additive effects on permeabilities and the assembly of data for the completion of the annual report of work showing effects on permeability will be evaluated.

Experimental measurements of polymer and fluid-loss additive effects on permeabilities and the assembly of data for the completion of the annual report of work showing effects on permeability will continue.

The following reports and papers are expected to be completed during the second quarter of FY 78:

Internal report on current research on "Effects of Interface Conductivity on Electric Logging"

Internal report on "Mapping and contouring Formation Water Resistivity"

Internal report on "Rock-Frac Fluid Interaction"

Contracts expected are as follows:

Contract on interpretation of neutron logs in western tight gas sands

Contract on interpretation of acoustic logs in western tight gas sands

Contract on design of in situ R_w instrument

5.2 Lawrence Livermore Laboratory

Lawrence Livermore Laboratory (LLL) has embarked on a research program to obtain an understanding of the stimulation processes including how the formation properties interact with and affect these processes. The program is primarily investigative with no major field programs currently proposed. The major lines of endeavor are:

Theoretical modeling of the hydraulic fracturing process.

Hydraulic fracturing laboratory experiments.

Logging tool development and application and the analysis of log data.

Cataloging and evaluation of pertinent geological and geophysical reservoir data.

Measurement of pertinent reservoir properties.

Reservoir analysis.

Evaluation of other stimulation techniques.

Environmental assessments of DOE supported projects.

During FY 78 the development and application of theoretical two-dimensional fracturing models will continue with the results compared with laboratory and field data commencing during the third quarter. Development of hydraulic fracturing models will begin during the first quarter. These models are being developed under a subcontract with MIT. A different solution philosophy will be pursued in these models than is currently being applied in the LLL models.

The laboratory experimental programs will proceed in conjunction with and in support of the theoretical modeling. The emphasis will be to continue to experimentally model the hydraulic fracturing process for various layer configurations and under various confining stresses. A subcontract with Professor B. Haimson of the University of Wisconsin has been initiated to test the sensitivity of the orientation of the created fractures to the intermediate principal stress.

The acquisition of geological and geophysical data will continue with the characterization of reservoirs expected to start near the end of the second quarter. Data defining the mechanical and breakage characteristics of the tight western gas reservoirs will be sought and compiled. Core material from the gas sands and interbedding shales will be gathered for mechanical characteristics measurements to supplement existing data. Measurement of these properties will begin as the core becomes available. These data are required in the theoretical models for analysis of the fracturing characteristics of the reservoirs.

The application of the USGS borehole gravity tool in western tight gas sands will be assessed. Borehole gravimeter log data will be analyzed and compared with the other suites of logs and core material where available as soon as application begins.

During the first quarter, parametric studies of fracture conductivities and the effects of fluid invasion into the fracture faces will be started. Analysis of the effects of stimulation treatments will be performed as well test data become available.

Environmental assessments as required will be written to support DOE's gas stimulation program. Figure 5-5 is a generalized schedule.

Interaction with industry and other government laboratories and organizations is important in the implementation of the LLL program. Duplication of existing results, measurements and effort will be avoided wherever possible. The progress of the program will be reported in informal monthly progress reports and formal quarterly reports. Important conclusions and completed segments of the work will be summarized in separate formal reports.

5.3 Sandia Laboratories

5.3.1 Mineback Activities

The objective of the program is to develop an understanding of the fracturing process for stimulation and thereby improve the production of natural gas from low permeability reservoirs. This will be accomplished by conducting controlled fracture experiments which are accessible by mineback for direct observation and evaluation. DOE's Nevada Test Site provides this opportunity through use of the existing tunnel complex and extensive support facilities. This site has about 1,400 to 1,500 ft of overburden made up of bedded and welded tuff formations that have similar strength and permeability characteristics to the low permeability gas reservoirs of interest.

Sandia has performed several hydraulic fracturing experiments and the feasibility of mineback and coring to delineate the fractures has been demonstrated. In situ stress distributions, fracture orientation, the independence of closely-spaced fractures, and the effect of tunnels have been determined. Mineback and evaluation of two different fracture regions are underway.

The role of mineback testing is shown schematically in Figure 5-6, and the general schedule of activities is shown in Figure 5-7. Mineback evaluation is based upon direct observation and comparison with measured material properties, fluid behavior and the operational parameters. This provides significantly more information than the evaluation of a commercial stimulation job which is based primarily upon gas production and pressure data. Industry and service company participation in the mineback program will ensure that the results will impact the experience and knowledge base used in production, and industry interest has been high. This program will provide a unique opportunity to quantify fracture behavior and is not being done elsewhere.

Proposed program tasks include:

1. Controlled testing with mineback for direct fracture observation and evaluation.

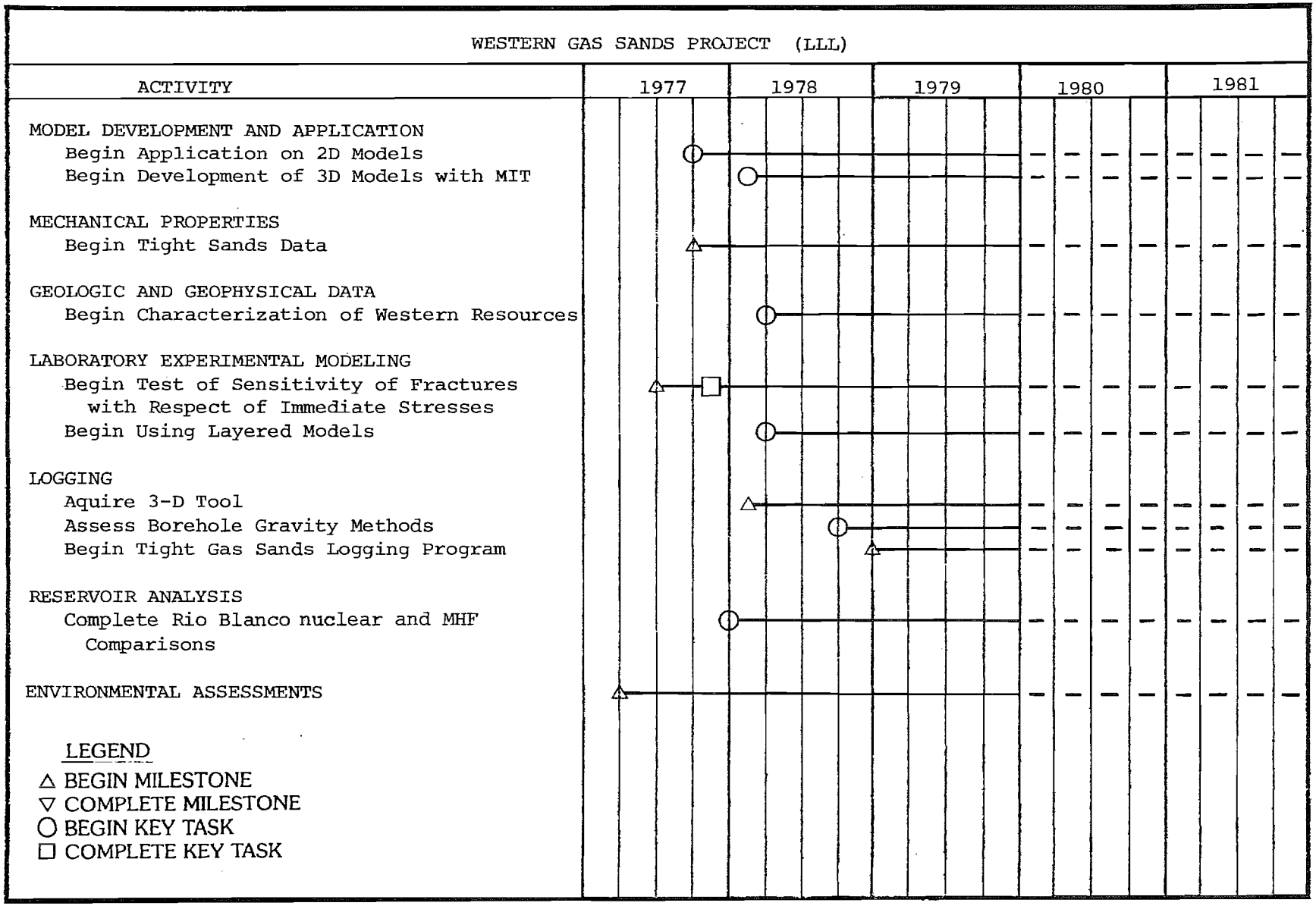


Figure 5-5 Milestone Chart (Schedule of Model Development Activities-LLL)

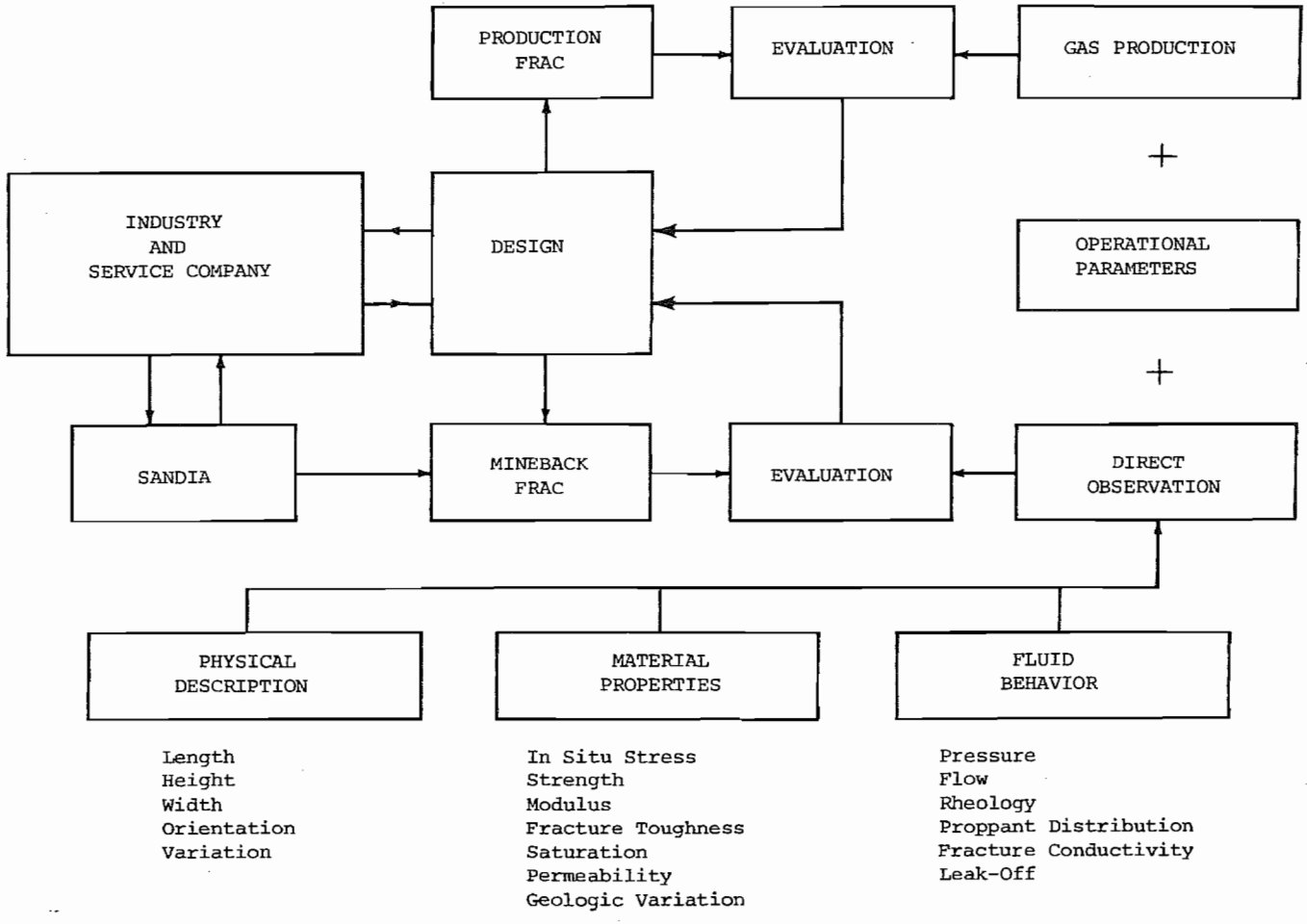


Figure 5-6 Schematic Showing the Role of Mineback Testing

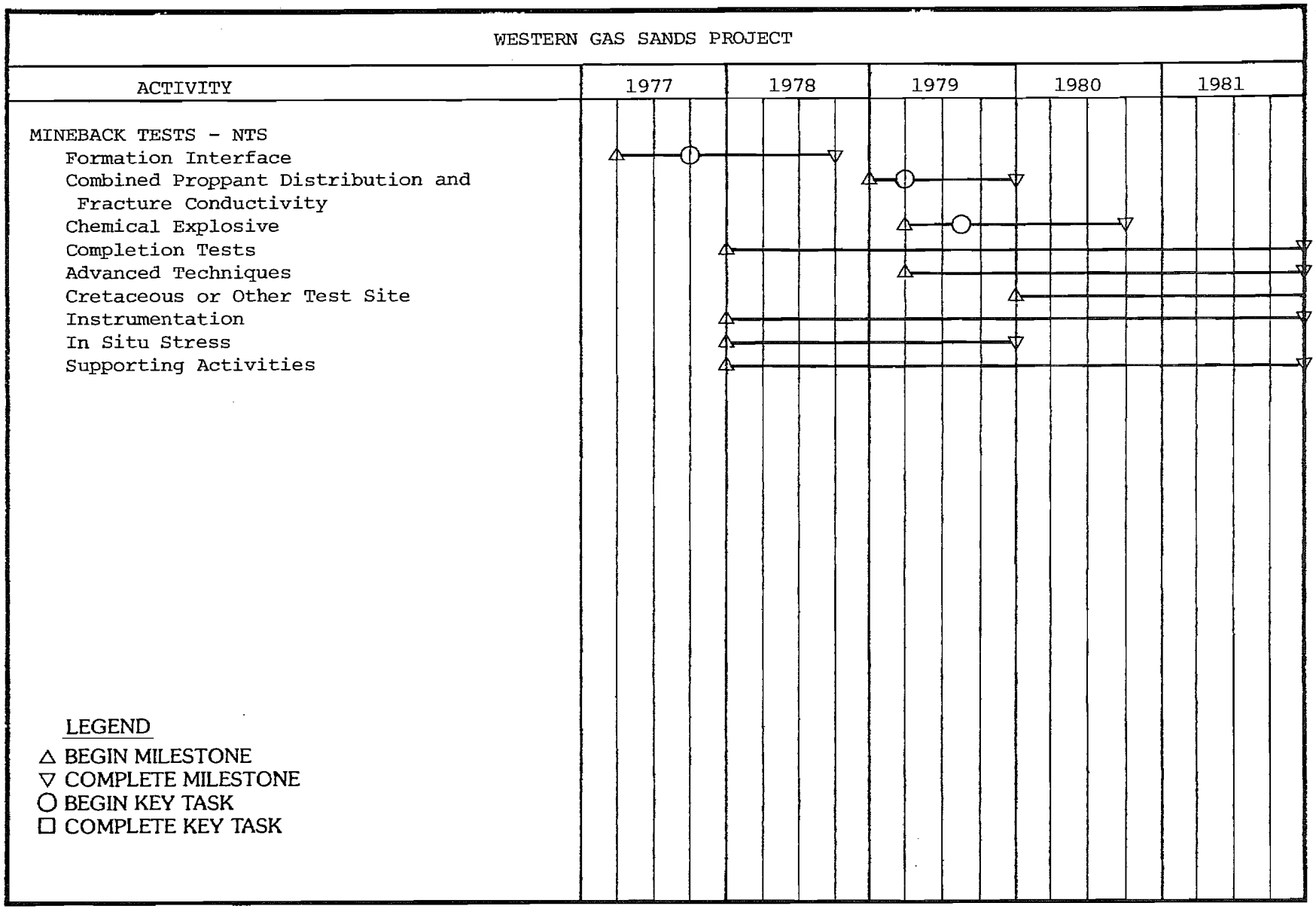


Figure 5-7 Milestone Chart (Schedule of Mineback Tests-Sandia)

2. Supportive rock mechanics, fluid dynamics and geochemical studies required to interpret observed fracture behavior.

3. Incorporation of the results into improved stimulation design models and calculations.

4. Assessment and calibration of logging and instrumentation techniques for fracture mapping and characterization.

5. Testing of innovative stimulation techniques.

Tasks 1, 2 and 3 form the heart of the program, and industry interaction and participation is necessary if the program objective is to be met. This will be done by:

Seeking and incorporating industry's suggestions and priorities into program planning.

Active industrial participation in design and conducting the fracture test and in any other aspect (material properties, laboratory experimentation, modeling, etc.) to whatever extent possible.

Widespread information dissemination via publications and reports, briefings and review meetings.

Specific activities in FY 78 are:

Mineback and evaluation of the formation interface test including detailed material property and in situ stress determinations at the fracture region.

Initiation of the supportive rock mechanics and geophysical studies.

Initiation of an in situ stress comparison in conjunction with the mineback.

Possibly conducting limited completion and perforation tests in conjunction with the mineback.

Limited FY 78 activities reflect reduced funding level.

5.3.2 Fracture Orientation and Geometry Instrumentation

By participating in MHF experiments, Sandia has developed the surface electrical potential system for fracture orientation determination. Development of this system has been incremental and it has successfully

demonstrated that not only can fracture orientation be determined but also the asymmetry of the two fracture wings can be shown. Other geophysical techniques for fracture characterization have been investigated and in the case of microseismic recording has caused redirection of the activity. Surface monitoring appears to be of limited value as a result of low seismic signal amplitudes; however, a down-hole seismic sensor may offer a better opportunity to measure the fracture height and orientation in the near field of the wellbore.

Development of the seismic diagnostic technique could shift emphasis from the surface detection of fracture related signals to a down-hole system to detect close-in fracture profiles. This will require an increased emphasis on wave transmission properties, formation properties and source signals. An improved understanding of these principles will also be beneficial for improved exploration seismology and logging.

During FY 78, progress will continue on the seismic down-hole diagnostic mapping system. The design, fabrication, and fielding will be completed with several experiments conducted to obtain fracture behavior in the near field of the wellbore. Fracture vertical growth boundaries and containments will be investigated. Efforts on the surface electrical potential technique will be directed at improving its capabilities to provide information on actual fracture dimensions. The laboratory will be used to support several stimulation experiments of the Western Gas Sands Project. Figure 5-8 shows the generalized schedule of activities.

5.3.3 Reservoir Characteristics

An evaluation of the possible use of a seismic reflection system to map the boundary of lenticular sand reservoirs will be conducted. The evaluation will be conducted during the first two quarters; and if the approach is feasible, hardware will be purchased during the third quarter. Efforts will continue to improve electric logging techniques. Formation water sampling techniques also will be investigated.

The downhole seismic system has been tested in a 400 ft well and will be tested at the Nevada Test Site during the first quarter of FY 78. Amoco will test it in the Wattenberg Field in January. Data analysis will be a continuing task throughout the year.

5.3.4 Improved Coring Tool

Cores are taken to determine the lithology and fluid content that exist in subsurface formations. The many variations in formation properties and characteristics make examination of unaltered cores in the in situ condition valuable in reservoir evaluation and designing optimum hydrocarbon recovery techniques.

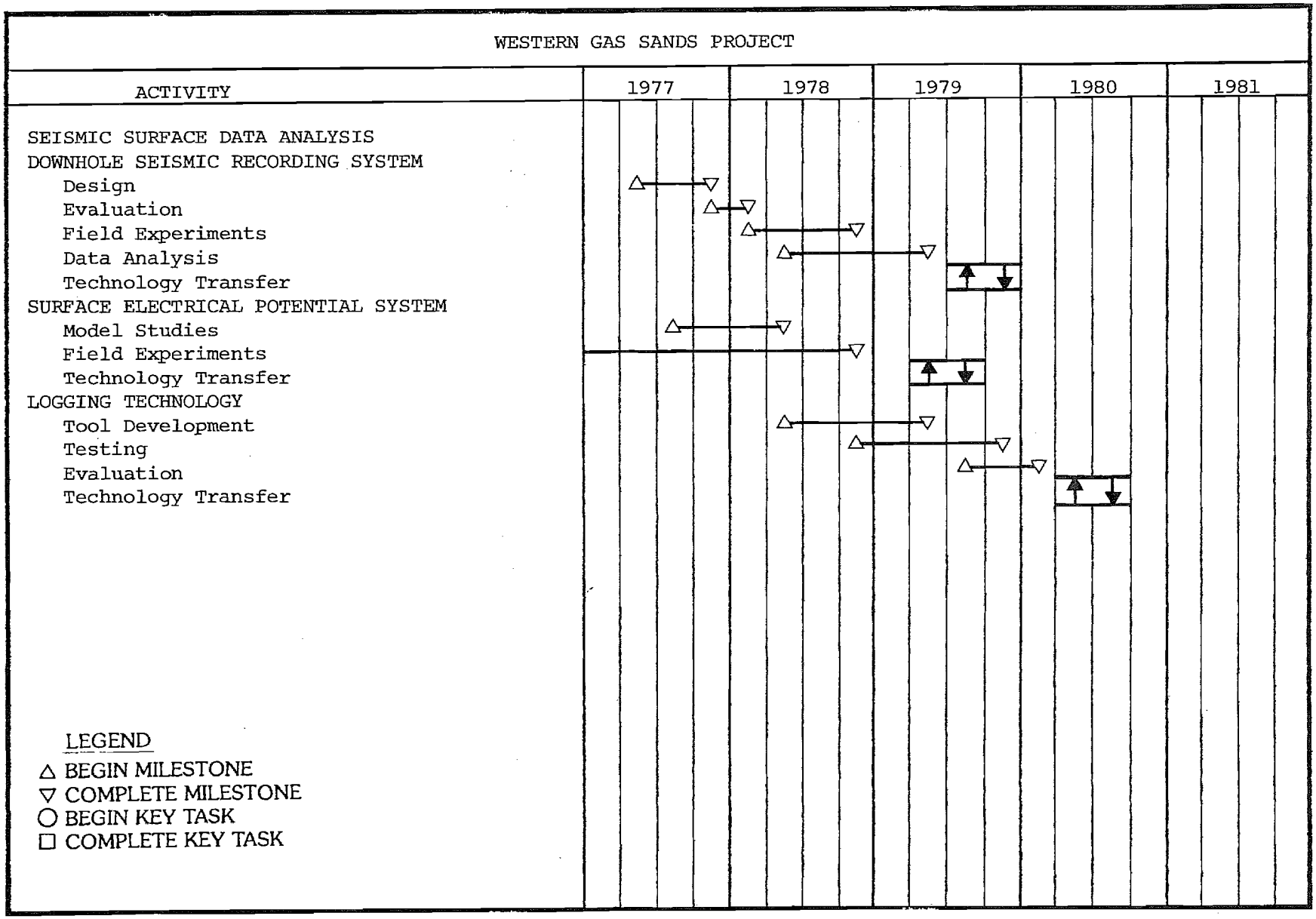


Figure 5-8 Milestone Chart (Schedule of Fracture Orientation and Geometry Instrumentation Activities-Sandia)

The objective of this project, which is being performed by Sandia under contract to BERC, is to design a coring system that will cut a core with minimum contamination from drilling fluid invasion and to seal the core barrel in situ, allowing the sample to be retrieved with formation fluids and pressure intact. The system will include a bit, sealing core barrel and non-invading fluid dispenser.

The first phase of the project will be limited to the design and concept evaluation testing of the system. A limited experimental program will be conducted which will aid in this design. The second phase will consist of fabrication and field testing.

In order to design an improved coring tool that has a high reliability in retrieving the core and preventing fluid invasion, several conditions are necessary. The mechanical components must be reliable and free from fouling and jamming in the downhole environment. The system will be designed to seal and operate at working pressures up to 10,000 psi at temperatures of 275°F. Additionally, the core must be cut rapidly and it must be protected, both during cutting and while tripping out of the hole, by a non-invading fluid to reduce contamination by the normal drilling fluid. Finally, the core must be easy to retrieve and handle for analysis. These conditions dictate the division of the program into various tasks. The work tasks for Phase I of the program are:

Core retriever design

Coring fluid selection

Bit design

Under the current contract, the subcontractor, Maurer Engineering, Inc. is responsible for the core retriever design and Sandia Laboratories will design a suitable core bit and select the best available fluid for core protection. There will be considerable liaison between Sandia, Maurer and BERC. Figure 5-9 is the milestone chart.

5.3.5 Mobile Well Test Facility

The DOE mobile well testing facility, consisting of two vehicles, is to provide a deep well instrumentation and investigation system to monitor and evaluate the productive potential of all types of wells.

The first vehicle is a 10 ft x 50 ft trailer, housing 3 draw works for 20,000 feet of seven conductor, 15/32 in. diameter armored cable, 20,000 feet of single conductor, 7/32 in. diameter armored cable, and 20,000 feet of .091 in. diameter wire line. All draw works will be electrically driven and hydraulically controlled with standard instrumentation and controls such as depth measurement, tension, line speed

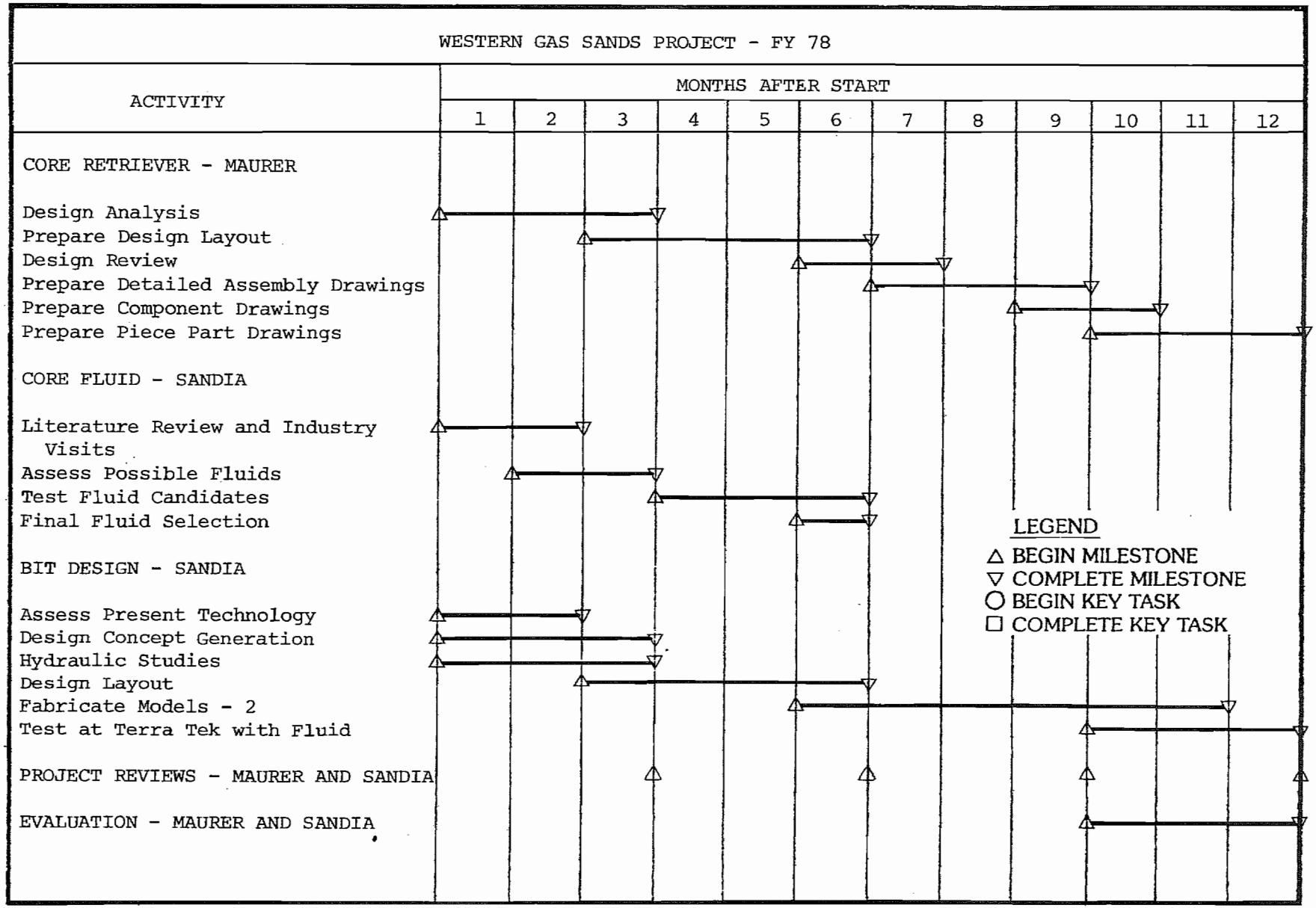


Figure 5-9 Milestone Chart (Schedule of Coring Tool Activities)

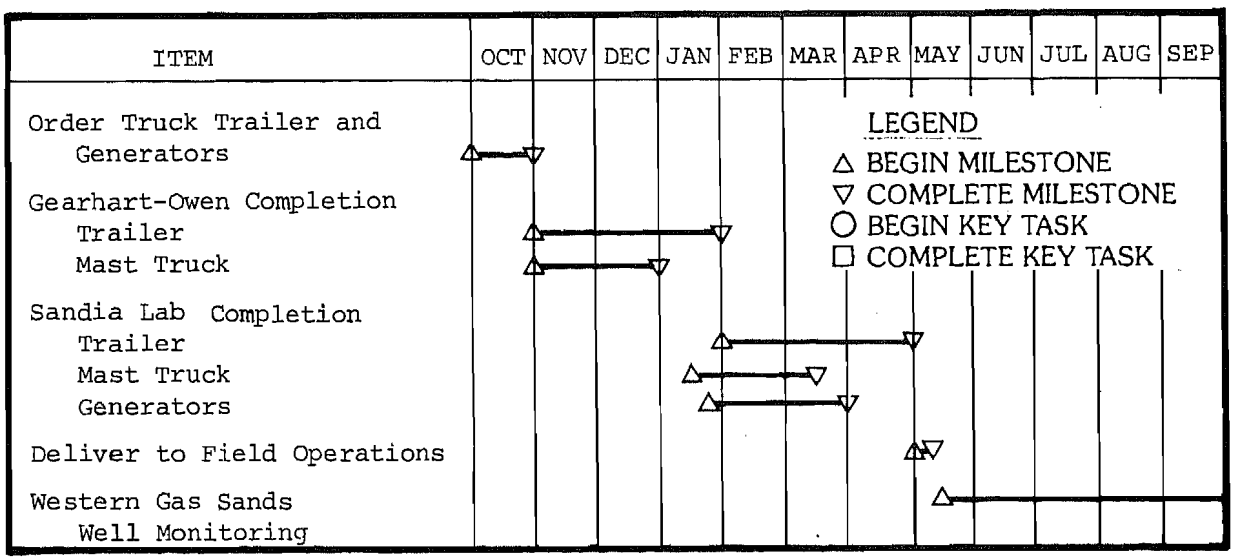
indicator and variable speed controller. The trailer will also house an instrument cabin for the draw works operator, racks for logging recorders, PDP-11 computer, mechanical and electronics maintenance work benches, spare parts storage and normal life support facilities for operating personnel working a 24-hour per day well testing program.

The second vehicle is a two-ton truck mounting a fifty-foot telescoping, tubular mast of 15,000 lb capacity. The mast will be hydraulically controlled as will the truck leveling outriggers. A 4,000 lb capacity catline will be available for raising and lowering equipment above the well to be tested. A grease injection system for the lubricator will also be mounted on the truck along with ample storage areas for the lubricator, tubing cross-overs and miscellaneous pipe fittings.

Individually trailer-mounted 30 and 90 KW electric generators accompany the two vehicles to provide necessary electric power for operation of the test facility.

Both vehicles will be modified by Gearheart-Owen Industries, Inc. of Fort Worth, Texas under Sandia Laboratories contract number CRB/05-6191.

A schedule for completion of the well test facility by Gearhart-Owen Industries and subsequent check-out by Sandia Laboratories is as follows:



With the combination of equipment available on the well test facility, a complete suite of logs will be possible including video scan. However, final determination of what logging equipment will be available has not yet been made.

6. FIELD TESTS AND DEMONSTRATIONS

Field tests and demonstrations comprise an essential part of the Western Gas Sands Project as through these, the application of new skills and techniques are implemented for evaluation. A breakdown of activities is shown in Figure 6-1.

Four ongoing field projects with the following organizations will carry over into FY 78. These are detailed in the following sections.

One additional contract has been let for a Joint DOE/Industry stimulation project with Colorado Interstate Gas Corporation. In addition, a MHF proposal from Mitchell Energy Corporation has been received and is presently being evaluated.

Table 6-1 is a tabulation of completed and ongoing MHF projects, excluding those for which contracts were let recently. Figure 6-2 shows the location of the active projects, and Figure 6-3 shows the generalized schedule of activities for the active projects for FY 77 and FY 78.

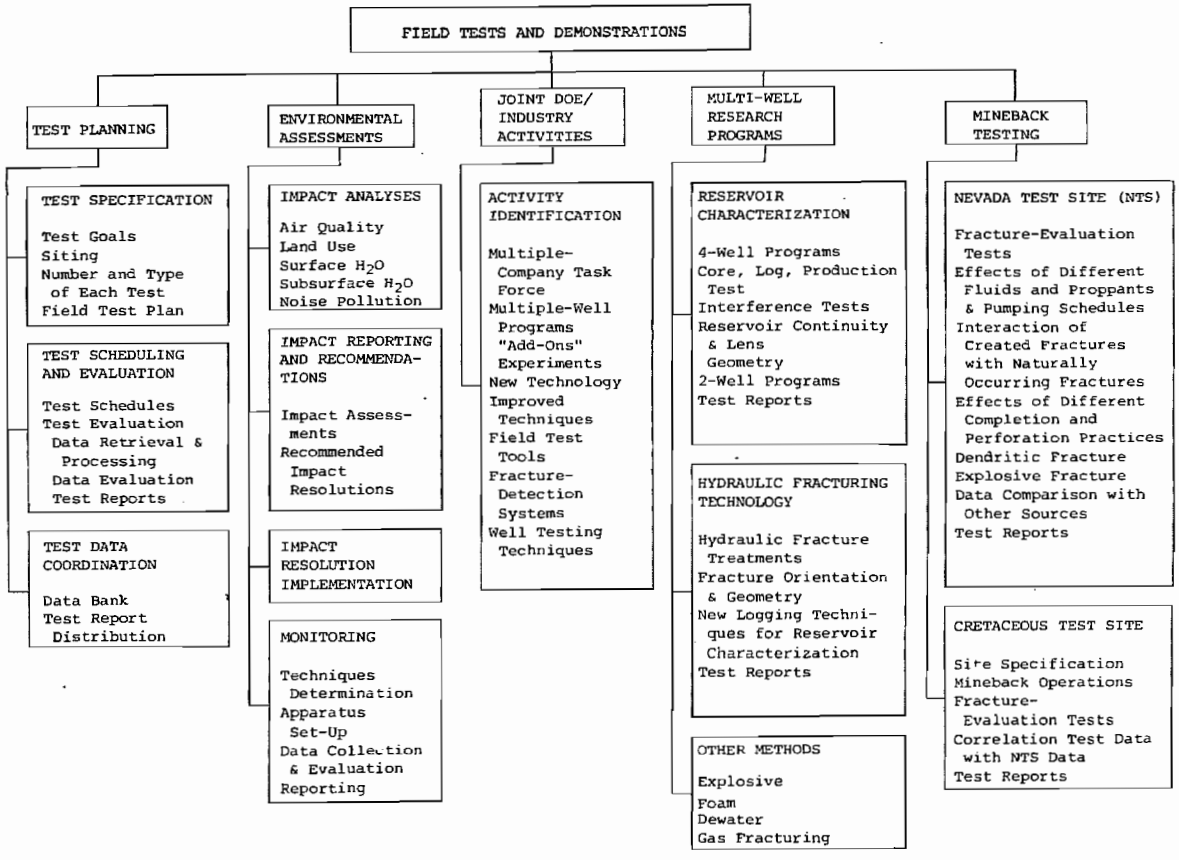


Figure 6-1 Tabulation of Completed and Continuing MHF Projects

Table 6-1 MHF Contract Locations and Frac Data

COMPANY, BASIN AND FORMATION	LOCATION	WELL	INTERVAL FRACTURED	FRAC. DATE	FRAC TREATMENT	FLUID INJECTED
	T / R / Sec		Feet		Lbs. of Sand	10^3 Gal.
AUSTRAL Piceance, Mesaverde	7S, 94W, S3 Garfield Co. Colorado	Federal 3-94	5,170-6,333	8-25-76	1,140,000	542 gel H_20
CONSORTIUM MANAGED BY CER CORPORATION Piceance, Mesaverde	3S, 98W, S11 Rio Blanco Co. Colorado	RB-MHF-3	8,048-8,078 7,760-7,864 5,925-6,016 5,851-5,869	10-23-74 5- 2-75 5- 4-76 11- 3-76	400,000 880,000 815,000 448,000	117 Gel 285 Gel 400 Gel 228 Gel
GAS PRODUCING ENTERPRISES, INC. Uinta, Wasatch and Mesaverde	10S, 22E, S10 Uintah County Utah	Natural Buttes No. 18	6,490-8,952	9-22-76	1,480,000	745 Gel
	10S, 21E, S21 Uintah County Utah	Natural Buttes No. 19	7,224-9,664	9-21-76 9-28-76	1,053,000	655 Gel
	9S, 21E, S22 Uintah County Utah	Natural Buttes No. 14	6,646-8,004	3-15-77	1,093,000	544 Gel
	9S, 21E, S28 Uintah County Utah	Natural Buttes No. 20	8,498-9,476	6-22-77	826,000	322 Gel
	10S, 22E, S21 Uintah County Utah	Natural Buttes No. 21				
	10S, 22E, S18 Uintah County Utah	Natural Buttes No. 22	6,858-8,550	11-21-77	1,091,000	479 Gel

Table 6-1 (Continued)

COMPANY, BASIN AND FORMATION	LOCATION	WELL	INTERVAL FRACTURED	FRAC. DATE	FRAC TREATMENT	FLUID INJECTED
	T / R / Sec		Feet		Lbs. of Sand	10^3 Gal.
DALLAS PRODUCTION Fort Worth, Bend Cong.	Ben D. Smith Survey A-779 Wise County, Texas	Ferguson A-1	5,957-6,794	9-10-76	506,000	139 Foam 198 Emul.
EL PASO NATL. GAS Northern Green River, Fort Union	30N, 108W, S5 Sublette Co. Wyoming	Pinedale Unit No. 5	10,950-11,180 10,120-10,790	7- 2-75 10-20-75	518,000 1,422,000	183 Emul. 8 Gel 459 Gel
MOBIL Piceance Mesaverde	2S, 97W, S13 Rio Blanco Co. Colorado	F-31-13G	10,549-10,680 9,392- 9,534	6-22-77 8-24-77	580,000 600,000	316 Gel 260 Gel
PACIFIC TRANSMISSION Uinta, Mesaverde	8S, 23E, S25 Uintah County Utah	Fed 23-25	NO FRACS PERFORMED			
RIO BLANCO Piceance, Mesaverde	4S, 98W, S4 Rio Blanco Co. Colorado	Fed 498-4-1	6,150-6,312 5,376-5,960	10-22-76 11-30-77	776,000 275,500	276 Gel 164 Gel
WESTCO Uinta, Mesaverde	10S, 19E, S34 Uintah County Utah	Home Fed. No. 1	7,826- 9,437 10,014-10,202	12-21-76 10- 1-76	500,000 600,000	412 Gel 248 Gel

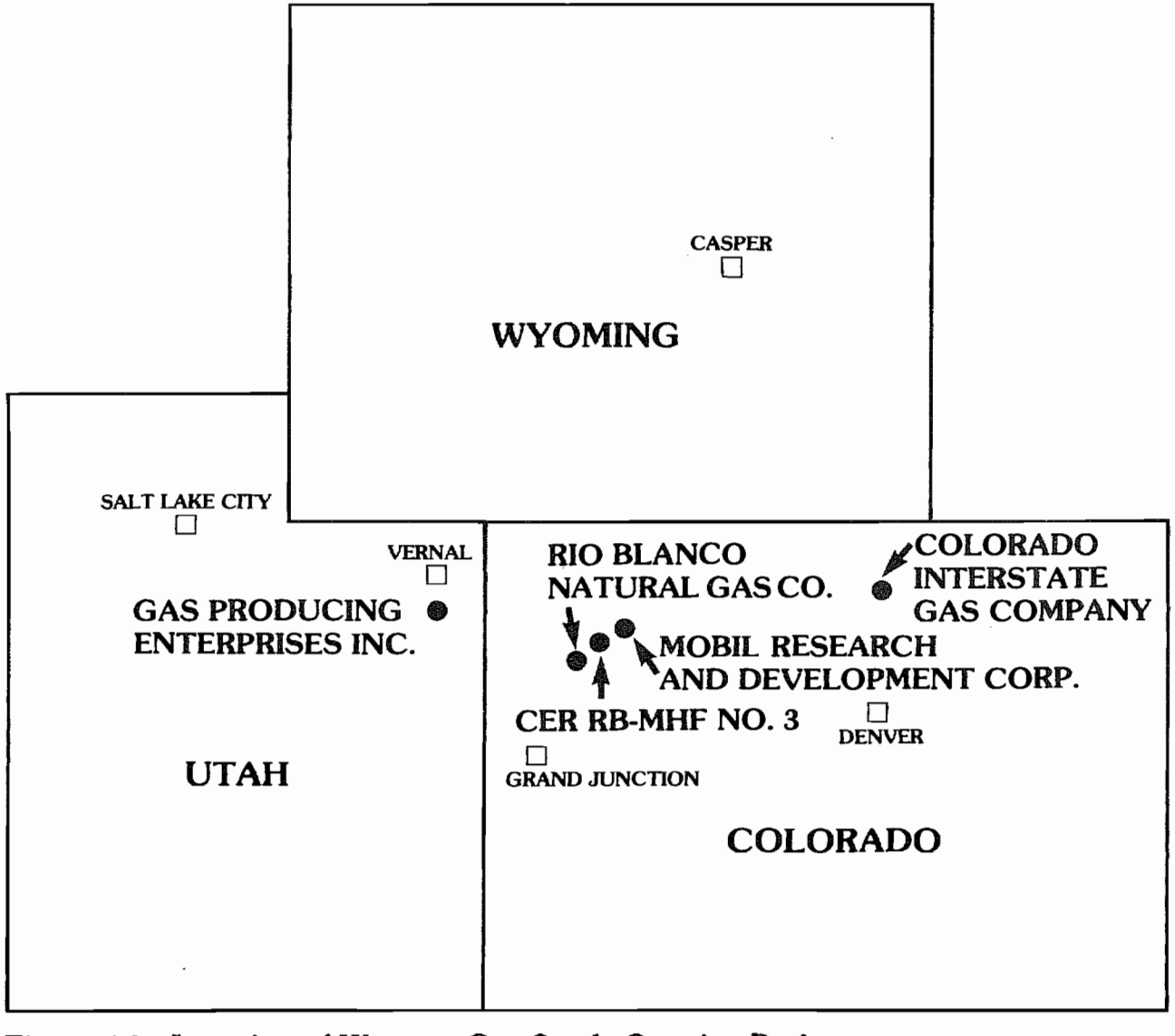


Figure 6-2 Location of Western Gas Sands Ongoing Projects

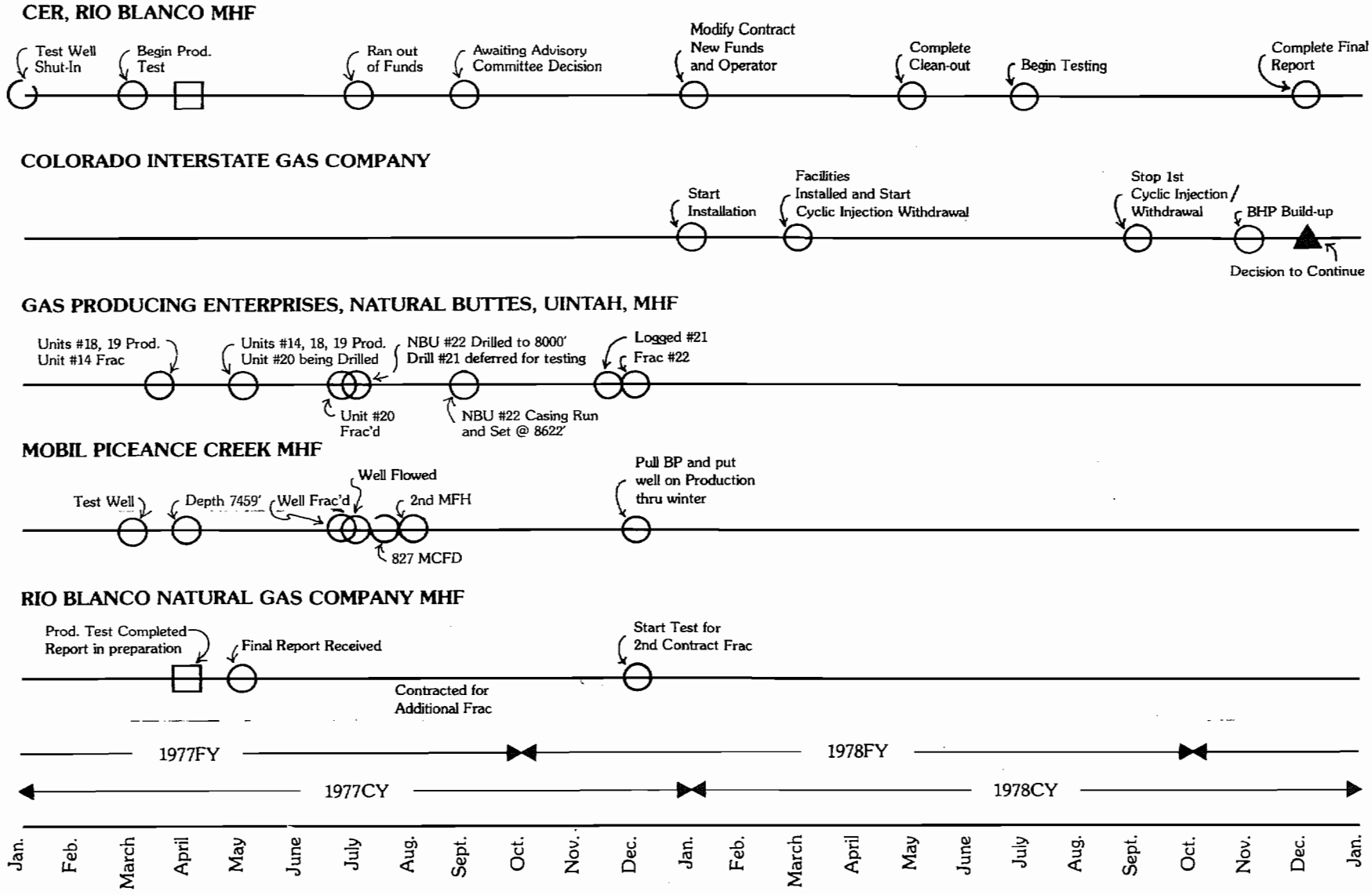


Figure 6-3 Schedule of Activities of Continuing Field Tests and Demonstrations

6.1 CER/MHF III

CER Corporation was awarded a contract with DOE on June 19, 1974 to manage a consortium of industry companies to perform a stimulation experiment in low permeability gas reservoirs in the Piceance Basin in western Colorado.

INTERAGENCY AGREEMENT DATE:	June 19, 1974
PROJECT COST (ESTIMATED):	DOE $1,975,000
	INDUSTRY . . 1,500,000
	TOTAL . . $3,475,000
PRINCIPAL INVESTIGATOR:	G.R. Luetkehans
TECHNICAL ADVISORY FOR DOE:	C.H. Atkinson, BERC

From the members of the consortium, Technical and Advisory Committees were formed to set guidelines and to aid in conducting the experiment.

The test was to apply advanced hydraulic fracturing technology where it had not previously been possible to obtain commercial production rates. The test was located about one mile from the 1973 Rio Blanco nuclear stimulation site and was to permit comparison of nuclear and hydraulic fracturing techniques.

Following the production test of the fourth zone fractured in the well (5,851 - 5,869 ft), the well was shut in on January 2, 1977. The build-up test was terminated on March 10, 1977. Bridge plugs separating the fractured zones were to be drilled out and all four zones commingled for a two-month production test, but because of mechanical problems and the resulting expenditure of all funds allotted for this work, plans for further work are awaiting an Advisory Committee decision.

6.2 Colorado Interstate Gas Company

The Colorado Interstate Gas Company (CIG) was awarded DOE Contract EY-77-C-08-1514 to determine if the productivity of wells completed in low permeability natural gas reservoirs can be improved by reducing the interstitial water saturation around the wellbore.

CONTRACT DATE:	September 1, 1977
ANTICIPATED COMPLETION:	December, 1980
PROJECT COST:	DOE . . . . . $ 75,000
	CONTRACTOR . . 99,000
	TOTAL . . $174,000

The method used to accomplish this reduction of water saturation will be a cyclic injection of dry natural gas. In addition, cyclic injection of dry natural gas may improve the productivity through dehydration of matrix clays and the removal of formation damage adjacent to the surfaces of induced fractures.

The project location is in the Wattenberg Field of northeastern Colorado. The producing formation in this field is the Dakota J which has a potentially productive area of about 625 square miles.

CIG will utilize two wells which were contributed by the Machii-Ross Petroleum Company, both completed in the Dakota J sand for the project.

After the facilities are installed and serviceable, and the initial bottom hole pressure (BHP) buildup completed, the Miller No. 1 well will be put on production and the Sprague No. 1 well will be set up to received the produced gas. The produced gas, water saturated at wellhead flowing temperature and pressure conditions, will be dehydrated to a water content of 5 lbs per MMCF before injection.

Mode 1 operations will be continued for seven days at which time it is estimated that the Sprague No. 1 wellhead injection pressure will be about 1,500 psi, and the Miller No. 1 wellhead flowing pressure at 50 MCFD will be about 300 psi.

At seven days, or when the wellhead injection pressure on Sprague No. 1 reaches 2,500 psi, mode 1 will be ended and the production and injection reversed for the mode 2 operations. At the end of about six months, the wells will be shut in for a 60-day BHP build up. Based on seven-day intervals of operation in each mode, data will be available for 12 operating intervals in each mode. Changes in the interval of operation in each mode, however, may be required, based on dew point and pressure data. The three-year term of the project will permit three subsequent six-month periods of cyclic injection, each followed by BHP build up surveys. Figure 6-4 shows a generalized schedule of activities, dependent on decisions to continue.

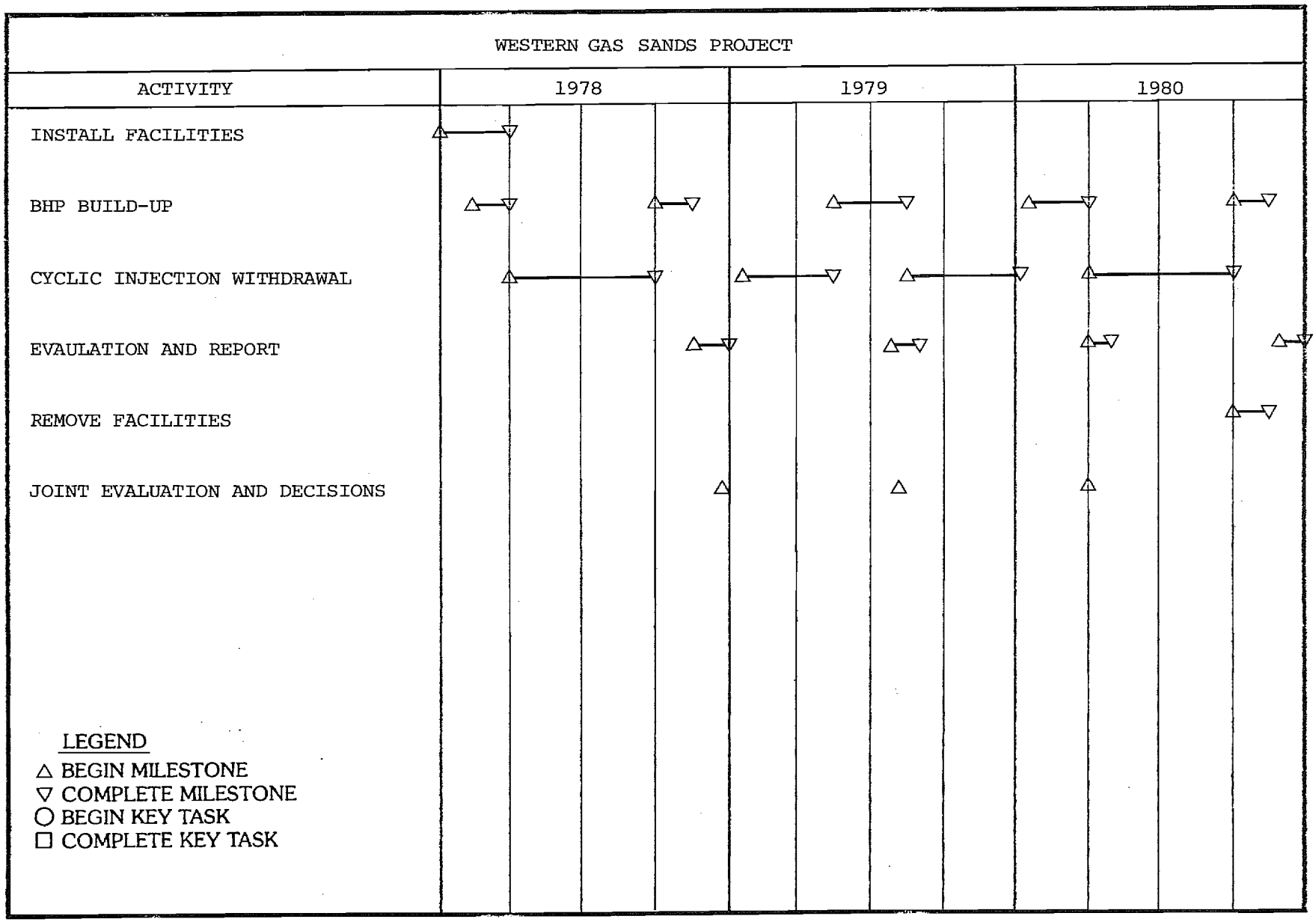


Figure 6-4 Scheduled Activities for Colorado Interstate Gas Company

6.3 Gas Producing Enterprises, Inc.

On July 1, 1976 a Contract EY-76-C-08-0681 was entered into between DOE and Gas Producing Enterprises, Inc. concerning the conduct of a MHF experimental program in the Natural Buttes Unit, Uintah County, Utah. The program involves nine massive hydraulic fracturing treatments over a two-year period in an attempt to determine a cost-effective method of recovering gas from low permeability sands. This will be accomplished by testing and evaluating the following:

Effect of fracture length on deliverability and ultimate recoverable reserves.

Orientation of fractures.

In situ fracture conductivity created by different combinations of proppants and fracture fluids.

Fracture fluid efficiency in transporting sand, controlling frac height, avoiding formation damage and breaking gels after frac.

Fracture of all sands in a 3,500 ft gross interval including marginal and less well developed gas-bearing sands.

Different methods of treatment and sand placement.

Other relating parameters will also be evaluated. All tests will be performed under field conditions and the wells will be placed on production immediately.

Figure 6-5 is a milestone chart showing the treatment schedule and the individual operations for each well. A summary of the remaining wells in the program to be tested showing estimated formation characteristics and thickness, amount and type of treating materials and other information is shown on Table 6-2. Table 6-3 summarizes the fracture treatments of the four wells already completed.

A contract modification for Phase V of the MHF Demonstration Contract provides for an add-on to the CIGE No. 21 well to arrange for coring and analysis, running of extra logs, and to run production and build up tests on approximately six individual sand members within two or more sections of the Mesaverde.

The core data, including special analyses, and production test data will be correlated with log characteristics for better prediction of potential productivity of a sand member by electric log interpretation alone.

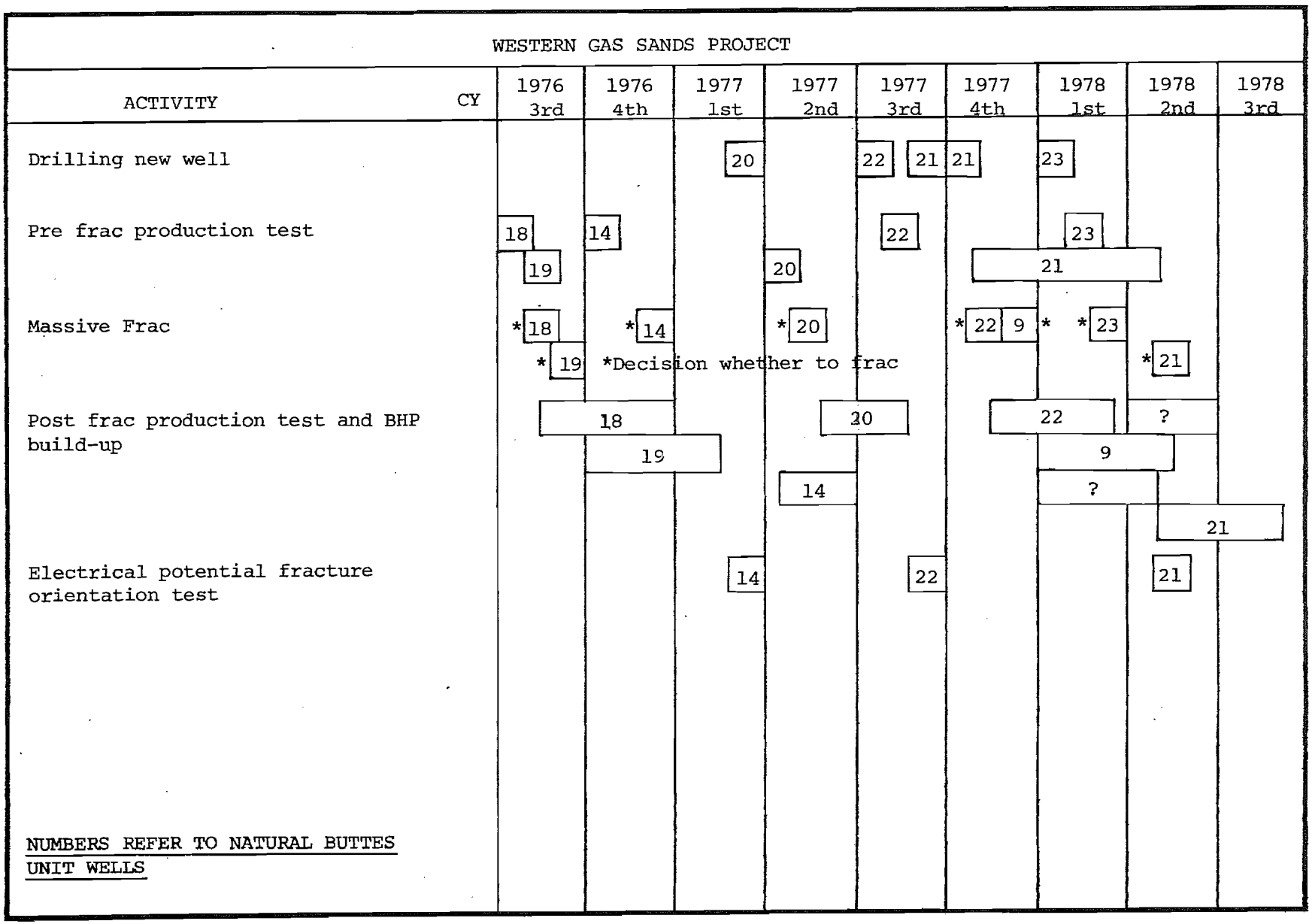


Figure 6-5 Milestone Chart of the Gas Producing Enterprises Inc. Project

Table 6-2 Well Treatment Program for FY 78

WELL NUMBER	JOB SIZE	COST	FLUID	FRAC LENGTH	SAND TYPE	FRAC ORIEN-TATION	AVERAGE ZONE QUALITY AND NET PAY	REMARKS
NBU (CIGE) No 21	750,000 gals 1,500,000 lbs	$450,000 + Add On	Final changes based on previous results	1,600'	To be determined	To be tested	Ø = 8.8% Sw = 53% h = 500'	Comparison of log data and core data to help determine zones to be perforated. Success probability - 95+%. Testing of cored intervals.
NBU No 9	To be determined	$200,000	New design, CO_2	800'	40-60	NA	Ø = 8.5% Sw = 55% h = 400'	Old well. Success probability 60%.
NBU No 22	500,000 gals 1,260,000 lbs	$400,000	Cross-linked KCl water	1,500'	100 M 40-60 + beads	To be tested	Ø = 8.5% Sw = 60% h = 600'	Success probability = 90+%.
OPTIONAL PROGRAM								
NBU No 23	To be determined	$350,000	Finalized design	To be de-termined	To be determined	NA	Ø = 9.0% Sw = 50% h = 350'	Success probability = 90+%.
NBU (CIGE) No 2	To be determined	$400,000	Finalized design	1,500'	To be determined	NA	Ø = 9.0% Sw = 50% h = 350'	Success probability = 90+%.

Table 6-3 Summary of Completed MHF Treatments

WELL	No. of Zones Perf.	Net Ft. of Pay	AVERAGE				Type of Fluid	Gals of Gel	Pounds of Sand	Frac Length Ft.
			Net Ft. Per Zone	Ø	S_w	% Sd				
NATURAL BUTTES NO. 18	28	224	12.5	10.0	48	88.0	VERSA FRAC	745,000	1,480,000	882
NATURAL BUTTES NO. 19	19	194	10.2	9.5	47	87.0	40# GUAR GUM	655,000	1,053,000	950
NATURAL BUTTES NO. 14	15	271	18.0	9.9	49	65.0	YF4-PSD	544,000	1,093,000	879
NATURAL BUTTES NO. 20	8	65	8.1	9.9	44	88.5	YF4-PSD	322,000	826,000	1,150

CONTRACT DATE:	July 1, 1976	
ANTICIPATED COMPLETION:	September 30, 1978	
TOTAL PROJECT COST:	DOE	$2,827,000
	INDUSTRY (PRIOR). .	1,881,000
	INDUSTRY (NEW). . .	3,045,000
	TOTAL	$7,753,000
PRINCIPAL INVESTIGATOR:	W.E. Spencer	
TECHNICAL PROJECT OFFICER:	C.H. Atkinson, BERC	

The contract modification provides for DOE contribution of an extra $672,000 with GPE contributing roughly $100,000. CIGE No. 21 was spudded on September 18, 1977.

6.4 Mobil Research and Development Corporation

Mobil was awarded DOE Contract EY-76-C-08-0678 along with Signal Drilling in the amount of $2.51 million for a MHF experiment in Rio Blanco County, Colorado.

CONTRACT DATE:	July 1, 1976	
ANTICIPATED COMPLETION:	December 31, 1978	
PROJECT COST:	DOE	$2,510,000
	CONTRACTOR (PRIOR).	2,376,485
	CONTRACTOR (NEW). .	1,590,515
	TOTAL	$6,477,000
PRINCIPAL INVESTIGATOR:	J.L. Fitch	
TECHNICAL PROJECT OFFICER:	C.H. Atkinson, BERC	

The well was to be drilled to a depth of 10,600 ft but mud gas at that depth resulted in a revised TD of 10,798 ft. Dual induction, sonic, caliper, long-spaced sonic, temperature log in casing, borehole televiewer and noise logs were run. The first perforated interval was 10,549 - 10,680 ft with 35 holes substantiated by BHTV.

During the first MHF treatment, a large unexpected treating pressure increase occurred which began as soon as fracturing pressure was reached and was quite large before any sand entered the perforations.

After zone 2 was abandoned because of a low production rate, the intervals 9,392 - 9,432 ft (3B sand) and 9,517 - 9,538 ft (3A sand) were perforated. After the breakdown the well flowed at 930 MCFD, declining to 799 MCFD in two days. The MHF was performed using 232,000 gal of Apollo Gel-40 and 600,000 lbs of 20-40 sand.

Early production tests showed the following rates:

DATE	FLOW RATE
Sept 3	3.2 MMCFD
Sept 4	2.7 MMCFD
Sept 5	2.6 MMCFD

The well will be shut in for pressure build up measurements and then, during October, Mobil will perforate and test zone 4.

The same procedure will be used in testing additional zones, i.e. perforate, run BHTV, breakdown with KCl water, flow, run noise/temperature

log and perform pressure buildup. Suitability of the zone for MHF will be determined from the test data. If the zone is found suitable for MHF, it will be fractured and tested in the same manner. If not, additional zones will be similarly tested until a suitable zone is found. It is estimated that as many as 6 intervals will be fractured. Present plans call for three frac jobs in calendar year 1977 and three in 1978.

6.5 Rio Blanco Natural Gas Company

In June, 1976 DOE Contract EY-76-08-0677 was signed with Rio Blanco Natural Gas Company. The scope of work consisted of preparing an existing well (Federal 498-4-1) for the MHF treatment. The MHF design was planned to utilize approximately 280,000 gal of gelled water and approximately 770,000 lb of sand.

CONTRACT DATE:	August 1, 1976
ANTICIPATED COMPLETION	March 31, 1978
PROJECT COST:	DOE . . . . . $ 410,000
	CONTRACTOR . . . 592,736
	TOTAL . . . $1,002,736
PRINCIPAL INVESTIGATOR:	R.E. Chancellor
TECHNICAL PROJECT OFFICER:	C.H. Atkinson, BERC

Contract MHF treatment performed October 22, 1976, used a total of 276,000 BBL pumped, including sand volume and flush.

The post frac cleanup proceeded satisfactorily. Gas flow increased from gas-cut water to 800 MCFD, but within 22 days the flow had declined to the 200 MCFD range.

The production rate appeared to stabilize at about 130 MCFD after three months of production.

The rapid decline in flow rate may be indicative of fracture healing due to sand grain crushing or imbedment. DOE and Rio Blanco Natural Gas Company entered into a supplemental agreement, effective October 1, 1977, to determine whether the previous fracture may have closed due to proppant crushing or whether less gas is available than originally estimated.

It is the basic purpose of the proposed fracture to inject essentially the identical frac materials used in the MHF (although in smaller quantity) into the same depositional sequence of rocks, under approximately the same reservoir conditions; the key controlled variable being the addition of 12/20 mesh glass beads. These are high strength propping material and will be mixed with the sand proppant normally used during the latter part of the fracture treatment.

Post frac flow characteristics of the proposed stimulation compared with those of the first MHF will yield important data relating to proppant efficiency in sustaining fracture conductivity.

An additional result of the project would be that combined with the three previous stimulations, it will complete a cumulative treatment using KCl based hydraulic fracs, of the entire 1,600 ft thickness of Mesaverde rocks penetrated by the well. Thus the commingled deliverability of the well will be a measure of the productive capability of this rock sequence under existing "state of the art" conditions.