Field Fracturing Multi-Sites Project

Annual Report
August 1, 1995 - July 31, 1996

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1.0 Introduction

This Annual Technical Progress Report gives a project summation, as well as field results accomplished in the third year (August 1995 - July 1996) of the Field Fracturing Multi-Sites Project (Project). The work accomplished during the past year has been jointly funded by the Gas Research Institute (GRI) and the U.S. Department of Energy, Morgantown Energy Technology Center (DOE). The results represented in this document have been developed by the team of GRI/DOE contractors, which include CER Corporation (CER), Sandia National Laboratories (Sandia), Resources Engineering Systems (RES), Branagan & Associates (B&A), and Fix & Associates.

1.1 OVERALL OBJECTIVE OF THE FIELD FRACTURING MULTI-SITES PROJECT

The objective of the Field Fracturing Multi-Sites Project (M-Site) is to conduct experiments to definitively determine hydraulic fracture dimensions using remote well and treatment well diagnostic techniques. In addition, experiments are to be conducted to provide data that will resolve significant unknowns with regard to hydraulic fracture modeling, fracture fluid rheology and fracture treatment design. These experiments will be supported by a well-characterized subsurface environment, as well as surface facilities and equipment conducive to acquiring high-quality data. The primary Project goal is to develop a fully characterized, tight reservoir-typical, field-scale hydraulic fracturing test site to diagnose, characterize, and test hydraulic fracturing technology and performance. It is anticipated that the research work being conducted by the multi-disciplinary team of GRI and DOE contractors will lead to the development of a commercial fracture mapping tool/service.

1.2 PROJECT BACKGROUND

1.2.1 Program Goals

Research work performed by the GRI and the DOE over the past several years (1993 to 1996) at the M-Site has been directed at acquiring comprehensive data sets before, during and after hydraulic fracture treatments on a number of wells. Researchers have made significant advancements in several areas from these data, including formation characterization, the modeling of fracture propagation, characterizing the azimuth and height of induced fractures, and the modeling of gas production profiles from naturally fractured reservoirs.

Advancements have also been made in the development and application of technologies which help to define the stress characteristics of various rock layers before, during and after a fracture treatment. These technologies support propagation models which predict shape and extent of the resulting hydraulic fracture.

Although considerable technological advancement has been made through these experiments, a number of technical issues are still pending. For instance, the input parameters used in fracture propagation models used by industry can vary widely due to various assumptions regarding the in-situ hydraulic fracturing process. In addition, current diagnostic systems are capable of determining only fracture azimuth and height; promising techniques that can accurately determine fracture length, have not been thoroughly field tested.

1.2.2 Site Selection

The M-Site hydraulic fracture experimentation is being conducted at the former DOE Multiwell Experiment Site (M-Site) located near Rifle, Colorado (Figure 1). The Site infrastructure initially included three closely spaced wells, namely the MWX No.1, the MWX No. 2 and the MWX No. 3 wells.

The M-Site experimentation is being executed in several sandstone units which are present in what is defined as the upper Mesaverde Group. These are shallow sandstones, which are present between 4,130 ft and 5,500 ft, are desirable for the experiments conducted under the Project for a number of reasons:

- 1) The fluvial and paralic depositional environments of the upper Mesaverde were conducive to the deposition of thick, generally low permeability sandstone bodies;
- 2) The previous MWX Project did not perform any hydraulic fracture stimulations above 5,500 ft;
- 3) Few wellbore obstructions (e.g., bridgeplugs) exist within the above referenced wells above 5,500 ft;
- 4) The projected shallow intervals decrease operational costs associated with conducting proposed experiments; and
- 5) The shallow formation depths promote the acquisition of higher quality data from surface-deployed instrumentation.

Within the gross interval from 4,130 ft to 5,500 ft, there are three sandstone units which have been identified for diagnostic and modeling experimentation. These units are informally referred to as the A-, B- and C-Sand intervals, with the A-Sand being the deepest unit and the C-Sand the shallowest zone (Figure 2).

The fluvial and paralic sections of the upper Mesaverde, which includes the A-, B- and C-Sands, is characterized by thick, laterally discontinuous, low-permeability sandstone units. As an example, the average dry-core permeability of the sandstone unit between 4,290 ft and 4,366 ft in the MWX No. 2 Well is 0.107 millidarcies (md) and the average porosity for this same zone is 5.2 percent as determined from core analyses. The uppermost Mesaverde sands are interpreted to have very high water saturations (up to 100 percent). Gas saturations, however, increase with depth below 4,500 ft.

Within the proposed test interval, there are abundant data which exists as a result of the research conducted at the M-Site. Some of this data includes:

- This entire proposed Mesaverde interval, that is from 4,170 ft to 5,550 ft, was continuously cored in the MWX No. 1 Well. This core is now stored at Sandia and is available for continued analysis. Routine and special core analyses have been performed on much of this core to determine rock mechanical and reservoir properties. Mineralogic, petrographic and sedimentological analyses have also already been performed and results documented. The MWX No. 2 Well was also cored in select intervals of the upper Mesaverde;

Figure 1 Location of Multi-Site Project

Figure 2 Test Intervals, A-, B- and C-Sands of the Mesaverde Group

- Thirteen cased-hole stress tests have been performed in the MWX No. 2 Well between 4,170 ft and 5,502 ft;
- Multiple overlapping runs of high-quality wireline log data exist over the interval and are archived at CER. The log and core data have been compiled into a depth-shifted, digital database which is also maintained at CER; and
- Seismic data in the form of high-resolution 3D, vertical seismic profile and cross-borehole is available.

Below the proposed test interval, there are additional data and information which will be useful to M-Site research. These data and information include the following:

- Hydraulic fracture azimuth was determined to be N78°W based on seven techniques in the deeper Mesaverde in the MWX wells;
- 3D fracture modeling was previously performed on a hydraulic fracture treatment at 5,530 ft; therefore, there is information on model behavior;
- Natural fractures and the associated onset of over-pressuring are known to occur primarily below 5,500 ft (below the proposed interval); and
- Through work in ten separate completion intervals, there were no indications of any near-wellbore effects during fracturing experiments. Therefore, fracture treatment modeling is not expected to be hindered.

1.2.3 Verification of M-Site Suitability

The viability of the MWX wells and upper Mesaverde Group rock units for use in seismic mapping experimentation was confirmed through a series of tests conducted in September and October 1992. These tests involved the use of existing stress data from the MWX wells and the acquisition of new seismic and fracture treatment data collected during field operations. These assessments confirmed the following conditions:

- Wellbore and cement conditions of the MWX No. 2 and MWX No. 3 wells were suitable for acquiring high-quality seismic signals with low ambient noise levels;
- Log-derived stress data calibrated with in-situ stress test data indicate that a stress contrast ranging from 500 to 1,000 psi exists between the target sandstone units and the bounding lithologies. This stress contrast was considered suitable for limiting excessive fracture height growth;
- There were no unusual occurrences (e.g., near-wellbore effects) in pressure responses which inhibited 3D modeling of the mini-fracture treatment; and
- Remote-wellbore monitoring during the mini-fracs was clearly able to identify over 1,000 microseisms during the hydraulic fracture injections. Limited analysis of these data indicated that the seismic signals can be spatially located and used for mapping the hydraulic fracture.

Based on these positive assessments, it was concluded that the MWX site is suitable for conducting additional comprehensive M-Site fracture diagnostics and fracture model verification experiments. Complete documentation of the field operations and results is found in GRI Topical Report No. GRI-93/0050 titled "Multi-Site Project Seismic Verification Experiment and Assessment of Site Suitability."

1.2.4 Contractor Team and Responsibilities

The GRI and the DOE are jointly sponsoring the research conducted at the M-Site Project. The contractor team which has been organized to execute the research Project includes CER, Sandia, RES and B&A. The responsibilities of each of these organizations are described as follows:

CER Corporation

CER, under contract to both the GRI and the DOE, conducts multiple functions at the M-Site Project. These responsibilities include the following:

Site Operator - CER has the primary responsibility for the supervision and coordination of field operations and experiments conducted in the Project to assure that they are performed in a safe and efficient manner.

Data Acquisition Systems Development and Operation - CER had responsibility for developing, installing, field checking and routine operations/maintenance of the conventional-speed data acquisition and computer networking systems used during the experiments through February 1996. Since early 1996, B&A has had the responsibility in maintaining such systems.

Diagnostics and Treatment Experiment Design/Analysis - CER shares responsibility with the other GRI contractors in designing and supervising experiments supporting fracture diagnostics or fracture modeling goals. In addition, CER shares responsibility with the other contractors in designing fracture treatments and evaluating fracture treatment data.

Cost Administration - CER has responsibility for field and office administration of the costs of equipment, materials and services required to implement experiments at the M-Site.

Sandia National Laboratories

Under contract to the GRI, Sandia has multiple responsibilities associated with the M-Site Project:

Fracture Diagnostics and Treatment Design/Supervision - Sandia has primary responsibility for design, technical supervision and interpretation of fracture diagnostics experiments. In addition, Sandia shares responsibility with the other contractors in designing fracture treatments and evaluating fracture treatment data.

Seismic Instrumentation and High-Speed Data Acquisition System Development and Operation - Sandia has responsibility for developing, installing, field checking, and routine operations/maintenance of the downhole seismic arrays and high-speed data systems used for fracture diagnostics experiments. Sandia also has primary responsibility for analysis of the microseismic data acquired in the fracture mapping experiments.

Resources Engineering Systems

RES, under contract to the GRI, has responsibilities for activities described as follows:

Fracture Treatment Design and Modeling - RES has primary responsibility for fracture treatment modeling efforts conducted in the Project. As a part of this effort, RES shares responsibility for design of fracture treatments and fracture diagnostics experiments.

Branagan & Associates

Under contract to the GRI, B&A has responsibilities for activities which are described as follows:

Fracture Treatment Experiment Design, Modeling and Analysis - B&A shares responsibility with other GRI contractors in designing, supervising and analyzing experiments supporting fracture diagnostics and fracture modeling goals. In addition, B&A shares responsibility with the other GRI contractors in designing fracture treatments and evaluating fracture treatment data.

All of the GRI contractors involved in the Project share responsibility for documenting certain accomplishments of the research through various means available (e.g., technical papers and reports, topical reports, workshops, etc.).

Subcontractors

Technical services of various other subcontractors are being used to assist in performing experimentation at M-Site, particularly, the services of James Fix & Associates, Inc. As the need arises, the technical services of other organizations may also be subcontracted.

1.3 PROJECT PHASES AND TASK OBJECTIVES

1.3.1 Project Phases

In summary, the Project, as currently defined, is divided into two phases, namely Phase I and Phase II, and as described as follows:

Phase I, Fracture Diagnostics Tests at the MWX Site, involved the installation and testing of fracturing diagnostics instrumentation; and the performance and analyses of a series of field experiments in order to measure the geometry of induced fractures. Passive seismic monitoring tools are installed in an existing MWX well, and in a special instrumentation well. Fracturing tests are conducted in another existing MWX well.

Phase II, Fracture Model Verification and Fracture Diagnostic Tests, has involved the drilling of a special directional well, with two or more lateral extensions. The placement of the boreholes has been designed to intersect induced fractures, as well as positioned for the intersection of subsequent induced fractures, in order to support the characterization of such fractures and to support predictive fracturing model verification experiments.

1.3.2 Task Descriptions

Each Project Phase has been further subdivided into given tasks which are described as follows:

Phase I: Fracture Diagnostics Tests at the MWX Site

Task 1: Drill, Evaluate, and Instrument a Seismic Monitor Well

Task 1 included the drilling, testing and instrumentation of a monitoring well (Monitor No. 1 Well) which was drilled in the fall of 1993 at a location adjacent to the MWX well pad. The well was drilled to a depth of approximately 5,000 ft, logged and selectively cored so as to detail given rock properties. An oriented core was taken to specifically determine the preferred hydraulic fracturing azimuth in the top of the Mesaverde section in order to effectively place diagnostic instrumentation. This task also included site preparation and installation of site infrastructure, to include utilities and work housing for researchers and instrumentation..

Task 2: Conduct Fracture Closure Stress Tests

In conjunction with mini-fracture injections into the MWX No. 2 Well, fracture closure experiments have been conducted in the MWX No. 3 Well to evaluate various independent closure determination techniques. Evaluated methods have included injection well pressure falloff, inclinometer output from the Monitor Well, and hydraulic impedance and tubewave characteristics in the MWX No. 2 Well.

Task 3: Conduct Seismic Fracture Diagnostics Tests

Using MWX No. 2 Well as the fracture well, and the MWX No. 3 Well and the Monitor No. 1 Well as observation wells, a number of mini-fracs have been conducted to analyze fracture length and height. Multiple three-component geophone and accelerometer assemblies installed in the observation wells in order to collect seismic signals generated during the mini-fracs. These signals, along with injection data, are collected in real time and have been analyzed to derive fracture geometry and propagation behavior.

Phase II: Fracture Model Verification and Fracture Diagnostic Tests

Task 4: Drill Directional Well Pilot Hole and High-Angle Leg No. 1; Intersection No. 1 Well, B-Sand Lateral.

In 1995, a directional well (Intersection No. 1 Well) was drilled to the south of the projected fracture azimuth, as defined in the MWX No. 2 Well. The Intersection Well No. 1 consisted of a vertical hole drilled to approximately 4,050 ft and thereafter, kicked off to form a high-angle leg. The well was designed to intersect the target B-Sand which had previously been propped fracture. Coring, logging and the recording of the fracture tracer were used to detail the fracture intersection.

Task 5: Conduct Fracture Conductivity and Seismic Tests, B-Sand.

Fracture conductivity tests have been conducted utilizing the MWX No. 2 Well and the Intersection No. 1 Well, utilizing appropriate instrumentation in both wells. Gathered information has been used to verify fracture models. Such information includes:

- propped fracture width;
- proppant bed effective permeability;
- proppant settling pattern; and
- proppant crushing and/or embedment.

In addition, diagnostics tests helped to determine propped fracture dimensions.

Task 6: Drill High-Angle Leg No. 2, C-Sand Lateral Well

A shallow C-Sand interval was selected as an intersection target, and a second lateral was drilled during July 1996, from the above referenced Intersection No. 1 Well wellbore. The new leg intersecting the target sand was left in an open hole state in order to permit fracture pressure testing. The target sand was logged to characterize the C-Sand prior to intersection by a hydraulic fracture and to determine variability of the reservoir.

Task 7: Perform Fracture Pressure and Seismic Tests, C-Sand

Future experiments will be designed and conducted to: 1) measure the hydraulic pressure at the leading edge of the fracture; and 2) provide a direct indication of the horizontal growth rate of the fracture wing. The objective is to provide independent comparisons to fracture length from seismic experiments. Data gathered in these tests would support fracturing model verification. The experiments would utilize the high-angle C-Sand lateral as well as other test site wells.

Task 8: Project Documentation and Technology Transfer

Complete documentation of activities and results will lead to continuous tech transfer via technical progress reports, technical publications, topical presentations at technical meetings, topical workshops and reports, and direct communication to industry at the field site. Formal topical reports on activities, experiments and results of special technical or newsworthy interest, such as a novel diagnostics experiment and its results, shall be prepared.

2.0 Work Performed From August 1, 1995, to July 31, 1996

Technical progress in the third year of the Project is documented by task number in the following sections.

2.1 TASK 1: DRILL, EVALUATE AND INSTRUMENT A SEISMIC MONITOR WELL

2.1.1 Site Infrastructure

After significant first and second year efforts were expended by CER in extending the site facilities requirements for conducting fracture diagnostics experiments, the infrastructure of the M-Site was maintained in the third year of the Project. The third year efforts are summarized as follows:

- A leased office/central conference trailer was maintained at the M-Site. This trailer houses the primary telephone/fax communications equipment, computer network server, printer, copier, and computer workstations where researchers received data from satellite locations during fracturing experiments.
- Utilities (e.g., commercial power, water, sanitation, communications) services continue to service the site. During the second Project year, commercial power was run to the Monitor Well instrumentation trailer. All units supplied by commercial power systems have been backed up by uninterruptable power supplies for short-term interruptions and the DOE 90 kw generator for longer term interruptions. No long-term interruptions in power were experienced at the site during the report period.
- General site and equipment maintenance activities were performed, to include site grading, calibration of surface electronic devices, calibration of the downhole surface readout pressure probes, acquisition of certain supplies for the wireline units and other required services to maintaining the site infrastructure.

2.1.2 Data Acquisition and Instrumentation Systems

In the third year of the Project, the computer equipment, data acquisition systems (DAS) and instrumentation package were maintained to handle the needs of the Project experiments (Figure 3). As a form of review, the following paragraphs describe the systems which have been purchased as GRI property.

2.1.2.1 Data Acquisition Sytem

Conventional-Speed Data Acquisition System

This equipment is to provide field personnel with easy access to onsite, low-to-moderate speed data acquisition and to assure the acquisition of high quality data. The Data Acquisition System (DAS) includes three complete data acquisition subsystems which are individually positioned as follows:

Figure 3 Layout of M-Site Infrastructure

Figure 3 Data Acquisition Systems for Fracture Diagnostics Experiments

1. The trailer for acquisition of data transmitted from the Monitor No. 1 Well inclinometer array;
2. The GRI data acquisition trailer for acquisition of surface and bottomhole pressure data, temperature data, injection rate, and other treatment well parameters; and
3. The DOE data acquisition trailer for back up and peripheral data acquisition.

Data gathered from these three satellite systems is automatically transferred to the central client/server (located in the technical evaluation trailer) in a specific format for systematic review, analysis and archiving. Basic data acquisition and display software are used in order to monitor instrumentation status as well as the status of the acquired engineering data. This is done through a series of graphic and tabular screen displays and a variety of print media.

High-Speed Data Acquisition System

The high-speed data acquisition system is used to acquire and store all microseismic data from two observation wells, the MWX No. 3 Well and the Monitor No. 1 Well. Sandia has had primary responsibility for the design specifications of the two data acquisition systems which provide the following basic functions:

- Low-noise, high-bandwidth data acquisition sites capable of accepting as many as 96 seismic receivers per well;
- Event detection and transferring of specific data across the communications link to the central client server; and
- Local high density (DAT) tape storage of all processed signals.

These high-speed DAS were fabricated from commercially available hardware and software, although the integration, testing and interfacing of this complex system required considerable care, effort and technical management both in the development and subsequent fielding phases.

Central Computer/Client Server/Local Area Network Hub

A PC-based central computer system functions as the focal point for the Project's Local Area Network (LAN) and client server. The purpose of this system is to provide a central hub to receive, distribute and store large data arrays from the satellite data acquisition systems (high-speed and conventional DAS) as well as to allow Project personnel easy access to all real-time data. The client server includes the following basic functions:

- High-speed Novell LAN system;
- Fiber optic and hardwire ethernet connections;
- High-capacity disk storage; and
- Work stations and local PCs for real-time analysis.

Subsequent system upgrades in 1995 included the addition of a data-pack storage system and a compact disc reader/writer. With these hardware additions, large volumes of data acquired during the various experiments are copied from the field computer hard drives to data packs for transport to B&A.

These tapes are then reloaded onto a computer hard drive where they are edited and subsequently copied to compact discs. The data packs are returned to the site for re-use with a duplicate set returned for archiving and reference.

2.1.2.2 Instrument System

A comprehensive package of thirty seismic instruments (accelerometers), six earth tilt instruments (inclinometers), and their respective cable systems were fabricated for emplacement in Monitor Well No. 1, to be used in fracture diagnostics data acquisition (Figure 4). The instrument emplacement was to secure the instruments and associated cabling to a tubing string; protect the instruments from abrasion and load shock with decentralizers as the string was lowered in the wellbore; assure positioning within the gross interval between 4,000 ft and 5,000 ft; and assure suitable seismic/mechanical coupling with the earth by cementing the entire tubing string and instrumentation assembly in the 9-5/8 in. casing.

Accelerometers /Cabling

Each of the thirty accelerometers were steel banded (e.g., stainless-steel, worm-driven hose clamps) to the tubing at nominal thirty foot intervals on the lowermost 875 ft of tubing. Each accelerometer was molded at pre-determined depths into a polyurethane-coated electrical cable having a diameter of 0.84 inches. This cable was periodically secured to the tubing with nylon cable ties, hose clamps, and kellys. All accelerometers were azimuthally aligned with respect to one another as they were attached to the tubing string. No attempt was made to align the accelerometers to an absolute azimuth. Each accelerometer included a set screw with an affixed Iridium (Ir^{190}) to assure that the final depth and orientation of each accelerometers was precisely defined through the use of an oriented gamma ray logging tool. Once in the wellbore, final testing of the accelerometers indicated that of the 90 data channels (x, y, z axes on thirty instruments), 88 were functioning within specifications.

Inclinometers /Cabling

Each of the six inclinometers were consistently aligned with respect to the instrument X-axis, leveled and secured with steel bands (hose clamps) such that the long axis of each instrument was parallel to the tubing axis. The maximum inclinometer cable size was represented by six 0.415 in. urethane-coated cables molded together every 100 ft. Individual cable connectors on pigtailed placed at appropriate depths allowed individual instruments to be connected. Similar to the accelerometers, a set screw with an Ir^{190} bead affixed to it was set in each inclinometer to facilitate the determination of depth and orientation. Inclinometers have been placed such that their depth positions occurred in, above and below the B-and C-Sands of the Mesaverde Group.

Figure 4 Wellbore Status, Monitor No. 1 Well

2.2 TASK 2: CONDUCT FRACTURE CLOSURE STRESS TESTS

2.2.1 Objectives

Hydraulic fracture treatments executed as a part of the M-Site Project continued to be comprehensively analyzed during year three, using various 3D fracture models. In as many areas as possible, efforts have been made at the M-Site Project to constrain the 3D models with measured data so that comparisons are made between the model-derived fracture dimensions and the dimensions as determined from microseismic mapping. Therefore, to support the 3D modeling effort, a comprehensive stress testing program was initiated so that a complete stress profile of the upper Mesaverde target interval could be developed. Log-derived stress data and several sets of in-situ stress data had already been acquired as a part of the previous DOE Multiwell Experiment. However, additional stress tests in and around the B and C Sands have been necessary to complete the stress profile.

2.2.2 Historical Testing Operations

Stress testing field operations were sequentially performed in the MWX No. 2 and MWX No. 3 wellbores, starting in the second year and carrying through the third year of the Project.

The initial phase of the stress testing operation involved perforating the seven intervals in MWX No. 3 Well and three intervals in MWX No. 2 Well. These intervals were selected to target lithologies within or adjacent to the A-, B- and C-Sand intervals of the Mesaverde Group. All perforations were 19 gram charges, four jet shots per foot (jspf) with 120° phasing.

The equipment used to isolate each two-foot perforated interval were Halliburton Pin Point Injection (PPI) tools (20 ft between upper and lower packer elements) run on 2-7/8 in. tubing. A mechanical pressure gauge was run beneath the lower packer to assess potential pressure leaks around the lower packer during the injections. Surface readout bottomhole pressures were measured with a surface readout bottomhole pressure gauge seated in the downhole shut-in device to eliminate wellbore storage. The CER injection/flowback manifold was used to accurately control fluid injection and flowback. The stress test data set included injection rate (gpm), bottomhole pressure (psi), surface tubing pressure (psi), casing pressure (psi), and bottomhole temperature (degrees F). All data collected during stress testing, including inclinometer and hydraulic impedance, were time stamped with a time code generator.

Earth tilt measurements were simultaneously acquired during each of the stress test injections. These data were measured by an oriented six-inclinometer array which had been cemented in Monitor No. 1 Well. The measured surface distance from the Monitor Well to the MWX No. 3 Well and the MWX No. 2 Well is 512 ft and 402 ft, respectively. Twelve channels (i.e., x and y axes for six instruments) of earth tilt data were acquired at the remote Monitor No. 1 Well instrument trailer and placed on the M-Site computer network to enable simultaneous observations of pressure and tilt data during stress tests.

Hydraulic impedance data were also acquired following stress test injections in several intervals as another independent technique for assessing fracture closure. Data for hydraulic impedance analysis were acquired by generating and measuring wellbore pressure oscillations through rapid opening and closing a bleed-off valve on the pressurized wellbore. Conceptually, this "surging" perturbs flow

conditions in the well, causing a pressure wave to travel to the bottom of the well where it is reflected upward. Upon returning to the wellhead, the wave is again reflected back downward (i.e., forced oscillations). The process of propagation and reflection continues until the wave is fully damped by friction and by energy losses into the hydraulic (stress test) fracture. In hydraulic terms, the frequency content and damping of pressure oscillations are controlled by a property known as the "hydraulic impedance" of the fracture. Subsequent analysis of the pressure oscillations indicates whether the hydraulic fracture is open or closed.

2.2.3 Results

The stress testing and hydraulic impedance results continued to be assessed during the third year of the Project by GRI contractors B&A and Sandia. The stress data were used to develop a normalized stress profile for modeling fracture treatments conducted in subsequent tests within the B- and C-Sand intervals. The inclinometer data acquired during stress testing was found to be marginally useful. The small injection volumes, separation distances from the injection wells and the Monitor No. 1 Well, and certain electrical noise problems all combined to substantially mask any subtle mechanical shifts in the earth which may have resulted from stress testing.

2.3 TASK 3: CONDUCT SEISMIC FRACTURE DIAGNOSTICS TESTS

2.3.1 Introduction

One of the primary goals for the third year of the Project was to complete fracture diagnostic tests in the B-Sand interval. The B-Sand experiments involve a series of field operations which were designed to extend fracture mapping capabilities and hydraulic fracturing technology. Task 3 work was initiated in the second year and completed in June 1996. The basic chronological sequence of field operations for the B -Sand experiments is summarized as follows:

- 1) **Conduct a Staged Series of Fracture Treatments.** A series of seven injections were planned for the B-Sand interval. The initial treatment (Injection 1-B) consists of a small-volume, crosslinked gel breakdown. Several somewhat larger volume KCl-water pump-in tests were to be performed in Injection No. 2-B. This was to be followed by two successively larger volume fluid-only mini-fractures (Injection Nos. 3-B and 4-B). Two fluid-only injections (Nos. 5-B and 6-B) with even larger fluid volumes and an injection with proppant (No. 7-B) were also planned. Several radioactive, chemical, and physical property (i.e., color) tracers were to be included in the fluid of Injections Nos. 1-B through 7-B.
- 2) **Drill a Hydraulic Fracture Intersection Well (DOE Task 4).** Drill a well (Intersection No. 1 Well), which intersects the hydraulically fractured B-Sand interval at a point some distance from the treatment well. The well is to be cored and logged.
- 3) **Perform Injection/Recovery Treatments (DOE Task 5).** A series of injections using the combination of the MWX No. 2 treatment well, Intersection No. 1 Well and the identified connecting hydraulic fracture will be performed.

Fracture diagnostics and fracture technology experiments were designed in association with these operations. The objectives of these experiments are summarized in the following generic categories:

Hydraulic Fracture Mapping/Diagnostics

Microseismic event detection using a wireline accelerometer array (single or multi-level) and the Monitor Well grouted-in instrumentation array to be active during each of the B-Sand injections. These seismic data will be used for accurate mapping of length and height extent of the hydraulic fracture(s). Similarly, the inclinometer data will be interpreted to determine fracture height. Hydraulic fracture azimuth will be confirmed by identifying the spacial position of the B-Sand hydraulic fracture in the Intersection Well Phase of the Project. The azimuth will be compared to that of the microseismic event cloud mapped in the B-Sand injections and to the multiple other techniques which have predicted hydraulic fracture azimuth at this site.

Hydraulic Fracture Modeling

With knowledge of stress in layers in and adjacent to the B-Sand and measurements of bottomhole pressure data during the B-Sand injections, fracture modeling will be performed to estimate fracture dimensions. The mapped fracture dimensions and modeled fracture dimensions will be compared and mechanisms for differences isolated and evaluated.

Hydraulic Fracture Technology

Several experiments will be performed in the B-Sand interval which are associated with the development of hydraulic fracturing technology. These experiments are summarized as follows:

Fracture opening and closure associated with each B-Sand injection will be assessed with the Monitor Well inclinometer array and pressure-based techniques.

Propped fracture width/proppant distribution will be assessed by coring the B-Sand hydraulically fractured interval in the Intersection Well phase of the Project. With recovery of the propped hydraulic fracture, an assessment of fracture width at the intersection point can be determined.

Single or multiple fracture generation will be assessed by using various fluid and proppant tracers (radioactive, colored proppant) which are to be included in the B-Sand injections. The hydraulic fracture(s), with their unique tracer elements, will be identified in the Intersection Well core by visual inspection, gamma scanning the core, and spectral gamma ray logging tools run in the Intersection Well.

Fracture conductivity will be performed using injection tests in the B-Sand perforated interval in the treatment well and monitoring bottomhole pressure in the Intersection Well, thereby allowing pressure drop down the fracture to be assessed. Fracture conductivities will also be measured in propped fractures recovered in B-Sand core samples.

2.3.2 Injections, Numbers 5-B and 6-B

Field operations associated with initiating hydraulic fracturing experiments within the B-Sand interval began in the second year and carried into the third year of the Project. The B-Sand within the MWX-2 Well was perforated from 4,527 ft to 4,557 ft (59-19 gram charges, 2 jspf, 0.5 in. diameter holes, 120° phasing). Following the primary perforating and logging run, nine additional "noise shots" (3.2 gram charges, 0.25 in. diameter holes, 0° phasing) were fired for verification of the Monitor No. 1 Well

accelerometer orientations. These charges occurred in an interval from 4,537 ft to 4,548 ft. Subsequent field operations included several breakdowns and several pump-in/flowback tests (Injection Nos. B-1 through B-4, see Annual Technical Report, July 1994 to July 1995).

Injections 5-B and 6-B were initiated in the third year of the Project. These injections included two 484 barrel, 40 lb. per 1000 gallon linear gel minifrac in the B-Sand interval within the MWX No. 2 Well. Each treatment was pumped down the casing/tubing annulus at an average rate of 20 barrels per minute (bpm), respectively. Flow back of Injection No. 5-B was initiated following a two hour shut-in period. A sixteen hour shut-in was performed after Injection No. 6-B prior to flow back. Each of these injections included a radioactive isotope (Fe^{59} in Injection No. 5-B and Zr^{94} in Injection No. 6-B) to uniquely tag the propagated hydraulic fractures.

Data acquisition during both injections were identical and are described as follows:

- The comprehensive thirty-instrument accelerometer and six-instrument inclinometer arrays in the Monitor Well were operational during the injections;
- The five-level accelerometer array on a fiber optics wireline was operational in the MWX No. 3 Well;
- Bottomhole pressures were monitored during and following each treatment with a surface readout bottomhole pressure gauge set below the perforated interval at 4,650 ft; and
- Several spectral gamma ray logging runs were performed, one survey before and after Injections No. 5-B and No. 6-B. Tagged fracture fluid was reversed out of the wellbore prior to the second and third logging runs to avoid saturating the logging tool with radioactive tracer which had not been injected into the formation.

Injections Numbers. 5-B and 6-B were designed to accomplish several objectives.

- Using duplicate pump volumes, compare and map microseismic events in rock which is unfractured and then refractured;
- Acquire earth tilt data for fracture geometry interpretations, as well as for assessing fracture opening and closure;
- Through the use of radioactive tagging, identify the fractures propagated in each injection; and
- Acquire bottomhole fracture treatment pressure data for inclusion in 3D fracture models. Data from these fracture models are to be compared to fracture diagnostics, with any differences isolated and quantified.

2.3.3 Injection Number 7-B

In August 1995, a 40 lb. per 1000 gallon cross-link gel carrying 76,500 lbs of 20/40 mesh resin-coated proppant was performed in the B-Sand interval. The injection was pumped down casing at an average rate of 20 bpm. Injection 7-B included two radioactive isotopes (Sr^{192} microencapsulate and Ir^{192} Zero-wash® beads) to uniquely tag the propagated hydraulic fracture(s). A final, post-frac spectral gamma ray logging run with two repeat sections were performed from 4,900 ft to 4,250 ft after having circulated the wellbore with clean fluid. In addition to the placement of the radioactive tracer, the

proppant had been colored orange, green and brown. The primary reason for the resin coat was to facilitate the coloring of the proppant.

Data acquisition during Injection No. 7-B was similar to that of Injections 5-B and 6-B, and included the following:

- The comprehensive thirty-instrument accelerometer and six-instrument inclinometer arrays in the Monitor Well were operational during the injections;
- The five-level accelerometer array on a fiber optics wireline was operational in the MWX No. 3 Well;
- Bottomhole treating pressures were monitored during and after the treatment with the RTD pressure telemetry tool set below the perforated interval. The pressure tool successfully transmitted data to the surface at one sample per second intervals. Redundant memory gauge data (internal to the RTD tool) was also acquired; and
- A post-fracture spectral gamma ray logging run was performed following Injection 7-B. Tagged fracture fluid was reversed out of the wellbore prior to the logging run to avoid saturating the logging tool with radioactive tracer which had not been injected into the formation.

Injection No. 7-B was designed to accomplish several objectives:

- Earth tilt data were acquired for further assessment of fracture geometry as well as for the assessment of fracture opening and closure;
- Microseismic data were acquired for fracture mapping during the injection and during the fracture closure on the proppant;
- The fracture(s) propagated in the injection were tagged with unique radioactive tracers to estimate near wellbore fracture height growth and to facilitate fracture identification in the later B-Sand Intersection Well phase of the Project;
- The fracture(s) propagated in each injection were tagged with radioactive tracers to facilitate fracture identification in the B-Sand Intersection Well; and
- Bottomhole fracture treating pressure data were acquired for inclusion in 3D fracture models. Data from these fracture models would be compared to fracture diagnostic results with any differences isolated and quantified.

An H/Z seismic survey, using a single triaxial accelerometer on a seven-conductor wireline, was performed in the MWX No. 2 Well in conjunction with Injection No. 7-B. A baseline H/Z survey was performed prior to the injection and involved acquiring background data at 25 depth stations between 4,100 ft and 4,825 ft. Depth stations between 4,100 ft and 4,350 ft were spaced 50 ft apart and from 4,375 ft to 4,825 ft the intervals were spaced at 25 ft. The H/Z seismic survey was performed following Injection No. 7-B in order to estimate fracture height growth.

2.3.4 Results of Injections 5-B through 7-B

Only preliminary fracture diagnostics and fracture modeling results from Injection Nos. 5-B through 7-B are available as of this report period. Final results will be documented in GRI/DOE topical reports by B & A, and summarized in the DOE Final Report.

2.4 TASK 4: DRILLED DIRECTIONAL HIGH-ANGLE WELL, INTERSECTION NO. 1 WELL (B-SAND)

2.4.1 Introduction

The Task 4 objective of drilling a well which intersects the B-Sand hydraulic fracture was previously summarized in the Task 3 introduction. Task 4 was performed in the third year of the Project. However, in preparation for drilling activities, a well plan was developed in the second Project year. The projected purpose of the Intersection No. 1 Well was to recover core across a northwest-southeast trending propped and tagged hydraulic fracture treatment conducted in the Mesaverde B-Sand. It was deemed desirable to core across this hydraulic fracture at an angle of 60° off vertical in order to penetrate possible multiple fracture traces. A surface location in close proximity to the Monitor Well provided the most direct and least expensive wellbore trajectory to the Mesaverde B-Sand target.

2.4.2 Drilling Plan

The following basic drilling procedures were followed in the drilling and casing of the Intersection No. 1 Well, B-Sand lateral well.

2.4.2.1 Location

The surface location of the Intersection No. 1 Well is located in the southwest quarter of the northwest quarter of Section 34, T6S-R94W, Garfield County, Colorado (Figure 5). The ground elevation of the well location is 5,385.5 ft. This surface location is approximately 18 ft west and 10 ft south of the surface location of the Monitor No. 1 Well. This 20.4 ft offset provided sufficient standoff from the Monitor well to minimize the chance of the two wellbores intersecting during drilling, and allowed the use of an existing location and reserve pit.

2.4.2.2 Drilling Operation

- *Conductor Casing:* Preliminary field operations began on September 1, 1995 with a rathole rig drilling a 28 in. hole to 39.5 ft. A 20 in. conductor pipe was run to a total depth and cemented back to surface.
- *Surface Casing:* A drilling rig was subsequently moved in and rigged up to drill the remainder of the well. An 8 ¾ in. pilot hole was drilled to a depth of 325 ft. The pilot hole was subsequently opened to 17-1/2 in. and 13-3/8 in. casing was run to 318 ft and cemented back to surface.
- *Intermediate Casing:* Due to a boulder field encountered in the four offset wells between the depths of 200 ft and 1,100 ft, intermediate casing was run to eliminate potential for

Figure 5 Well Plot, Intersection No. 1 Well, B-Sand

uphole problems during directional drilling operations. Drilling resumed with an 8-3/4 in. bit and a pilot hole was drilled to 1,166 ft kelly bushing (KB). The 8-3/4 in. pilot hole was subsequently opened to 12-1/2 in. and 9-5/8 in. casing and cemented back to surface.

- **Production Casing:** An 8-3/4 in. hole was drilled out from under the 9-5/8 in. casing at 1,155 ft on September 21, 1995 and continued in a vertical mode to the kickoff point at 4,049 ft which was reached on September 30, 1995. The intervals 1,535 ft to 1,796 ft and 1,796 ft to 2,044 ft were drilled with two FlowDril Corporation downhole pumps of slightly differing design. The improvement in ROP with the two downhole pumps over conventional rotary drilling was 1.4:1 (pump 1) and 1.7:1 (pump 2), respectively. (Further information on the downhole pumps being developed through a DOE/GRI coordinated effort can be obtained by contacting Scott Veenhuizen of Flow Dril in Kent, WA.)

At 4,049 ft, the drillpipe was strapped out of the hole, a gyroscope survey was run to tie the surface location to the kickoff point, the Sperry Sun directional drilling assembly was run in the hole, the tool face on the directional drilling assembly was gyroscopically oriented to due North with directional drilling initiated on October 2, 1995. Directional drilling continued to the end of the build section at 4,606 ft measured depth (MD), 4,524 ft true vertical depth (TVD). Hole angle was built at an average rate of 10.6°/100 ft from the kickoff point at 4,049 ft to the end of the build at 4,606 ft. At the end of the build section, the bottom hole location was projected to be 259.0 ft north and 56.2 ft east of the surface location, at a hole angle of 56° with an azimuth of N31°E. Two 8-3/4 in. Hughes insert bits were used to drill the angle build section. Three separate reaming runs were made between 4,300 ft and 4,600 ft to eliminate suspected dog legs prior to conditioning the hole and running casing. The 7 in. production casing was run to 4,588 ft without incident and cemented back to surface on October 10, 1995. The bottom 16 joints (636 ft) of casing was equipped with buttress connections to compensate for bending stresses in the angle build section of the hole, while the remaining 102 joints (3,952 ft) of casing were equipped with Atlas Bradford connections.

A 6-1/8 in. hole was subsequently drilled out from under the 7 in. casing at 4,588 ft MD to the core point at 4,609 ft. Five conventional cores were then cut from 4,609 ft to 4,738 ft using a 4-3/4 in. OD by 34 ft barrel with a 6-1/8 in. x 2-5/8 in. PDC core head.

Coring Operations Summary in the Mesaverde B-Sand

<u>Item</u>	<u>Top (ft)</u>	<u>Bottom (ft)</u>	<u>Description</u>
Core No. 1	4,609	4,626	Cut 17 ft, Rec. 16 ft
Core No. 2	4,626	4,656	Cut 30 ft, Rec. 29.9 ft
Core No. 3	4,656	4,686	Cut 30 ft, Rec. 30.5 ft
Core No. 4	4,686	4,709	Cut 23 ft, Rec. 23 ft
Core No. 5	4,709	4,738	Cut 29 ft, Rec. 27.1 ft

- **Drilling Fluids:** The drilling fluid used to drill the B-Sand Intersection Well No. 1 was a low-solids non-dispersed fresh water mud system. Mud weights ranging from 8.7 to 9.8 pounds per gallon (ppg) were maintained during drilling. A cost effective approach to drilling fluid maintenance was used including several solids control equipment items (dual screen shale

shakers, mud centrifuge, dual pumps, etc.) and recirculation of reserve pit volumes to limit fluid hauling and chemical cost.

- *Directional Drilling:* Wellbore deviation was controlled and monitored during the drilling of both the vertical as well as the deviated portion of the well. During the drilling of the vertical portion of the hole, Sperry-Sun single shot gyroscopic surveys were taken at 200 ft intervals to ensure that drilling this section of the hole did not interfere with the geophysical instrumentation in the Monitor No. 1 Well. At the kick-off point, Scientific Drilling International ran a multi-shot gyroscopic survey from surface to independently confirm the results from the single shot surveys and to orient the Sperry Sun directional drilling assembly to true North prior to initiating drilling operations.

The angle build portion of the well from 4,049 ft to 4,606 ft was drilled with two 8-3/4 in. Hughes insert bits using a 6-3/4 in. low speed Sperry Drill motor with a 1.83° adjustable housing. A brief run was made below 4,301 ft with the adjustable housing set at 2.12° but this proved to be too aggressive and the housing was reset at 1.83°. The average build rate resulting from this configuration was 10.6°/100 ft from 4,049 ft to 4,606 ft. The drilling fluid circulation rate during directional drilling averaged 300 gpm at 1,350 psi standpipe pressure.

Hole inclination, wellbore azimuth, tool face orientation, tool temperature, and a continuous gamma ray log of formations penetrated was obtained using Sperry Sun's Directional Gamma While Drilling system. The gamma ray log was played back on true vertical depth and provided excellent correlation with vertical offsets in order to pick core point. Due to the proximity of the Monitor No. 1 Well and with concern of inadvertently drilling into this wellbore, the hole azimuth and inclination in Intersection No. 1 Well was independently monitored using Scientific Drilling International's single shot gyroscope until the bottom hole location was determined to be north of the Monitor No. 1 Well. Figures 6 and 7 illustrate the plan view and the vertical section of the Intersection Well.

- *Casing and Cementing:* The casing program is noted on Figure 8, Wellbore Diagram Intersection No. 1 Well. The 13-3/8 in., 54.5 lb./ft, J55 ST&C surface casing was set at 318 ft and cemented back to surface with 400 sacks of Class G cement. The 9-5/8 in., 36 lb./ft, J55, ST&C intermediate casing was cemented back to surface with 275 sacks of 50/50 Pozmix followed by 200 sacks of Class G cement. The 7 in., 23 lb./ft, N80 BT&C and FL4S combination casing string was cemented back to surface with 418 sacks of Lite Pozmix followed by 478 sacks of Self Stress II cement. Cement was circulated to surface and maintained at surface for all three casing strings. The 5 in., 18 lb./ft, P110 liner set at 4,630 ft was left uncemented.

2.4.2.3 Operational Results

The results of logging and core work outlined in Task 4 will be summarized by B&A in the B-Sand Final Report prepared for the GRI.

Figure 6 Plan View, Intersection No. 1 Well, B-Sand

Figure 7 Vertical Section, Intersection No. 1 Well, B-Sand

Figure 8 Wellbore Diagram, Intersection No. 1 Well, B-Sand

2.5 TASK 5: B-SAND CONDUCTIVITY EXPERIMENTS

2.5.1 Objective

Fracture conductivity testing is the objective of this experimentation. This testing used the combination of the MWX No. 2 treatment well, propped hydraulic fracture established in the B-Sand interval (4,527 ft to 4,557 ft) and the Intersection No. 1 Well. The Intersection Well has been interpreted to have eleven individual hydraulic fractures which are established over a lateral distance of three feet.

2.5.2 Technical Approach

A series of injections and flow tests involving pressure, flow rate and fluid loss measurements were employed to define the conductivity of the B Sand hydraulic fractures. As noted above, to implement the B-Sand fracture conductivity tests, the Intersection No.1 Well and the MWX No. 2 Well were utilized.

2.5.3 Conductivity Testing

- Prior to initiating the B-Sand injections, all gas in the fracture and wellbore systems were circulated out and replaced with fresh water.
- Started conductivity testing by pumping fresh water down the tubing of the MWX No. 2 Well and recording flows from the Intersection Well. Injection was at a rate of one barrel per minute (bpm) with a maximum surface pressure of 650 psi. However, during this initial pump phase, no returns were recorded from the Intersection Well. Pumping was continued down the tubing in the MWX No. 2 Well with the Intersection Well open. The Intersection Well began to flow at a cumulative rate of 145 bbls. The Intersection Well was subsequently shut-in while additional fluid was pumped into MWX No. 2. A total of 182 bbls of initial fluid was pumped before the well was shut-in. Rates during the last 2½ hours of the pump-in were approximately ¼ bpm at 700 psi.
- With the Intersection Well shut-in and with pressure at 200 psi, the MWX No. 2 Well was again opened and fluid was again injected down the tubing at an initial rate of one bpm until the surface pressure reached 700 psi.. After which, the injection rate was reduced to ¼ bpm. Total injected fluid was 250 bbls.
- The Intersection Well remained shut-in as additional pump-ins were performed in the MWX No. 2. Shut-in pressures in the Intersection Well at the beginning of the third day of conductivity testing were 319 psi on the tubing and 365 psi on the casing. With the Intersection Well shut-in, another pump-in was executed down the tubing in the referenced MWX well. Pump rates started at ½ bpm until surface pressure reached 700 psi, and decreased thereafter to ¼ bpm. The well was subsequently shut-in. Total fluid injected into the MWX No. 2 through day three was 300 bbls.
- An attempt was made to run a spinner survey in the Intersection Well. However, after a number of attempts, the survey was abandoned. With the MWX No. 2 Well open, a pump-in was performed down the tubing in the Intersection Well. Total fluid injected into the Intersection Well totaled 36 bbls. The flowmeter in the MWX well was reversed to read fluid flow from the tubing into the tank. Total fluid flow recorded from MWX No. 2 was 66 bbls.

A second injection was initiated in the Intersection Well and monitored at the MWX No. 2 Well. Forty-four barrels of water was injected into the tubing of the Intersection Well with 48 bbls of discharge water was recorded from the MWX well.

- A reverse production conductivity test was initiated, using the MWX No. 2 Well as the injector. Approximately 50 bbls of fresh water was pumped down the tubing and out the casing to evacuate gas from the system. Water was then injected into the MWX No. 2 Well with flow rates and pressures recorded at the Intersection Well. One hundred and forty-one barrels of water was injected into the MWX No. 2 Well, with 66 bbls recorded fluid flow through the Intersection Well.
- A final spinner survey was run in the Intersection Well on the last day of testing. However, the tool was again inoperable and this concluded the conductivity test within the B-Sand.

2.5.4 Results of B-Sand Conductivity Tests

Only preliminary fracture diagnostics and fracture modeling results from the conductivity tests within the B-Sand are available as of this report period. Final results will be documented by B & A in GRI/DOE topical reports and summarized in the DOE Final Report.

2.6 TASK 6: DRILL DIRECTIONAL HIGH-ANGLE WELL, INTERSECTION NO. 2 WELL (C-SAND)

2.6.1 Objective

Following the execution of the B-Sand fracture conductivity tests, the C-Sand experimentation phase of the Project was to be implemented. To implement the planned C-Sand experiments, a new lateral borehole was to be emplaced in the C-Sand prior to initiating hydraulic fracture treatments. Conceptually, this deviated borehole was to be a shallow kickoff from a window cut in the vertical portion of the existing Intersection No. 1 Well, with an openhole completion in the C-Sand to facilitate subsequent fracture pressure and borehole image data acquisition.

2.6.2 Location

The surface location of the existing Intersection No. 1 Well is presented as follows:

County:	Garfield
State:	Colorado
Surface:	2,464 ft FNL, 733 ft FWL, Section 34, T6S, R94W
Bottomhole:	2,136 ft FNL, 1,000 ft FWL, Section 34, T6S, R94W; 423 ft N39°E of surface location
Elevation:	5,398 ft KB, 5,385 ft GL
Projected TD:	4,584 ft MD, 4,425 ft TVD

2.6.3 Prognosis

The drilling procedure presented herein outlines the drilling of a 6-1/8 in. diameter build section and a 50° to 55° lateral through the Mesaverde C-Sand to a total depth of 4,584 ft TMD. The purpose for drilling the Mesaverde C-Sand lateral is to provide a monitoring point approximately 300 ft from the

MWX No. 2 Well in which a series of hydraulic fracture treatments are to be conducted. It is necessary to drill the C-Sand leg at a low angle to ensure that the hydraulic fracture will intersect the borehole. The newly drilled C-Sand borehole is to be left as an openhole completion to facilitate pressure measurements and wireline logging runs to be made in the subsequent experiments. Data acquisition operations in the openhole are to be inclusive of borehole image logging, e.g. Formation Microscanner (FMS) which will be used to establish the baseline formation character prior to fracturing into the borehole. Future FMS log data is to be compared to this baseline data in order to determine the locations of hydraulic fractures.

2.6.4 Plug and Abandonment Operation

The following basic procedures were followed in the plugging and abandoning of the Mesaverde B-Sand lateral:

- Moved in and rigged up well service unit; installed BOPE;
- Pull 2-7/8 in., 6.5 lb/ft N80 tubing from the well;
- Picked up casing scraper and made a scraper run from surface to 4,000 ft. Pulled 2-7/8 in. tubing and casing scraper; and
- Ran and set a CIBP on wireline at 4,500 ft. Placed 10 sacks of cement on top of the CIBP.

2.6.5 Directional Drilling Operations

- An angle-build bottom hole assembly was utilized to drill the angle build section from the kickoff point at 3,725 ft to 4,398 ft TMD (4,312 TVD), with a location of 218 ft north and 178 ft east of the surface location. The hole angle was built to 52° off vertical at a build rate of approximately 10°/100 ft using both drilling motors and surface rotation. The hole azimuth was projected at N39°E at the top of the Mesaverde C-Sand interval. The hole angle and the hole azimuth through the build section were measured using gyroscopic steering up to the point where the wellbore passed the Monitor No. 1 Well. MWD tools were used from this point to total depth. The angle build section began at the casing window, reaching 52° four feet into the C-Sand at 4,387 ft MD. The Mesaverde C-Sand section was drilled with an angle-hold bottom hole assembly to total depth (Figure 9).
- Fresh water was used as drilling fluid in the cutting of the window in the 7 in. casing. Two ditch magnets were used to recover metal at the surface during drilling, and the pits were dumped and cleaned following completion of the operation.
- A polymer, gel, low solids non-disperse mud system was used while drilling the 6-1/8 in. diameter hole from the window at 3,725 ft to total measured depth of 4,584 ft. This highly shear-thinning system was chosen because it has a minimum of solids for improved penetration with minimum viscosity at the bit and a maximum annular viscosity for hole cleaning. Polymer

○ MWX-3

○ MWX-1

MWX-2 at C Sand Mid-Perf
MWX-2

328.8 ft. S85.6°E

304.6 ft. S80.5°E

291.3 ft. S74.3°E

288.6 ft. S73.2°E

289.7 ft. S80.4°E

IW1-C @ Base C Sand, 4515 ft MD

IW1-C @ Base Lower Shale Break, 4469 ft MD
IW1-C @ Top Upper Shale Break, 4461 ft MD

IW1-C @ Top C Sand, 4380 ft MD

Monitor Well

Intersection Well
(Surface Location)

0 50 100
Distance, ft

Figure 9 Plan View, Intersection No. 2 Well, C-Sand

was used to extend the yield of the bentonite while selectively flocculating low yield drilled solids. Polymer was added at a rate of one bucket per 100 bbls. Of drilling fluid for maximum effectiveness. Caustic soda was used to control pH at approximately 9.0 to 9.5. Drillpac was also used to control filtration at the desired level.

- Solids control was very important in the angle build portion of the hole. Mud weight was maintained between 8.8 ppg to 9.0 ppg from 3,725 ft to 4,584 ft TMD. The rig was equipped with one double screen shale shaker, a desander, a desilter and a mud centrifuge.
- Significant torque or drag was anticipated in the angle-build portion of the wellbore. As such, a blend of non-hydrocarbon lubricating agents (TORKease™) was used as a drilling fluid additive to impart lubricity to the drill string, bit and borehole. The coating action prevented the hydration and consolidation of shale cuttings, aided in the elimination of sloughing shales and promoted the effective removal of drill cuttings.
- After reaching a total depth of 4,584 ft, an open hole logging suite was run, consisting of the FMS and the Litho-Density, Compensated Neutron Log with gamma ray and caliper log.
- The open hole section across the C-Sand was plugged back with 20/40 frac sand and capped with three sack cement plug. The top of the cement plug was four feet below the top of the C-Sand, at 4,383 ft. This cement plug ensured that there was no circulation of the sand during liner cement displacement.
- A liner consisting of approximately 849 ft of 5 in., 18lb/ft, N80 seamless casing with Hydril 521 connections was run through the angle build to a depth of 4,383 ft and tied back to the 7 in. production casing at 3,534 ft. The liner was cemented in place using 100 sacks of Class G regular cement (Figure 10).

2.7 TASK 8: PROJECT DOCUMENTATION AND TECHNOLOGY TRANSFER

Two Project reports which document the major M-Site field activities, data acquisition and data analysis were finalized and distributed in the second year of the Project. These report titles are as follows:

Results of Multi-Site Experimentation in the A-Sand Interval: Fracture Diagnostics, Fracture Modeling and Crosswell Tomography documents the A-Sand experimentation performed in October 1995. Distribution date of the report was February 1996.

GRI/DOE Multi-Sites Fracture Diagnostics Project: Monitor Well No. 1 Drilling, Data Analysis and Instrument Emplacement documents the drilling activities and data analyses which resulted from drilling the Monitor Well. Distribution date of the report was February 1995.

A Project report is currently being prepared by B & A which will document the results of M-Site experimentation in the B-Sand interval.

To more effectively distribute information on activities and research occurring at the M-Site Project, CER initiated the distribution of the "Information Update." This one-page newsletter was distributed to select individuals having an interest in fracture diagnostics or hydraulic fracturing in April 1995.

Figure 10 Vertical Section, Intersection No. 2 Well, C-Sand

CER participated in the DOE contractor review meeting held in Baton Rouge, Louisiana, April 1995. The results of the A-Sand seismic mapping experiments were presented. Similarly, CER represented the M-Site Project at the GRI Project Advisor's Group meeting held in Grand Junction in July 1995. CER, Sandia and B & A presented Project results, gave guided tours of the M-Site infrastructure, and demonstrated the capabilities of the Project data acquisition systems.

The M-Site fracture diagnostics experiments are providing results that research and industry groups may find challenging to their current concepts of hydraulic fracture propagation. To more effectively describe and promote the M-Site results, a series of technology transfer workshops are proposed by Sandia and B & A during the third year of the contract.

3.0 Future M-Site Activities

3.1 TASK 7: C SAND FRACTURE DIAGNOSTICS AND FRACTURE TECHNOLOGY EXPERIMENTS

Activity in this task is scheduled to occur in the fourth year of the Project.