Naturally Fractured Tight Gas Gas Reservoir Detection Optimization

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Quarterly Status Report

CONTRACT NO.:

DE-AC21-93MC30086

CONTRACTOR:

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CONTRACT NAME:

Naturally Fractured
Tight Gas Reservoir
Detection Optimization

CONTRACT PERIOD:

1/01/98 – 3/31/98

CONTRACT OBJECTIVE: No change.

TECHNICAL APPROACH CHANGES: No change.

FIELD PERFORMANCE TEST PLAN:

The primary goal of this work is to partition and high-grade the greater Green River basin for exploration efforts in the Cretaceous tight gas play. The work plan for the quarter of January 1, 1998 – March 31, 1998 consisted of three tasks:

1. Acquire necessary data and develop base map of study area,
2. Process data for analysis,
3. Initiate structural study.

The first task and second tasks were completed during this reporting period. The third task was initiated and work continues.

Introduction

During this quarter, work began on the regional structural and geologic analysis of the greater Green River basin (GGRB) in southwestern Wyoming, northwestern Colorado and northeastern Utah. The ultimate objective of the regional analysis is to apply the techniques developed and demonstrated during earlier phases of the project to sweet-spot delineation in a relatively new and underexplored play: tight gas from continuous-type Upper Cretaceous reservoirs of the GGRB.

In concert with the regional analysis, detailed structural analyses were initiated in two areas within the GGRB: 1) the Jonah field, a recent discovery of previously bypassed tight-gas production from the Upper Cretaceous Lance Formation; and 2) the Stratos-1 well site, a horizontal test of the Middle Cretaceous Second Frontier Formation on the western flank of the Rock Springs uplift, where drilling operations were suspended after no significant natural fracturing was encountered during drilling of the initial, vertical, characterization well. Detailed analysis of these areas will likely provide useful insights regarding structural attributes conducive to natural fracture formation and enhanced tight gas production.

The following sections describe the tasks performed during this quarter as part of the GGRB regional analysis effort.

Tasks 1 and 2. Data Acquisition/Processing and Base Map Generation

These tasks require two data types: primary data and ancillary data. Primary data, such as satellite imagery and potential field measurements, will be processed and the analysis will be original work. Ancillary data are collected and from previous publications (e.g., geologic maps) and public domain databases (e.g., cartographic data), and are digitally reformatted and compiled. The integrated analysis of all the data, both primary and ancillary, provides a basis for delineating the structural framework of the basin, an essential part of the effort to partition the greater Green River basin.

The different types of data collected and, where appropriate, the processing procedures applied, are described in the sections below.

Landsat TM Satellite Imagery

Digital Landsat TM imagery was selected to provide the basis for mapping the regional geologic setting and internal structural characteristics of the GGRB. Eight Landsat Thematic Mapper (TM) images were purchased from the Landsat data archive at the US Geological Survey EROS Data Center (EDC). Each TM image covers a 180km x 180km area with a spatial resolution of 28.5 meters. The TM sensor simultaneously measures reflected solar radiation in six discrete spectral bands covering visible to mid-infrared wavelengths, and emitted heat energy in a single spectral band in the thermal infrared.

To maximize atmospheric and radiometric consistency across the area, images were selected to correspond closely in time. Autumn imagery was favored because the moderate sun elevation, and typically low humidity, enhances terrain features.

The TM images are identified by orbital position and acquisition date as follows:

<u>Path / Row</u>	<u>Acquisition Date</u>
35/31	October 03, 1987
35/32	October 03, 1987
36/31	October 10, 1987
36/32	October 10, 1987
37/30	October 27, 1987
37/30	October 01, 1987
37/31	October 01, 1987
37/32	October 01, 1987

The October 27 duplicate of P37/R30 was purchased because a small area of forest-fire smoke appeared on the October 1 image near the southern end of the Wind River Range.

A variety of spectral band combinations was evaluated. The final combination selected was Band 7 (mid-infrared) displayed as red, Band 4 (near infrared) displayed as green, and Band 1 (blue) displayed as blue. In semiarid regions, this band combination usually provides the greatest color variation among soil types and lithologic units. It has the added advantage of providing a "natural" look, in that vegetation appears in shades of green, clouds and snow appear white, and water appears as dark blue. The images in the middle of the basin (Path 36) were interactively enhanced to emphasize geologic and terrain information, using a linear contrast stretch algorithm calibrated to minimize the effects of atmospheric scattering due to dust and haze. Digital histogram matching was performed on the adjacent images (Paths 35 and 37) to provide a consistent appearance across the study area. A standard 3x3 filter was applied to all the images to provide non-directional edge enhancement, effectively sharpening the appearance of fine terrain features and improving the structural interpretability of the final product.

The TM images were digitally georectified by developing a tight network of and image-to-map ground control points (GCPs). All of the GCPs were road intersections. Precise locations of the GCPs were derived using digital cartographic data (1:100,000 scale Digital Line Graph) available from the US Geological Survey. The images were then resampled to fit a Universal Transverse Mercator map projection (UTM Zone 12, North America 1927 datum, Clarke 1866 ellipsoid), using a second-order polynomial transform function with a least-squares linear fit to the GCPs. The controlled images were mosaicked together by picking image-to-image tie points in the overlap areas between images. The final horizontal positioning error of the mosaic was less than 100 meters (rms), with a pixel size of 50 meters.

The mosaic was used to create an image map exhibiting the entire greater Green River basin annotated with standard map information, including latitude/longitude and map grid tick marks, scale bar, north arrow, projection information, image information, state boundaries, and miscellaneous geographic features (Figure 1). The map was printed on heavy bond paper at 1:750,000 scale using a Hewlett-Packard DesignJet 650 large-format color inkjet printer.

Greater Green River Basin

Wyoming - Colorado - Utah, U.S.A.

Satellite Image Map

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Figure 1. Landsat TM satellite image mosaic of the greater Green River basin.

IRS 1-C Satellite Imagery

High-resolution panchromatic image data from the Indian satellite IRS 1-C were obtained to provide greater structural detail for large-scale analyses of the Jonah field and Stratos well site. IRS 1-C images cover a 70km x 70km area with a spatial resolution of 5 meters, measuring reflected solar radiation in a single broad band spanning the blue-green to near-infrared portion of the electromagnetic spectrum. Unlike TM, the IRS panchromatic sensor is "pointable." Images are often acquired with an off-nadir viewing geometry described by the sensor's "tilt angle," or deviation from vertical. Two cloud-free images were purchased from the data archive of the commercial distributor, Space Imaging EOSAT:

<u>Area</u>	<u>Path/Row</u>	<u>Tilt Angle</u>	<u>Acquisition Date</u>
Jonah Field	256/039	-25°	October 21, 1996
Stratos-1 Well Site	256/040	+25°	March 19, 1996

Ideally, these images would have both been acquired in autumn, with a near-zero tilt angle, to better correspond with the illumination and geometric characteristics of the TM imagery. However, the IRS data archive is sparse for this area, and cloud cover was the determining factor for selecting the images.

The IRS images were georectified by picking image-to-image tie points with the controlled TM imagery, and digitally resampling to match the tie points using a second-order polynomial transform function with a least-squares fit. The final horizontal positioning error, relative to the TM mosaic, was less than 10 meters (rms).

The rectified images were contrast-enhanced and filtered to sharpen terrain detail. The IRS images were digitally merged with the full-resolution (28.5 meters), georectified TM imagery, using a cubic convolution model that multiplied the IRS and TM pixel values and rescaled the result. The merged product incorporates the spectral information contained in the TM imagery with the superior high-resolution terrain detail of the IRS imagery, providing an excellent dataset for surface geologic analysis at mapping scales recently limited to aerial photography.

Image maps were made for the Jonah and Stratos sites that correspond to their respective USGS 7.5-minute topographic quadrangles, "Stud Horse Butte" (Figure 2) and "Clay Buttes SW" (Figure 3). The maps were printed at 1:24,000 scale.

Potential Field Data

Basement structural analysis is a critical part of Advanced Resource's integrated basin evaluation technique. Basement composition and topography are revealed by measurements of the magnetic field intensity. For this study, we obtained gridded aeromagnetic residual data from the USGS. These data have a grid spacing of

Figure 3. TM / IRS merge image map of the Stratos-1 well site.

2 kilometers. We digitally reprojected the data to fit the map projection used for this project (UTM, Zone 12, NAD27), and color-coded the data to enhance abrupt gradients in the magnetic field strength (Figure 4). Such gradients indicate the approximate position and trend of significant structural and/or compositional boundaries in the basement. The color-coded aeromagnetic data were used to create a 1:750,000 scale mapsheet to match the TM mosaic.

Gravity field data also reveal important subsurface information. As with magnetic field strength, abrupt gradients in topographically corrected, isostatically compensated gravity measurements indicate significant regional structures that have juxtaposed rocks with contrasting densities, or caused by major vertical offset in crystalline basement. We obtained 2-kilometer gridded isostatic gravity field data from the USGS, and reprojected and color-coded it as we did the aeromagnetic data (Figure 5). A 1:750,000 scale mapsheet of the color-coded gravity data was created.

Other Data

Digital Line Graph (DLG) data, produced from 1:100,000 scale USGS topographic maps, were acquired for the study area. These data included transportation routes (roads, railroads, airports, pipelines, power lines), hydrography (lakes, reservoirs, rivers and streams), administrative boundaries (state and county boundaries, public lands), and the public land survey system grid (township and range). These data were used to extract GCPs for georectifying the imagery, and to provide informative reference annotation for various map products, including a complete base map of the GGRB (Figure 6).

A database of well locations, production and completion information was derived from the latest Petroleum Information (PI) / Dwight's data CD-ROM for the northern Rocky Mountain region. Wells were included if they were located within any of the counties underlain by the greater Green River basin, as delineated by the USGS. Well information will be used to correlate structural findings, based on the image and aeromagnetic data analysis, with patterns of production and reservoir characteristics across the basin.

Several basinwide geologic datasets were incorporated into the database, derived from maps obtained from the USGS central map library in Reston, Virginia. These datasets include structural contours, compiled from various stratigraphic horizons (Figure 7); major fold axes and basin-margin fault systems (Figure 7); boundaries of oil and gas fields (Figure 8); and heat flow (contours showing depth to 180° F) (Figure 9).

A detailed structural map was obtained for the Jonah field from a journal article (Warner, 1997). Structural contours (top of Lance Fm.) and faults were digitized from this source (Figure 10).

Figure 4. Aeromagnetic anomaly map of the greater Green River basin.

Wyoming - Colorado - Utah, U.S.A.

Isostatic Gravity Residual Map

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Figure 5. Isostatic gravity anomaly map of the greater Green River basin.

Figure 6. General location and reference base map of the greater Green River basin.

Figure 7. General structure map of the greater Green River basin.

Figure 8. Gas field map of the greater Green River basin.

Figure 9. Heat flow map of the greater Green River basin.

Task 3. Structural Analysis

Basinwide structural analysis was performed to determine the variations in structural settings and styles, as the underpinning for developing a framework that would partition the basin into discrete structural blocks. The ideal approach is to integrate regional surface mapping with subsurface and basement structural information, to find structural indicators that correspond throughout the stratigraphic column. Such correspondence reveals basement-involved structures that have been persistently active throughout basin formation and deformation. These structures can exert profound influences on depositional and diagenetic facies patterns, local tectonics, stress, and fracture distribution. Once the structural analysis has been performed, production and reservoir properties from well data can be integrated with the structural framework to identify key basin features that influence natural gas production.

Satellite Image Analysis

Regional surface mapping was performed using the TM mosaic displayed at full screen resolution (~1:150,000 scale). Major surface folds were noted, but the structural mapping focused on identifying faults and fractures. On satellite imagery at this scale, faults and fractures are manifested by linear geomorphic features, or "linears": distinct, non-cultural, straight-line elements of the land surface that are revealed by abrupt variations in color, brightness, and/or texture on the imagery. Advanced Resources employs a strict geomorphic criteria to identify linears. Linears were mapped on-screen using the following classification scheme:

- Straight drainage = straight river or stream segments carrying flowing surface water.
- Straight erosional features = straight dry valley segments, washes, and rills.
- Straight scarps = straight escarpments; very closely spaced, aligned cliffs and notches.

To minimize confusion with cultural constructs, no linears smaller than 1000 meters (7.5 millimeters at 1:150,000 scale) were mapped. After the initial round of mapping, a complete second round of verification was conducted for quality control by overlaying DLG information (transportation and boundaries) to eliminate any remaining features with probable human origin (Figure 11).

The next phase of the image analysis required carefully examining the spatial distribution of linear features to identify geomorphic alignments that are regionally continuous expressions of aligned linears. Geomorphic alignments are broad belts of aligned and/or closely spaced linear features that represent important structural trends. In our experience, alignments of scarps are likely to result directly from faulting; erosional features are generally smaller and less continuous than the other two classes of linears, and tend to reveal regional fracture trends. Important deep-seated structural boundaries often exhibit alignments of all feature types.

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Figure 11. Linear geomorphic features analysis of the greater Green River basin.

Jonah Field

Linear geomorphic analysis, as described in the preceding section, was conducted for the Jonah field area using the high-resolution Landsat/IRS merge imagery corresponding to the Stud Horse Butte topographic quadrangle. Mapping was done on-screen at 1:18,000 scale (Figures 12 - 14).

At this scale, new features are mapped that do not appear clearly on the regional Landsat imagery alone. We believe these features more closely represent the actual surface traces of individual fracture planes; whereas features mapped on TM represent locally concentrated fracture sets, which may comprise individual fractures having different orientations than the observable feature. For this reason, the linears derived from basinwide analysis of the TM are considered complementary structural information to the linears derived from the high-resolution imagery.

Potential Field Analysis and Integration

Both the gravity and the aeromagnetic datasets were interpreted to discern gross basement structure (Figures 4, 5). Steep gradients in the potential field data, caused by abrupt changes in basement composition and/or topography, indicate the presence of important basement faults or shear zones. Correlation between geomorphic alignments from the satellite imagery, and steep gradients in the potential field data, reveals persistent basement structures that influence surface geomorphology and, by inference, other physical properties throughout the intervening rock column. These important trends can comprise the boundaries of distinct structural blocks that exhibit differing fracture patterns, partitioning the basin into discrete exploration and development domains.

Once the significant geomorphic alignments were delineated, they were overlain on the color-coded aeromagnetic residual and isostatic gravity data for direct comparison with the delineated potential field gradients. Preliminary structural boundaries were determined from close correspondence between the surface and basement features. These boundaries will be progressively refined as the analysis proceeds.

Future Work

Well data will be analyzed to provide quantitative assessment of variations of key reservoir characteristics, EUR, and production patterns, both basinwide and within the Jonah field area. Structural partitions will be compared with this information to refine the primary structural boundaries, provide a final structural framework, and determine the relative importance of observable structural features for determining reservoir quality. Within structural partitions, the orientations of geomorphic linear features will be statistically described using conventional rose diagrams to infer the principal stress field orientation for each partition.

Figure 12. Detailed linear geomorphic features analysis of the Jonah field area.

Figure 13. Geomorphic alignments map of the Jonah field area.

Figure 14. Structural trends inferred from geomorphic alignments in the Jonah field area.

Additional detailed studies of individual fields will be conducted using high-resolution imagery and magnetic field measurements. These detailed studies will provide critical information regarding structural styles and effects on production within some of the structural partitions.