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Naturally Fractured Tight Gas Gas Reservoir Detection Optimization

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Quarterly Status Report

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Quarterly Status Report

CONTRACT NO.:

DE-AC21-93MC30086

CONTRACTOR:

Advanced Resources International, Inc.
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CONTRACT NAME:

Naturally Fractured
Tight Gas Reservoir
Detection Optimization

CONTRACT PERIOD:

07/01/97 – 09/30/97

CONTRACT OBJECTIVE: No change.

TECHNICAL APPROACH CHANGES: No change.

FIELD PERFORMANCE TEST PLAN:

The previous report provided a detailed summary of the work to date on the project at the Rulison field. Key to this report was the finding that the regions where wells showed good EURs were spatially associated with faulting. Specifically, areas considered more permeable due to the presence of natural fractures are generally located in the high-side (footwall) of reverse faults. While this association seems to hold in the Rulison seismic data coverage, this association requires corroboration. Thus the work plan for the quarter of July 1, 1997 – September 30, 1997 consisted of three tasks:

1. Perform detailed fault mapping of Rulison 3-D seismic data with Barrett Resources,
2. Review SOCO 2-D seismic fault mapping and structural interpretations,
3. Initiate work into developing a predictive method for locating fault-related natural fractures.

The first two tasks were initiated and completed during this reporting period. The work involved required a collaborative effort between the field operators and ARI staff. The third task marks the beginning of quantitative fracture mechanics analysis of the geologic processes that are involved for the development of fault-related natural fractures. The goal of this work is to develop a predictive capability of locating natural fractures prior to drilling.

TASK 1. Detailed fault mapping of Rulison 3-D seismic

Background

Recent advances in understanding the genetic relationship between faults and the natural fracture system in the Rulison field (see previous quarterly report) provide the impetus to map the fault geometry as accurately as possible. Detailed fault mapping is possible due to the high quality of the 3-D seismic data collected over the field by Western Geophysical. Advanced Resources International began an in-house effort to map these faults using the SeisVision software package. The intent of this task is to provide as much information on the small reverse faults found within the survey in a well-documented manner. ARI's analysis will be compared with Barrett Resources' interpretation. This comparison will help remove any interpretation that does not pass review and strengthen the final mapping. This information will be the basis for close comparison with EUR mapping.

Fault mapping Rulison 3-D seismic data

The N150E azimuth 3-D seismic data over the Rulison field, **Figure 1**, was imported by ARI into SeisVision from the SEG-Y format delivered by Western Geophysical. No enhancements were necessary with this high-quality data. The criteria for fault mapping were to map only the observable offsets of distinct horizons thus reducing ambiguity in the interpretation. In addition, horizons marking the tops of Mesaverde, "top of gas saturation," SS2, Cameo, Rollins, and Dakota were picked. The time/structure maps were useful in demonstrating the relative displacement across the fault systems, their vertical extent, and the orientation of the fault.

A number of reverse faults were identified in the survey that trended NW and dipped to the NE. The prominent fault in terms of offset, labeled NW2, enters the survey from the southeast and terminates to the NW within the survey. The fault decreases dip as it cuts up section to when it terminates near the SS2 horizon in the sands above the Cameo, it dip nearly 30°. Offsets are small across the fault with the largest amount of offset occurring in the Cameo Coal section. **Figure 2** shows how the fault cuts up into the Cameo section where it is nearly vertical and terminates near the SS2 horizon. Time structure maps show the westward translation of the fault as it cuts up section.

Figure 1. Location of 3-D seismic data over Rulison field. A-A' marks location of seismic profile in Figure 2.

Figure 2. Southwest to northeast seismic profile showing prominent NW2 reverse fault.

Beginning with the Rollins time-structure map, **Figure 3**, the NW2 fault can be observed as entering the survey from the southeast in section 22 and terminating to the northwest in the southeastern corner of section 16. At the Cameo horizon, the other prominent faults are now apparent in the time-structure map, **Figure 4**. The NW2 fault now cuts the northeastern corner of section 21—a westward translation of approximately $\frac{1}{4}$ of a mile. The NW2 fault shows both reverse and lateral displacement. A time-slice of the 3-D seismic data at the Cameo horizon distinctly exhibits left-lateral offset, **Figure 5**. The other prominent faults appear at this level. The NW1's lower terminus appears in the southwest corner of the survey. This reverse fault apparently initiates in the Cameo coal section, dips to the northeast and continues into the Williams Fork sequence beyond the survey. To the North, the NW3 fault appears. The fault enters the survey boundary at a low angle (approximately 30°) and its initiation point, either in the Cameo coals or deeper, occurs north of the survey's boundary.

Fault NW2a is a splay off the main NW2 fault. It too shows reverse motion and trends northwest, but it dips to the southwest and initiates at the NW2 fault in the Cameo coals. Between the NW2a splay and the larger NW2 fault is a pop-up structure, **Figure 6**. This structure is the only region in the 3-D survey where the Cameo horizon is folded into a small anticline parallel to the NW2 fault.

At the SS2 horizon, a constant reflector that probably relates to the coastal sands in the lower Williams Fork member, little deformation associated with the reverse faults is evident, **Figure 7**. From that horizon upwards, no faulting was observed. The only observable seismic attribute that may be related to deformation in the Williams Fork sandstone is the amplitude dimming of the reflected signal in the southwestern part of the survey.

Other numerous possible small faults can be observed in the Cameo coals. Alternatively, the offsets may be due to stratigraphic pinch-outs, also a common occurrence in the coal section. Below the coals, the signal weakens and no obvious faults were mapped. The reflection of the Dakota is

Figure 3. Time-structure map of the first coal above the Rollins horizon. Note that the only the NW2 fault penetrates this horizon.

Figure 4. Time-structure map of the Cameo horizon. At least four faults cut the horizon with most terminating within the coal beds (NW1, NW2a, NW3). B-B' is location of profile in Figure 5.

Figure 6. Time-slice map at 1.23 seconds, near the Cameo horizon. Note lateral offset at NW2 fault due to both reverse and left-lateral motion across fault.

Figure 5. Southwest to northeast seismic profile showing NW2a splay of NW2 reverse fault and associated pop-up structure between faults.

Figure 7. Time-structure map of the SS2 horizon. Note that the expression of the NW2 fault is almost gone as fault terminates at this horizon.

apparent antiform developed in the Dakota, **Figure 8**, and this structure may have had an influence in locating the deformation in the Cameo coal sequence.

Review of fault mapping with Barrett

The fault mapping performed by Advanced Resources was then compared with Barrett Resources' mapping of the 3-D volume. There was very close agreement on the geometry of major reverse faults. The main difference between the two interpretations is that the Barrett interpretation included many of the smaller faults in the Cameo coal sequence. Notably, Barrett mapped a small low-angle splay of the NW2 fault that dipped to the northeast and terminated before the top of the Cameo coal, **Figure 9**.

TASK 2. Review Snyder Oil's 2-D seismic structural interpretations

Background

The Mamm Creek area east of Rulison field has also been producing gas from the Williams Fork member of the Mesa Verde group, though at shallower levels and lower rates. Snyder Oil Company (SOCO) is the main operator of the field and they agreed to collaborate with ARI in re-examining their seismic data in light of our new understanding of fault-related natural fractures. The 2-D seismic data purchased by SOCO is of various vintages, all of which is proprietary. All examination of the 2-D seismic data by ARI was performed within SOCO's offices in Denver and due to license constraints, we cannot reproduce the data in this report.

2-D fault mapping in the Mamm Creek area

The structures in the Mamm Creek area are much more pronounced than those discovered in the Rulison field with the 3-D seismic survey. Again, most of the faults are reverse, northwest-trending and dip to the northeast, **Figure 10**. At the Rollins horizon, two major faults cut up through the Cameo coals. The most easterly fault bisects the main part of the field and extends from section 36 of T7S-R92W to section 25 of T6S-R93W. Just to the west, a second reverse fault occurs and extends from section 24 to section 4 of T7S-R93W. The displacement across these faults is small, around 50

Figure 8. Time-structure map of the Dakota horizon. The horizon shows a subtle northwest plunging antiform. The eastern edge of the antiform is directly beneath the NW2 fault and may have influenced the fault's development.

Figure 9. 3-dimensional display of mapped faults in the Rulison field. Note series of small splay faults in front (southwest) of Nw2.

Figure 10. Map of the Rulison-Mamm Creek area showing the distribution of faulting. Time-structure contours around Mamm Creek are at Rollins horizon.

milliseconds. Moving west and away from the Divide Creek structure, the displacements across the faults diminishes. This is evidenced by the two most westerly faults observable on SOCO's 2-D data set. One is observed on a single seismic line at section 6 of T7S-R93W and therefore its extents are unconstrained. The westernmost fault observed extends from section 11 of T7s-R94W to section 18 of T7S-R93W and shows displacements on the order of 25 milliseconds(close to resolution of data).

The 2-D data shows a relatively distinct basement reflection and a number of breaks can be observed in this horizon. The basement faults appear to be reverse faults that dip to the northeast and are most likely northwest-trending. The reverse faults that cut the Cameo section, however, are laterally displaced from basement faulting and are not directly related to basement structure.

Comparison of production and fault location at Mamm Creek

A review of the spatial correlation between production (EURs) and the location of faulting yields similar results to that in the Rulison field. The wells with the highest EUR values tend to be located in the footwall (southwest) of the reverse fault systems, **Figure 11**. Thus the fault-related natural fracture affinity occurs in a broad region in this part of the southern Piceance basin.

TASK 3. The Prediction of Fault-related Natural Fractures

From the evidence presented here and in previous reports, Advanced Resources advocates the importance of local natural fracture development in the formation of permeable "sweet-spots" in the Williams Fork reservoir of the southern Piceance basin. This differs from previous investigations in the area that concentrated on understanding the regional natural fracture system. While the presence of a regional fracture system does provide a baseline permeability for an area, it seems that the presence of another set of local natural fractures, which may be oriented obliquely to the regional set, provides the important boost in permeability due to increased density and connectivity of the overall system. Till recently, geologist have despaired over locating local sets of natural fractures prior to drilling thinking that they are "random" occurrences. The spatial

Figure 11. Map of the Mamm Creek area showing the wells with high EURs located in the footwalls of reverse faults (southwest of faults).

association between natural fracture development and faulting, however, provides a means to the prediction of local “sweet-spots” in low-permeability reservoirs.

The mechanics of rock deformation can provide a quantitative assessment towards locating the development of natural fracture due to local deformation. It has been well demonstrated in the laboratory, theory, and field observations that secondary structures such as natural fractures accompany local deformation such as faults. The mechanical explanation of this phenomenon is that deformation generally initiates at regions where the local stress field is elevated beyond the regional. These stress concentrations (also called stress perturbations) can be theoretically calculated given the remote stress field, fault/fold geometry, and displacement of the local structures. Simple relationships have been investigated numerically by either boundary element or finite element analysis. In the last decade, significant advances have occurred in the field of numerical analysis and modeling of geologic deformation, principally the development of three dimensional capability.

Advanced Resources plans to investigate this opportunity by using a public-domain 3-D boundary element program and applying it to the situation found at the Rulison field. In the initial stages of investigation, we do not intend to change the public domain code but concentrate on developing a methodology for capturing the appropriate input information from the seismic survey and comparing the output of the program to reservoir permeability calculated from production history. Before delving into this opportunity, Advanced Resources first intends to present the results of the Rulison field study at various conferences and meetings with operators. The feedback from these technology transfers will help assess the industry interest in such an attempt.