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Naturally Fractured Tight Gas Reservoir Detection Optimization

Quarterly Report
July 1 - September 30, 1994

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For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
P.O. Box 880
Morgantown, West Virginia 26507-0880

By
Advanced Resources International, Inc.
1110 North Glebe Road
Suite 600
Arlington, Virginia 22201

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U.S. DEPARTMENT OF ENERGY
MORGANTOWN ENERGY TECHNOLOGY CENTER
QUARTERLY STATUS REPORT
FOR THE PERIOD
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CONTRACT NO.:
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CONTRACTOR:
Advanced Resources International, Inc.

CONTRACT NAME:
Naturally fractured tight gas reservoir detection optimization

CONTRACT PERIOD:
September 30, 1993-March 31, 1997

CONTRACT OBJECTIVE: No Change

TECHNICAL APPROACH CHANGES: No Change

TASK NO. 1:

A. SUBCONTRACTS

Indiana University:

Indiana University:

Two primary tasks have occurred during this quarter. The first involves data collection necessary to calibrate and confirm the numeric model, and the second involves the creation and debugging of computer code necessary for the simulation/modeling effort.

1) DATA COLLECTION FOR MODEL VERIFICATION

A. A continuing task is organization of published and publically-available data on fractures, textures and sedimentology in the Piceance Basin and the development of protocols for

data management. These data will be required for basin simulator input and comparison with geologic observations and interpretations previously performed in this region at the MWX site. A search is also in progress for a modern analog to be used to determine the starting conditions for the model. A search and review of all modern fluvial environments is occurring and will continue for several months to determine the range of mechanical and chemical parameters suitable for a model starting point.

2) NUMERICAL MODELING

A. Two-dimensional basin simulator: Priority has temporarily shifted from solute transport (which remains partially complete) in the CIRF.B2 code, to implementation of a fracture model. The fracture model will allow release of fluid pressure via hydraulic fracturing, by simulating the corresponding changes in matrix permeability and fluid velocity. Phenomenology for authigenic mineral nucleation has been implemented in the code and is currently being tested. A subroutine has been added that accounts for mechanical grain rotation as the grain aspect ratio changes; this allows enhanced grain dissolution at the grain free-face compared to the vertical grain surfaces. This subroutine is nearly completed and is currently being fine-tuned. Work has also commenced on the next generation of the textural model that allows interaction between minerals of difference species; the current model assumes that all grain interaction occurs between grains of the same mineralogy.

B. Three dimensional basin simulator: Work continues on increasing the numerical precision and integrity of the pressure solver. A method for direct calculation of pressure, instead of overpressure, was attempted and abandoned because of numerical difficulties. Coding and testing of the energy balance equation for calculating temperature and the boundary conditions (notably imposed heat flux from below) have been completed. Problems remain in the implementation of the finite difference stress solver. For contacts between units in which the textural differences are gradational, it is fully operational. For sharp contacts, the local error in calculated stress can be greater than the vertical change in stress between adjacent grid points. The current effort is attempting to develop a strategy that both reduces computational error and smoothes the numerical noise introduced by the error. A smoothing algorithm has been developed that reduces noise but that preserves key properties of the solution, notably local force

balance and boundary conditions. Work continues on the finite element stress solver; the elastic module is coded and being tested. A viscoelastic module is currently being developed. Debugging and testing should be completed in the next month. The sediment input module is complete. Lateral data interpolation (X and Y directions) for subsidence, sedimentation rate, and mineralogy is completed and will soon be completed for input sediment texture in the next month. Implementation of a fracture model has begun. This model includes propagation, extension and healing history of the fractures.

C. Data analysis and database: All petrographic data for the MWX site have been entered into the Excel database. Thermal histories for sixteen sites (Sandia National Labs and the U.S.G.S.) have been developed from published burial histories. Data are being evaluated to determine if calculated thermal histories appropriately match temperature gradient maps and vitrinite reflectance data. Thermal conductivity data for ten different rock types at the MWX site have been collected and will be used to calibrate the relation between texture and mineralogy with thermal conductivity. A database manager has been chosen for a trial period, to determine if it suits the needs of the project. Work is progressing on an interface that will make the use of CIRF.B* codes easier. This interface is approximately half-finished.

D. Organic reactions and multi-phase flow: The strategy developed for aqueous fludi-gas (biphase) flow has been implemented and added to the three-dimensional pressure solver. Work has begun on solving mass balance and chemistry of the gas-water system. In particular, a code is being developed to determine the gas saturation. Ths initial program will intially allow only water and gas to occupy the gas phase.

D. Grid optimization: The grid optimization technique for a two-dimensional grid with regular boundaries has been completed. The technique has been generalized for problems with irregular boundaries and work continues on coding and testing.

World Geoscience:

DOE approval of the NEPA assessment and the World Geoscience aeromagnetic flyover subcontract has been completed. Flight commencement is planned for early October 1994. Because existing digital data is available for the overall basin (flown with 1 mile spacing with 3 mile tie-lines), we have chosen a subset of the basin for our higher-resolution survey to be flown.

The existing, lower-resolution aeromagnetic map for the basin will be used as a basemap to which the enhanced data set will be added. The proposed survey will be flown at a 400 meter spacing with 1600 meter ties. (1/4 mile spacing with 1 mile ties). This higher resolution will permit us to more precisely define the subsurface structure as defined by magnetic information.

B. GEOLOGIC ASSESSMENT OF THE PICEANCE BASIN

Research for the first part of the fourth quarter completed the assessment on the geometry of the gas and water-saturated zones for the Williams Fork and Iles Formations in the basin. This work was presented in the form of a poster session at the AAPG Annual meeting held in Denver in mid-June. ARI presented a poster session outlining the nature of the gas-centered basin geometry and demonstrated the gas and water-saturated conditions for the Williams Fork, Cozzette and Corcoran reservoir horizons throughout the basin. Intitial and cumulative production data indicate that these reservoir horizons are gas-saturated in most of the south-central and eastern basin. The primary conclusion of the presentation was that development of this resource base in the central and eastern basin is dependent on the presence of adequate fracture permeability.

To assess the nature of the gas and water-saturated intervals, all publically-available hydrocarbon (mud) logs from throughout the basin were collected and the location of the gas-saturated zone was determined. From a subset of these logs, a cross-section across the basin was constructed by digitizing the total gas curve and the gamma log trace. The combined gas and gamma log traces for wells extending across the basin were hung on a structural datum to illustrate the basin geometry. Relevant information such as the location of the overpressured zone, stratigraphic correlations and vitrinitite reflectance values (isotherms) were added to the section.

To assess gas and water-saturated conditions, gas-saturated conditions were initially recognized by the presence of gas fields producing from that particular reservoir horizon. This was confirmed by verifying the presence and magnitude of gas shows in mud logs from that area. Mud logs are preferable to neutron density logs because the so-called "gas effect" or neutron cross-over is not always present in gas-saturated zones in the Piceance Basin. Numerous examples were found where significant gas shows were observed on the hydrocarbon log and the

neutron density log did not show any crossover effect. Because of this, the cross-over effect was not used. Operators in the region (e.g. Barrett Resources) have found similar relationships in their work.

Water-saturation was determined by using initial production data (generally determined by most operators after approximately 6 months of flow to remove load or hydraulic fracture water returns from production information) and flagging all wells in the basin showing greater than 5 barrels of water per day. The production data for these producers were then examined to determine if the wells flowed more than 10 BWPD. From this information, the boundaries of the gas and water-saturated zones were delineated. Because many areas show complex water production, those areas with increasing water production over time were labelled as transitional. Future work will attempt to determine if water production is controlled by fracturing and/or the source of water in the basin. Examples of this complexity are found in Rulison field where most Cozzette sandstone wells show large amounts of associated water production. This appears to be especially true for horizontal wells. More recently (1994), Barrett Resources has completed a horizontal well that is neither gas-bearing nor water producing. This is in an interval in which adjacent wells produce large gas volumes and associated water. Resolution of this problem and complexity will have tremendous importance for gas producers in this region and will have profound implications for subsurface geometry and the connectivity of fractures in the basin.

Research effort continued on creation of a new structural map of the southeastern Piceance Basin to update the earlier work of Johnson (1983). This new map contains updated structural data obtained during the past ten years of exploration and development drilling. This map area expands the Parachute-Rulison area to better define regional trends. In addition, it serves to fully delineate the NW-trends in the eastern basin. In the process of making this map for the top of the Rollins Sandstone member of the Iles Formation, additional stratigraphic picks were made for the Cozzette and Corcoran members and for the top of the Mesaverde Group. The collection of this additional data will allow us to contrast the differences between structural datums and will provide insight into the structural evolution of the basin. The top Mesaverde (Cretaceous-Tertiary unconformity boundary) will be especially informative because it has not been previously studied with as much well control as we have for this area. The planarity of this surface and its suitability as a structural datum will be more fully documented as a result of our

work. Preliminary maps of these surfaces are attached. Work in progress is revising these maps to eliminate sources of error from incorrect kelly bushings, incorrect stratigraphic picks and other problems. It is estimated that final versions will be completed by the end of October. In addition the collected data will allow isopach/isochore maps to be made of the Corcoran, Cozzette, Rollins and total Mesaverde Group package. These maps can be used to determine depositional systems evolution for each of these various intervals.

A fortuitous additional benefit realized by this mapping was the ability to completely update our existing computer databases, merge various data sets to create a unified system available for basin analysis. In the process, extensive error checking was performed to insure data accuracy and database integrity.

Well test and production data from Parachute and Rulison fields have been analyzed to determine the effectiveness of hydraulic stimulations used by the various operators (Barrett Resources, CER, Northwest Exploration) in the two fields. Work in progress is attempting to delineate the reason for the variable effectiveness of the stimulations and the controlling geologic influences.

Geochemical data from throughout the Piceance Basin was purchased at reasonable rates from commercial sources to verify the gas-centered basin hydrocarbon model proposed in the AAPG poster session. Work in progress is determining significant regional trends for the various geochemical species.

Production, well completion and drilling information from Grand Valley field have been collected in order to evaluate how production trends from Parachute-Rulison area extrapolate into this area. Work in progress is generating maps of the relationship between subsurface structure and production trends. This information, in what is thought to be another fractured reservoir, will allow us to contrast the differences between production in the overpressured zone (Rulison field), from the transitional areas (Parachute field), to the normally-pressured zone (Grand Valley field). This transition is also accompanied by slight changes in structural intensity that may or may not correspond to production variability.

Detailed mapping of the southwest Piceance Basin (Debeque area) in Plateau and Shire Gulch fields is underway to determine the geometry of subsurface structure in this area. This region serves as a contrast to the Parachute-Rulison area because available data indicate the

reservoirs are fractured. The subsurface structure, however, trends nearly E/W instead of the WNW and NW-trends observed along the eastern half of the basin. Detailed photogeologic interpretation of this region has also been started in order to contrast the two regions.

Preliminary efforts on a regional wellbore breakout map to elucidate the geometry of present-day stress in the basin has commenced. Approximately 25 logs were collected from throughout the basin. These logs will need to be digitized for computer-based analysis of wellbore ellipticity prior to creation of the modern stress map. Contact will be made with regional operators to add additional data to the set before additional efforts will be made on this task.

Additional ancillary data has been collected on the geometry and sedimentology of the Cameo Coal Group throughout the basin. This information is essential to our understanding of thermal maturity information and modeling performed on the coals in this interval.

C. Remote Sensing Interpretation

Remote sensing data interpretation is proceeding with analysis of TM data from throughout the basin. This interpretation has been completed and final review and interpretation is in progress. Additional detailed interpretation is being performed in the western basin in the Debeque Canyon-Shire Gulch areas.

Additional work has resulted in the development a Monte Carlo computer simulation to determine the level of statistical signficance of various lineament orientations. The output from this simulator has been put into a spreadsheet format to allow ready manipulation of lineament data files. The graphical output of this program allows rapid comparision and recognition of significant regional trends. Future efforts will attempt to modify this statistical algorithm to allow length-weighted determination of statistical significance instead of using only the orientation-based Monte Carlo simulation that we have already developed. It is possible that we may be able to link the two parameters (orientation and lineament length) for a combined measure of statistical significance (i.e. a true length-weighted orientation statistical measure). This technique would permit a means of combining the significance intervals resulting from the two methods.

D. REVIEW OF REGIONAL LITERATURE

Additional references of topical importance were collected this quarter with particular emphasis on regional syntheses of western Colorado geology, mechanics of fractured sandstone reservoirs and methods of determining regional stress magnitudes. Future literature review will continue along topical lines.

E. FIELD TRIPS AT AAPG MEETING:

Two members of the ARI staff and two members of the Indiana University Subcontractor Group attended field trips in the Piceance Basin. Peter Blomquist (ARI), John Comer and Dorothy Payne (Indiana Geological Survey & Indiana University, respectively) attended a pre-meeting field trip led by Ron Johnson of the USGS-Denver. This trip provided an excellent overview of structural and stratigraphic patterns throughout the Piceance Basin. In addition, numerous operators attended this trip and provided useful opportunities to interact with gas producers in this region.

Lateral variations of the Mesaverde sandstone members were examined in many outcrops during several localities around the basin perimeter. A trip stop at the closed adit of the Fruita Coal Mine showed the stratigraphic relationship of the Cameo Coal and the Rollins Sandstone and the laterally discontinuous nature of the Rollins Sandstone. Structural aspects of the basin were emphasized during stops at Rifle Gap, Douglas Pass, Rangely, and White River Dome. The influence of structure on lithologic and thickness variations in the Mesaverde Group and Tertiary Wasatch Formation were also the focus of discussion at Douglas Pass. The relationship between structure and gas accumulations was outlined during presentations at the Grand Valley-Rulison-Parachute and White River Dome gas fields, by geologists from Barrett Energy and Fuelco, respectively. The structural influence at Grand Valley Field is permeability enhancement by fracturing, whereas at White River Dome Field, gas is trapped within fractured, structural closures.

Oil shale was also discussed and formed a secondary focus of the field trip. Relevant stops were made at the New Paraho Corporation facility to hear about their new asphalt additive, SOMAT. Additional discussions were held at the headframe of the Cathedral Bluffs oil shale mine, and at several oil shale outcrops throughout the basin.

The field trip was well attended by approximately 28 people. These attendees represented a variety of oil companies, consultanting firms, and government agencies. The oil companies represented included Amoco, Barrett Energy, Chevron, Fuelco, Legacy Energy, Oxy USA, Stewart Petroleum, and Texaco. The trip provided an exceptional opportunity to familiarize many of these operators with the DOE-METC Fracture Detection Program. In addition, the trip allowed ARI and Indiana University attendees to learn the objectives of these operators and become aware of their problems and concerns in development strategies in this region.

Following the meeting, Thomas Hoak (ARI) and Dorothy Payne (Indiana University) attended a field trip led by John Lorenz and Larry Teufel (both of Sandia Laboratories) on fracture geometries and evolution in the Piceance Basin. This trip commenced by examining fractures in the the Wasatch, Williams Fork and Iles Formation in outcrop along the Grand Hogback at Rifle Gap. The trip then went to the MWX site for a detailed discussion of results obtained there and a examination of core. Terry Barrett of Barrett Resources (the operator associated with ARI in the fracture detection program) presented a detailed analysis of Parachute and Rulison fields and exploration methodologies used by Barrett Resources in tight gas fractured reservoirs. The overall conclusion of Barrett Resources is that fracturing (probably controlled by basement features) is the key to development of efficient exploitation strategies. The primary obstacle lies in being able to predict the density and orientation of subsurface fractures.

The second day of the trip looked at fracture patterns in the Debeque Canyon (Debeque Anticline) area in the western basin. This overview was followed by examination of fracturing in the Colorado National Monument outside Grand Junction. The dominant WNW fracture trend seen in the eastern half of the basin shifts orientation to a near E/W trend. The reason for this is presently unclear. Overall, the concensus was that a major shift in structural domains occurs in the basin center. The aeromagnetic flyover will more closely address this transition zone.

Overall, the trip was quite good, particularly as it allowed significant feedback and discussion between the numerous fracture experts attending the trip. In addition, the trip provided the opportunity to explain the methods and objectives of the DOE-METC fracture detection program to other outside specialists and obtain their suggestions for improving the overall project strategy.

OPEN ITEMS: None

SUMMARY STATUS AND FORECAST

Proposed future work will address the present-day stress orientations in the basin by analysis of wellbore breakouts from throughout the basin. In addition, a water chemistry study is being conducted to more precisely delineate the subsurface flow and geochemical evolution of formation waters. Work continues on a regional structure map. In addition, analysis of remote sensing imagery will conclude shortly and integration of this interpretation with other data sets will continue until the end of the calendar year. Field verification of significant linear trends will occur in October.

Additional effort by the subcontractors will address the subsurface basin structure as revealed by aeromagnetic data. Numerical modeling of the basin geochemical and mechanical evolution is proceeding as planned. Determination of suitable model input parameters has been completed. At this time, a completed database of measured present-day parameters has been compiled to verify the program output.

A. David Decker, Project Manager