Final

GEOLOGICAL AND PETROPHYSICAL CHARACTERIZATION OF THE FERRON SANDSTONE FOR 3-D SIMULATION OF A FLUVIAL-DELTAIC RESERVOIR

(Contract No. DE-AC22-93BC14896)

TECHNICAL PROGRESS REPORT

Submitted by

Utah Geological Survey
Salt Lake City, Utah 84109
July 28, 1995

Contract Date: September 29, 1993
Anticipated Completion Date: September 29, 1996
Government Award (fiscal year): $ 1,225,482
Program Manager: Thomas C. Chidsey, Jr.
Principal Investigator: M. Lee Allison

Contracting Officer's Representative

Robert Lemmon
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Reporting Period: April 1 - June 30, 1995

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Objective

The objective of this project is to develop a comprehensive, interdisciplinary, and quantitative characterization of a fluvial-deltaic reservoir which will allow realistic inter-well and reservoir-scale modeling to be constructed for improved oil-field development in similar reservoirs world-wide. The geological and petrophysical properties of the Cretaceous Ferron Sandstone in east-central Utah will be quantitatively determined. Both new and existing data will be integrated into a three-dimensional representation of spatial variations in porosity, storativity, and tensorial rock permeability at a scale appropriate for inter-well to regional-scale reservoir simulation. Results could improve reservoir management through proper infill and extension drilling strategies, reduction of economic risks, increased recovery from existing oil fields, and more reliable reserve calculations. Transfer of the project results to the petroleum industry is an integral component of the project.

Summary of Technical Progress

Technical progress this quarter is divided into regional stratigraphy, case studies, stochastic modeling and fluid-flow simulation, and technology transfer activities. The regional stratigraphy of the Ferron Sandstone outcrop belt from Last Chance Creek to Ferron Creek is being described and interpreted (Fig. 1). Photomosaics and a database of existing surface and subsurface data are being used to determine the extent and depositional environment of each parasequence, and the nature of the contacts with adjacent rocks or flow units.

For the second field season, detailed geological and petrophysical characterization of the primary reservoir lithofacies typically found in a fluvial-dominated deltaic reservoir, is continuing at selected case-study areas. Interpretations of lithofacies, bounding surfaces, and other geologic information are being combined with permeability measurements from closely spaced traverses and from drill-hole cores (existing and planned). Petrophysical analyses are being incorporated with the geological characterization to develop a three-dimensional model of the reservoirs through fluid-flow simulation. Technology transfer consisted of publication of seven abstracts presenting project results, public release of the subsurface drill-hole database, and a project overview presented to the staff of an industry research lab.

Regional Stratigraphy

The Utah Geological Survey (UGS) continues to combine digitized land-based and aerial photographs of the Ferron Sandstone outcrop belt into reproducible photomosaics using image-editing software (Fig. 2). A total of 1823 photos depict 80 miles (130 km) of Ferron Sandstone outcrop. Interpretation of parasequence boundaries, lithofacies, and various field data (such as measured section and gamma-ray transect locations) are being plotted on the photomosaics as part of both the regional and case-study analyses. These interpretations are being checked in the field.

Data were collected from wells that penetrate the Ferron Sandstone in the area from Last Chance Creek in the south to Ferron Creek in the north (Fig 1). Lithologic and other data from coal-company exploration wells; oil, gas, and stratigraphic test wells; and government test wells were entered into the UGS Ferron Sandstone database. Stratigraphic data were transferred from the database to software which drafted strip logs and lithologic descriptions (Fig. 3). These strip logs, a total of 489, are being used for regional correlation of parasequences and lithofacies mapping. The files which produced the strip logs have been archived for possible future use and manipulation.

Digitized 7.5 minute base map files were converted to latitude/longitude coordinates from the existing 7.5 minute digitizer-inch coordinates. Rose diagrams of paleocurrents and other data are being plotted on the base maps for use in regional paleogeographic interpretation.

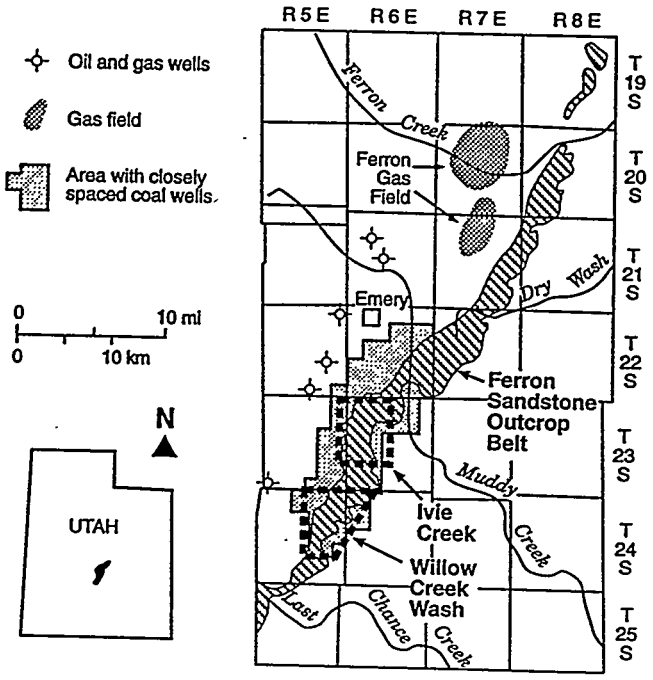

Fig 1. Location map of the Ferron Sandstone study area (outcrop belt cross-hatched) showing detailed case-study sites (outlined by heavy dashed lines).

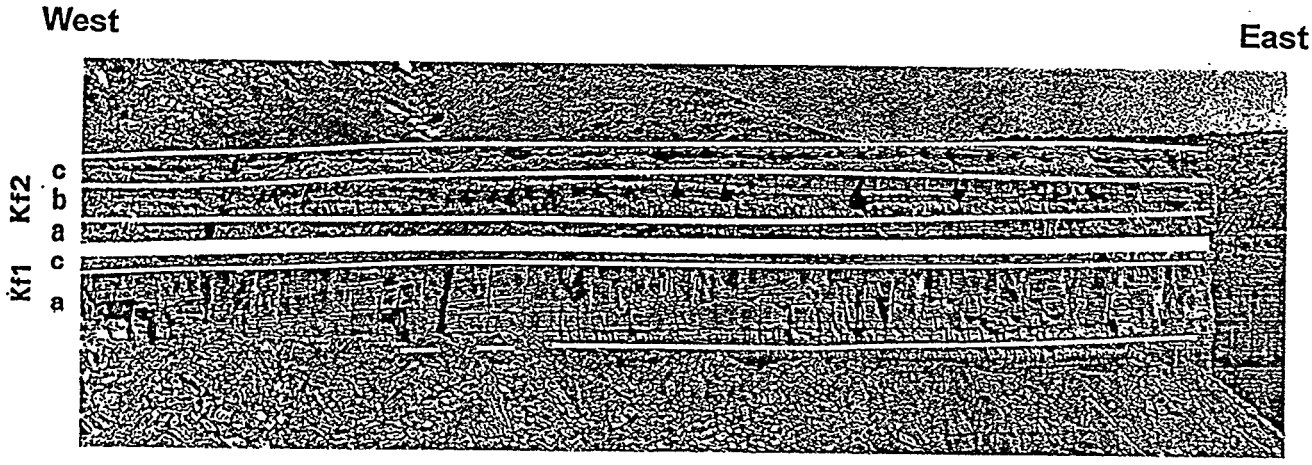

Fig 2. Part of a photomosaic, looking north (SW1/4NE1/4 section 16, T. 23 S., R. 6 E.), used in regional analysis and the Ivie Creek case-study area. The heavy, white, horizontal line is a parasequence set boundary and is underlain by parasequence set Kf1 and overlain by parasequence set Kf2. The thin, white, horizontal lines are boundaries separating parasequences (designated with letters).

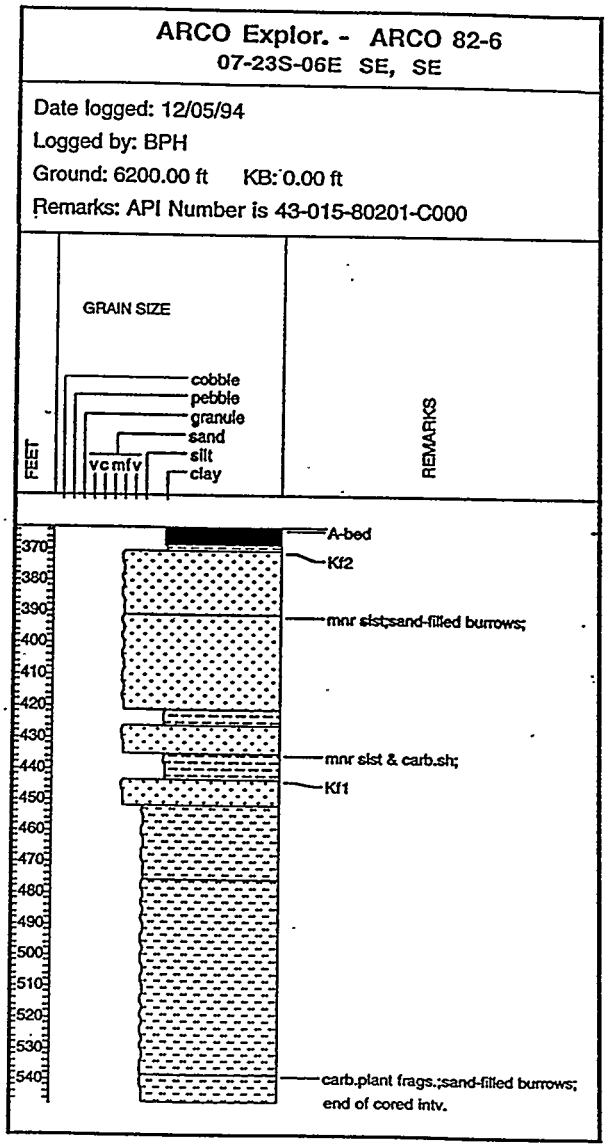

Fig. 3. Typical strip log and lithologic description, from ARCO Exploration Company 82-6 well (section 7, T. 23 S., R. 6 E., Salt Lake Base Line, Emery County, Utah) for Ferron Sandstone regional stratigraphic interpretations.

Case Studies

Field Work

Four outcrop sections and four well cores (Ivie Creek Nos. 3, 5a, 9a, and ARCO 82-6) through the Nos. 1 and 2 parasequence sets in the lower part of the Ferron Sandstone, were described in the Ivie Creek case-study area (Figs. 1 and 4). Description of the individual units in the outcrop sections and cores include the following information: (1) primary and secondary lithology, composition, color, and grain size of the rocks; (2) sedimentary structures, biologic structures, and fossils in the rocks; and (3) bounding surfaces and depositional environment of the unit. These sections and cores are being correlated with the 32 sections measured during the 1994 field season to develop interpretations of the stratigraphy and lithofacies. Paleocurrent measurements have also been made at Ivie Creek and in the Willow Springs Wash case-study area to the south (Fig. 1).

Core-Hole Program

Two new core-hole locations are being permitted in the Ivie Creek case-study area; the Ivie Creek Nos. 10 and 11 (Fig. 4). These locations are set far enough back from the outcrop to avoid the coal burn and fracture zones encountered during the 1994 drilling program. Cores and geophysical logs from these wells will provide data for three-dimensional morphologic interpretation of individual lithofacies. The total depths of the core holes will be 500 ft and the Nos. 1 and 2 parasequence sets will be cored (about 150 ft thick).

Staking and permitting procedures were initiated through the Utah Division of Oil, Gas and Mining (DOGM), the oil and gas regulatory agency for Utah, and the U.S. Bureau of Land Management (BLM). The UGS plans to drill and complete the core holes by the end of September, 1995. An on-site inspection was conducted by the BLM which is also evaluating a request for surface right-of-way. An "Application for Permit to Drill" (APD), for an eight-point drilling program, was filed with DOGM and an application to appropriate water was filed with the Utah Division of Water Rights.

Mini-Permeameter and Gamma-Ray Measurements

A large quantity of new permeability data was collected from both the Nos. 1 and 2 parasequence sets along five vertical permeability transects in the Ivie Creek case-study area. Transect locations contained examples of the majority of the lithofacies present in the delta-front sequences. An electronic, miniprobe permeameter (mini-permeameter) supplied by the Mobil Exploration/Producing Technical Center was used to make laboratory permeability measurements on trimmed, whole core plugs taken from the outcrops. Measured stratigraphic sections were tied to the permeability transects.

The lab permeability results, when combined with field and lab measurements taken during the 1994 field season and detailed geologic mapping, will improve understanding of the lateral variability in permeability for specific bedform types. Vertical permeability transects provide a preliminary view of vertical permeability variations. Data from these transects will be used to determine the statistical structure of the spatially variable permeability field within the

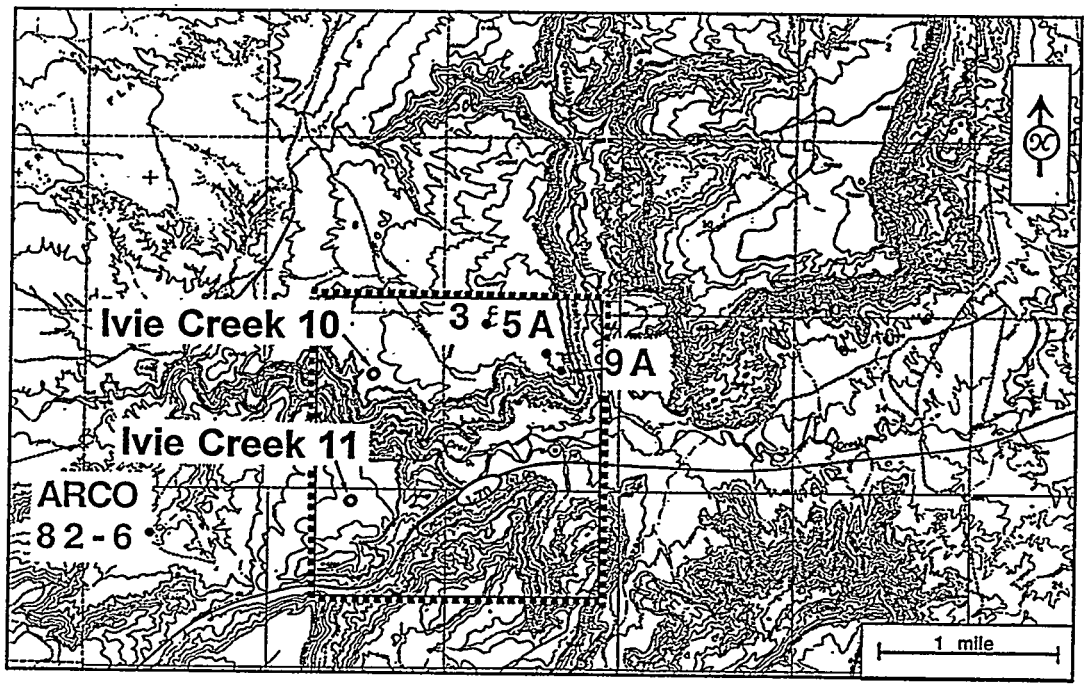

Fig. 4. Locations of two proposed core holes (Ivie Creek Nos. 10 and 11) being permitted in the Ivie Creek case-study area, sections 17 and 20, T. 23 S., R. 6 E., Salt Lake Base Line, Emery County, Utah, to core the Nos. 1 and 2 parasequence sets. Core holes 3, 5A, and 9A were drilled by the UGS during the 1994 field season. The ARCO 82-6 well was drilled in 1984. A 2 mi by 2 mi detailed case-study site is outlined. Base map from U.S. Geological Survey, Mesa Butte and Walker Flat 7.5' topographic maps; contour interval is 40 ft.

delta front and to investigate how geological processes control the spatial distribution of permeability.

Outcrop gamma-ray measurements were taken along permeability transects to: (1) determine variations in clay-mineral content (or sand/shale ratios), (2) permit detailed correlation among and between outcrop traverses and core-hole gamma-ray logs, and (3) detect possible diagenetic changes associated with precipitation of uranium. Field measurements were taken using a portable 256-channel gamma-ray spectrometer capable of determining total natural gamma counts as well as concentrations of potassium, thorium, and uranium. Each transect consisted of 200 to 400 measurements at 0.5 to 1.0 ft intervals. Gamma-ray spectrometer readings are related to clay content in shaly sandstones; clay content influences the compartmentalization of flow units.

Photomosaic Scaling

In the Ivie Creek case-study area, a laser theodolite and a tape measure were used to position and scale information about lithofacies and polygons (modeling units based on lithology, permeability, grain size, and sedimentary structures) on photomosaics. In the area of the No. 1a parasequence, for which detailed reservoir models will be developed, dimensional data need to be determined at a high level of precision. To achieve this, a number of points were surveyed with a laser theodolite followed by reduction of the survey data to yield horizontal and vertical scales. These scales were plotted on the photomosaics and will be used to determine dimensions of lithofacies units and polygons. These survey data also are being reduced to develop x-y-z coordinates to be used in making the three-dimensional geologic model of the case-study area.

A less precise technique was developed to produce horizontal and vertical scales for photomosaics throughout the rest of the case-study area where reservoir modeling will be at a coarser scale. For this information, there is no need to precisely position lithofacies and polygons, and horizontal and vertical scales were produced using a 50-ft nylon measuring tape. A 35 to 50 ft interval (horizontal or vertical) was measured in the field and the endpoints were recorded on the photomosaics. Key features on the photomosaics were recorded on 7.5 minute topographic maps and will be used to generate x-y-z coordinates for the three-dimensional geologic model.

Most field-interpreted photomosaics in the Ivie Creek case-study area have been redrafted and acetate overlays added which show the interpretation of parasequences and deltaic subfacies. The photomosaics will be the base for construction of scaled cross sections. In turn, the cross sections, which are being digitized, will form the base for construction of the three-dimensional model of the reservoir architecture.

Petrophysical Analysis

Petrophysical measurements were made on 180 Ferron core plugs processed through Amoco Production Research's Geoscience Evaluation Module (GEM). The measurements consisted of: (1) saturated, dry, and grain densities, (2) effective and Boyle's Law porosities, (3) compressional and shear wave velocities as a function of effective pressure, (4) magnetic susceptibility, (5) qualitative and quantitative mineralogy, (6) air permeability, and (7) thin section-image analysis. The specific details of the GEM procedures used are given by Sondergeld and Rai.[1-3] Velocities were measured using the pulse transmission technique of Schreiber, et al.[4]

and mineralogy was determined using a transmission infrared technique described by Griffiths and de Haseth.[5] The final results are being compiled into hard copy and digital reports.

Stochastic Modeling and Fluid-Flow Simulation

The homogenization code for one-, two-, and three-dimensional problems has been completed and tested extensively. The tests involved approximately 100 individual cases in one, two, and three dimensions. The test cases involved data sets with well known solutions and random examples to test the codes on more realistic problems. In addition to the homogenization codes, algorithms for computing the arithmetic, harmonic, and geometric averages of the permeability data were implemented to aid in testing the homogenization codes. The homogenization results should always be between the arithmetic and harmonic averages. This method is useful for testing the random cases even though the exact answer is not known. The codes were written in a form that is easy to install and test. All the test data sets are available and are generated in a self-contained program. The subroutines that compute the homogenized permeabilities can be plugged in at any point to a code with at most a minor amount of translation between data structures. The two-dimensional code has been written to simulate Ferron lithofacies and will be used as a means of extrapolating the outcrop data to both two and three dimensions. The permeability data from the transects collected from the Ivie Creek case-study area has been obtained and is being analyzed. The analysis involves the use of spectral decompositions and possibly wavelet representation. This data is being used to build depositional models.

Technology Transfer

The UGS released all subsurface drill-hole data (489 wells) collected as part of the Ferron project in an open-file report entitled "Ferron Sandstone Drill-Hole Database, Ferron Creek to Last Chance Creek, Emery and Sevier Counties, Utah." This report is available in both hard copy[6] and a computer-readable format.[7]

A presentation entitled "Geological and Petrophysical Characterization of the Ferron Sandstone (Utah), for 3-D Simulation of a Fluvial-Deltaic Reservoir" was given to the Geoscience Technology Division staff of Amoco Production Research Company, Tulsa, Oklahoma, June 23, 1995. The project objectives and description, status of deliverables and accomplishments, potential application of results, benefits, and value were discussed.

Seven abstracts for presentation at the 1995 American Association of Petroleum Geologists (AAPG) Rocky Mountain Section meeting were published this quarter.[8-14]

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NEXT QUARTER PLANNED ACTIVITIES

Activities planned for the next quarter include:

1. Continue 1995 field season case-study work (measured sections, lithofacies interpretation, etc.).

2. Continue plotting locations of measured sections, paleocurrent sites, and gamma-ray and mini-permeameter transects on base maps. Complete production of columnar presentations of new measured-section data and rose diagrams of paleocurrents using computer software designed for the display of stratigraphic data. Post paleocurrent rose diagrams on the digital base maps.

3. Complete graphical log displays of gamma-ray measurements taken from outcrops in the Ivie Creek case-study area.

4. Complete cataloging and printing of digitized ground-based and aerial photographs, and construction of photomosaics for regional stratigraphic and case-study analysis.

5. Continue regional outcrop mapping and interpretation.

6. Permit, drill, core , and log two new core holes in the Ivie Creek case-study area. Describe core, enter the data into the database, and draft columnar logs.

7. Complete 1995 mini-permeameter/gamma-ray transects in the Ivie Creek case-study area. Document results in spreadsheet and graphic format.

8. Complete 1995 core-plugging program for petrophysical analysis.

9. Digitize versions of geologic trace maps with a grid. Produce gridded cross sections as a basis for constructing digital fence diagrams. Simulate two-dimensional cross sections mapped by the project field team.

10. Continue quantifying sedimentary and petrophysical data to develop statistical models.

11. Document computer codes describing the method in intuitive terms and how to use the codes. Modify TETRAD, the modeling program provided by Mobil, to test the homogenization methods in real oil industry simulators. The modifications require the inclusion of full tensor permeabilities.

12. Begin production of cross sections and lithofacies maps for the Ivie Creek case-study area.