DISCLAIMER

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

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Utah Geological Survey (UGS), Salt Lake City, Utah 84114

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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

Two activities continued this quarter as part of the geological and petrophysical characterization of the fluvial-deltaic Ferron Sandstone: (1) evaluation of the Ivie Creek case-study area and (2) technology transfer.

Evaluation of the Ivie Creek Case-Study Area

The Ivie Creek case-study evaluation work during the quarter focused on the two parasequence sets, the Kf-1 and Kf-2, in the lower Ferron Sandstone. This work included: (1) clinoform characterization, (2) parasequence characterization from elevation and isopach maps, and (3) three-dimensional facies modeling. Scaled photomosaic panels from the Ivie Creek amphitheater (south-facing outcrop belt) and Quitchupah Canyon (Fig. 1) provide a deterministic framework for two apparent-dip cross sections. These panels along with other photomosaic coverage and data from five drill holes, ten stratigraphic sections, and 22 permeability transects (Fig. 1), acquired during two field seasons, provided the necessary information for this geologic evaluation and creation of the models to be used in reservoir simulations.

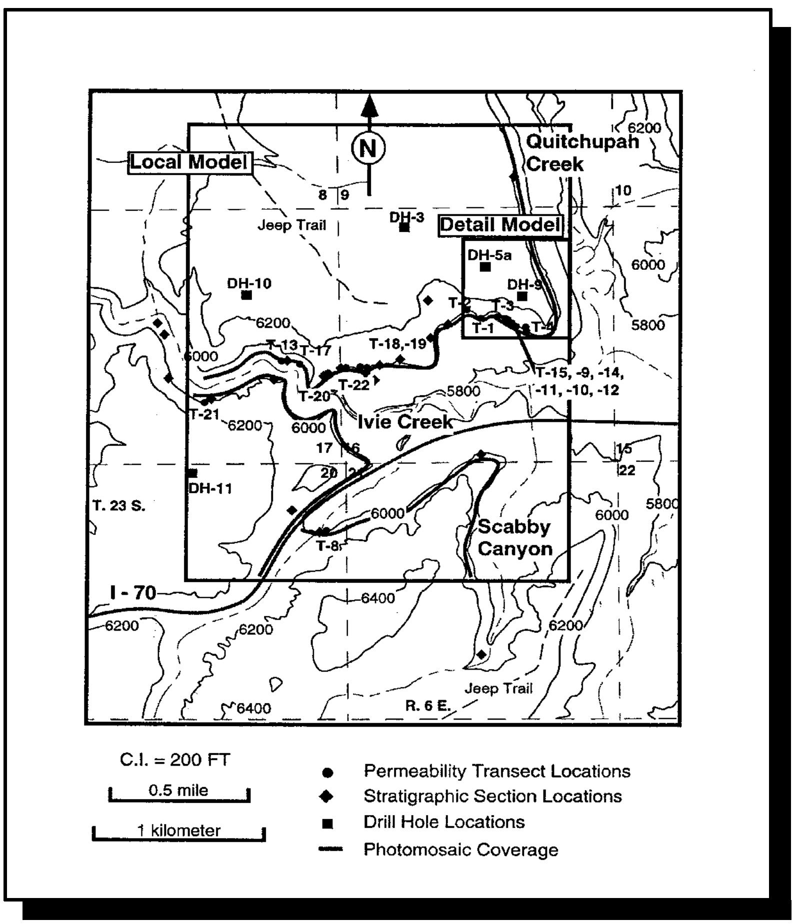

Fig. 1. Data collection point locations in the Ivie Creek case-study area.

Kf-1-Ivie Creek-a Parasequence Clinoform Characterization

The Kf-1-Ivie Creek-a (Kf-1-Iv-a) parasequence is characterized by clinoform geometries that dip basinward. The fluvial-dominated bodies were deposited into an area with minimal wave influence, therefore, the primary bedforms are preserved. In contrast, the Kf-2 parasequence set is characterized by more tabular bedforms that are laterally more extensive than those in the Kf-1-Iv-a. The Kf-2 parasequences were deposited into an area with moderate wave energy which reworked the sediments to create more tabular shapes.

To characterize the clinoform bedforms, measurements were taken of: (1) the overall length of the clinoform body, (2) the inclination angle from datum at quartiles along the bedform, and (3) the bedform thickness at quartiles along the bedform (Fig. 2A).[1] Some interesting observations arise from the quantitative analysis of the apparent inclination angle data. Upon visual inspection, apparent inclination angles appear to be the same for the Ivie Creek amphitheater and Quitchupah Canyon for a given clinoform facies. However, when the apparent inclination angles are averaged, the angles found in Quitchupah Canyon (~14°) are steeper than those in the amphitheater (~11°). This implies that Quitchupah Canyon is closer to being a "true dip section" than the amphitheater.

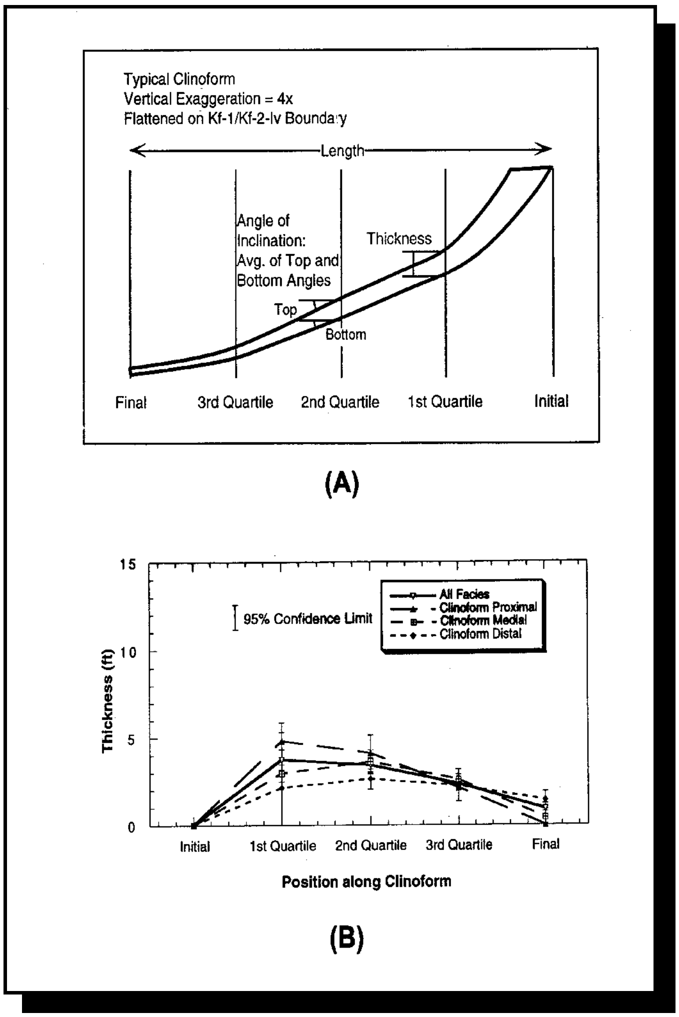

Fig. 2. (A) Diagram of measurements used for clinoform characterization. (B) Bedform thickness vs. position along clinoforms in the Kf-1-Iv-a parasequence, Ivie Creek amphitheater.

The other parameters necessary to create a typical clinoform shape are the length and thickness of the body. Clinoform lengths range from 40 ft to greater than 2000 ft. A plot of thickness as a function of quartile shows that the first quartile is the thickest part of the clinoform (Fig. 2B). Quartile thickness as a function of facies decreases from clinoform proximal facies to clinoform distal facies. The thickness data combined with the apparent inclination angle data present a two-dimensional picture of the geometry of typical clinoform.

Clinoform facies can also be described as a function of position within a clinoform bedform. For the clinoform bodies analyzed, the dominant facies at the initial position in a bedform are clinoform proximal and clinoform medial. At the final position, the dominant facies is clinoform distal. The facies percentage at each quartile can provide rules to populate clinoform bodies with facies data.

When clinoform facies, permeability, and geometric data are brought together, a "typical clinoform" is constructed. This is a two-dimensional building block that may be used to create a reservoir simulation model based on facies.

Parasequence Characterization from Elevation and Isopach Maps

Depositional trends may be estimated from parasequence surface elevation and isopach maps generated by ordinary kriging. Elevation maps provide insight to paleotopography as referenced to a datum. Isopach maps provide insight into the sediment source and depositional patterns. Analysis of these two data types is used to interpret the delta evolution during the deposition of the Kf-1 and Kf-2 parasequence sets.[1]

In general, surface elevation maps of the Kf-1 parasequences show dip to the north-northwest which represents different fluvial-dominated deltaic lobes (Fig. 3A). By contrast, surface elevation maps of the Kf-2-Iv parasequences show dip to the east representing a wave-modified, prograding shoreline (Fig. 3B).

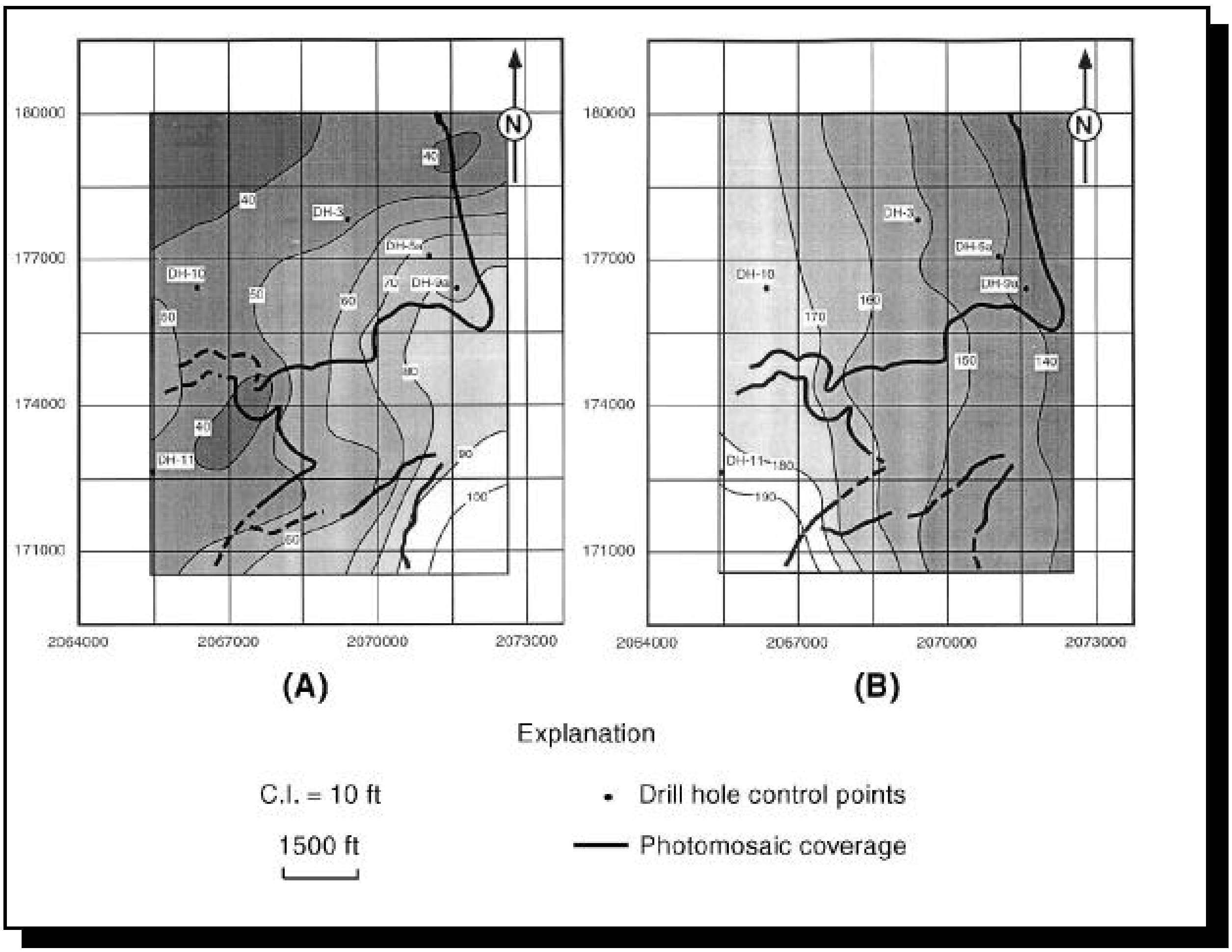

Fig. 3. Kriged surface elevation maps for the local model using state plane coordinates. (A) Top of the Kf-1-Iv-a parasequence, and (B) base of the Kf-2-Iv-c parasequence. Extent of local model is shown in Fig. 1.

Isopach maps indicate sediment source during a particular cycle. These maps show that the Kf-1 parasequences were deposited in irregular sediment distributions. The Kf-1-Iv-a parasequence was deposited in a fan-like shape and thickens to the east (Fig. 4A). The Kf-2-Iv-a parasequence is wedge-shaped and thins to the east (Fig. 4B). The Kf-2-Iv-b and the Kf-2-Iv-c parasequences are generally tabular, but the Kf-2-Iv-c pinches out to the southwest. The sediment source switches from the east to the west through the time frame of these parasequences.

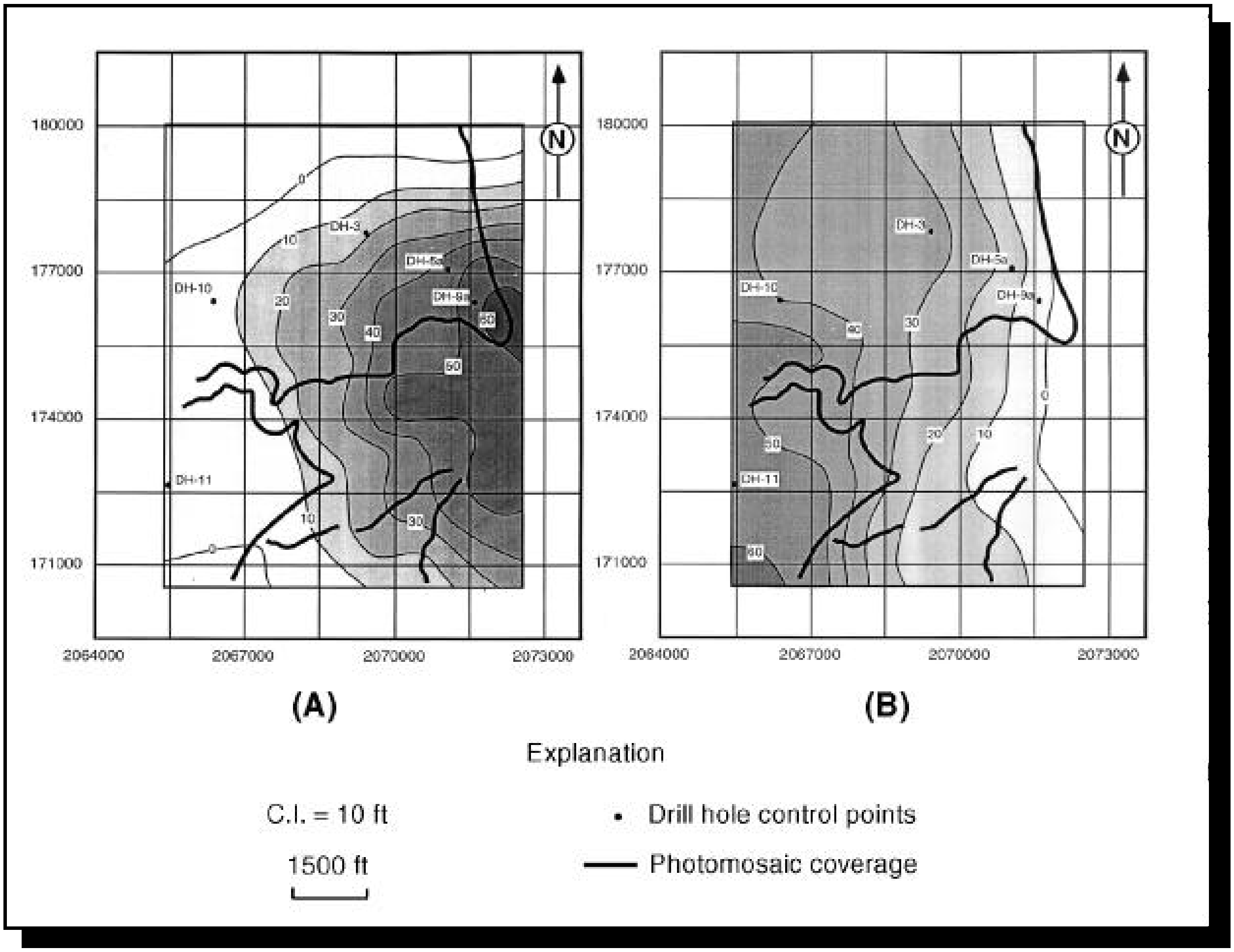

Fig. 4. Isopach maps for the local model using state plane coordinates. (A) Kf-1-Iv-a parasequence, (B) Kf-2-Iv-a parasequence. Extent of local model is shown in Fig. 1.

In general, the Kf-1 cycles exhibit more localized sediment accumulation as a delta lobe, sourced from a point. The pods of sediment accumulation in the Kf-1 cycles indicate deposition in a protected environment such as a bay. In contrast, the Kf-2 cycles exhibit sheet-like accumulations that pinchout laterally and form a wedge. The Kf-2 sediments were reworked into a linear trend by wave-action along the delta front.

Three-Dimensional Facies Model: Detail Model

An essential element for reservoir simulation is a framework in which to distribute petrophysical data. This framework can be built in a deterministic or stochastic manner. For the three-dimensional Kf-1-Iv-a parasequence reservoir simulation model, the framework is a deterministic model based on clinoform facies.[1]

The control for the three-dimensional facies model was eight vertical cross sections which were discretized into 4 x 20 ft blocks of clinoform facies (Fig. 5). Facies data from the vertical sections was transferred to horizontal slices throughout the domain and the facies were interpolated between control points. This results in a volume that is coherent from layer to layer, and agrees with the depositional hypothesis of arcuate lobes that were sourced from the east-southeast. The facies distribution in the model is most complex around the 60-ft elevation layer (Fig. 6). The complexity decreases toward the top (dominantly proximal) and bottom (dominantly distal) portions of the model.

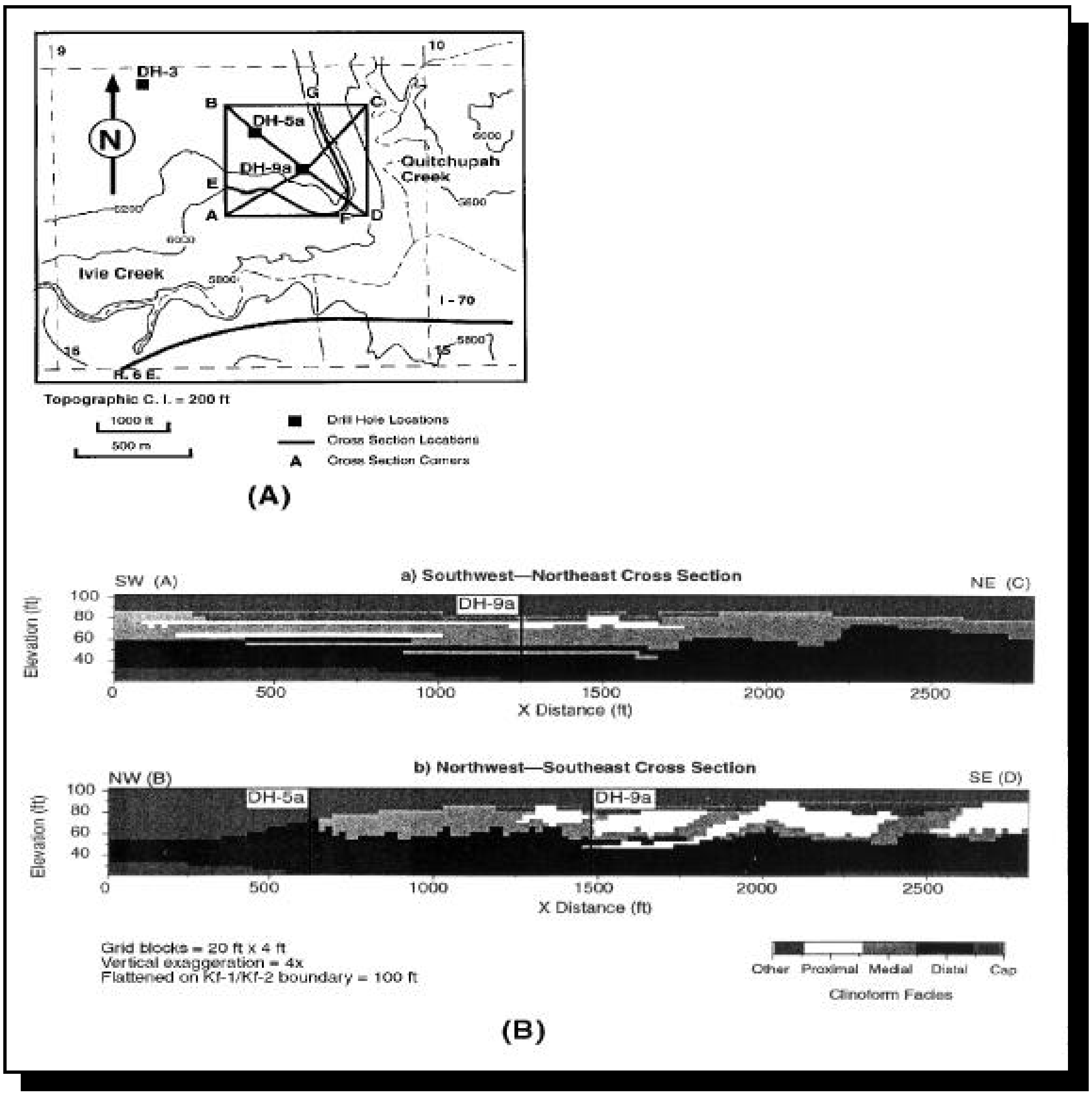

Fig. 5. (A) Cross section locations for three-dimensional clinoform facies model, Kf-1-Iv-a detail model. (B) Southwest to northeast and northwest to southeast cross sections through drill hole 9a. Extent of local model is shown in Fig. 1.

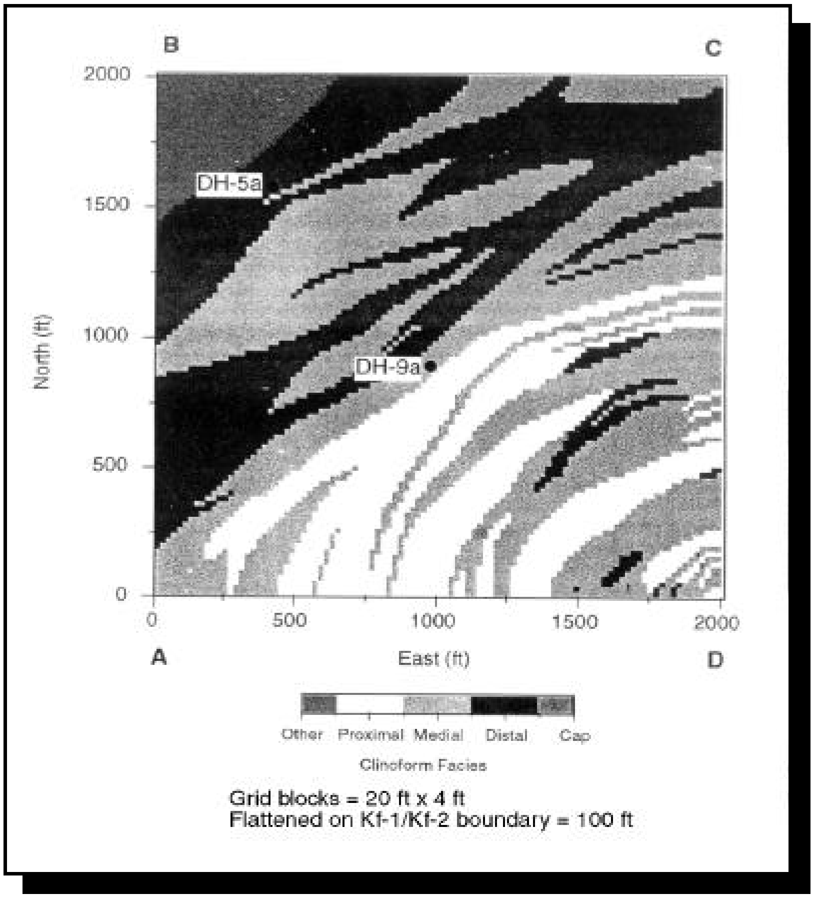

Fig. 6. Kf-1-Iv-a three-dimensional facies model, 60 ft elevation layer. Plan view of detailed model area shown in Fig. 5A index map.

The final step before reservoir simulation is assigning petrophysical parameters to each block. Each block represents one clinoform facies type. One permeability distribution is constructed by assigning the geometric mean of the clinoform facies permeability data to each grid block. This method is somewhat simplistic, but provides a means to compare a three-dimensional flow model with the two-dimensional flow model developed earlier.

The resulting facies model provides a realistic geologic model that can be used as an input to reservoir simulation to be completed next quarter. Because the model incorporates outcrop photomosaics, stratigraphic sections, and drill-hole data, it provides a great deal more information than a model based only on drill-hole data. Although the high degree of detail may not be necessary for accurate reservoir predictions, a detailed image of the subsurface provides a comparative case with more generalized models.

Technology Transfer

The UGS and its partners continued to present results of the project to both academia and industry. During the quarter, road logs were completed for two-day field trips to be conducted during the 1997 Geological Society of America (GSA) and 1998 American Association of Petroleum Geologists (AAPG) annual national meetings. These meetings will be held in Salt Lake City, Utah, October 19-22, 1997 (GSA) and May 17-20, 1998 (AAPG).

The field trip road logs and Ferron interpretations, titled *Fluvial-Deltaic Sedimentation and Stratigraphy of the Ferron Sandstone*, will be published in the fall of 1997 in a two-volume GSA guidebook.[2] The field trip has two parts, each with a different emphasis: (1) a review of regional stratigraphy and (2) detailed analysis of depositional environments and permeability trends. The primary objective of day one will be to provide a detailed interpretation of the regional stratigraphy of the Ferron Sandstone outcrop belt from Dry Wash to Last Chance Creek. The primary objective of day two will be to develop a detailed sedimentological characterization of the facies in the Ivie Creek area just north of Interstate 70 (I-70). The Ivie Creek area was selected because it contains abrupt facies changes in Kf-1 and Kf-2. Access to the area is excellent because of the close proximity to I-70. The field trip participants will examine the major reservoir types (mouth-bar complex, wave-modified and fluvial-dominated delta front, distributary channel, and tidal deposits) associated with the Ferron Sandstone.

A short course titled *Core and Reservoir Modeling Workshop: Fluvial-Deltaic Nearshore Sands of Ferron Sandstone* will also be offered during the AAPG meeting. The course will take the participants from outcrop to reservoir modeling and flow simulation results of the Ferron project. Integration of geological parameters and methods in setting up a reservoir modeling data set will be presented. The field trip and short course presented at the AAPG meeting will be sponsored by the UGS, National Petroleum Technology Office - DOE, Mobil Technology Company, and Amoco Production Company.

Project material was displayed at the UGS booth during the AAPG annual convention held in Dallas, Tex., April 6-9, 1997. Ferron team members presented a paper describing sandstone exhumation effects on velocity and porosity.[3] A lecture (using Ferron project data and results) titled *Methods for Characterization of Fluvial-Deltaic Reservoirs* by Laura Watkins was presented at the 1997 annual spring meeting of the Intermountain Section of the Mathematical Association of America held at Utah State University, Logan, Utah, April 10-12, 1997. The UGS also released the April 1997 issue of *Petroleum News* featuring the Ferron Sandstone project. Three abstracts were submitted to the GSA for presentations during the 1997 annual national meeting. These abstracts discuss the: (1) reservoir facies architecture and characterization of the Ferron, (2) impact of two-dimensional clinoform architecture on reservoir performance, and (3) impact of three-dimensional clinoform architecture on reservoir performance.

References

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2. P. B. Anderson, T. C. Chidsey, Jr., and T. A. Ryer, Fluvial-Deltaic Sedimentation and Stratigraphy of the Ferron Sandstone, in *Mesozoic to Recent Geology of Utah*, B. J. Kowallis and P. K. Link (Eds.), Brigham Young University Geology Studies, 42 (2). In press.

3. R. D. Jarrard and S. E. Erickson, Sandstone Exhumation Effects on Velocity and Porosity: Perspectives from the Ferron Sandstone [abs.]: *Amer. Assoc. of Petrol. Geol. Annual Convention, Program with Abstracts*: A55 (1997).