-12

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

(Contract No. DE-AC22-93BC14896)

Utah Geological Survey (UGS), Salt Lake City, Utah 84109

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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, and technology transfer activities. The focus of the regional and case study work was on two parasequence sets referred to as the Kf-1 and Kf-2. The Kf-1 represents a river-dominated delta deposit which changes from proximal to distal (where the sandstone pinches out) from east to west across the Ivie Creek area. The Kf-2 contains more and cleaner sand, indicating a more wave-modified environment of deposition.

The regional stratigraphy of the Ferron Sandstone outcrop belt from Last Chance Creek to Ferron Creek (Fig. 1) was described and interpreted. 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. 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 (described this quarter). Petrophysical and statistical analyses are being incorporated with the geological characterization to develop a three-dimensional model of the reservoirs through fluid-flow simulation. Important flow boundaries in the Ivie Creek case-study area, identified on photomosaics, were digitized, scaled, and scanned to create graphical reconstructions to be used for cross section construction and reservoir modeling. Technology transfer consisted of publishing project results.

Regional Stratigraphy

The Utah Geological Survey (UGS) completed combining digitized land-based and aerial photographs of the Ferron Sandstone outcrop belt into reproducible scaled photomosaics using image-editing software. Interpretations of parasequence boundaries, lithofacies, and various field data covering 80 miles of Ferron Sandstone outcrop (Fig. 1) were completed during the quarter using these photomosaics. The photomosaics were given vertical and horizontal scales. Scale of the photos was determined in the field by measuring between locatable points on the photograph and those same points on the ground. During field mapping, coverage of each photomosaic was plotted on a 7.5-minute topographic quadrangle map with the aid of aerial photos. The photomosaics were annotated with parasequence, parasequence set, and lithofacies boundaries.

Case Studies

Drill-Hole Core Description

In September 1995, two stratigraphic test wells were drilled, logged, and plugged in the Ivie Creek case-study site: the Ivie Creek Nos. 10 and 11. These wells were located to evaluate the lithofacies and reservoir characteristics of the Kf-1 and Kf-2 parasequence sets. Core and geophysical logs will provide data for a three-dimensional morphologic interpretation of individual lithofacies and capture the various reservoir changes in the Kf-1 and Kf-2 parasequence

sets over an area analogous in size to a small oil field.

A total of 156 ft of core was recovered from the Ivie Creek No. 11 well (the Ivie Creek No. 10 was not cored). During the quarter, this core and core obtained from the 1994 drilling program (the Ivie Creek Nos. 3, 5A, and 9A) were described. Descriptions of the individual units in the core sections include the following information: (1) primary and secondary lithology, composition, color, and grain size of the rocks; (2) size, shape, and degree of induration of the beds; (3) sedimentary structures, biologic structures (trace fossils), and fossils in the rocks; and (4) bounding surfaces and depositional environment of the unit. Sections were correlated to develop preliminary interpretations of the stratigraphy and lithofacies.

Stratigraphic data from project drill-hole cores and geophysical logs (four) were transferred from the UGS database to software which drafted core sections and core descriptions (Fig. 2). This software generated graphic logs of core sections at scales of 1 in: 2.5 ft and 1 in: 10 ft. Logs at both scales contain attributes such as: lithology, sedimentary structures, and parasequence designations. General comments, grain sorting, grain roundness, and degree of consolidation were also noted on the 1 in: 2.5 ft logs. The core sections were adjusted to match the gamma-ray log which was plotted to the left of the rock column. All attributes will be used to define reservoir components in the statistical and reservoir-modeling parts of the project.

Petrophysical Analysis

Eighteen thin sections were made from selected sandstone core plugs with varied lithology, delta-front position, and permeability values in the Ivie Creek Kf-1a parasequence (lowermost Ferron). The sandstone samples ranged from largely very fine-grained to medium-grained with some silt and coarse-sand fractions. The samples are typically quartz arenite to quartzo feldspathic arenite. Most samples are poorly to moderately sorted with varying degrees of rounding. Most sandstone show a moderate to strong degree of compaction.

Petrographic analysis of the sandstones indicate a complex diagenetic history with as many as five stages of cementation. Quartz overgrowths in Ferron Sandstone thin sections probably represent an early diagenetic stage. Calcite cement and dolomite rhombs are middle diagenetic stages, followed by late phases of iron/hematite staining or replacement of the carbonate minerals (such as the dolomite rhombs). Final stages of diagenesis are dissolution of those same carbonate phases and development of microfractures. Some grains of feldspar were altered to clay and/or replaced by carbonate. Squashed rock fragments are common. Many of the samples have undergone significant compaction leaving little remaining primary porosity. Porosity values are variable, but generally less than 15%. There is considerable secondary porosity development which is evidenced by dissolution of carbonate minerals. Much of this secondary porosity development is unevenly distributed.

An "unexpected" petrographic find was from a rippled sandstone with a relatively high permeability value that can be attributed to small (microscopic) microfractures (approximately 0.2-0.4 mm thick) filled with gypsum. These gypsum veins run parallel to the bedding and contain secondary porosity (through dissolution) between some of the gypsum crystals. These veins probably act as conduits for fluid migration through an otherwise low permeability sample composed of fine-grained sandstone with its intergranular porosity occluded by calcite and dolomite cements.

Geostatistics

Spatial variations in lithofacies, sedimentary structures, permeability, and other data are being quantified through geostatistical analysis. The Kf-1a parasequence in the Ivie Creek case-study area has been subdivided into three general facies: proximal delta front, medial delta front, and distal delta front. During this quarter, a block of outcrop from the south-facing Ivie Creek cliffs was selected for detailed statistical analysis. The sand and silt grain-size distributions (based on megascopic observations) were calculated for the three facies (Fig. 3A). As one might expect, the proximal delta-front sandstones are the coarsest and the distal delta-front sandstones are the finest. The proximal sandstones also contained the greatest variations in grain sizes. The relative frequency of sedimentary structures was also calculated for the three facies (Fig. 3B). Horizontal bedding is the most common sedimentary structure in all three facies. Ripple cross-laminated beds are also common in all three facies. Trough and hummocky cross-stratified beds are common only in the proximal delta-front facies.

Development of Reservoir Models Utilizing Field Data

Dimensional data from the Kf-1a parasequence in the Ivie Creek case-study area are being used to develop detailed reservoir models. Clinoform boundaries in the Kf-1a parasequence identified on photomosaics were digitized and scaled to: (1) provide internal consistency for spatial relationships of field data, (2) correct all data (photomosaics) for distortions, (3) tie to a common datum (the Kf-1/Kf-2 parasequence set boundary), and (4) provide a framework for scaled cross sections and fence diagrams.

Elevation profile picks were positioned on the 7.5 minute topographic maps utilizing tie points on rock panels that were identified in the field. Location of photomosaics, wells, measured sections, and permeability transects were marked on a summary base map. The Kf-1a outcrop location was marked and scaled on the base map using field-survey data. This effort included locating all measured points on photomosaics (approximately 200 points, spaced about 100 ft apart) and converting these points to state plane X-Y coordinates. The scaled, photomosaic line work was scanned into a well-log digitizing package to produce scaled Ivie Creek reconstructions (Fig. 4). Various units seen as open polygons on the reconstructions were closed for integration into the reservoir model.

General facies categories were assigned to units (polygons) on the scaled photomosaic panels based on geometry, sedimentary structures, and apparent shale content. Graphic logs along permeability transects and measured sections were adjusted to fit the scaled line work to form the base for construction of cross sections and the three-dimensional model of the reservoir architecture.

Technology Transfer

During 1995, technology transfer efforts of the Ferron Sandstone project benefited energy development in Utah. The Ferron project was originally submitted to the U.S. Department of Energy as a study of a surface analogue to fluvial-dominated deltaic oil reservoirs worldwide. Since that time, the Ferron Sandstone itself has become a major coalbed methane play. Databases, strip logs, and maps produced from the project have been used by operators exploring and developing this new resource (Fig. 5). Based on data generated from this project, the UGS

estimates the coalbed methane play will support 3400 wells, nearly doubling the total number of producing gas wells in Utah. The UGS released all subsurface drill-hole strip logs (489 wells) for the Ferron project[2] and Ferron total coal, depth to top, and vitrinite reflectance maps[3] in open-file reports.

During the quarter, an abstract presenting the regional Ferron sequence stratigraphy and facies analysis was submitted for presentation at the 1996 American Association of Petroleum Geologists Rocky Mountain Section meeting in Billings, Montana. A summary of the Drunkards Wash field (which produces coalbed methane from the Ferron Sandstone) was submitted to the Utah Geological Association for publication in the second edition of *Oil and Gas Fields of Utah*[4].

References

1. D. E. Tabet, *Utah's 1994 Coalbed Methane Developments*, Utah Geological Survey, Survey Notes 27(2): 9 (April 1995).

2. B. P. Hucka, S. N. Sommer, D. A. Sprinkel, and D. E. Tabet, *Ferron Sandstone Drill-hole Strip Logs, Ferron Creek to Last Chance Creek, Emery and Sevier Counties, Utah*, Utah Geological Survey Open-File Report 331: 1417 pp., 2 volumes (December 1995).

3. D. E. Tabet, B. P. Hucka, and S. N. Sommer, *Maps of Total Ferron Coal, Depth to the Top, and Vitrinite Reflectance for the Ferron Sandstone Member of the Mancos Shale, Central Utah*, Utah Geological Survey Open-File Report 329: 3 plates, 1:250,000 (November 1995).

4. B. G. Hill and S. R. Bereskin (editors), Oil and Gas Fields of Utah, *Utah Geological Association* Publication 22: unpaginated, (September, 1993).

FIGURE CAPTIONS

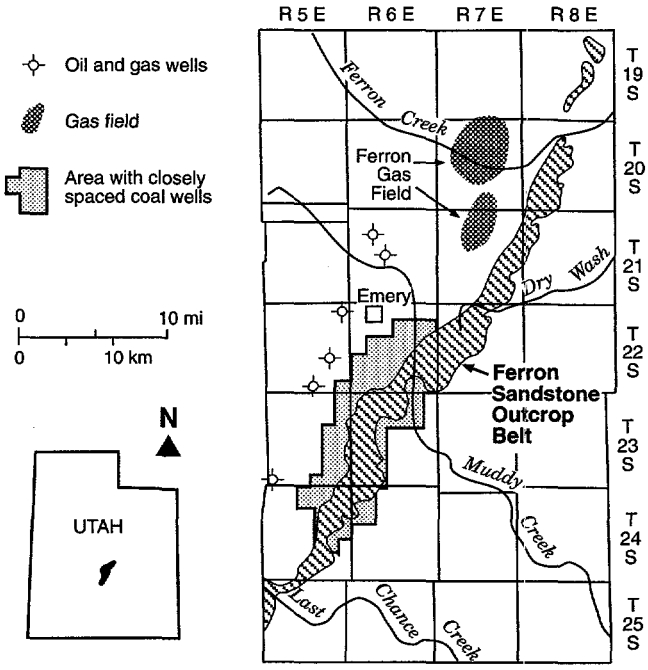
Fig 1. Location map of the Ferron Sandstone outcrop belt (cross-hatched), the area of regional stratigraphic evaluation.

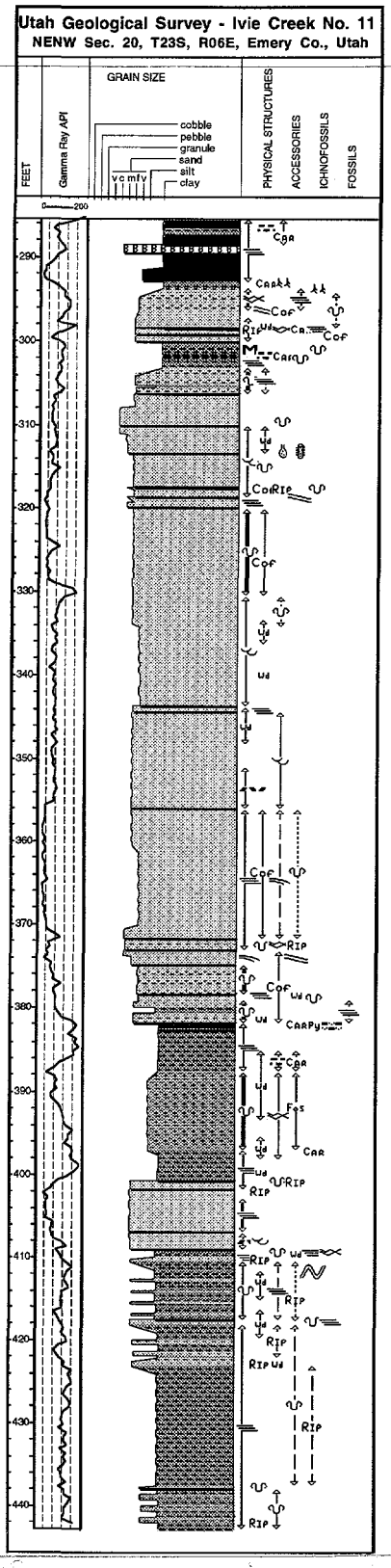
Fig. 2. Graphic interpretation of core, with gamma-ray curve, from the Ivie Creek No. 11 drill hole, NE1/4NW1/4 section 20, T. 23 E., R. 06 E., Ivie Creek case-study area, Emery County, Utah.

Fig. 3. Statistical analyses of the proximal, medial, and distal delta-front facies from a detailed block of the Kf-1a parasequence in the Ivie Creek case-study area: (A) histogram showing grain-size distributions (megascopic observations) in each facies, and (B) histogram showing relative frequency of sedimentary structure versus facies.

Fig. 4. Scaled reconstruction of Ivie Creek photomosaic from scanned line work to be used for cross section construction and reservoir modeling.

Fig. 5. Location of the Ferron coalbed methane "fairway", Drunkards Wash field, and drilling prospects, Carbon, Emery, Sanpete, and Sevier Counties, Utah[1].


Oil and gas wells
Gas field
Area with closely spaced coal wells
0
10 mi
0
10 km
N
UTAH
R5E
R6E
R7E
R8E
T 19 S
T 20 S
T 21 S
T 22 S
T 23 S
T 24 S
T 25 S
Ferron Creek
Ferron Gas Field
Dry Wash
Emery
Ferron Sandstone Outcrop Belt
Muddy Creek
Last Chance Creek



Explanation

LITHOLOGY

Sand
silty sand
shaly sand
sandy silt
clayey silt
Shale
silty shale
sandy shal
coal
Bentonite

CONTACTS

Sharp
Uncertain

PHYSICAL STRUCTURES

- Trough Cross-strat.
- Horizontal Planar
- Hummocky Cross-strat.
M - Massive/Homog
- Soft Sediment
- Irregular Lamination
RIP - Unspecified Ripples
- Planar inclined

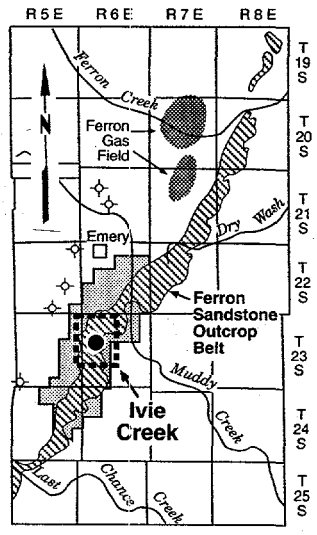
LITHOLOGIC ACCESSORIES

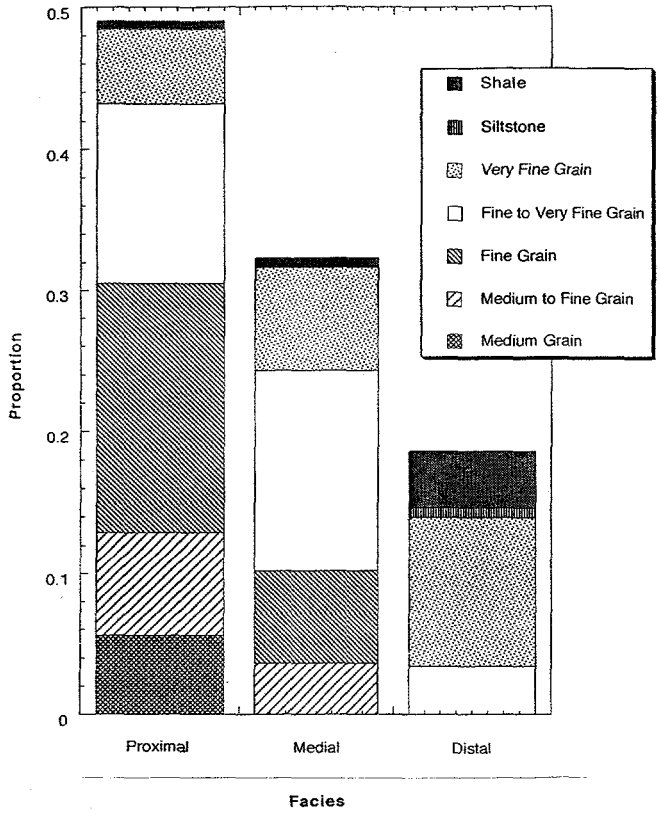
Py - Pyrite
- Rip Up Clasts
CAR - Carbonaceous
- Coaly
- Boney
Wd - Woody
COF - "Coffee Grounds"
Fos - Unspecified Fossils.

ICHNOFOSSILS

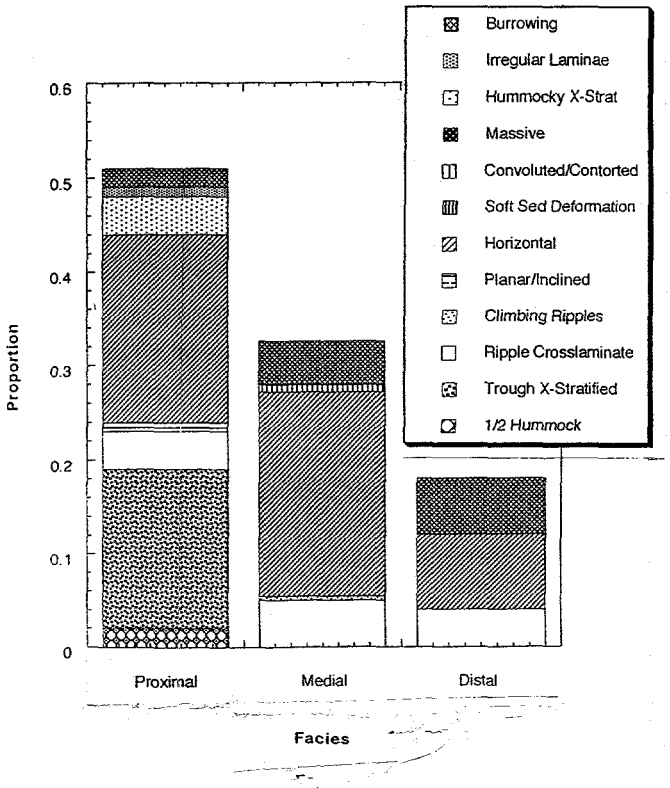
- Rootlets
- Ophiomorpha
- Bored HardGround
- Unspecified burrows

Location

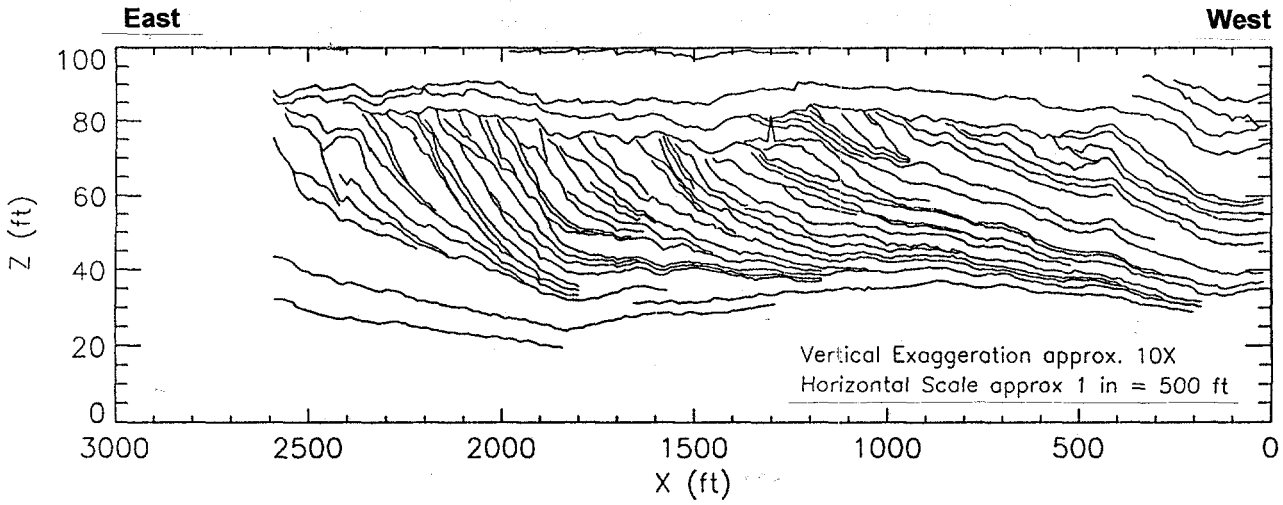


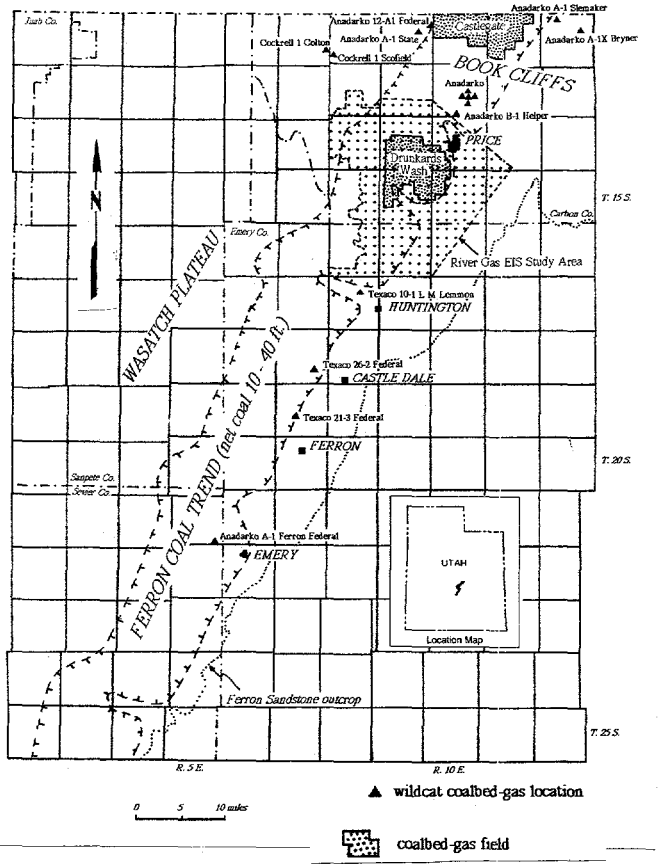

0.5
0.4
0.3
0.2
0.1
0
Proportion
Shale
Siltstone
Very Fine Grain
Fine to Very Fine Grain
Fine Grain
Medium to Fine Grain
Medium Grain
Proximal
Medial
Distal
Facies

(A)


0.6
0.5
0.4
0.3
0.2
0.1
0
Proportion
Burrowing
Irregular Laminae
Hummocky X-Strat
Massive
Convoluted/Contorted
Soft Sed Deformation
Horizontal
Planar/Inclined
Climbing Ripples
Ripple Crosslaminate
Trough X-Stratified
1/2 Hummock
Proximal
Medial
Distal
Facies

(B)


East
West
100
80
60
40
20
0
Z (ft)
3000
2500
2000
1500
1000
500
0
X (ft)
Vertical Exaggeration approx. 10X
Horizontal Scale approx 1 in = 500 ft


Anadarko A-1 Slemaker
Anadarko 12-A1 Federal
Castlegate
Anadarko A-1X Bryner
Cockrell 1 Colton
Anadarko A-1 State
Cockrell 1 Scofield
BOOK CLIFFS
Anadarko
Anadarko B-1 Helper
PRICE
Drunkards Wash
T. 15 S.
Carbon Co.
Emery Co.
River Gas EIS Study Area
Texaco 10-1 L. M. Lommen
HUNTINGTON
WASATCH PLATEAU
Texaco 26-2 Federal
CASTLE DALE
Texaco 21-3 Federal
FERRON
T. 20 S.
Sanpete Co.
Sevier Co.
Anadarko A-1 Ferron Federal
EMERY
FERRON COAL TREND (net coal 10 - 40 ft.)
UTAH
Location Map
Ferron Sandstone outcrop
T. 25 S.
R. 5 E.
R. 10 E.
0 5 10 miles
wildcat coalbed-gas location
coalbed-gas field