TITLE: ANISOTROPY AND SPATIAL VARIATION OF RELATIVE PERMEABILITY AND LITHOLOGIC CHARACTER OF TENSLEEP SANDSTONE RESERVOIRS IN THE BIGHORN AND WIND RIVER BASINS, WYOMING

D.O.E. Contract No. DE-AC22-93BC14897

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Date of Report: January 12, 1996
Award Date: September 15, 1993
Completion Date: September 14, 1996

Government Award for Current Fiscal Year: \$239,353

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Reporting Period: October 1, 1995 - December 31, 1995

Objectives

This multidisciplinary study is designed to provide improvements in advanced reservoir characterization techniques. This goal is to be accomplished through:

1. an examination of the spatial variation and anisotropy of relative permeability in the Tensleep Sandstone reservoirs of Wyoming;
2. the placement of that variation and anisotropy into paleogeographic, depositional, and diagenetic frameworks;
3. the development of pore-system imagery techniques for the calculation of relative permeability;
4. reservoir simulations testing the impact of relative permeability anisotropy and spatial variation on Tensleep Sandstone reservoir enhanced oil recovery; and
5. a geochemical investigation of the spatial and dynamic alteration in sandstone reservoirs that is caused by rock-fluid interaction during CO₂-enhanced oil recovery processes.

Summary of Technical Progress

Regional Frameworks

This research will associate spatial distributions and anisotropy of relative permeability with the depositional subfacies and zones of diagenetic alteration found within the Tensleep Sandstone. The associations between depositional lithofacies, diagenetic alteration, and pore geometry will strongly link relative permeability with the distinct and measurable dimensions of lithofacies and authigenic mineral facies. Effects of the depositional processes and burial diagenesis will be investigated.

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surface intervals are usually paired with bounding surface intervals, and marine intervals are usually paired with marine intervals.

In using data from Tensleep cores, we discovered a similar cyclicity that represents the spacing of some extremely low permeability values in the data. Figure 1B shows the cyclicity that is apparent on large scales in data from the Pitchfork field. Of particular interest are the intervals within a sandstone unit that might point towards important boundaries to flow. Data from the Pitchfork field contains few eolian sandstone intervals that are complete enough and extensive enough to reveal a spatial trend. Figure 1C shows a variogram of one sandstone interval's permeability values. The range in this graph occurs at 8-10 ft. A careful examination of the actual permeability values shows that both high permeability values and lower values that represent bounding surfaces are clustered in zones of 6-10 ft. Therefore the range in this set of data shows a good correlation with boundaries to flow in the Tensleep.

Relative permeability measurements. Relative permeability measurements have continued during the past quarter. Another six samples were completed in the laboratory, representing three horizontal-vertical pairs. Two vertical samples were too tight for our current apparatus (under 1md), so the two corresponding horizontal cores could not be paired. The other pair yielded good results. Other samples have been sent to Tulsa for relative permeability determination in a different apparatus at K&A Labs.

Horizontal Well Production. Production data from Oregon Basin field has been obtained in order to examine the results from horizontal drilling in a mature Tensleep waterflood project. Marathon has completed a number of horizontal wells in the Tensleep, but only one well has produced long enough to project stabilized rates. The production increase due to horizontal drilling is significant for only a few months. An accompanying decrease in the water-oil production ratio is also considered desirable, yet returns to original rates after a few months. Such behavior can be explained by changing the flooding direction and displacing additional oil due to relative permeability anisotropy. The process is possibly similar to hydraulic washing, where various directions of flow are utilized to achieve complete removal of wastes. In the oil field, additional oil is recovered when new flow directions are first introduced. Then the system again stabilizes at rates similar to before the direction change. Bedding and bounding surfaces within the Tensleep are acting as directional baffles to flow. Localized flow direction changes do occur when a horizontal well is put into production. These changes recover additional oil and temporarily drop the water-oil production ratio as observed in the Oregon Basin field.

CO₂ Flood -- Formation Alteration and Wellbore Damage

The work of this task is to establish criteria for susceptibility of Tensleep reservoirs to formation alteration resulting in a change in absolute or relative permeability and possible wellbore scale damage during CO₂ enhanced oil recovery. This advanced reservoir characterization technology will be used to optimize recovery efficiency. This task includes: (a) flow experiments on core material to examine the effects of CO₂ flooding on the alteration of the fluid and rock system; (b) examination of regional trends in water chemistry; (c) examination of local water chemistry trends at field scale; and (d) chemical modeling of both the reservoir and experimental systems in order to scaleup the experiments to reservoir conditions.

A. Synthetic permeability data, md

Parameters

Pairs: 5161
Direct: 0.0
Tol.: 90.0
MaxBand: n/a

Data statistics

Minimum: 0.1
Maximum: 349.9
Mean: 178.8
Variance: 11328

B. All permeability data, md; Pitchfork No. 87

Parameters

Pairs: 16085
Direct: 0.0
Tol.: 90.0
MaxBand: n/a

Data statistics

Minimum: 0.0
Maximum: 680.0
Mean: 122.4
Variance: 14230

C. Eolian sandstone interval permeability, md; Pitchfork No. 87

Parameters

Pairs: 810
Direct: 0.0
Tol.: 90.0
MaxBand: n/a

Data statistics

Minimum: 0.0
Maximum: 680.0
Mean: 152.2
Variance: 15918

Fig. 1. Variograms of paired permeability data versus increasing distance (h).