

Crosswell Seismic in Carbonate Reservoirs – Examples of High-Resolution Reservoir Delineation*

By
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Search and Discovery Article #40307 (2008)
Posted September 3, 2008

*Adapted from oral presentation at AAPG International Conference & Exhibition, Barcelona, Spain, September 21-24, 2003. See companion article, “Carbonate Reservoir Delineation from Seismic Data – Examples of Crosswell Seismic,” Search and Discovery Article #40299 (2008).

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Abstract

Crosswell seismic tomography provides better reservoir resolution than surface 2D or even 3D data; therefore, there should be value added in reservoir delineation. Examples of crosswell seismic data from two U.S. Permian Basin fields illustrate the resolution and some potential applications of this type of data: (1) defining greater geologic detail between wells (heterogeneity of reservoir), (2) recognizing laterally continuous zones for improved development (well positioning, completions, injection), and (3) input for reservoir models (layering and assigning porosity).

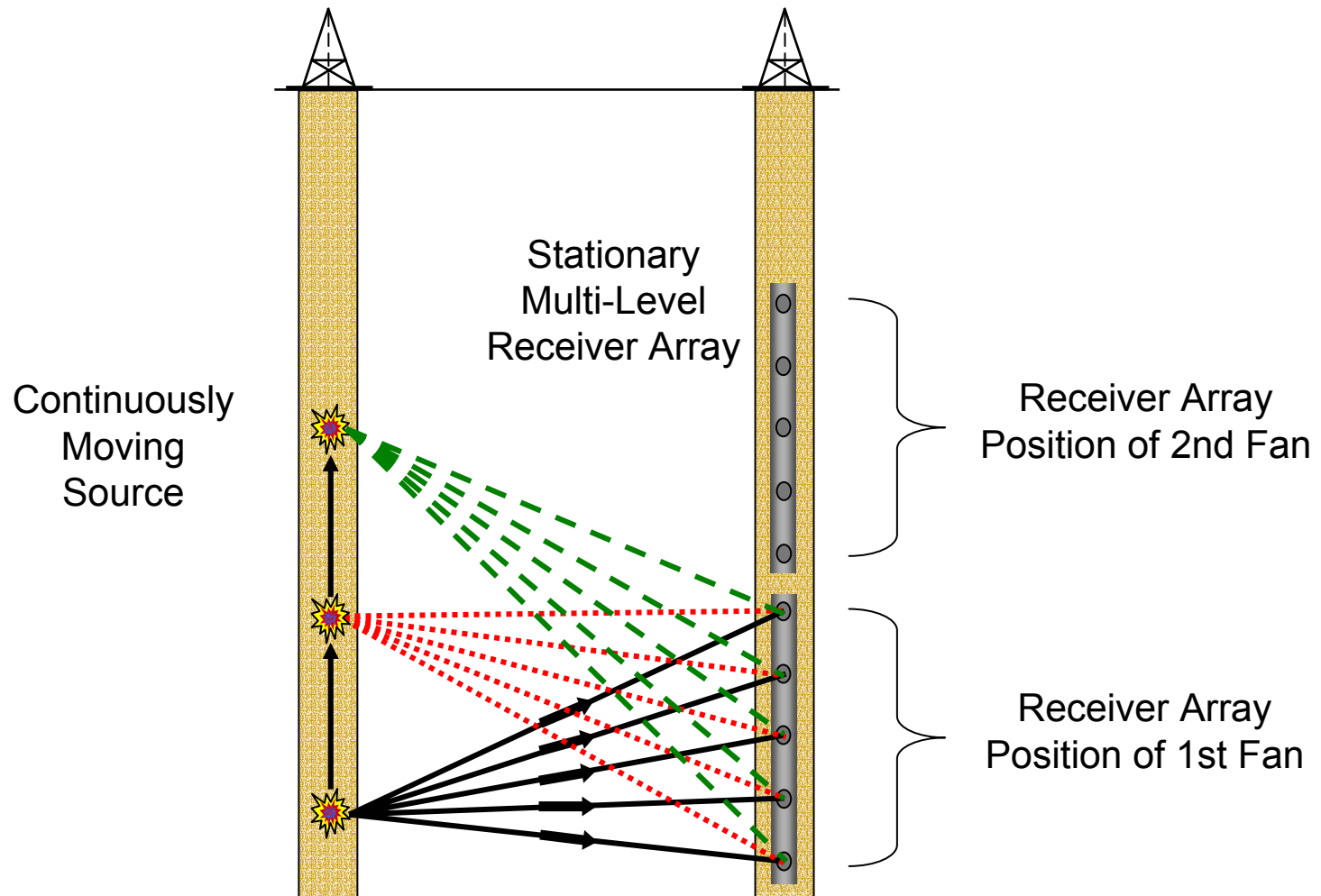
In the first example, the producing formation is limestone with minor dolomite and shale. 3D seismic and downhole log data suggest lateral discontinuities, but details are ambiguous due to the poor resolution. Crosswell data defines the nature of some of the reservoir discontinuity, in that clinoforms which are imaged can potentially isolate reservoir compartments. A comparison with outcrop facies geometries provides some sense of the reservoir facies to be expected between wells.

The second example is a diagenetically complex cyclic shelf dolomite. Variations in amplitude on the crosswell data are the most striking lateral features, and nearly every positive-amplitude event coincides with a significant increase in velocity on sonic logs. Both the seismic and log data respond to the same diagenetic overprint and its resulting petrophysical characteristics; therefore, log-derived facies relate to the crosswell data better than core lithofacies. Comparing crosswell data with geostatistical porosity models to further analyze the potential imaging of lateral porosity variation suggests lateral changes in porosity of less than 56 m but more than 15 m are being imaged.

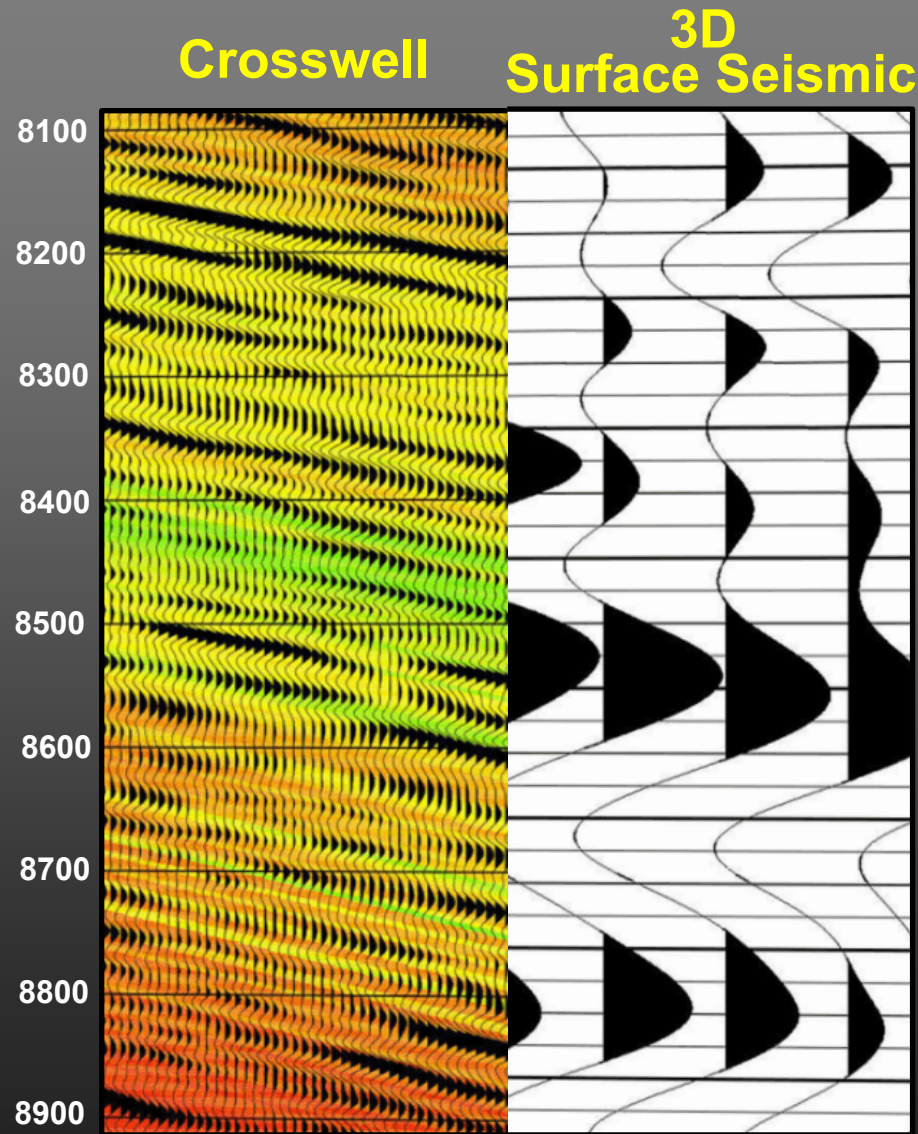
CROSSWELL SEISMIC IN CARBONATE RESERVOIRS – EXAMPLES OF HIGH-RESOLUTION RESERVOIR DELINEATION

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DATA ACQUISITION



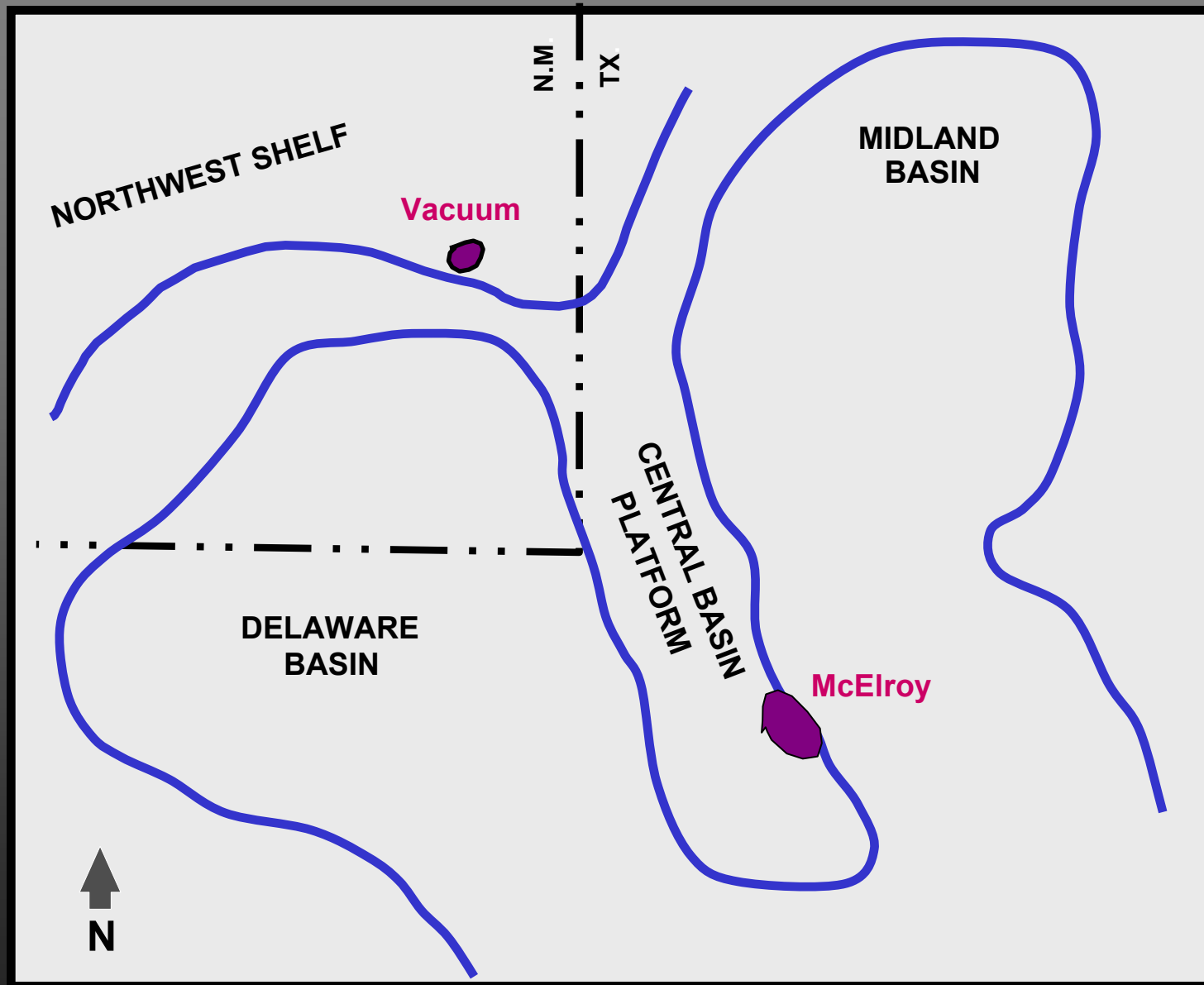
DATA RESOLUTION



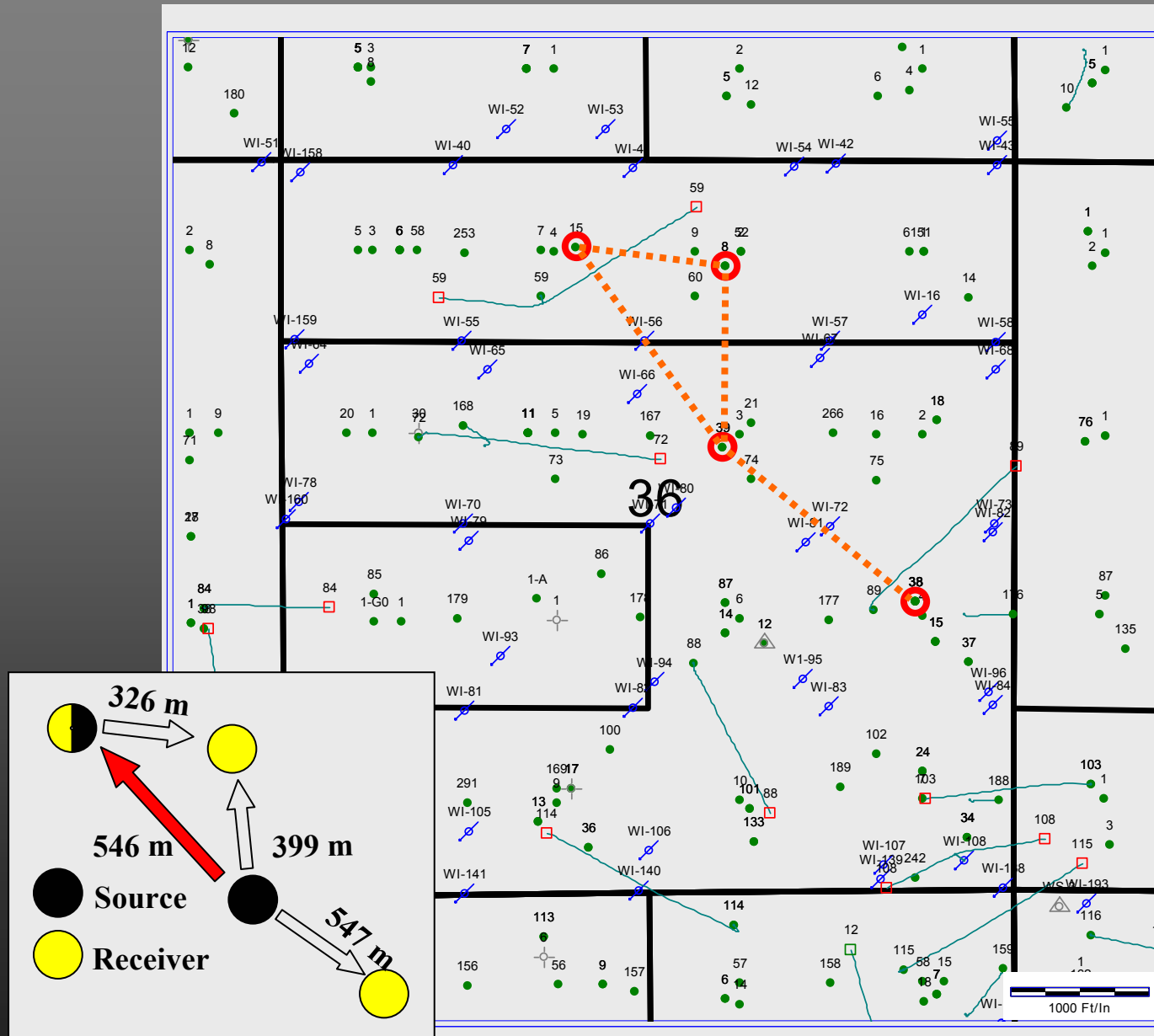
CROSSWELL SEISMIC APPLICATIONS

- *Reservoir Characterization*
 - *Detailed stratigraphy and structure*
 - *Precise tie to logs and cores*
 - *Facies inference*
 - *Static properties*
- *Reservoir Monitoring*
 - *Time-lapse monitoring*
 - *Dynamic properties*
- *Surface Seismic Calibration / Alternative*
 - *Velocity/anisotropy determination*
 - *Shoot below surface problems*

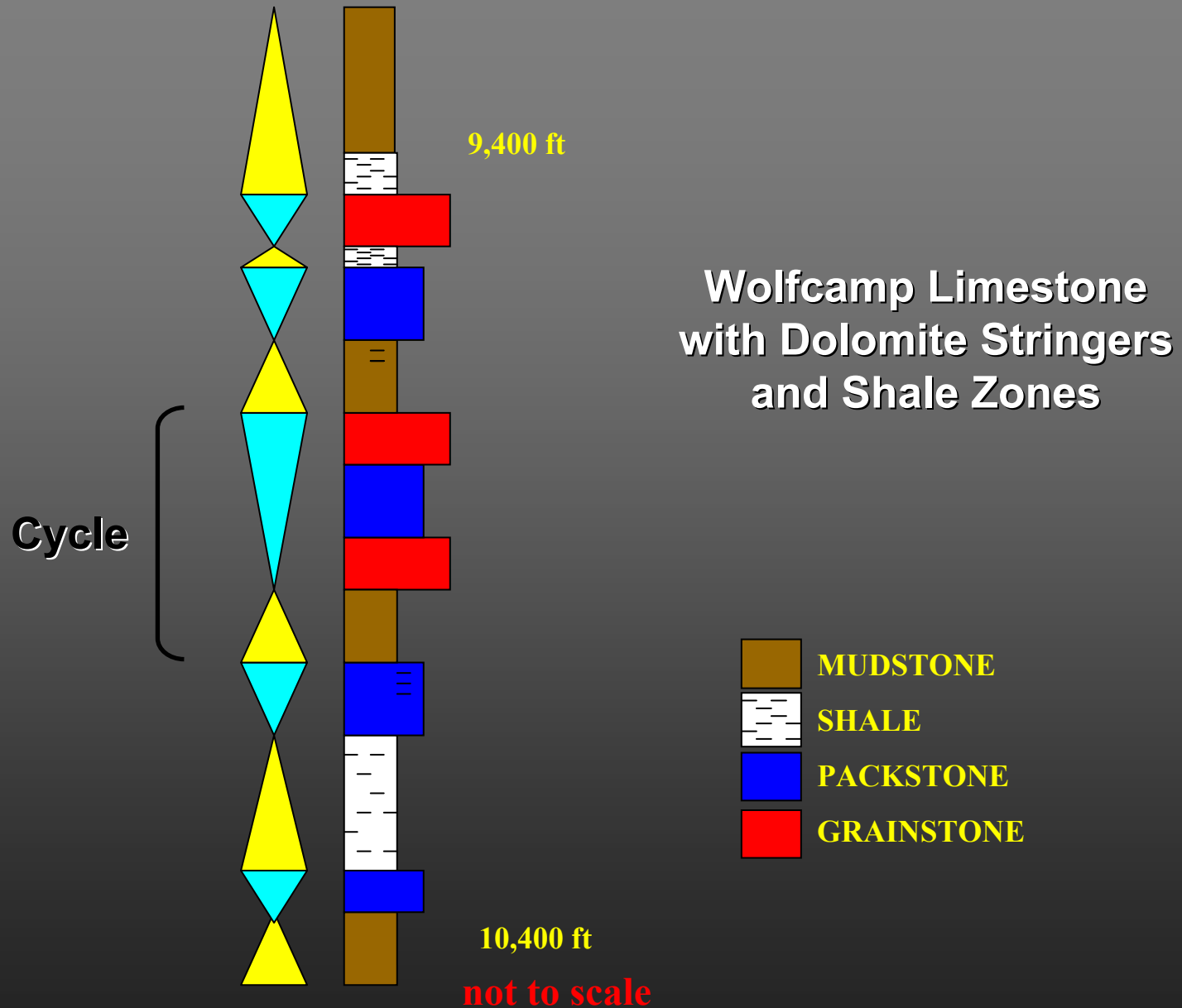
CASE STUDIES



DATA ACQUISITION IN VACUUM

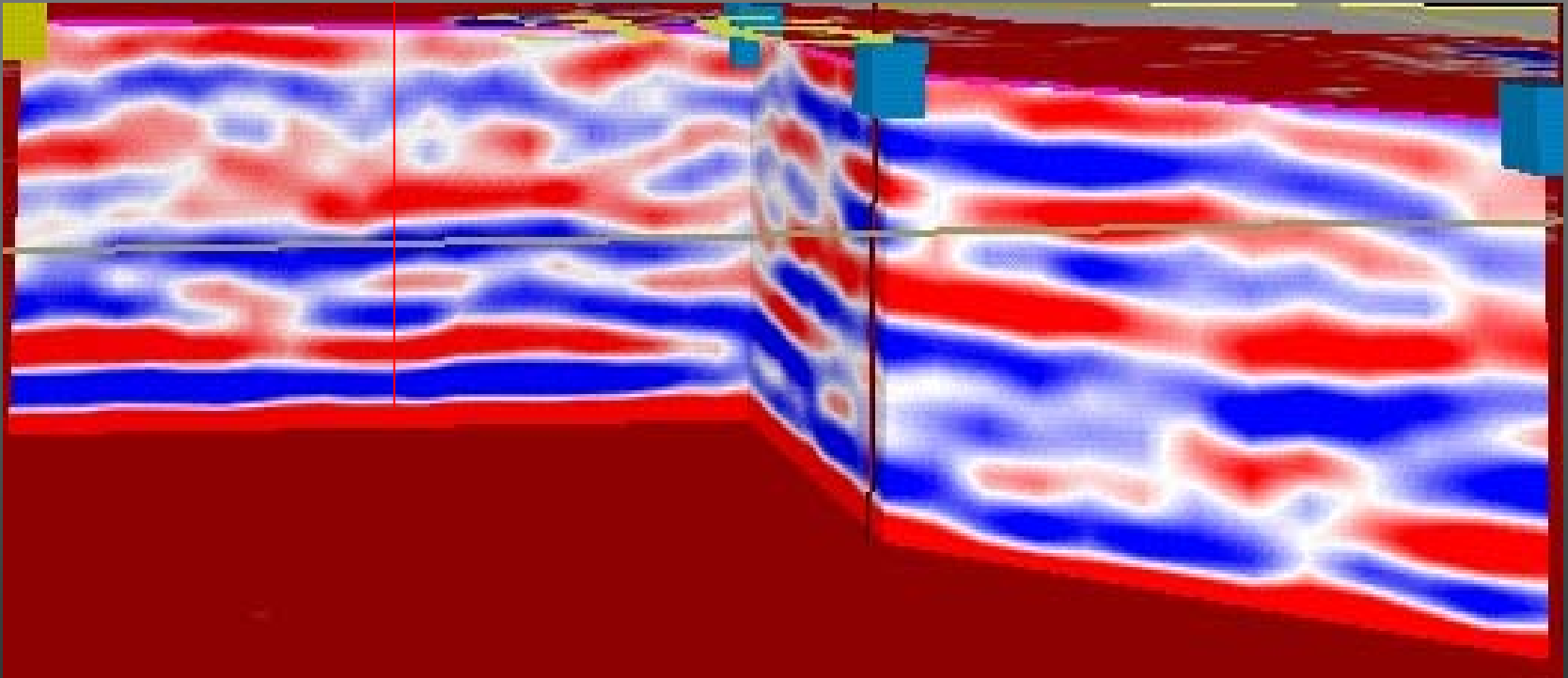


GENERALIZED STRATIGRAPHY



SURFACE 3D SEISMIC

Key Well
With Core

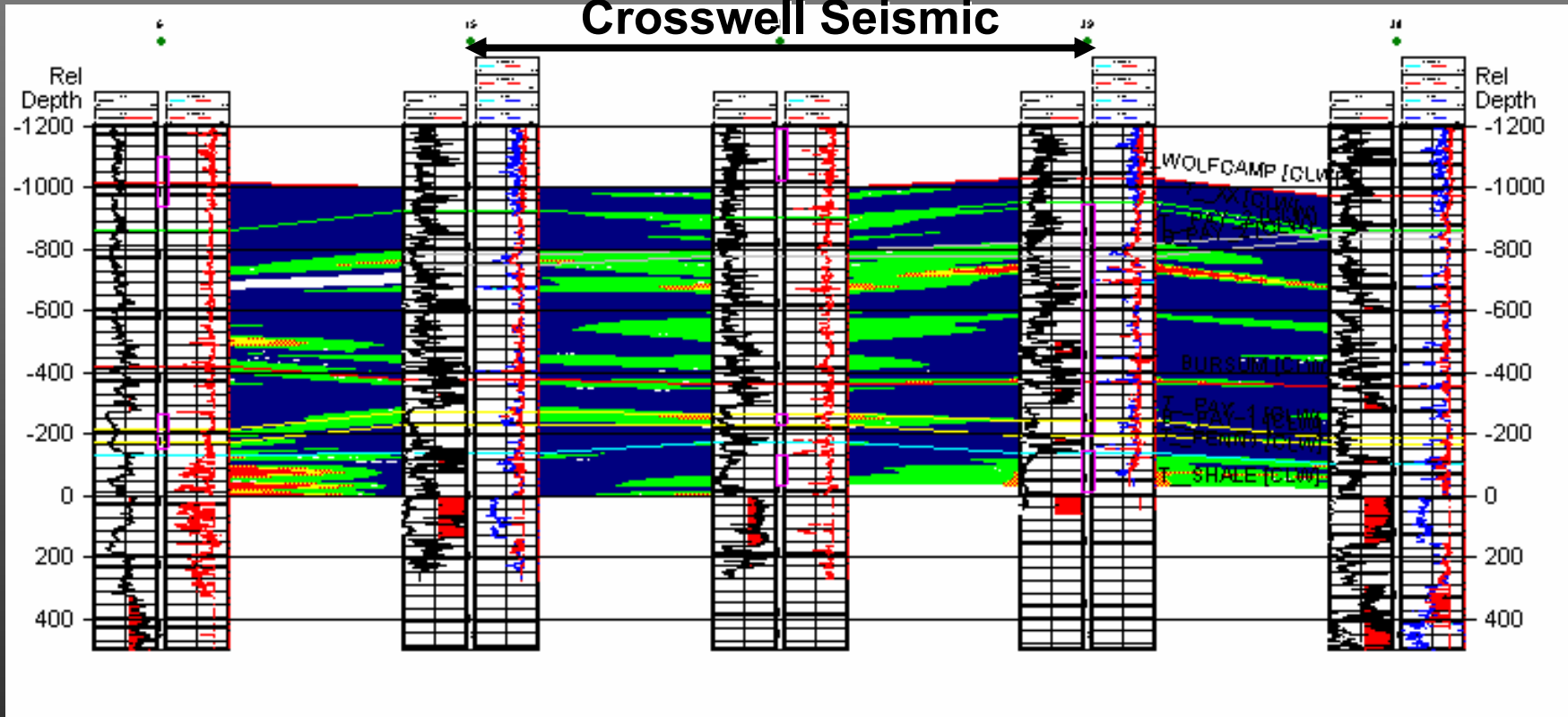


Poor Resolution of Reservoir Discontinuity

POROSITY DISTRIBUTION

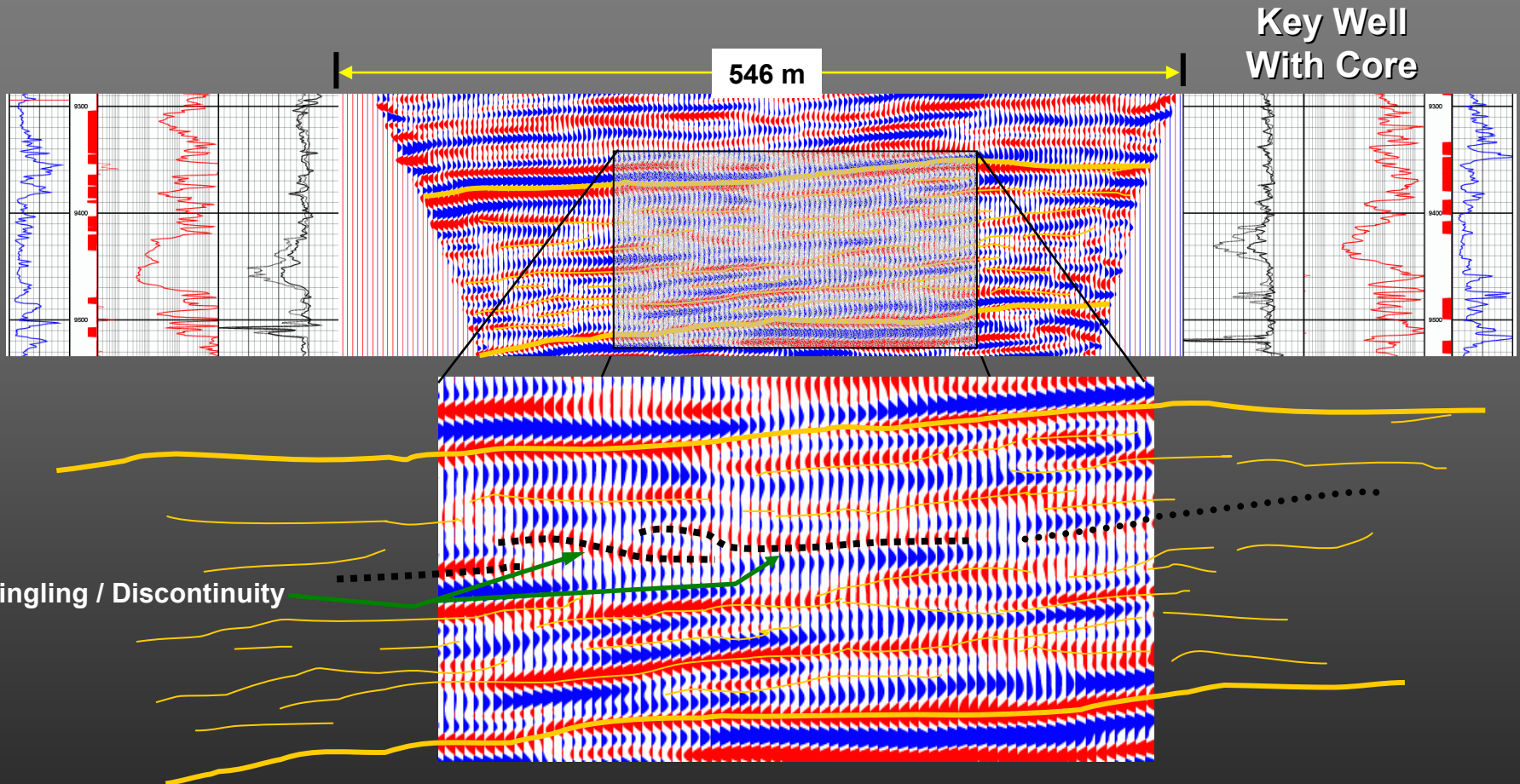
Key Well
With Core

Crosswell Seismic



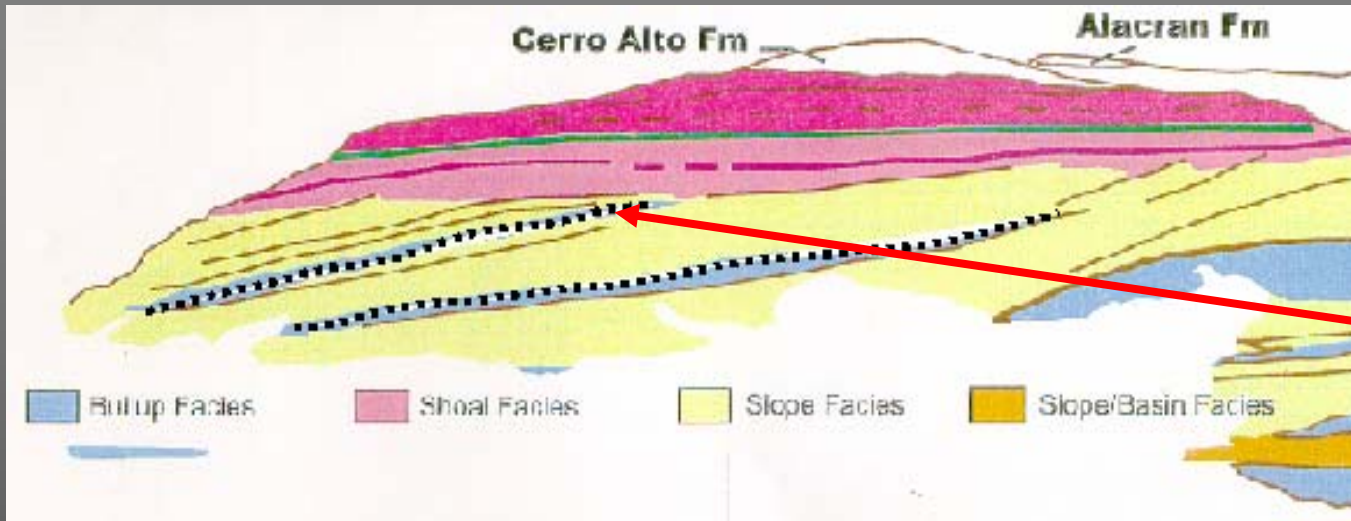
Discontinuous Pay Zones and Questionable Correlation

HIGH RESOLUTION FEATURES

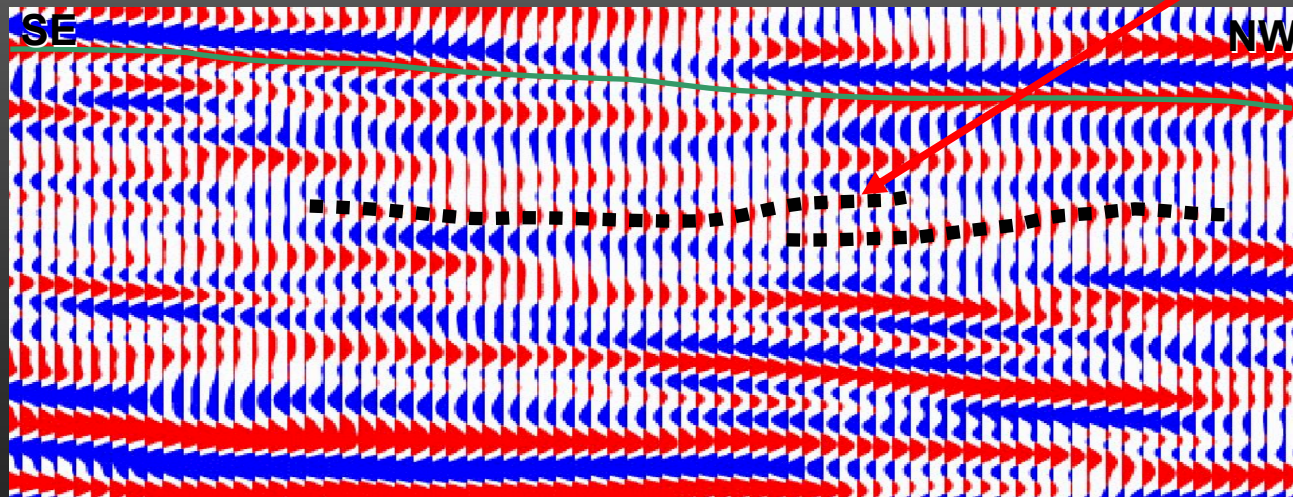


Zones May Be Isolated by Clinoforms

OUTCROP-SCALE RESOLUTION



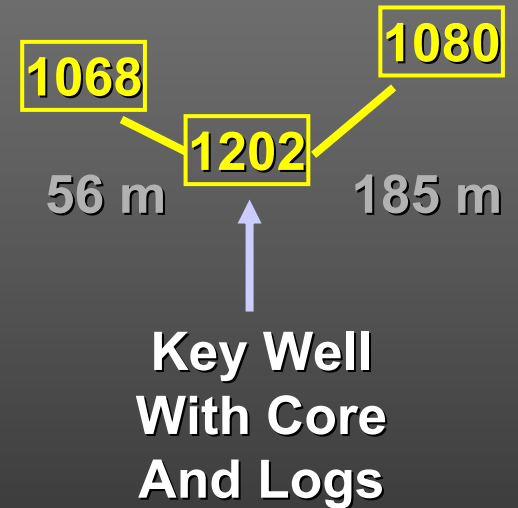
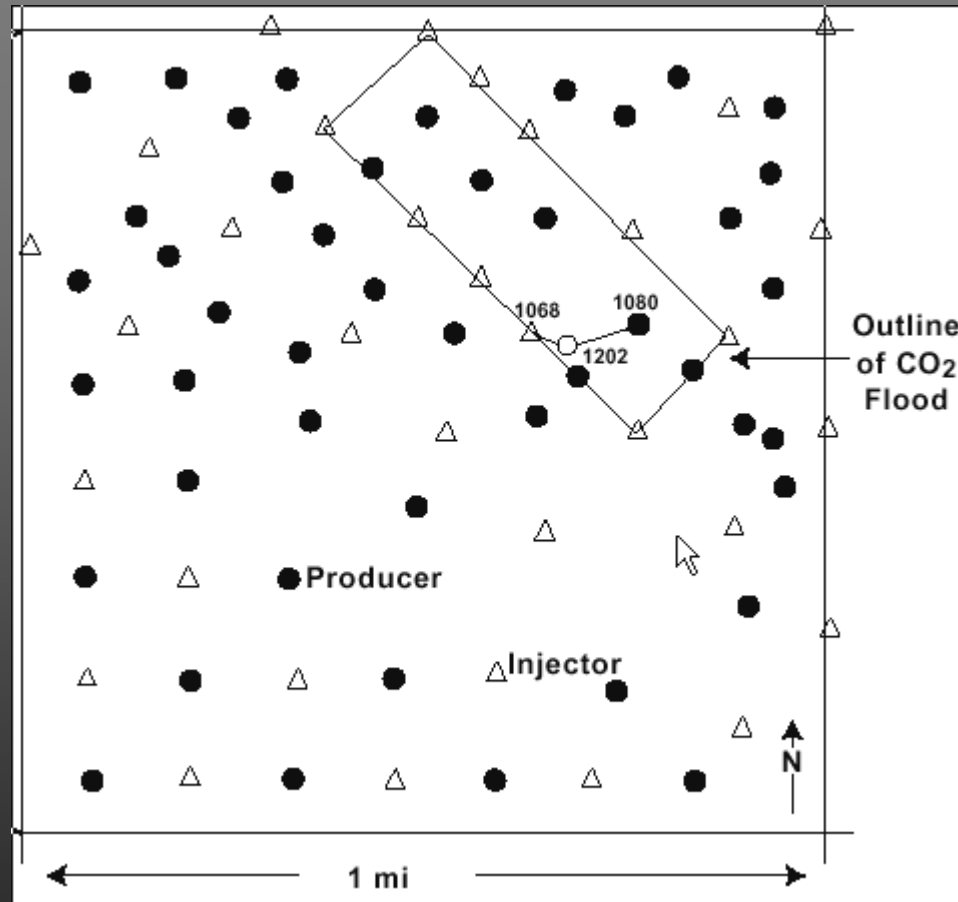
Climoforms
believed to
represent
similar
environments



Key Well
With Core

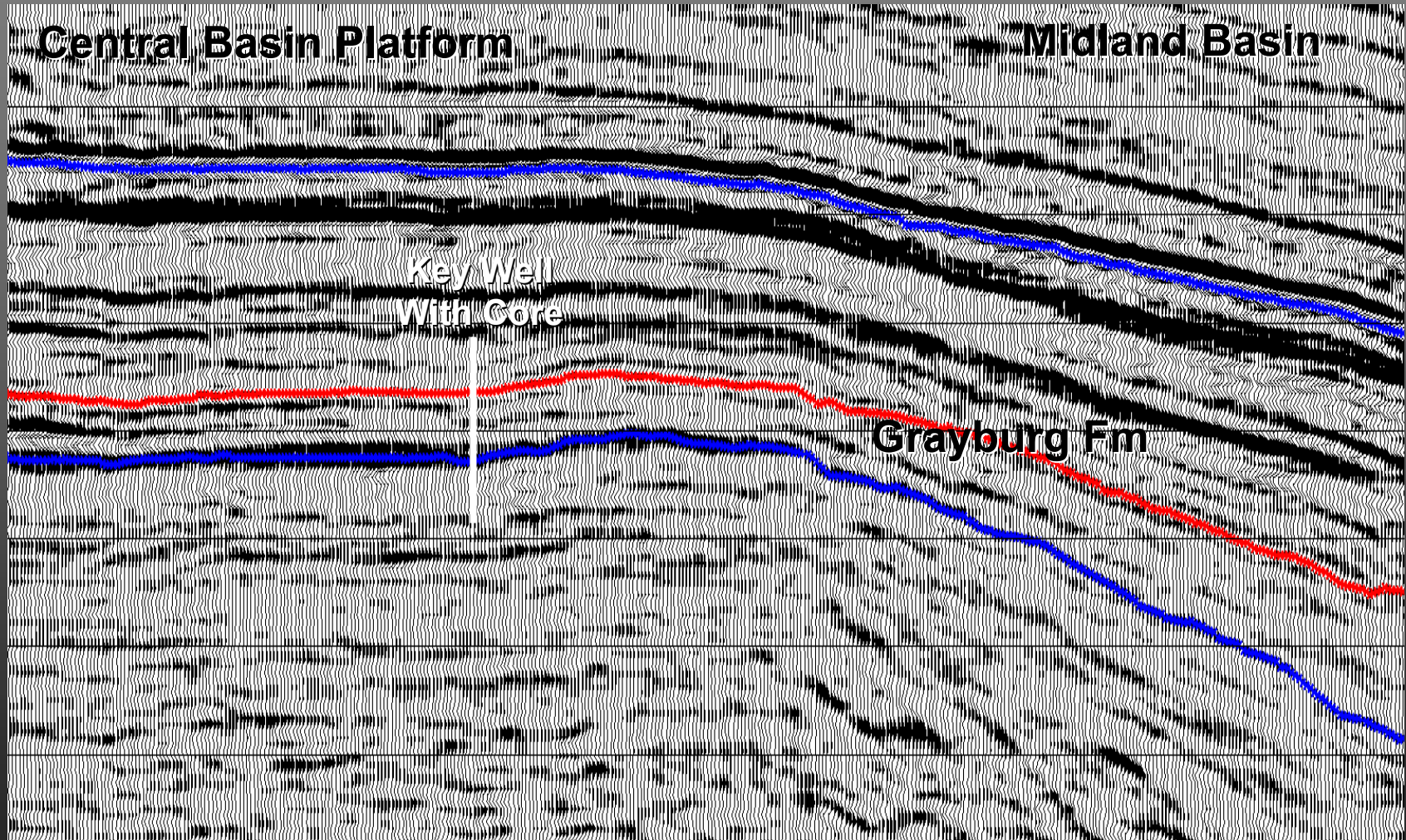
AFTER MARTIN ET AL, 2002

DATA ACQUISITION IN MCELROY

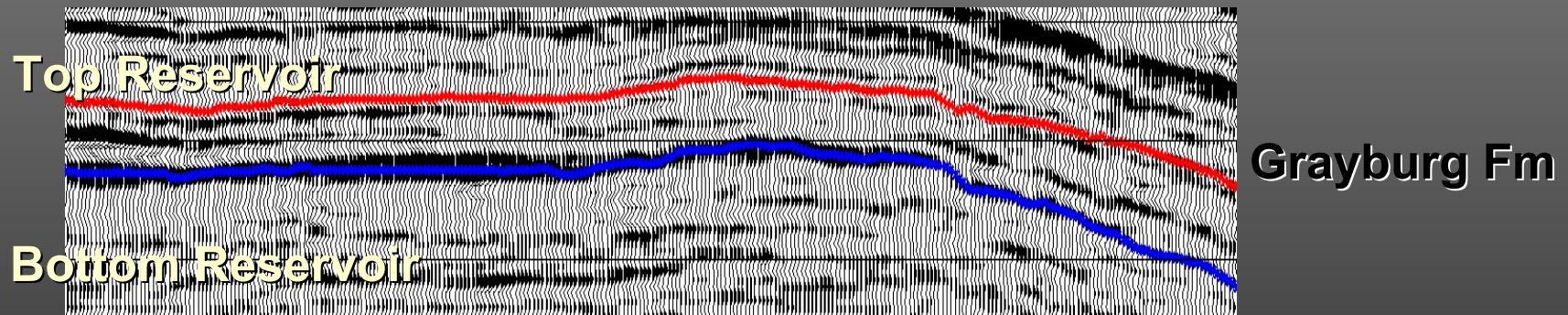


AFTER TUCKER ET AL, 1998

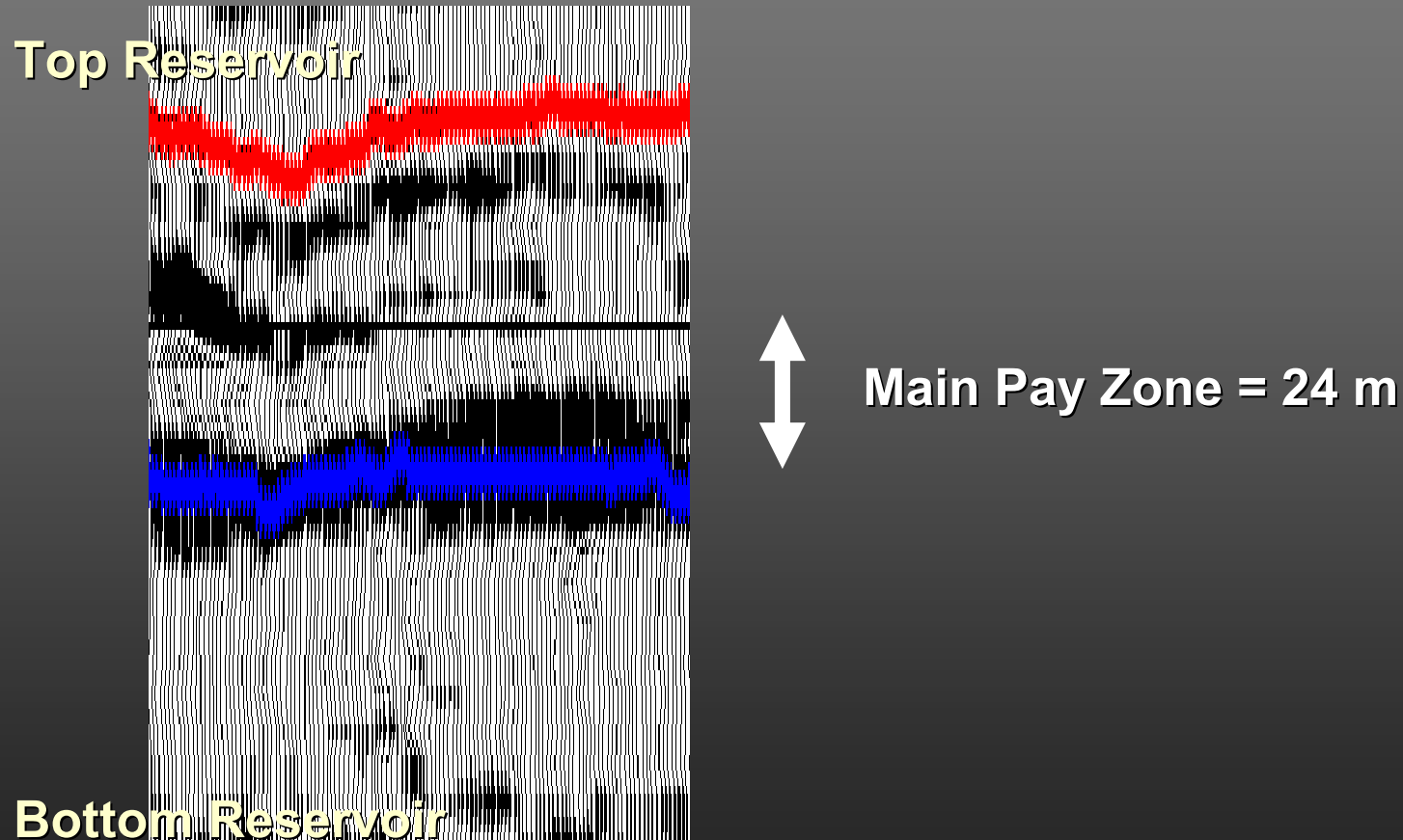
SURFACE 3D SEISMIC



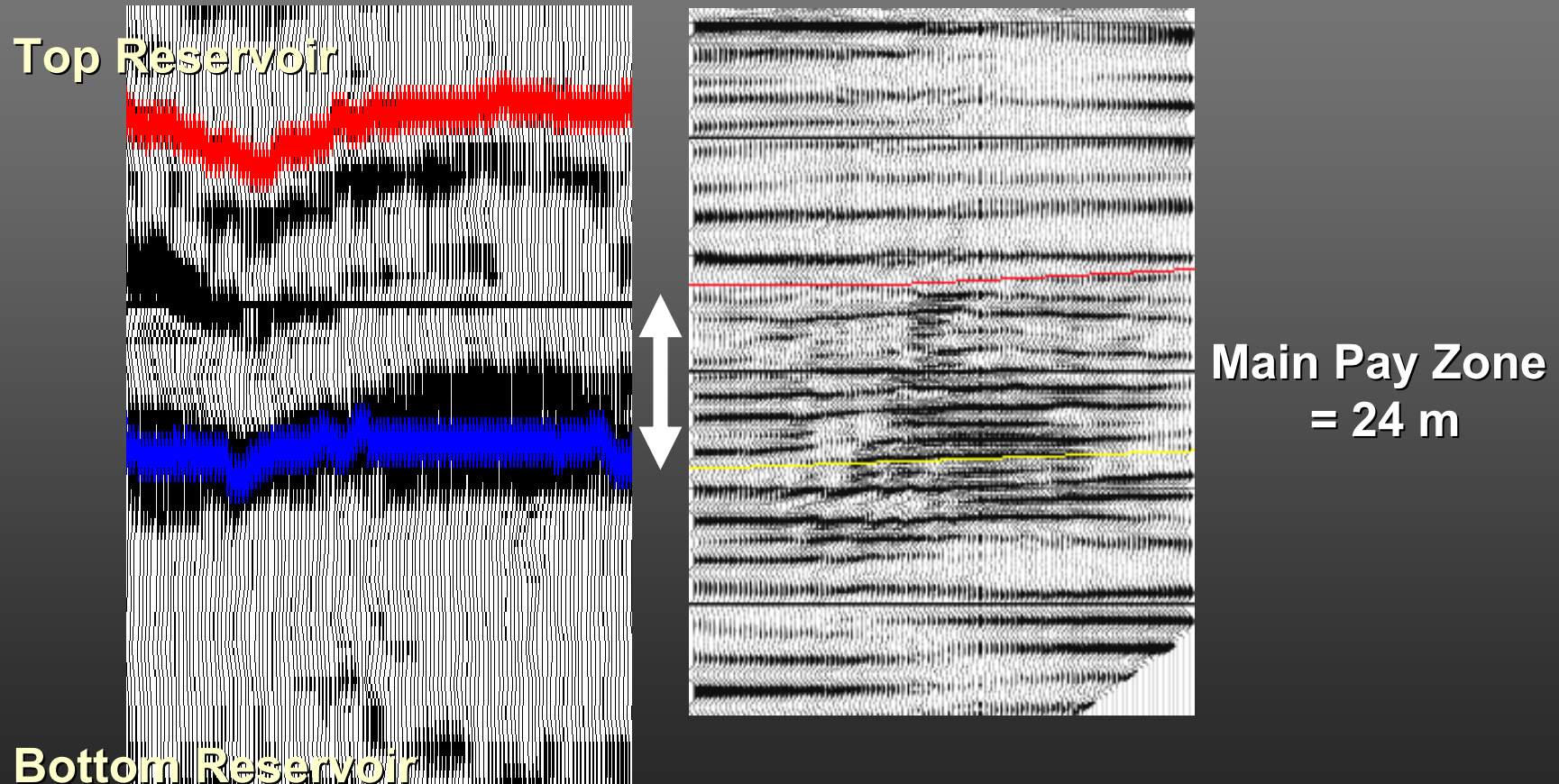
SURFACE 3D SEISMIC RESERVOIR INTERVAL



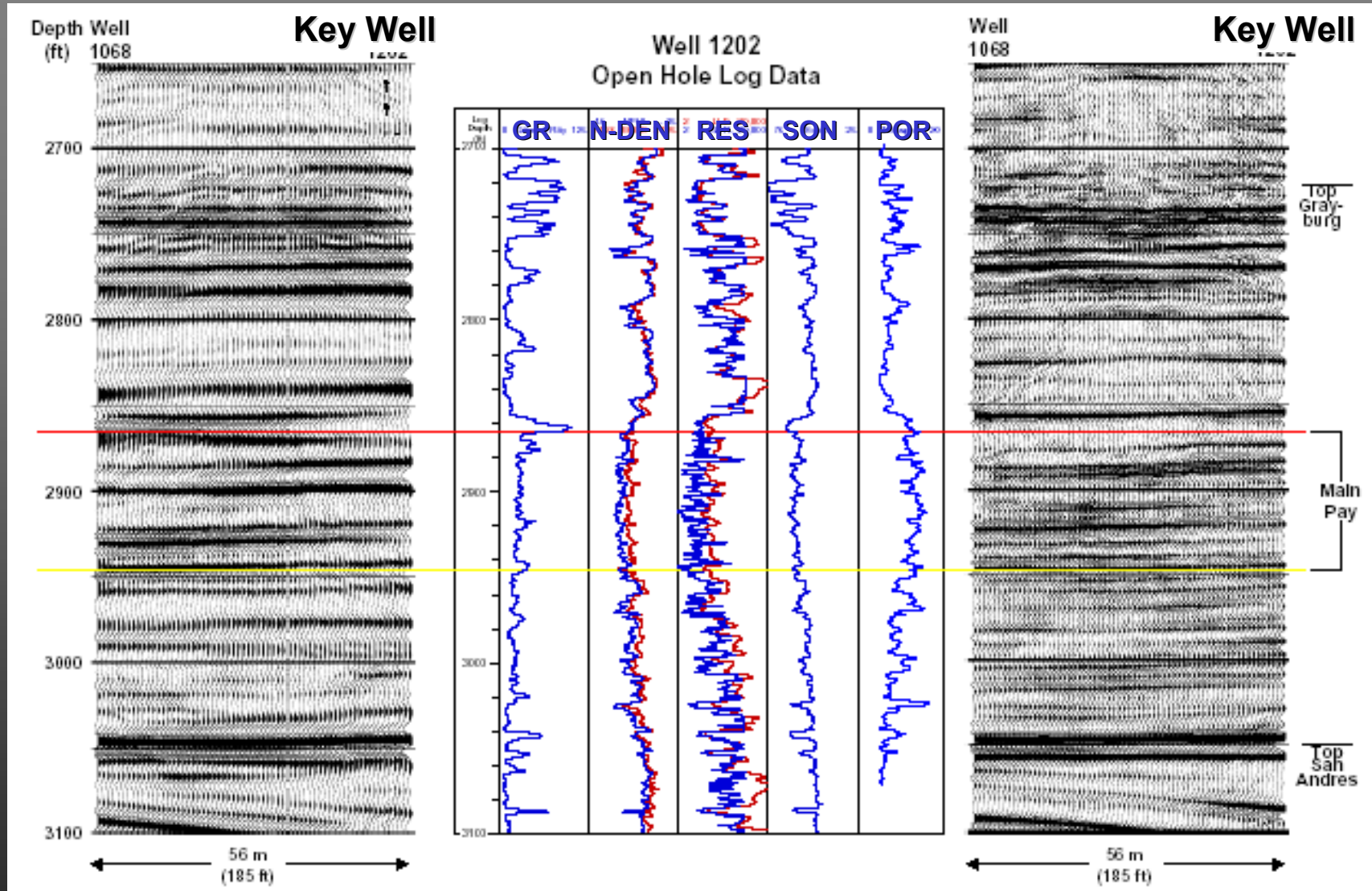
SURFACE 3D SEISMIC RESERVOIR INTERVAL EXPANDED



COMPARISON OF SURFACE 3D AND CROSSWELL SEISMIC



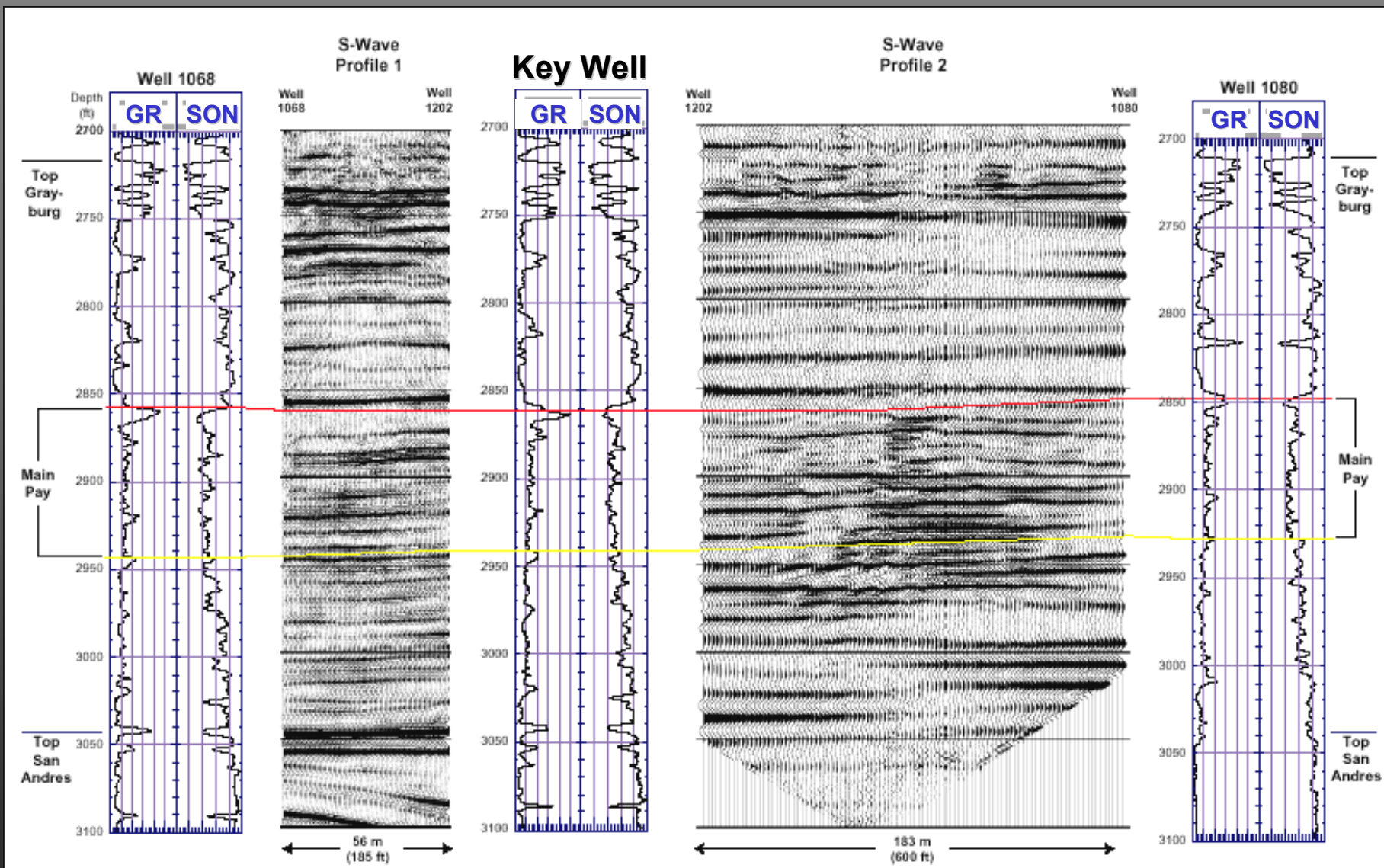
CROSSWELL SEISMIC AND LOGS



AFTER TUCKER ET AL, 1998

Reflectors = Increases in Sonic, Resistivity, and Bulk Density, also Decreases on Neutron from High to Low Porosity (or Gypsum)

INTERWELL VARIATION

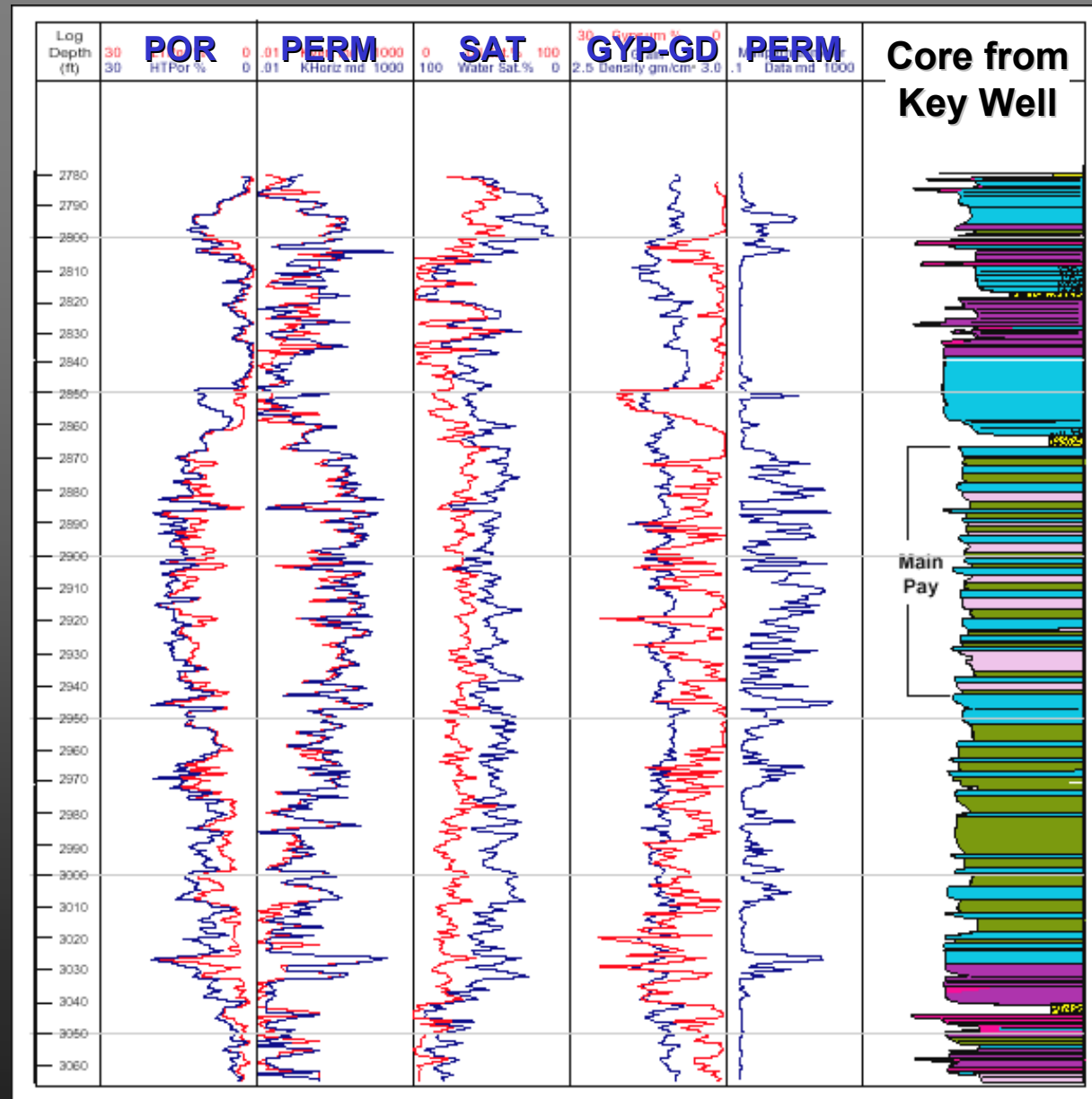


AFTER TUCKER ET AL, 1998

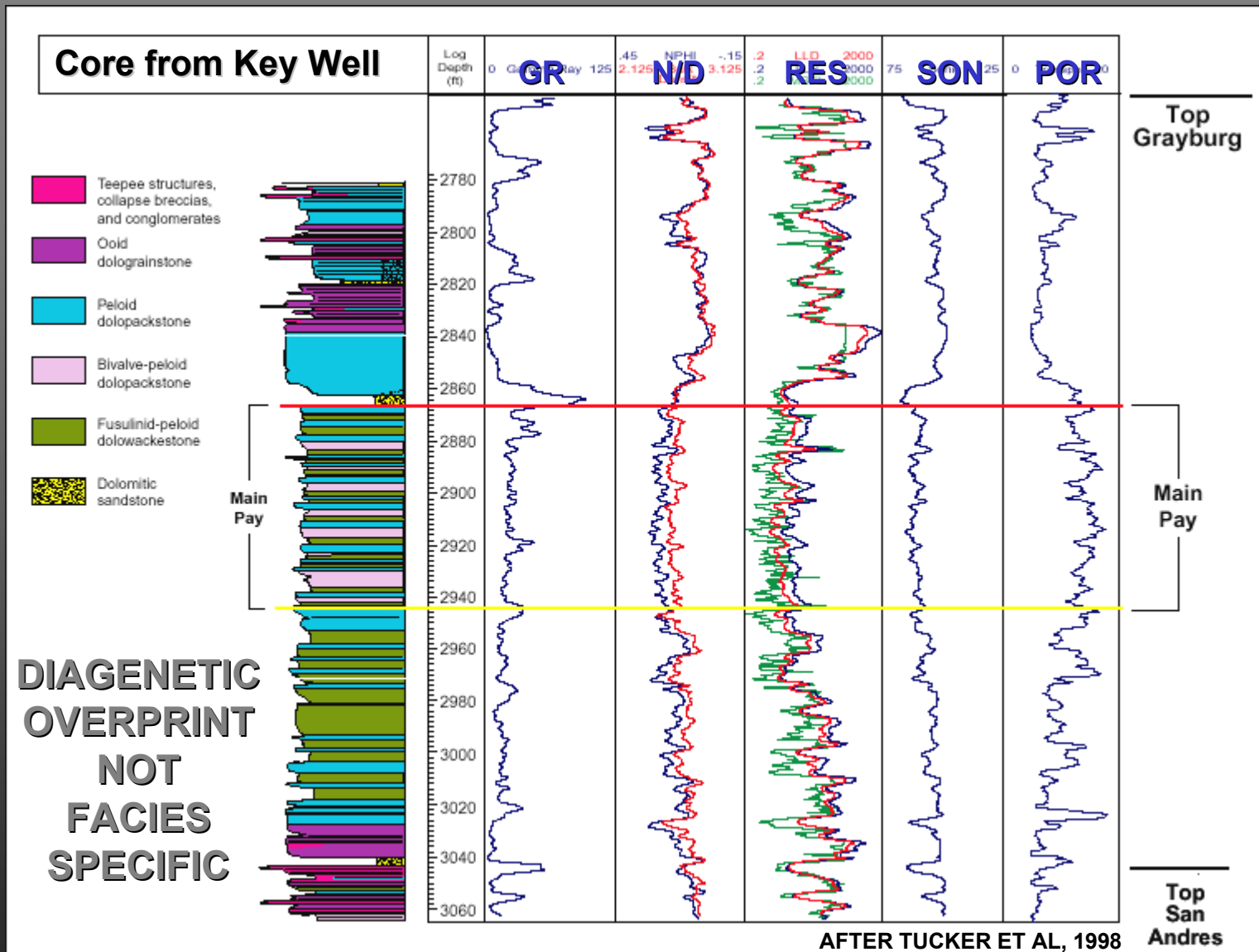
Reflectors, Along With GR and Sonic Log, Suggest Interwell Variation

RESERVOIR QUALITY AND FACIES

Poor Correlation
Between Measured
Variables and Core-
Based Lithofacies

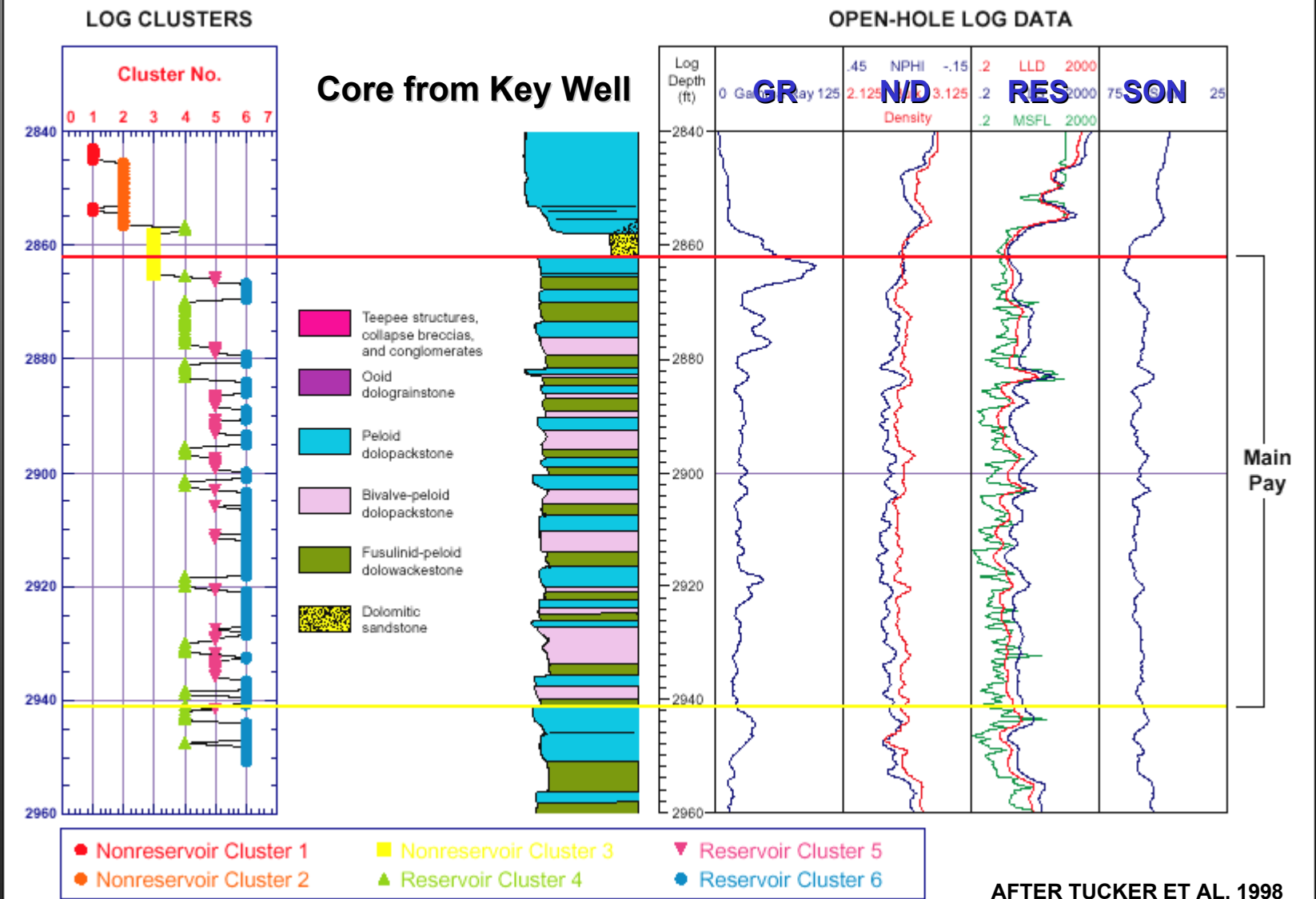


DOWNHOLE LOGS AND FACIES



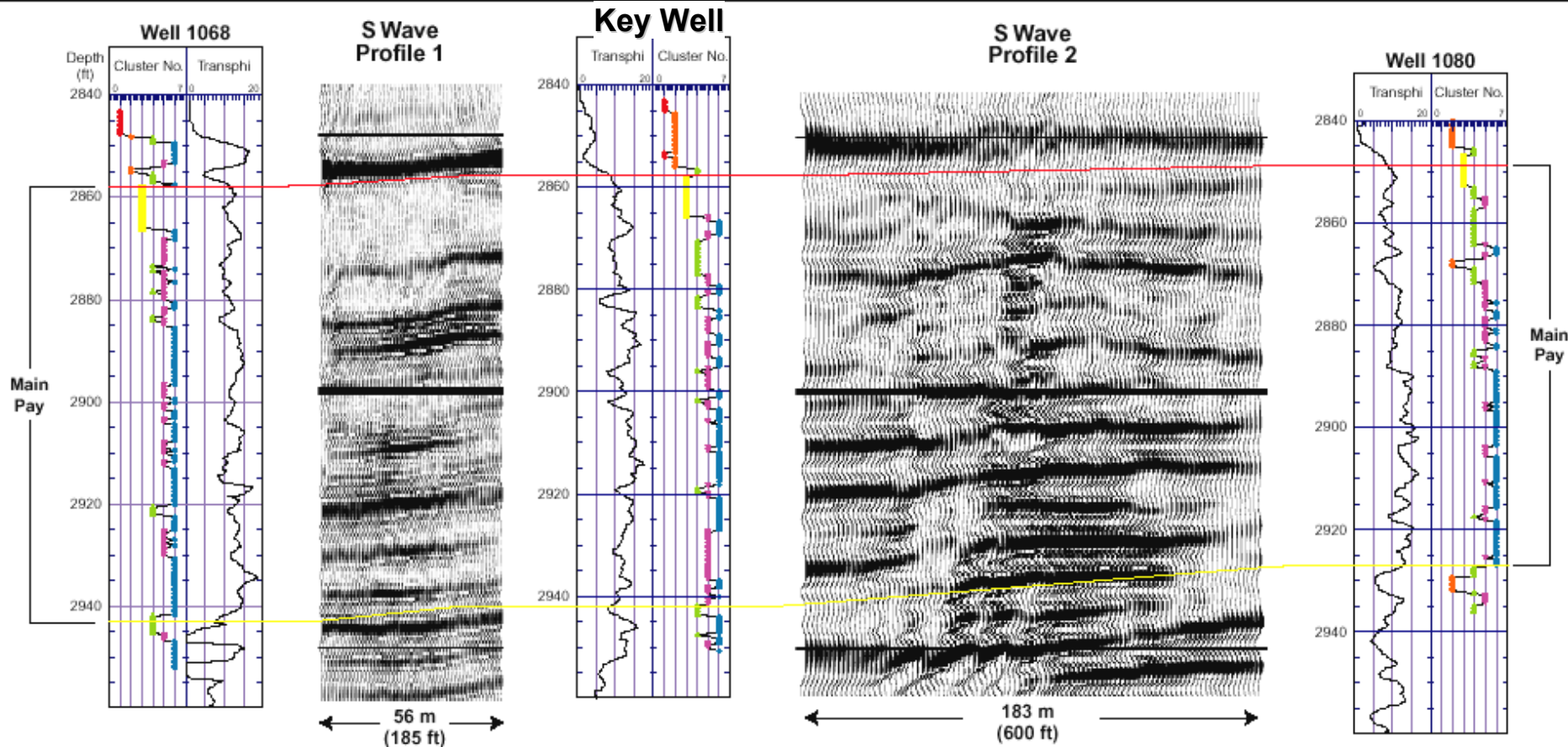
Poor Correlation Between Logs and Core- Based Lithofacies

LOG-BASED FACIES



Log-based Clusters Do Not Consistently Match Core Facies

LOG FACIES

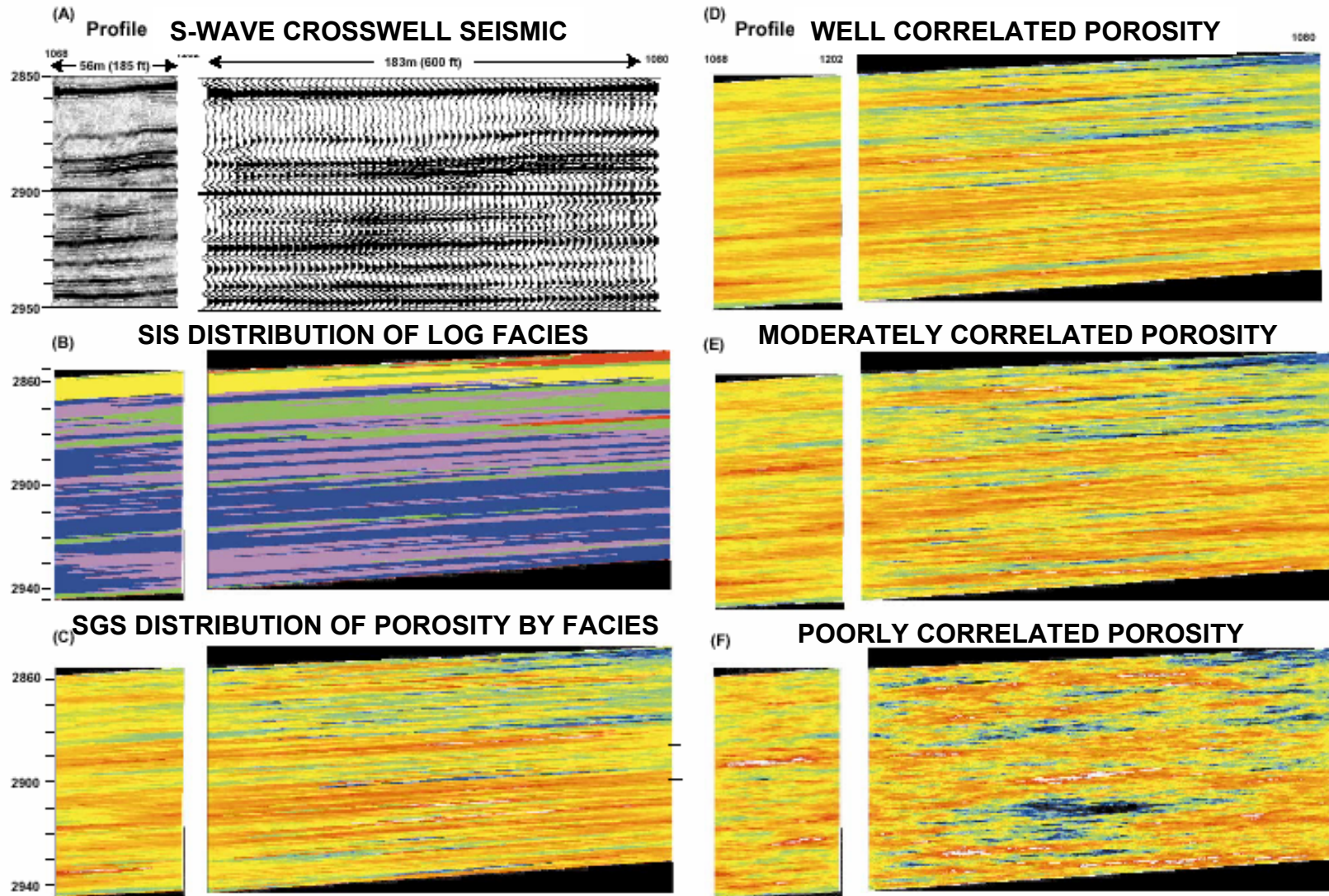


AFTER TUCKER ET AL, 1998

Log Facies Better Relate to Porosity and Seismic Reflections

LATERAL RESOLUTION

VALUE IN LAYERING AND ASSIGNING POROSITY TO MODEL

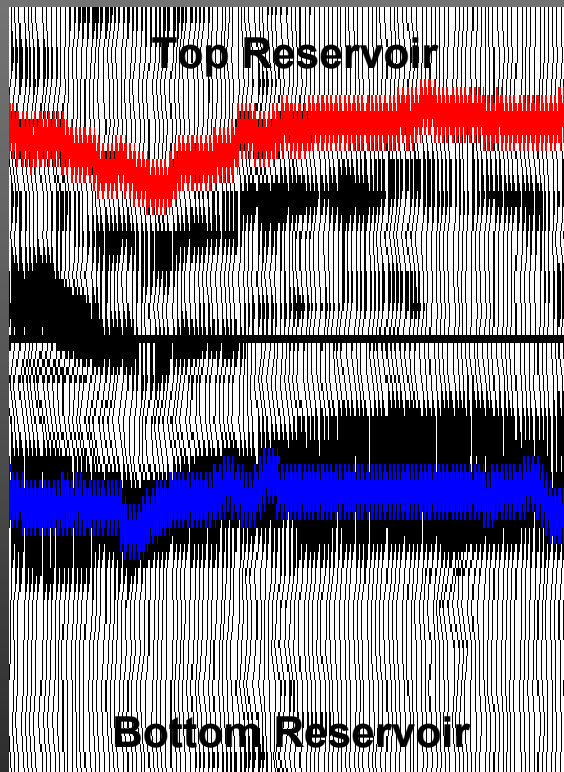


AFTER TUCKER ET AL, 1998

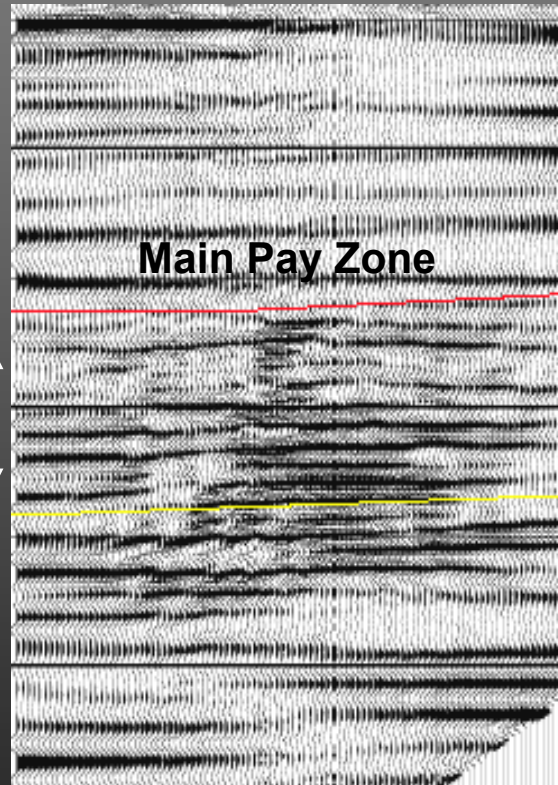
Images Resolve Lateral Changes in Porosity <56 m but >15 m

COMPARISON OF SEISMIC AND OUTCROP

SURFACE SEISMIC



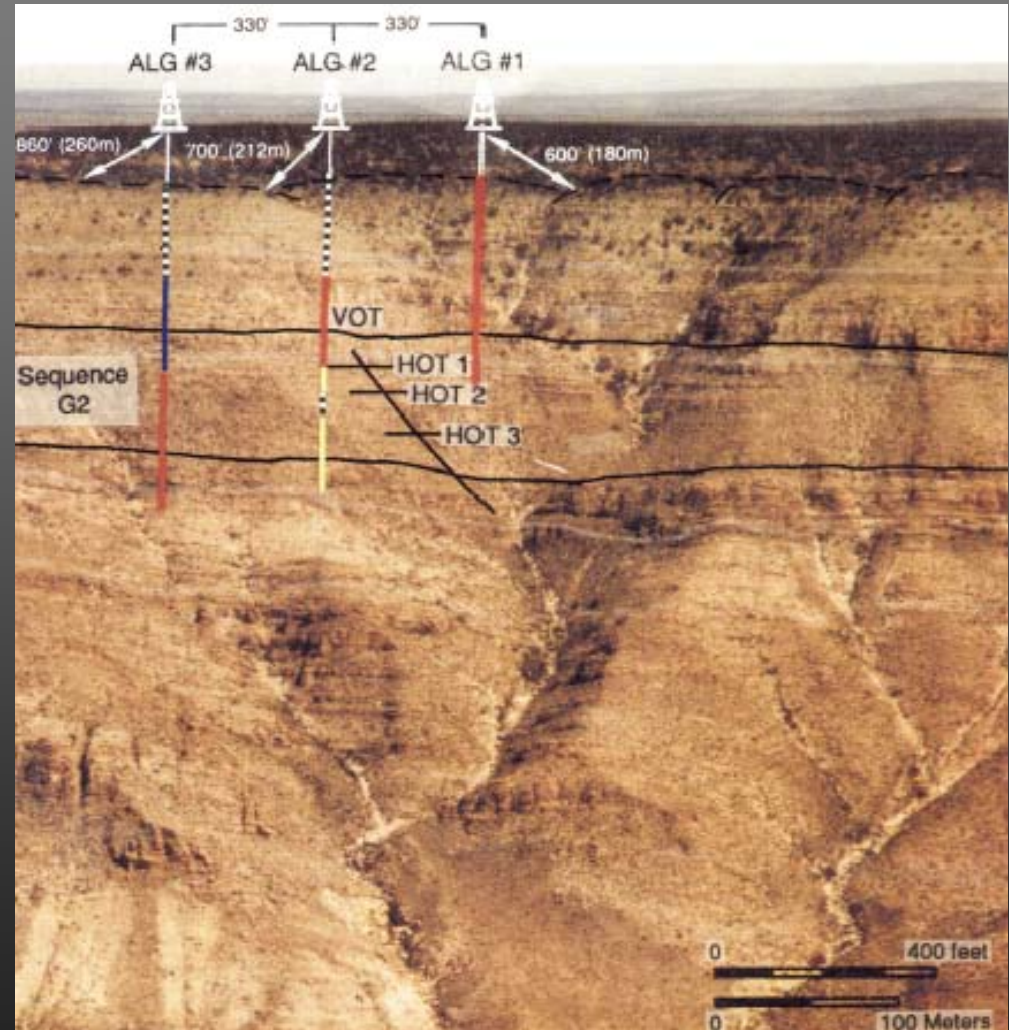
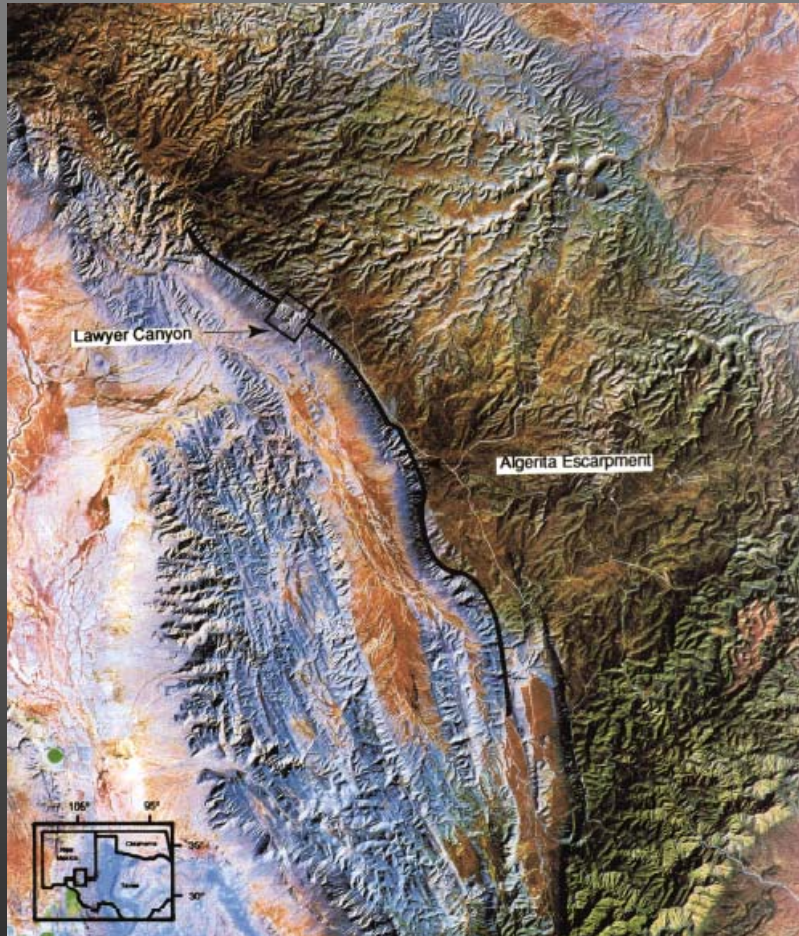
CROSSWELL SEISMIC



OUTCROP

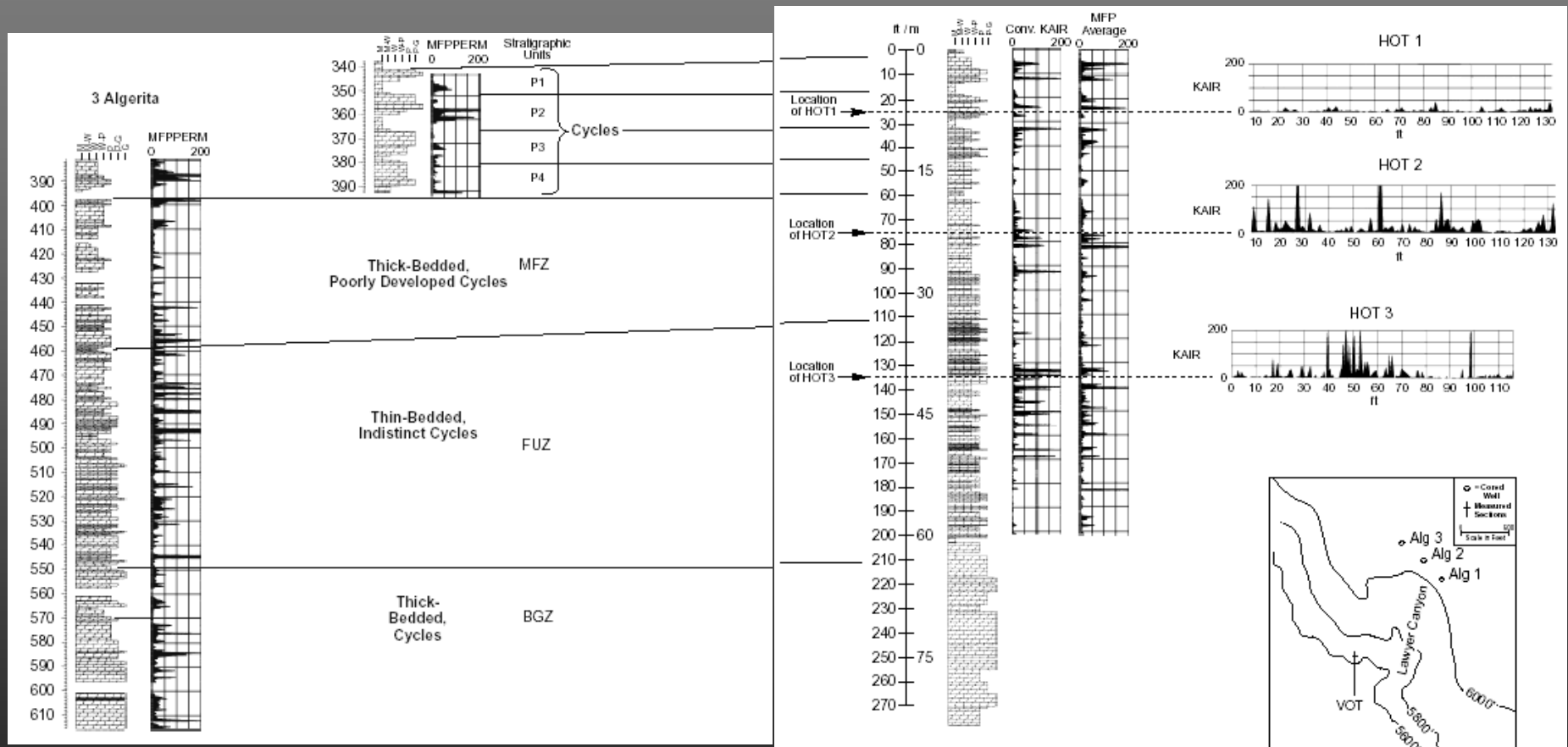


RESERVOIR-SCALE HETEROGENEITY STUDIES ON OUTCROP



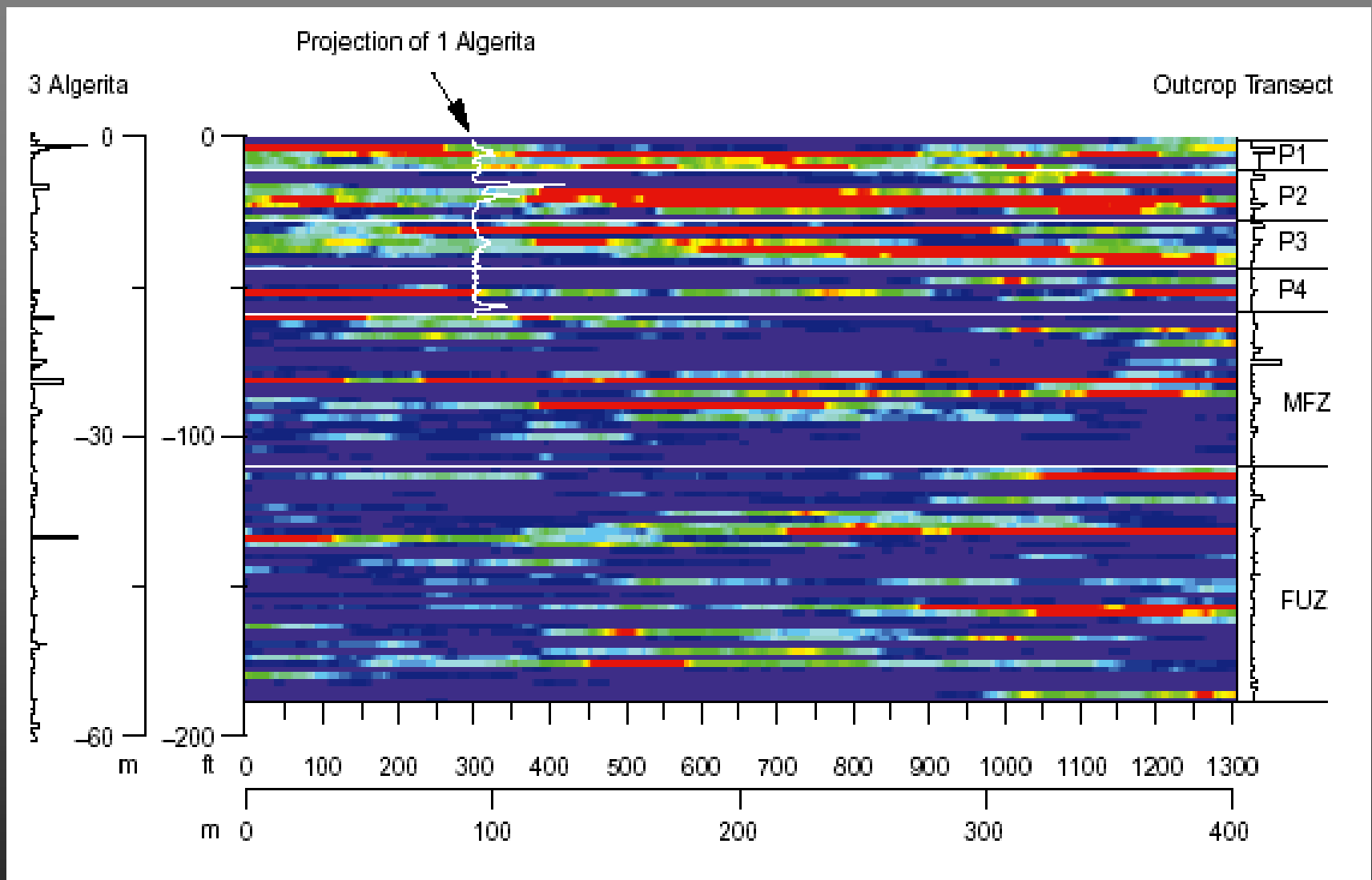
AFTER EISENBERG ET AL, 1994

STRATIGRAPHY, FACIES, AND PERMEABILITY



AFTER EISENBERG ET AL, 1994

MODELING PERMEABILITY

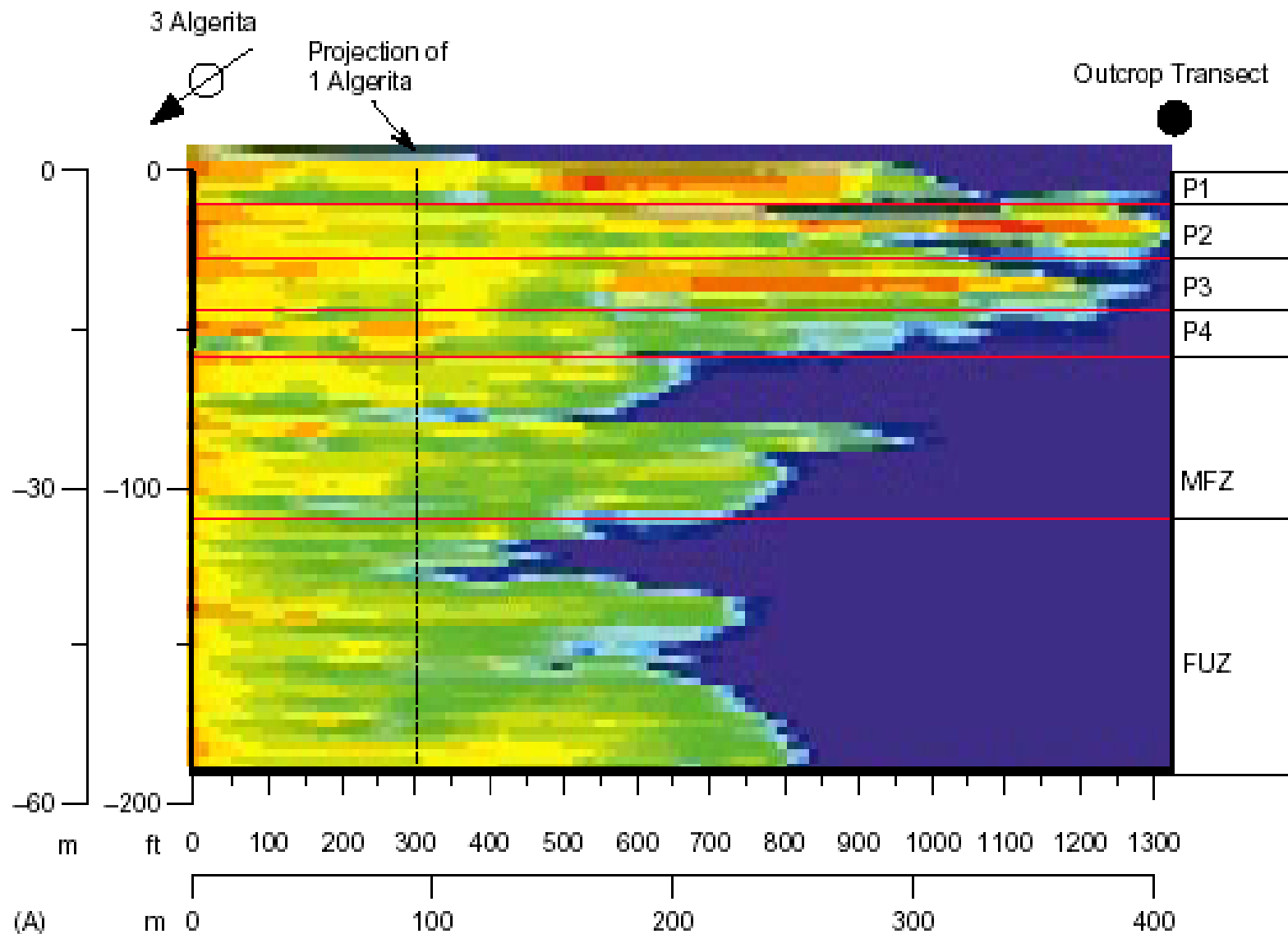


Permeability (md)



AFTER EISENBERG ET AL, 1994

MODELING FLUID FLOW



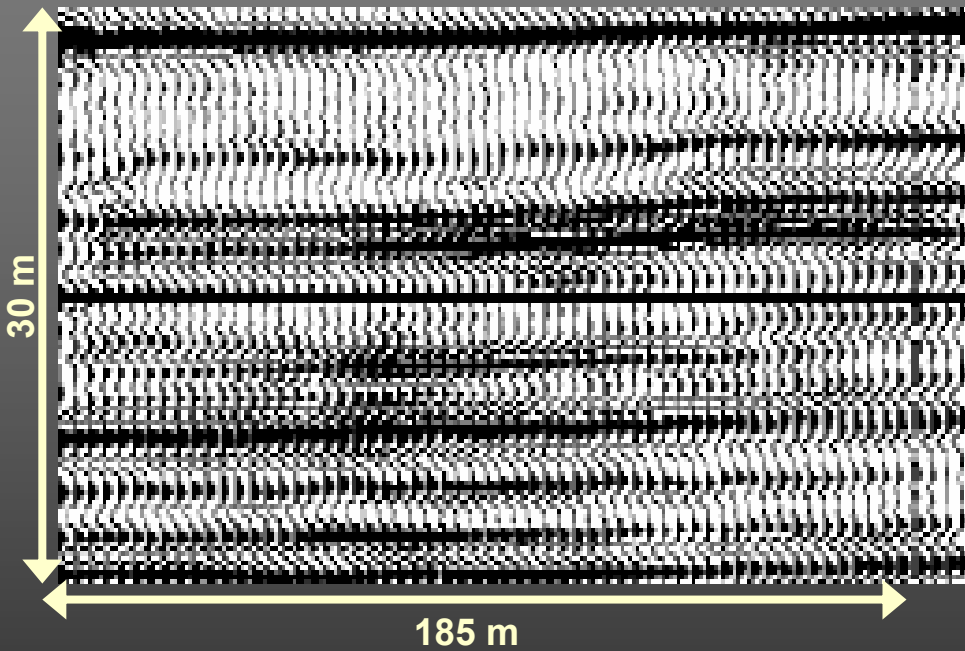
Water Saturation



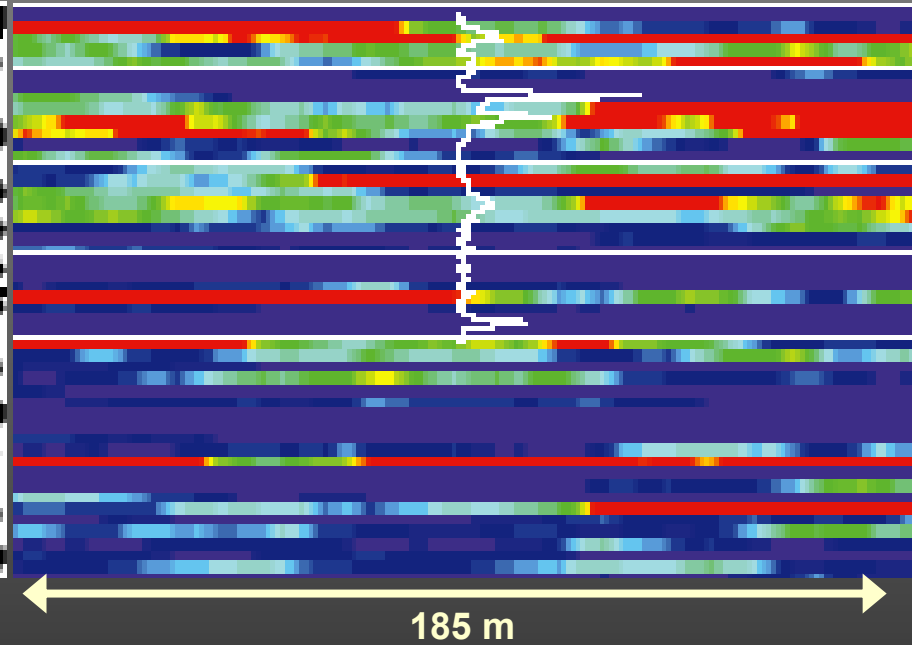
AFTER EISENBERG ET AL, 1994

CROSSWELL RESOLUTION

CROSSWELL SEISMIC



OUTCROP PERMEABILITY



Images Resolve -

Small-Scale Cycles
Lateral Changes in Porosity Comparable
to Outcrop

CROSSWELL SEISMIC VALUE IN RESERVOIR DELINEATION

- **Define greater geologic detail between wells (heterogeneity of reservoir)**
- **Recognition of laterally continuous zones for improved development (well positioning, completions, injection)**
- **Input to reservoir models when tied to facies (layering and assigning porosity)**