Unique Approaches to Analysis of a Cyclic Shelf Dolomite Reservoir*

By
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Abstract

The McElroy Field, Central Basin Platform of the US Permian Basin, produces approximately 17,000 BOPD under a mature waterflood from the Grayburg Formation. Core studies document the stacking of numerous small-scale cycles within a larger-scale progradational motif; i.e., upward shallowing, for the main producing zone in the field. Dolograinstones are dominated by intercrystalline/intergranular porosity with a narrow size range of pore throats that results in most of the nearly 20% porosity being effective to oil flow. In contrast, dolopackstones are less porous and contain both moldic and intercrystalline/intergranular porosity. Their bimodal pore system results in a wider range of pore throat size and more ineffective porosity.

Layering in this type of dolomite reservoir is stratigraphically controlled; therefore a thorough understanding of the stratigraphy is needed for determining reservoir architecture. Lateral and vertical shifts of facies must be understood to assess reservoir variation within layers, as facies boundaries generally equate with subtle variations in dolomite characteristics and associated reservoir quality. The typically fine crystalline dolomite results in low permeability reservoirs, but a long production history for the field attests to good connectivity. Meteoric overprint produced moldic and enhanced intercrystalline porosity, leading to patchily distributed zones of higher porosity and permeability, whereas evaporite cementation and replacement further complicates the reservoir quality distribution. Because of its complexity and long production history, McElroy field has been investigated in a great amount of detail, including the utilization of some unique approaches to reservoir analysis.

Crosswell Seismic

Geologic “ground-truthing” suggests that crosswell seismic data, when integrated with facies-based porosity models, adds value to reservoir characterization. The coincidence of reflectors with decreases in porosity or gypsum cement from whole-core analysis suggests that total porosity and mineralogy dominantly influence velocity. Reflectors correlate fairly well with major log variations; S-wave reflectors correspond almost exactly with increases in sonic velocity, resistivity, and bulk density, and decreases on the neutron log from high to low porosity (or gypsum). Although major stratigraphic boundaries (sequence boundaries and flooding surfaces) generally coincide with reflectors, lithofacies and small-scale depositional cycles do not relate directly to the seismic data. Comparing geostatistical porosity models directly to the seismic suggests that S-wave reflection images appear to be resolving lateral changes in porosity of less than 56 m but more than 15 m.

Log Facies

A significant result of the diagenetic complexity of the McElroy reservoir is that reservoir quality does not match original depositional facies. Both the seismic and log data respond to the same diagenetic overprint and its resulting petrophysical characteristics; therefore log facies derived from cluster analysis, rather than core lithofacies, better relate to the crosswell seismic. Many of the seismic reflectors correspond to vertical transitions between more and less porous log facies; this indicates the strong relationship between velocity and porosity. In addition, lateral variations in many of the positive-amplitude events can be tied to changes in porosity and differences in log facies between wells.

Dual Porosity-Permeability Modeling

Heterogeneity is increased significantly in the central portion of McElroy field by thin high porosity-permeability vuggy zones. A method was developed to identify the vuggy zones on logs, create geostatistical models of porosity and permeability incorporating the vuggy zones, and characterize them in simulation models.

The method involved the following: (1) developing a log trace to identify zones of high vuggy porosity, (2) creating a detailed geostatistical model of total porosity using well log data, (3) creating a geostatistical permeability model based on total porosity, (4) creating a separate detailed geostatistical model of secondary porosity, and (5) superimposing exceptionally high permeability in areas of the permeability model defined by high secondary porosity.

UNIQUE APPROACHES TO ANALYSIS OF A CYCLIC SHELF DOLOMITE RESERVOIR

Paul M. (Mitch) Harris
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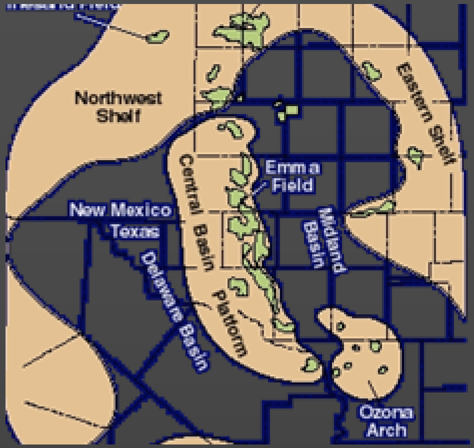
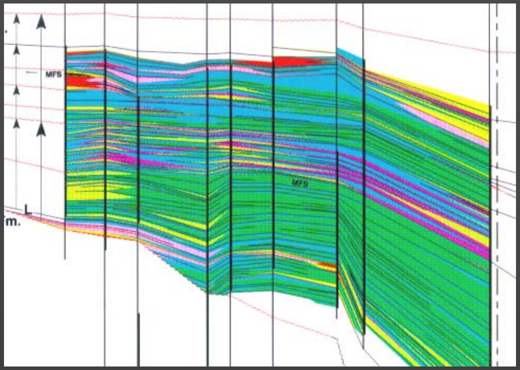
San Ramon, CA

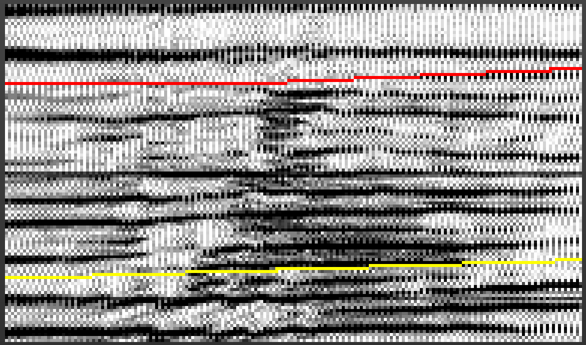
OUTLINE



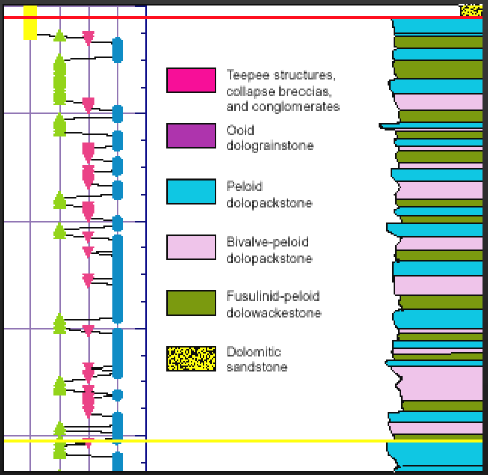
General Background



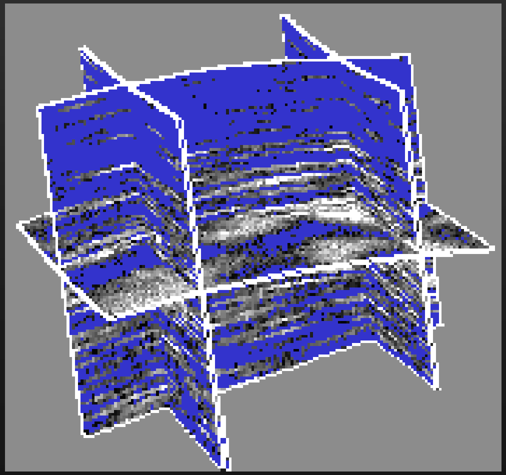
Field Introduction



Crosswell Seismic

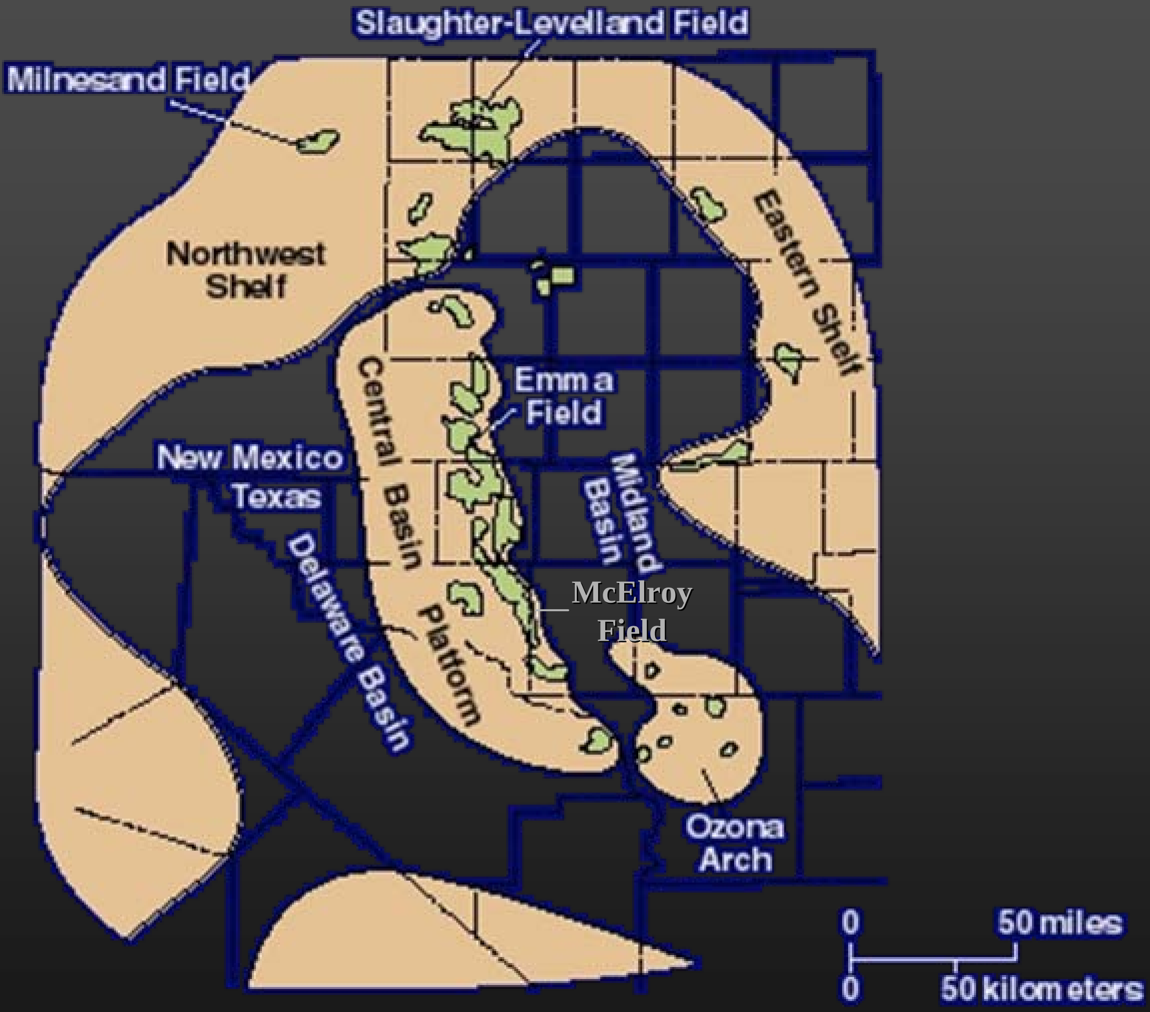


Log Facies



Porosity-Permeability Modeling

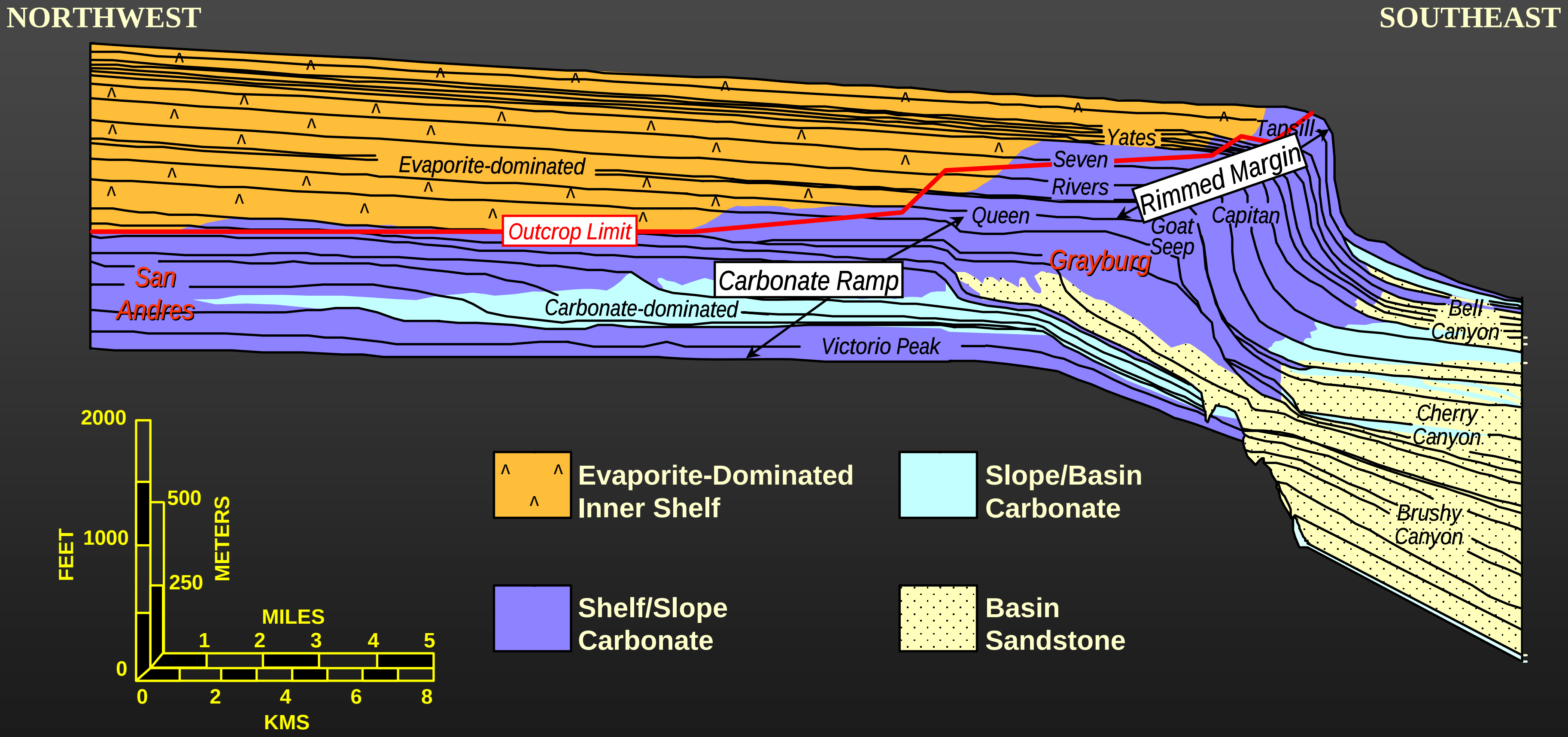
PERMIAN BASIN EXAMPLES OF CYCLIC SHELF DOLOMITE



Northwest Shelf			
Late Permian	Ochoan		"Salado"
	Guadalupian	Late	Tansill
			Yates
			Seven Rivers
		Middle	Queen
			Grayburg
		Early	San Andres
Early Permian	Leonardian		Yeso

Allan and Wiggins, 1993 (after Hild, 1986)

SAN ANDRES AND GRAYBURG BROAD, LOW-RELIEF SHELVES

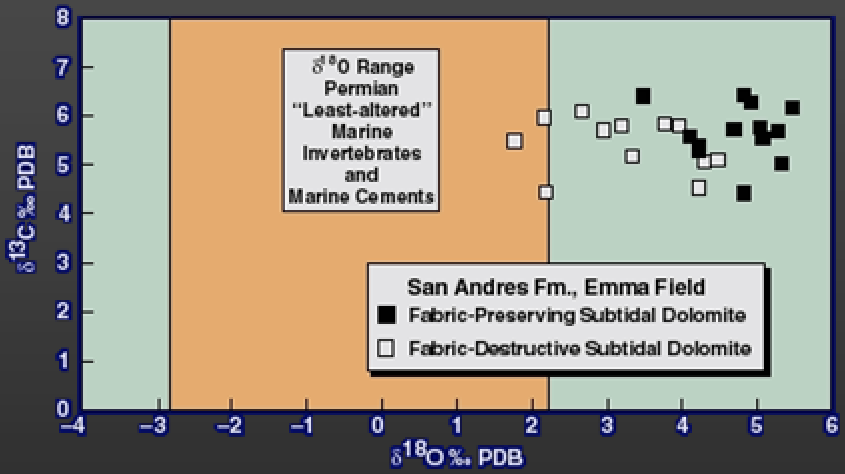


AFTER KERANS ET AL, 1991

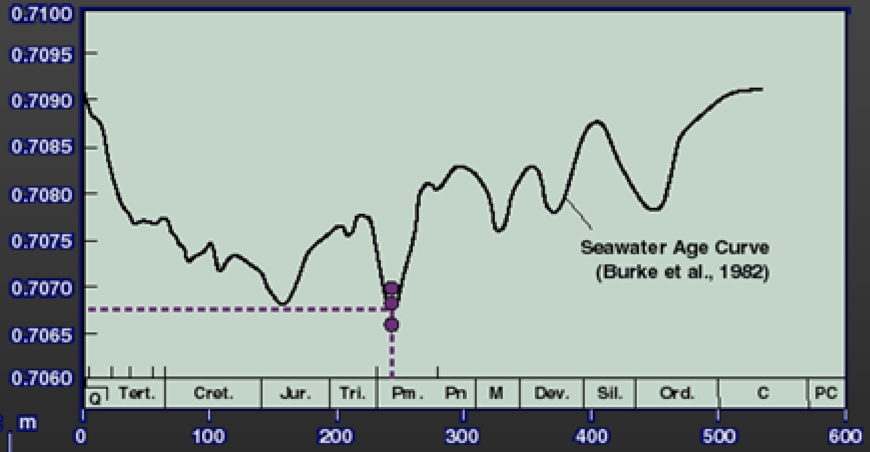
GEOCHEMISTRY OF PERMIAN BASIN DOLOMITES

Single Evaporation-Concentrated Brine

- Later Recrystallization Shifted δ^{18}O to Lighter Values and Produced Fabric-Destructive Texture

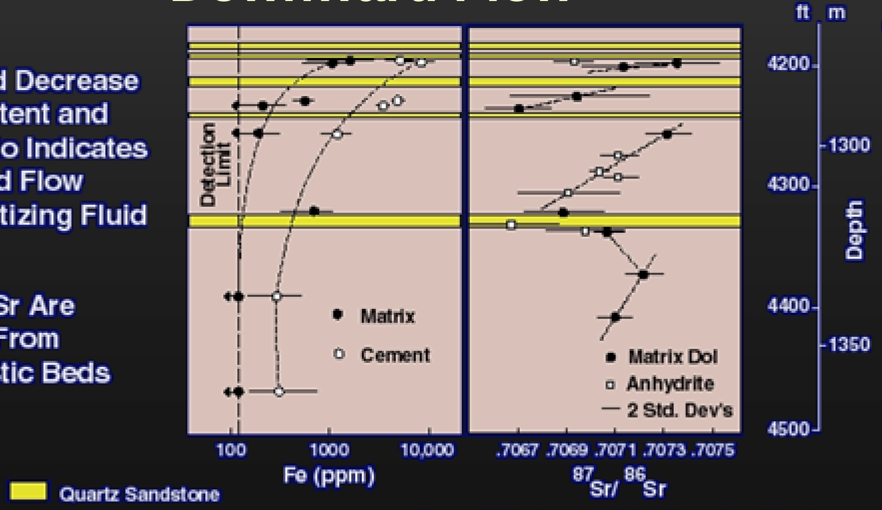


Late Permian Timing



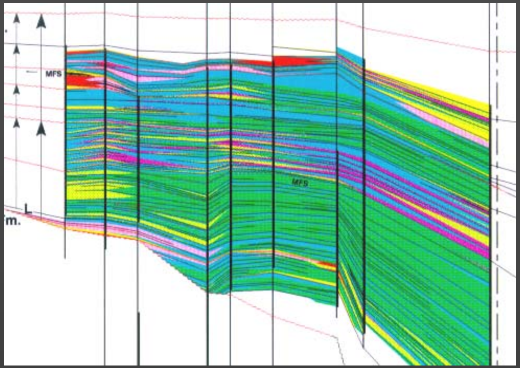
Downward Flow

- Downward Decrease of Fe Content and 87/86 Ratio Indicates Downward Flow of Dolomitizing Fluid
- Fe and ^{87}Sr Are Derived From Siliciclastic Beds



AFTER LEARY AND VOGT, 1986;
ALLAN AND WIGGINS, 1993; AND
RUPPEL AND CANDER, 1988

OUTLINE



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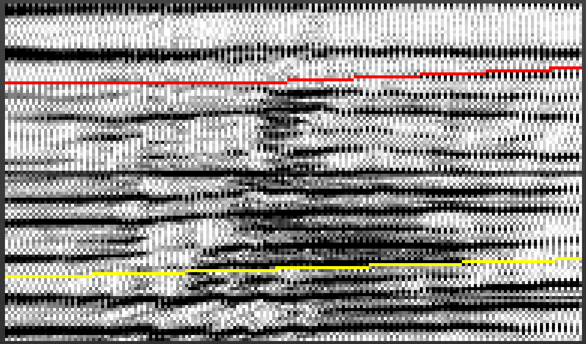
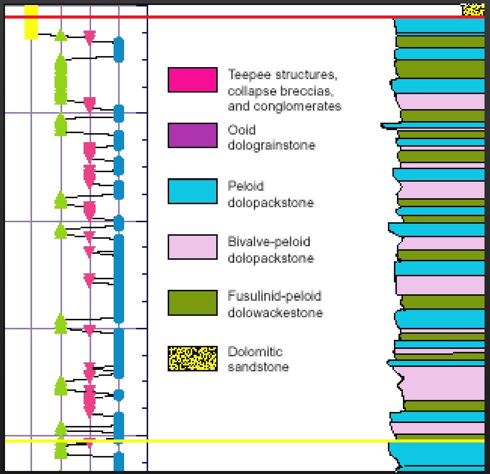
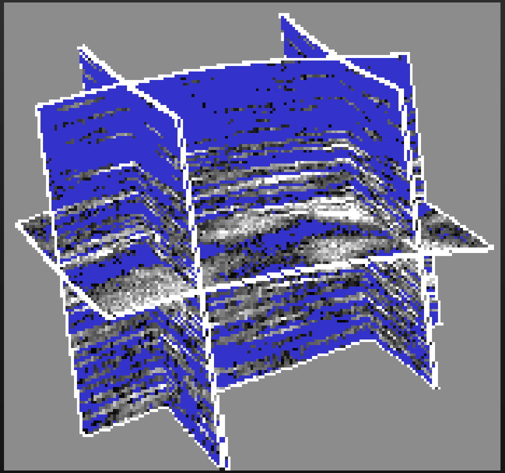


Crosswell Seismic

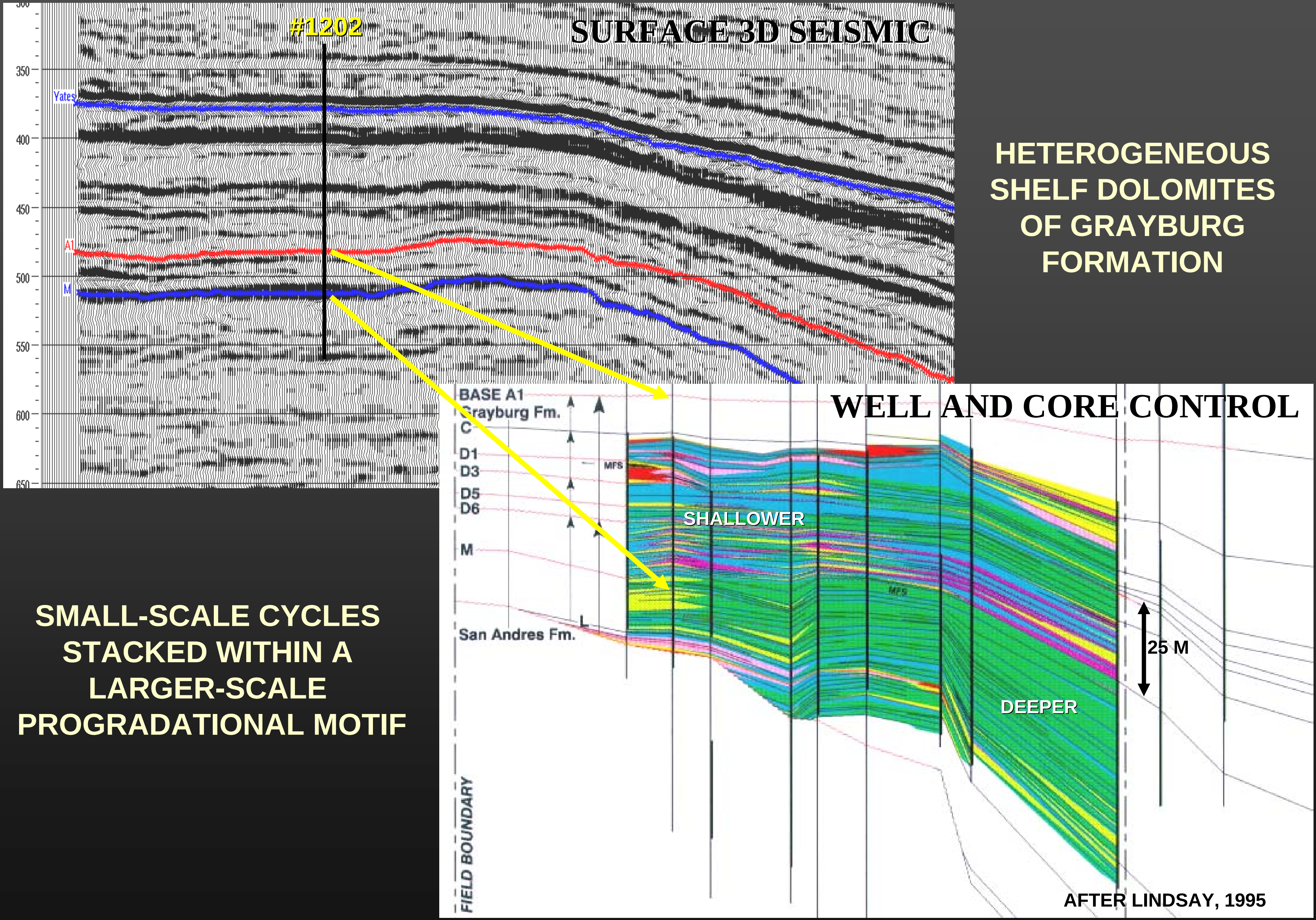


Log Facies



Porosity-Permeability Modeling

MCELROY FIELD



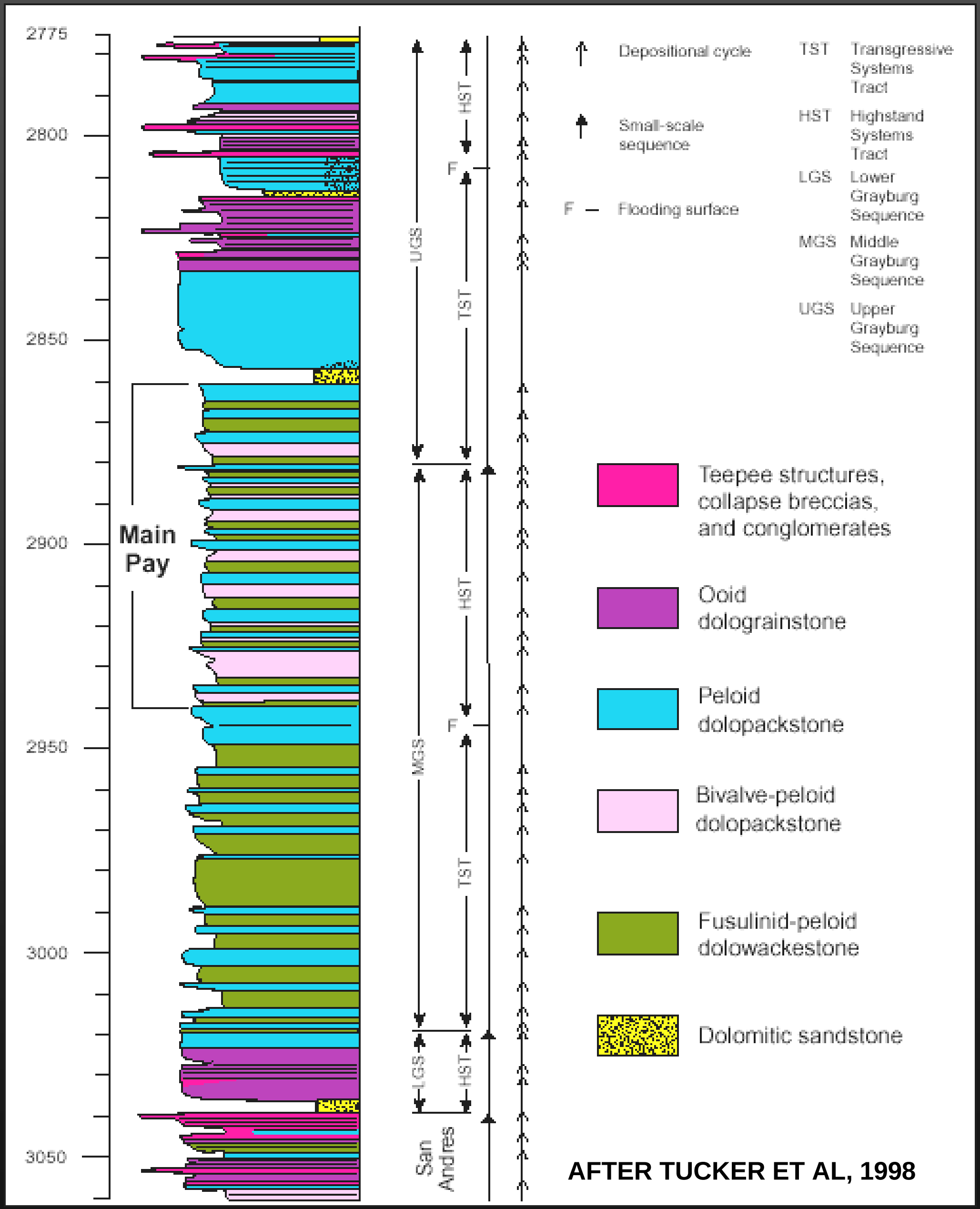
AFTER LINDSAY, 1995

HETEROGENEOUS SHELF DOLOMITES OF GRAYBURG FORMATION

SMALL-SCALE CYCLES STACKED WITHIN A LARGER-SCALE PROGRADATIONAL MOTIF

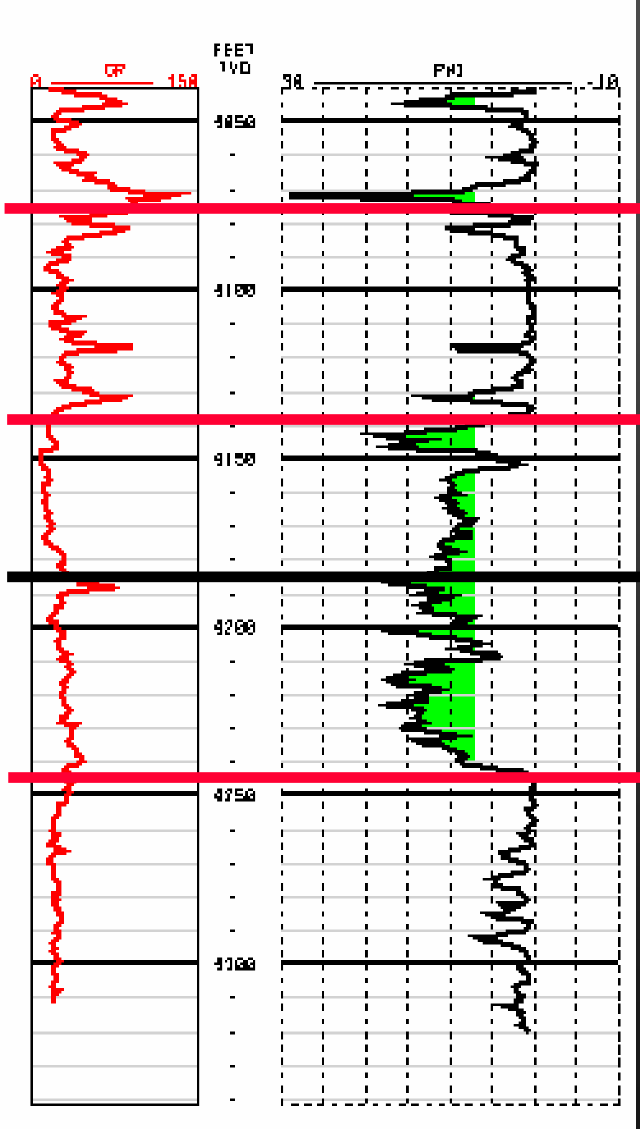
LITHOFACIES AND STRATIGRAPHY

DOLOPACKSTONES AND WACKESTONES WITH COMPLEX DIAGENETIC OVERPRINT



AFTER TUCKER ET AL, 1998

LOG RESPONSE

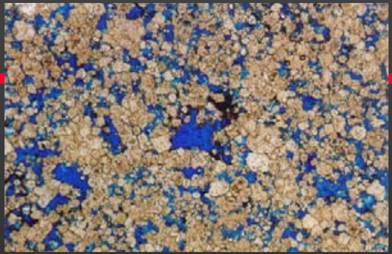


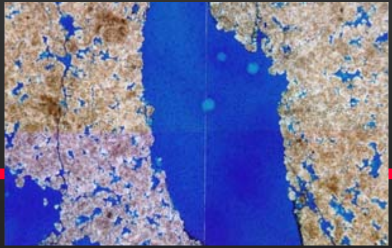
Tidal Flat

Shallow Shelf

Deeper Shelf

DOLOPACK-GRAINSTONE



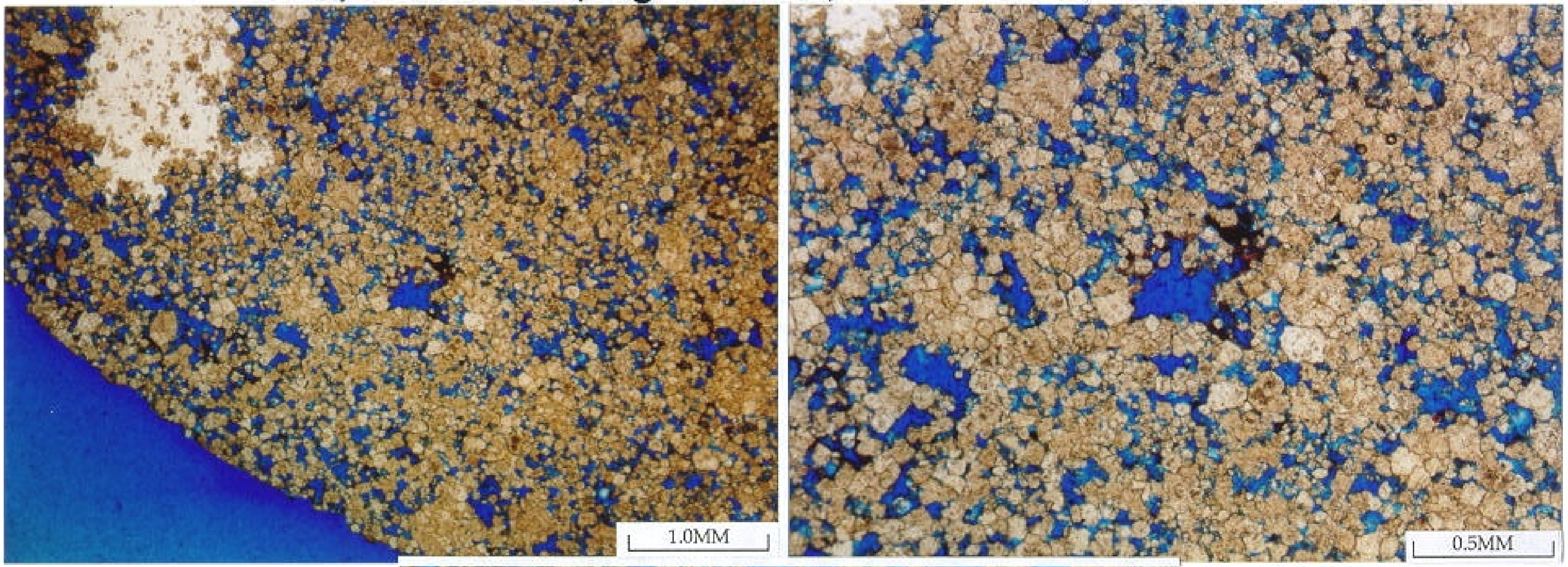


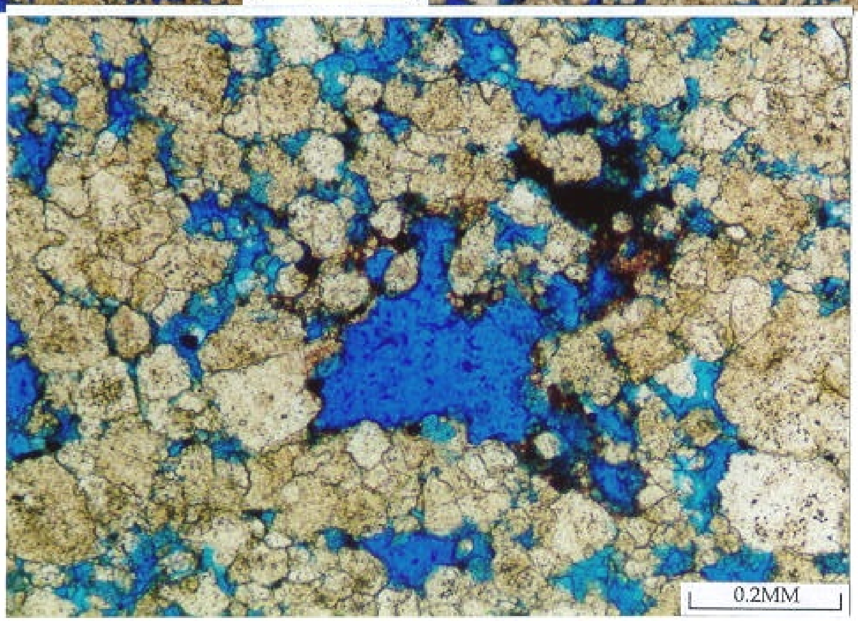
DOLOWACKE-PACKSTONE

shading at 7% porosity cutoff

PORE SYSTEM IN DOLOPACKSTONE

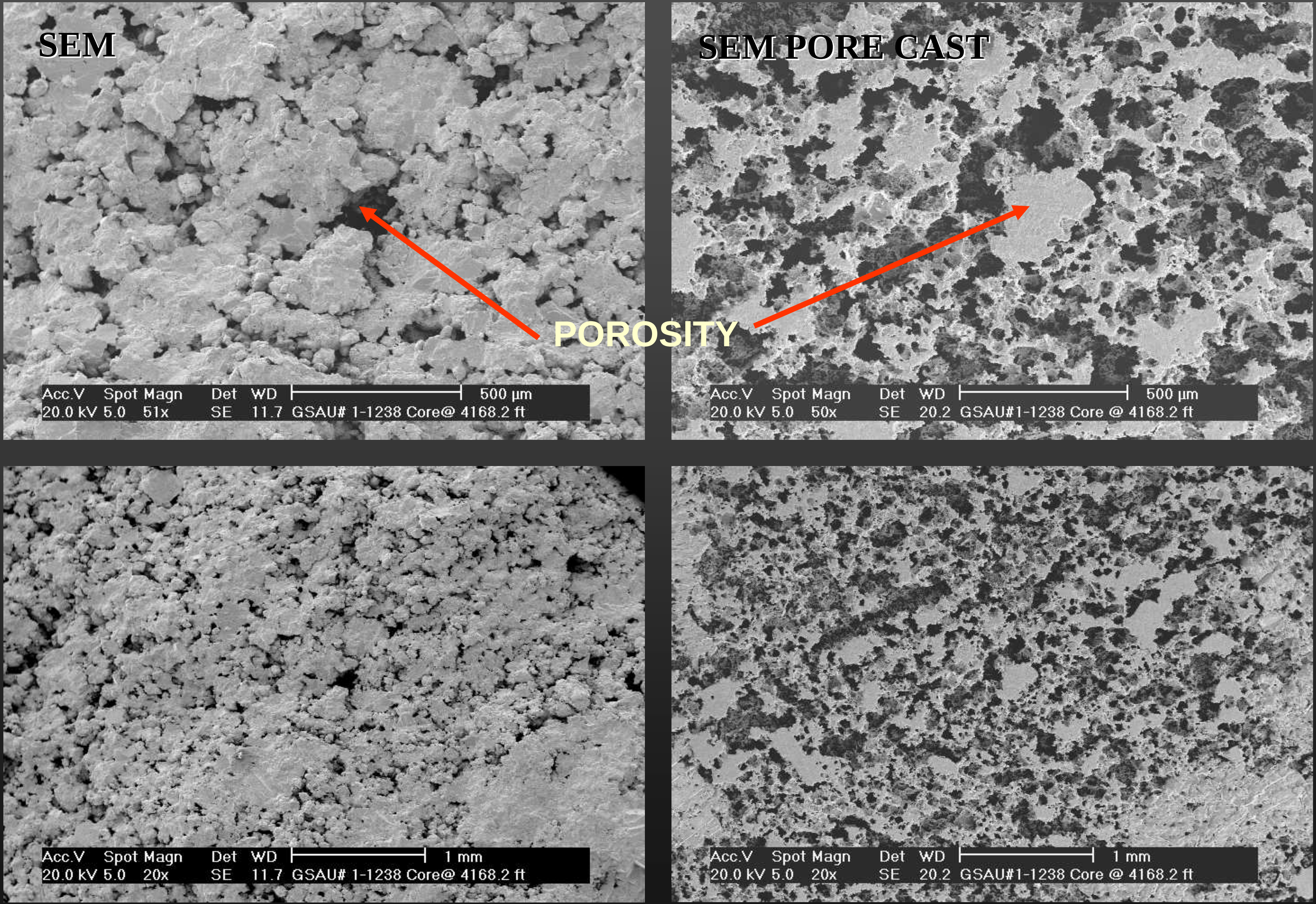
He Φ 19.9%, K 269.0 md, Hg Φ 20.3%, Eff Φ 18.8%, Ineff Φ 1.5% to Oil





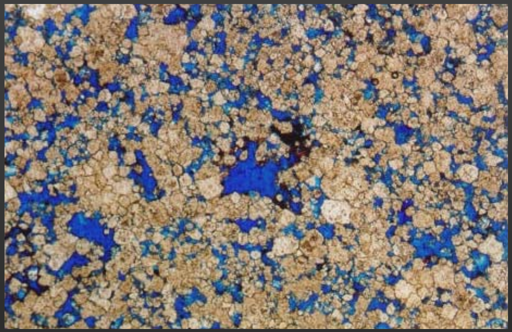
Intercrystalline/ Intergranular Porosity

DETAILS OF PORE SYSTEM

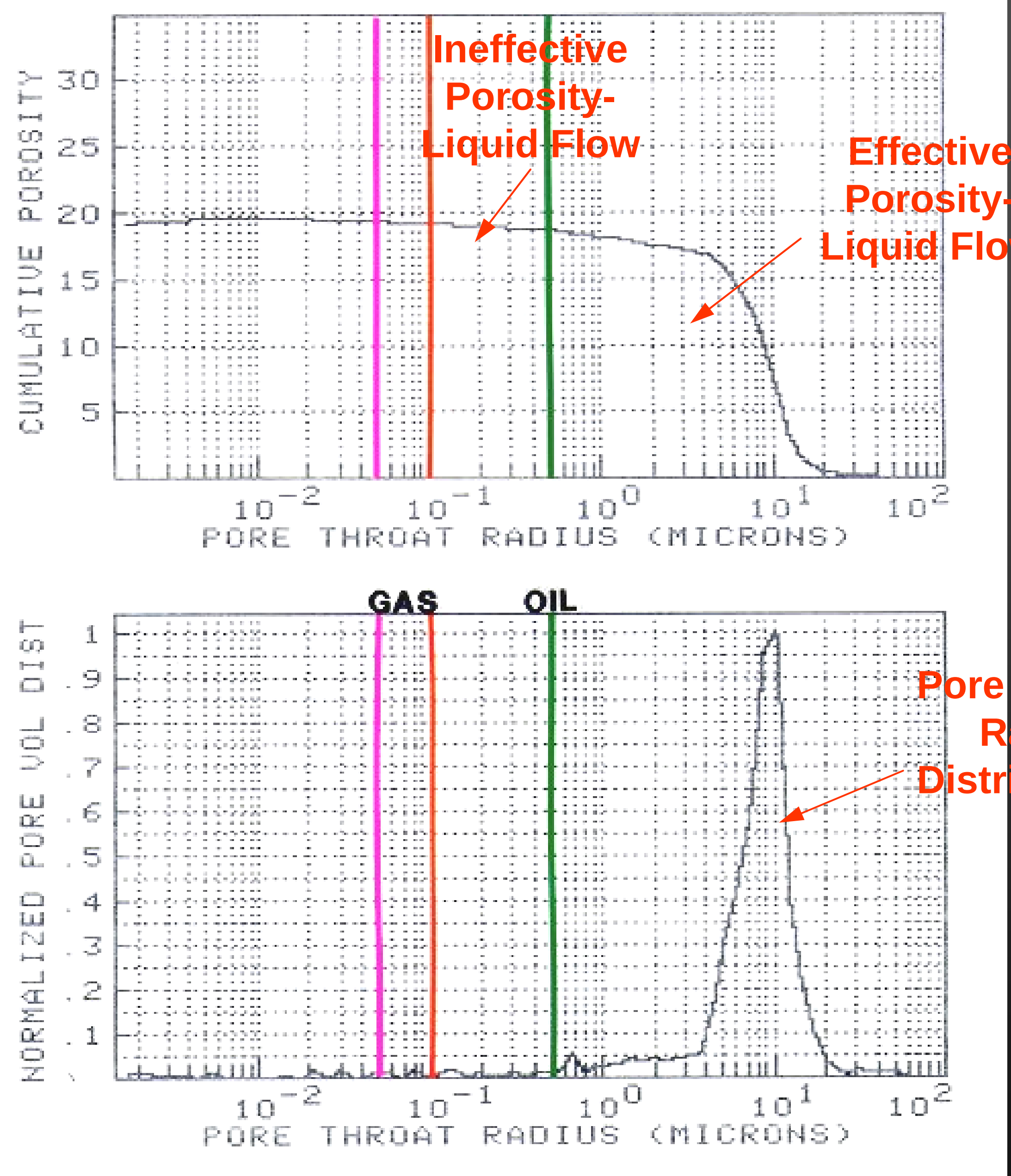


PORE THROATS AND EFFECTIVE POROSITY

DOLOPACKSTONE



Intercrystalline/ Intergranular Porosity



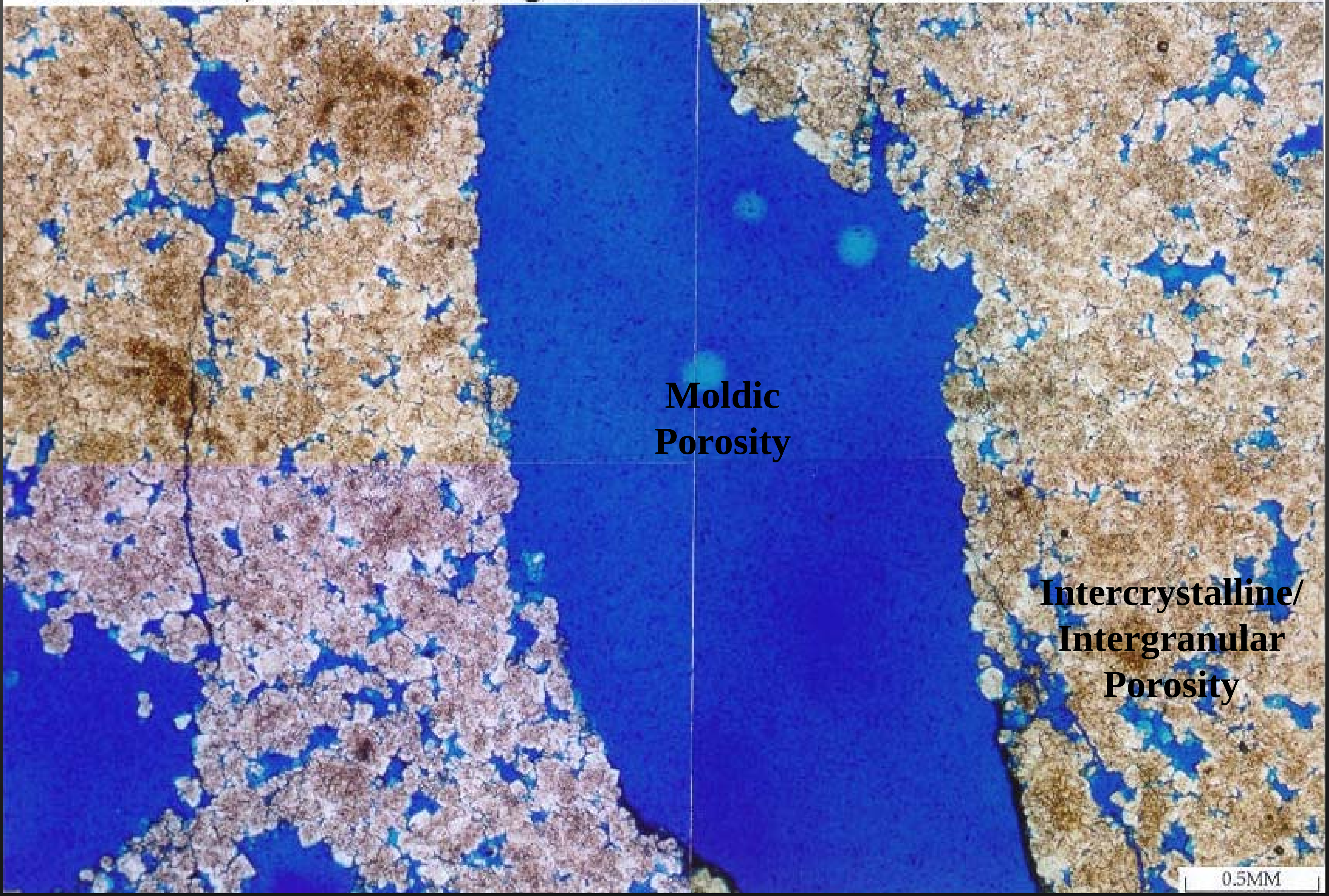
Ineffective Porosity- Liquid Flow

Effective Porosity- Liquid Flow

Pore Throat Radii Distribution

PORE SYSTEM IN DOLOWACKESTONE

He Φ 18.3%, K 102.0 md, Hg Φ 11.0%, Eff Φ 8.7%, Ineff Φ 2.3% to Oil



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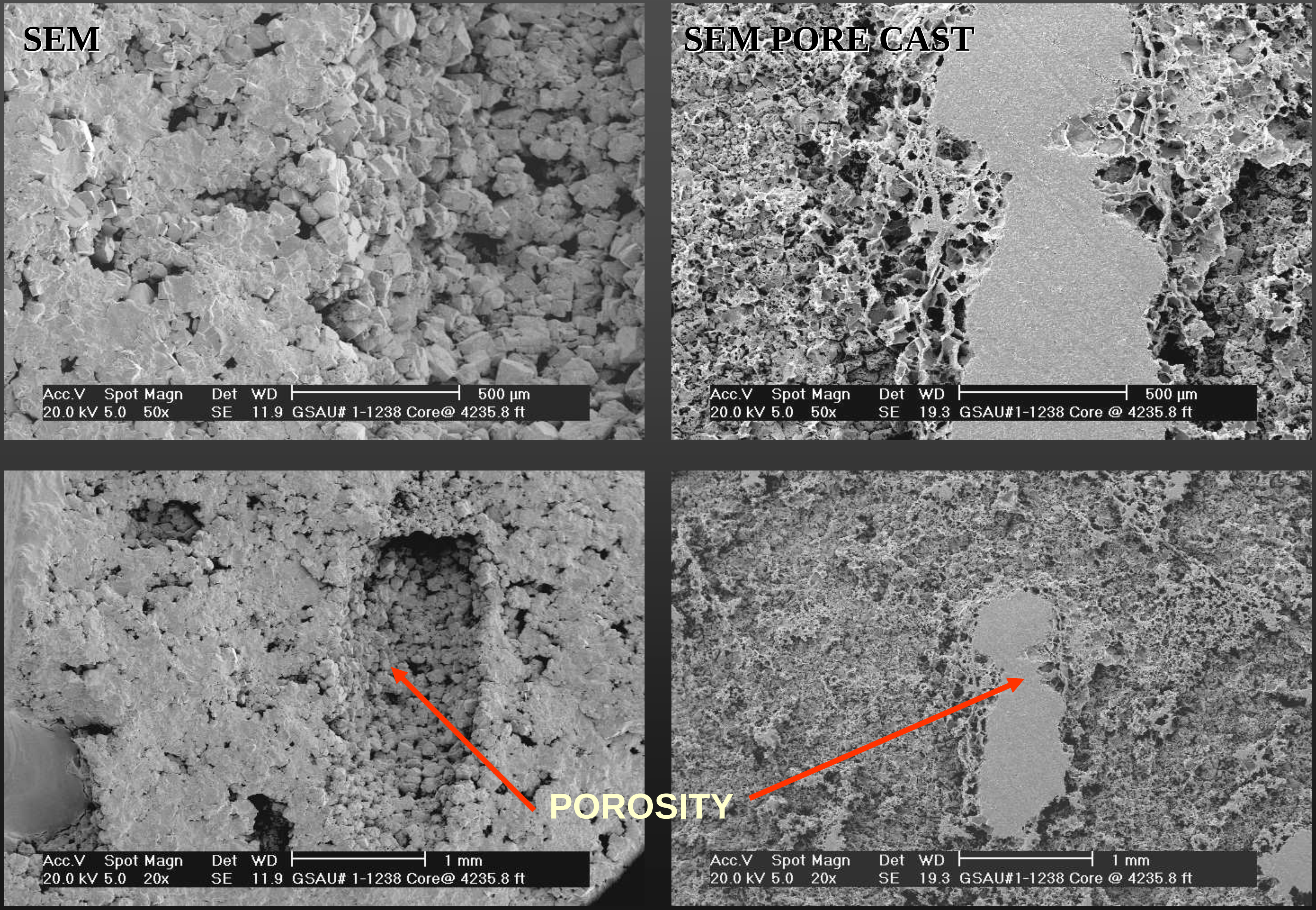
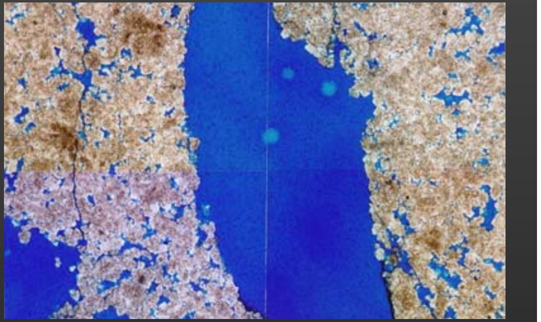
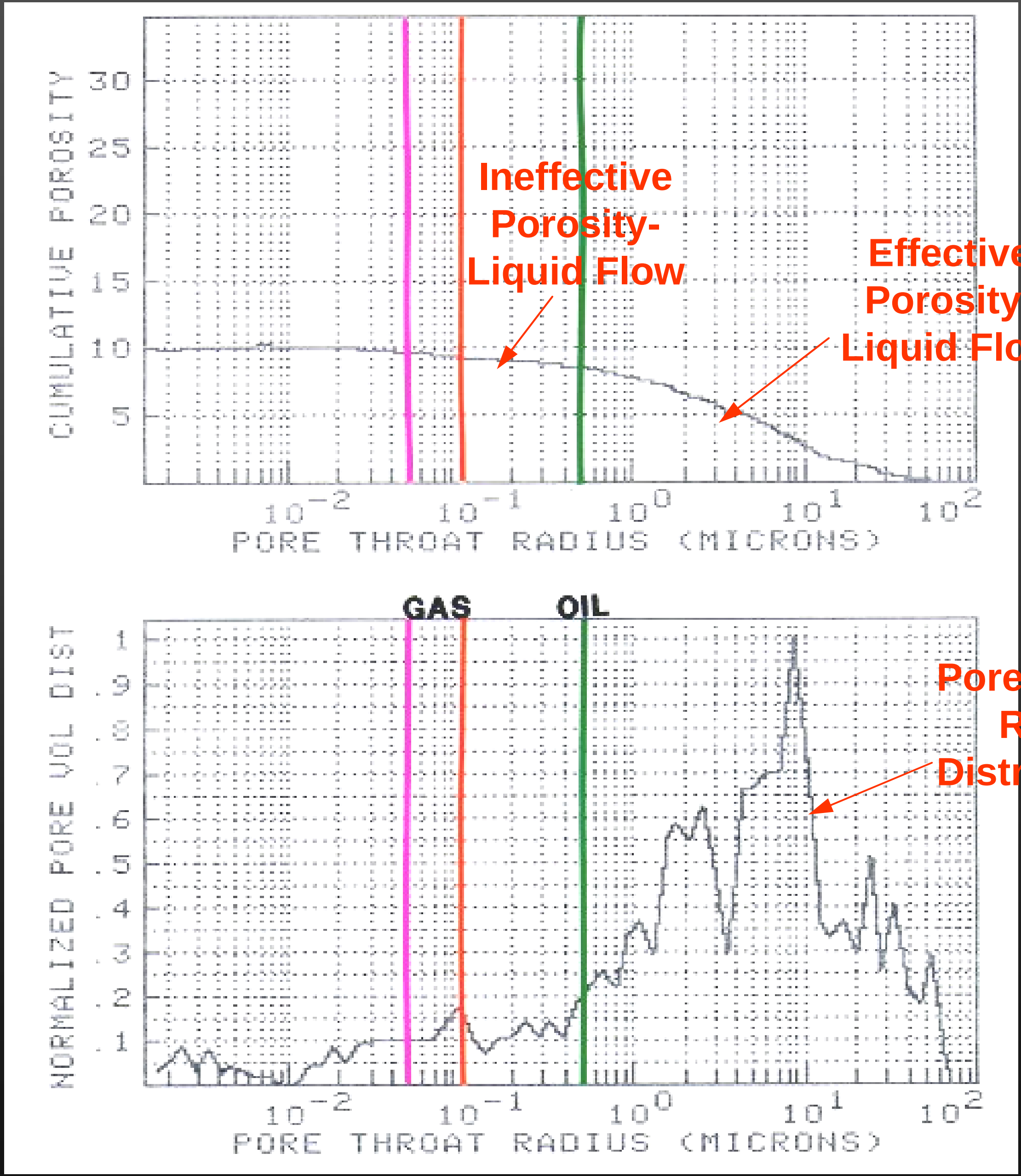


PORE THROATS AND EFFECTIVE POROSITY

DOLOWACKESTONE



Intercrystalline/
Intergranular
and Moldic
Porosity

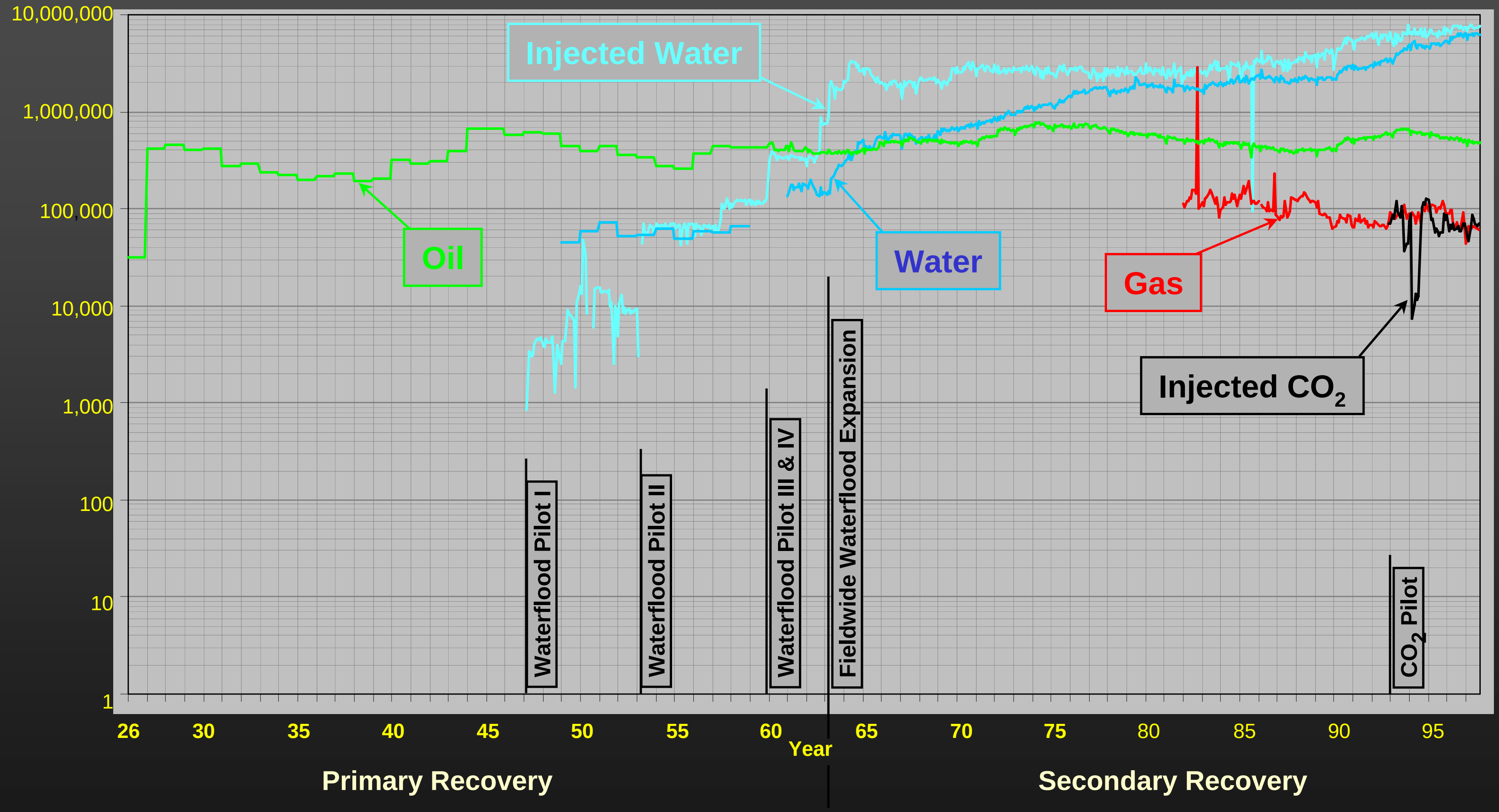


Ineffective
Porosity-
Liquid Flow

Effective
Porosity-
Liquid Flow

Pore Throat
Radii
Distribution

LONG PRODUCTION HISTORY



KEY ASPECTS OF CYCLIC SHELF DOLOMITE RESERVOIRS

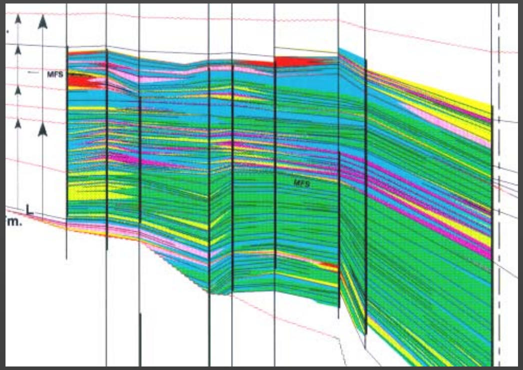
Large Volume Dolomite Reservoir with Fine Intercrystalline Porosity and Low Permeability

Layering is Stratigraphically Controlled, i.e. Stacked Upward-Shallowing Cycles

Variation within Layers Controlled by Facies Changesand Diagenesis

- **Recrystallization**
- **Isolated Zones of Moldic/Vuggy Porosity**
- **Scattered Evaporite Cementation/Replacement**

OUTLINE



General Background

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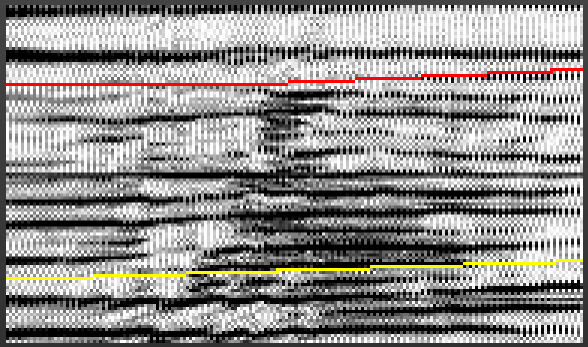
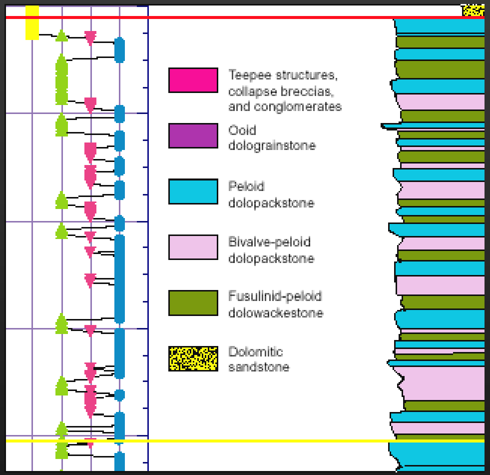
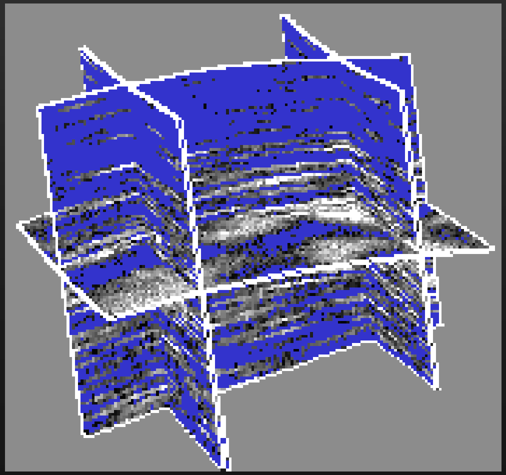


Crosswell Seismic

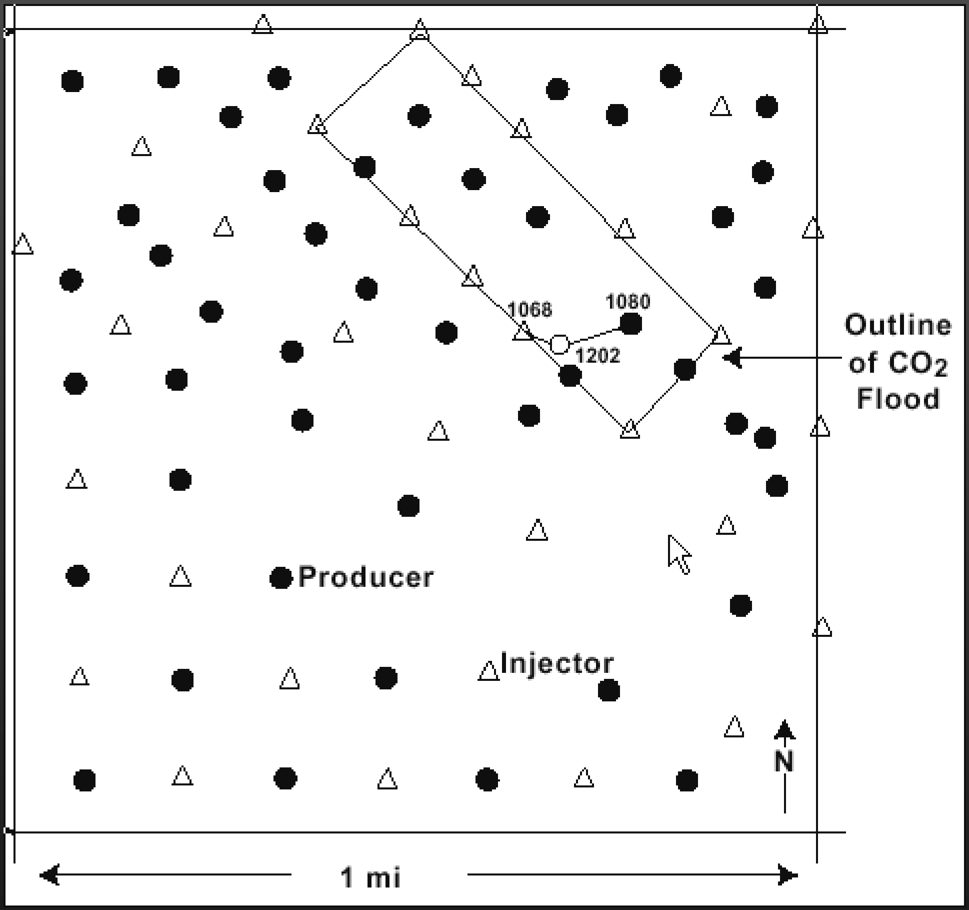


Log Facies

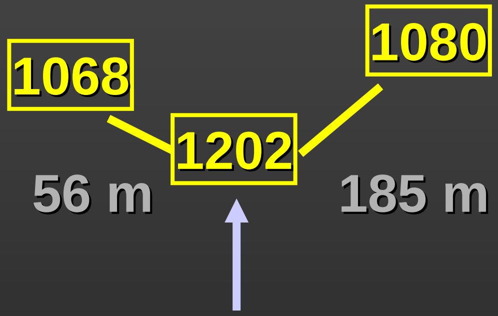


Porosity-Permeability Modeling

CROSSWELL SEISMIC

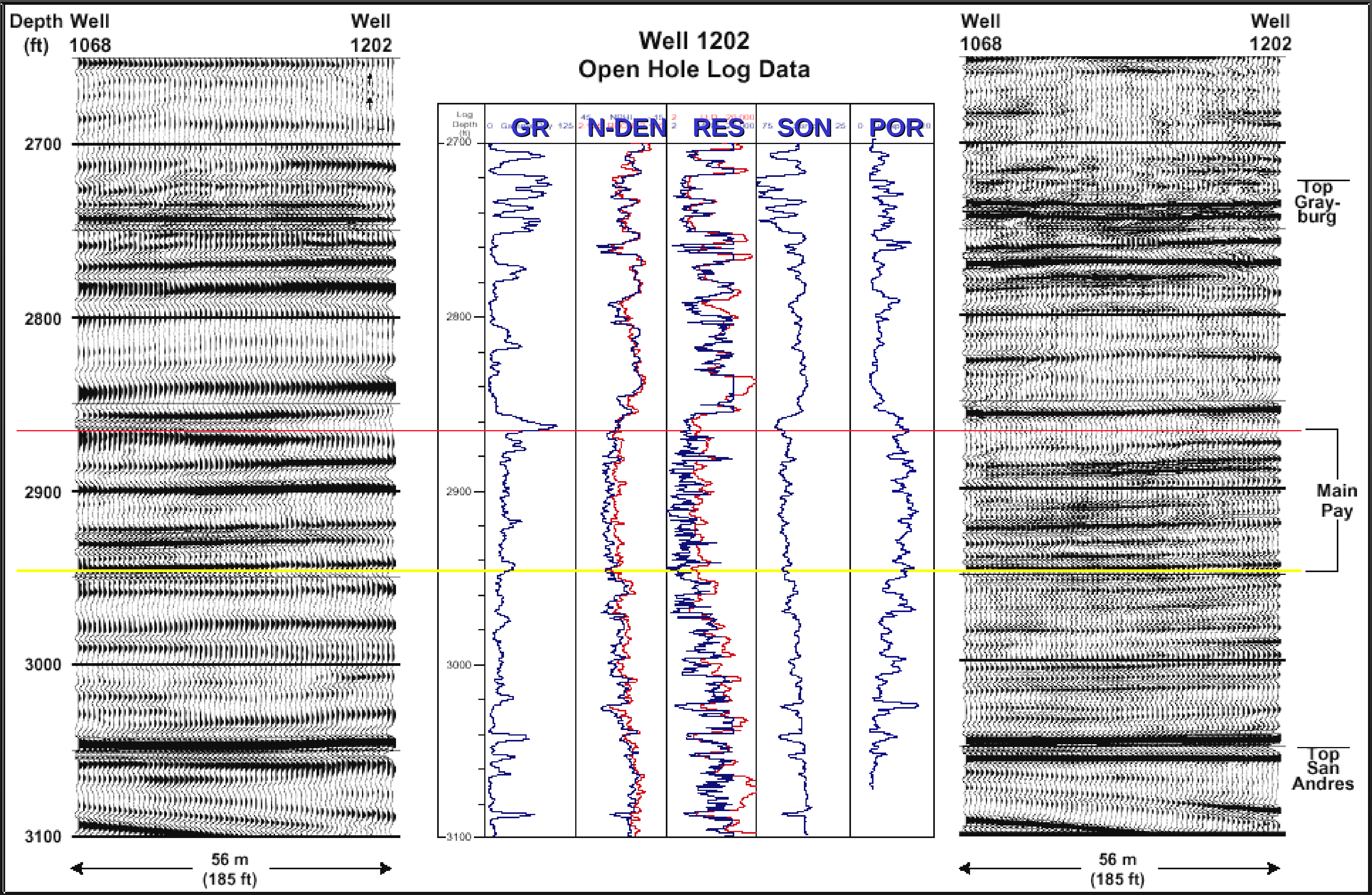


AFTE TUCKER ET AL, 1998



KEY WELL WITH CORE AND LOGS

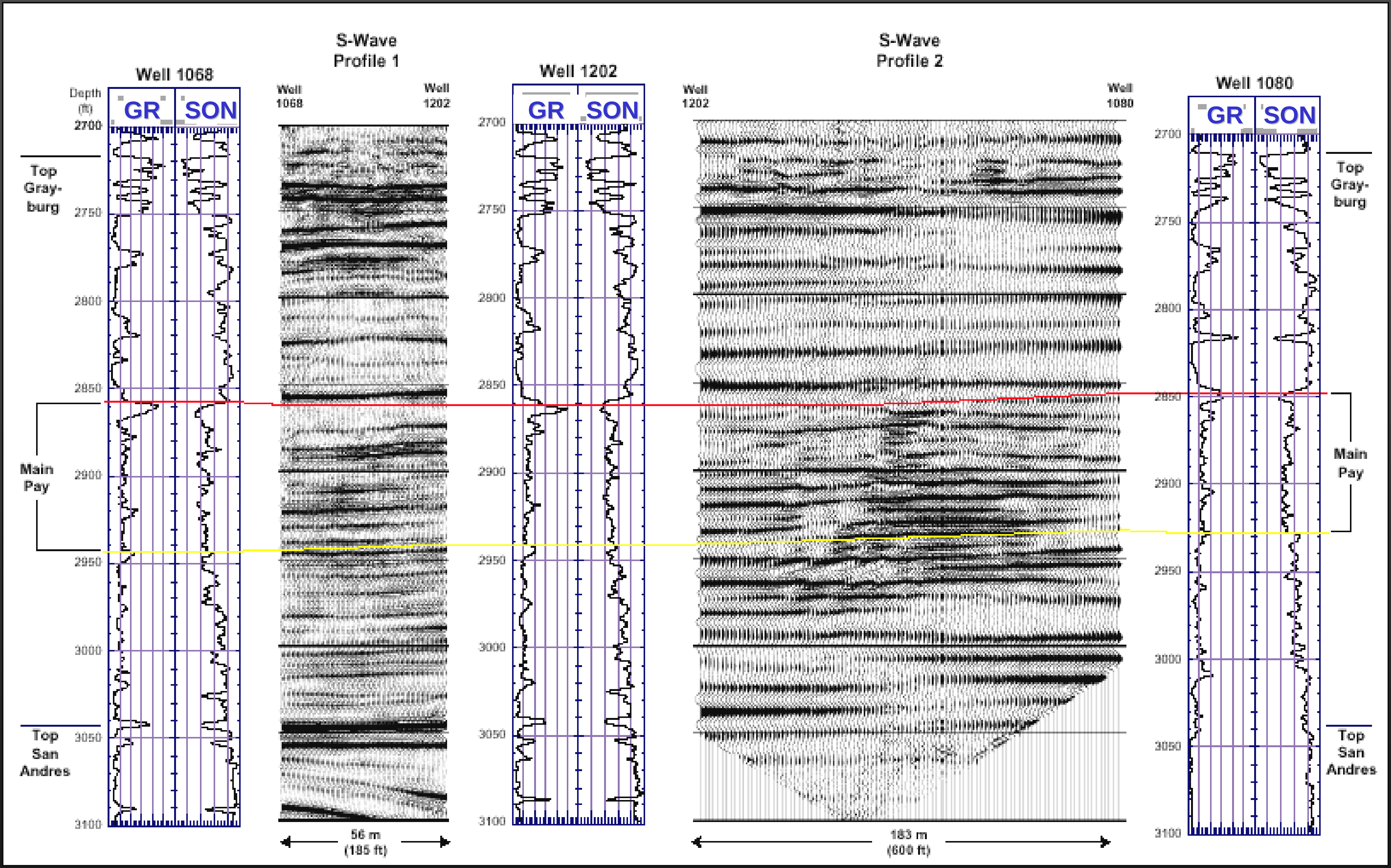
SEISMIC AND LOGS



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

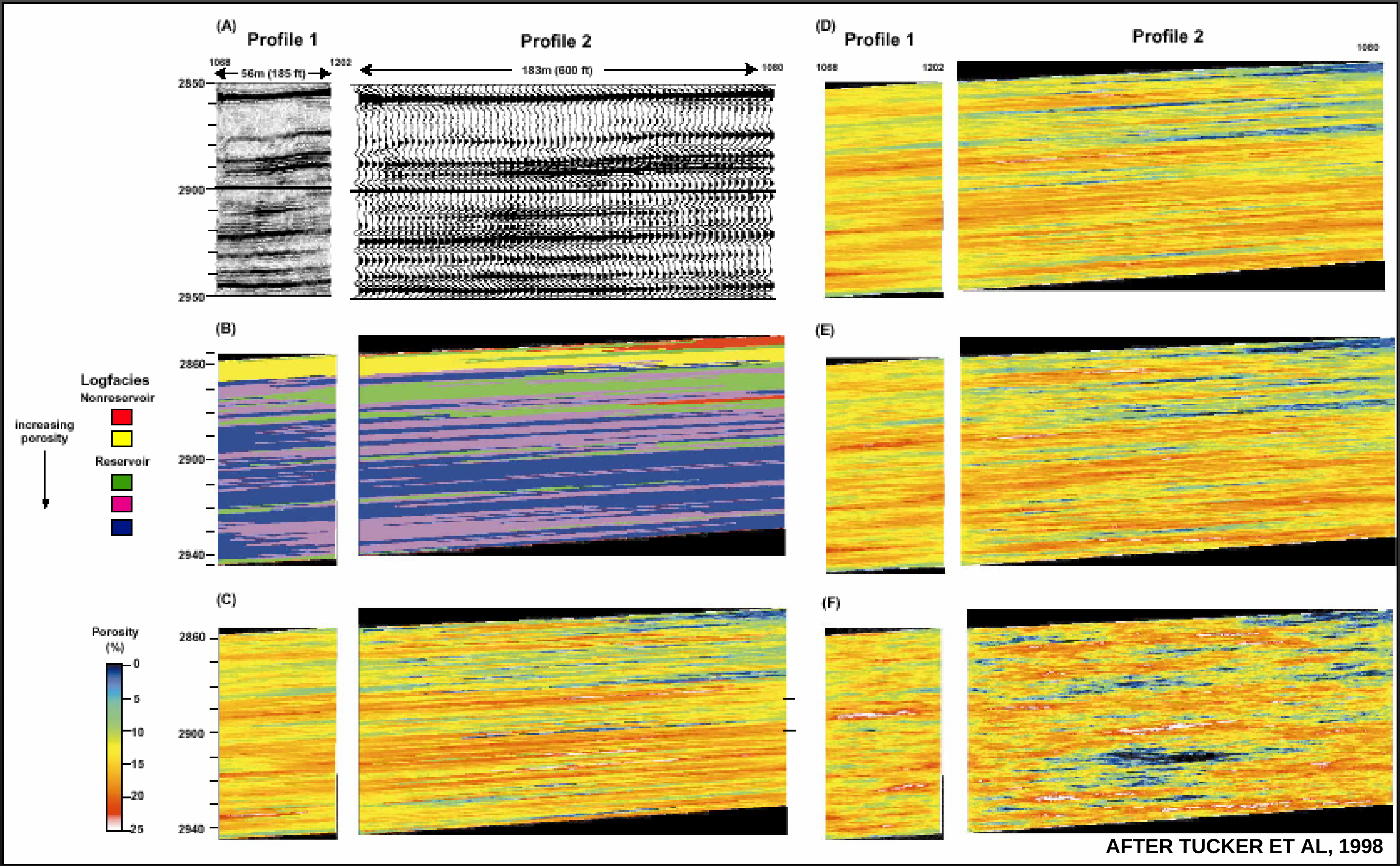


AFTER TUCKER ET AL, 1998

Reflectors, along with GR and sonic log, suggests interwell variation

LATERAL RESOLUTION

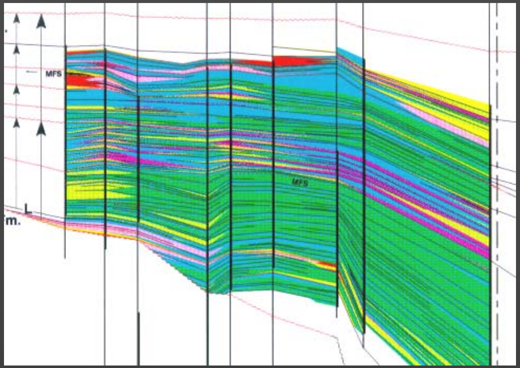
VALUE IN LAYERING AND ASSIGNING POROSITY TO MODEL



AFTER TUCKER ET AL, 1998

Images resolve lateral changes in porosity <56 m but >15 m

OUTLINE



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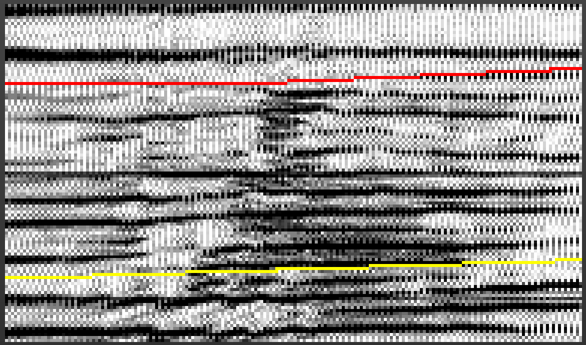
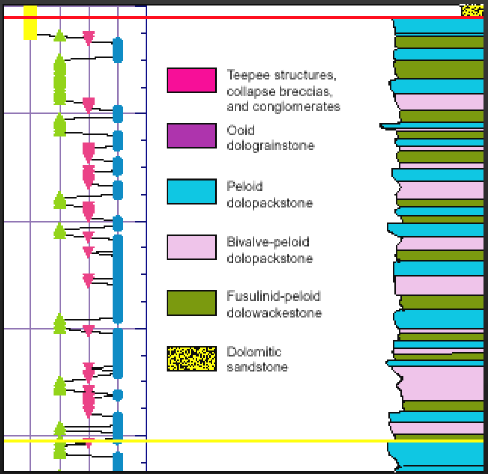
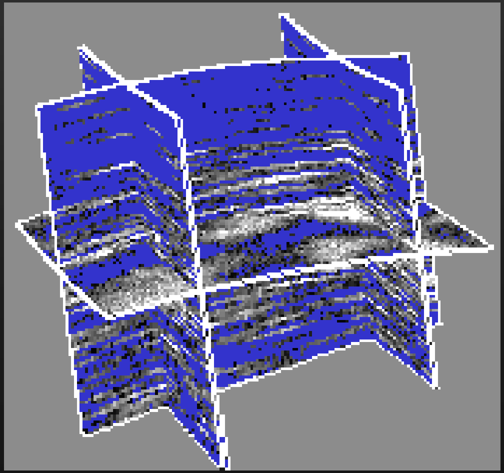


Crosswell Seismic



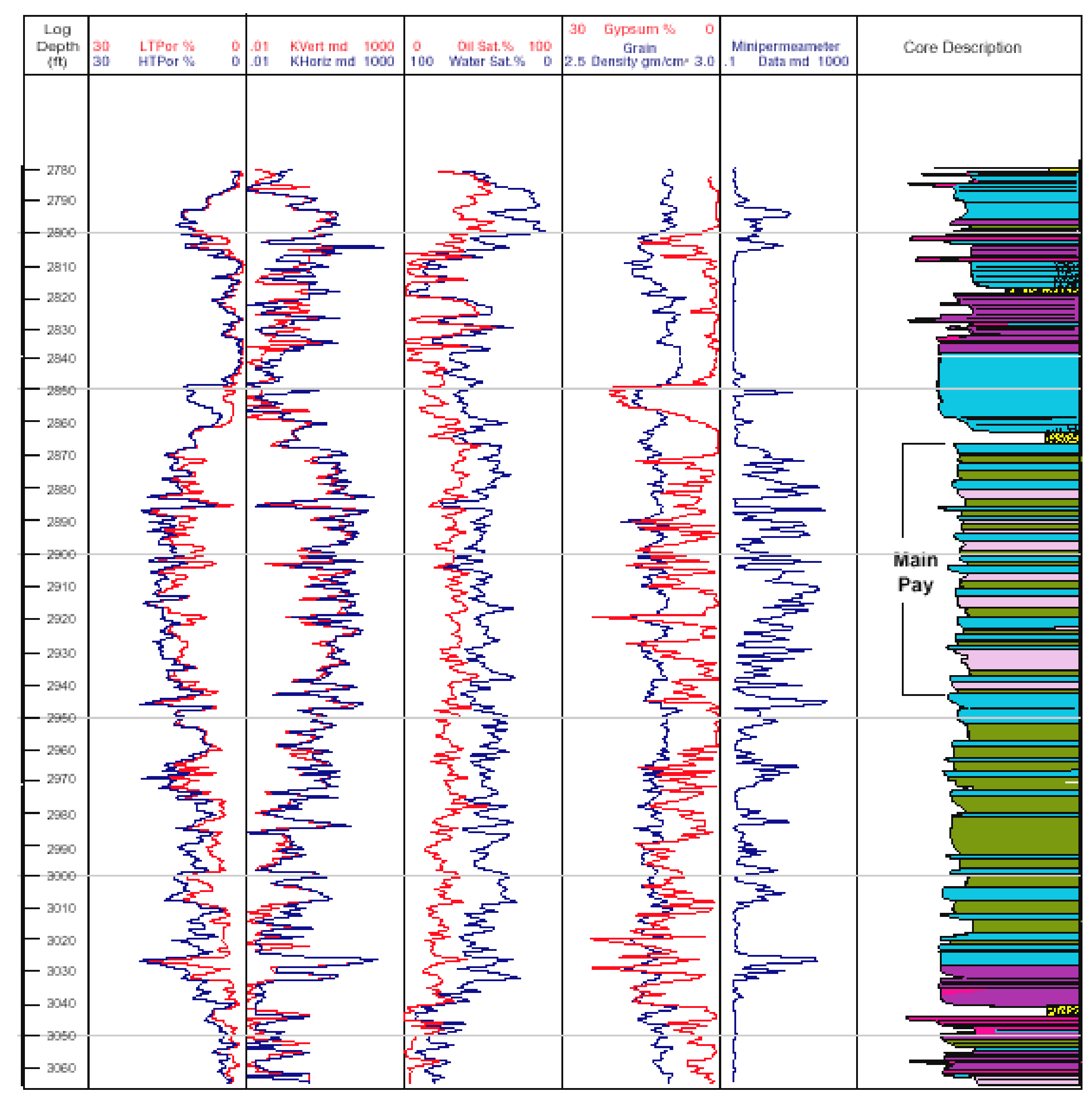
Log Facies



Porosity-Permeability Modeling

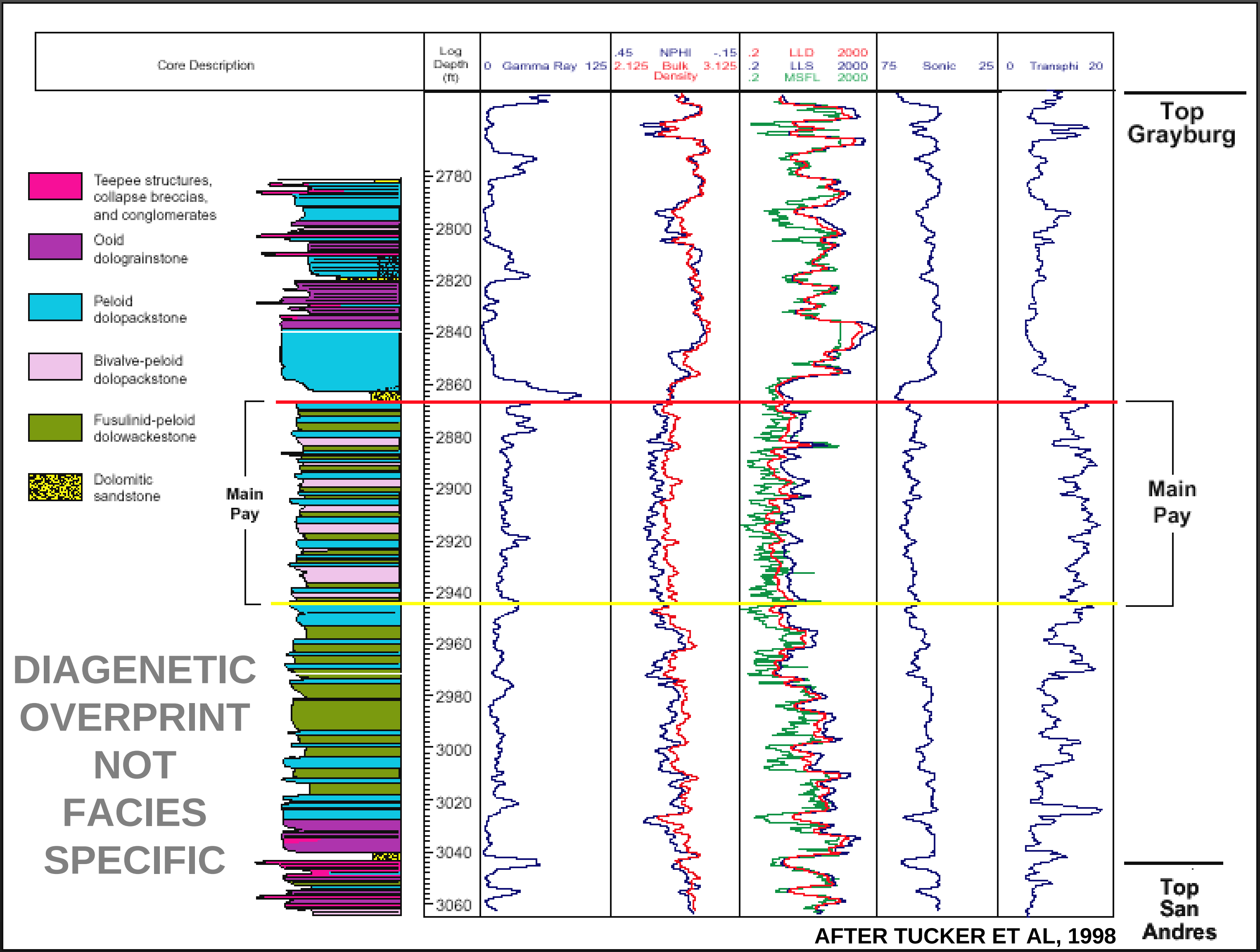
RESERVOIR QUALITYAND FACIES

POOR CORRELATION BETWEEN MEASURED VARIABLES AND CORE- BASED LITHOFACIES



AFTER TUCKER ET AL, 1998

DOWNHOLE LOGS AND FACIES

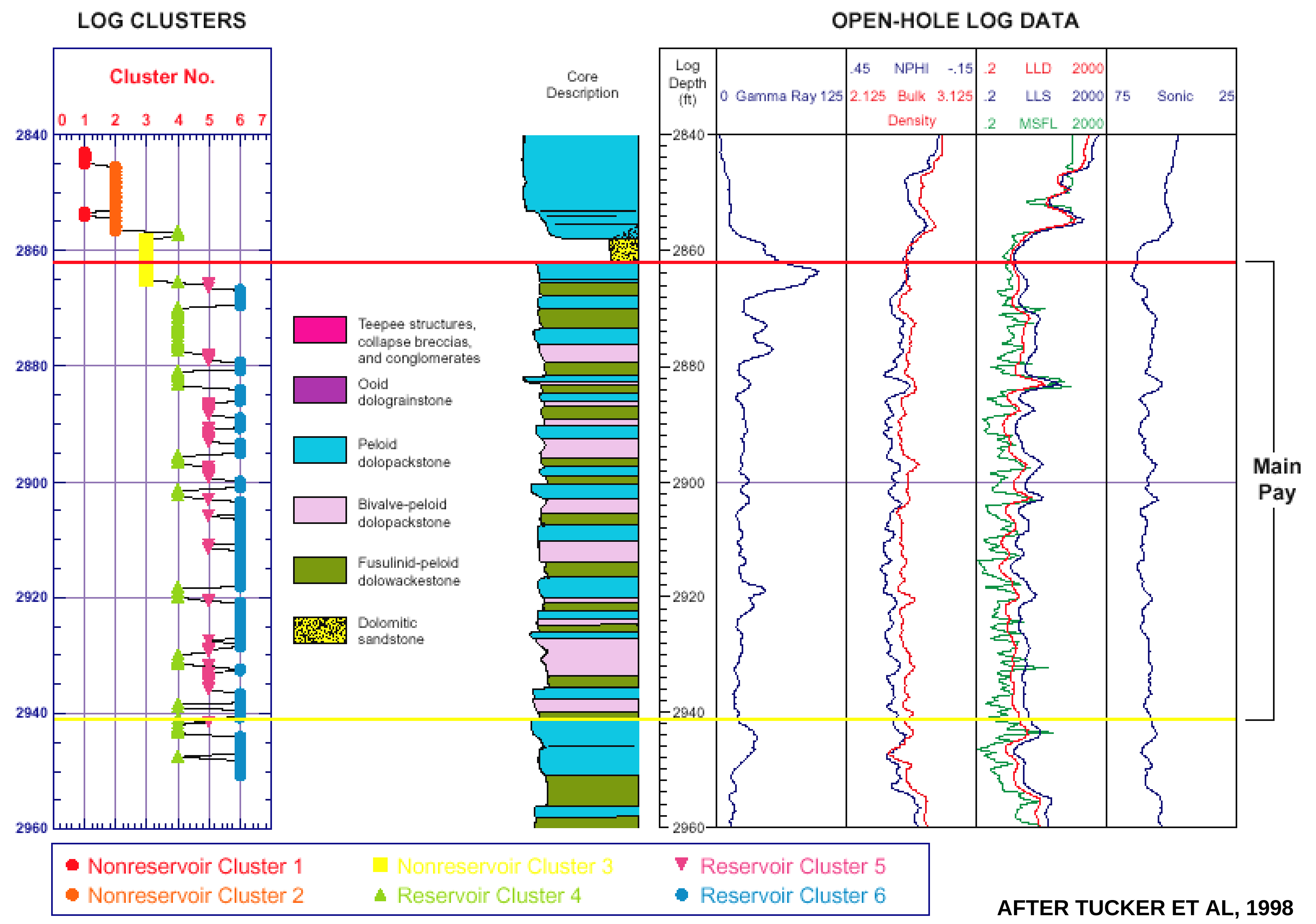


DIAGENETIC OVERPRINT NOT FACIES SPECIFIC

AFTER TUCKER ET AL, 1998

Poor Correlation Between Logs and Core- Based Lithofacies

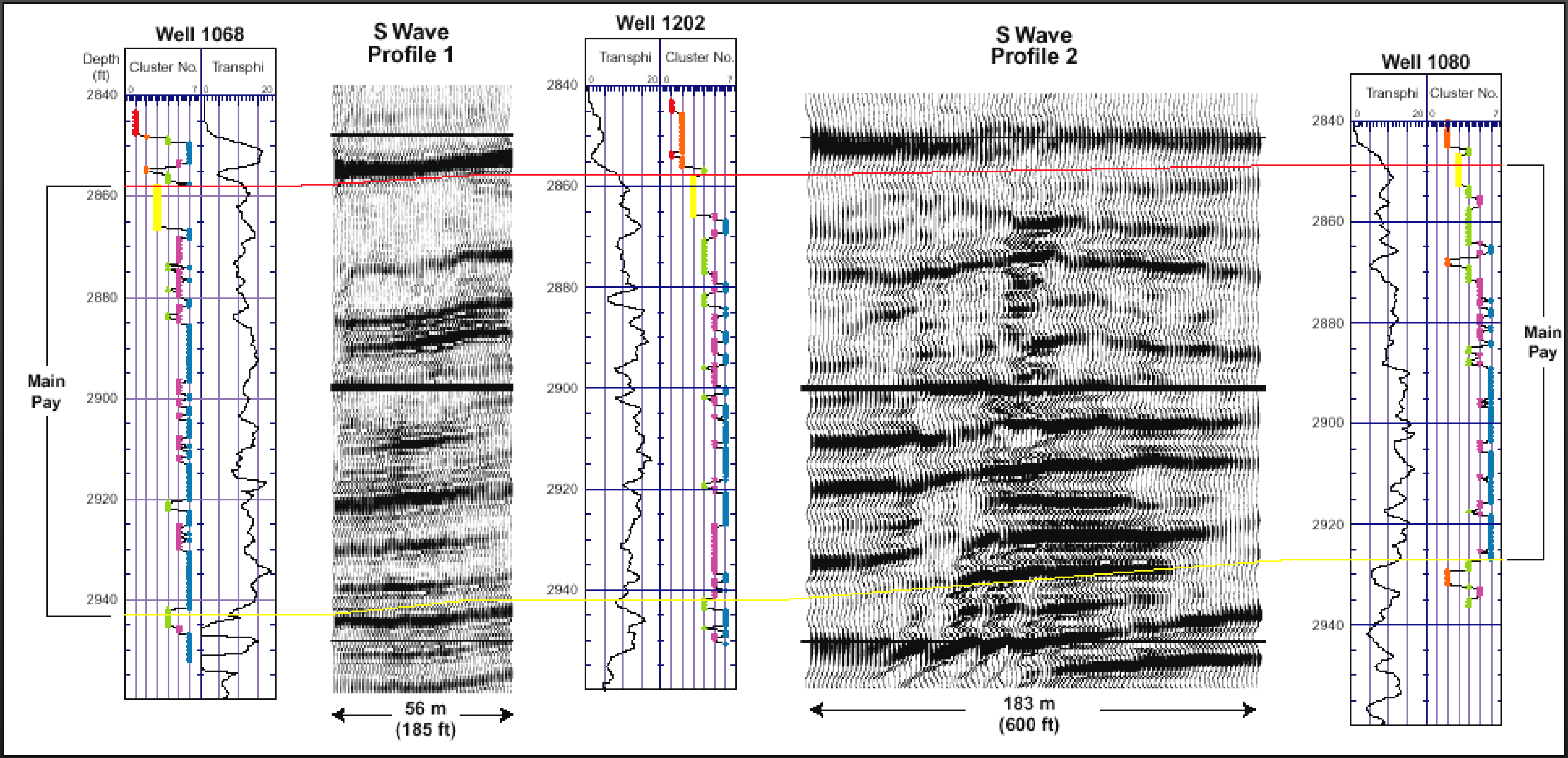
LOG-BASED FACIES



AFTER TUCKER ET AL, 1998

Log-based Clusters Do Not Consistently Match Core Facies

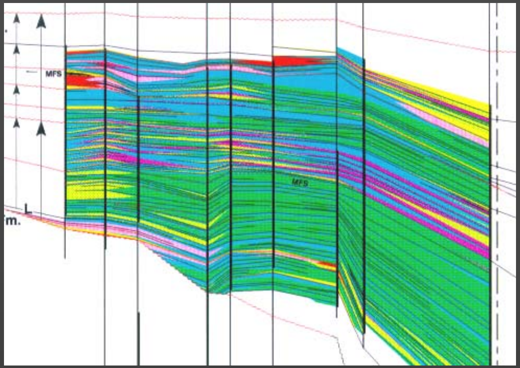
LOG FACIES



AFTER TUCKER ET AL, 1998

Log Facies Better Relate to Porosity and Seismic Reflections

OUTLINE



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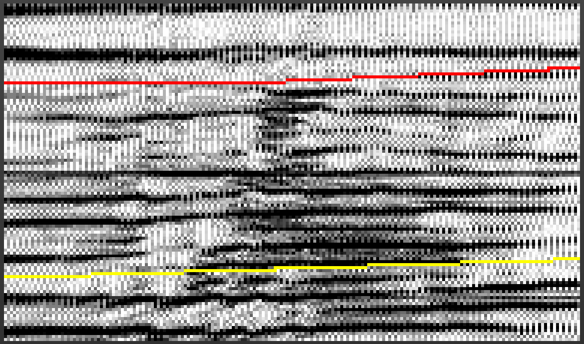

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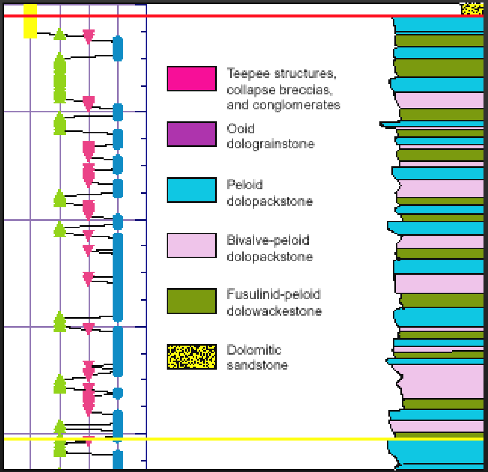

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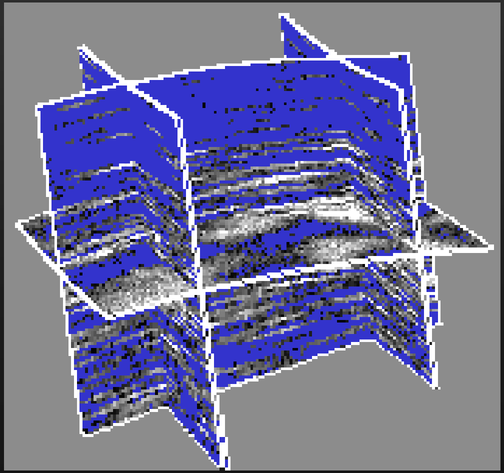


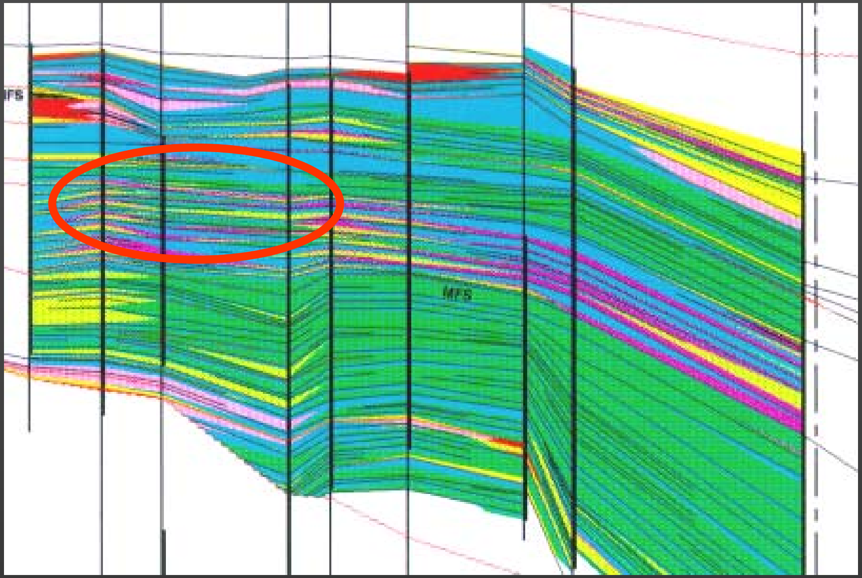
Porosity-Permeability Modeling

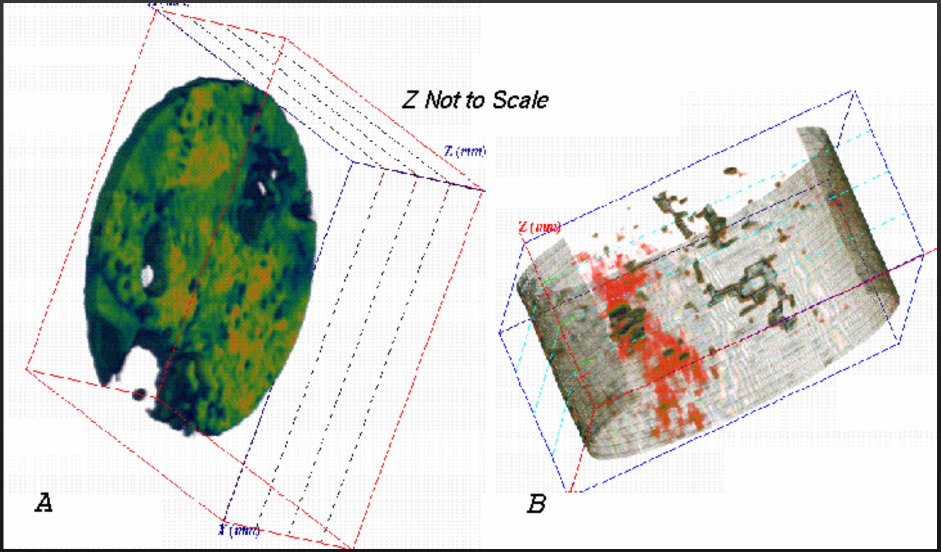
POR-PERM MODELING

VUGGY ZONES

- Logs, Cores, CT Scans, and Production History
- Thin Zones of High por and k
- Early Water Breakthrough in Waterflood
- High Production and Injection Rates

SPATIAL DISTRIBUTION AND K NOT KNOWN



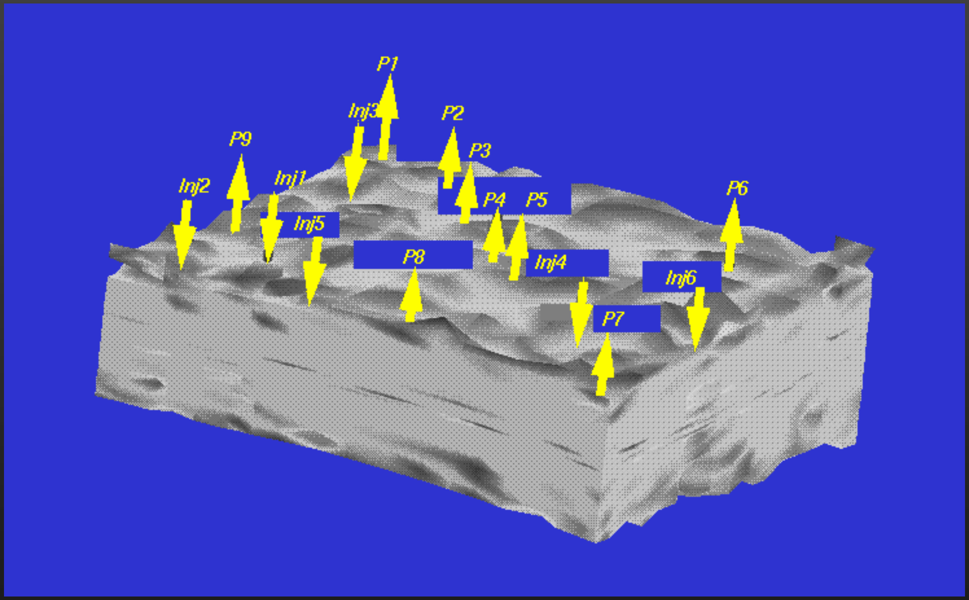


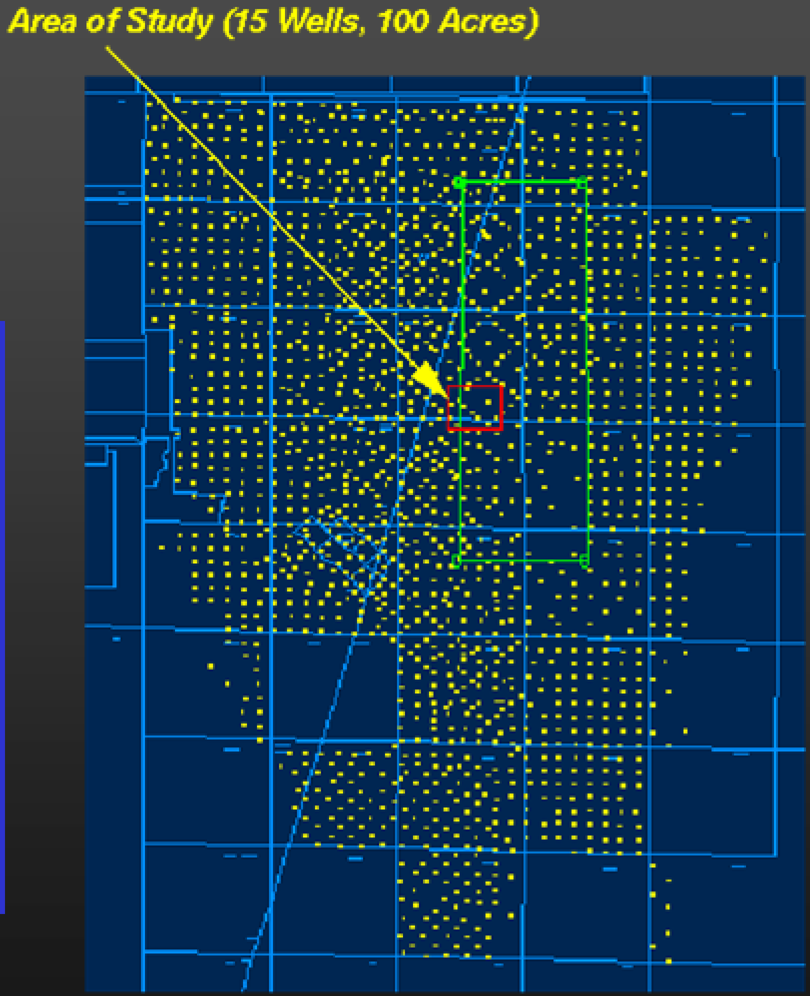
AFTER DEHGHANI ET AL, 1999

MODEL AREA

100 Acre Area in the Vuggy Part of the Field

9 Producer and 6 Injector Wells

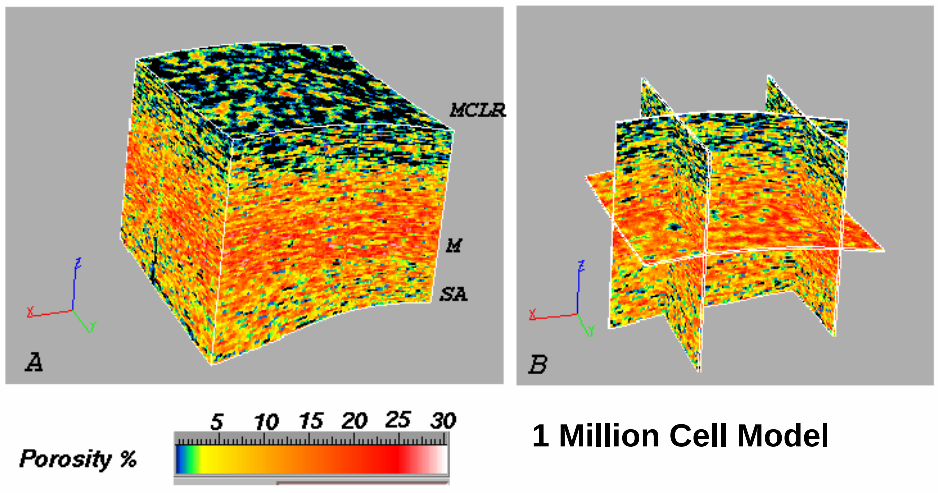




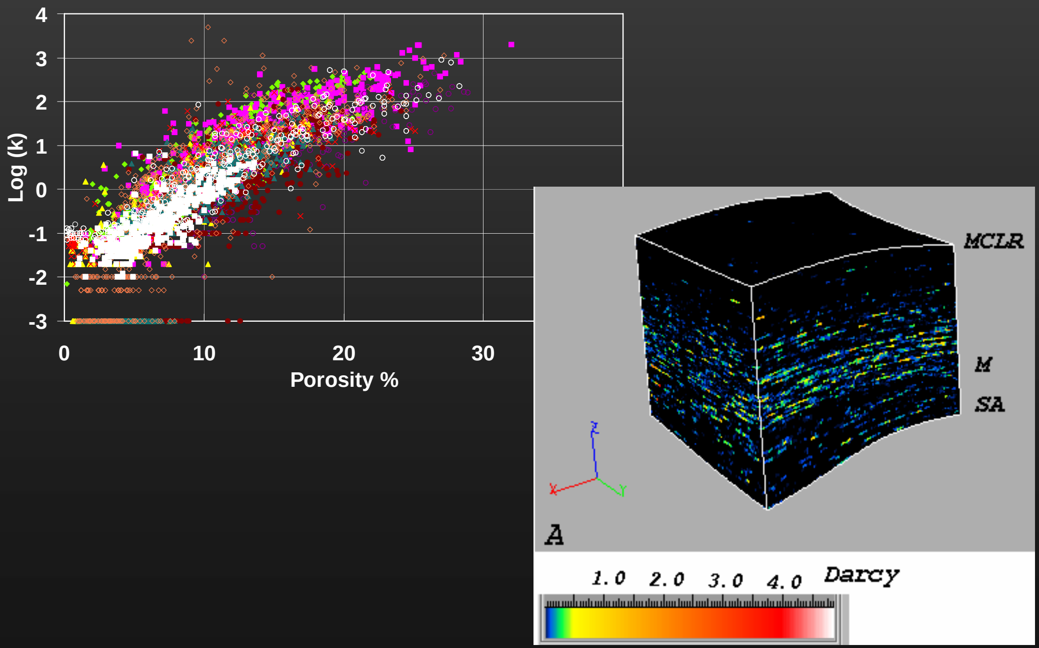
AFTER DEHGHANI ET AL, 1999

MODELING STEPS

Generate Geostatistical Distribution of Total Porosity



Use Por-k Scatter Diagram from Closest Cored Wells and Cloud Transform to Generate Permeability Cube



AFTER DEHGHANI ET AL, 1999

MODELING STEPS

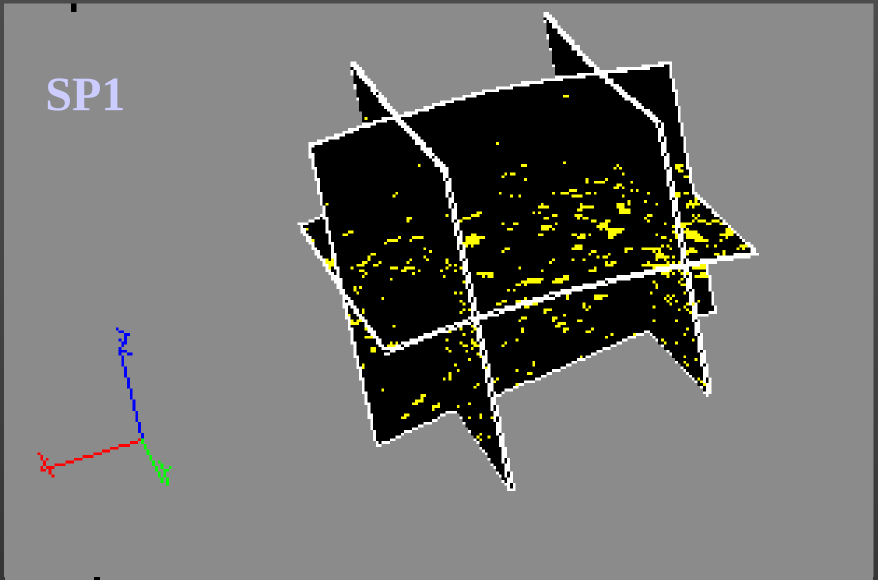
DISTRIBUTE VUGGY ZONES

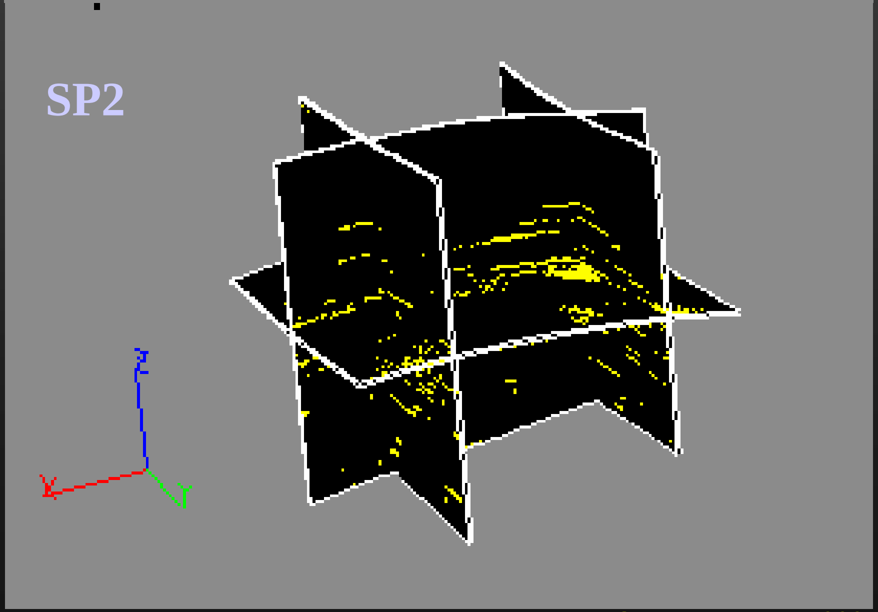
Sonic Log Derived Porosities
Represent Matrix Porosities

Total Porosities from Other Logs

Total - Matrix Porosity > 0.08
Indicates “Vuggy” Zones

Delta Porosity Trace from 291
Wells Used to Generate Two
Cubes of Secondary Porosity

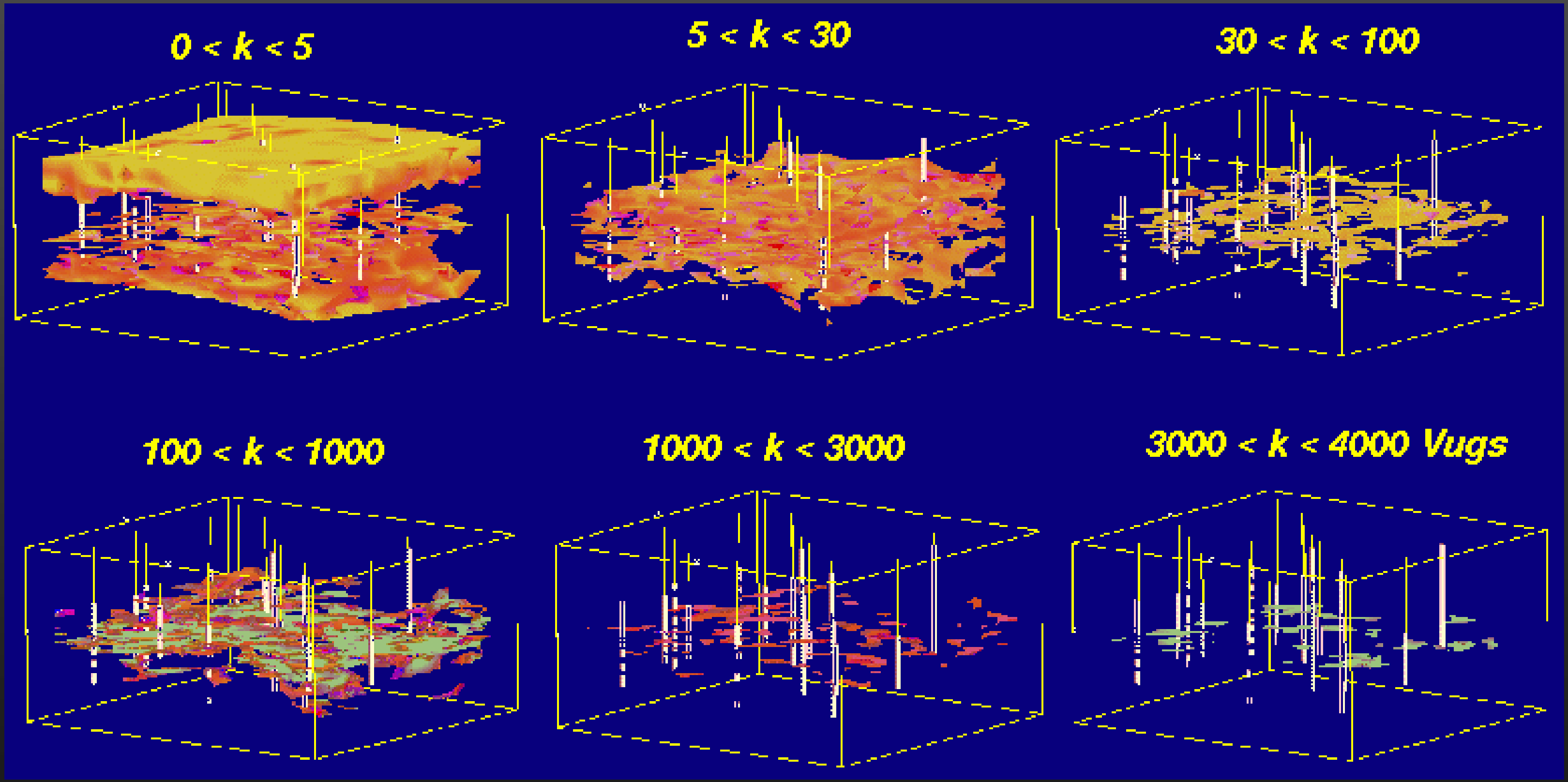




AFTER DEHGHANI ET AL, 1999

MODELING STEPS

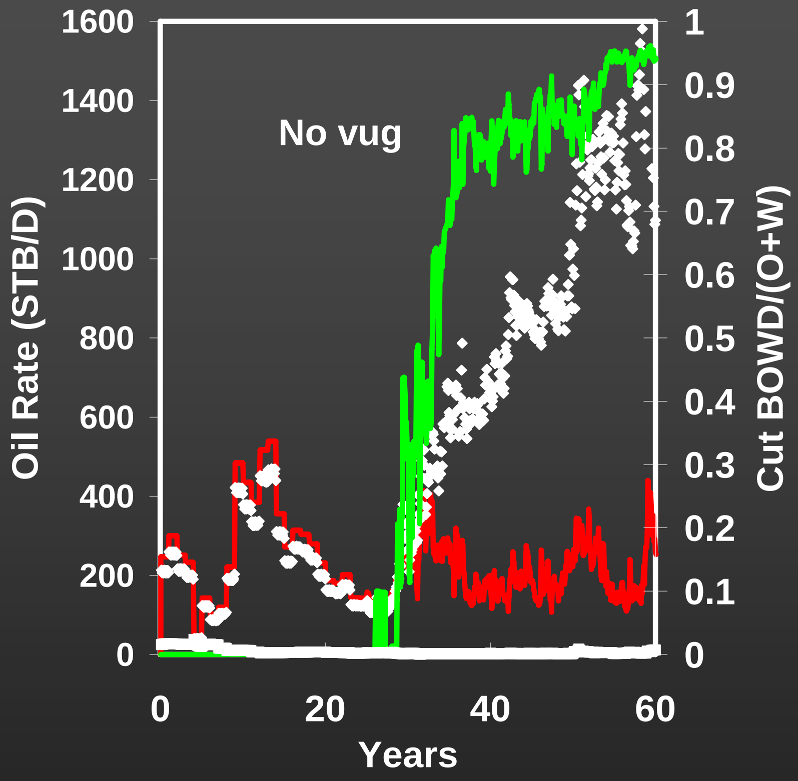
Superimpose Secondary Porosity Cube on Permeability Cube and Assign High Permeability to Vugs

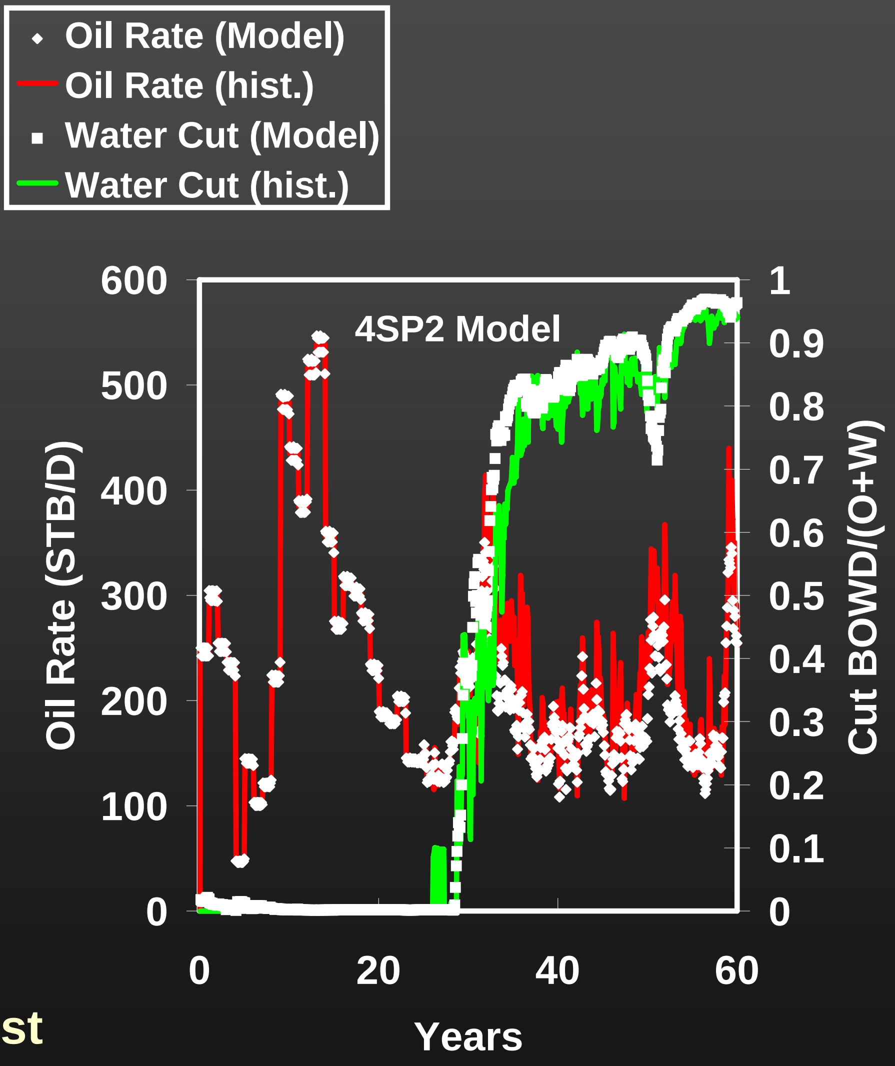


AFTER DEHGHANI ET AL, 1999

Vuggy Zones were Assigned Permeability of 3, 4 or 5.5 Darcy

MODEL VALIDATION





Primary Recovery and Waterflood Periods Were History Matched

Higher permeability and better correlated vuggy zones matched best

AFTER DEHGHANI ET AL, 1999

TALK SUMMARY FROM A RESERVOIR ANALYSIS PERSPECTIVE

Cyclic Shelf Dolomite Reservoirs - Stratiform, widespread, stratigraphy and facies critical, low perm with scattered vuggy zones and evaporites

Unique Approaches to Reservoir Analysis

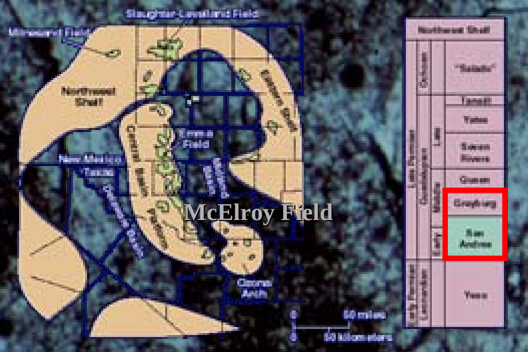
Crosswell Seismic - Improved layering and porosity interpolation

Log Facies - Better tie to porosity variation and seismic in complex diagenesis cases

Por-Perm Modeling - Models incorporating vuggy por-perm best match well history

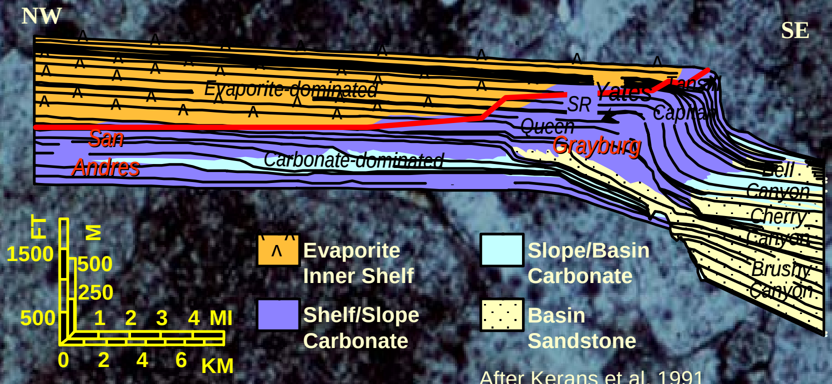
UNIQUE APPROACHES TO ANALYSIS OF A CYCLIC SHELF DOLOMITE RESERVOIR

Paul M. (Mitch) Harris, ChevronTexaco Energy Technology Company, San Ramon, CA

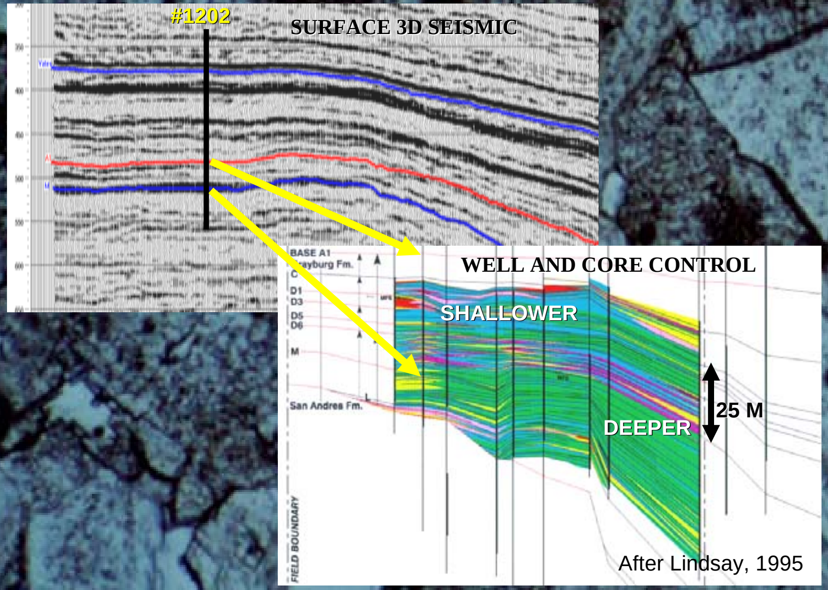


Allan and Wiggins, 1993 (after Hills, 1984)

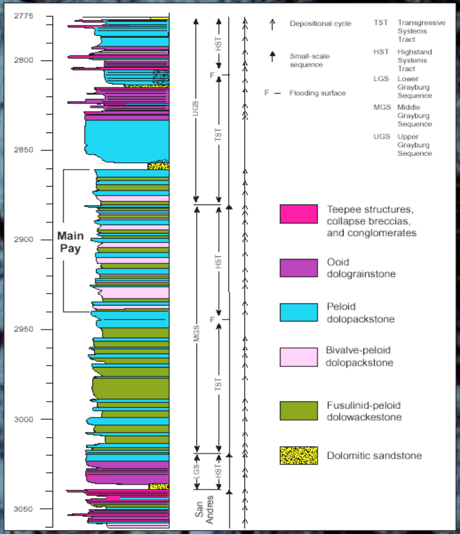
The McElroy Field, Central Basin Platform of the US Permian Basin, produces approximately 17,000 BOPD under a mature waterflood from the Grayburg Formation.



After Kerans et al, 1991



After Lindsay, 1995



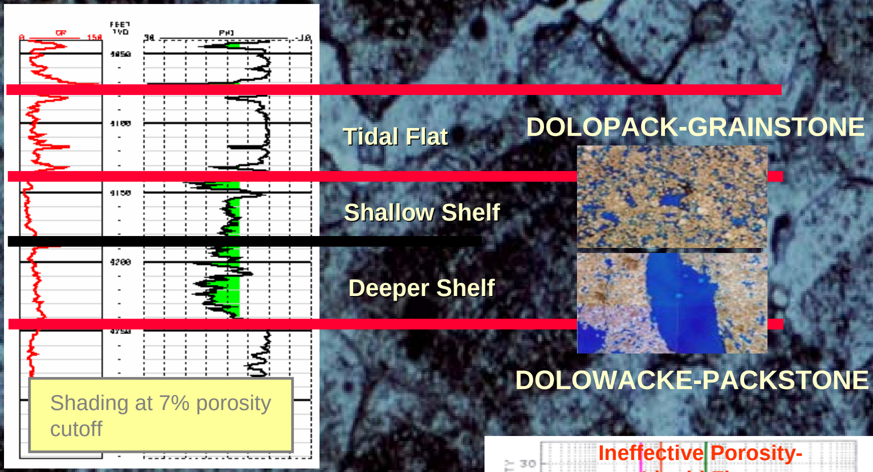
Core studies document the stacking of numerous small-scale cycles within a larger-scale progradational motif, i.e., upward shallowing, for the main producing zone in the field.

Layering in this type of dolomite reservoir is stratigraphically controlled; therefore a thorough understanding of the stratigraphy is needed for determining reservoir architecture. Lateral and vertical shifts of facies must be understood to assess reservoir variation within layers, as facies boundaries generally equate with subtle variations in dolomite characteristics and associated reservoir quality.

"Carbonate Reservoir Characterization and Simulation: From Facies to Flow Units"

UNIQUE APPROACHES TO ANALYSIS OF A CYCLIC SHELF DOLOMITE RESERVOIR

Dolograinstones are dominated by intercrystalline/intergranular porosity with a narrow size range of pore throats that results in most of the nearly 20% porosity being effective to oil flow. In contrast, dolopackstones are less porous and contain both moldic and intercrystalline/intergranular porosity. Their bimodal pore system results in a wider range of pore throat size and more ineffective porosity.



Tidal Flat

Shallow Shelf

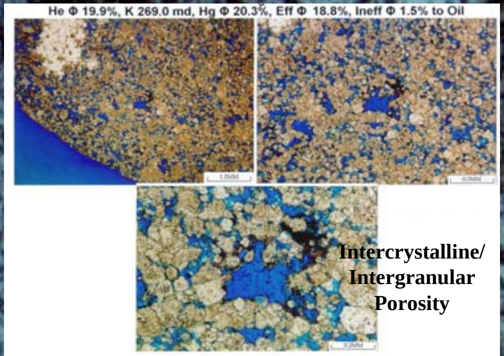
Deeper Shelf

DOLOPACK-GRAINSTONE

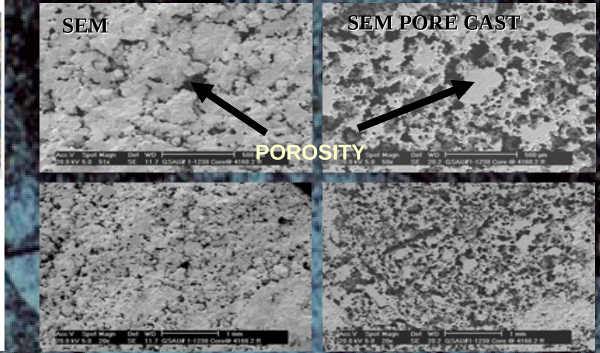
DOLOWACKE-PACKSTONE

Shading at 7% porosity cutoff

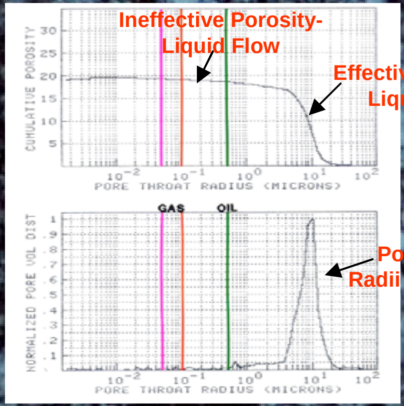
DOLOPACK-GRAINSTONE



Intercrystalline/ Intergranular Porosity



POROSITY

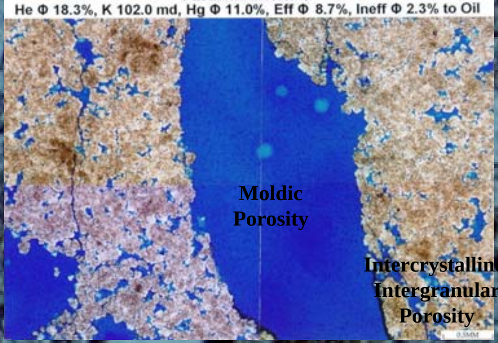


Ineffective Porosity-Liquid Flow

Effective Porosity-Liquid Flow

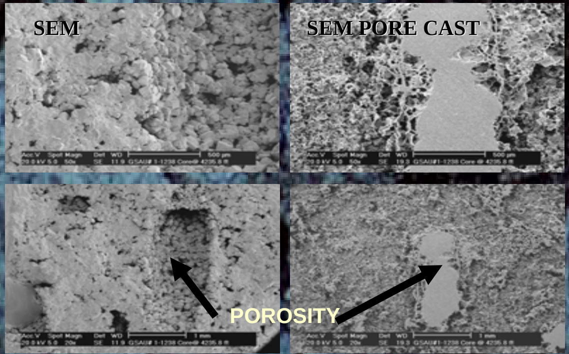
Pore Throat Radii Distribution

DOLOWACKE-PACKSTONE

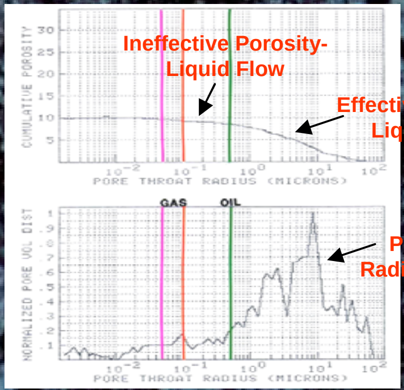


Moldic Porosity

Intercrystalline/ Intergranular Porosity



POROSITY



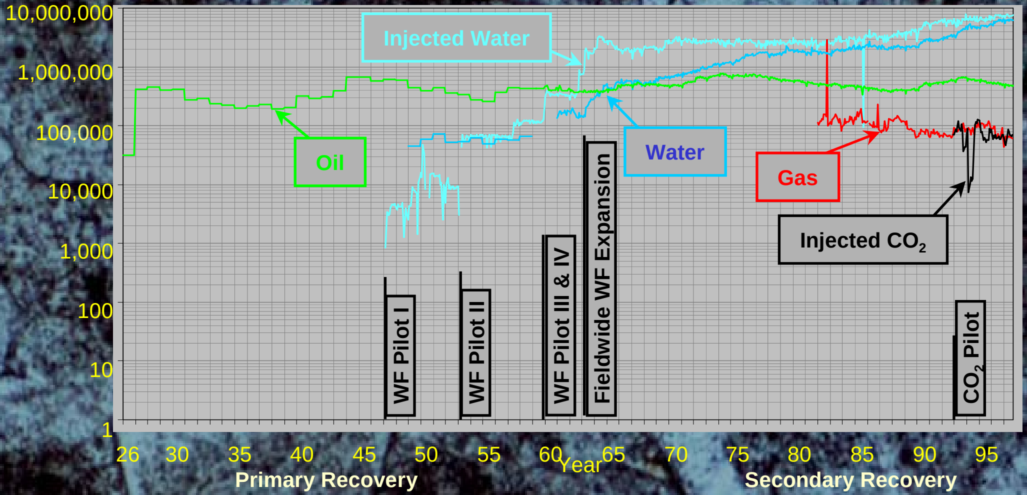
Ineffective Porosity-Liquid Flow

Effective Porosity-Liquid Flow

Pore Throat Radii Distribution

The typically fine crystalline dolomite results in low permeability reservoirs, but a long production history for the field attests to good connectivity. Meteoric overprint produced moldic and enhanced intercrystalline porosity leading to patchily distributed zones of higher porosity and permeability, whereas evaporite cementation and replacement further complicates the reservoir quality distribution.

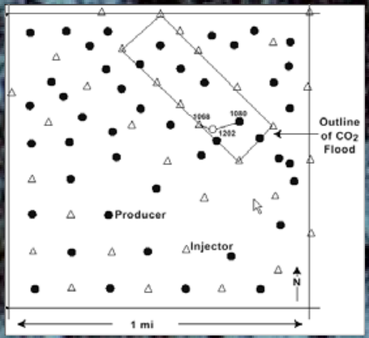
UNIQUE APPROACHES TO ANALYSIS OF A CYCLIC SHELF DOLOMITE RESERVOIR



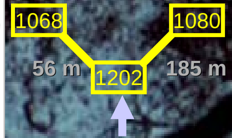
Because of its complexity and long production history McElroy field has been investigated in a great amount of detail, including the utilization of some unique approaches to reservoir analysis

Crosswell Seismic

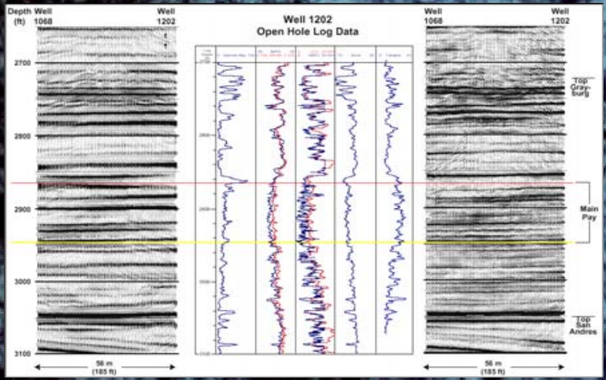
Geologic "ground-truthing" suggests that cross-well seismic data, when integrated with facies-based porosity models, adds value to reservoir characterization. The coincidence of reflectors with decreases in porosity or gypsum cement from whole-core analysis suggests that total porosity and mineralogy dominantly influence velocity. Reflectors correlate fairly well with major log variations; S-wave reflectors correspond almost exactly with increases in sonic velocity, resistivity, and bulk density, and decreases on the neutron log from high to low porosity (or gypsum). Although major stratigraphic boundaries (sequence boundaries and flooding surfaces) generally coincide with reflectors, lithofacies and small-scale depositional cycles do not relate directly to the seismic data. Comparing geostatistical porosity models directly to the seismic suggests that S-wave reflection images appear to be resolving lateral changes in porosity of less than 56 m but more than 15 m.



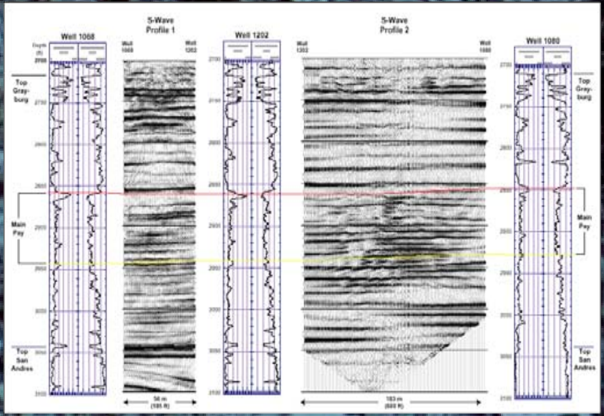
After Tucker et al, 1998



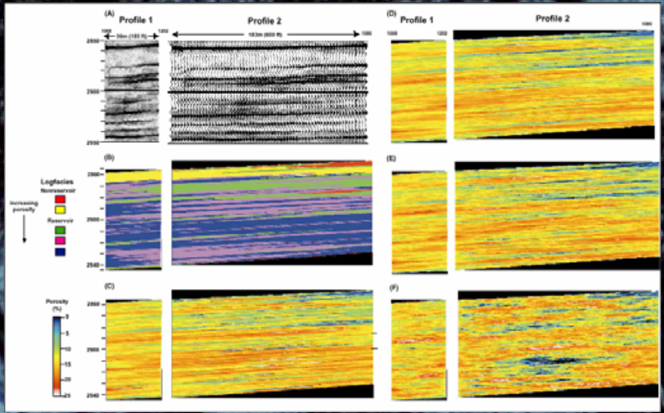
KEY WELL WITH CORE AND LOGS



Reflectors = increases in sonic, resistivity, and bulk density also decreases on neutron from high to low porosity (or gypsum)



Reflectors, along with GR and sonic log, suggests interwell variation

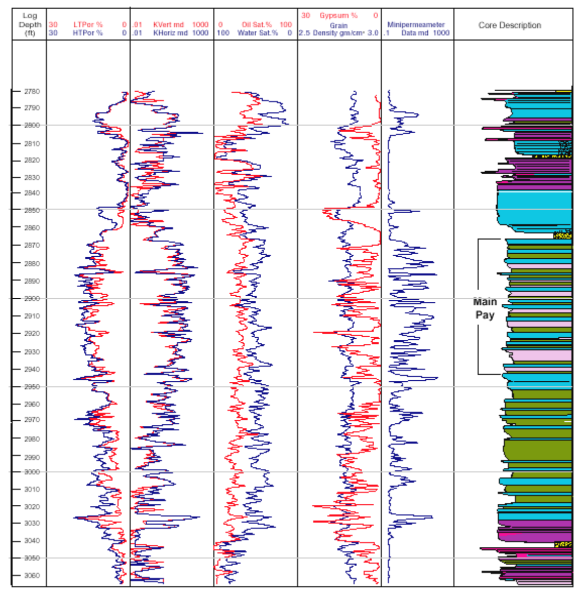


Images resolve lateral changes in porosity <56 m but >15 m

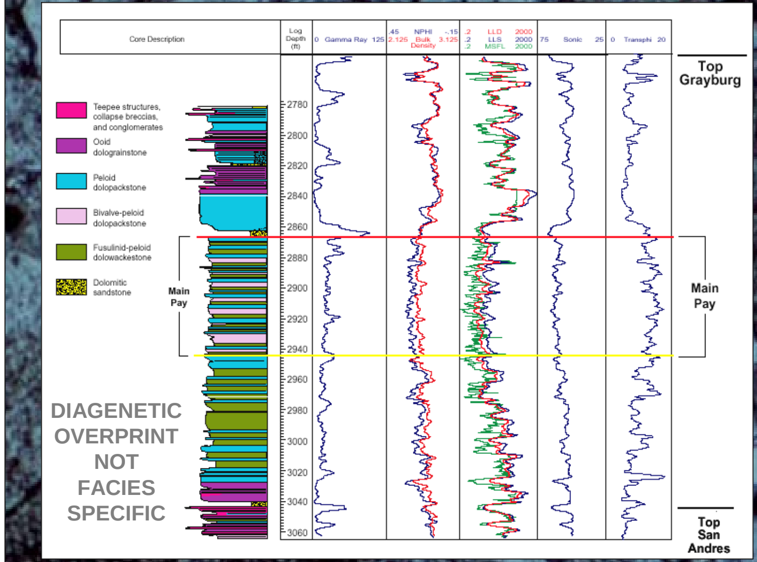
UNIQUE APPROACHES TO ANALYSIS OF A CYCLIC SHELF DOLOMITE RESERVOIR

Log Facies

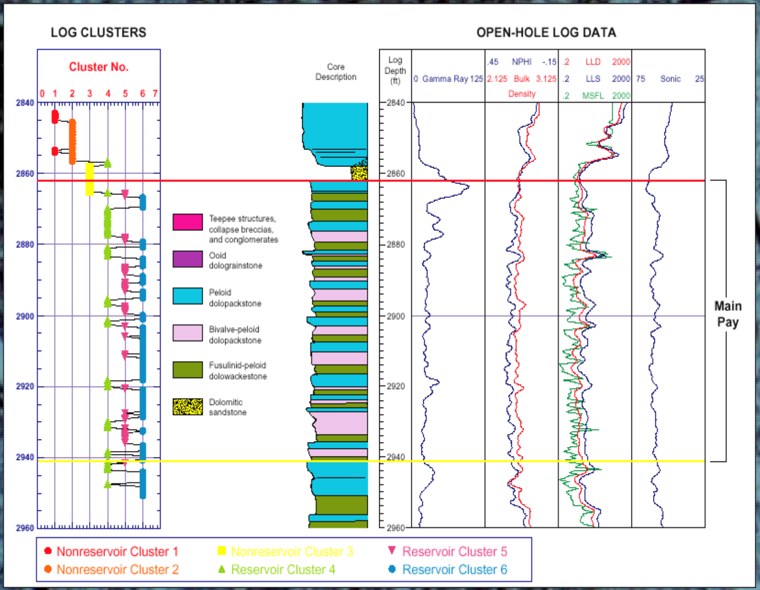
A significant result of the diagenetic complexity of the McElroy reservoir is that reservoir quality does not match original depositional facies. Both the seismic and log data respond to the same diagenetic overprint and its resulting petrophysical characteristics; therefore log facies derived from cluster analysis, rather than core lithofacies, better relate to the cross-well seismic. Many of the seismic reflectors correspond to vertical transitions between more and less porous log facies, which indicates the strong relationship between velocity and porosity. In addition, lateral variations in many of the positive-amplitude events can be tied to changes in porosity and differences in log facies between wells.

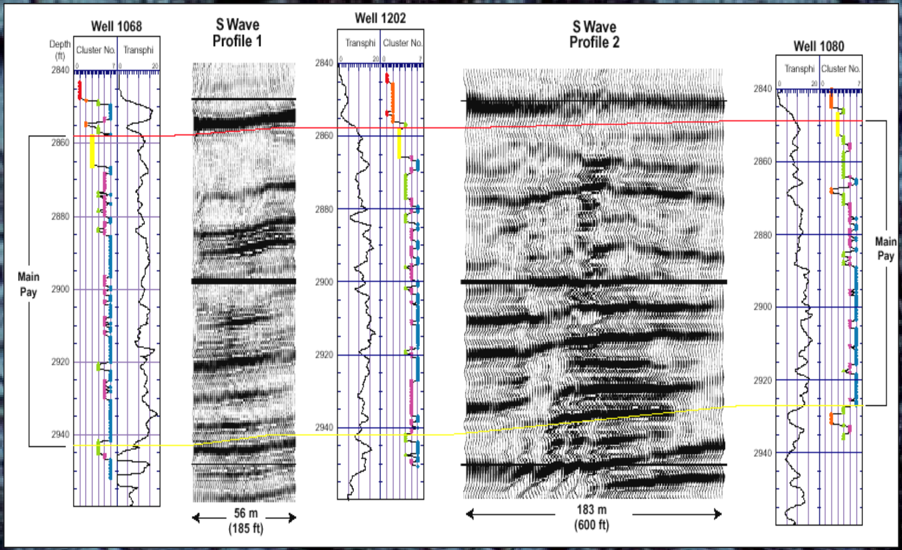


Poor Correlation Between Measured Variables and Core-Based Lithofacies



Poor Correlation Between Logs and Core-Based Lithofacies





Log Facies Better Relate to Porosity and Seismic Reflections

Log-based Clusters Do Not Consistently Match Core Facies

After Tucker et al, 1998

UNIQUE APPROACHES TO ANALYSIS OF A CYCLIC SHELF DOLOMITE RESERVOIR

Dual Porosity-Permeability Modeling

Heterogeneity is increased significantly in the central portion of McElroy field by thin high porosity-permeability vuggy zones. A method was developed to identify the vuggy zones on logs, create geostatistical models of porosity and permeability incorporating the vuggy zones, and characterize them in simulation models. The method involved the following: (1) developing a log trace to identify zones of high vuggy porosity, (2) creating a detailed geostatistical model of total porosity using well log data, (3) creating a geostatistical permeability model based on total porosity, (4) creating a separate detailed geostatistical model of secondary porosity, and (5) superimposing exceptionally high permeability in areas of the permeability model defined by high secondary porosity.

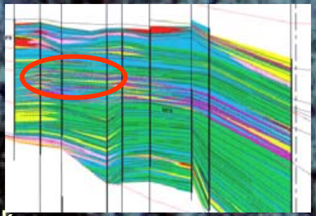
VUGGY ZONES

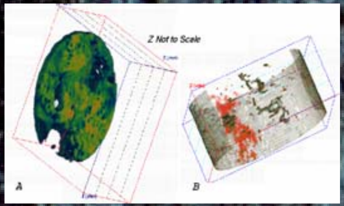
Logs, Cores, CT Scans, and Production History

Thin Zones of High por and k

Early Water Breakthrough in Waterflood

High Production and Injection Rates





100 Acre Area in the Vuggy Part of the Field

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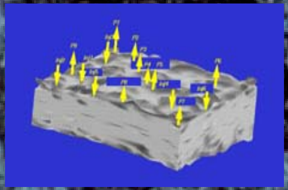
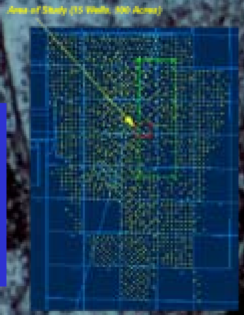
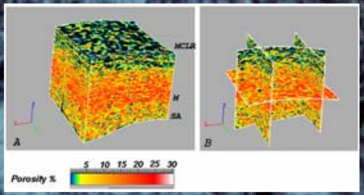




Generate Geostatistical Distribution of Total Porosity



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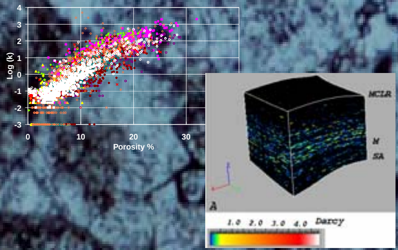

DISTRIBUTE VUGGY ZONES

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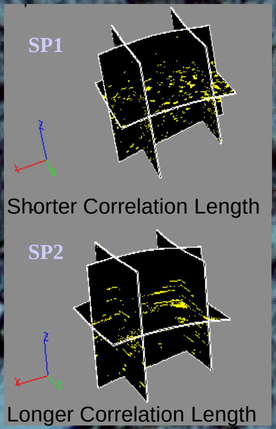
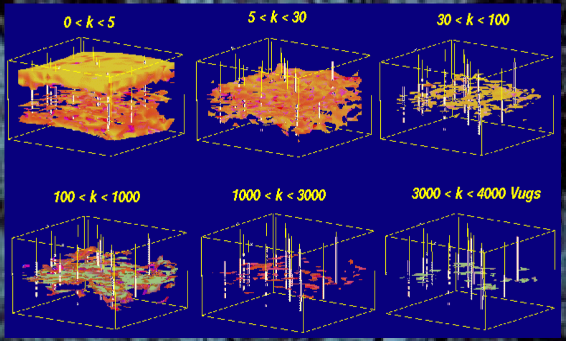
Delta Porosity Trace from 291 Wells Used to Generate Two Cubes of Secondary Porosity



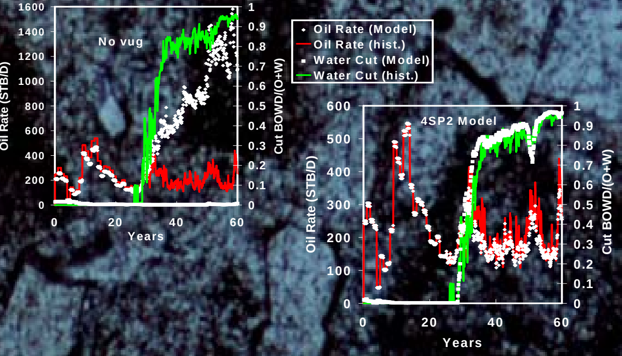
Shorter Correlation Length

Longer Correlation Length

Superimpose Secondary Porosity Cube on Permeability Cube and Assign High Permeability to Vugs

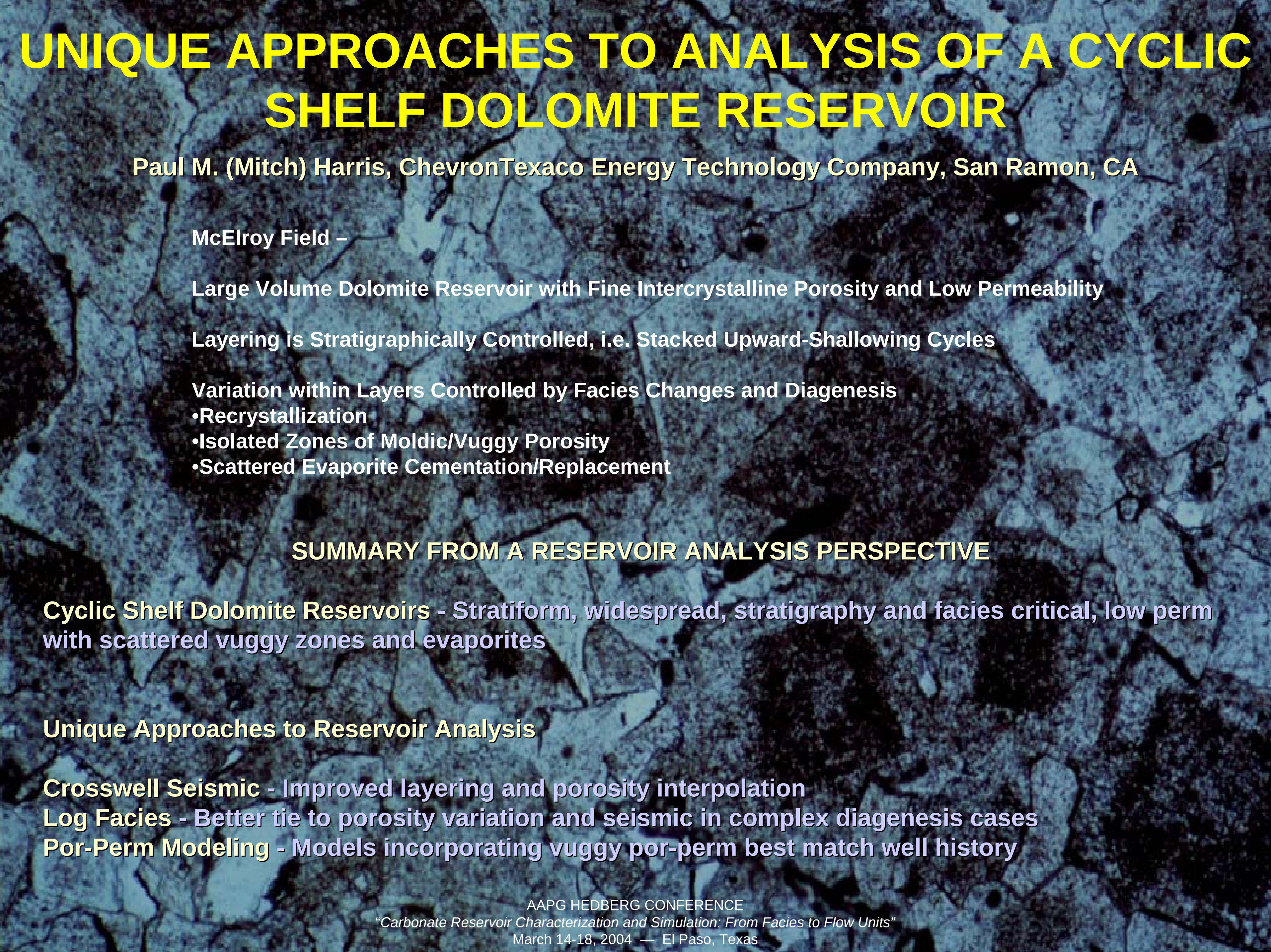


Vuggy Zones were Assigned Permeability of 3, 4 or 5.5 Darcy



Primary Recovery and Waterflood Periods Were History Matched
Higher Permeability and Better Correlated Vuggy Zones Matched Best

After Dehghani et al, 1999



UNIQUE APPROACHES TO ANALYSIS OF A CYCLIC SHELF DOLOMITE RESERVOIR

Paul M. (Mitch) Harris, ChevronTexaco Energy Technology Company, San Ramon, CA

McElroy Field –

Large Volume Dolomite Reservoir with Fine Intercrystalline Porosity and Low Permeability

Layering is Stratigraphically Controlled, i.e. Stacked Upward-Shallowing Cycles

Variation within Layers Controlled by Facies Changes and Diagenesis
- **Recrystallization**
- **Isolated Zones of Moldic/Vuggy Porosity**
- **Scattered Evaporite Cementation/Replacement**

SUMMARY FROM A RESERVOIR ANALYSIS PERSPECTIVE

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AAPG HEDBERG CONFERENCE
"Carbonate Reservoir Characterization and Simulation: From Facies to Flow Units"
March 14-18, 2004 — El Paso, Texas