Characterization of Pliocene Repetto Formation Turbidites at Ventura Avenue Field, Ventura, California*

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Abstract

The Pliocene Pico and Repetto Formation turbidites of the Ventura Basin were the subject of some of the early research on deep-water sedimentation. Combinations of cores, subsurface well logs, and outcrop data have been used to characterize the sandstone reservoirs and interpret depositional setting and sand-body geometry. The sandstones deposited in this broad, elongate-trough basin have been recognized as differing from turbidites that make up the lobes of a traditional submarine fan setting. They have been variously described as ribbon or shoestring sands, compensationally stacked elongate-lobe elements, and components of a braided-lobe complex. The majority of the sands are the result of high concentration flows and are poorly sorted. Our study utilizes recently acquired subsurface data from cores and well logs, and new analytical techniques that link these data types, to progress our understanding of depositional environments, facies distributions and rock properties. A key element is a well-log-based petrofacies model that directly ties to lithofacies. This technique enables us to delineate lithofacies stacking patterns and lateral facies variations in wells without core. Well-log correlation, linked with core observations and petrofacies determination helps to define the geometry of stratigraphic elements on the scale of 50-100 feet (15-30 m) and identify key stratigraphic surfaces. Petrofacies also are key for predicting reservoir properties, since porosity and permeability are closely correlated to lithofacies. In the coarsest-grained stratigraphic elements, we identify two lithofacies stacking patterns that likely represent different depositional settings. Both have pebble-to-gravel-sized clasts in a sandy matrix and angular mudstone clasts at their bases. We interpret these elements to have been deposited in axial positions within the depositional system. One element exhibits a fining upward stacking pattern and potentially represents a distributary channel system that eventually migrates or is abandoned. The second coarse-grained element has a blocky stacking pattern and remains coarse-grained nearly to the top of the unit. Overall deposition of the amalgamated sands

was likely very rapid. This depositional geometry could be consistent with a braided-lobe complex. Thinner-bedded, generally finer-grained sandstones show more variability in stacking pattern and are more difficult to map over larger distances using well-log correlation. The correlation geometry of these stratal elements is generally planar and subparallel, but the individual sands are less continuous or change thickness. The sands are often interbedded with mudstones and sometimes slurry deposits. We interpret these units to represent off-axis or distal deposition. The coarsest-grained bedsets are deposits of high-density turbidites. They are generally amalgamated, poorly sorted sands, with lower matrix porosity and permeability. The tops of graded bedsets, and the thin-bedded sandstones, tend to be finer-grained and better sorted. They usually have higher matrix porosity and permeability.

Selected References

Hsu, K.J., 1977a, Studies of Ventura Field, California, I: Facies geometry and genesis of Lower Pliocene turbidites: AAPG Bulletin, v. 61/2, p. 137-168.

Hsu, K.J., 1977b, Studies of Ventura Field, California, II: Lithology, compaction and permeability of sands: AAPG Bulletin, v. 61/2, p. 169-191.

Hsu, K.J., K. Kelts, and J.W. Valentine, 1980, Resedimented Facies in Ventura Basin, California, and Model of Longitudinal Transport of Turbidity Currents: AAPG Bulletin, v. 64, p. 1034-1051.

Rotzien, J.R., D.R. Lowe, and J.R. Schwalbach, J.R., 2014, Processes of sedimentation and stratigraphic architecture of deep-water braided lobe complexes: the Pliocene Repetto and Pico Formations, Ventura basin, U.S.A.: Journal of Sedimentary Research, v. 84, p. 910-934.

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Schwalbach, J.R., J.W. Holloway, E. Steel, and R. Coldewey, in review, Pliocene Repetto Formation Turbidites at Ventura Avenue Field, Ventura, California: Linking Reservoir Properties, Lithofacies and Stratigraphic Elements: in, K. Marsaglia, R. Behl, and J.R. Schwalbach, (eds.), From the Mountains to the Abyss, The California Borderland as an Archive of Southern California Geologic Evolution in honor of Donn Gorsline, SEPM Special Publication.

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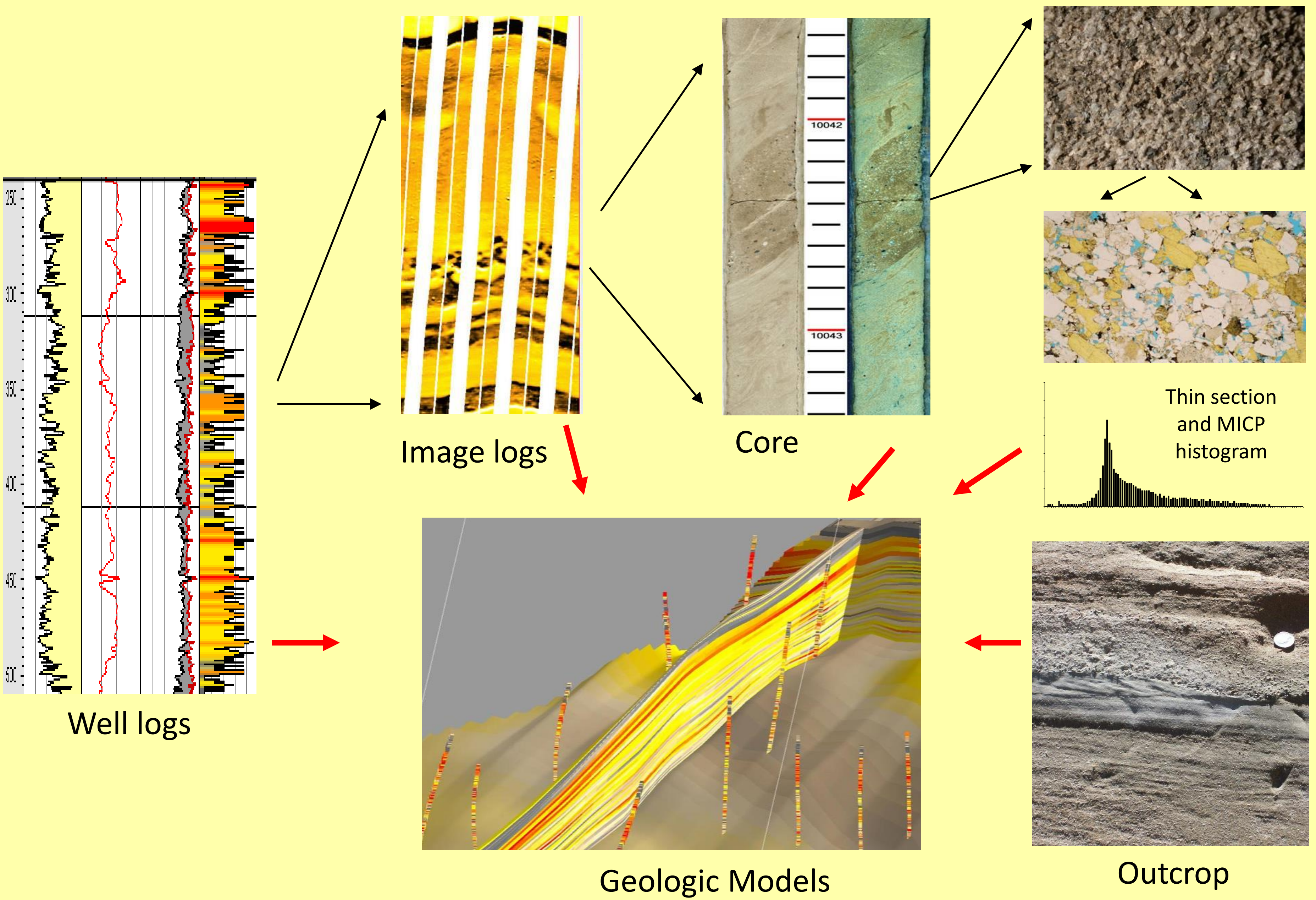
Jon Schwalbach, James Holloway, and Elisabeth Steel

2016 PS SEPM Session: California Borderland, in Honor of Donn Gorsline

AERA®

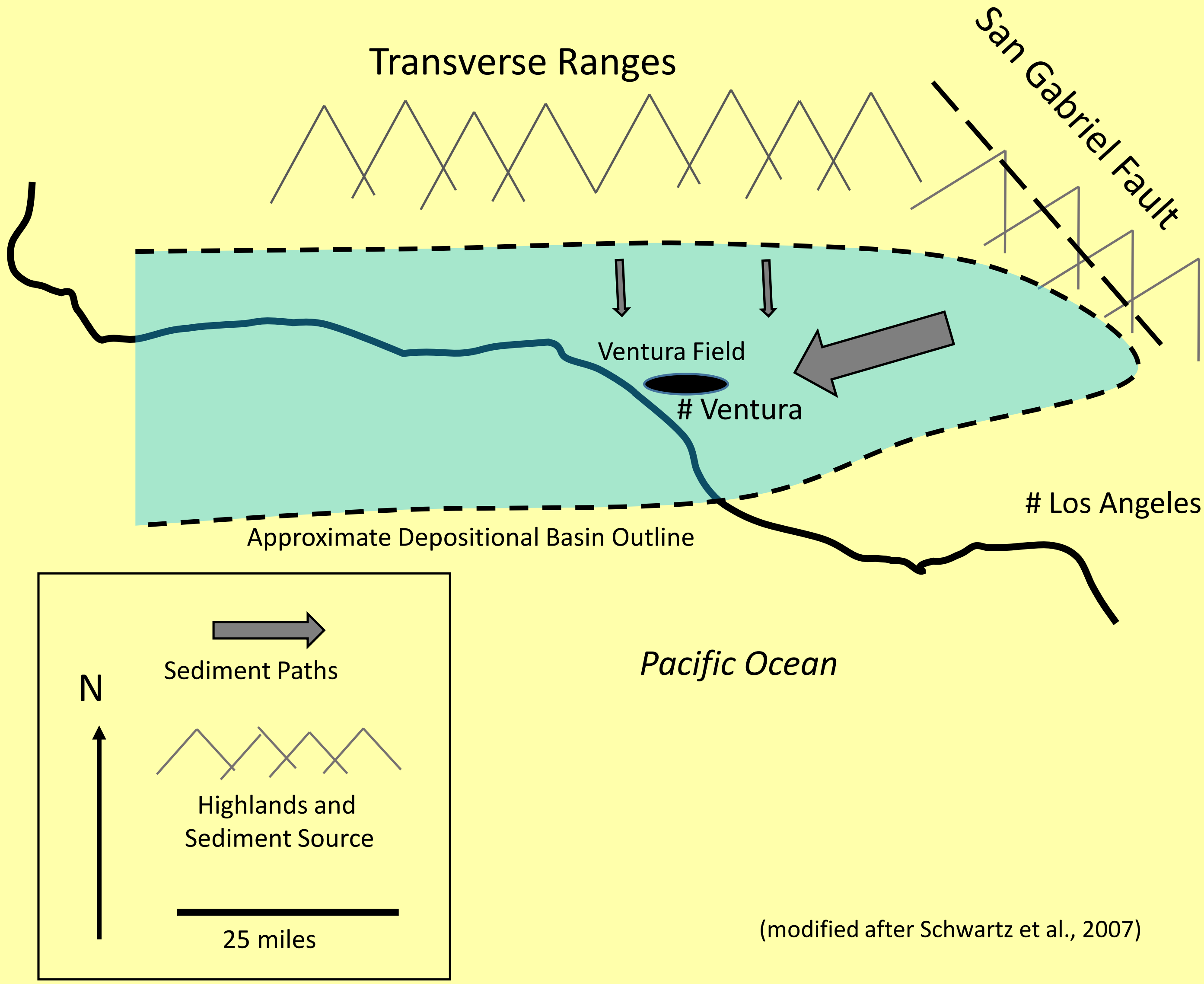
Integrating data to improve reservoir characterization



Ventura Avenue Field

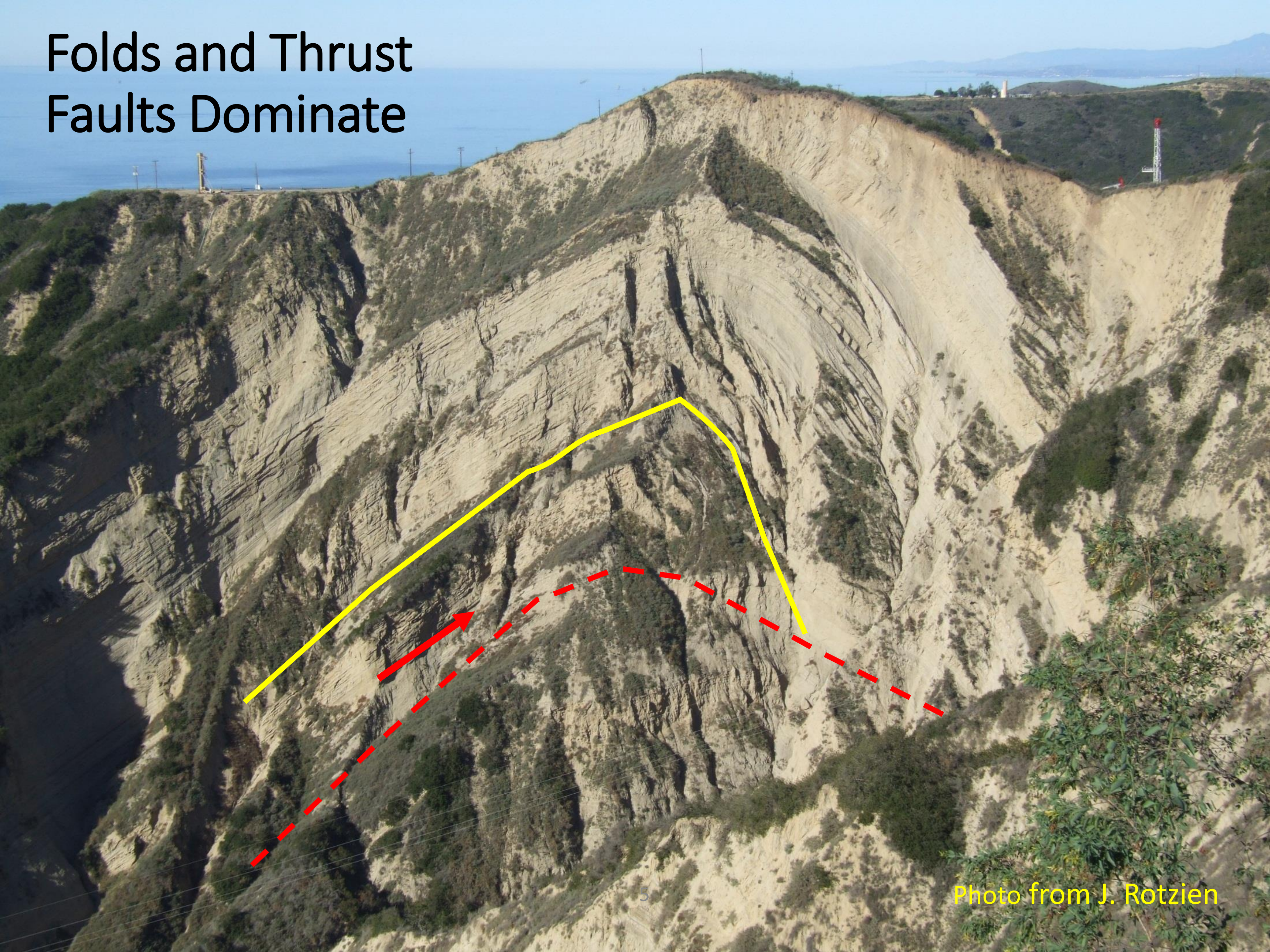
- Discovered 1896, First commercial production 1916
- 9 miles long, complexly thrust-faulted anticline with a 10,000 ft of productive column in stacked Pliocene Pico/Repetto turbidites
- Peak production 1954 (76,600 bopd), reached 1 Billion Barrels December 2009
- Waterfloods initiated 1965, current production approx. 13,000 bopd

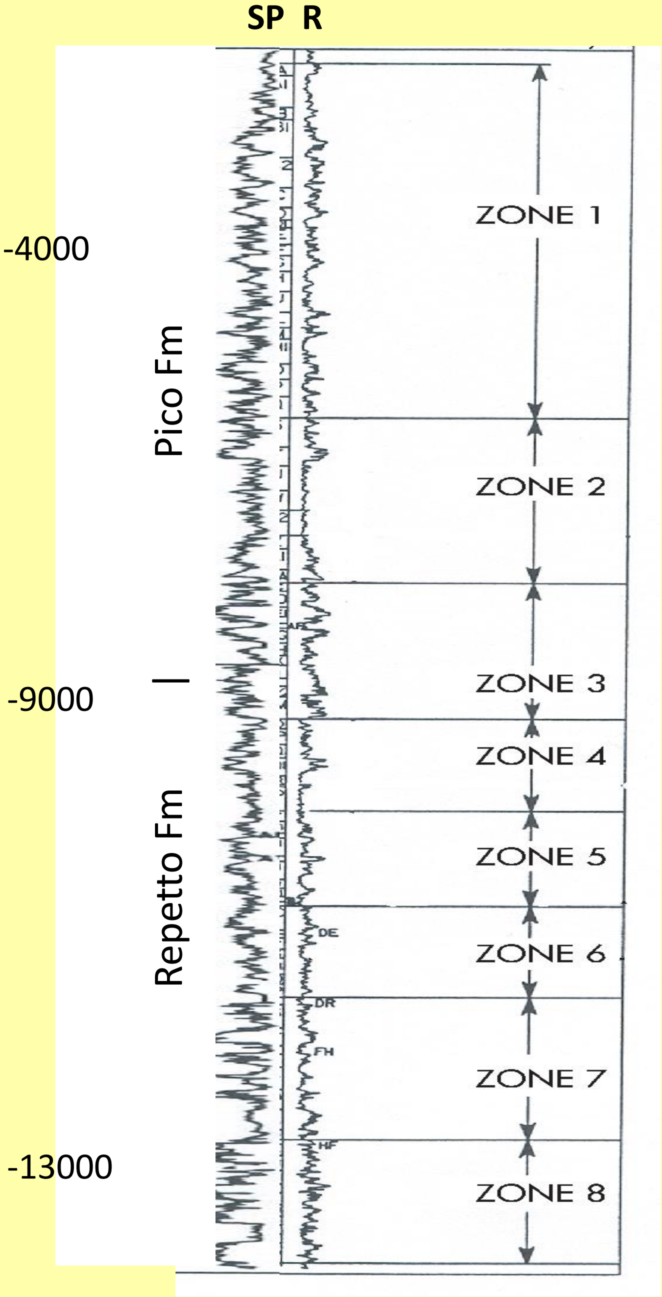
Schematic Ventura Basin Map



(modified after Schwartz et al., 2007)

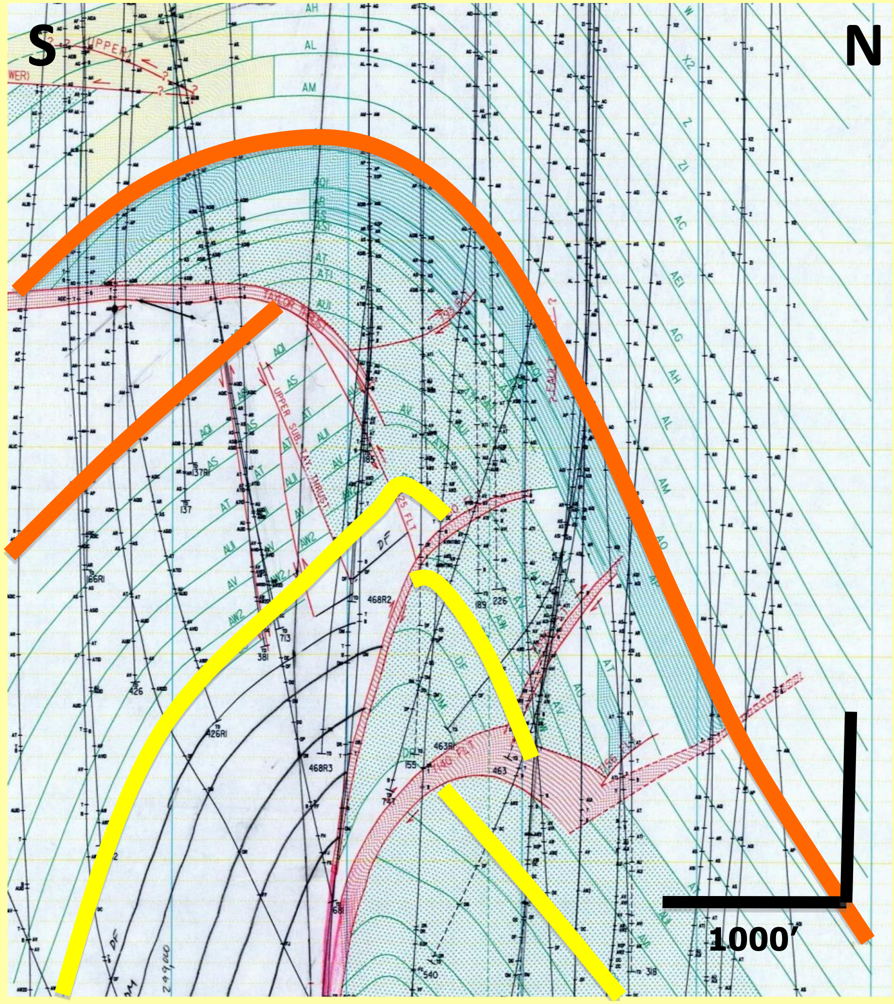
Folds and Thrust Faults Dominate





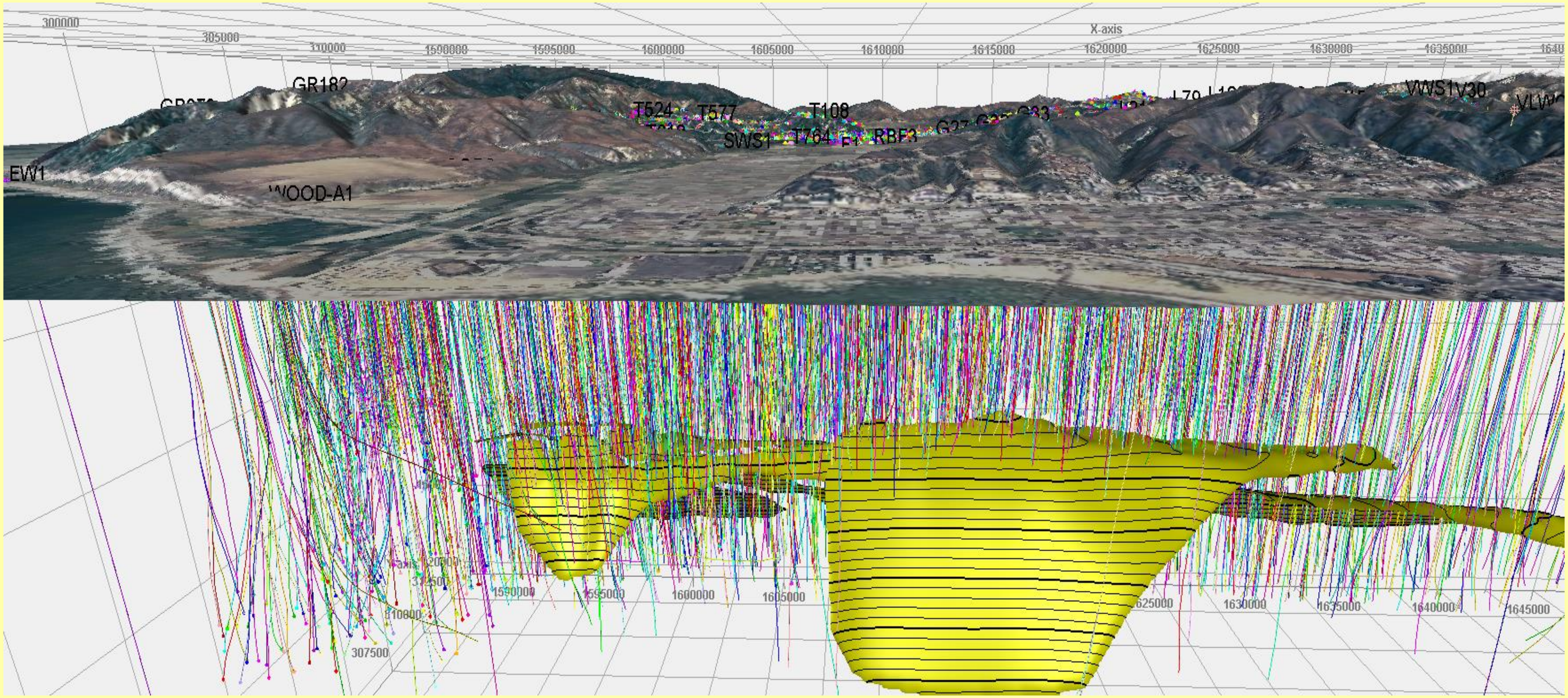
Type Log: Thick Stratigraphic Column

Ventura Field



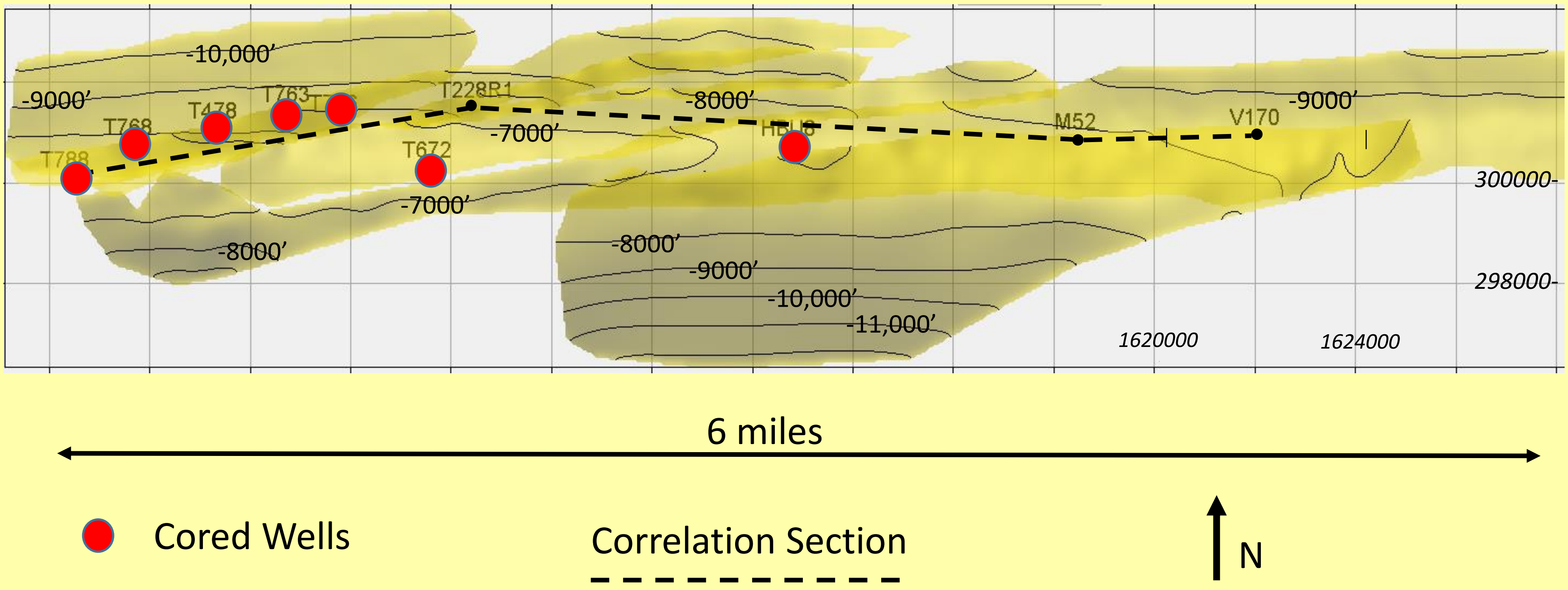
- 1:1 Cross Section with well paths
- Orange and Yellow horizons highlight thrust faults (Shaded Red)
- Green Shading illustrates oil column

Ventura Field View From South



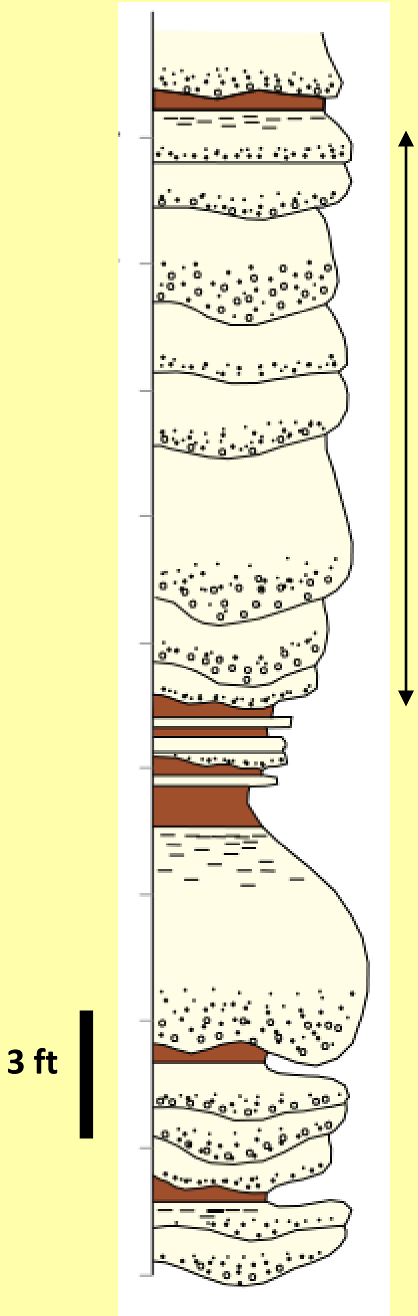
Wells (2500+) are the dominant data source

Structure map on DC abandonment surface illustrating core locations and key stratigraphic section



Cores Provide Critical Data for Facies, Dep'l Environment, and Rock Properties

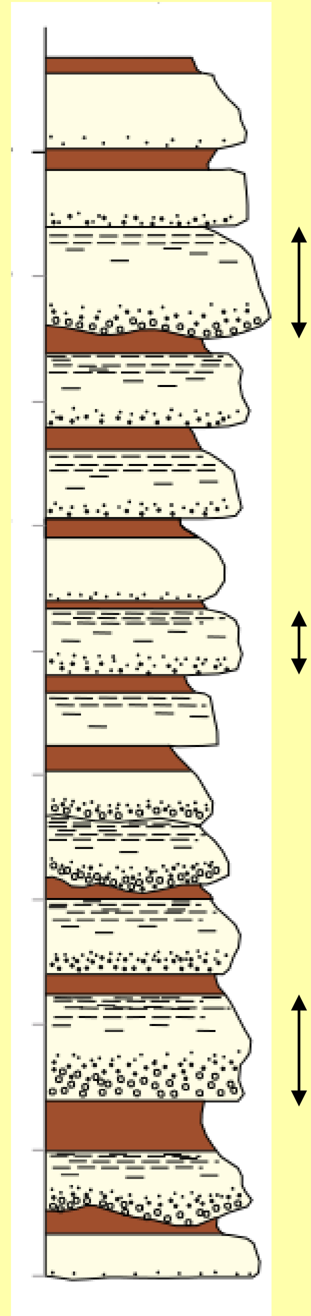
Turbidite Bedsets and Stacking Patterns



Amalgamated, mostly high-density turbidites

Thicker Beds
Poorly Sorted
Lower Porosity

Higher Net/Gross
Higher Kv/Kh



Non-Amalgamated, mostly low-density turbidites

Graded
Thinner Beds
Better Sorted
Higher Porosity

Lower Net/Gross
Lower Kv/Kh

Depositional Processes Impact Rock Properties

High Density Turbidites

- *Population II Grains (Pebbles through Medium Sand)*
- *Most deposition from higher-energy, high sediment concentration flows*
- *Particles supported by grain interactions and fluid turbulence*

Low Density Turbidites

- *Population III Grains (Medium Sand and Finer)*
- *Most deposition from lower-energy, lower sediment concentration flows*
- *Particles supported by fluid turbulence*

Sorting is significantly better in rocks deposited by low density flows.

(after Lowe, 1982, 2000)

Angular shale rip-up clasts and pebbles in sandy matrix

Pebbles, granules, coarse sand – poorly sorted

Amalgamated, coarsest-grained units

Rapid deposition

Some evidence of local erosion

Occasional S1-S2, typically Ta/S3

Basal Lobe and Axial Position of Distributary or Braid Channels

(3' core strips, plain light)

Amalgamated Sands

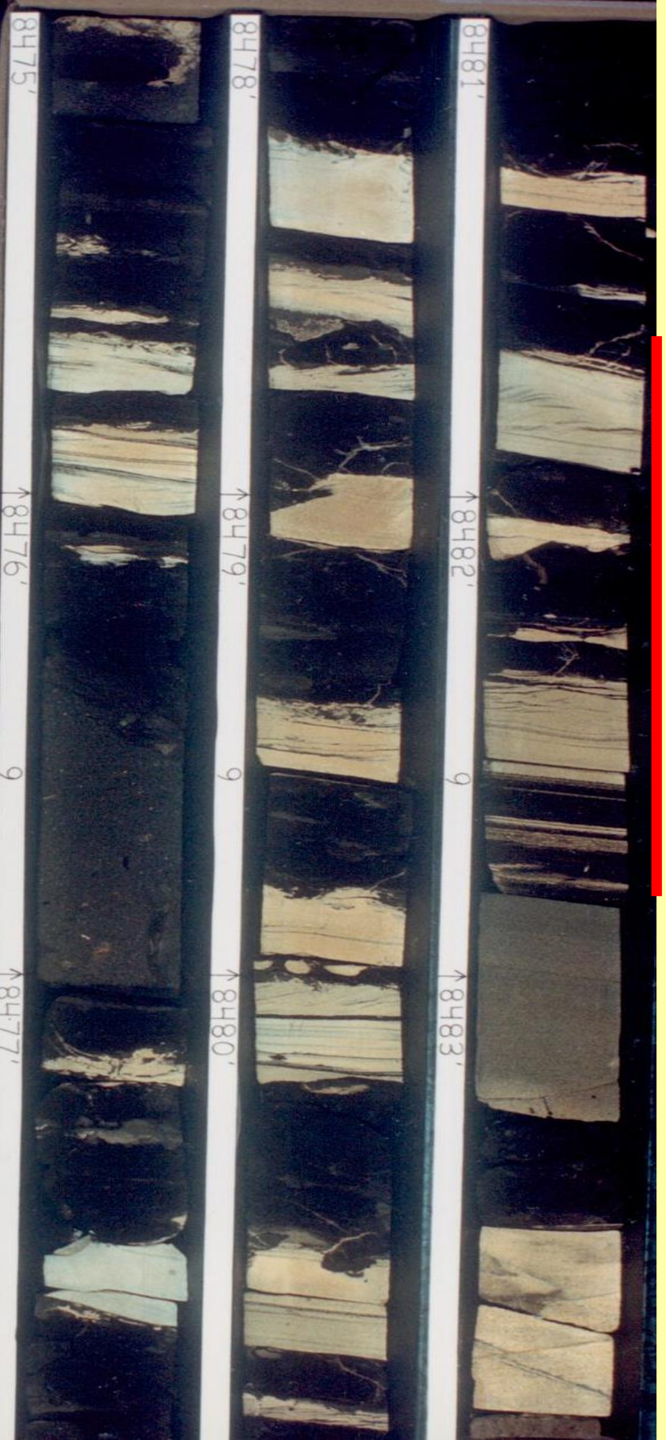
Granules to medium sand, dominantly "high density" turbidites (Ta/S3)

Occasional pebbles at base of flow units

Some "caps" of fine-medium sands, disrupted bedding common

No shale beds between depositional flow units, thick packages readily correlate

Rapid Lobe Deposition/ Amalgamated Bar forms



Non-Amalgamated: Thin-Bedded Turbidites and Mudstones

Classical or "Low Density" Turbidites

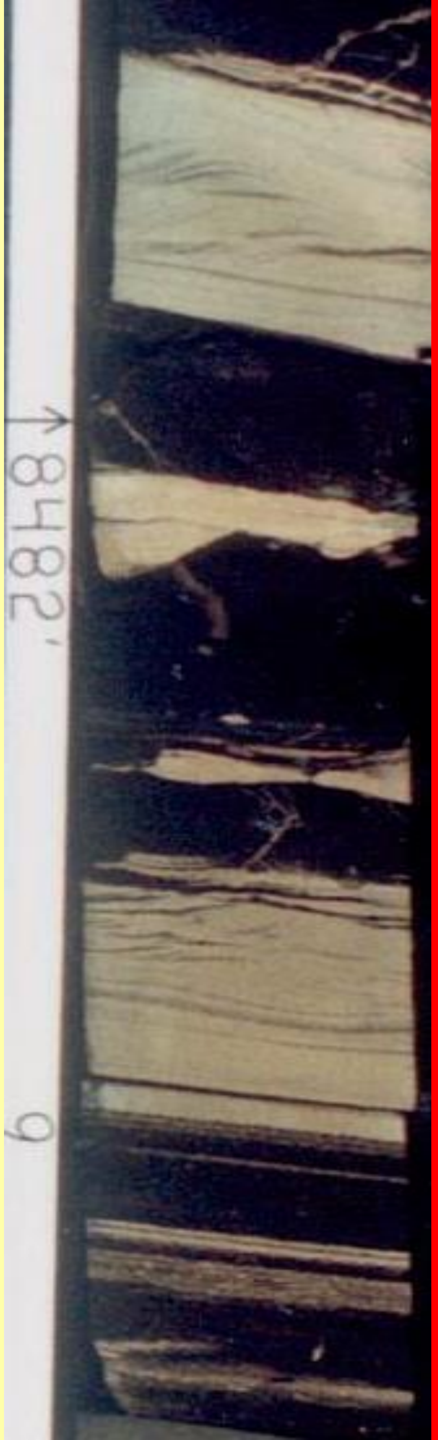
Interbeds of Medium-Fine Sand and Mudstone

Planar-Parallel and Current-Ripple Lamination Common

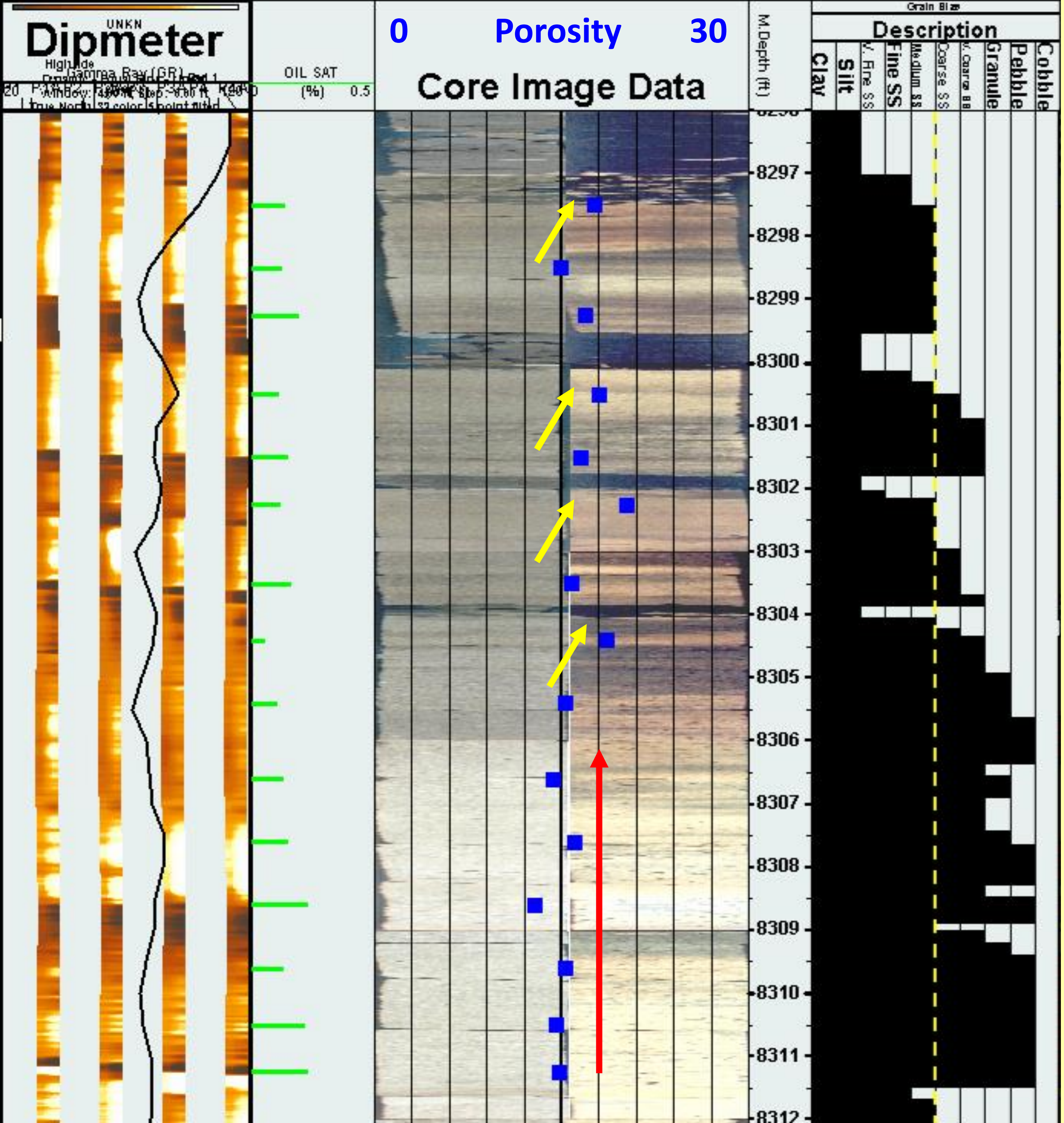
$T_{b\text{-}e}$ dominates , some debrite and slurry flows

Lobe Fringes, Off-Axis or Inter-Bar Positions, Abandonment Periods

(3' core strips, UV light)



Outcrops show similar facies and geometry



Taylor 672R1

Bedset Stacking and Porosity Distribution

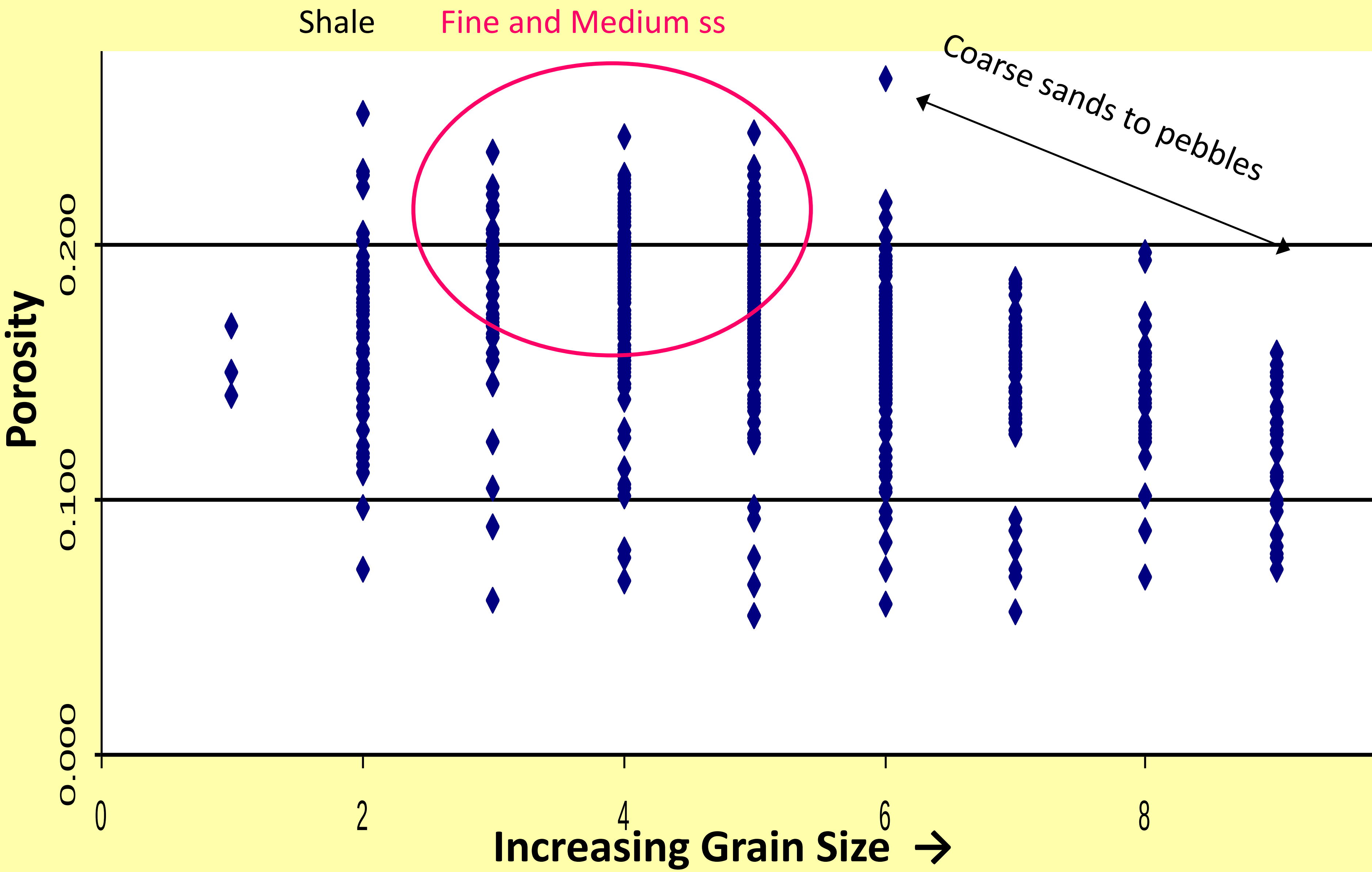
Non-Amalgamated
Thinner-Bedded
Base: Med. to V. Coarse SS
Caps: Fine SS and Mudstone

- **Better Sorting**
- **Higher Porosity**

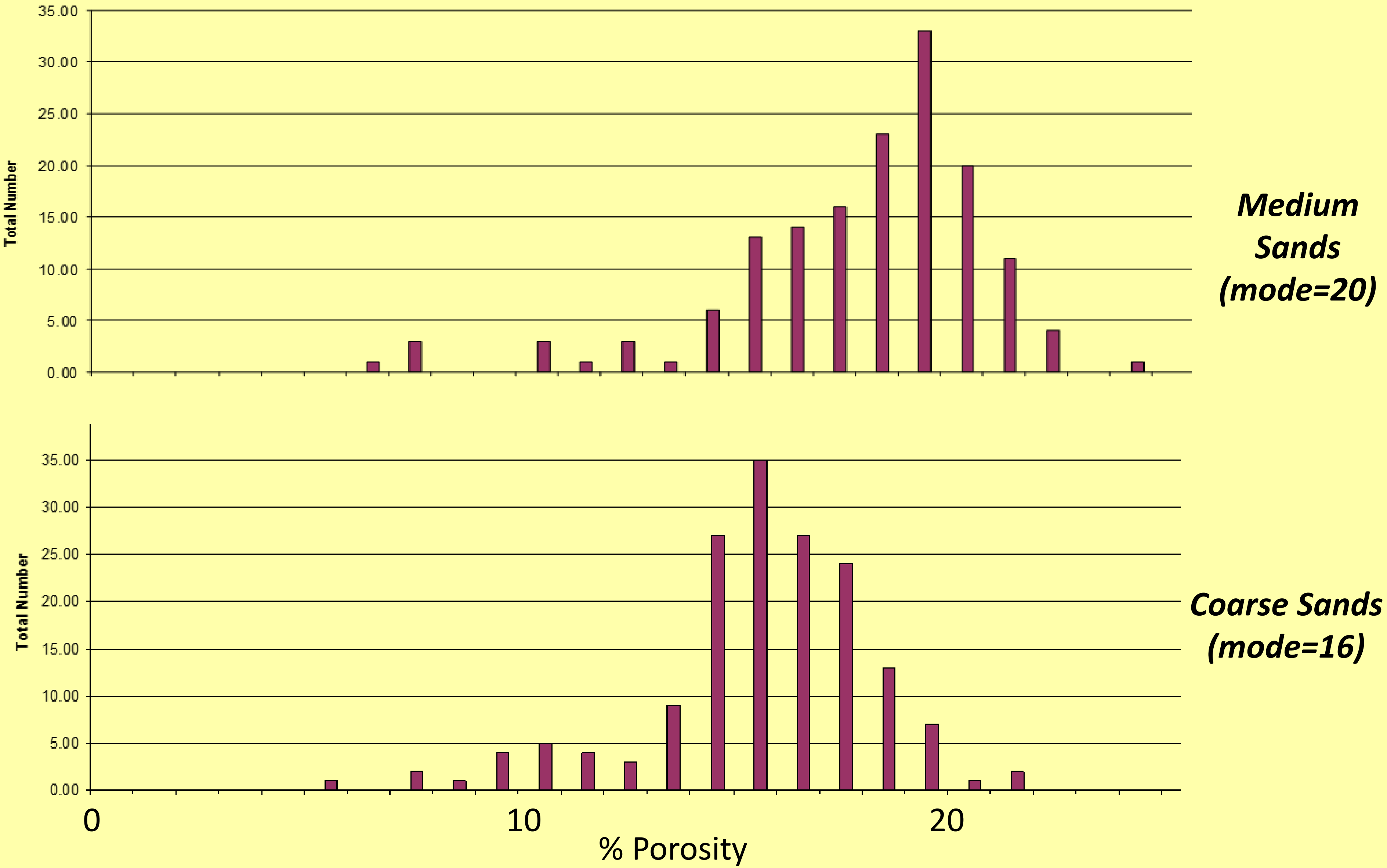
Amalgamated
Thicker-Bedded
Pebbles to Coarse Sand

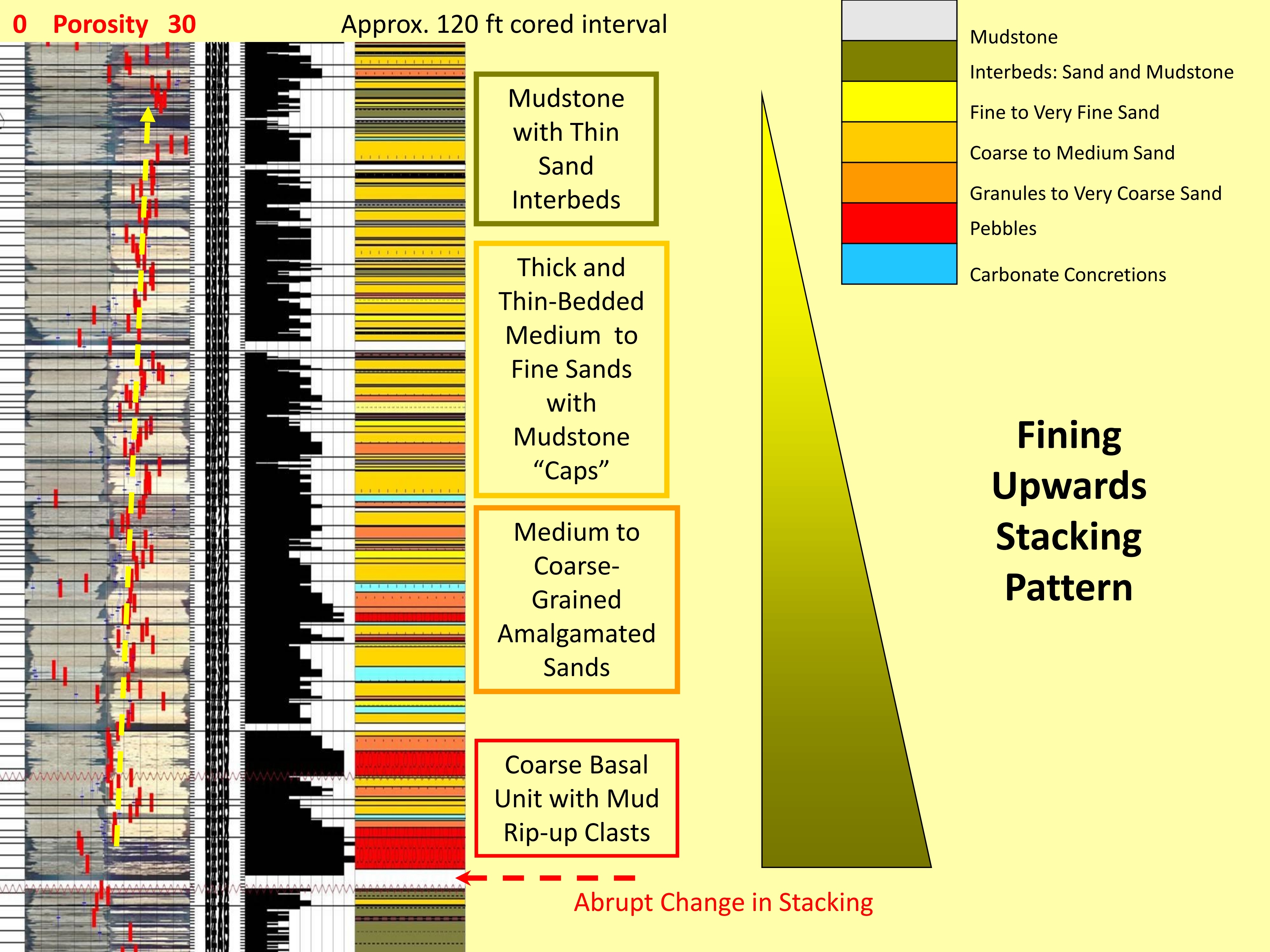
- **Poorly Sorted**
- **Lower Porosity**

Repetto Formation Core Data: Grain Size vs. Porosity

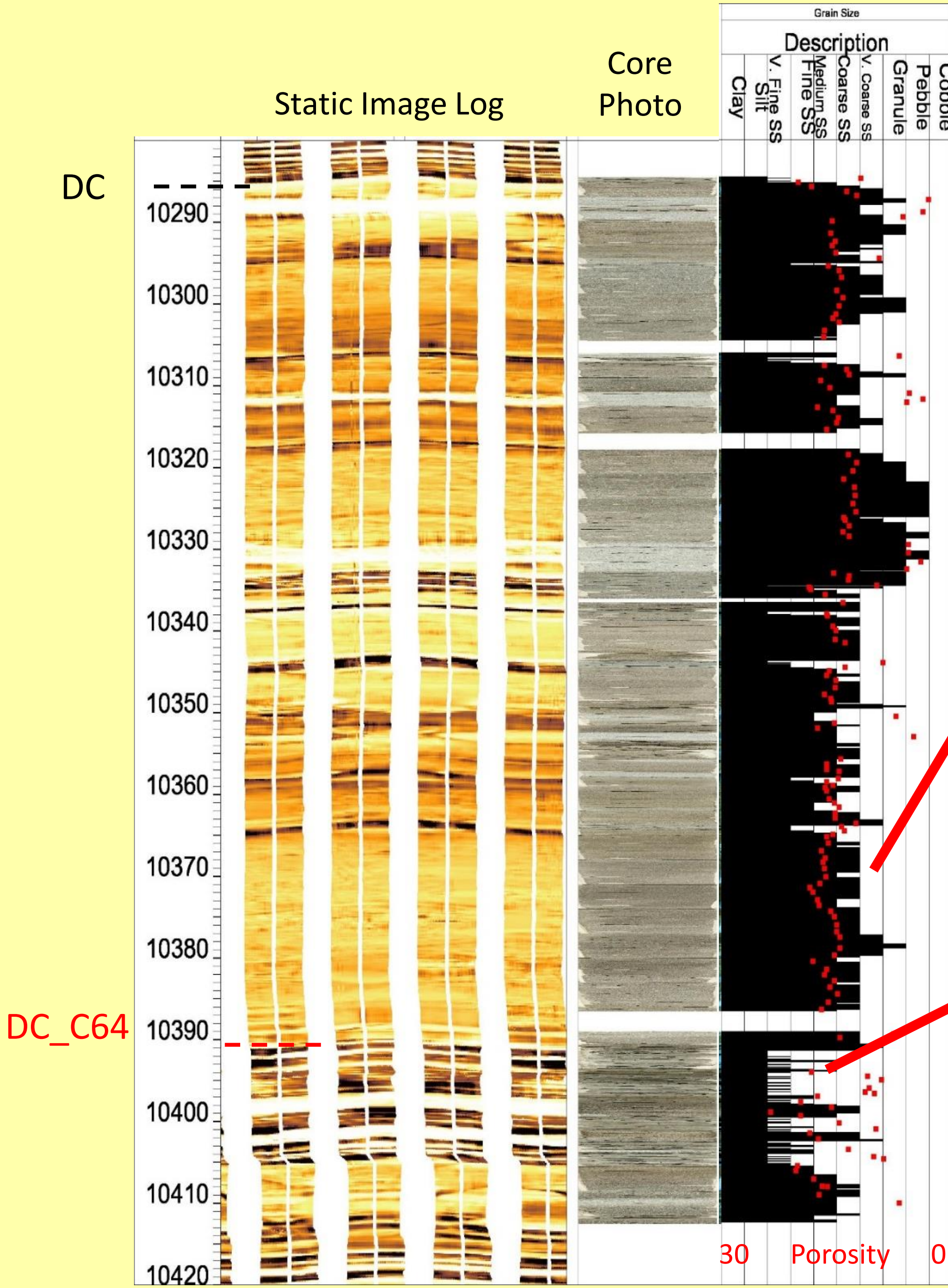


Histograms of Porosity Distribution

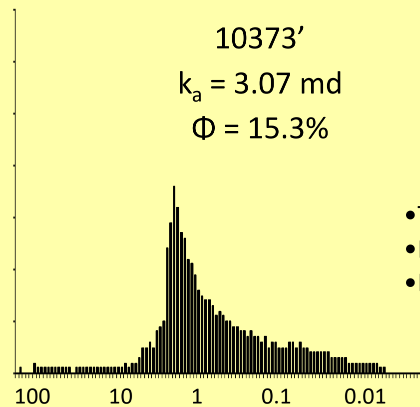



0 Porosity 30
Approx. 120 ft cored interval
Mudstone with Thin Sand Interbeds
Thick and Thin-Bedded Medium to Fine Sands with Mudstone "Caps"
Medium to Coarse-Grained Amalgamated Sands
Coarse Basal Unit with Mud Rip-up Clasts
Abrupt Change in Stacking
Mudstone
Interbeds: Sand and Mudstone
Fine to Very Fine Sand
Coarse to Medium Sand
Granules to Very Coarse Sand
Pebbles
Carbonate Concretions
Fining Upwards Stacking Pattern

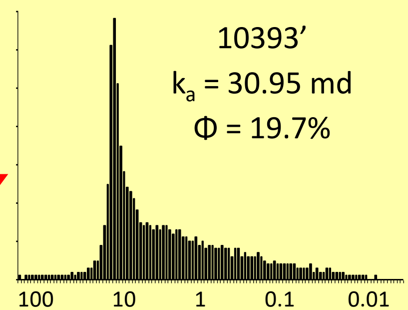
HBU-8 Cored Well



MICP Histograms



- Thick-bedded, high density
- Poorly sorted
- Lower Phi, K



- Thin-bedded, low density
- Better sorted
- Higher Phi, K

Equivalent Pore Throat Diameter (microns)

Integrating Image Logs

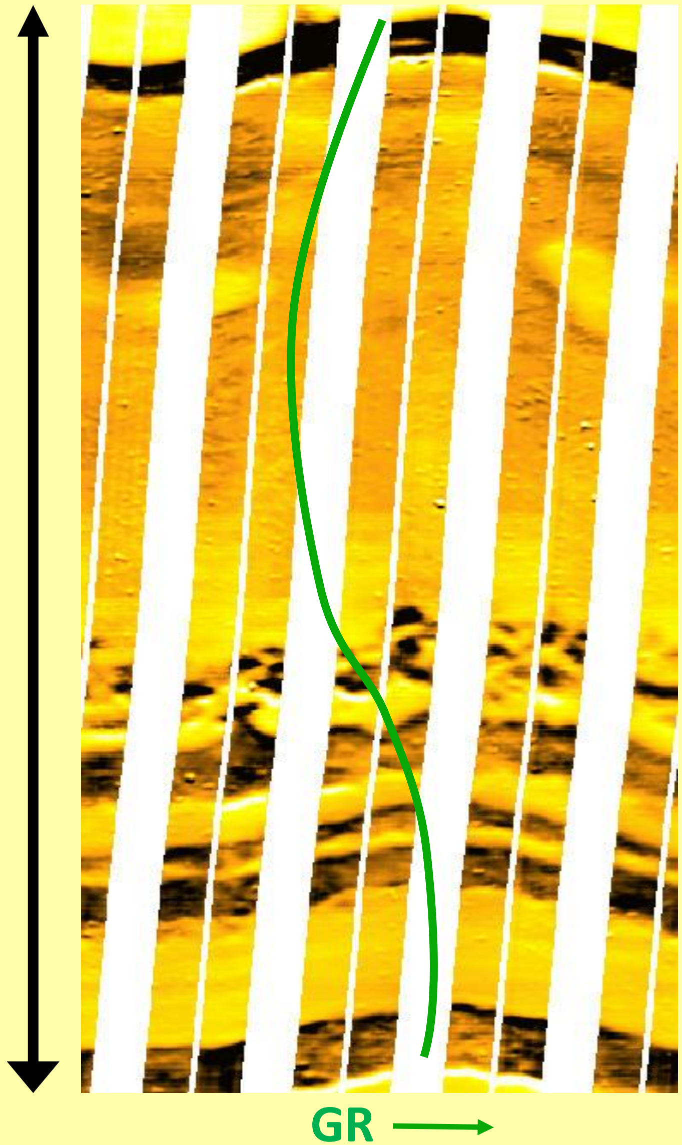
High resolution stratigraphic and structural information

- Bedding surfaces, structural orientation
- Rock fabric and facies information
- Quantify sand/mudstone
- Fault locations and orientations
- Fractures

Cored wells provide calibration

- Compare core facies to image log facies
- Extend to areas without core
- Integrates with other log techniques

Lloyd 252
Dynamic Image



Detailed Sedimentologic / Facies Interpretation

Mud cap at top of bed

Pebbles or concretions

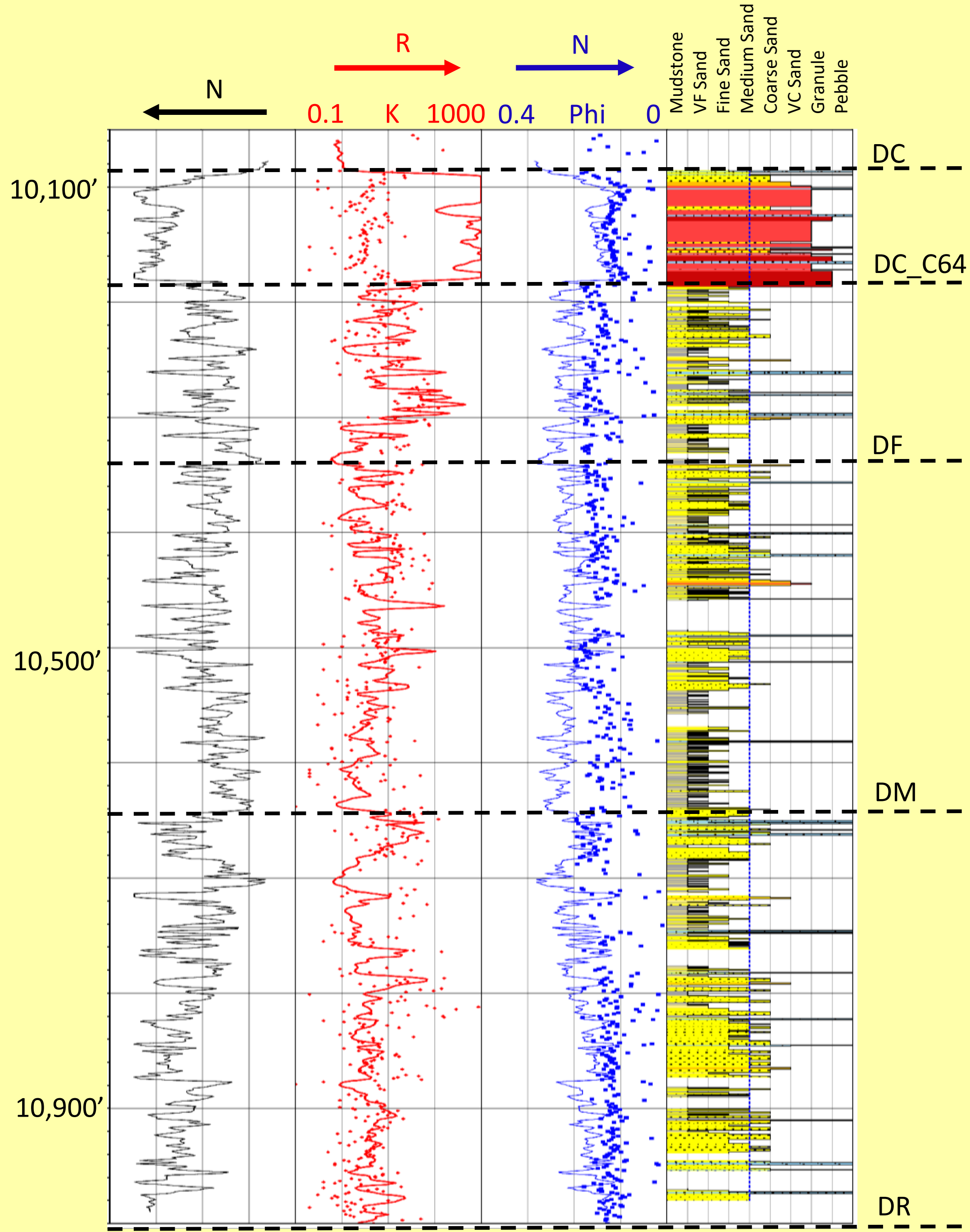
Thicker-bedded turbidites

Clay rip-up clasts at base of sand

Loading features at bed boundary

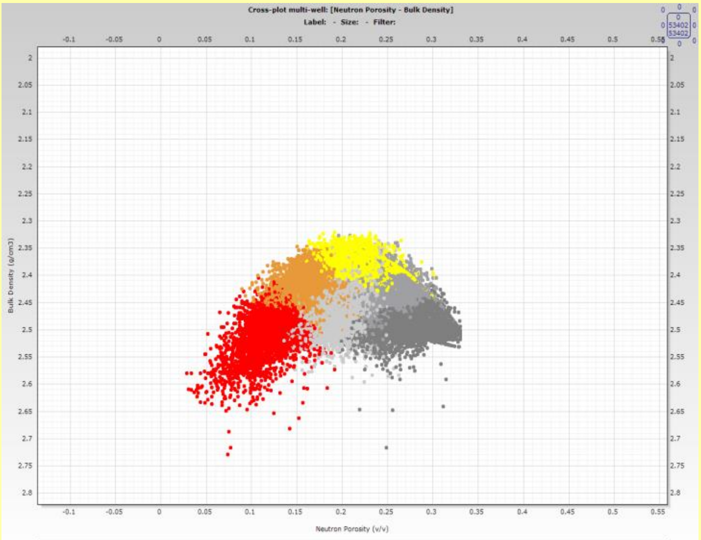
Thin-bedded turbidites, laminated

A key element for subsurface extrapolation is calibrating the cores to the well logs

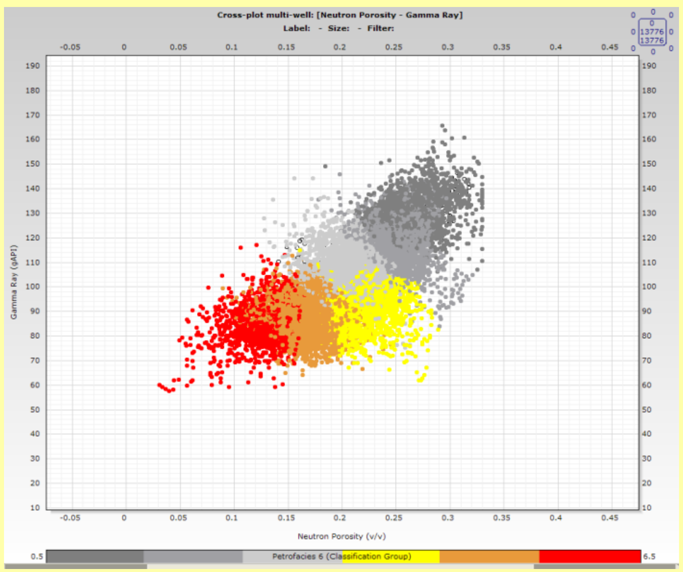


Petrofacies Calibration

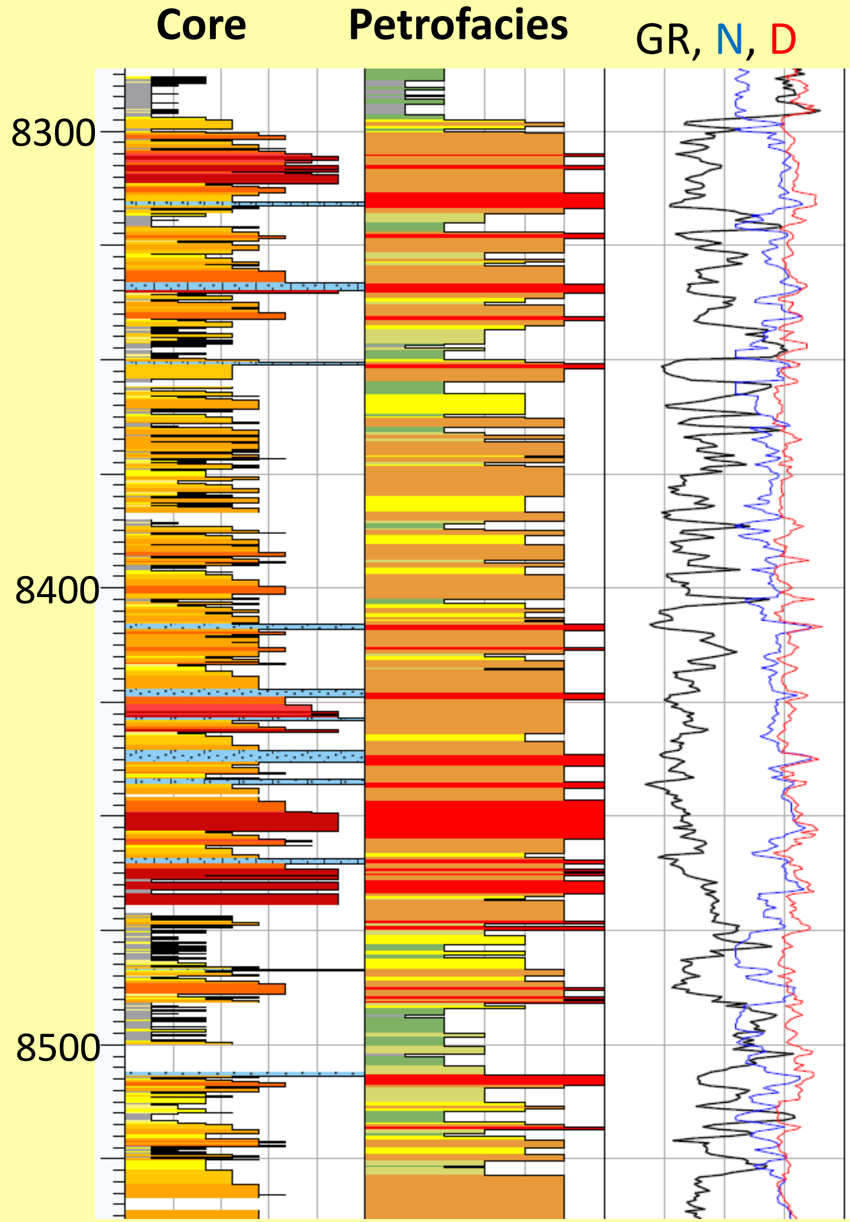
Rhob



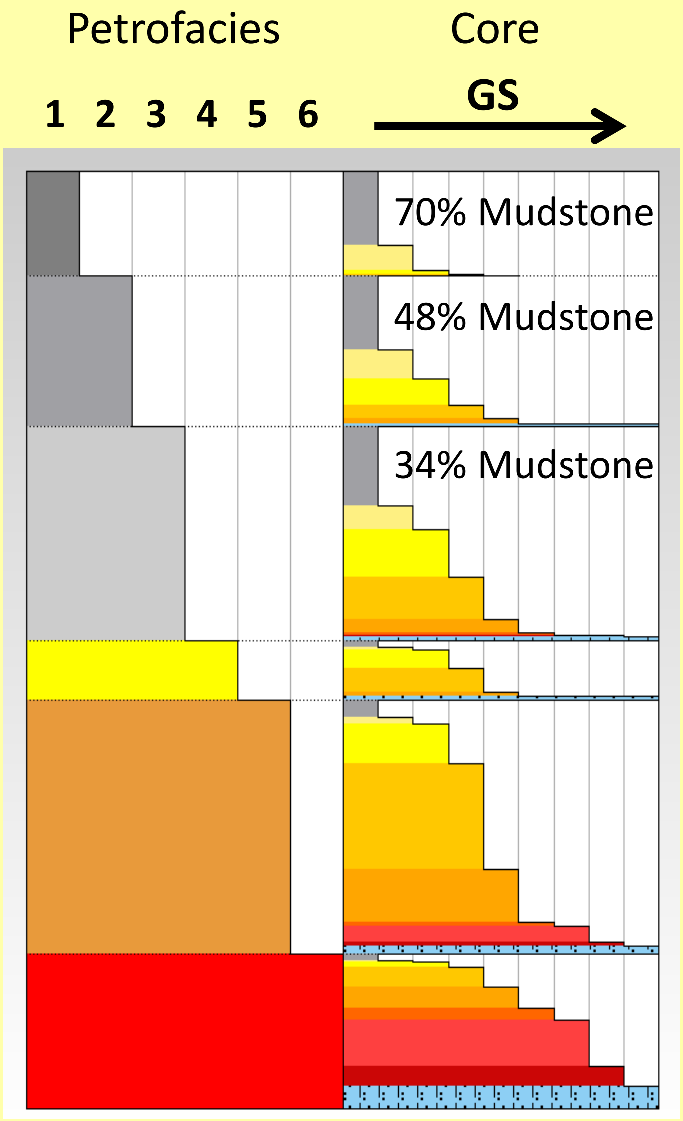
Gamma Ray

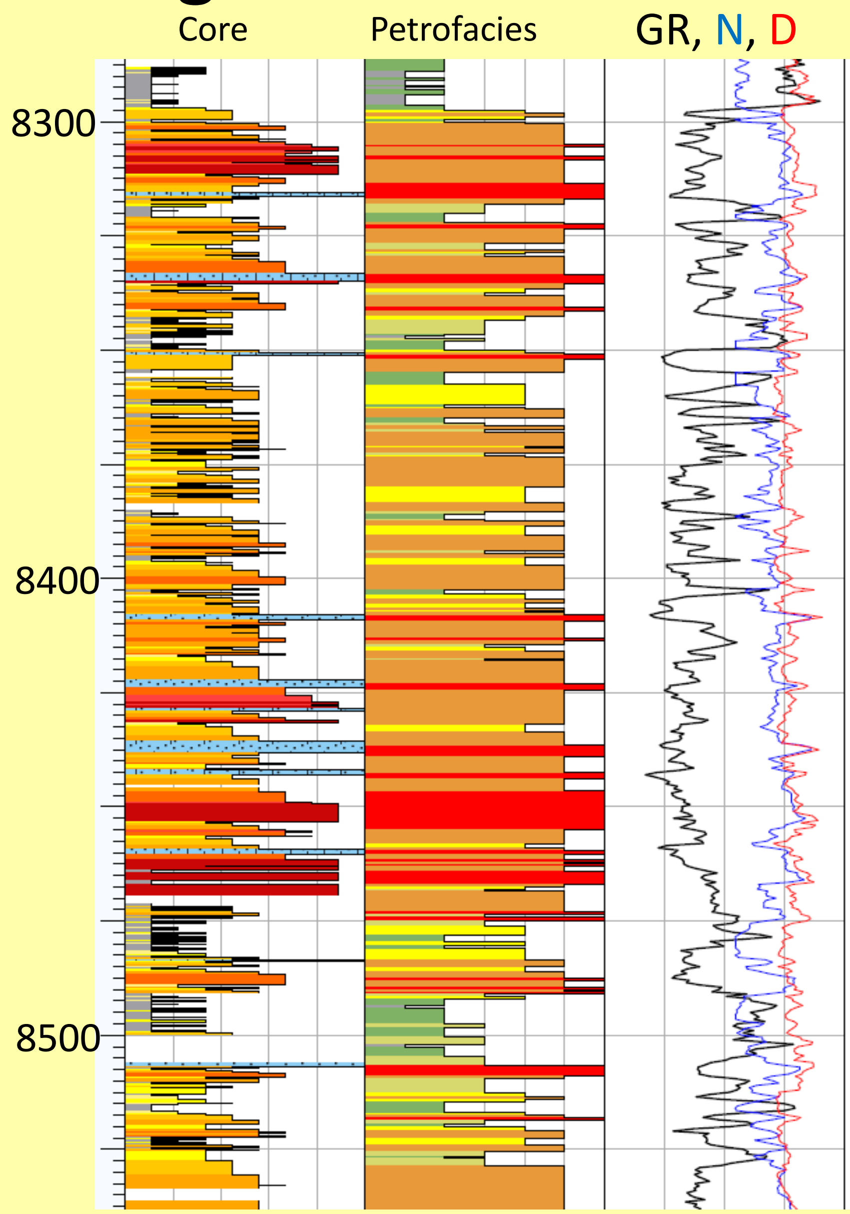


Nphi

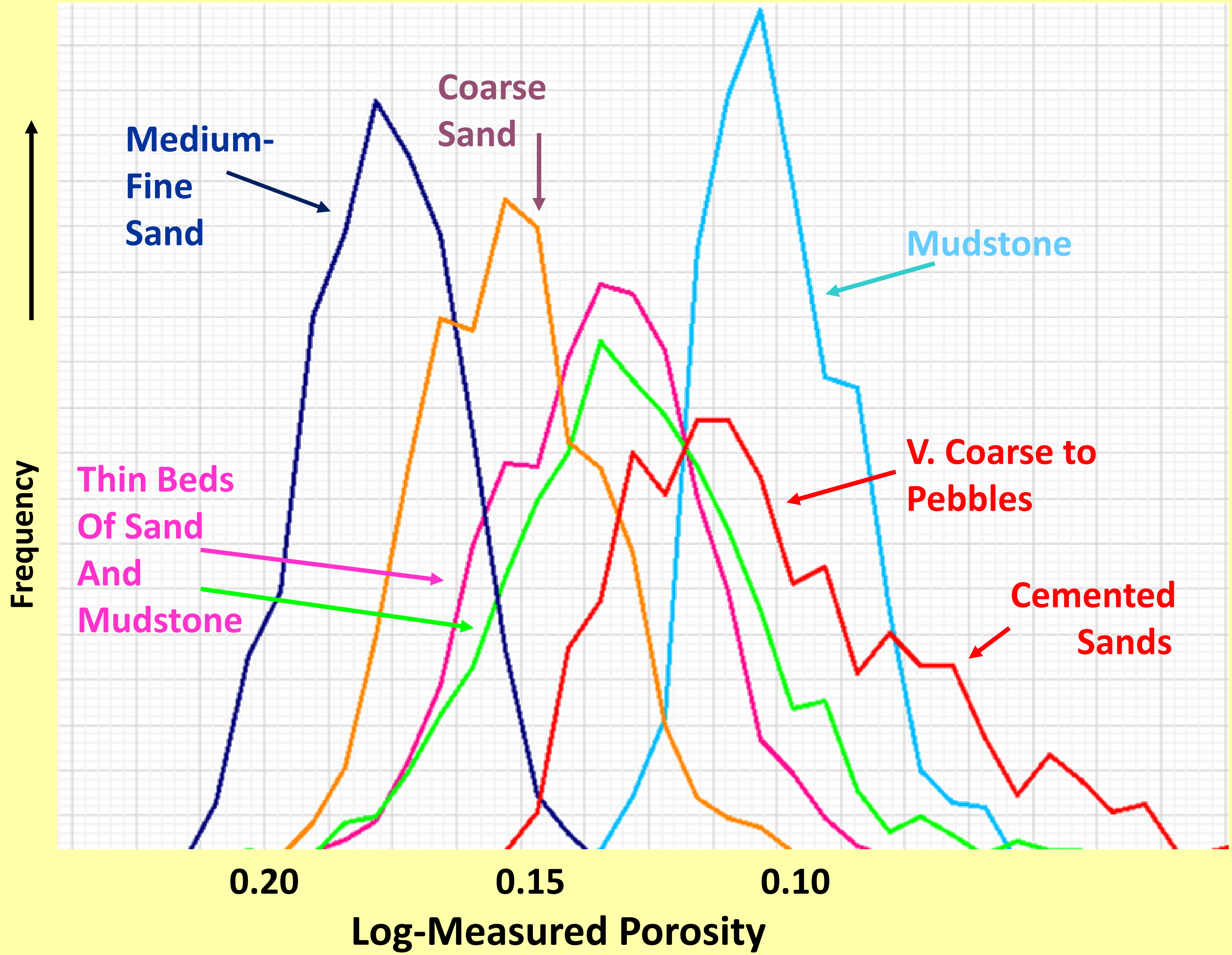


Petrofacies Modeling Results



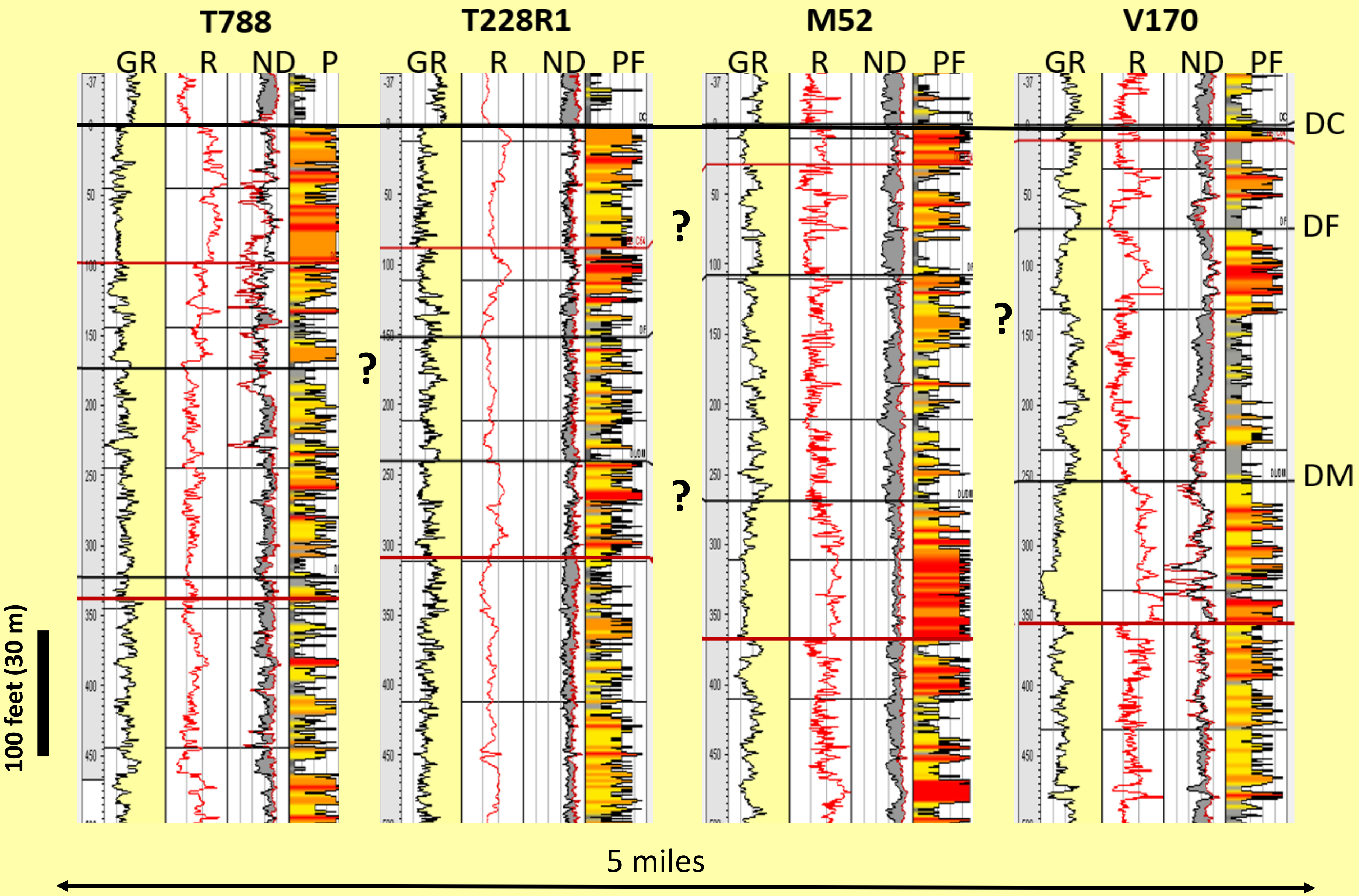


Unique Distributions of Rock Properties Characterize the Lithotypes and Grain Sizes



- Similar to core porosity distributions
- Petrofacies can be used to distribute properties in wells without core

What Criteria Guides Our Correlations?



Outcrop and Well Log Observations Provide a Guide for Building the Stratigraphic Framework

- Best surfaces for well-log correlation are regional flooding or abandonment surfaces
- Generally planar parallel geometry on large scale, but bedsets exhibit significant internal geometry
- Some scour and truncation, but it is on the order of 10’s of feet, not 100’s of feet
- Amalgamated sand packages are most correlative and persist over thousands of feet in the E-W (strike) direction
- Individual sands in thin-bedded packages are less continuous
- Stacking patterns of lithofacies are generally consistent, and can be used for correlation

Dominant depositional geometry is planar, mostly parallel


Approx. 25 ft
Lithofacies changes are generally subtle but do occur over distances of hundreds of feet

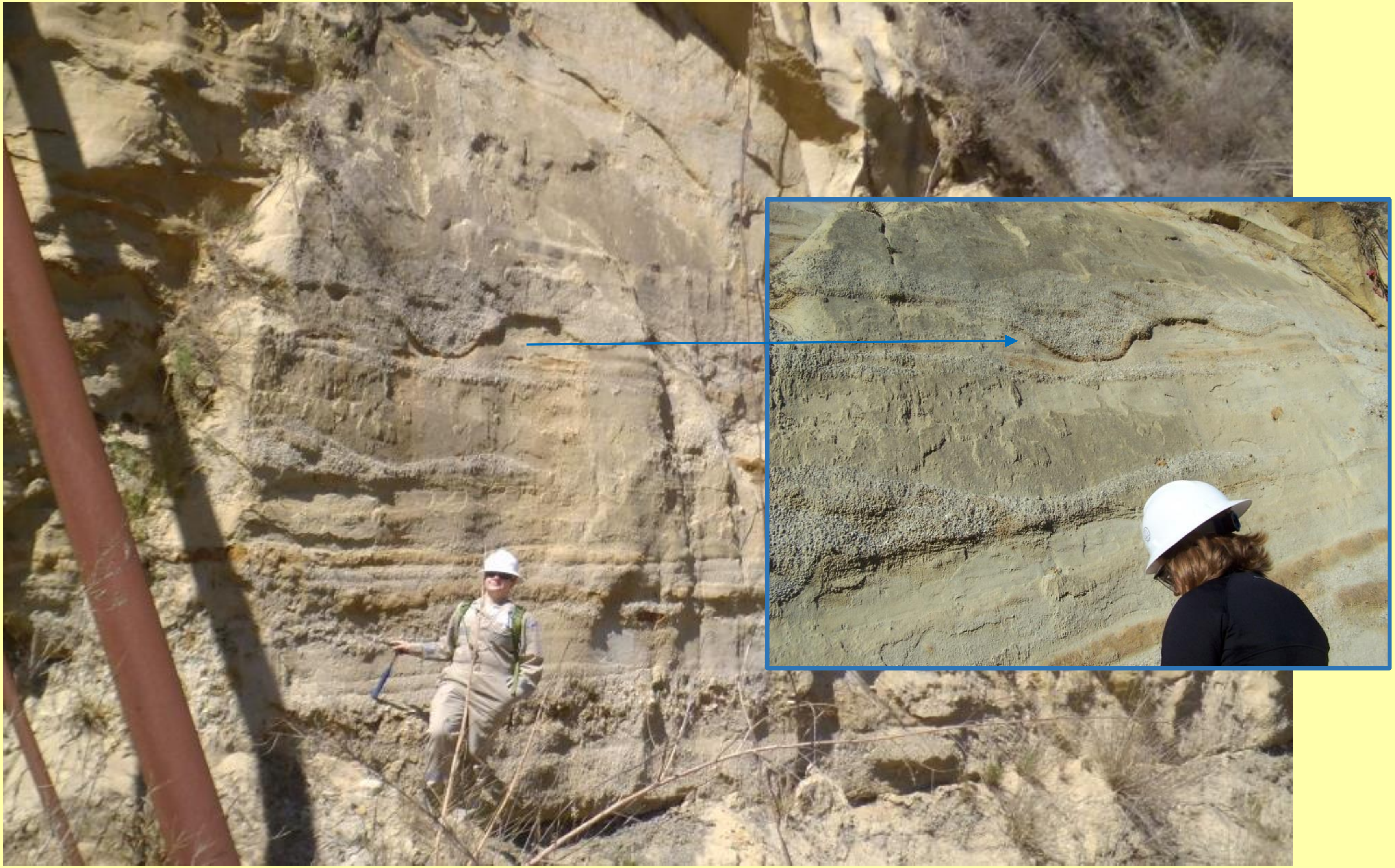
Base of thick-bedded amalgamated sands are abrupt and often erosional


V-83
Amalgamated sands
Thin sands and mudstone

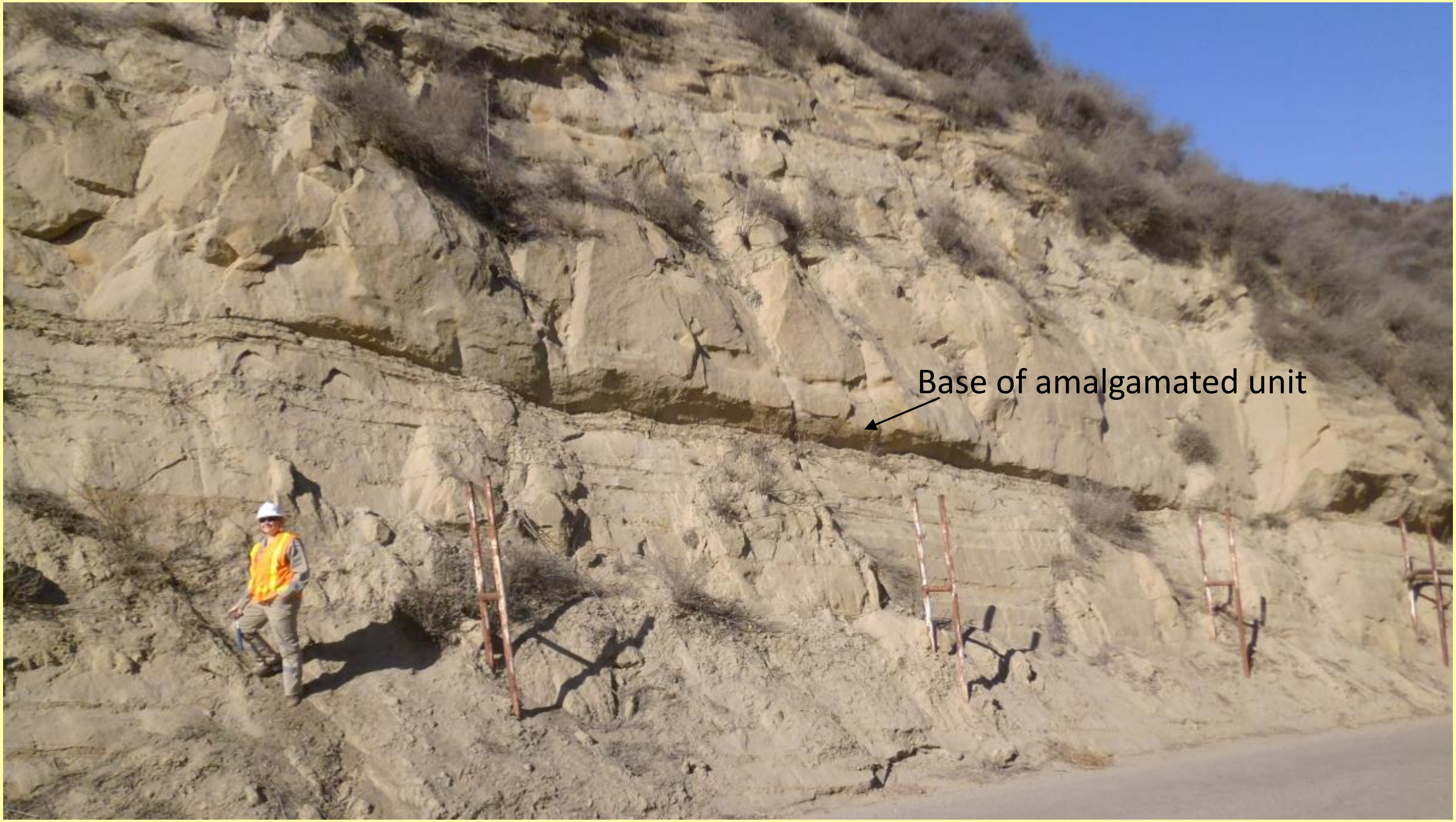

Poorly-sorted
pebble bed
Mudstone


Cobbles and
large shale
rip-up clasts

Internal geometry of amalgamated sands includes pebble lags and internal scours



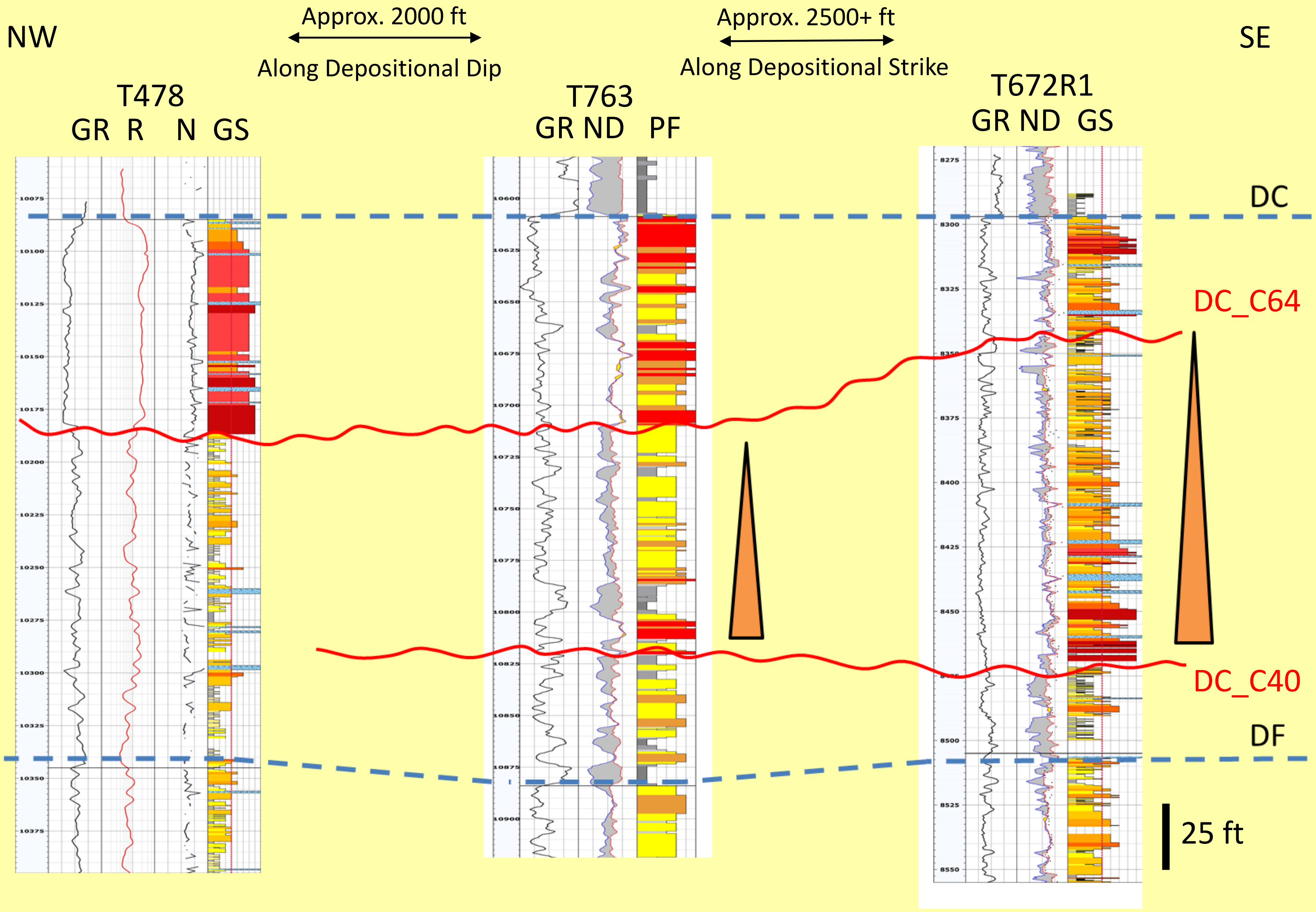
Bedsets generally exhibit planar, parallel geometry, with some low-angle truncation and scour



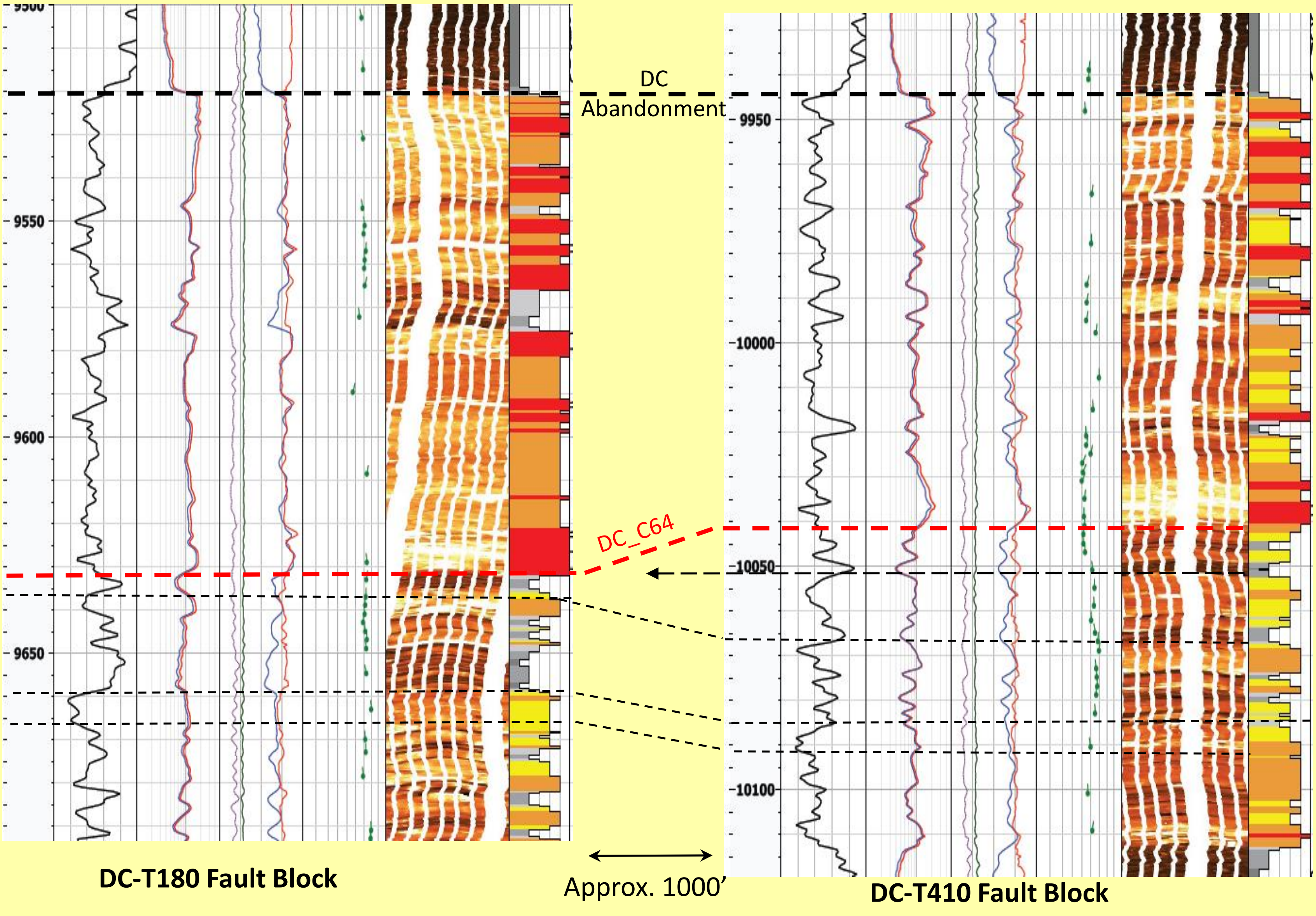
Low-angle scour in thin-bedded units

Thin-bedded sandstones less continuous than thick-bedded units

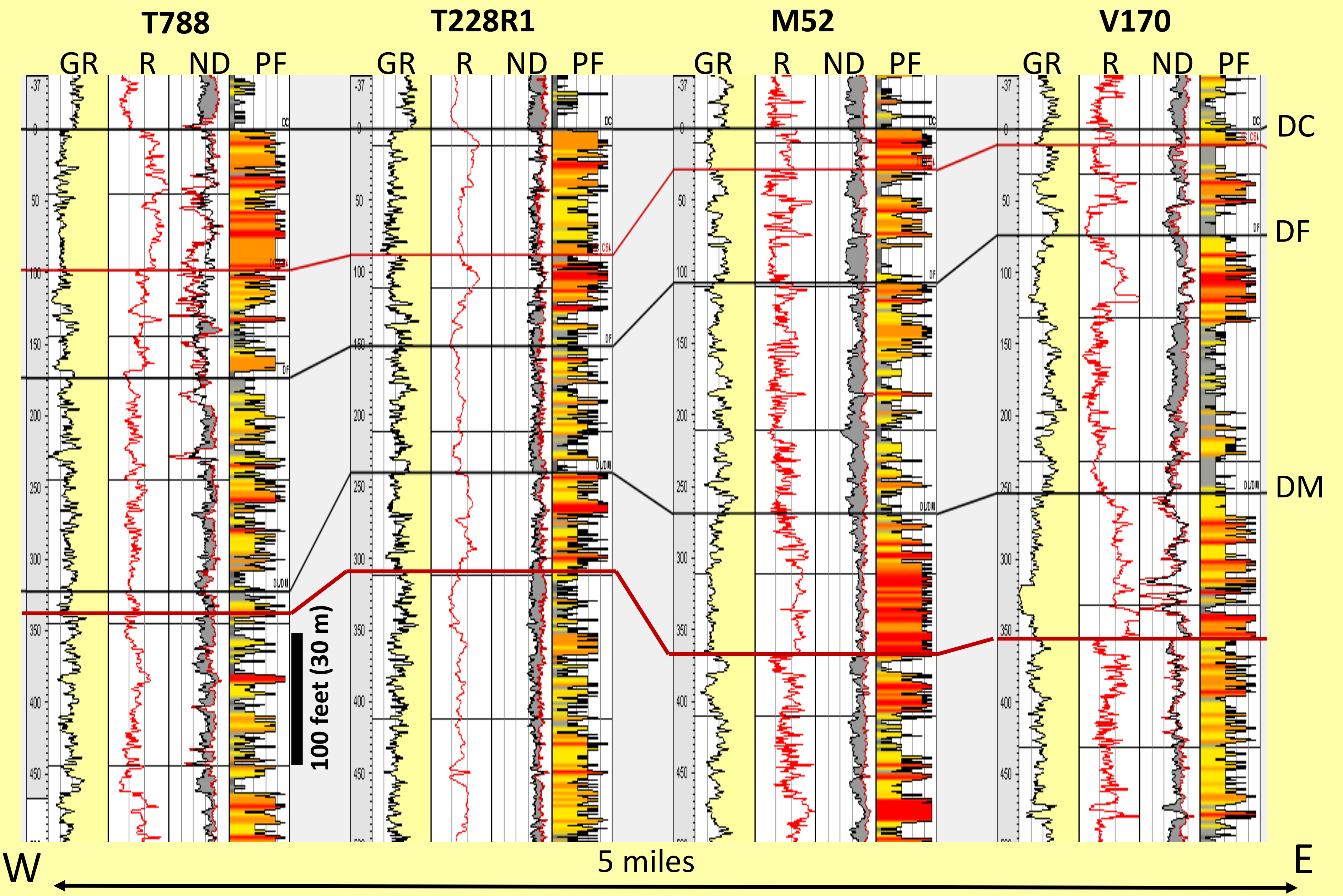
Example of Correlations Guided by Stratal Surfaces and Petrofacies Stacking Patterns



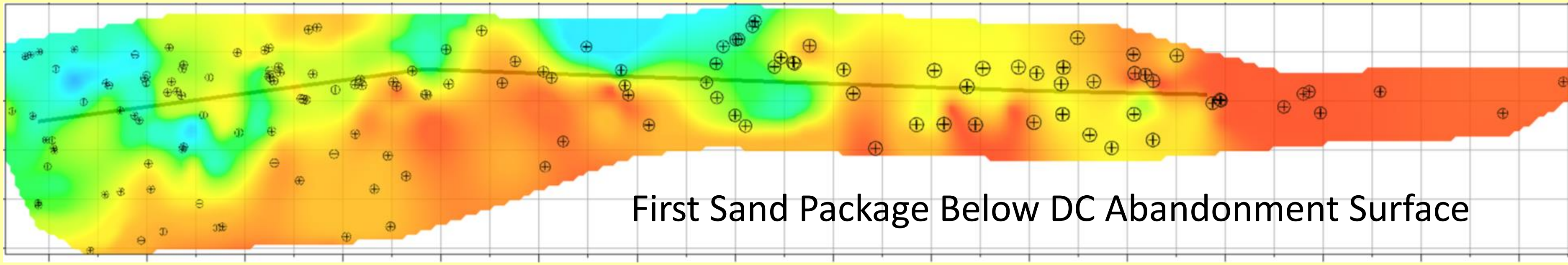
Correlating DC interval in repeat section of Taylor 786 well

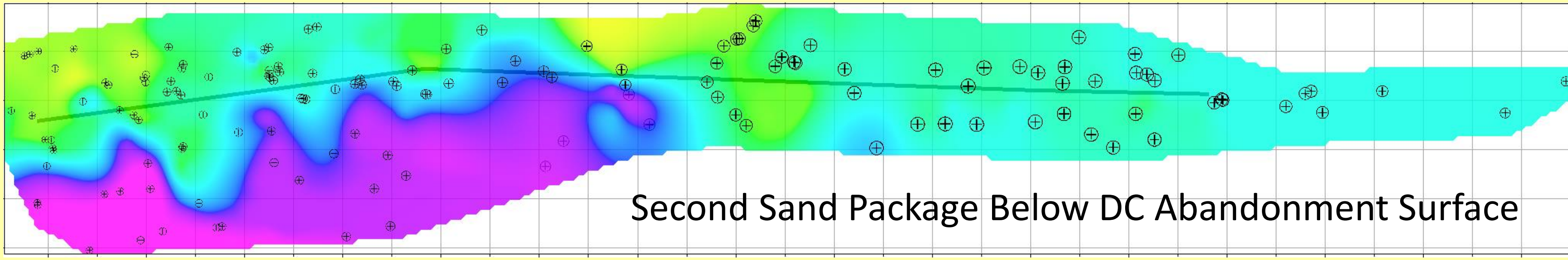


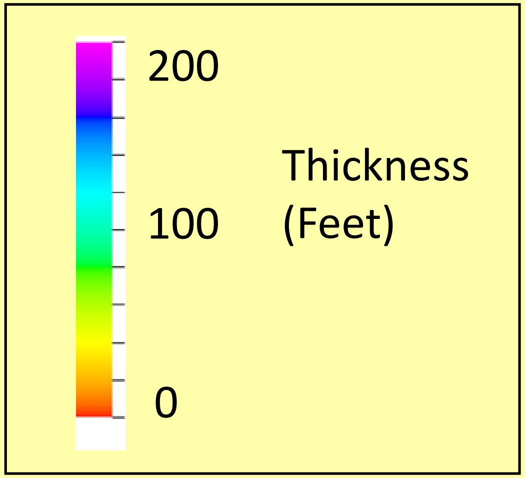
Correlation based on key stratal surfaces and stacking



Compensational Stacking







True Stratigraphic Thickness Maps of Sand Packages

Background grid boxes are 1000' by 1000'

Gray solid line is the location of W to E Cross Section

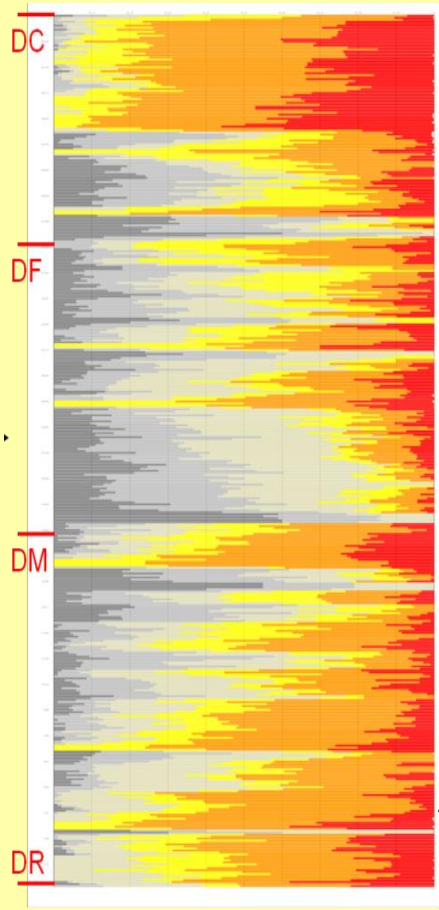
Summary and Conclusions

Identified and evaluated the critical elements for building a well-based geologic model

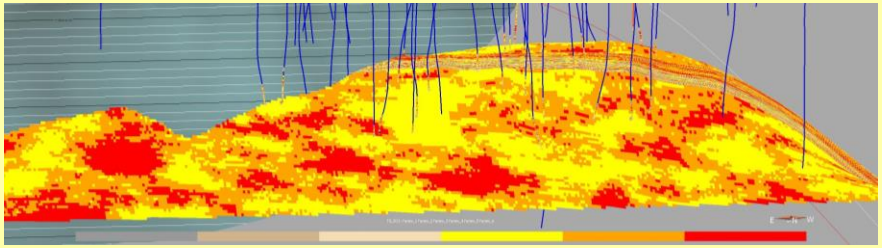
- Cores and outcrops to delineate depositional facies and property distribution
- Petrofacies model extrapolate facies and property distribution away from cored wells
- Outcrop and subsurface observations to identify key stratigraphic surfaces and geometry, helping to establish the stratigraphic framework

Integrating data of multiple scales, from multiple sources, provides building blocks for a robust geologic model that can be used for development decisions and reservoir simulation

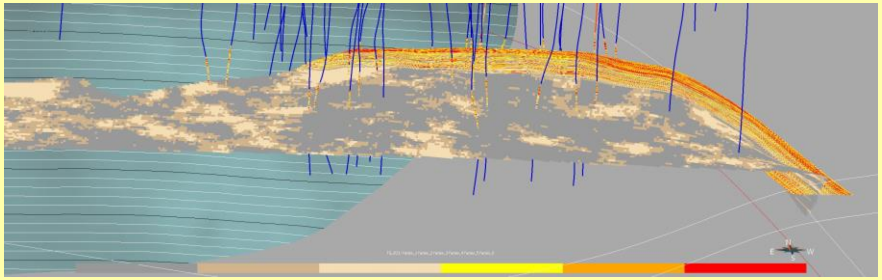
Example Layers in the Geologic Model



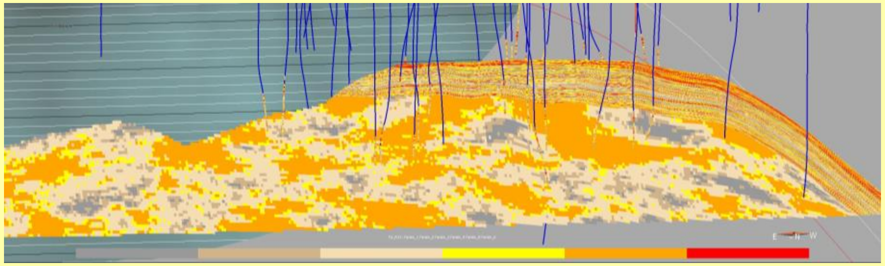
441 layer VPC



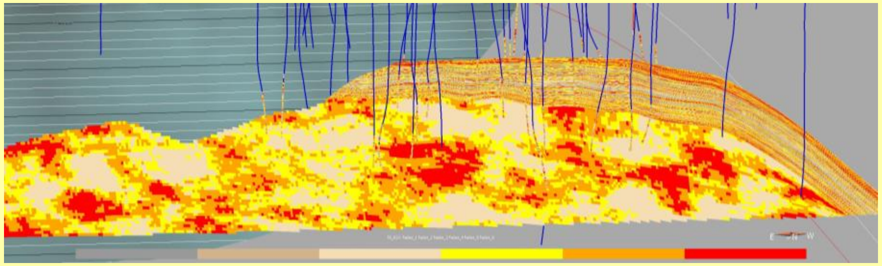
Amalgamated sands have best continuity



"Abandonment" mudstone-dominated layers



Amalgamated and layered sand with limited mudstone



Amalgamated and layered sand with no continuous mudstone

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