Integration of Core-based Chemostratigraphy and Petrography of the Devonian Jauf Sandstones, Uthmaniya Area, Ghawar Field, Eastern Saudi Arabia*

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Abstract

The Devonian Jauf gas reservoirs in the Ghawar Field of Saudi Arabia are composed of estuarine-tidal sandstones interdigitated with barrier bar and foreshore marine sandstones. Tidal bar complexes, 30 - 50 feet thick, represent the best reservoir facies in the Uthmaniyah area, but correlation of reservoir sand bodies across the field is complicated by erosional truncation at the top of the Jauf, absence of a high-resolution biostratigraphy, rapid vertical facies changes, intraformational disconformities, and differential clay and quartz diagenesis.

Chemostratigraphy combined with thin-section petrography helped to unravel this complexity. Over 390 feet of core from two wells were characterized and closely sampled from all facies (~1 sample per foot) for chemostratigraphic and petrographic analyses. Thin-sections prepared from core-plug-end trims were statistically point-counted, with geochemical samples taken immediately adjacent to them.

Elemental ratios recorded provenance, climatic, diagenetic and facies signals and revealed a previously unknown intraformational disconformity within the Lower Jauf. Point count data were used to modify the mineralogical model derived from the elemental data and provided evidence of a cementation history that alternated between clay-dominated and quartz-dominated diagenetic events, which strongly influenced reservoir quality.

Chemostratigraphic correlation identified 6 geochemical packages and 23 individual units, correlatable to 10-foot intervals between the two wells, which were virtually identical to a previous gamma ray log-only correlation; a geochemical signal for an important intraformational biomarker was also recognized. This chemostratigraphic correlation was used as the basis for a comprehensive layering scheme for 21 wells in an object-based geocellular model.

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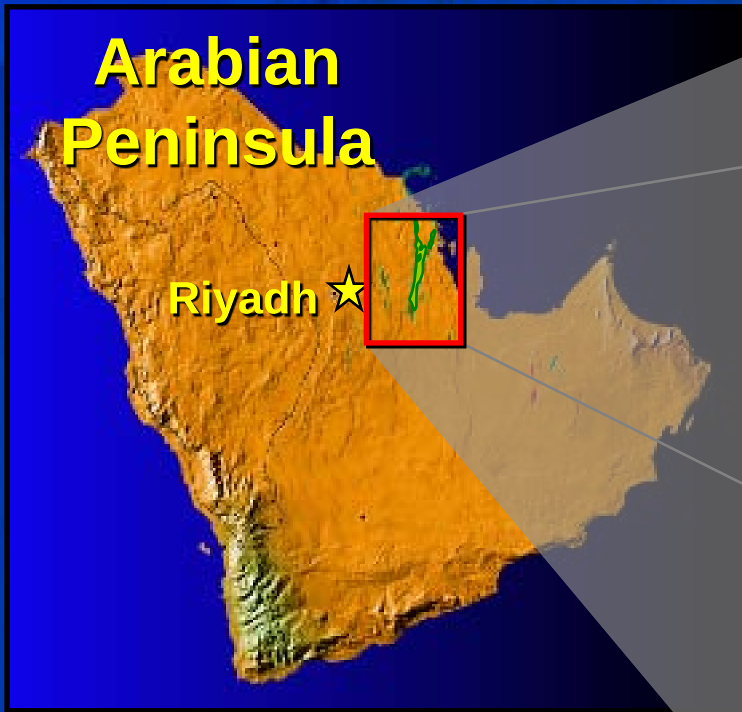
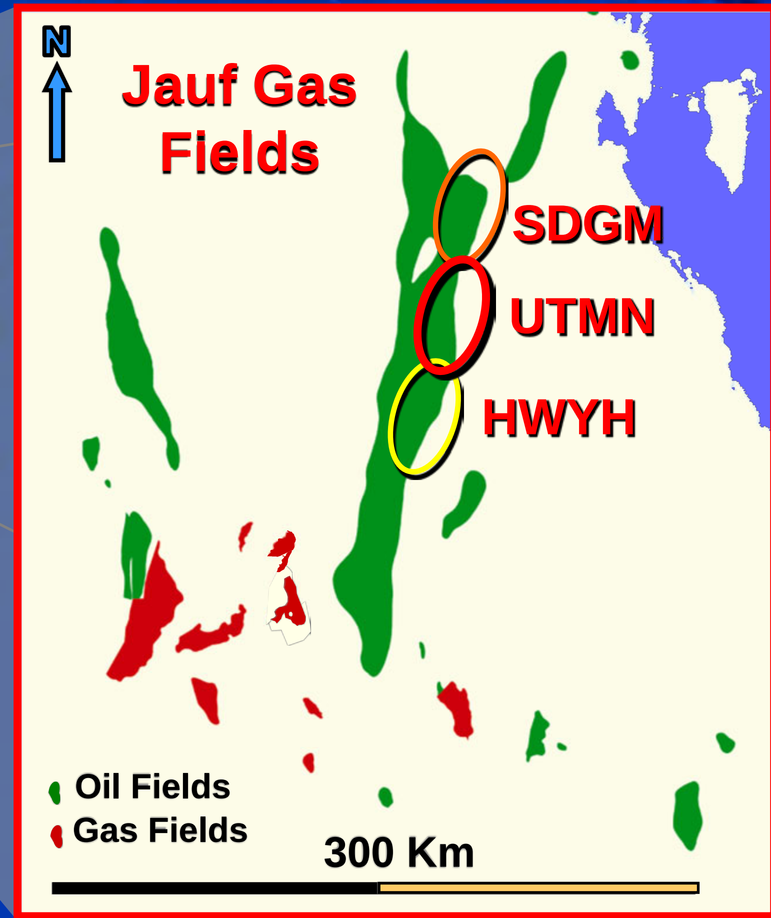
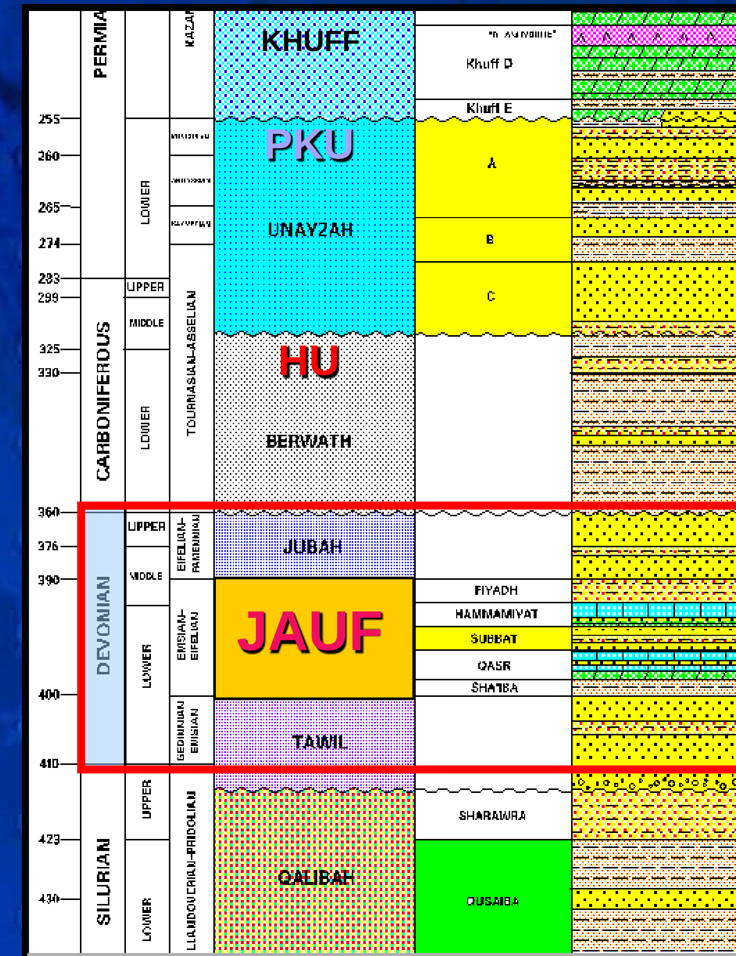
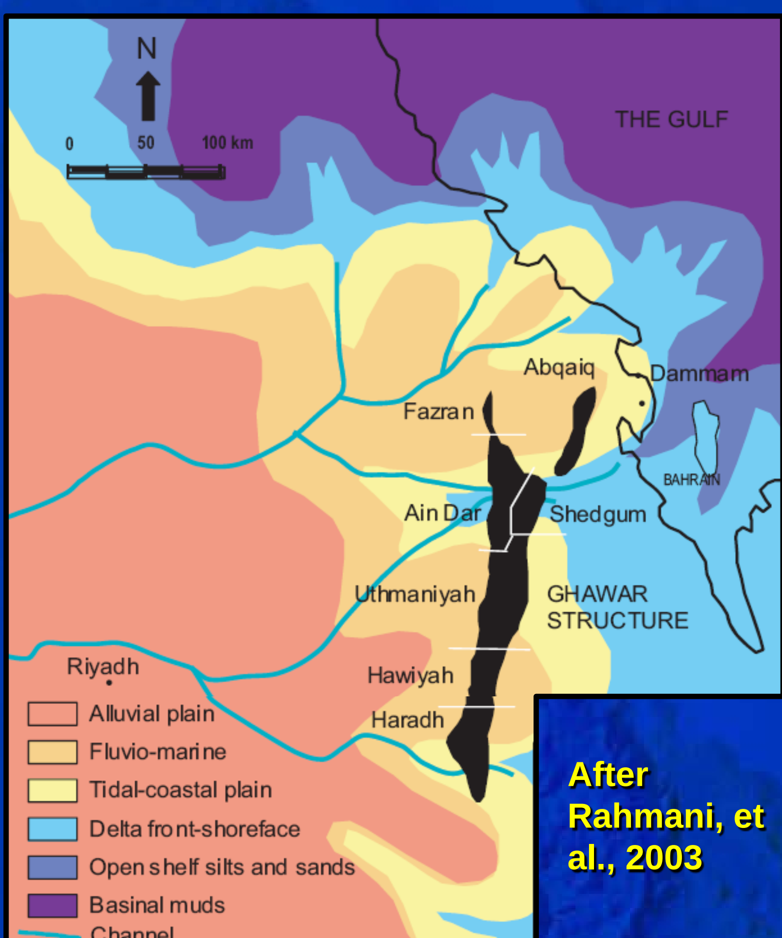


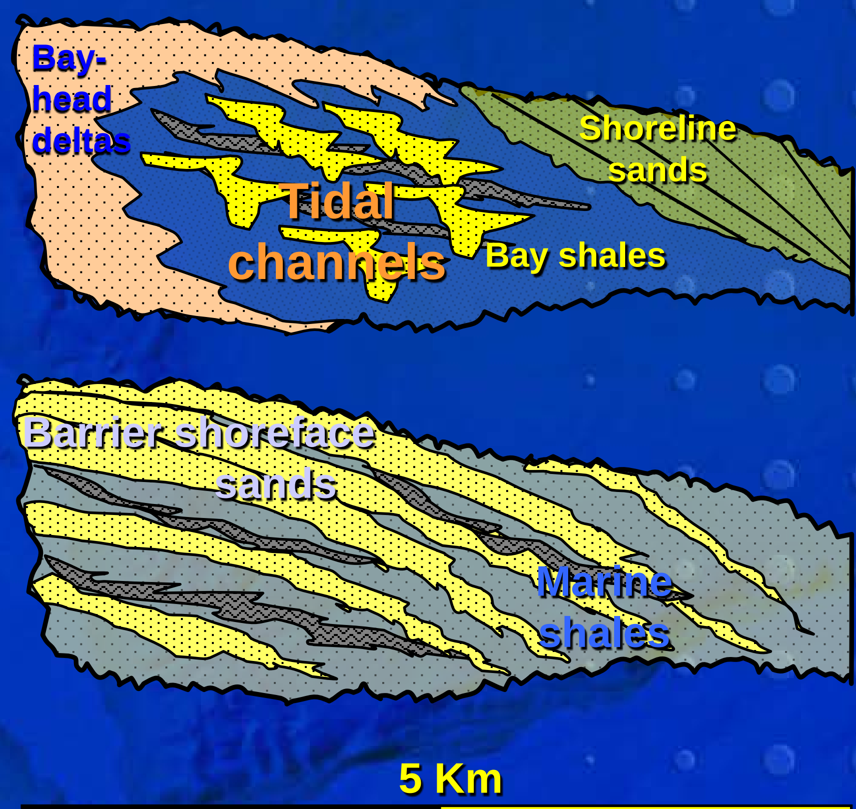




Stratigraphic Column

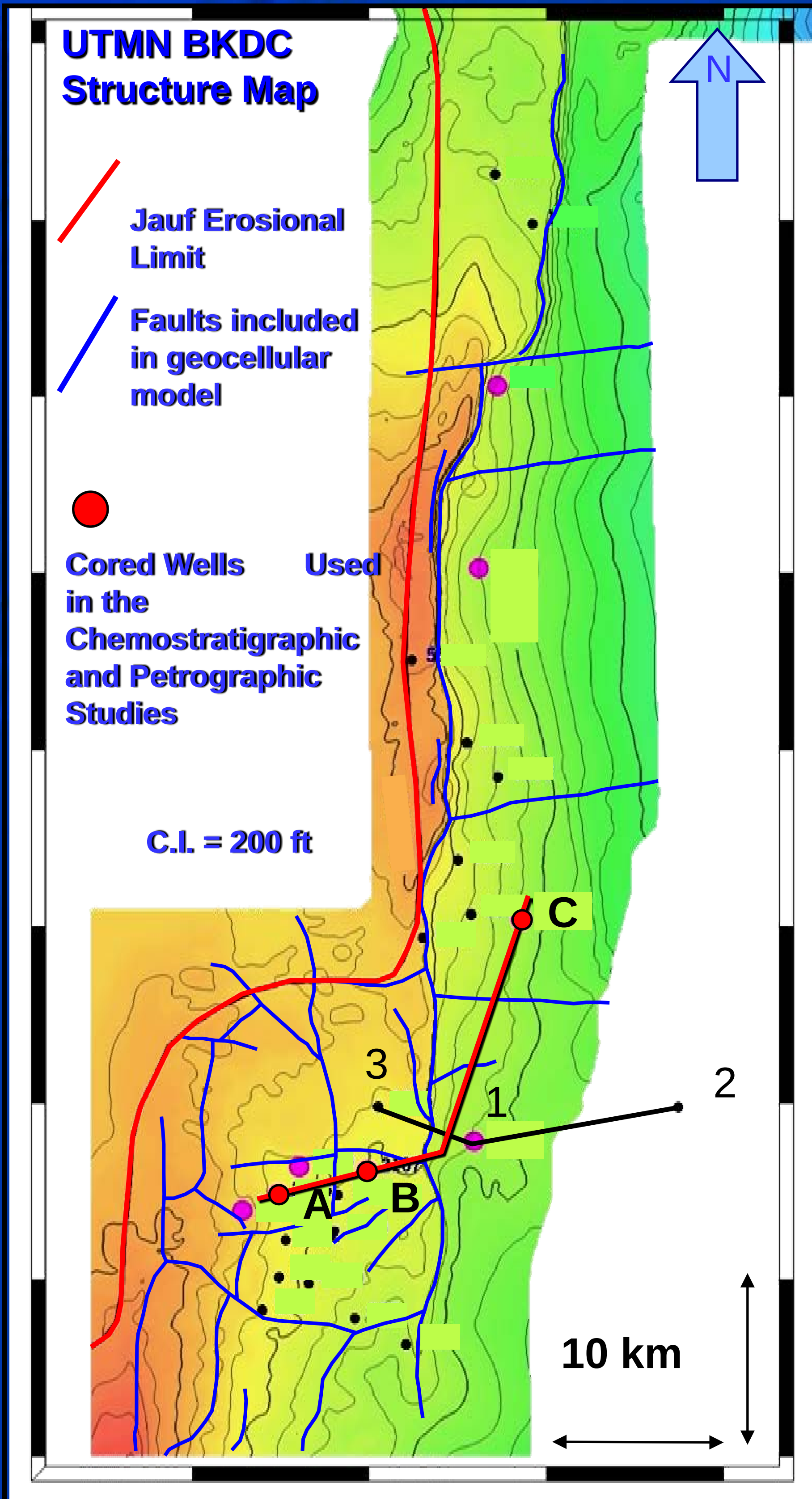


After Rahmani, et al., 2003

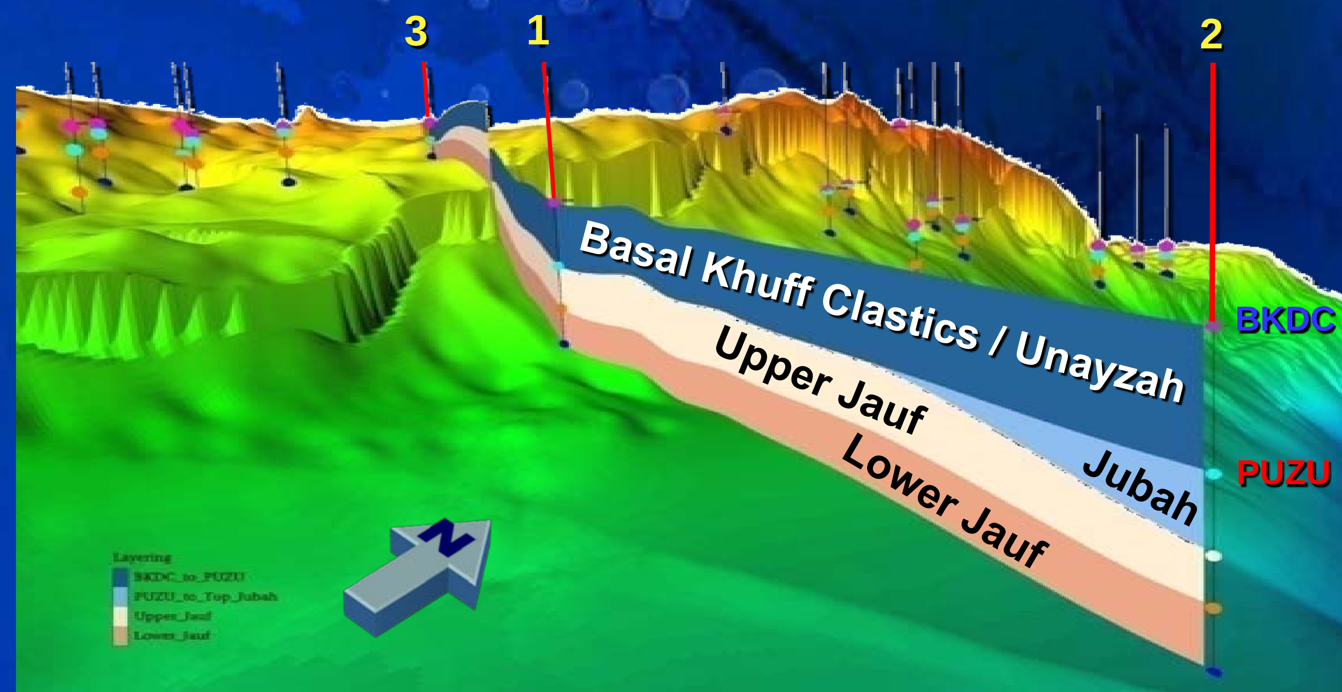


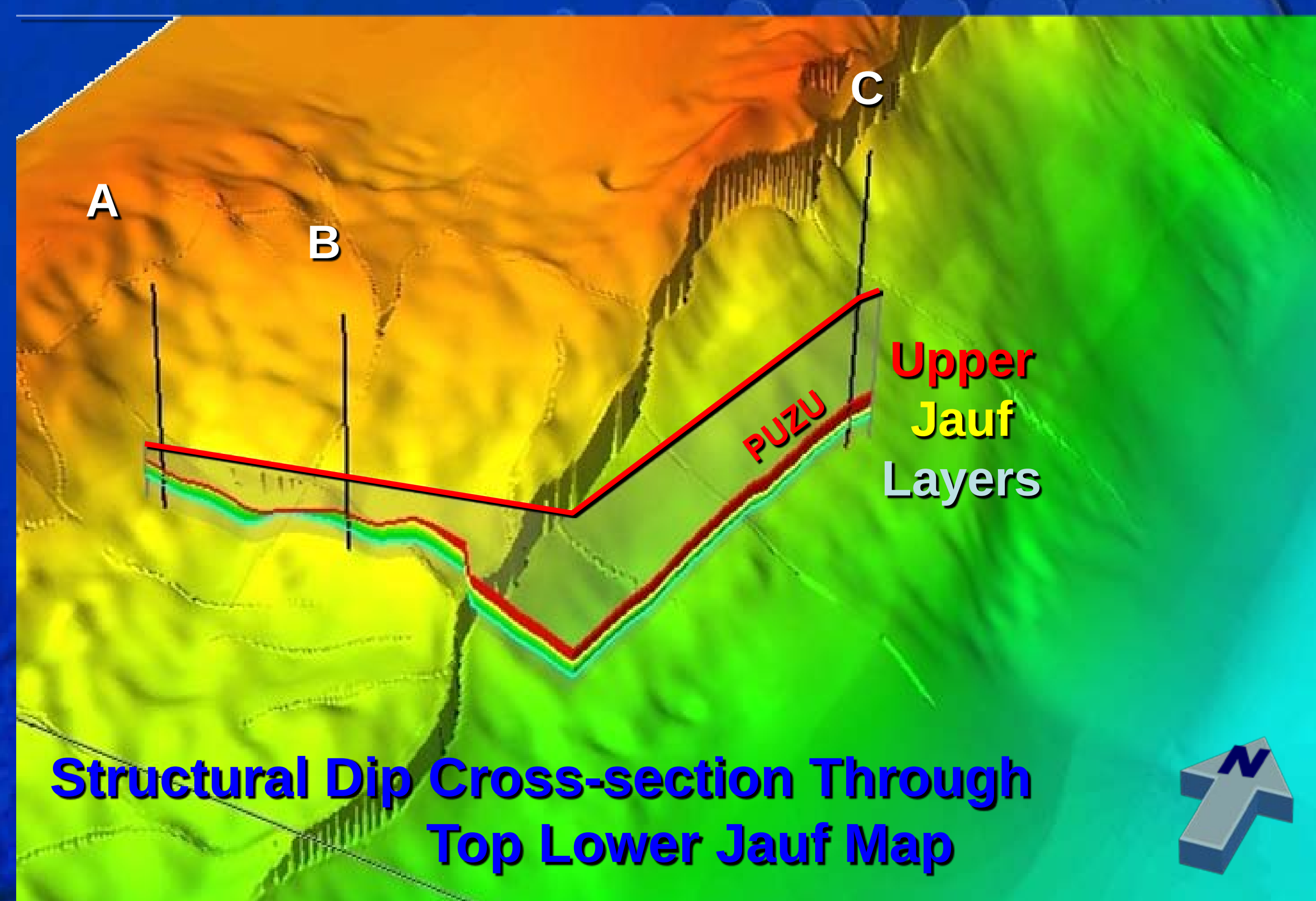
Upper Jauf: Discontinuous reservoirs, Excellent quality

Lower Jauf: Continuous reservoirs, Moderate / poor quality

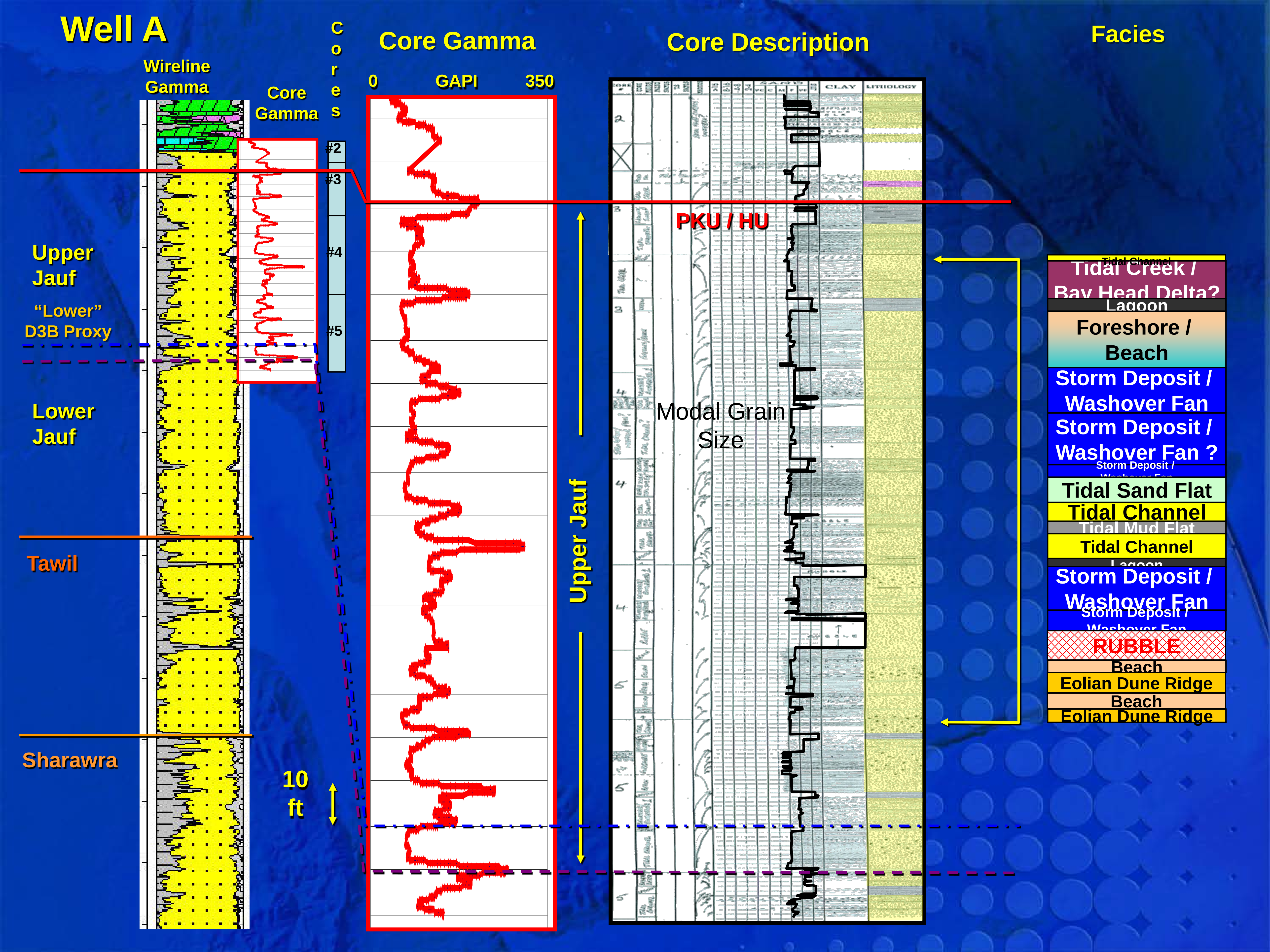


Structural Dip Cross-section Through Top Upper Jauf Map



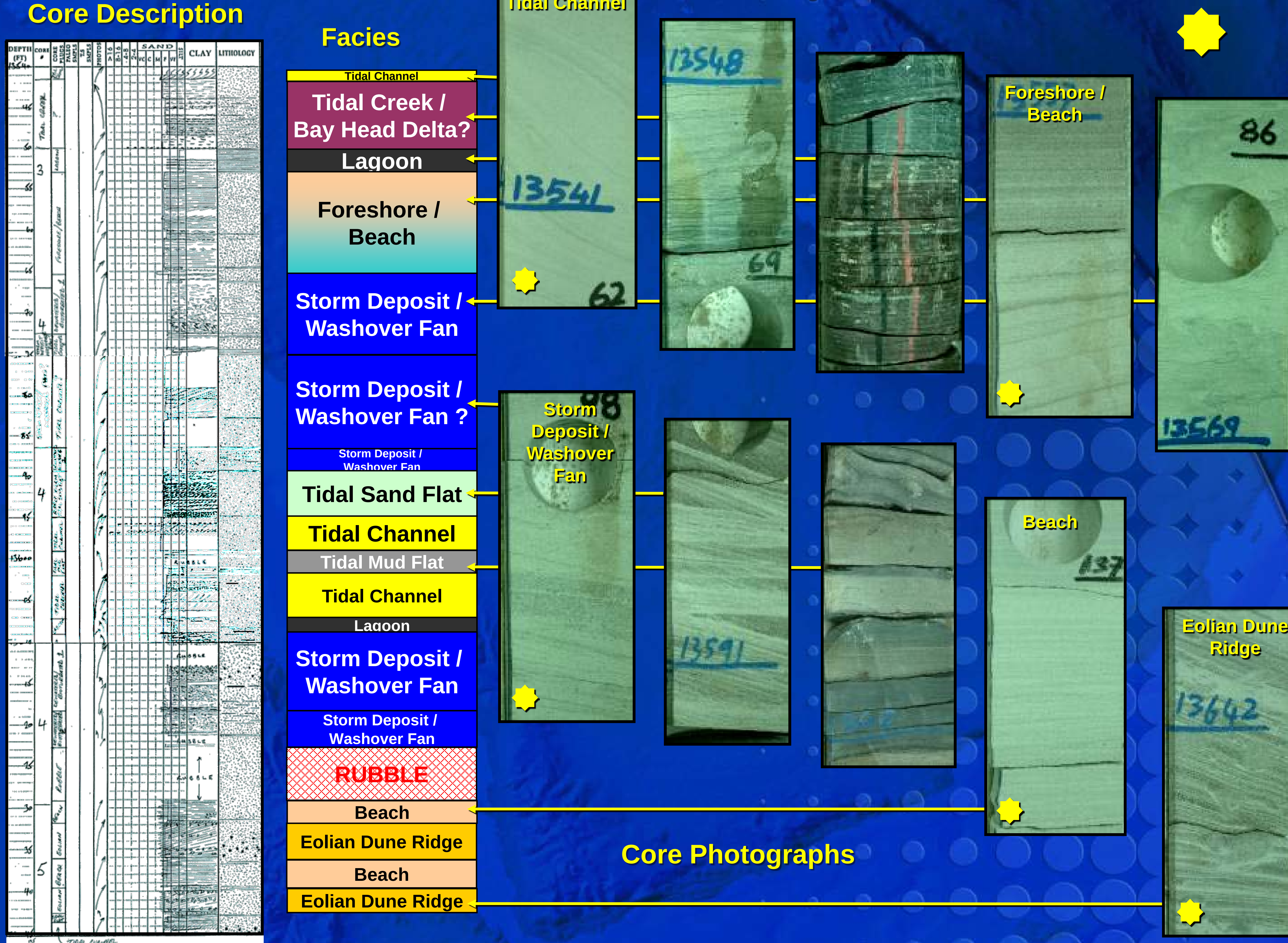


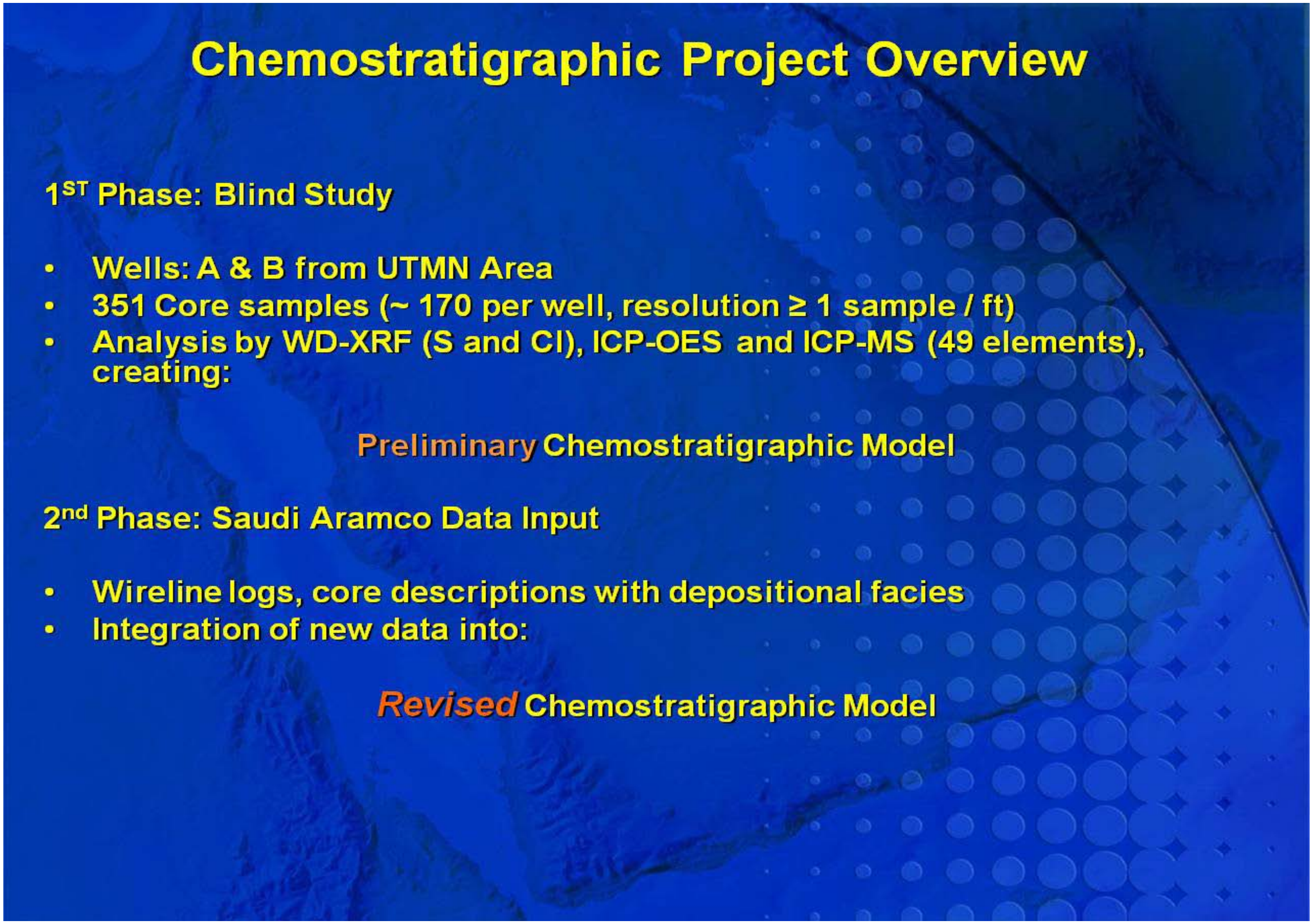
Structural Dip Cross-section Through Top Lower Jauf Map



Well A
Wireline Gamma
Core Gamma
Cores
#2
#3
#4
#5
Core Gamma
0
GAPI
350
Core Description
CLAY
LITHOLOGY
PKU / HU
Modal Grain Size
Upper Jauf
Upper Jauf
"Lower" D3B Proxy
Lower Jauf
Tawil
Sharawra
10 ft
Facies
Tidal Channel
Tidal Creek / Bay Head Delta?
Lagoon
Foreshore / Beach
Storm Deposit / Washover Fan
Storm Deposit / Washover Fan ?
Storm Deposit /
Tidal Sand Flat
Tidal Channel
Tidal Mud Flat
Tidal Channel
Storm Deposit / Washover Fan
Storm Deposit /
RUBBLE
Beach
Eolian Dune Ridge
Beach
Eolian Dune Ridge

Major Jauf Reservoir Facies

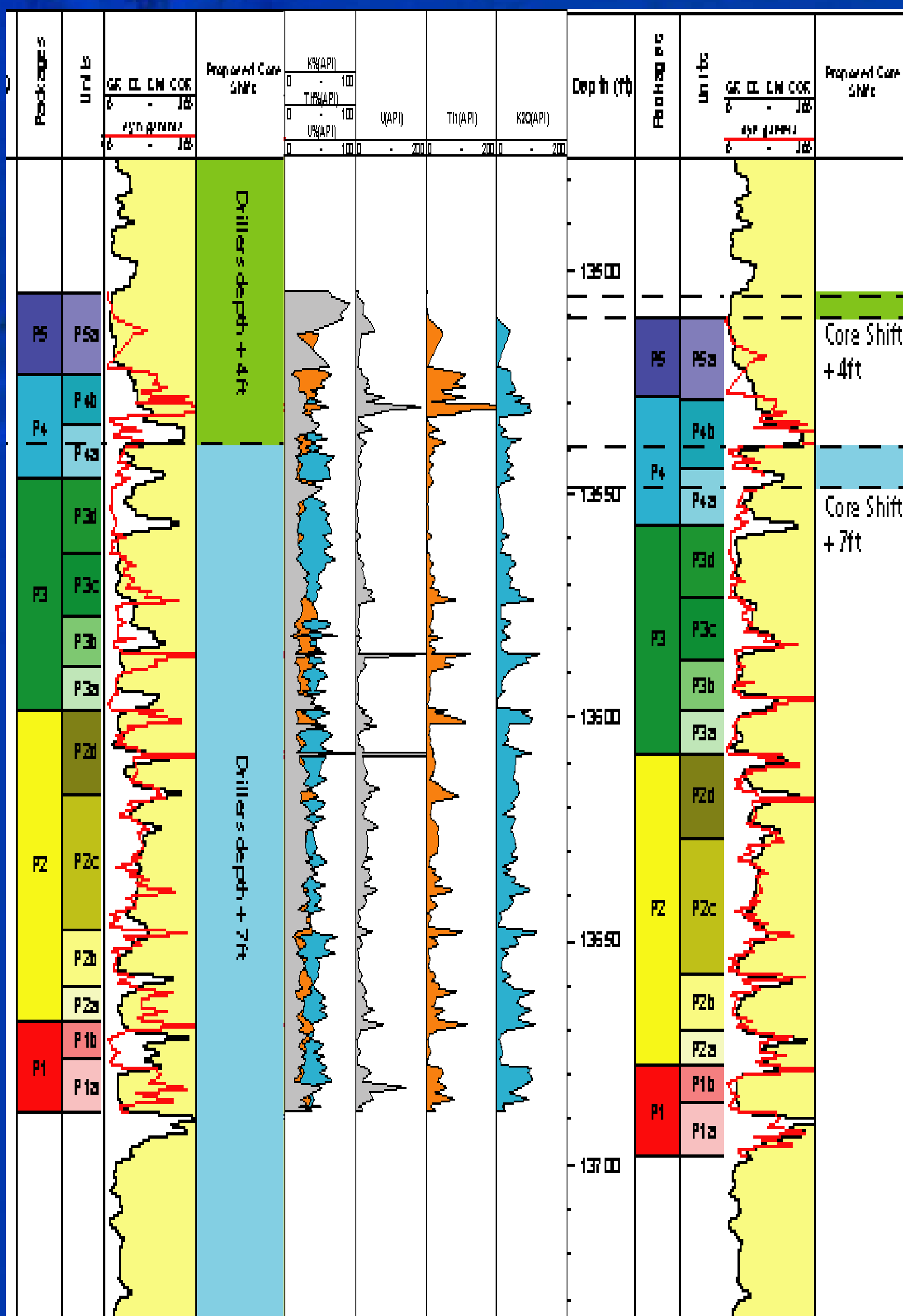




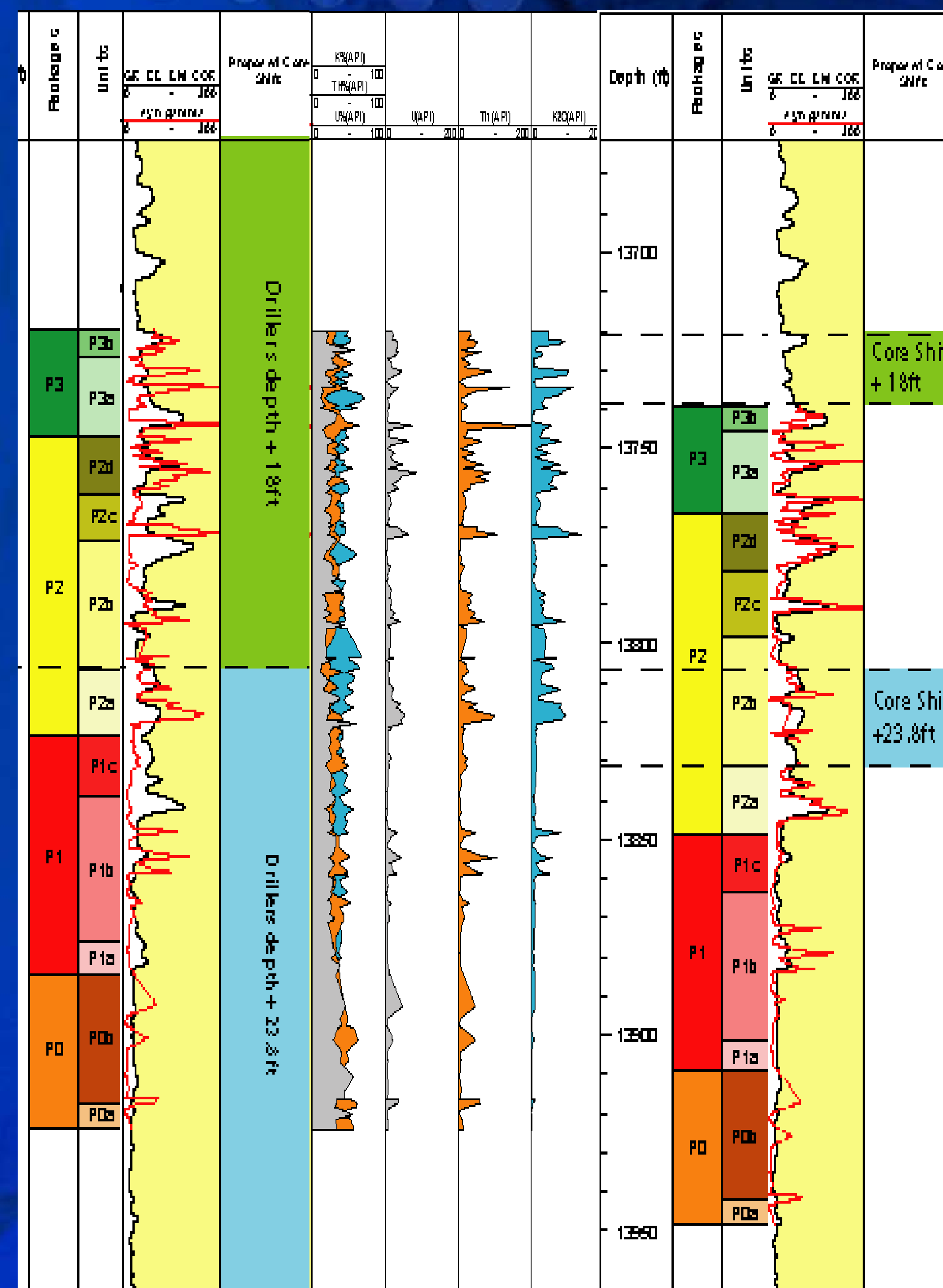
The study involved the analysis of 351 core samples by Inductively-Coupled Plasma - Optical Emission Spectrometry (ICP-OES) and Inductively-Coupled Plasma - Mass Spectrometry (ICP-MS), with data being acquired for 49 elements. In addition, the samples have been analysed by Wavelength-Dispersive X-ray Fluorescence (WD-XRF), in order to obtain Sulphur (S) and Chlorine (Cl) data.

Synthetic Gamma Log - Application

Well A

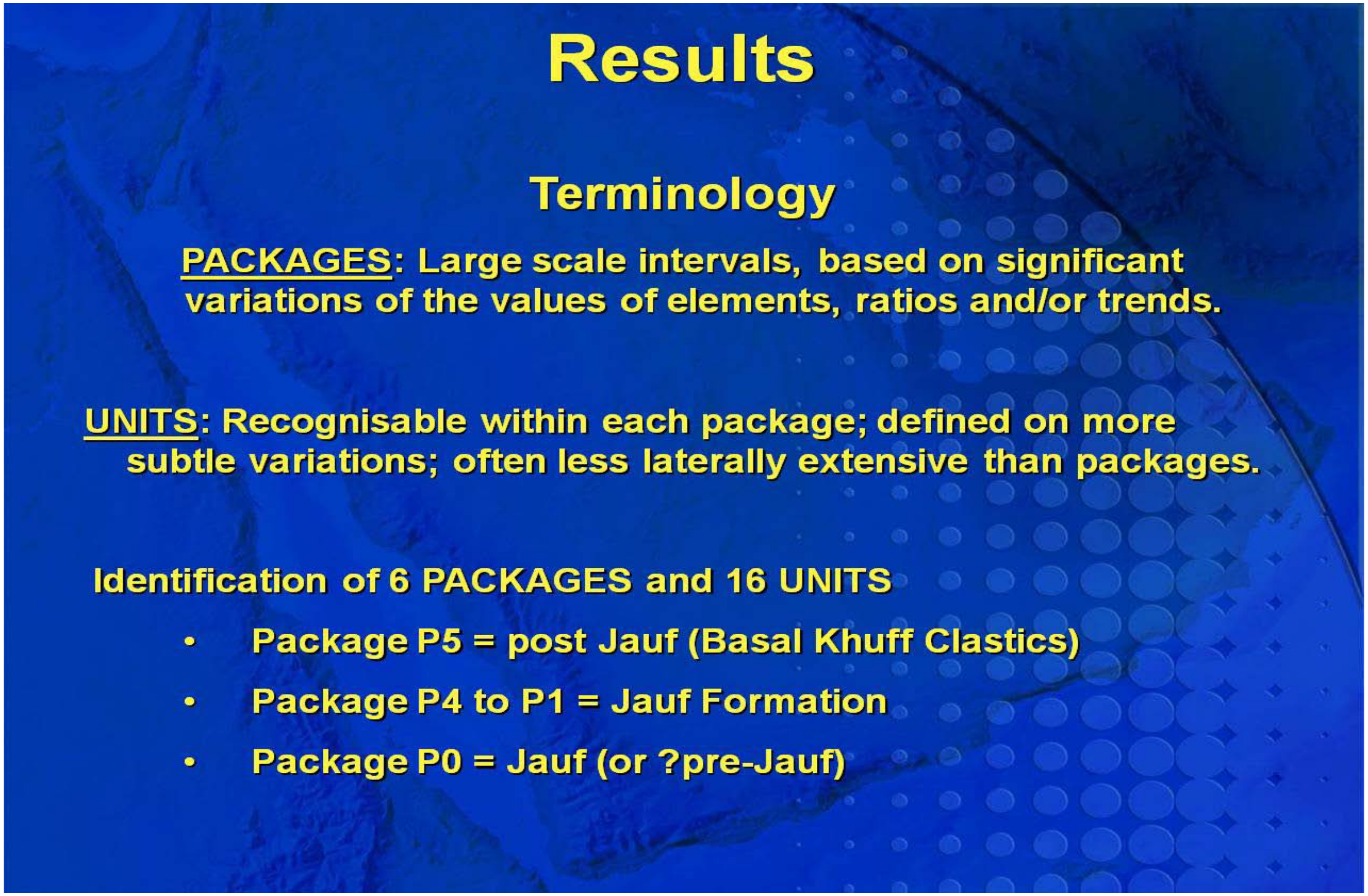


Well B



High sample quality

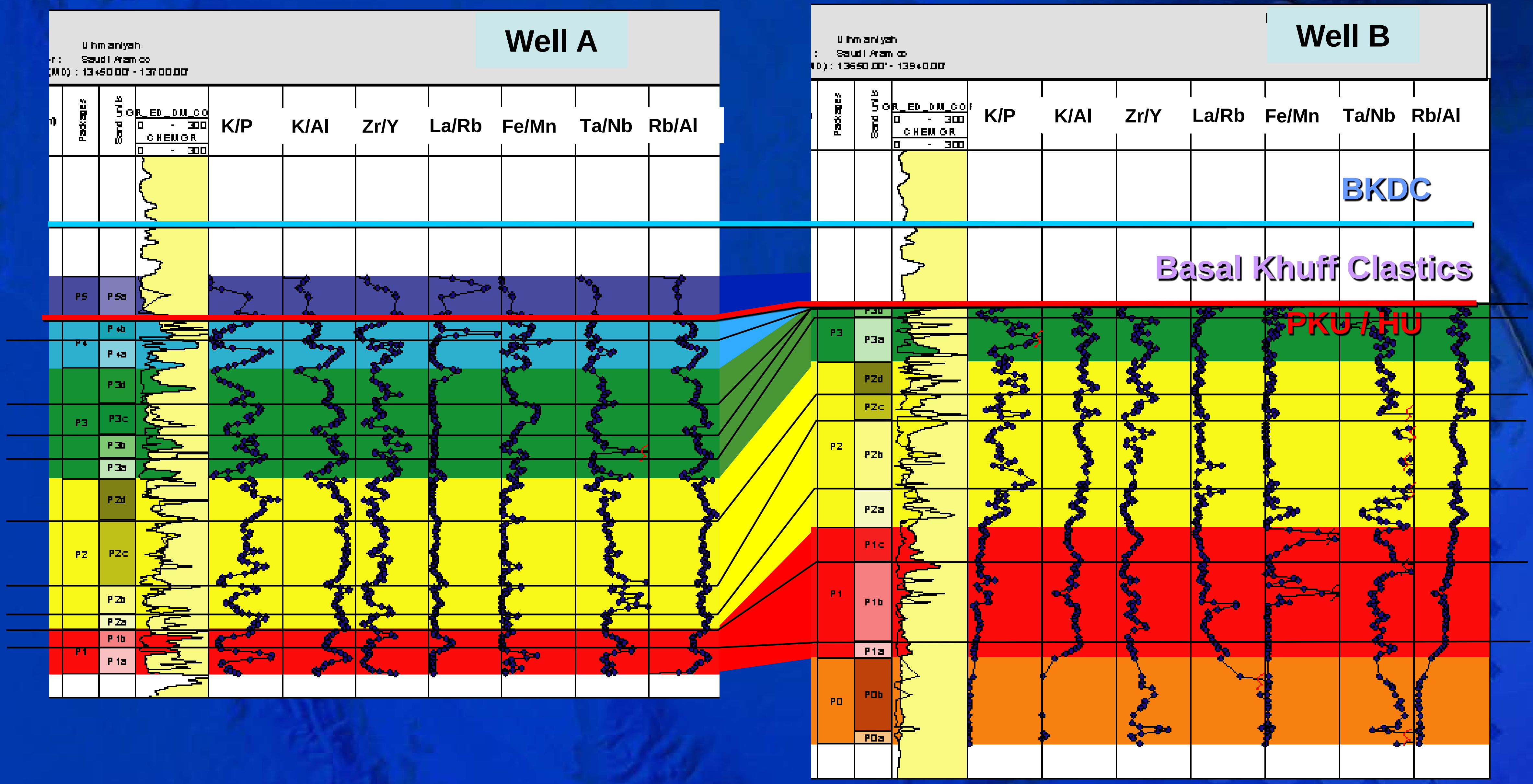
Core depth shift needed



Chemostratigraphic correlation is based on the identification of 6 geochemical packages (P0 to P5) and 16 units. Packages P3 to P1 occur in both well UTMN-2105 and well UTMN-2107. Package P5 and P4 are only present in well UTMN-2105, whereas Package P0 was only identified in well UTMN-2107, respectively.

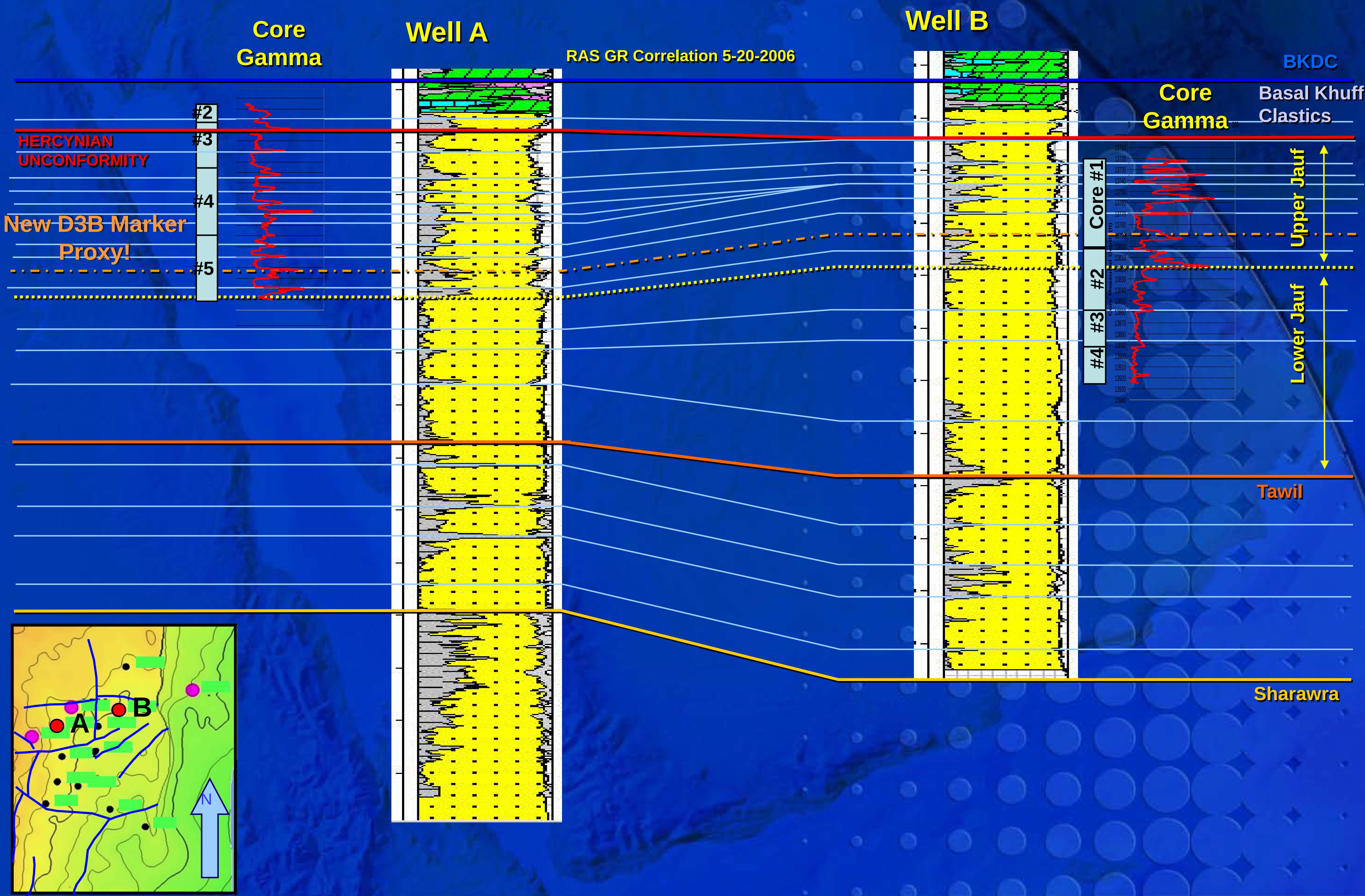
Chemostratigraphic Zonation

Geochemical Packages

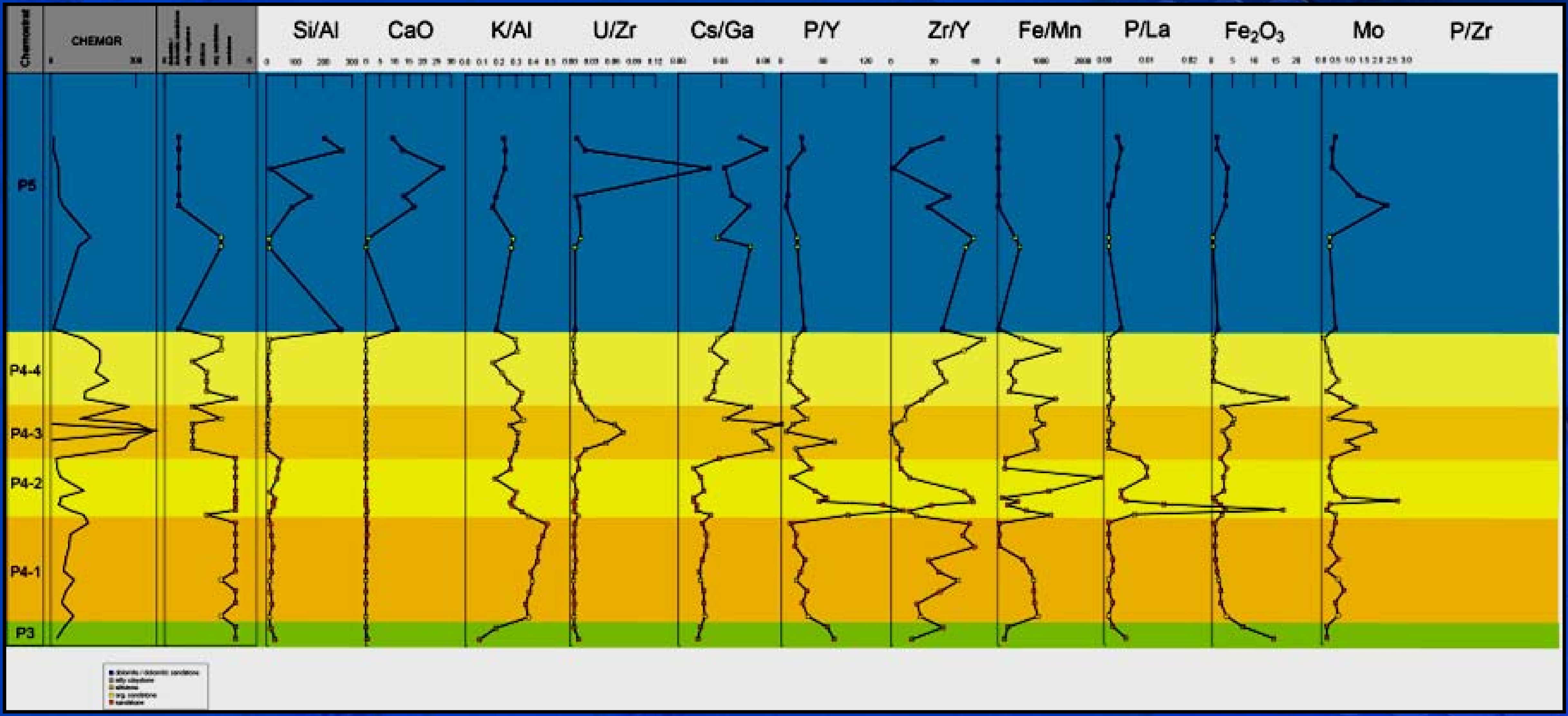


Key element ratios: K/P, K/Al, Zr/Y, La/Rb, Fe/Mn, Ta/Nb and Rb/Al

Palynological and Chemostratigraphic Correlation and Layering



High Resolution Layering Within Packages – Down to ~ 5 Feet!



Chemostratigraphic Zonation

Geochemical Packages

Well A

Well B

Core Gamma

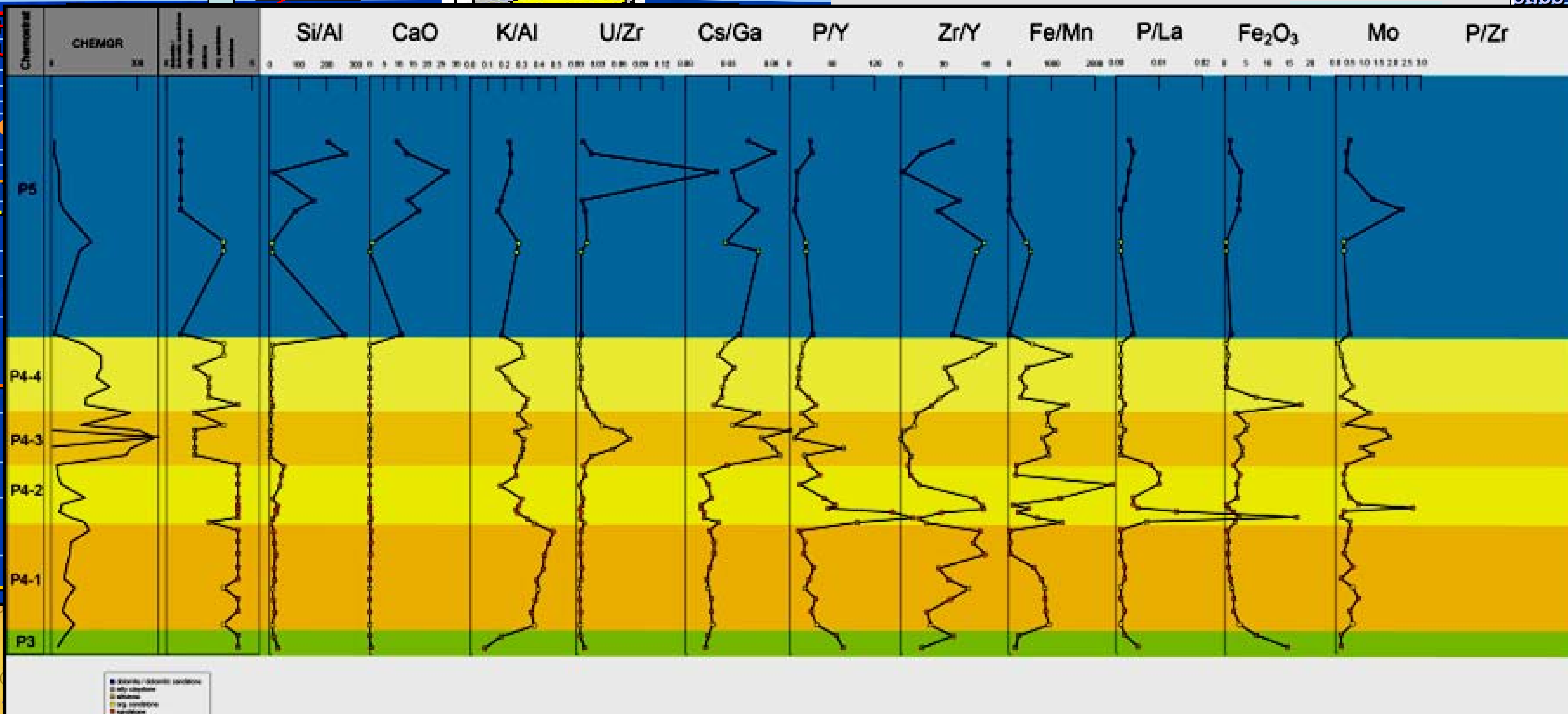
RAS GR Correlation 5-20-2006

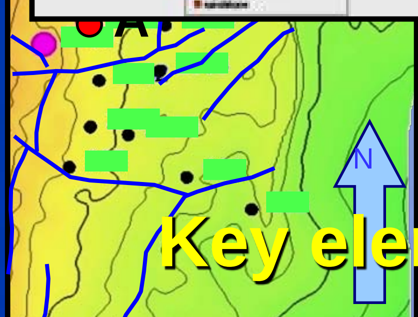
High Resolution Layering Within Packages – Down to ~ 5 Feet!

BKDC

Core

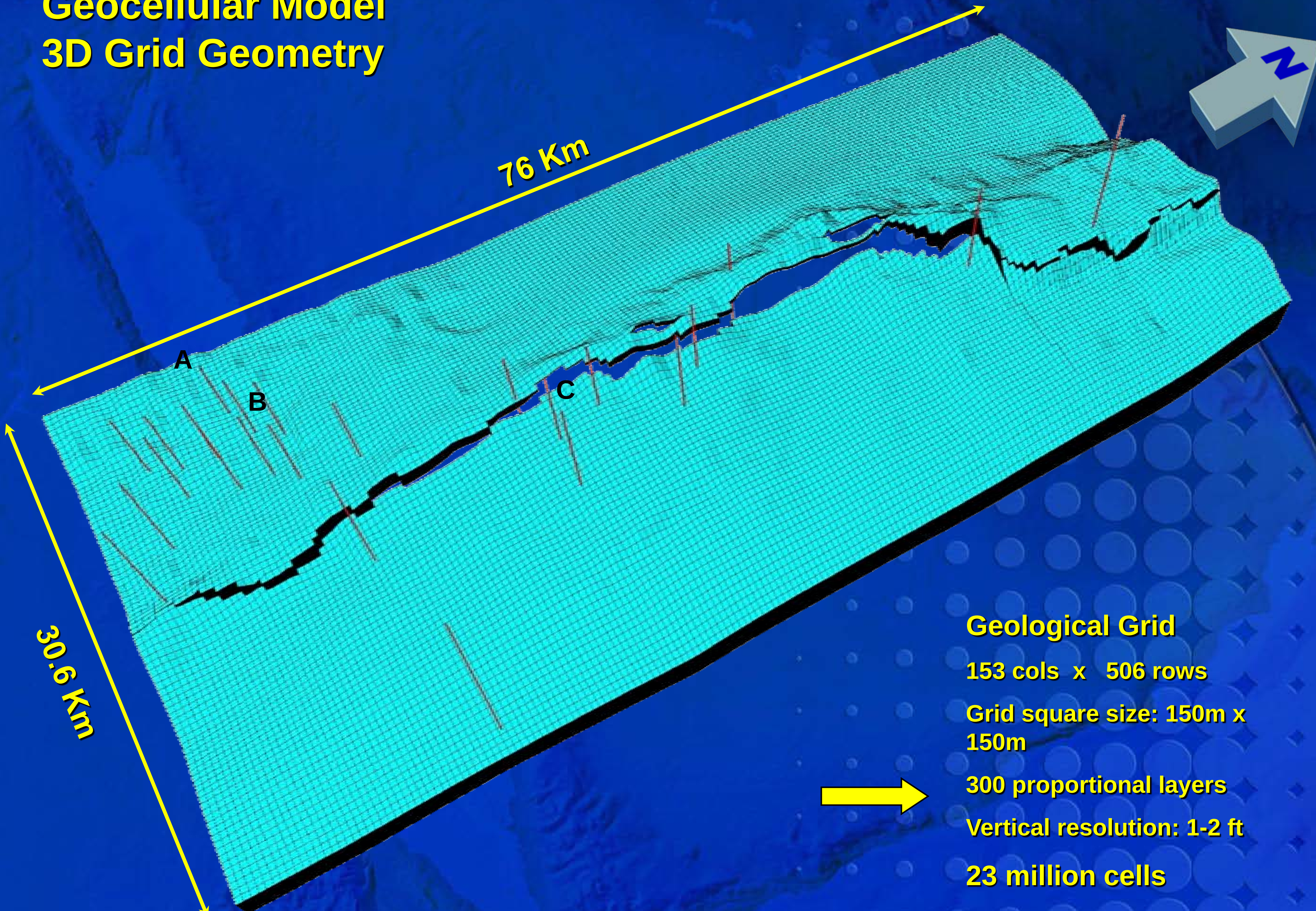
Basal Khuff Clastics





Key element ratios: K/P, K/Al, Zr/Y, La/Rb, Fe/Mn, Ta/Nb and Rb/Al

Geocellular Model
3D Grid Geometry



Geological Grid

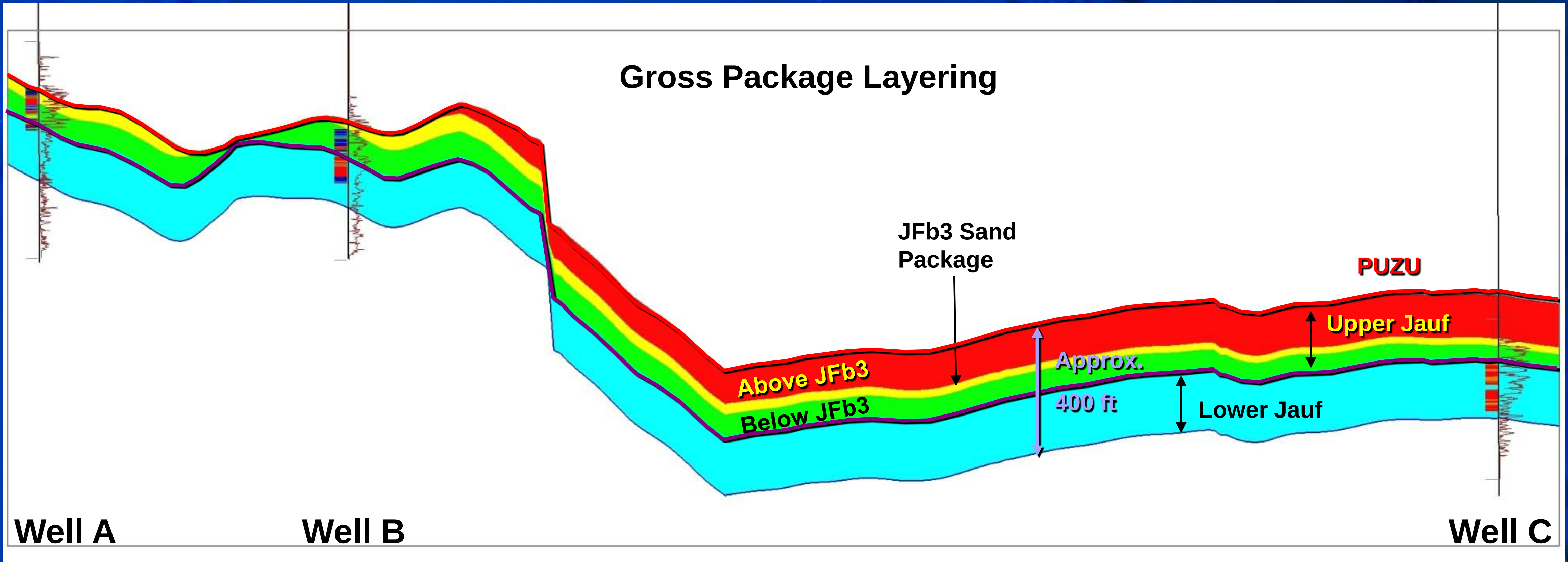
153 cols x 506 rows

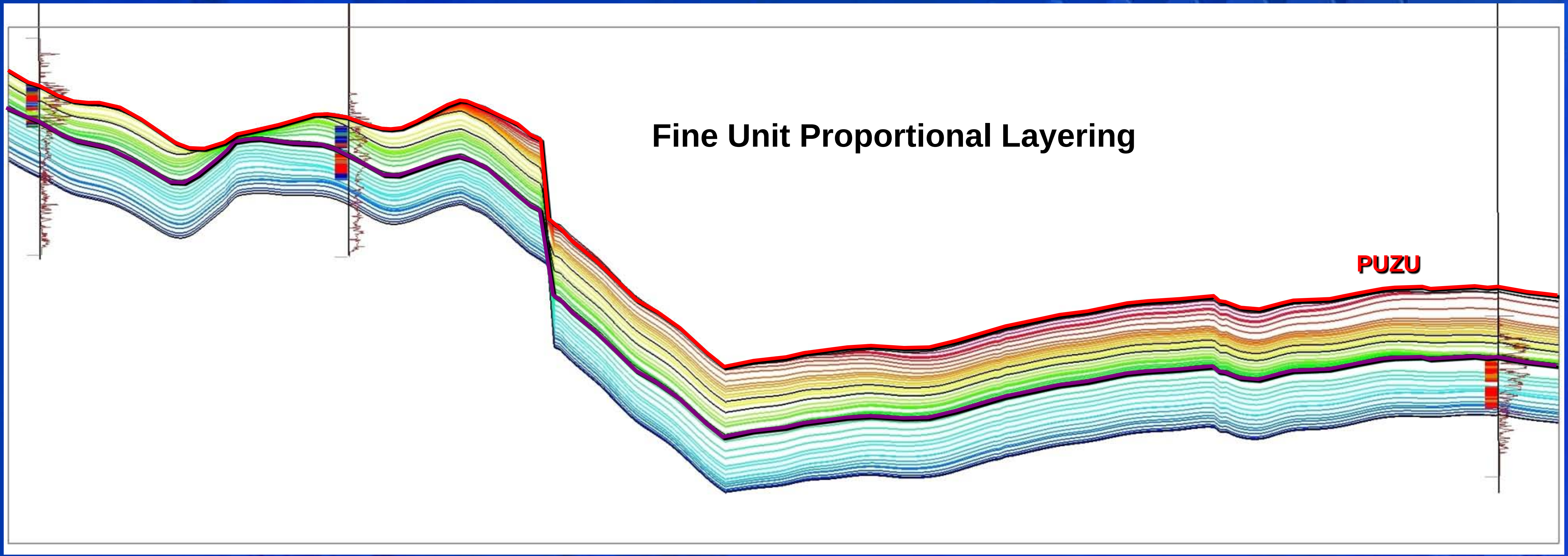
Grid square size: 150m x 150m

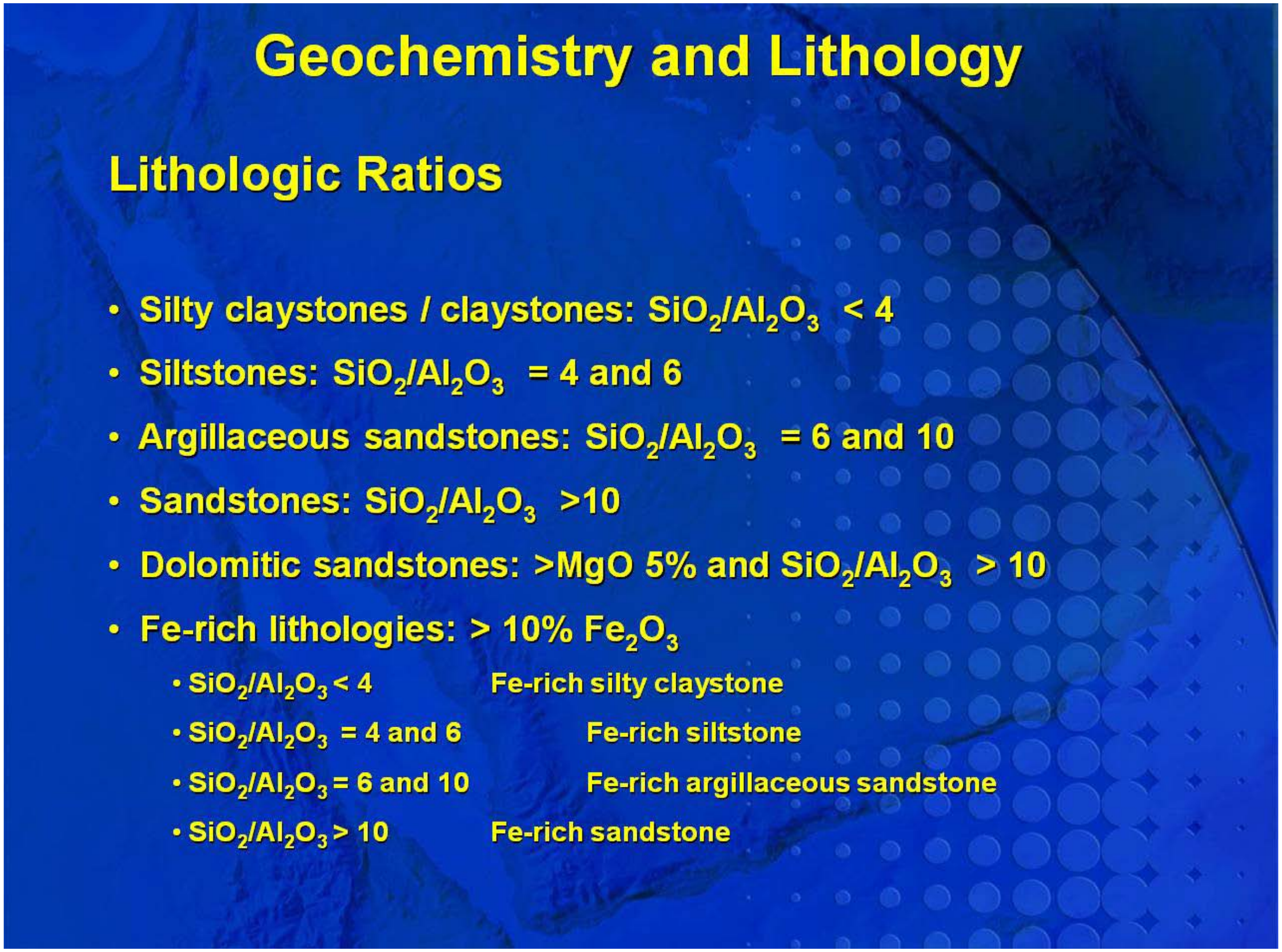
300 proportional layers

Vertical resolution: 1-2 ft

23 million cells

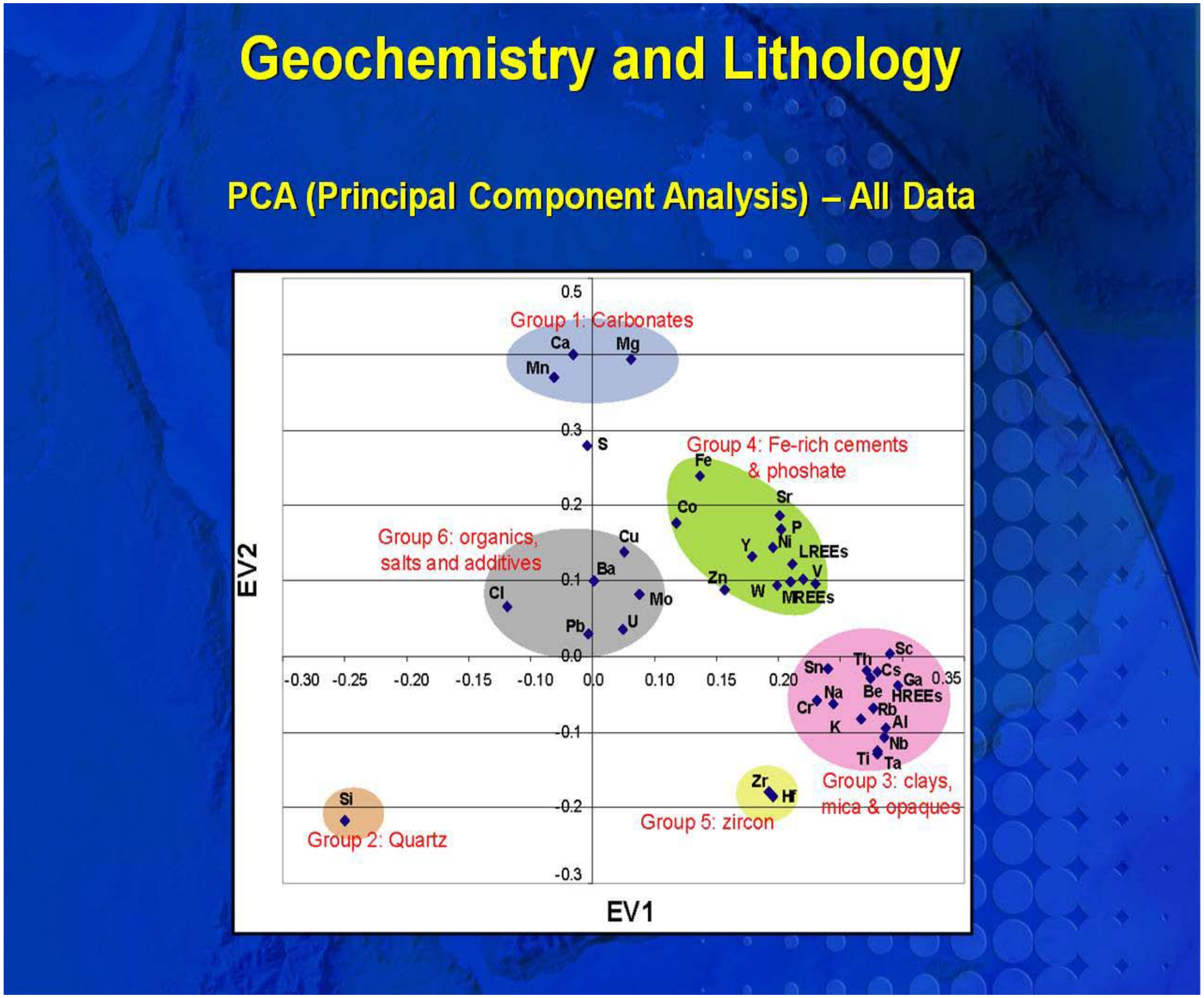

Gross Package Layering
JFb3 Sand
Package
PUZU
Upper Jauf
Approx.
400 ft
Above JFb3
Below JFb3
Lower Jauf
Well A
Well B
Well C


Fine Unit Proportional Layering
PUZU



Based on their visual descriptions, the samples are grouped into five different lithologies, namely dolomites and dolomitic sandstones, silty claystones, siltstones, argillaceous sandstones and sandstones.

Group 1: includes Ca, Mg and Mn, and is characterised by +ve EV2 values and -ve to +ve EV1 values. The abundance of these elements is controlled by the abundance and distribution of carbonate minerals, of which dolomite is most important, followed by calcite.



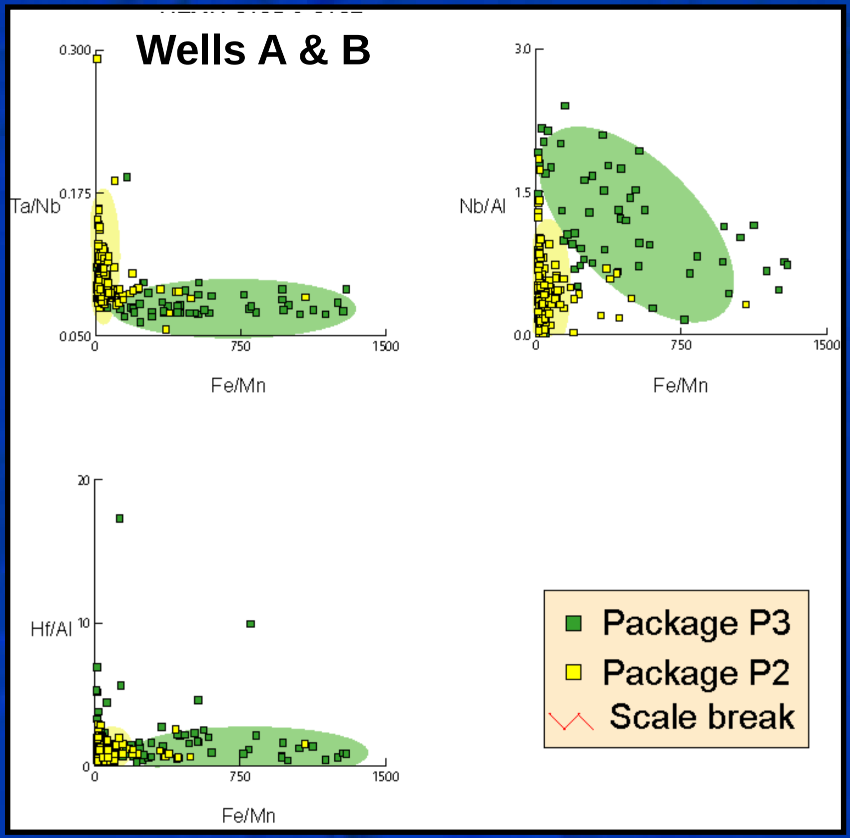
Group 2: includes Si and is characterised by –EV1 and +ve EV2 scores and is attributed to the distribution of quartz.

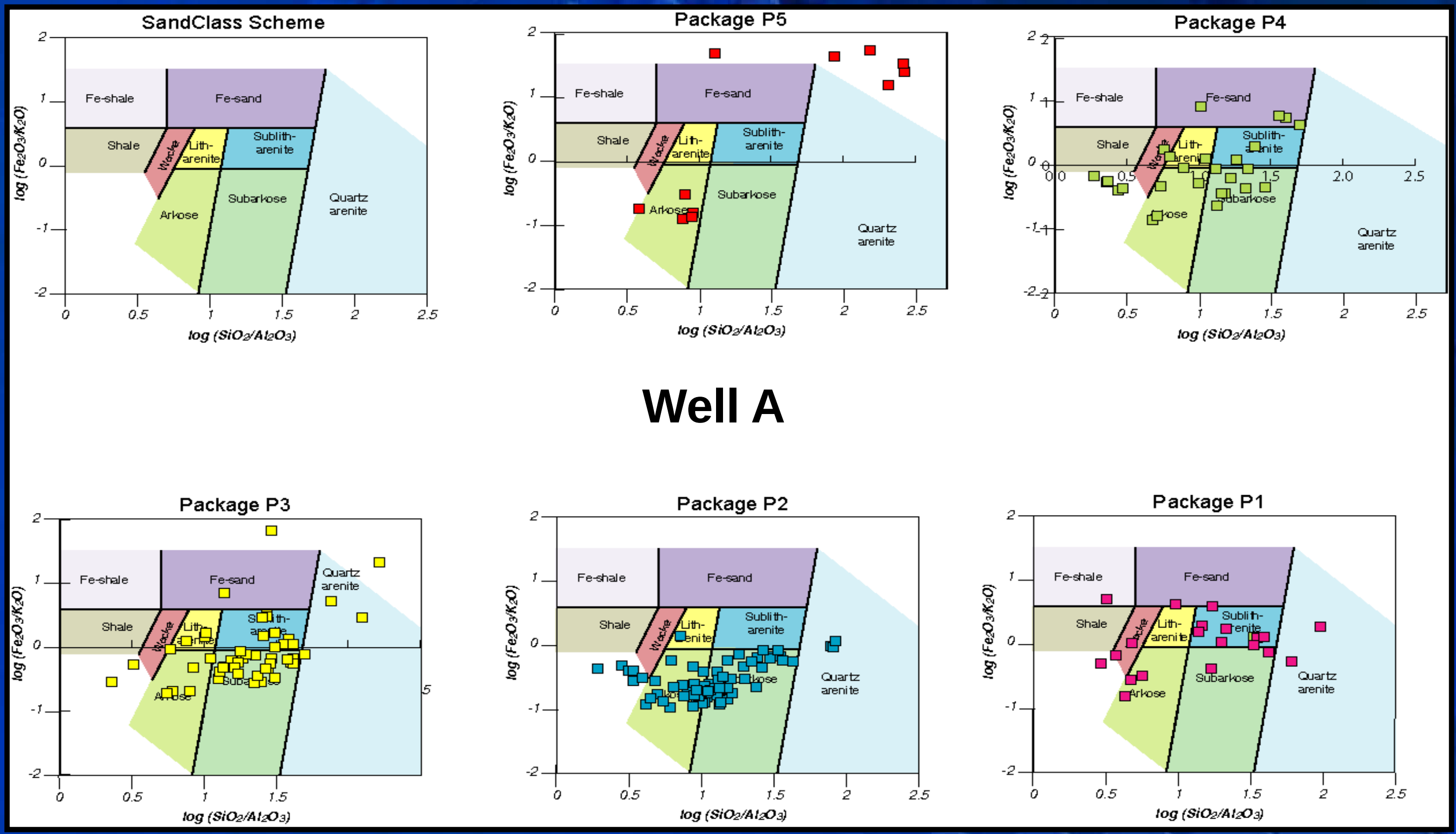
Group 3: includes Al, K, Rb, Cs, Ga, Nb, Ta, Th, Sc, Ti, Nb, Ta, Be, Zr, Hf, U and the HREEs, and is characterised by +ve EV1 values and -ve EV2 values. These elements are associated with those minerals tending to occur in clay minerals (mainly kaolinite and illite), mica, opaque minerals and minor amounts of K feldspar. The inclusion of U in this group, along with Zr and Hf, implies this element might have an affinity with zircon in the sandstones.

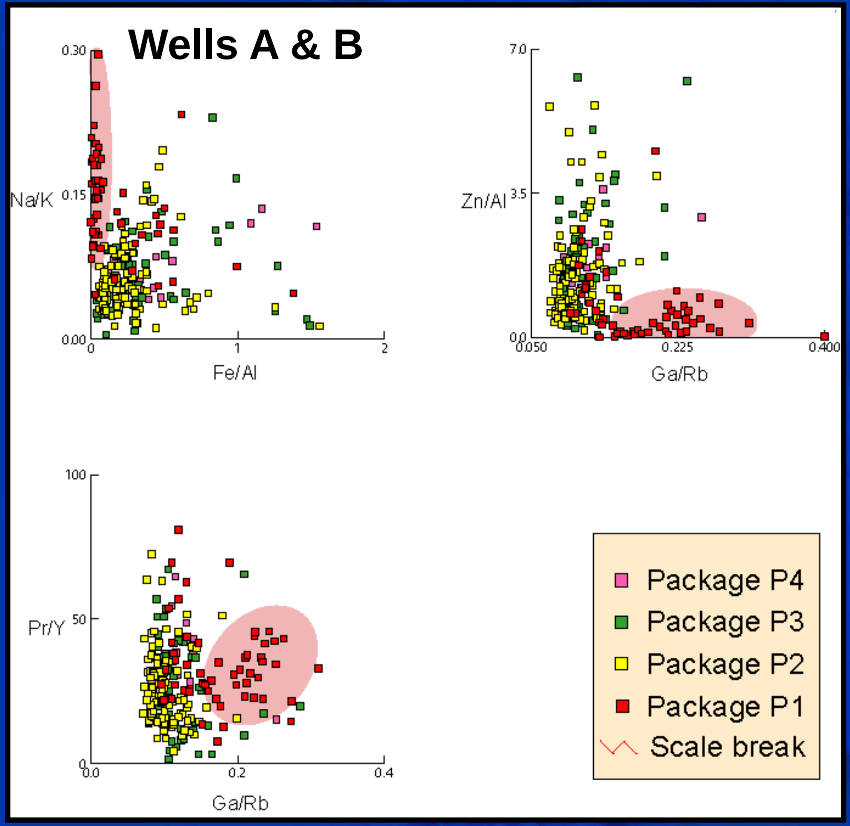
Group 4: includes Fe, P, Y, Sr, the LREEs, the MREEs, Co, Zn, Ni, V and W, and is characterised by +ve EV1 values and +ve EV2 values. Fe, V, Co and Ni are chiefly associated with the distribution of Fe-rich cements such as siderite and haematite, whereas P, Y, Sr and the REEs have affinities with phosphate and, to a lesser extent, with phosphatic heavy minerals, e.g., apatite and monazite.

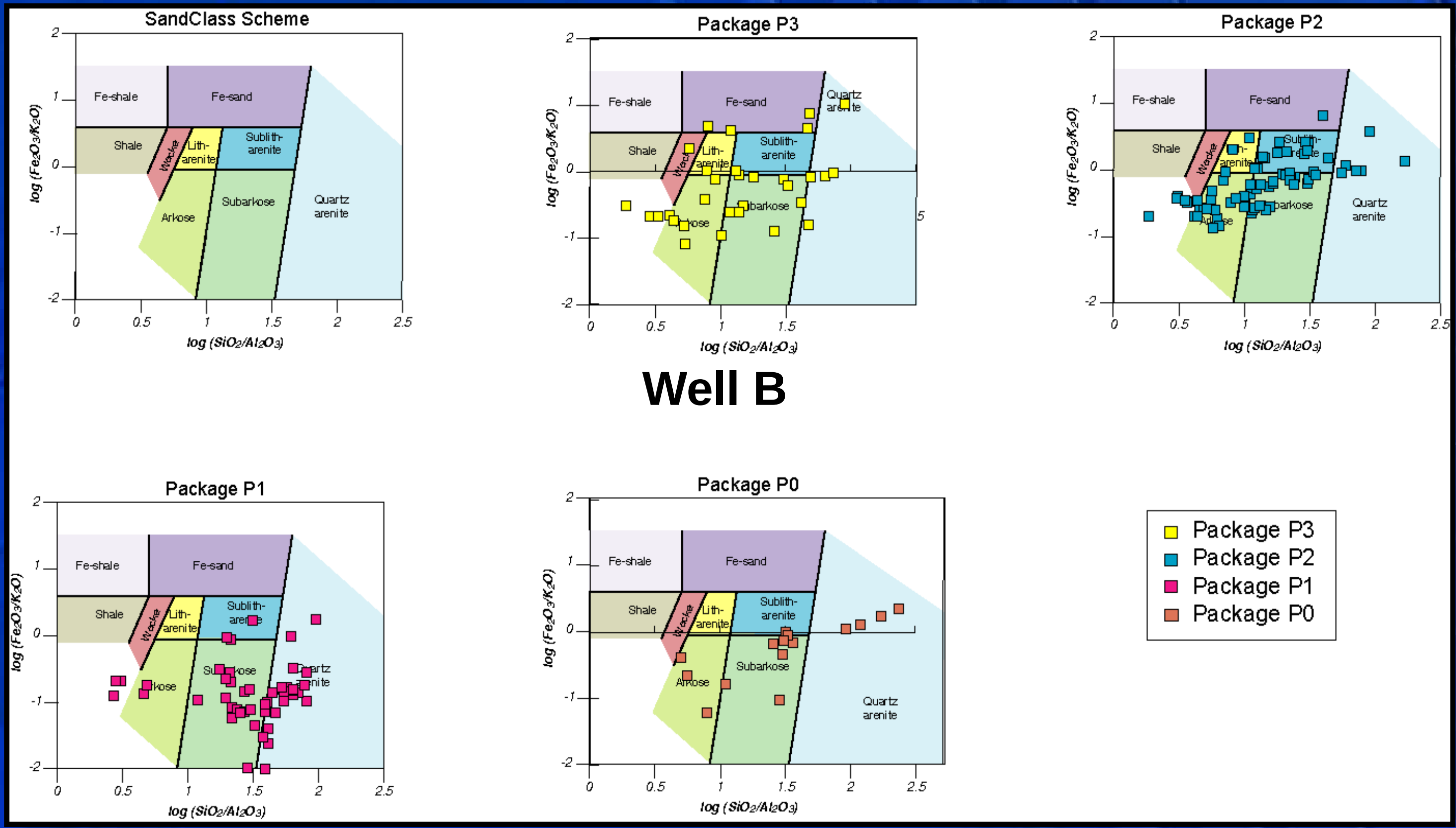
Group 6: includes Ba, Pb, U, Mo, Cu, W and Sn, and is characterised by +ve to -ve EV2 values and +ve to -ve EV1 values. Mo is associated with organic matter (?bitumen), whereas Ba is linked with barite, the abundance of which is probably influenced by the presence of minor amounts of barite-based drilling additives that have invaded the core samples, though the occurrence of localised barite cements cannot be completely discounted. Sn and W may be associated with metallic material, possibly either in the form of contamination in the drilling muds or could have been derived from the rock saw when the core was slabbed.

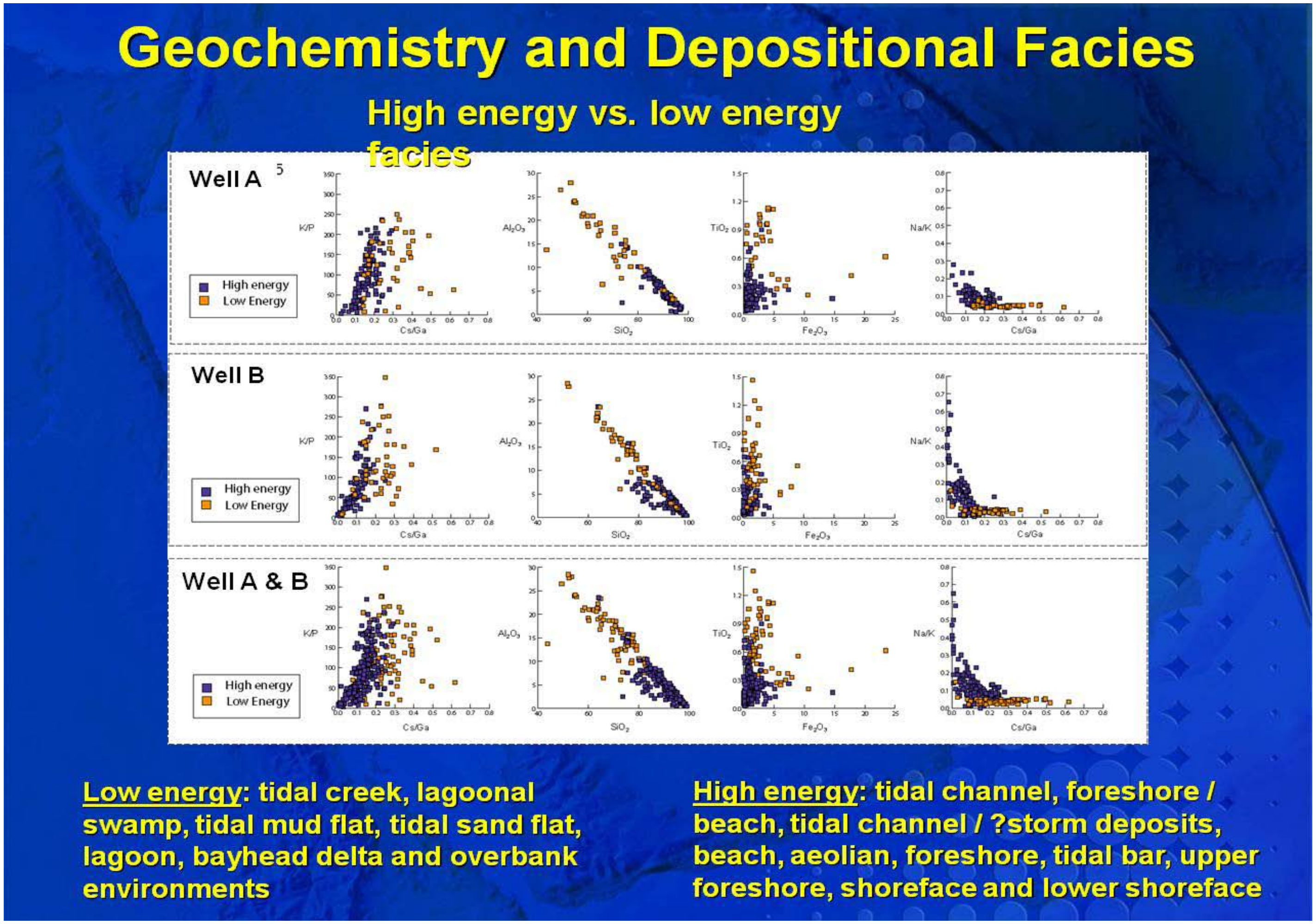
Package Differentiation







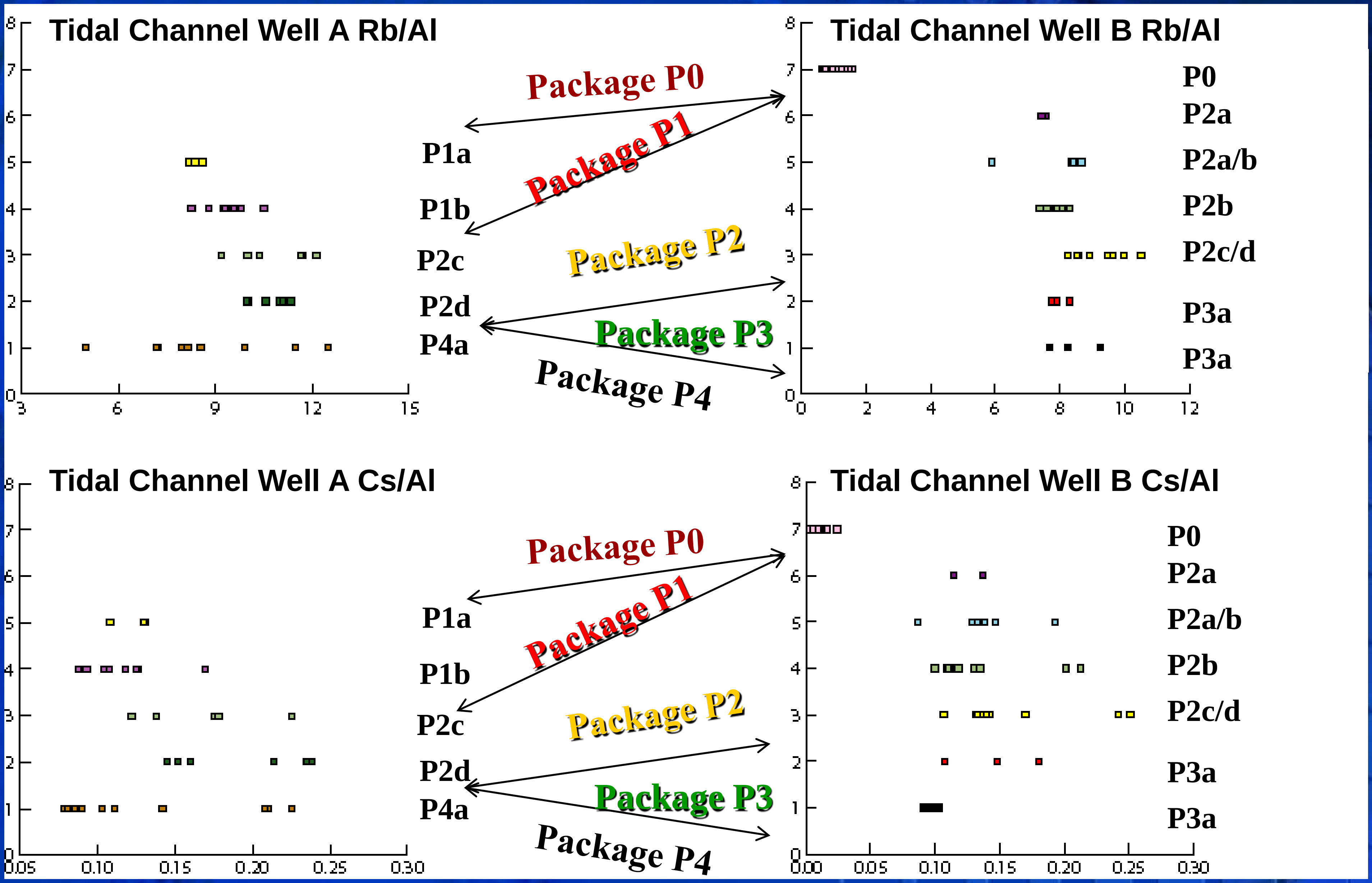




Low-energy depositional environments: tidal creek, lagoonal swamp, tidal mud flat, tidal sand flat, lagoon, bayhead delta and overbank environments.

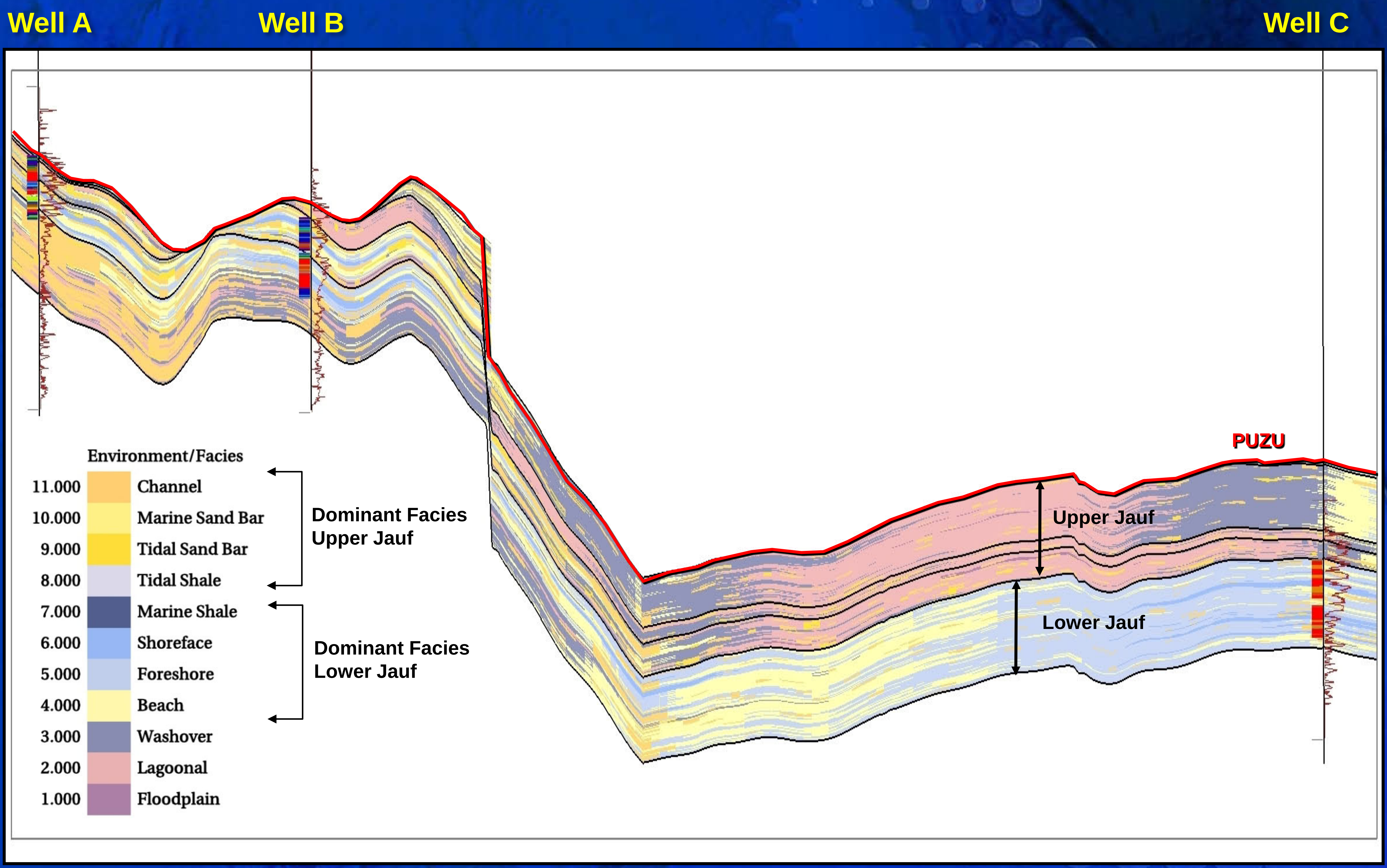
High energy depositional environments: tidal channel, foreshore / beach, tidal channel / ?storm deposits, beach, aeolian, foreshore, tidal bar, upper foreshore, shoreface and lower shoreface .

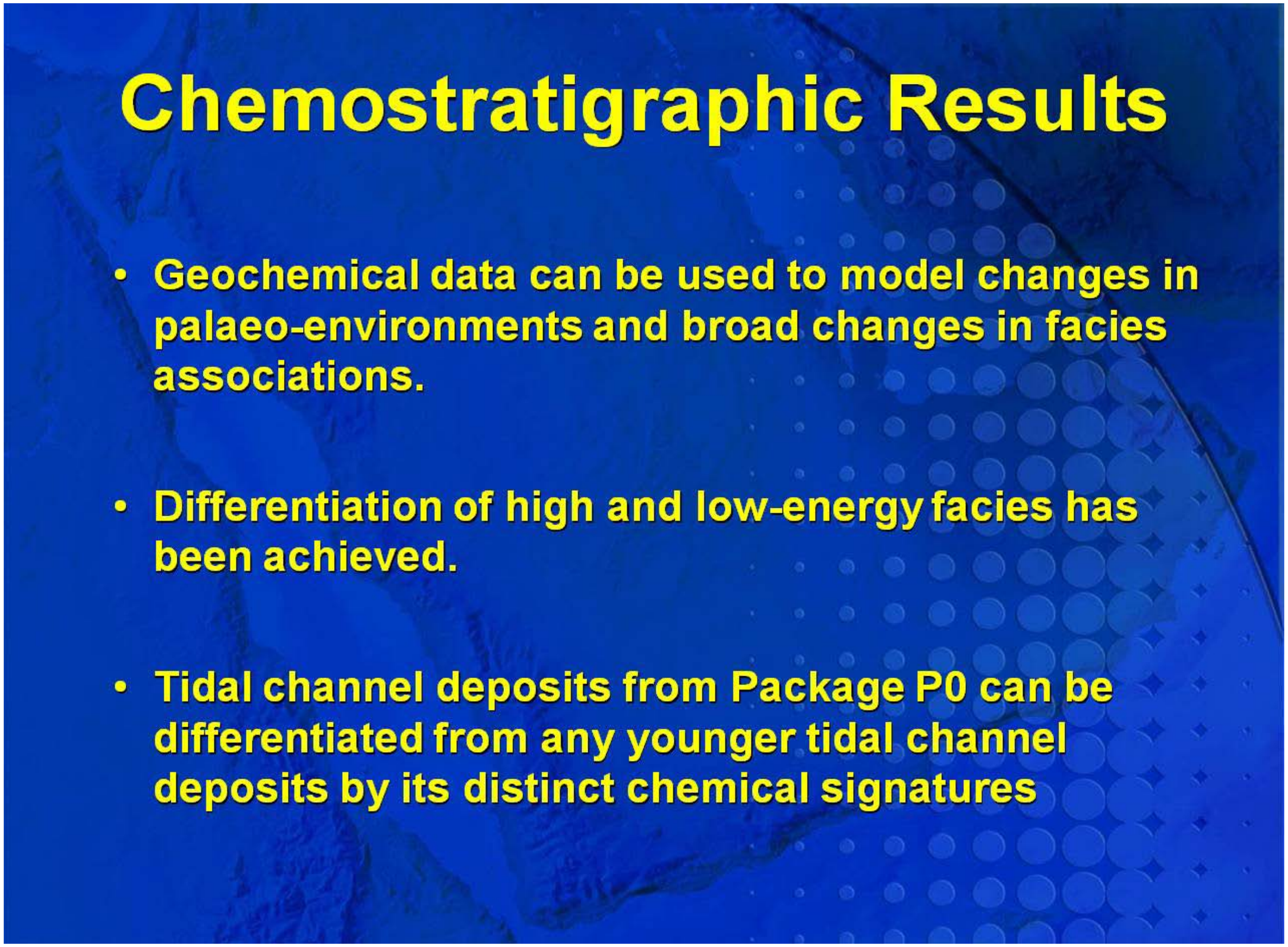
Geochemistry and Depositional Facies



- Package P0 tidal channel has a distinct geochemical signature
- Package P0 = possibly ?pre-Jauf or different member

Depositional Facies Controls on Chemostratigraphy





Geochemical data can be used to model changes in palaeo-environments and broad changes in facies associations. Differentiation of high- and low-energy facies has been achieved. Tidal channel deposits from package P0 can be differentiated from any younger tidal channel deposits by its distinct chemical signatures.

Petrographic Project Overview

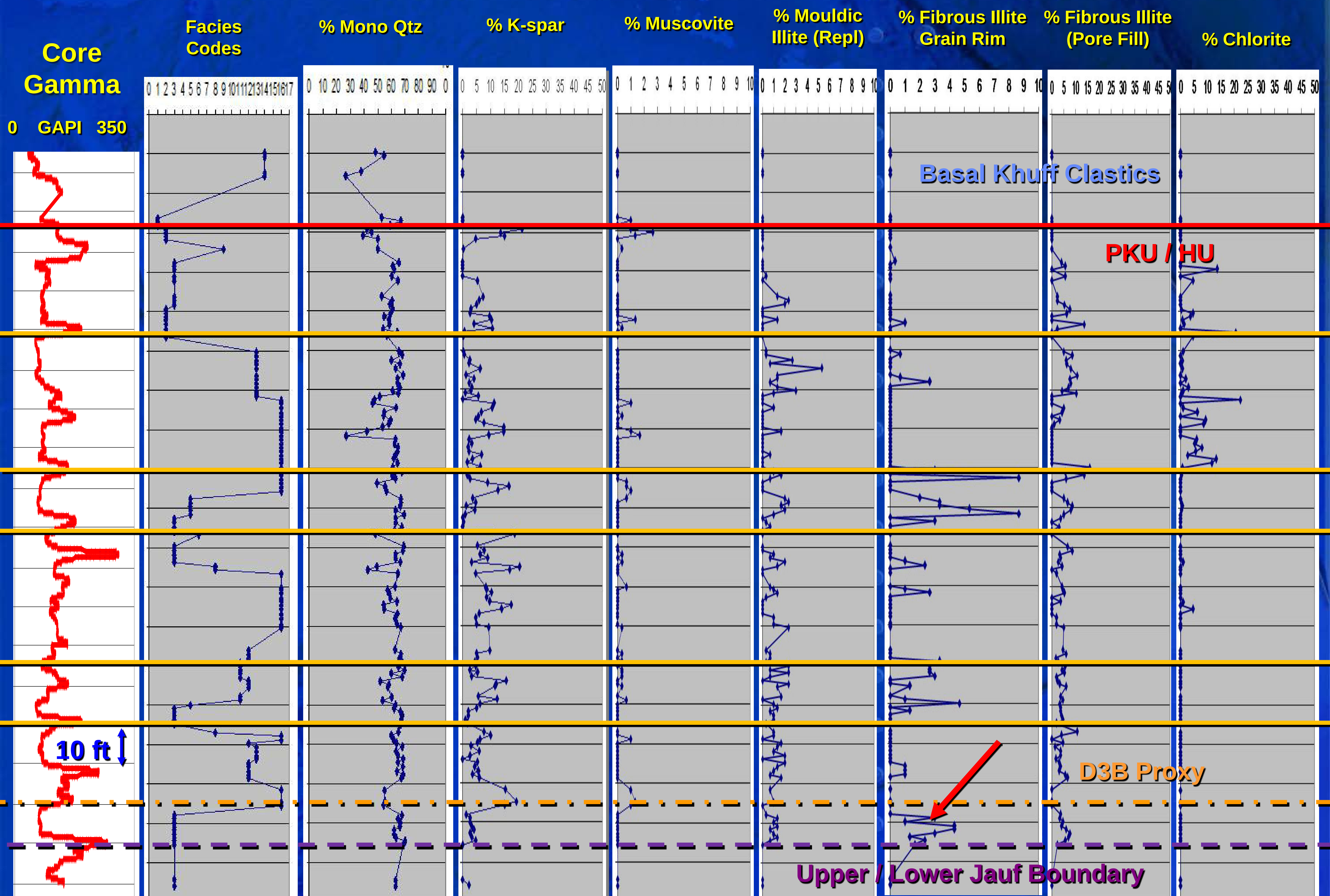
- Well A
  139 thin sections, 36 SEM & 36 WR XRD
- Well B
  146 thin sections, 40 SEM & 40 WR XRD
- Well C
  162 thin sections, 39 SEM & 39 WR XRD

- 300 point counts per slide

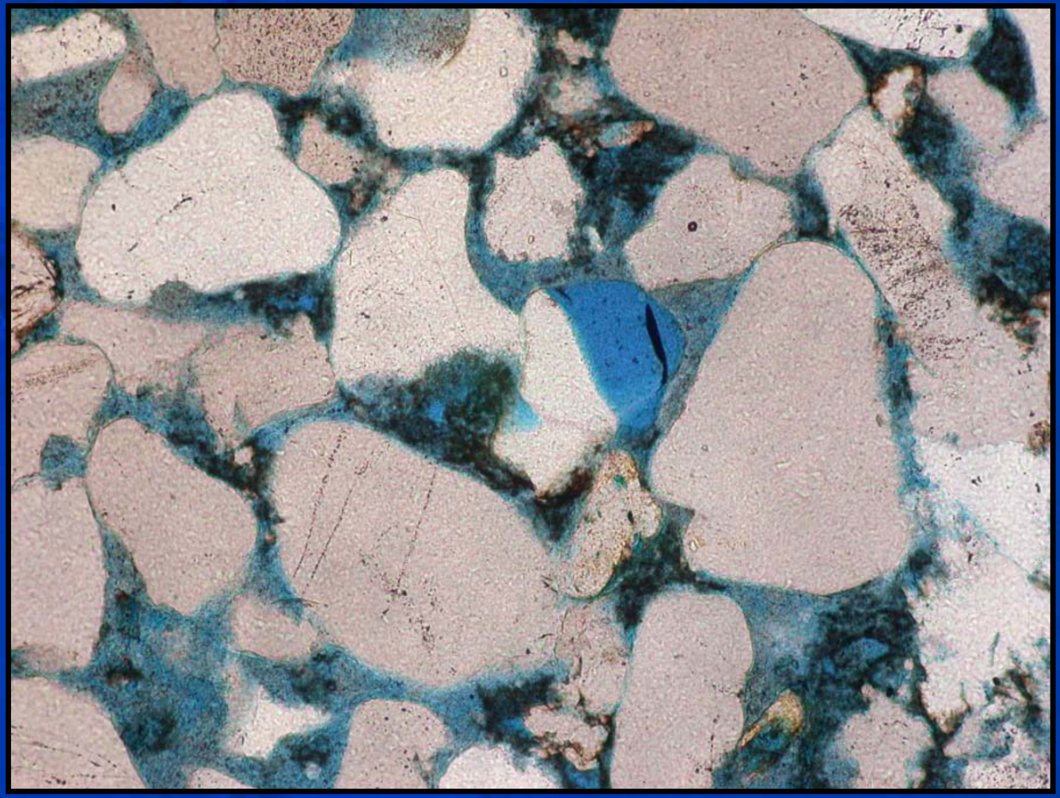
- Conventional core analysis data (ΦHe, Ka & GD)

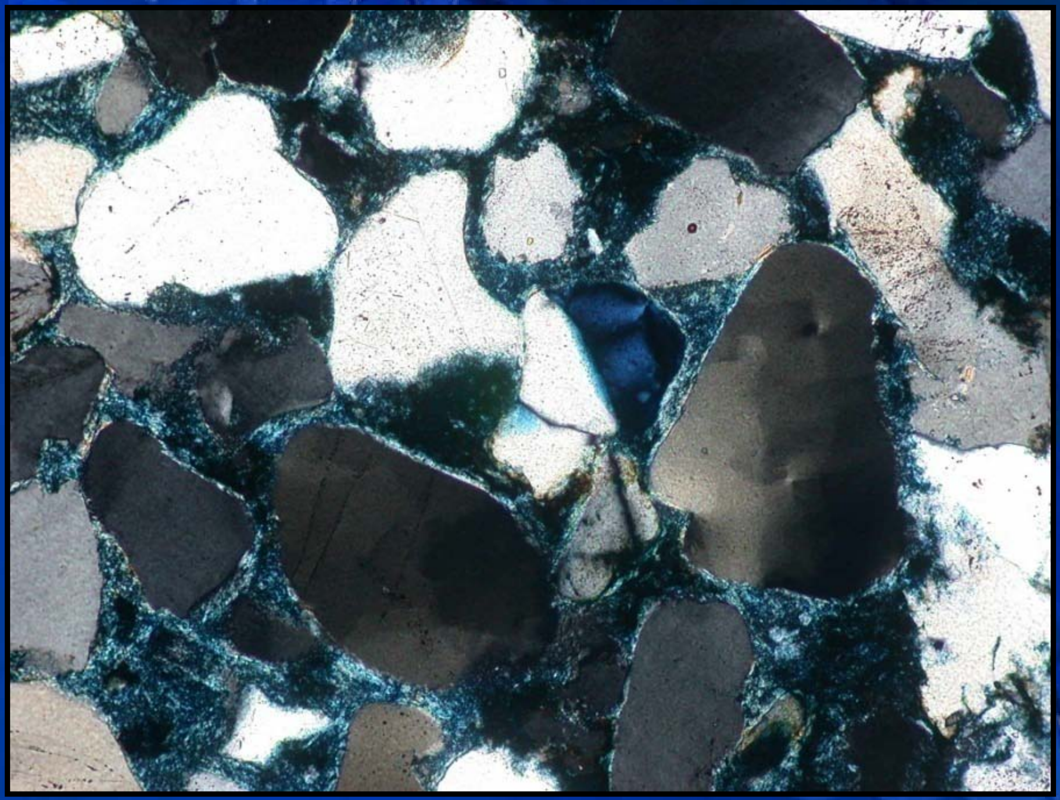
- Samples from Wells A & B from same depths as chemostratigraphic samples

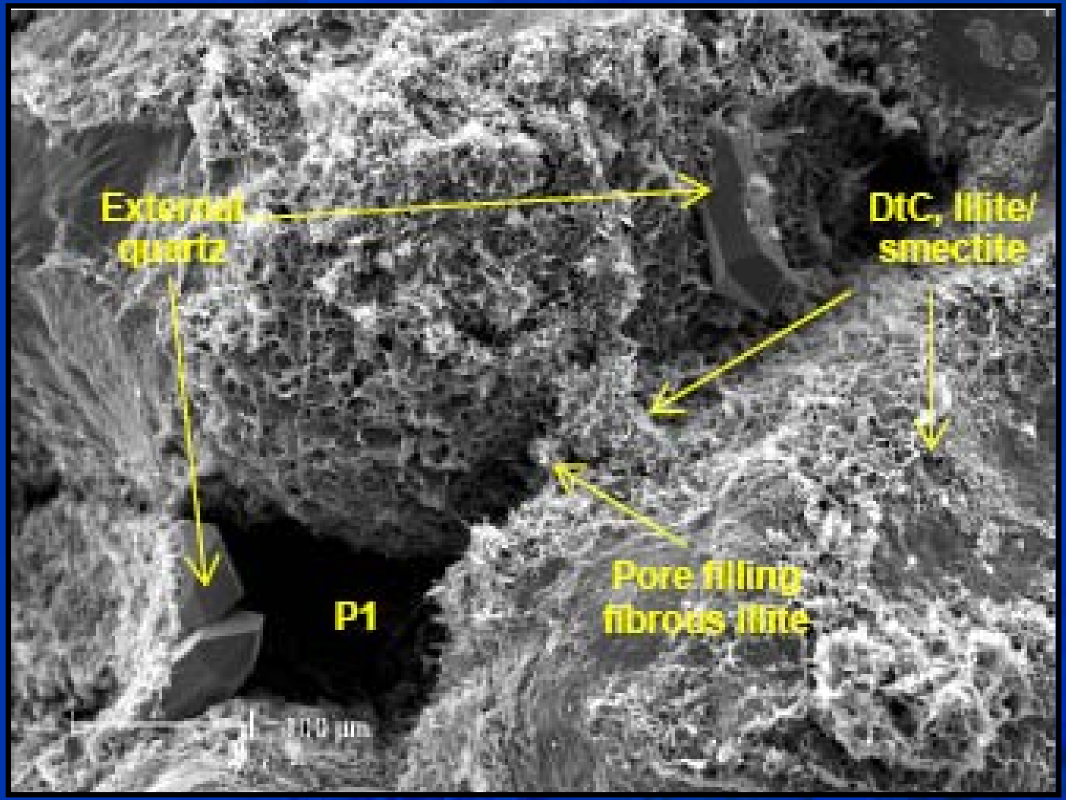
Well A: Representative Normalized Point Count Data

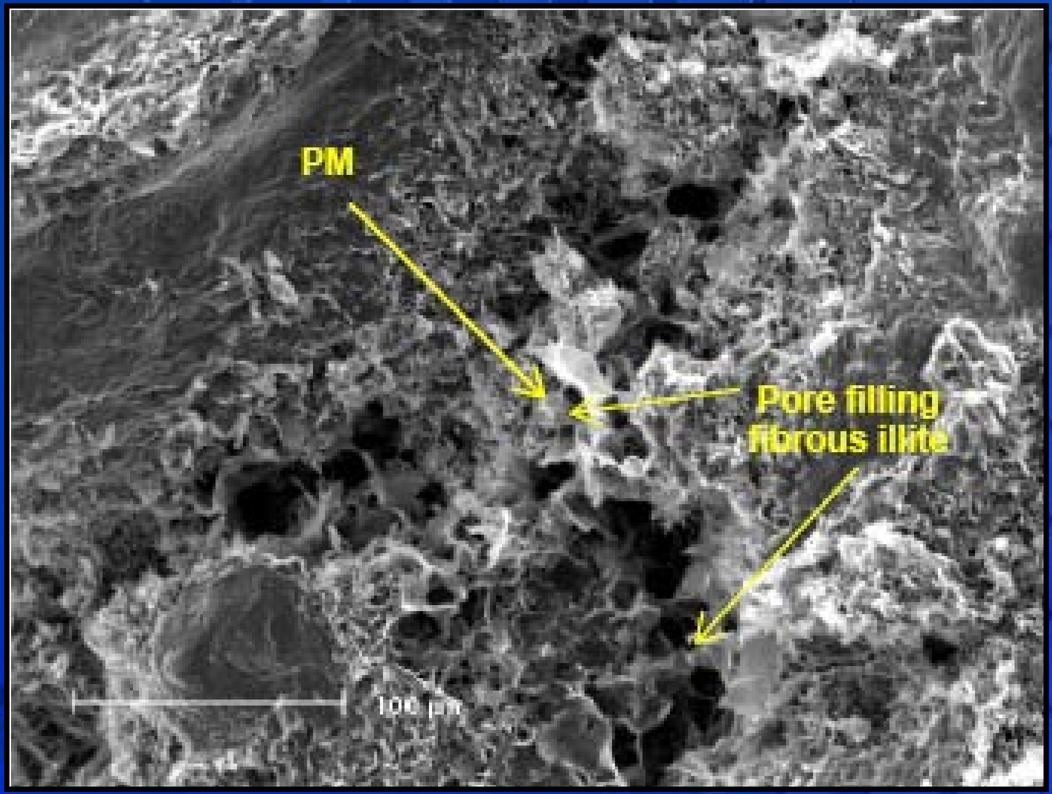


Well A Petrographic Thin Section / SEM Views

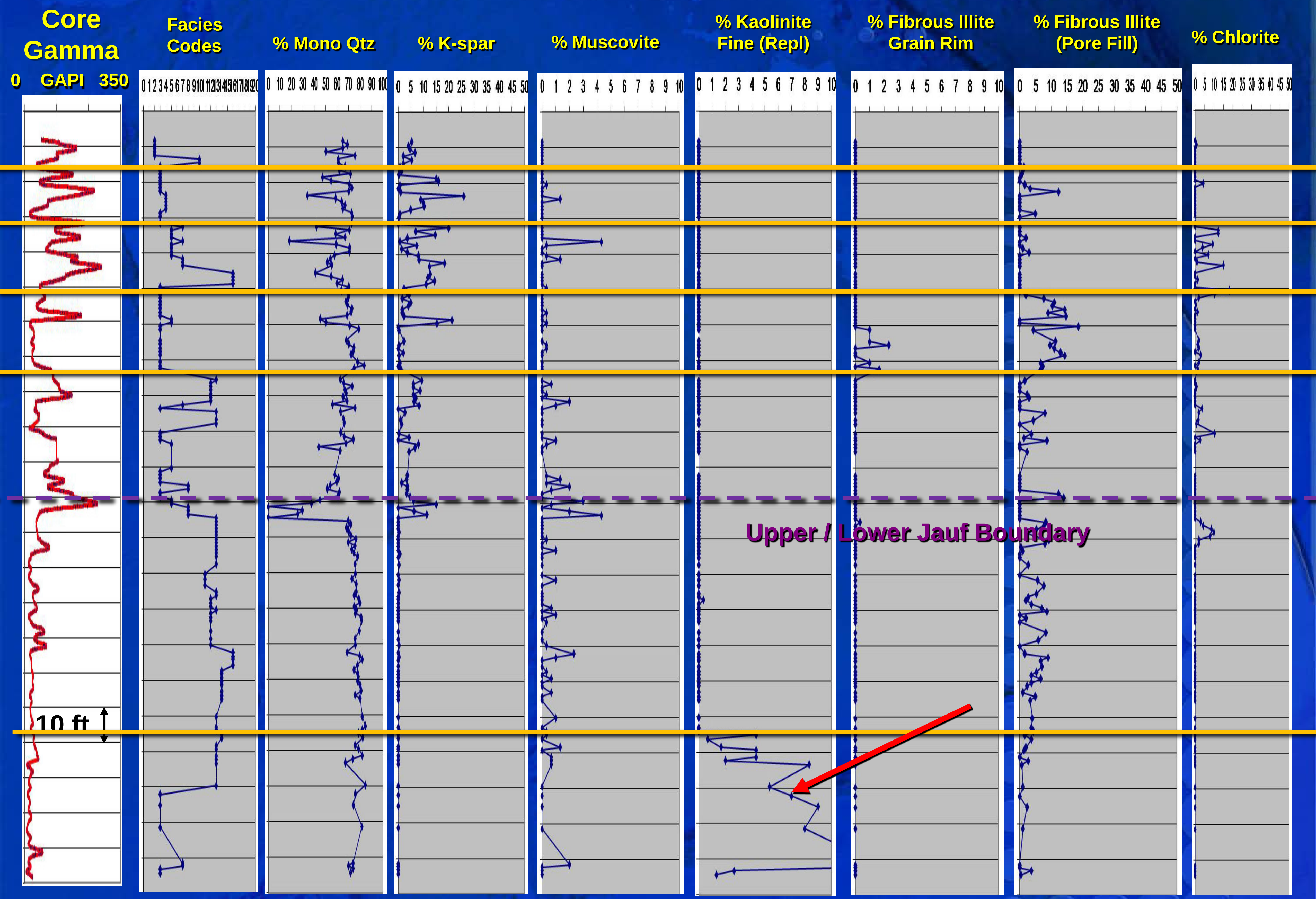




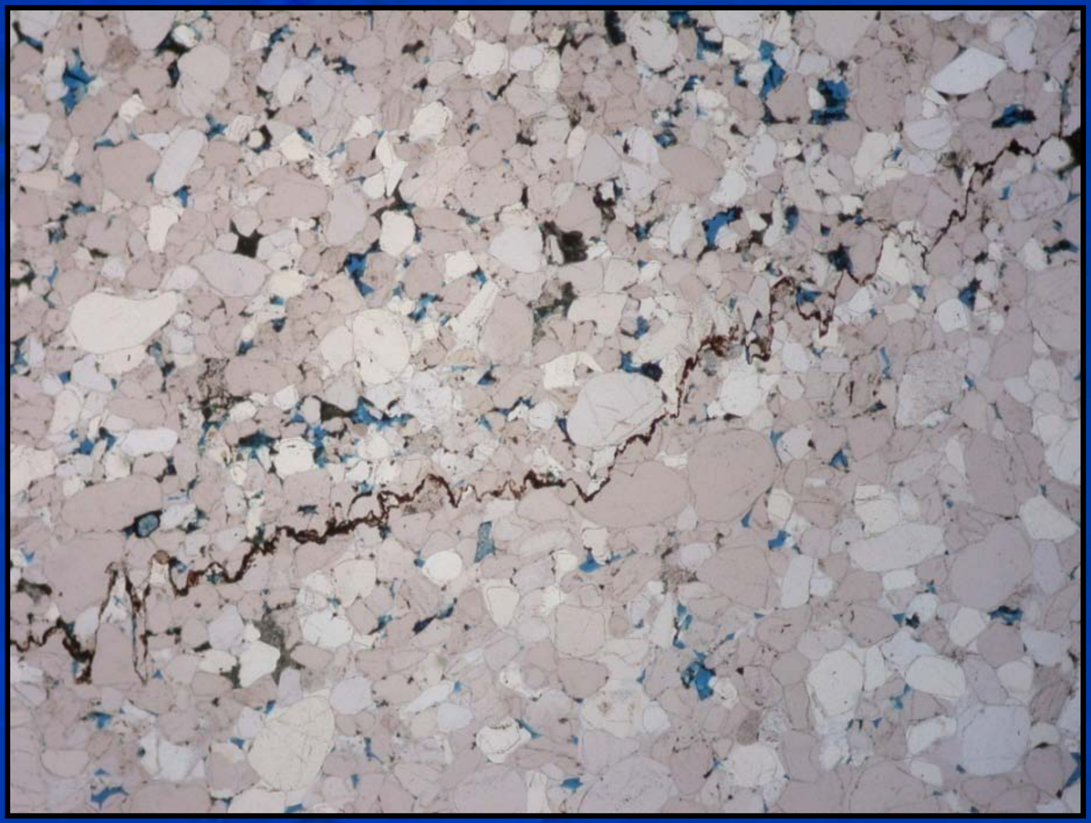


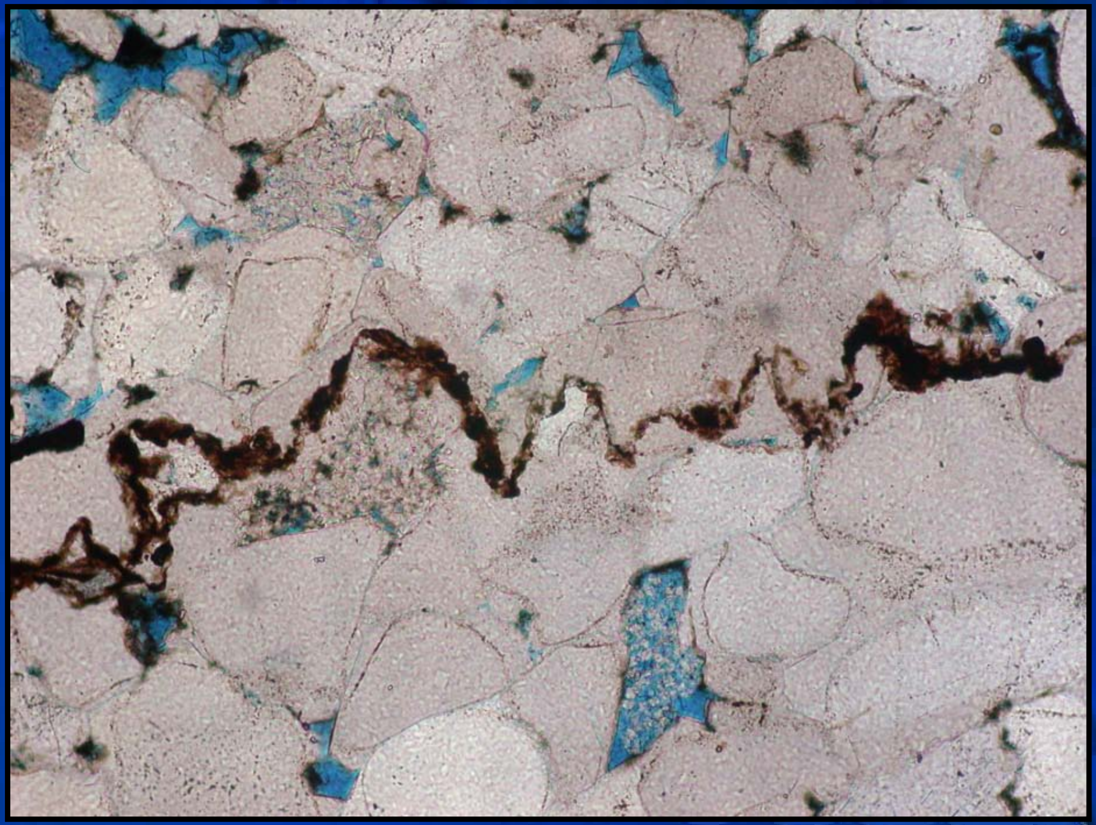


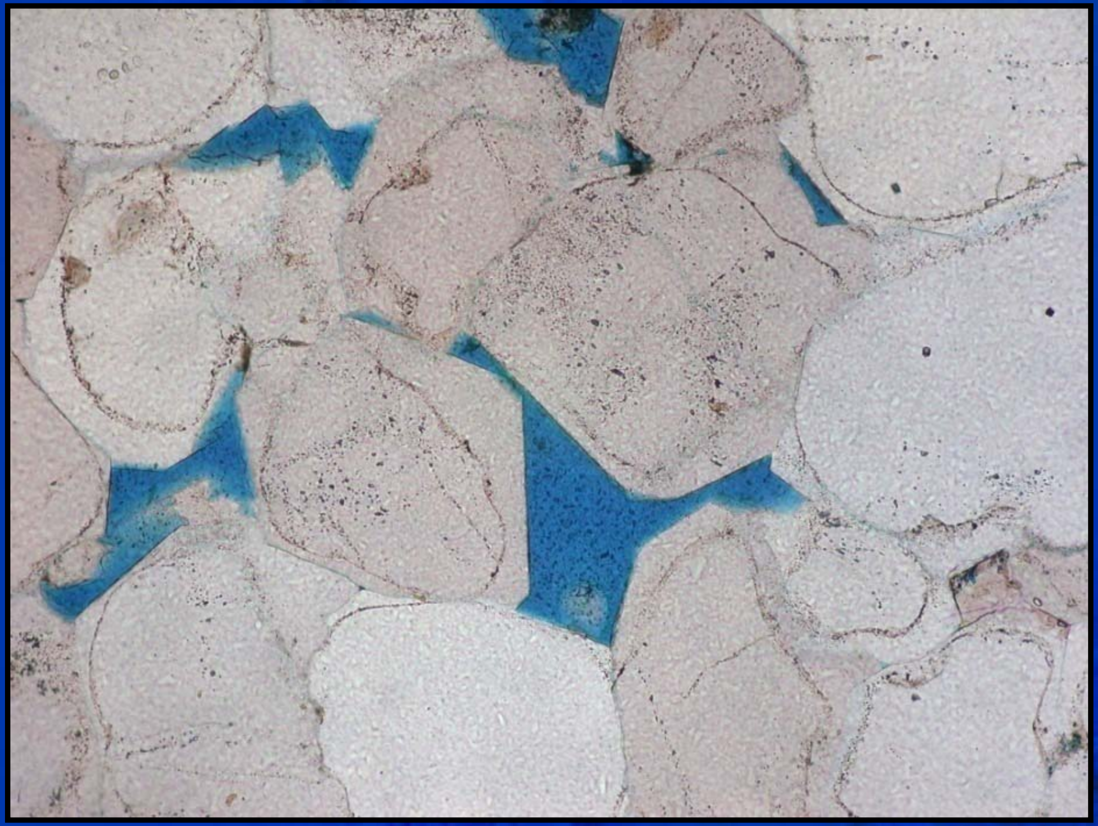
Well B Representative Petrographic Point Count Data

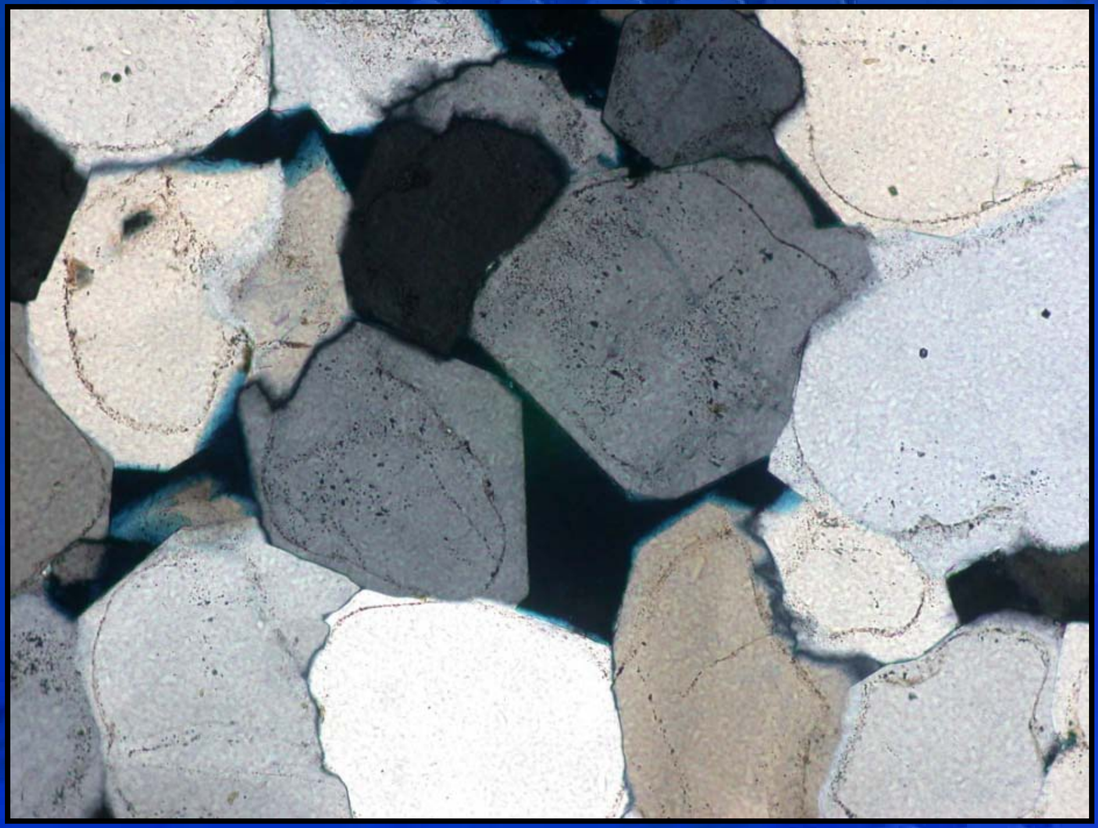


Well B Petrographic Thin Section Views

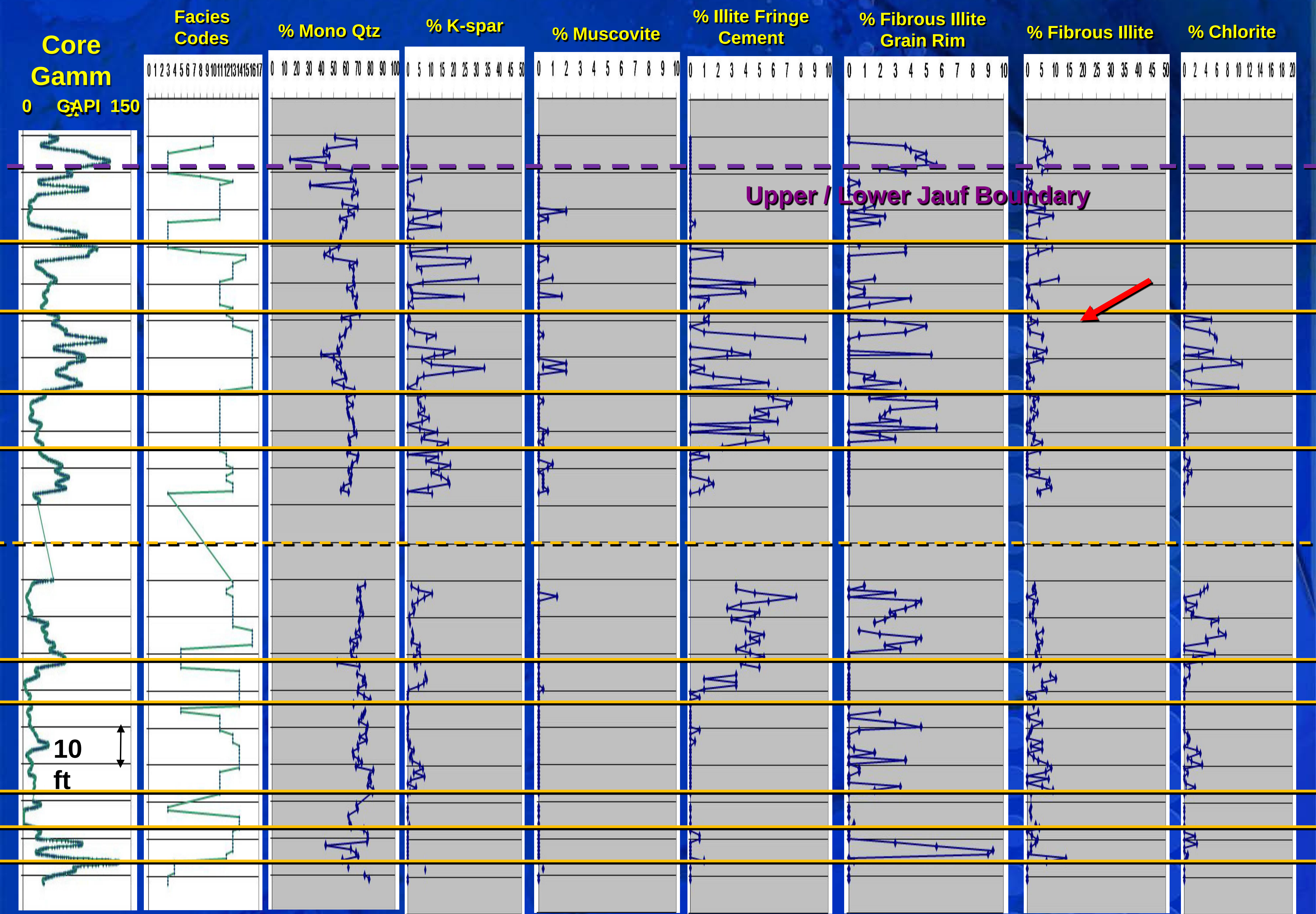




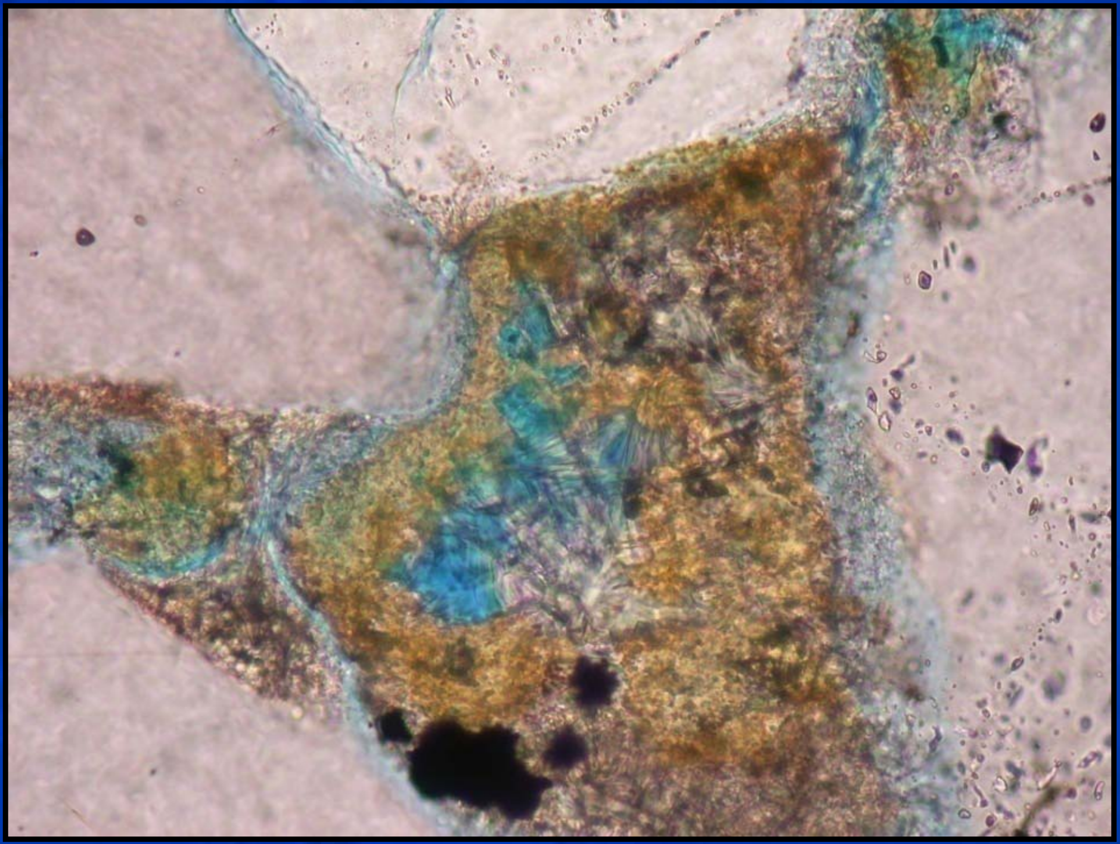


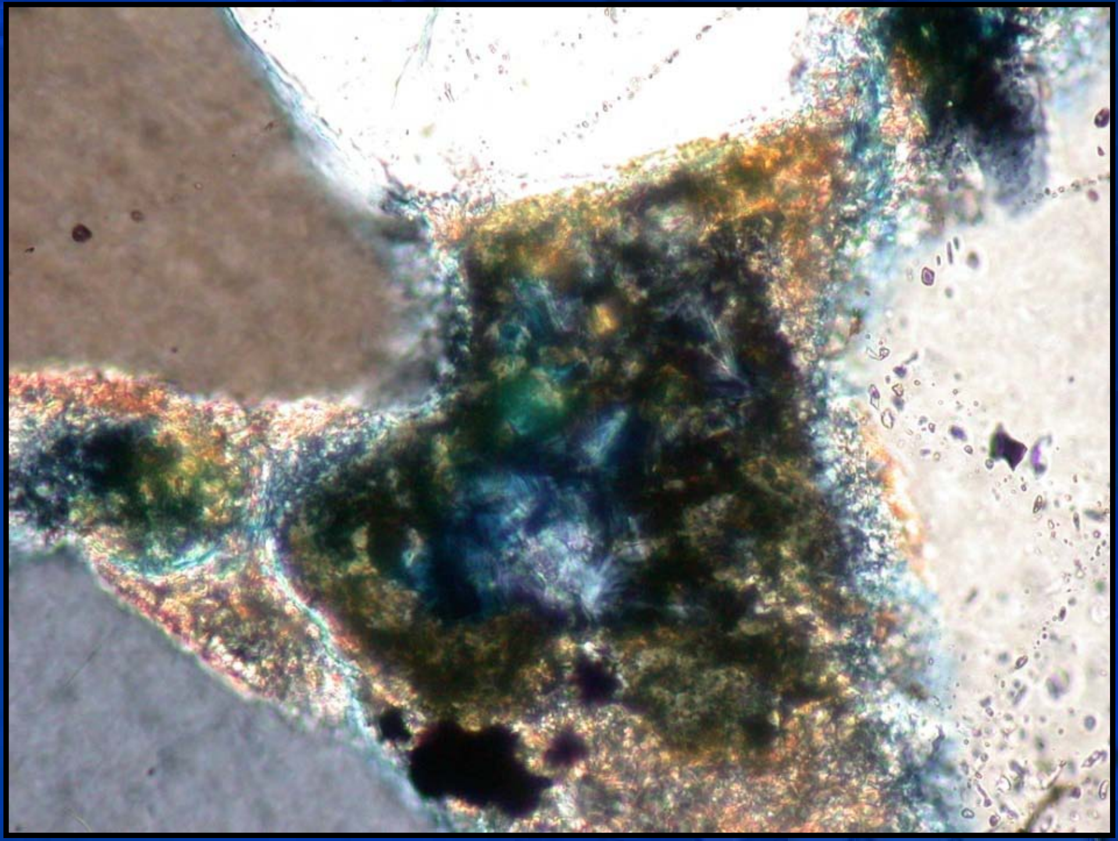


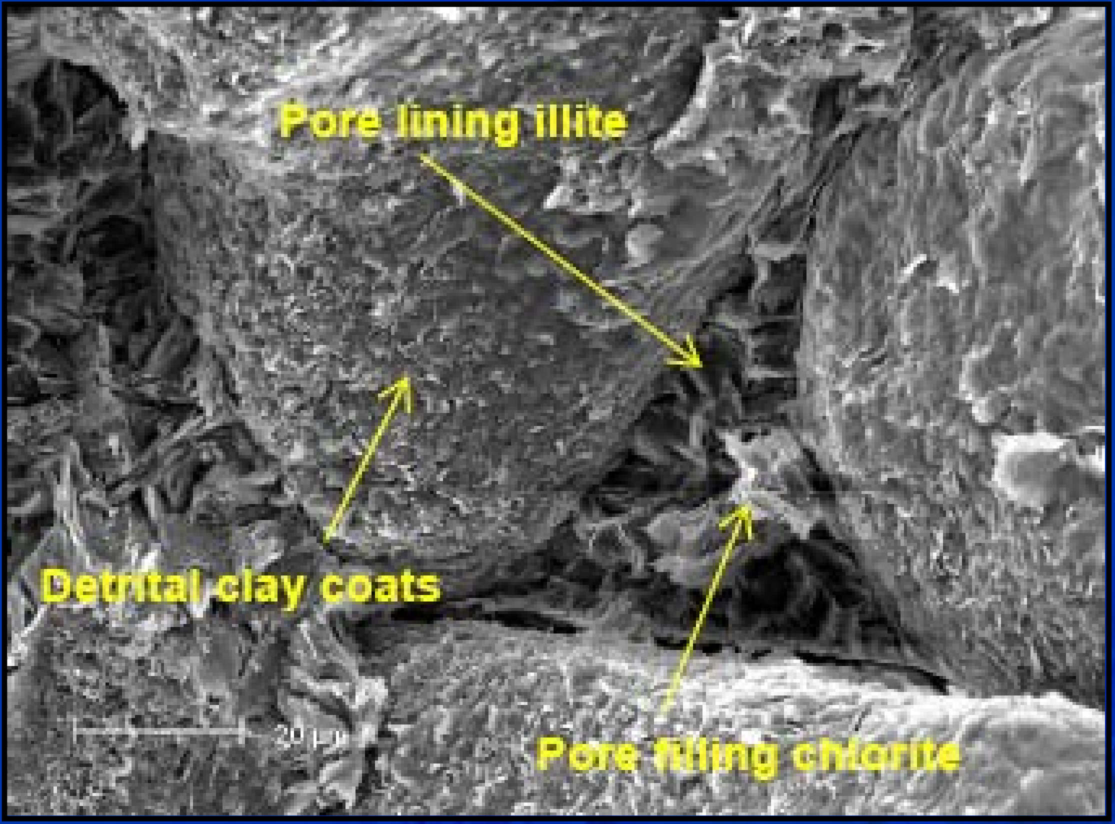
Well C Representative Petrographic Point Count Data

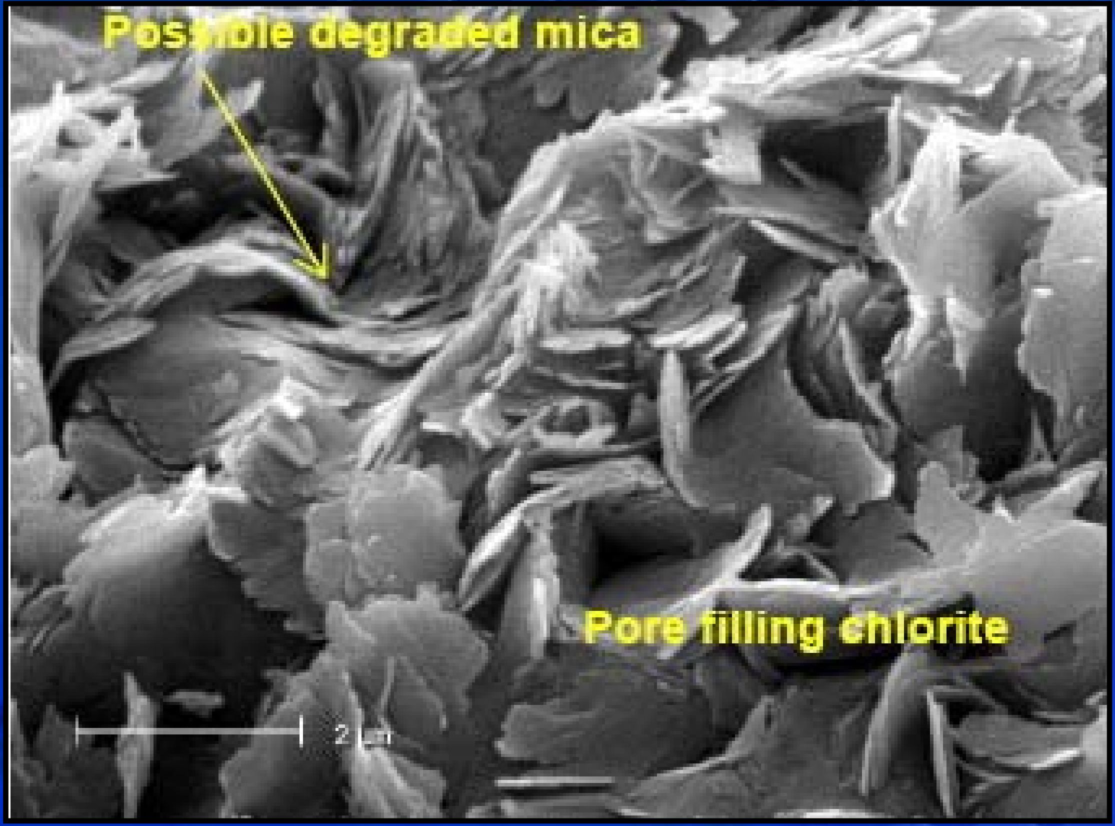


Well C Petrographic Thin Section / SEM Views

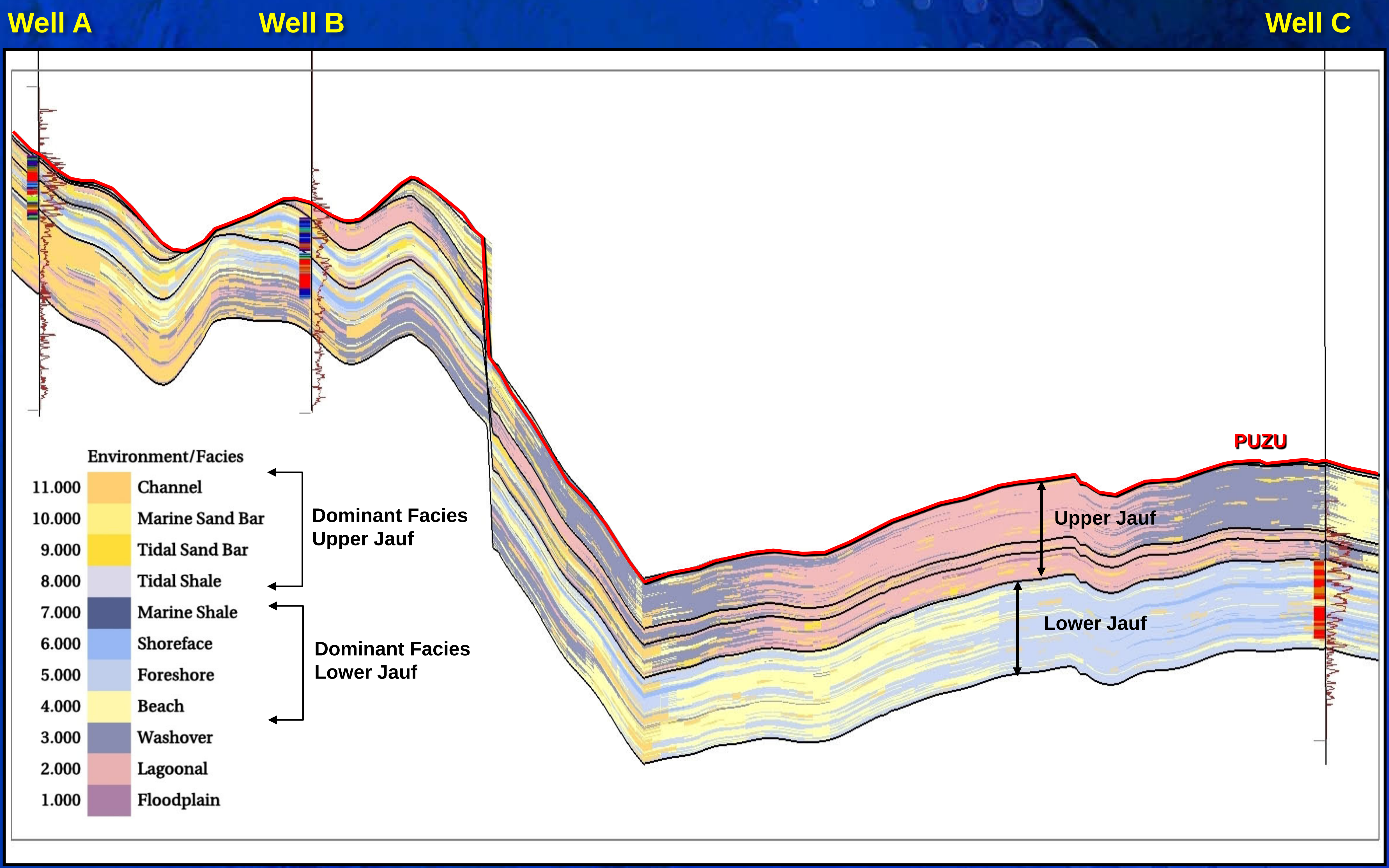




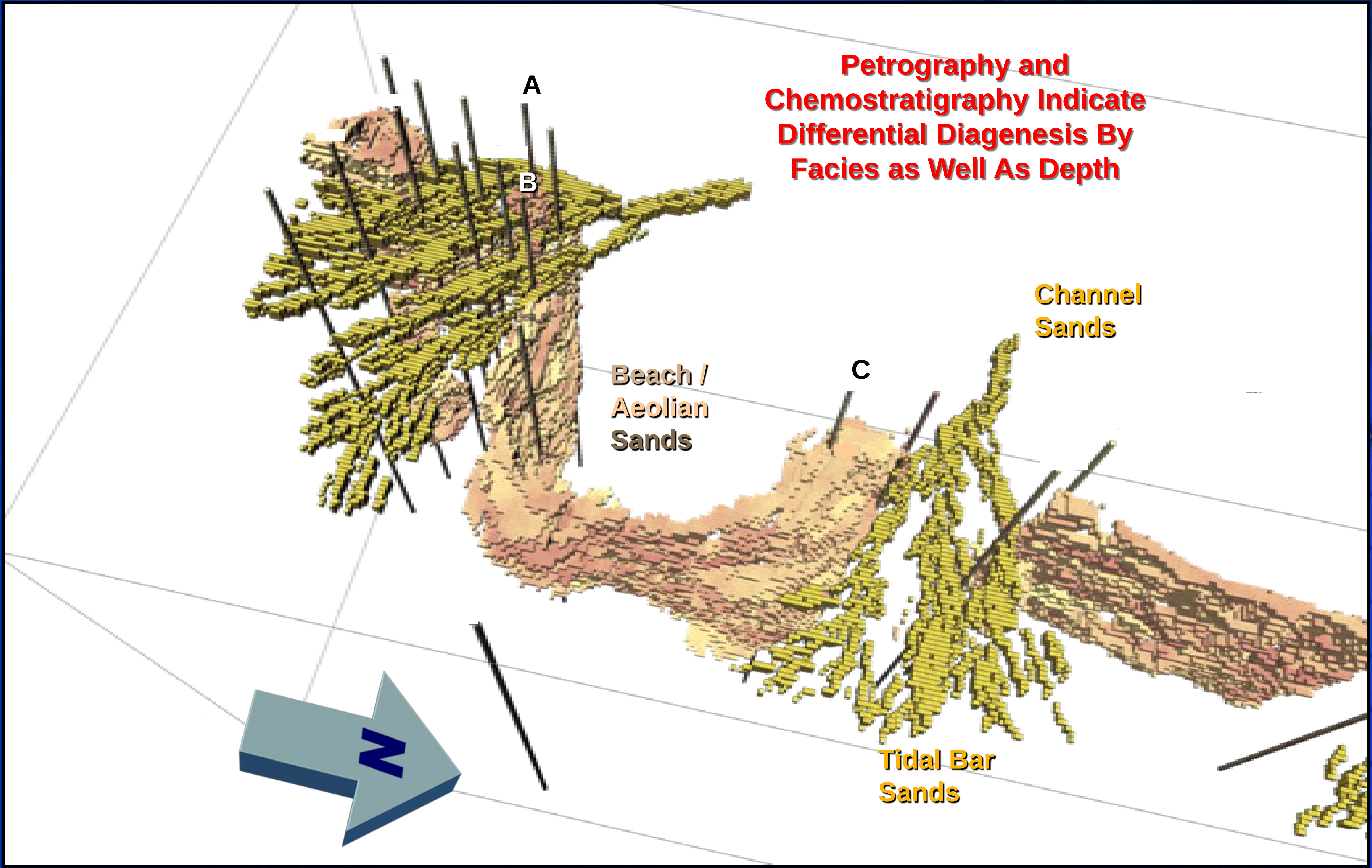




Depositional Facies Controls on Petrography



Beach / Aeolian and Tidal Bar / Channel Sands Distribution



Conclusions

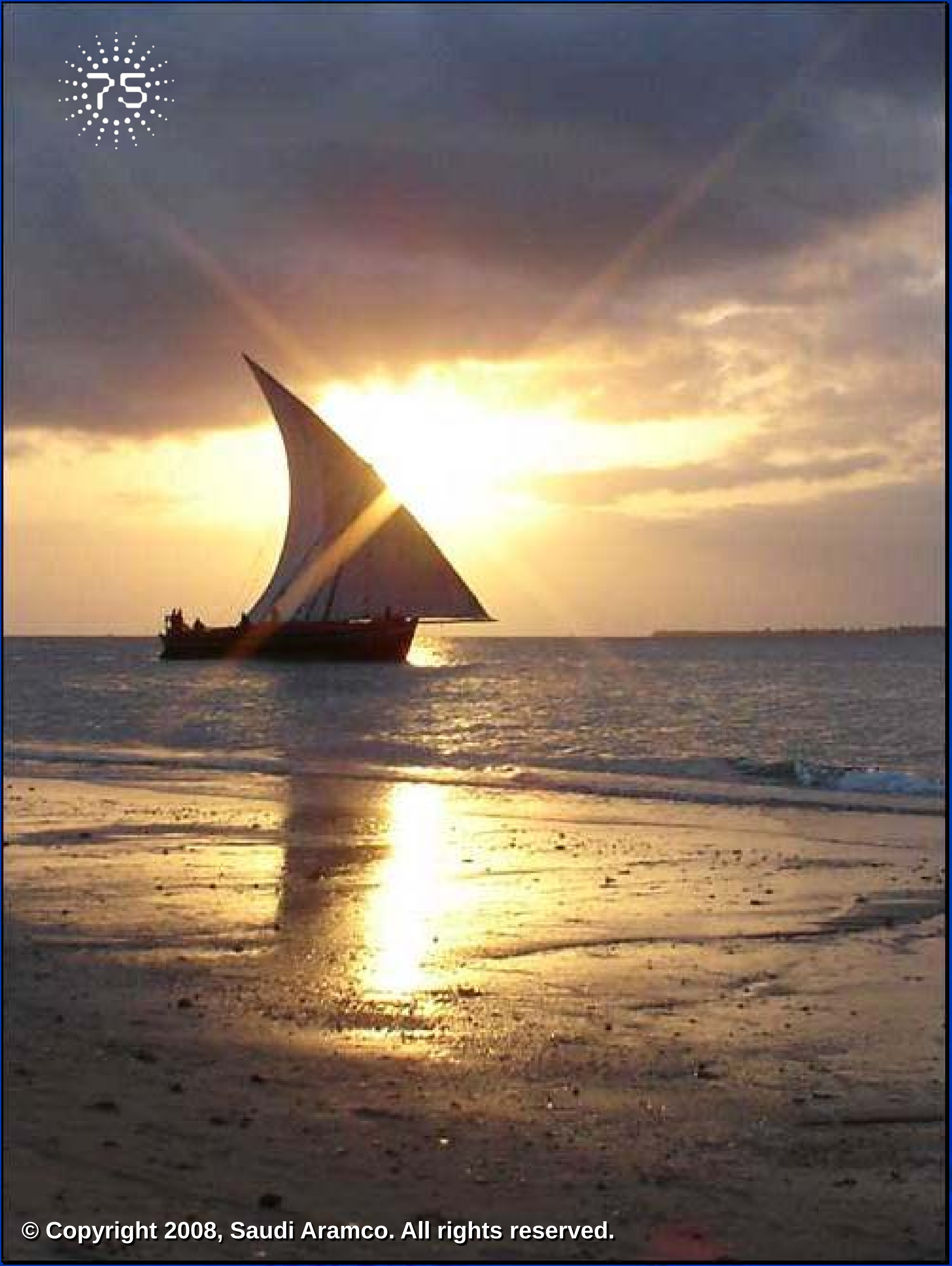
- Chemostratigraphic correlation was able to resolve sedimentary packages and units to *5 feet* vertical resolution in two wells 5 km apart

- Chemostratigraphic correlation heavily influenced the geocellular model layering scheme, and strongly supported a sequence stratigraphic correlation across the UTMN area

- Integration of chemostratigraphy and petrography proved facies-based differential diagenesis – directly related to *facies-specific* reservoir quality

Reference

Rahmani, R.A., R.J. Steel, and A.A. Duaiji, 2003, Concepts and methods of high-resolution sequence stratigraphy; applications to the Jauf gas reservoir, Greater Ghawar, Saudi Arabia: GeoFrontier, I, p. 15-21.



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Thank You!