# Effects of Steam-Induced Diagenesis on Heavy-Oil Production in Miocene-Pleistocene Sands from Kern River Oil Field, California*

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## Abstract

Kern River oil field in Kern County, California was discovered in 1899. Although over two-billion barrels of oil have been produced from this field, substantial reserves remain. The reservoir consists of braided alluvial sands and gravels of the Kern River Formation (Miocene-Pleistocene). Currently heavy oil (12° - 13° API) is produced using steam injection. Steam injection typically results in good production from well sorted medium to very coarse sands, but less well sorted sands and gravels are commonly bypassed and remain unproduced, with residual oil saturations 10-30 saturation units higher than the adjacent rock despite heating to temperatures of 220° F and greater. This study examined mineralogy and pore geometry in sands that had not been heated, sands that had been heated but were not drained, and sands that had been swept of hydrocarbons by steam. The sands of the Kern River Formation are composed predominantly of quartz, K-feldspars (orthoclase and microcline), plagioclase (andesine-oligoclase), microphanerites of granitic composition, and minor biotite (1-3%), reflecting their source from granites in the southern Sierra Nevada. Clays of detrital and authigenic origin typically make up 5-13% of the rocks. The clays are dominated by mixed illite/smectite with 80-90% smectite layers; there is also minor kaolinite. Samples that have been heated but not drained of oil are generally similar to unheated samples. Introduction of steam into the rocks as the sands were drained of oil resulted in the breaking apart of microphanerites, dissolution of feldspars, and a slight increase in the amount of clays; notably there is no significant change in total porosity. Texturally there are significant differences in the distribution of clays and the geometry of the pore networks between unsteamed sands and those that have been swept of hydrocarbons. The disintegration of microphanerites and subsequent rotation of the grain fragments has changed the sorting and reduced pore-throat diameters. Recrystallization and precipitation of mixed illite/smectite has resulted in an increase in the amount of pore-filling clay cements, including as bridges across pore throats that may have restricted fluid flow. The extent to which this may have affected subsequent production is under investigation.

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## References

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Dott, R.H., 1964, Wacke, graywacke, and matrix — what approach to immature sandstone classification?: Journal of Sedimentary Petrology, v. 34, p. 625-632.

Kodl, E.J., 1988, Texaco, unpublished in-house report.

# EFFECTS OF STEAM-INDUCED DIAGENESIS ON HEAVY-OIL PRODUCTION IN MIOCENE-PLEISTOCENE SANDS AT KERN RIVER OIL FIELD, CALIFORNIA

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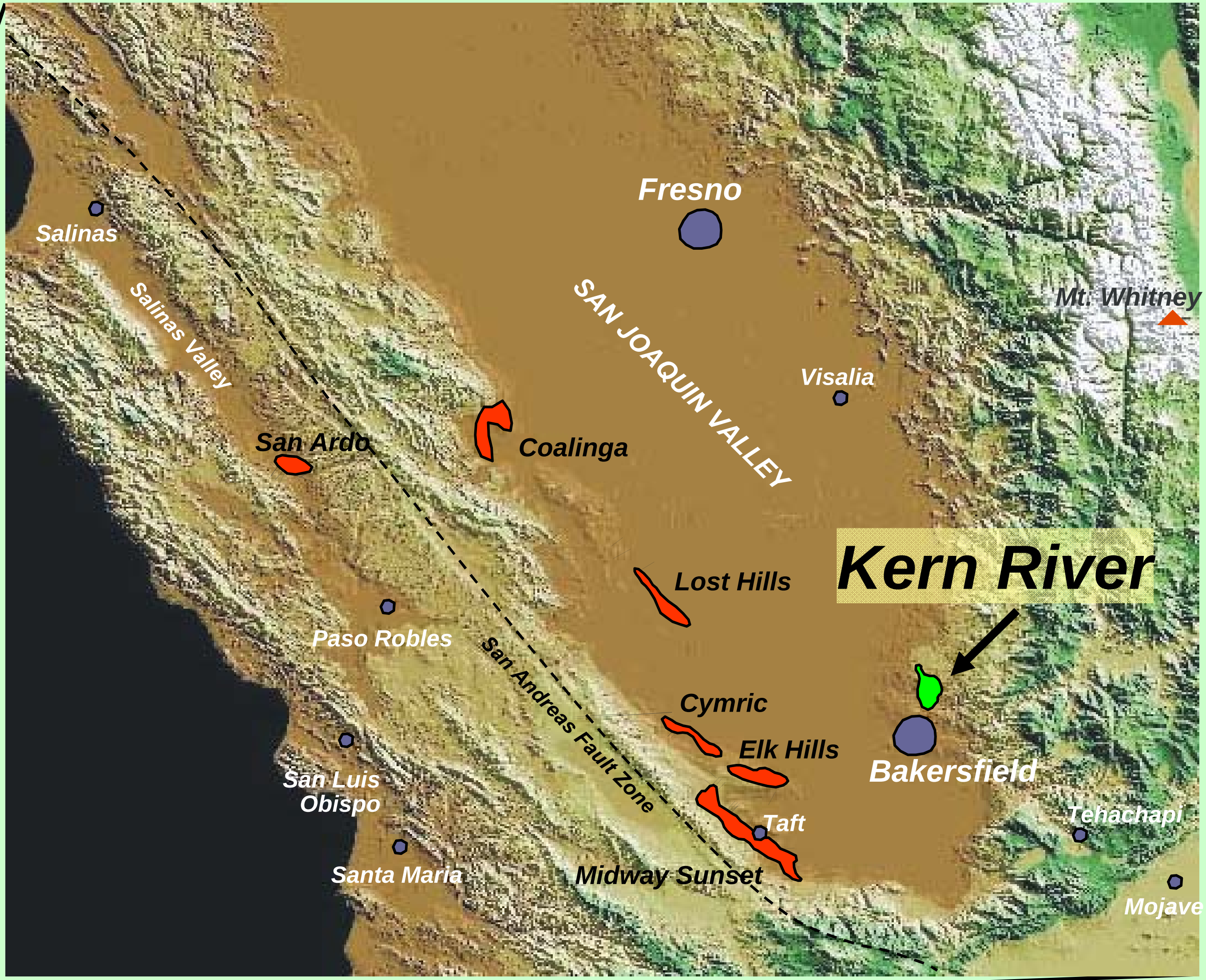
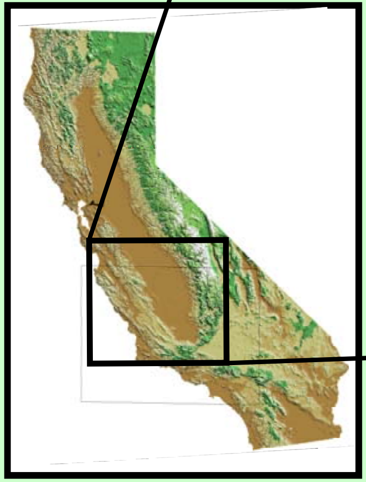
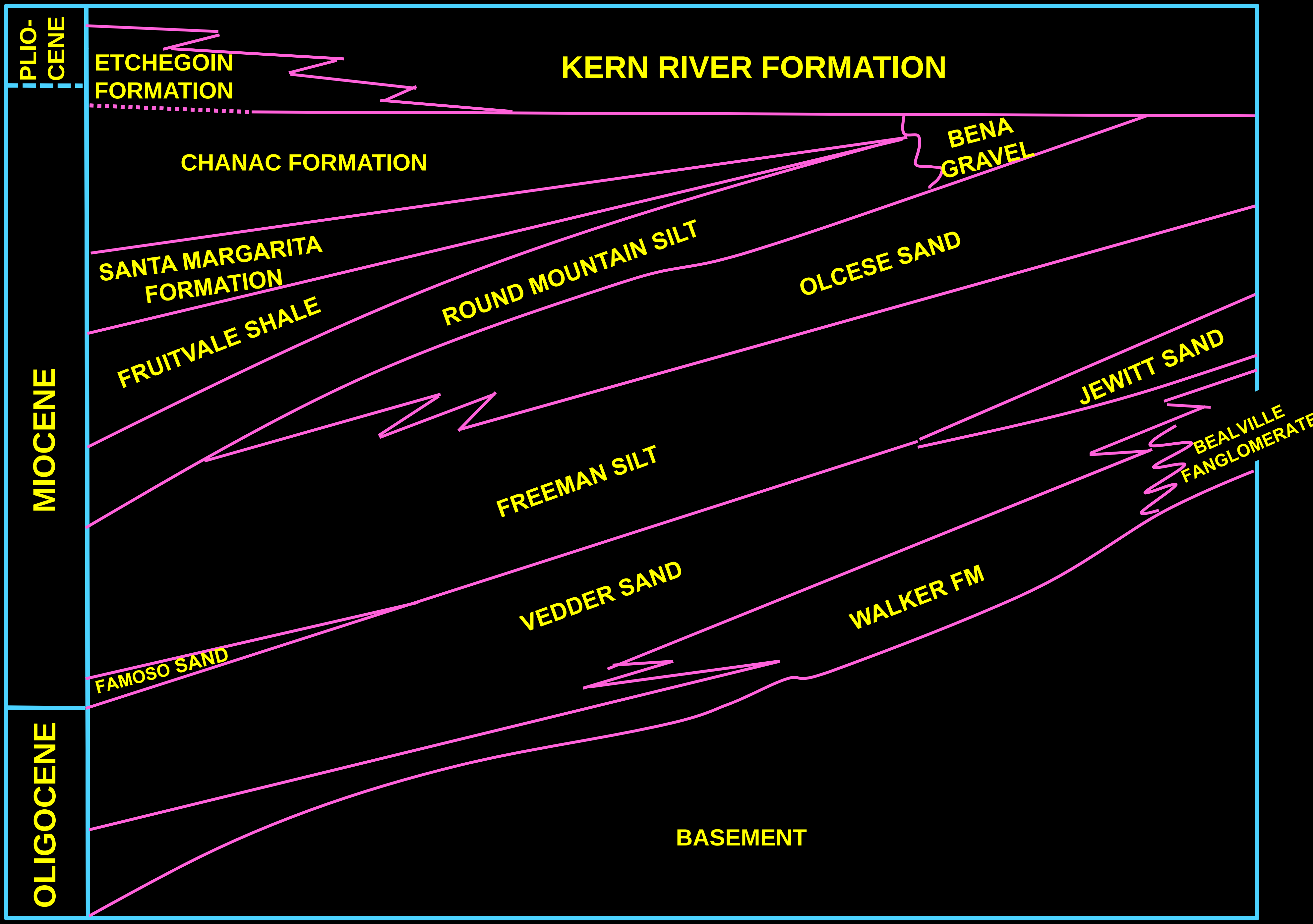
# Field Location



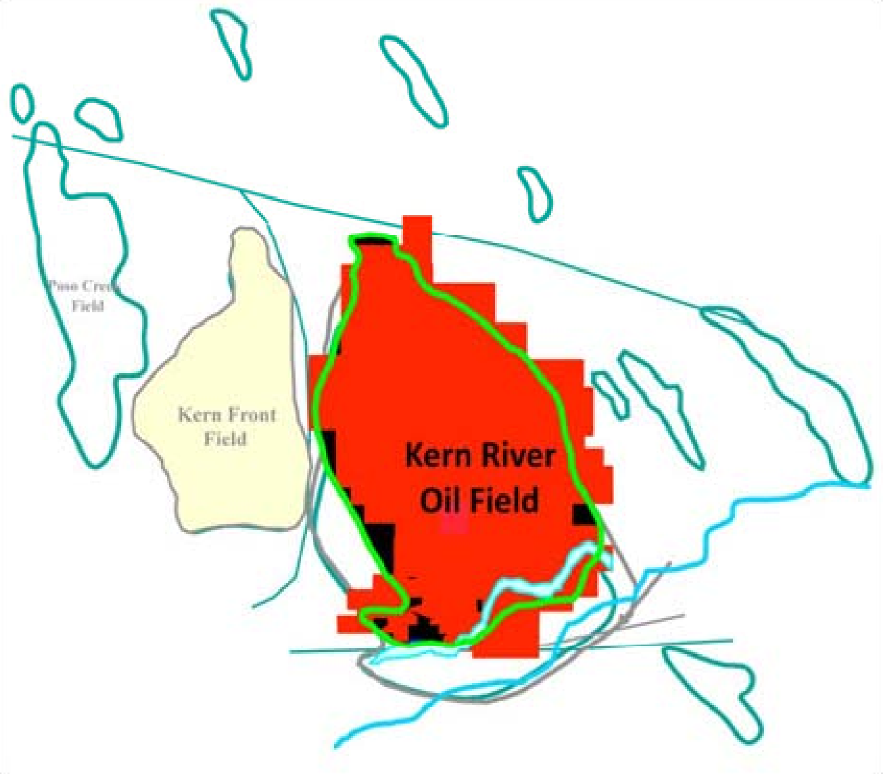



# EAST-SIDE SAN JOAQUIN BASIN STRATIGRAPHY



# Kern River Oil Field Geologic Framework: Structure

- Gentle dipping homocline (3.5 degree to the SW)



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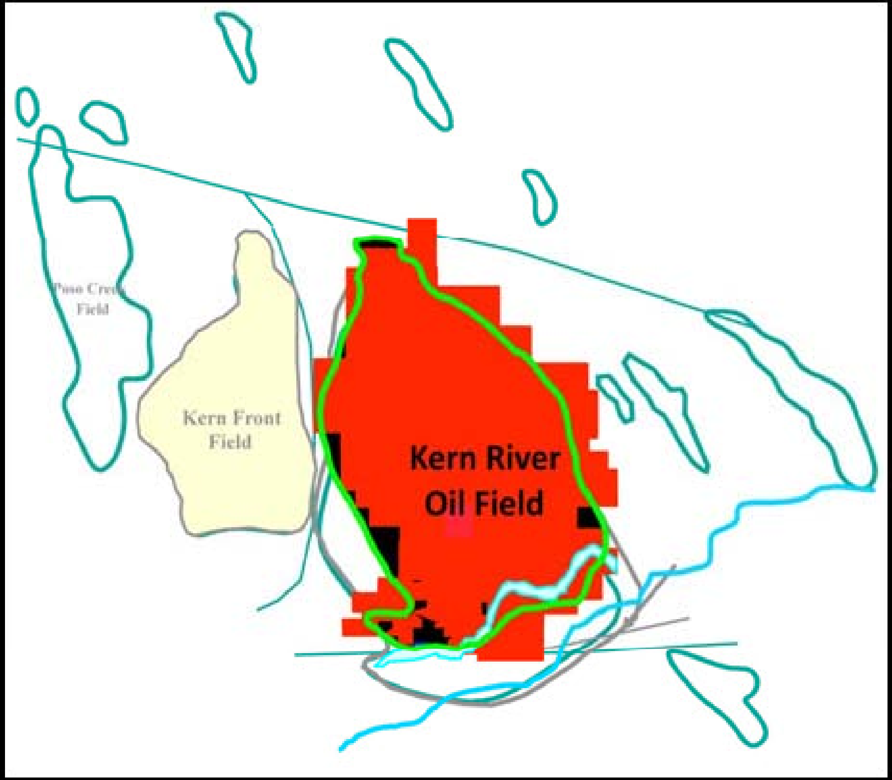
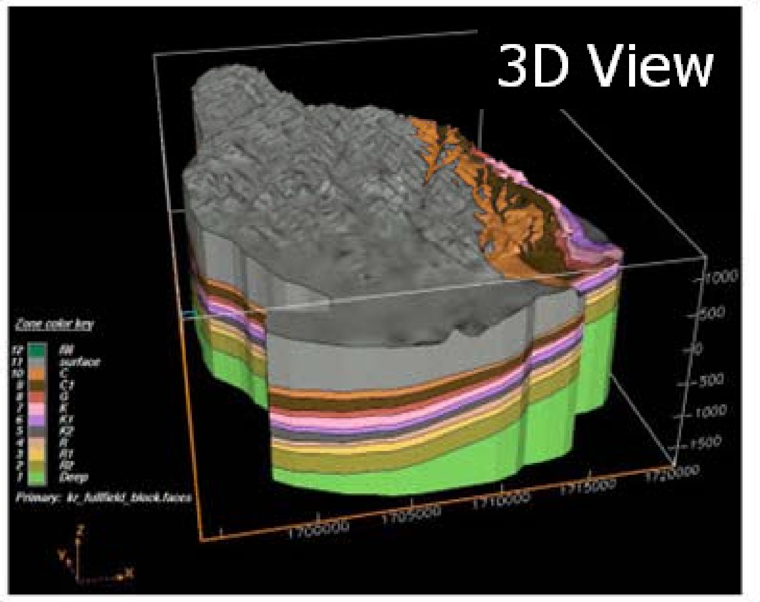
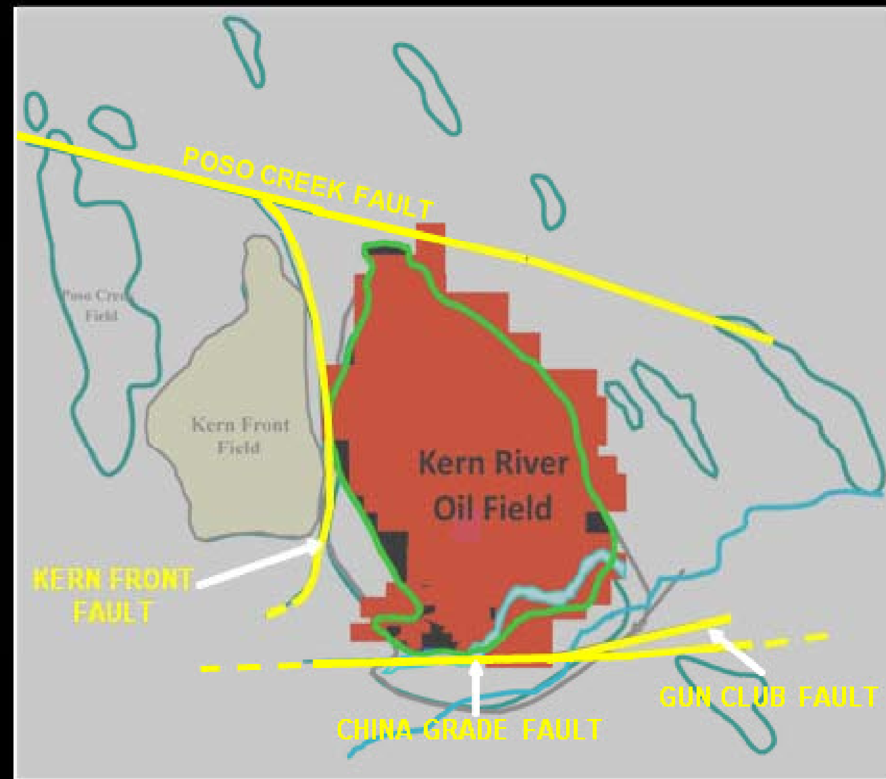
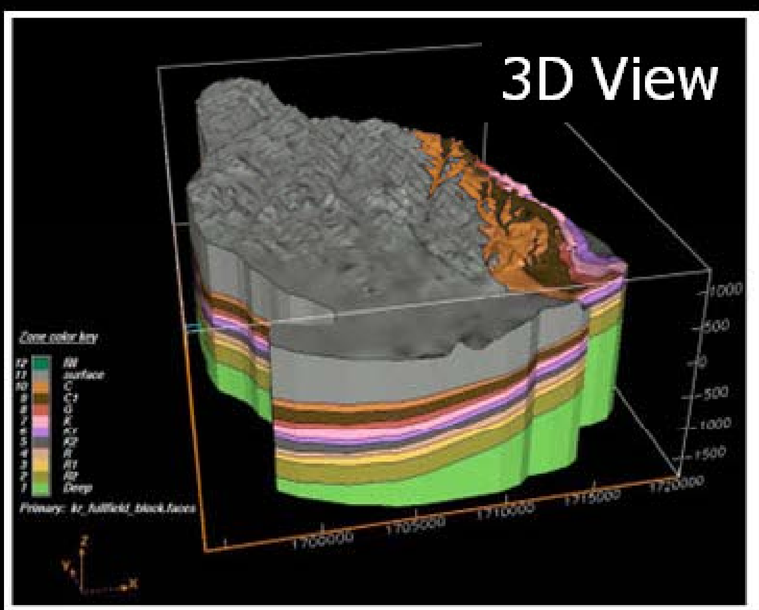


# Kern River Oil Field Geologic Framework: Structure

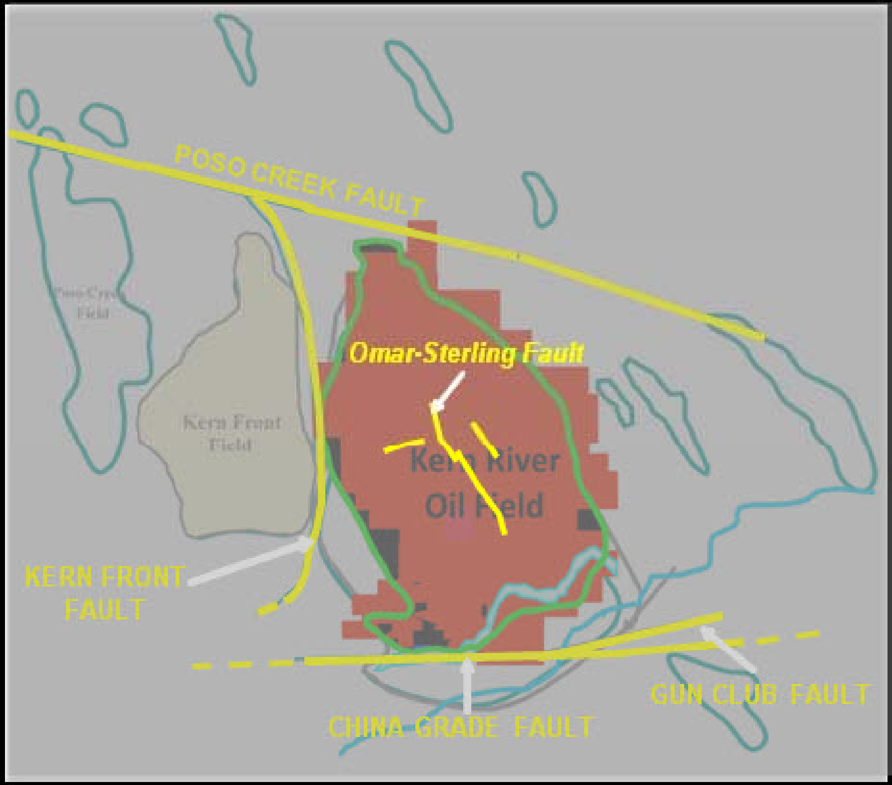
- Gentle dipping homocline (3.5 degree to the SW)
- Bounding faults: >100' offset

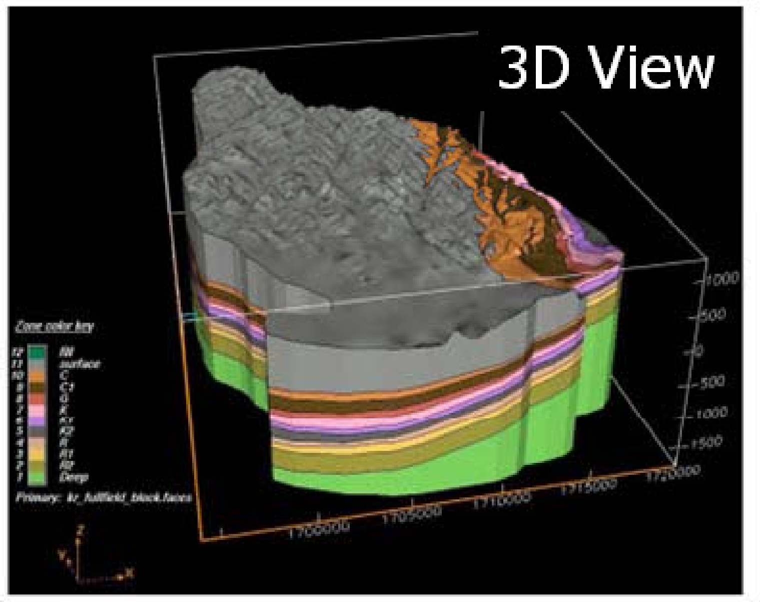


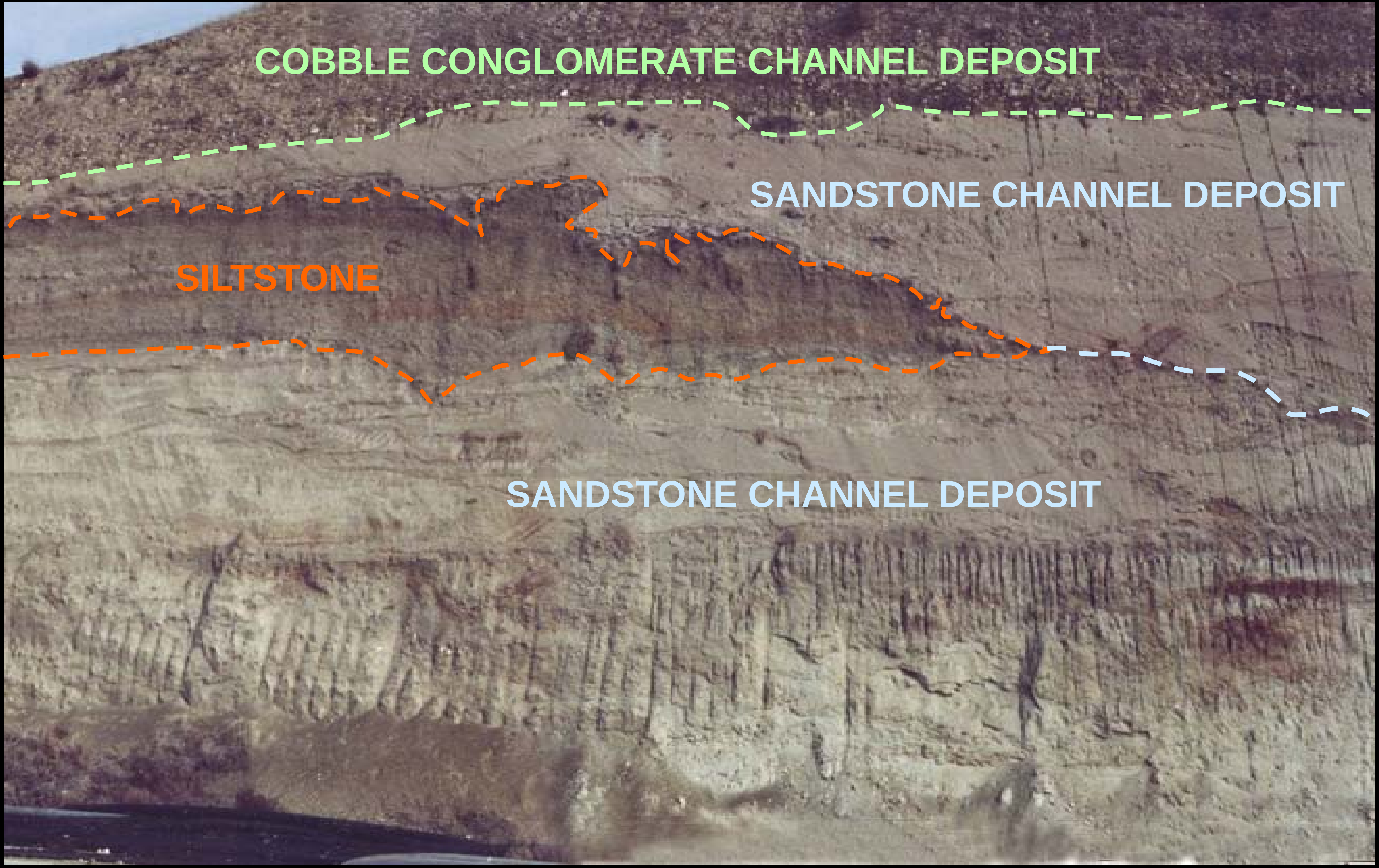
# Kern River Oil Field Geologic Framework: Structure

- Gentle dipping homocline (3.5 degree to the SW)
- Bounding faults: >100' offset
- Several internal faults: 20-50' offset

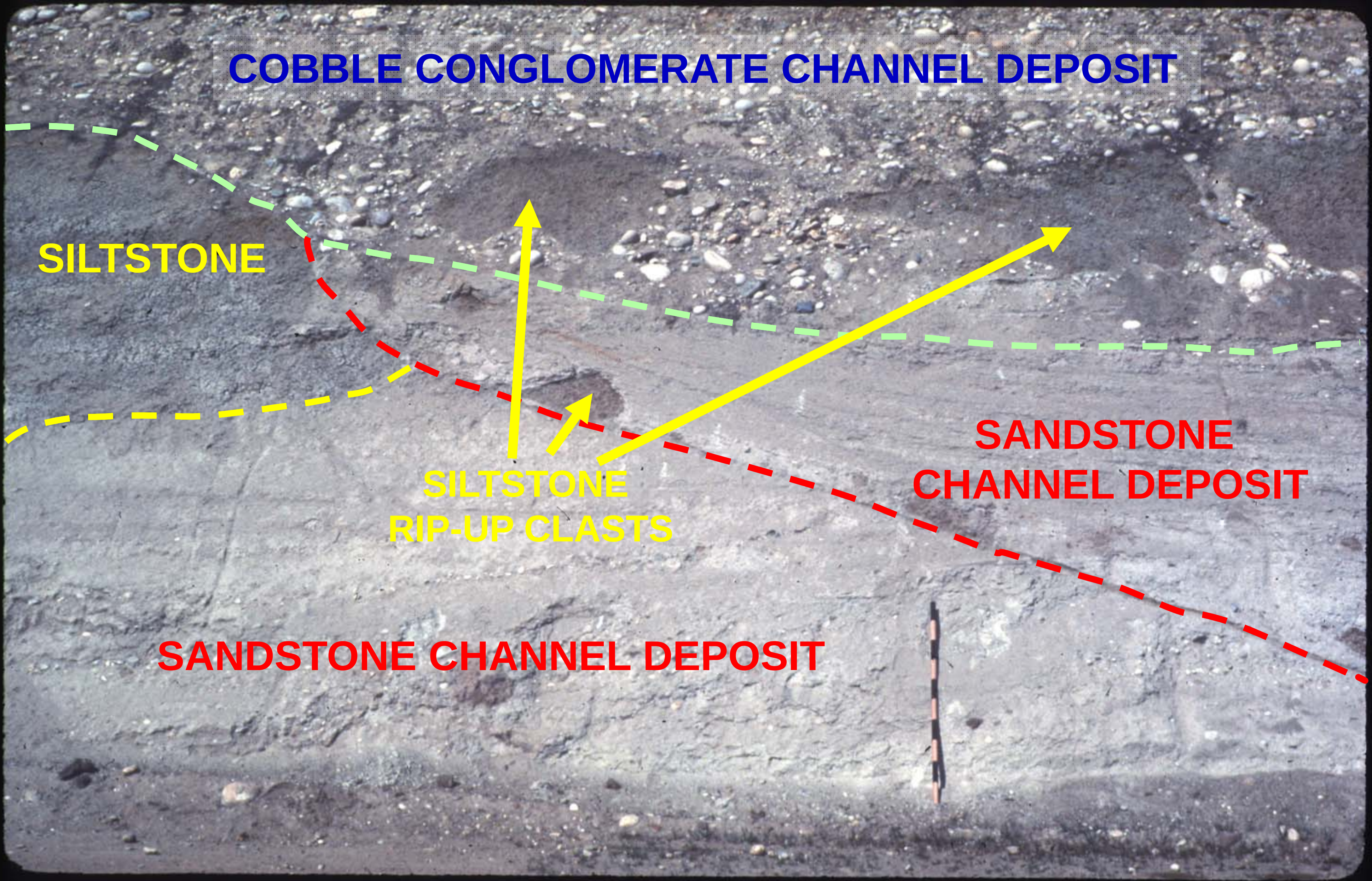


# DEPOSITIONAL SYSTEMS



# DEPOSITIONAL SYSTEMS

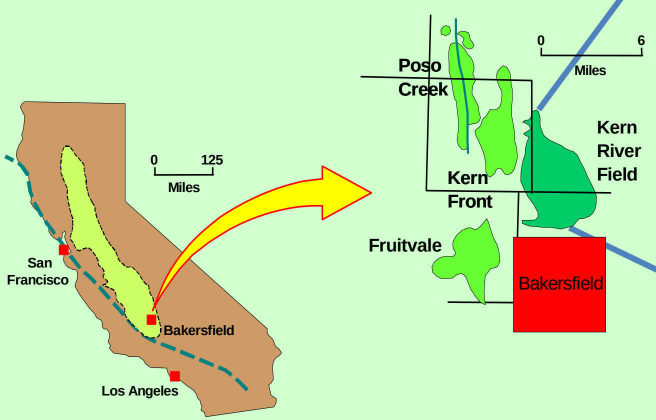


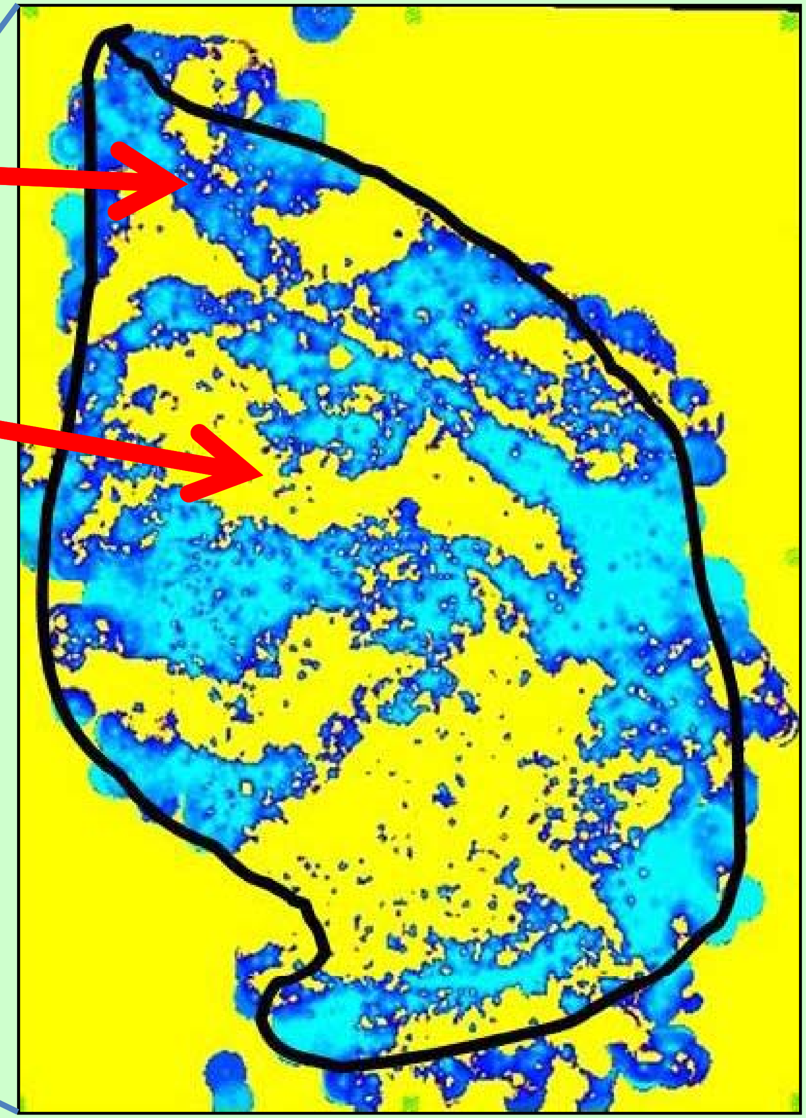
# DEPOSITIONAL SYSTEMS

**Fluvial Sand Channels and braided stream beds (blue)**

**Overbank Siltstone/shale (yellow)**

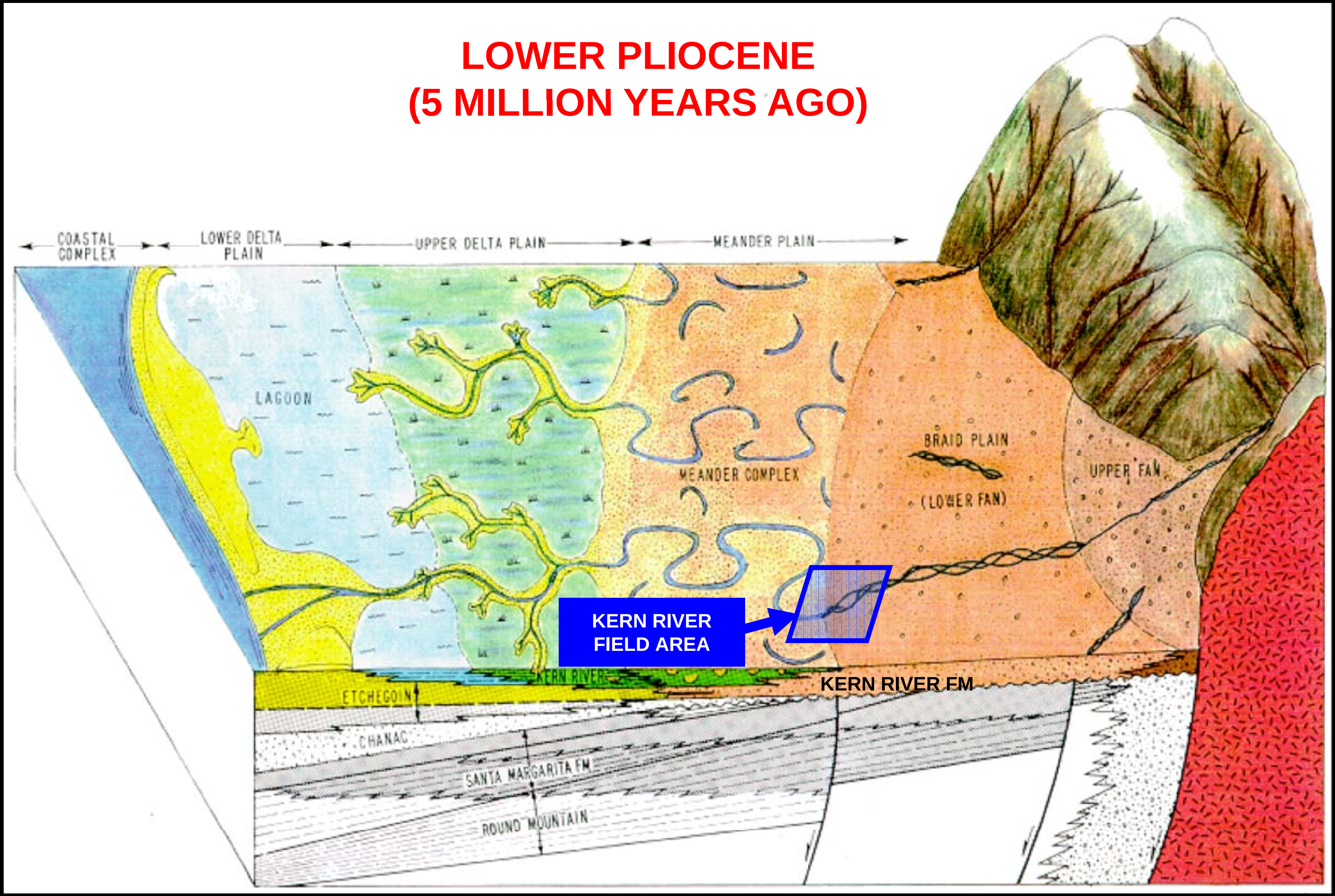
**KERN RIVER LOCATION**



**Horizontal slice through 3D resistivity data cube consisting of 9000+ log traces.**

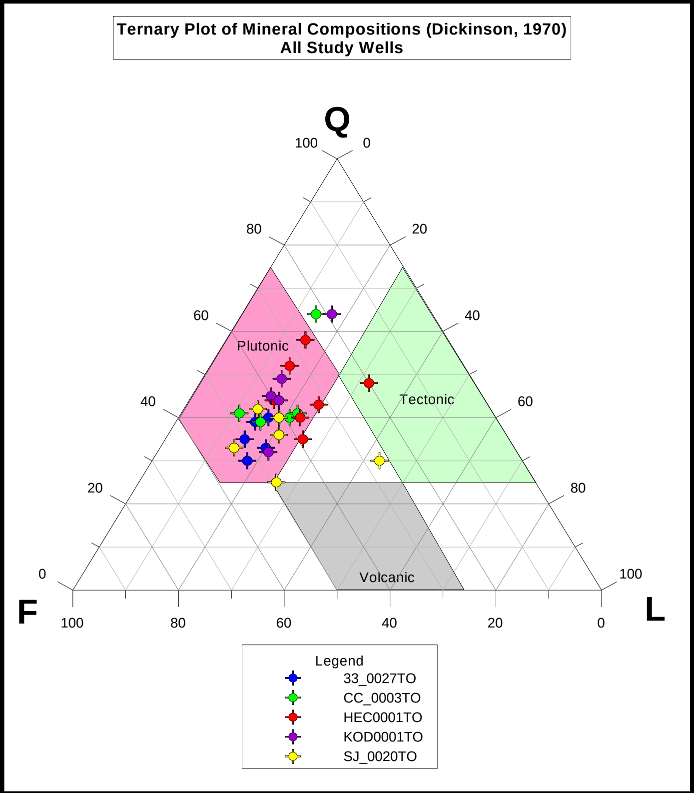
# Kern River Formation Depositional Environment

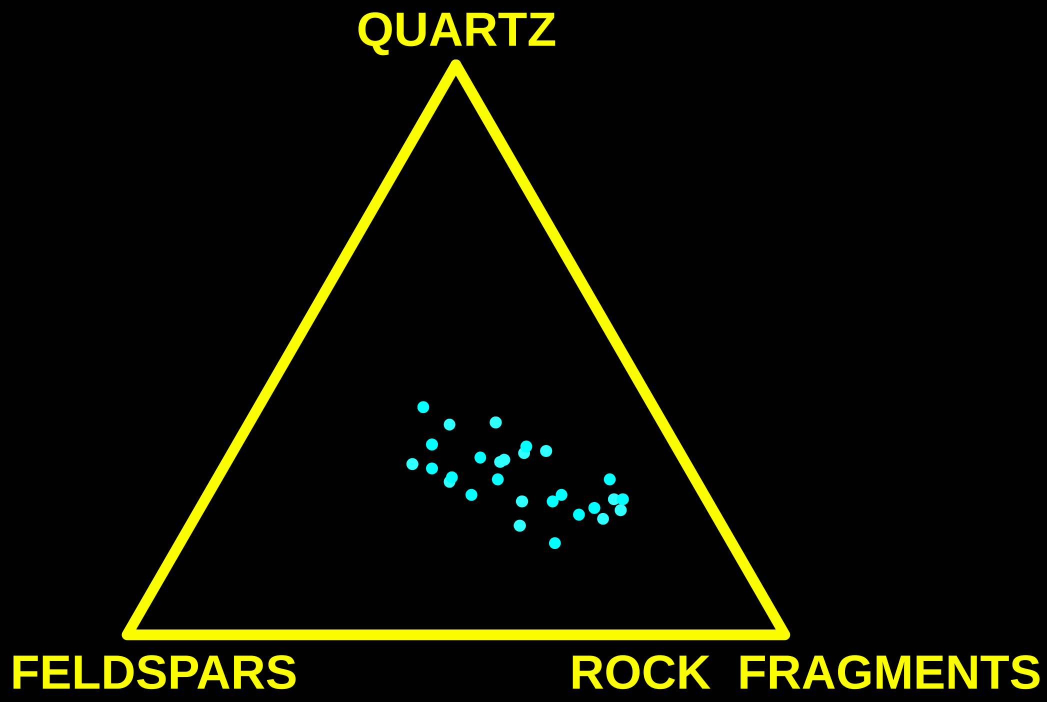



Modified from Kodl 1988

# SEDIMENT COMPOSITION

- SAND, SILT, and GRAVEL
- MOSTLY DERIVED from SIERRA NEVADA BATHOLITH with MINOR INPUT FROM OVERLYING METAMORPHIC ROCKS
- SOME REWORKING of OLDER SAN JOAQUIN BASIN SEDIMENT

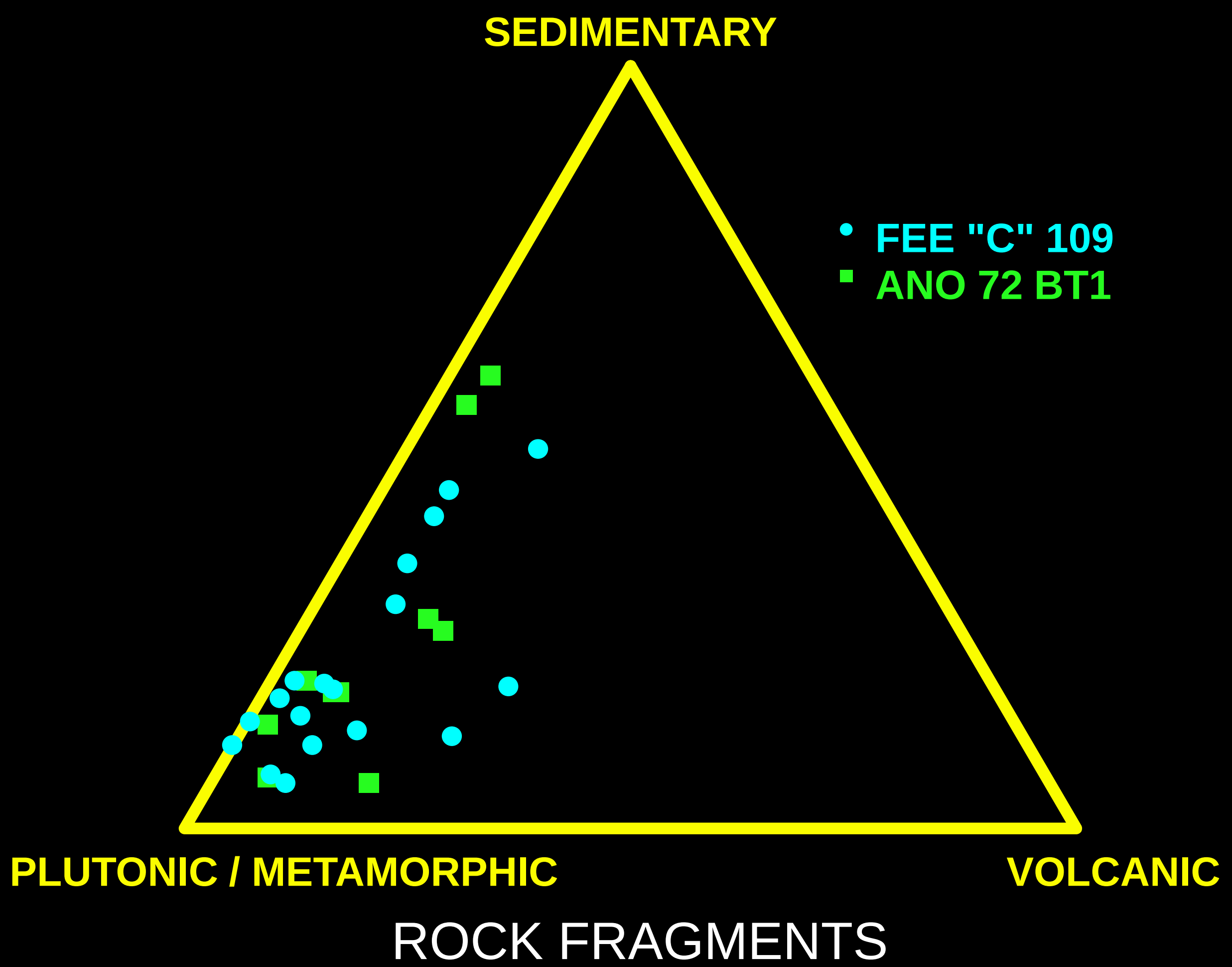



Dott, 1964, & Pettijohn et al., 1987

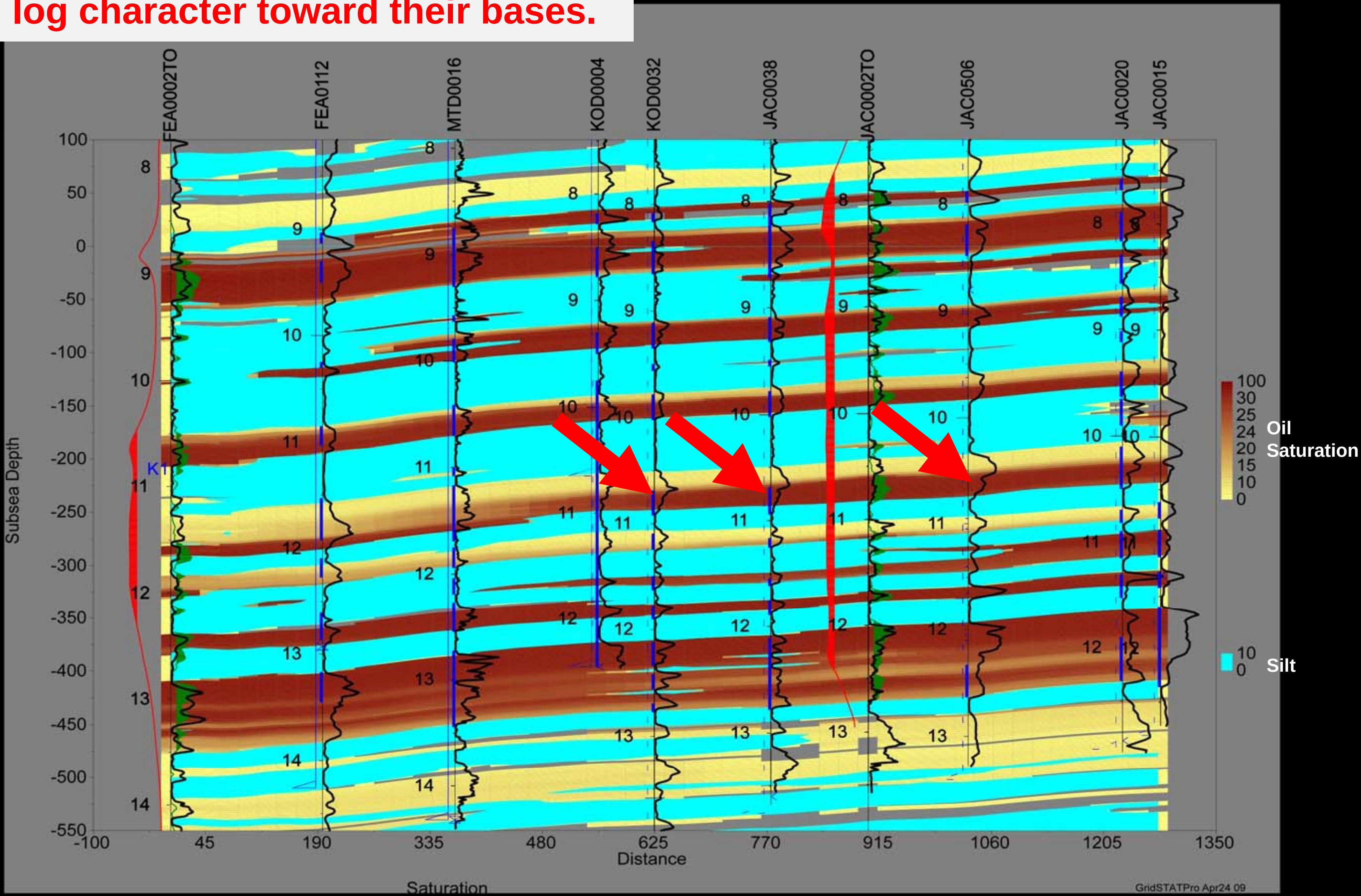
# SEDIMENT COMPOSITION

- SOME REWORKING of OLDER SAN JOAQUIN BASIN SEDIMENT

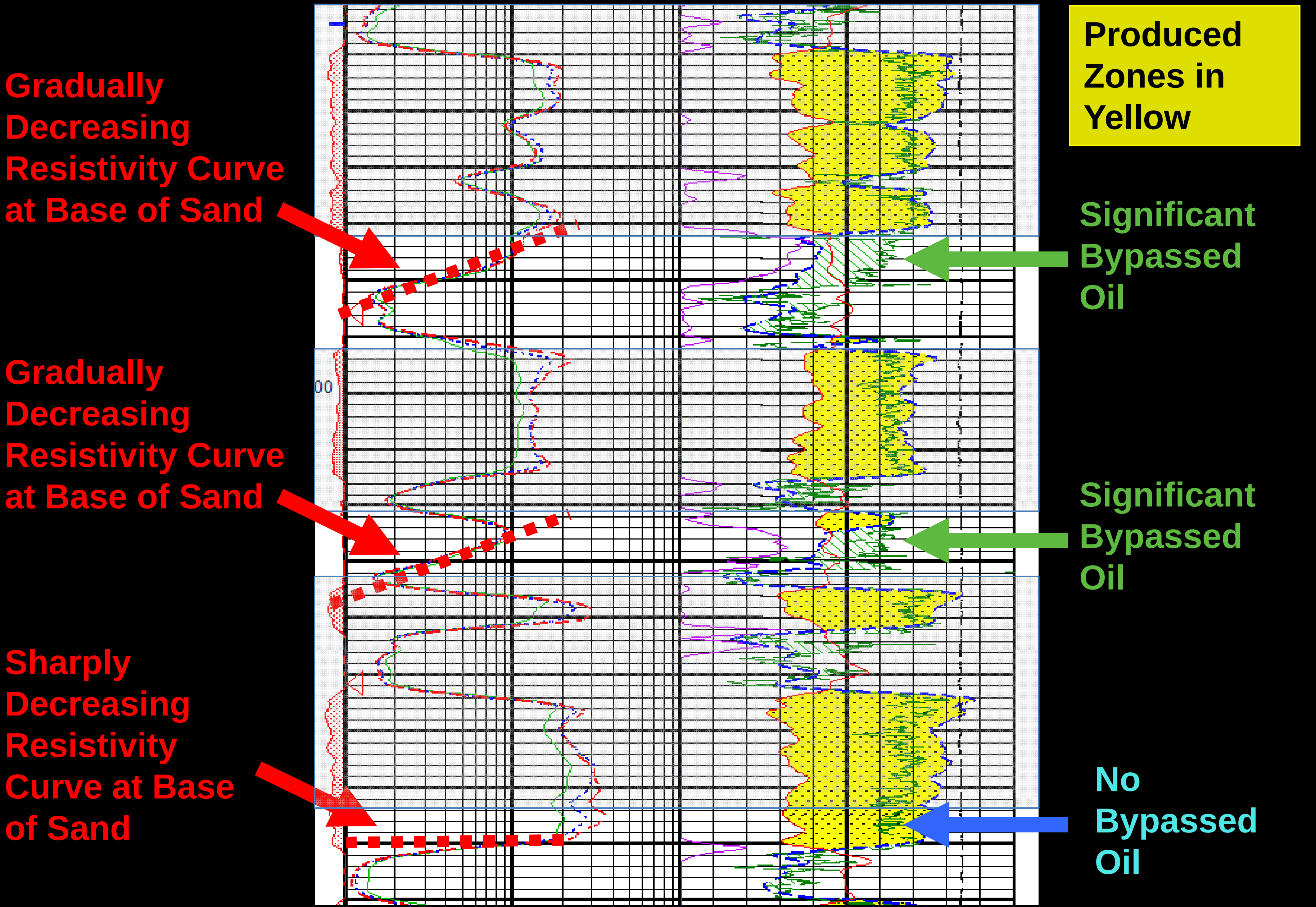


# BYPASSED OIL ZONES

**Much of the bypassed oil in this area is in sands that exhibit gradually decreasing resistivity log character toward their bases.**



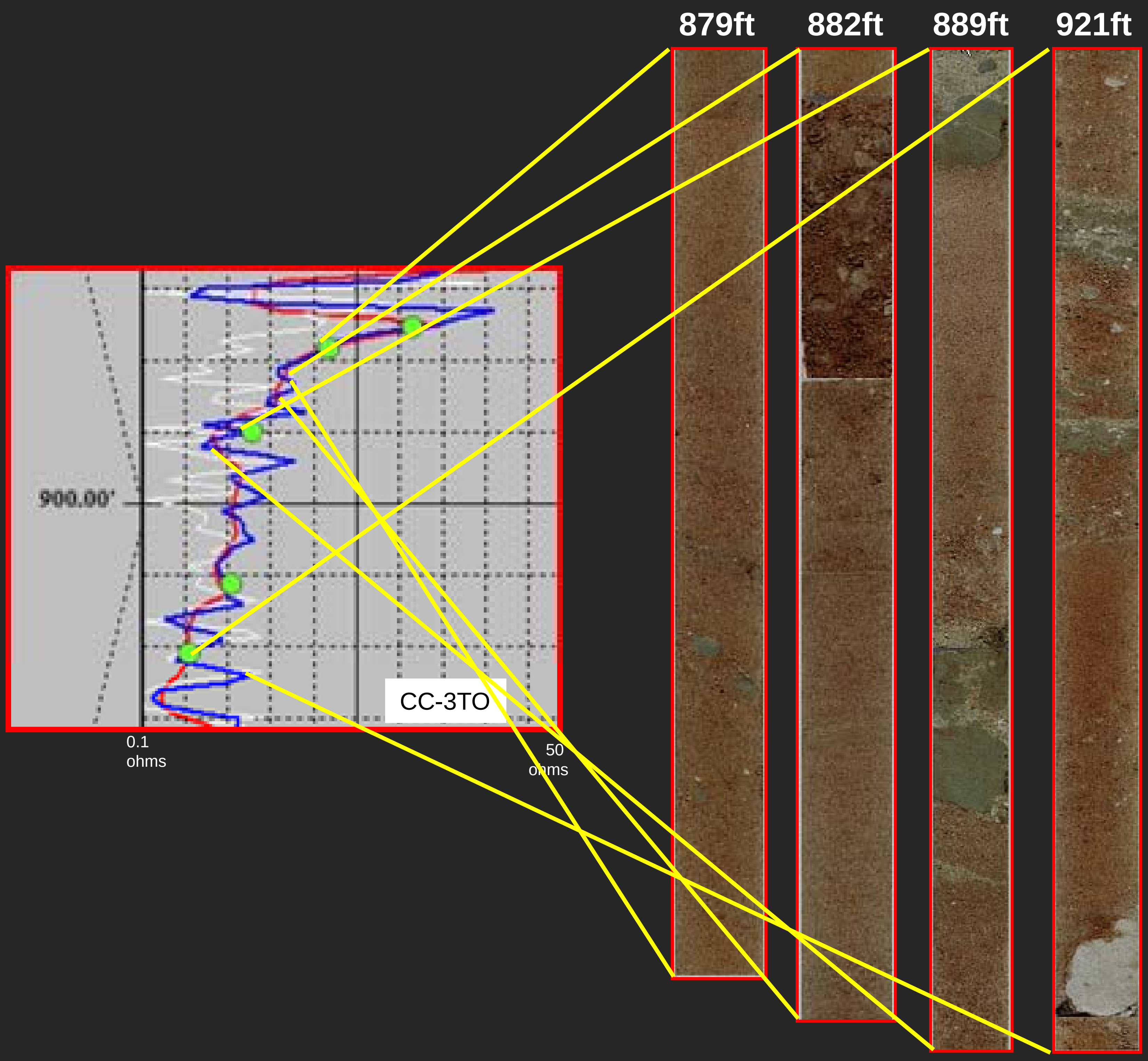
# BYPASSED OIL ZONES



# CAN THESE ZONES BE PRODUCED?

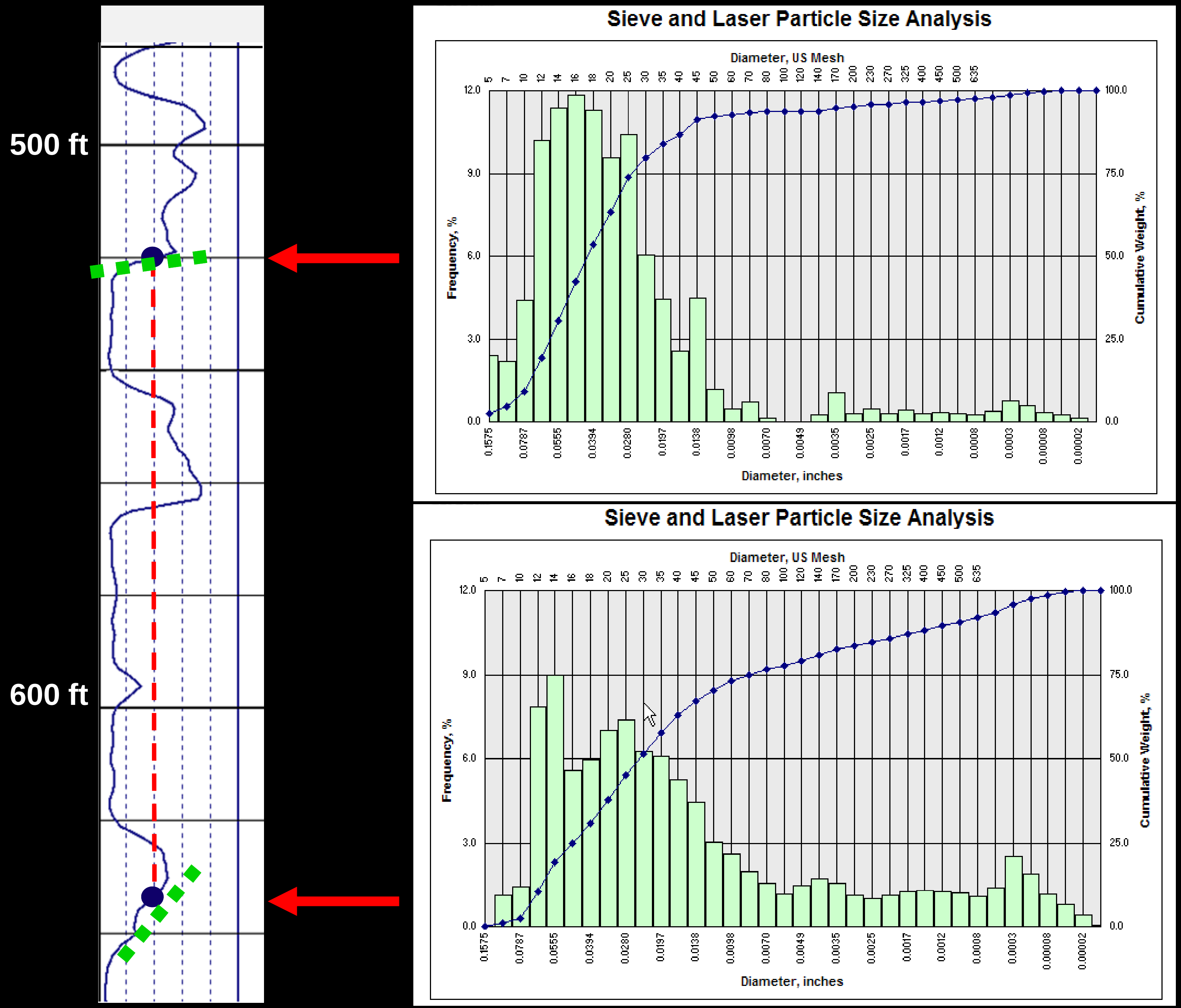
- How are bypassed zones different from productive zones?
- How does steam affect reservoir properties?

674.70
677.70
680.70
683.70
686.70
688.00
689.70
692.60
695.50
698.50
701.40
704.30
688.00
689.70
PRODUCED
NOT PRODUCED
677.70
680.70
683.70
686.70
692.60
695.50
698.50
701.40
704.30
707.20



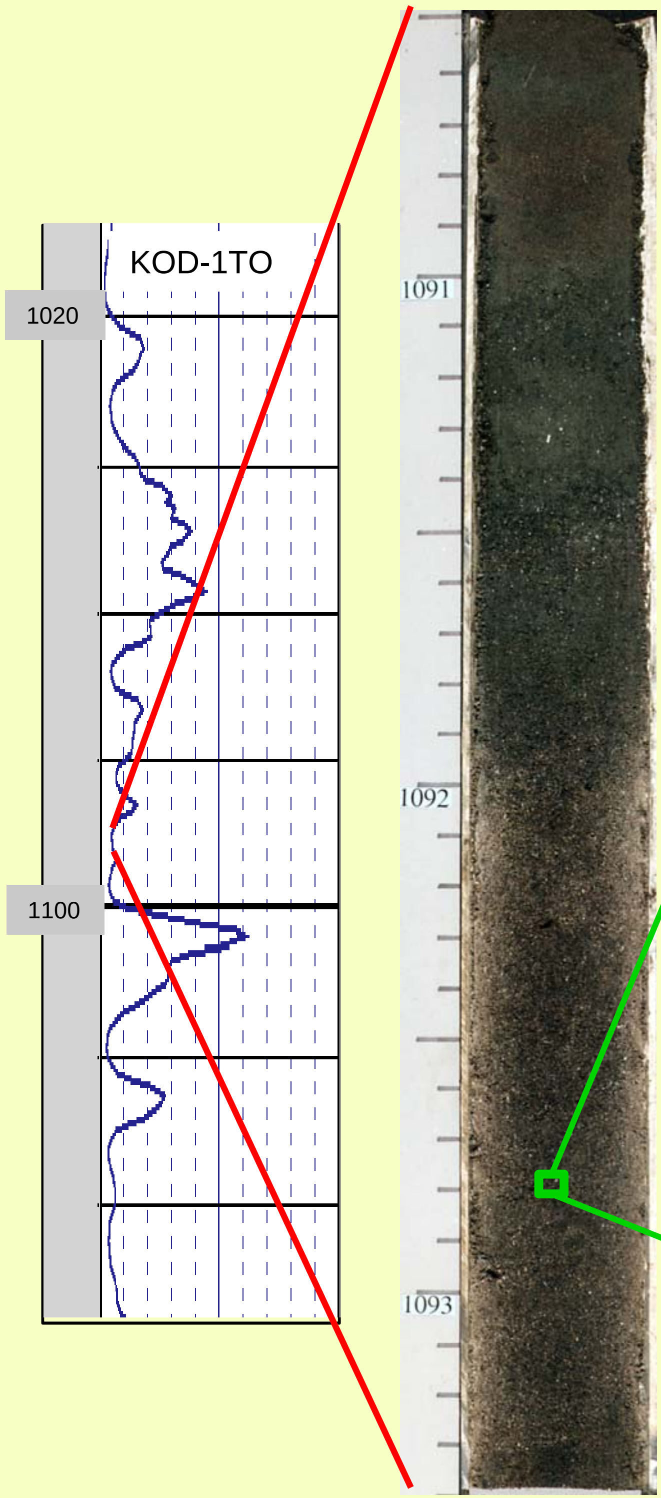
879ft
882ft
889ft
921ft
900.00'
CC-3TO
0.1
ohms
50
ohms

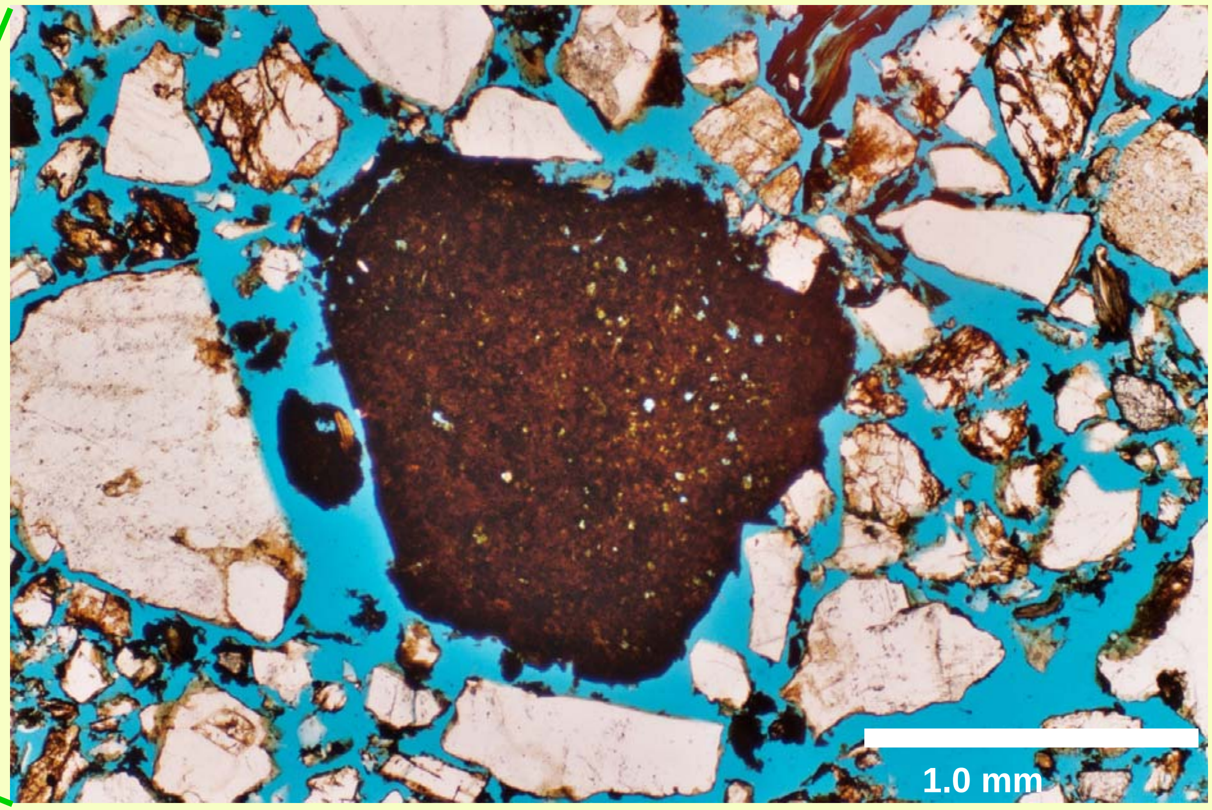
# GRAIN-SIZE SORTING



# Bypassed Zone

## POORLY SORTED SAND FROM BYPASSED ZONE

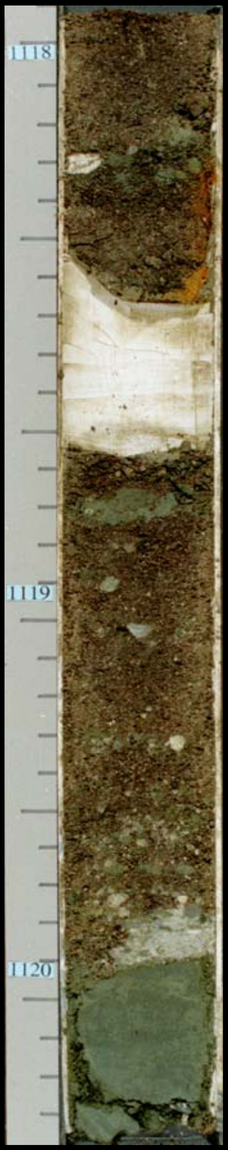


**Moderately** sorted sand from **top** of decreasing resistivity zone.

**Oil saturation decreased from 40% to 10% after 15 years**

**75% Recovery**

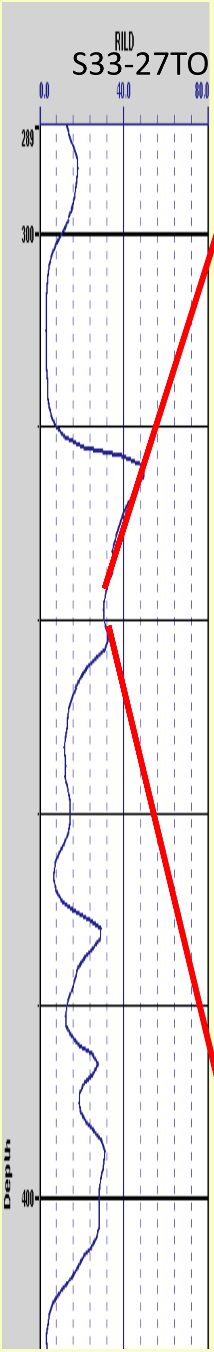

**Poorly** sorted sand from **bottom** of decreasing resistivity zone.

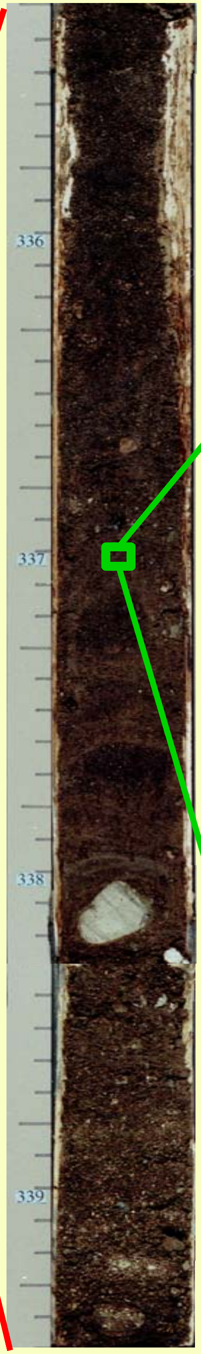
**Oil saturation decreased from 44% to 32% after 15 years**

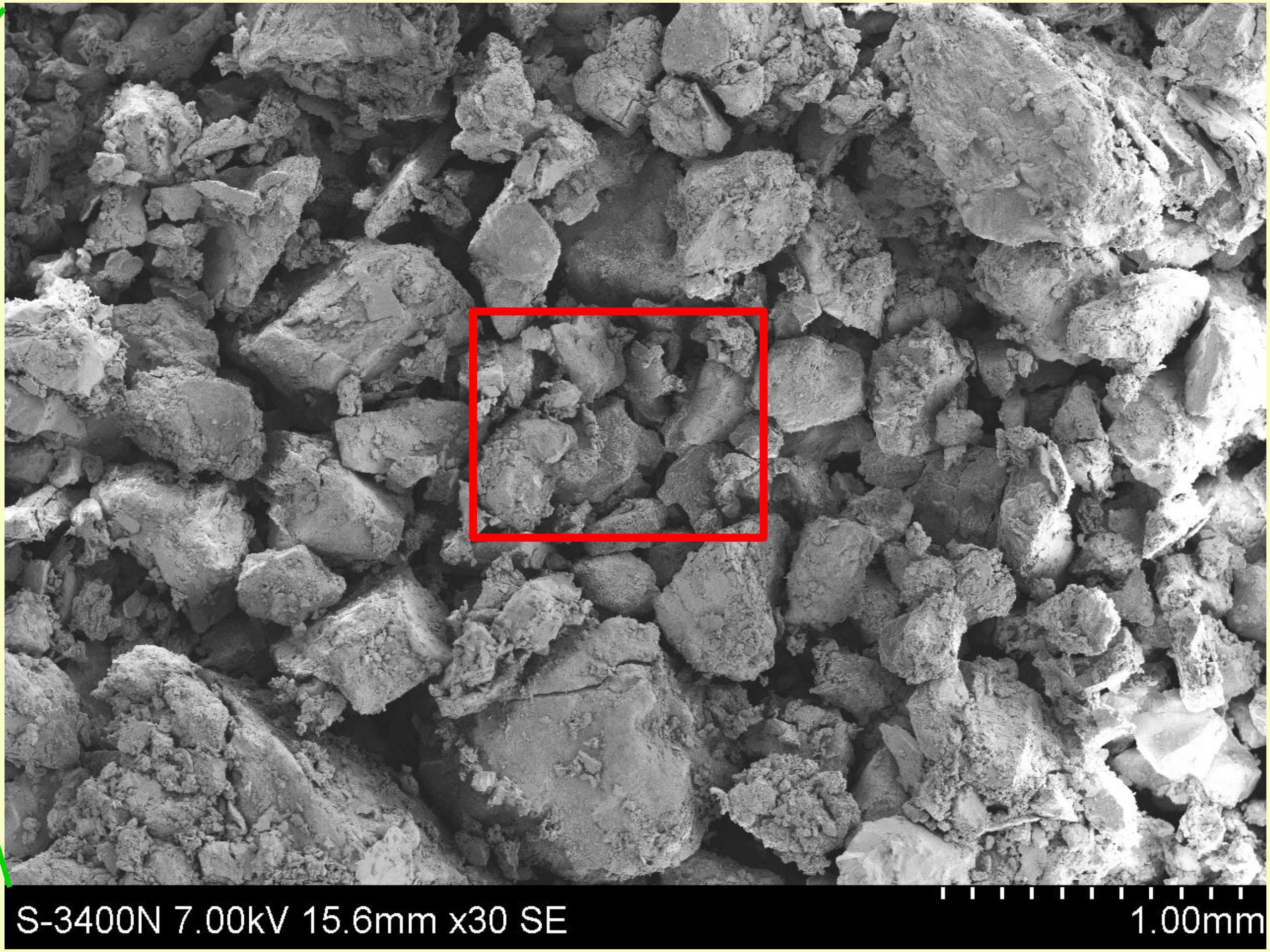
**25% Recovery**

# Pre-Heating

## Productive Sand Just Above Decreasing Resistivity Zone

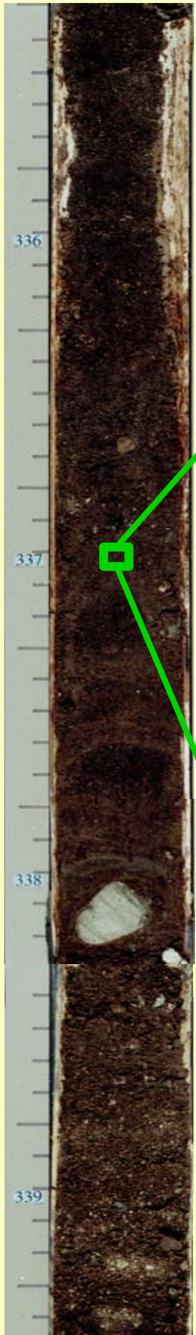


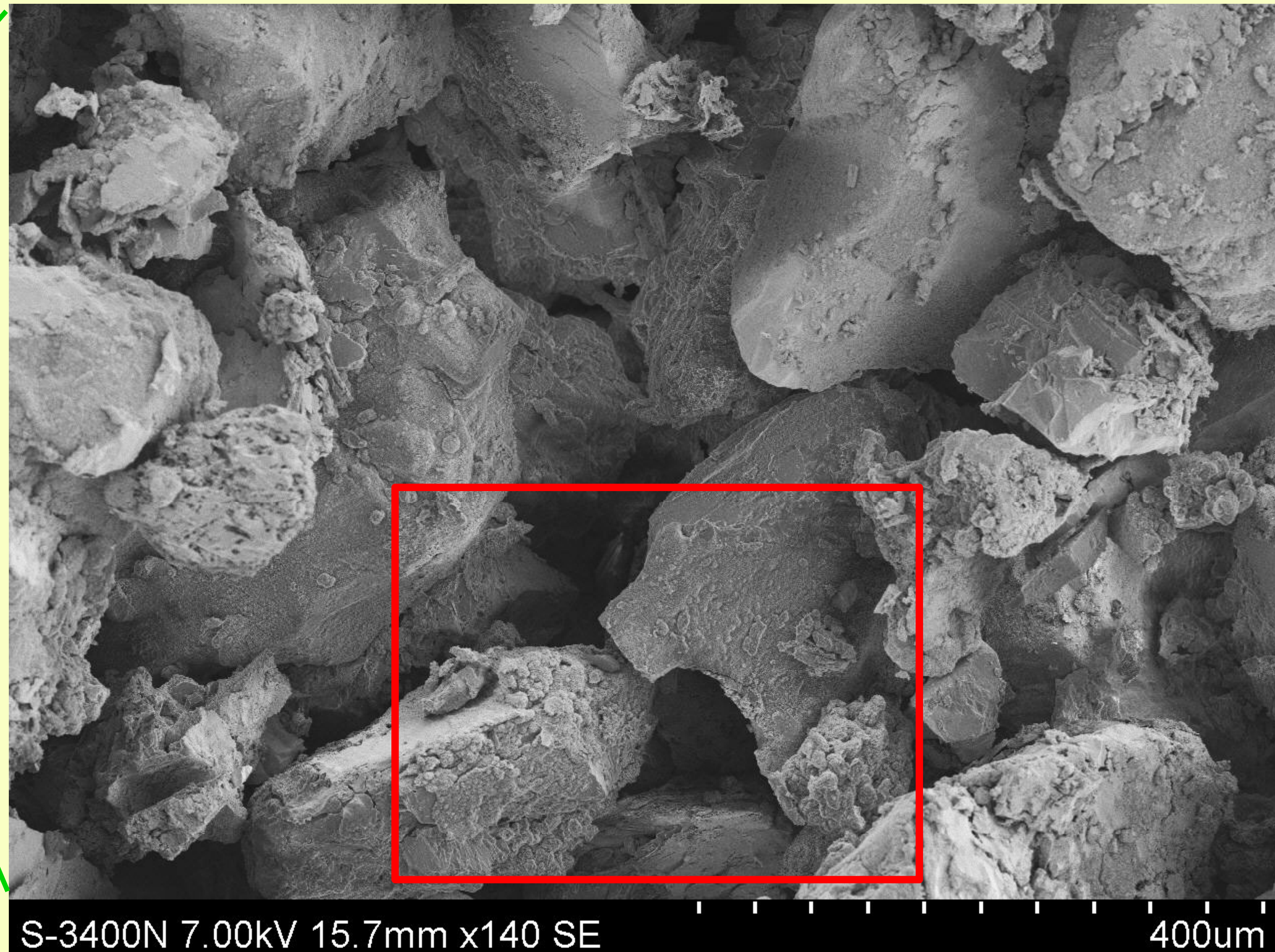



# Pre-Heating

## Productive Sand Just Above Decreasing Resistivity Zone
## Showing Open Pore Network

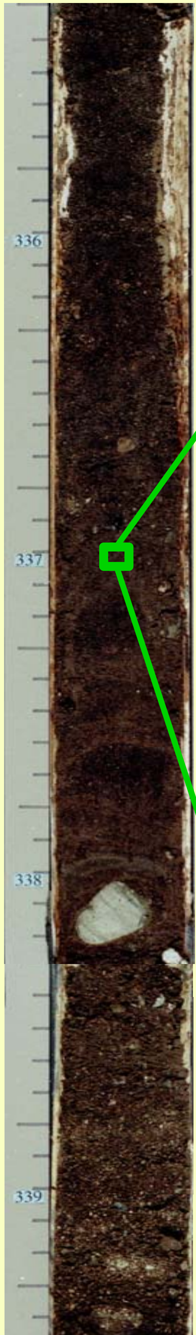


# Pre-Heating

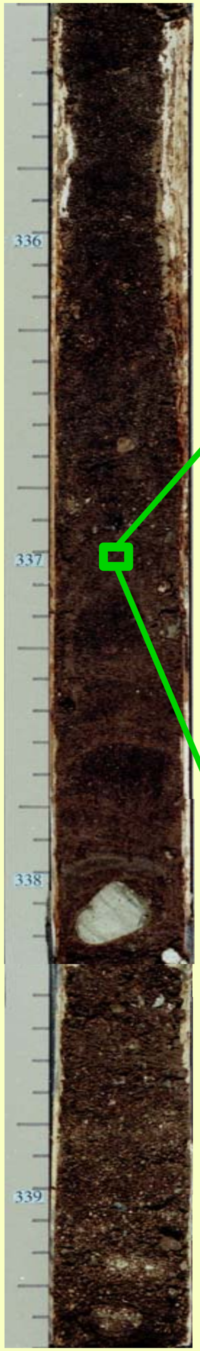
## Productive Sand Just Above Decreasing Resistivity Zone

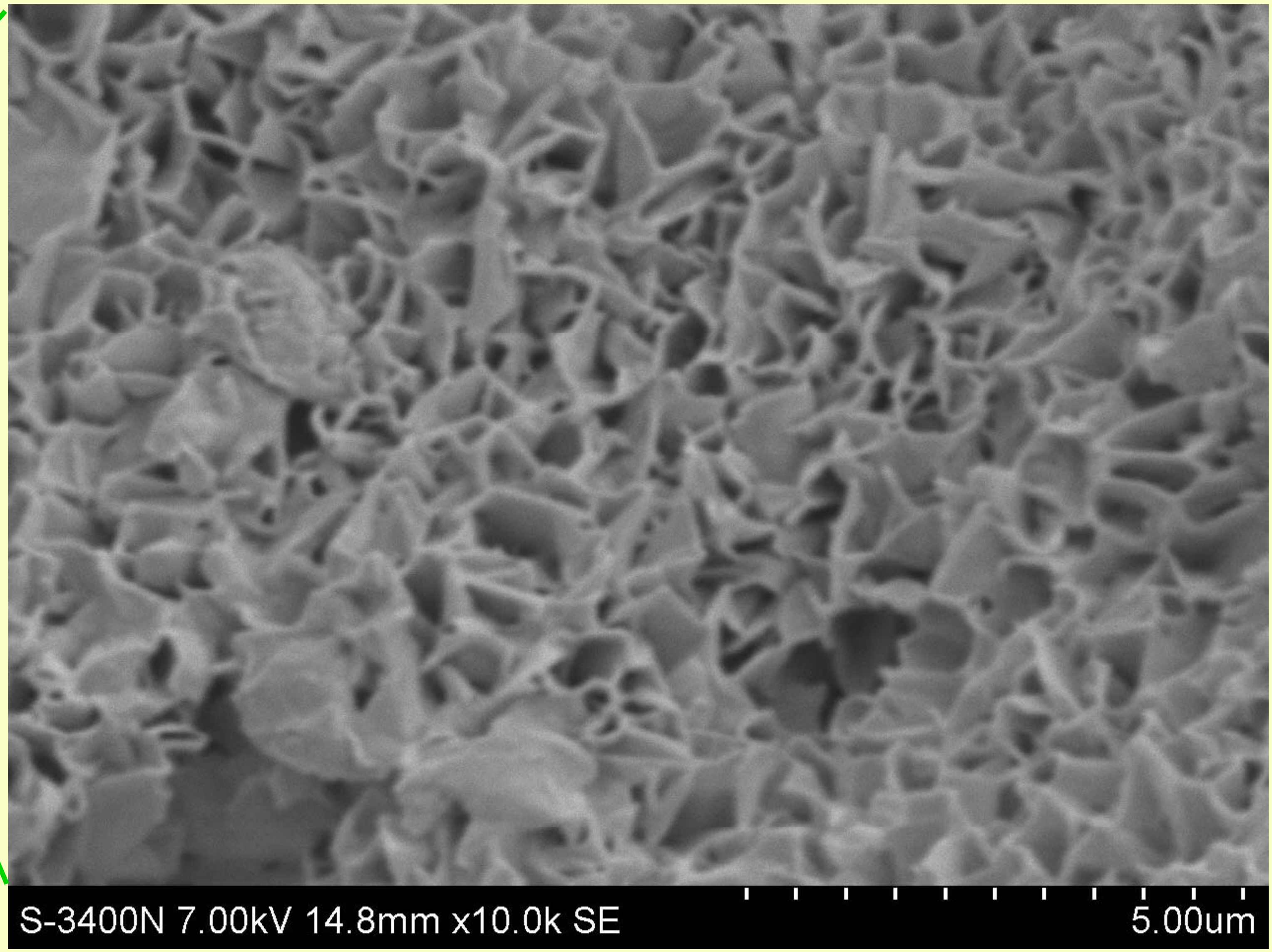
## Showing Open Pore Network and Clay Coatings on Grains




# Pre-Heating

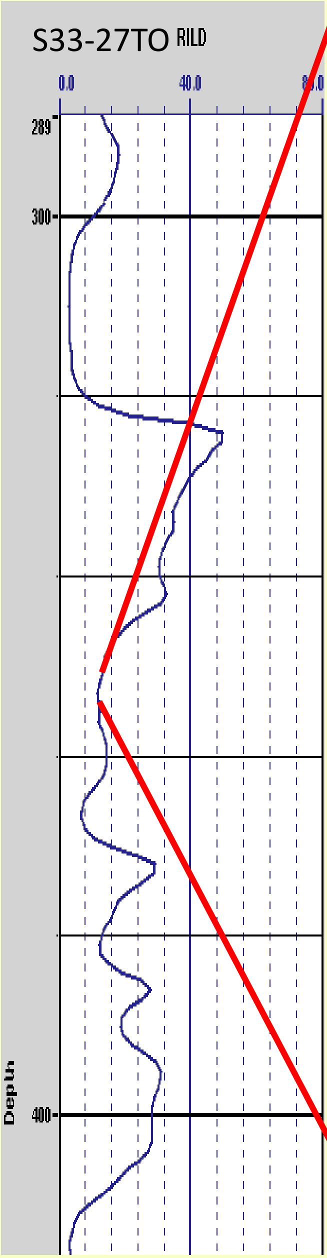
## Clay Coatings on Grains

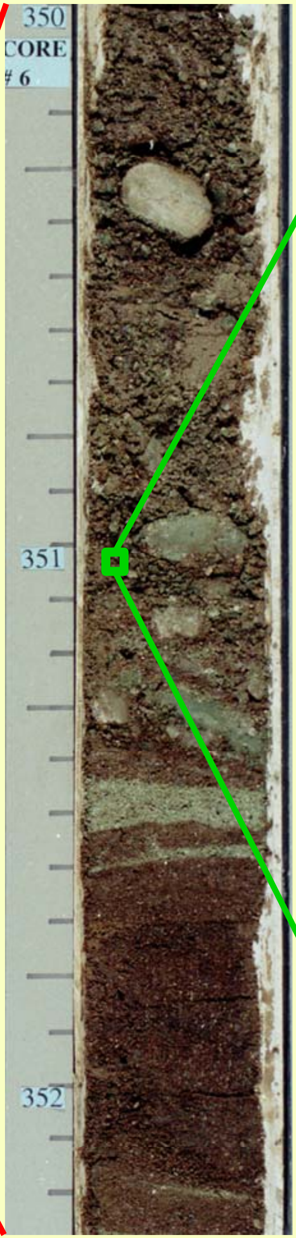


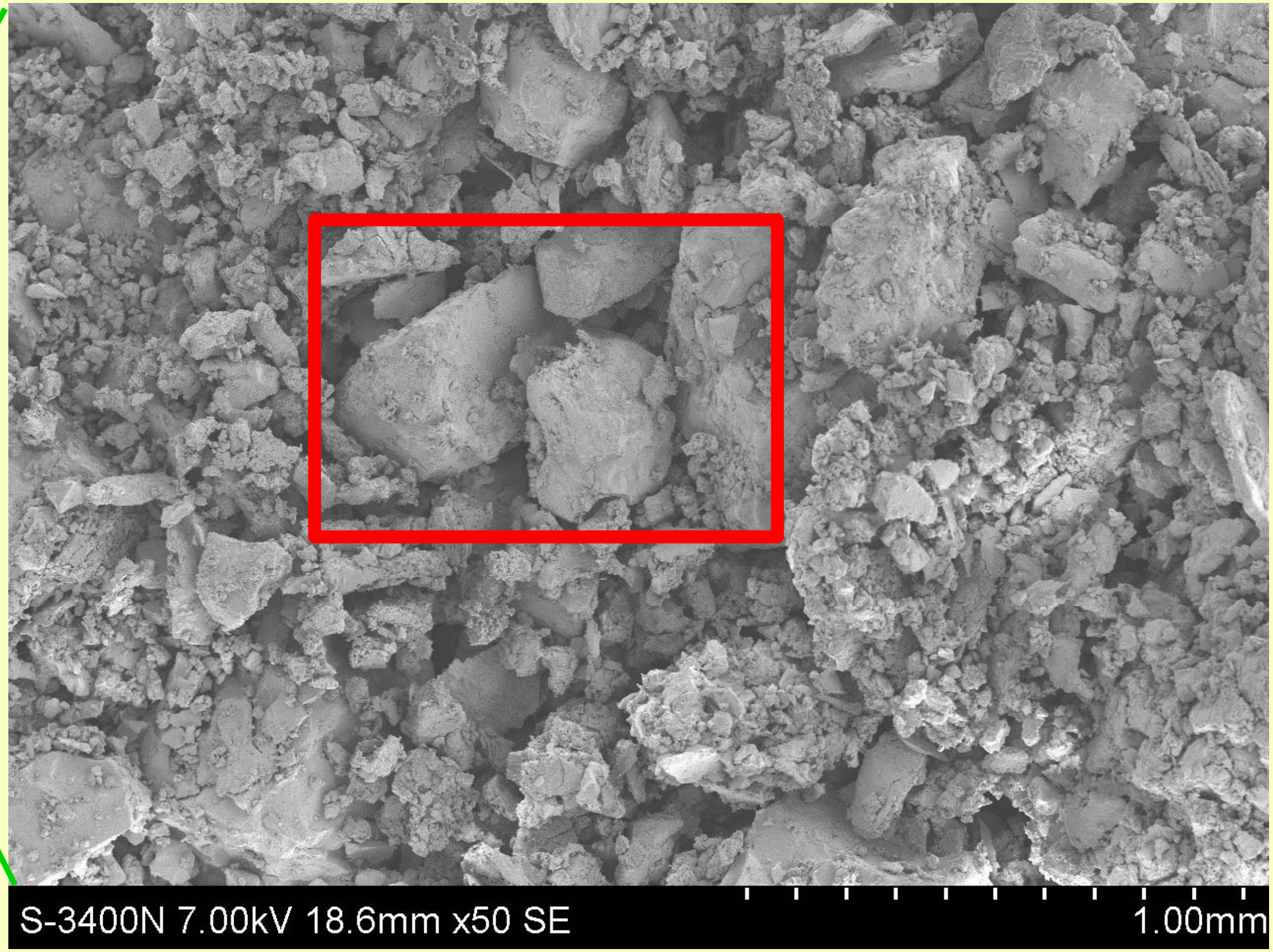



# Pre-Heating

## Poorly Sorted Sediment Near Bottom of Decreasing Resistivity Zone



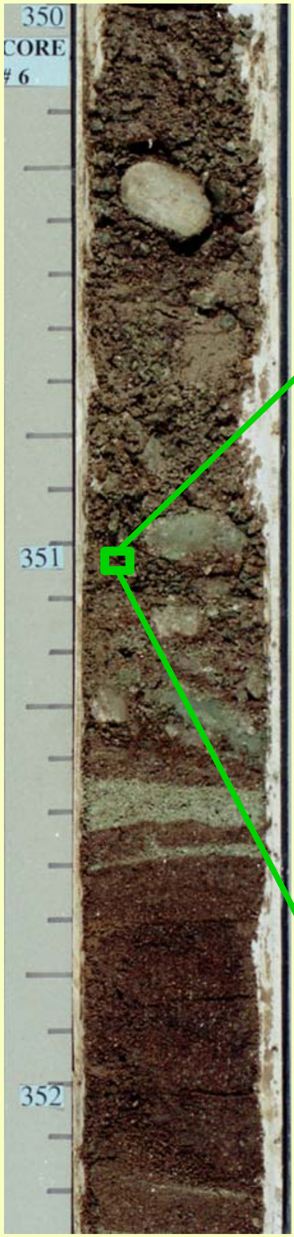



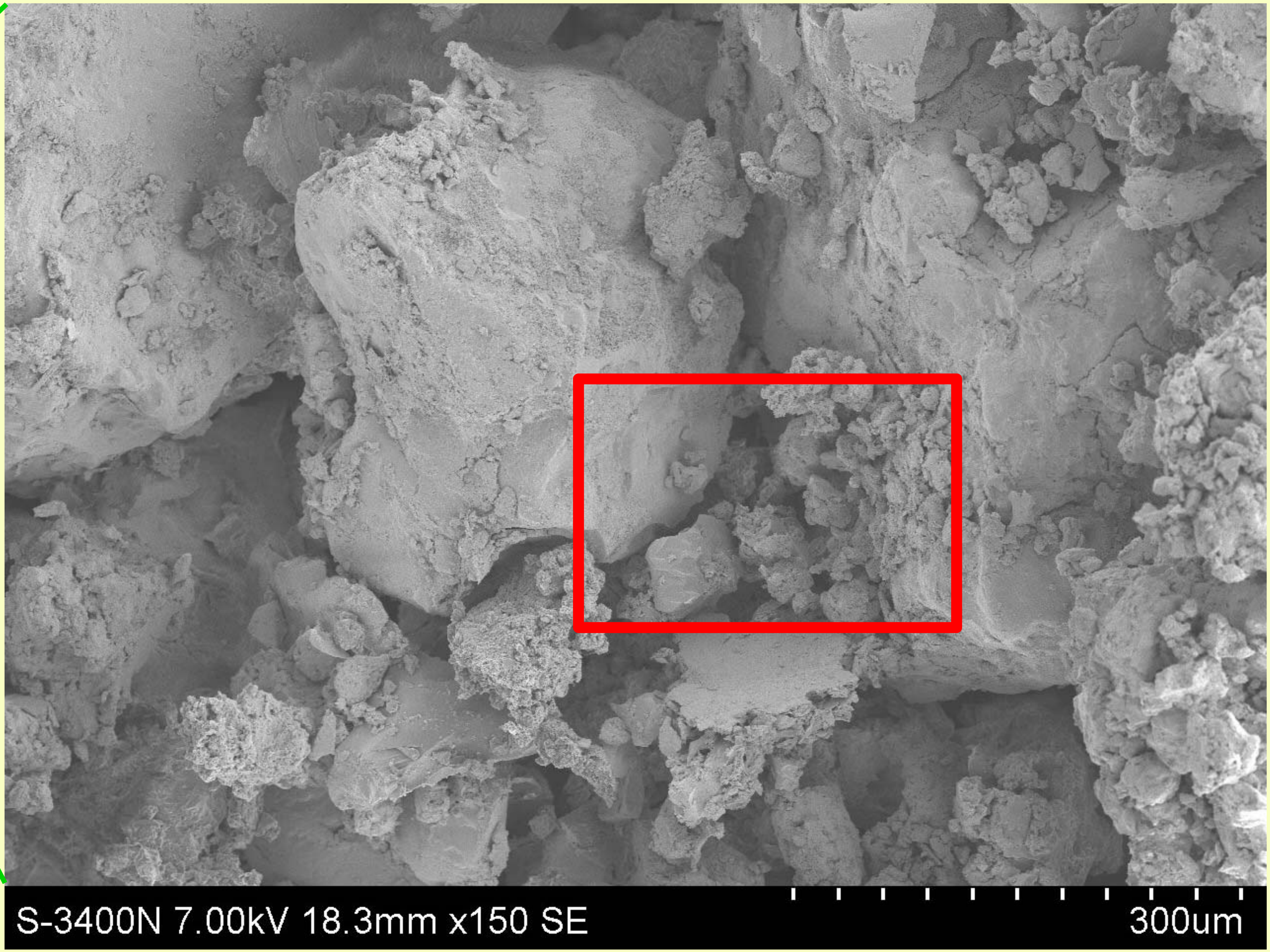



# Pre-Heating

## Poorly Sorted Sediment Near Bottom of Decreasing Resistivity Zone

## Showing Less Open Pore Network

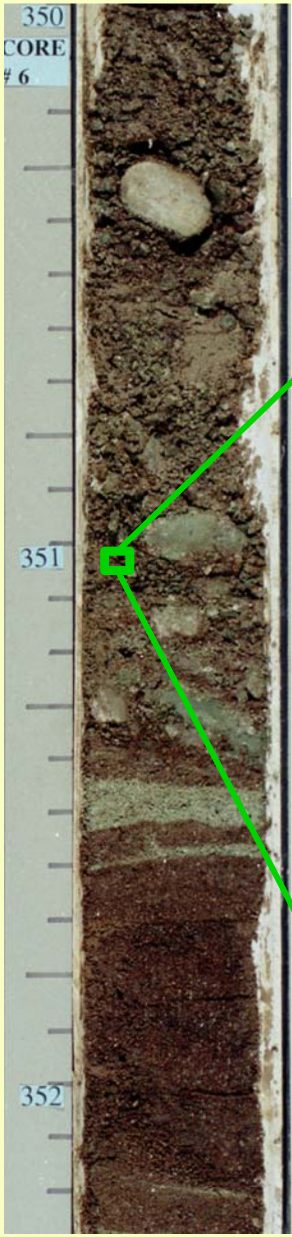


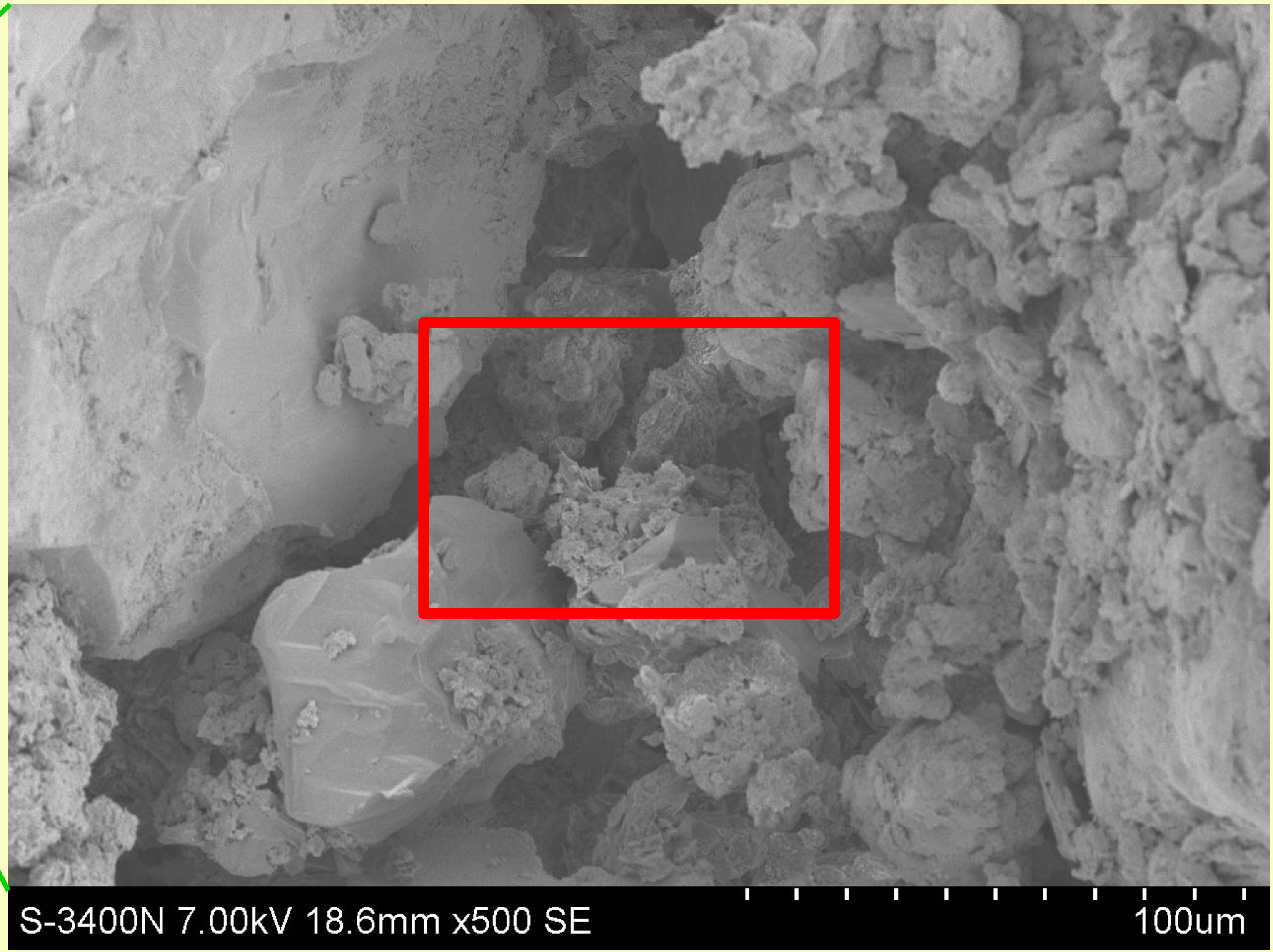



# Pre-Heating

## Poorly Sorted Sediment Near Bottom of Decreasing Resistivity Zone

## Showing Less Open Pore Network

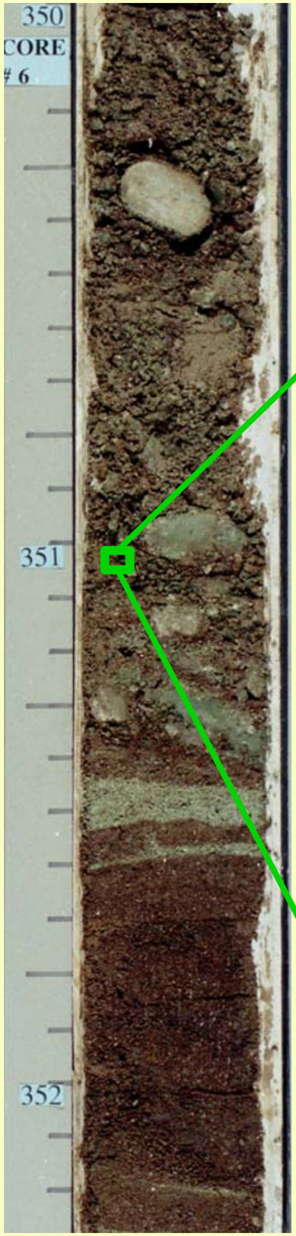


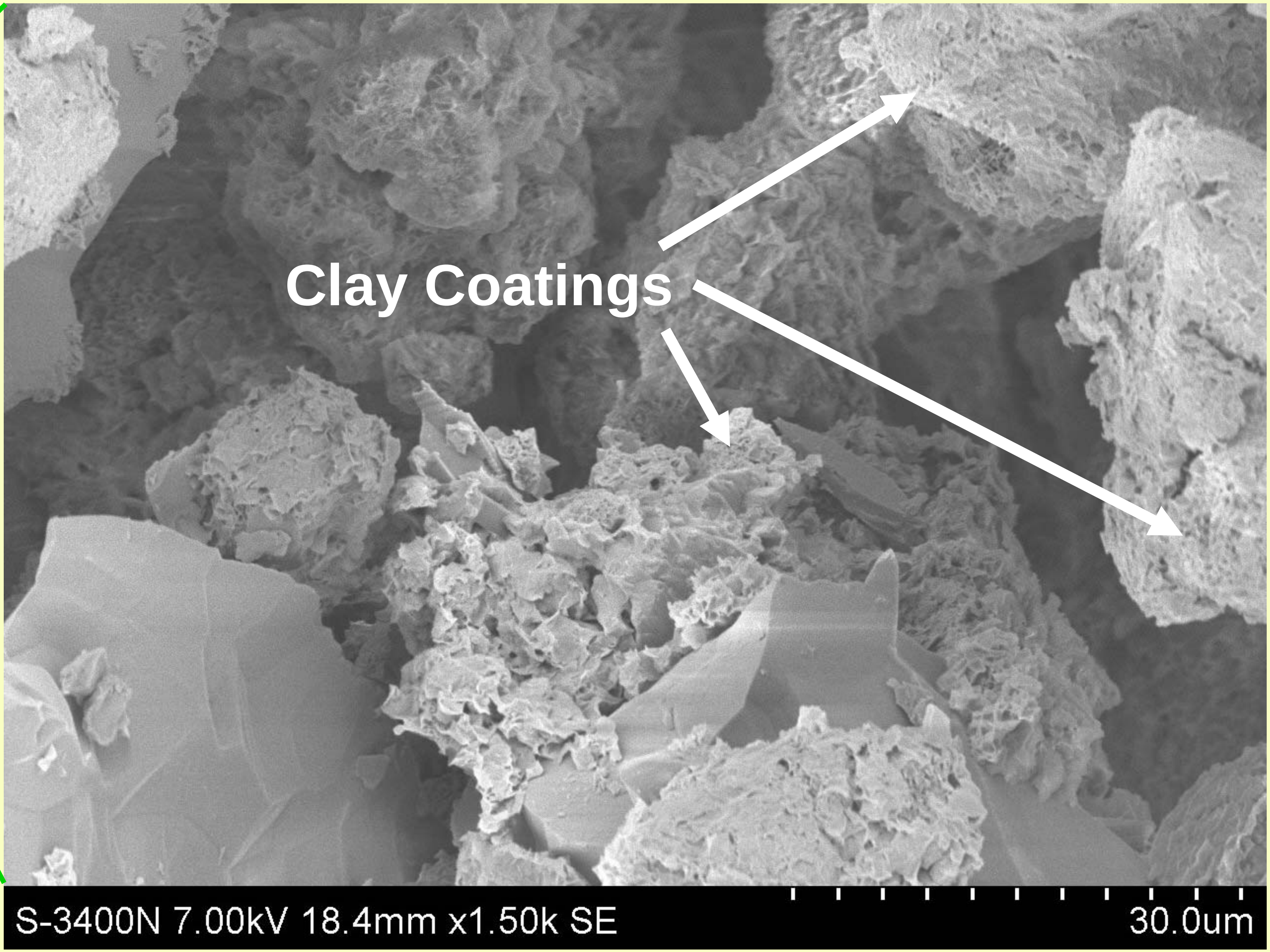



# Pre-Heating

**Poorly Sorted Sediment Near Bottom of Decreasing Resistivity Zone Showing Less Open Pore Network and**

## Clay Coatings on Smallest Grains



# Pre-Heating

## Extremely Poorly Sorted Sediment Below the Decreasing Resistivity Zone

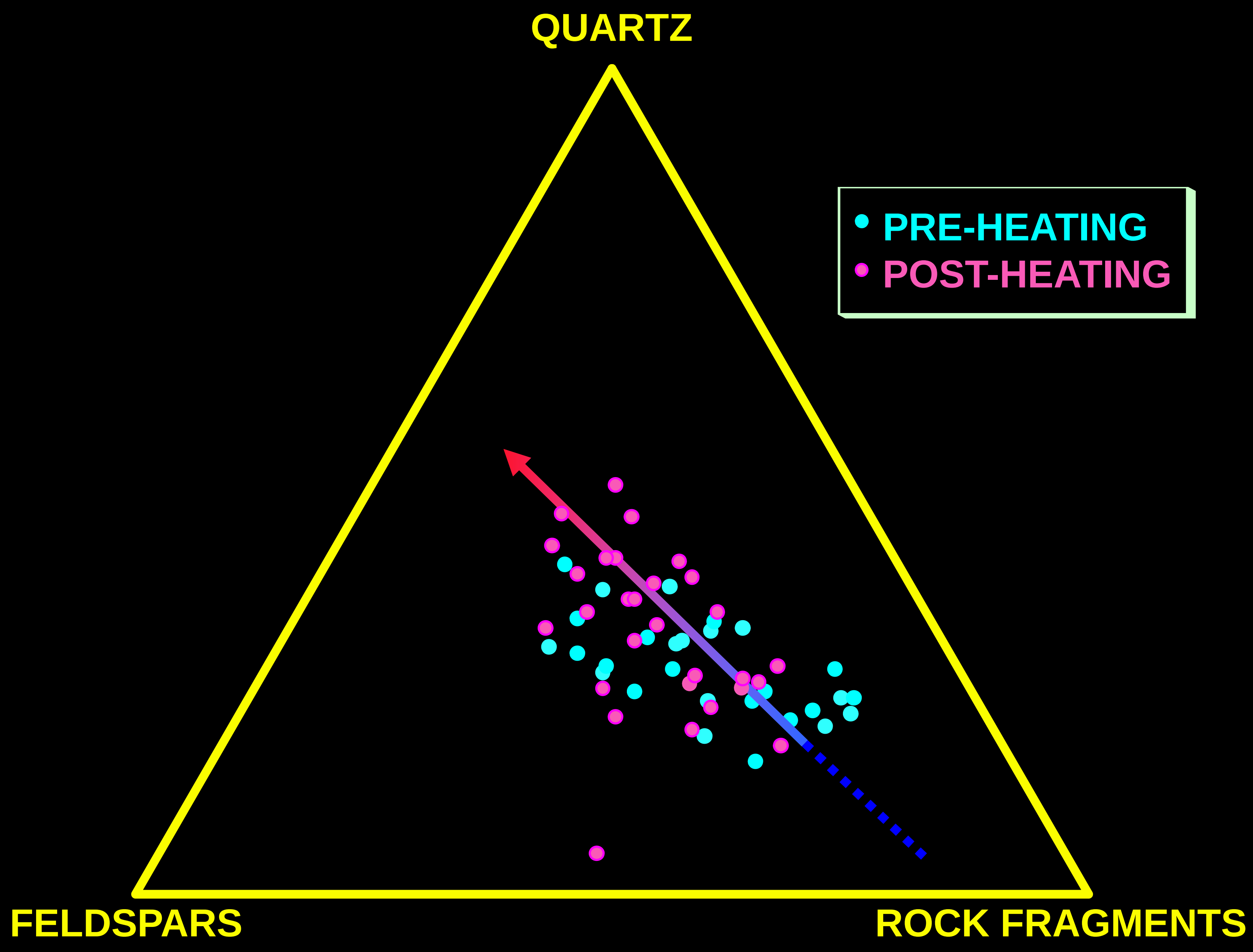
# How are bypassed zones different from productive zones?

- Productive zones are much better sorted than bypassed zones.
- Productive zones have more open pore networks than bypassed zones.

# CAN THESE ZONES BE PRODUCED?

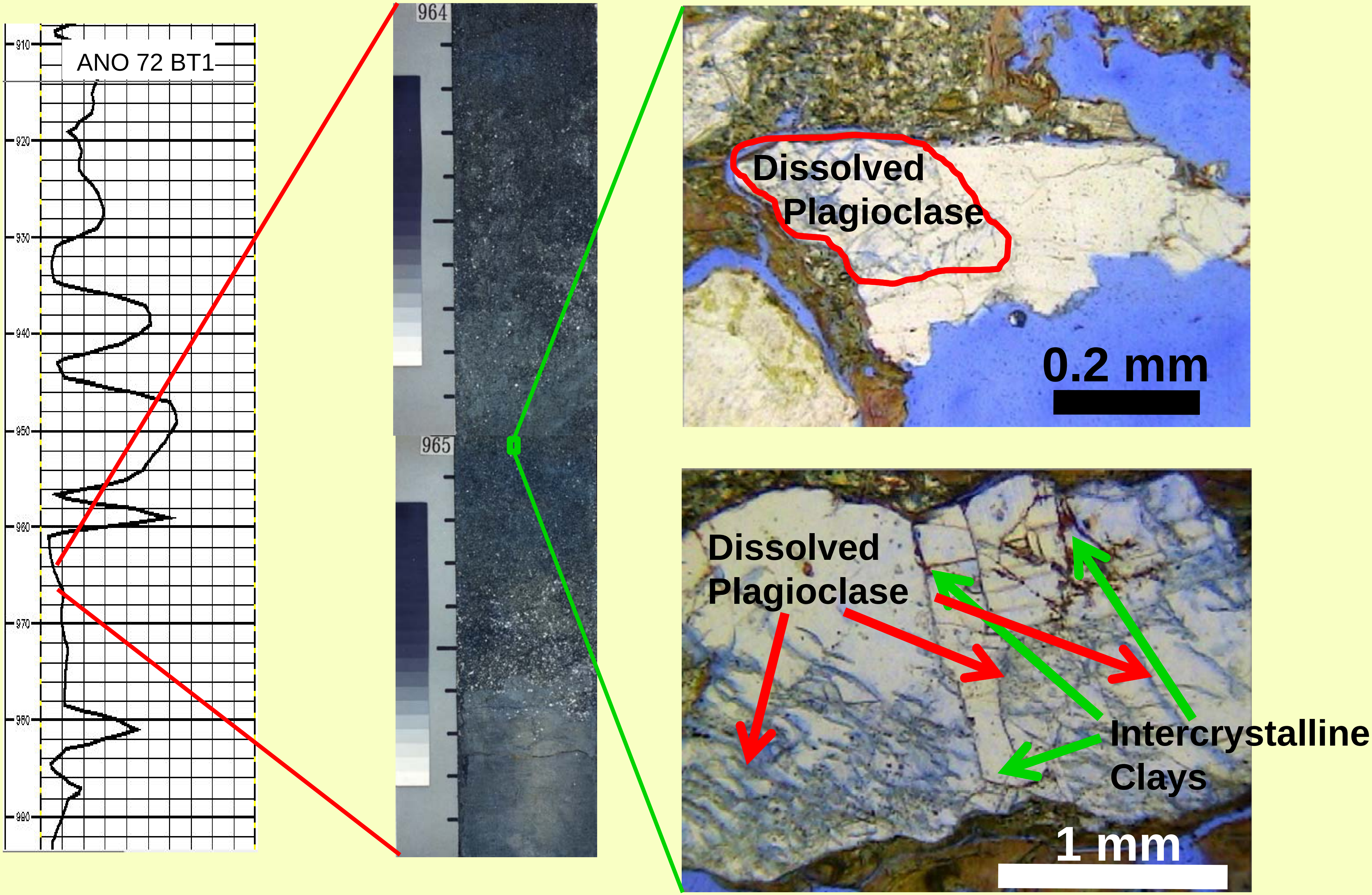
- **How are bypassed zones different from productive zones?**
- **How does steam affect reservoir properties?**

# CHANGES DUE TO INTRODUCTION OF STEAM

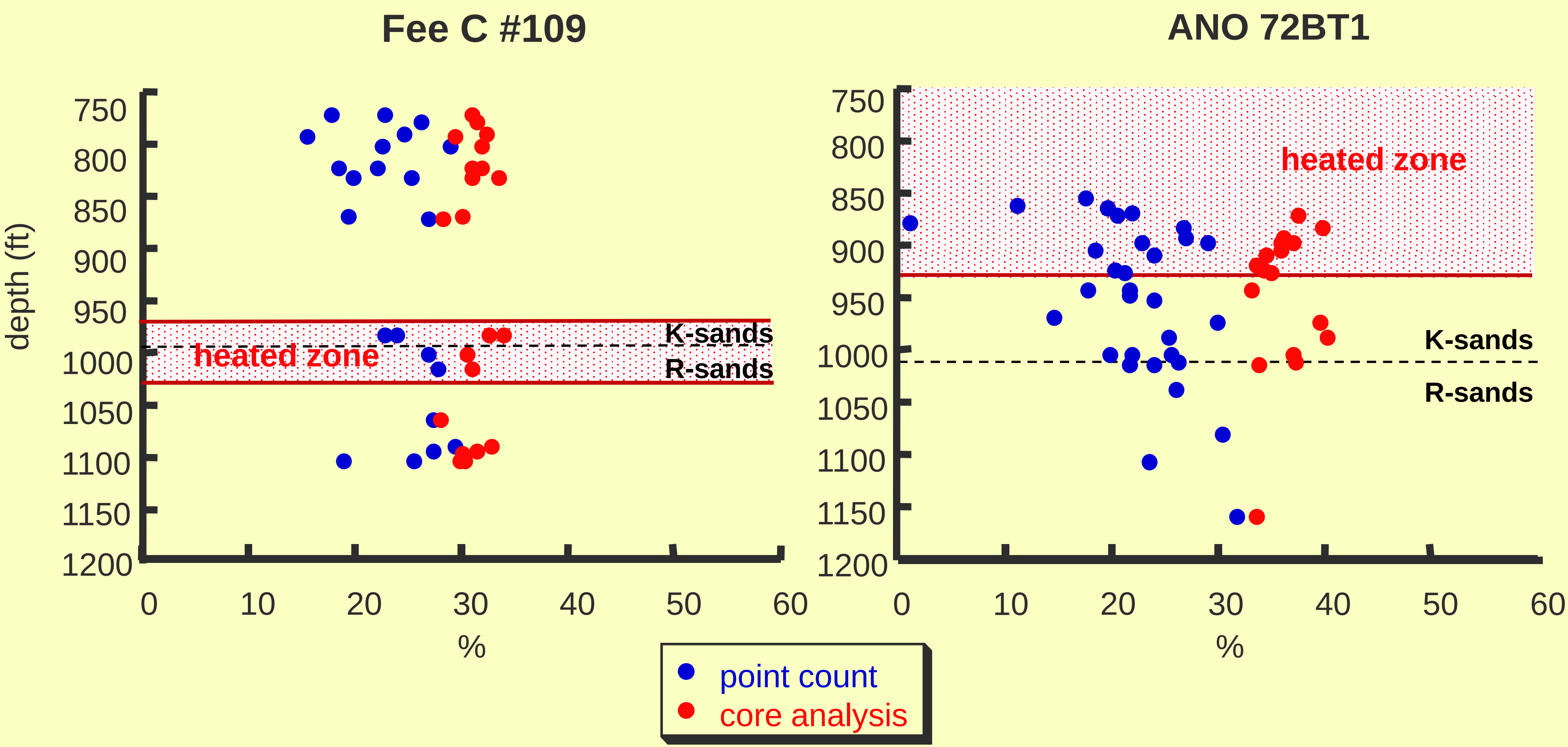


# Post-Heating

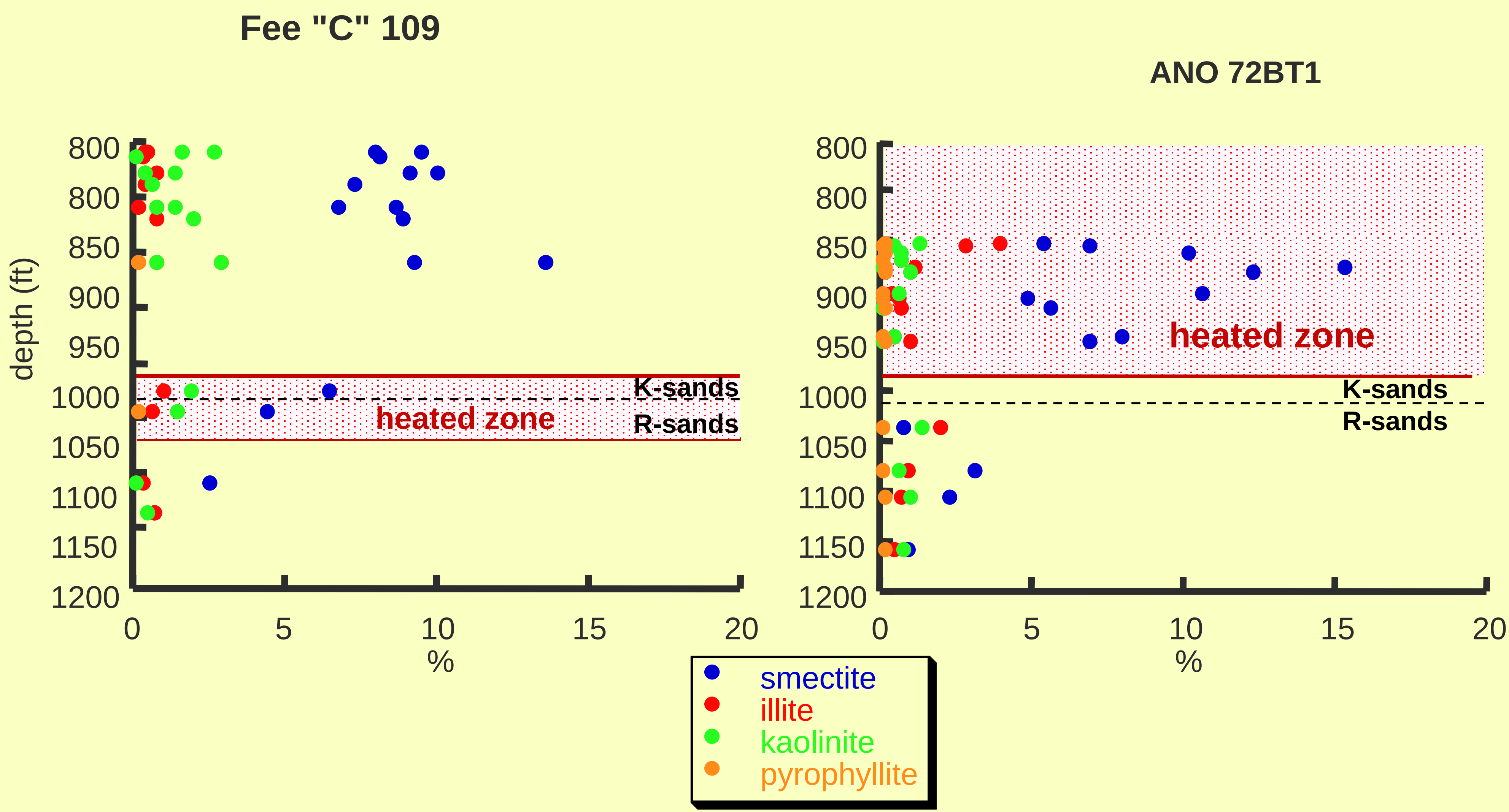
## DISSOLVED FELDSPARS in GRANITIC ROCK FRAGMENTS

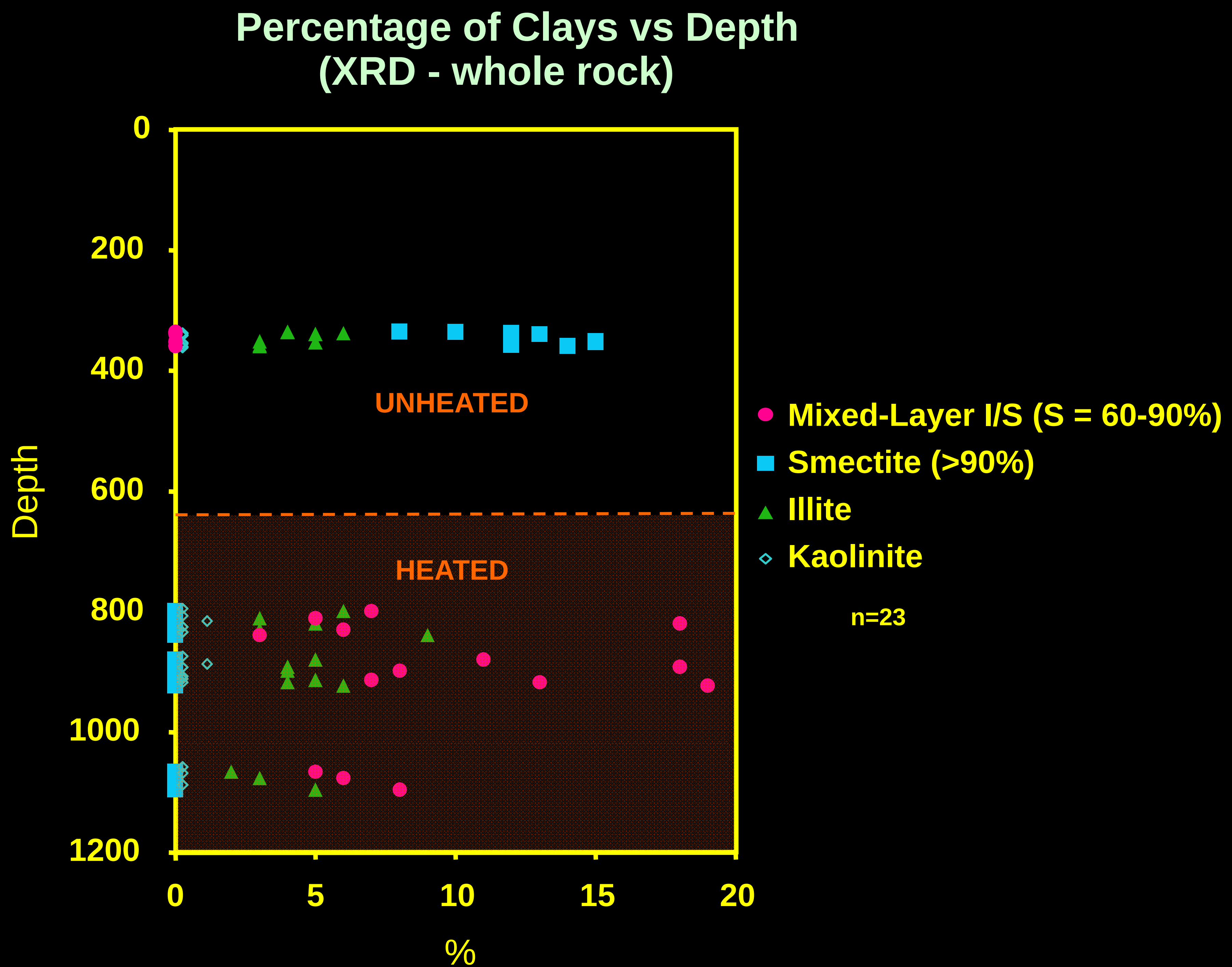


# % Total Porosity



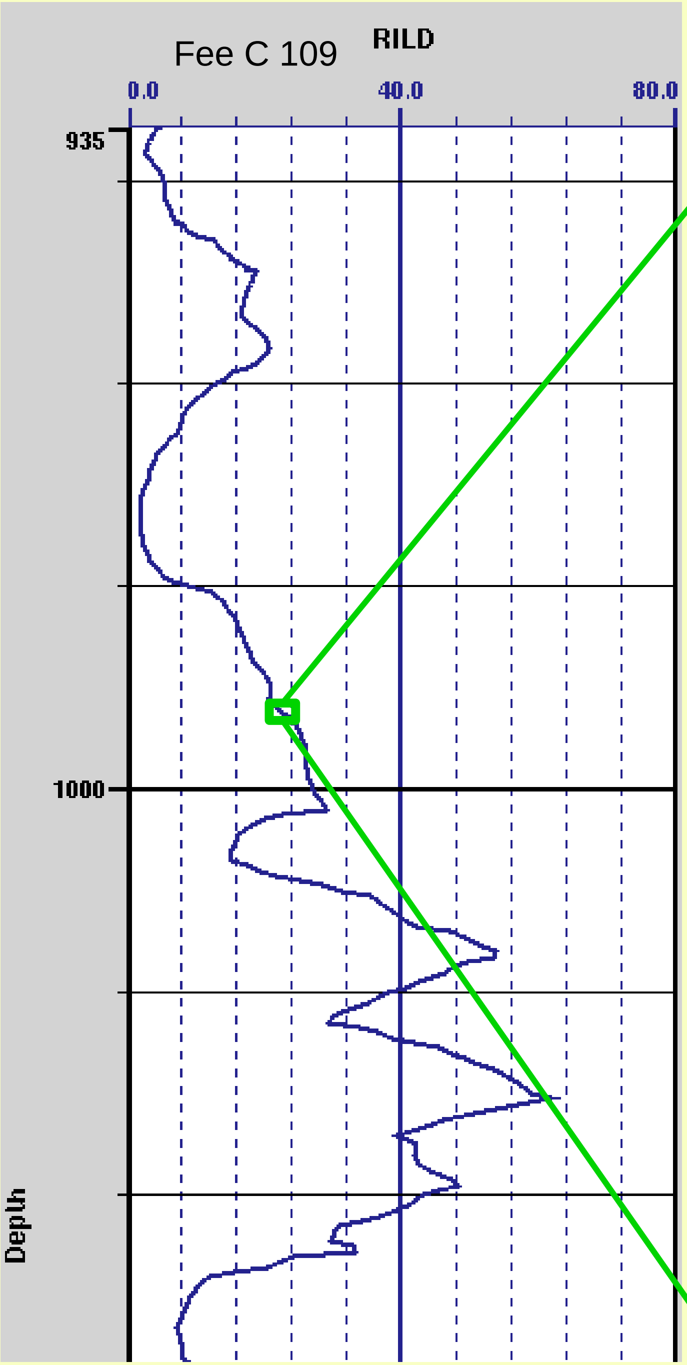
## Percentage of Clays vs Depth
## (XRD - whole rock)

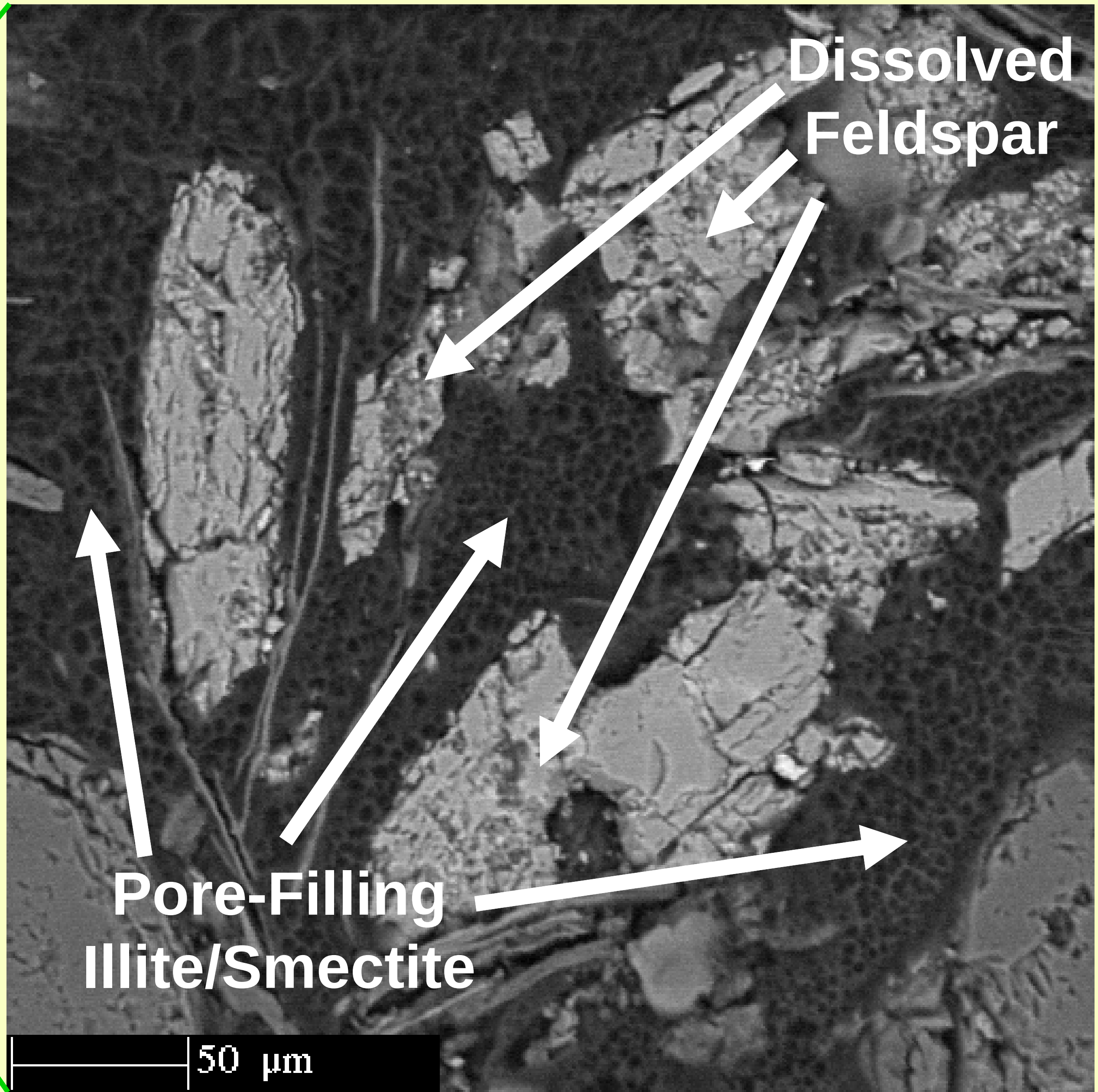



Percentage of Clays vs Depth
(XRD - whole rock)
0
200
400
600
800
1000
1200
Depth
UNHEATED
HEATED
0
5
10
15
20
%
Mixed-Layer I/S (S = 60-90%)
Smectite (>90%)
Illite
Kaolinite
n=23

# Produced Sand

## DISSOLVED FELDSPARS
## PORE-FILLING MIXED-LAYER I/S

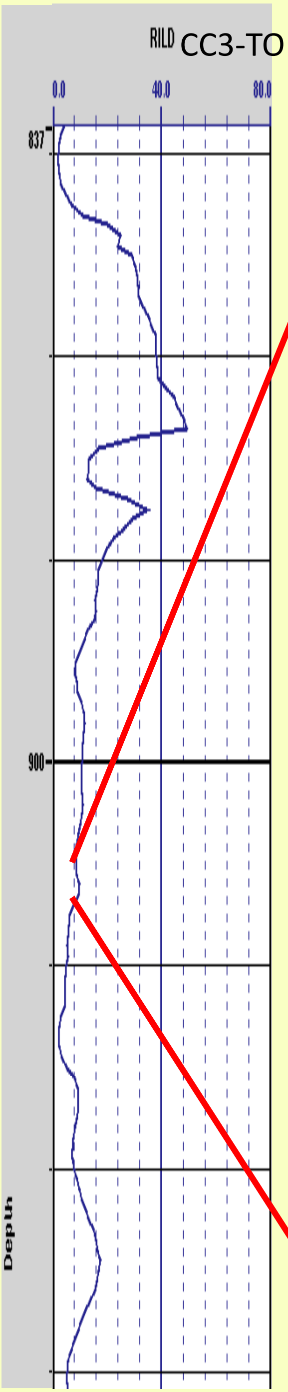


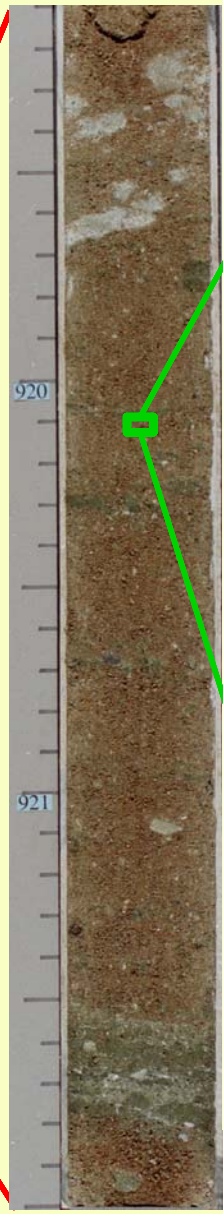



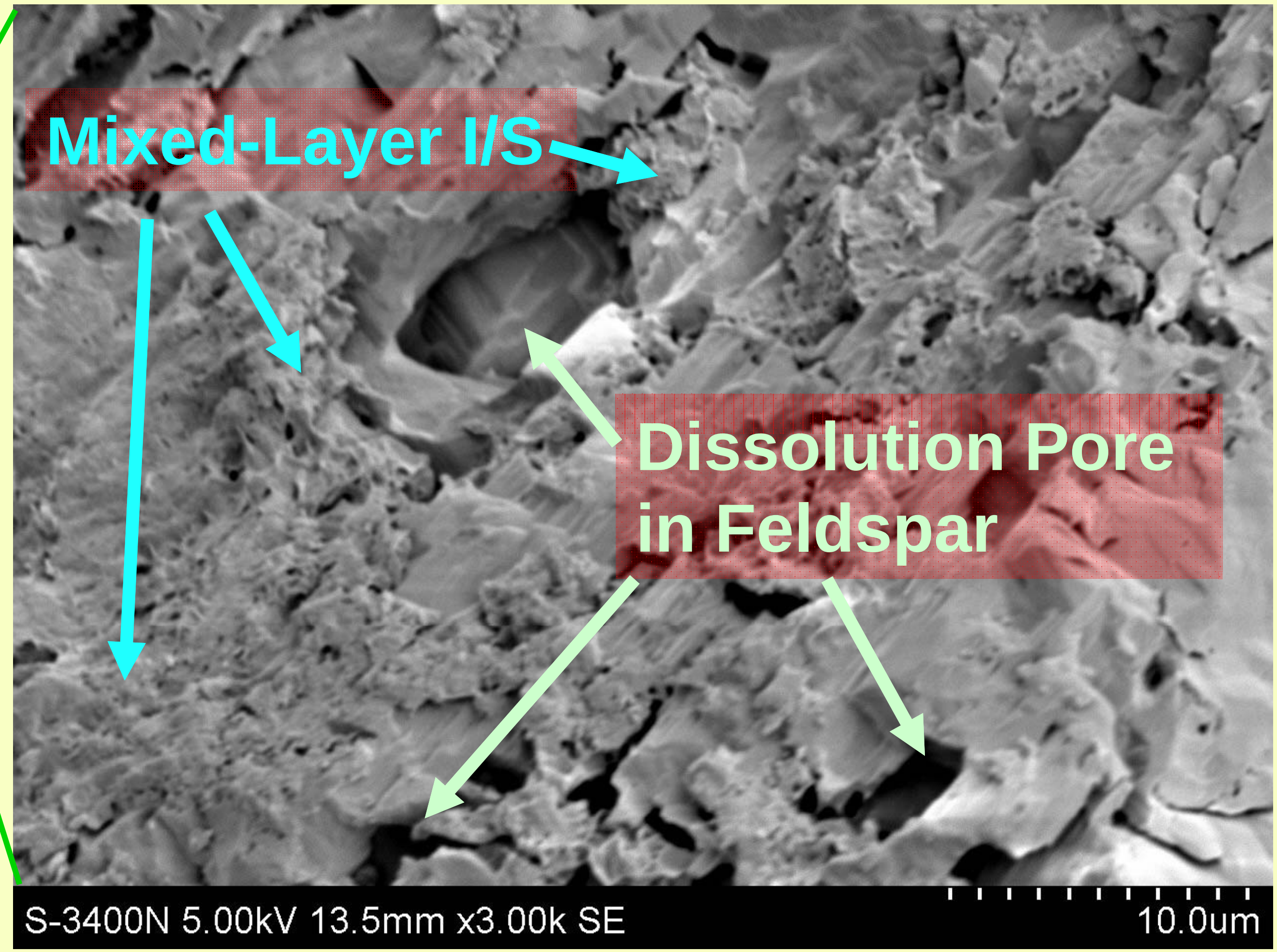
# Produced Sand

## FELDSPAR DISSOLUTION

## PRECIPITATION OF MIXED-LAYER I/S



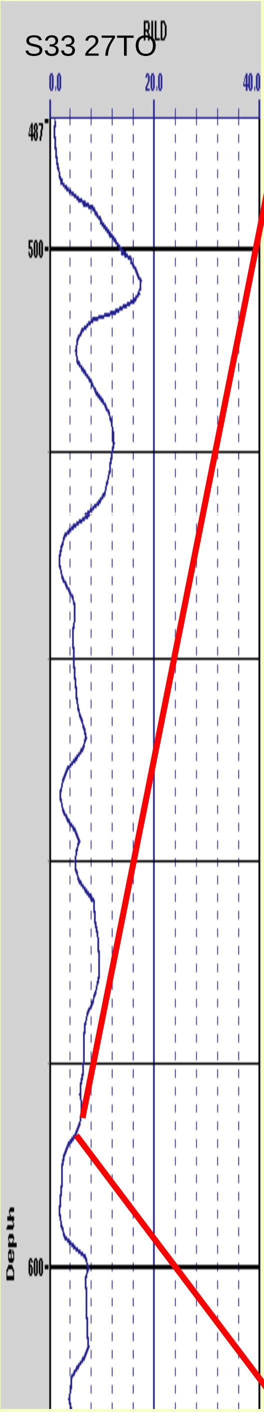



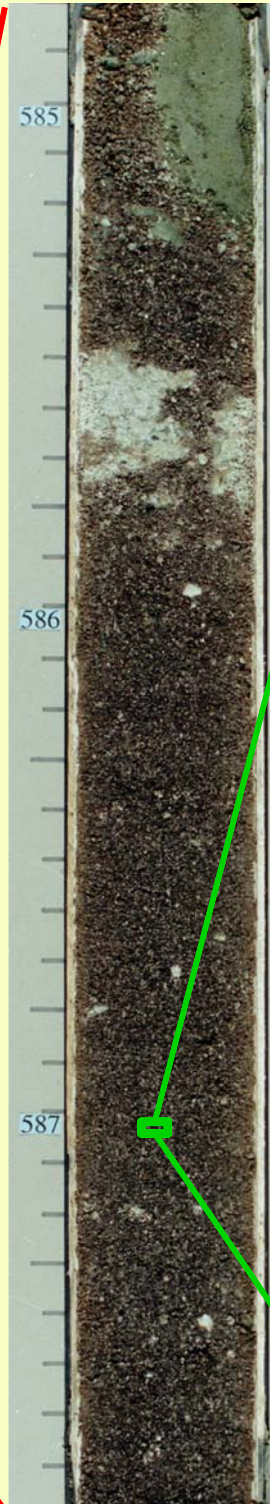



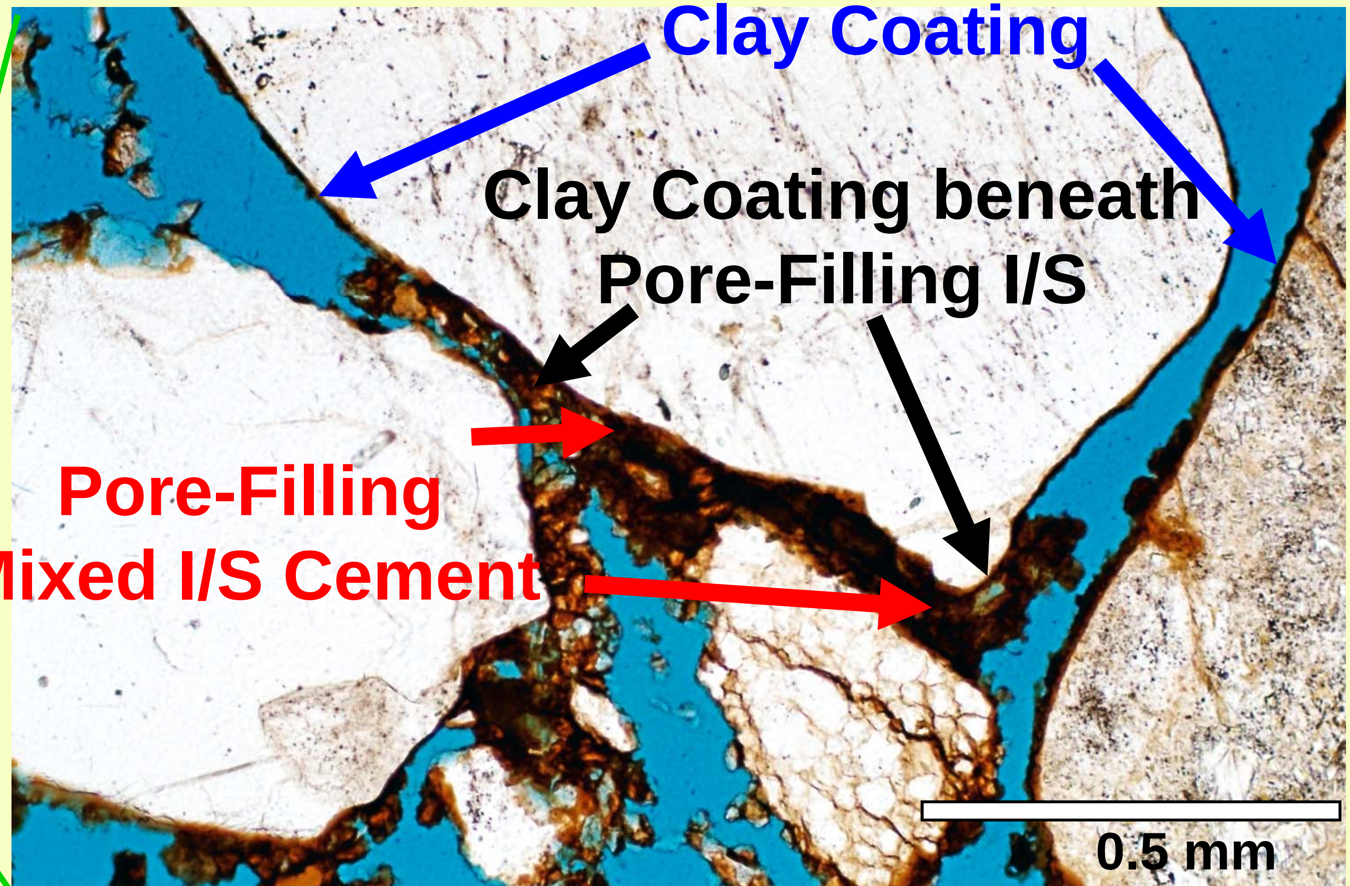
# Bypassed Zone

**PRE-HEATING CLAY COATINGS**

**POST-HEATING PORE-FILLING MIXED-LAYER ILLITE/SMECTITE**

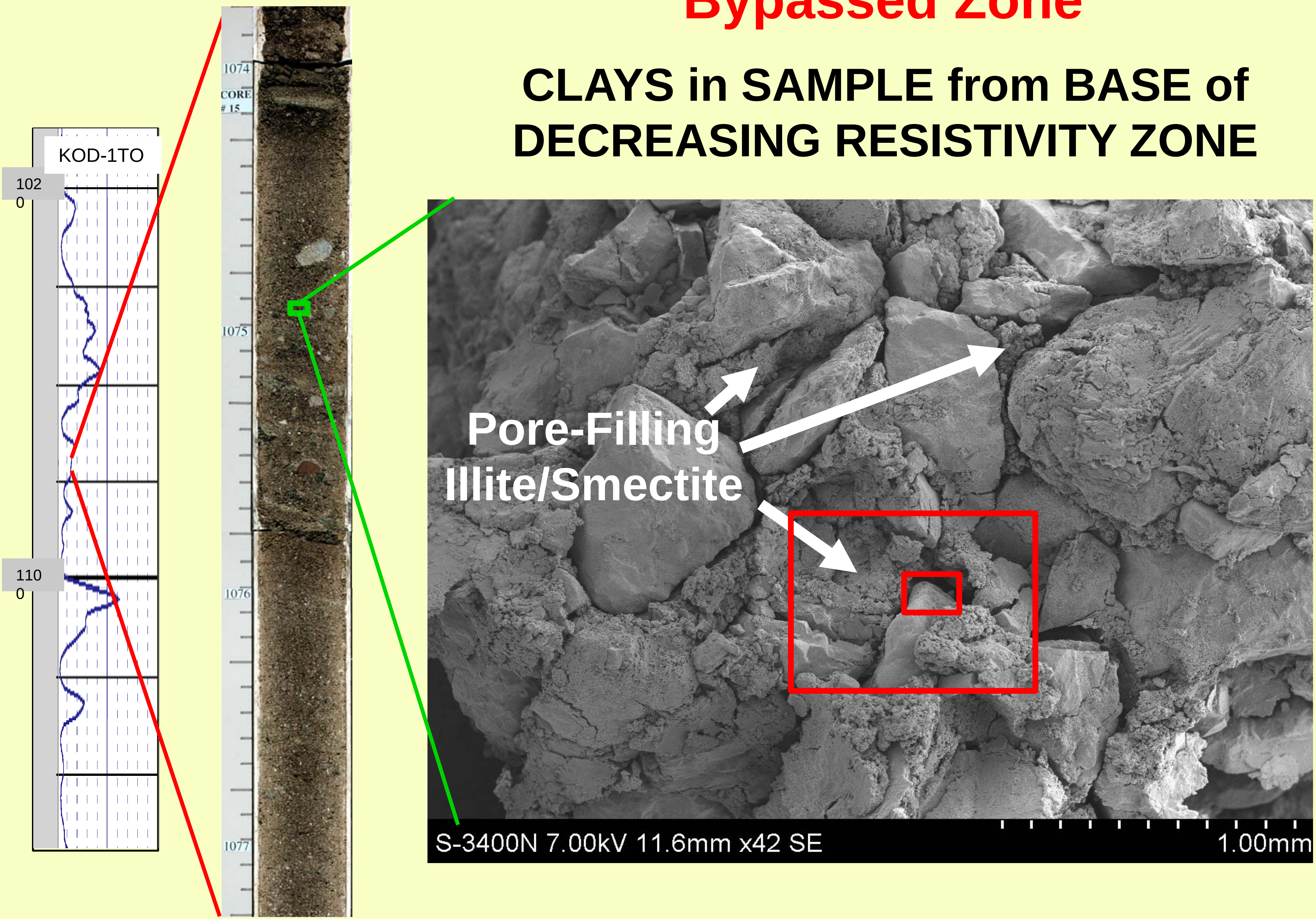


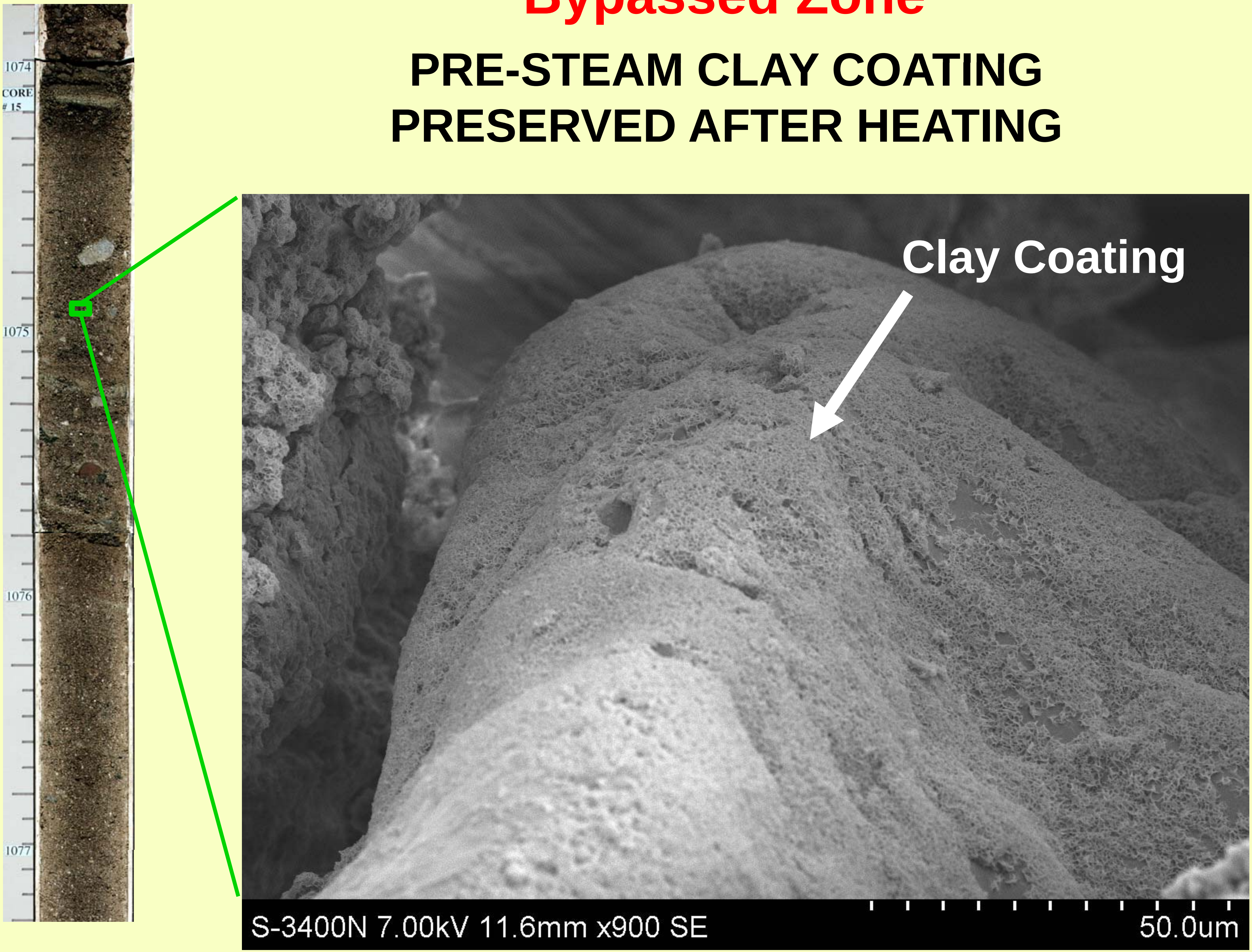
# Bypassed Zone

## CLAYS in SAMPLE from BASE of DECREASING RESISTIVITY ZONE



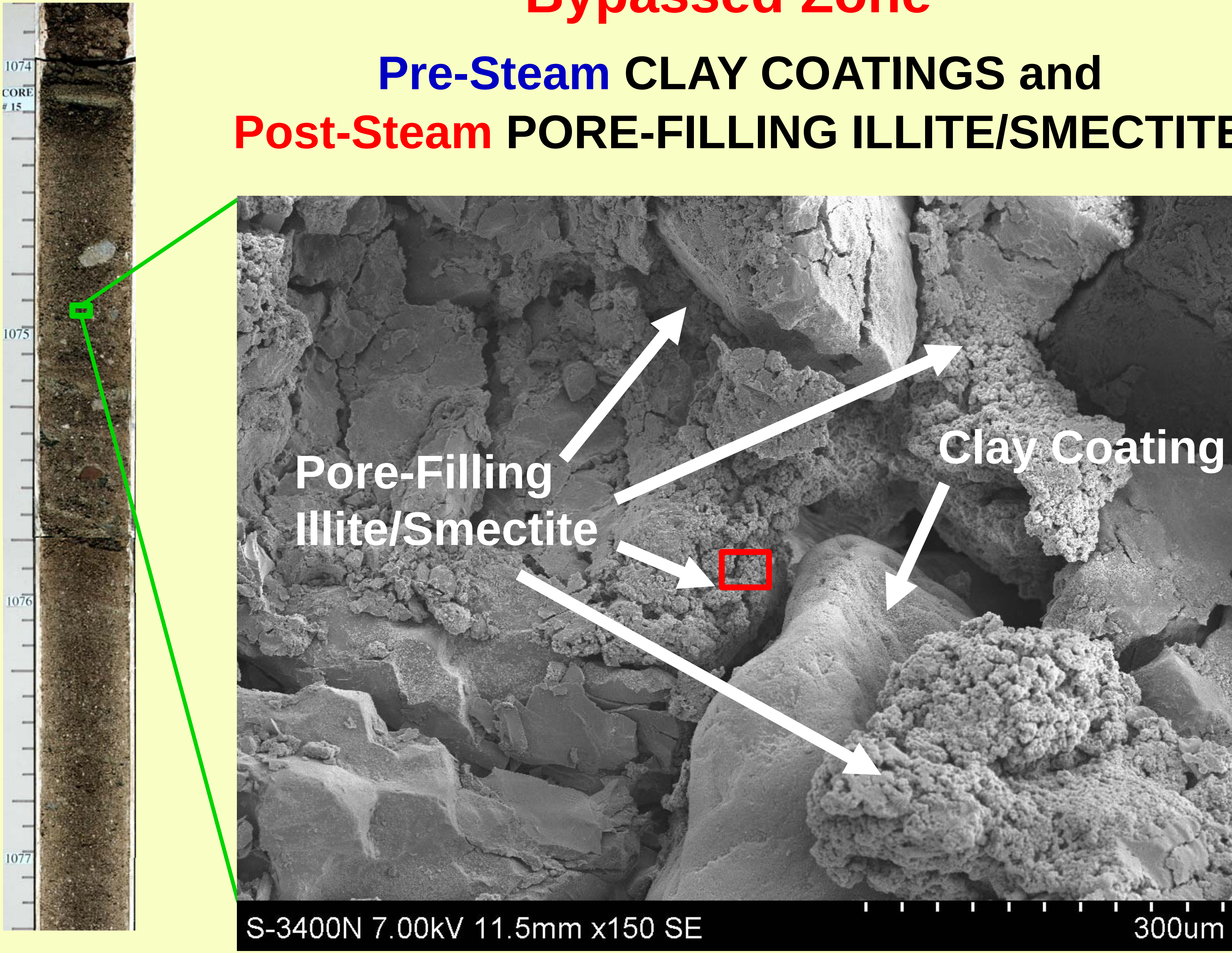
# Bypassed Zone

## PRE-STEAM CLAY COATING PRESERVED AFTER HEATING



# Bypassed Zone

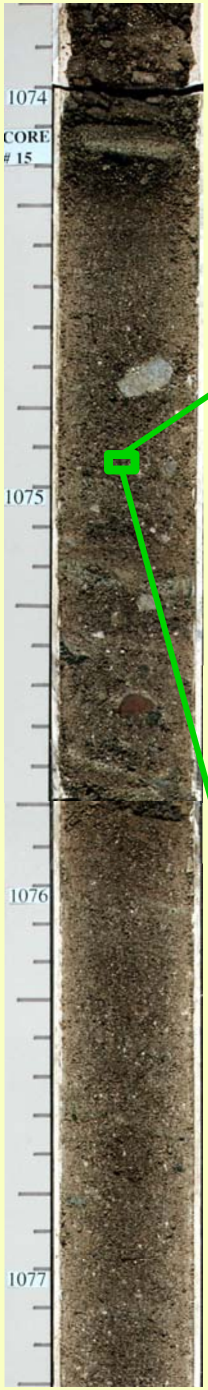
## Pre-Steam CLAY COATINGS and
## Post-Steam PORE-FILLING ILLITE/SMECTITE

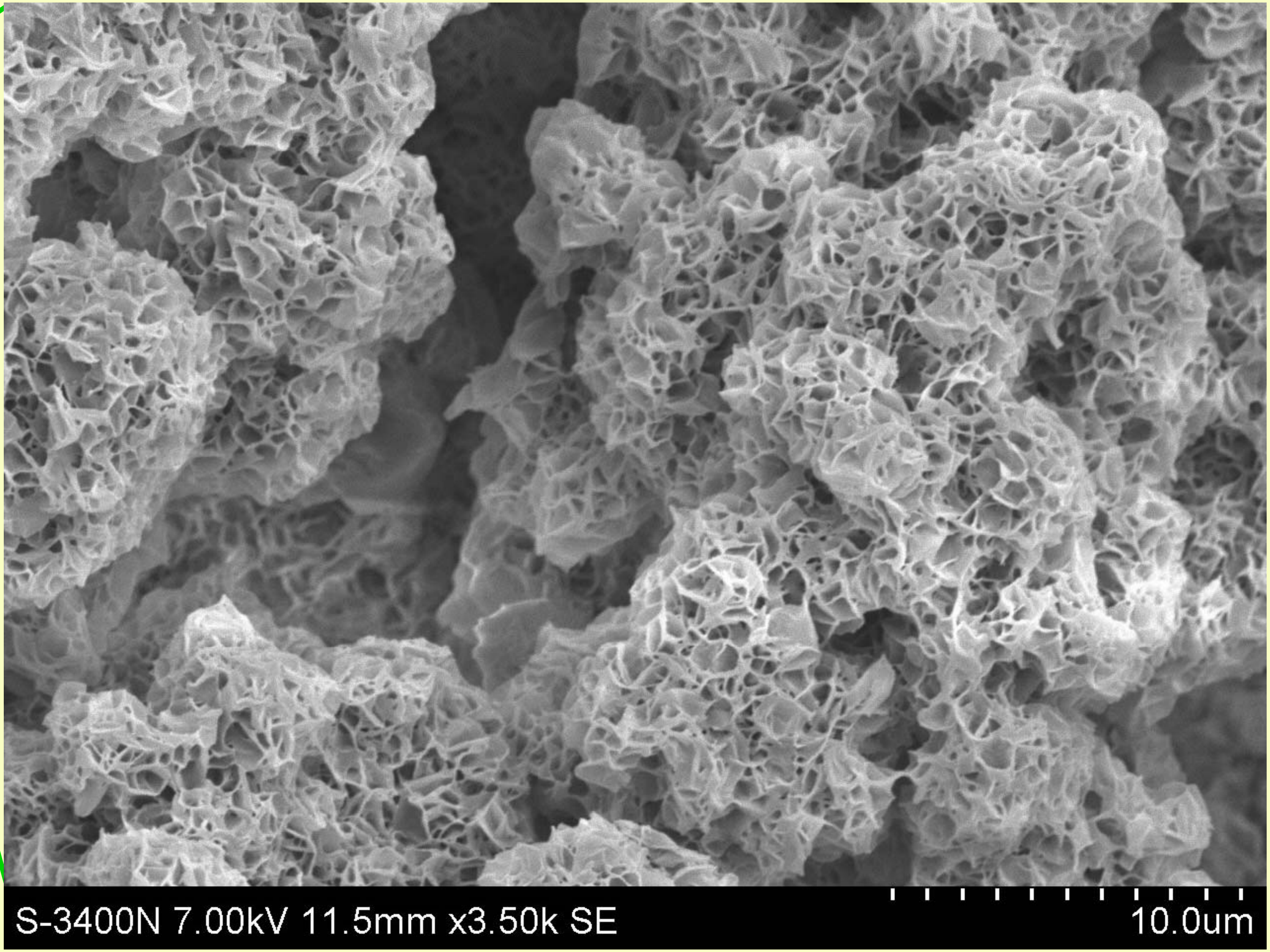


# Bypassed Zone

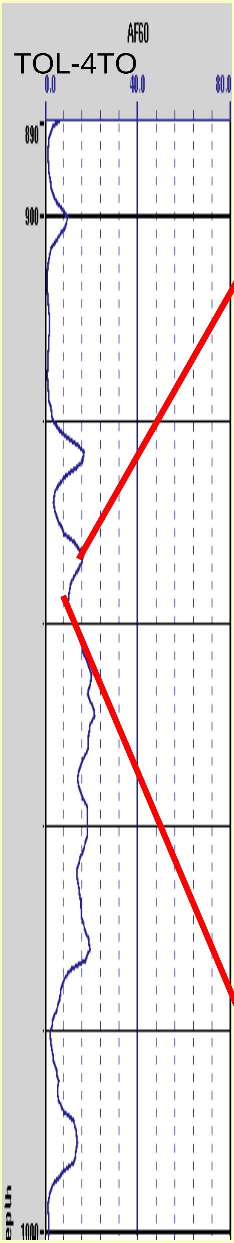
**Post Steam** PORE-FILLING MIXED-LAYER ILLITE/SMECTITE

HIGH POROSITY BUT RESTRICTED PORE NETWORK



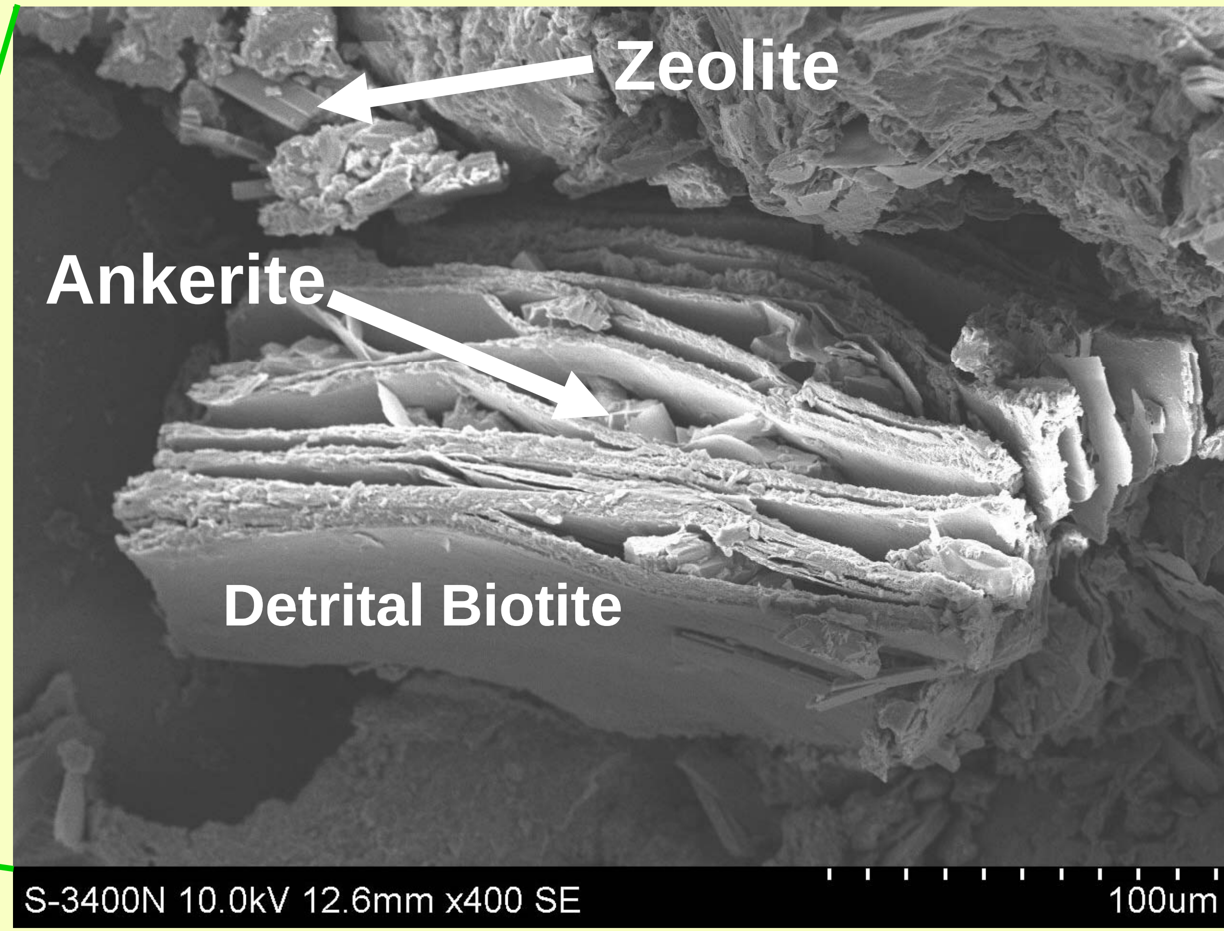



# Produced Sand



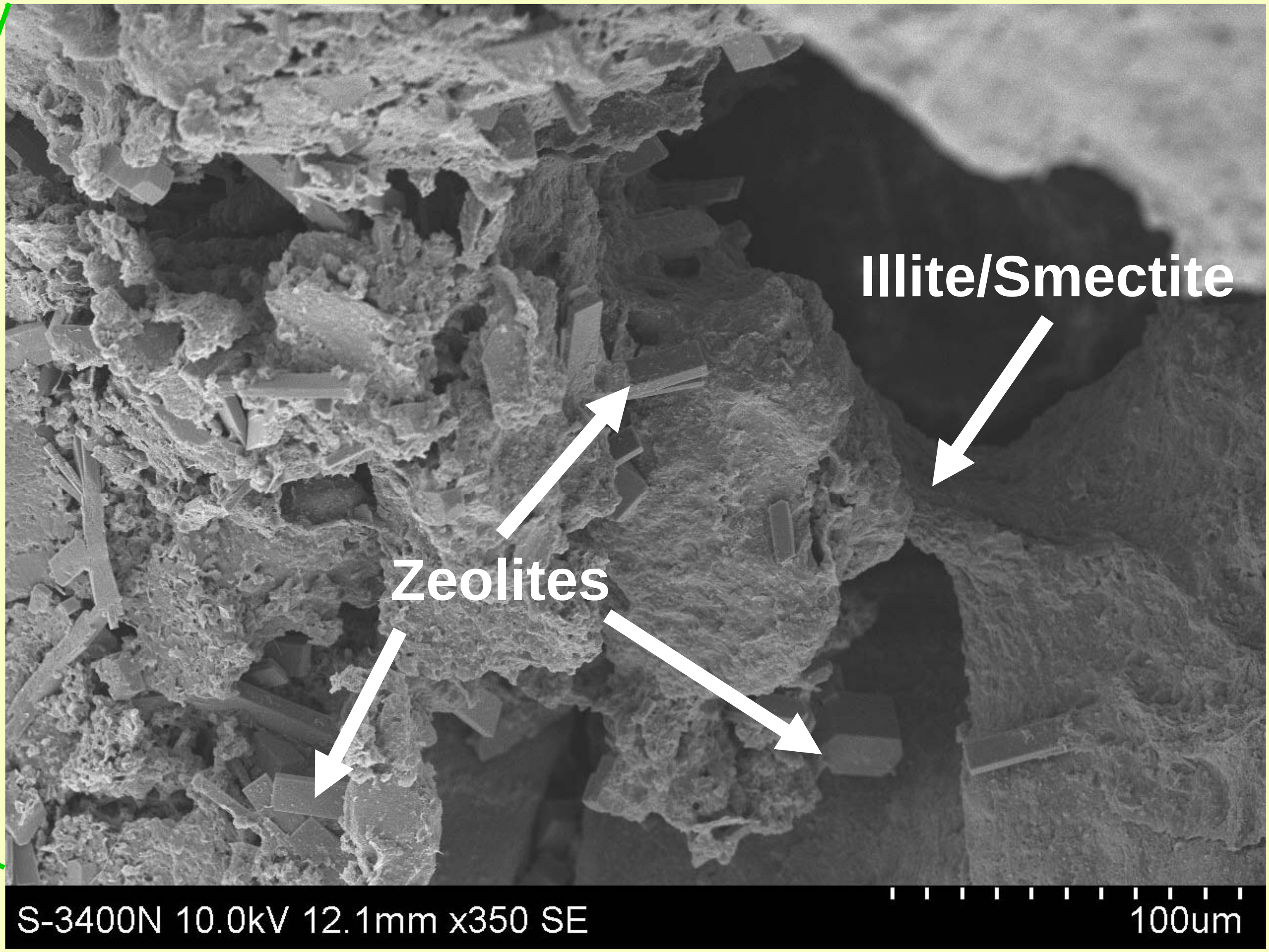


## CARBONATES AND ZEOLITES FORMED DURING HEATING



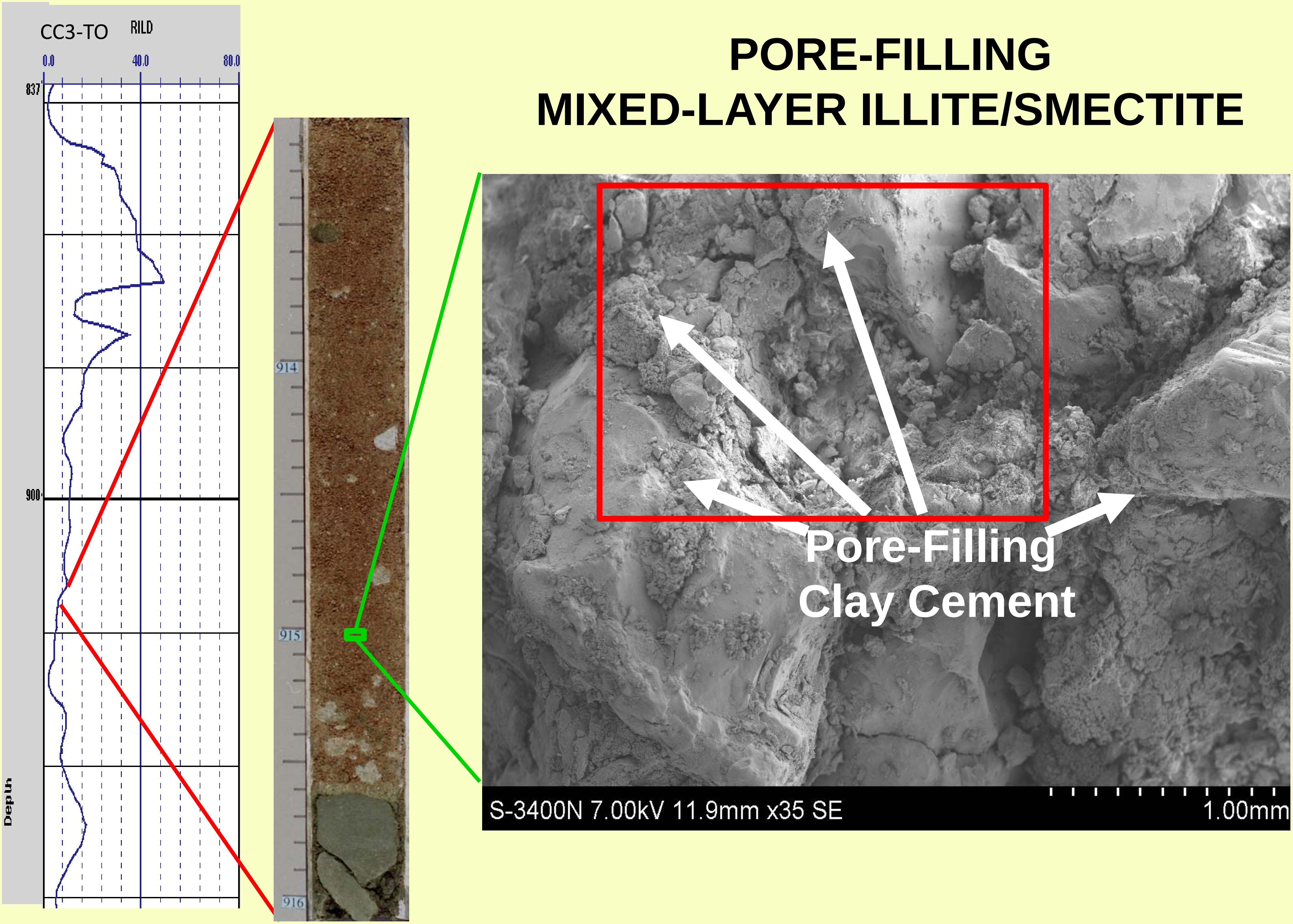
# Produced Sand

## PORE-BRIDGING ILLITE/SMECTITE
## ZEOLITES

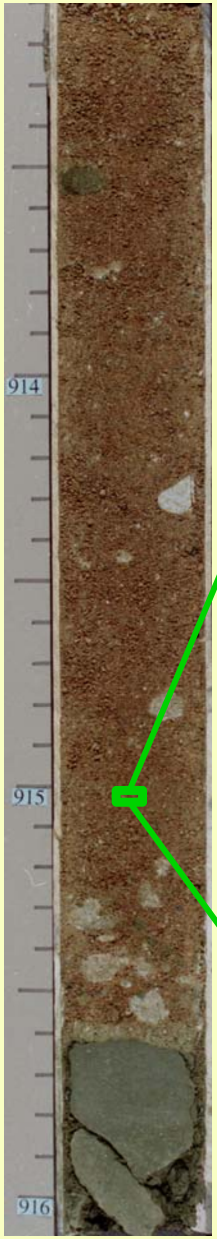
# Produced Sand

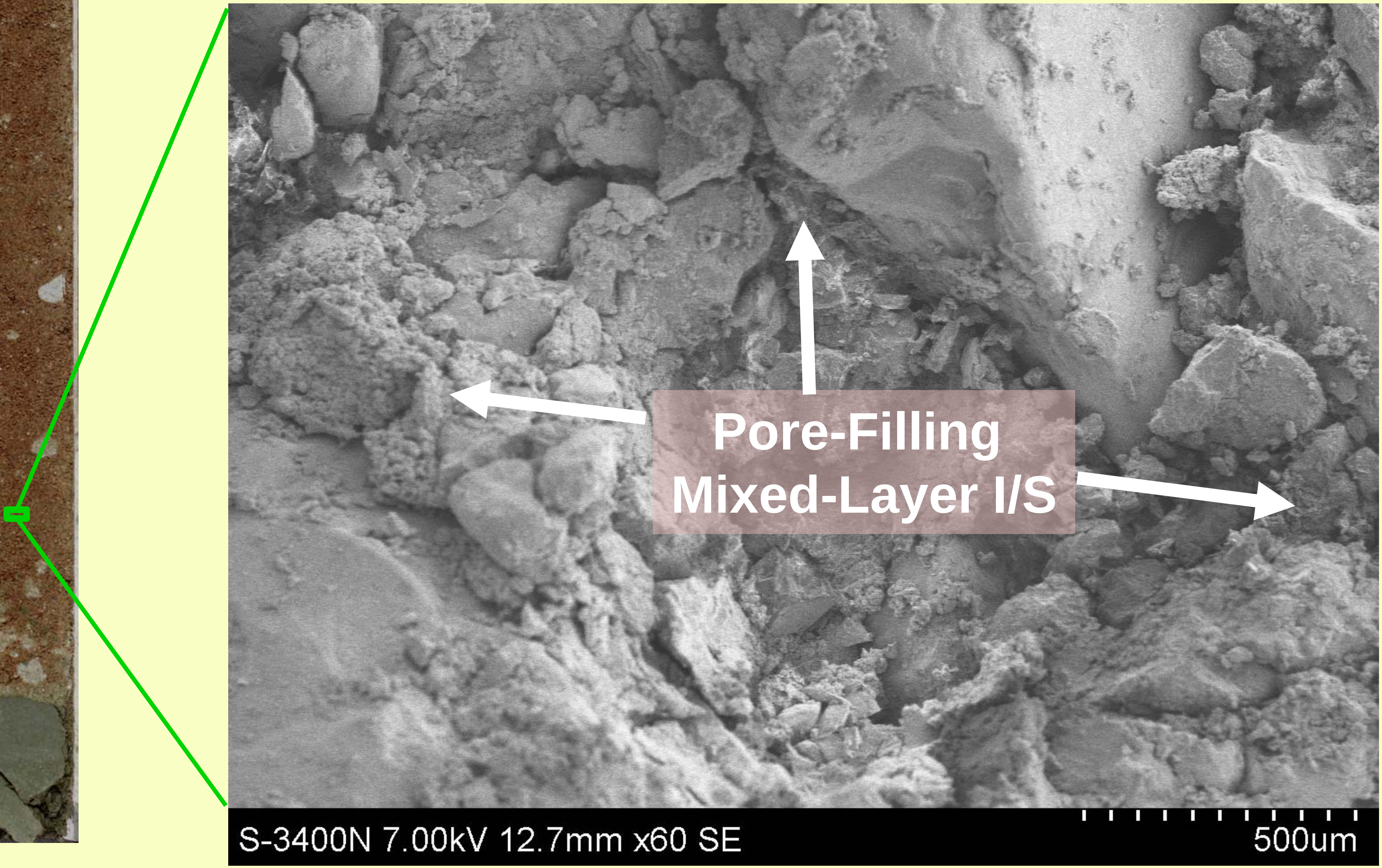
## PORE-FILLING
## MIXED-LAYER ILLITE/SMECTITE



## Produced Sand

# PORE-FILLING ILLITE/SMECTITE



# CONCLUSIONS

- **Bypassed oil resides in sediments with gradually decreasing resistivity curves at their bases**
- **The decreasing resistivity curves reflect a change from moderately sorted sands to poorly sorted gravels with less open pore networks**

# CONCLUSIONS

- **Heating during steam injection resulted in dissolution of feldspars, decomposition of rock fragments, changes in clay compositions, and precipitation of pore-filling mixed-layer illite/smectite**

- **Precipitation of mixed-layer illite/smectite may have reduced permeability thereby resulting in diminished production**

# CONCLUSIONS

- **This shows the usefulness of obtaining cores and studying the rocks to augment well logs and other geophysical or petrophysical data when characterizing a reservoir and planning an EOR program**