Diagenesis of Organic-Rich Shale: Views from Foraminifera *Penetralia*, Eagle Ford Formation, Maverick Basin, Texas*

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Abstract

Diagenetic studies for conventional reservoirs is well-established by the petroleum industry to better understand the geologic controls of reservoir quality, designing appropriate completion fluids, and evaluating potential rock-fluid changes during primary and enhanced recovery. Until recently, shales were not considered as important petroleum reservoirs, and industry interest in shale diagenesis has been much more limited, mainly concentrated on clay diagenesis, fluid expulsion and the genesis of overpressure. Recent advances in sample preparation and scanning electron microscope (SEM) techniques have allowed researches to adequately image clay-sized gains and to peer into nanometer scale pores that lie beyond the capabilities of optical microscopy. This study presents new methods and observations using color-enhanced backscattered electron SEM images to interpret mineral cement and organic matter paragenesis to develop a diagenetic model for Eagle Ford organic-rich shale and reservoir quality evolution. Planktonic foraminifera tests are abundant and widespread in the Eagle Ford shale of south Texas. The initially hollow internal chambers of these minute foraminifera tests (commonly less than 100 mm long) provide sturdy and stable miniature crucibles that offer a unique opportunity to study the evolution of diagenetic products resulting from changing thermo-chemical reactions during sediment burial. Cement mineralogy and paragenesis within a single SEM specimen differs between foraminifera chambers the interparticle pores found within the surrounding calcareous and siliceous matrix. These differences may reflect fluid flow circulation and chemistry differences between the relatively isolated and restricted foraminifera chambers and the more open matrix pore network.

References Cited

Camp, W.K., E. Diaz, and B. Wawak, 2013, Electron microscopy of shale hydrocarbon reservoirs: AAPG Memoir 102, 260 p.

Jarvie, D.M., R.J. Hill, T.E. Ruble, and R.M. Pollastro, 2007, Unconventional shale-gas systems: The Mississippian Barnett Shale of north-central Texas as one model for thermogenic shale-gas assessment: AAPG Bulletin, v. 91/4, p. 475-499.

Diagenesis of Organic-Rich Shale: Views from Foraminifera Penetralia, Eagle Ford Formation, Maverick Basin, Texas

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AAPG Rocky Mountain Section

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Purpose

Preliminary results of a study to address three main questions:

1. Do cements exist in shale (mudstone) reservoirs?
2. How can cements be identified?
3. What are the potential diagenetic impacts on reservoir quality and completion response?

Outline

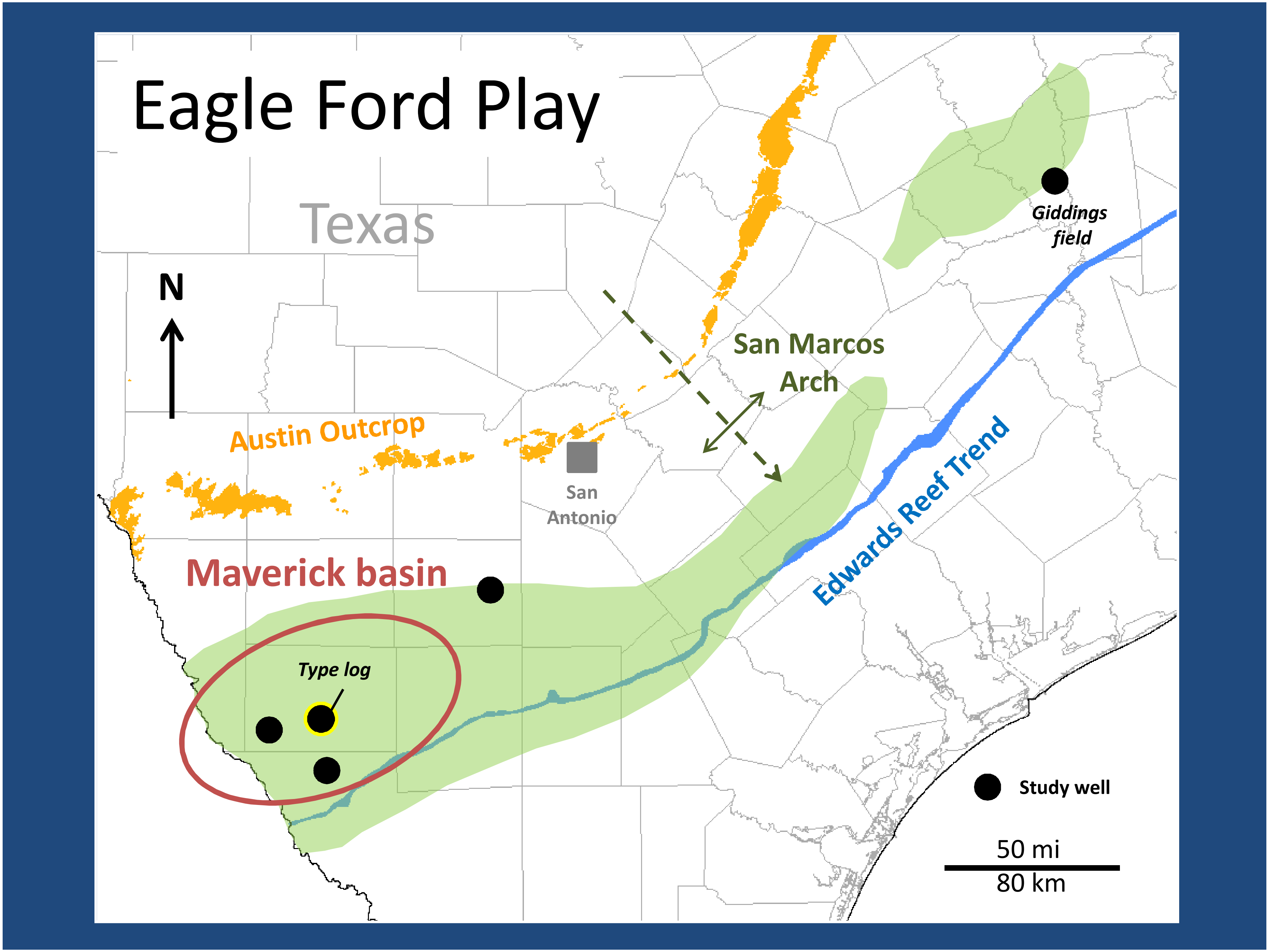
- Introduction
- Methodology
- Observations
  - Cements
  - Porosity
- Diagenetic Model
- Summary

Diagenesis

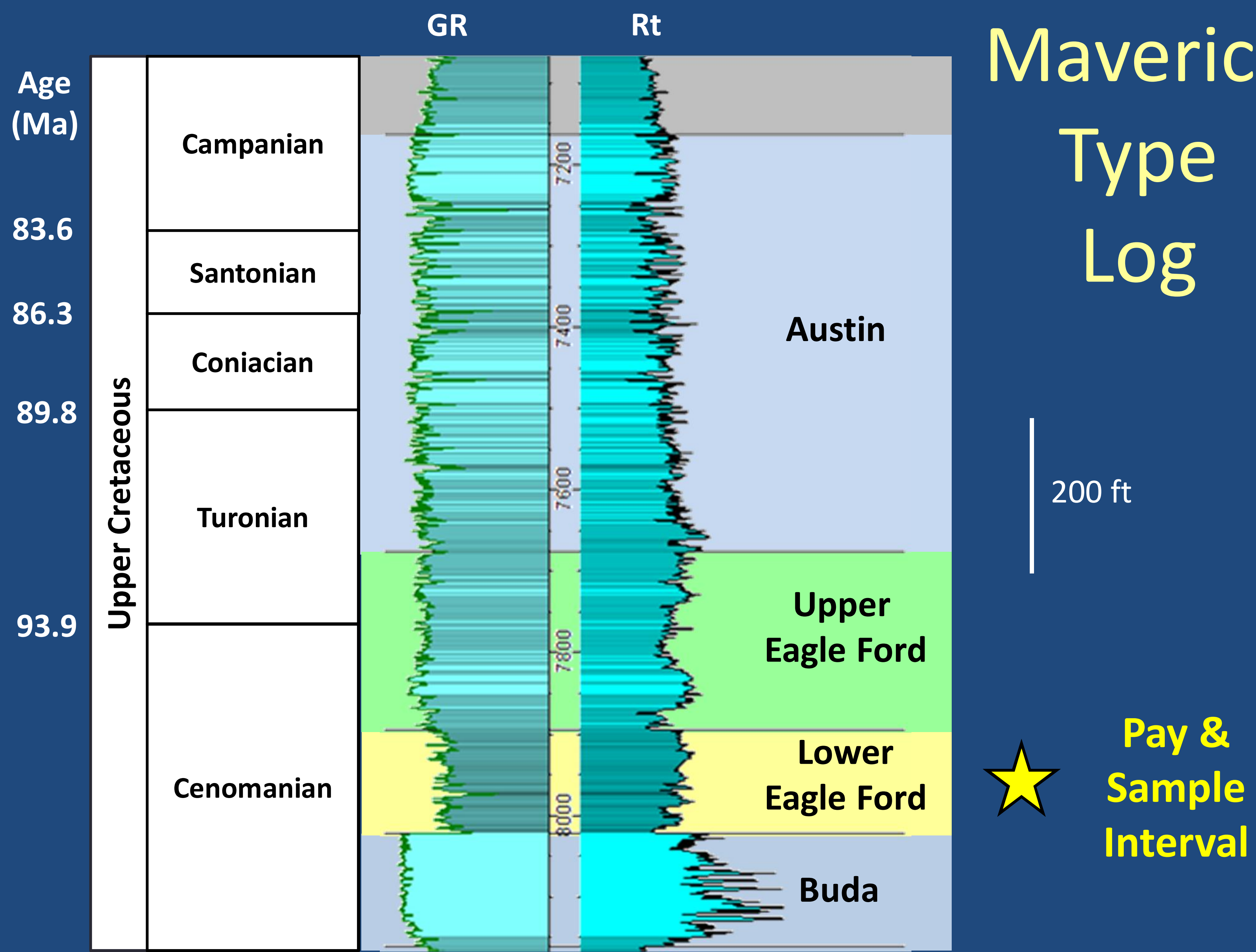
- Pre-metamorphic physical and chemical changes of sediments during burial
  - Physical Processes
    - Bioturbation
    - Compaction
  - Chemical Processes
    - Cementation
    - Grain replacement
    - Dissolution
    - *Hydrocarbon generation*

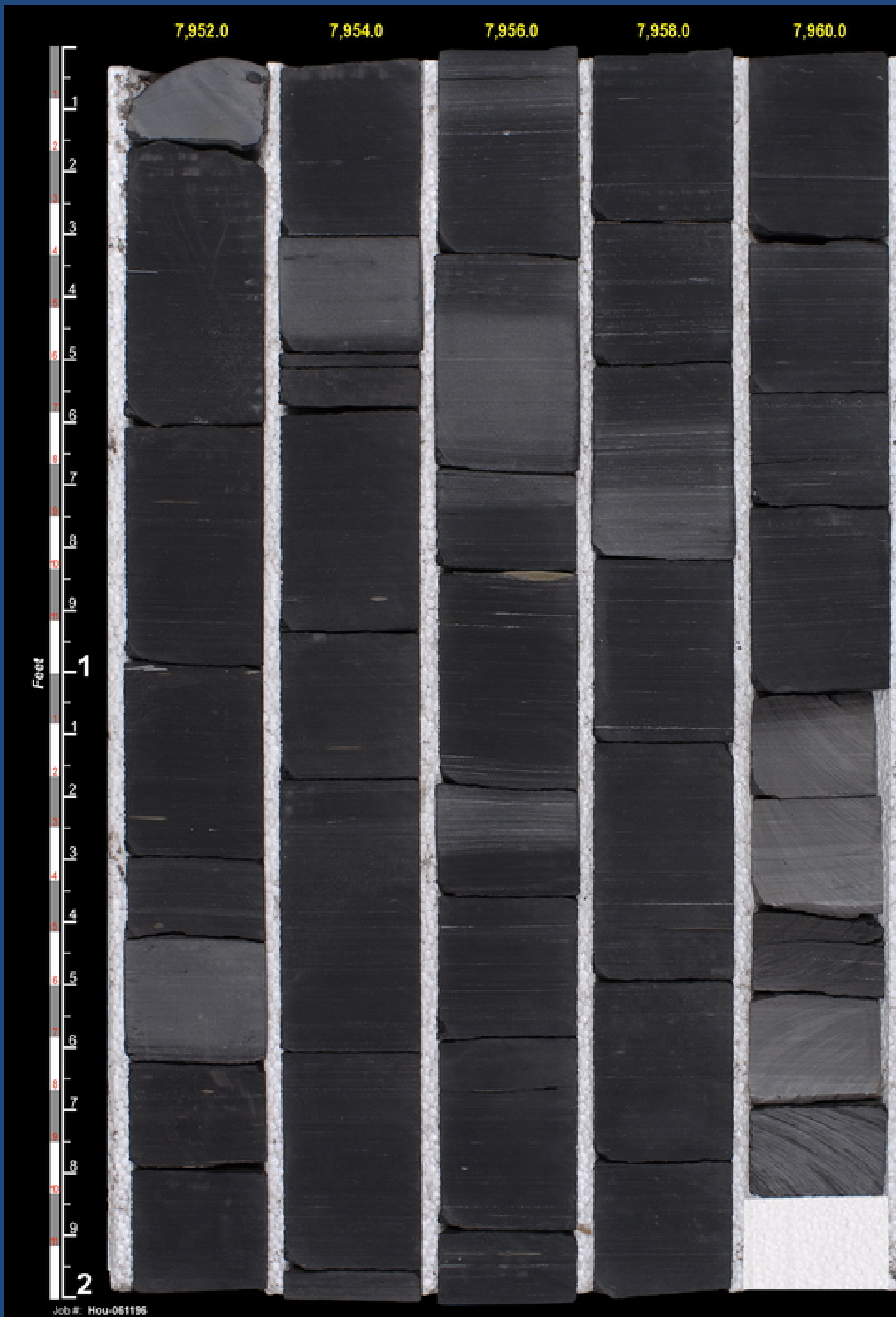
Potential Applications

- Reservoir quality
  - Porosity occlusion
  - Secondary porosity development
- Source rock quality
  - Type and maturation of organic matter
  - Organic matter porosity
- Mechanical properties
  - Grain fabric, rigidity
- Fluid sensitivity


Eagle Ford Play
Texas
N
Austin Outcrop
San Antonio
San Marcos Arch
Giddings field
Edwards Reef Trend
Maverick basin
Type log
Study well
50 mi
80 km

Maverick Type Log





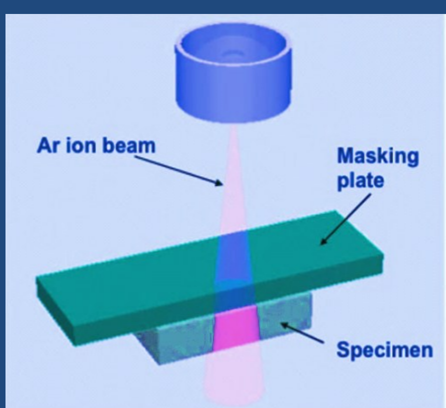
Lower Eagle Ford

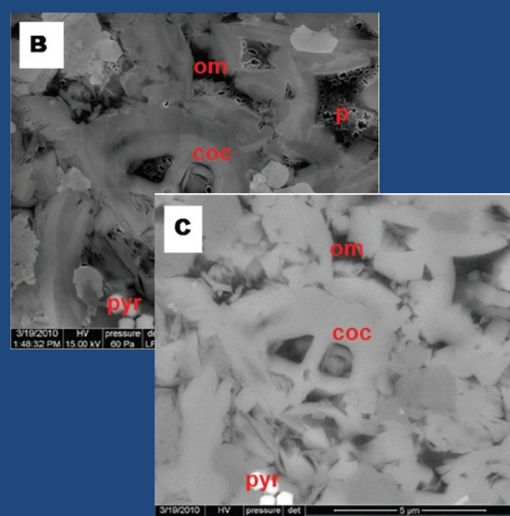
- Laminated, gray-dark gray, fossiliferous mudstone
- Organic rich (TOC > 2wt%)
- Local thin bentonite (volcanic ash) interbeds

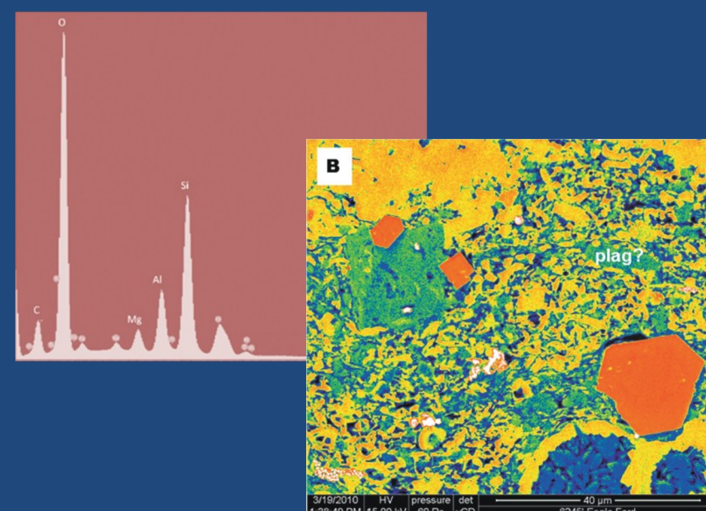
METHODOLOGY

SEM Methodology

- Ar-ion milled, uncoated, FE-SEM imagery
  - Backscattered (BSE) & secondary electron (SE)
  - EDS mineral identification
  - Pseudocolor enhancement





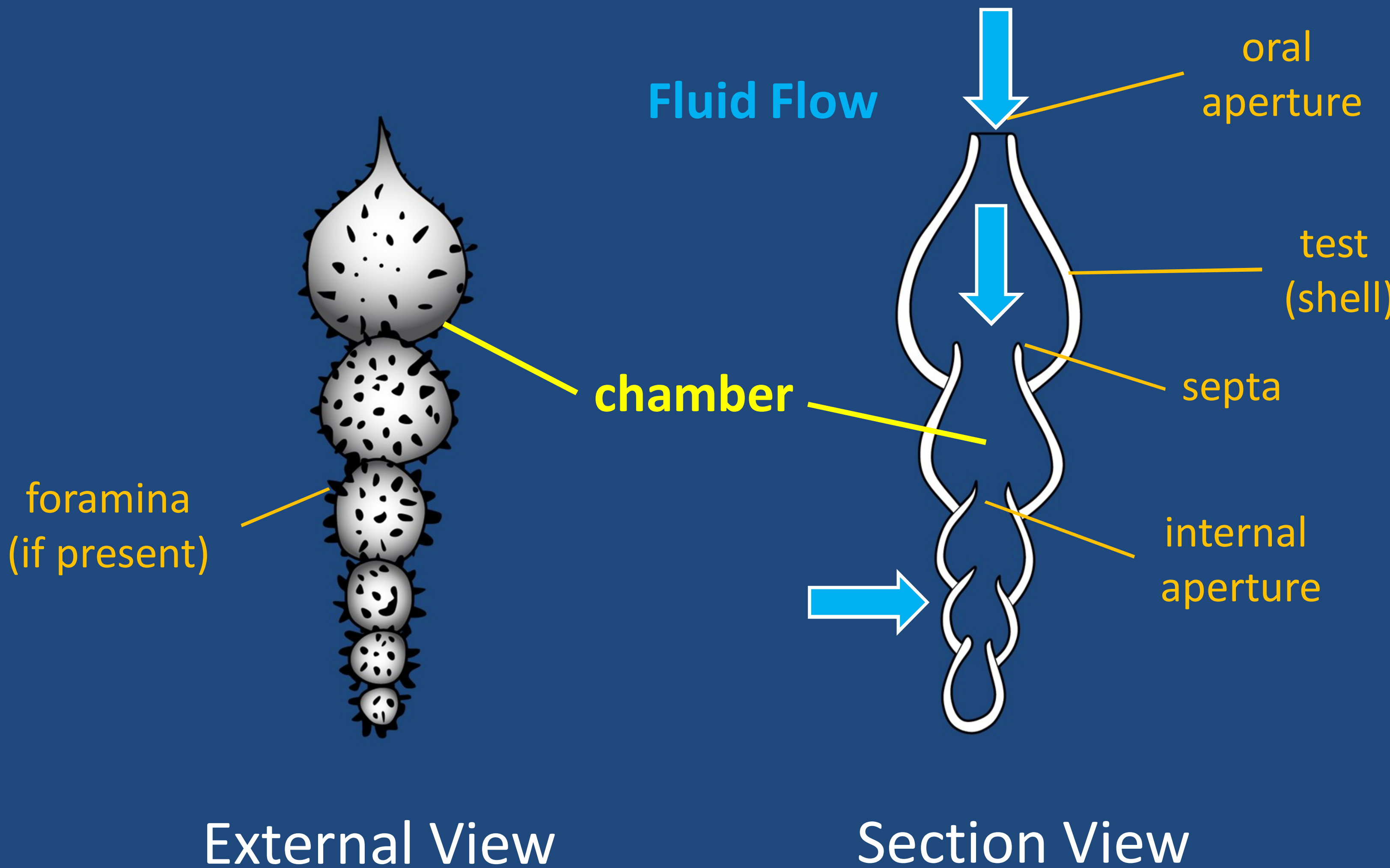


AAPG Memoir 102 (2013)

Why Forams?

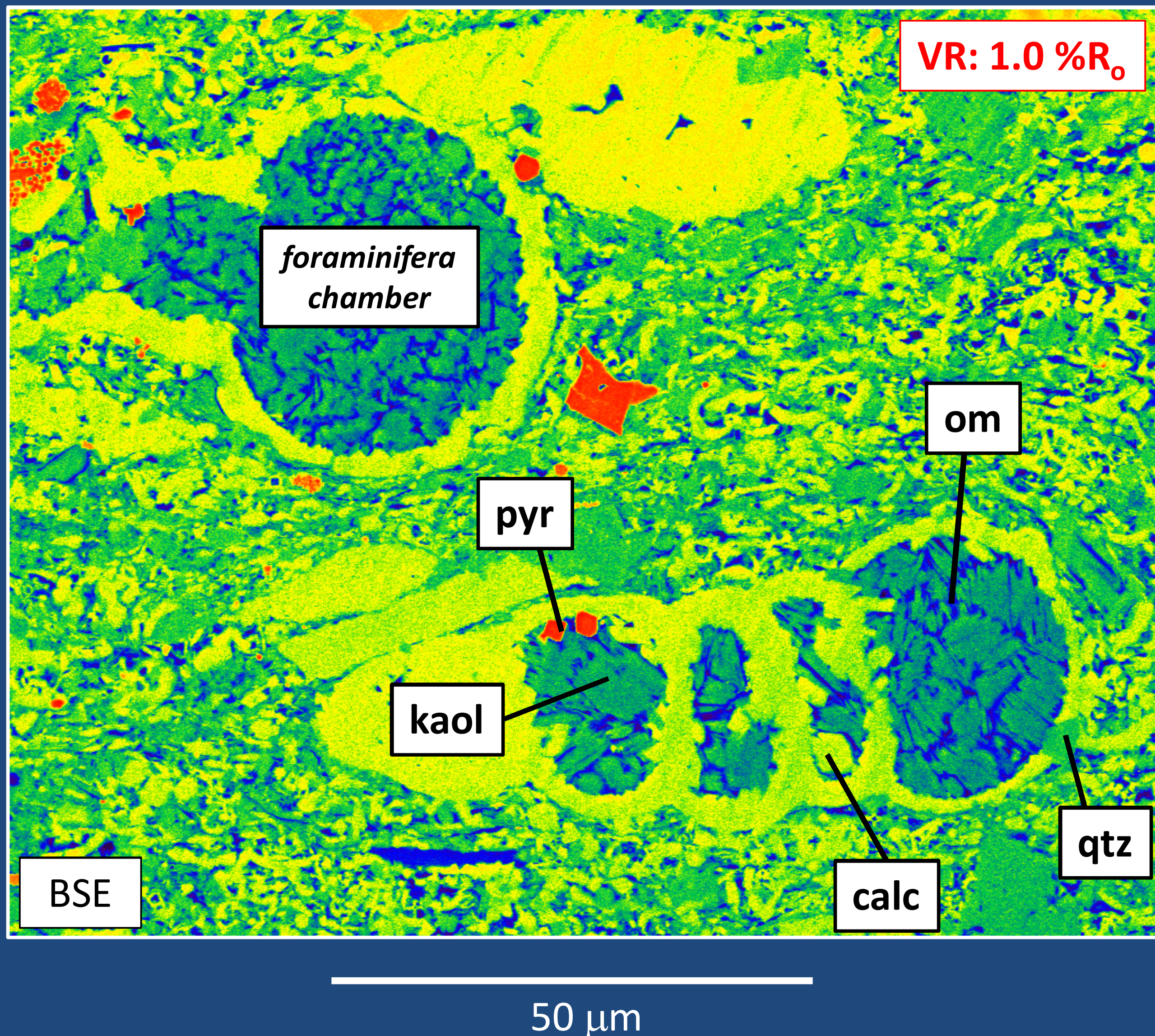
- Foraminifera chambers provide a sturdy, stable and fairly uniform "crucible" from which to study thermo-chemical reactions (diagenetic products)
- Chambers originally void and significantly larger than matrix pores
  - Facilitates interpretation and tie to optical petrography
- Abundant and widespread in Eagle Ford shale
  - Vertical and lateral (basin-scale) comparisons

Foraminifera Morphology

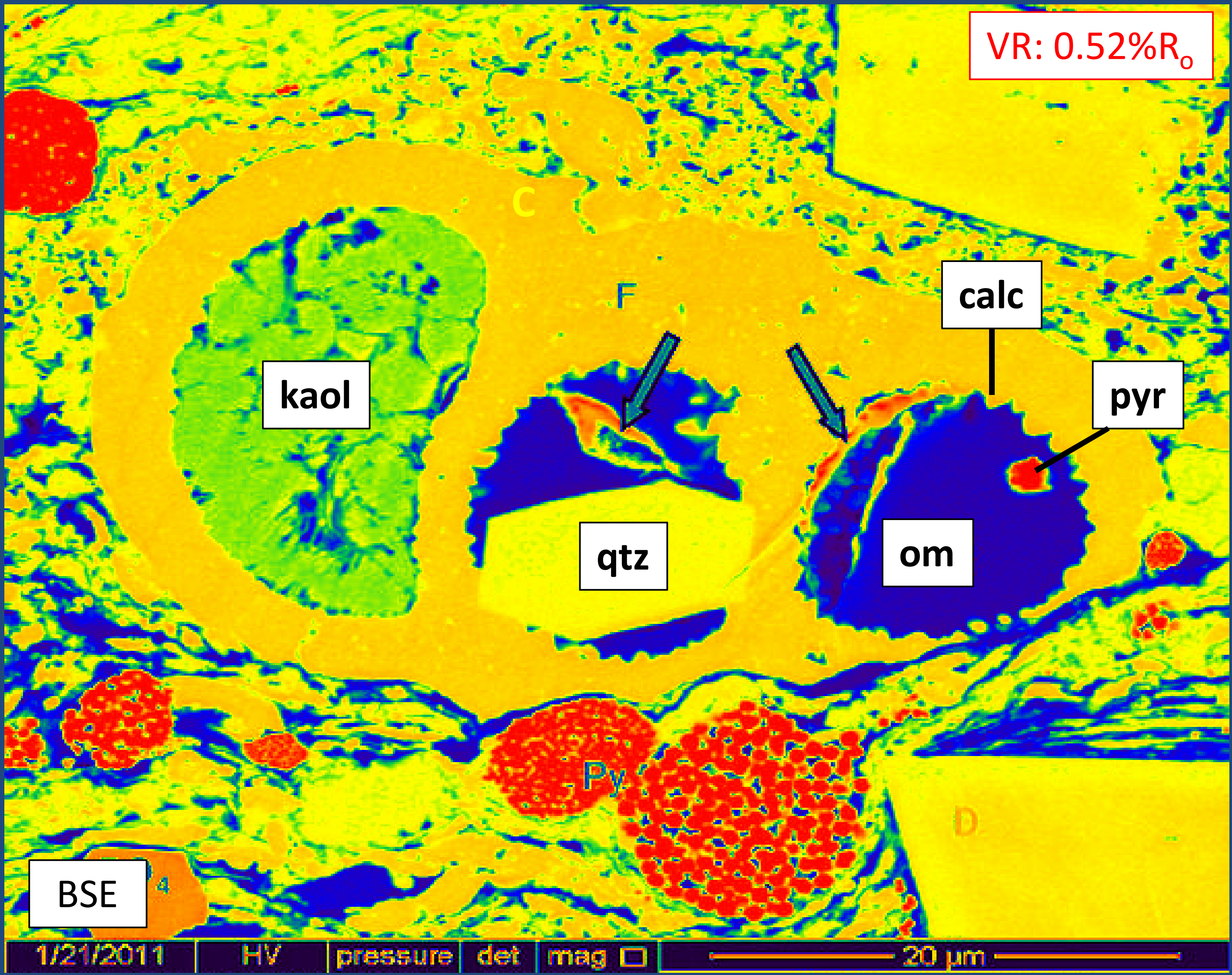


MINERAL CEMENTS

Foram Cements-Maverick (SW)

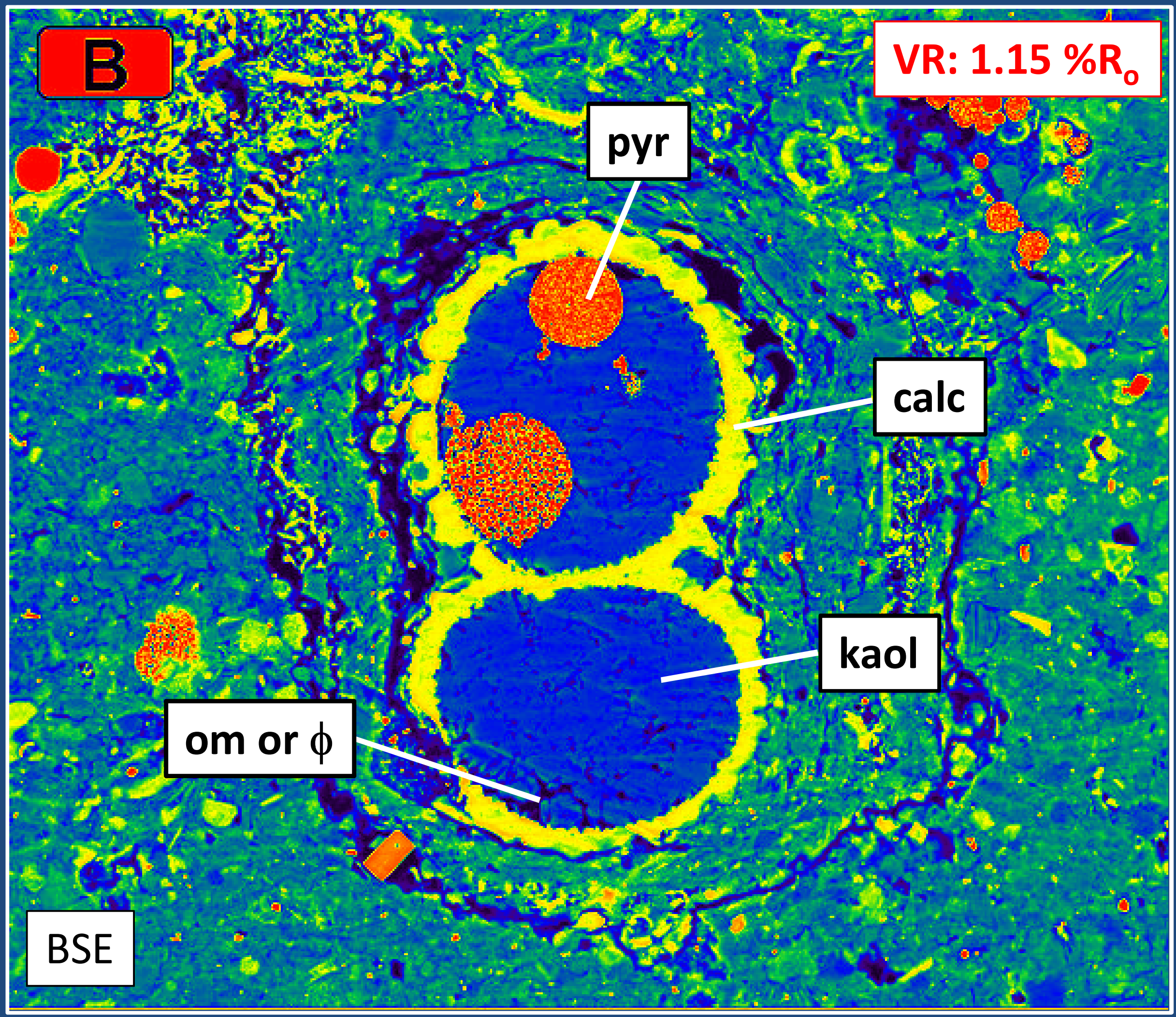


Foram Cements-Maverick (NE)



SEM image courtesy Core Laboratories

Foram Cements-Giddings



50 μm

ORGANIC CEMENTS

Dispersed Organic Matter (TOC Components)

immature — *Increasing thermal maturity* → *overmature*

Kerogen
(insoluble)

Bitumen
(soluble)

Oil
(liquid)

Residual Oil
(soluble)

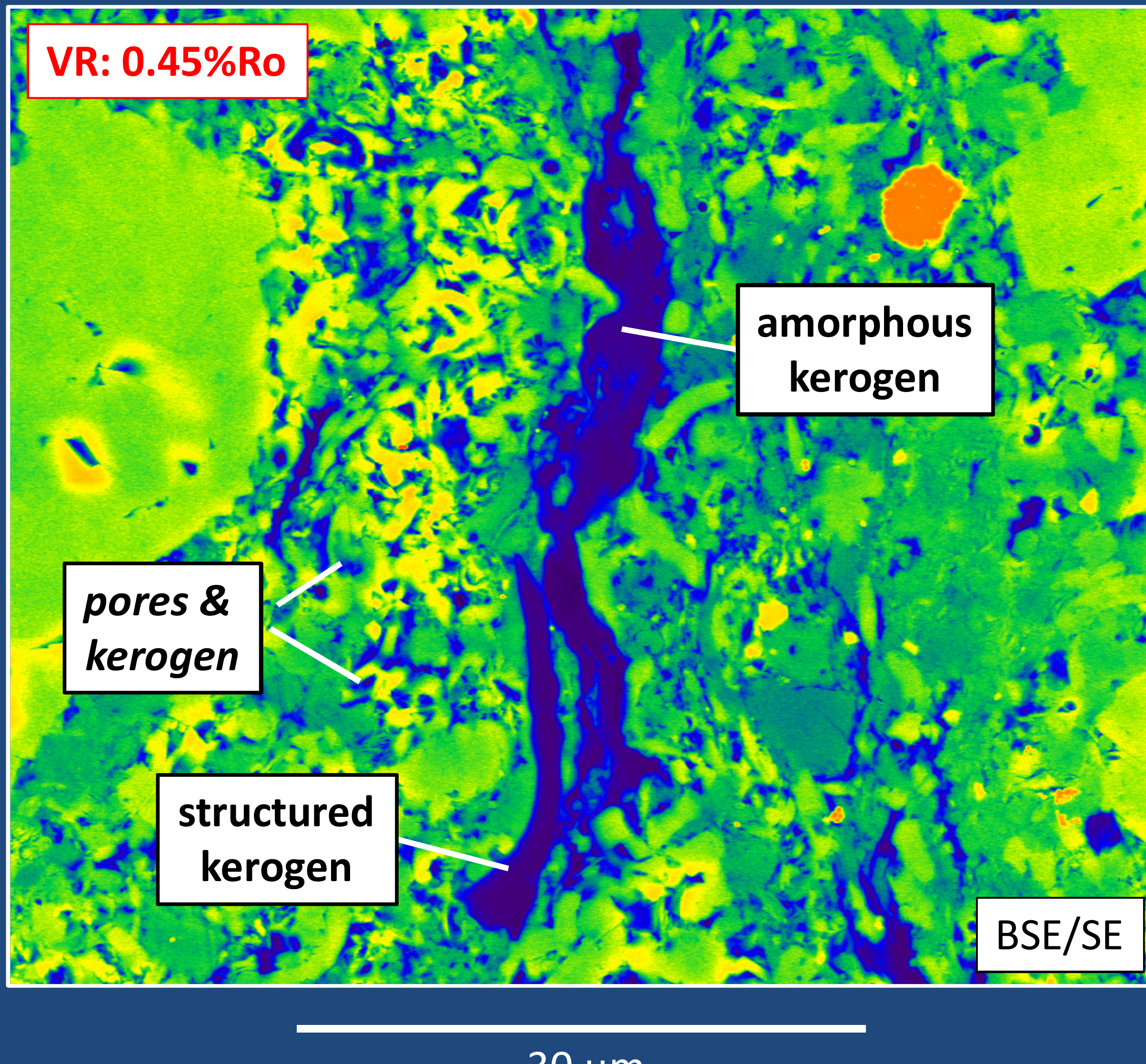
Pyrobitumen
(insoluble)

matrix

not imaged in SEM

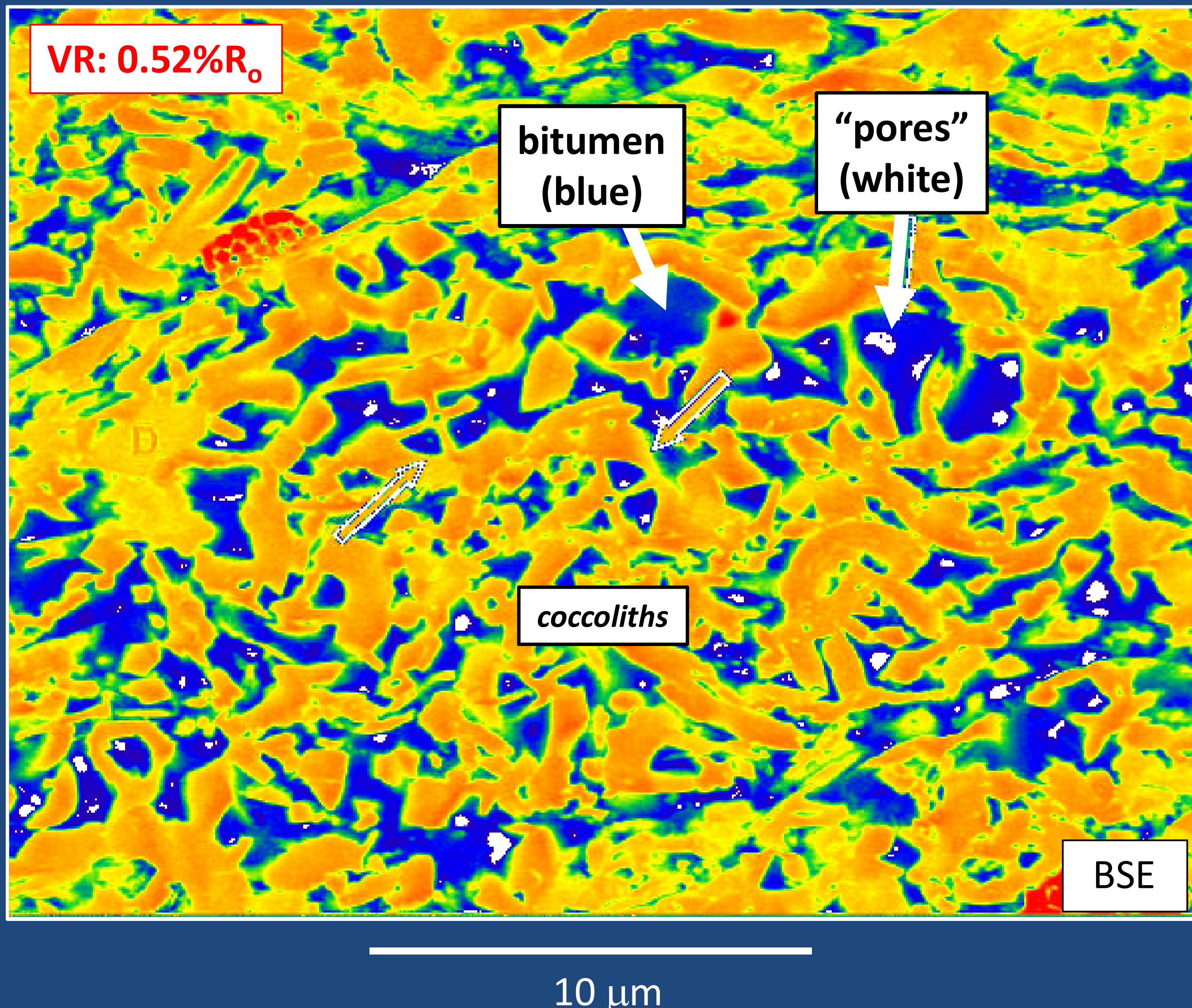
cements

Outcrop Kerogen (Matrix)



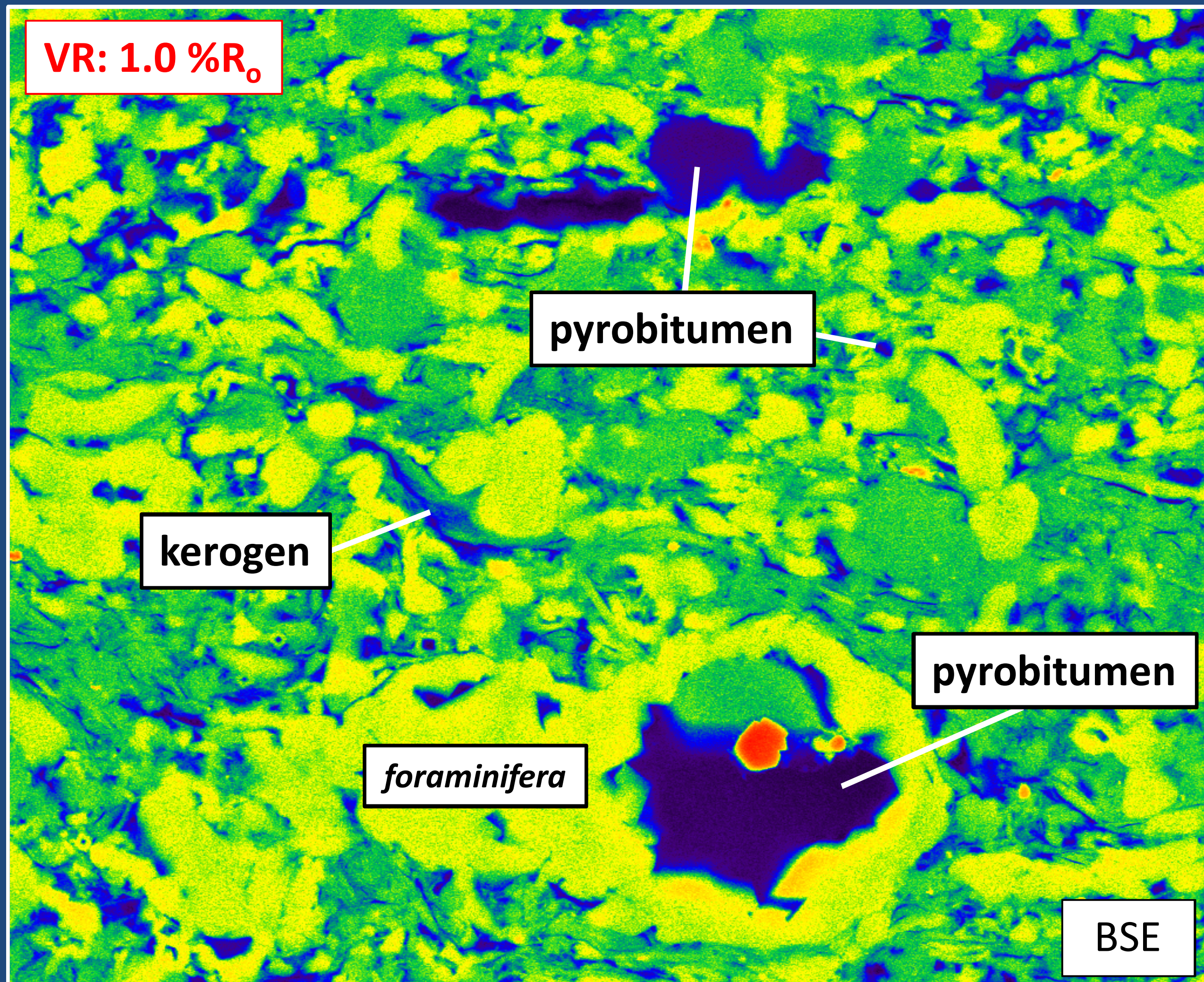
SEM image courtesy B. Wawak

Residual Oil (Migra-Bitumen)



SEM image courtesy Core Laboratories

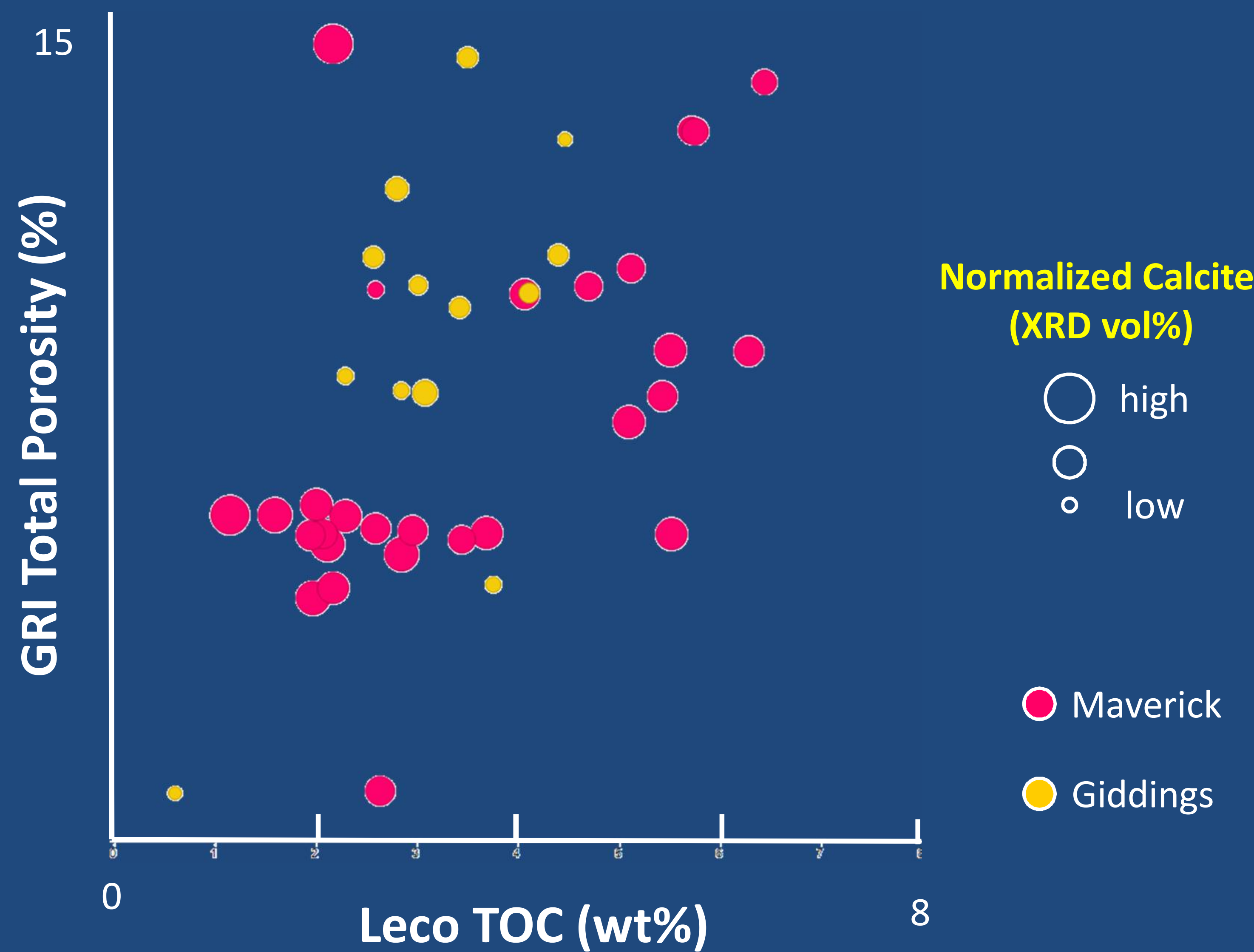
Pyrobitumen



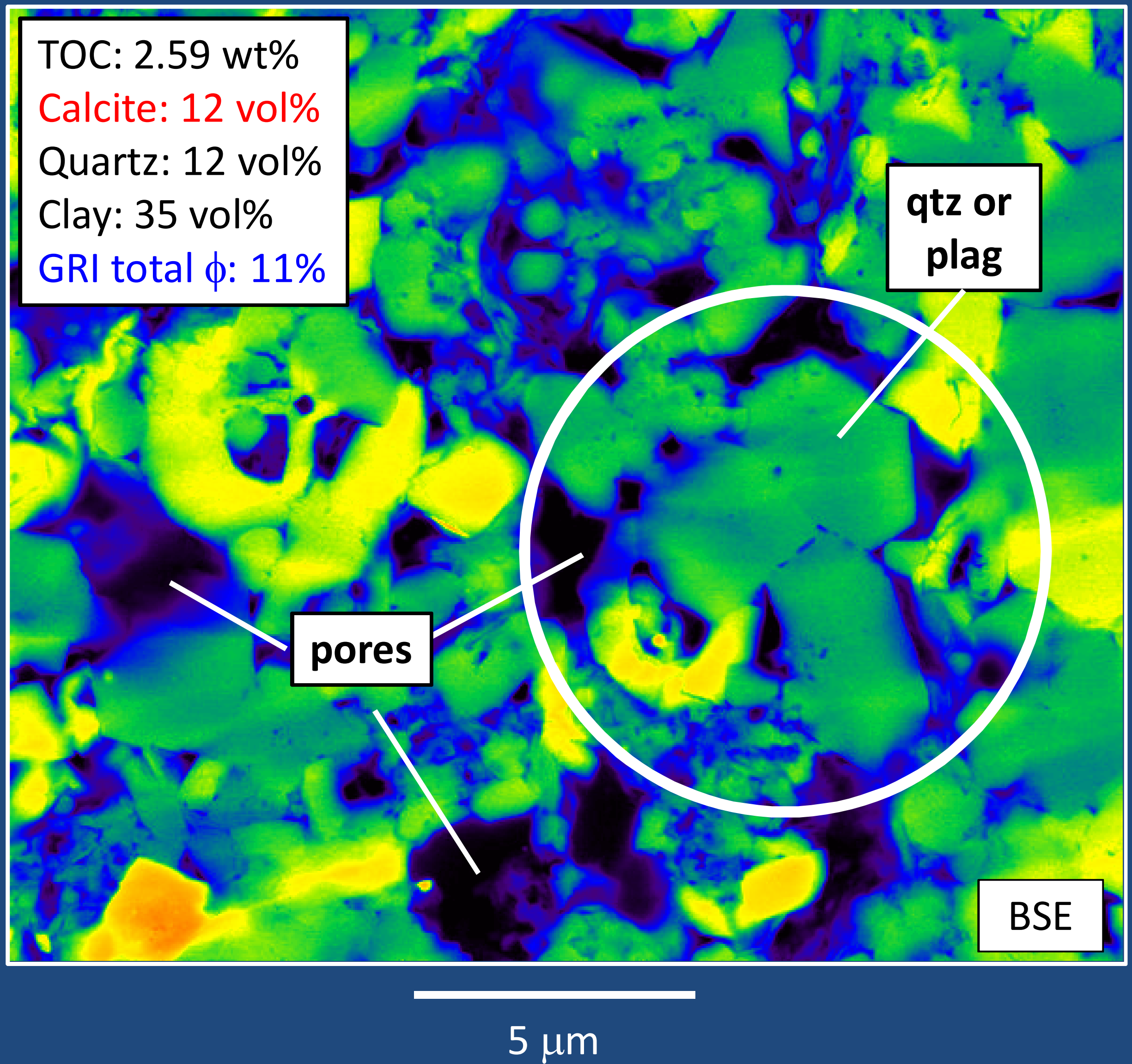
20 μm

MATRIX POROSITY

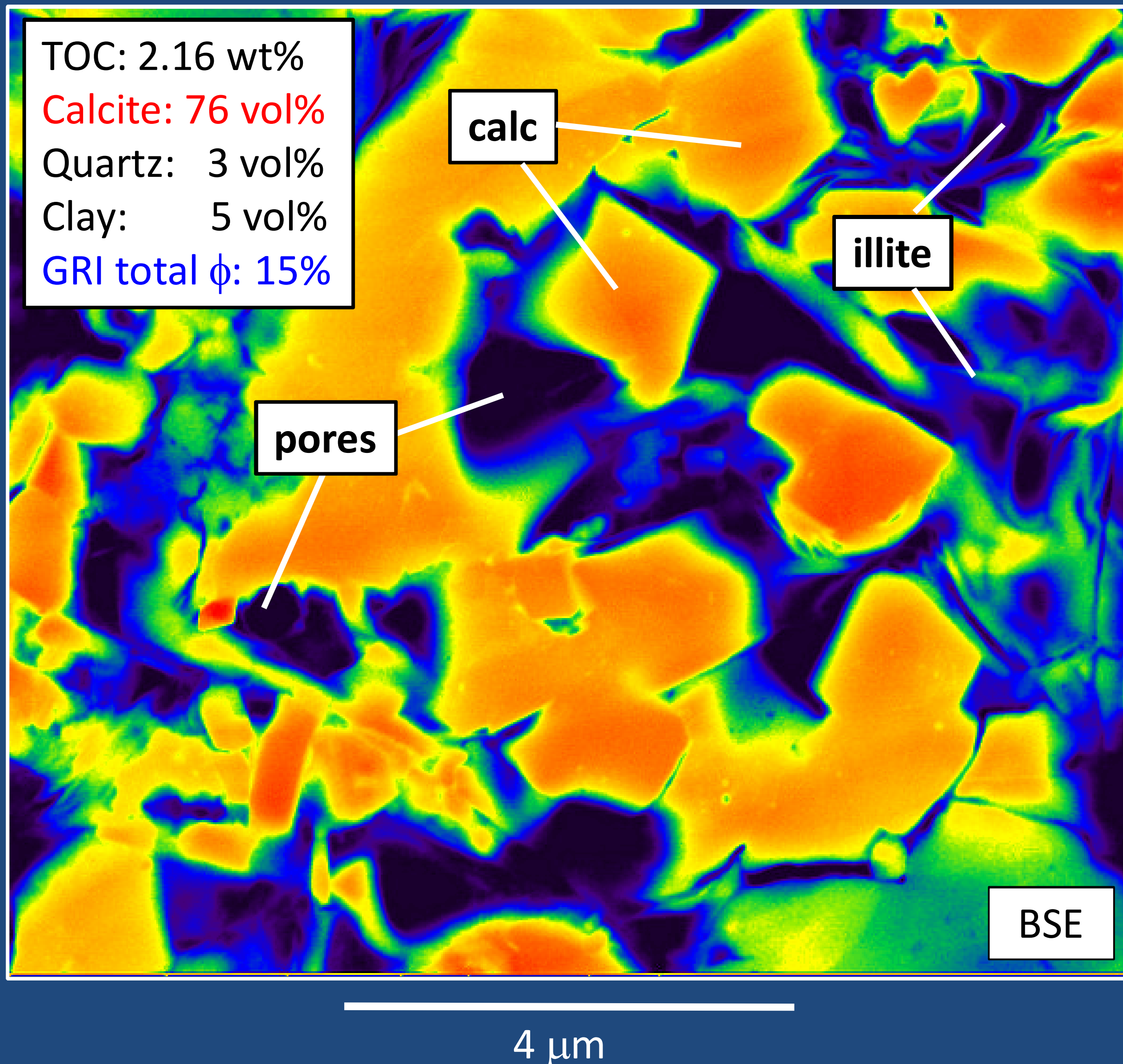
Calcite, TOC & Porosity



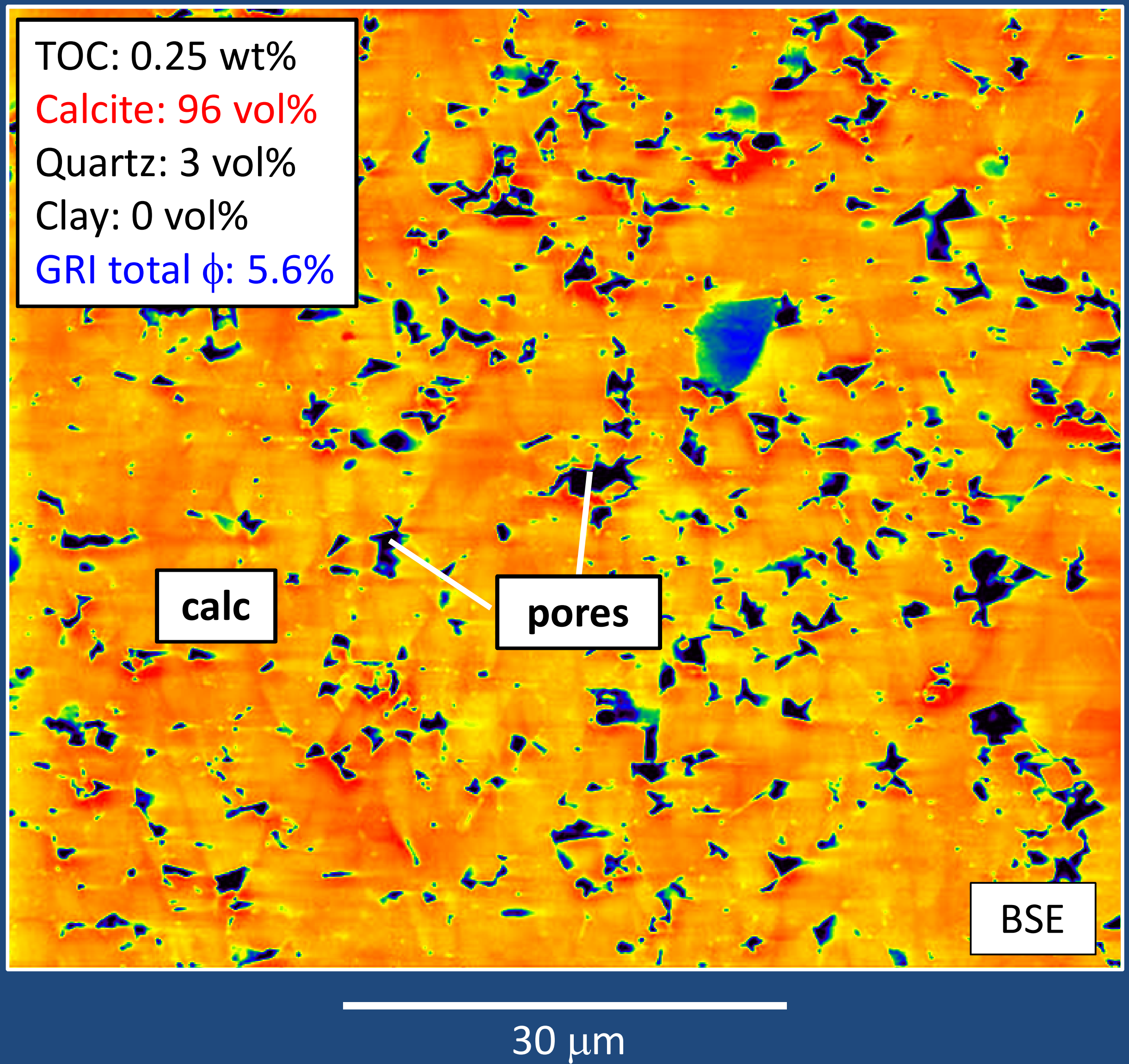
Matrix Overgrowths



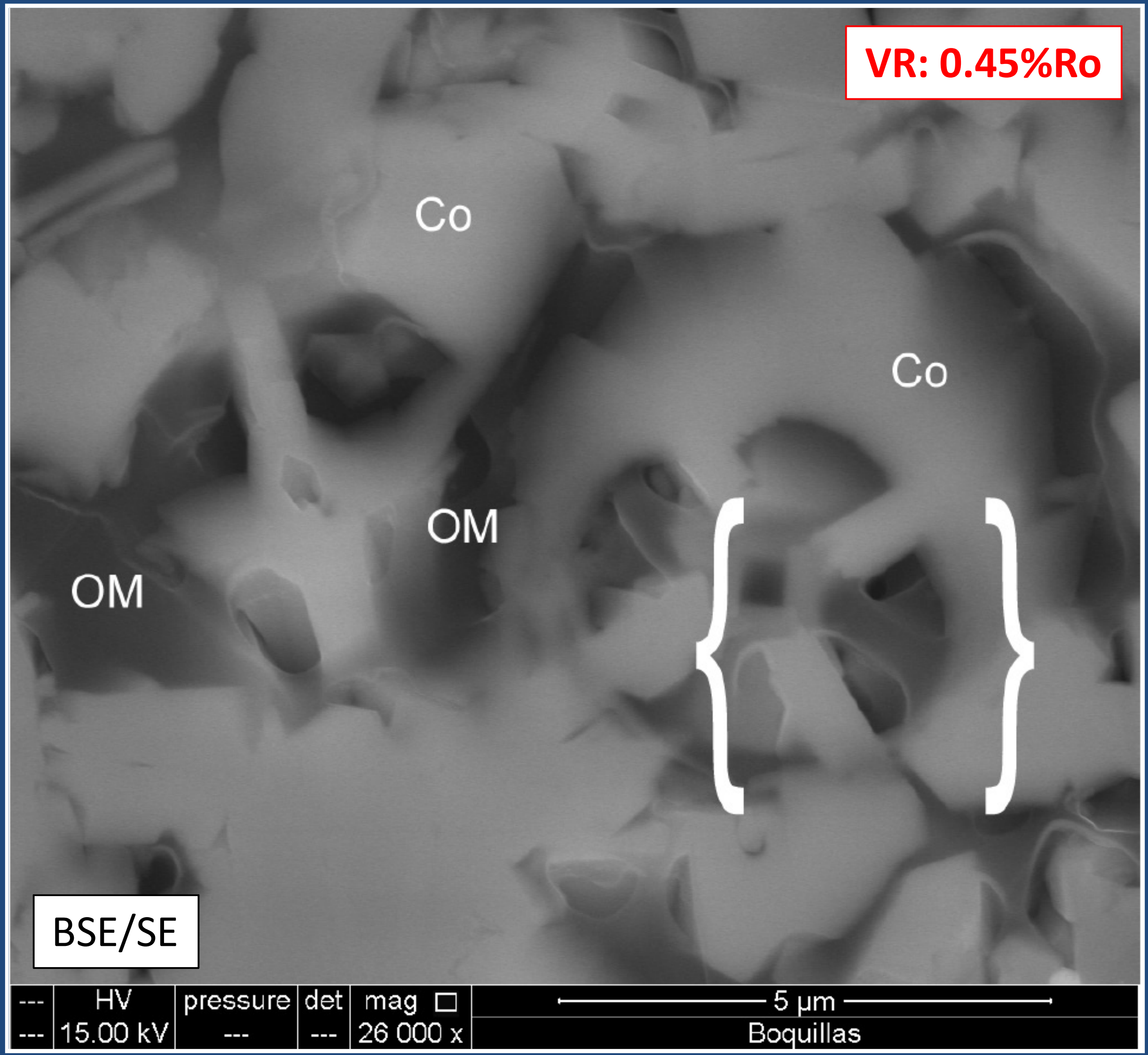
Matrix Calcite & Illite Cement



Calcite Cemented Matrix



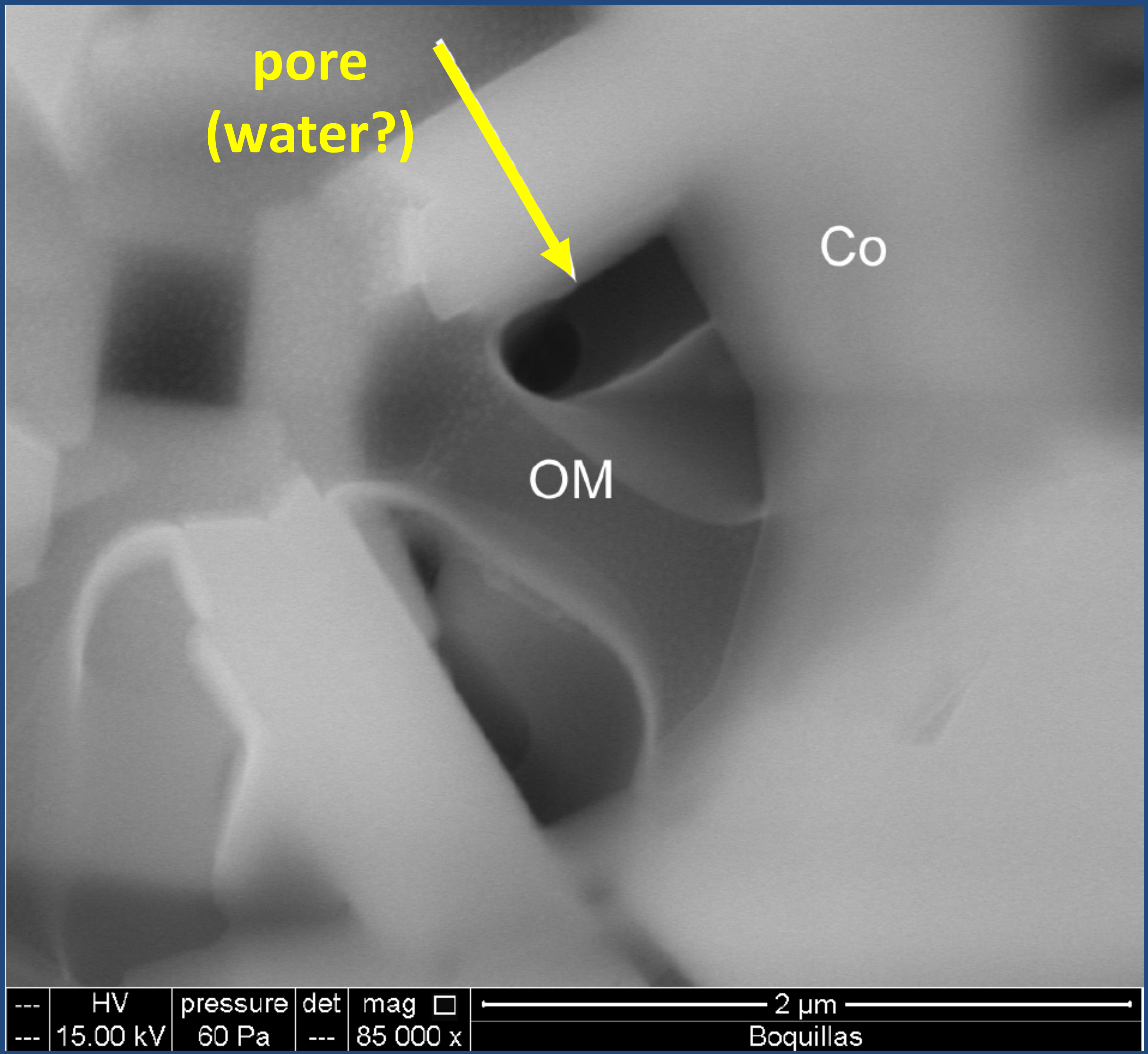
Pre-Oil Bitumen(?) Meniscus Cement



Enlarged area next slide

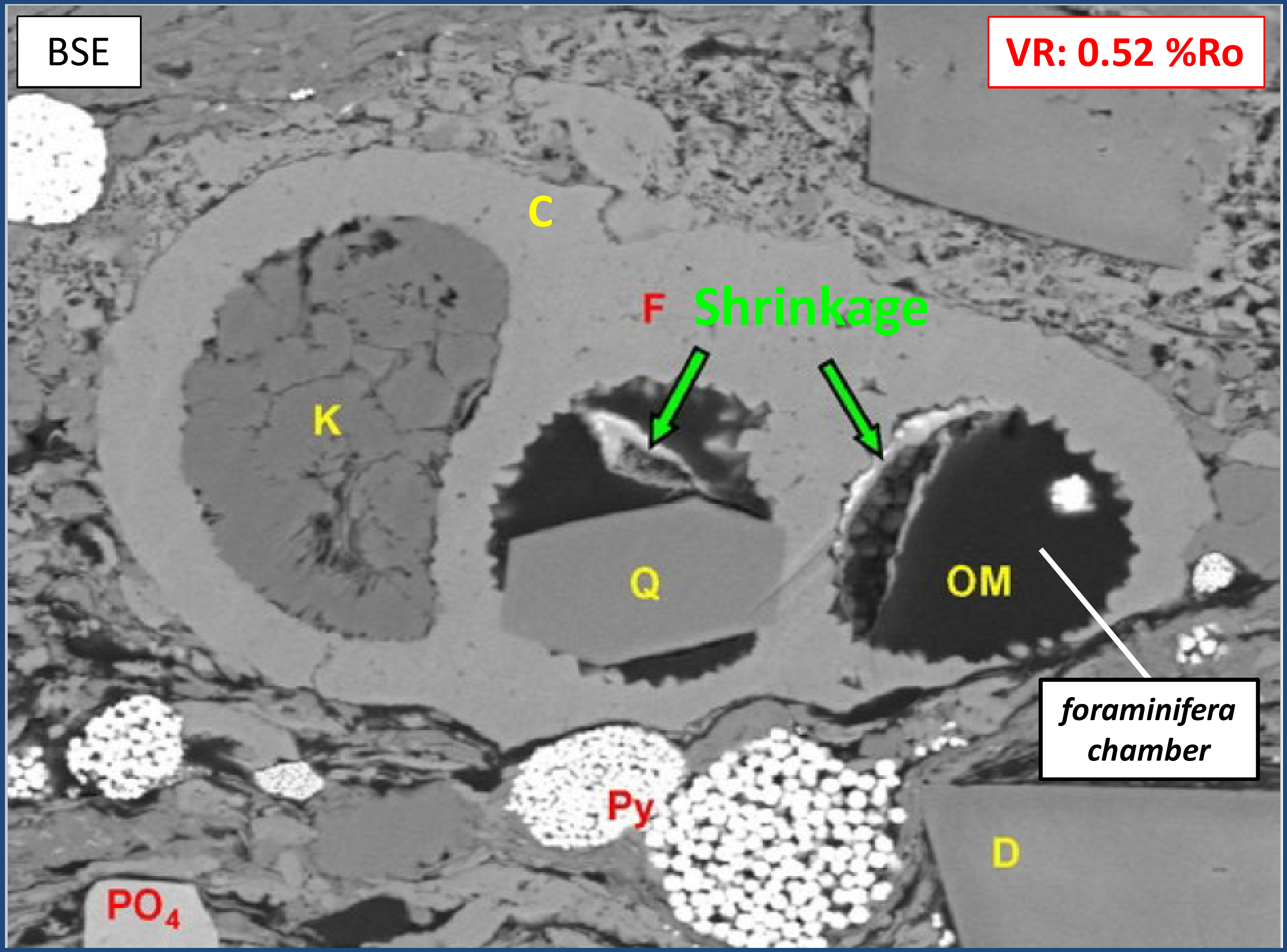
Wawak (2013)

Pre-Oil Bitumen(?) Meniscus Cement



Wawak (2013)

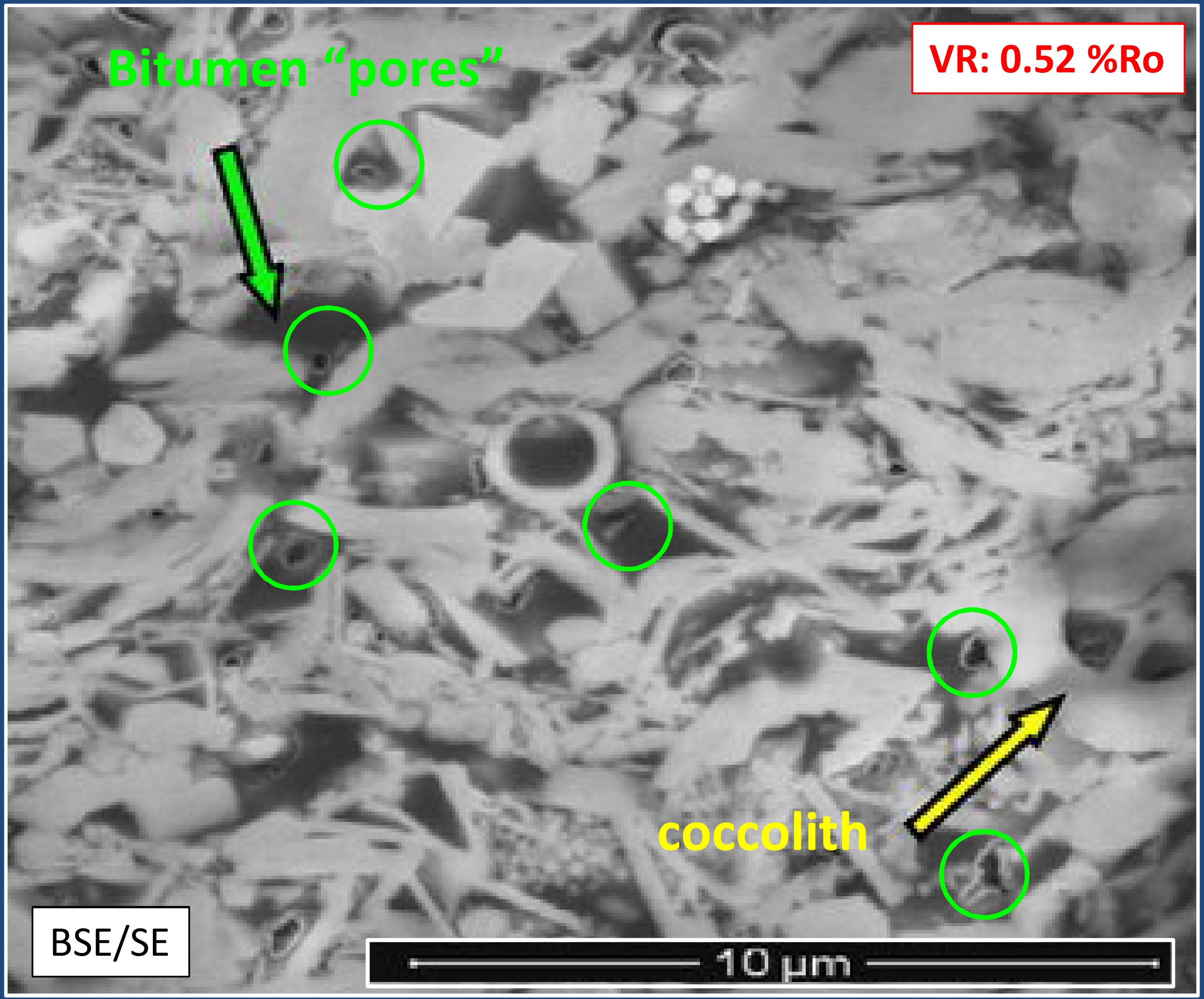
Bitumen Shrinkage Artifacts



20 µm

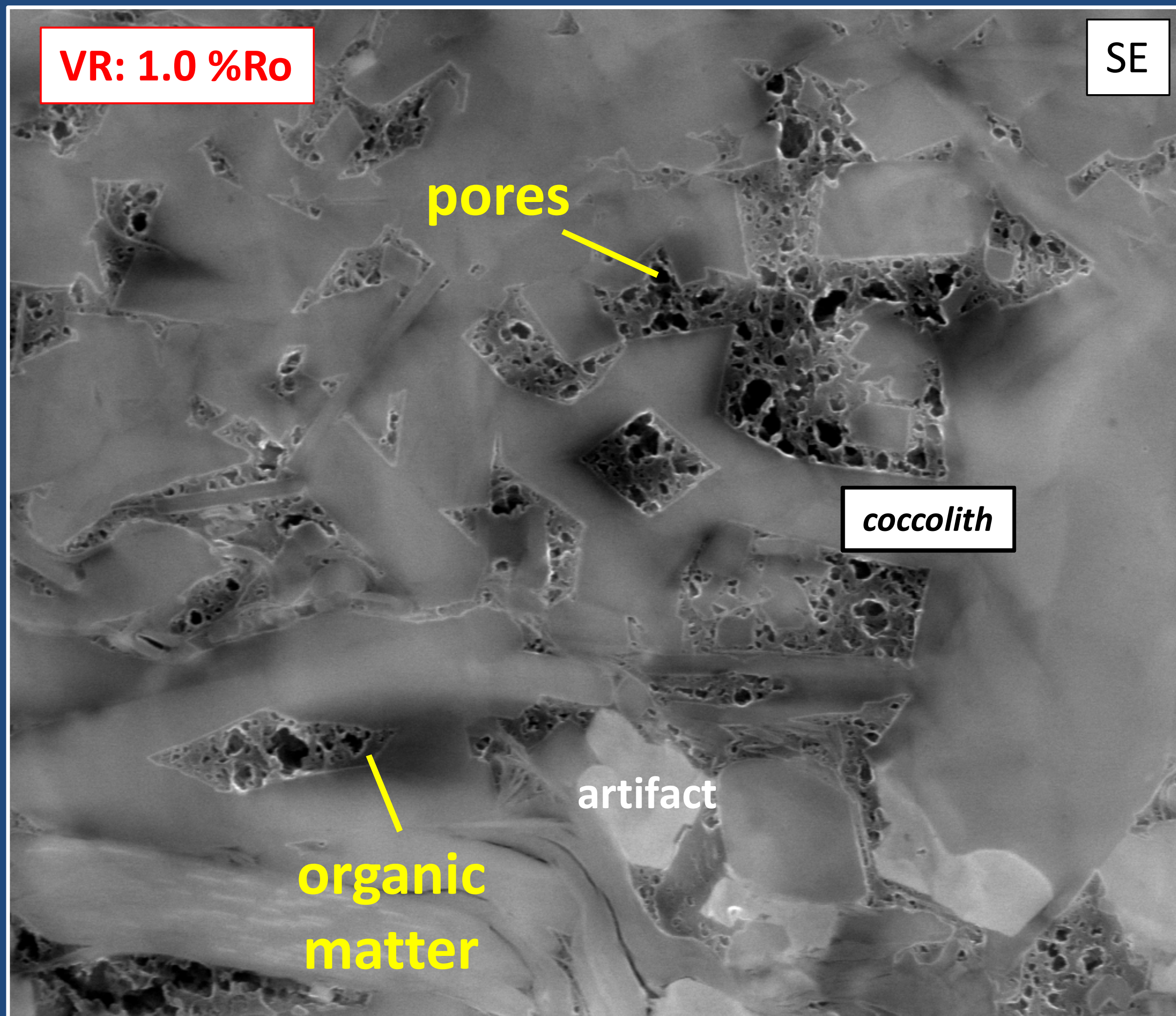
SEM image courtesy Core Laboratories

Bitumen Matrix "Porosity"



SEM image courtesy Core Laboratories

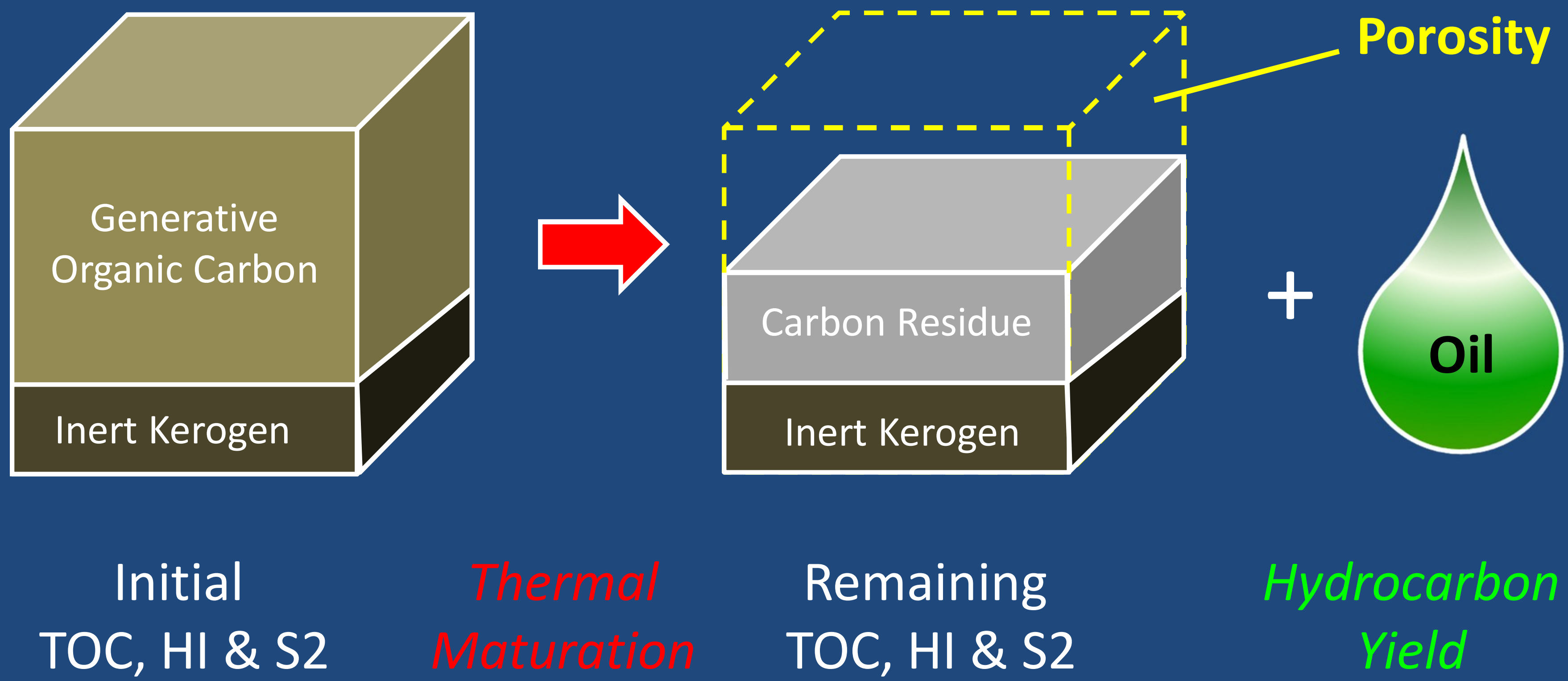
Pyrobitumen Porosity



4 µm

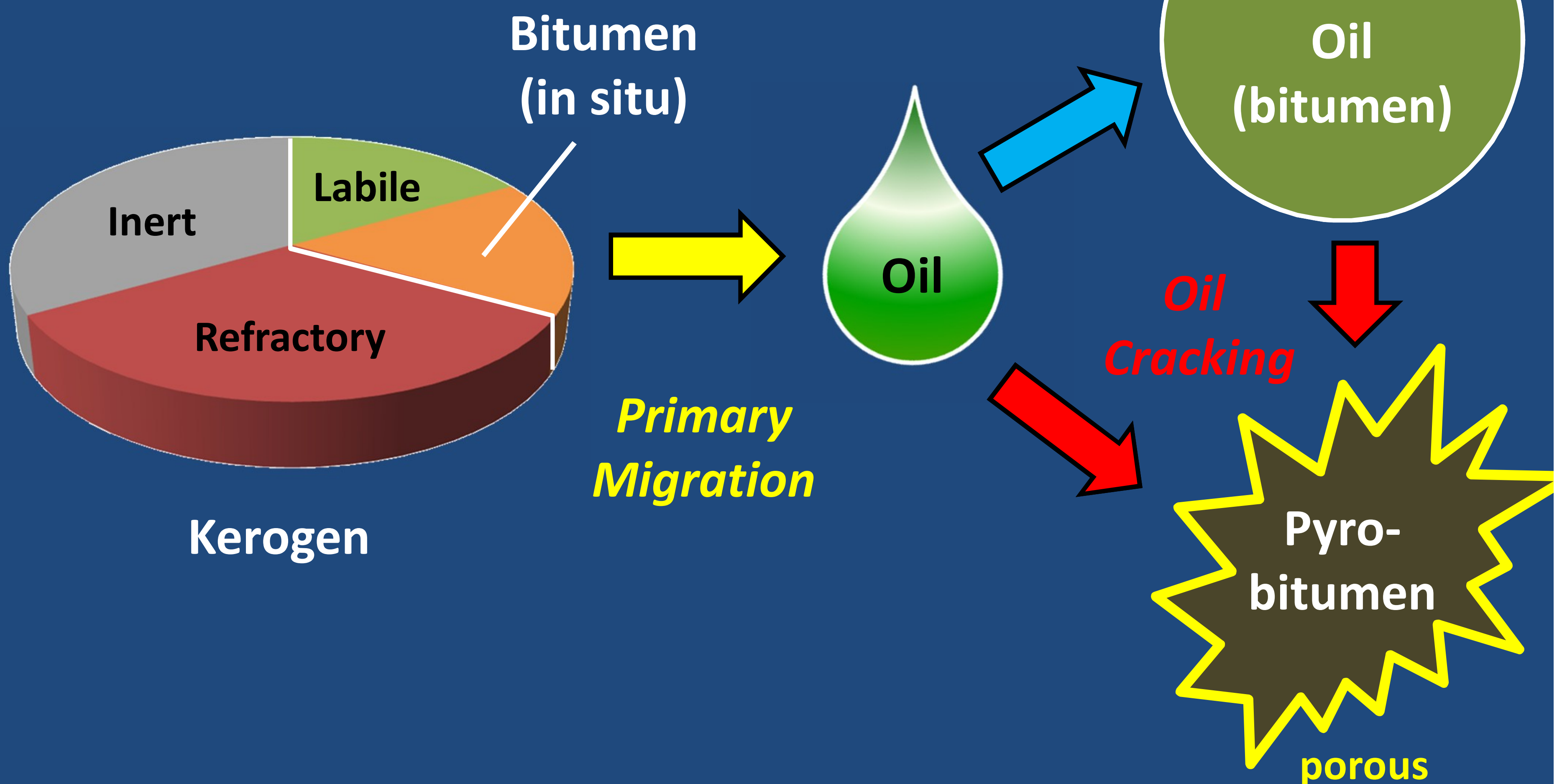
Kerogen Porosity Model

(Barnett Shale-Jarvie et al, 2007)

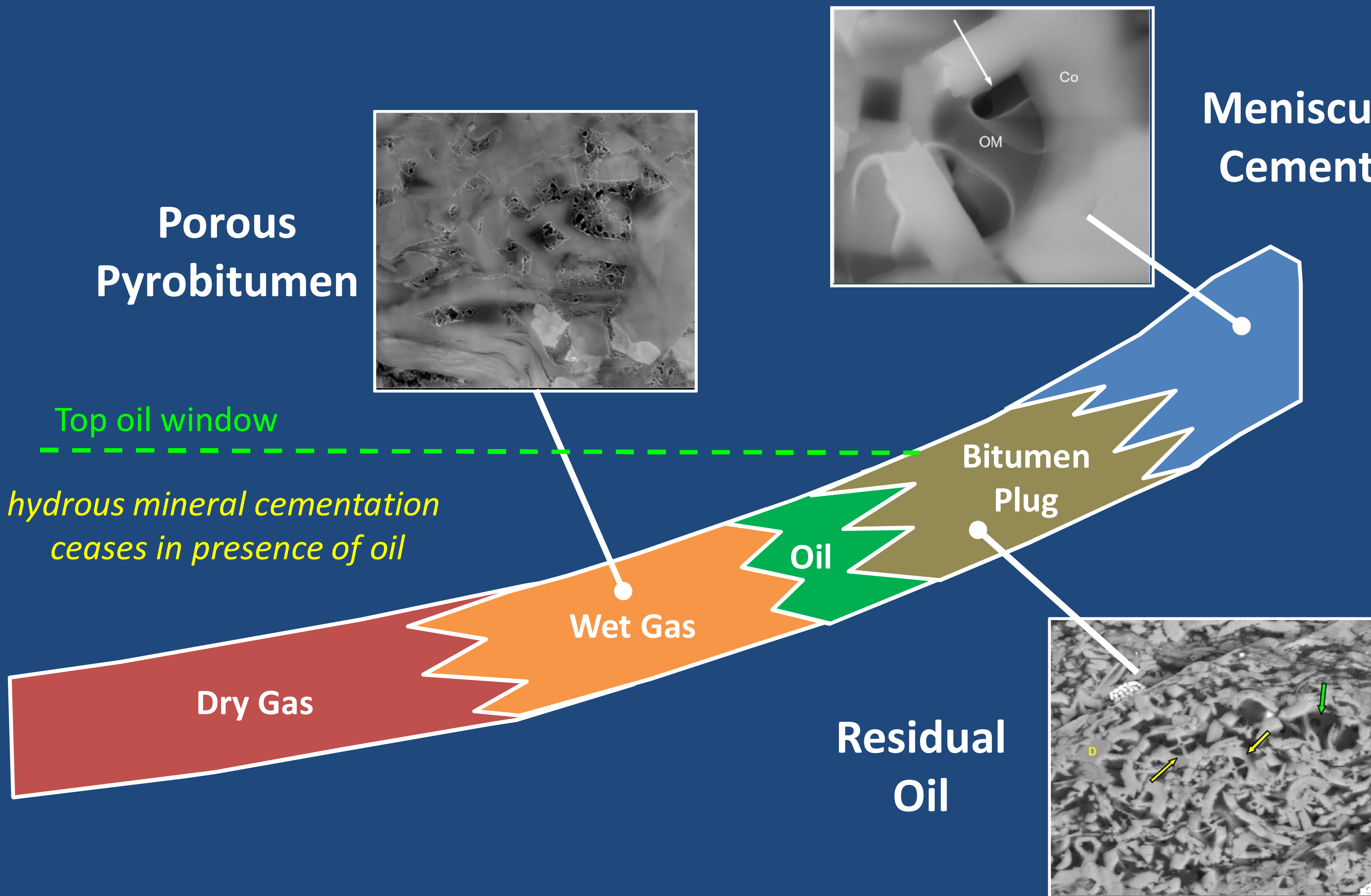


OM Porosity Evolution Model

(Eagle Ford)



OM Diagenesis Model



Summary

- Mineral and organic cements are observable with SEM within foraminifera chambers & the matrix
- Foraminifera cement associations & paragenesis exhibit little variation regionally
  - Suggests uniform (predictable) diagenetic processes
- Cement diversity is greatest within the matrix
  - Potentially reflects variation in matrix grain composition, and pore fluid chemistry & circulation
- Organic cements are the most pervasive type
  - Form updip lateral seals (bitumen plugs), and
  - Down dip interconnected porous networks
- Most mineral cements predate primary oil migration (except late stage pyrite)

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Core Laboratories

- For providing SEM images

References Cited

- Camp, W.K., E. Diaz and B. Wawak, eds., 2013, Electron microscopy of shale hydrocarbon reservoirs: AAPG Memoir 102, 260 p. ISBN13:978-0-89181-383-5
- Jarvie, D.M., et al., 2007, Unconventional shale-gas systems: The Mississippian Barnett Shale of north-central Texas as one model for thermogenic shale-gas assessment: AAPG Bull., v. 91, p. 475-499. DOI:10.1306/12190606068