Energy & Environmental Research Center (EERC)

ADVANCED CHARACTERIZATION OF UNCONVENTIONAL OIL AND GAS RESERVOIRS TO ENHANCE CO_2 STORAGE RESOURCE ESTIMATES

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U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

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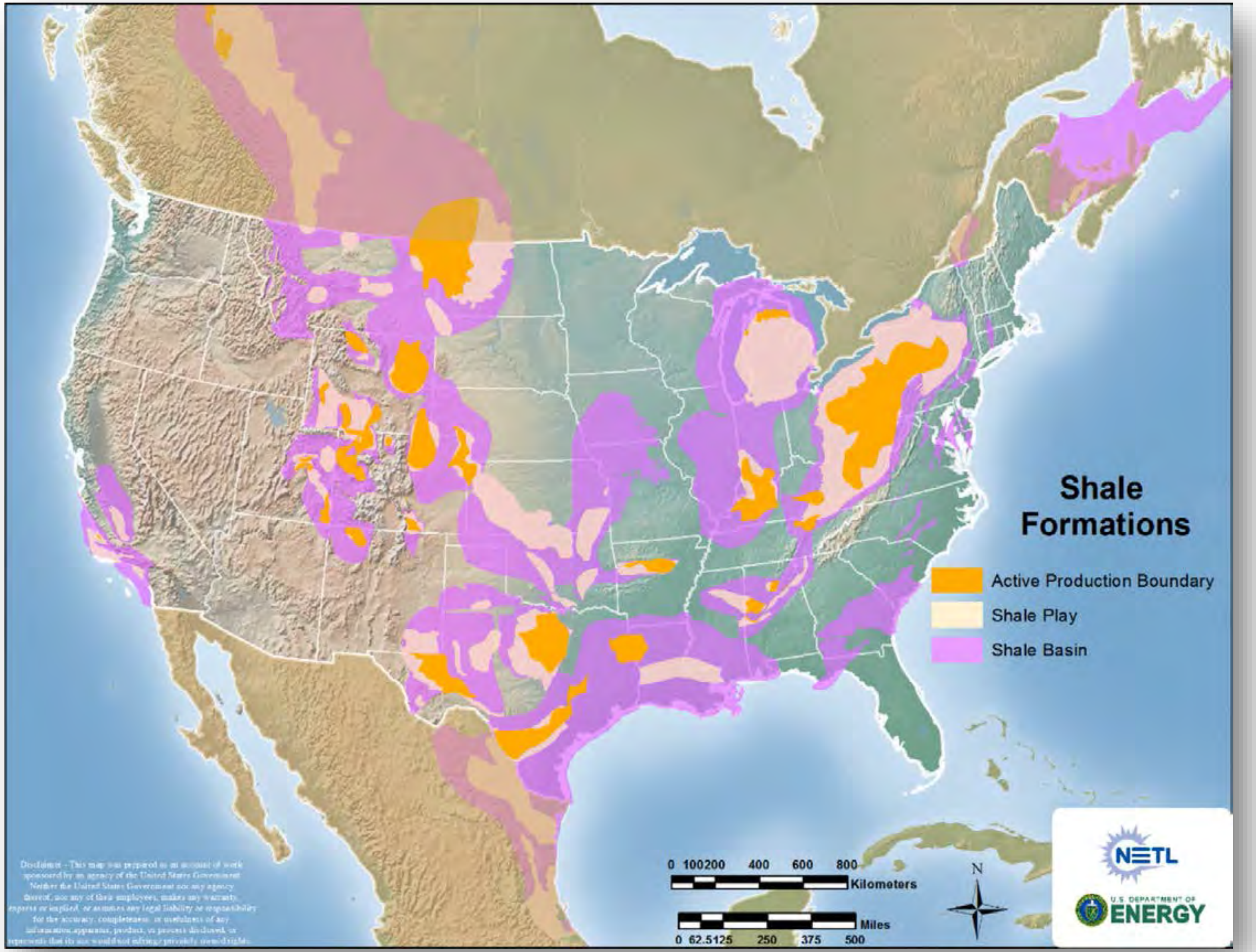
Critical Challenges. Practical Solutions.

PROJECT TEAM

- DOE NETL
- Energy & Environmental Research Center (EERC) at the University of North Dakota
- Hitachi High Technologies America

PROJECT GOALS

- Development of advanced characterization methods and/or procedures to better identify the properties of organic-rich shales (and other unconventional reservoirs) that affect CO_2 transport and storage.
- Application of those methods to improve the existing equations used to volumetrically estimate CO_2 storage capacity.



J.S. Levine et al., International Journal of Greenhouse Gas Control 51 (2016), 81–94.

NETL MASS STORAGE EQUATION

$$G_{CO_2} = V_e\left[\rho_{CO_2}\phi E_\phi + \rho_{sCO_2}(1-\phi)E_s\right]$$

Levine et al., 2016; Goodman et al., 2014.

where:

G_{CO2} = CO_2 mass storage resource of organic-rich shale formation;

V_e = Volume of formation that can effectively be accessed for CO_2 storage;

ρ_{CO2} = Density of CO_2 at reservoir conditions;

ϕ = Total porosity due to pores and fractures;

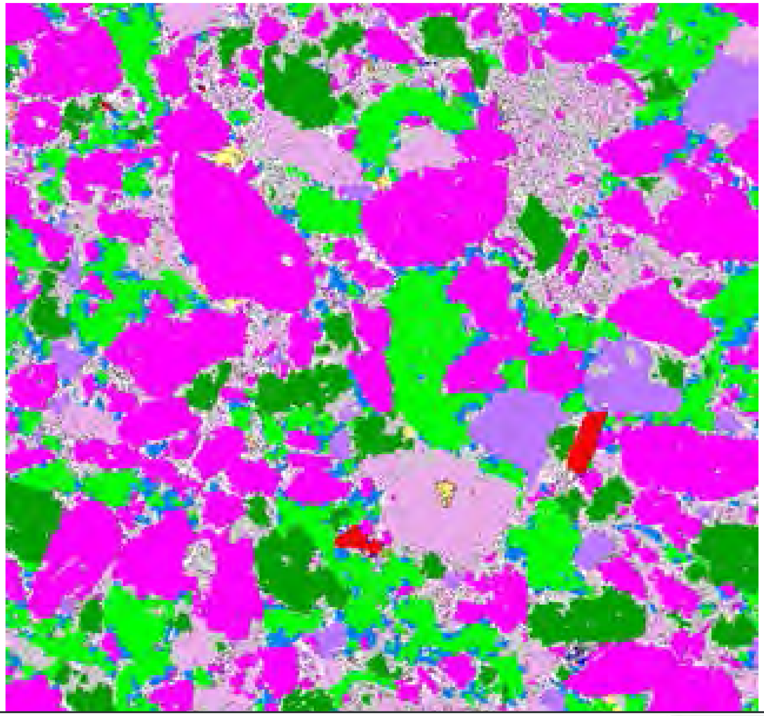
E_ϕ = Fraction of total porosity available for CO_2 storage

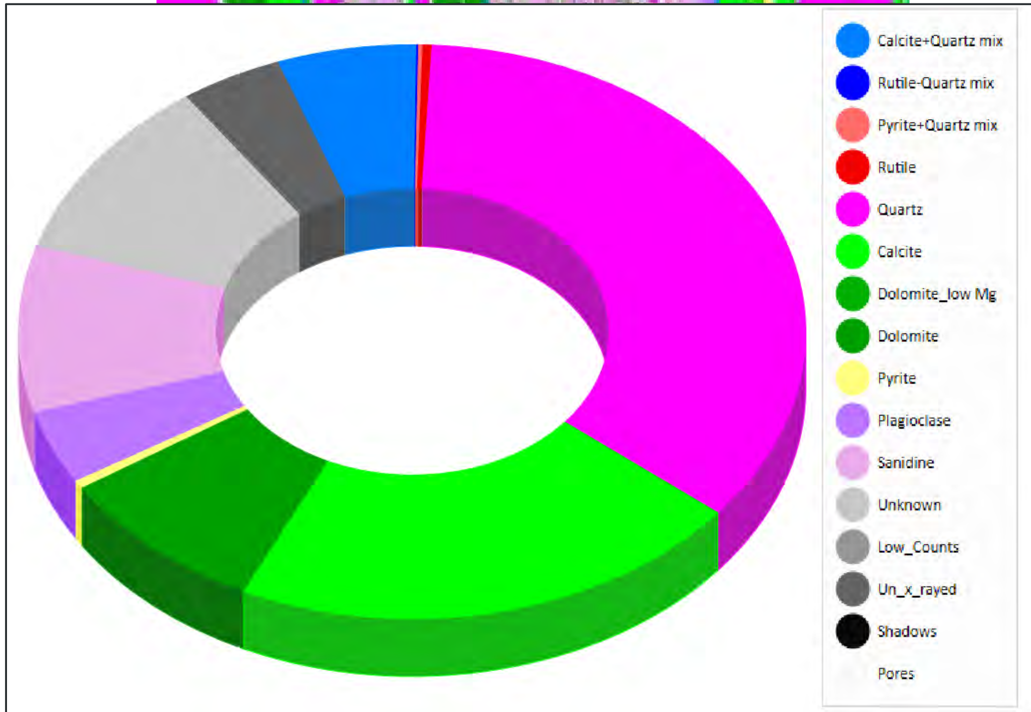
ρ_{sCO2} = Maximum mass of CO_2 sorbed per unit volume of solid phase rock $(1 - \phi)$; and,

E_s = Fraction of solid phase available for CO_2 sorption.

PROJECT OBJECTIVES

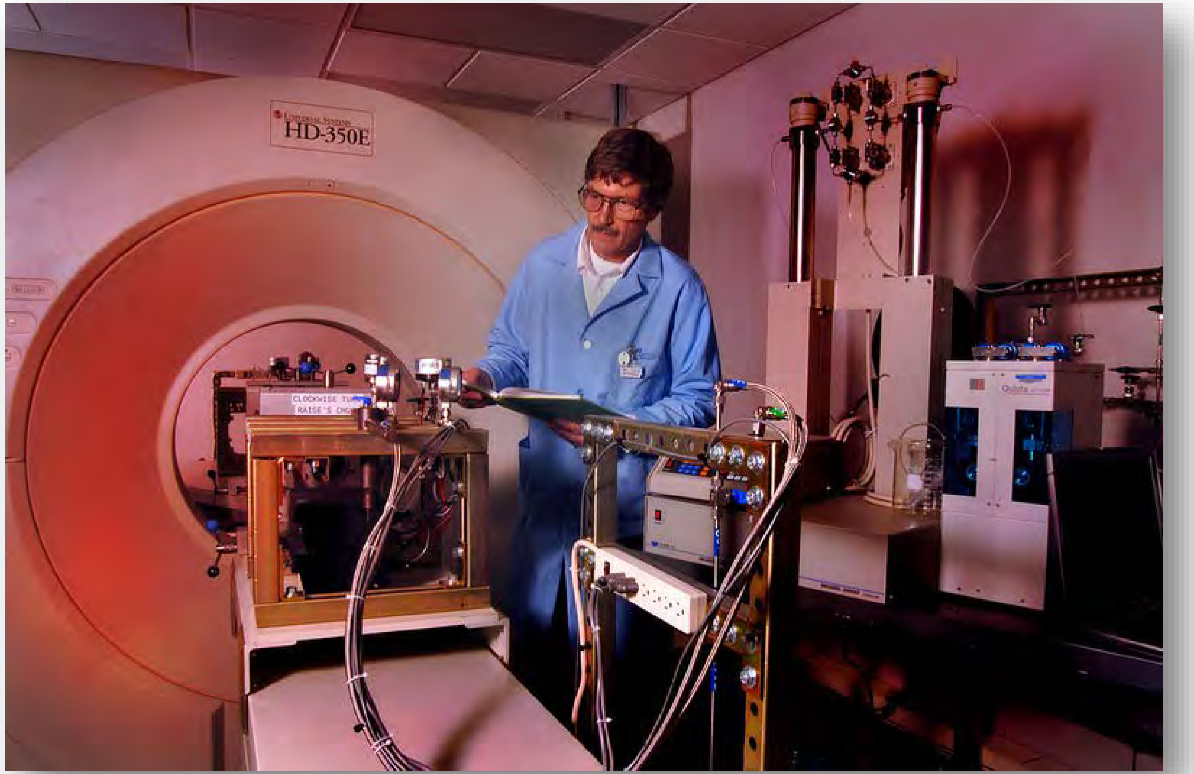
- Development of advanced field emission scanning electron microscopy (FESEM) and image analysis methods to better characterize the following within organic-rich shales and other tight formations:
  - Mineralogy and organic matter (OM)
  - Porosity and pore-size distributions
  - Fracture networks
- Collaboration with Hitachi to develop and/or improve data processing and image analysis routines to better characterize and quantify features of interest in unconventional formation samples.





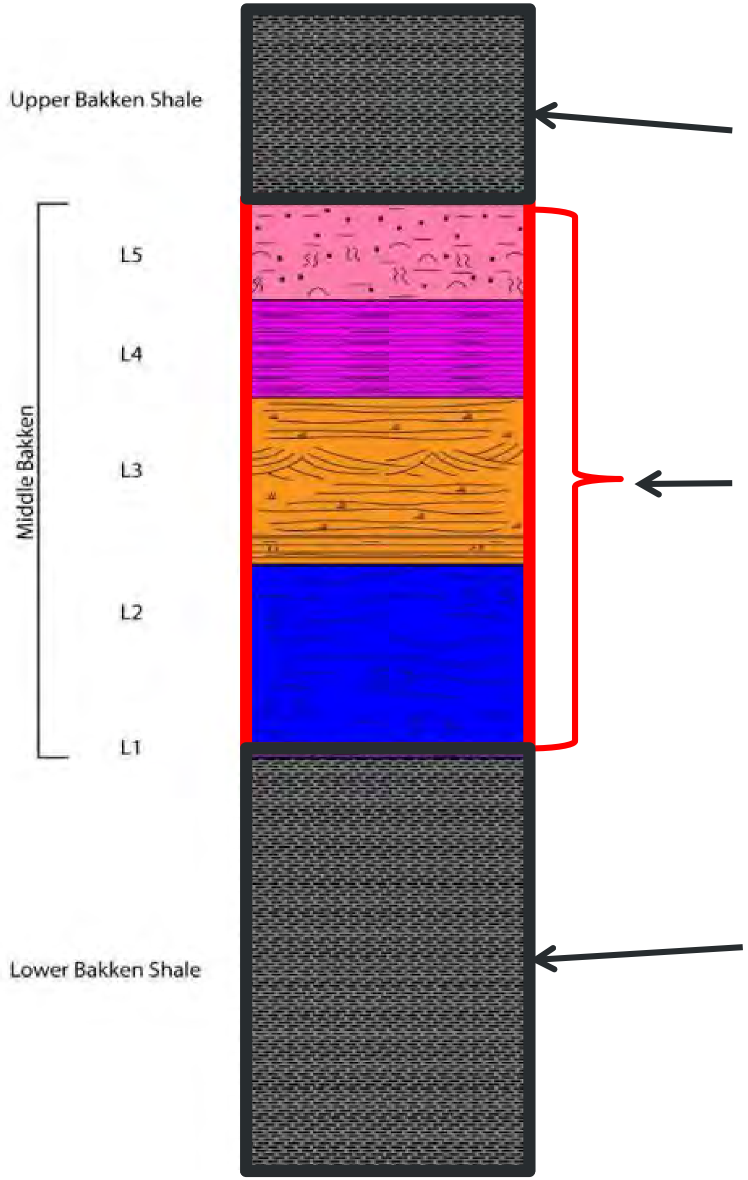
PROJECT OBJECTIVES (continued)

- Collaboration with NETL's CT Scanning Laboratory to investigate the effects of CO_2 exposure on organic-rich shales at the core scale.
- Development of image analysis-based methods to estimate the storage resource potential of unconventional formations in collaboration with NETL staff.



https://www.netl.doe.gov/research/coal/carbon-storage/research-and-development

BAKKEN FORMATION LITHOLOGY



Upper Bakken Shale: Brown to black, organic-rich

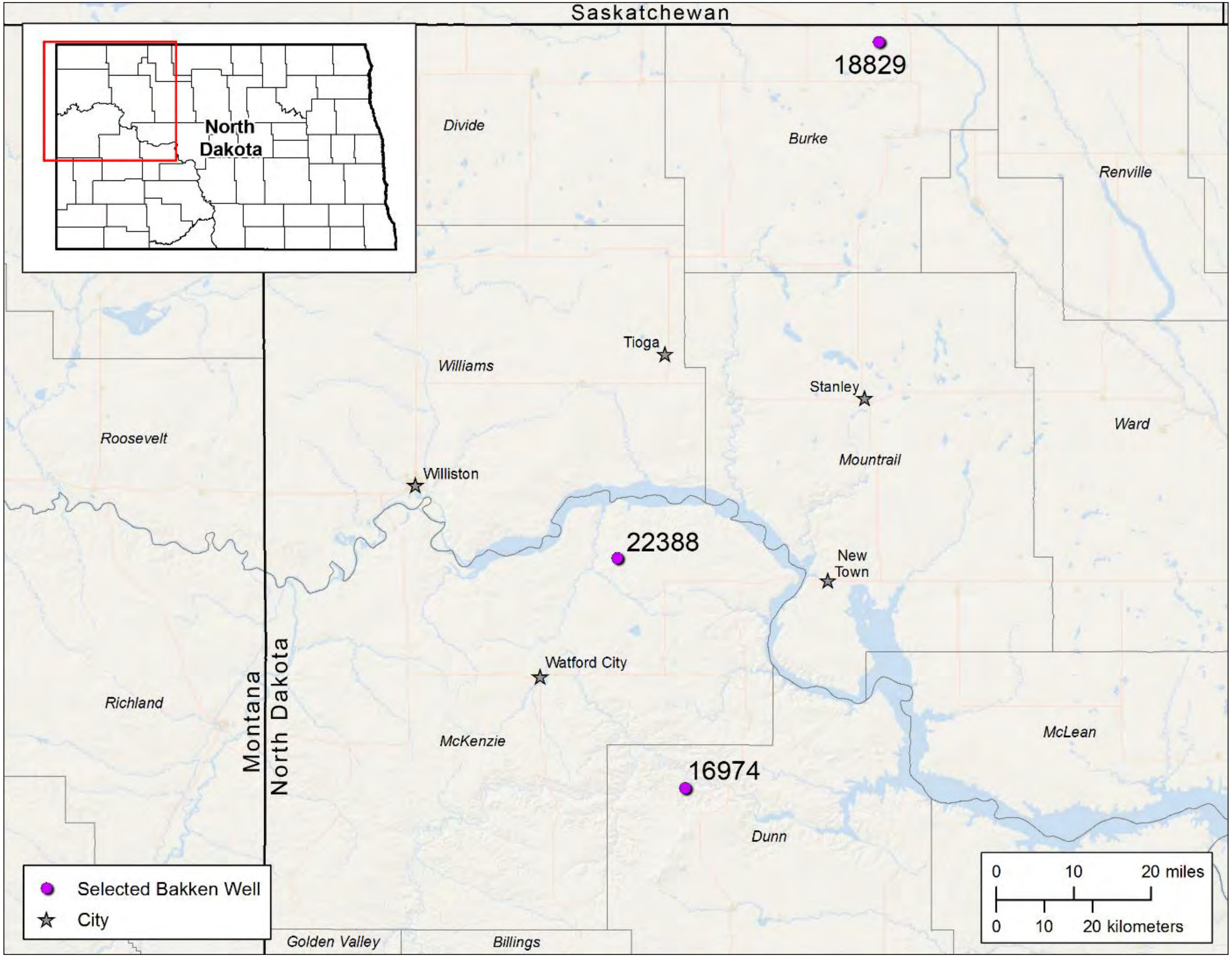
- **Bakken source rock**

Middle Bakken: Variable lithology (up to nine lithofacies), ranging from silty sands to siltstones and tight carbonates

- **Bakken tight reservoir rock (horizontal drilling target)**

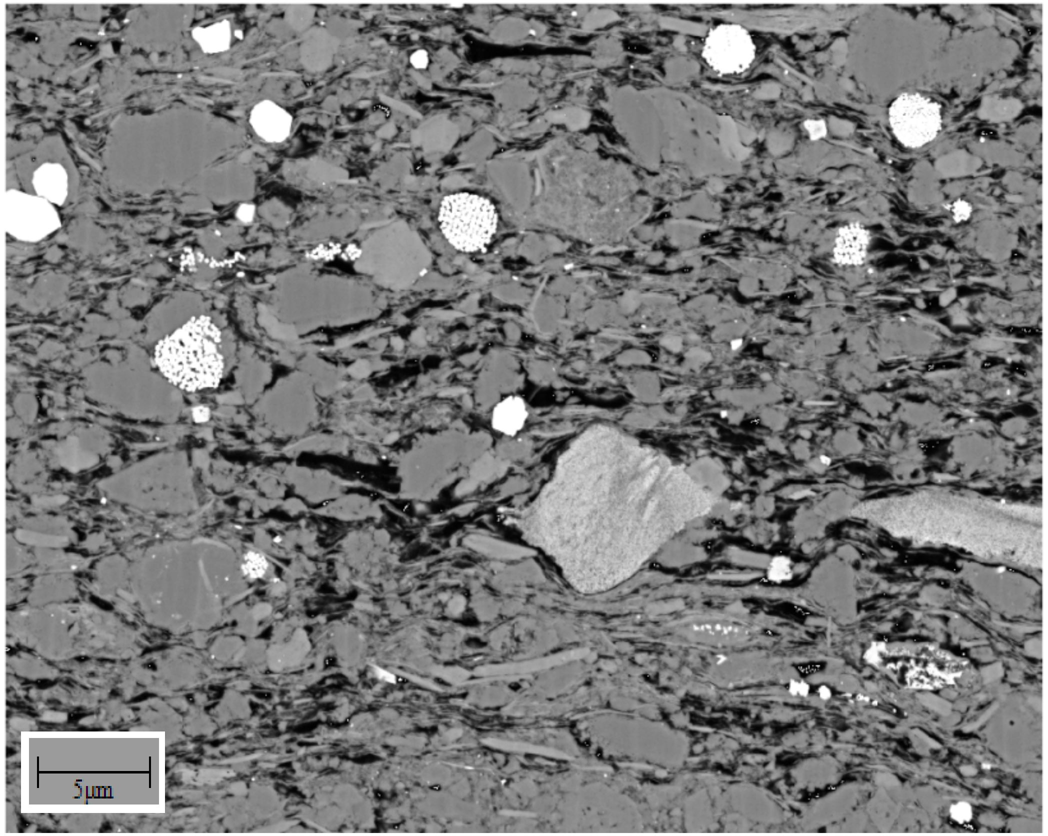
Lower Bakken Shale: Brown to black, organic-rich

- **Bakken source rock**

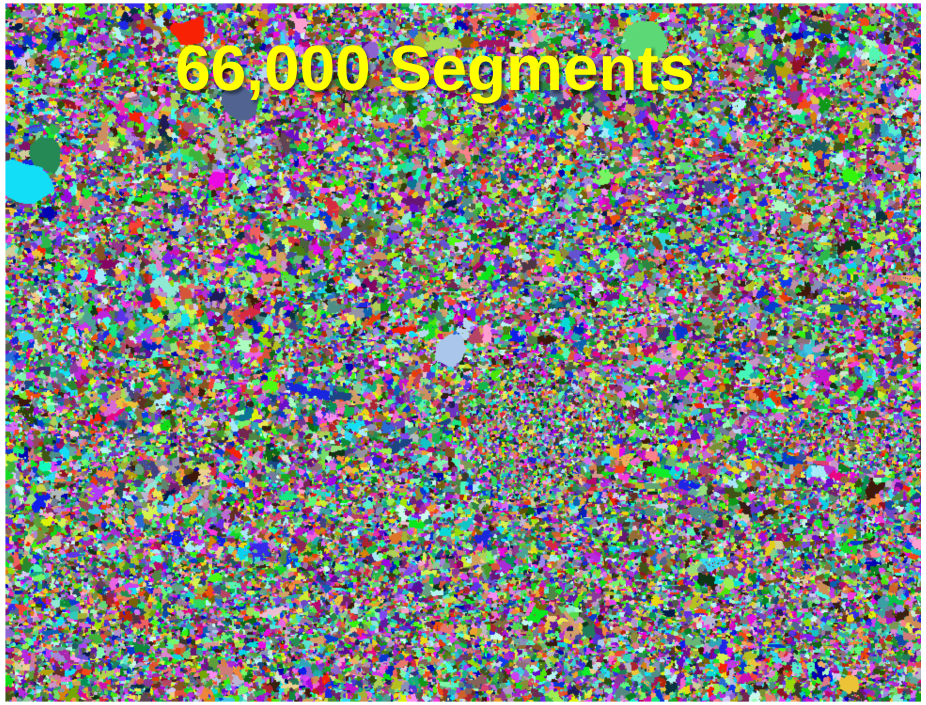


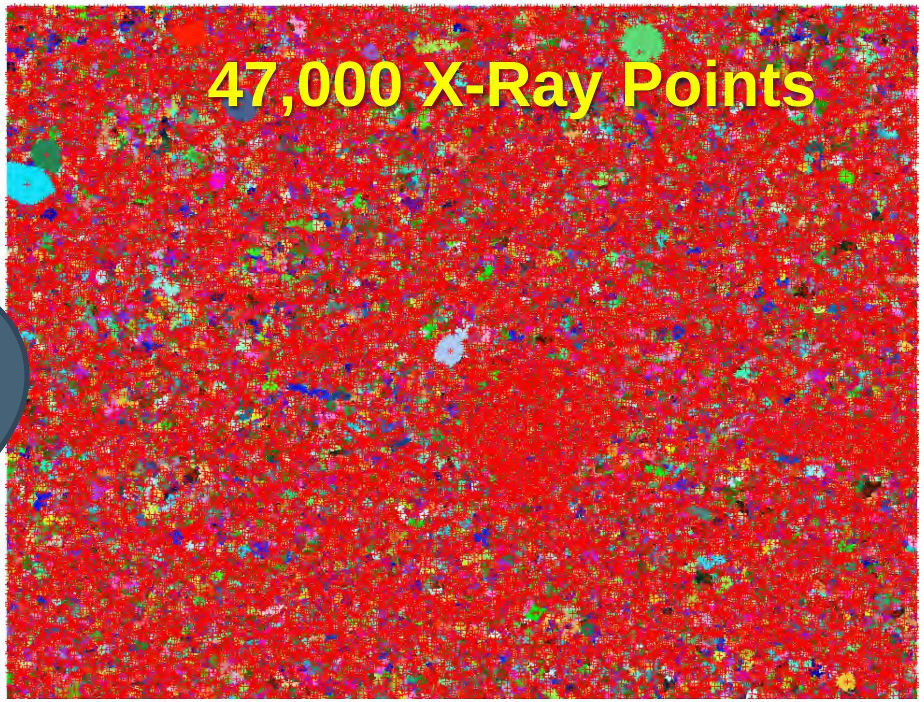
Saskatchewan
North
Dakota
18829
Divide
Burke
Renville
Tioga
Williams
Stanley
Ward
Roosevelt
Mountrail
Williston
22388
New
Town
Watford City
Richland
Montana
North Dakota
McKenzie
McLean
16974
Dunn
Selected Bakken Well
City
Golden Valley
Billings
0
10
20 miles
0
10
20 kilometers

DATA ACQUISITION WITH AMICS



LBS
Example





Big Data Process!

Field Parameters:

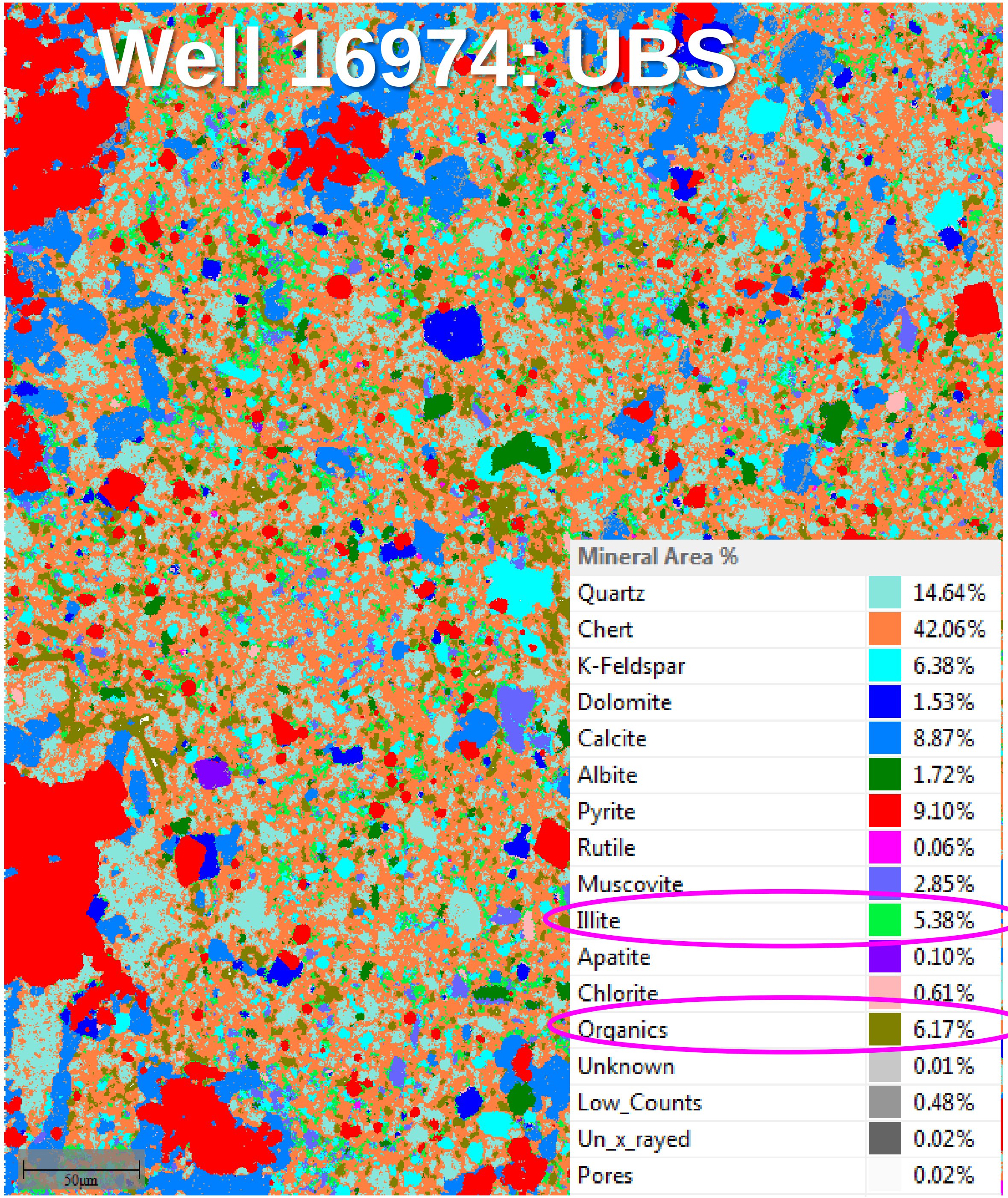
Magnification – 1500x

Image Resolution – 40 nm/pixel

Field Size – 85 µm x 85 µm

Total pixels per frame – 4.5 million

Final mineral map frames – 40


Well 16974: UBS
Mineral Area %
Quartz 14.64%
Chert 42.06%
K-Feldspar 6.38%
Dolomite 1.53%
Calcite 8.87%
Albite 1.72%
Pyrite 9.10%
Rutile 0.06%
Muscovite 2.85%
Illite 5.38%
Apatite 0.10%
Chlorite 0.61%
Organics 6.17%
Unknown 0.01%
Low_Counts 0.48%
Un_x_rayed 0.02%
Pores 0.02%
50μm

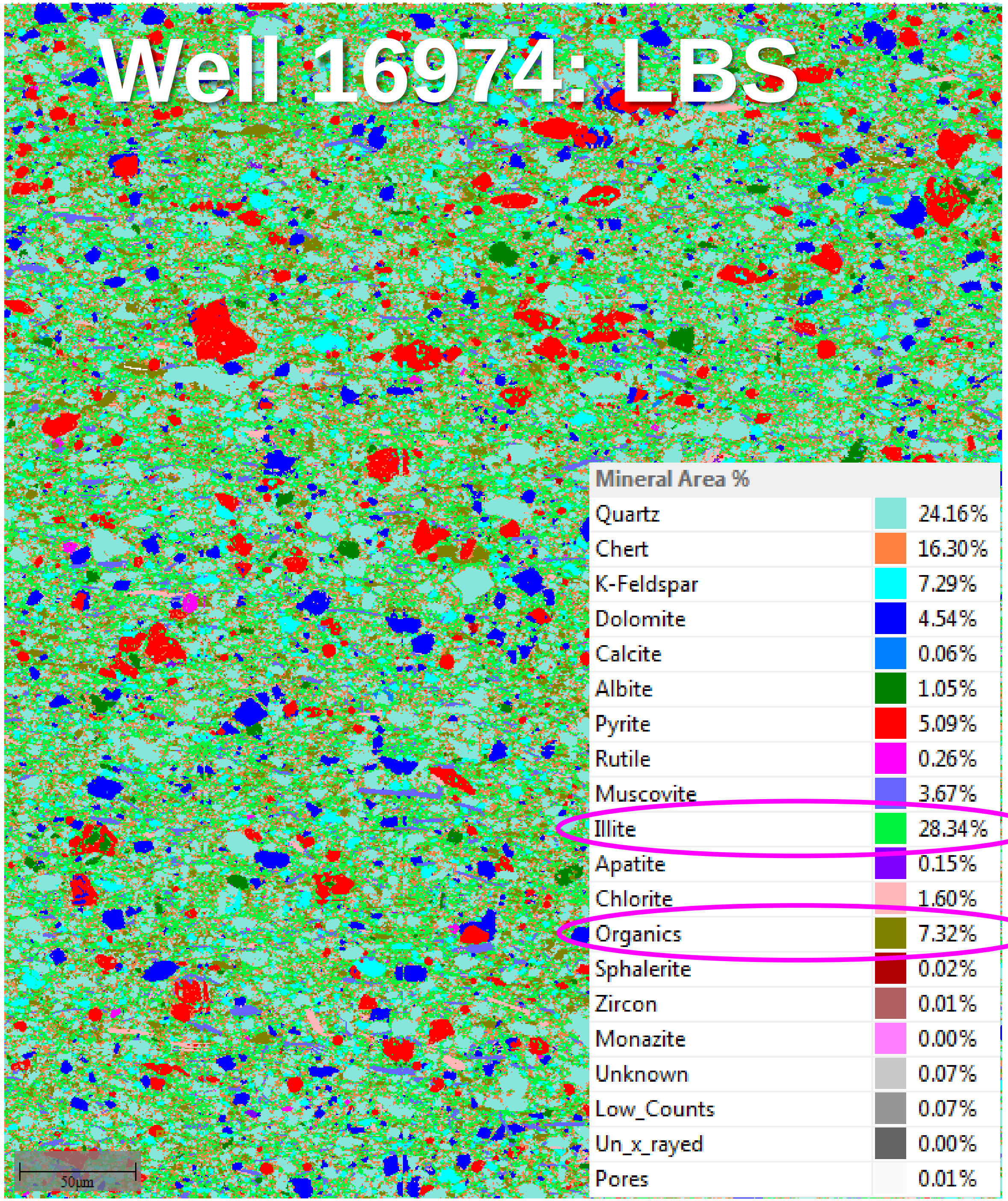
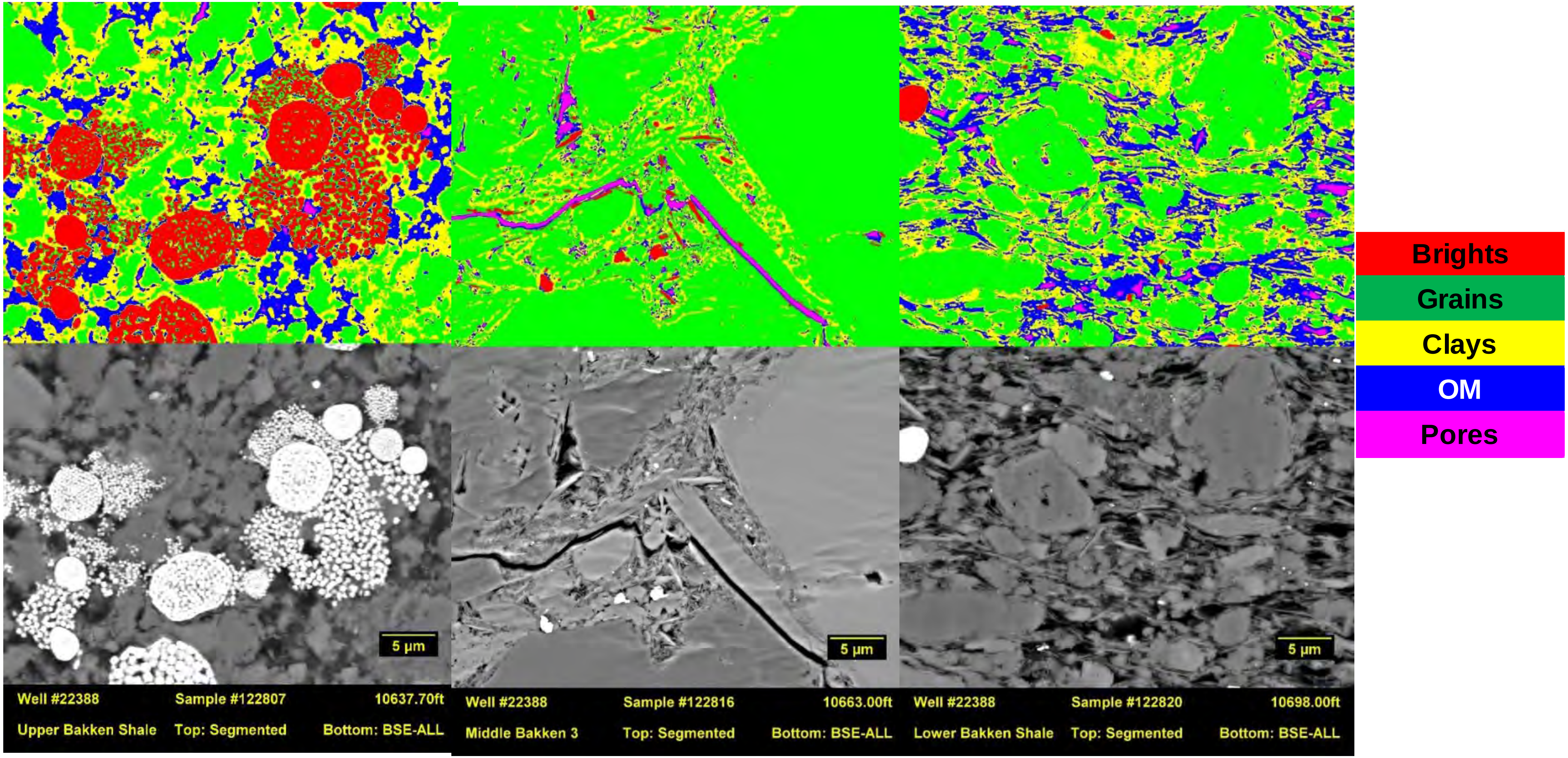
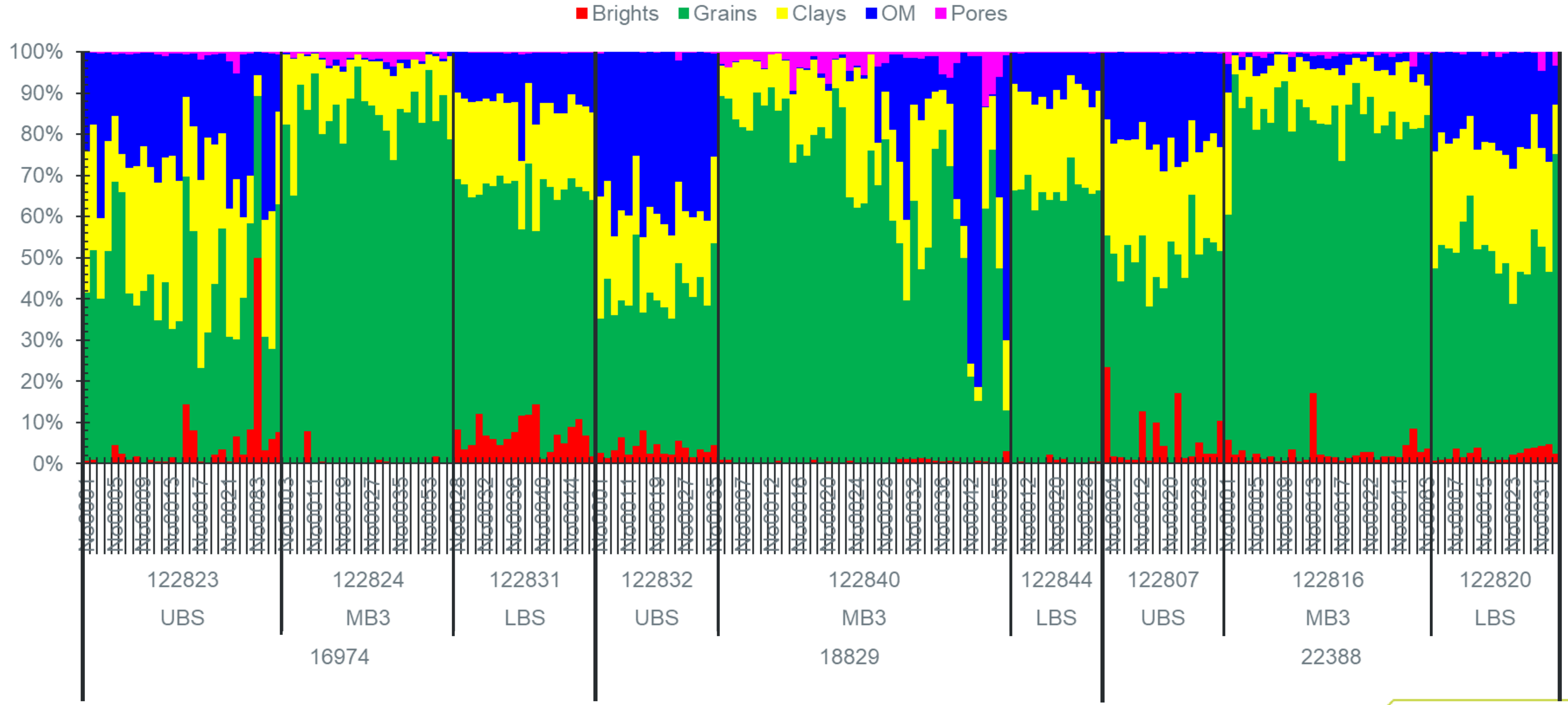

Well 16974: LBS
Mineral Area %
Quartz 24.16%
Chert 16.30%
K-Feldspar 7.29%
Dolomite 4.54%
Calcite 0.06%
Albite 1.05%
Pyrite 5.09%
Rutile 0.26%
Muscovite 3.67%
Illite 28.34%
Apatite 0.15%
Chlorite 1.60%
Organics 7.32%
Sphalerite 0.02%
Zircon 0.01%
Monazite 0.00%
Unknown 0.07%
Low_Counts 0.07%
Un_x_rayed 0.00%
Pores 0.01%
50μm

IMAGE SEGMENTATION USING ILASTIC

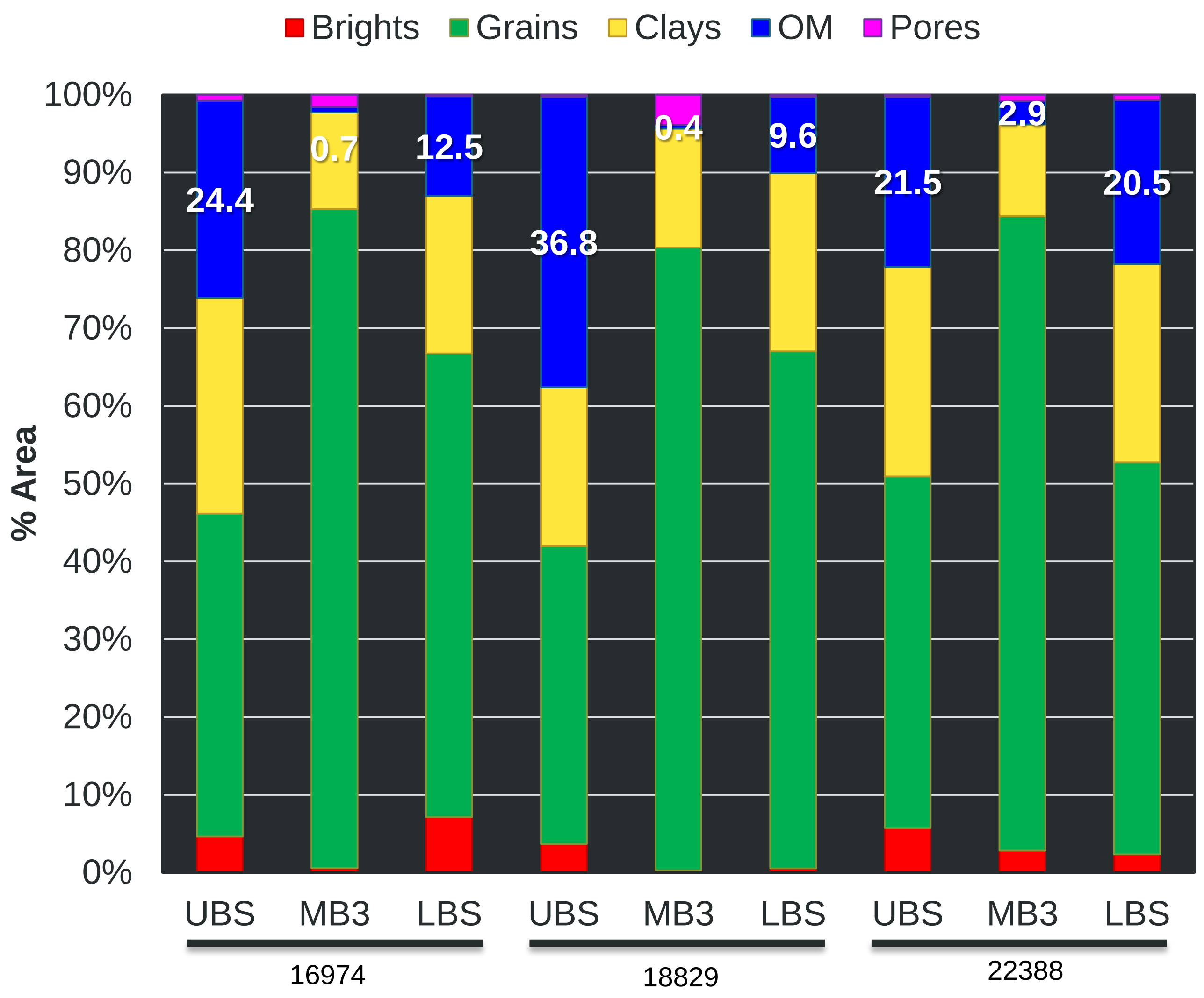


OCCURRENCE OF KEY COMPONENTS (AREA %) IN EACH SCENE

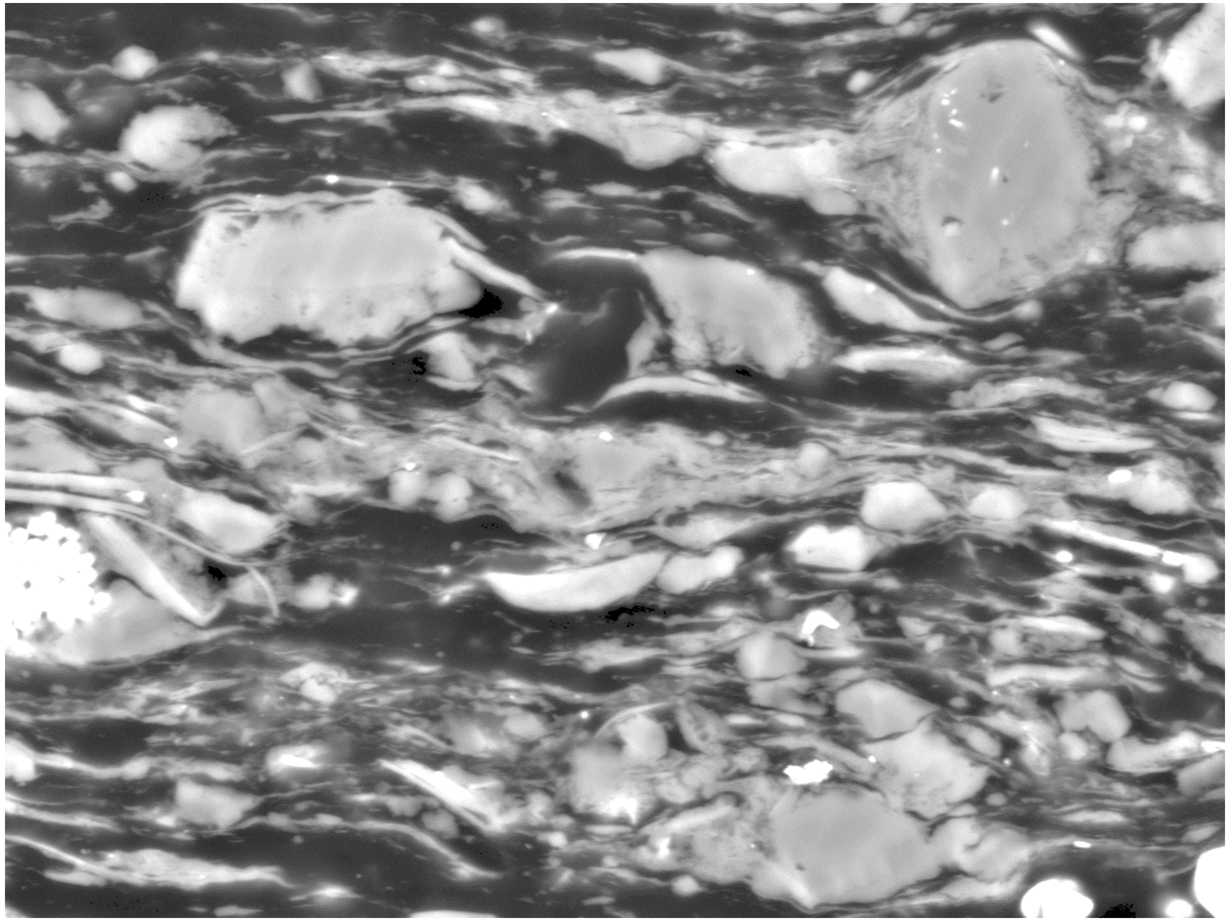


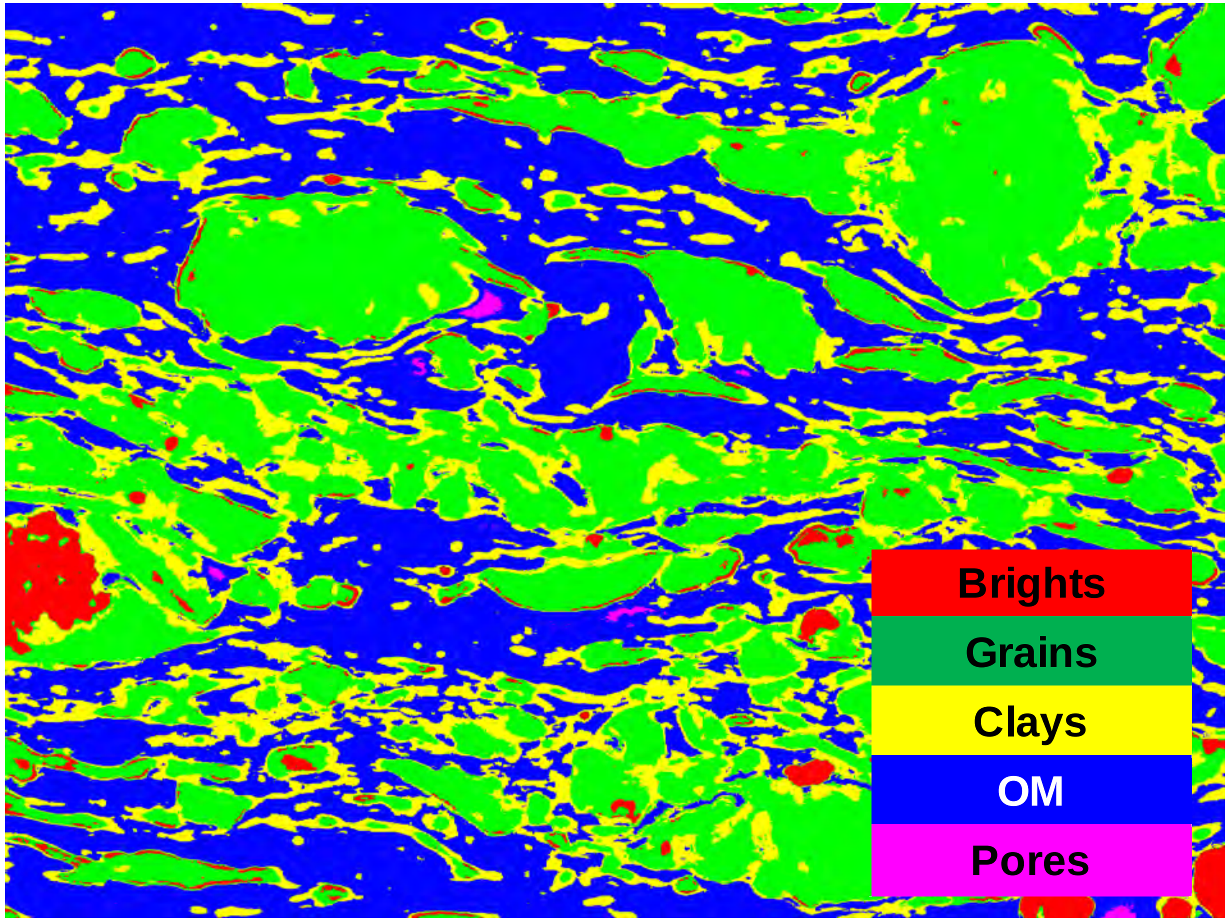
SUMMATION OF KEY COMPONENTS

- The image analysis data also allow us to evaluate:
  - Statistical parameters to assess key sample properties, such as compositional variability.
  - Grain and pore size distribution.
  - Fracture porosity.
- Currently working on a method to approximate the volume of the various sample components based on 2-D extrapolation.

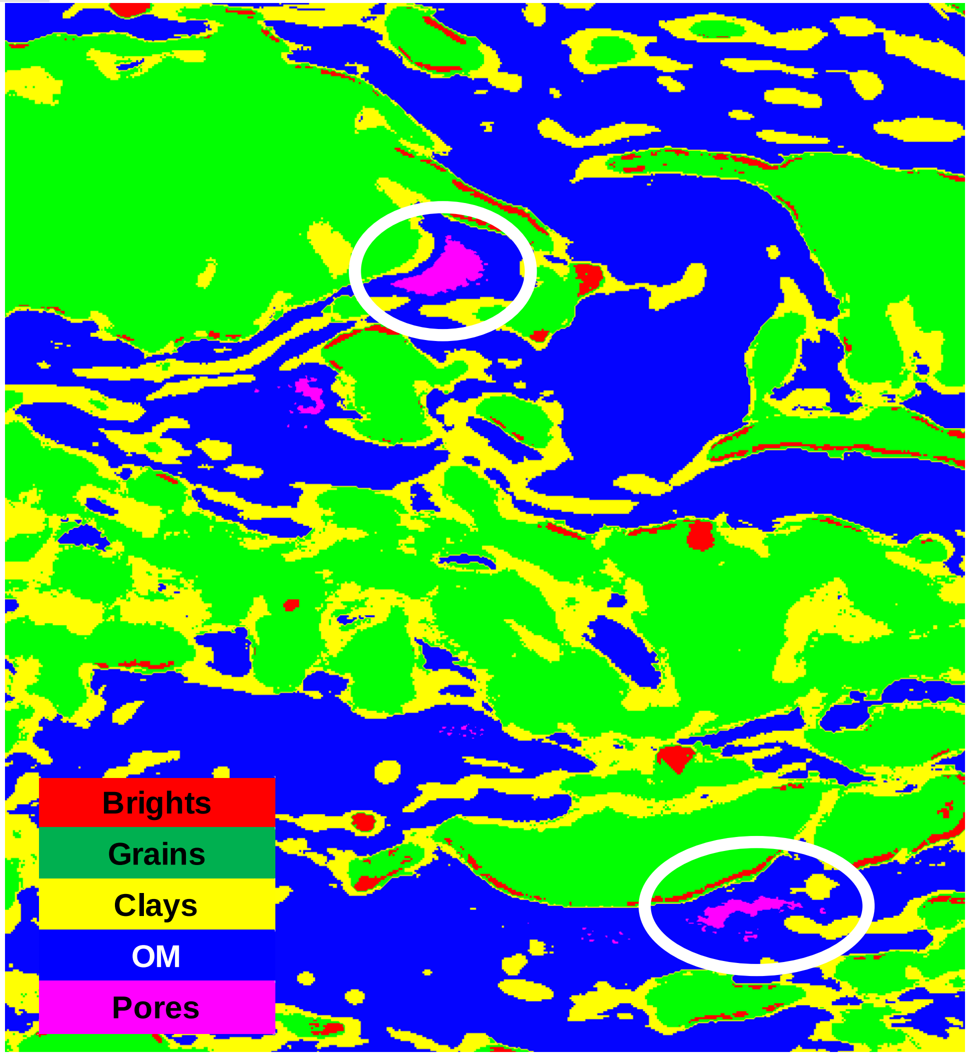


ESTIMATING EFFICIENCY FACTORS USING IMAGE ANALYSIS





SHARED BORDER ANALYSIS

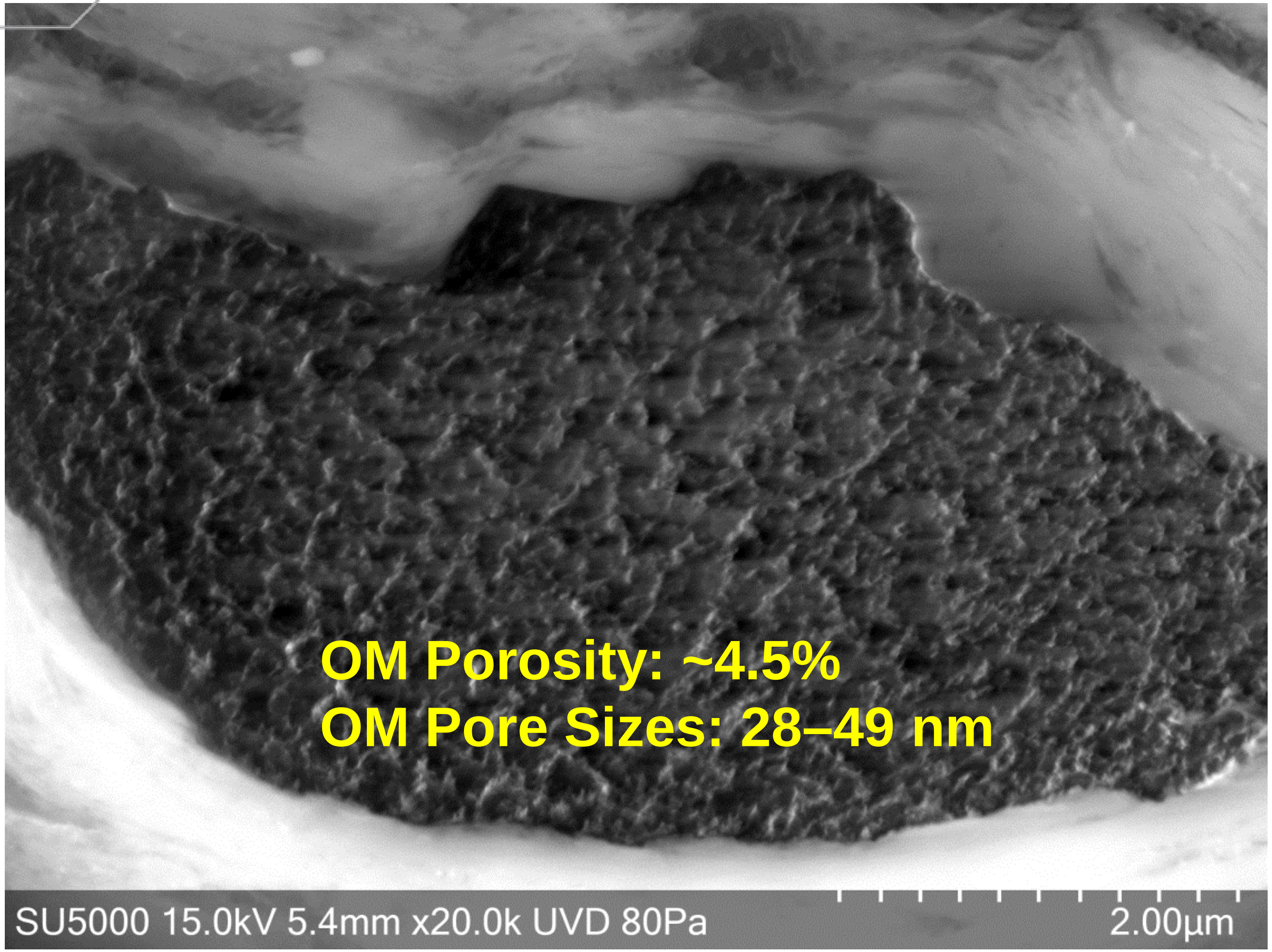


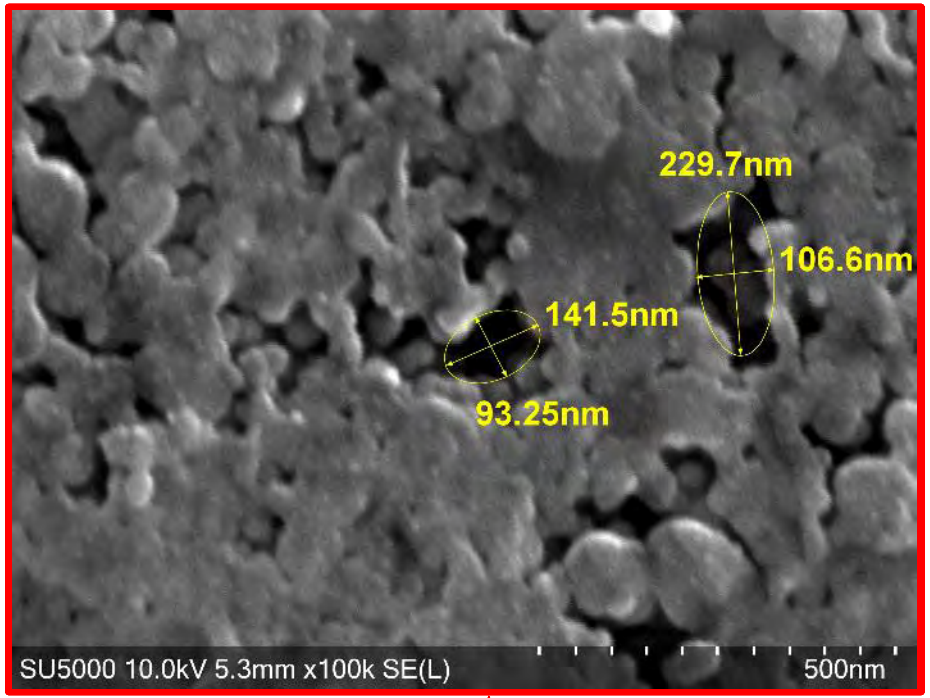
Label	Area, μm^2	Perimeter, μm
Brights	34.4	6.9
Grains	481.5	34.2
Clays	275.9	59.6
OM	550.9	31.3
Pores	1.9	0.4

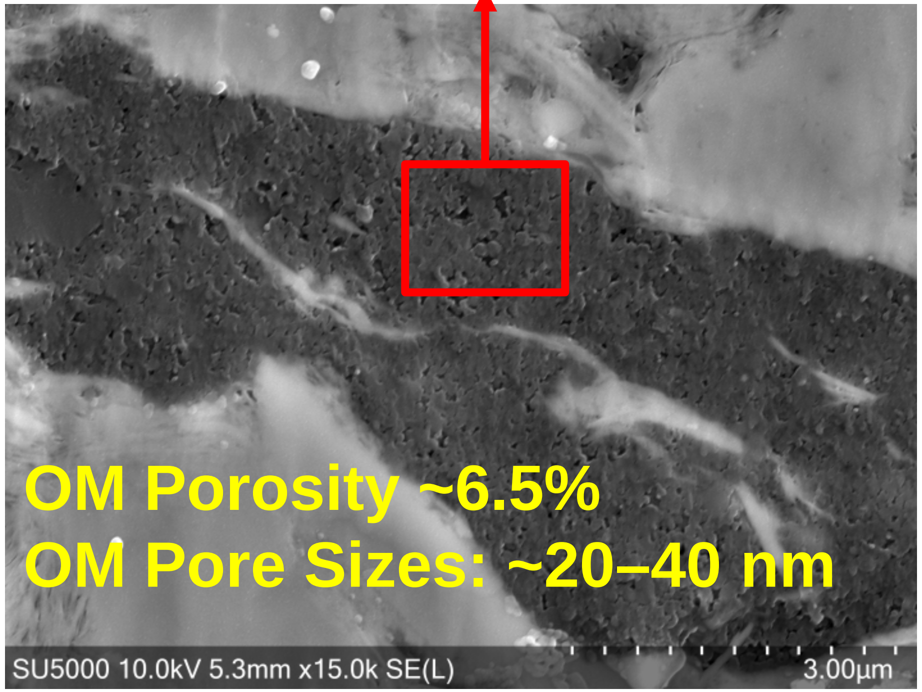
Phases	Shared Border, μm
Brights AND Grains	6.1
Brights AND Clays	3.1
Brights AND OM	1.3
Brights AND Pores	0.0
Grains AND Clays	27.9
Grains AND OM	9.1
Grains AND Pores	0.0
Clays AND OM	31.3
Clays AND Pores	0.0
OM AND Pores	0.3

SOLID BITUMEN STRUCTURE AND POROSITY

18829 – LOWER BAKKEN SHALE

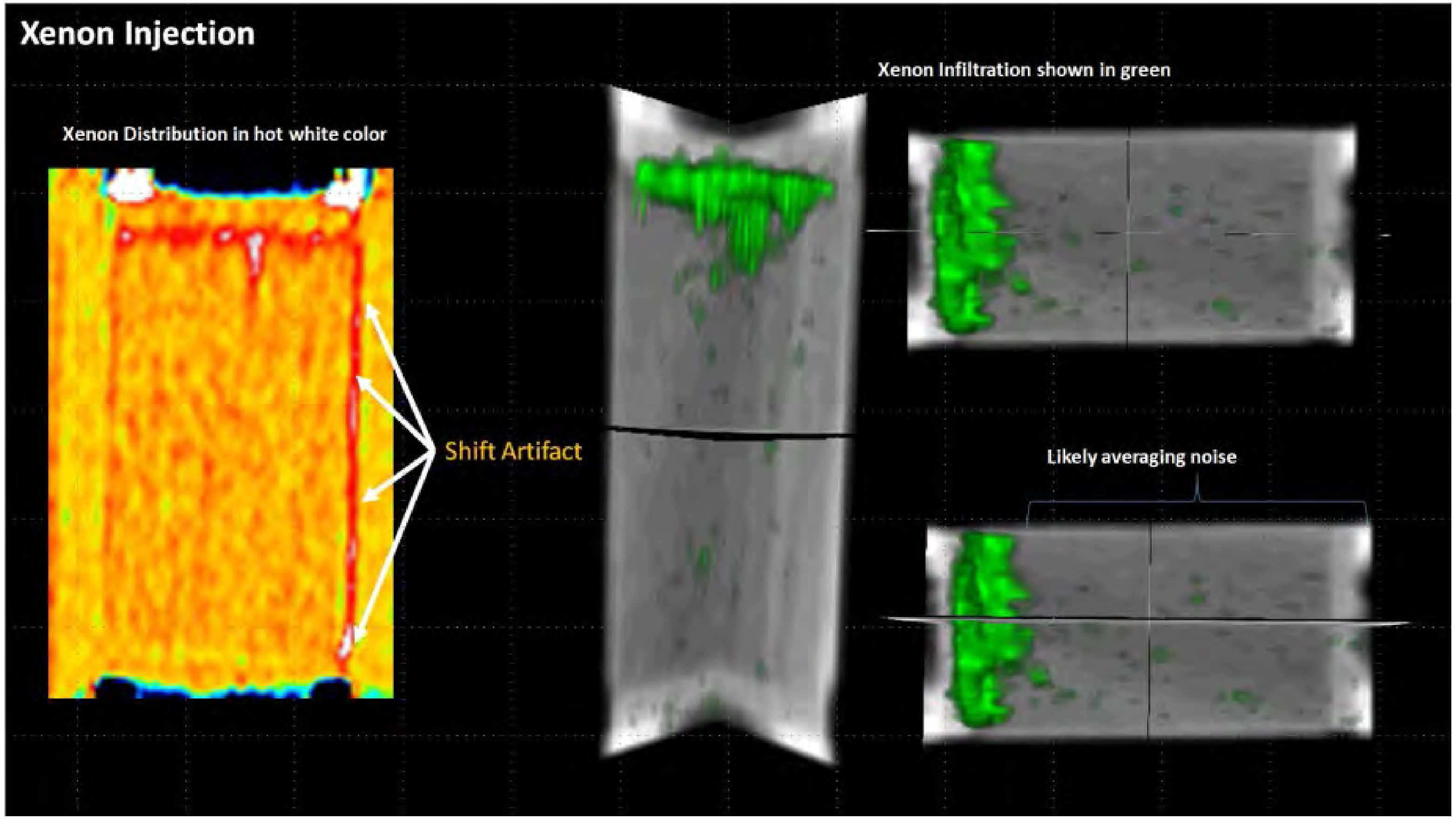






NETL COLLABORATION

- Evaluation of CO_2 permeation/flow over time into fractured and unfractured Bakken core plugs.
- Multiple experiments have been completed:
  - Helium injection
  - Xenon injection
  - CO_2 injection
- All experiments accompanied by CT scanning and image analysis.



ACCOMPLISHMENTS TO DATE

- Development of advanced FESEM and image analysis methods to better characterize key components in organic-rich shales and other tight formations that could affect CO_2 storage.
- Collaboration with Hitachi to improve the data-processing and image analysis routines to better characterize and quantify features of interest in unconventional formation samples.
- Evaluation of CO_2 permeation rates and changes over time in fractured and unfractured Bakken core plugs.

LESSONS LEARNED

- A shale is not a shale is not a shale…
- Uncertainties using FESEM to detect nano-scale porosity.
  - How do we account for CO_2 permeation and adsorption/absorption on or in nano-scale pore networks within OM?
  - Can we infer connectivity from CO_2 extraction data?
  - What relationships can be developed between measured sorption data and image analysis-derived parameters.
- Need additional adsorption data for kerogen and different clay types at reservoir pressure (4000–7000 psi).

SYNERGY OPPORTUNITIES

- This work helps us better characterize and quantify the physical and geochemical factors that affect CO_2 transport, migration, and sorption in unconventional (and conventional) reservoirs or other subsurface CO_2 storage targets.
- By better understanding the relationships between porosity, OM and clays in an undisturbed state, we are able to develop a method to estimate how much CO_2 might contact OM vs. clays (or reactive minerals).
  – This information allows us to expand NETL's volumetric storage equation for organic-rich shales by providing a method to estimate the storage efficiency factors related to CO_2 adsorption on clays versus OM.

PROJECT SUMMARY

- Advanced classification of FESEM imagery is a great way to better understand the occurrence of and relationships between key factors that can affect CO_2 migration and storage in tight rocks.
- Bakken-specific observations:
  - The majority of pore space within the Bakken shales occurs within OM.
  - Most of the pore networks within the Middle Bakken are filled with illite.
  - OM porosity (as determined using FESEM) varies widely within individual samples and between samples from different wells and/or depths.
- Current work is focused on acquiring measured CO_2 adsorption data at reservoir conditions.
- Collaboration with NETL is ongoing to expand the volumetric storage equation for shales by accounting for the efficiency factors associated with CO_2 sorption onto clays and organic matter.

CONTACT INFORMATION

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THANK YOU!

APPENDIX

BENEFIT TO THE PROGRAM

To improve understanding of the key geologic factors that influence CO_2 storage resource estimates in organic-rich shales and other unconventional reservoirs and to better define the efficiency factors associated with each key parameter, the Energy & Environmental Research Center (EERC) is developing advanced analytical techniques to better understand the distribution of clay minerals and organics, porosity type and volume, and natural fracture occurrence and characteristics in representative shale and tight rock samples. This effort supports NETL's Carbon Storage Program goal of improving the ability to predict CO_2 storage capacity in geologic formations to within ±30% through improved characterization of key features that affect CO_2 storage in unconventional reservoirs.

PROJECT OVERVIEW

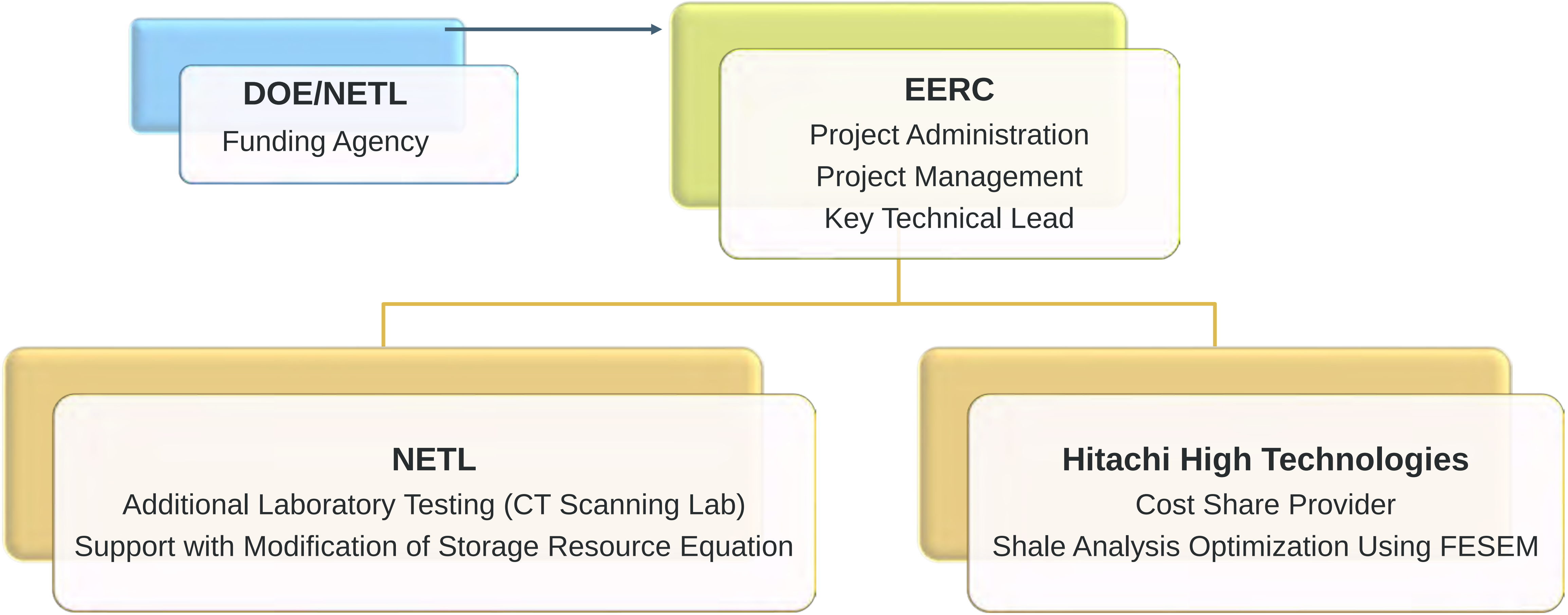
GOALS AND OBJECTIVES

The main goal of this project is to develop advanced characterization methods and/or procedures for studying the properties of organic-rich and other tight shale formations using advanced analytical techniques, with the aim of improving assessment methods for estimating the CO_2 storage capacity of such formations. The overall goal of the project will be accomplished through the following seven objectives:

- Develop advanced FESEM and image analysis methods to better characterize the mineralogy and kerogen content of organic-rich shales and other tight formations.
- Develop improved methods to better estimate porosity and pore-size distributions in organic-rich shales and other tight formations.
- Develop enhanced methods to improve the characterization of fracture networks within organic-rich shales and other unconventional rocks.
- Collaborate with Hitachi to develop and/or improve data processing and image analysis routines to better characterize and quantify features of interest in unconventional formation samples.
- Collaborate with NETL's CT scanning laboratory in Morgantown to investigate the effects of CO_2 exposure on organic-rich shales at the core scale and evaluate CO_2 sorption within organic-rich shales.
- Develop improved methods to estimate the storage resource potential of unconventional formations in collaboration with NETL staff.
- Evaluate and quantify CO_2 sorption in Bakken shales.

The above tasks directly relate to NETL's Carbon Storage Program goal of improving the ability to predict CO_2 storage capacity in geologic formations to within ±30%. How the project goals and objectives relate to the program goals and objectives. Eight milestones have been developed and are being tracked to ensure completion of the project goals and objectives.

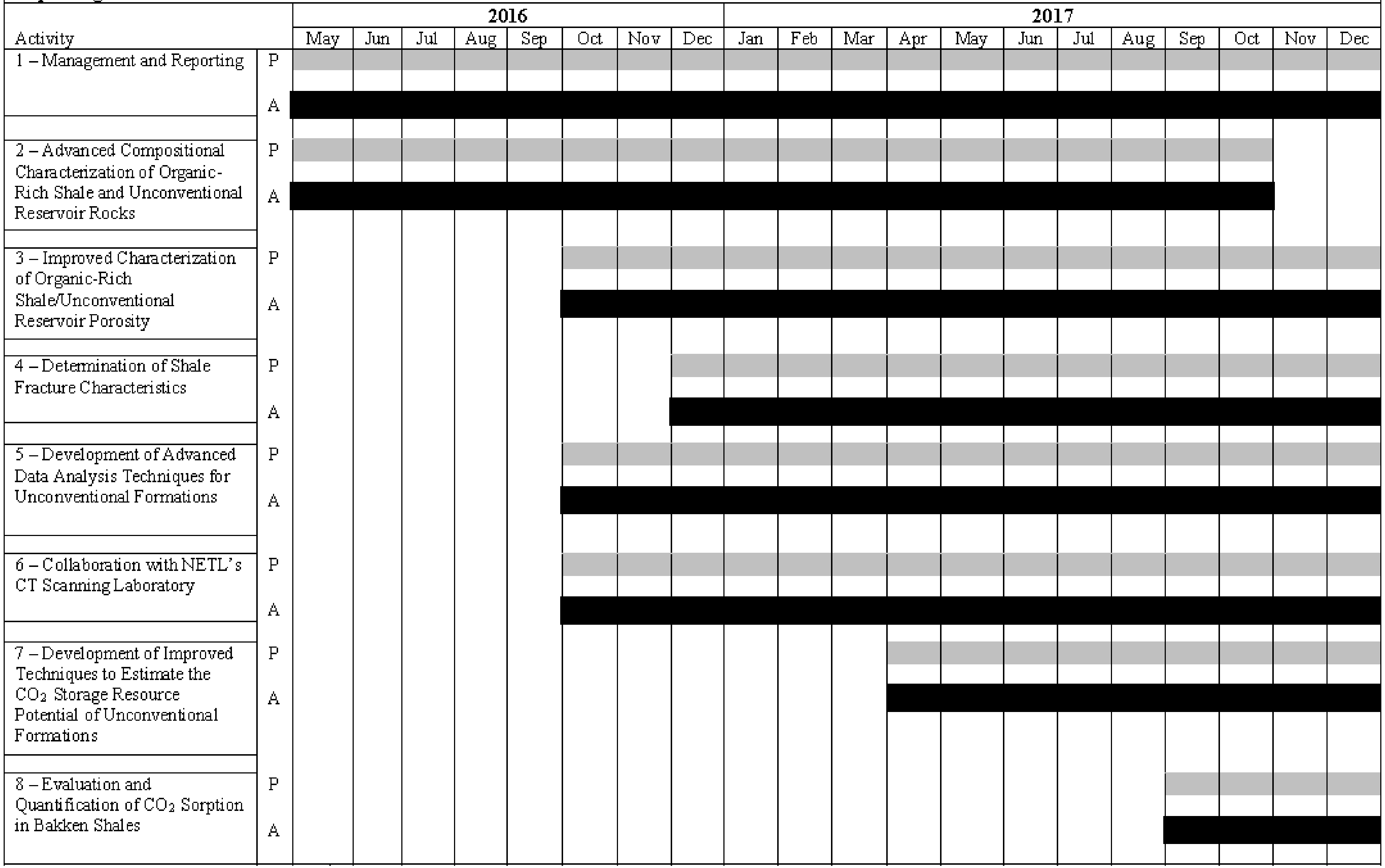
ORGANIZATION CHART



GANTT CHART

Subtask Time Line

Program Title: EERC–DOE Joint Program on Research and Development for Fossil Energy-Related Resources
Cooperative Agreement No.: DE-FE0024233
Subtask Title: Subtask 1.1 – Advanced Characterization of Unconventional Oil and Gas Reservoirs to Enhance CO_2 Storage Resource Estimates
Subtask Manager: Bethany Kurz
Period of Performance: 5/1/16 – 4/30/19
Reporting Period: 4/1/18 – 6/30/18



GANTT CHART (CONTINUED)

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