PS Pore Distribution in the Ordovician Shale of the Utica/Point Pleasant Sub-Basin*

Michael Murphy[1], Jeff Daniels[1], David Cole[1], Julie Sheets[1], and Susan Welch[1]

Search and Discovery Article #50605 (2012)**
Posted May 28, 2012

*Adapted from poster presentation at AAPG Annual Convention and Exhibition, Long Beach, California, April 22-25, 2012

[1]School of Earth Sciences, The Ohio State University, Columbus, OH (murphy.150@osu.edu)

Abstract

Shale and mudstones are potential reservoir seals for geologic sequestration of carbon dioxide. When rich in organic matter, they are critical in the creation and distribution of hydrocarbons. The objective of this investigation is to characterize and image pore networks in shale. The techniques used in this study characterize porosity in small samples at the nanometer to micron scale. Linking pore types to depositional environments can help to scale up laboratory measurements. Pore types were classified by their size, shape, and connectivity, and then analyzed in relation to facies distributions in the Utica/Point Pleasant sub-basin. The sub-basin is an Ordovician feature in the Midcontinent United States flanked by carbonate platforms to the northwest and southwest, and the Taconic foreland basin to the east. Core samples from six wells were used to investigate porosity in the Utica Shale, the Point Pleasant Formation, and the Logana Member of the Lexington Limestone. Mercury intrusion porosimetry was used to estimate total pore volume, pore size distribution, connectivity, and capillary breakthrough pressure. Pulse and probe permeameters were used to measure permeability. A scanning electron microscope with Quantitative Evaluation of Minerals by Scanning Electron Microscope (QEMSCAN) software was employed to image pores and for quantitative analysis of mineralogy, texture, and porosity. Two samples were analyzed with a dual beam focused ion beam scanning electron microscope (FIB-SEM). The FIB-SEM analysis produced 3D representations of pore networks and organic matter distribution. Initial results indicate that pore size, shape, and connectivity vary with the distributions of clay and carbonate matrix and organic matter. These differences correspond to location within the sub-basin and to stratigraphic position. The matrix pores tend to be larger and more connected, but with narrow pore throats. Pores are smaller in organic matter and fossil fragments, but in some cases are locally highly connected. Pore distribution shows a high correlation to rock texture and fabric. Maps of pore networks will be compared with organic matter and other mineral distributions.

References

Loucks, R.G., R.M. Reed, S.C. Ruppel, and D.M. Jarvie, 2009, Morphology, Genesis, and Distribution of Nanometer-Scale Pores in Siliceous Mudstones of the Mississippian Barnett Shale: JSR, v. 79/12, p. 848-861.

Pope, M.C., and J.F. Read, 1997, High Resolution Subsurface Sequence Stratigraphy of Late Middle to Late Ordovician (Late Mohawkian-Cincinnatian) Foreland Basin Rocks in Kentucky and Virginia: AAPG Bulletin, v. 81/11, p. 1866-1893.

Repetski, J.E., R.T. Ryder, D.J. Weary, A.G. Harris, and M.H. Trippi, 2008, Thermal Maturity Patterns (CAI and %R0) in Upper Ordovician and Devonian Rocks of the Appalachian Basin: A Major Revision of USGS Map I-917-E Using New Subsurface Collections: USGS Scientific Investigations Map SIM-3006.

Pore Distribution in the Ordovician Shale of the Utica/Point Pleasant Sub-Basin

Michael Murphy[1], Jeff Daniels[1], David Cole[1], Julie Sheets[1], Susan Welch[1]
[1]Subsurface Energy Materials Characterization and Analysis Laboratory (SEMCAL) School of Earth Sciences, The Ohio State University, *murphy.150@osu.edu*

1. Project Goals

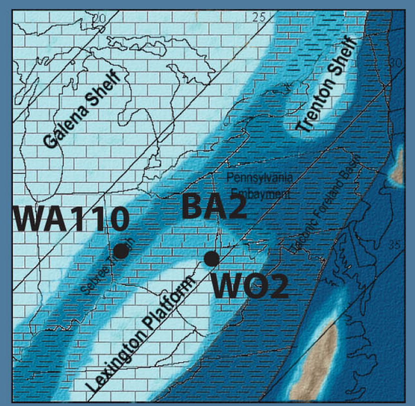


Figure 1: Map of the Utica/Point Pleasant Sub-Basin during middle to late Ordovician time. The location of the three samples discussed in this poster are indicated. Image from the Harvard Museum of Comparative Zoology (www.mcz.harvard.edu).

The overall goal of the research is to characterize pore features and to examine pore distribution in the Utica/Point Pleasant Sub-Basin. Specific goals include:

- Determine pore distribution.
- Quantitative assessment of porosity.
- Analysis of the relationship between porosity and mineral fabric, especially organic content.

2. Pore Features

In all samples, we found porosity to range from 1-3% with median pore diameters of 3.9-6.9 nm. The predominate pore size was <10 nm.

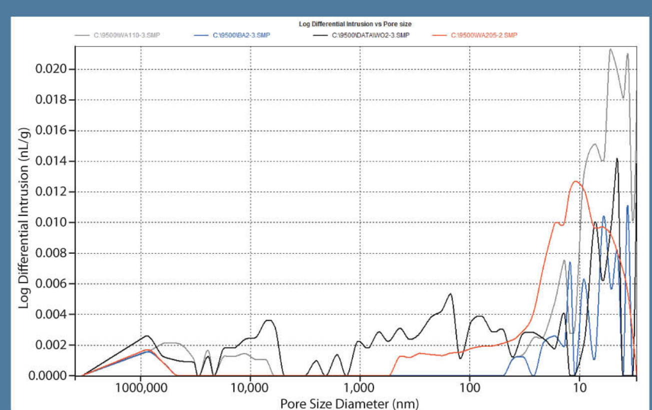


Figure 2.1: Mercury intrusion porosimetry measured pores down to 4 nm. The black curve represents the pore size distribution of the most thermally mature sample (WO2). Most pores are <10 nm, but there are pores up to 10 microns. The blue curve is a sample of intermediate maturity (BA2). A greater portion of pores are <10 nm, and none are larger than 75 nm. The gray curve is the least mature sample (WA110). Nearly all of the pores are <10 nm. For comparison, the red curve shows the pore size distribution of an organic-poor sample of the Eau Claire mudstone. Most of the pores are >10 nm.

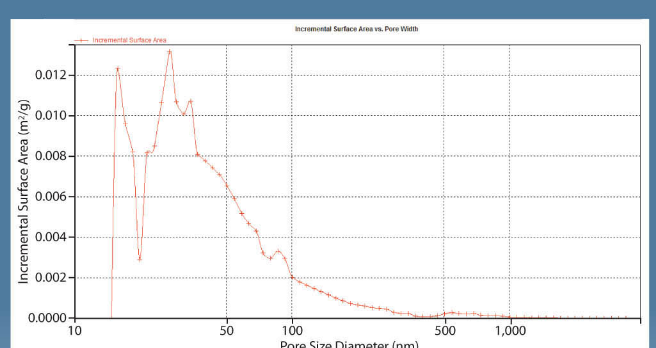
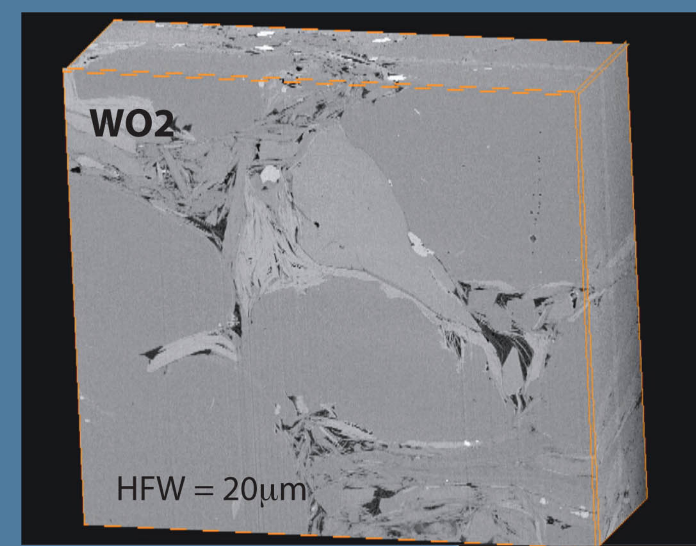


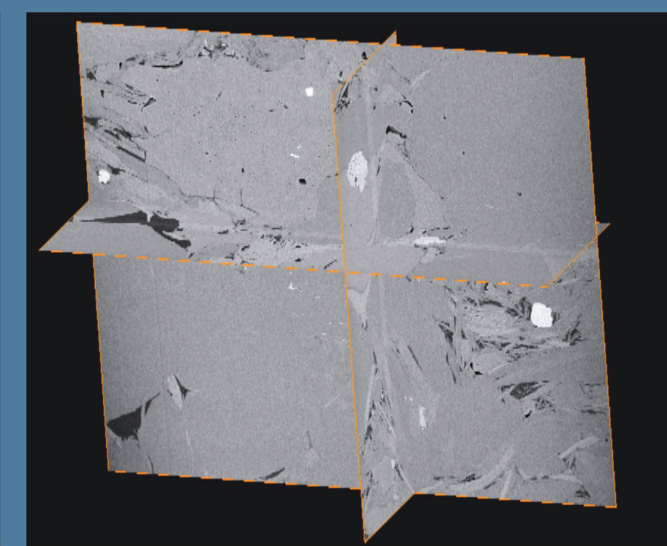
Figure 2.2: The results of gas sorption analysis showed a significant number of pores between 1.5-4.0 nm.

4. Dual-Beam Focused Ion Beam/Scanning Electron Microscope (FIB/SEM)

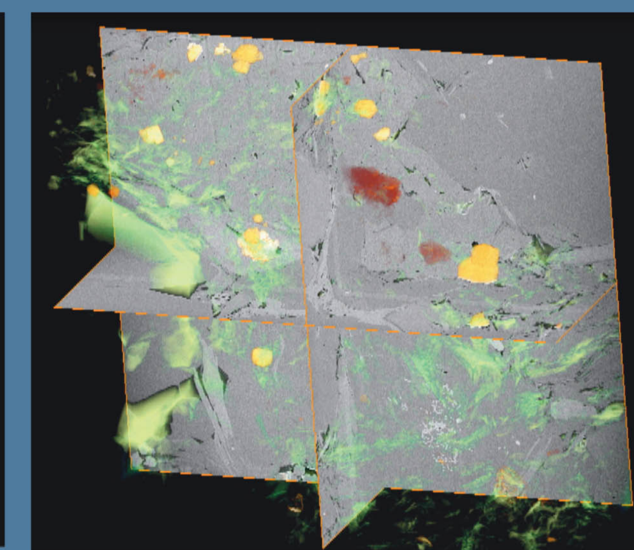
Because most pores are only a few nanometers in diameter, the rough surface of mechanically polished shale samples makes distinguishing pores from topographic lows difficult. To better image and quantify porosity distribution, a dual-beam (FIB/BSEM) was used to create a 3-D reconstruction of a shale sample.



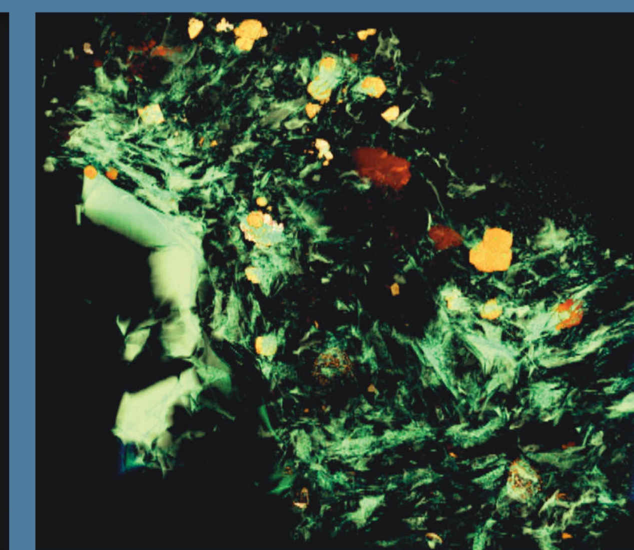
Ion milling provided a smooth enough surface to image pores with diameters of 10s of nanometers.



The FIB milled more than 600 slices at 10 nm intervals.



The slices were reconstructed using FEI's slice and view software.



A false color 3-D flood-fill was added to indicate organic matter (green) and pyrite (red-yellow).

5. Immature vs. Mature Pores

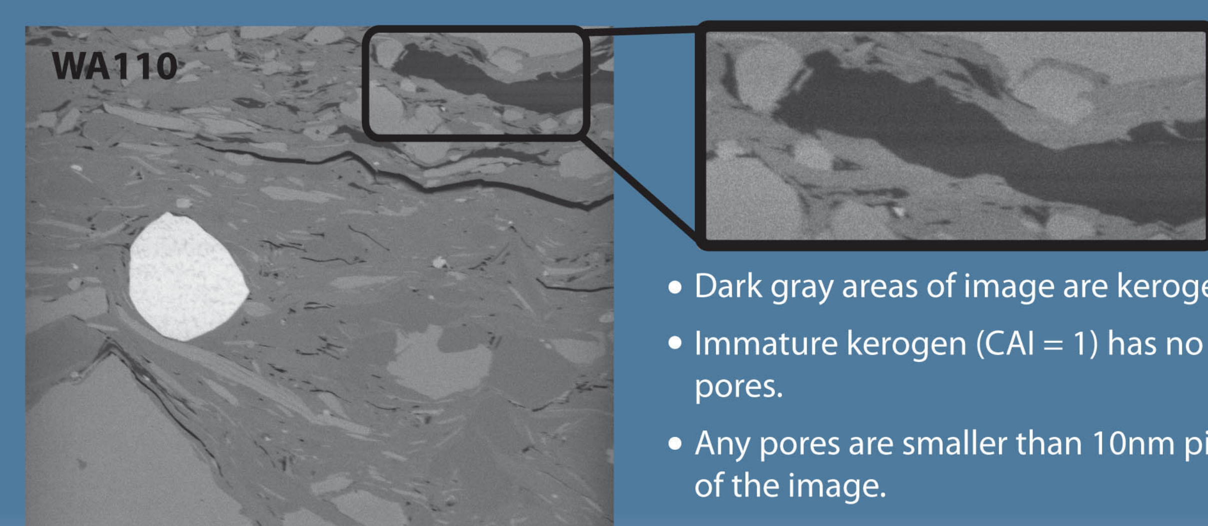


Figure 5.1: Ion-milled image of sample WA110.

- Dark gray areas of image are kerogen.
- Immature kerogen (CAI = 1) has no visible pores.
- Any pores are smaller than 10nm pixel size of the image.

- The circular dark features within the kerogen are pores.
- Mature kerogen (CAI = 3.0-3.5) has visible pores.
- The pores in the image are 10's of nm and well connected.

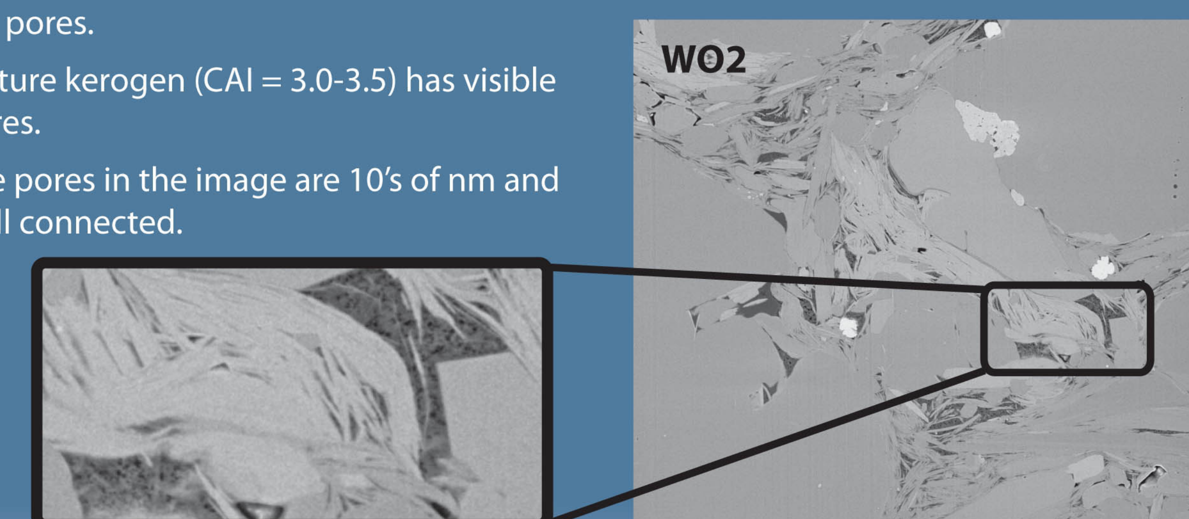


Figure 5.2: Ion-milled image of sample WO2.

6. Conclusions & Future Work

Our preliminary research has found that:

- Pores in organic matter account for up to 80% of effective porosity.
- Intrakerogen pores appear to increase in number and in size with thermal maturity.
- Shale fabric influences the connectivity of intrakerogen pores.

Based on these preliminary findings, we will continue our efforts characterize porosity evolution as a function of organic matter maturity by:

- Improving quantification of pore networks by application of stereological models to dual-beam FIB/SEM data.
- Using an X-ray CT scanner to analyze kerogen pore networks up to the meter scale.
- Inducing kerogen maturation in the lab and measuring and imaging changes in porosity.

References Cited

R. Loucks et al., Morphology, Genesis, and Distribution of Nanometer-Scale Pores in Siliceous Mudstones of the Mississippian Barnett Shale, Journal of Sedimentary Research, v. 79, 848-861 (2009).

M. Pope and J.F. Read, High Resolution Subsurface Sequence Stratigraphy of Lat Middle to Late Ordovician (Late Mohawkian-Cincinnatian) Foreland Basin Rocks in Kentucky and Virginia, AAPG Bulletin, vol. 81, no. 11 (1997).

J. Repetski et al., Thermal Maturity Patterns (CAI and %R0) in Upper Ordovician and Devonian Rocks of the Appalachian Basin: A Major Revision of USGS Map I-917-E Using New Subsurface Collections, USGS (2008).

Acknowledgements

We would like to thank the Ohio Department of Natural Resources Division of Geological Survey for providing samples and guidance. FEI provided use of their dual beam FIB/SEM and analysis for the 3-D data. Funding for SEMCAL graduate student research comes in part from grants from the U.S. Department of Energy and the Ohio Coal Development Office.

3. Mineralogy & Fabric

Mineralogy was assessed via scanning electron microscopy (SEM) with Quantitative Evaluation of Minerals by Scanning Electron Microscopy (QEMSCAN) software. QEMSCAN creates mineral maps of a sample surface scanned by an electron beam. Mineral classification is based on chemical composition derived from X-ray analysis and backscatter electron (BSE) brightness.

Two general lithofacies are found:

1. Point Pleasant (samples BA2 & WO2): argillaceous lime stone with bioturbation and fossiliferous beds (transgressive systems tract)
2. Utica (sample WA110): calcareous mudstone containing abundant pyrite and apatite, with a more distinct planar lamination and lack of bioturbation (highstand systems tract).

Porosity analysis indicates most connected pores are in organic matter. The distribution of organic matter follows the mineral fabric. It appears in clay lamina, often in association with pyrite and apatite.

Depth: 859.5 ft
TOC: 1-2%
Porosity: 3.1%
Pore Diameter: 4.7 nm

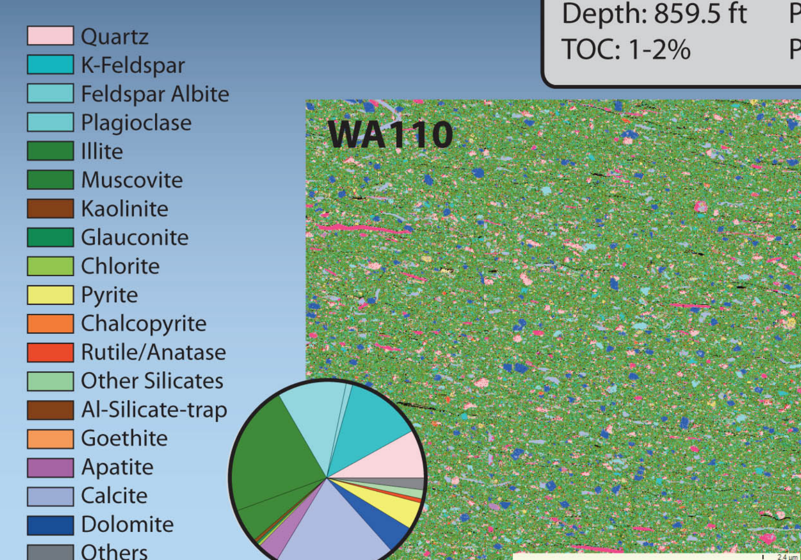


Figure 3.1: Mineralogy and fabric of sample WA110 (pixel size 2.5 µm).

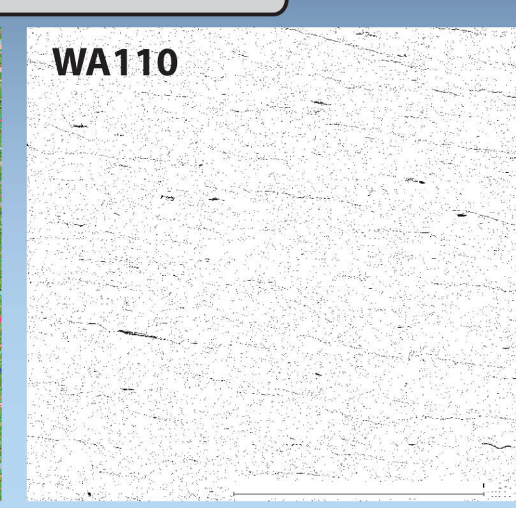


Figure 3.2: Distribution of organic matter and pore space in sample WA110.

Depth: 5,681 ft
TOC: 3%
Porosity: 1.4%
Pore Diameter: 5.7 nm

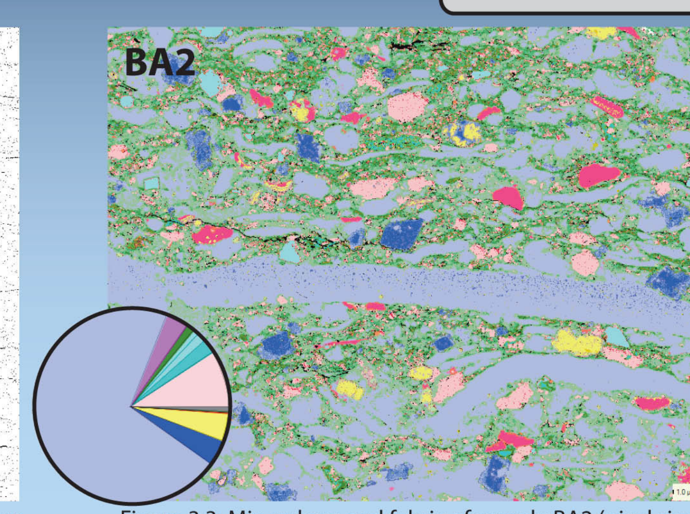


Figure 3.3: Mineralogy and fabric of sample BA2 (pixel size 1.0 µm).

Figure 3.4: Distribution of organic matter and pore space in sample BA2.

Depth: 9,502 ft
TOC: 3-4%
Porosity: 2.7%
Pore Diameter: 5.7 nm

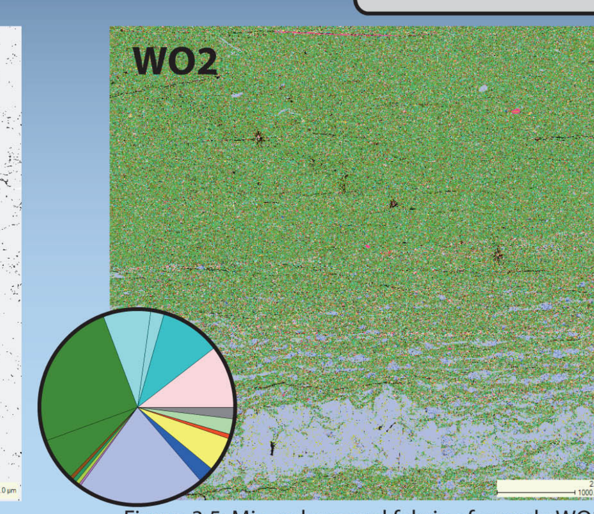


Figure 3.5: Mineralogy and fabric of sample WO2 (pixel size 2.5 µm).

Figure 3.6: Distribution of organic matter and pore space in sample WO2.

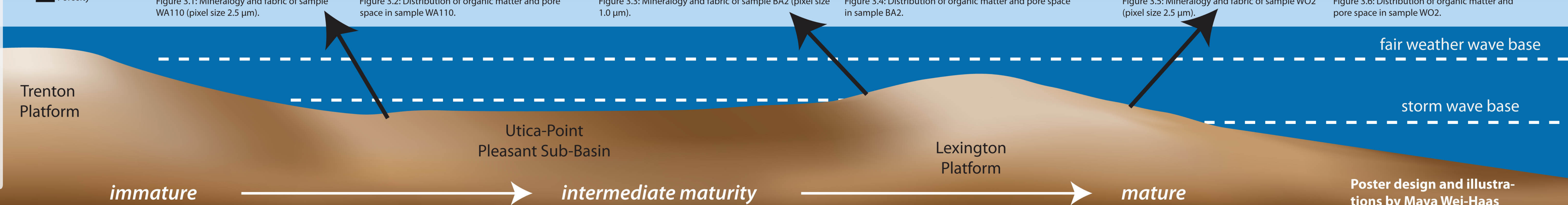


Image adapted from Pope & Read.

Poster design and illustrations by Maya Wei-Haas