Origin and Classification of Pores in Mudstones from Shale-Gas Systems*

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Abstract

Pore networks in mudstones of shale-gas systems are variable and complex. A spectrum of pore types has been identified on the basis of analyzing a number of shale-gas systems, including the Devonian Woodford Shale in the Permian Basin, Mississippian Barnett Shale in the Fort Worth Basin, Pennsylvanian Atoka Shale in the Permian Basin, Jurassic Haynesville and Bossier Shales in East Texas Basin, Lower Cretaceous Pearsall Shale in southwest Texas, and Upper Cretaceous Eagle Ford Shale in south Texas. Each shale-gas system has its own characteristic combination of pore types, depending on the mineralogy, texture, and fabric of the mudstone. The pores were analyzed using Ar-ion milled samples that provide extremely flat surfaces and viewed using a field scanning election microscope that allowed recognition of pores as fine as 2 nanometers.

Pore sizes seen in the analyzed suite of mudstones range from approximately 5 nm to several microns. The pore types can be classified as (1) interparticle pores (between particles), (2) intraparticle pores (within discrete particle boundaries), and (3) organic-matter intraparticle pores. Primary interparticle pores between grains are related to original mudstone pore space and are very common in shallow buried muds. These pores make up the primary pore system that is generally connected. Interparticle pores occurring between grains are reduced in size during burial by compaction and/or cementation. Intraparticle pores can be primary or secondary pores, but they occur within a discrete particle, such as in pyrite framboids, porous phosphate particles, or as molds of fossils, crystals, or grains (i.e., feldspars). Organic-matter intraparticle pores are related to thermal maturation of organic matter during hydrocarbon generation and may form a connected pore network.

Pores observed in mudstones suggest that a pore network may have one dominant pore type or a complex combination. Mudstones from the Barnett Shale have a pore network dominated by organic-matter intraparticle pores, whereas the Pearsall Shale appears to have a pore network dominated by interparticle and intraparticle pores. Organic-matter pores and interparticle pores have a better probability to be connected and form a permeable pathway than isolated intraparticle pores.

Selected References

Day-Stirrat, R.J., K.L. Milliken, S.P. Dutton, R.G. Loucks, S. Hillier, A.C. Aplin, and A.M. Schleicher, 2010, Open system chemical behavior in deep Wilcox Group mudstones, Texas Gulf Coast, USA: Marine and Petroleum Geology, v. 27/9, p. 1804-1818.

Loucks, R.G., 2010, Petrographic controls on reservoir quality of the Upper Cretaceous Woodbine Group, East Texas Field, *in* T.F. Hentz, (ed.), Sequence Stratigraphy, Depositional Facies, and Reservoir Attributes of the Upper Cretaceous Woodbine Group, East Texas Field: Bureau of Economic Geology, University of Texas at Austin, Report of Investigations #274, p. 83-93.

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MSRL

Shale-Gas System

- In a shale-gas system the “shale” is source, reservoir, and the seal
- No surprise: Shales are sources of hydrocarbons and seals
- Surprise: Shales are reservoirs

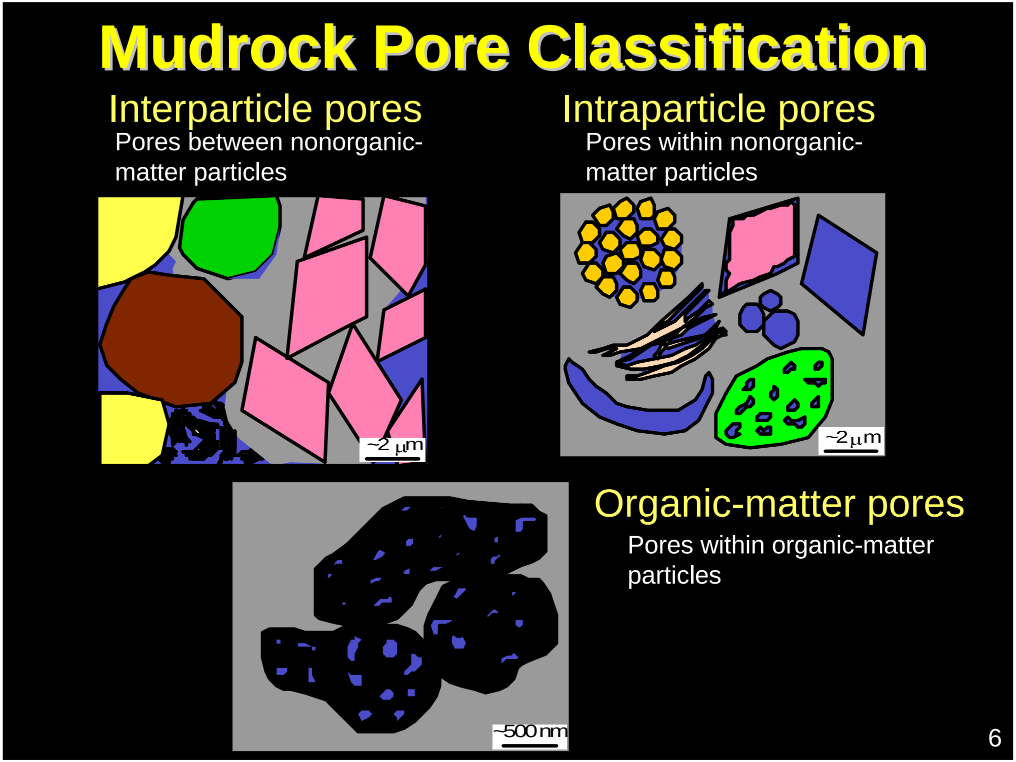
Reservoir = Pores

Goals

- Introduce a mudrock matrix-pore and pore-network classification
- Present examples of pore networks

Understanding where the holes are is important!

Classification of Mudrock Pores



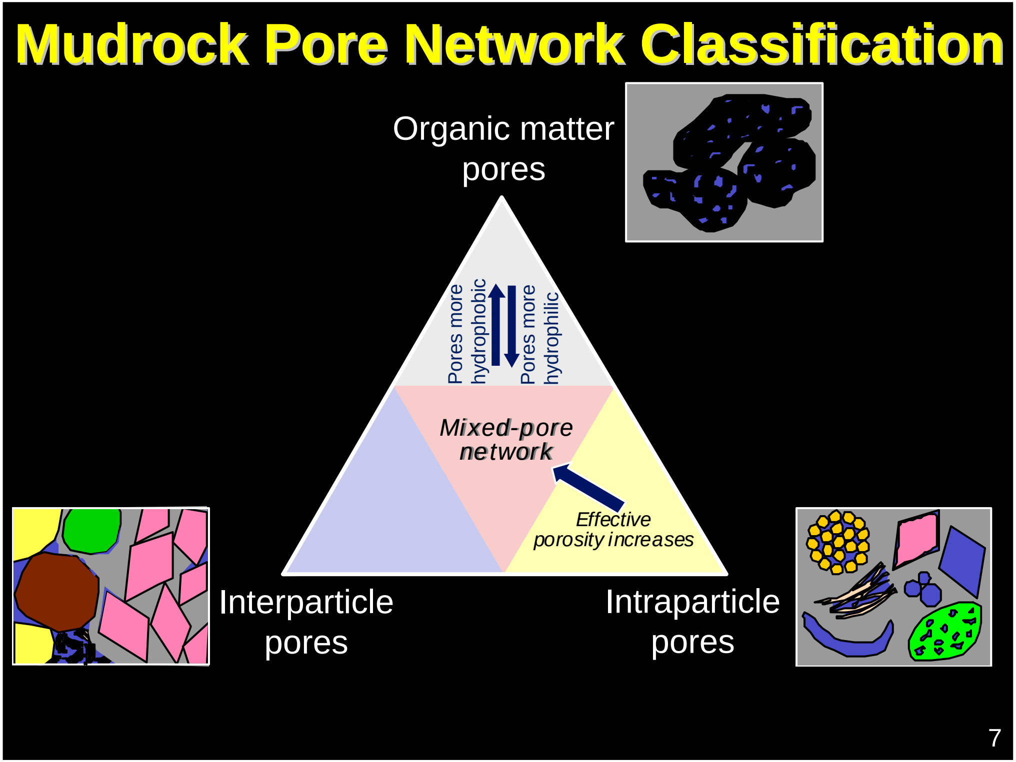
Presenter's notes: We divide mudrock pores into three classes. First we separate pores between pores associated with organic matter and pores not associated with organic matter.

Nonorganic matter pores consists of two classes:

1.Interparticle pores: These are pores between nonorganic particles such as grains and crystals.

2.Intraparticle pores: These pores are within grains. They may be primary or secondary but they are contained within a grain boundary. Examples here are intercrystalline pores in pyrite framboid, dissolution rim around dolomite microrhomb, and dissolution mold of a microfossil.

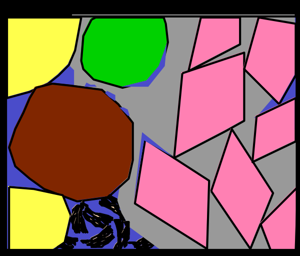
Organic-matter pores are pores that form within organic particles during hydrocarbon maturation.

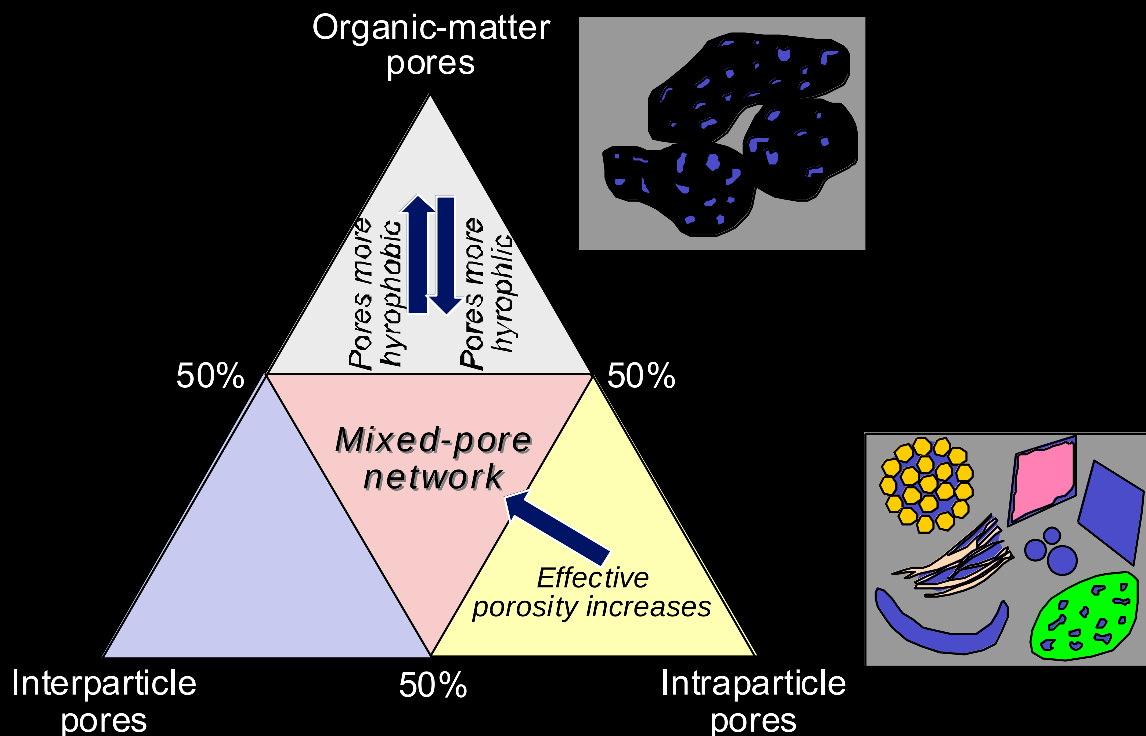


Presenter's notes: 7,177' = 2,187.5 m

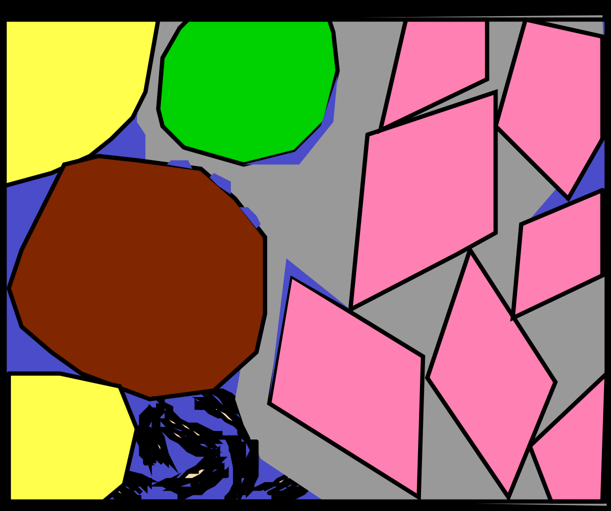
Why a limited ternary classification system?

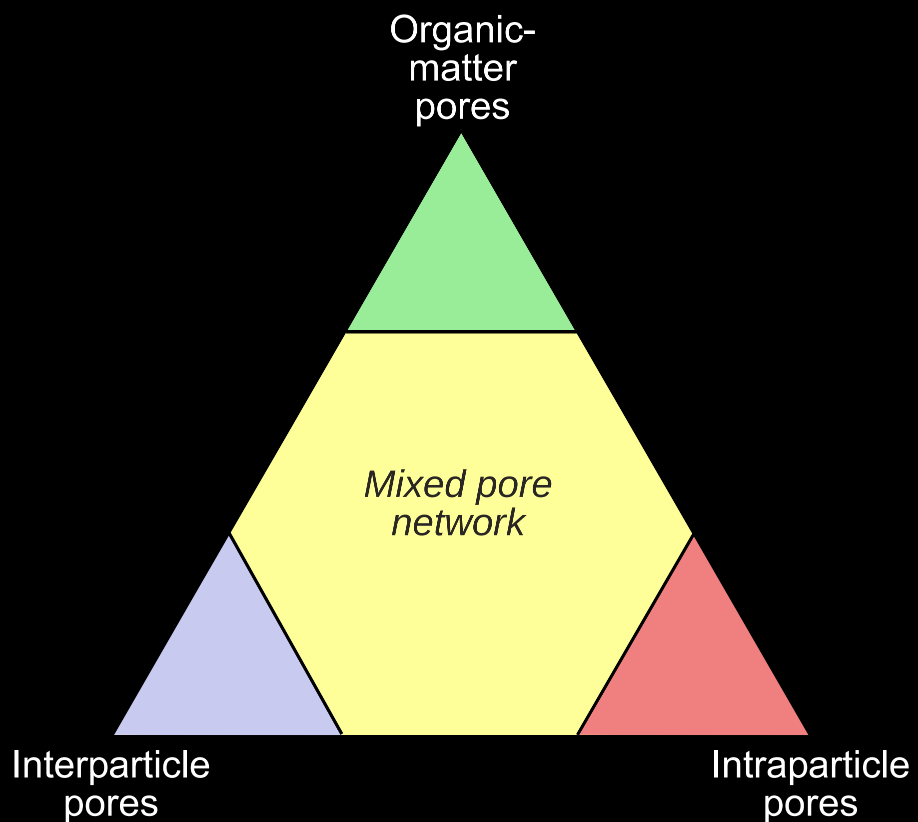
- Captures relative effectiveness of a pore network (connectivity/permeability)
- Allows comparison of pore networks
- Simple



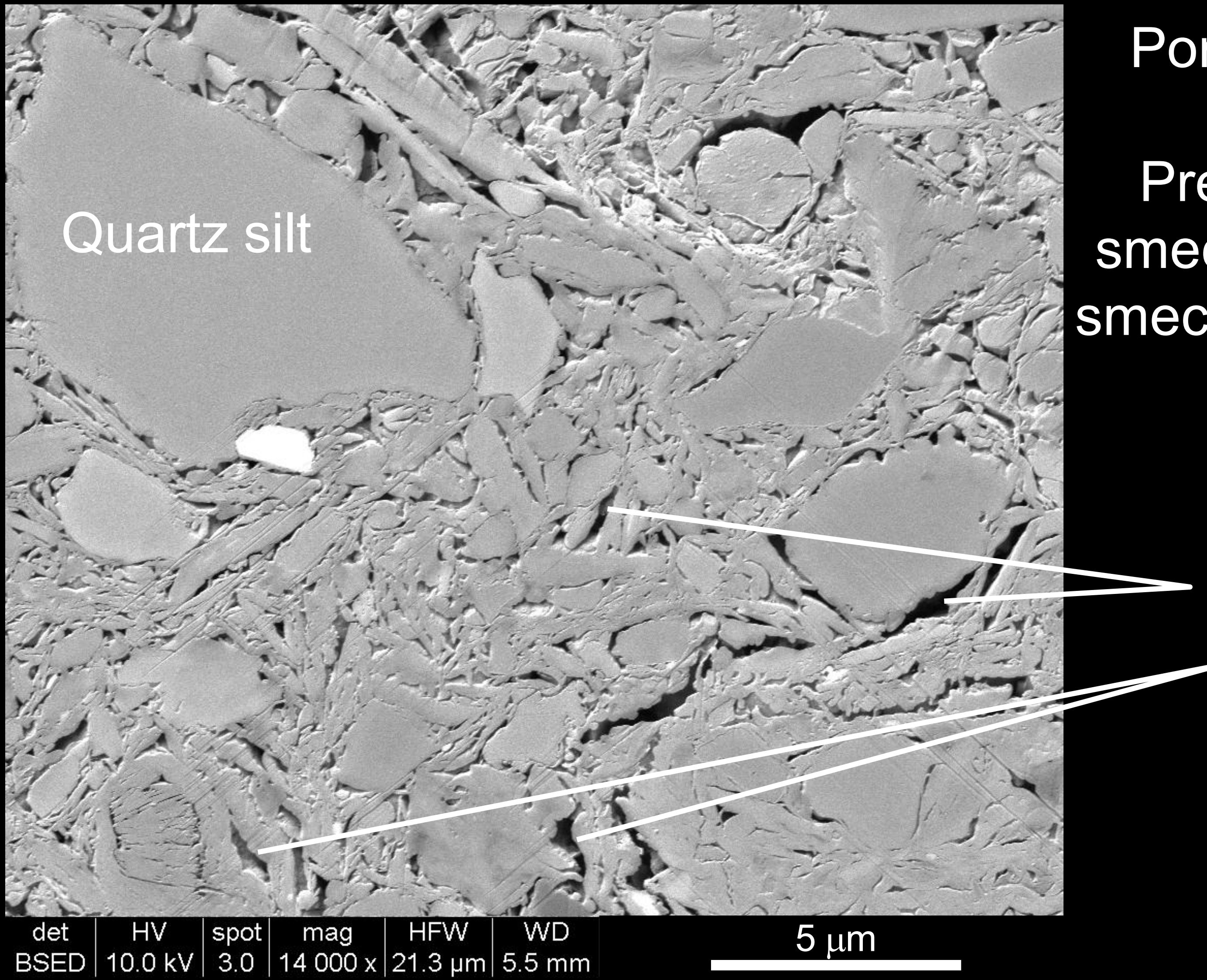


Interparticle Pores





Interparticle Pores



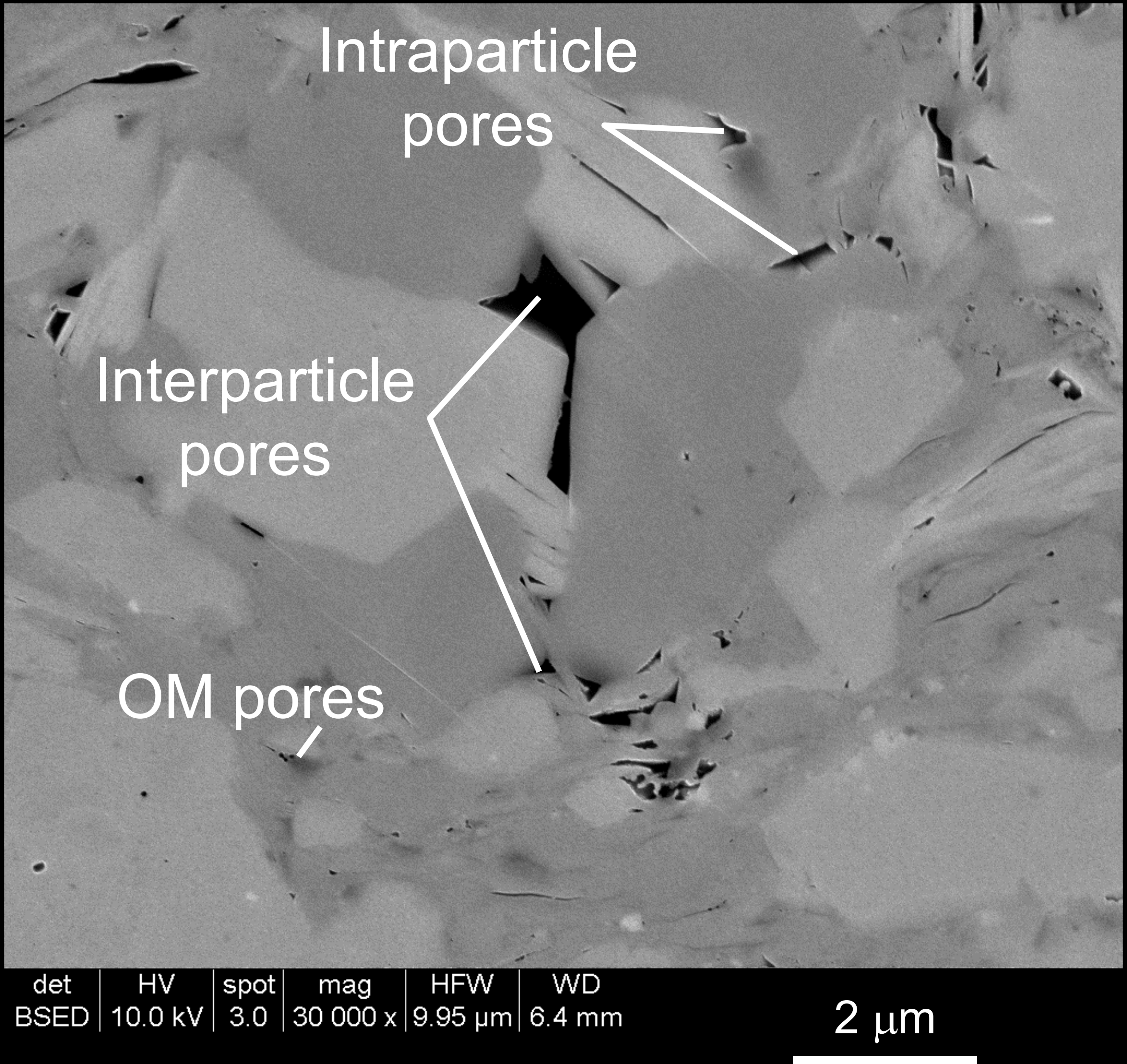
Porosity = 38%

Predominantly smectite-rich illite-smectite and quartz silt

Ursa Basin (GOM) PioPleistocene 1161’

Day-Stirrat et al. (2010)

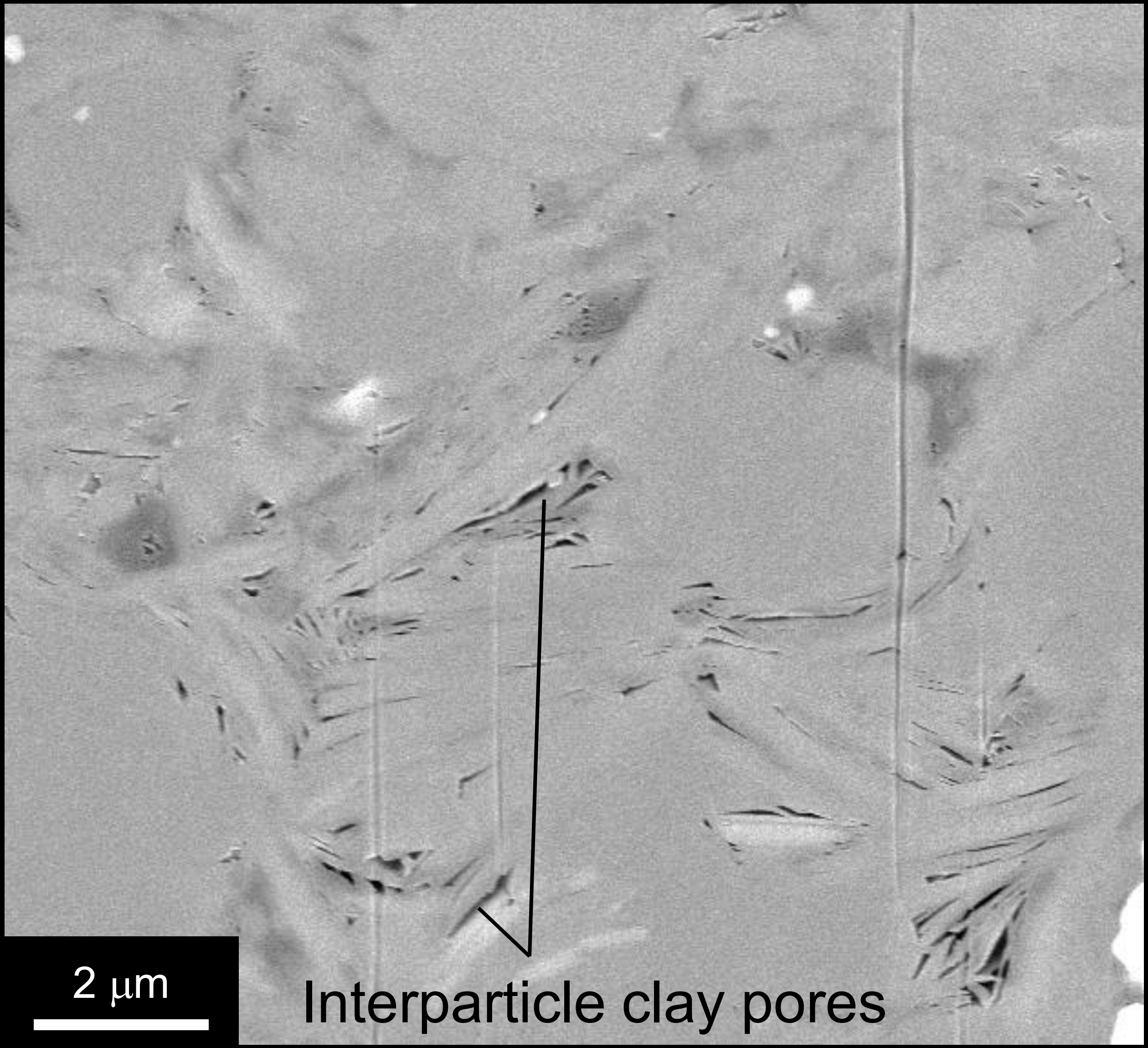
Interparticle Pores



Interparticle pores between grains with overgrowths

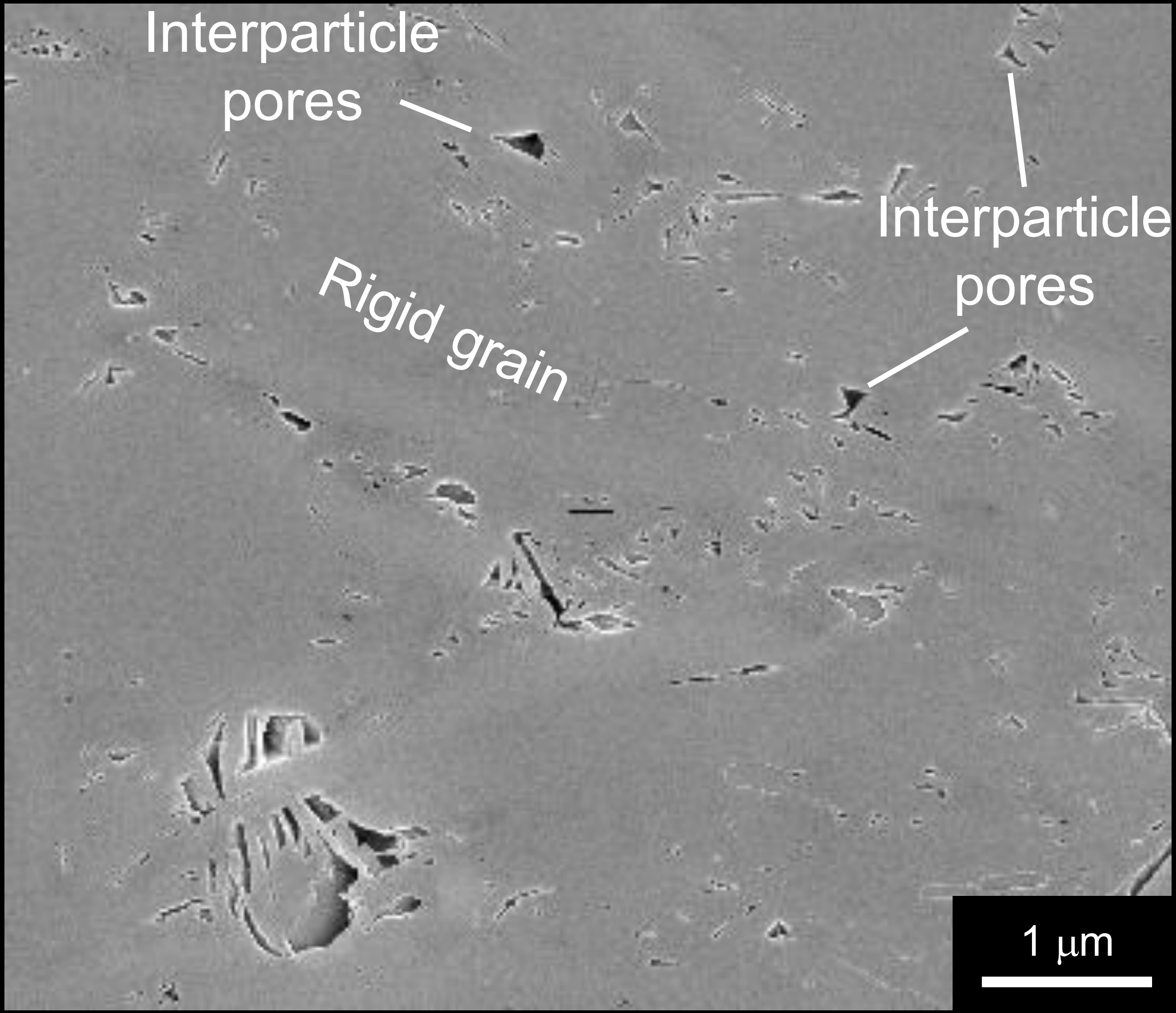
Pearsall Shale 8,427’

Interparticle Pores



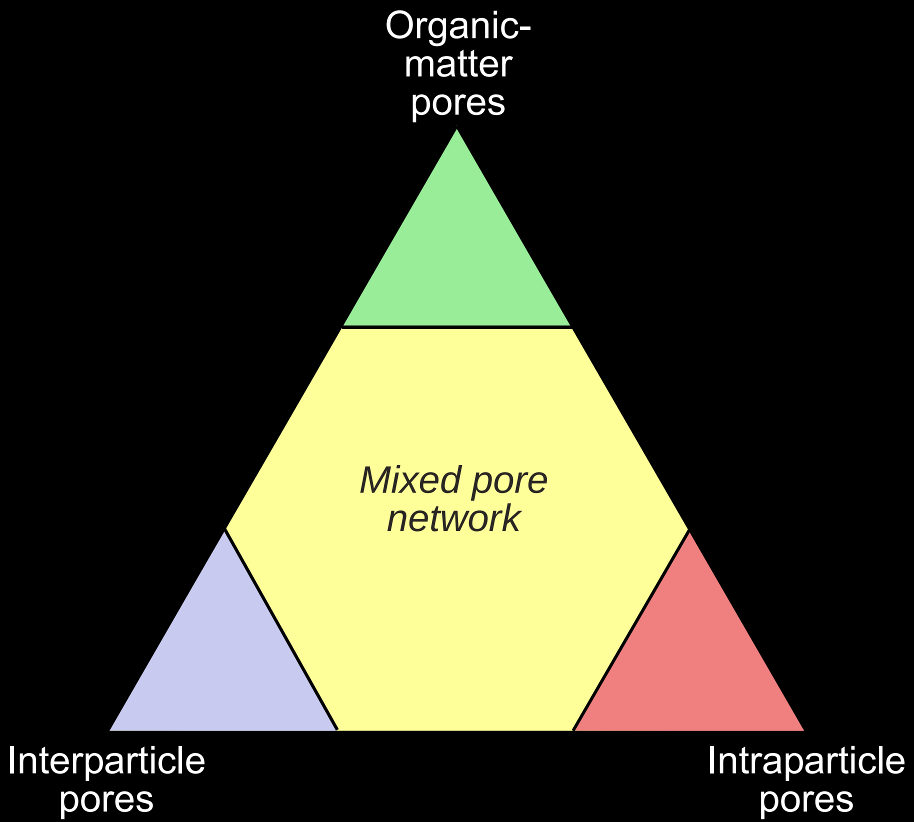
New Albany ~2000 ft. (Sample provided by Noble Energy)

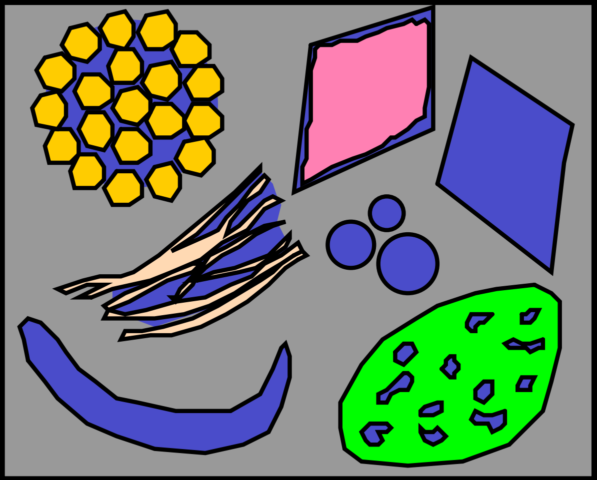
Interparticle Pores



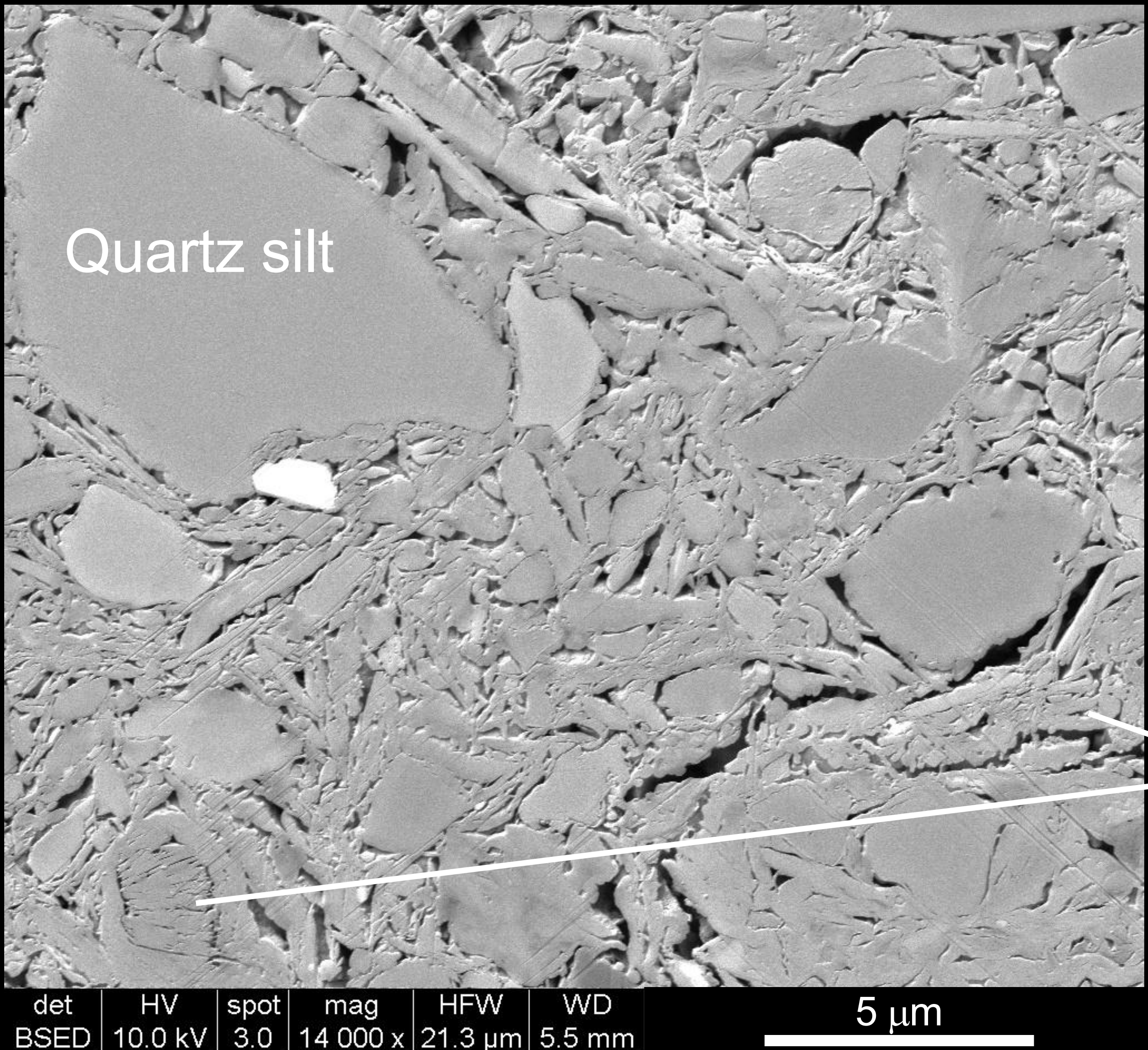
Haynesville/Bossier Shale 12,474 ft.

Intraparticle Pores





Intraparticle Pores



Porosity = 38%

Predominantly smectite-rich illite-smectite and quartz silt

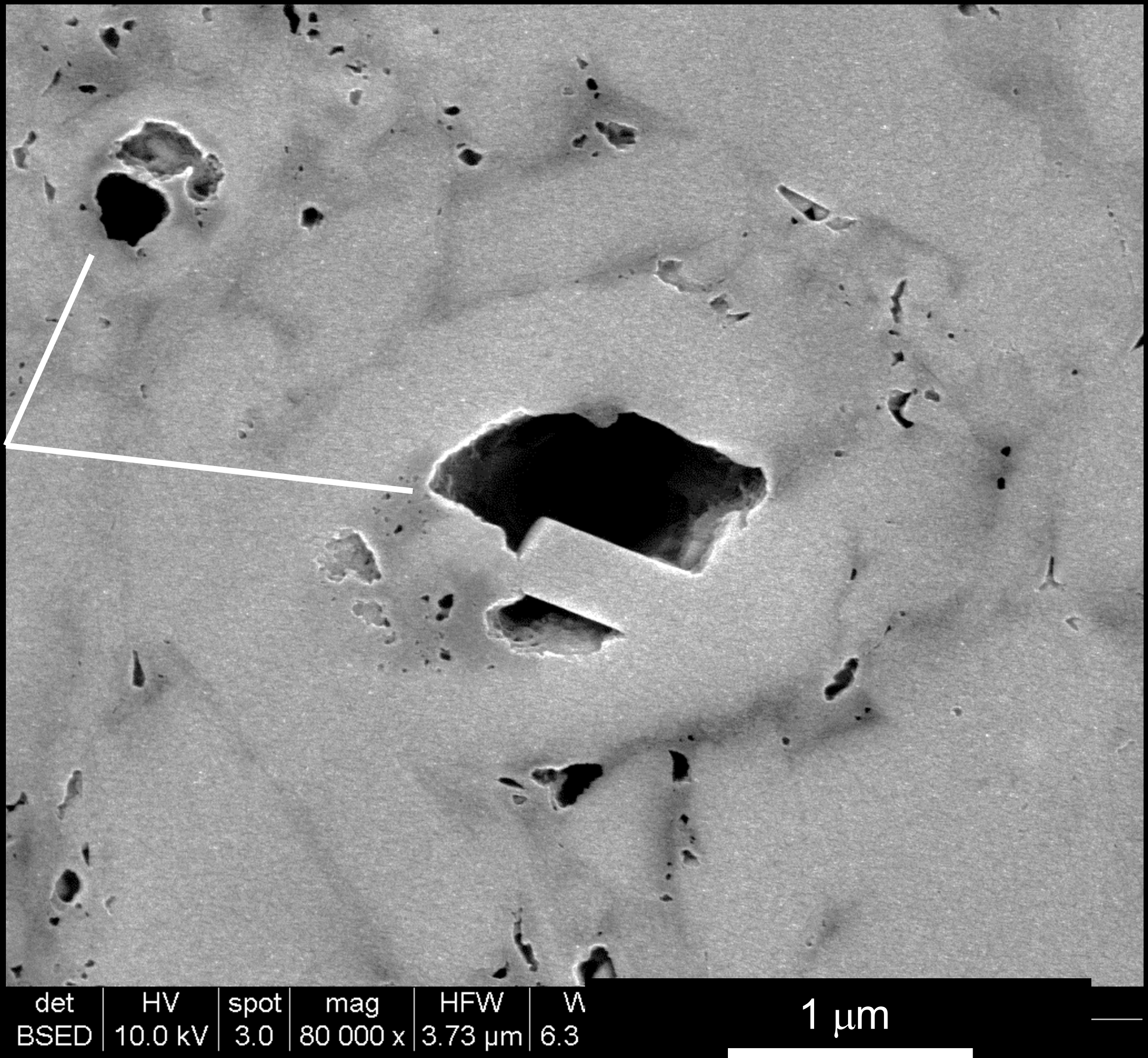
Intraparticle pores

Ursa Basin (GOM) PlioPleistocene 1,161’

Day-Stirrat et al. (2010)

Intraparticle Pores

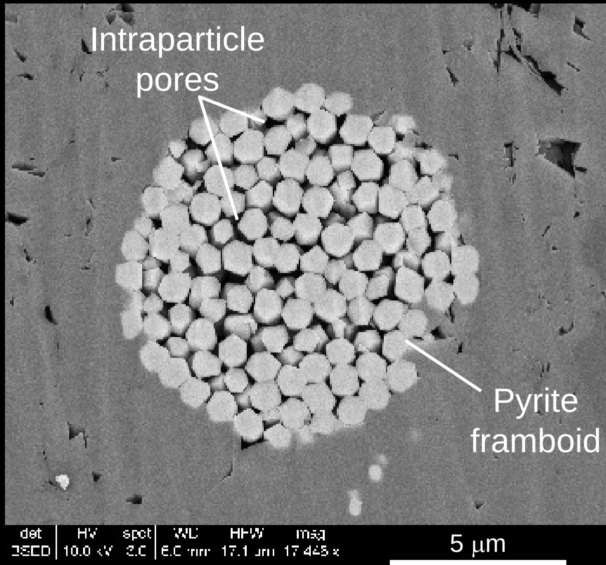
Fossils with intraparticle pores



Intraparticle pores in fossil cavity

Pearsall Shale 8,470’

Intraparticle Pores

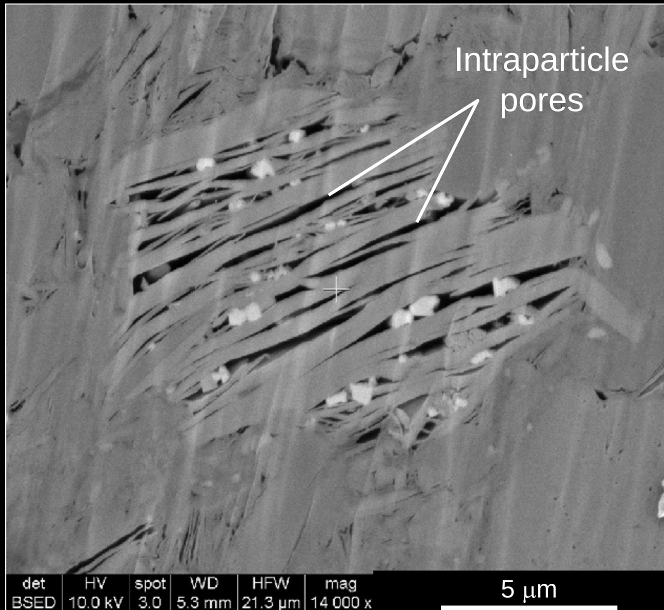


Intercrystalline pores in pyrite framboids

Eagle Ford Shale 6,900’

Presenter’s notes: In both the PB and the FWB, in high and low maturity samples, especially in framboids, there is a strange association of pores and pyrite. VRo ~ 1.2

Intraparticle Pores

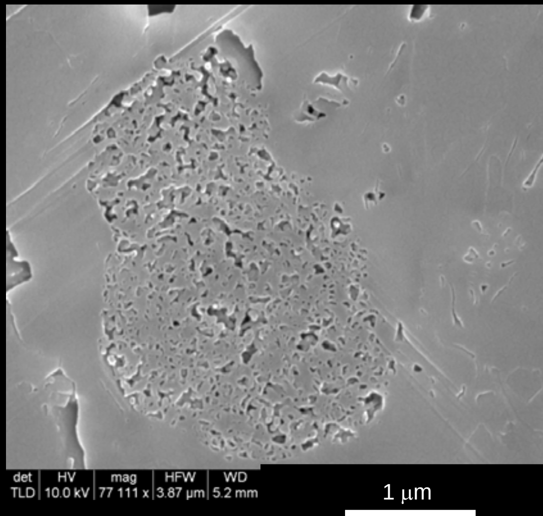


Haynesville Shale 11,209’

Cleavage pores in mica

Presenter’s notes: In both the PB and the FWB, in high and low maturity samples, especially in framboids, there is a strange association of pores and pyrite. VRo ~ 1.2

Intraparticle Pores

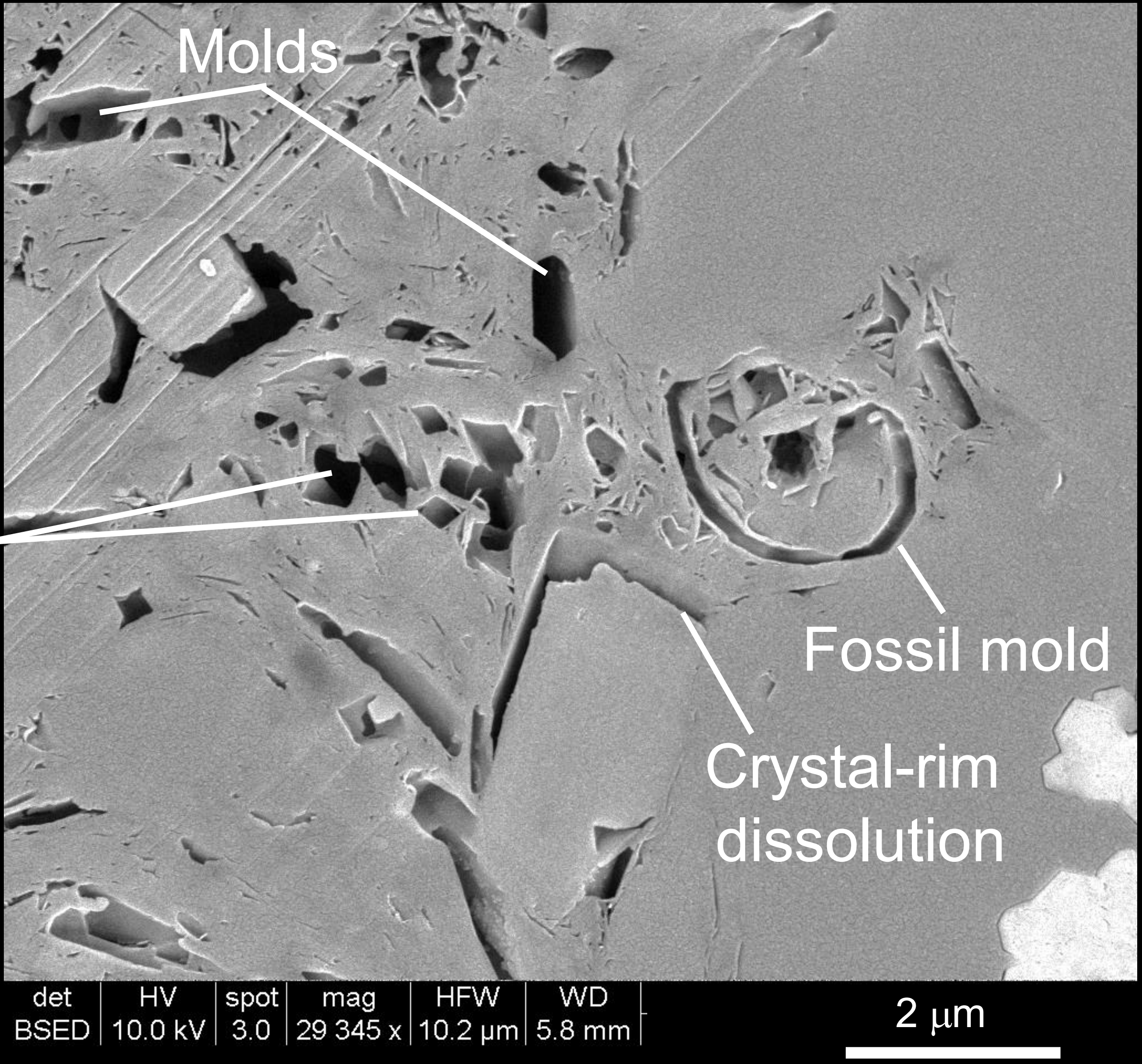


Sponge-like pores in phosphate grain

Pearsall Shale 8,845’

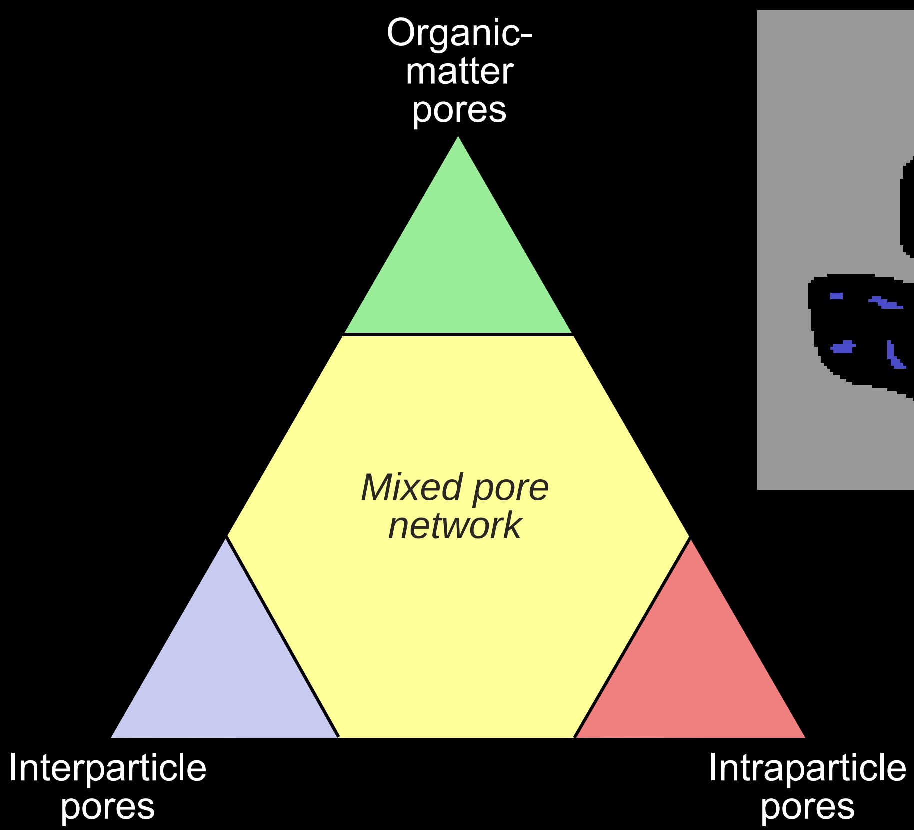
Presenter’s notes: In both the PB and the FWB, in high and low maturity samples, especially in framboids, there is a strange association of pores and pyrite. VRo ~ 1.2

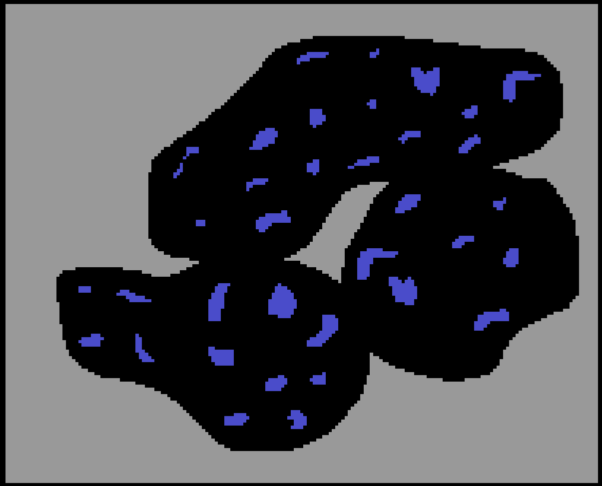
Intraparticle Pores



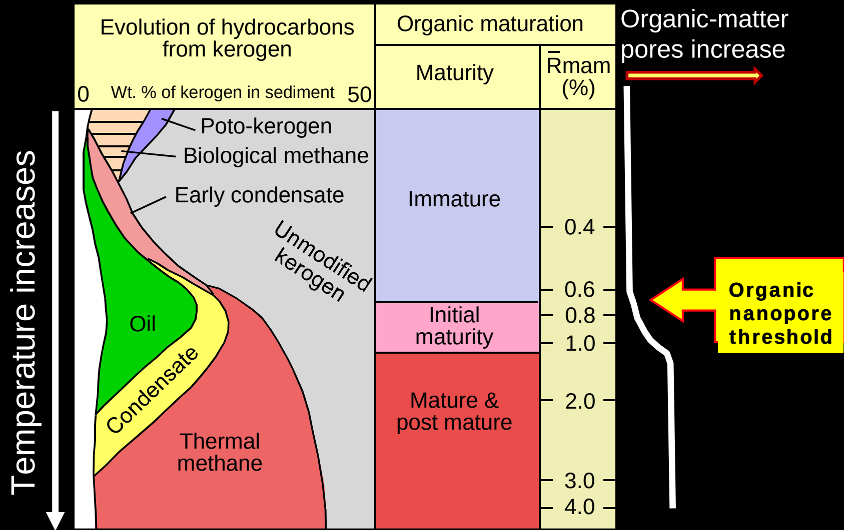
Pearsall Shale 15,934’

Organic-Matter Pores





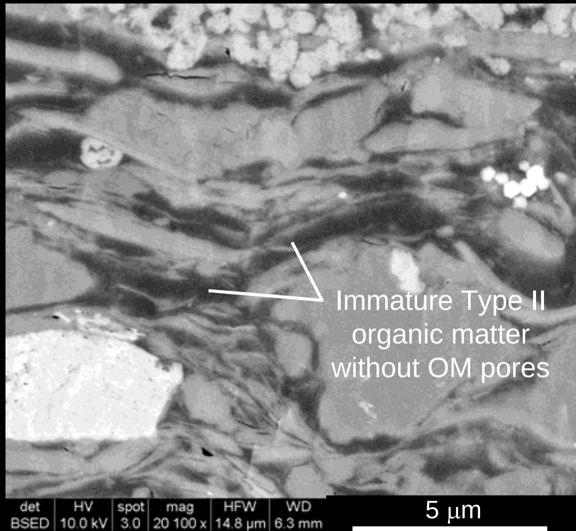
Development of Organic-Matter Pores vs. Thermal Maturity



After Miri (1991) and Potter (2008)

Presenter's notes: Suggests that it may be thermal methane that drives the formation of nanopores, not just any hydrocarbon.

Low-Maturity Organics

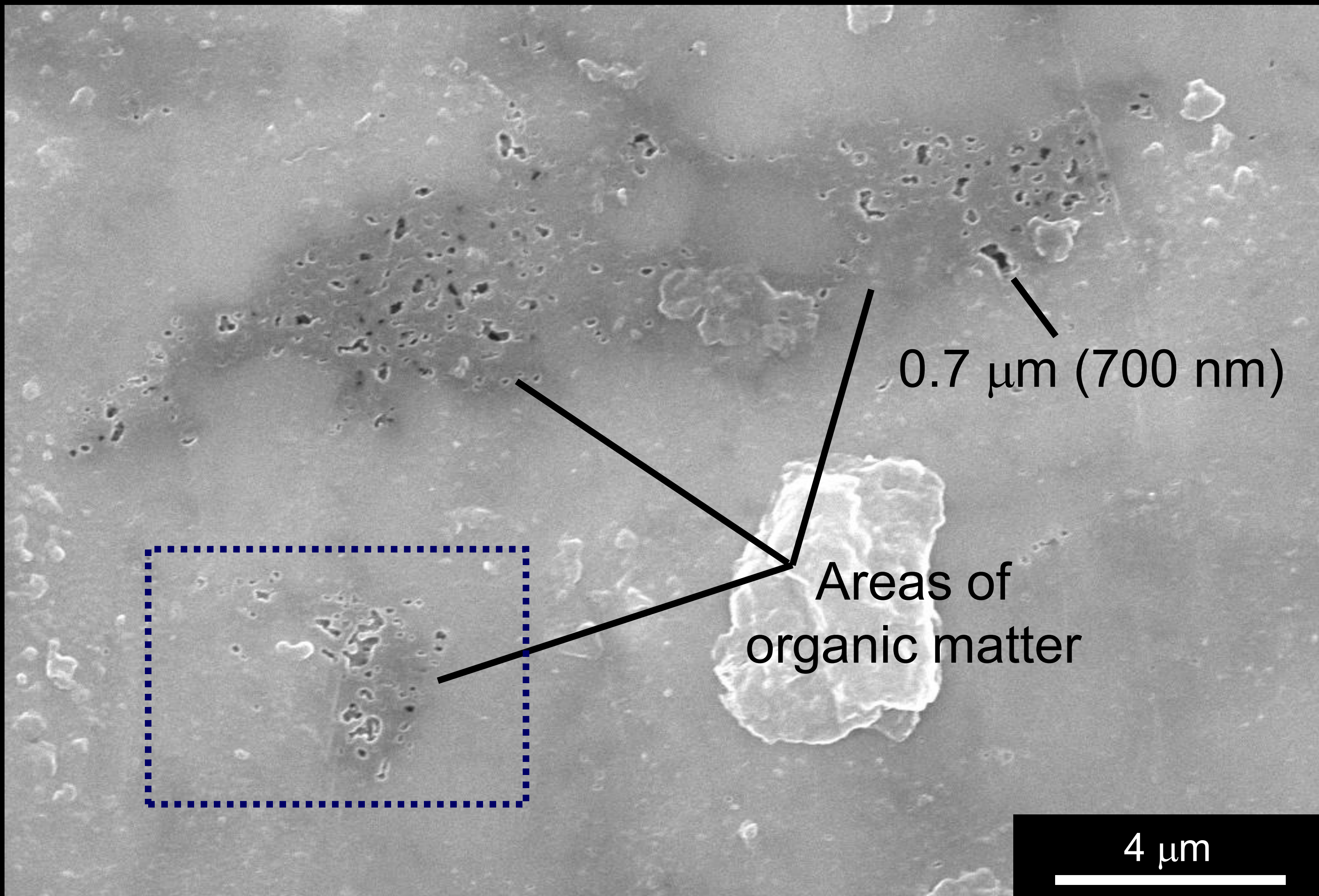


Low VR_o (~0.5), mudstone sample; no organic matter pores

Barnett Shale 648’

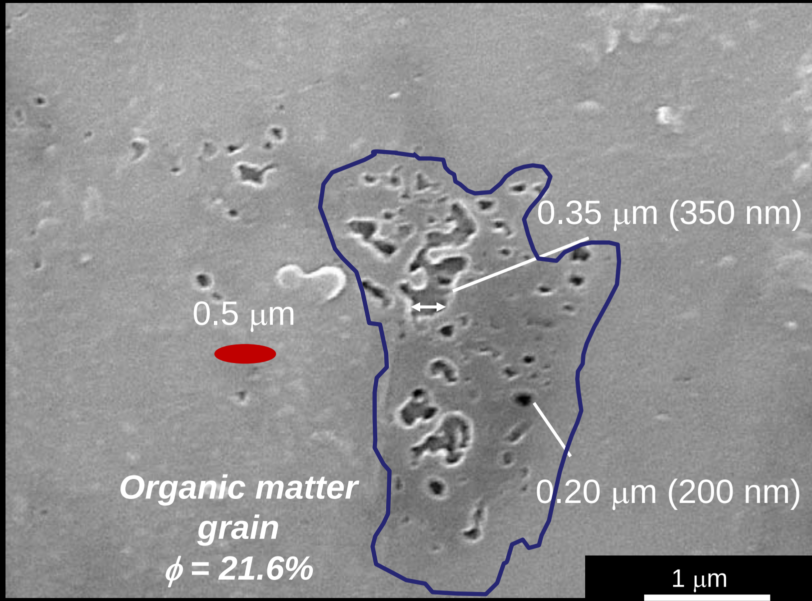
Presenter’s notes: Suggests that it may be thermal methane that drives the formation of nanopores, not just any hydrocarbon.

Organic-Matter Pores



Barnett Shale 7,111’ VR$_o$ = 1.6

Organic-Matter Pores



Barnett Shale 7,111′

Presenter's notes: Grain outline based on backscattered electron image, BL 7206'

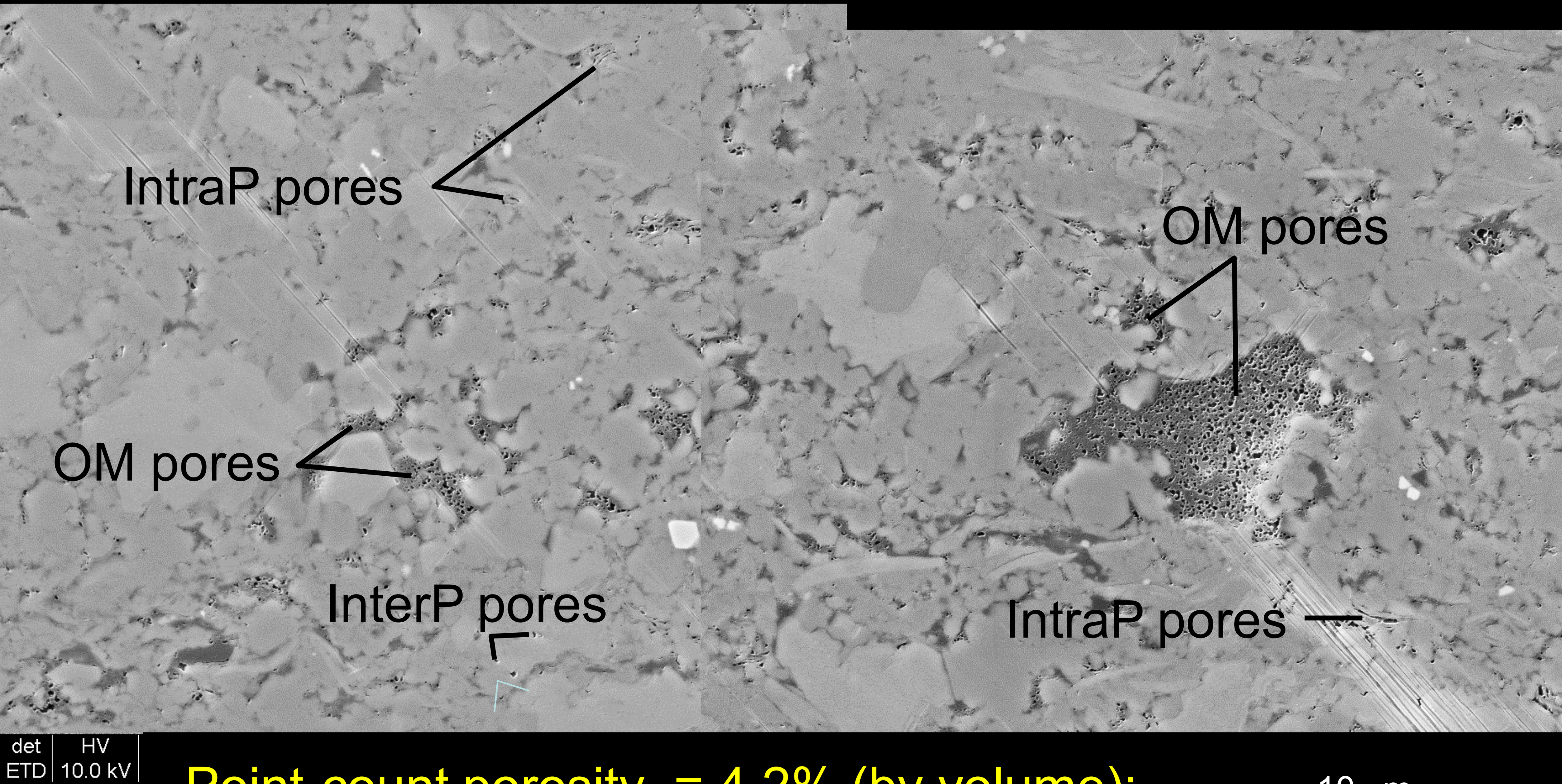
Organic-Matter Pores

Pore distribution controlled by original material

Barnett Shale 7111′

Pore Networks

Organic-Matter-Dominated Pore Network

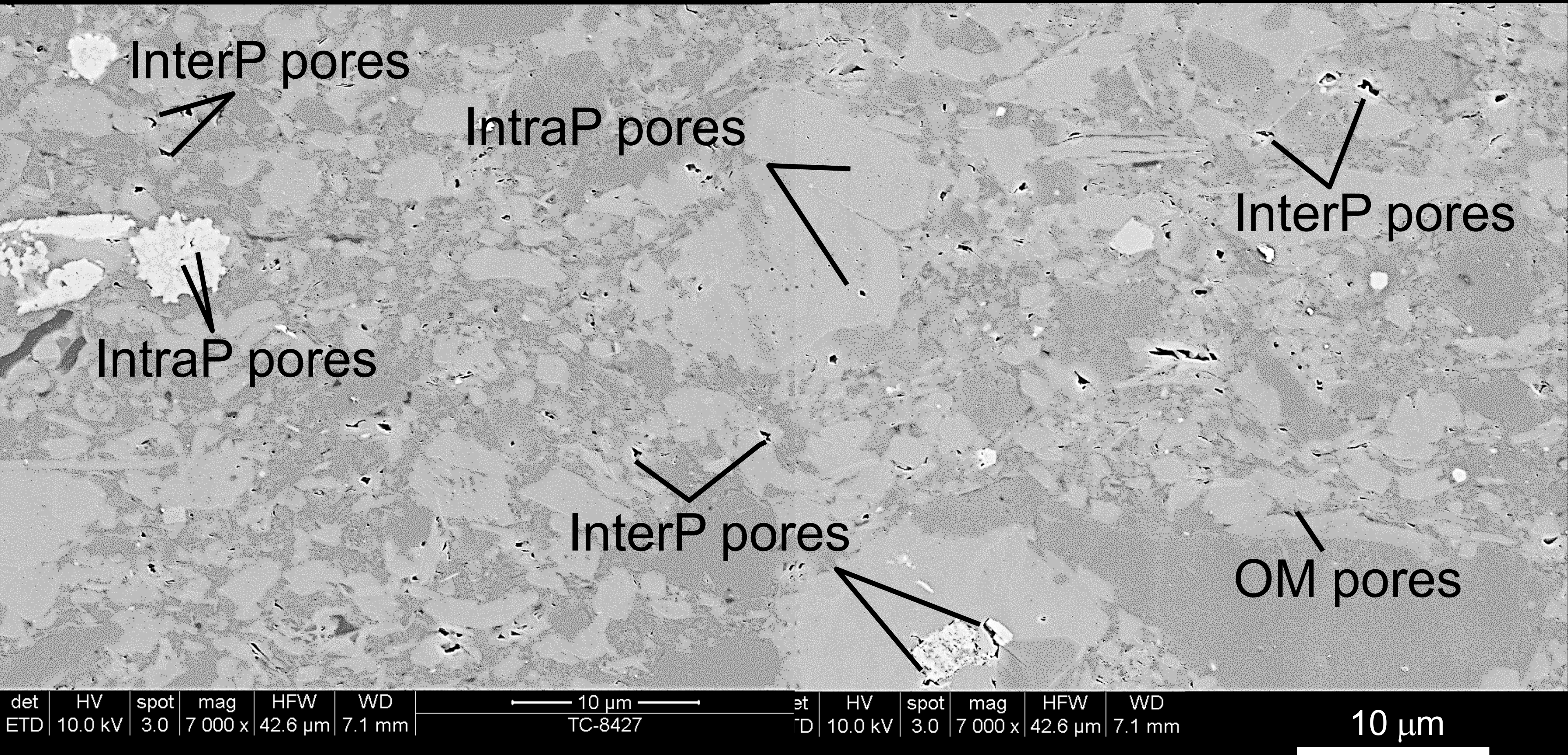


Point-count porosity = 4.2% (by volume):

10 μm

InterP pores = trace
IntraP pores = 4.8%
OM pores = 95.2%

Interparticle-Dominated Pore Network

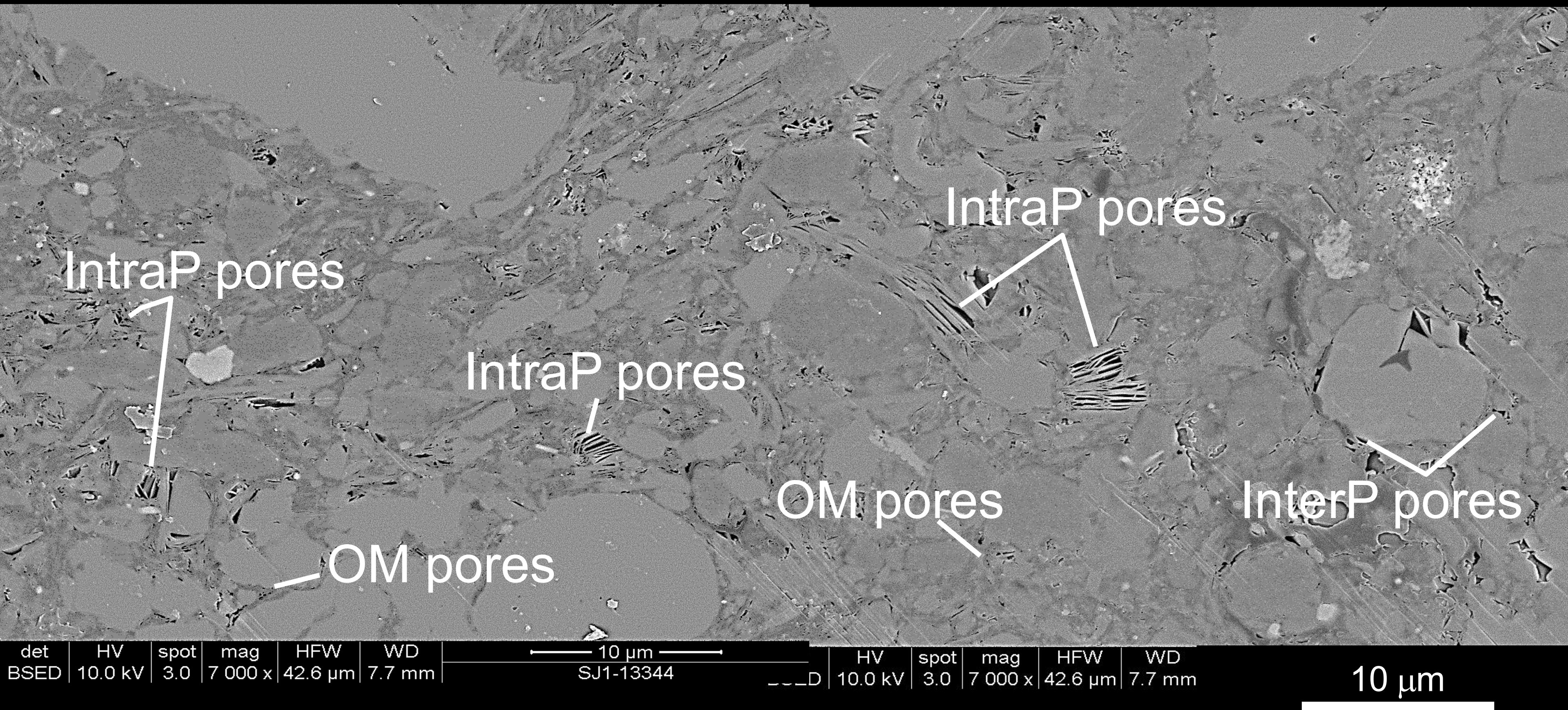


Point-count porosity = 1.8% (by volume):

InterP pores = 69.4%
IntraP pores = 30.6%
OM pores = trace

Pearsall Shale 8,427’

Intraparticle-Dominated Pore Network

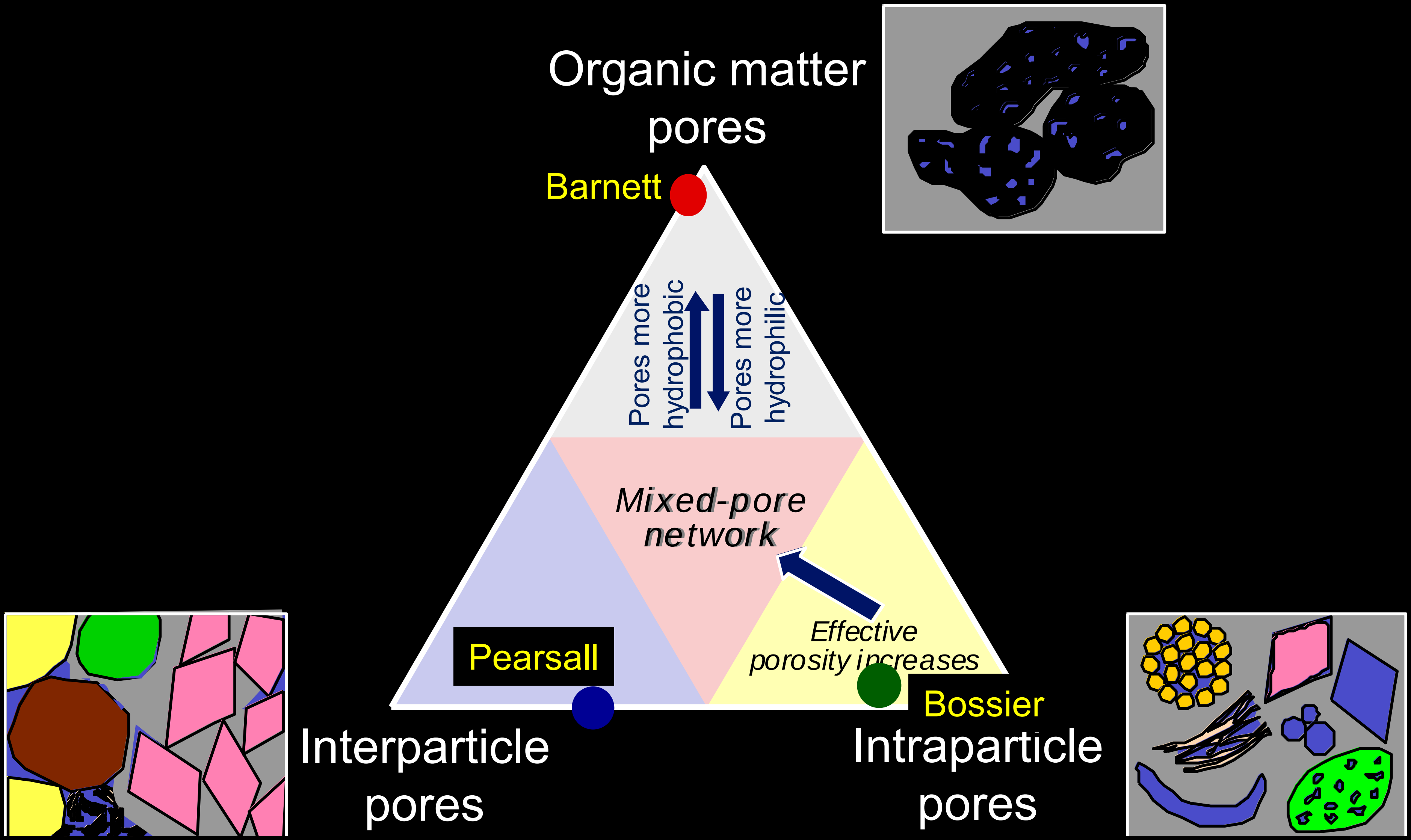


Point-count porosity = 7.2% (by volume):

InterP pores = 19.6%
IntraP pores = 75.5%
OM pores = 4.9%

Bossier Shale 13,344'

Mudrock Pore Network Classification



Mod. From Loucks et al. 2010

Conclusions

There are Many Types of Pores in Mudstones and Pore Networks vary among Different Mudrock Systems