Pore Types in the Barnett and Woodford Gas Shales: Contribution to Understanding Gas Storage and Migration Pathways in Fine-Grained Rocks*

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Abstract

The identification of 'organo-porosity' (micro- and nano-scale pores within organic matter in shales), its importance to storage and perhaps transfer of gas molecules through shales, and methods for gathering 3D images of the pores [most notably through argon-ion milling/field emission scanning electron microscopy (FESEM)] have all been well documented and discussed for unconventional gas shales, most notably the Barnett Shale of north Texas. However, other types of pores within the Barnett and Woodford, and probably other shales provide both porosity and permeability. Also, there are other techniques for preparing, imaging and identifying these pores.

Floccules are common within these shales; spaces between the flocculated particles can provide significant---possibly interconnected---pores. Fecal pellets, with up to 15% porosity, are also common, and often concentrated in discrete laminae or beds which might provide pore connectivity. Fossil fragments, such as sponge spicules, are also common shale constituents; spicules originally have hollow central chambers, but many of these become closed during burial either by silica diagenesis or by filling with clay and organic particles. Microchannels within shale matrix, which may be the bounding surfaces of scours or micro-sedimentary structures, serve to provide permeability pathways for hydrocarbon migration. Fractures occur at a variety of scales, including across individual mineral grains, and across brittle laminae, beds, bedsets and stratal packages.

When present in sufficient quantity, these pore types offer potential gas (and oil) molecule storage spaces and permeability pathways through the shales. In addition, the occurrence of fractures which cross-cut brittle beds, such as chert, but not interbeds of ductile shale, suggest that artificial fractures in subsurface reservoirs probably hold proppant in the brittle beds, but less so in interbeds of ductile shale.

Selected References

Bennett, R.H., N.R. O'Brien, and M.H. Hulbert, 1991, Determinants of clay and shale microfabric signatures: processes and mechanisms, *in* R.H. Bennett, W.R. Bryant, and M.H. Hulbert, (eds.), Microstructure of Fine-Grained Sediments: New York, Springer-Verlag, p. 5-32.

O'Brien, N.R., and R.M. Slatt, 1990, The fabrics of shales and mudstone; an overview, *in* J.F. Burst, W.D. Johns, (chairs) Clay Minerals Society, 27th annual meeting, program and abstracts: Clay Minerals Annual Conference, v. 27, p. 99.

Totten, M., Jr., 2011, Electron Probe Micro-Analysis of the Woodford Shale, South Central Oklahoma: M.S. thesis University of Oklahoma, Norman, Oklahoma.

Pore types in the Barnett and Woodford Gas Shales: Contribution to understanding gas storage and migration pathways in fine-grained rocks

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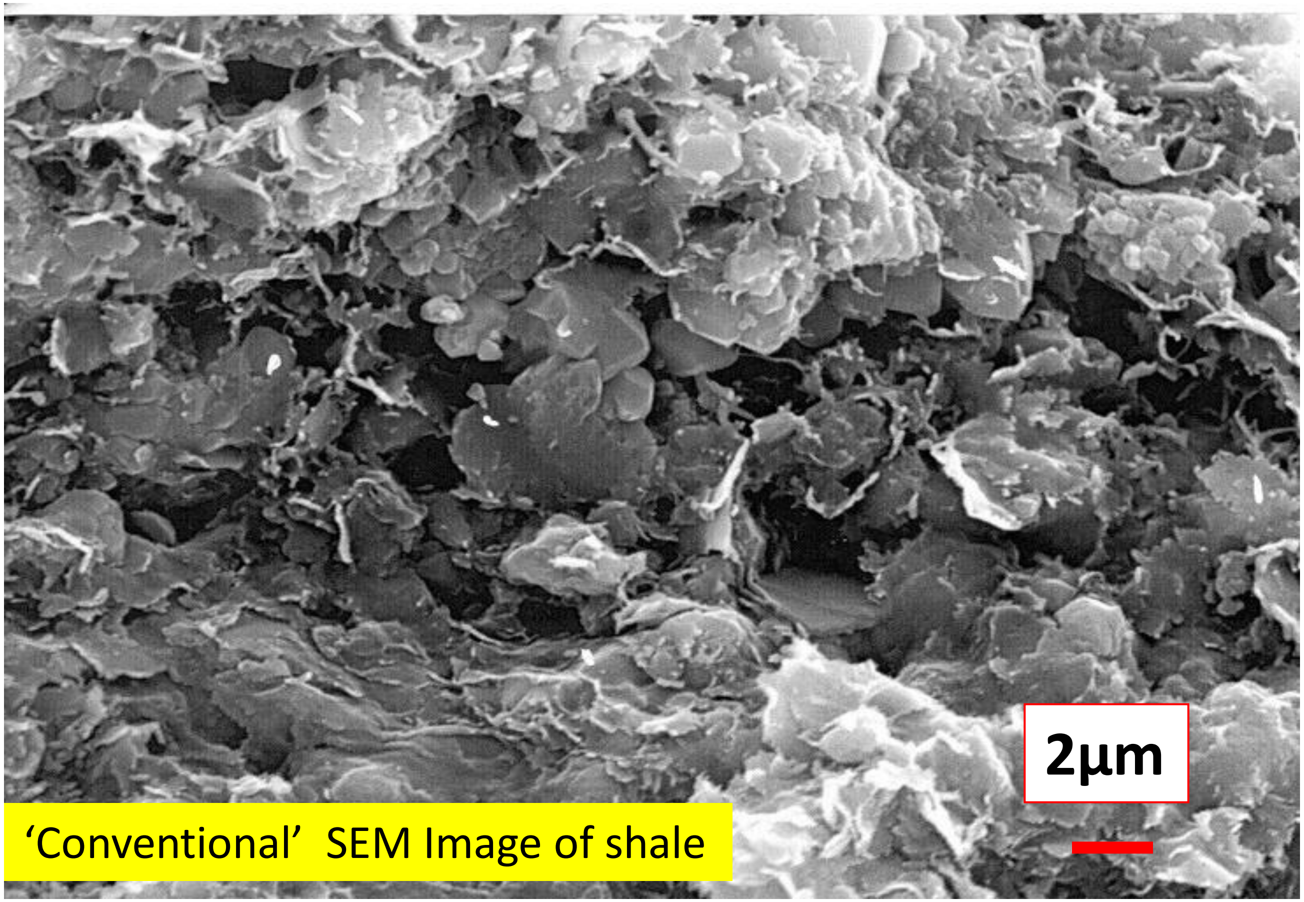
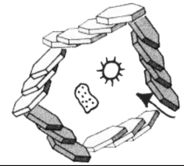
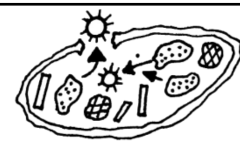
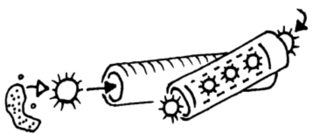
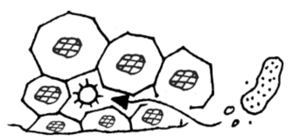
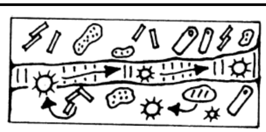
Neal R. O'Brien, SUNY Potsdam



Pore Type	Image	Distinctive Features
Porous Floccules		Clumps of electrostatically charged clay flakes arranged in edge-face or edge-edge cardhouse structure. Pores up to 10's of microns in diameter. Pores may be connected.
Organo-porosity		Pores in smooth surfaces of organic flakes or kerogen. Pore diameters are at nanometer scale. Pores are generally isolated. Porous organic coatings can also be adsorbed on clays.
Fecal Pellets		Spheres/ellipsoids with randomly oriented internal particles, giving rise to intrapellet pores. Pellets are sand-size and may be aligned into laminae.
Fossil Fragments		Porous fossil particles, including sponge spicules, radiolaria, and cysts (*Tasmanites?*). Interior chamber may be open or filled with detrital or authigenic minerals.
Intraparticle Grains/Pores		Porous grains, such as pyrite framboids which have internal pores between micro-crystals. Grains are of secondary origin, and are usually dispersed within the shale matrix.
Microchannels and Microfractures		Linear nano-micrometer-sized openings that often cross-cut bedding planes. Occur at nano-meter and larger scales.

Symbols used:

 Clay Flake

 Organic particle

 Silt grain

 Fossil fragment

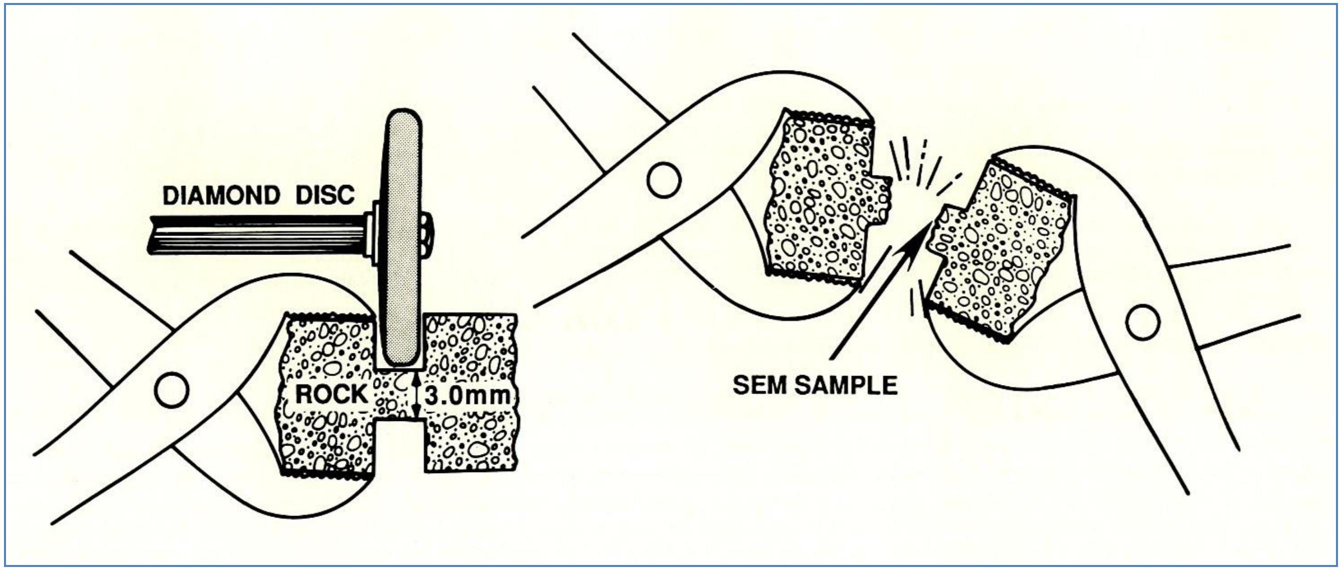
 Gas

 Gas migration

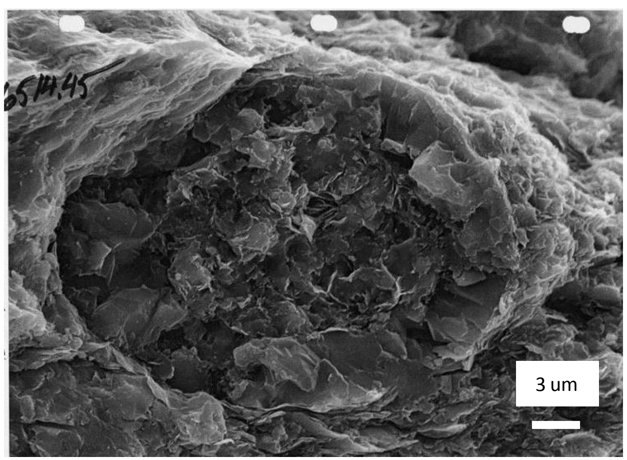
 Microchannel microfracture

Classification of pore types in shales.

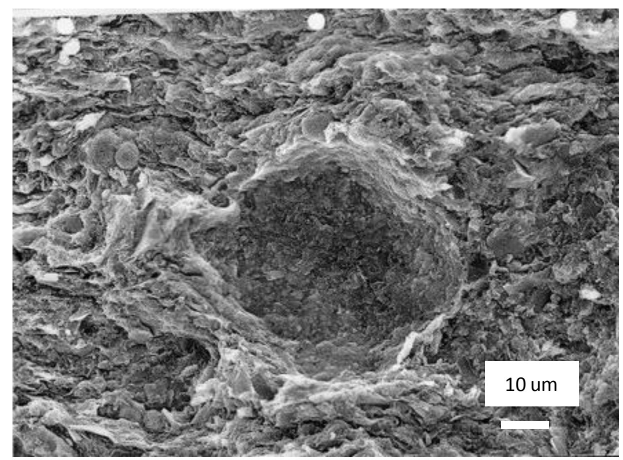
SEM SAMPLE PREPARATION



Care must be taken to ensure that 'pores' are not holes from plucked grains

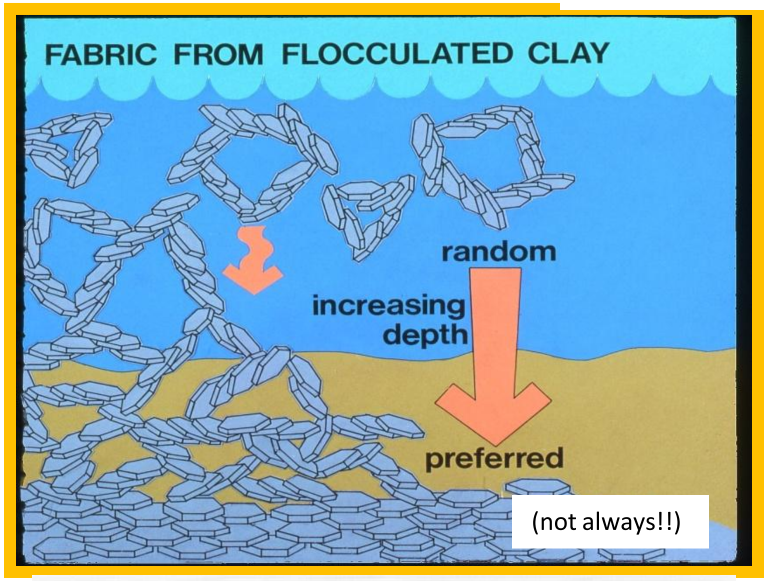


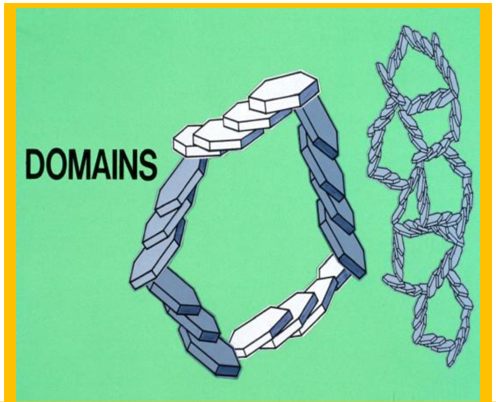
Fecal pellet with tangential clay flakes due to compaction.



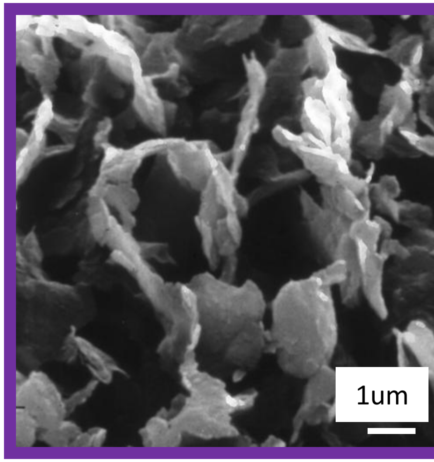
Hole from plucked grain. Note tangential clay flakes, which are common for plucked holes (artificial pores).

Floccules with pores

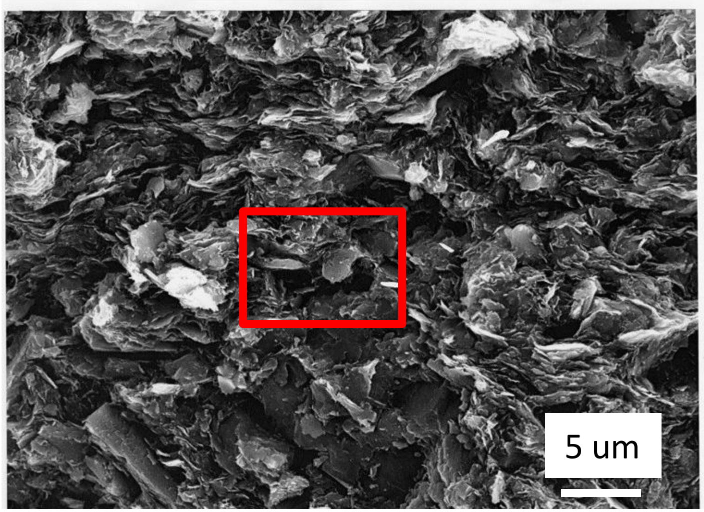


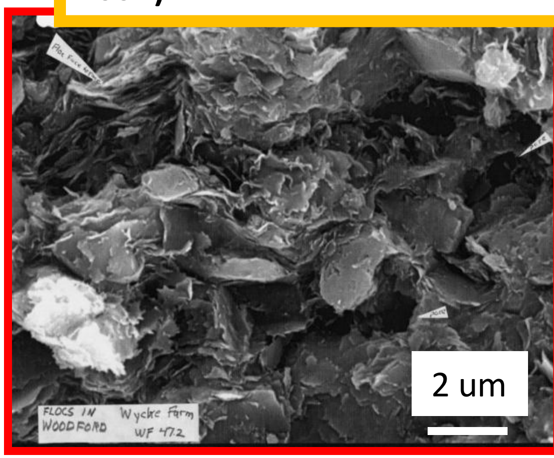


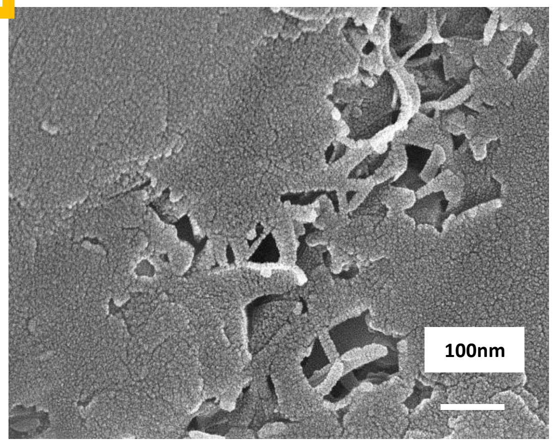
Cartoons of flocculated, electrically-charged clay flakes and internal pores. (O'Brien and Slatt, 1990; Bennett et al., 1991)



Freeze-dried, flocculated illite in distilled water.

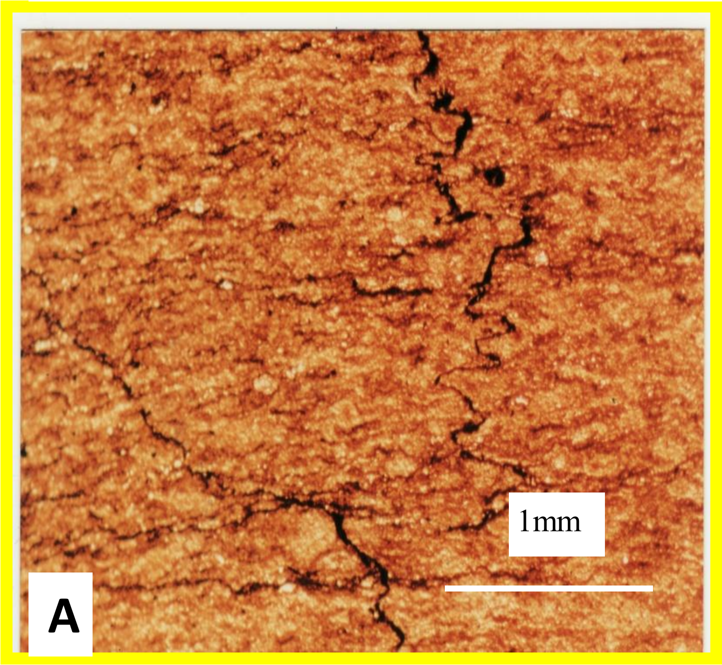


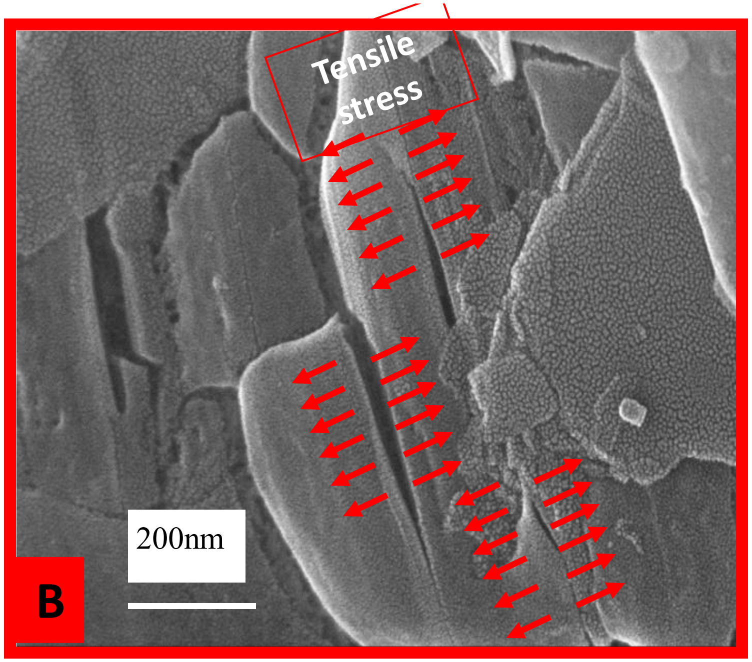


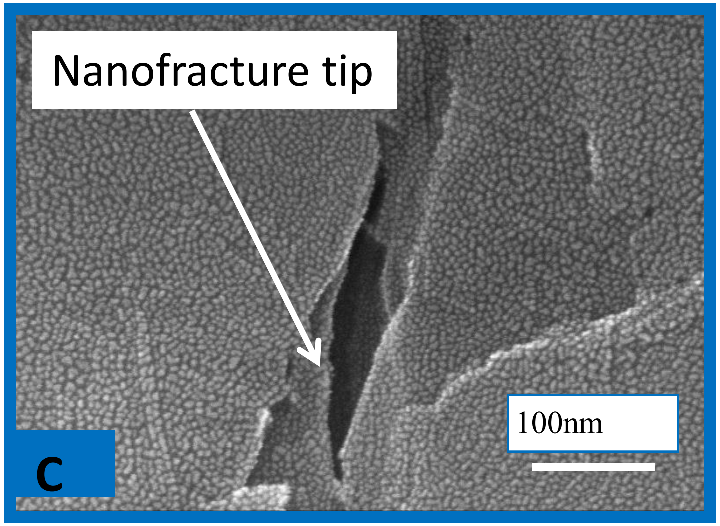


Floccules in Woodford Shale

Micro- and nano-fracture pores





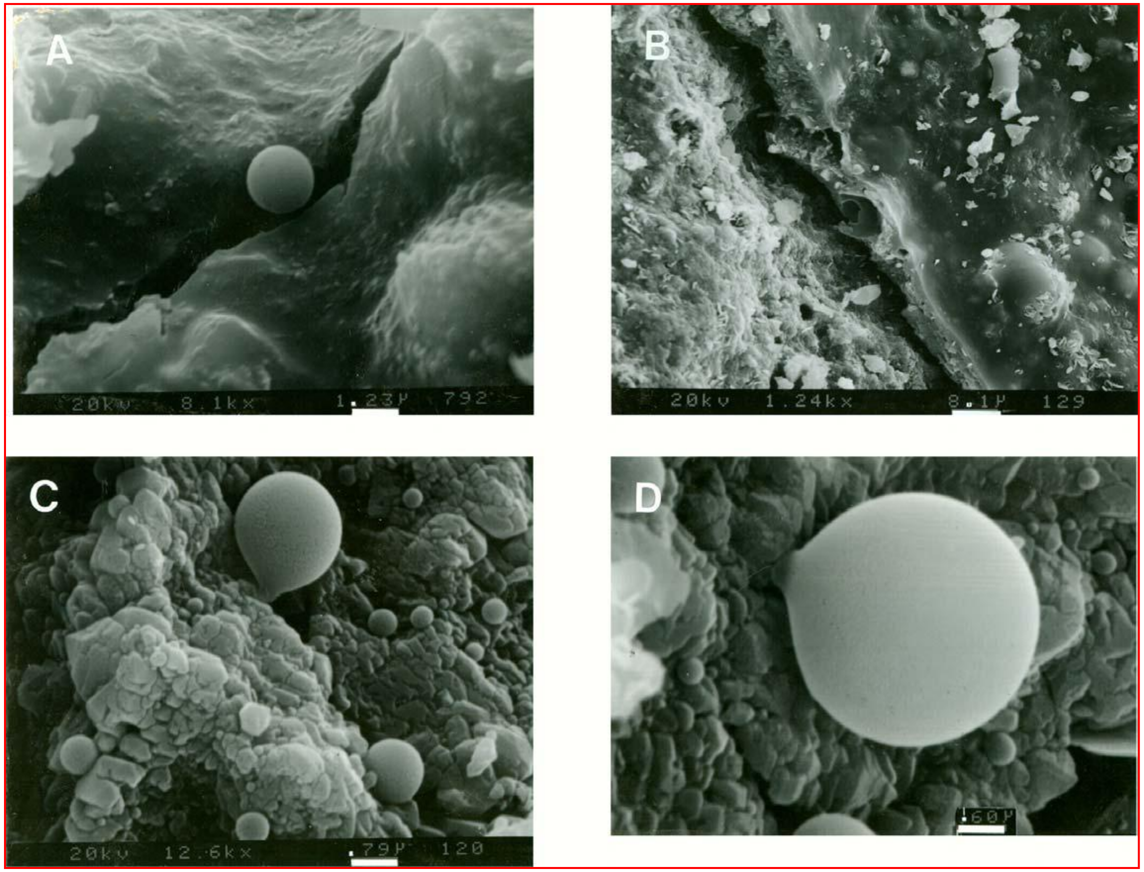


A. Photo showing zig-zag tracks of bitumen-filled fracture

B. Induced, nanometer-scale tensile fractures apparently aligned along crystal axes.

C. X200,000 magnification of fracture tip shown in B.

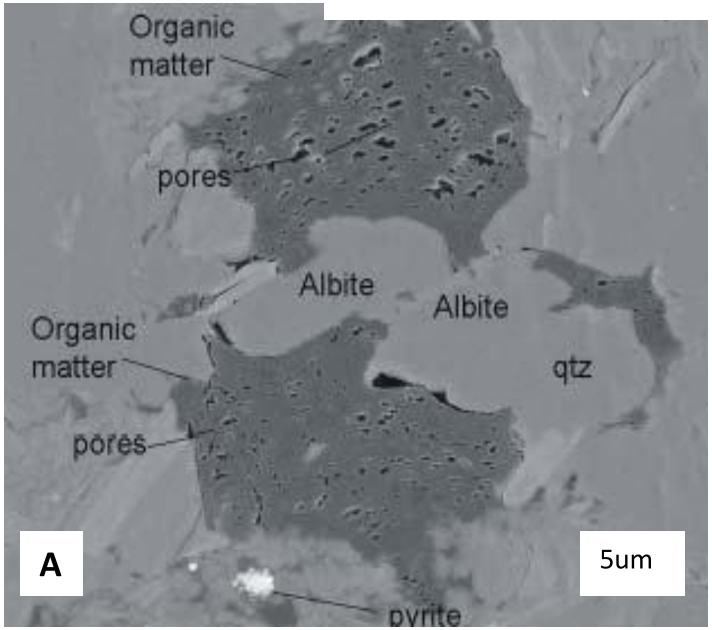
A) Oil droplet in micro- fracture
B) Oil slick near micro-fracture.
C&D) Oil droplets oozing from rock matrix into open micro-fractures.

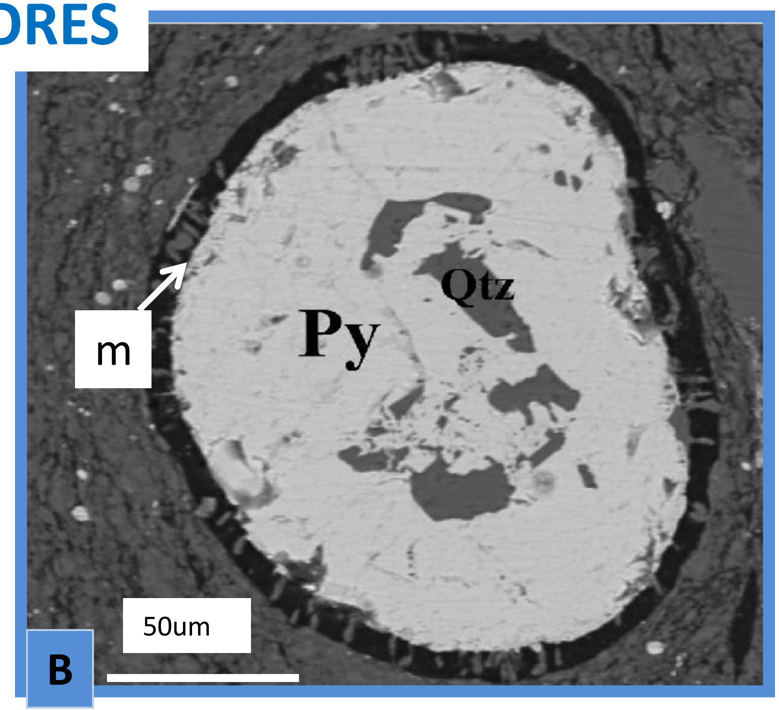


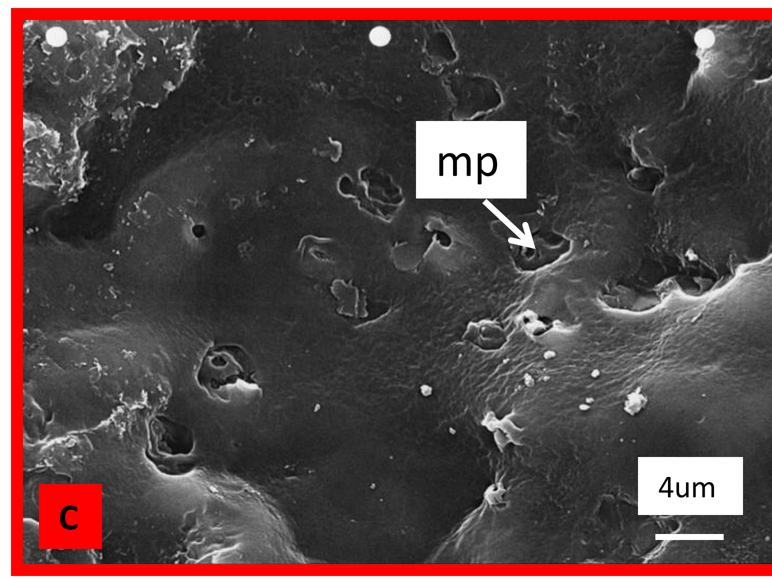
Furnace and sample holder (arrow) used in hydrous pyrolysis experiments

SEM micrographs of the Woodford Shale during hydrous pyrolysis experiment – heating to 350ºC for 4 days.

ORGANIC MATTER AND PORES





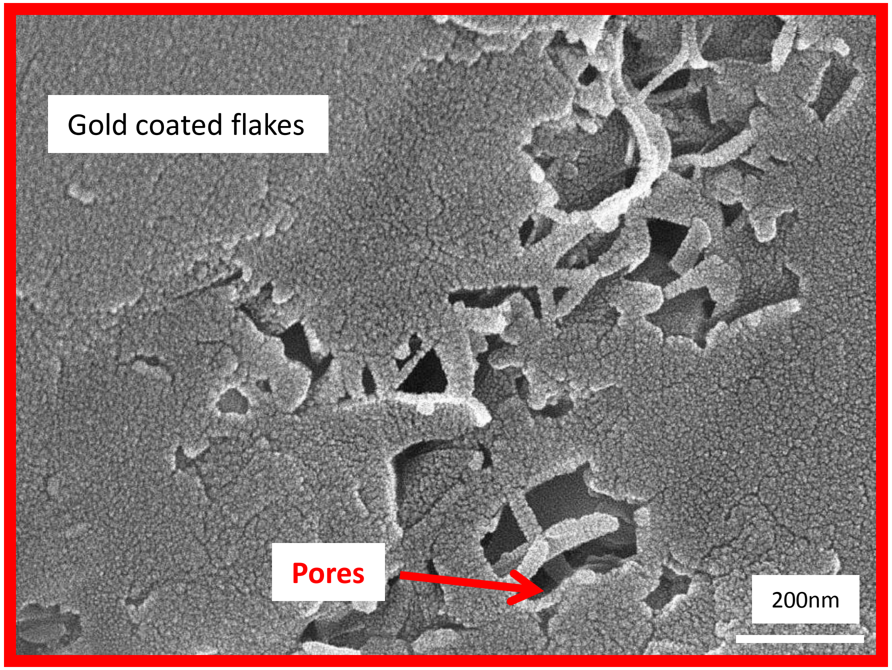


A. Ar-Ion milled surface, FESEM. Backscatter image showing pores (black areas) within organic matter. Longmaxi Shale, China. Picture Provided by M. Zheng, M.S. thesis OU.

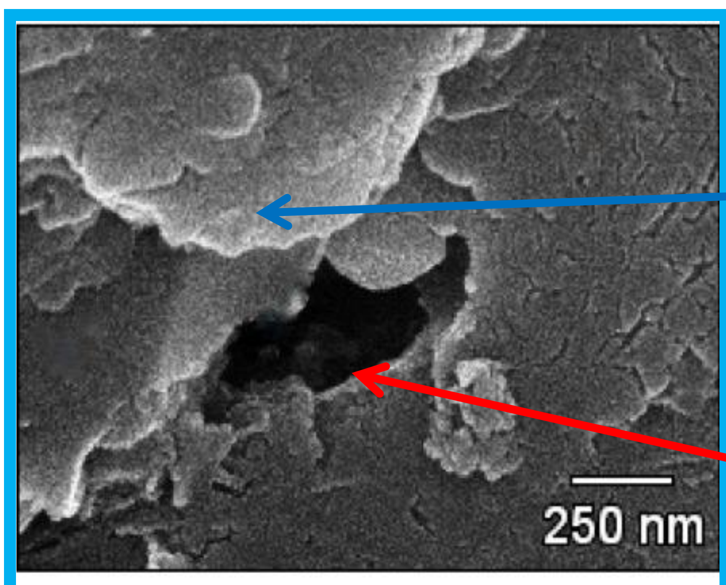
B. Organic mucus (m) or coating around a pyrite (Py) framboid from electron microprobe polished surface. Some quartz (Qtz) is present in the interior of the pyrite. Woodford Shale. Picture provided by M. Totten Jr., M.S. thesis OU

C. Organic surface with micropores (mp), Woodford Shale.

‘Organic-clad ‘clay flakes with pores



Pores in organic-clad clay flakes as viewed from FESEM

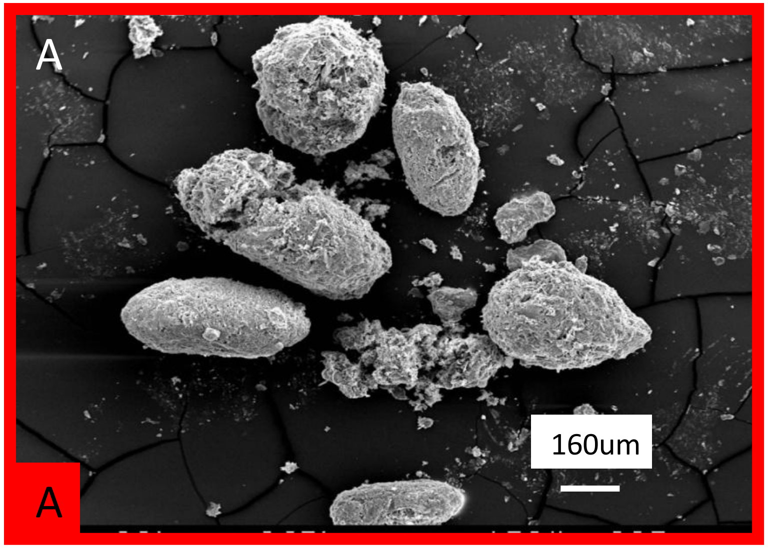


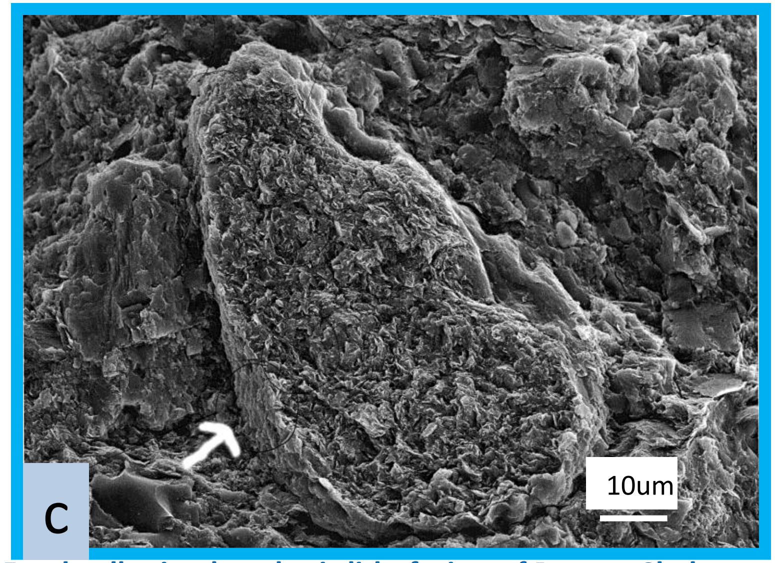
48% C
26%Si,
3%Al,
<10% Mg-K

0% C,
68% Si,
4% Al,
<10% K.

Organic- clad clay contains charged organics adsorbed onto charged clay flakes. Chemical composition from EDX analysis. Crenulated surface is 5-10nm gold coating. No carbon occurs at base of pore (black area)

Fecal pellets with pores



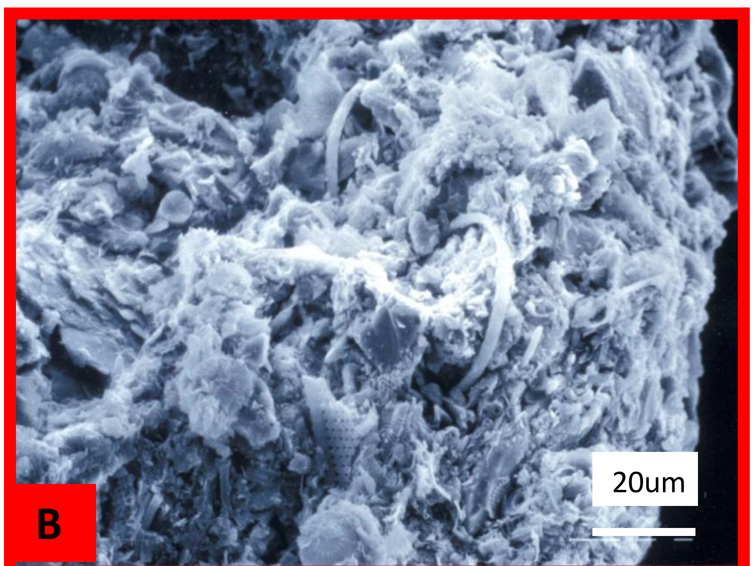


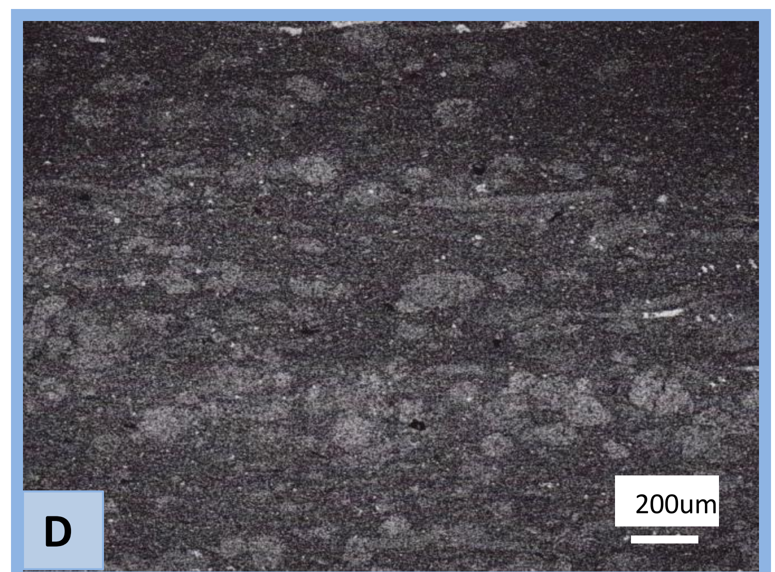
A. Modern fecal pellets from Emerald Basin, Atlantic Ocean

B. Interior of a fecal pellet, showing pores and random particle orientation, including skeletal fragments.

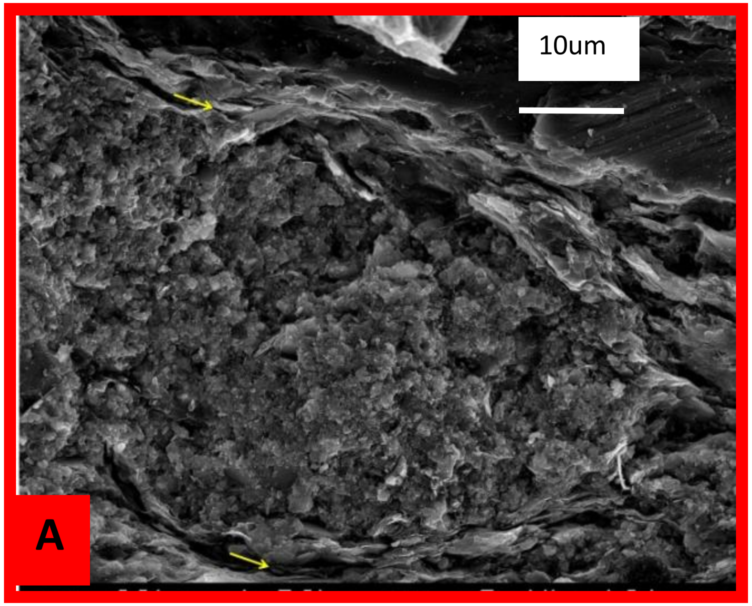
C. Fecal pellet in phosphatic lithofacies of Barnett Shale.

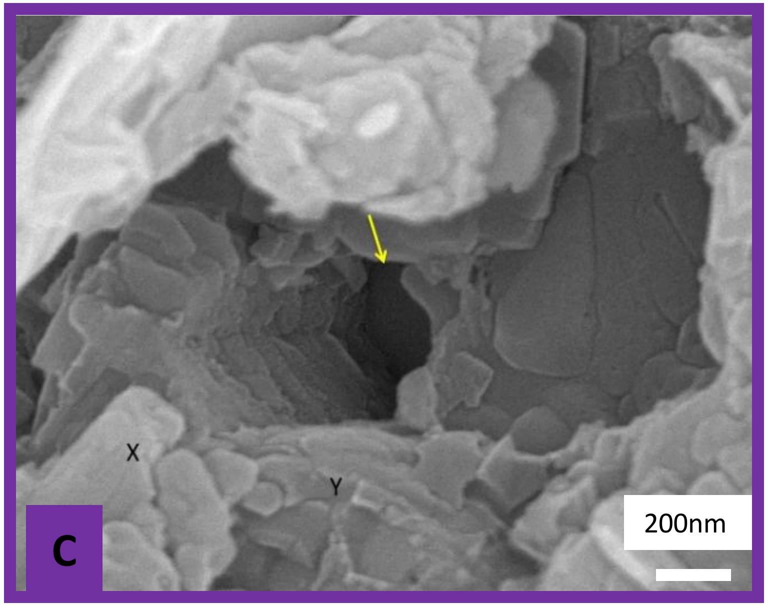
D. Pellet-rich (light colors) lamination in phosphatic lithofacies thin section.

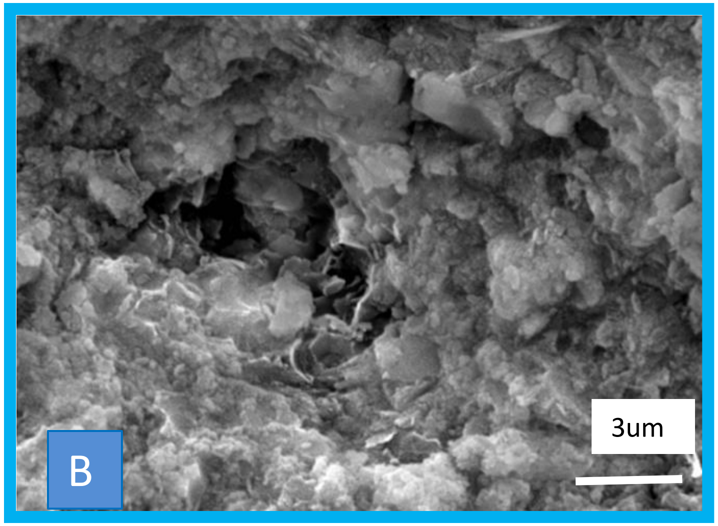




Fecal pellets with pores (cont.)







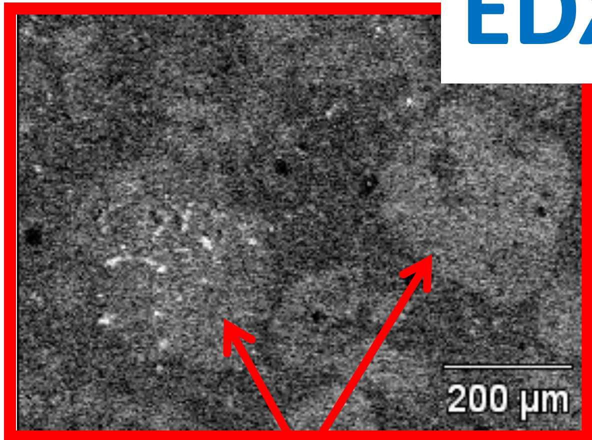
Fecal pellet in Barnett Shale phosphatic lithofacies.

A.Section within a broken pellet showing nano- and micro-porosity (dark areas).

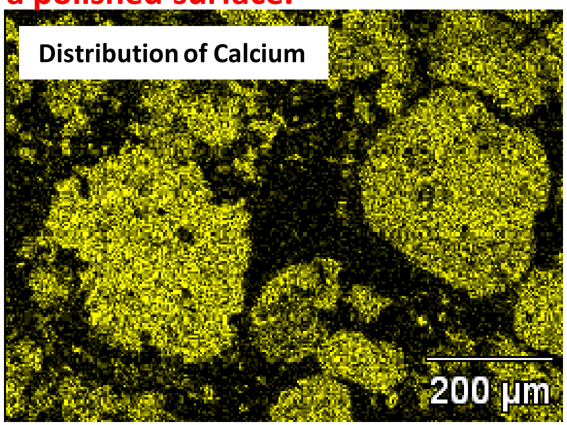
B.Close-up view of nano- and micro-porosity in pellet.

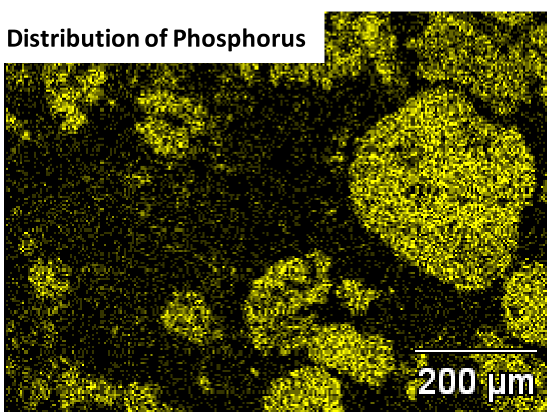
C.Close-up view of nano-pore (arrow) in pellet. X and Y are fluorapatite crystals.

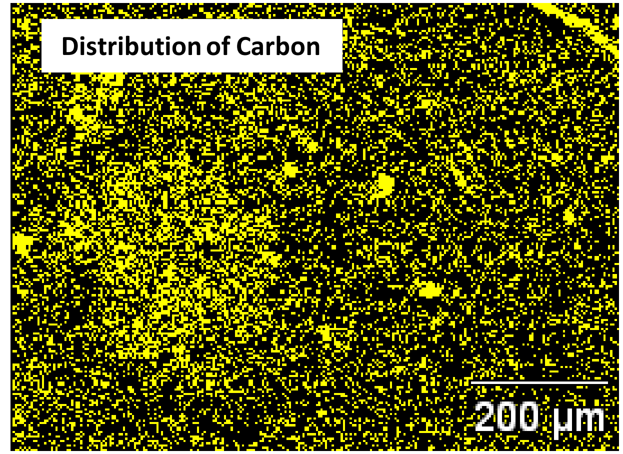
EDX Chemistry of fecal pellets

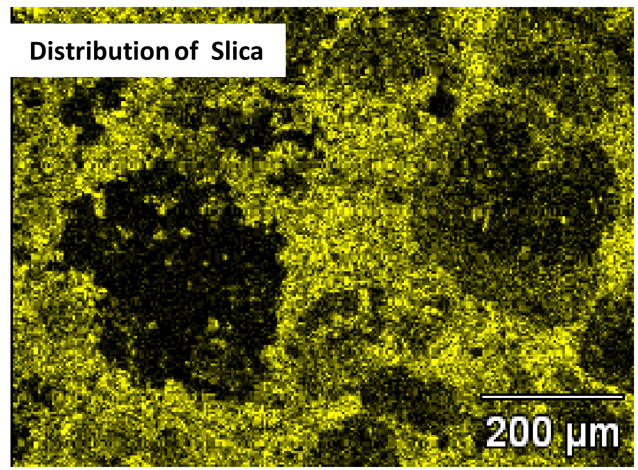


Secondary electron image of pellets on a polished surface.



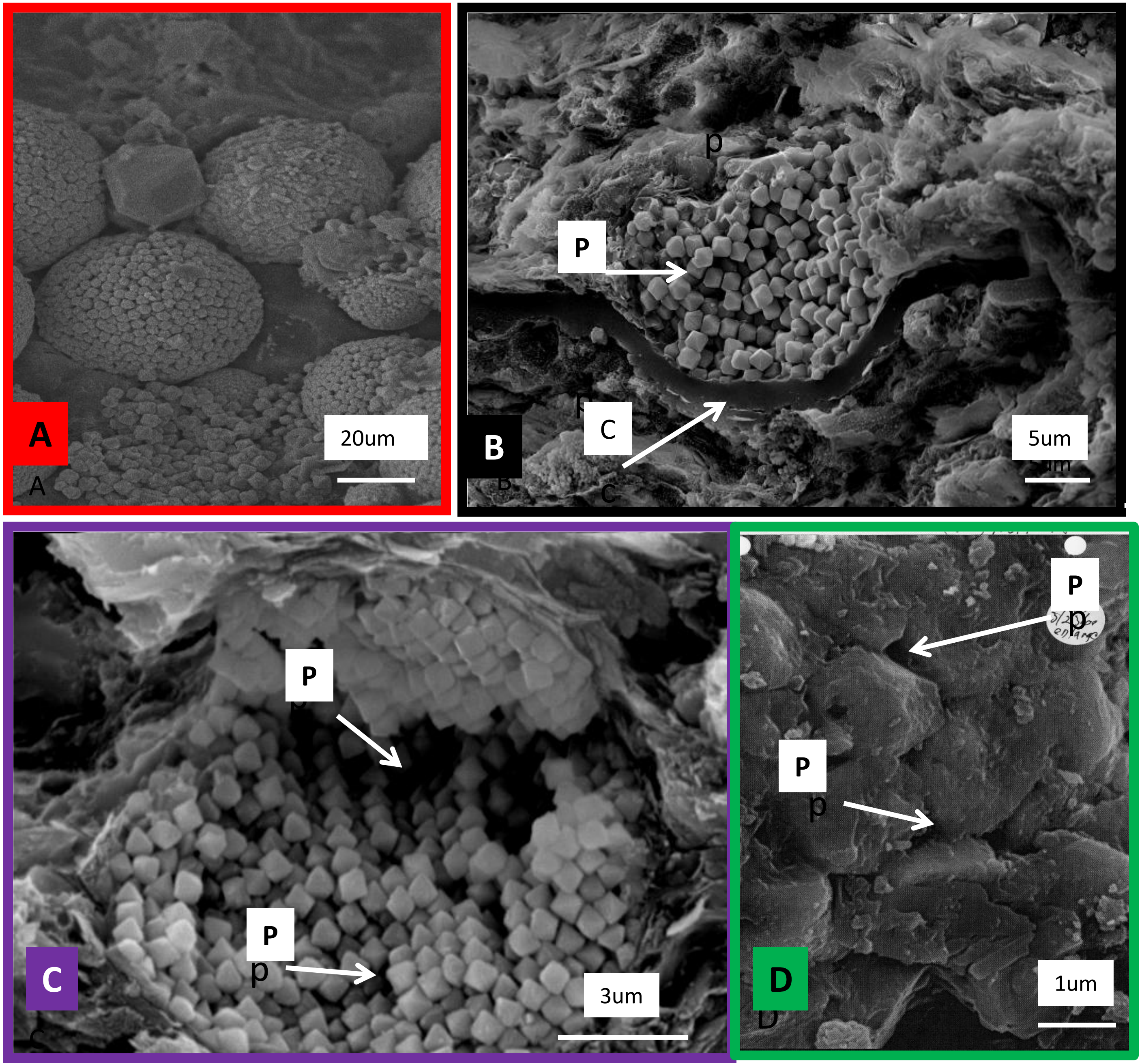






EDX elemental distributions of key elements in two pellets. Note the scarcity of Silica in the two large pellets and that both pellets contain Calcium, but only one contains Phosphorus. Also, Carbon is enriched in the Calcium-rich (no Phosphorus) pellet.

Minerals with pores



A. Framboidal pyrite with some quartz crystals.

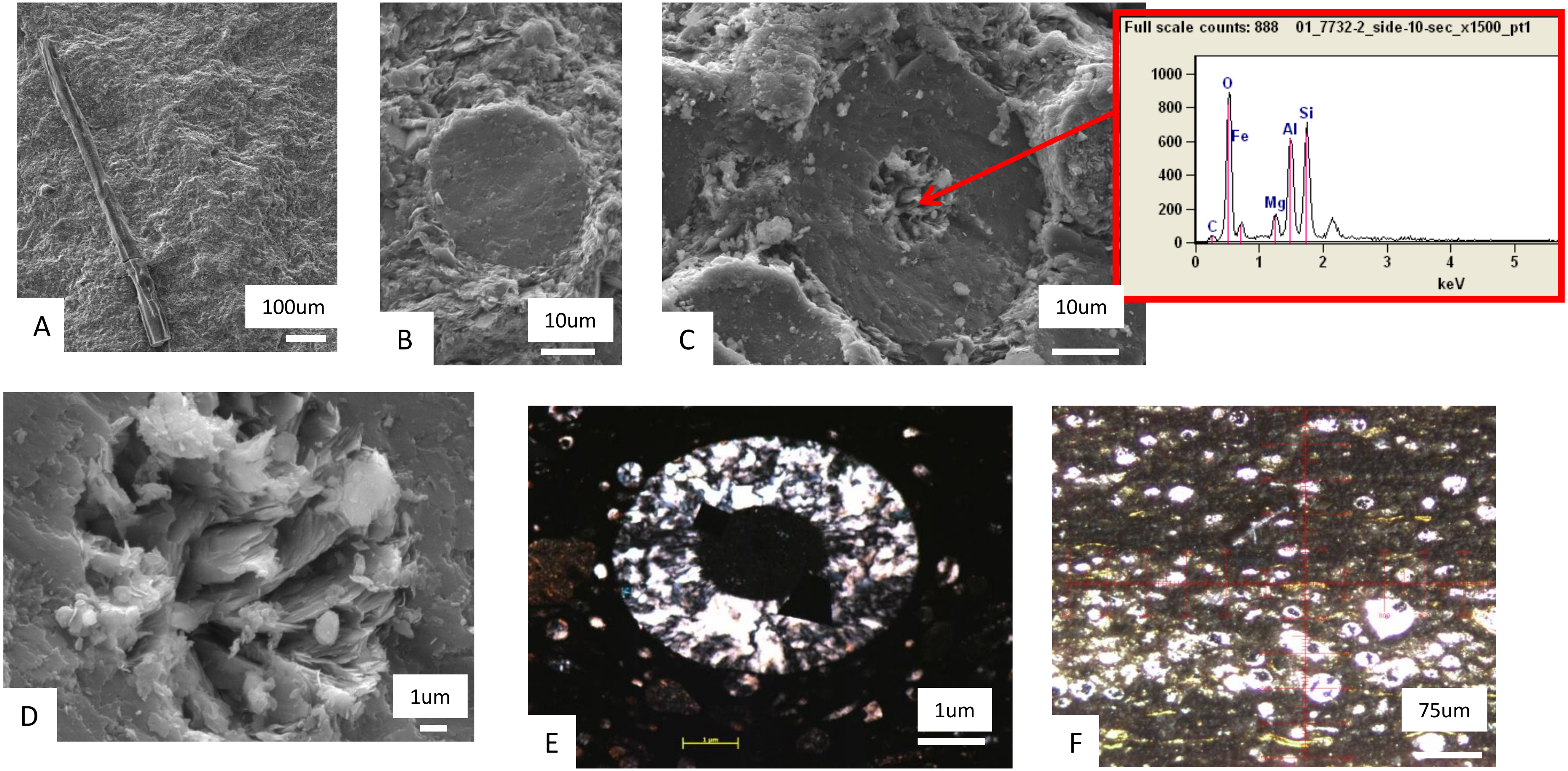
B. Internal view of broken framboid. Small pyrite crystals almost completely fill the framboid. Collapsed cyst (c) is wrapped around the lower part of the framboid.

C. Close-up of framboid showing pyrite crystals and microporosity (p).

D. Pyrite crystals with intergranular micro-porosity (p).

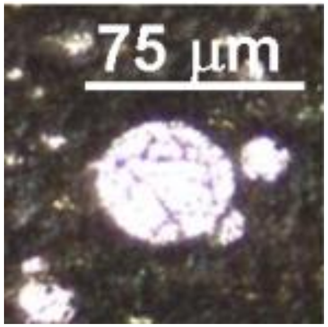
Pore = P in figures B-D.

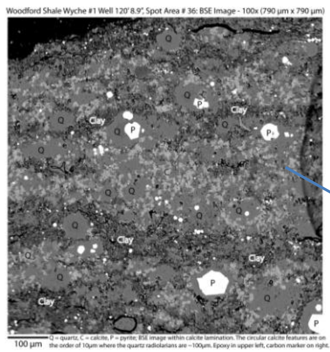
Fossil sponge spicules (recrystallized Quartz), sometimes with pores



A. SEM image of **sponge spicule** in Barnett Shale.
B. Cross section of recrystallized quartz spicule.
C. Cross sections of spicule with clay-filled central chamber (EDAX chemistry confirms clay).
D. Close-up of partially-filled central chamber of spicule in C. There is some remnant porosity.
E. Thin section of spicule with a central chamber.
F. Photomicrograph of spicule-rich layer in Barnett Shale.

Fossil radiolaria (recrystallized Quartz)

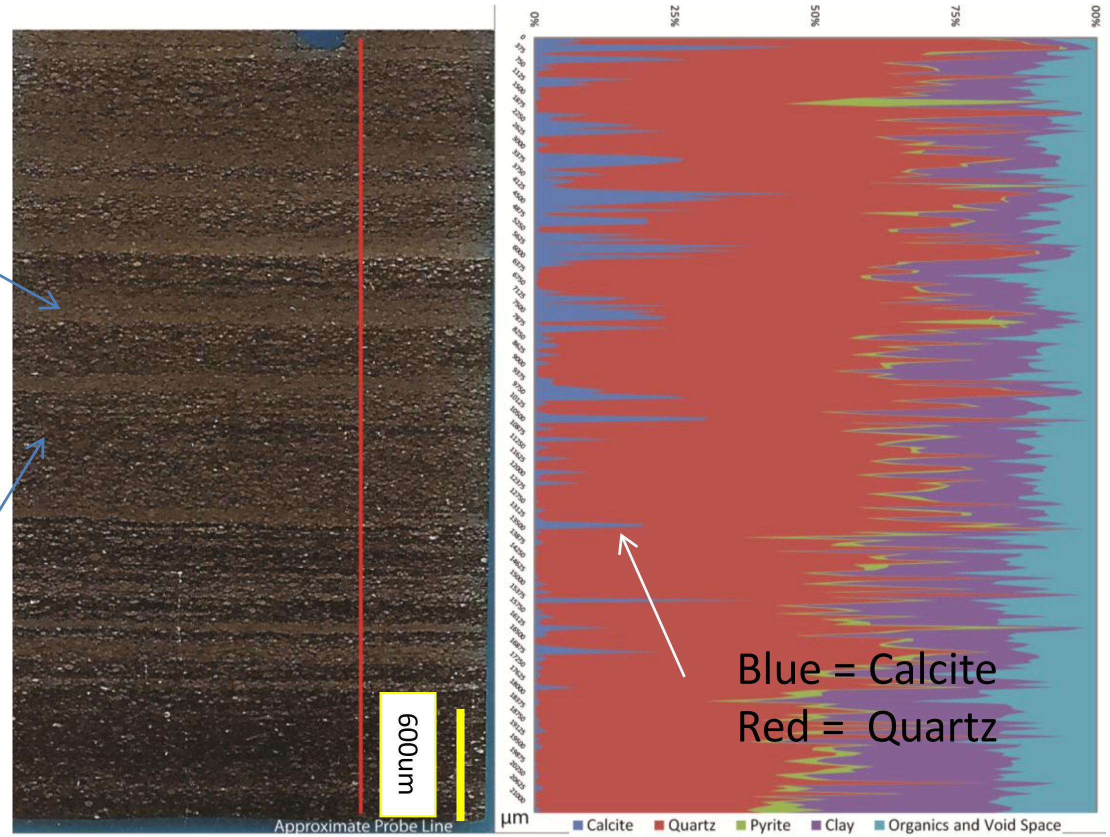




Recrystalized Radiolaria (quartz) within crystalline Calcite cement

Clay-rich laminae, no apparent cement

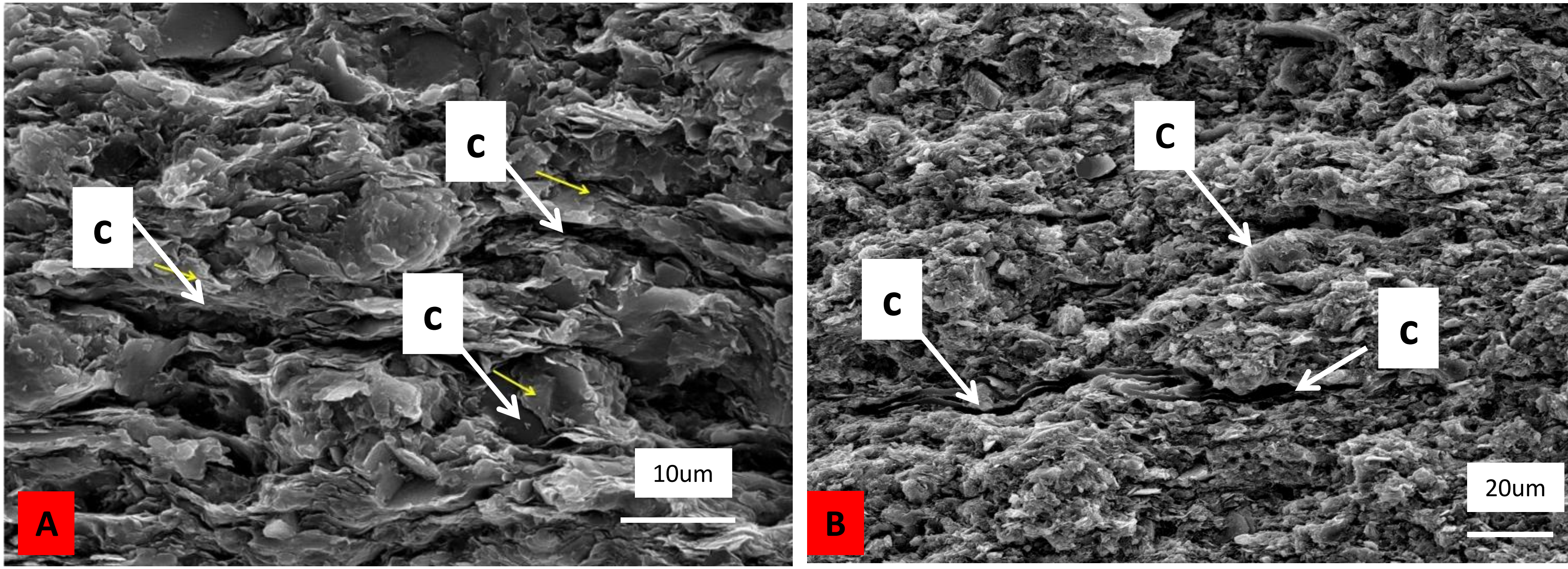
0 cumulative wt. % 100

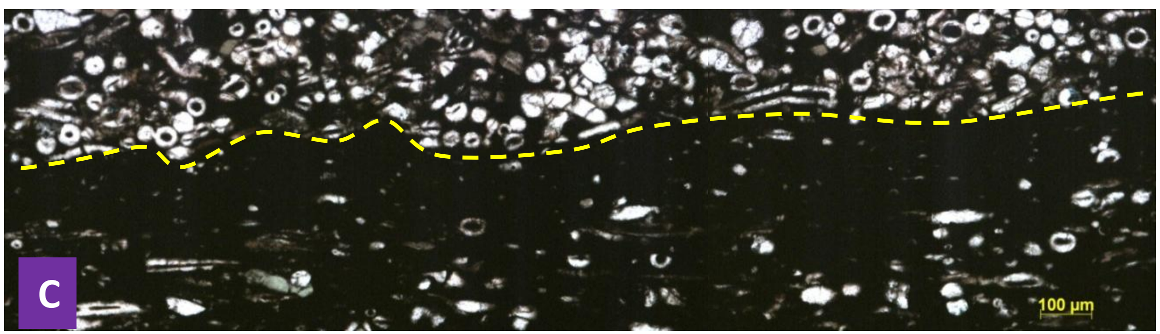


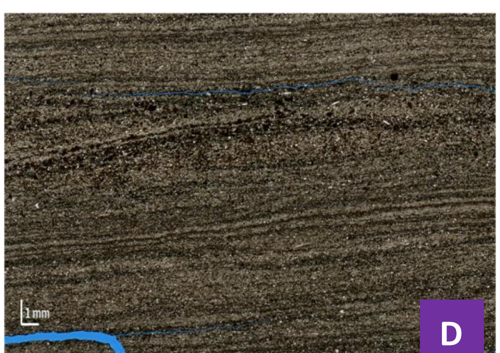
Electron microprobe analyses of laminated Woodford Shale. Figure provided by M.Totten, M.S. thesis

Periodic blooms????

Microchannels







A-B SEM images of microchannels (c) in Woodford Shale.

C-E. Micro-sedimentary structures in thin sections of Barnett Shale that may provide microchannels (planes of weakness).

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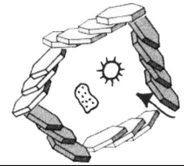
Porous Floccules		Clumps of electrostatically charged clay flakes arranged in edge-face or edge-edge cardhouse structure. Pores up to 10's of microns in diameter. Pores may be connected.
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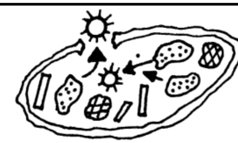
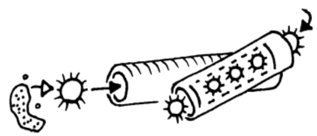
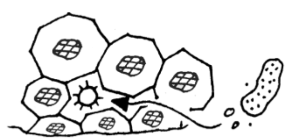
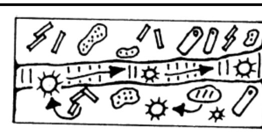
Fecal Pellets		Spheres/ellipsoids with randomly oriented internal particles, giving rise to intrapellet pores. Pellets are sand-size and may be aligned into laminae.
Fossil Fragments		Porous fossil particles, including sponge spicules, radiolaria, and cysts (*Tasmanites?*). Interior chamber may be open or filled with detrital or authigenic minerals.
Intraparticle Grains/Pores		Porous grains, such as pyrite framboids which have internal pores between micro-crystals. Grains are of secondary origin, and are usually dispersed within the shale matrix.
Microchannels and Microfractures		Linear nano-micrometer-sized openings that often cross-cuts bedding planes. Occur at nano-meter and larger scales.

So what's next???