From Radiolarian Ooze to Reservoir Rocks: Microporosity in Chert Beds in the Upper Devonian-Lower Mississippian Woodford Shale, Oklahoma*

Neil Fishman[1], Geoffrey S. Ellis[1], Stanley T. Paxton[2], Marvin M. Abbott[2], and Adam R. Boehlke[1]

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[1]U.S. Geological Survey, Denver, CO (nfishman@usgs.gov)
[2]U.S. Geological Survey, Oklahoma City, OK

Abstract

The mechanism of gas storage in shale-gas systems is a key element in characterizing these potentially prolific, low porosity/permeability reservoirs. This study integrates mineralogy, organic geochemistry, and porosity/permeability data of samples collected from the Upper Devonian-Lower Mississippian Woodford Shale, Arbuckle Mountains, Oklahoma, at locations previously described through detailed stratigraphic and spectral gamma surveys. The primary objective of this study was to characterize the rocks to further an understanding of gas storage in Woodford reservoirs in the adjacent Anadarko Basin.

Rock types of interest in the Woodford are broadly divided into chert and mudstone lithofacies that display different characteristics. Cherts (>90 wt% quartz, <5 wt% clays) have an average TOC content of 4.5%. Quartz occurs in cherts in a cryptocrystalline form (mosaic or granular chalcedony) that fills fossil radiolarian tests and composes much of the rock volume; the quartz formed diagenetically early from recrystallization of radiolarian skeletal parts (tests, spines, etc.). The organic matter is present as an amorphous organic material (AOM) in micropores (<10 μm across). Micropores occur 1) between minute quartz crystals within chalcedonic masses; or 2) between the colloform, bulbous masses of chalcedony. In contrast, mudstones (38-81 wt% quartz, 15-40 wt% clays), are more organic rich (avg. TOC 13.3%), with organic matter largely present as AOM and Tasmanites microfossils. Quartz in mudstones is largely detrital (subangular silt grains) but some are authigenic monocrystalline "grains" infilling Tasmanites. Limited mercury injection capillary pressure analyses (at 50% Hg saturation) reveal that 1) cherts have a) variable porosity (0.59 to 3.46%), b) low permeability (0.001 to 0.033 μD), and c) small pore mean apertures (6.4 to 7.9 nm); and 2) mudstones, compared to cherts, generally have a) greater porosity (2.3 to 11.9%), b) greater permeability (0.014 to 2.06 μD), and c) larger mean pore apertures

(6.2 to 1.78 nm). Microfractures also contribute to rock porosity, but appear to be lithologically controlled and are best developed in cherts (brittle), but poorly developed or absent in adjacent clay-rich mudstones (ductile).

Owing to their microporosity, cherts of the Woodford may provide important, overlooked sites of gas storage in the formation, and upon artificial stimulation (fracing) may contribute a significant portion of the gas that is produced.

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Energy Resources Science Center -- Denver

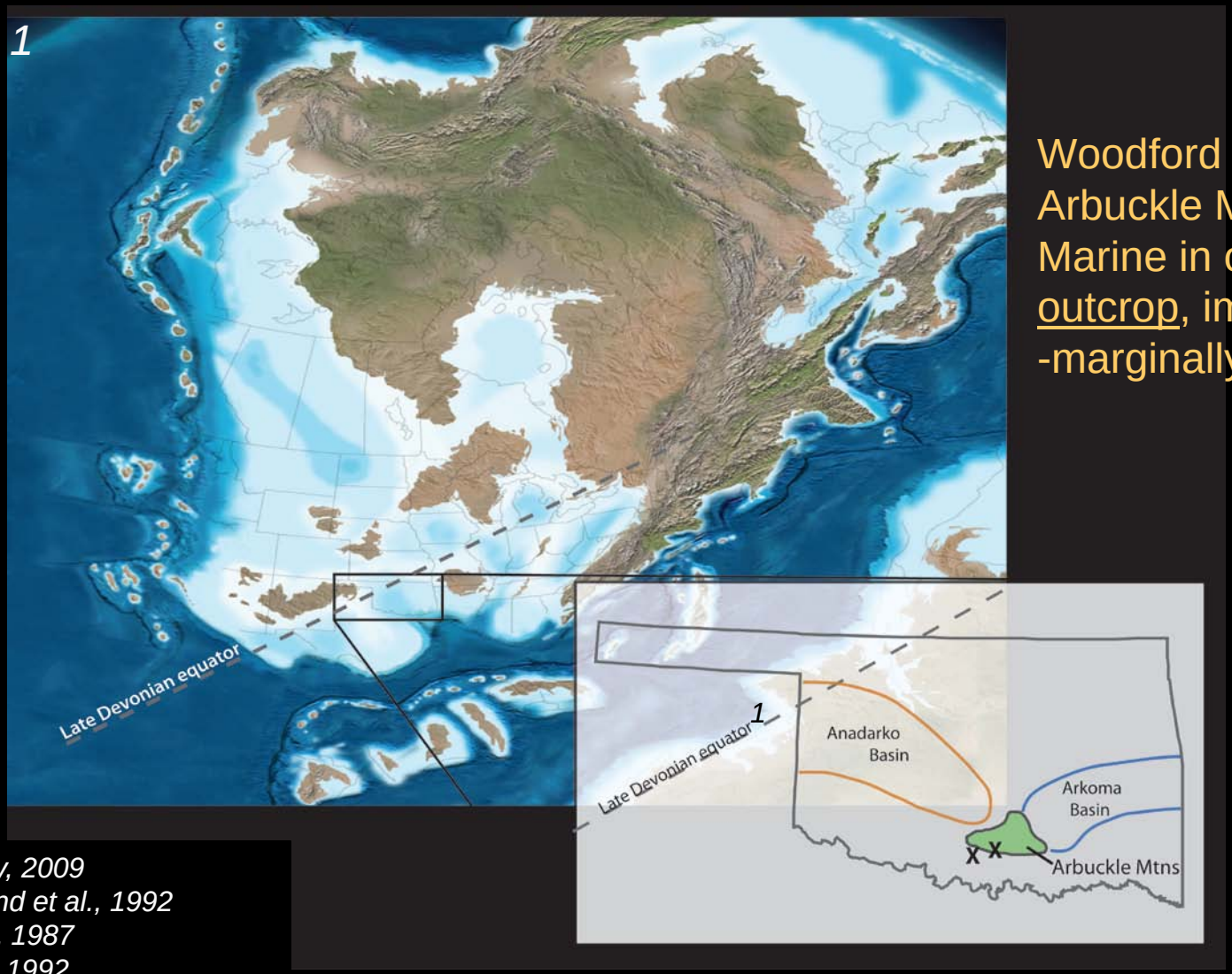
U.S. Department of the Interior
U.S. Geological Survey

Outline

- Introduction
- Lithological Variability
- MICP
- Where are the pores?
- Implicatio
- Conclusio

USGS

Introduction

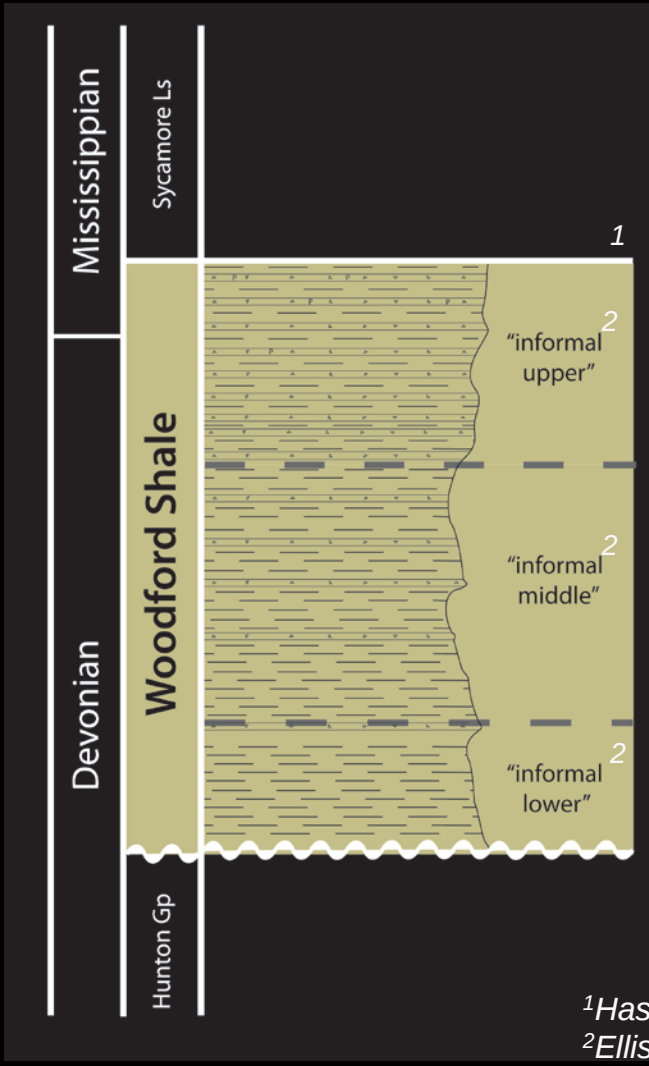


Woodford in the Arbuckle Mtns. Marine in origin[2], <u>outcrop</u>, immature -marginally mature[3]

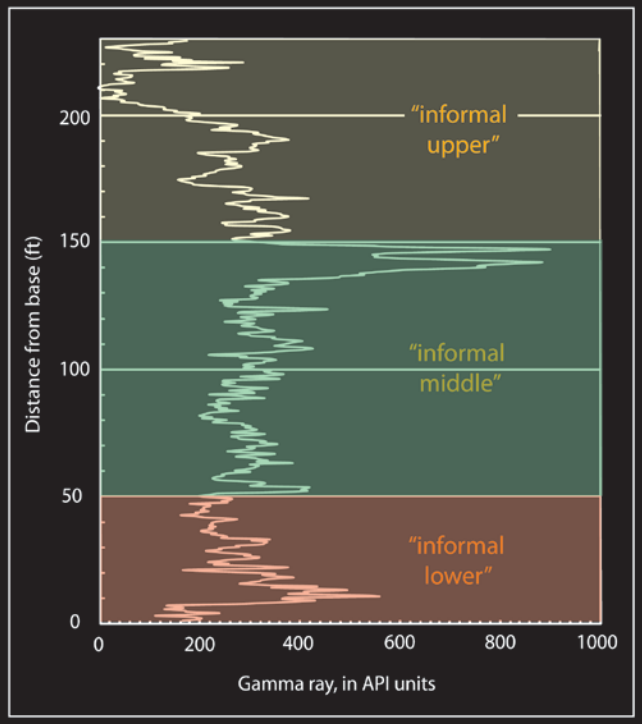
[1,2]*Blakey, 2009*
[1,2]*Kirkland et al., 1992*
[3] *Lewan, 1987*
[3]*Comer, 1992*
[3]*Paxton & Cardott, 2008*

Introduction

- Late Devonian-Early Mississippian
- Up to 250' thick
- Sampling in Carter County, OK



Outcrop gamma log[3]



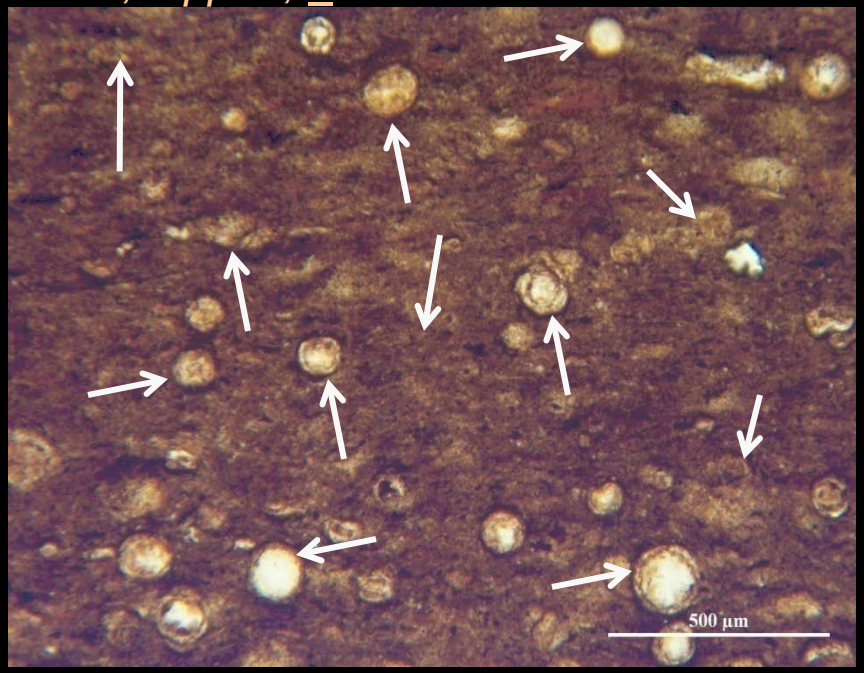
[1]Hass and Huddle, 1965; Hamm, 1969; Kirkland et al., 1992
[2]Ellison, 1950; Urban, 1960; Hester et al., 1990; Comer, 1991; Lambert, 1993
[3]Paxton et al, 2006

Woodford—lithologic variability

Principal lithologies

Chert –radiolarite

"lower", "upper", ± "middle"



Radiolaria microfossils (bio. qtz rextallized during early diagenesis); Corg is AOM

"Radiolarian ooze"—(hi bio. content, very low detrital)

Siliceous mudstone

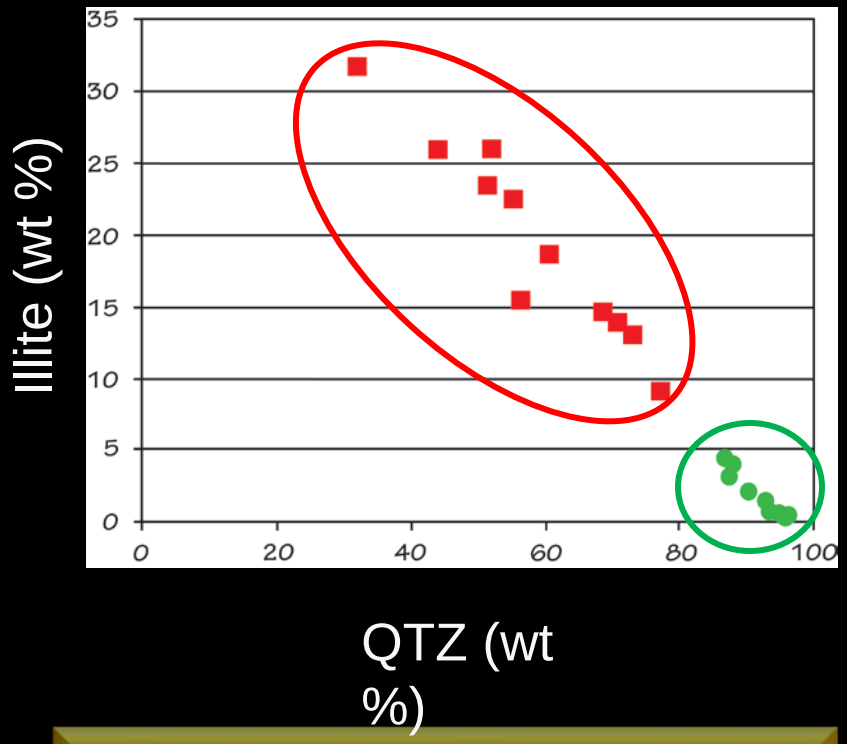
all informal members

Tasmanites (cyst stage of marine green? algae)microfossils (det. & minor bio. qtz); Corg is AOM & *Tasm*

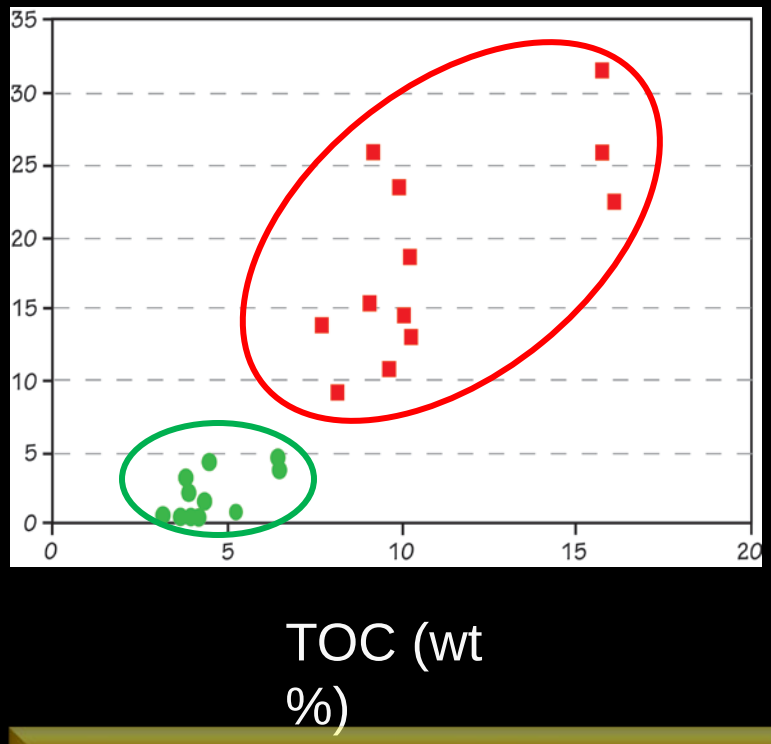
(hi detrital material, hi fossils, mod. to low biogenic)

Woodford lithologic variability

Quantitative XRD



Quantitative XRD & LECO TOC

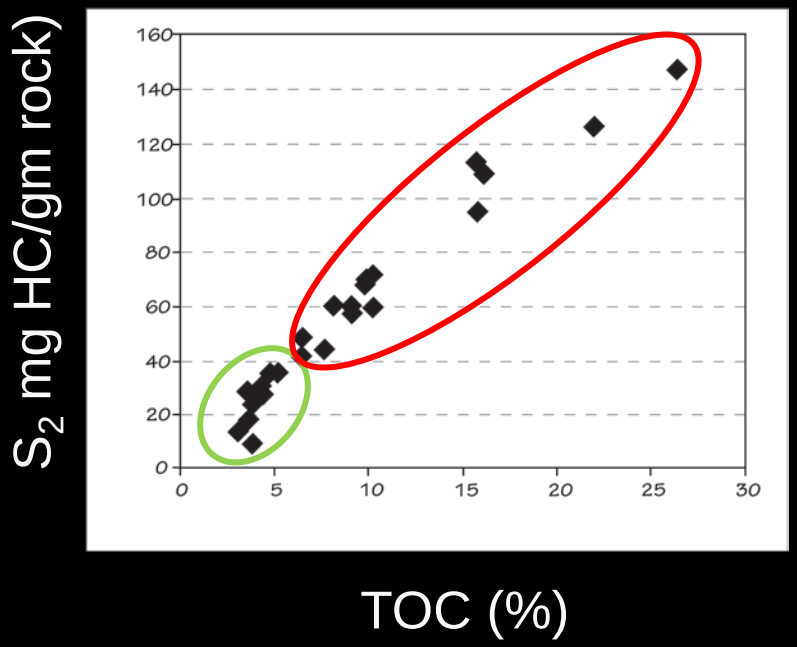


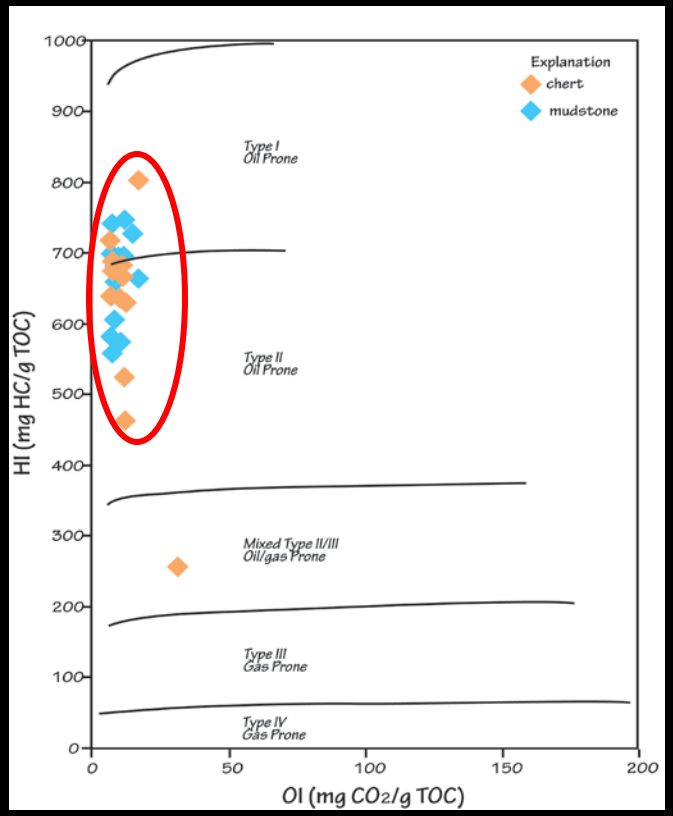
- **Cherts—low illite content**
- **Mudst—variable, higher illite**
- **Chert—rextal. of rad skeletal parts, but little other inorg det.**

- **Cherts—lower TOC (ave = 4.5%)**
- **Mudst—high TOC (ave = 13.3%)**
- **Illite (clay/organic) instrumental in Corg accum.**

Woodford lithologic variability

RockEval

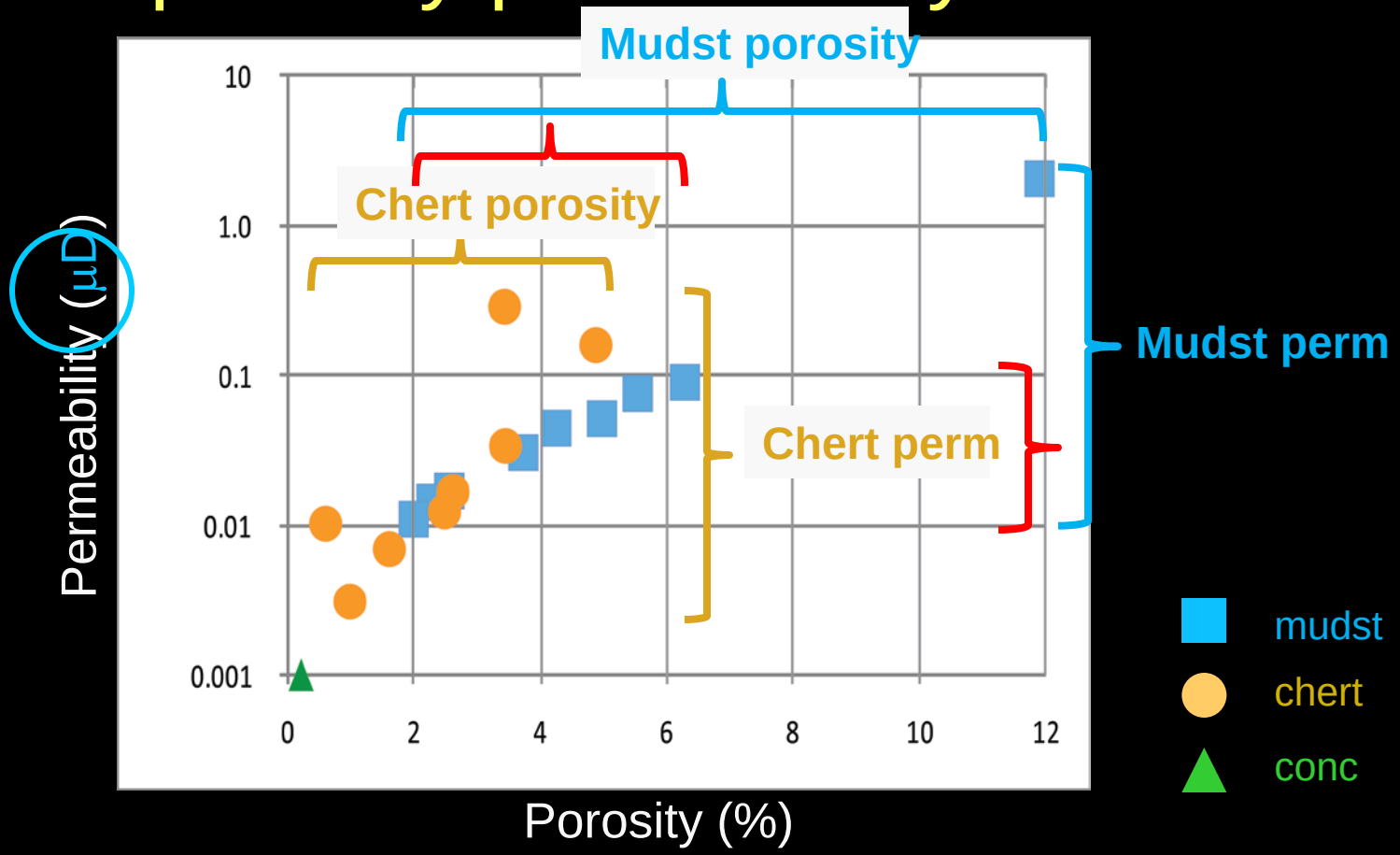




- S_2 vs TOC—similar Corg type in both lithologies (S_2, generatable HC)
- HI>450—marine, Type II—both lith.

Chert, good; mudst world class source

MICP—porosity/permeability



Chert (n = 8)
Porosity = 0.59-4.90%
Perm = 0.003-0.274 μD

Mudstone (n = 10)
Porosity = 1.97-11.9%
Perm = 0.011-2.06 μD

MICP—pore apertures

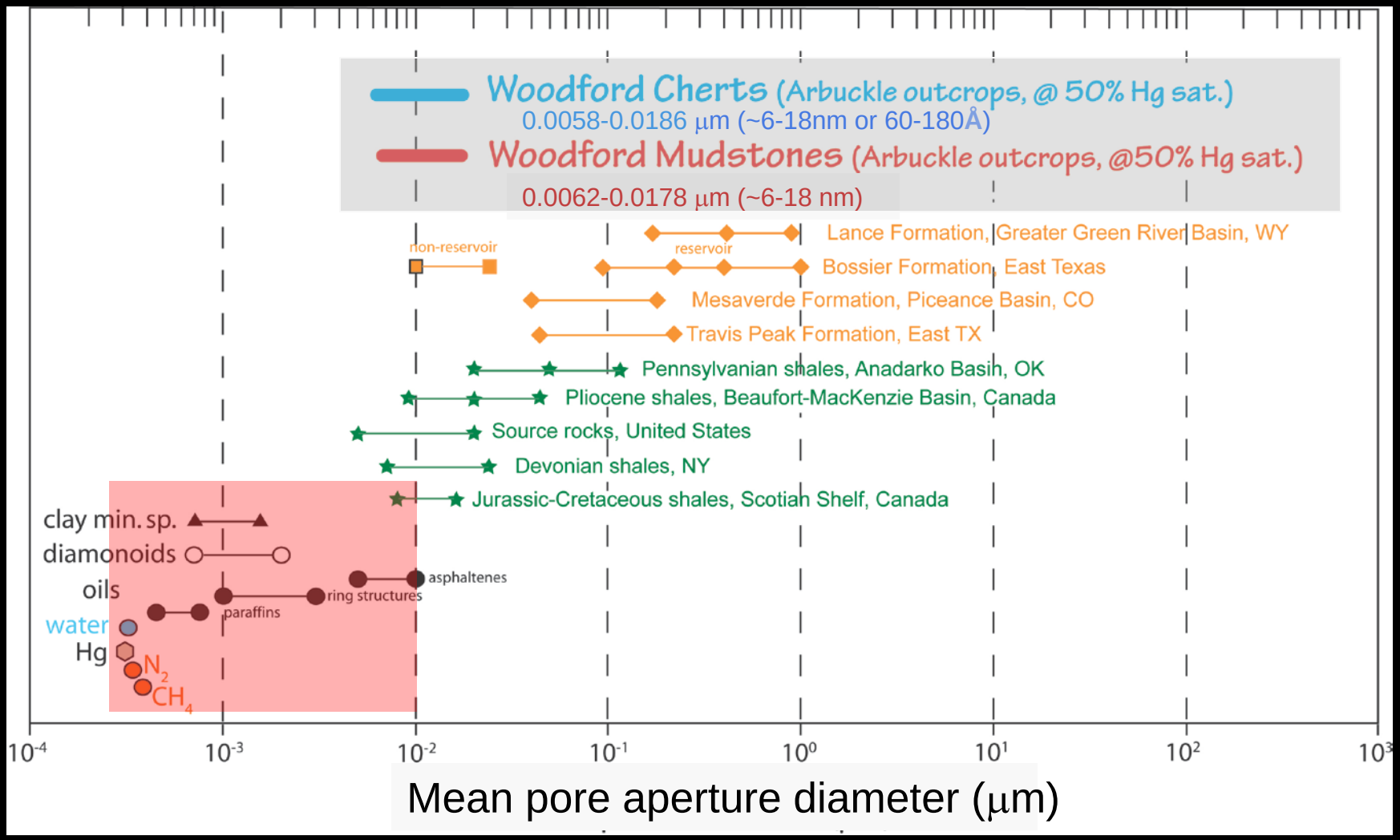
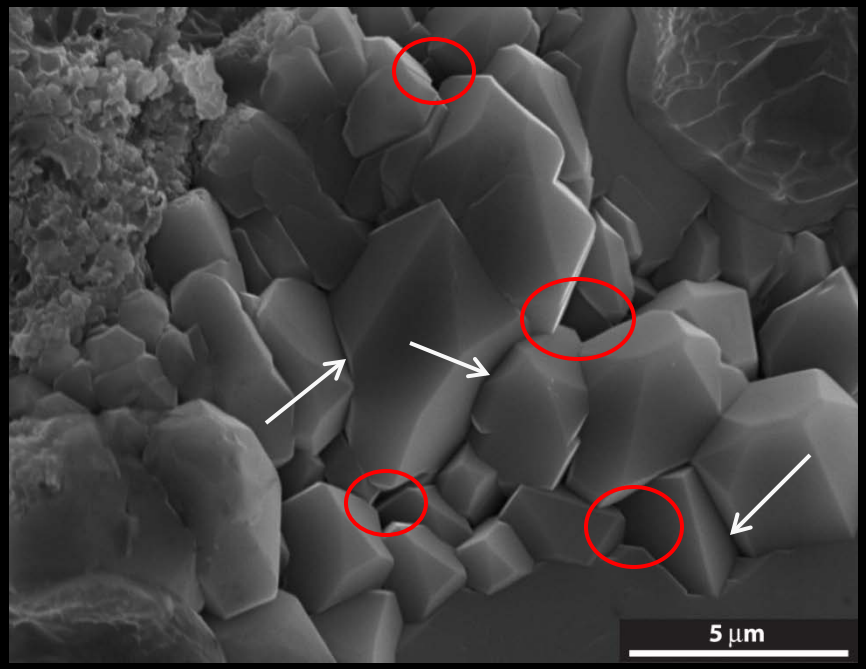
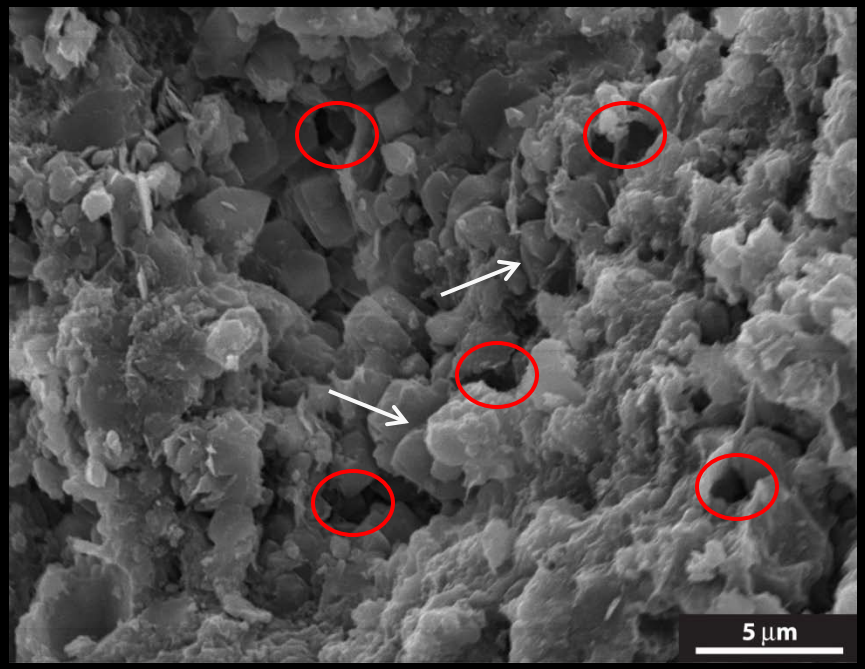


Chart modified from Nelson, 2009

Where are the pores?

Where are the pores in cherts?



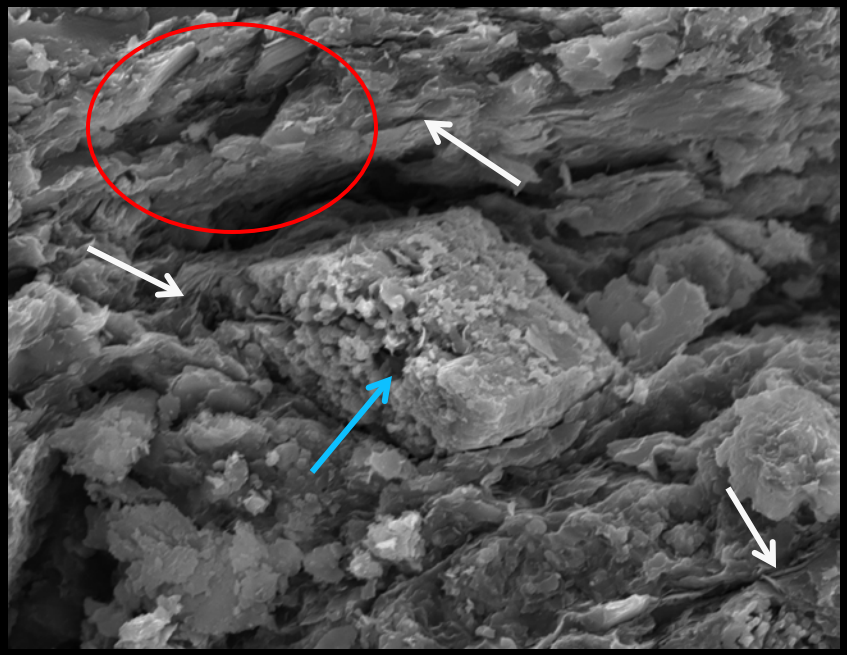


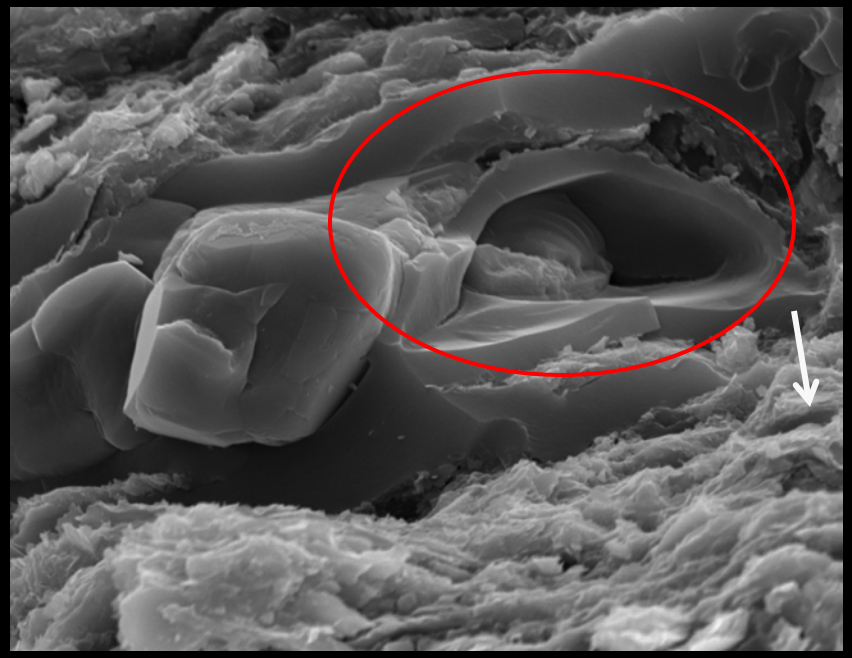
Matrix porosity in chert
"Slot" (between quartz xtals)

Matrix porosity in chert
Micropores (qtz, pyrite,)

Matrix porosity in chert
Moldic (k-spar—up to ~1% XRD)

Where are the pores in mudstones?



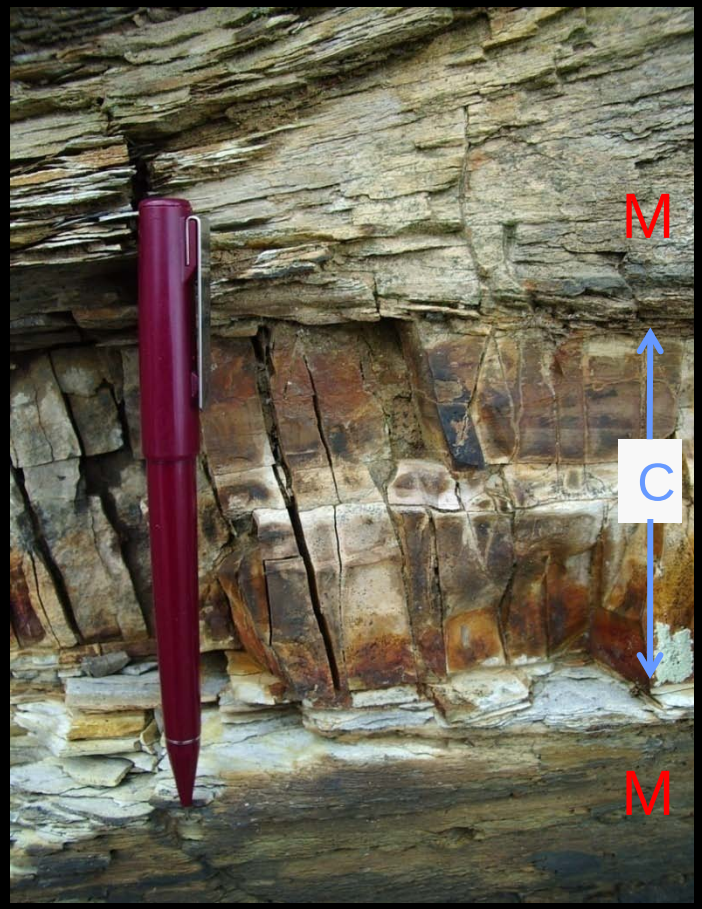


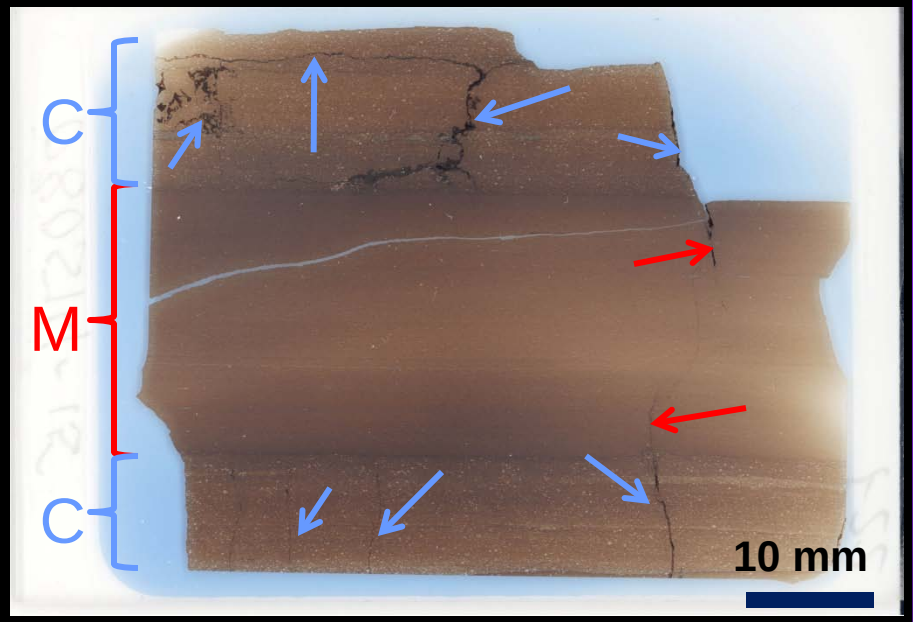
Matrix porosity in mudst
"Slot" (between clay particles)

Matrix porosity in mudst
Micropores (py, *Tasmanites*, etc)

Matrix porosity in mudst
Moldic (k-spar—up to ~6% XRD)

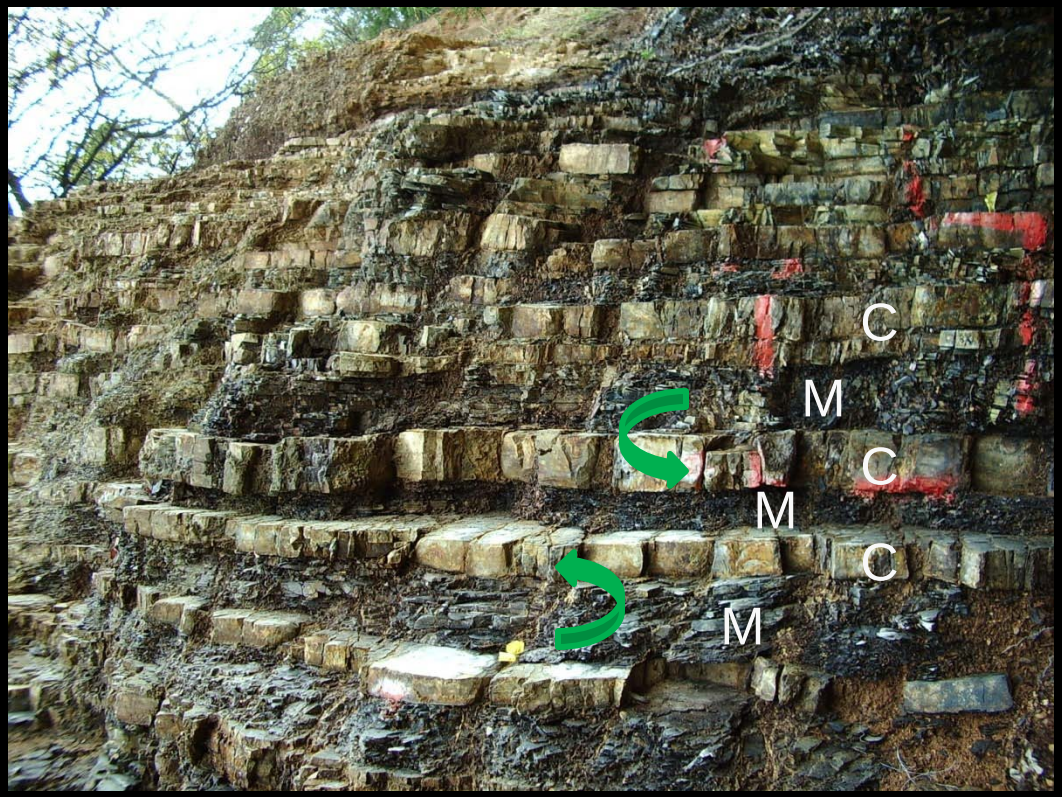
Where are the pores? (fractures)





High quartz content of chert = more brittle rock;
Minor mineralization in fractures in outcrop

Implications—from outcrop into basin



- Cherts = rigid framework from rextal. biogenic qtz (diagenesis)
- Chert microporosity & pore apertures resistant to effects of mechanical compaction—preserv. of storage capacity—reservoirs.
- Mudst = ductile framework
- Mudst microporosity & pore ap. Decrease w/ mech. compaction; reduction of storage capacity
- Corg in chert & mudst may provide sites of 2nd porosity w/maturation. Mudst>chert
- Chert porosity leads to storage of internally generated O&G
- If pressure drive existed, chert may hold some oil/gas generated in adjacent mudst.
- Chert more fraccable—conduit

Conclusions

- Woodford outcrops, Arbuckles; dominant lithologies –chert (radiolarian ooze) & mudstone (*Tasmanites*-bearing)
- Chert porosity slightly lower than mudst., but overlap
- Pore types (chert & mudstones)
  - "slot" between minerals (qtz_{chert} & $clays_{mudst}$)
  - Micropores—between mineral $masses_{chert}$/$Tasm_{mudst}$ or primary voids
  - Moldic—2nd pores after mineral dissolution ($<1_{chert}$-6_{mudst}%)
- Chert perm greater variability & extremes than mudstones, but overlap
- Chert entry pressures generally higher than mudstones, but overlap
- <u>Inferences from outcrop samples into subsurface</u>
  - Hi quartz in chert favors porosity/pore aper. preservation w/burial
  - Hi clay & *Tasm* in mudst promote more severe mechanical compaction w/burial—loss of microporosity & decrease of pore apertures

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