Geological Controls on Reservoir Properties and Production Potential of Lower Paleozoic Shale Gas Plays in Sichuan Basin*

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Abstract

Silurian "hot shale" with high thermal maturity is known as source rock of Paleozoic petroleum systems and now the unique self-contained reservoir in situ with advances in horizontal drilling and multi-stage hydraulic fracturing. It has evolved through several tectonic events which form different sets of existing natural fractures in response to regional stress models. The comparison of geological characteristics about marine shale reservoirs between the individual regions inside and outside China, especially located on siliciclastic shelves, provides a useful method to delineate the evolution and distribution of the organic rich shale formation.

Upper Ordovician to Lower Silurian shale analysis such as logs, Pyrolysis, XRD, XFD, thin sections, CL, SEM and QEMSCAN indicate that mineralogical composition variations and fabric anisotropy at scales are notable in Sichuan Basin and surrounding regions. These variables are integrated to recognize several lithofacies rather than a whole homogeneous unit. The stacking patterns and trends of Lower Palaeozoic hydrocarbon-bearing shale successions of the area, associated with complex present regional in-situ stress data, confirm the impact of depositional environments and tectonic events on rock geochemical and geomechanical characteristics correlate with these lithofacies which at least partially control the response to hydraulic fracturing stimulation and then production potential of shale gas in multi zones. Furthermore, the comprehensive geologic approach shows some insights into understanding key geological factors and processes in different areas to identify prospective shale gas fairway over Sichuan Basin.

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May 19-22, 2013 – AAPG Pittsburgh, Pennsylvania

Outline

- Contribution to Resources Assessment
- Shale Reservoir Properties
- Sweet Spot and Production Potential
- Summary and Discussion

Chinese Shale Gas TRR and Activities

– EIA (2011) : 1275Tcf （36Tcm）for two large marine shale basins of China, 343 Tcf for Silurian shale

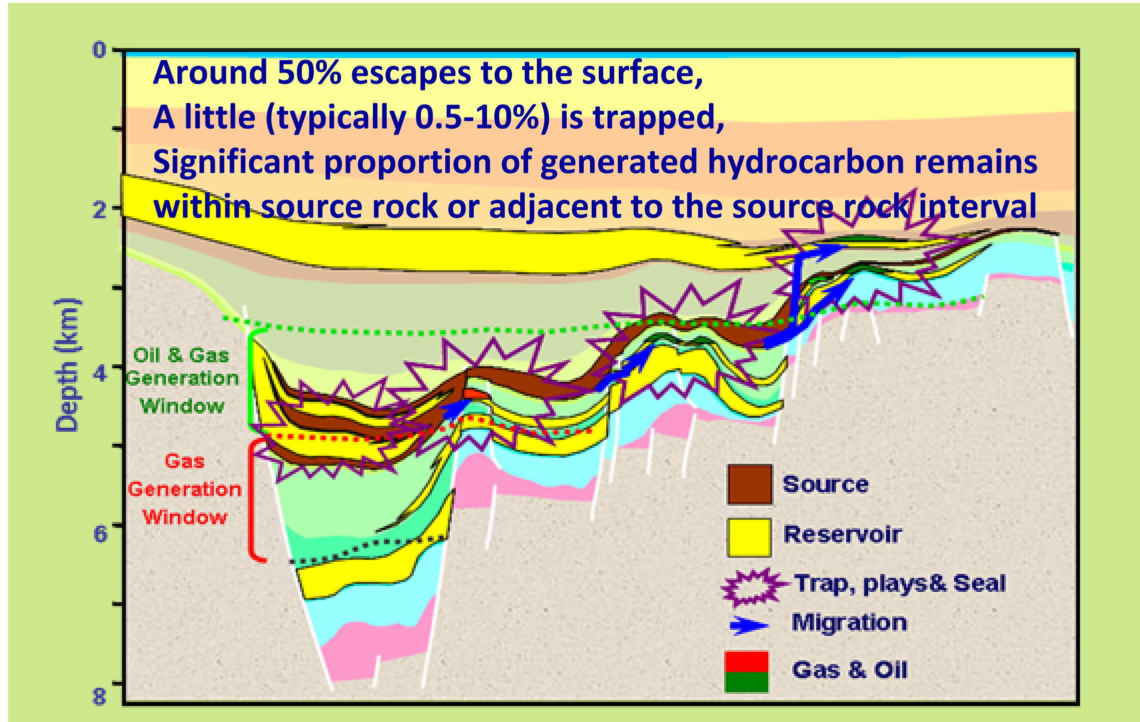
– Chinese Ministry of Land and Resources (2012): 25Tcm

– PetroChina (2010): First R & D well

– Shell (2013): First shale gas ODP

Chinese Shale Gas TRR and Activity

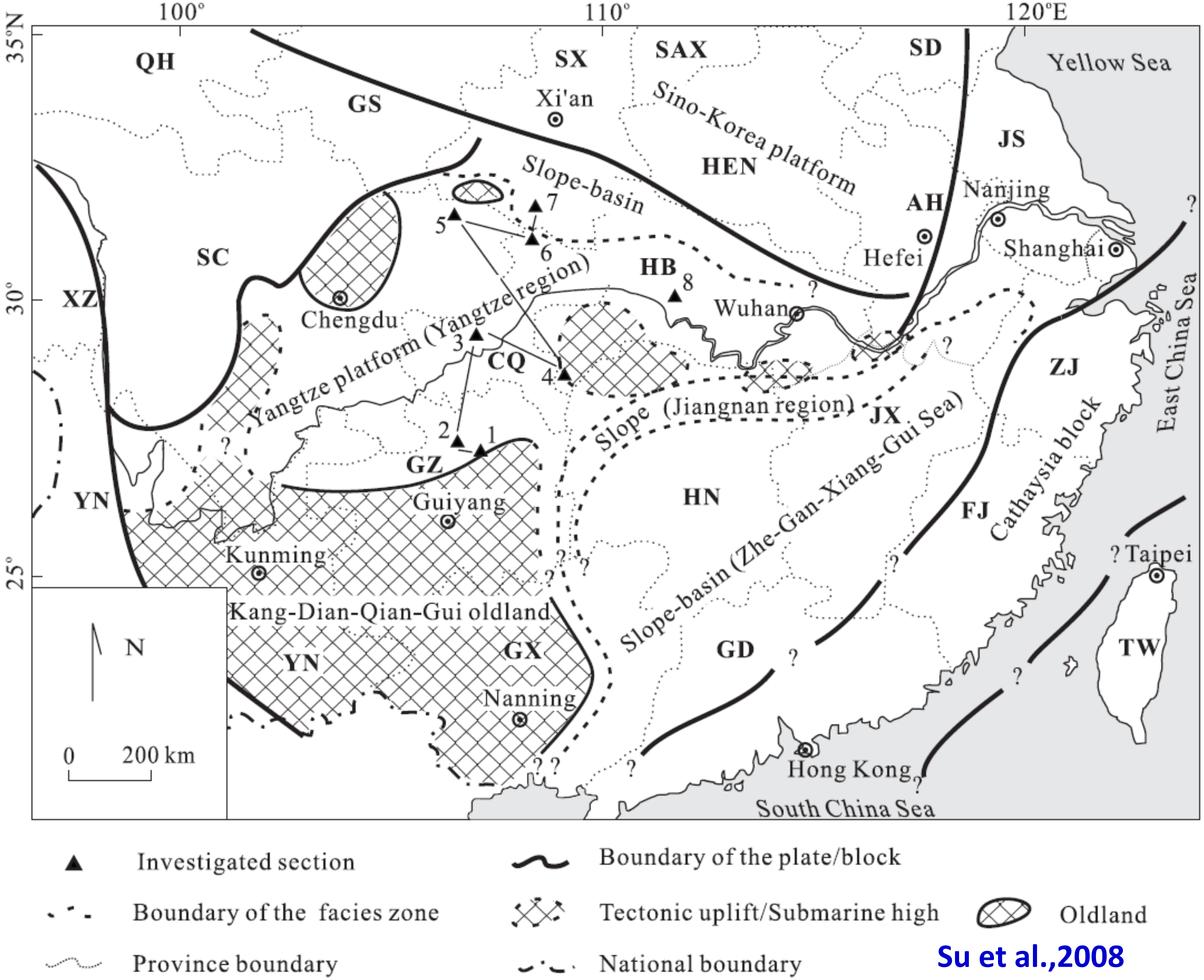
Courtesy of Heineken



Courtesy of ExxonMobil, Kimmeridge Energy

Petroleum system elements and relationship between conventional and unconventional. Inherent inefficiency of oil expulsion make the prospective chance for shale gas

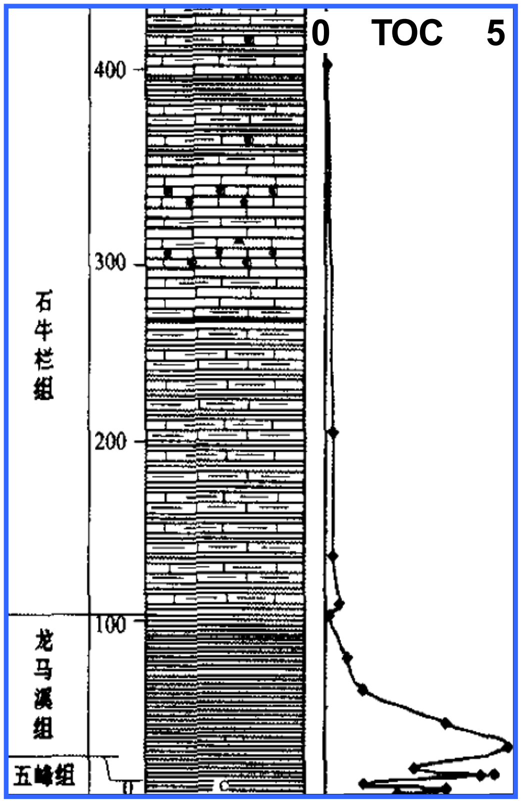
Late Ordovician Tectonic Units and Sedimentary Facies in Southern China



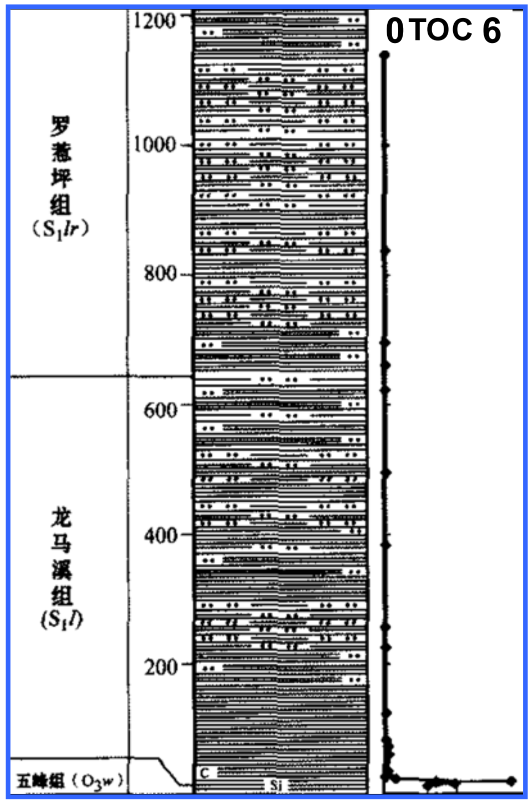
Su et al.,2008

Vertical Sections from Outcrop

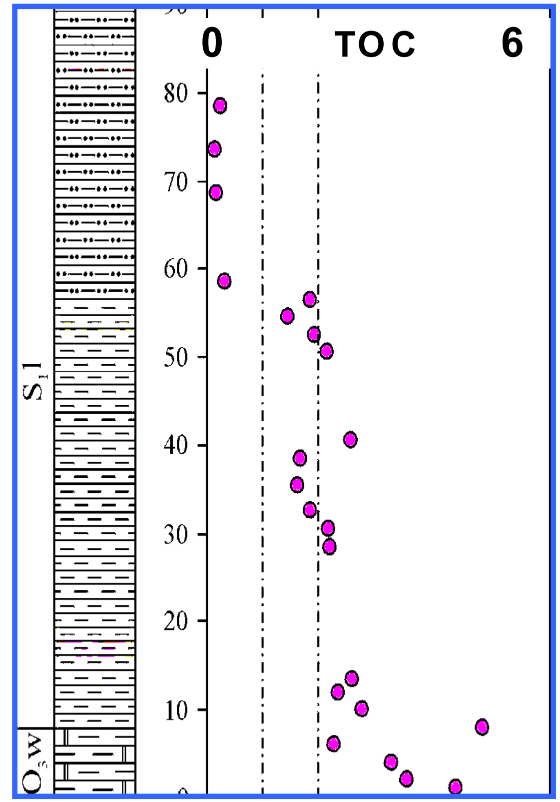
Guizhou	Hunan	Hubei
TOC=0.07-4.4%	TOC=0.59-5.0%	TOC=0.2-5%
Hot shale thickness=50m	Hot shale thickness<20m	Hot shale thickness=52m



Guizhou



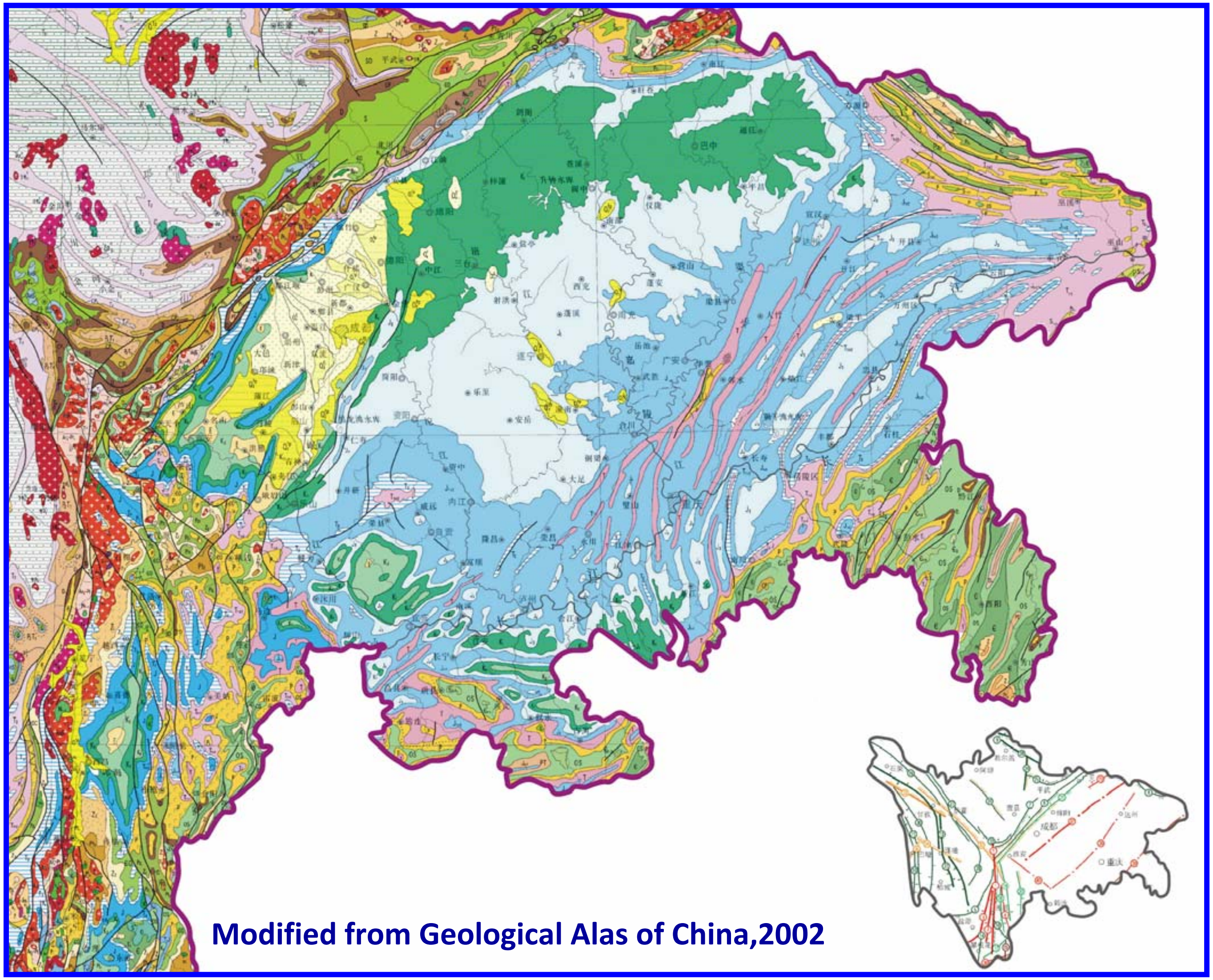
Hunan



Hubei

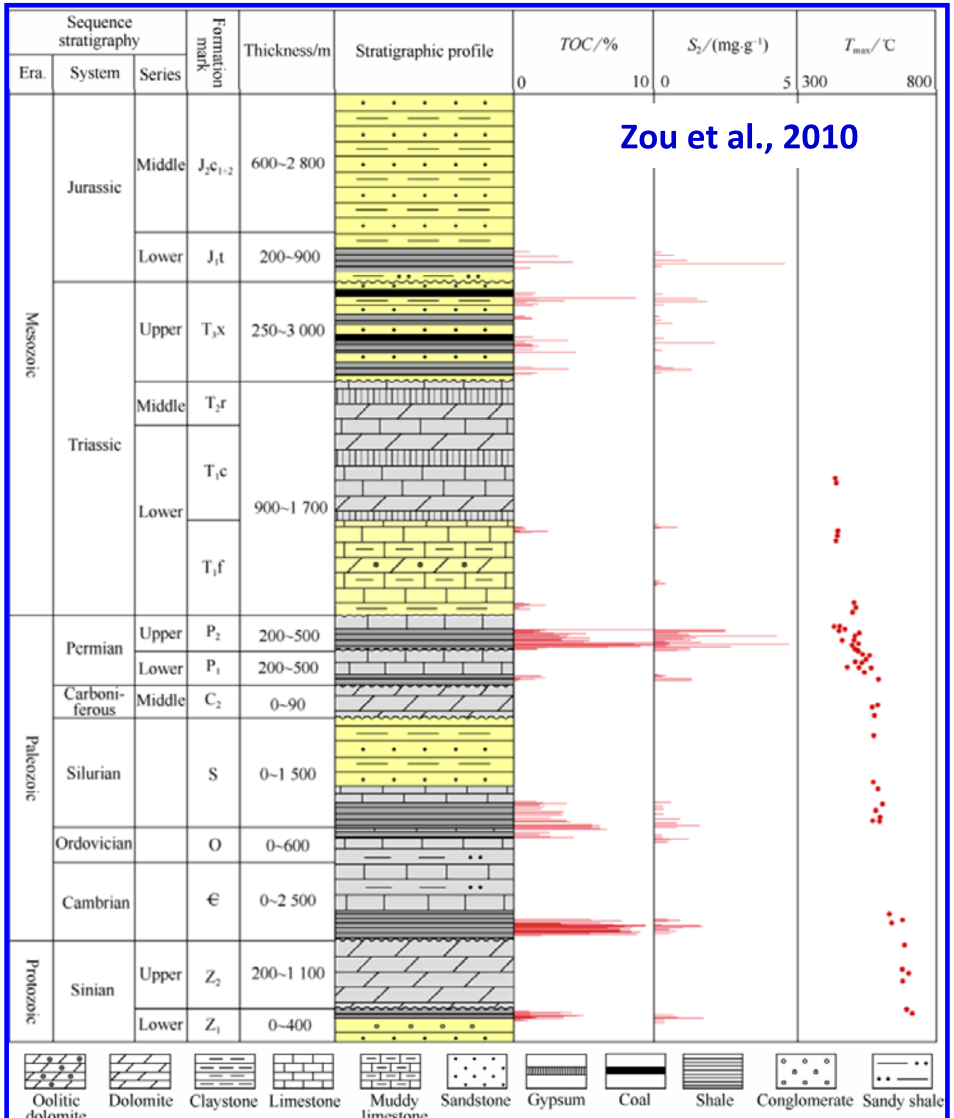
After documents

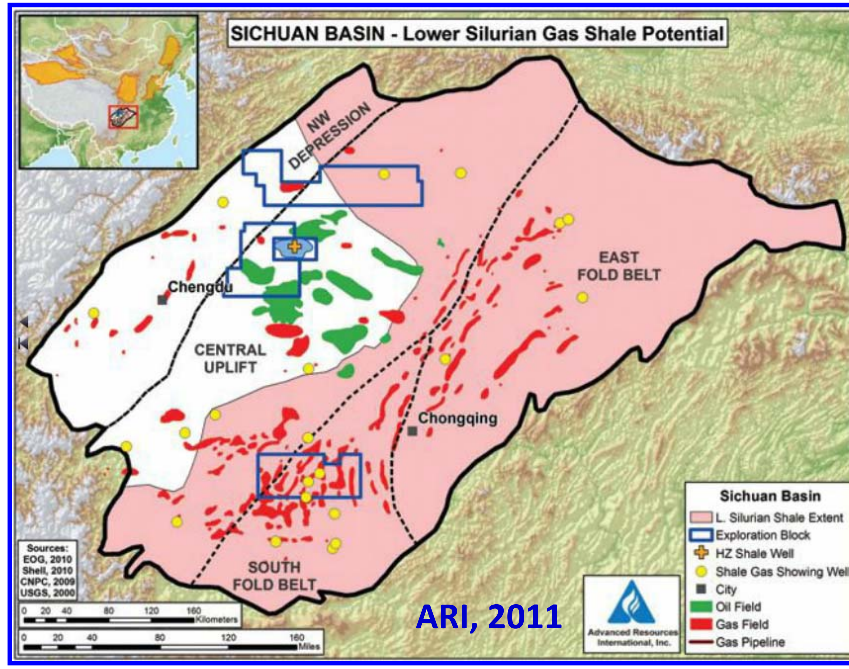
Geologic Setting, Sichuan Basin



Modified from Geological Alas of China,2002

Shale Gas Play Locations

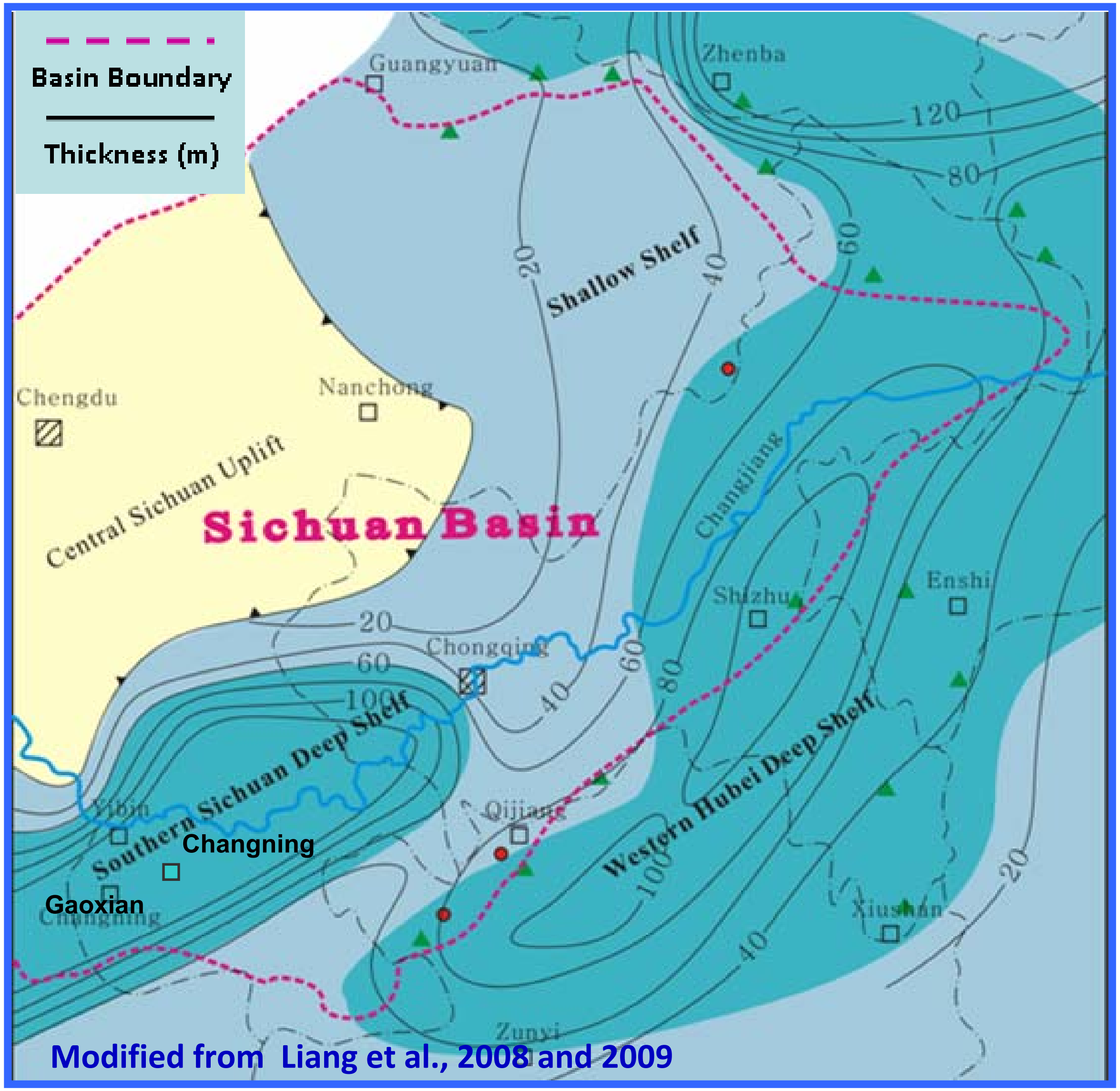




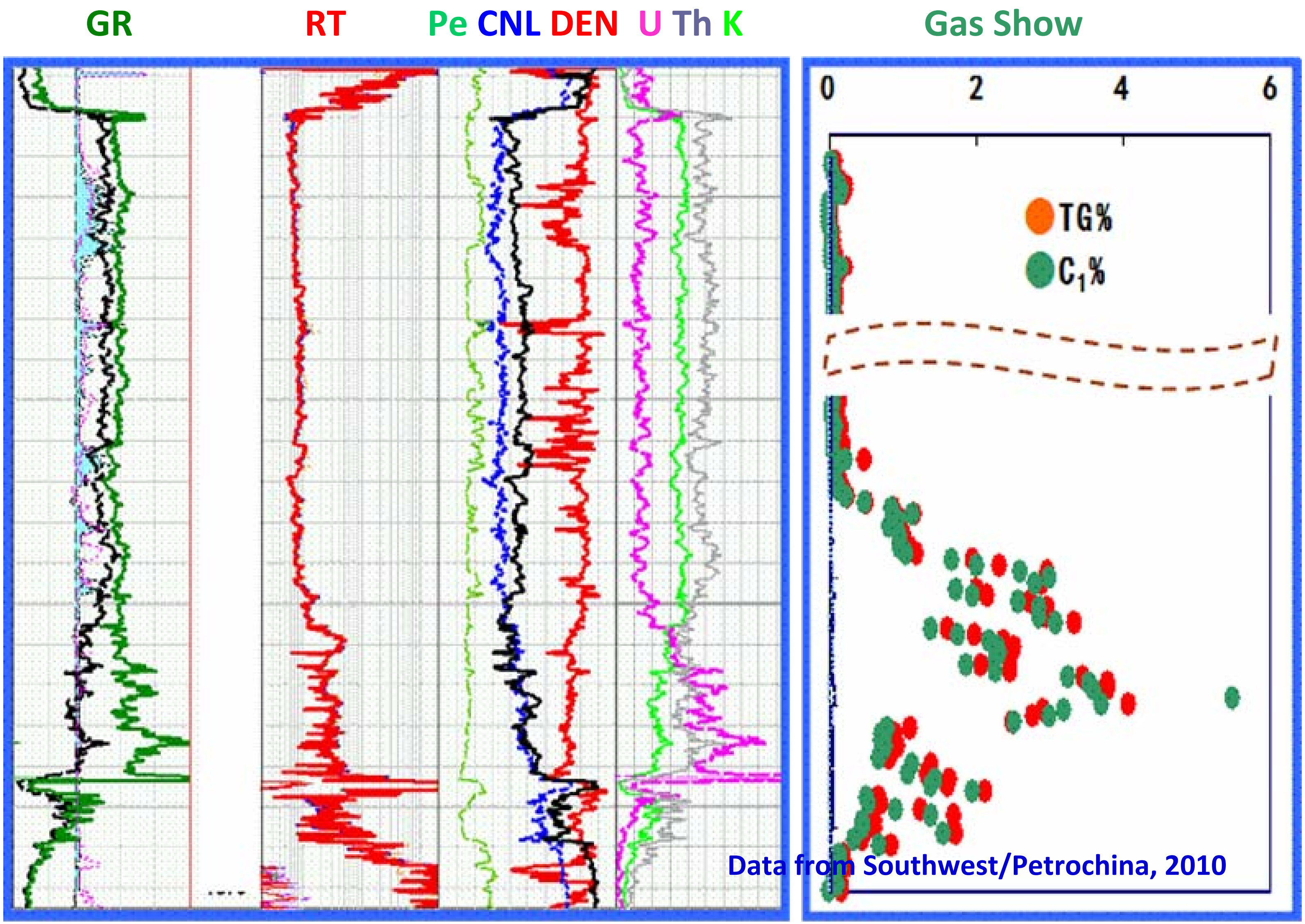
Prospective Lower Silurian Shale Gas Areas, Sichuan Basin: Central Uplift, East and South Fold Belts ?

Stratigraphy column of Paleozoic black shale in Sichuan Basin

Isopach Map of Upper Ordovician-Lower Silurian Source Rocks

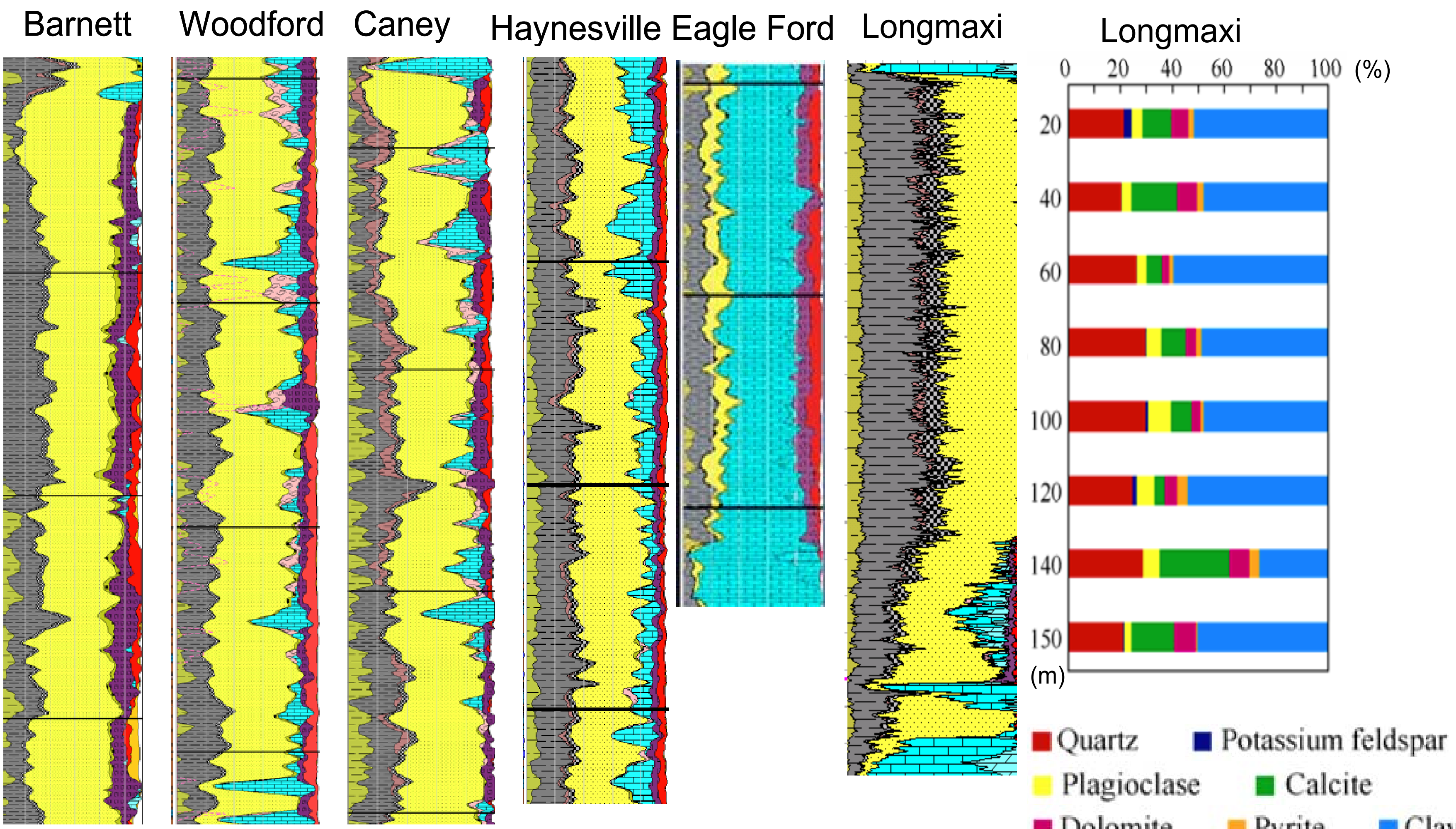


Target Prospect for Longmaxi Shale (S_1l)



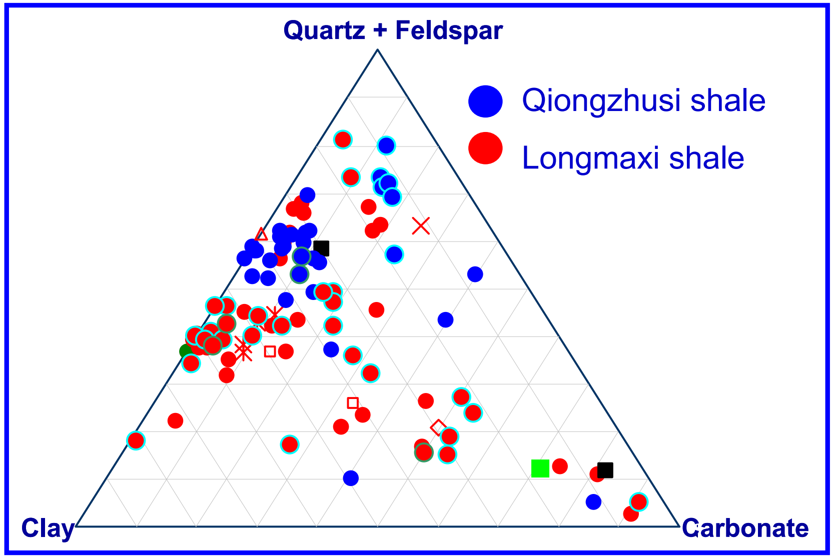
Data from Southwest/Petrochina, 2010

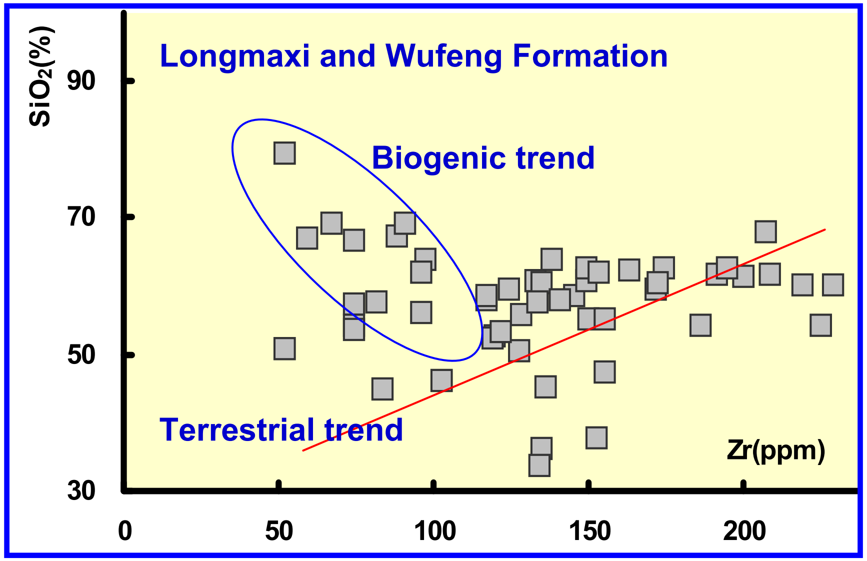
Mineral Composition for Different Shales

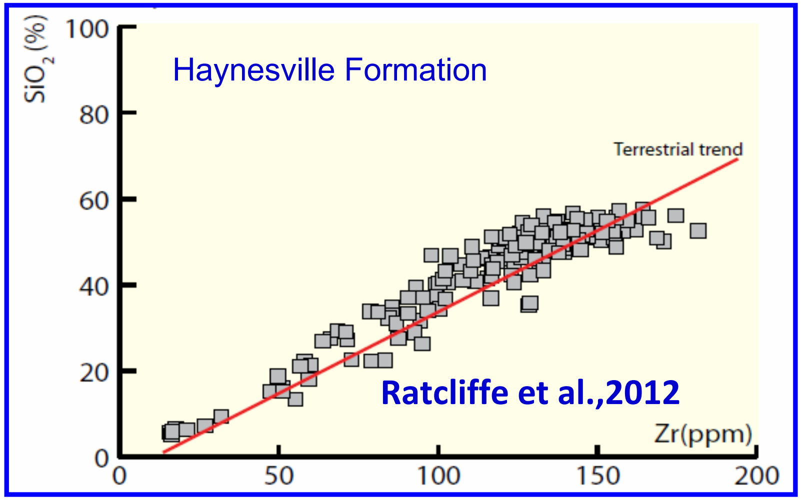


Schlumberger,2009; Southwest/Petrochina,2010; Zou et al., 2010

Mineral Distribution, Major & Minor Element



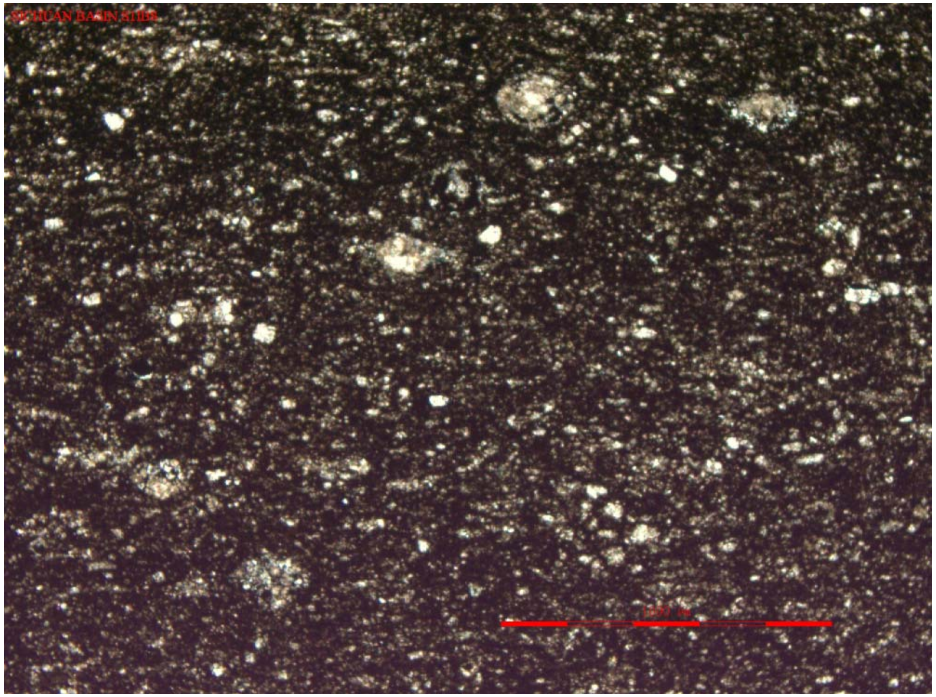


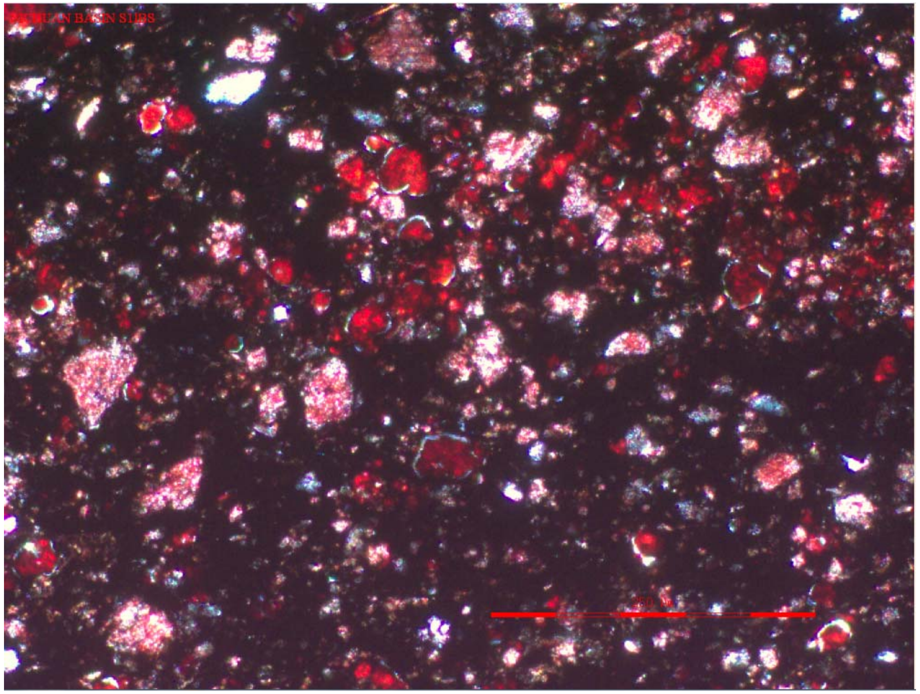


Different Silica Source:

Terrestrial trend and
Biogenic trend

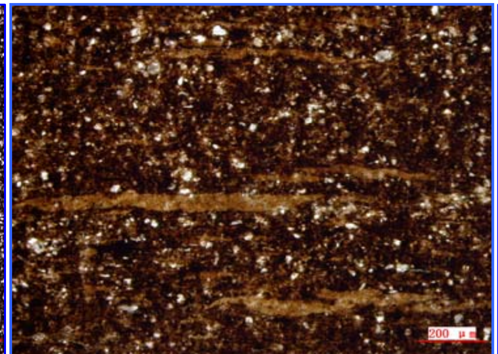
Silica Source

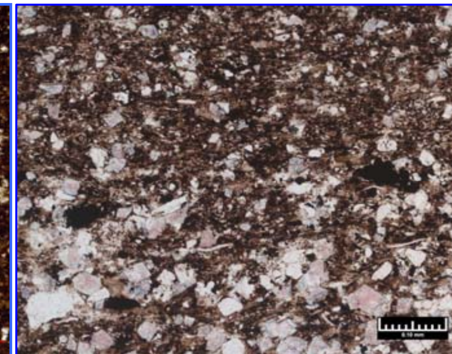




Evidence for biogenic silica and calcium from thin sections in target zone

Hot Shales with Typical Lithofacies

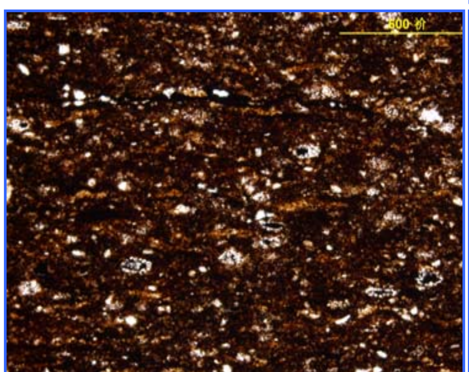


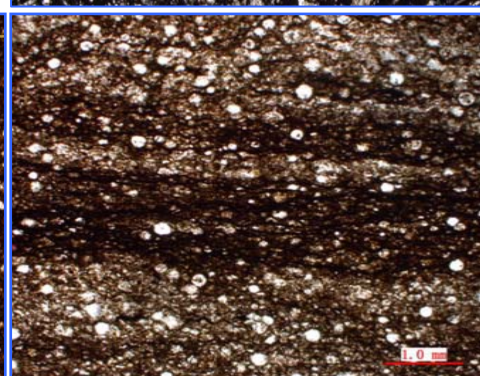


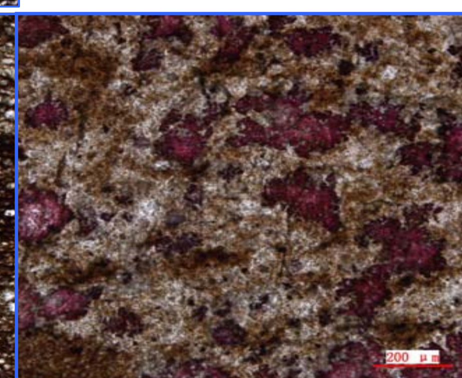
S_1l

Bioclast layers

O_3g

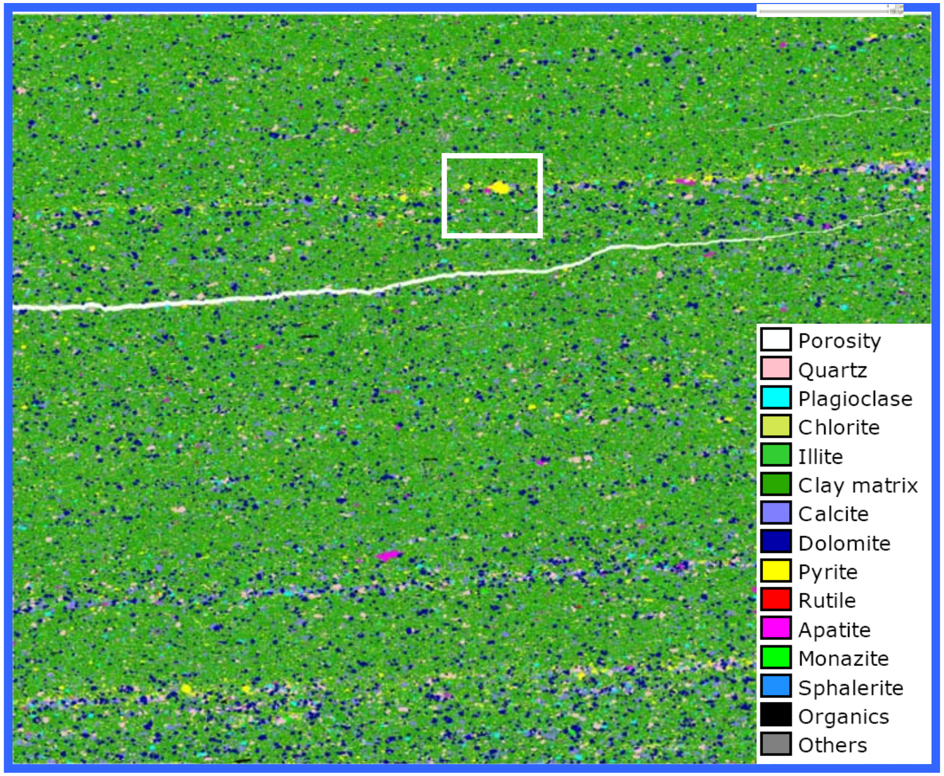


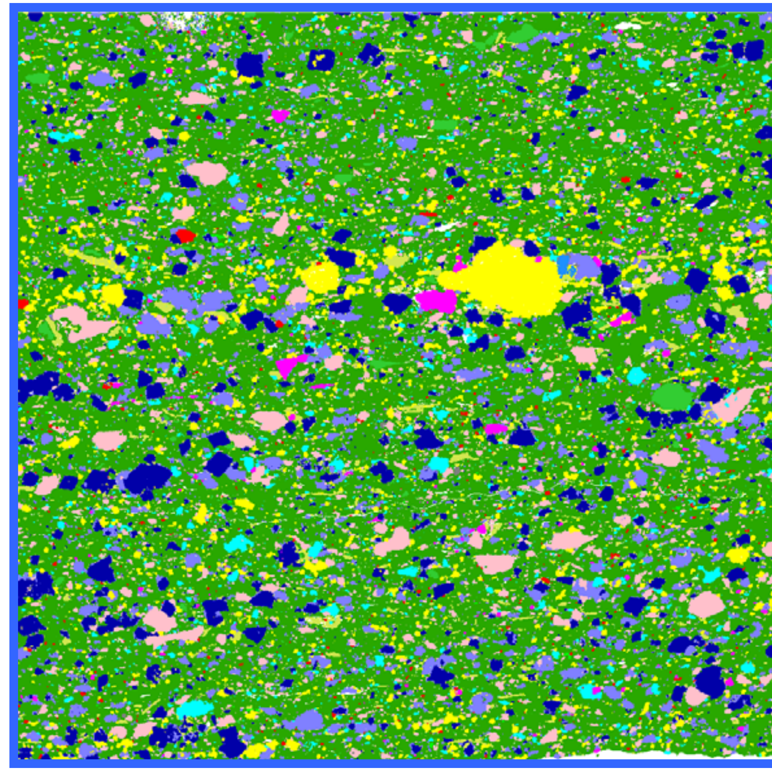




O_3w

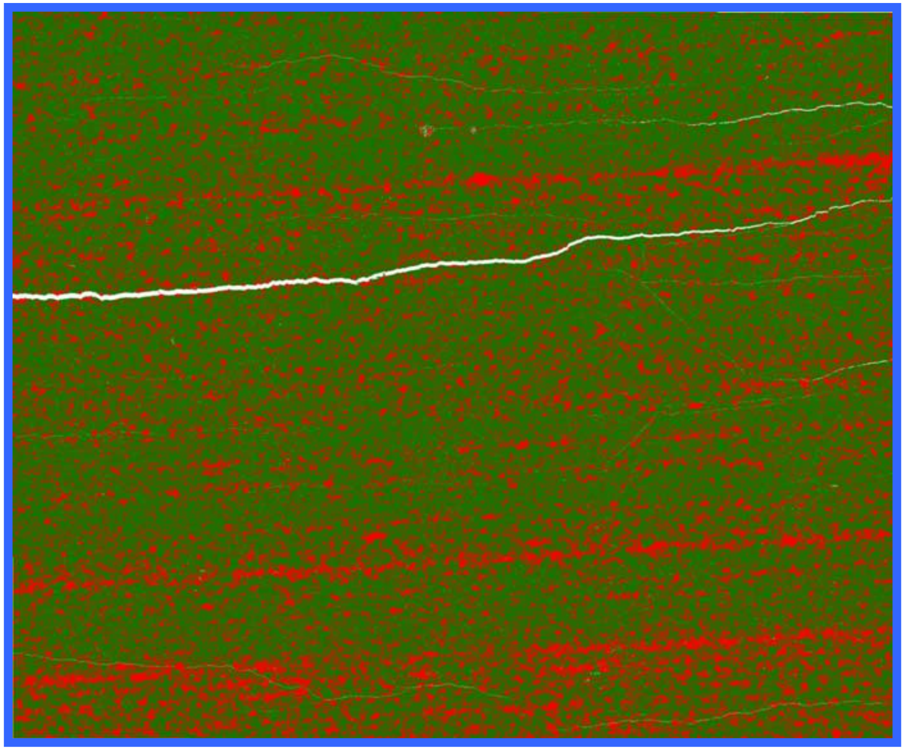
Comparison of QEMSCAN Images

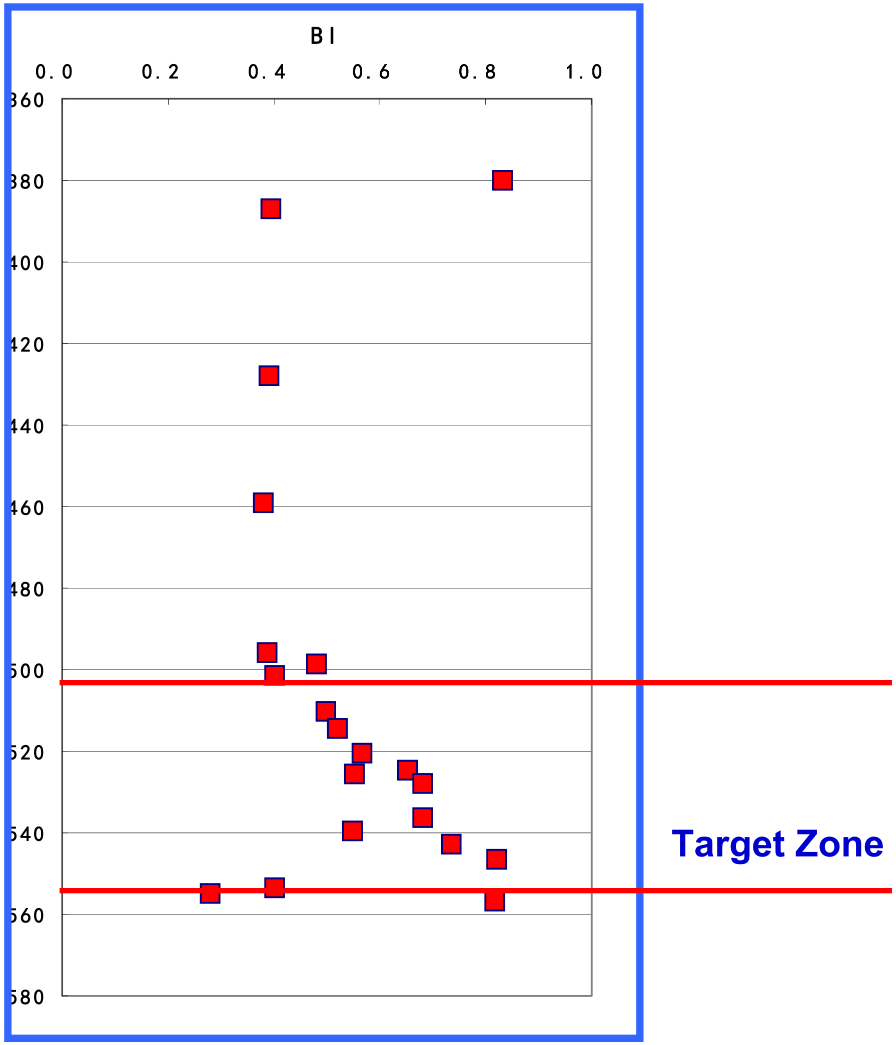




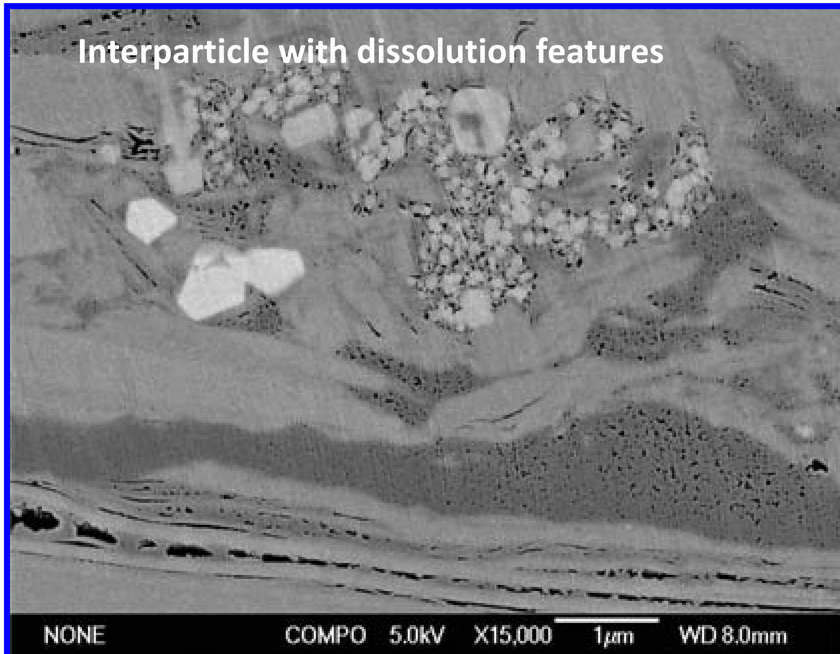
Images in scales showing the lamination of very fine carbonate and quartz grains Longmaxi Shale

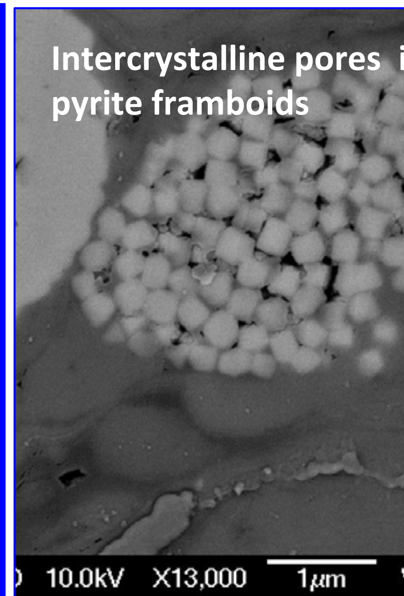
Brittleness Indexes

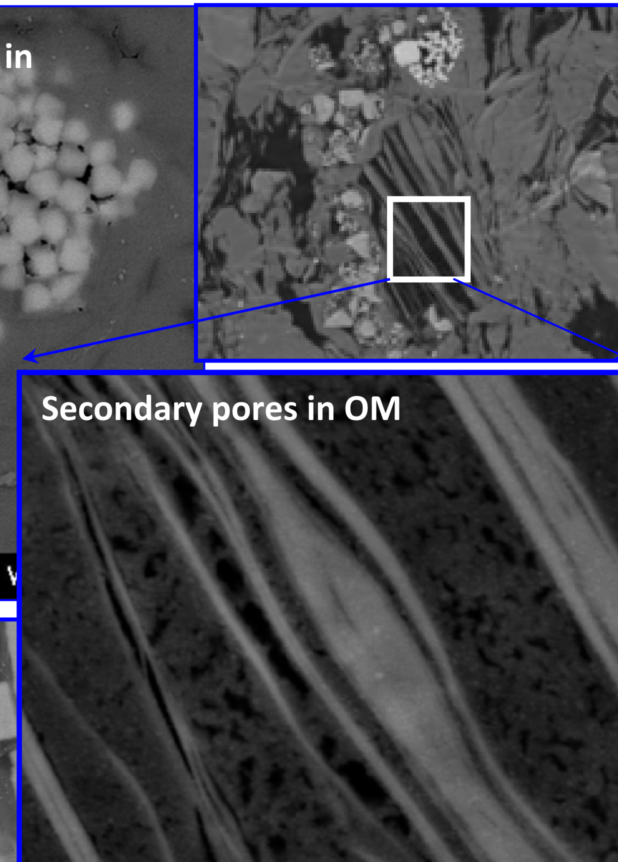


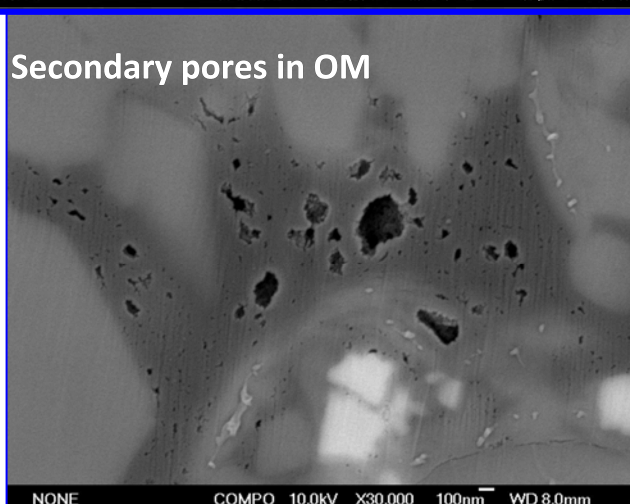


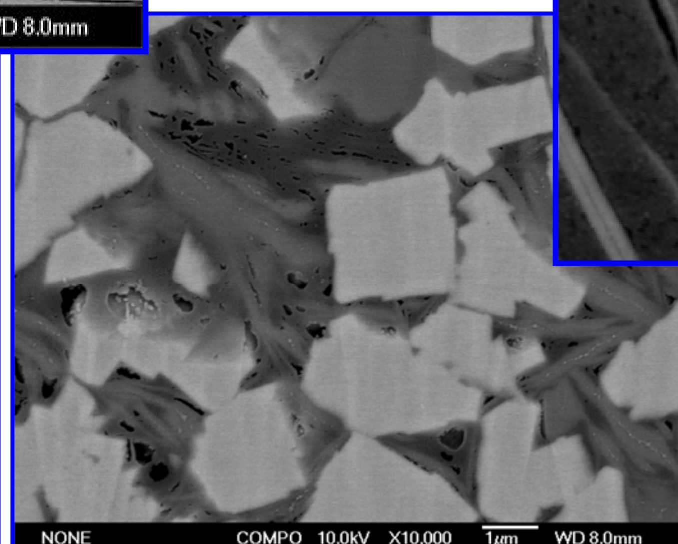
Micro & Nano-pore Types of Longmaxi Hot Shale









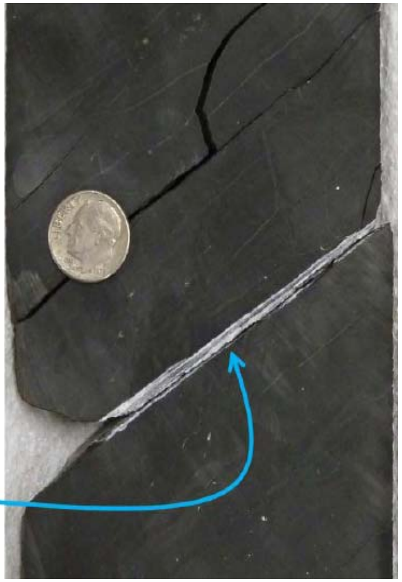


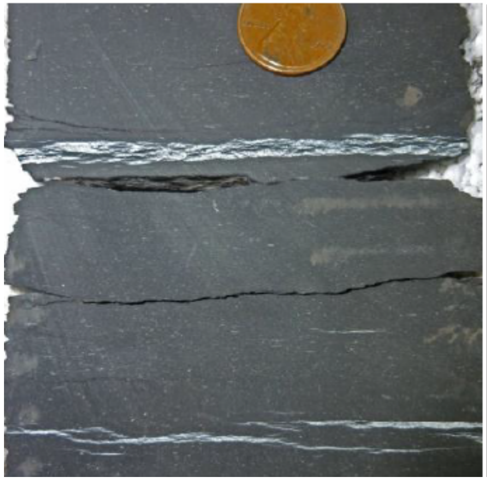
Intraparticle pores

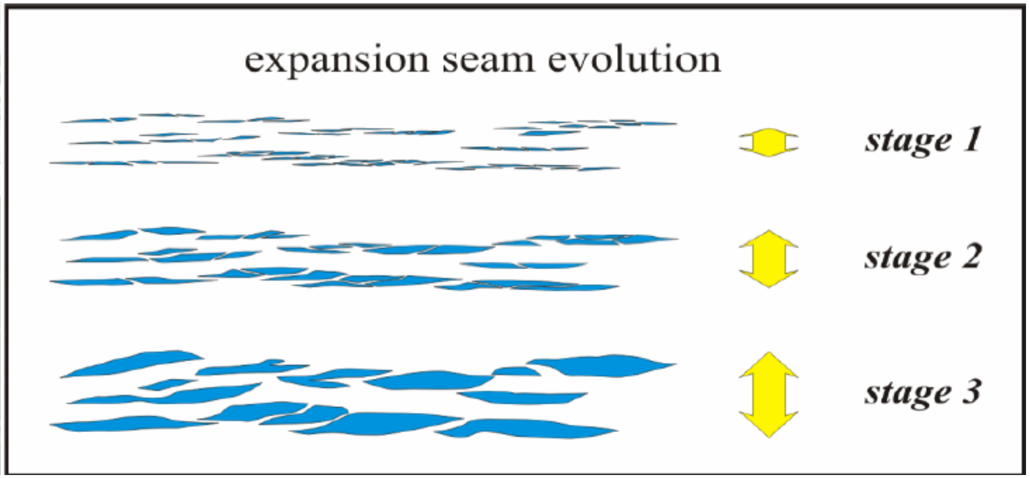
Evidence for Fluid Overpressure during Hydrocarbon Generation

Left: Calcite-lined shear zone and slip surface in dipping beds on flank of large detachment zone, Longmaxi Fm.

Bottom: Bed-parallel expansion seams, or "beef," in core from the Haynesville Fm. (right) Diagram to illustrate the evolution of expansion seams.

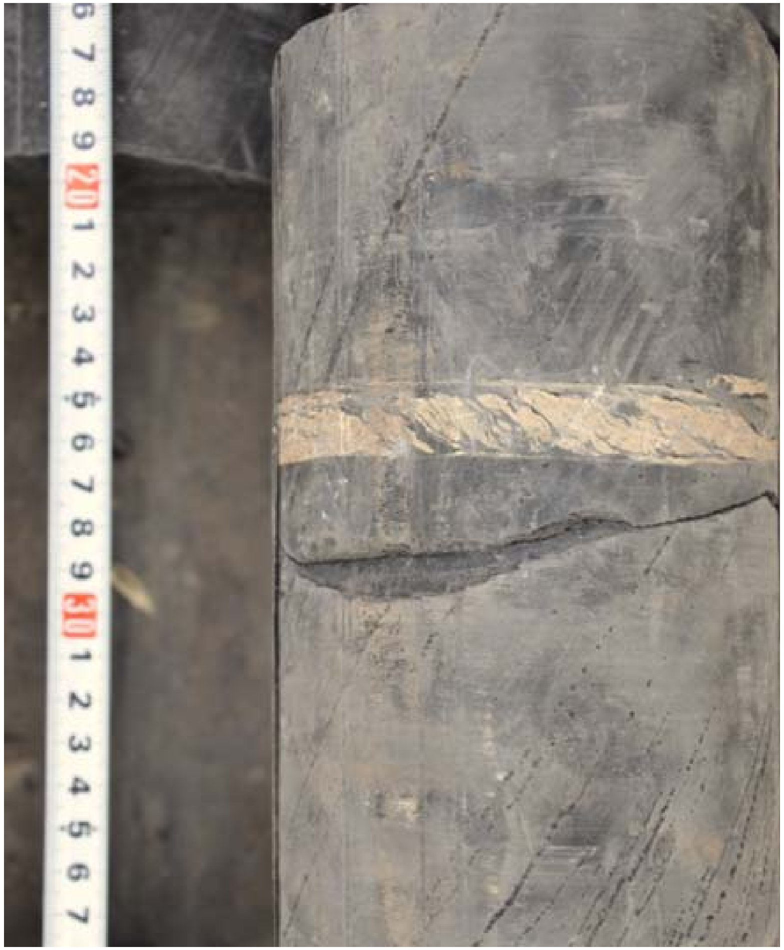






Jamison, 2013

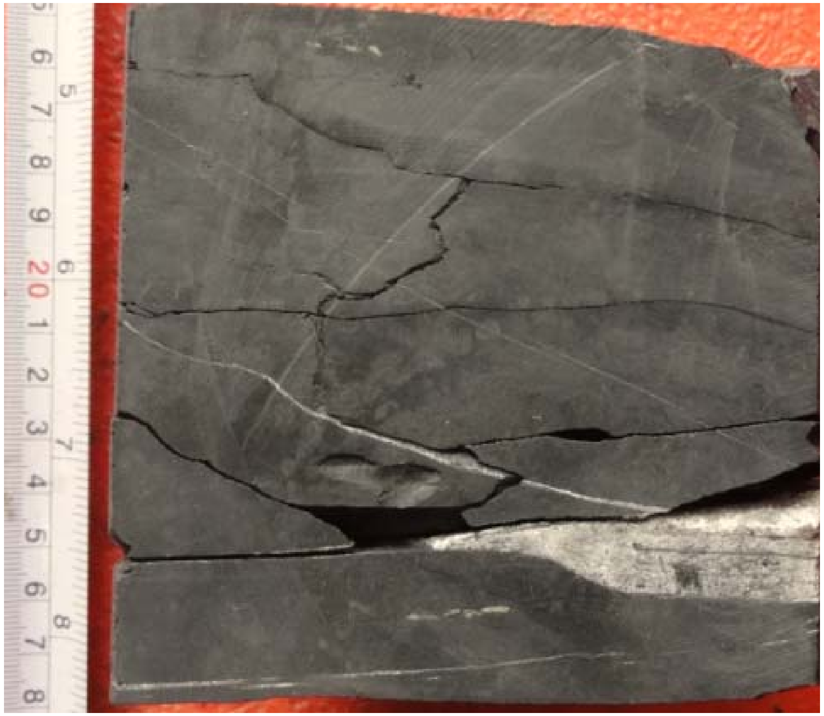
Bed-parallel Expansion Seams



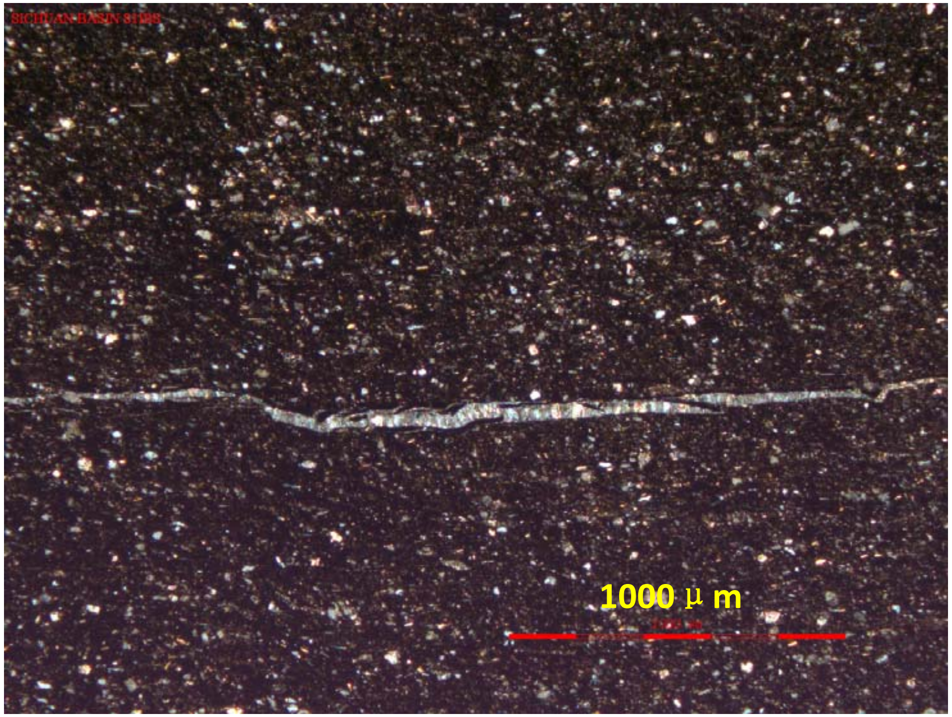
S_1l 2300.6m

O_3w 3170.8m

Bed-parallel Expansion Seams



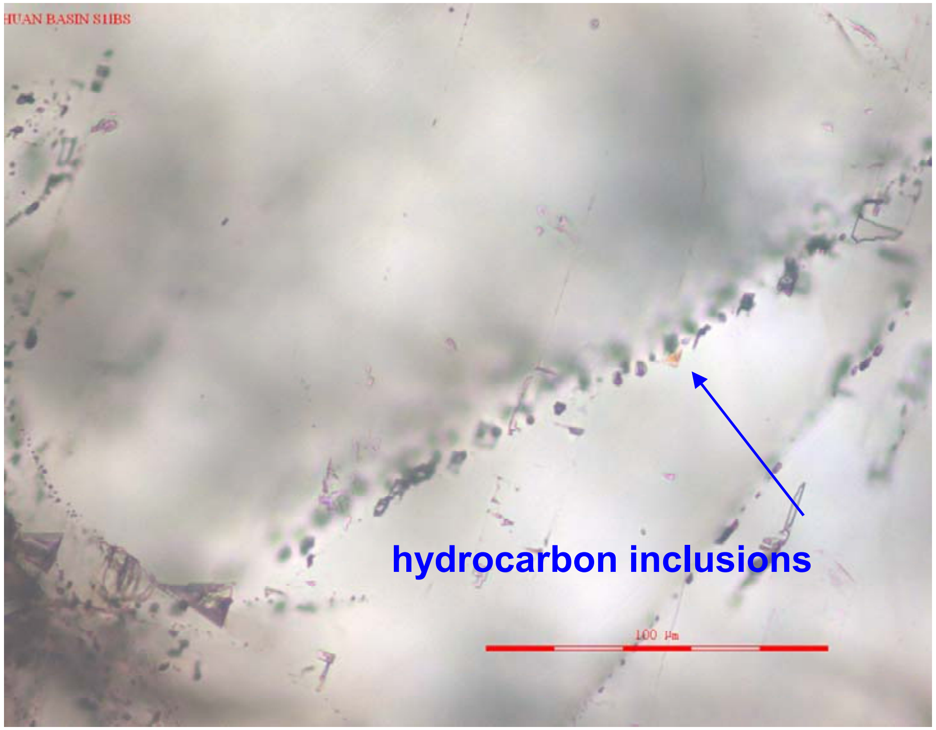
Longmaxi Fm

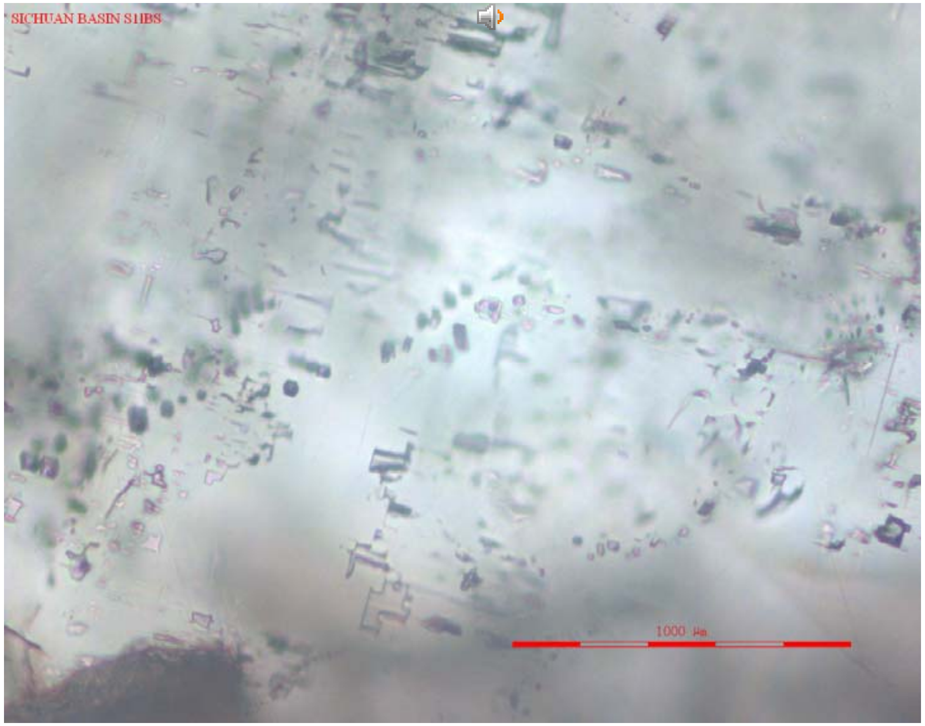


Thin section from the same sample

Hot shale with horizontal fracture filled with calcite

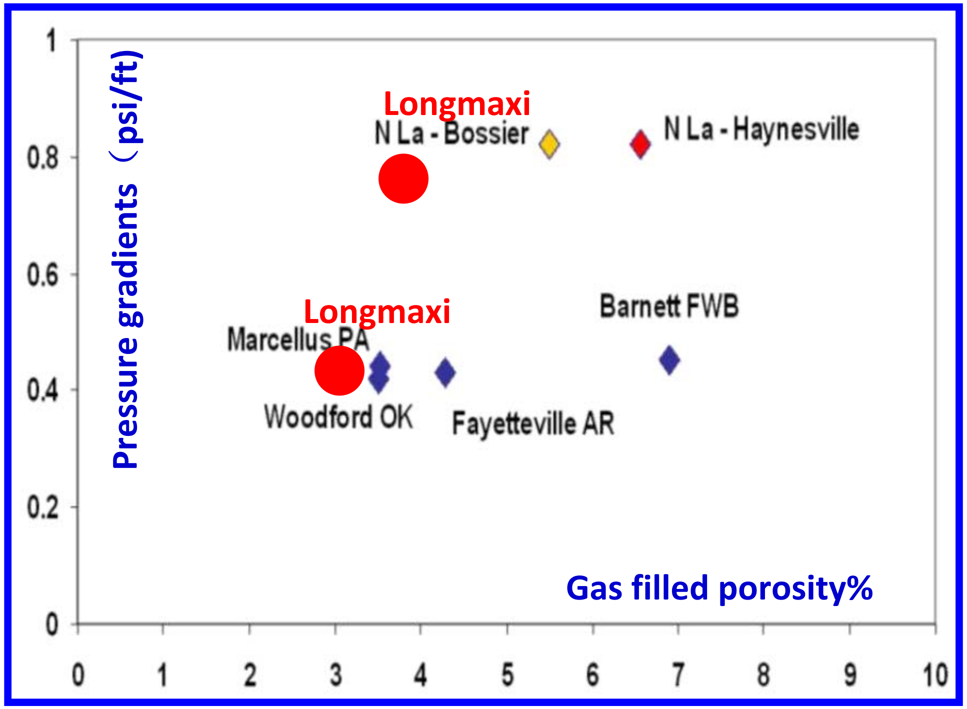
Fluid Inclusions in Bed-parallel Expansion Seams

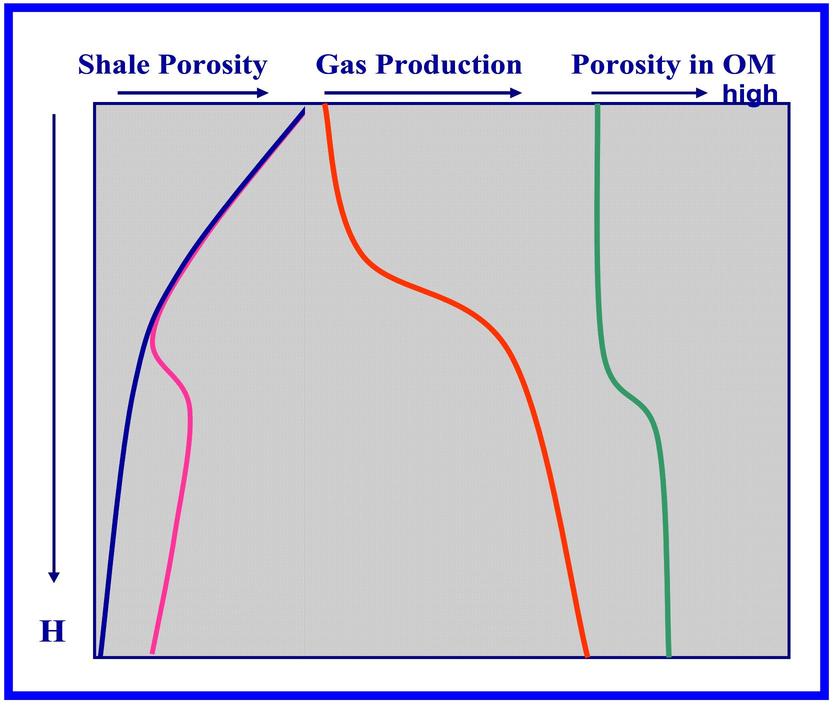




Fluid inclusions homogenization temperature range, 114-143 ℃

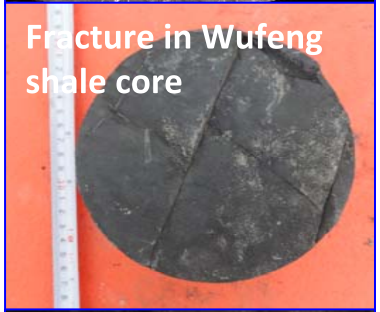
Controls on Sustainable Overpressure?

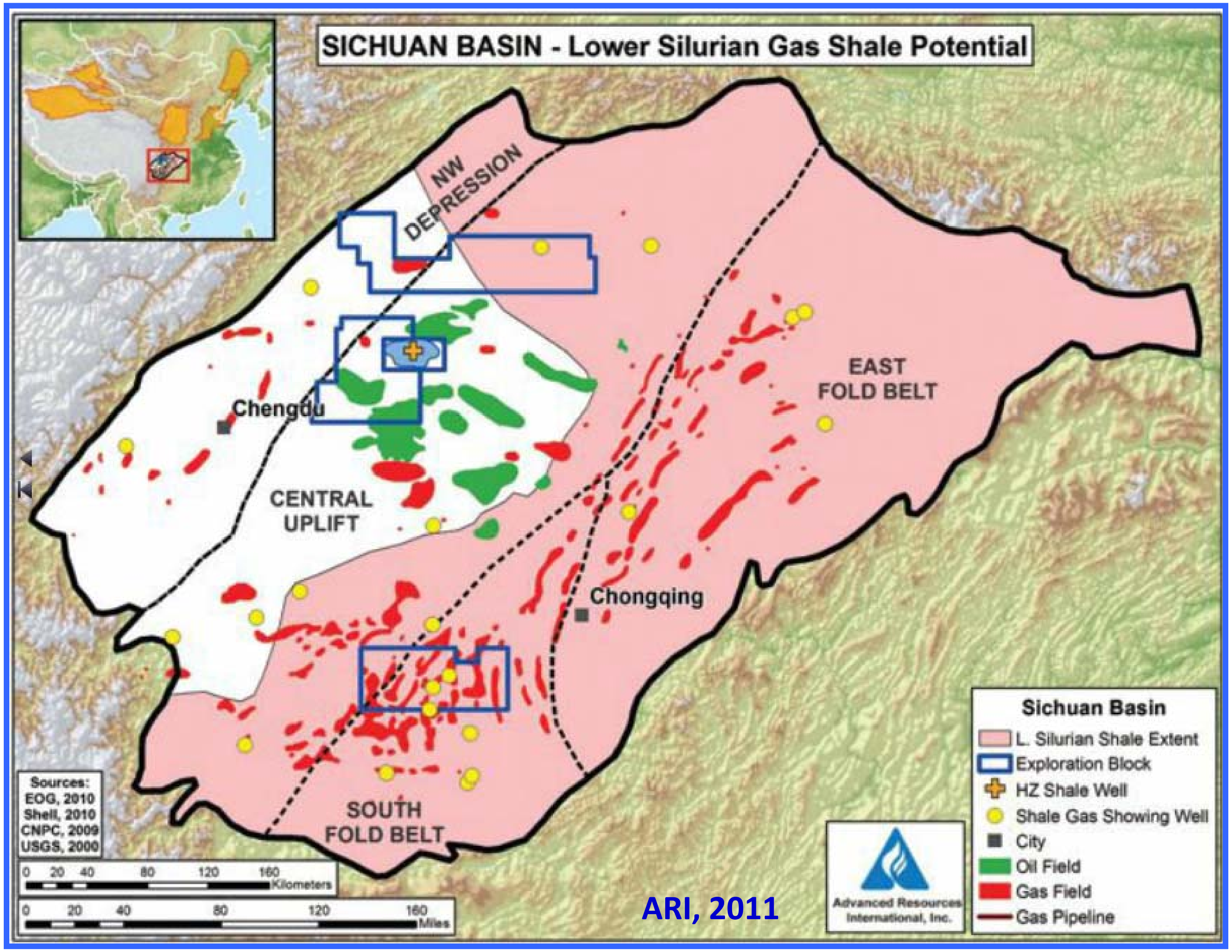




Modified From documents

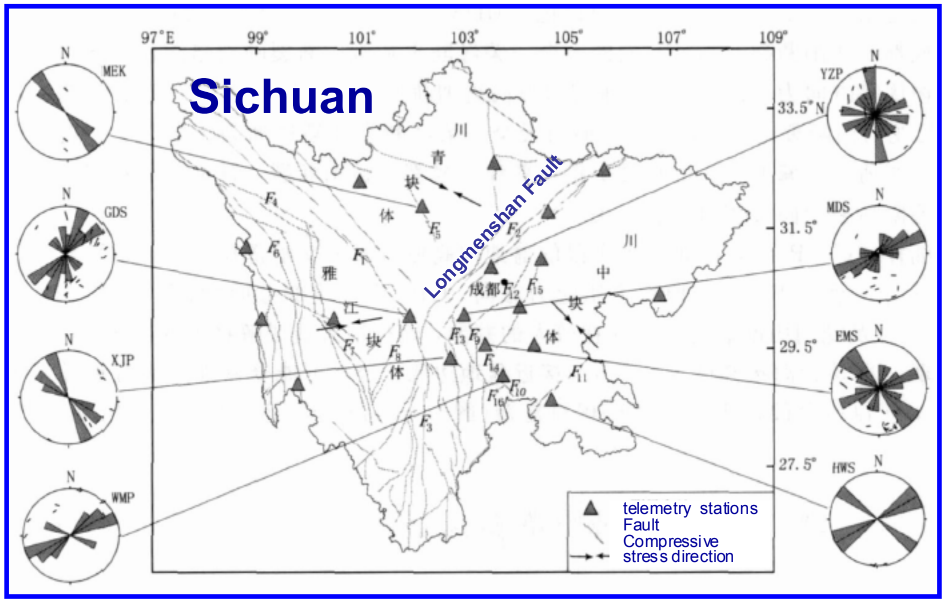
Shale Fractures in Core and Outcrop





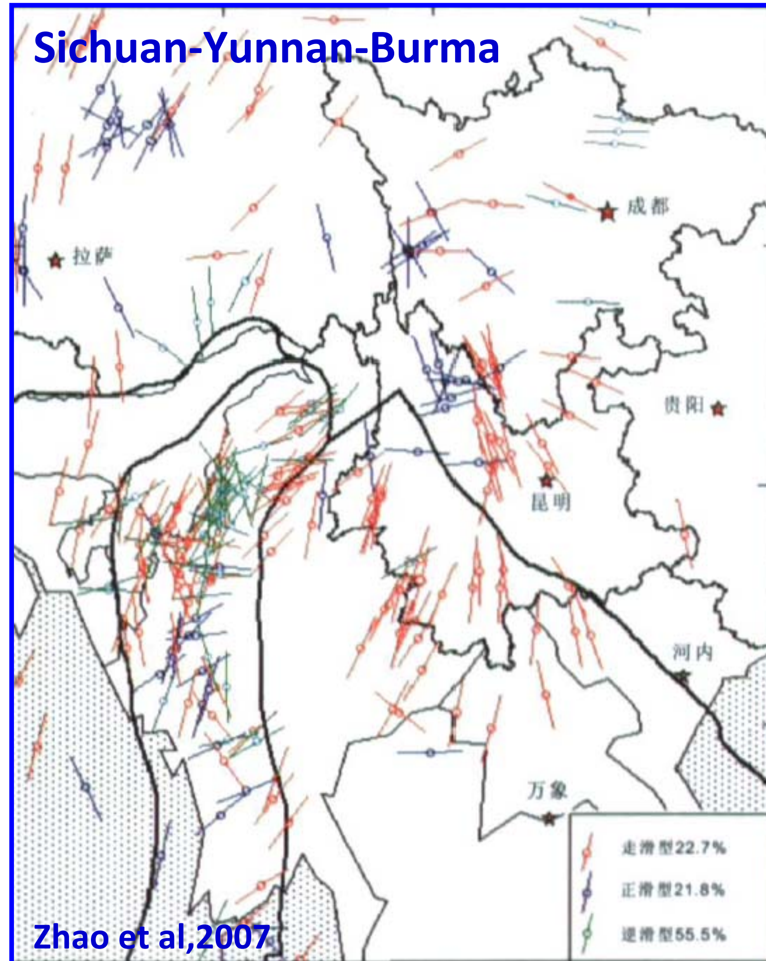
Considerable structural complexity

Stress Variations and Production Potential



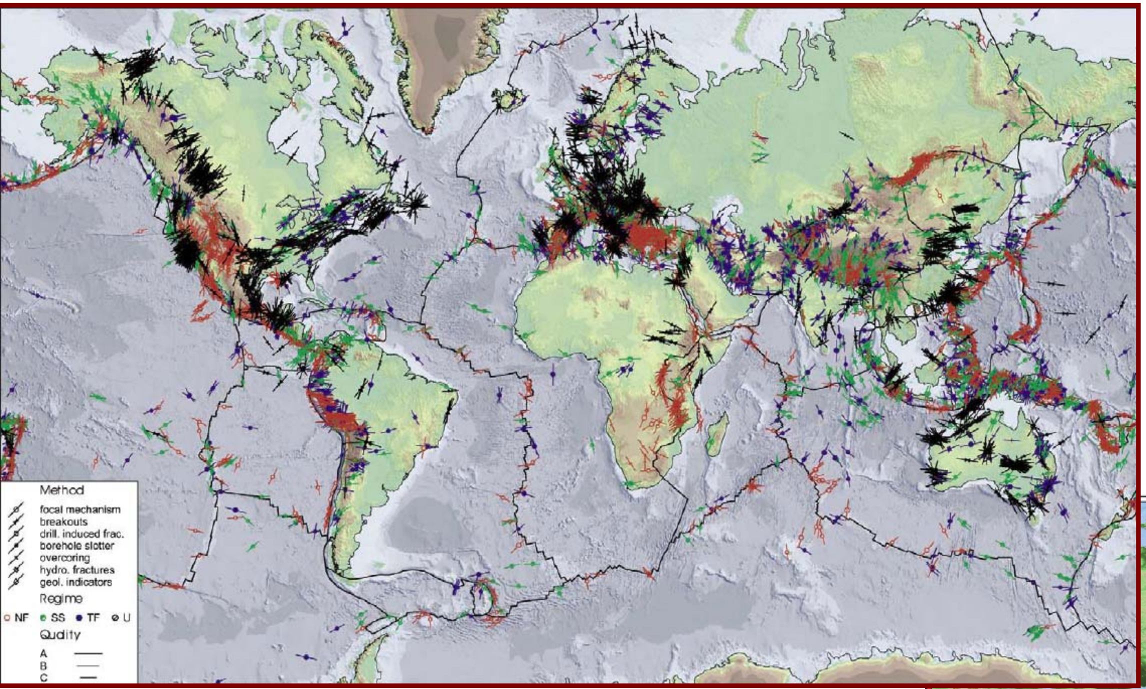
Zhang,2008

Polarization of fast shear-wave



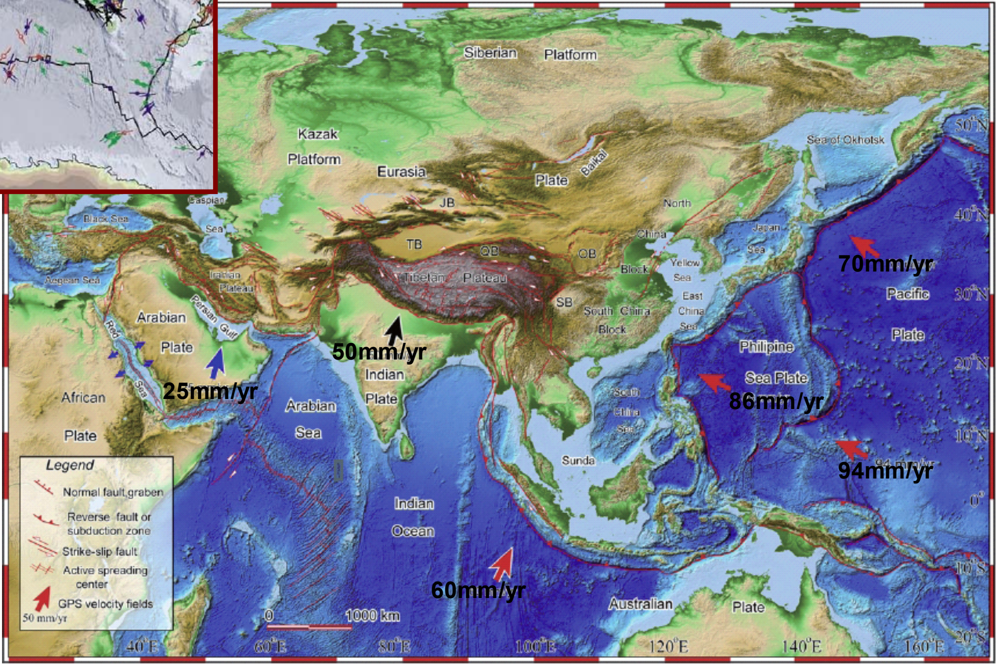
Focal mechanisms: strike slip faulting
Principal compressive stress: NNE

Study Implications and Ongoing Work



One of the trigger mechanism for overpressure release and/or sustainable capability through tectonic history?

Tingay, Müller and Reinecker,et al,2005



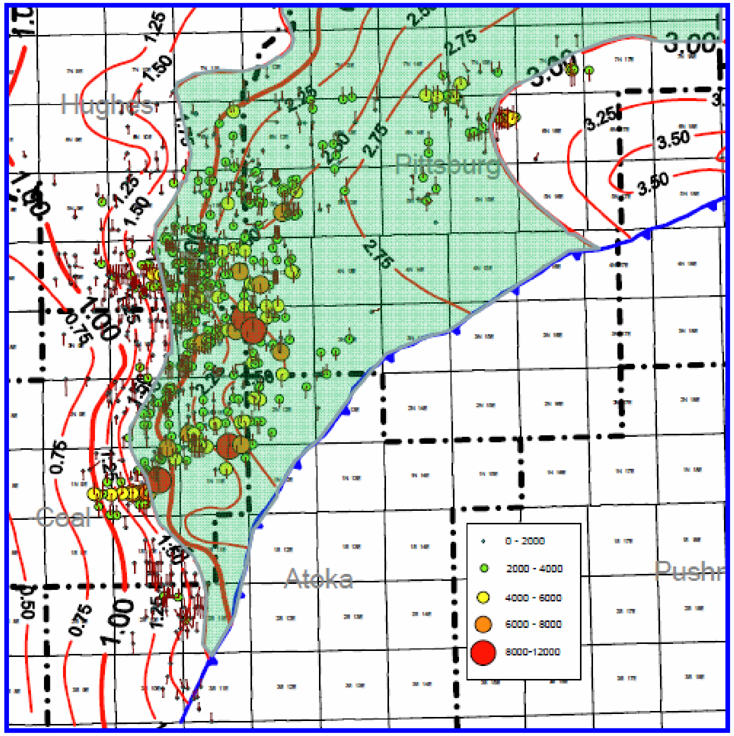
Tapponnier, 2001;
Taylor and Yin, 2009;et al

Screening Criteria and Sweet Spot

Woodford New %Ro Target with Well EUR:
Empirical Wisdom 1.75%<Ro<3.0%

PARAMETER	TARGET RANGE	Western Arkoma WOODFORD	Fort Worth CANEY/ BARNETT	Eastern Arkoma CANEY/ FAYETTEVILLE
Total Organic Carbon	2 – 10%	3 – 10%	3 – 8%	3 – 8%
Thermal Maturity Vitrinite % Ro	1.1 – 3.0%	1.1 – 3.0%	1.2 – 2.0%	1.2 – 4.0%
Mineralogy/ Silica Content	30 – 80%	60 – 80%	40 – 60%	40 – 60%
Gas Filled Porosity	2 – 8%	3 – 6.5%	3 – 5.5%	3 – 5.5%
Depth (meters)	NA	1,800 – 3,150m	1,800 – 2355m	390 – 1980m
Thickness (meters)	NA	30.5 – 67m	78 – 150m	15 – 100m

Craig, 2011



Gilman and Robinson,2011

Presenter's notes: To define sweet spots or favorable geological environments in the Sichuan Basin by a single value of screening parameters is not fully effective. The effects of regional tectonics might be another important consideration for the specific shale reservoir.

Summary and Discussion

1. Unconventional gas resources is not an issue for high and over-thermal maturity marine shale in Southern Sichuan Basin.

2. Process-based analysis for multivariate is one of better ways to improve understanding specific shale reservoirs and production potential.

3. Considerable structural complexity might be not always negative. Not every shale reservoir is the same.

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