Upper Ordovician-Lower Silurian Gas Reservoirs in southern Sichuan Basin, China*

Xinjing Li¹, Caineng Zou², Zhongjian Qiu³, Jianzhong Li², Gengsheng Chen⁴, Dazhong Dong², Liansheng Wang⁴, Shiqian Wang⁴, Zonggang Lü⁴, Shejiao Wang², and Keming Cheng²

Search and Discovery Article #10341 (2011)
Posted July 31, 2011

*Adapted from oral presentation at AAPG Annual Convention and Exhibition, Houston, Texas, USA, April 10-13, 2011

1Research Institute of Petrochina Exploration and Development, Beijing, China (xinjingli@petrochina.com.cn)
2Research Institute of Petrochina Exploration and Development, Beijing, China
3China National Petroleum Corporation, Beijing, China
4Petrochina Southwest Oil and Gas Field Company, Sichuan, China

Abstract

Extensive later Ordovician and initial early Silurian black marine shales are important Paleozoic source rocks deposited in a partly restricted environment related to a worldwide transgression in Southern Sichuan Basin, Upper Yangzi platform, China. Lowermost Longmaxi Formation is organic-rich black graptolitic shale with subordinate limestone and siltstones overlain by grey greenish shale and siltstone. Hirnantian Stage Kuanyinqiao Member between Longmaxi and Wufeng Formation preserves Hirnantia-Dalmanitina fauna in the marlstone and calcareous mudstone. Lower Silurian in Southwestern and Middle-Lower Silurian in Southeastern Sichuan Basin only remain for the erosion due to Caledonian movement.

The average total organic content of the target interval for shale gas is about 3 wt. % that is the consequence of hydrocarbon generation and expulsion during higher maturation (Ro 2.3-3.4%). Fieldworks in the Southern Sichuan provided some preliminary insight into the good potential for shale gas of lowermost Silurian ‘hot’ graptolitic shale. Widespread gas shows presented in Silurian Formation in drilled wells. In some cases, the elevated gamma-ray and resistivity values suggest the presence of the “hot” shale. The first shale gas exploration well further proves good gas content in the cored interval with a typical response on wireline logs. In addition, one of significant characteristics of Longmaxi target interval is that a great deal of micropores and nanopores are well developed in organic matter at higher maturity that the remaining hydrocarbon potential is almost zero, though its petrology, bioclasts layers, primary pore spaces, and types are unique compared with those of Barnett Shale in core area, Eagle Ford Shale in outcrop and etc.. Moreover, Silurian “hot” shale and later Ordovician Wufeng Formation are enveloped by lower tight Baota Limestone, primary frac barriers. The grey greenish organically lean shale may be a weak upper barrier.
Upper Ordovician-Lower Silurian shale analysis of logs, Pyrolysis, thin-sections, CL, QEMSCAN, XRD, and XFD indicate that the vertical lithological variations and fabric anisotropy are notable, not only the clay (mainly illite), carbonate, quartz, and pyrite content, but the primary origin and geological evolution. Integrated data sets can be used to characterize several lithofaces units rather than a whole homogeneous unit as the porosity, permeability, and geomechanical properties of “hot” shales can be related to the lithologies. We conclude that there is a strong potential of shale gas in southern Sichuan Basin, despite it poses different challenges for the development of higher and over maturity black shale.

**Selected References**


Upper Ordovician-Lower Silurian Shale Gas Reservoirs in Southern Sichuan Basin, China

Xinjing Li¹, Caineng Zou¹, Zhongjian Qiu², Jianzhong Li¹, Gengsheng Chen³, Dazhong Dong¹, Lansheng Wang ³, Shiqian Wang³, Zonggang Lü³, Shejiao Wang¹, Keming Cheng¹

¹ Research Institute of Petrochina Exploration and Development, Beijing, China
² China National Petroleum Corporation, Beijing, China
³ Petrochina Southwest Oil and Gas Field Company, Sichuan, China

April 10-13, 2011 – Houston
Outline

- Geologic overview
- Minerals and lithology
- Pores spaces and types
- Summary and discussion
Late Ordovician Tectonic Units and Sedimentary Facies in Southern China

(Su et al., 2008)
Stratigraphy and Paleozoic “Hot Shales” of Sichuan Basin

(Zou et al., 2010)
Isopach Map of Upper Ordovician-Lower Silurian Source Rocks

(Basin Boundary)

Thickness (m)

Sichuan Basin

(After Liang et al., 2008 and 2009)
Target Prospect for Longmaxi Shale ($S_1l$)

(after Southwest/Petrochina, 2010)
Mineral Composition and Heterogeneity

Triangular diagram of mineral composition

(Li, 2010)  (Halliburton, 2007)
Mineral Composition for Different Shales

(Schlumberger, 2009; Southwest/Petrochina, 2010; Zou et al., 2010)
Hot Shales with Rich Bioclasts Layers

Bioclast layers alternating with clay- and organic matter rich layers

Barnett: TOC=2.06%
Quartz=51% ± Clay=37% ±
Carbonate=12% ±

Barnett: TOC=1.33%
Quartz=25.7%; Clay=24.7%
Carbonate=40%

Eagle Ford: TOC=5.26%
Quartz=17.3%; Clay=13.3%
Carbonate=64.9%

Weiyuan county - O₃w
Changning county - O₃g
Qilin county – S₁l
QEMSCAN false colour image showing the lamination of very fine carbonate and quartz grains
QEMSCAN Longmaxi Shale
Pores and Textural Occurrence

Left: Organics (black) and Pores (red)
Right: Ductile minerals (green) including clays, micas and organics
Brittle minerals (red) including all other inorganic minerals
Two Patterns of Organic Matter Disposition

Laminated and minute horizontal bands indicating the carbon-rich kerogen layers

Two Basic Patterns
- Chang7, Ordos Basin
- Longmaxi, Sichuan Basin

Middle Pattern
- Longmaxi, Sichuan Basin
- Eagle Ford, Outcrop
Pore Spaces and Types of Longmaxi Hot Shales

- Hot Shale
- Intergranular nano-scaled pores
- Micro-fractures in OM
- Second nano-scaled pores in OM
Pore Spaces and Types of Longmaxi Hot Shales

Calcite intraparticle dissolution pores

Intercrystalline pores in pyrite framboinds

Pores in OM

Plane porosity=24.7%
SEM image of Secondary Dissolution Pores for Eagle Ford Shale

Outcrop in south Texas (AAPG Hedberg conference, 2010)

- Intergranular pores
- Pores in OM
- Pores inside Foraminiferal crust

TOC = 0.25%
Conceptual Model for the Origin of Shale Pores

- Secondary micro-, nano-pores in OM
- Micro-, nano-scale interlayer pores in clay minerals
- Residual intergranular pores
- Secondary dissolution pores

(Javadpour et al., 2007)

(Li, 2010)

(Loucks et al., 2010)
Geological Evolution of Porosity

(Li, 2010)
Summary and Discussion

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

2. Shale reservoirs are heterogeneity and the laminations are of quite different textural features between detrital silt and matrix silica, calcareous fossil debris and authigenic calcite and dolomite, organic matter and inorganic minerals, ductility and brittleness.

3. Potential productive gas shale systems are mainly composed of different types of porous media.
Acknowledgements

Special thanks to Aukje Benedictus of FEI, Michael Dixon, Marvin Floyd and Christopher Laughrey of Weatherford Laboratories, for QEMSCAN sample preparation and in-depth analysis.

Many thanks also to Robert Reed of Bureau of Economic Geology, Jackson School of Geosciences, The University of Texas at Austin, for the guidance of making ion-milled samples, Chad Hartman of Weatherford Laboratories and Daniel Jarvie of Worldwide Geochemistry for offering valuable advice and kind communication.

Thanks to the supports of RIPED/Petrochina, Petrochina Southwest Oil and Gas Field Company and China Postdoctoral Science Foundation.
Thanks for Your Attention!