Late Jurassic-Early Cretaceous Rifting in the Tugrug and Taatsiin Tsagaan Nuur Basins, Gobi-Altai Region of SW Mongolia — Implications for Petroleum Exploration*

Kurt Constenius¹, James Coogan¹, Bolor Erdenebat¹, Justin Tully¹, Cari Johnson³, Stephan Graham², and Dickson Cunningham⁴

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1Petro Matad LLC, Ulaanbaatar, Mongolia (Kurt.Constenius@petromatad.com)
2School of Earth Sciences, Stanford University, Stanford, CA
3Department of Geology and Geophysics, University of Utah, Salt Lake City, UT
4Department of Geology, University of Leicester, Leicester, United Kingdom

Abstract

Exploration and drilling in eastern Mongolia’s Tamtsag basin and the Songlio and Hailar basins in adjoining parts of northeast China have established viable petroleum systems in Late Jurassic-Early Cretaceous age rift basins. The tectonic and burial history of these basins is complex in that they have sustained episodes of extension and subsequent contraction. The history of tectonism in the Tamtsag basin is relatively well understood based on an extensive industry database of seismic and borehole data. In contrast, prior to Petro Matad’s 2010-2011 exploration program of seismic, gravity and stratigraphic core drilling, no subsurface data existed in the Gobi-Altai region of southwestern Mongolia. These data combined with field investigations reveal that the Gobi-Altai region sustained considerable rift related extension and magmatism. The Tugurg and Taatsiin Tsagaan Nuur half grabens imaged on seismic reflection data contain up to four kilometers of folded and faulted basin fill. Thicknesses of basin fill were determined using depth conversion velocities derived from long offset refraction shooting and derived from PSDM based reflection tomography. The source-receiver offsets for the refraction spread ranged up to 16 kilometers and the velocity field for the first 1000-1500m of the subsurface was calculated using tomographic inversion processing of first arrivals. Accurate basin fill thickness estimates are critical because vitrinite reflectance and RockEval data from the core and exhumed parts of the Late Jurassic-Early Cretaceous rift basins indicate that the source rocks along basin flanks are thermally immature or just at the threshold of oil generation (Average Ro ~ 0.5-0.6). Field studies and core drilling document thick successions of lacustrine and peri-lacustrine strata. Petroleum system elements found in these sequences include: organic rich shales with TOC’s averaging 3-4 percent, with some as high as 6 percent, lacustrine and deltaic sandstone reservoir rocks, and stratigraphic and structural traps. Two discrete structural trap styles are imaged on the seismic reflection data: Late Jurassic-Early Cretaceous fault traps created by rift related normal faulting and Miocene-Recent transpressional folds formed during structural inversion of the half grabens.
Late Jurassic-Early Cretaceous Rifting in the Tugrug and Taatsiin Tsagaan Nuur Basins, Gobi-Altai Region of SW Mongolia

Kurt Constenius
James Coogan
Bolor Erdenebat
Justin Tully
Cari Johnson
Stephan Graham
Dickson Cunningham
Mongolia
Tugrug and Taatsiin Tsagaan Nuur Basins,
Located in Petroleum Blocks IV & V
Exploration Challenges

• Immense area (>60,000 km²) with no subsurface data and limited published literature.

• Questions: Do basins exist beneath the Valley of Lakes? Are there source and reservoir rocks? Thermal maturity of source rocks? Traps?

• Productive basins in Eastern Mongolia (Tamsag) and Northern China (Songliao & Hailar) are Jurassic-Cretaceous Rift Basins. Do these basins exist in the Gobi-Altai region?

• Assets - Mongolian Geologic Mapping 1:200,000 scale (ca. 1980's).
Exploration Challenges

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Profile Width ~ 29 km
Exploration Challenges

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Graham et al., 2001
Methodology

- 2010: Acquired and Licensed Bouguer gravity data (4 x 4 km regional grid). Reconnaissance 2D seismic data (350 km). Field studies conducted with academic collaboration (University of Texas, University of Leicester)
Methodology

- 2011: Drilled 1603m and 1440m continuous cores in Tugrug Basin and Biger basins, respectively. Acquired 1850 km 2D seismic mainly focused on Tugrug, Taatsiin and Biger basins and additional gravity data. Field and core studies conducted with Stanford University, University of Texas, University of Utah, and University of Arizona.
Field Geology

- Field investigations focused on search for potential source and reservoir rocks, establishing a complete stratigraphic framework, studying exhumed basins or parts of basins as exploration analogs. Eleven key field localities.
OSHIH HOLLOW EAST
Early Cretaceous Block V

**Thermal Maturity - Immature**
Vitrinite Reflectance - 0.58%
Range 0.51-0.65% (7 samples)
Palynology - 0.3-0.4%
Early Cretaceous
S_1/TOC, HI/T_{max} - Threshold Oil Window

**Source Rock Potential**
**Good to Excellent**

Total Organic Carbon (TOC)
Range 1.8-5.8% (18 samples)
Average 3.8%

Fischer Assay
Range 0.2-38.9 l/tonne
Average 12 l/tonne (13 samples)

Measured Thickness Oil Shale
179 m
Thermal Maturity
Immature

Vitrinite Reflectance 0.58%
Range 0.57-0.59%
(3 samples)

Palynology - 0.3-0.4%
Early Cretaceous
$S_1$/TOC, HI/$T_{max}$ - Immature
KHOID ULAAN BULAG - KUB
Early Cretaceous Shinhudag Fm Block IV

Total Organic Carbon (TOC) Range 1.7-27.2% (72 samples) Average 15.1%

Fischer Assay Range 5.2-244.3 l/tonne Average 111.2 l/tonne (70 samples)

Measured thickness Oil Shale 265 m

KHOID ULAAN BULAG - KUB
Early Cretaceous Shinhudag Fm Block IV

REMAINING HYDROCARBON POTENTIAL (S2, mg HC/g rock)

TOTAL ORGANIC CARBON (TOC, wt.%)
KHOID ULAAN BULAG
Early Cretaceous Shinhudag Fm Block IV

KUB-1 Corehole Key Summary

Total Organic Carbon (Orange Line):
*Mean TOC over 48 five-meter composite intervals representing 240m of core is greater than 5%, serving as a source rock interval with excellent hydrocarbon generating potential.

Fischer Assay (Blue Line):
*Mean oil yield over 48 five-meter composite intervals representing 240m of core is greater than 40 L/tonne, serving as an excellent, thick source rock interval.

Vitrinite Reflectance:
*Mean Ro value is 0.53%, thermally immature but close to the oil window (0.6%).

Ro = 0.51%
Ro = 0.54%
Ro = 0.54%
Ro = 0.52%
Ro = 0.54%
Reservoir sandstones identified in field - lacustrine and deltaic deposits. Detrital zircon study indicates provenance mainly from Permian-Triassic plutonic rocks (granite) favorable for good porosity and permeability. Cements?

**Undur Formation:**
Delta top-upper delta front facies. Cross and horizontally stratified SS

**Shinhudag Formation:**
Delta top-upper delta front facies. Amalgamated sheet SS w/ clay drapes.
TSAGAAN TSUVRAGA
Block IV - Sandstones

Tsagaan Tsuvarga Sandstone Porosity & Cementation

Note: Analysis performed by Dr. Brian Horton, University of Texas and provided in December 2011 Phase 2 Interim Report
BLOCK V – TUGRUG BASIN
SEISMIC GRID AND 5-4-1900 CORE

Nariin Gol

Dulaan Bogd

Ondai Sair

BLOCK V

5-4-1900 Core

Oshih Hollow East
5-4-1900 CORE
Block V – Rock Column & Basin Setting

SEISMIC LINE 10-5-4 PSDM

CORE 5-4-1900

North

South

DEPTH
Normalized probability density plot for all 5-4-1900 core samples (0-1000 Ma).

Sample 5-4-1900-136
Sample 5-4-1900-670.7
Sample 5-4-1900-1174.3
Sample 5-4-1900-1296.6

Data point error ellipses are 68.3% conf.

1174.3m
5-4-1900 CORE
Block V - Oil Stain & Fluid Inclusions

Oil Inclusions in thin section
392, 451, 495, 523, 663, 1075, 1225.5, 1225.9, 1245.4, & 1247m.

Oil Stained Sandstone
1225.5, 1225.9, 1245.4
INVERSION TOMOGRAPHY

Maximum source-receiver offset 16000 m
SEISMIC
PARAMETER REFINEMENT TO IMPROVE RESOLUTION & MAINTAIN LOW COST/KM

• The 2010 acquisition program designed as 350 km reconnaissance survey to maximize amount of coverage within vast Block IV-V region. **Bouguer gravity data were used to optimize placement of seismic lines.**

• Based on 2010 results and additional Bouguer gravity, a second much larger program (1850 km) of recon and basin evaluation seismic acquisition took place from June-October, 2011.

• Design criteria for the 2011 program focused on **improving resolution**, particularly at **shallow depths**. Simple changes yielded impressive improvements and maintained low cost structure.
These two lines meet end-to-end and show a direct comparison. Improvement in shallow imaging was obtained by decrease in source point interval and decrease in group interval. The 2010 line is explosive (6 kg @ 25m) versus the 2011 line which is vibroseis.
Seismic profiles are 4 km apart. Improvement in shallow imaging was obtained by decrease in source point interval (100m to 64m) and decrease in group interval (20m to 16m).

Number of recording channels was increased from 396 to 500 to maintain deep image quality. Balance costs - charge size and depths were reduced (6kg to 4kg of explosive, 25m to 20m hole depth.)
SEISMIC TUGRUG BASIN INTERPRETATION

TUGRUG BASIN - BASIN FILL THICKNESS MAP

0  10 km
Basin inversion structures are found along the south margin of the basin where regional crustal contraction has reactivated the master listric fault. The central and north parts of the basin largely preserve their original rift basin (half graben) structure.
Basin inversion structures are found along the east margin of the basin where regional crustal contraction has reactivated the master N-S oriented listric fault. The central and west parts of the basin largely preserve their original rift basin (half graben) structure.
Note surface expression of anticline in topography

Original Jurassic-Cretaceous rift basin structure

Neogene Contractional folds and faults

Dip line 11-5-4-1
Seismic profile 11-5-4-1 images anticlines formed in response to contraction of the basin. The fold contains an older synrift normal fault that could potentially partition or breach the trap.
Seismic profile 11-5-4-3 images anticlines formed by reverse motion on the rift basin normal fault and contraction of basin-fill (antithetic thrust faulting). Basement contraction has resulted in inversion of entire basin.
Seismic profile 11-5-4-3 images anticlines formed by reverse motion on the rift basin normal fault and contraction of basin-fill (antithetic thrust faulting). Basement contraction has resulted in inversion of entire basin.
Jurassic-Cretaceous rift basins exist in the Gobi-Altai region of southwest Mongolia!

Four major basins identified by geophysical surveys in the Valley of Lakes.

Oil has been generated in the Tugrug basin
- oil staining & oil inclusions in fractured quartz grains and cements identified in 5-4-1900 Core.
**BLOCKS IV V**  
**EXPLORATION FINDINGS & CONCLUSIONS**

- **Thick source rock assemblages** of lacustrine oil shale (10’s to 100’s meters thick; TOC ~3% average; 27% maximum) and evidence of good reservoir properties in deltaic sandstones.

- **Outcrops of source rocks thermally immature** but some at the threshold of generation. Modeling suggest oil generation at depths >1.5km in Tugrug basin.

- Potential oil containment in traps akin to eastern Mongolia - **footwall normal fault traps, unconformities, & anticlines.**
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