From the Gobi Desert to Genghis Khan: Exploring for Heavy Oil in Mongolia

Jürgen Kraus
Franconia Geoscience Ltd.
• Geography & History

• Oil & Gas in Mongolia

• The Big Picture: Geological Setting of Mongolia

• The East Gobi Basin

• The Nyalga Basin
Geography & History

Between Russia and China

Area: 1.6 MM km² (19th largest country)

Population: 3 MM 45% in Ulaanbaatar “The Red Hero”

Travel via Beijing

Area ruled by nomadic tribes

Mongol Empire established 1206: largest in the world history (33 MM km²)

https://en.wikipedia.org/wiki/Mongolia
Isolated until 1990s
Under Soviet control in 1924
Collapse of Soviet Union in 1989...
Multi-party system and market economy since 1990
New constitution in 1992
Genghis Khan “Universal Leader” (1162 – 1227)
Chinggis Khan Чингис хаан

John Wayne (1907 – 1979)

Upper Onon river, near Genghis Khan’s birthplace!

Ascending the throne in 1206
The benefit of stirrups: shooting backwards.

Death of G. Khan (27th Aug. 1227)

Military divided into groups of 10.

Tuul River, near Ulaanbaatar: 40 m tall.

Burial place unknown.

Kherulen River in Nyalga PSC block.
From Genghis Khan to Kublai Khan: The Mongol Empire 1206 – 1294 (33 MM km²: largest empire ever) Divided into 4 empires in 1294

https://en.wikipedia.org/wiki/File:Mongol_Empire_map.gif
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• First geological study in 1892
• Zuunbayan oil field found by Soviets in 1940s (E. Gobi basin): 4 MM tons of crude oil produced
• First PSC in 1993 (SOCO)
• First SOCO production from Block XIX in 1998...no refinery in Mongolia
• Since 1998 10.6 MMBL produced...10 MMBL exported to China
• Mongolia 2010: 272 MM tons of “proved” reserves [Blocks XIX and ‘97]
Petroleum Authority of Mongolia established in 1990 as state-owned petroleum agency


PSC holders: Mongolian, Chinese, and other foreign companies in approx. equal parts

Total Mongolian production in 2011: >260 MMBL

Other: Mongolia hosts 10% of the world’s coal reserves
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Fig. 1. Major oil and gas basins of eastern Mongolia and China.

Kraus and Lau (2011)
Three structural panels:
- Pre-Permian: independent *intraoceanic* developments
- Post-Permian broadly shared tectono-stratigraphic, petroleum-related, *intracontinental* developments

**CMBR: China-Mongolia Border Region**

Mongolian island arc collage (MC) amalgamated by end of Permian!

N-China block (NCB) docked onto MC at 294 to 234 Ma

Terminal collision of MC/NCB with Siberian continent at MO suture Early-Middle Jurassic; northward subduction

Lithospheric extension by slab breakoff/rollback in the Late Jurassic: *intracontinental* rifting, development of lacustrine basins

Plate readjustment: Renewed compression K2 – Tertiary
Formations of interest: Uppermost Jurassic (fluvial) through Cretaceous (lacustrine)

<table>
<thead>
<tr>
<th>Megasequence 5</th>
<th>Late Cretaceous – Tertiary</th>
<th>Transpression; inversion; fluv. sedimentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Megasequence 4</td>
<td>Mid Jurassic – Cretaceous</td>
<td>Transtension; rifting; volcanism; tectonic subsidence; lacustrine sedimentation</td>
</tr>
<tr>
<td>Megasequence 3</td>
<td>Triassic – Early Jurassic</td>
<td>Pre-rift: limited deposition; erosion</td>
</tr>
<tr>
<td>Megasequence 2</td>
<td>Devonian – Permian</td>
<td>Amalgamation of island arcs</td>
</tr>
<tr>
<td>Megasequence 1</td>
<td>Precambrian – Silurian</td>
<td>Oceanic: amalgamation of Caledon. fold belt</td>
</tr>
</tbody>
</table>

**Table 2:** CMBR megasequences. After Traynor and Sladen (1995) and Graham et al. (2001).
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Assumed analog of Nyalga basin:
- similar Post-Permian structural and sedimentary development
- similar petroleum system(s)
- better exposed
- better explored
- producing
Production in middle corridor: Hailar Tamsag and East Gobi!

Graham et al. (2001)
Complex tectonic history of transtension and transpression, mostly with a sinistral strike-slip component

The East Gobi basin consists of several large subbasins formed during Jurassic – Cretaceous rifting. Surface and subsurface mapping in the East Gobi basin suggests that the region has been subjected to at least five tectonic episodes:

Webb et al. (1999)
Evolution of Zuunbayan sub-basin

1. Rift initiation: Late Jurassic
2. Early rifting: J3-K1
3. Peak rifting: mid to late K1
3. Inversion: early K2

Fig. 12. Schematic evolution of Zuunbayan subbasin during Jurassic–Cretaceous time.

Johnson (2004)

Stratigraphy, East Gobi Basin

Seals are lacustrine shales of the Zuunbayan, and Sainshand formations

The reservoir consists of fluvial and alluvial sands in the Tsagaan Tsav and Zuunbayan formations

Source rock is the Bituminous member of the Zuunbayan Fm.
450 km drive from UB to Northern Gobi desert (Sainshand): 8h

No four-lane highway in Mongolia (2010)
Choir: end of paved road
Sainshand (K2 type location)
Northern Gobi Desert
Franconia Breakfast Video 1 Min. Video
Zuunbayan oil field (1953-1969; resumed in 2007)
4th member J3-K1 Tsagaantsav fm.: primary reservoir
Looking East!

K2 seal

K1 reservoir + source + seal

J3-K1 reservoir

Early syn-rift!
J3-K1 Tsagaantsav fm. on graben shoulder: primary reservoir
Looking west!

J3-K1 reservoir
K1 reservoir + source + seal

K2 seal
Zuunbayan Anticline
J3-K1 Tsagaantsav fm. coarse-grained sandstones (primary reservoir): 13-18% porosity (producing), 2 - 474 mD permeability (CNPC, 1995)
Fine upward from alluvial fan to braided stream to probable floodplain and lacustrine facies [record subsidence]
K1dz1 Zuunbayan fm. white paper shales (K1dz1 secondary reservoir?)
Bituminous K1dz1 Lower Zuunbayan fm (reservoir, source, seal)
“A possible secondary reservoir exists in channel sands of the K1 Zuunbayan Formation. Calculated porosities range from 5 to 18% and permeabilities from 0.25 to 16 md.” (Prost, 2004)
The most likely source rocks are Hauterivian to Albian lacustrine shales in the bituminous member of the K1 Zuunbayan Formation. The Zuunbayan Formation should be mature over large parts of the Unegt and Zuunbayan subbasins and has probably generated oil and some gas. (Prost, 2004)
K1dz2 Upper Zuunbayan fm. conglomerate with interbedded sandstone (reservoir)

Estheria middendorfii (phyllopod)

Post rift!

Lucoptera middendorfii
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Nyalga basin in northern corridor!

Graham et al. (2001)
Nyalga Basin – SRTM (Shuttle Radar Topographic Mission)

http://www2.jpl.nasa.gov/srtm/
Nyalga Block XVI

- Area 16,839 km²
- Subbasins up to 7000 m deep
- Proven source (K1dz1: ≤ 13% TOC and > 12 m thick)
- Potential reservoir: J3-K1, K1dz1, K1dz2
- Potential traps in syn-rift clastics sourced and sealed by lacustrine shales
- Soviet oil exploration since the 1950s
- >40 wells drilled: 700-1800 m deep
- 20 wells with hydrocarbon shows in K1dz1
- No commercial production
- No reliable well data preserved!
- BP studied basin in 1990
- Regional geophysical work conducted 1986-1991
- 2008 seismic survey: 458 km
- 2010 seismic survey: 466 km
- Gravity and Magnetic study in 2010
Nyalga, Kherulen sub-basin
2010 Seismic Survey: 466 km
8 transtensional/transpressional sub-basins
2 main orientations

Genghis Khan burial site?

Nyalga Geometry
2 main orientations: conjugate shears

same bottom fill:
simultaneous basin
initiation

50 km
### Nyalga basin: all type locations in East Gobi basin

<table>
<thead>
<tr>
<th>Age</th>
<th>Formation</th>
<th>Facies</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tertiary</td>
<td></td>
<td>Fluvial sandstones, conglomerates, minor mudstones</td>
<td>&lt;100 m</td>
</tr>
<tr>
<td>K2</td>
<td>Sainshand</td>
<td>inversion-related high-energy braidplain and fan sandstones and conglomerates; unconformity 2 at base</td>
<td>&gt;80 m</td>
</tr>
<tr>
<td>K1dz2</td>
<td>Up. Zuunbayan</td>
<td>coal swamps; fluvial migrational channel sandstones, pebble conglomerates, and allochthonous coals, with thin mudstones and reddened overbank sand bodies due to inversion; erosive lower contact</td>
<td>&gt;625 m</td>
</tr>
<tr>
<td>K1dz1</td>
<td>Low. Zuunbayan</td>
<td>syn-rift lacustrine, anoxic, saline shales &amp; mudstones, interbedded with sandstones</td>
<td>&gt;570 m</td>
</tr>
<tr>
<td>J3-K1</td>
<td>Tsagaantsav</td>
<td>continental &amp; lacustrine mudstones, limestones, siltstones, sandstones, conglomerates. With &gt;630 m of early syn-rift basalts and andesites and associated tuffs at the base.</td>
<td>&gt;&gt;630 m</td>
</tr>
<tr>
<td>J3</td>
<td>Sharilyn</td>
<td>lacustrine carbonates with minor intraformational fluvial and volcanioclastic rocks; unconformity 1 at base</td>
<td>&gt;500 m</td>
</tr>
<tr>
<td>Mid Triass. – J3</td>
<td></td>
<td>Continental red-beds: conglomerates, sandstones, minor mudstones, and basalts</td>
<td>&lt;1700 m</td>
</tr>
</tbody>
</table>

Compiled from BP (1991)

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### East Gobi basin

<table>
<thead>
<tr>
<th>Proton (2004)</th>
</tr>
</thead>
<tbody>
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<td>Nyalga Stratigraphy</td>
</tr>
</tbody>
</table>

#### Nyalga basin:
- **Reservoir**
- **Source**
- **Seal**

#### East Gobi basin:
- **Upper**
  - Undifferentiated
  - Nemegt
  - Baruunboyot
  - Bayanshiree
- **Lower**
  - Sainshand or Baruunboyot
  - Seal
- **Source**
  - Tsagaan Tsav
- **Reservoir Seal**
  - Shariyn
  - Khamar Khoovor
  - Tavan Tolgoi

#### Nyalga basin:
- **No regional Seal**
- **Reservoir, Seal**
- **K2**
- **K1dz2**
- **K1dz1**
- **J3-K1**
- **K1**
- **J3-K1**
What are we eating?

Kushuur!
Kherulen sub-basin
2010 seismic grid
& field work area

can seam in K1dz2

northern basin shoulder: refolded anticline indicates sinistral shear

J3-K1 [potential reservoir] exposed on shoulders
Standing on horst of Pz sediments in central Kherulen sub-basin: view northwest towards graben shoulder

Basin shoulder: J3-K1 early rift volcanics (no sandstones as in East Gobi basin)
Same horst of Pz sediments in Kherulen sub-basin, looking SE
No porosity!
J3-K1 Tsagaantsav fm. base of continental syn-rift section:
early syn-rift andesite tuff breccia on northern Kherulen sub-basin shoulder as part of a bimodal alkaline volcanic suite (basalt, andesite, rhyolite) extruded on the basin floor.
Lateral extent is unconstrained.
Poor reservoir (BP, 1991)
J3-K1 base of continental syn-rift section: >>630 m of andesitic rocks on basalt
Khumultei uplift (horst): J3-K1 volcanics
Khumultei Uplift (horst), Kherulen sub-basin: J3-K1 andesite tuff breccia

Extremely hard!

Early syn-rift!
J3-K1 limestone within andesites and tuffs at N-shoulder of Kherulen sub-basin:
Deposited on lacustrine footwall crests or hanging walls in low lacustrine environments
Tectonic subsidence or downstream?
Unlikely to be laterally extensive and very poor reservoir (BP, 1991)
Bayan Erkhet: 25 mmbbl bitumen in *K1dz1 Lower Zuunbayan fm.* (reservoir, source, seal): Lacustrine environment; peak rifting; deposition in half-grabens (“higher-order sub-basins”)

K1dz1: syn-rift paper shales, mudstones, interbedded with sandstones, lesser siltstones

Thickness: >570 m (4.5-7 km?)

Form deep pockets in half-grabens (risk: isolated source)

Lacustrine shales thicken into the basin (gravity lows)
25 mmbbl of bitumen in K1 sandstones [hc indicator!]
K1dz1/K1dz2 sandstones: best observed reservoir (BP + JK)

Bayan Erkhet:
10 m of coarse, bituminous (?fluvial) sandstones [reservoir!], pebbly sandstones and thin mudstones, at least 1 km laterally (reservoir facies?)
>2m of grey mudstones (source rock)
> 16 m Paper shales (best source rock potential: TOC ≤ 13%)
Coal Mine in K1dz2 Upper Zuunbayan fm. (reservoir, seal)
K1dz2 coal swamp environment: >625 m of allochthonous coals and fluvial channel sandstones over tens of kms (uniform basin fill)
Unconformity at base: sagging stage of basin?
Source rock potential (TOC ≤ 57%) but immature
K2 Sainshand fm.

>80 m of high-energy braid plain and fan deposits (rare silts and muds: not a regional seal);

Unconformity at base

Indicate renewed compressive tectonic activity and uplift and therefore postdate onset of basin inversion
Petroleum System

- **Reservoir:** J3-K1 sandstones? (primary in E. Gobi); K1dz1 and K1dz2 sandstones (secondary in E. Gobi)
- **Trap:** inverted half-grabens (8 types of structural and stratigraphic traps)
- **Seal:** K1 shales
- **Source:** K1 shales
- **Generation:** Upper Cretaceous
- **Key risks:** lack of syn-rift reservoir and source rock maturity; isolated source

East Gobi basin (Prost 2004)

Modeling by Prost (2004): early oil generation in the Zuunbayan and Tsagaan Els area during the Cretaceous (K1: 104–110 Ma).

K1dz2/K2 peak generation: 100 and 90 Ma (Unegt subbasin)
Summary of Nyalga basin evolution

1. Rift initiation: Late Jurassic (J3; dark green)
2. Early rifting: J3-K1 (red wedge)
3. Peak rifting: early K1 (grey)
4. End of rifting: late K1 (orange)
5. Inversion: early K2 (light green)
6. K2 subsidence
7. Tertiary inversion
Key Risk: Nyalga Reservoir Distribution

Stratigraphy in cross section based on >40 wells (no commercial production): Laterally coherent thick reservoir present?
J3-K1 sandstone sample? Primary reservoir from producing East Gobi basin present in Nyalga?
BP’s key risk: syn-rift reservoir and source maturity

BP’s projected field size: 12-62 MMBBL recoverable oil in anticlinal trap
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And they lived happily ever after.
The End

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