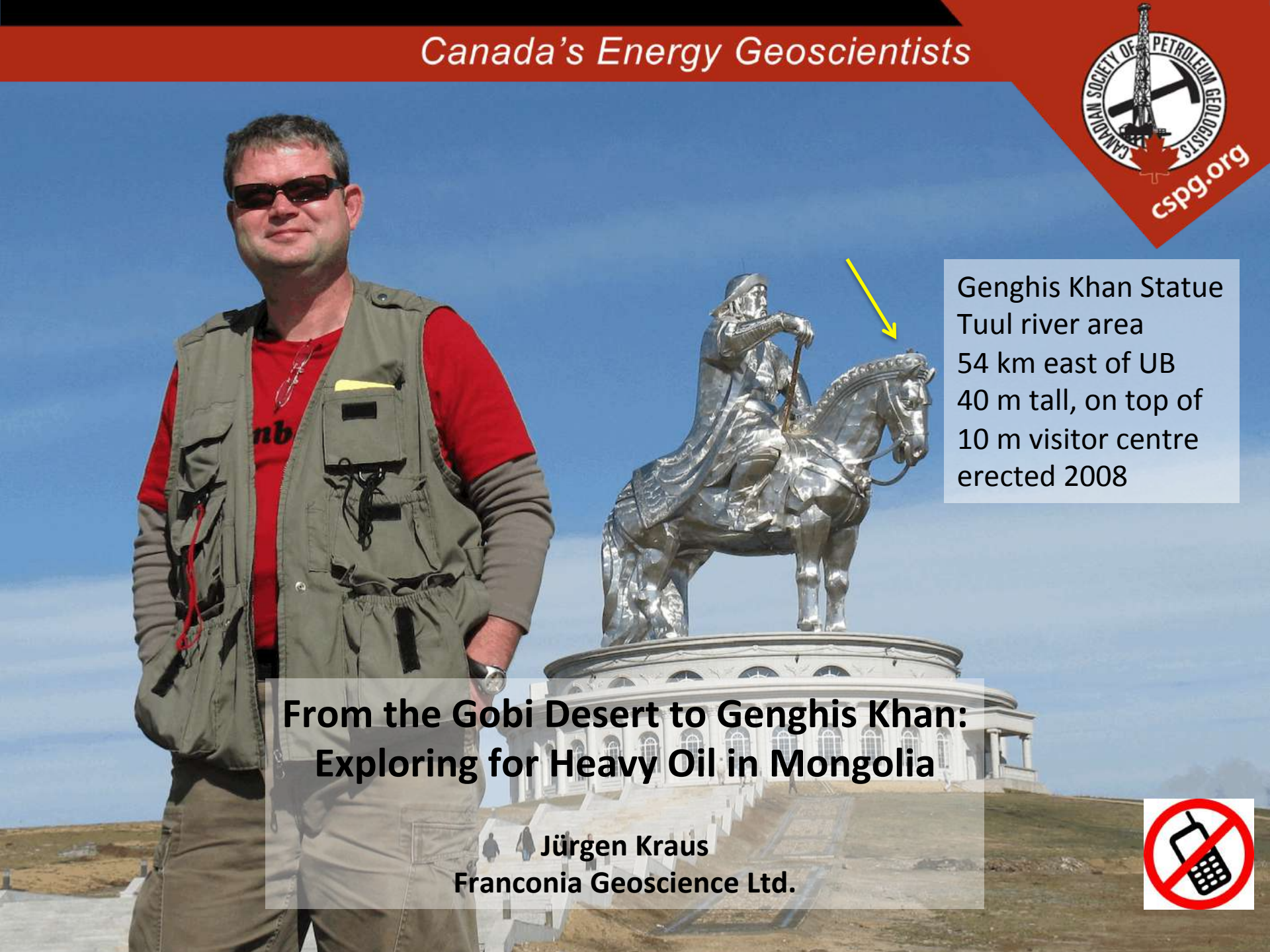
Canada's Energy Geoscientists



Genghis Khan Statue
Tuul river area
54 km east of UB
40 m tall, on top of
10 m visitor centre
erected 2008

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

Centre of the World

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

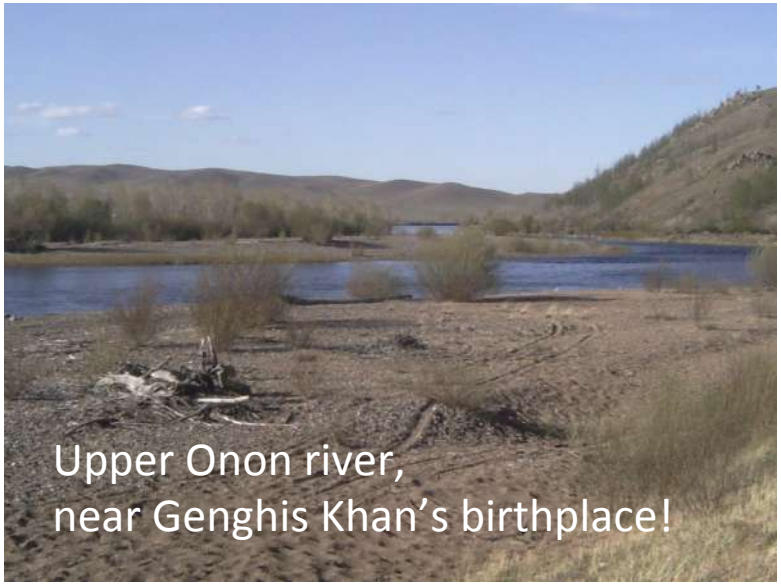
Mongol Empire established 1206: largest in the world history (33 MM km2)

https://en.wikipedia.org/wiki/Mongolia

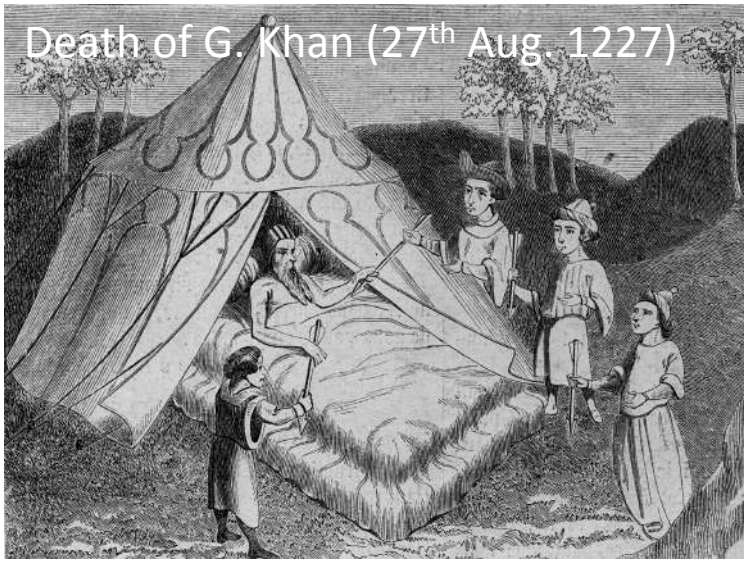

MONGOLIA
RUSSIAN FEDERATION
KAZAKHSTAN
CHINA
CHINA
Kyzyl
Irkutsk
Ulan Ude
Chita
Ulaangom
Tsagaannuur
Ölgiy
BAYAN-ÖLGIY
UVS
Dzel
Altay
Hödrögö
Hatgal
Bulgan
HÖVSGÖL
Mörön
Sühbaatar
Darhan
BULGAN
SELENGE
Erdenet
Dzöönharaa
Ereentsav
Bayan Uul
Eg
Bayan
Choybalsan
Dundbürd
Ulaanbaatar
(Ulan Bator)
EASTERN
Tamsagbulag
Ondörhaan
Dzuunmod
HENTIY
Bayasgalant
Dzüünbulag
Baruun Urt
SÜHBAATAR
Hongor
Dund-Us
Urgamal
DZAVHAN
Uliastay
Tögrög
NORTH HANGAY
Tsetserleg
HOVD
Altay
Dzag
Hujirt
Arvayheer
CENTRAL
Sangiyn Dalay
Mandalgovi
Taygan
Bayanhongor
Ulaan-Uul
GOVÏALTAY
SOUTH HANGAY
MIDDLE GOVÏ
Buyant-Uhaa
Talshand
Bulgan
Hovd
Öldzeyte Suma
Töhöm
Dzüünbayan
EAST GOVÏ
Erenhot
Baruunsuu
Agaruut
Saynshand
Tsoohor
Dalandzadgad
SOUTH GOVÏ
Hami
BAYANHONGOR
MOUNTAINS
GOBI DESERT
ALTAY
Transmongolian Railway
National capital
Provincial capital
Town, village
Major airport
International boundary
Provincial boundary
Main road
Railroad
0 100 200 300 400 km
0 100 200 mi
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)

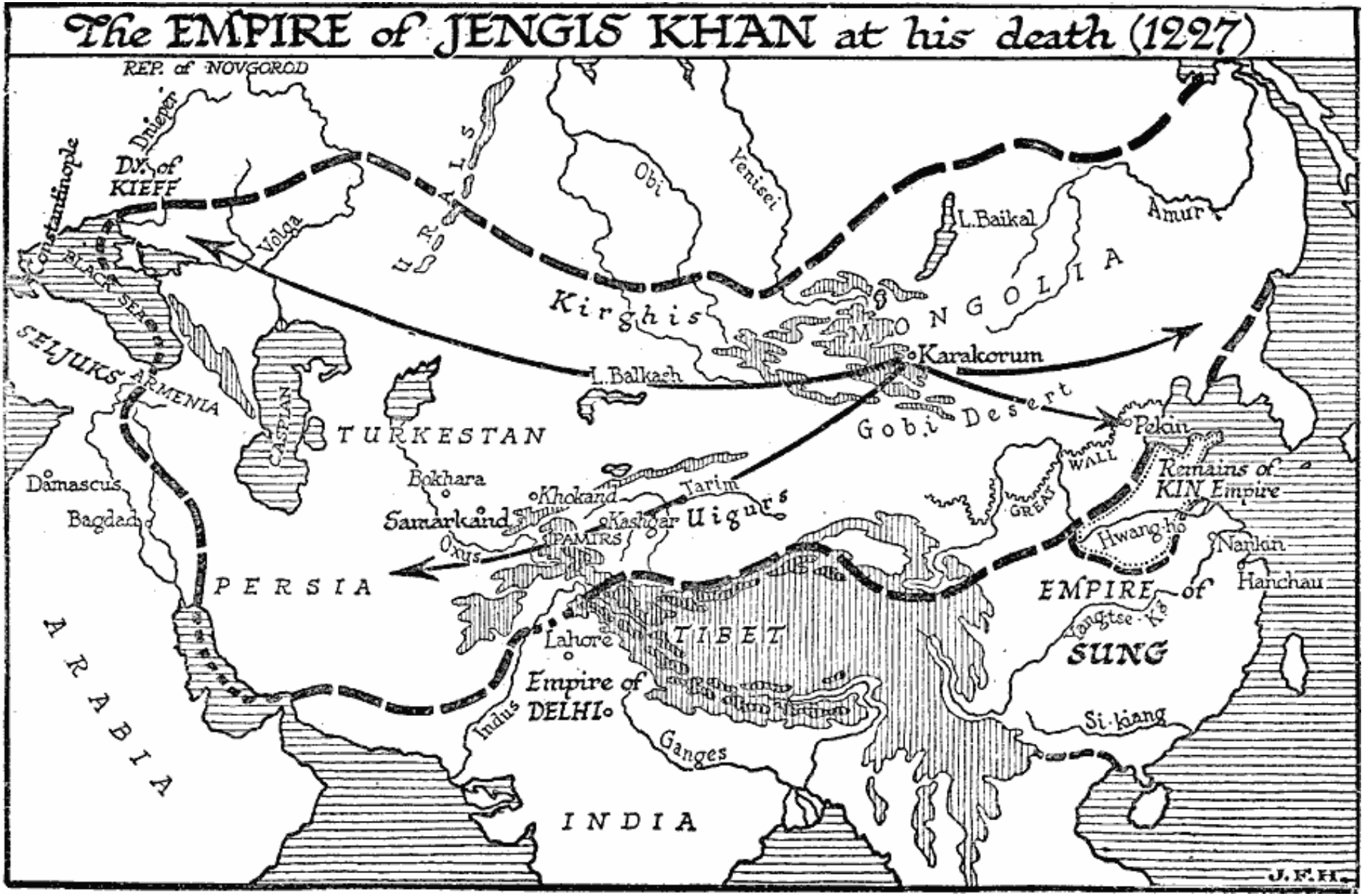



The benefit of stirrups: shooting backwards
Military divided into groups of 10

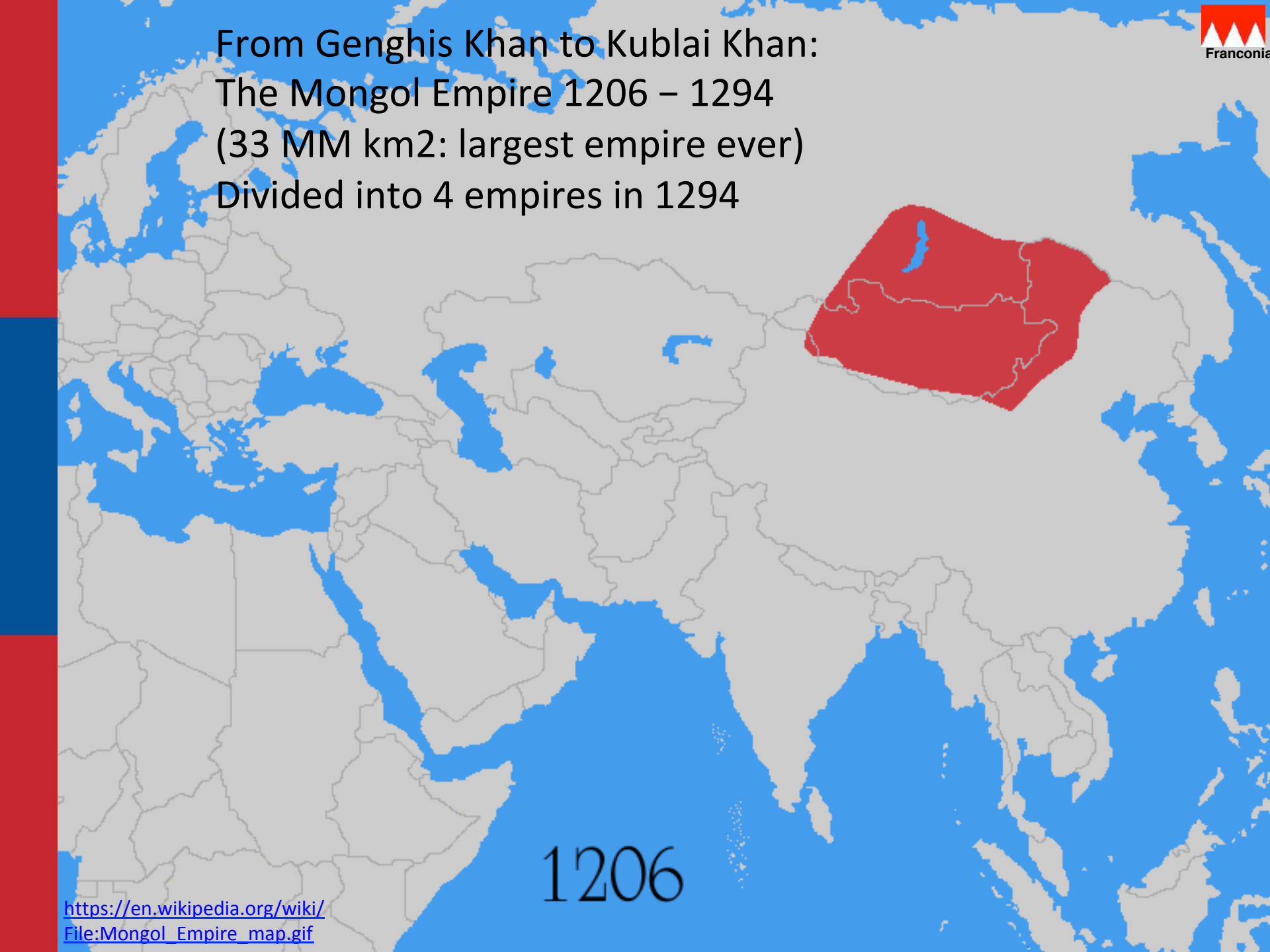

Death of G. Khan (27th Aug. 1227)


Tuul River, near Ulaanbaatar: 40 m tall


Burial place unknown!
Kherulen River in Nyalga PSC block


The EMPIRE of JENGIS KHAN at his death (1227)
REP. of NOVGOROD
Dnieper
Dy. of KIEFF
Constantinople
BLACK SEA
Volga
URALS
Obi
Yenisei
L. Baikal
Amur
MONGOLIA
Kirghis
L. Balkash
Karakorum
Gobi Desert
Pekin
SELJUKS
ARMENIA
CASPIAN
TURKESTAN
Bokhara
Khokand
Tarim
Samarkand
Kashgar
Uigurs
PAMIRS
Oxus
Damascus
Bagdad
PERSIA
ARABIA
GREAT WALL
Remains of KIN Empire
Hwang-ho
Nankin
Hanchau
EMPIRE of SUNG
Yangtse-Kiang
TIBET
Lahore
Empire of DELHI
Indus
Ganges
Si-kiang
INDIA
J. F. H.

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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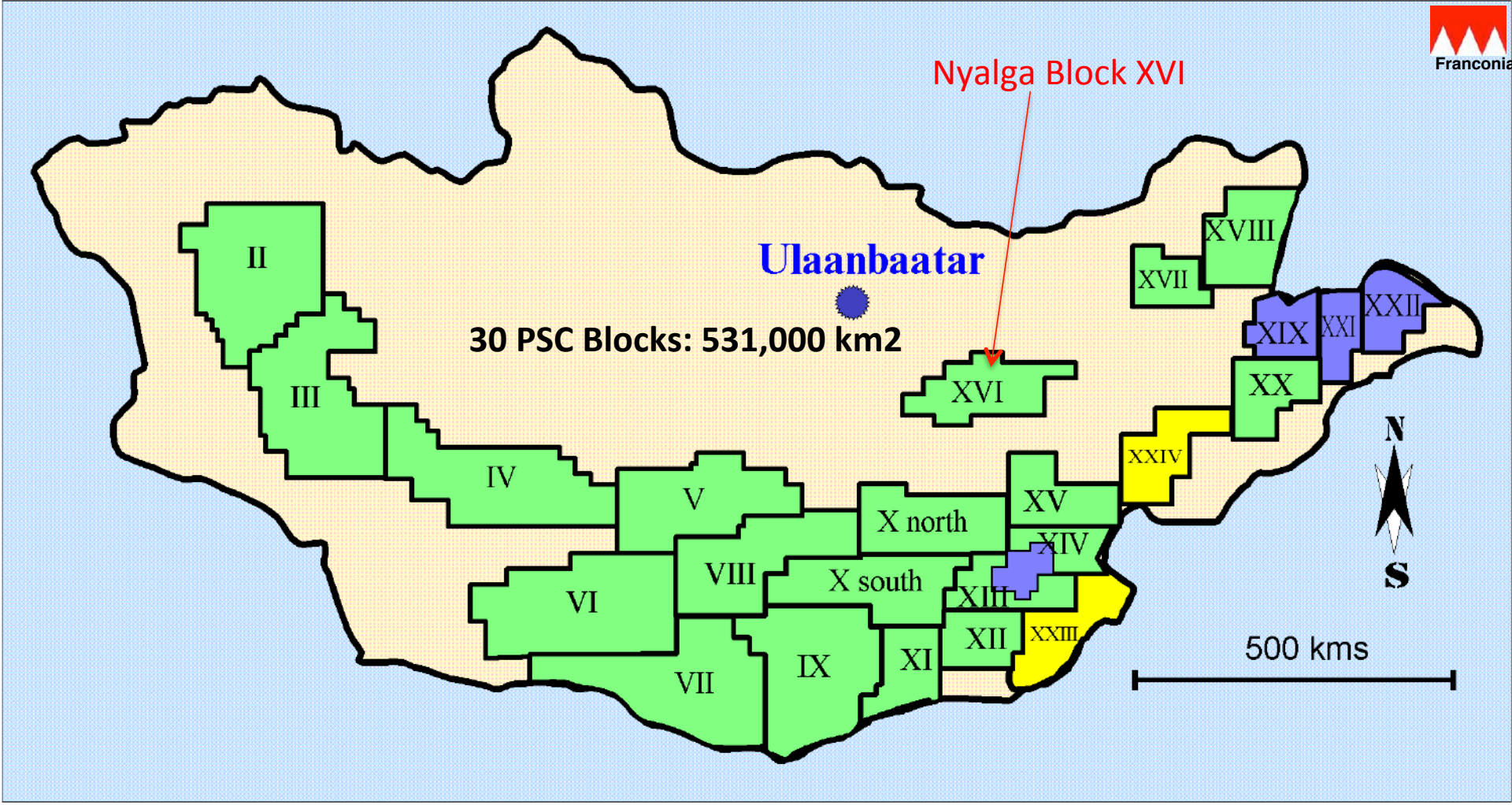
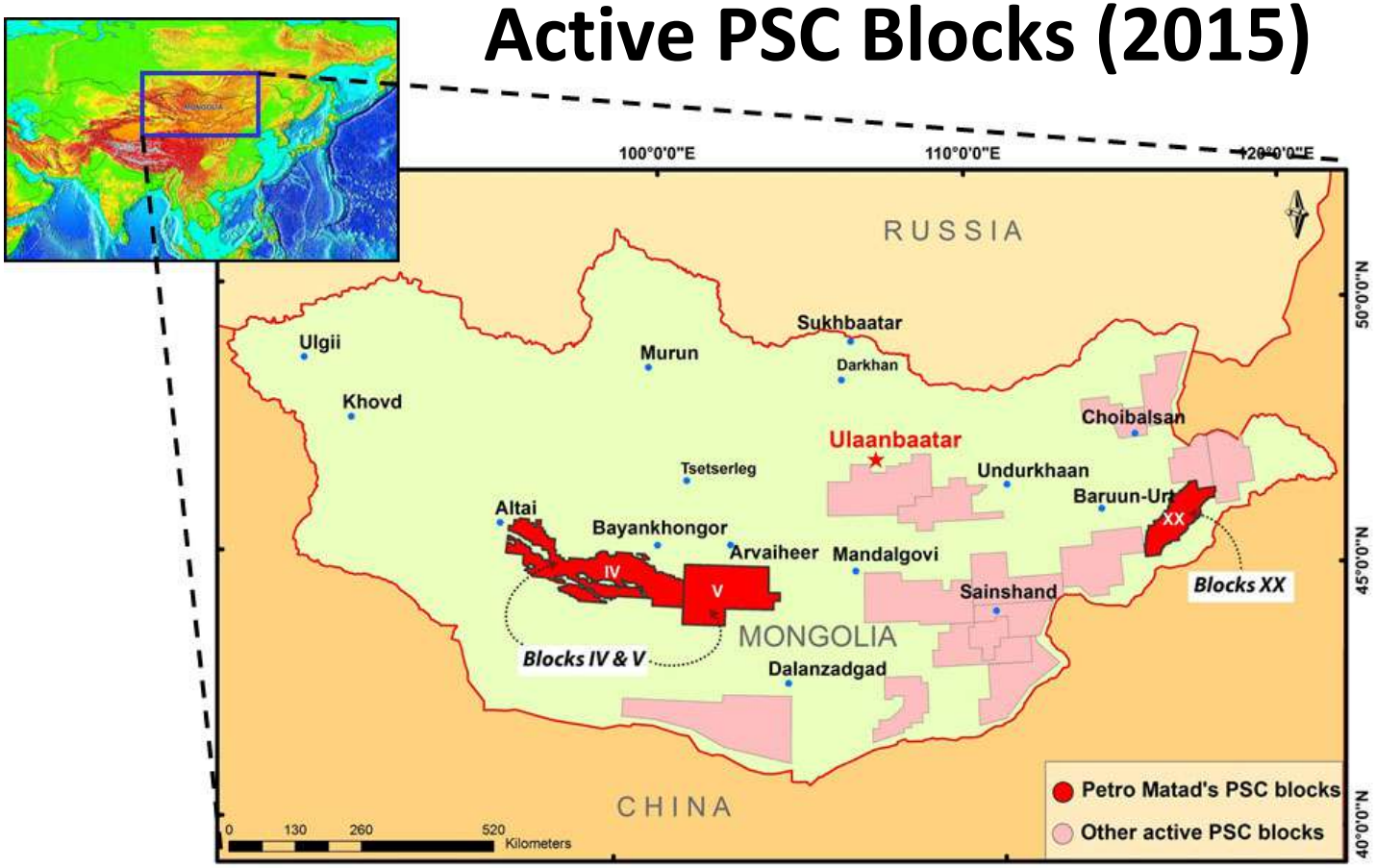


- First geological study in 1892
- Zuunbayan oil field found by Soviets in 1940s (E. Gobi basin): 4 MM tons of crude oil produced
- First PSC in 1993 (SOCO)
- First SOCO production from Block XIX in 1998…no refinery in Mongolia
- Since 1998 10.6 MMBL produced...10 MMBL exported to China
- Mongolia 2010: 272 MM tons of "*proved*" reserves [Blocks XIX and '97]

Active PSC Blocks (2015)



Source: PetroMatad

- Petroleum Authority of Mongolia established in 1990 as state-owned petroleum agency
- 2 producing basins: Tamsag (since 1998) & East Gobi (1953-1969; resumed in 2007)
- 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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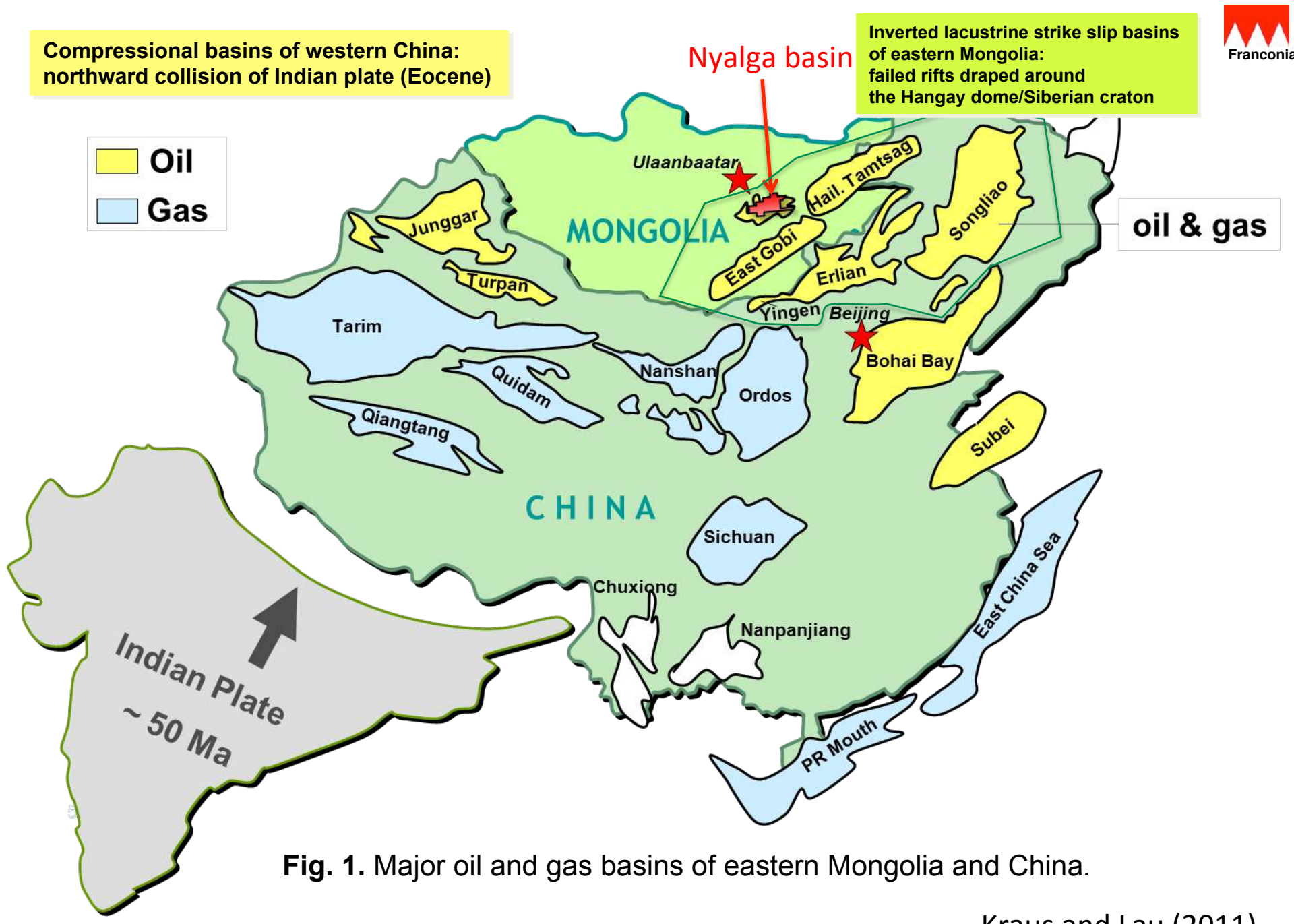
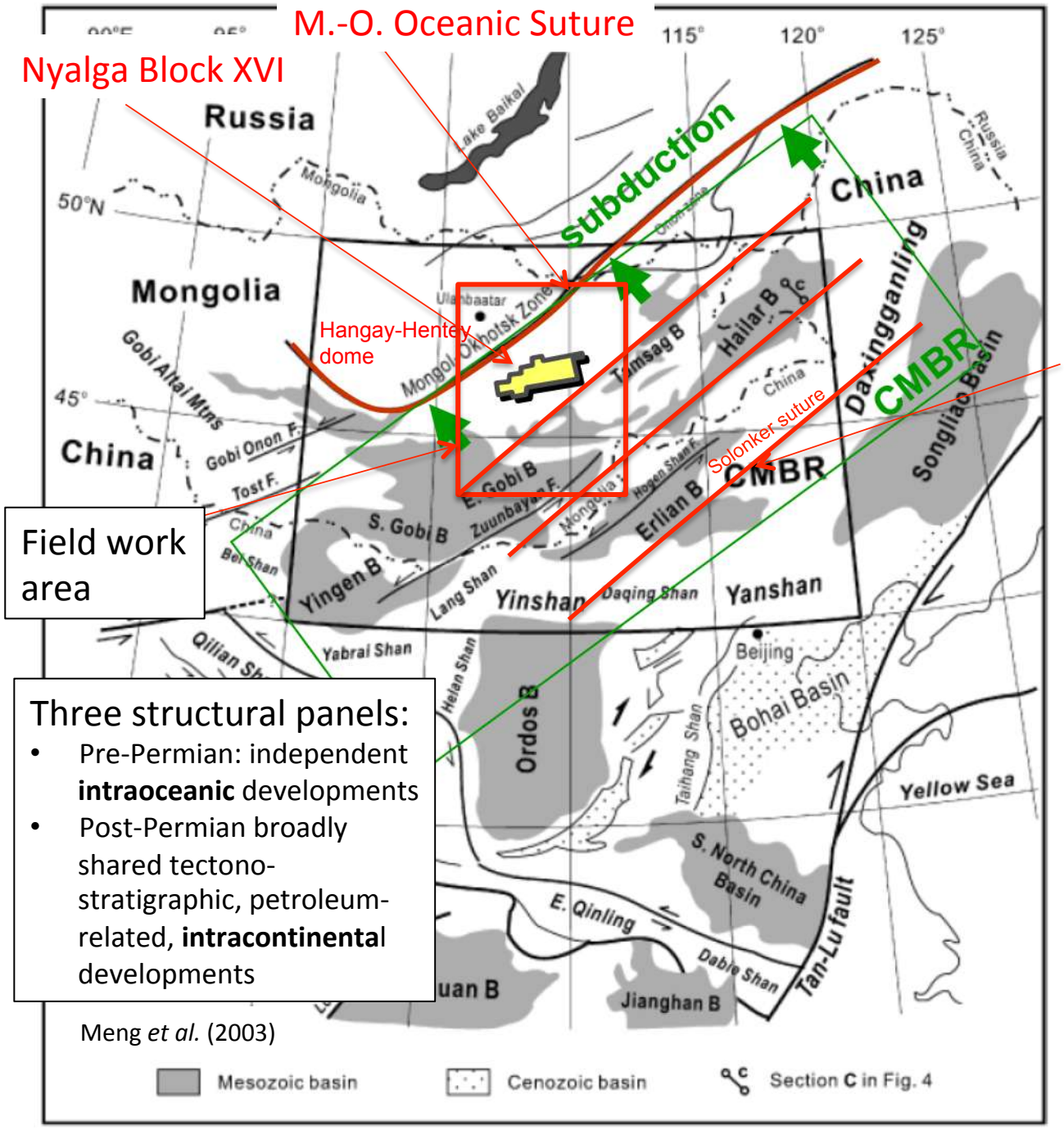


Fig. 1. Major oil and gas basins of eastern Mongolia and China.

Kraus and Lau (2011)



Field work area

Three structural panels:

- Pre-Permian: independent **intraoceanic** developments
- Post-Permian broadly shared tectono-stratigraphic, petroleum-related, **intracontinental** developments

Meng *et al.* (2003)

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: **intracon-tinental rifting**, develop-ment of lacustrine basins

Plate readjustment: Renewed compression K2 – Tertiary

Franconia

Formations of interest: Uppermost Jurassic (fluvial) through Cretaceous (lacustrine)

Onset of rifting: basins floored by alkaline volcanics

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

Table 2: CMBR megasequences. After Traynor and Sladen (1995) and Graham *et al.* (2001).

- Geography & History
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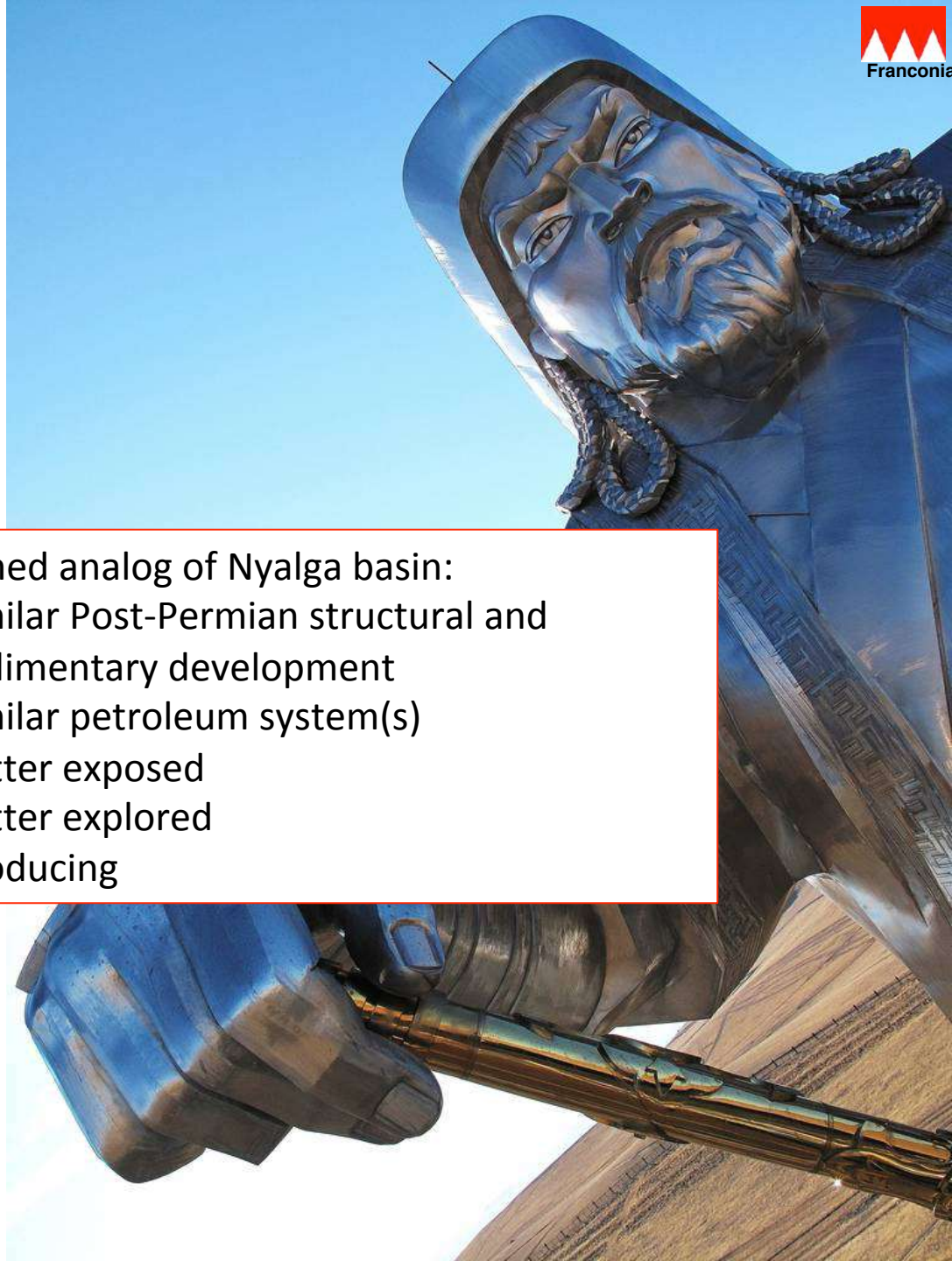
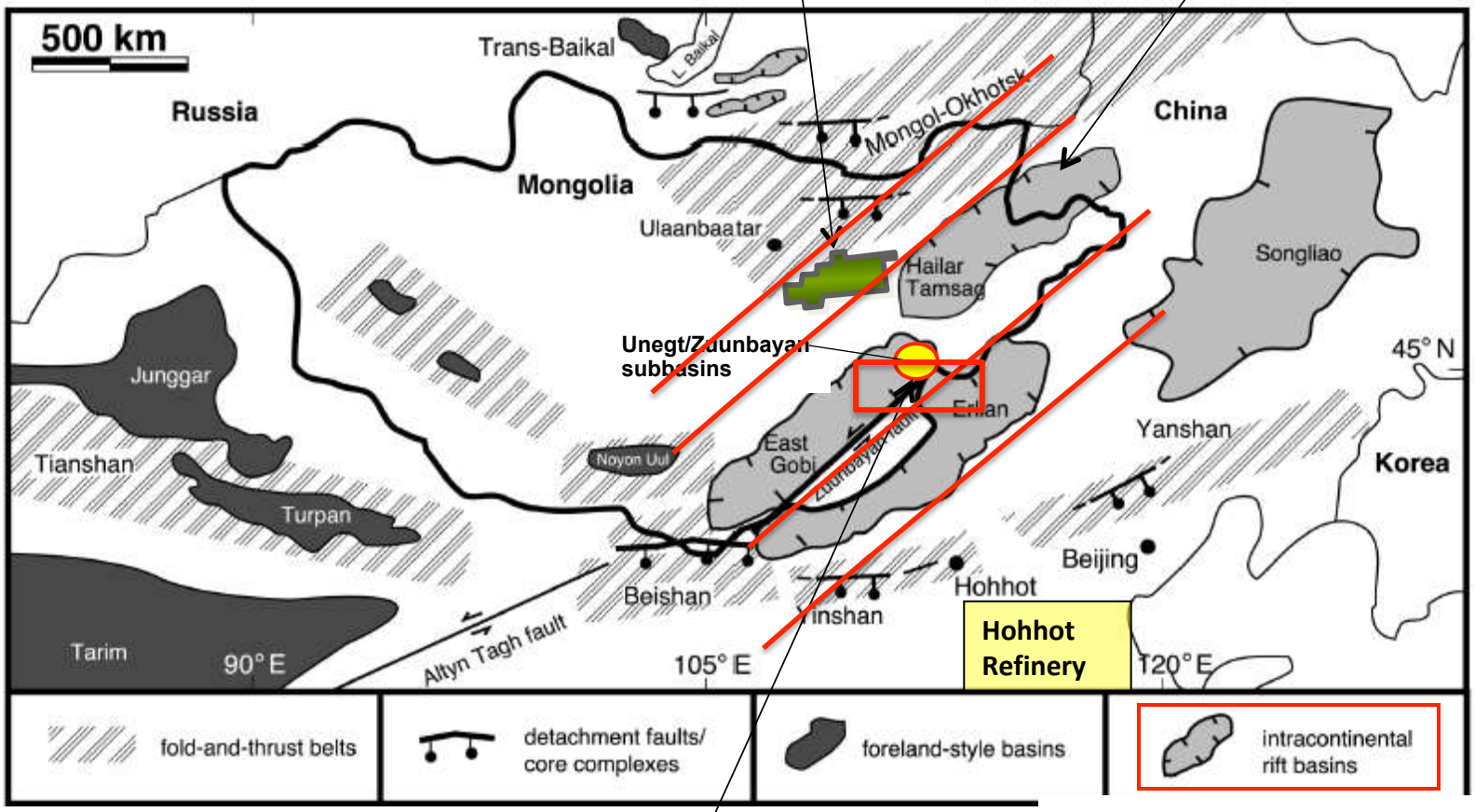


Assumed analog of Nyalga basin:

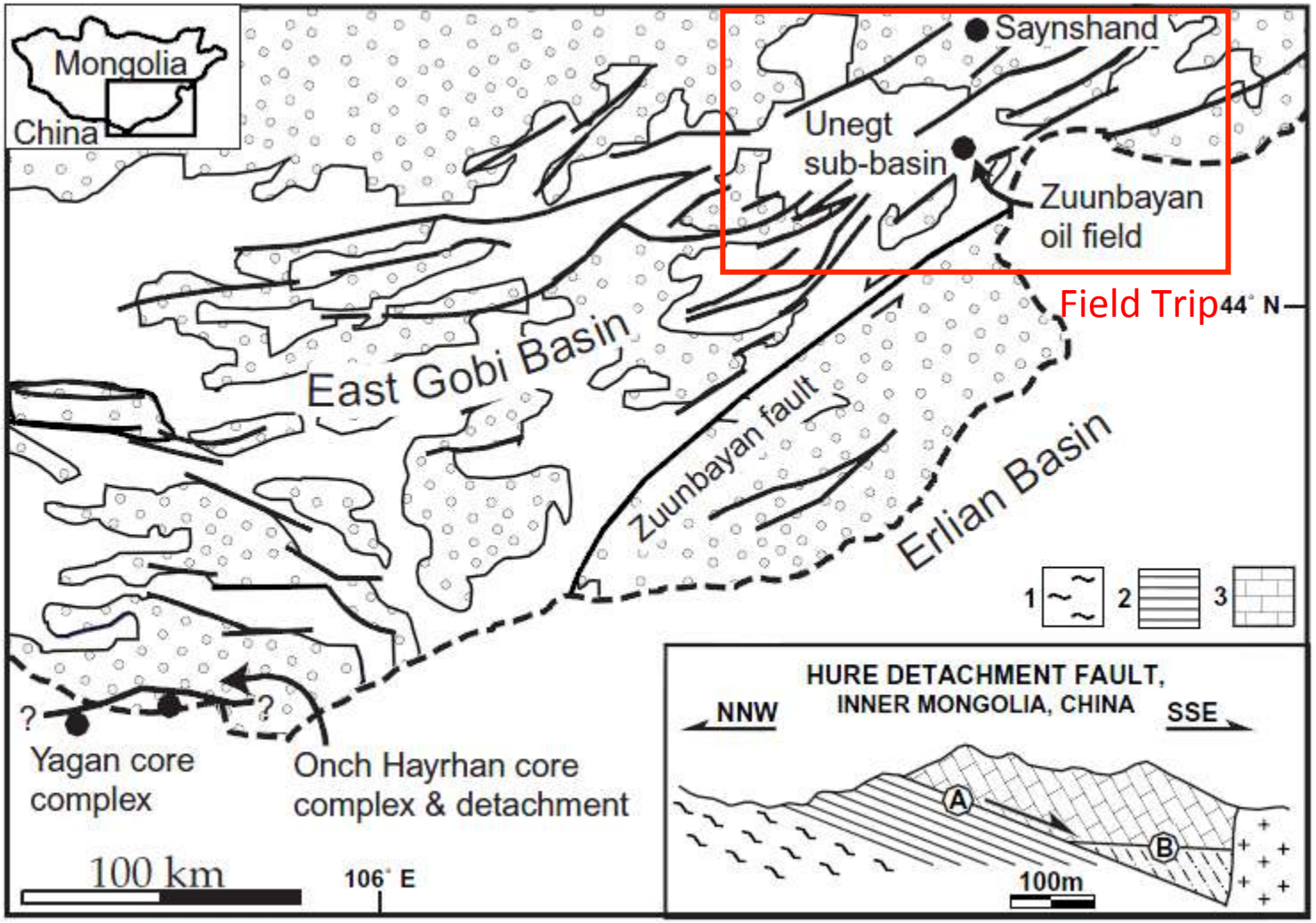
- similar Post-Permian structural and sedimentary development
- similar petroleum system(s)
- better exposed
- better explored
- producing

Production in middle corridor: Hailar Tamsag and East Gobi!



Graham *et al.* (2001)

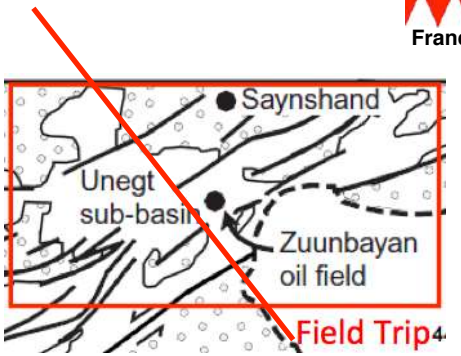
Complex tectonic history of transtension and transpression, mostly with a sinistral strike-slip component



Webb *et al.* (1999)

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:

Evolution of Zuunbayan sub-basin



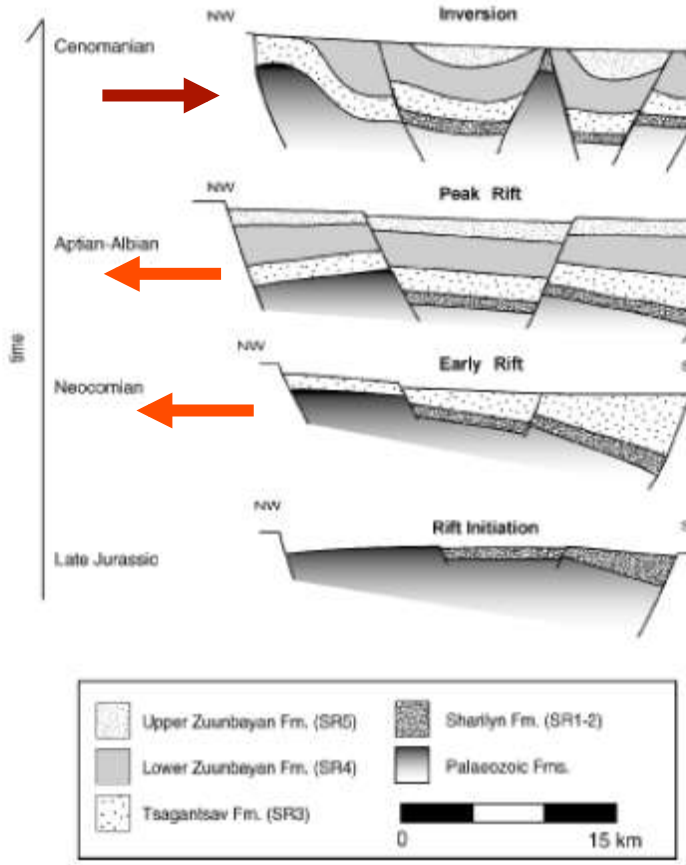


Fig. 12. Schematic evolution of Zuunbayan subbasin during Jurassic–Cretaceous time.

3. Inversion: early K2

3. Peak rifting: mid to late K1

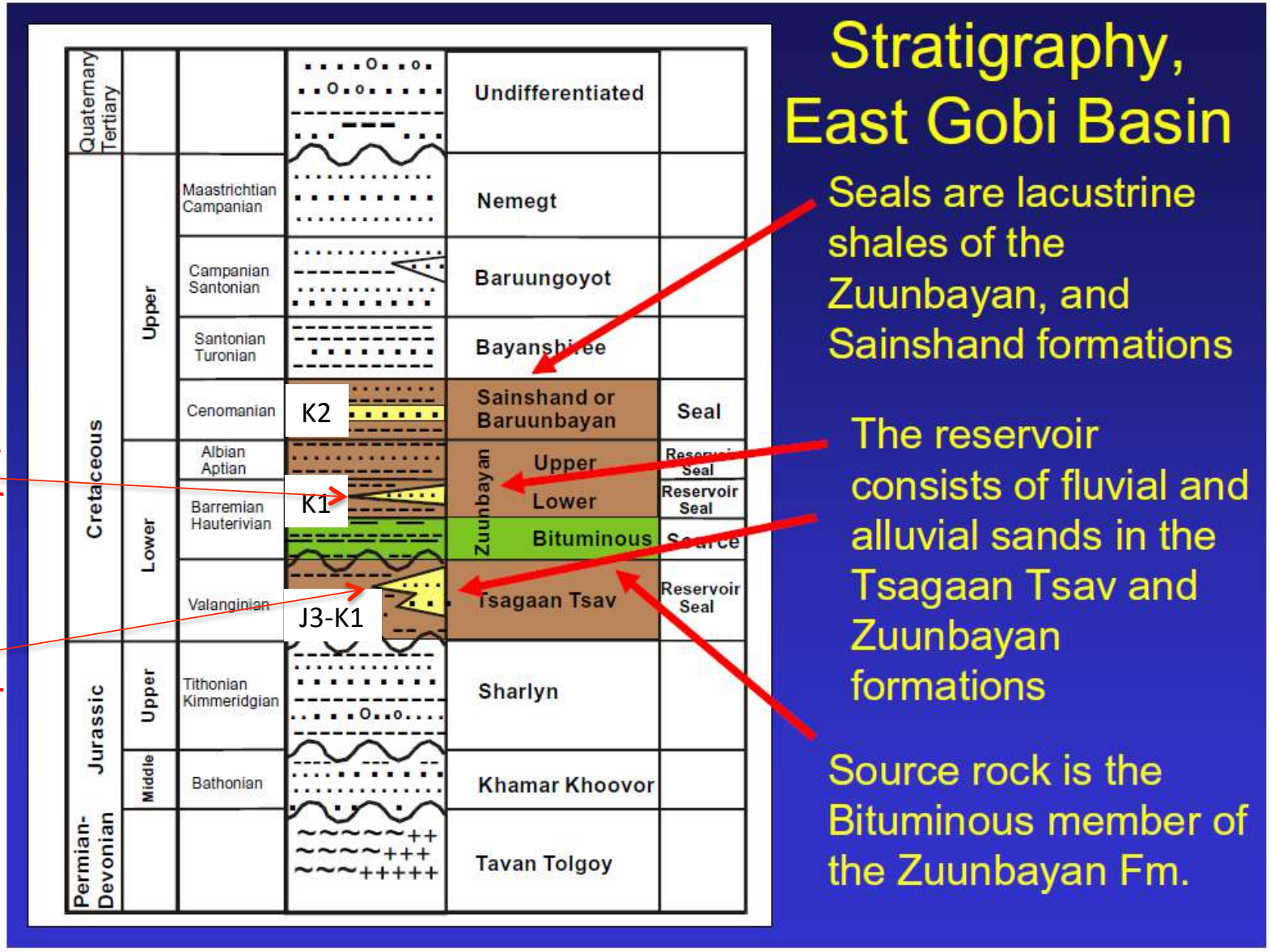
2. Early rifting: J3-K1

1. Rift initiation: Late Jurassic

Johnson (2004)

Prost (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)

[30 Sec. Video: Choir Soviet Airbase]

Choir: end of paved road


Sainshand (K2 type location)

Northern Gobi Desert

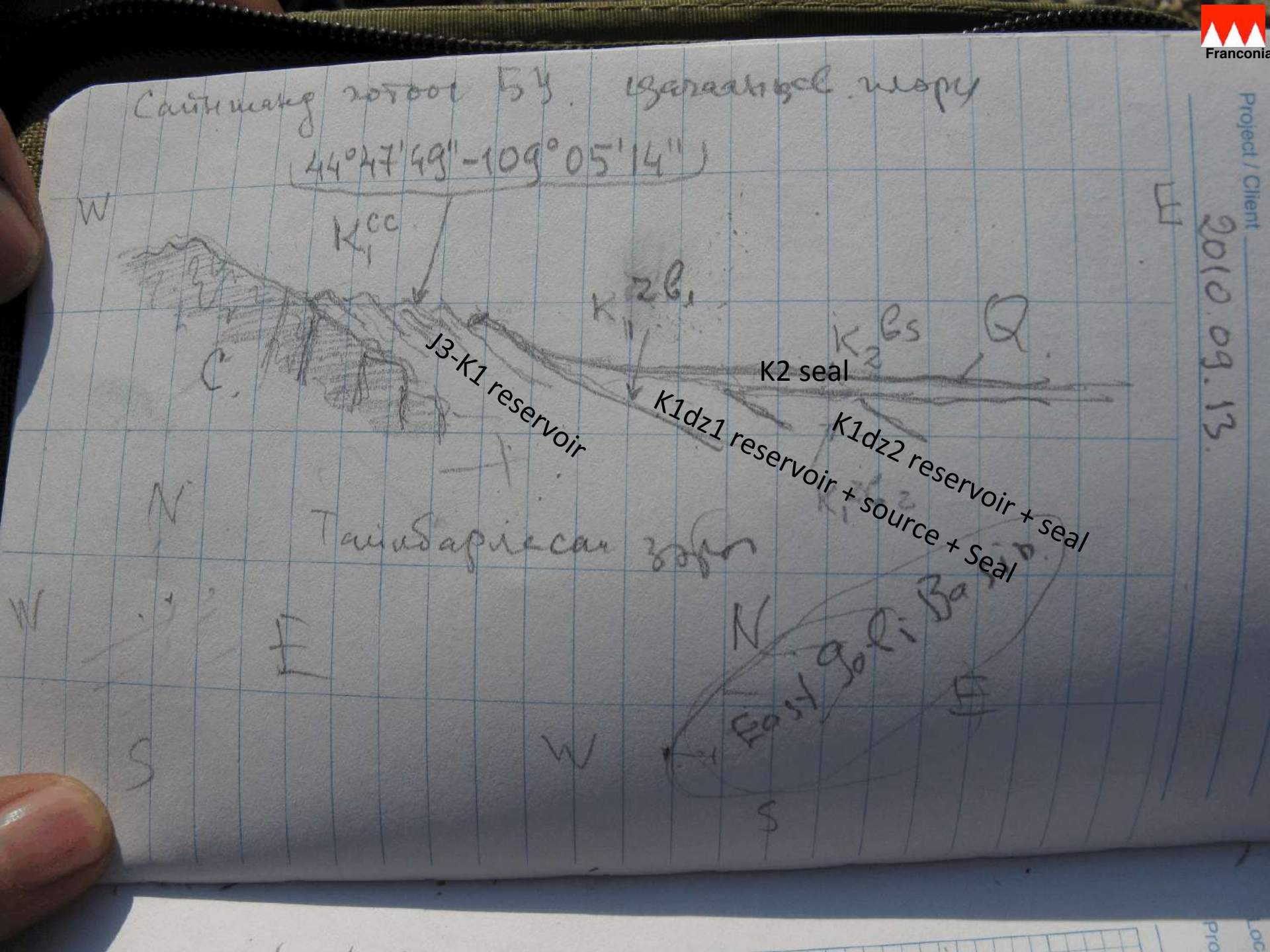
Breakfast Video

1 Min. Video

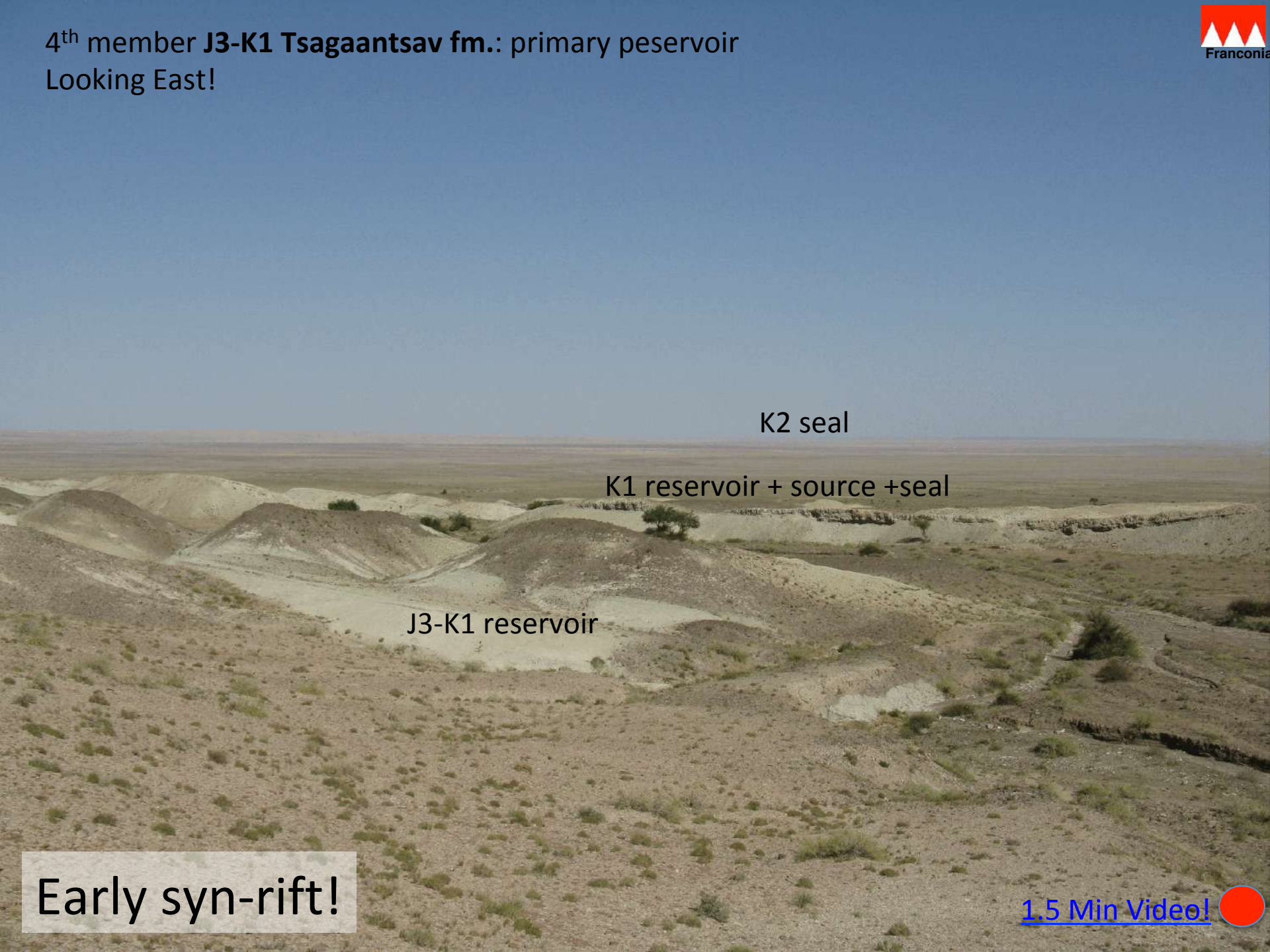
Zuunbayan
(type location
K1)

24 Sec. Video

Zuunbayan oil field
(1953-1969; resumed in 2007)


J3-K1 reservoir
K2 seal
K1dz1 reservoir + source + Seal
K1dz2 reservoir + seal

4th member **J3-K1 Tsagaantsav fm.**: primary peservoir
Looking East!



Early syn-rift!

1.5 Min Video!

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

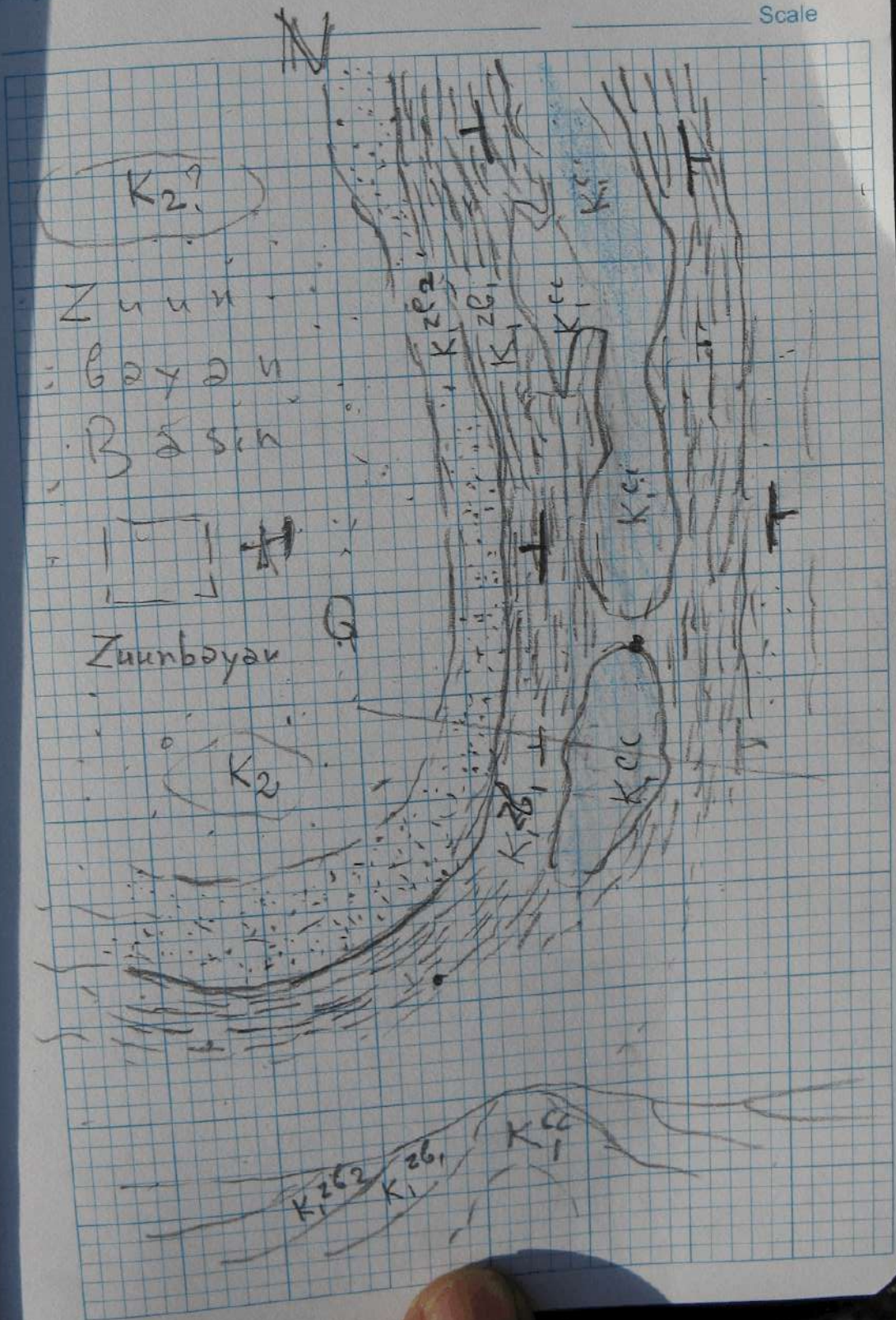
J3-K1 reservoir

K1 reservoir + source + seal

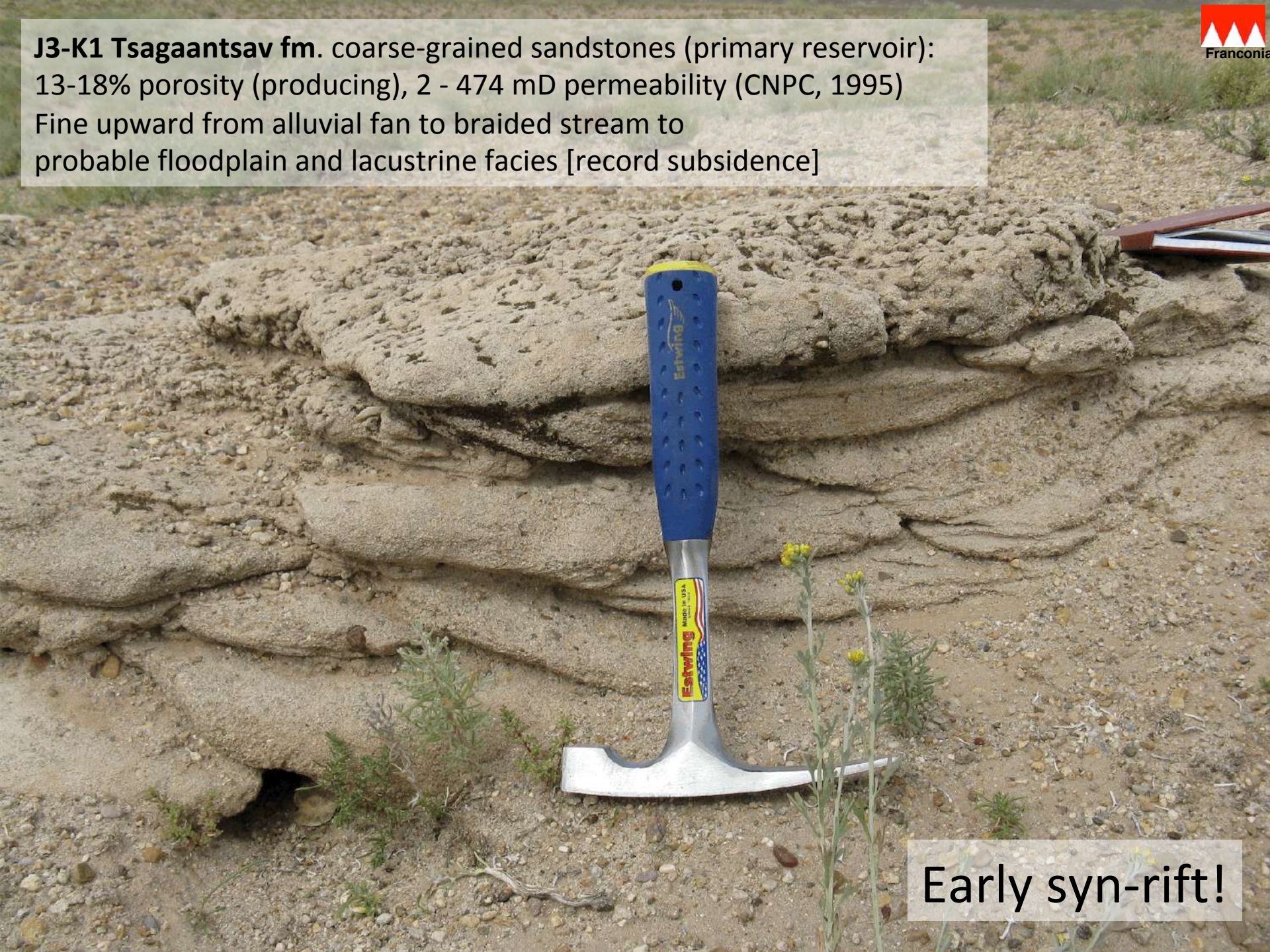
K2 seal

Location Зуунбаян Date

Project / Client Scale



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]

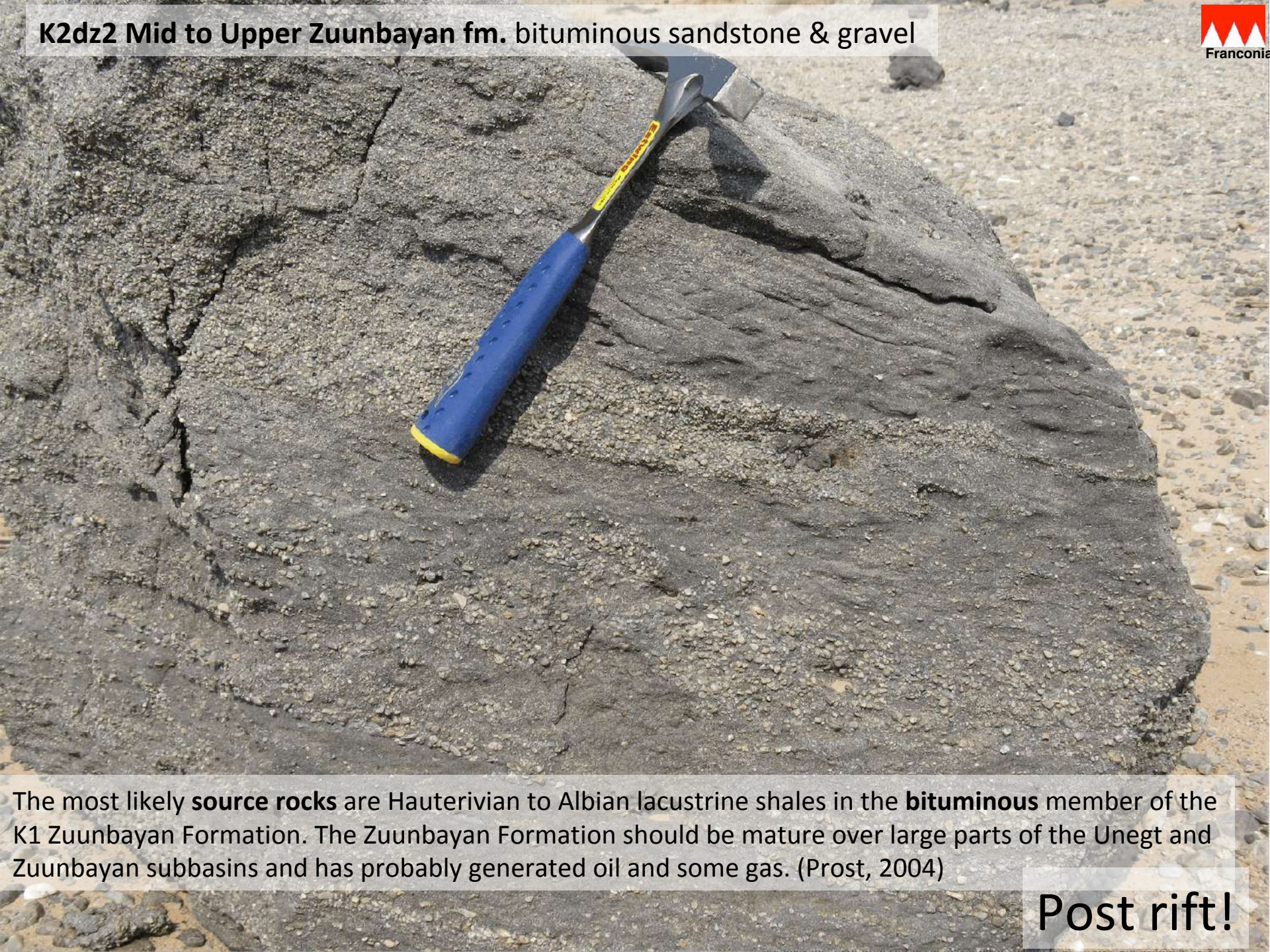
Early syn-rift!

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)

Peak rift!

K2dz2 Mid to Upper Zuunbayan fm. bituminous sandstone & gravel



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)

Post rift!

K1dz2 Upper Zuunbayan fm. conglomerate with interbedded sandstone (reservoir)

Post rift!

1 Min. Video

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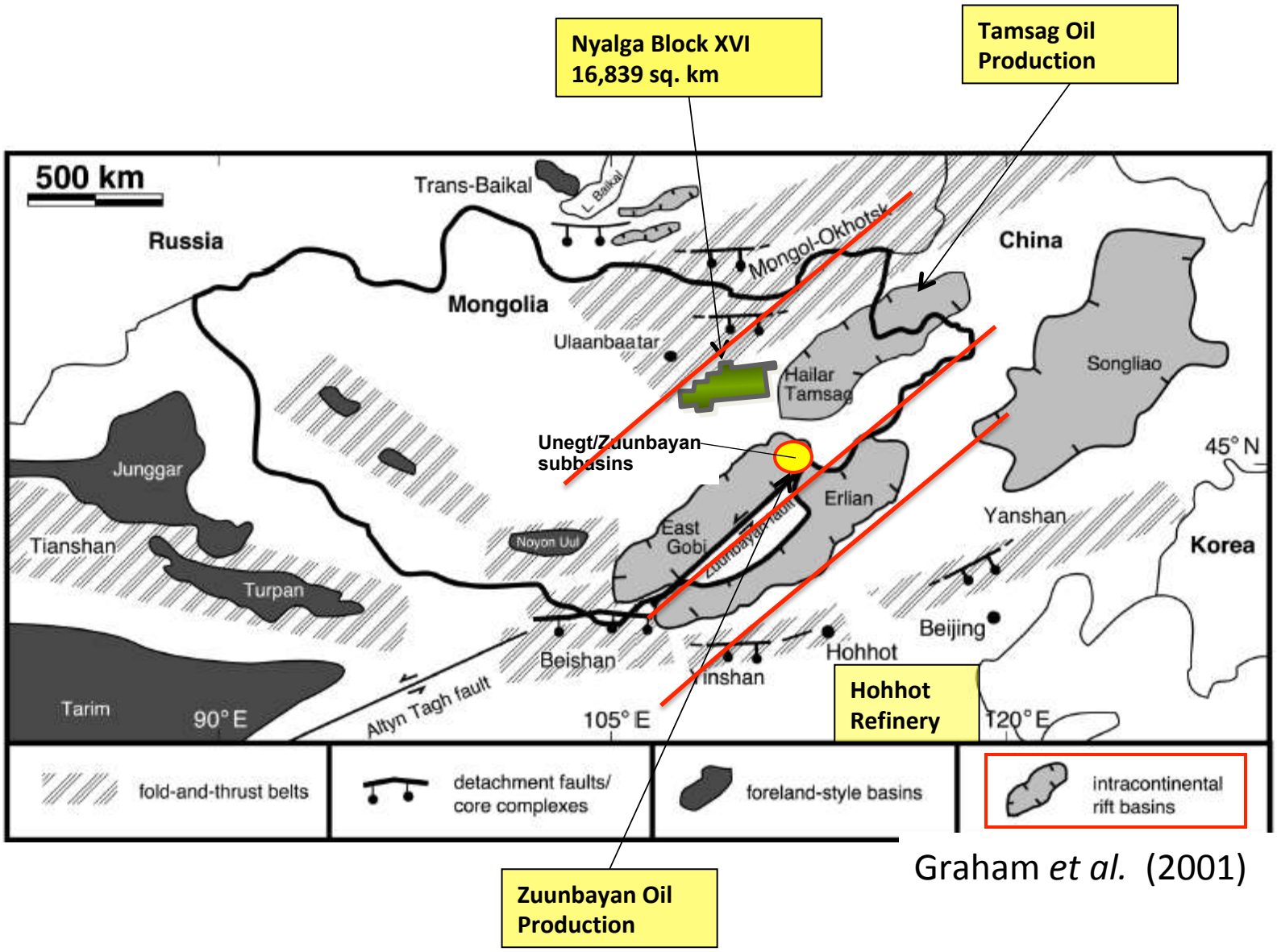
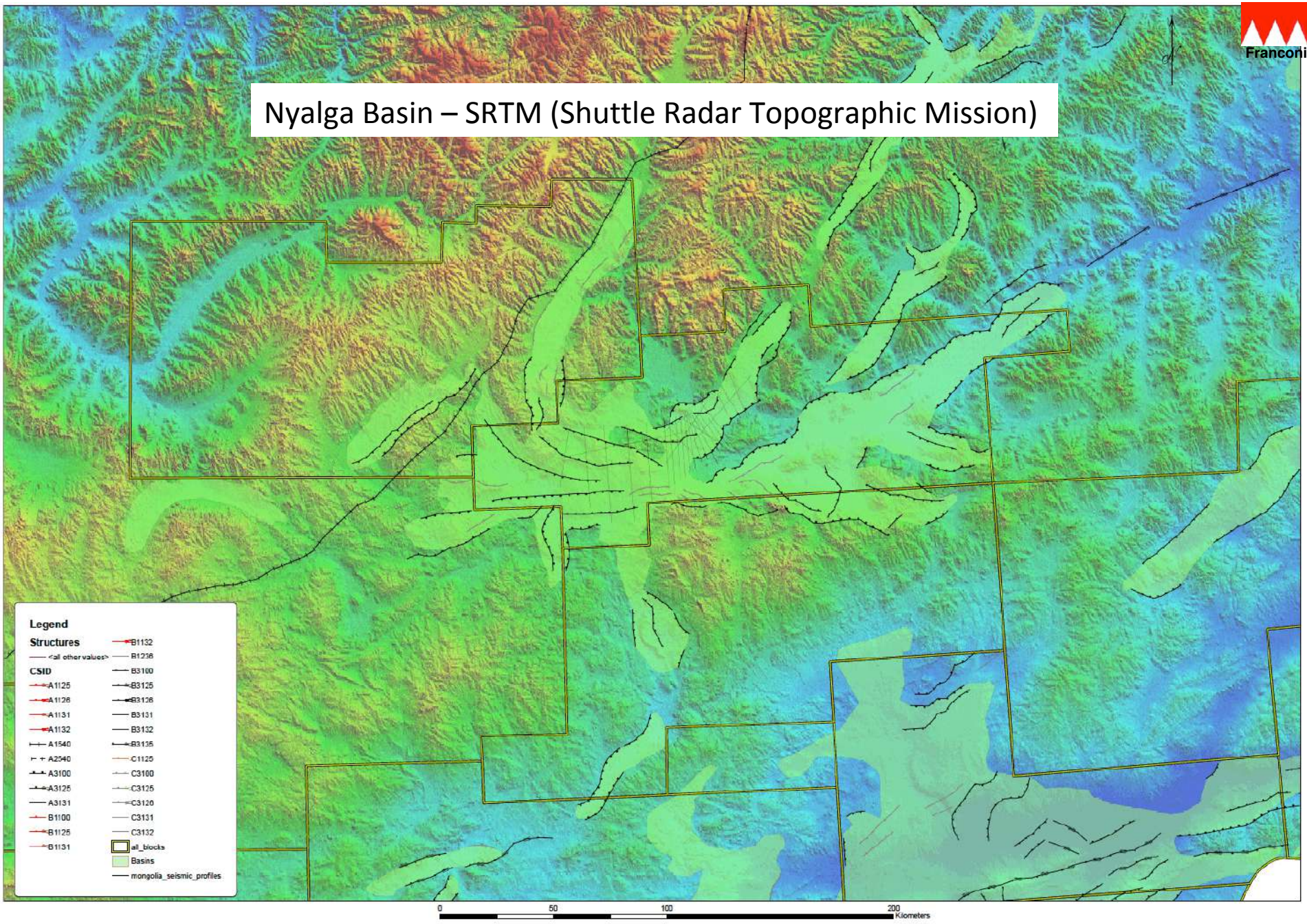
Nyalga basin in northern corridor!



Graham *et al.* (2001)

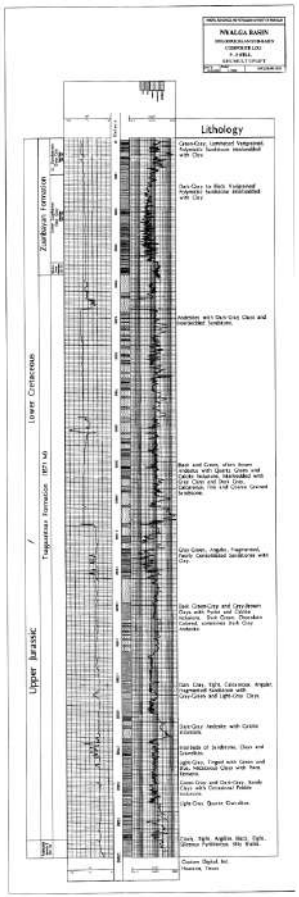
Nyalga Basin – SRTM (Shuttle Radar Topographic Mission)

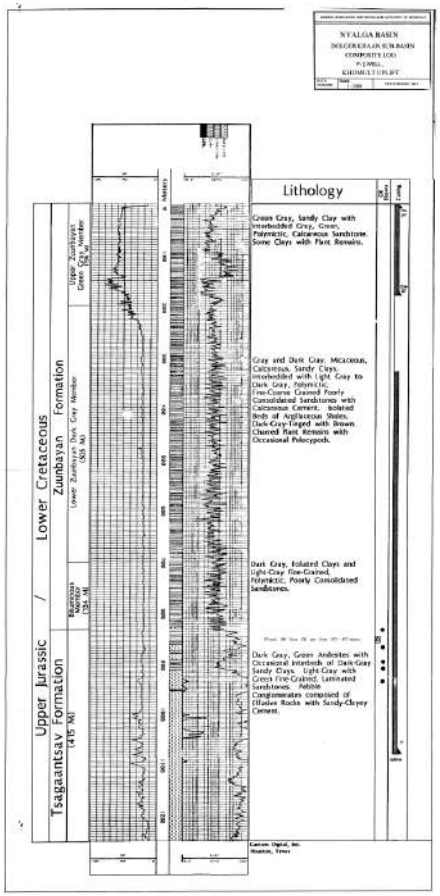


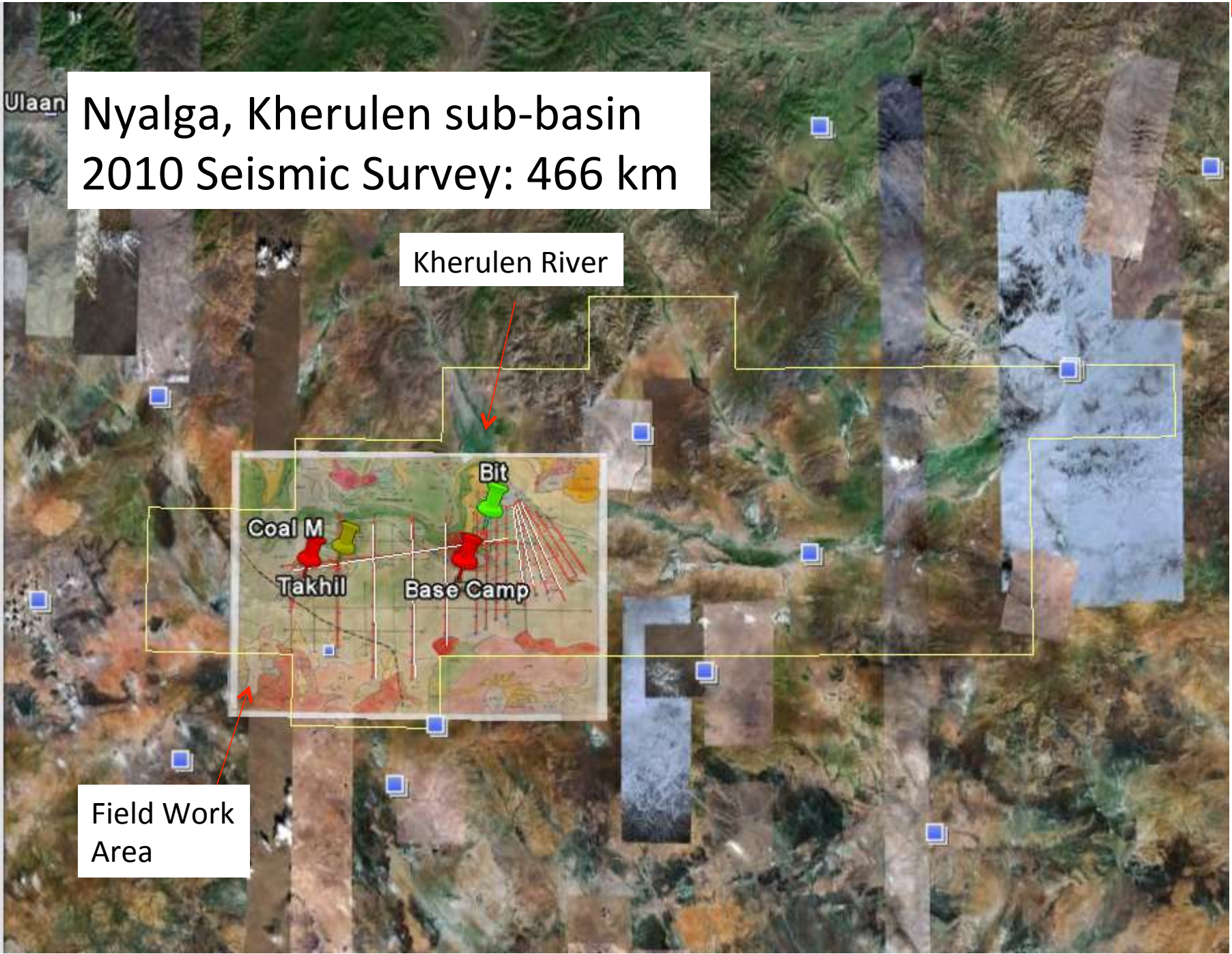
http://www2.jpl.nasa.gov/srtm/

Nyalga Block XVI

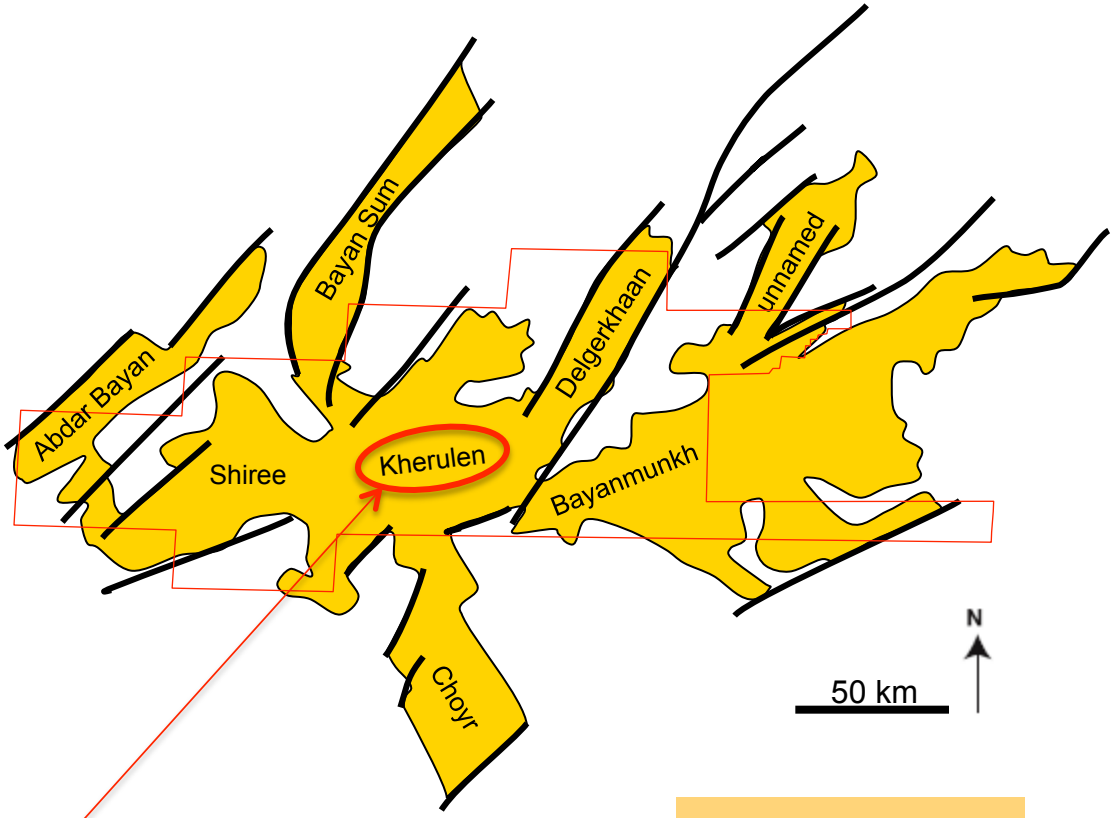
- Area 16,839 km2
- Subbasins up to 7000 m deep
- Proven source (K1dz1: ≤ 13% TOC and > 12m thick)
- Potential reservoir: J3-K1, K1dz1, K1dz2
- Potential traps in syn-rift clastics sourced and sealed by lacustrine shales
- Soviet oil exploration since the 1950s
- >40 wells drilled: 700-1800 m deep
- 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






Ulaan
Nyalga, Kherulen sub-basin
2010 Seismic Survey: 466 km
Kherulen River
Bit
Coal M
Takhil
Base Camp
Field Work
Area

8 transtensional/transpressional sub-basins
2 main orientations

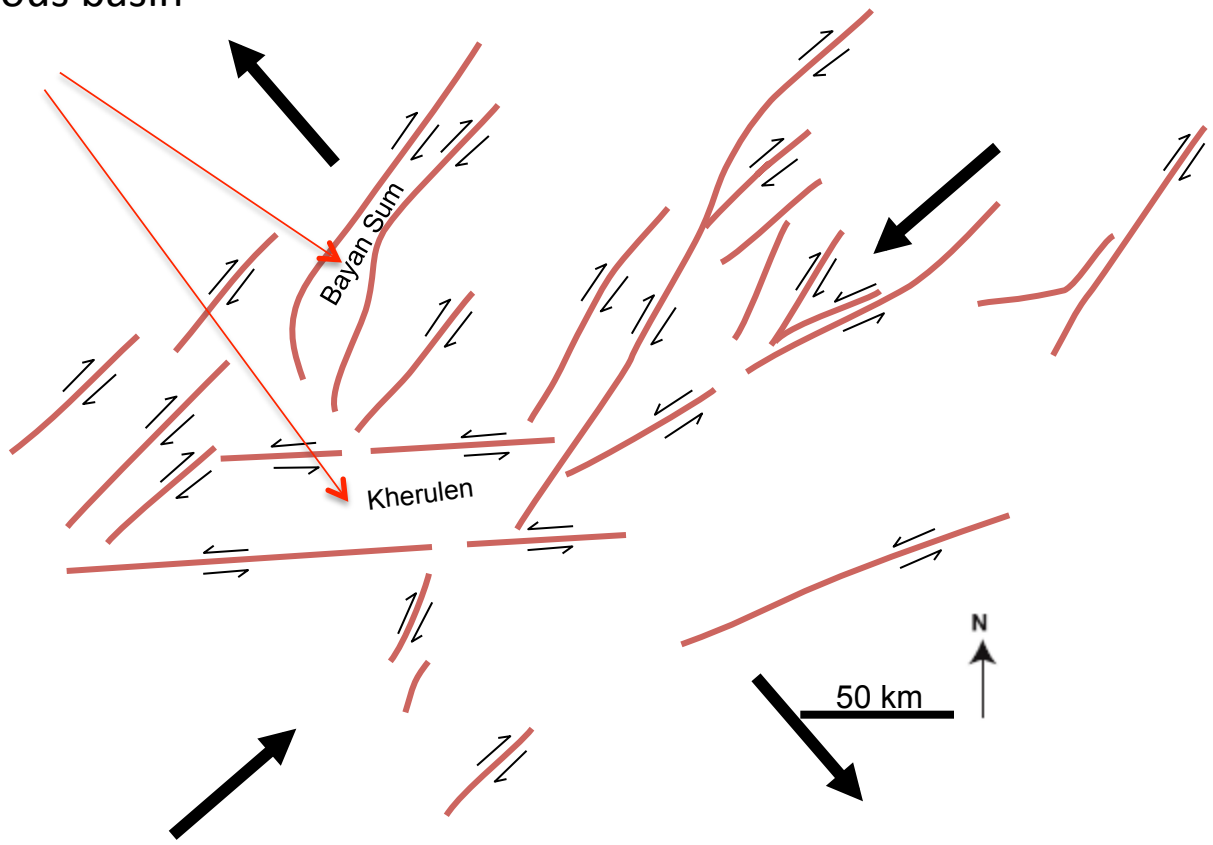


Genghis Khan burial site?

Nyalga Geometry

2 main orientations: conjugate shears

same bottom fill:
simultaneous basin
initiation



Nyalga Stratigraphy

Nyalga basin: all type locations in East Gobi basin

Age	Formation	Facies	Thickness
Tertiary	?	Fluvial sandstones, conglomerates, minor mudstones	<100 m
K2	Sainshand	inversion-related high-energy braidplain and fan sandstones and conglomerates; unconformity 2 at base	>80 m
K1dz2	Up. Zuunbayan	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	>625 m
K1dz1	Low. Zuunbayan	syn-rift lacustrine, anoxic, saline shales & mudstones, interbedded with sandstones	>570 m
J3-K1	Tsagaantsav	continental & lacustrine mudstones, limestones, siltstones, sandstones, conglomerates. With >630 m of early syn-rift basalts and andesites and associated tuffs at the base.	>>630 m
J3	Sharilyn	lacustrine carbonates with minor intraformational fluvial and volcani-clastic rocks; unconformity 1 at base	>500 m
Mid Triass. – J3	?	Continental red-beds: conglomerates, sandstones, minor mudstones, and basalts	<1700 m

No regional Seal

Reservoir, Seal

Source, Reservoir, Seal

Reservoir?

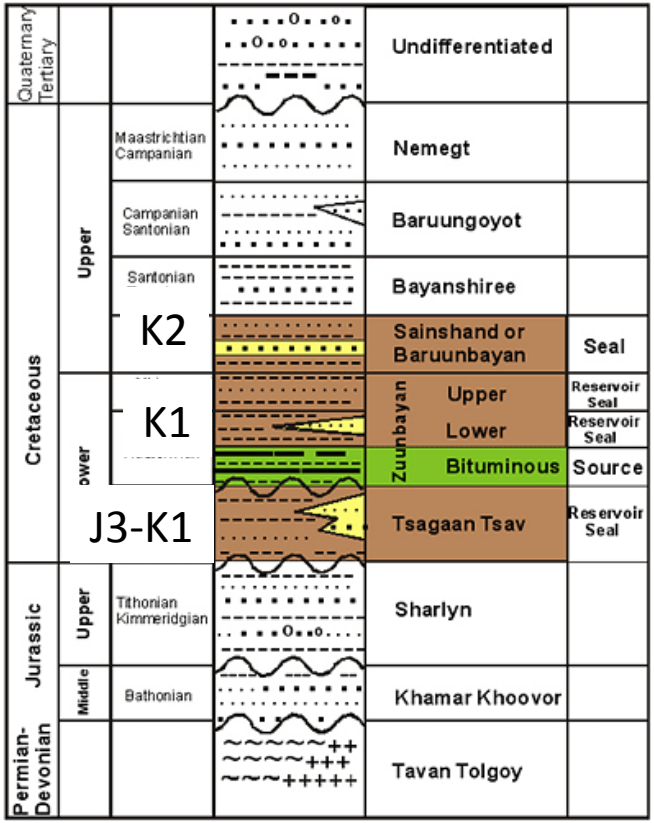
K2

K1

J3-K1

Compiled from BP (1991)

East Gobi basin



Prost (2004)

What are we eating?

Kherulen sub-basin 2010 seismic grid & field work area

northern basin shoulder: refolded anticline indicates sinistral shear

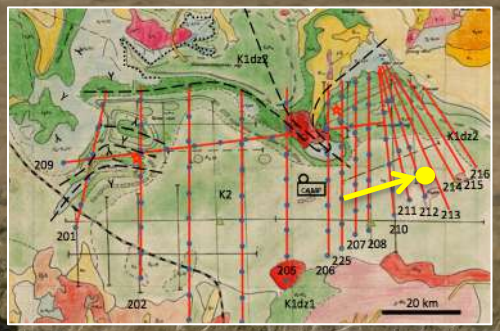
coal seam in K1dz2

J3-K1 [potential reservoir] exposed on shoulders

Standing on horst of Pz sediments in central Kherulen sub-basin:
view northwest towards graben shoulder

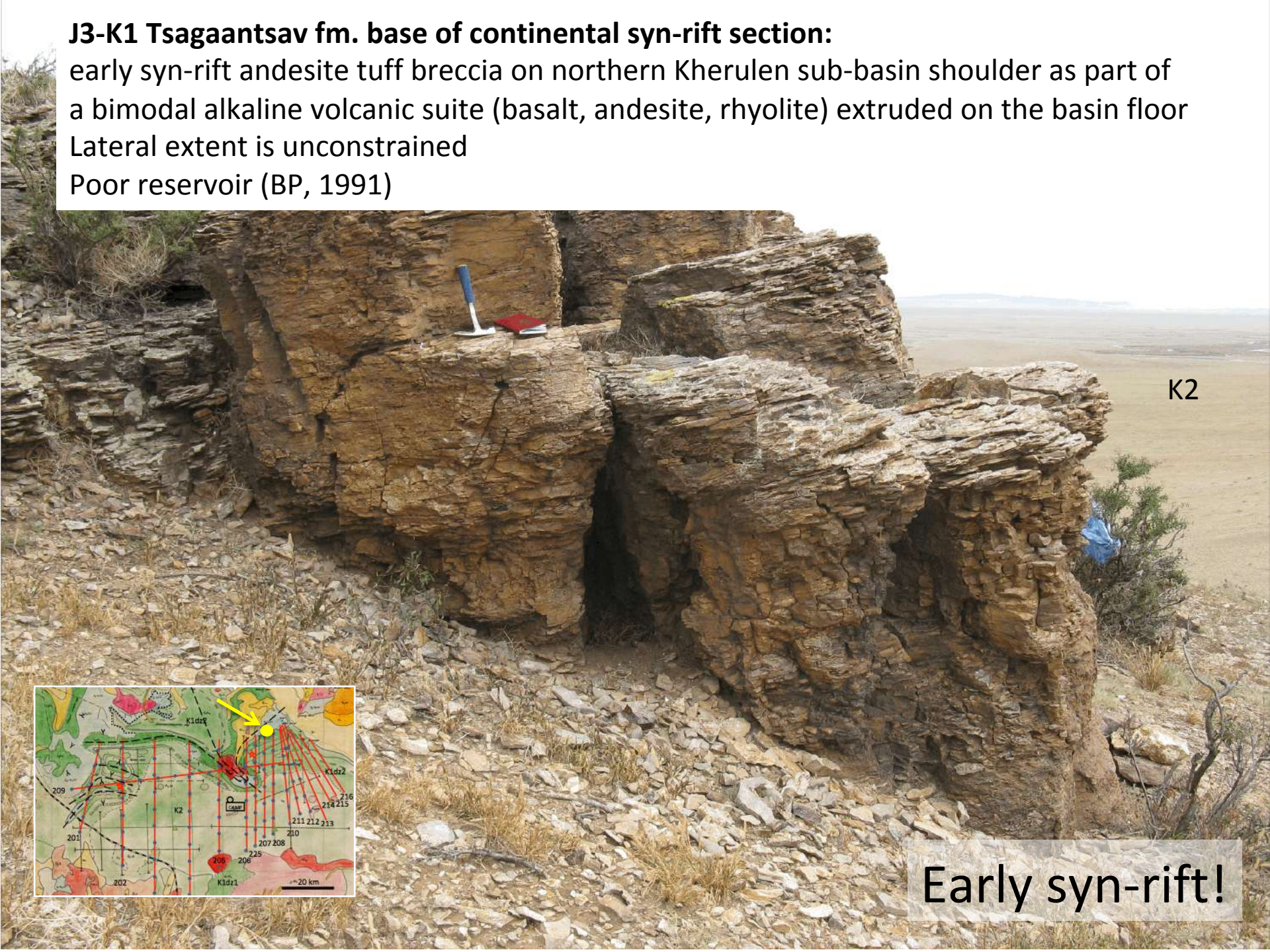
Basin shoulder: J3-K1 early rift volcanics (no sandstones as in East Gobi basin)

K2



Same horst of Pz sediments in Kherulen sub-basin, looking SE
No porosity!

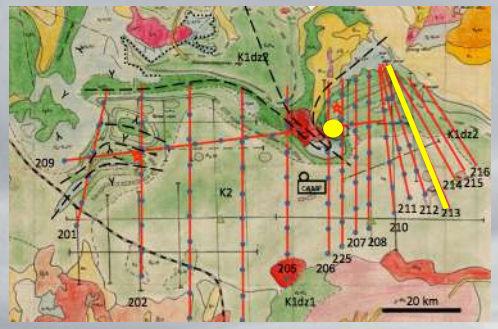
J3-K1 Tsagaantsav fm. base of continental syn-rift section:
early syn-rift andesite tuff breccia on northern Kherulen sub-basin shoulder as part of a bimodal alkaline volcanic suite (basalt, andesite, rhyolite) extruded on the basin floor
Lateral extent is unconstrained
Poor reservoir (BP, 1991)



J3-K1 base of continental syn-rift section: >>630 m of andesitic rocks on basalt

N

S



J3-K1

andesite

basalt

K1dz1

K2

K1dz1

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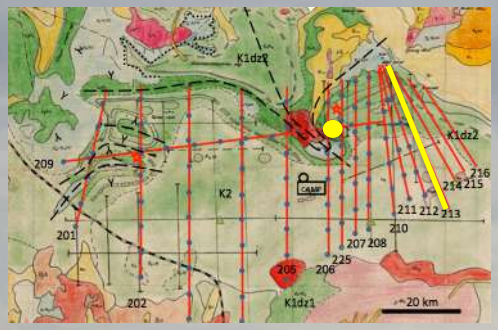


Khumultei uplift (horst): J3-K1 volcanics

K2

4347

1 Min. Video: on Khumultei Uplift

Khumultei Uplift (horst), Kherulen sub-basin: **J3-K1** andesite tuff breccia

Extremely hard!

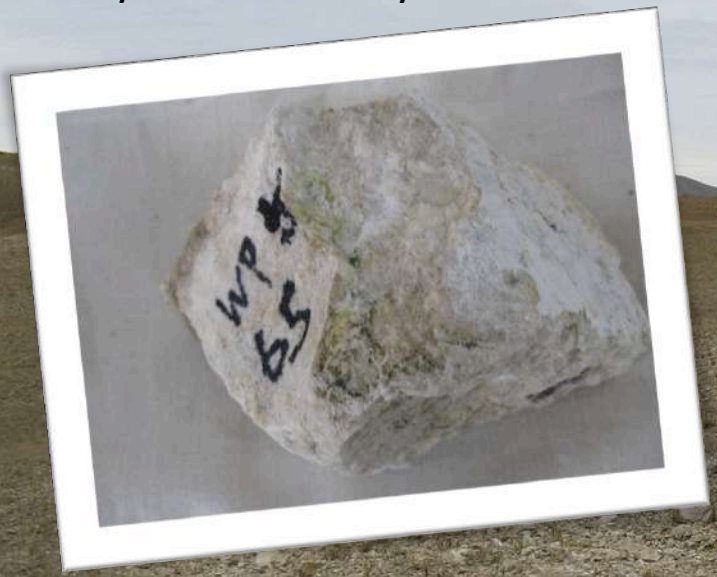
Early syn-rift!

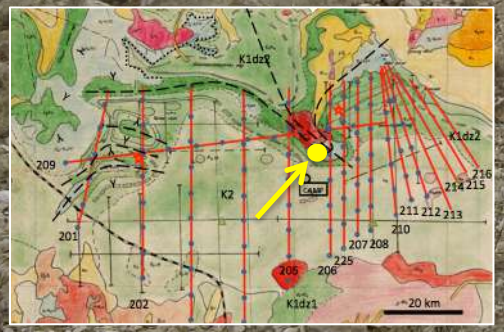
J3-K1 limestone within andesites and tuffs at N-shoulder of Kherulen sub-basin:

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)

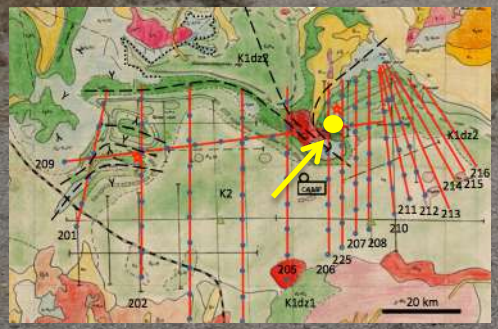




17 Second Video

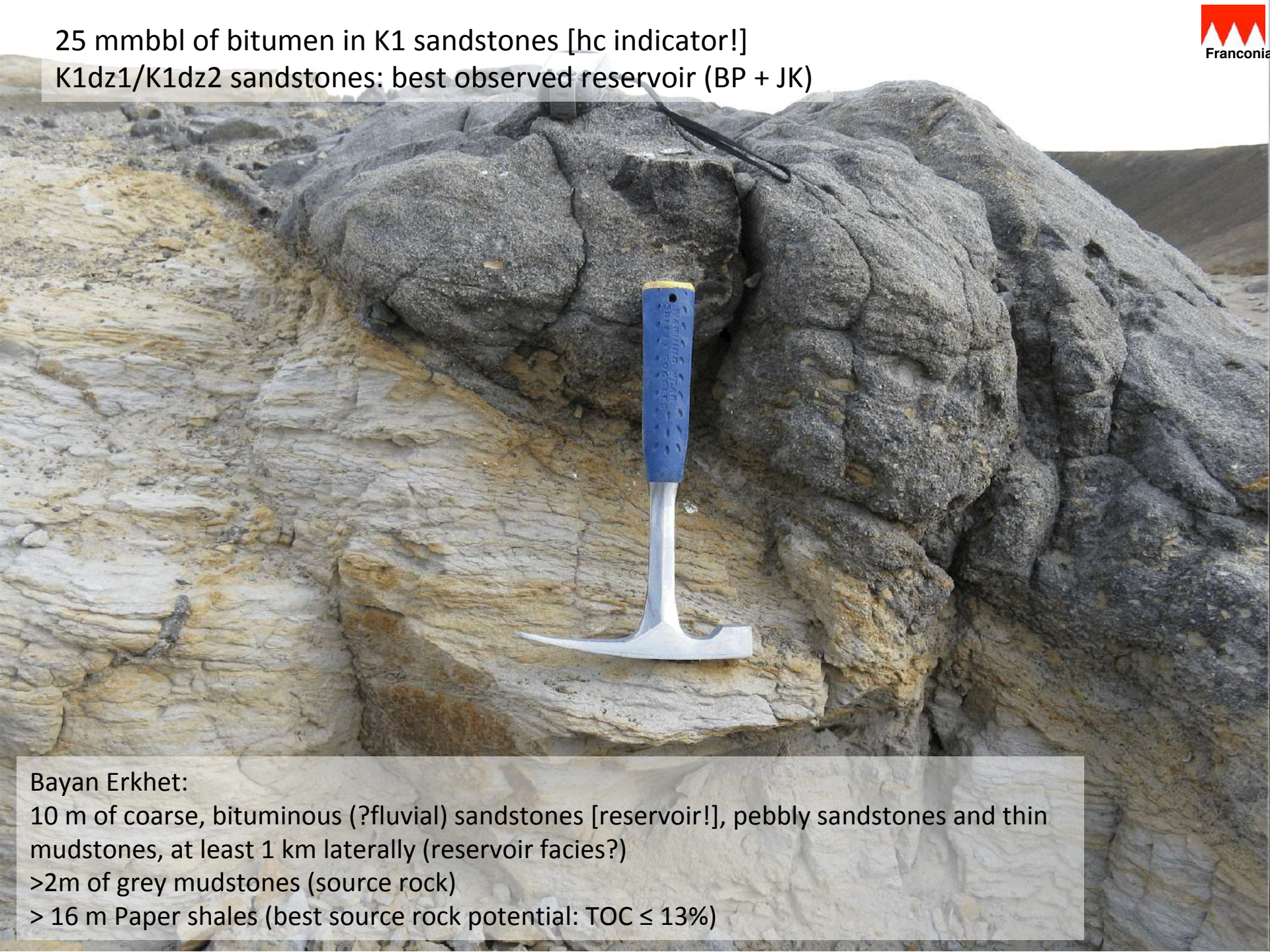
Early syn-rift!

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)



Peak rift!

25 mmbbl of bitumen in K1 sandstones [hc indicator!]
K1dz1/K1dz2 sandstones: best observed reservoir (BP + JK)



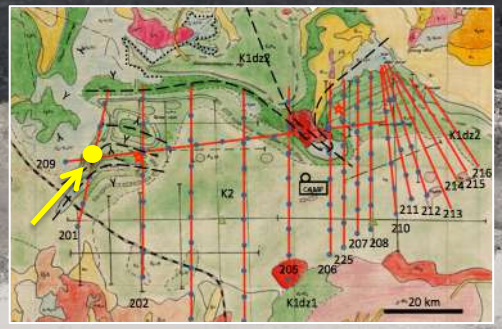
Bayan Erkhet:
10 m of coarse, bituminous (?fluvial) sandstones [reservoir!], pebbly sandstones and thin mudstones, at least 1 km laterally (reservoir facies?)
>2m of grey mudstones (source rock)
> 16 m Paper shales (best source rock potential: TOC ≤ 13%)

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



[38 Sec. Video]

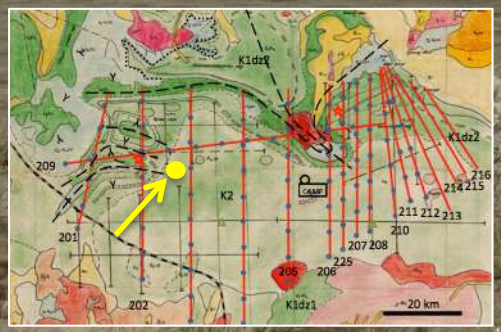
Post rift!

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

K2

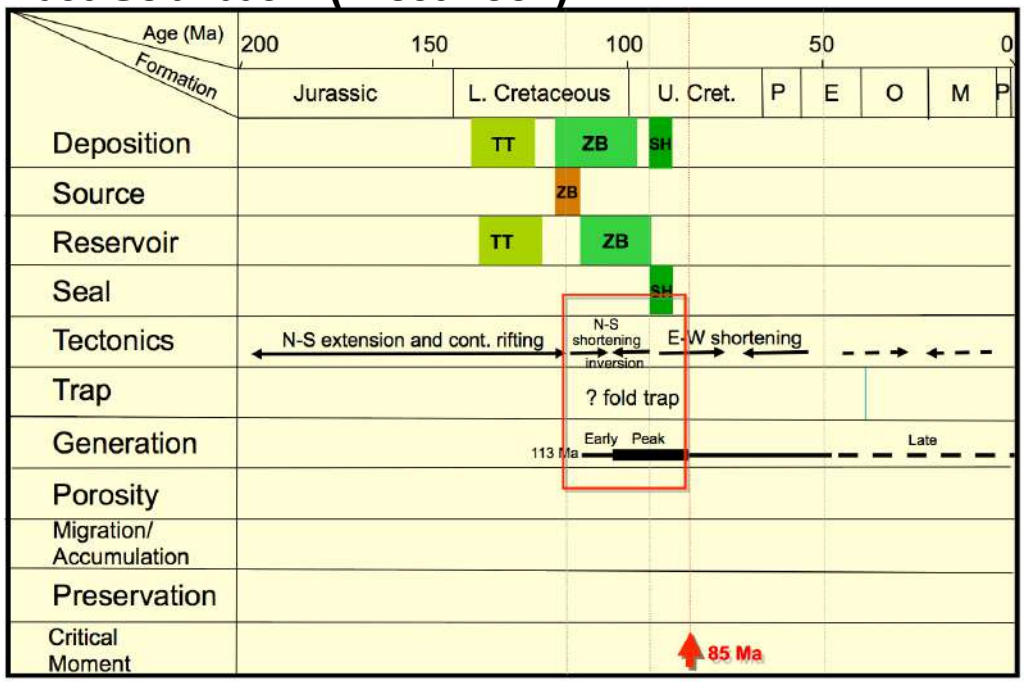


Inversion, followed by subsidence!

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

7. Tertiary inversion

6. K2 subsidence

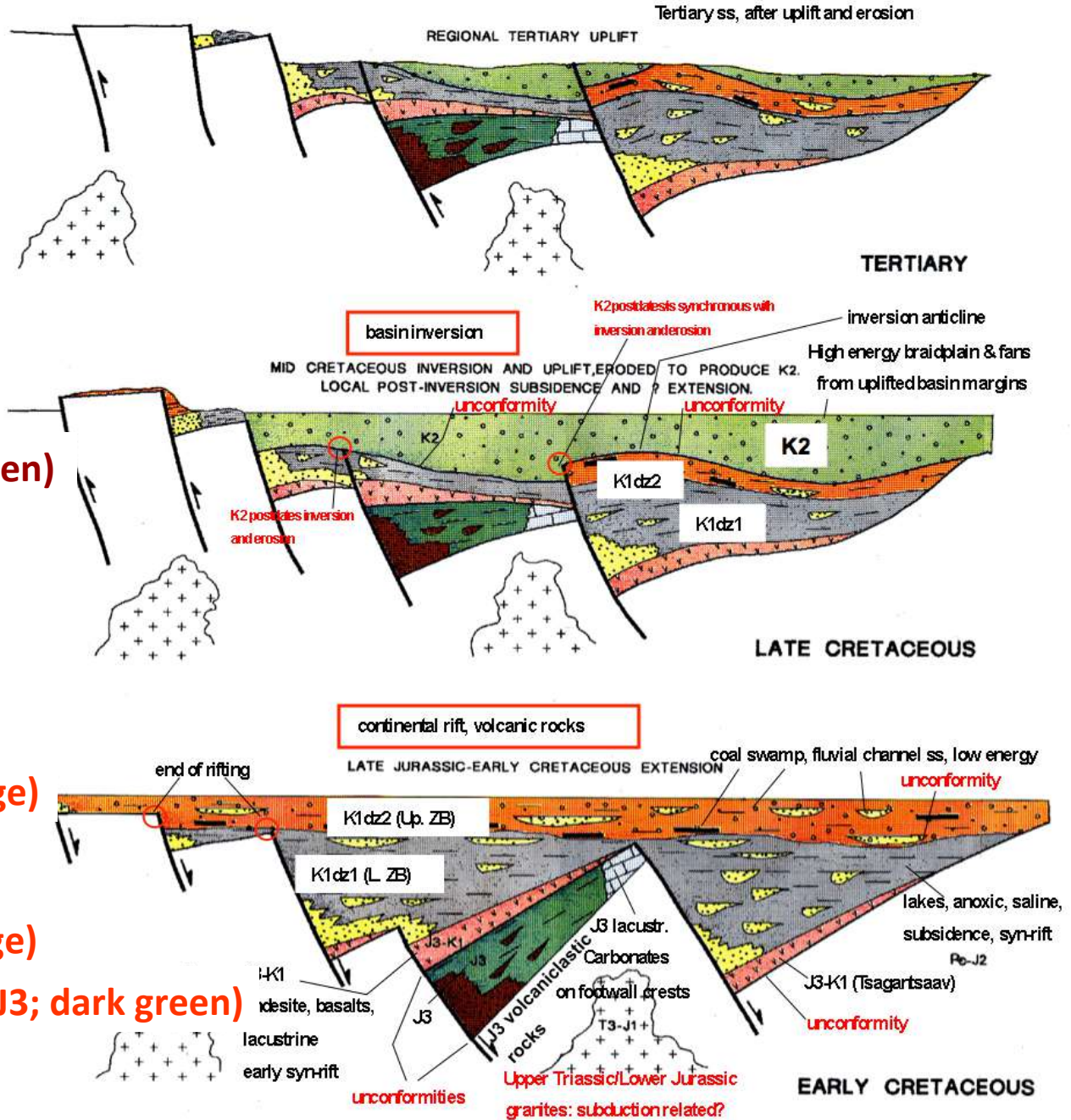
5. Inversion: early K2 (light green)

4. End of rifting: late K1 (orange)

3. Peak rifting: early K1 (grey)

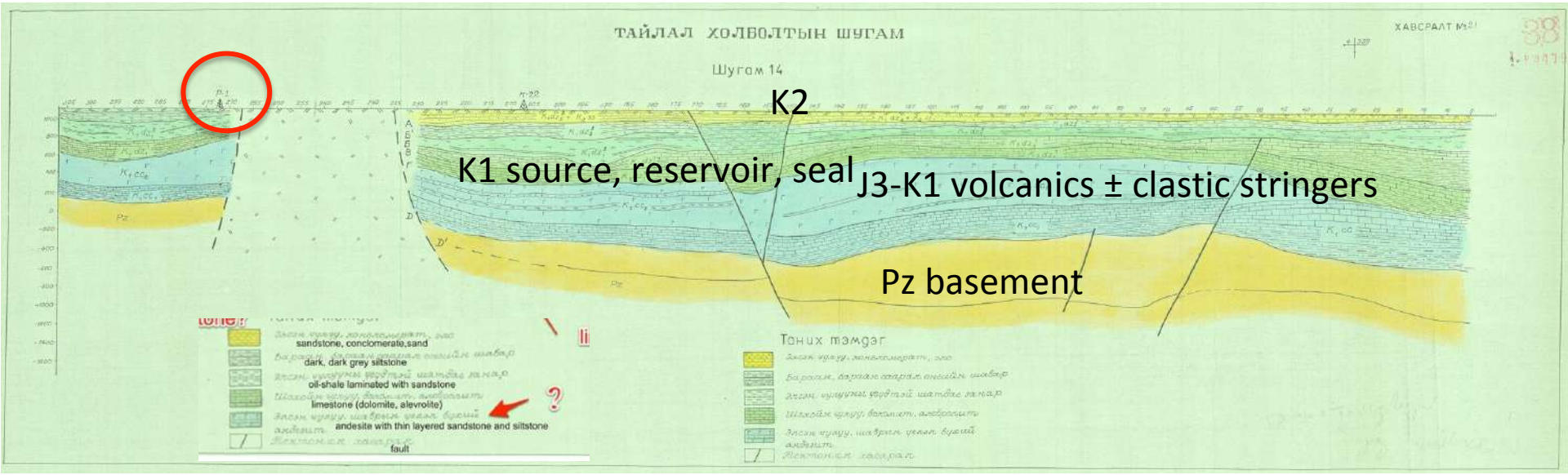
2. Early rifting: J3-K1 (red wedge)

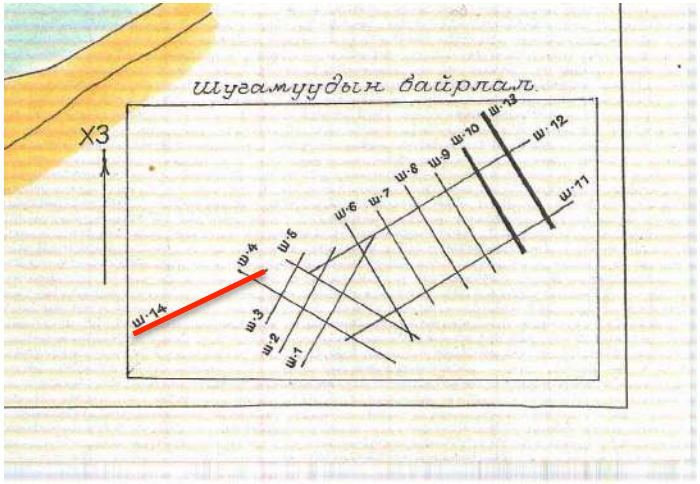
1. Rift initiation: Late Jurassic (J3; dark green)



Key Risk: Nyalga Reservoir Distribution

Stratigraphy in cross section based on >40 wells (no commercial production): Laterally coherent thick reservoir present?





Key Risk: Nyalga Reservoir Quality

calcite cements & authigenic clays
up to 50% 2ndary dissolutionion porosity

TABLE 1. Central Mongolia reservoir quality.

BASIN	SAMPLE	AGE	LITHOLOGY	POROSITY	RESERVOIR QUALITY
NILGA	UB/1/3N	K1DZ2	LITHIC SANDSTONE	21%	FAIR
NILGA	UB/1/3P	K1DZ2	SANDY LIMESTONE	10.70%	POOR
NILGA	UB/1/3S	K1DZ2	CALCITE-CEMENTED SLTST		VERY POOR
NILGA	UB/3/6E	K1DZ2	LITHIC SANDSTONE	23.90%	MODERATE
UGNUUR	UB/7/5C	K1	SILTSTONE	26.50%	MODERATE
UGNUUR	UB/7/5F	K1	SILTSTONE	17.40%	MODERATE
HARHORIN	UB/8/2I	K1	LITHIC SANDSTONE	20.80%	MODERATE
NILGA	UB/2/1B	J3	LONCOLITIC LIMESTONE	3.20%	VERYPOOR
NILGA	UB/2/1E	J3	IGNEOUS BRECCIA		VERYPOOR
NILGA	UB/2/1G	J3	SHELLY LIMESTONE	3.50%	VERYPOOR
NILGA	UB/3/2C	P	LITHIC CONGLOMERATE		VERYPOOR
NILGA	UB/3/3B	P	LITHIC SANDSTONE		VERYPOOR
NILGA	UB/3/5B	P	LITHIC WACKE		VERY POOR
NALAYH	UB/4/1A	C	LITHIC META-SANDSTONE		VERYPOOR
NILGA	UB/2/5A	D	LITHIC SANDSTONE	0. 70%	VERYPOOR

BP (1991)

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

Franconia

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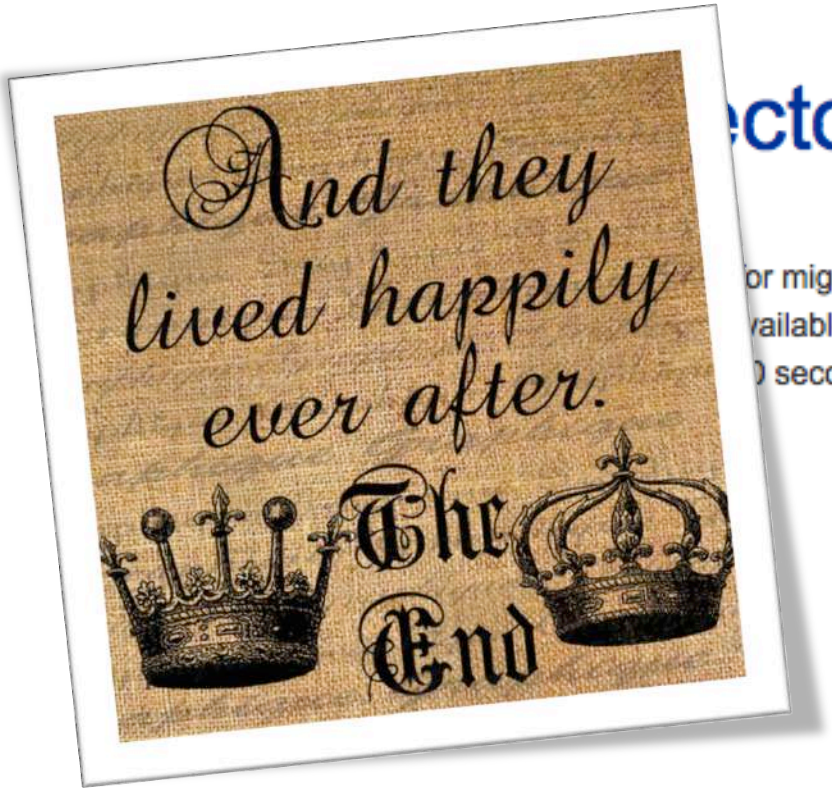

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