Shale Oil Exploration & Development in Japan

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Our (recent) publications:


  (the below are from AAPG Search & Discovery)
- Yokoi, S. and Tsuji, T., 2015: Tight Oil Potential in Neogene Monterey-like Biosiliceous Shale of Japan
- Yokoi, S. and Tsuji, T., 2018: Tight Oil Exploration in Monterey-like Biosiliceous Shale of Japan
- Tamagawa, T., 2018: Hybrid Fracturing Concept Based on Geologic Features of a Monterey-like Biosiliceous Shale, Japan
What is the **Onnagawa** (女川) Shale?

Same rocks are along the North Pacific.
The Onnagawa is Monterey-like diatomaceous/biosiliceous shale of Middle Miocene age, which deposited in a rift & silled basin along the paleo-Japan arc.
And the main source rock in Japan, with fairly high source-rock potential and average thickness of 500m.

TOC: 2% in average, up to 5% in part

Type II ~ type II-S kerogen comparable to (upper) Monterey
- What we have done for shale oil exploration in the Onnagawa

- What we have learned as source rock and reservoir stimulation technology

- Where are we going? How to explore? How to evaluate the potential?
Background / study history / the starting point

- We have a commercial oil & gas production from Onnagawa shale since 1985 in the Ayukawa-Yurihara field, which discovery is accidental although.
- Its cumulative production is getting over 1 MMBBL. (from conventional trap)
Porcelanite reservoirs with conventional trap polished core

Color banding:
black band: clay rich, better source rock
white band: reservoir property (~30%Φ 1md)

SEM image of “white”
the history of our study on the Onnagawa

90s Masuporo (Hokkaido)

2000s Daekhurin in Sakhalin

80s Onnagawa now as tight oil

2002
We have proposed a diagenetic trap model in Yurihara-Ayukawa field, where opal-CT porcelanite act as a seal and Qz porcelanite act as a reservoir (highly permeable "shale")

(SEM image)

(Mercury injection Porosimetry)

Porcelanite

Increasing $\text{Al}_2\text{O}_3$ content

- Throat M+L porosity lower than 20%
- Throat M+L porosity higher than 20%
- Hydrocarbon
- Open fracture

Tsuji et al., 2011 (AAPG) / Tsuji & Yokoi, 1994
Motivation for Onnagawa Tight Oil study

Bakken shale oil model

USGS 2008

Continuous accumulation without trap & below water (huge but hard to develop as conventional)

* Resources play in other words
We have two oil groups in terms of maturity in Ayukawa field:

Higher maturity: commercial oils
Lower maturity: low-productive oils (in tight reservoirs, mainly shale) relatively-productive zone with the best source rock potential
What is necessary for “shale oil”?

“productive” shale oil is close to the best source rock horizon
TOC 2%, S2 10mg / HI 500 (subject to maturity)
“Ayukawa model” (tight oil in the Onnagawa)

- We recognize two different hydrocarbon systems:
  - Productive, mature and migrated
  - Sub-commercial or non-productive so far, less-mature and indigenous
- We understand the latter is a part of basin-wide shale oil system, possibly with continuous accumulation.
In 2012, we started tight-oil exploration for the Onnagawa Shale, as a R&D project supported by JOGMEC.

As the first step, we tried acid stimulation on this non-commercial oil in an existing deviated hole.

Road map of Onnagawa shale/tight oil project

- **Joint study with JOGMEC**
  - 2011: phase 1 (engineering)
  - 2012: phase 1.5 (acidizing)
  - 2013 ~ 2015: phase 2 (fracturing @ Fukumezawa)
  - 2019 ~ (under planning)

A kind of practice for multi-stage fracturing, preparing for the Ayukawa project

**Ayukawa**
- Confirm 3 mmbbl by 2020

**Step out from Ayukawa**
- Expecting 30 mmbbl
(Joint study with JOGMEC in 2012)
acicizing test in Ayukawa field ⇒ another way to stimulate on shale
Acidizing performed in 2012-2013 ⇒ Success!

- A great improvement in its productivity;
  - 10 BOPD (intermittent) ⇒ 300 BOPD
  - 0.02 md ⇒ 5~9 md
- Production is ongoing with moderate decline,
  getting over 100,000bbl in cumulative production
Fukumizawa 1st multi-stage fracturing in Japan (horizontal well for tight oil)

Frac. Spec. for Fukumizawa:
fracturing stage: 5 stage (depth 1330m, horizontal 650m)
fracture shape (basic design):
  ellips (vertical 60m, horizontal 90m), width (~12mm)
frac. fluid: 160KL/stage, water (98% of the liquid)
  + additives (CleanStim™ system (Halliburton))
  proppant: ceramic, 50 t/stage
• What we have done for shale oil exploration in the Onnagawa

• What we have learned as source rock and reservoir stimulation technology

• Where are we going? How to explore? How to evaluate the potential?
What we have learned from the production profile in a acidized well?

**Contribution of fracture**

**Contribution of matrix pore**

**Figure 14.** Production decline curves from three shale oil plays in the United States by month in barrels of oil. (modified from Jarvie, 2014)
Why fracture contribution?

Matrix acidizing
for damage zone of Sandstone typically (back to initial condition)

Acid fracturing
for carbonates (above initial condition)

“Shale acidizing”
Stimulate natural fracture
dissolve minerals / open frac. (above initial condition)

Our concept:
as the third type of acidizing

Shale (best source)

10cm order
homogeneous

wormhole

10m order
heterogeneous
Concept of our acidizing:

- Targeting “tight oil” with weakly-fractured porcelanite in Kurosawa well
- Stimulating non-conductive fractures cemented with soluble minerals, with acid & over fracture-opening pressure

Preflush: 15% HCL (40KL)
Main Acid: 12%HCL+3%HF (a/a) for 40m interval
Flow-back water analysis

Dissolution of carbonate is clearly observed

- **Mg (mmol/L)**
- **Ca (mmol/L)**
- **Ca/Mg**

**Flow-back (gas lift)**

- **6 months after**
  - (2 weeks-flow)

**Start of continuous flow**
Key factor for success in our acidizing: “soft” fracturing.

Fracture Pressure

Acidizing operation

Pump Pressure [MPa @1525 m]

Formation pressure

Pump Rate [kl/day]

NH₄Cl
HCl
HF
NH₄Cl
HCl
HF
NH₄Cl
DV
HCl
HF
NH₄Cl
NH₄Cl
Key factor for success: “shut-in” period without immediate flow-back

Gained / regained the Productivity while 6 month shut-in with a half of the acid left

Productivity Index (KL/D/Mpa):

0.3 ⇒ (30) ⇒ (5) ⇒ 18
Why matrix contribution?

Qtz-porcelanite reservoirs of the acidized zone typically showing white & black banding same horizon in a well nearby (Ayukawa-kita)
Core analysis of the core above
Changing our mind as “hybrid” shale?

Bakken vs Onnagawa as hybrid shale (key for tight oil)

Bakken
- 5 - 10 %
- 0.1 md

TOC 11 %

Onnagawa/Monterey
- Φ 15 - 30 %
- k 0.1 md

reservoir

better source

TOC 3 ~ 2 %
Current understanding

Two main factors of commercial “tight oil” ;

- Successful acid stimulation of carbonate-cemented fractures, whose effect is estimated to be equivalent to that of a bi-wing artificial fracture several tens meters long.
- Matrix pores of Qtz-porcelanite, which pore size are comparable to that of common productive shales such as Bakken.

Although this is the first case of acidizing for this type of reservoir, we can expect a stimulation performance similar to hydraulic fracturing under certain conditions, which includes good matrix porosity with cemented natural fractures. (it is not rare)

We are now modeling our unusual acidizing job with a simulator, expecting further application as a cost-effective tool.

Simply speaking, we are going to use acidizing in stead of costly fracturing.
• What we have done for shale oil exploration in the Onnagawa

• What we have learned as source rock and reservoir stimulation technology

• Where are we going? How to explore? How to evaluate the potential?
Ayukawa oil & gas field
(subsurface structure map: top of Onnagawa shale)

Mid-term target: back to Ayukawa
(original plan)

1st area for development
horizontal well with stimulation
next candidates
(following sweet spot prediction)

“tight oil” with some productivity

Yurihara field

Kurosawa

Ayukawa oil & gas field
(subsurface structure map: top of Onnagawa shale)

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“tight oil” with some productivity
Ayukawa oil & gas field
(subsurface structure map: top of Onnagawa shale)

Mid-term target: back to Ayukawa

“tight oil” with some productivity

More acidizing!
- From the perspective of exploration, we are still in a conventional trap around the top of oil window, developing slightly-migrated oil.
- For further exploration, we shall go in deeper parts of the basin, expecting continuous accumulation,

**Conventional vs Continuous Resources**

**Continuous Shale Accumulations**

Future Exploration, where?

Our goal: Kitchen with much more oil

**Requirement**... the shale is now, or was at sometime in its history, within the oil or gas generation window
Future Exploration, where?

How is Bakken Shale after all?

"conventional vs continuous"
⇒ conventional ~ continuous

So, where is sweet spots?
⇒ conventional first anyway

Oil migration to conventional traps in part, just like "conventional"

modified from Theloy & Sonnenberg, 2013
Stepping out from Ayukawa to the kitchen (Nikaho sub-basin) to explore “continuous accumulation”; Shallower conventional traps first probably.

Small oil production from Onnagawa shale In these wells

(JOGMEC—JAPEX, 2015)
For further exploration in deeper parts of the basin, the preservation of matrix pores in porcelanite will be a critical issue.

We do not know much about this domain. But we may have a chance.

Targeting range so far; 
(CT/Qz change level) + 1000m
Continuity of “the best source” through the whole basin

**Well 1 in Ayukawa**

<table>
<thead>
<tr>
<th></th>
<th>TOC (%)</th>
<th>S2 (mg/g)</th>
<th>H.I. (mgHC/TOC)</th>
<th>Tmax (°C)</th>
<th>S1 (mg/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>2.468</td>
<td>420-440</td>
<td>4.99</td>
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Acidizing horizon

**Onnagawa**

**Well 2**

**Well 3**

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</tr>
</tbody>
</table>

**Well 3, 1, 2**

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図5 中新世中期末～後期初の堆積盆地、飯坂, 中～下部深海
How to evaluate the potential?

• It’s still under discussion.

Some comments with reference to UnCon Project Phase II mission;
• Our shale is “semi-conventional” reservoir
  ⇒ volumetric estimation with 1st priority

We however need some cut-off;
  source rock potential ⇒ horizon/interval cut-off
  reservoir property ⇒ “net”: “white / clean” porcelantite clastic = tight conventional reservoir

• For recoverable reserves estimation (final goal)
  ⇒ Only one type curve so far, so little information about RF.

We however can say it is comparable to “major” tight oil in terms of reservoir property / productivity.
Discussion on Recovery Efficiency Factor

SRV (stimulated reservoir volume) estimation with "SHIFT": flow simulator + fracturing simulator

Example: permeability enhancement
Discussion:
Recovery efficiency factor

"Shale acidizing"
Stimulate natural fracture
dissolve minerals / open frac.
(above initial condition)

Shale
(best source)

SRV*

OOIP:
\[
\pi \times 100^2 \times 40 \times 0.3 \times 0.5 = 188,000 \text{ KL}
\]
(S) (net) (Φ) (So)

COP: 17,000 KL, so far

→ RF. = 10% -
• assuming negligible contribution
  from outside of the SRV

r = 50m
(* 100% cemented case)

→ 100m
Thank you for your kind attention.

謝謝你的關注
경청 해 주셔서 감사합니다
Terima kasih atas perhatiannya
ขอขอบคุณสำหรับความสนใจของคุณ
សូមអរគុណចំពោះការយកចិត្តទុកដាក់របស់អនក

* Sorry for not fully covered.