A method for shale gas resource assessment: a case study of Jinju Shale, Gyeongsang Basin

CCOP-KIGAM Unconventional Oil & Gas Project
Mapping of Black Shale Formations for the Prediction of Shale Resources

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Introduction

• Methodology for basin- and formation-level assessment of shale gas resource includes the following topics
  - Conducting geologic characterization of basins and shale formations
  - Establishing the areal extent of the target shale formations
  - Defining the prospective area for shale gas formation
  - Estimating the risked shale gas in-place

• These assessment steps for the shale gas resource apply to the Jinju Formation in the Gyeongsang Basin as a case study
• The Korean peninsula is an important tectonic link between eastern China and the Japanese Arc

• In the Cretaceous, it was located behind the magmatic arc due to subduction of the proto-Pacific plate beneath the Asian continent, forming a number of non-marine basins
- The basin-fill: a thick succession of non-marine sedimentary rocks and diverse volcanic deposits
- Depositional setting: alluvial, fluvial, or lacustrine environments
- Formation boundary: distinct change in mud rock color
Overview – Jinju Formation

- Basin-fills: fluvio-lacustrine rocks up to 9,000 m thick
- Target Fm.: Jinju Fm., organic-rich shale up to 1,200 m thick

(KIGAM, 2015)
Overview – methodology

- Workflow for shale gas resource assessment (BGS)

Seismic data
Outcrop - stratigraphy, lithology & structure
Wells - stratigraphy & lithology
Structural and palaeogeographical model

Well & model-driven
Organic carbon

Maturity data from wells & outcrop inc new BGS analyses
Burial history

- gross rock volume
- shale percentage
- net shale volume

- maturity cut-off
- net mature shale volume

- apply depth cut-off from US data
- final mature shale volume

- final mature shale volume
  Gas-filled porosity
  Depth/pressure

- final mature shale volume
  Bulk density
  Adsorbed gas content
  Reservoir pressure

Free gas + Adsorbed gas = total in-place gas volume
• The Jinju Formation is generally undeformed, consistently dipping eastward to southeastward at low angles
Gross rock volume – Jinju Formation

- Jinju Formation formed during early stage of the basin development
- Its deposition was confined to narrow, NE-trending graben

Assumption for constructing 3D structural grid model of Jinju Formation
- Dip angle: 10 – 15 degree, dipping to E or SE
- Thickness: 1,000 – 1,800 m
- Location of graben-bounding fault
- 3D structural grid model
• 3D structural grid model
Net organic-rich shale volume – Jinju Formation

- Total Organic Carbon (TOC) : < 2%
- Percentage of organic-rich shale = 12%
- Organic type is poorly defined in modified van Krevelen diagram due to low S₂ value: Type III/IV

(KIGAM, 2015)
Net mature shale volume – Jinju Formation

- Thermal maturity of organic matter: over-mature

<table>
<thead>
<tr>
<th>Area</th>
<th>Vitrinite reflectance ($R_o$ random, %)</th>
<th>Tem. ℃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euiseong</td>
<td>2.62 - 4.98 (average = 3.60)</td>
<td>238</td>
</tr>
<tr>
<td>Daegu</td>
<td>2.51 - 3.80 (average = 3.25)</td>
<td>230</td>
</tr>
<tr>
<td>Hapcheon</td>
<td>3.51 - 4.27 (average = 3.93)</td>
<td>245</td>
</tr>
<tr>
<td>Jinju</td>
<td>2.54 - 3.71 (average = 3.09)</td>
<td>226</td>
</tr>
</tbody>
</table>

- Coal rank: Anthracite (over-mature)
- Fission Track analysis
  - Burial depth of the Gyeongsang Basin: 8 km
  - Burial Temperature: about 200 ℃
- **Gas rarely remains in the formation**
  
  ➔ Effect of metamorphic intrusion and deep burial
Net mature shale volume – Jinju Formation

- Apply a depth cut-off: below the depth where $R_o = 1.1\%$, present-day depth to top gas window

Pennine Basin, UK

Gyeongsang Basin, Korea

(KIGAM, 2015)
• Jinju Shale is over-matured in the present-day
• Assume mature shale preserved between 2,000 and 4,000 m below surface
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Free Gas-in-Place Volume

- Method: \( GRV \times N/G \times \text{Porosity} \times (1-S_w) \times (1/B_g) \)
- Input parameter

<table>
<thead>
<tr>
<th>GRV (m³)</th>
<th>N/G</th>
<th>Porosity</th>
<th>S_w</th>
<th>B_g</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1824 \times 10^{12}</td>
<td>0.12</td>
<td>0.017</td>
<td>0.3</td>
<td>0.00413</td>
</tr>
</tbody>
</table>

- GRV includes the interval between 2,000 and 4,000 m
- N/G represents a percentage of organic-rich shale
- \( B_g \) is calculated, assuming that formation temperature and pressure at depth of 3,000 m are 72 °C and 29.4 MPa
- Free gas-in-place volume = 7.55129 \times 10^{11} m³ (26 TCF)
Adsorbed Gas-in-Place Volume

\[ GIIP_{a} = A \times h \times \rho \times G \]

Where:
- \( A \) = area
- \( h \) = thickness
- \( \rho \) = rock density (analogue used, 2.55-2.6-2.65 g/cm\(^3\))
- \( G \) = adsorbed gas content of shale (volume of gas/weight of shale) (analogue used, 0.5 – 2.0 m\(^3\)/ton)
Adsorbed Gas-in-Place Volume

- Adsorbed gas content of shale (G)

\[ G = \frac{G_l \cdot P}{P_l + P} \]

Need experimental analysis of core samples to gain:

- \( G_l \) = Langmuir volume (volume of adsorbed gas at infinite pressure)
- \( P_l \) = Langmuir pressure (pressure where one-half of the gas at infinite pressure has been desorbed)
- \( P \) = Reservoir pressure
Example: adsorbed gas content of Jinju shale

Reservoir pressure = 4262@3000 m (hydrostatic)

$G$ of sample 7: \( \frac{102 \times 4262}{900 + 4262} = 84 \text{ scf/ton} \) (2.4 m$^3$/ton)

\[ G = \frac{\text{Langmuir volume} \times \text{RES p}}{\text{Langmuir pressure} + \text{RES p}} \]
Adsorbed Gas-in-Place Volume

- Method: mature shale volume \times \text{density} \times G
- Input parameter

<table>
<thead>
<tr>
<th>GRV (m$^3$)</th>
<th>Mature shale volume (m$^3$)</th>
<th>Density (g/cm$^3$)</th>
<th>G (m$^3$/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1824 \times 10^{12}</td>
<td>2.61888 \times 10^{11}</td>
<td>2.6</td>
<td>2.4</td>
</tr>
</tbody>
</table>

- GRV includes the interval between 2,000 and 4,000 m
- Adsorbed gas-in-place volume = 1.61963 \times 10^{12} m^3 (57 TCF)

Total gas in-place volume of Jinju Fm.: 26 TCF + 57 TCF = 83 TCF
Summary

• Jinju Formation has good TOC in general, but it has low shale gas potential because its organic matter is over-matured
• BGS’s workflow is useful to assess basin- and formation-level assessment of shale gas resource
• Many assumptions are used to calculate shale gas in-place volume of the Jinju Formation due to the lack of exploration data
• It is necessary to compile surface and subsurface geological data (e.g., geologic/structural/thickness maps and cross-section) in order to reduce major uncertainty derived from the formation volume calculation
Thank You