Lithium Brines: What can we learn from established brine production regions?
An Overview Of Lithium Brine Exploration for Resource Estimation

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Lithium Brine Deposits

Bradley et al., 2013
Geology Of Salars: Mature and Immature

Houston et al. (2011)
Brine Resource: Challenges

• Dynamic resource: it flows either naturally or by pumping
• Weather: precipitation can affect grade distribution
• Resource volume
  1. How to define resource lateral limits?
  2. How to link aquifer lithology with brine grade?
  3. Effective porosity, Sy or Ss?
• Dilution: fresh water lateral inflow (recharge)
Brine Resource: Classification

**Inferred**
- Secondary permeability, low confidence in hydraulic connectivity and/or grade

**Indicated**
- Physical evidence of sufficient hydraulic conductivity and transmissivity, statistical confidence in grade

**Measured**
- Technical and consistent support resulting in 3D model of hydro-lithology and grade

Increasing level of hydrogeological knowledge and confidence
Mineral Resource and Reserve Reporting For Brine Deposits

Application of Hydrogeological Concepts
Brine Volume

Brine volume / grade distribution

- Geological mapping
- Surface brine sampling: pitting
- Geophysics (e.g. geoelectrics, CSAMT)
- Diamond drilling: core and brine sampling
- Downhole lithology / geophysics
Aquifer Characterisation

Brine aquifer characterisation

- **Sy**: ex-situ lab testing on cores (e.g. Relative Brine Release Capacity, RBRC)
- **Hydraulic conductivity, Ss, anisotropy**: field hydraulic testing
- **Dispersivity**: field tracer tests
- **Dilution potential**: fresh water balance

*Houston et al., 2011*

\[
T_p > E_p; \ E_p = S_y + S_r
\]

*Stormont et al., 2011*
### Ex-situ Sy by RBRC: Typical values

<table>
<thead>
<tr>
<th></th>
<th>$P_t$ site lab</th>
<th>$P_t$ BGS lab</th>
<th>$P_e$ BGS lab</th>
<th>$S_y$ BGS lab</th>
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<tr>
<td></td>
<td>mean</td>
<td>SD</td>
<td>mean</td>
<td>SD</td>
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<tr>
<td>Sand dominant</td>
<td>0.31 (\pm 0.06)</td>
<td>0.32 (\pm 0.08)</td>
<td>0.26 (\pm 0.07)</td>
<td>0.13 (\pm 0.07)</td>
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<tr>
<td>Silt &amp; sand-clay mixes</td>
<td>0.37 (\pm 0.08)</td>
<td>0.38 (\pm 0.11)</td>
<td>0.32 (\pm 0.09)</td>
<td>0.06 (\pm 0.04)</td>
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<td>Clay dominant</td>
<td>0.42 (\pm 0.07)</td>
<td>0.44 (\pm 0.06)</td>
<td>0.37 (\pm 0.06)</td>
<td>0.02 (\pm 0.02)</td>
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<tr>
<td>Halite dominant</td>
<td>0.27 (\pm 0.14)</td>
<td>0.29 (\pm 0.10)</td>
<td>nd</td>
<td>nd</td>
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</table>

Source: Hydrominex Geoscience Consulting
In-situ Aquifer Characterisation

Constant rate pumping test
• Transmissivity / hydraulic conductivity
• \textit{In-situ} Sy, Ss

Step-drawdown pumping test
• Well efficiency
• Predictive analysis
Aquifer Anisotropy

Directionally controls drawdown propagation and brine movement

Please assess anisotropy and be a good neighbour!
Brine Resource

Brine chemistry / quality

3D grade distribution: Li, K, Mg, B; SO4, CO3 etc.

QA/QC program: representability, comparability, reproducibility, precision

Key chemical ratios: Mg/Li (<10), SO4/Li (<30), B/Li (<3)
Brine Resource: Geological Model

In situ drainable resource model:
- Geology + geophysics
- Core lithology + hole geophysics
- Lab and field $S_y$, $S_s$
- Hydrostratigraphic units
- Brine chemistry
- Geostatistics
Lithium Brine: Key points

- Diamond drilling exploration: the expert is the geologist
- Classic hydrogeology applied to hyper-saline solutions
- Brine reservoir assessment based on petrophysics and aquifer hydraulics
- Continuous brine quality assessment
- Main extraction mining engineer: Hydrogeologist
- Main process mining engineer: Chemical Engineer
- Main mine planning tool: Groundwater / solute transport numerical model
- Dynamic modeling: update and calibration throughout the LoM
We have a resource, but do we have a reserve?

Thank you for listening
Development of Lithium Brine Projects

Pablo Cortegoso, M.Eng. - SRK Consulting US
Perth, WA - August 16th, 2016

pcortegoso@srk.com
Why brines?

Why not???

No miners

No mining engineers

Low environmental impact

Low OPEX

Byproduct potential

Low surface impact

No miners
Lithium Resources

Contained Resources as Li metal (tonnes)

Brine
Non Brine

Small
Medium
Large
Extra Large
Lithium Brine Deposits - Overall

Bubble size represents Reported Contained Tonnes of Li Resources
Brine vs Hard Rock Evaluation

**Hard Rock**
- Tonnes
- Grade

**Brines**
- Extractable brine volume = $V_{\text{aquifer}} \times Sy$
- Average brine chemistry
- Permeability which determines brine hydraulic conductivity and transmissivity, to factor how fast the brine can be extracted
Brine Resource Estimate Model

\[ G_{xyz} = S_y^{zxy} \cdot C^{zxy} \cdot b^{zxy} \]

Where,

- \( G^{zxy} \) : Unit Volume tonnage in \( xyz \)
- \( S_y^{zxy} \) : Specific yield in \( xyz \)
- \( C^{zxy} \) : Elemental concentration in \( xyz \)
- \( b^{zxy} \) : Unit “thickness”

RESOURCES is the sum of \( G^{zxy} \)
Factors that matter - Extractability

Production Well

Initial brine elevation

Specific retention loss, $S_r$

Loss due to minimum well drawdown

Reserve base subject to an in-situ recovery factor

Brine elevation during exploitation
Factors that matter - Porosity

\[ Pt > Pe \ ; \ Pe = Sy + Sr \]
Porosity: JORC vs 43-101

CIM 43-101

• Guidance updated for brines in 2012
• Requires Sy to be determined using two independent methodologies

JORC

• JORC Table 1 does not include all items significant for brines, or for crystalline evaporites in brine/evaporite systems.
• Could use Total Porosity to estimate a brine resource
Numerical GW Model

Year 0

Year 20

Year 100
Mine planning tool

(a) Predicted Total Pumping Rate and Average Drawdown in Brine Extraction Wells

- Total Pumping Rate to Achieve Target Production
- Simulated Average Drawdown in Brine Extraction Wells

(b) Predicted Average Concentration of Li, K, and B

- Li
- B
- K

Quantity

Quality
Interpretation of MRMR studies applied to brine deposits

MRMR – Mineral Resource and/or Mineral Reserves
An interpretation of mineral resource classification

Increasing level of geological knowledge and confidence

**Inferred**
Secondary permeability, low confidence in hydraulic connectivity and/or grade

**Indicated**
Physical evidence of sufficient hydraulic conductivity and transmissivity, statistical confidence in grade

**Measured**
Technical and consistent support resulting in 3D model of hydro-lithology and grade
CIM Definition of Mineral Reserve (May 20, 2014)

A Mineral Reserve is the economically mineable part of a Measured and/or Indicated Mineral Resource. It includes diluting materials and allowances for losses, which may occur when the material is mined or extracted and is defined by studies at Pre-Feasibility or Feasibility level as appropriate that include application of Modifying Factors. Such studies demonstrate that, at the time of reporting, extraction could reasonably be justified.
Mineral resource to mineral reserve for brine deposits

**Indicated**
Physical evidence of sufficient hydraulic conductivity and transmissivity, statistical confidence in grade

**Probable**
Long term model predictions (e.g., after 5 years), lower confidence in-situ recovery

**Measured**
Technical and consistent support resulting in 3D model of hydro-lithology and grade

**Proven**
Short term model predictions (e.g., less than 5 years), higher confidence in-situ recovery

Modifying Factors: consideration of mining, processing, economics, marketing, legal, environmental, social and governmental factors
Your mineral reserve estimate should…

• Account for in-situ recovery factors for raw brine extraction from the salar
• Be limited to measured and indicated mineral resource classifications
• Include ex-situ recovery factors which must be offset by additional raw brine extraction
• Address spent brine handling and/or process water supply which may impact predicted mine life
• **Remain economic**
Traditional Brine Process

SQM Ponds, Atacama, Chile

Salar del Rincon, NW Argentina
Value Creation

Investment $

Stage of Project Development

- Start-up/Commissioning
- Detailed Engineering
- Interesting geological anomaly
- PFS Reserve
- QP/CP Resource Report
- PEA/Scoping Study
- FS Reserve
- Construction
- Target Production

Start-up/Commissioning
Detailed Engineering
Interesting geological anomaly
PFS Reserve
QP/CP Resource Report
PEA/Scoping Study
FS Reserve
Construction
Target Production
### Lithium Brine Projects Development Timeline

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<th>Step</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
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<td>Start-up/ Commissioning</td>
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<td>Target Production</td>
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• Brine moves!
• Brines can be very profitable
• Technically complex to explore and estimate resources
• Transition from Static Resource to Dynamic Resource using the continuum of geologic stratigraphy through the use of sequence stratigraphy and onto the final use of HSU’s
• Choice of process that fits the situation, brine chemistry, weather, etc.
• Take good care of your hydrogeologist, you will thank him later