Probabilistic Geologic Models of Krafla Constrained by Gravimetric Data

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Motivation

• Geologic models communicate understanding of subsurface structure
• Usually only display one possible interpretation
• Need for geologic models that convey uncertainty
• Integrating geophysical data into model building process

Approach

• Gravimetric data constrain lithology and density structure
• Reference geologic model from ÍSOR (2015)
• Statistical treatment of rock properties (density, porosity)
• Bayesian inference scheme (MCMC) implemented in GeoModeller
Krafla geothermal system

Gravity data from Magnússon (2016)
Reference Geologic Model

Original Petrel model (ÍSOR, 2015) rebuilt in GeoModeller
Rock properties

<table>
<thead>
<tr>
<th></th>
<th>Bulk wet density [g cm(^3)]</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Hyaloclastite</td>
<td>2.30</td>
</tr>
<tr>
<td>Lava flow</td>
<td>2.66</td>
</tr>
<tr>
<td>Basement intrusions</td>
<td>2.74</td>
</tr>
</tbody>
</table>

- Icelandic Rock Property Database (ÍSOR and Landsvirkjun)
- Bulk wet density assumes constant fluid density (0.75 g cm\(^3\))
- Prior assumption: assume bulk wet densities are normally distributed
MCMC Stochastic Inversion Scheme

- Initialize density distribution based on lithology
- Compute gravity response of model
- Select random voxel, postulate change to model
- Compute gravity response of new model
- Using gravity misfit, compute likelihood of changed model
- Randomly, also accept some models that are worse fit

\[ p(\text{model}|\text{data}) \propto p(\text{data}|\text{model}) \cdot p(\text{model}) \]

**Posterior** probability of parameter values given observed data

**Likelihood** to observe data, given parameters

**Prior** probability of uncertain parameters (density and lithology)
Evolution of gravity misfit (RMSD)
Gravity

Observed

Calculated (final)

Bouguer Anomaly [mgal]
Posterior probability - lithology
‘Most probable’ model
Uncertainty Quantification

\[ H = - \sum_{i}^{N} p_i \log p_i \]
Possible causes of ESE-WNW gravity low

Spearman correlation = 0.53
Pearson correlation = 0.54

Hyaloclastite density

Mean Hyaloclastite Density [g cm\(^{-3}\)]

Thickness of hy.
Summary

Probabilistic geologic models show:

- Multiple model realizations may be consistent with geophysical data
- High uncertainty near lithologic boundaries
- Quantitative links between geophysics and geology

Gravity potential field data unable to resolve deep (>1.5 km) density structure.

**Speculation:** ESE-WNW oriented gravity low with low-density hyaloclastites may indicate buried fault that acts as barrier to fluid circulation and restricts alteration

Better laboratory measurements of the effect of alteration on rock properties (resistivity, density) is necessary to use electro-magnetic field data (MT) as an additional constraint.
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New ‘reference’ model with intrusion

Intrusion (µ = 2.5 g cm$^{-3}$, σ = 0.05)
Inversion Results – with intrusion

Calculated
Revisiting the reference model