Challenges and Advancements Associated with Deep Drilling in Crystalline Geothermal Systems

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Drilling in Deep Crystalline Environment

- **Depth exceeding 2000 m depth**
- **High Temperature exceeding 200 C**
- **Volcanic rock types varying between basalts, andesites, rhyolites**
- **Drilling with high uncertainty**

Associated Challenges:

- Overheating of drilling fluids
- Temperature limitation on tools used
- Drill cuttings that are not returned to surface – “blind drilling”
- Land and landscape effects
- Noise pollution
- CO_2 and H_2S emission
- Limited research in crystalline geothermal systems

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- **Temperature limitations of the geophysics logging tools:** mud temperature over 180 C limits the number and type of measured parameters.
- **"Blind drilling" in crystalline environments:** no cuttings to show what rock type is being drilled, increases uncertainty and risk, and increases cost of drilling due to limited experience drilling in, and high variability of, crystalline rock types.

Ice houses (iglos) covering the producing wells in Krafla

- **Technological developments using artificial intelligence:** will reduce dependency of data analysis on rock cuttings from the subsurface.
- **Technological developments in logging tools:** such as high-temperature, real-time logging while drilling (LWD) are necessary for geothermal exploration and exploitation; tools that predict the rock ahead of the bit would be a real game changer.
- **Machine Learning Algorithms:** will help correlate between real time logging data and drilling data to predict type of rock being excavated.
- **Understanding the rock-bit interaction:** through the correlation between logging and drilling data will help differentiate between bit wearing challenges and drilling problems.

Viti Crater

- **High reservoir temperature heats up the mud** used as a drilling fluid, which is used to clean up the whole while drilling from excavated rocks.
- Heating the mud results in **changing the mud properties and its effectiveness** in cleaning the drill hole.
- **Solution: mud coolers** are used to regulate the temperature of the mud returned to surface.

Misconceptions from oil and gas industry

- **Destruction of land and scenery views** is absent in Iceland as the production wells are nicely covered with igloos and abandoned wells are impossible to identify. Furthermore, the power plants are tourist and farm friendly. This was easy to notice in Krafla where the plant and Viti crater are accessible for tourists, and in Theisteryeker where cows and sheep farms are meters away from the plant.
- **Land deformation due to geothermal exploitation as subsidence and uplift** are carefully monitored and have magnitude of millimetres.
- **Induced seismicity** in Iceland is not due to geothermal exploration and exploitation, however its mainly due to the volcanic activity!

Emission CO_2e	grams CO2e/kwh
Krafla CO_2e tonne	55
Þeistareykir CO_2e tonne	10

Emission H2S	Grams H2S/kwh
Krafla H2S tonne	9
Þeistareykir H2S tonne	4

- **Noise pollution** due to steam flashing especially close to residential areas is reduced by using large mobile separators, which works like a muffler in a car.
- **CO_2 and H_2S gas emissions** from geothermal plants are considerably less than from oil and gas. The highest CO_2 emitting field in Iceland is Krafla, with 55 g/kwh, compared to 185 g/kwh for natural gas, and over 900 g/kwh for coal. Efforts are being made now to reinject CO_2 into the volcanic rocks in the subsurface and turn it into calcite to further reduce the CO_2 emissions. Furthermore, Iceland has a regulation to limit the H_2S level in the atmosphere to below 50 µg/m³, and it is by monitored it every hour to ensure that this limit is not exceeded.

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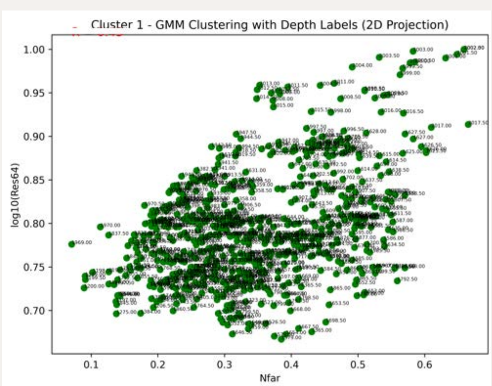
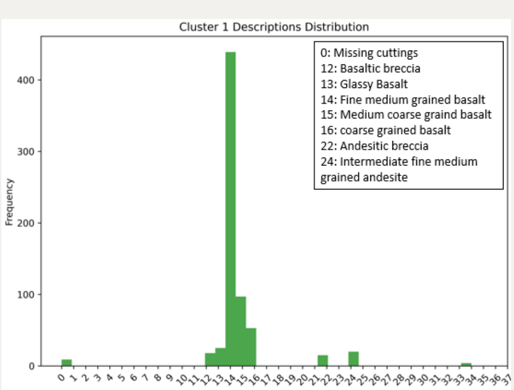
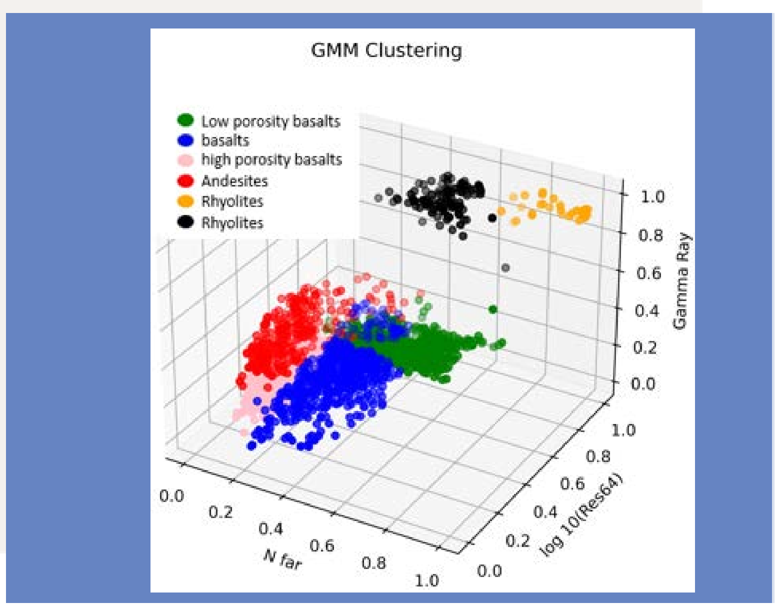
Advancements in process!

- Additional data and knowledge have been acquired during the STSM which pushed the project on developing a machine learning tool to help predict rock types independent of cuttings from the well.
- Using machine learning to process geophysical well log data that is limited due to high temperature it was possible to effectively cluster the rocks throughout the IDDP-1 wellbore into broad classes of igneous rock types including mafic, intermediate and felsic. We also achieved a distinct differentiation between the upper and lower reservoir and lower and higher porosity mafic rocks.
- The results obtained help in predicting the rock types where cuttings are missing and therefore regenerate a complete lithology log.
- The results obtained will provide valuable support for the next drilling stage by offering insight into the depth and nature of the encountered rock types, lithological boundaries and rock-magma interface.
- This will be possible to achieve without the need to wait for the cuttings to emerge from the well to the surface, utilizing real time logging (LWD) and drilling data.







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