Reversing Carbon Emissions in the Geothermal Energy Industry Project: A Geoscience Perspective

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ABSTRACT

This research aims to help reduce Green House Gas (GHG) emissions by creating processes that will enable trapping gases, especially CO_2, in solid form while boosting the fluid production from geothermal resources. This will require characterising the unique geochemical, geological, petrophysical, and fluid dynamic properties to investigate potential mechanisms for trapping GHGs, to allow negative-emission energy generation.

CO_2 entrapment is favoured when there are significant quantities of available cations for chemical and mineralogical reactions to take place. We will build a pressure chamber to conduct laboratory experiments on typical Taupo Volcanic Zone geothermal host rocks placed inside the chamber. The novel part of this programme involves an approach based on injecting chemical agents into the pressure chamber to increase the quantity of available cations, which will encourage permanent entrapment of GHG.

The availability of reactive surface areas is also an important control of chemical and mineralogical reactions. Rock characteristics, such as textures, voids, crystal size, and shape, all play a role in enhancing or inhibiting reactions. We will assess the suitability of various TVZ host rocks for GHG entrapment. The programme involves an innovative multi-step process designed to document the elemental composition, textural characteristics, and mineralogy of rocks pre-, during, and post-pressure chamber conditions. Laboratory analyses will include X-Ray Diffraction, Scanning Electron Microscopy, Energy Dispersive Spectroscopy, Computerised Tomography, and chamber fluid analyses. This will enable the most suitable TVZ Formations to be targeted for our field trials and determine the optimal chemical agents required for injection that will favour permanent GHG entrapment. The programme is further supported by modelling the predictive behaviour of chemical reactions based on our laboratory results and field trials. As our programme advances during field trials, we plan to monitor the GHG storage capability of various TVZ rock formations.

1. INTRODUCTION

Aotearoa, New Zealand, is taking significant steps towards addressing climate change and reducing its environmental impact. The nation has set a goal to achieve a 50% reduction in net greenhouse gas emissions by 2030, as outlined during the UN's COP26 climate summit. To drive this transition, the Renewable Energy Strategy has been established, focusing on both expanding the energy supply and transitioning to a net-zero carbon emissions status by 2050. The Geoheat Strategy aims to bolster the energy supply by adding 7.5PJ per annum through the implementation of new geothermal energy projects by 2030.

Geothermal fluid carries several magmatic -originated gases, including >90% CO_2 along with smaller quantities of H_2S, NH_3, CH_4, and H_2. These gases are currently captured undiluted (without mixing with the air) in the steam condensers. Geothermal wastewater offers the opportunity to dissolve and permanently capture the GHG before reinjection. This has been the focus of several international trials, e.g., Iceland (Gislason et al. 2018), USA (Richard, 1990), Japan (Yanagisawa, 2010 and Kaieda et al. 2009), Türkiye (Yücetaş et al. 2018), and The Philippines (Joselito et al. 2005).

Some of these trials rely on the mineral entrapment of these gases in specific deep geological formations, such as basalt (Gislason et al. 2018). The potential for CO_2 sequestration in basalts was also investigated by McGrail et al. (2006), Matter et al. (2007), and Snæbjornsdottir et al. 2014 in the United States and Iceland, on land and offshore. Keeping CO_2 underground in mineral form is important for long-term storage because mineralization provides a stable and predictable means of storing CO_2. It significantly reduces the volume of stored CO_2, and mitigates the risks associated with potential CO_2 leakage, migration, and associated operational and environmental impacts.

The effectiveness and permanence of CO_2 storage in geological structures depend on the interplay of structural, stratigraphic, solubility, and mineral trapping mechanisms. Field characterisation, geochemical and geophysical monitoring, understanding the fluid-rock interactions and numerical modeling, including reactive transport, are essential tools to assess and predict the behavior of CO_2 within the reservoir.

In the scope of this programme, we will implement these concepts in non-ideal rock formations through incorporating chemical modifications such as introducing supplementary materials, specific ions into the reinjected water, as well as adjusting the pH. This approach aims to promote the desired fluid-rock interaction necessary for permanent storage through mineral entrapment.

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We have designed and are in the process of constructing instrumentation for a complex laboratory setup. The experimental configuration facilitates concurrent investigation of multiple parameters. It includes:

- An advanced dissolution reactor (adsorption column) designed for studying NCG dissolution in water.
- A dedicated corrosion testing chamber devised for testing diverse metals and alloys within varying fluid mixtures.
- A reactor capable of reaching temperatures up to 200 °C to allow testing of different chemical additives and various rock types.

In collaboration with our industry partners, we are actively working on assessing the reactive fluid flow and geochemical transport to make decisions on their strategies (i.e. for reinjection rates, fluid composition and temperatures of the reinjection fluid) for their operations. We have been creating 1D, 2D numerical models which can serve as a tool for investigating fluid-rock interaction parameters within reservoir-scale investigations (Kaya, 2021; Castillo Ruiz et al. 2021; Altar and Kaya 2023). These models also investigate fluid-rock interaction parameters in large scale fractured media, potential precipitation and trapping mechanisms, and corrosion risks, all in the context of assessing the impact of NCG on geological formations representative of New Zealand geothermal reservoirs. This comprehensive approach also allows us to identify primary and secondary minerals that have been identified in the various host rocks common in the diverse reservoir rocks prevalent within the Taupo Volcanic Zone (TVZ) geothermal systems.

We have also been working on creating a generic 3D large-scale numerical reactive transport model. This model is designed to serve as a tool for investigating the development of geothermal reservoirs over time, including mineral alteration sequences, locations of mineral deposits, fluid chemistry evolution and their effects to porosity and permeability. This model also aimed to explore the potential applications of reactive transport modelling to resource management as well as CO2 sequestration potential.

2. PREVIOUS MINERALOGICAL STUDIES THAT SUPPORT THIS PROJECT

To complement existing information from the literature, the PhD students will have access to previous mineralogical studies undertaken by their co-supervisor, Bridget Lynne. These mineralogical analyses were performed on core from a range of Formations from geothermal fields located within the TVZ, New Zealand. Mineralogical analyses included Scanning Electron Microscopy, Energy Dispersive Spectroscopy, petrographic thin sections, X-Ray Diffraction and Computerised Tomography (Figs. 1-4). Cored samples from other TVZ geothermal fields are also available for laboratory experiments. Figures 1 to 4 provide examples of our existing analytical results already available to support this project. They also highlight the variability of the TVZ geothermal host rocks. Using our previous analytical results will decrease the time required to establish the most suitable rock samples for our pressure chamber laboratory experiments.

From a broad TVZ host rock perspective, these existing mineralogical and chemical analyses can be used to:

- Create a database of TVZ host rock mineralogies and textures that are likely to be used during laboratory experiments.

- Create an elemental composition database of the various TVZ geothermal host rocks. This will identify Formations with the most suitable chemical composition for CO_2 injection.

- Establish the degree of variability within specific TVZ rock Formations (mineralogies, lithologies, textures and elemental compositions), which will need to be considered for both laboratory and field experiments.

Of further relevance to the project is that some of the TVZ core analyses were undertaken on the Waiora Formation (Lynne, 2010). Currently the Waiora Formation is used for injection at one of New Zealand's geothermal fields Jober et al., (2011) documented the stratigraphy of this injection well. Their lithologic descriptions document lithologic and mineralogic variability within the Waiora Formation.

Our mineralogical, textural and elemental compositional analyses already completed on core from wells within the Waiora Formation, will provide important rock compositional information critical to our laboratory experiments (Lynne 2010). This supporting database of information is beneficial for the project in the following ways:

- Enables the PhD students to focus on a host rock Formation already in use as an injection Formation in the TVZ, making the project commercially-applicable.

- Provides the PhD students with immediate access to relevant mineralogical, textural and compositional information that will directly assist in their laboratory trials and choice of rocks to use.

- Advances the project rapidly, by enabling critical pre-laboratory experimental assessment of potential rock-CO_2 chemical reactions, based on existing Tauhara core elemental compositional analyses.

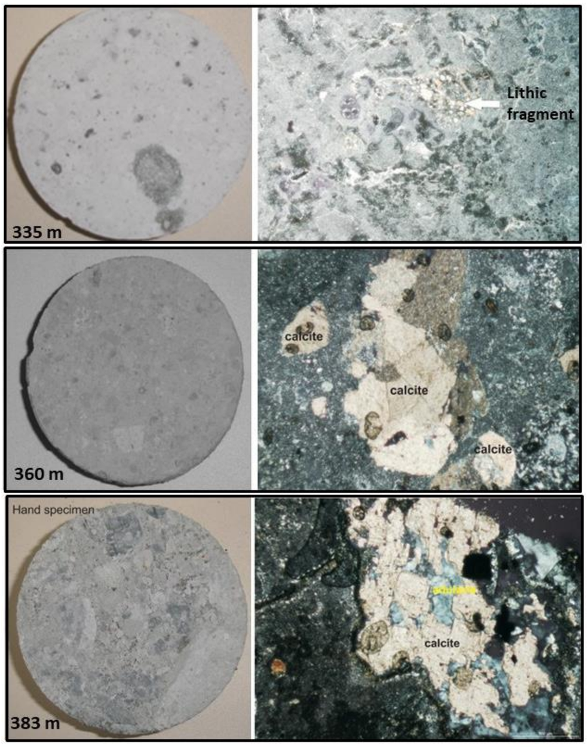

Figure 1: Cores from different depths within the Waiora Formation, showing differences/similarities in texture and mineralogy. Left: Core photographs. Right: Petrographic thin section images (Lynne, 2010).

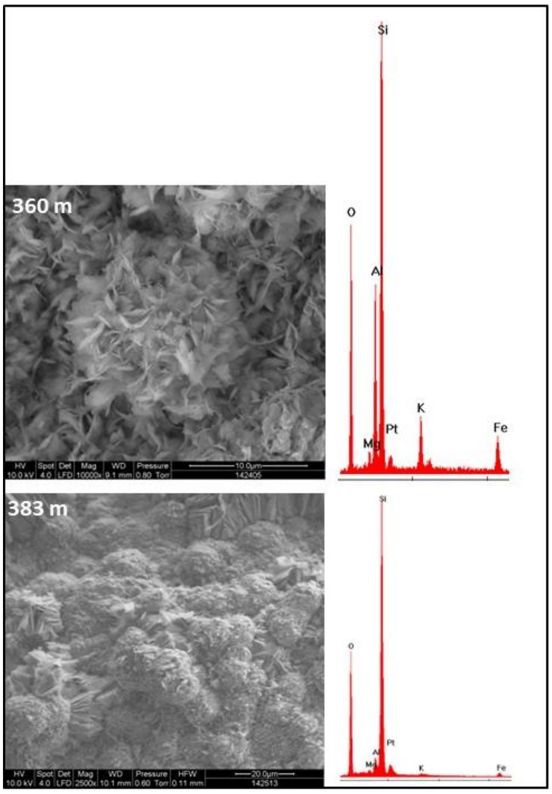

Figure 2: Differences in clay mineralogy and elemental composition within the Waiora Formation, (Lynne 2010).

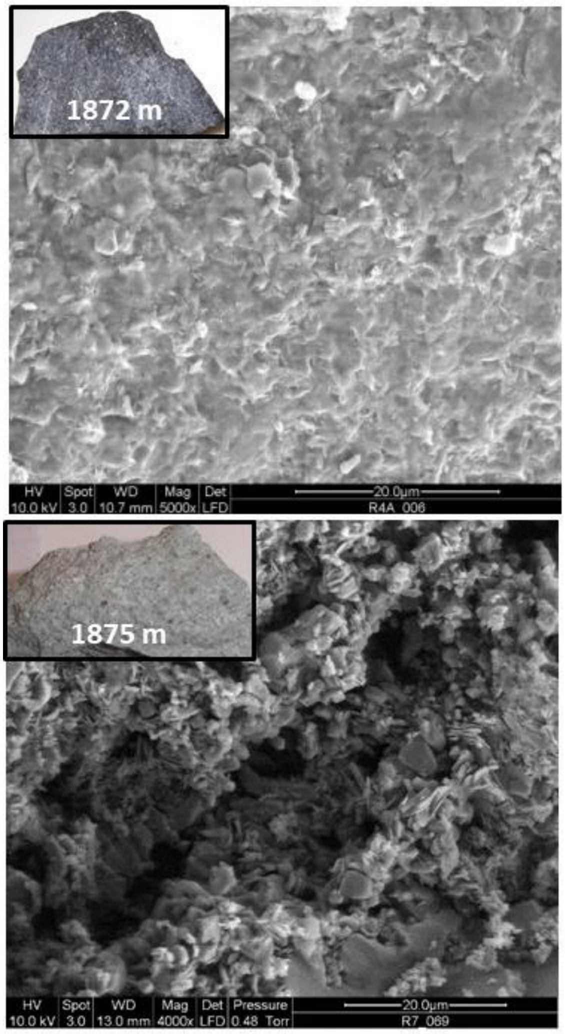

Figure 3: Variation in mineralogy and reactive surfaces from two cored andesite samples from an injection well in the TVZ (Lynne, 2013a).

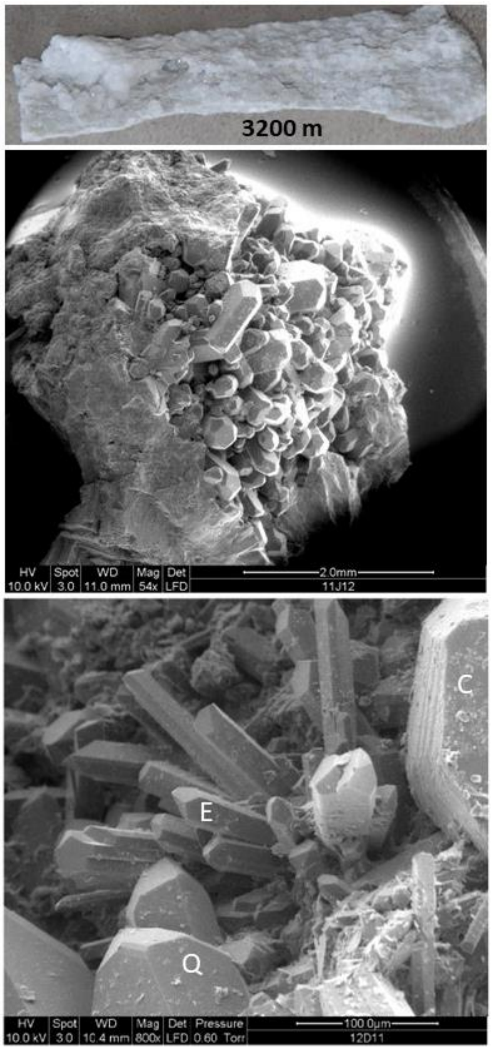

Figure 4: Abundant crystals and open spaces increasing potential reactive surfaces. Sample from a TVZ geothermal field (Lynne, 2013b).

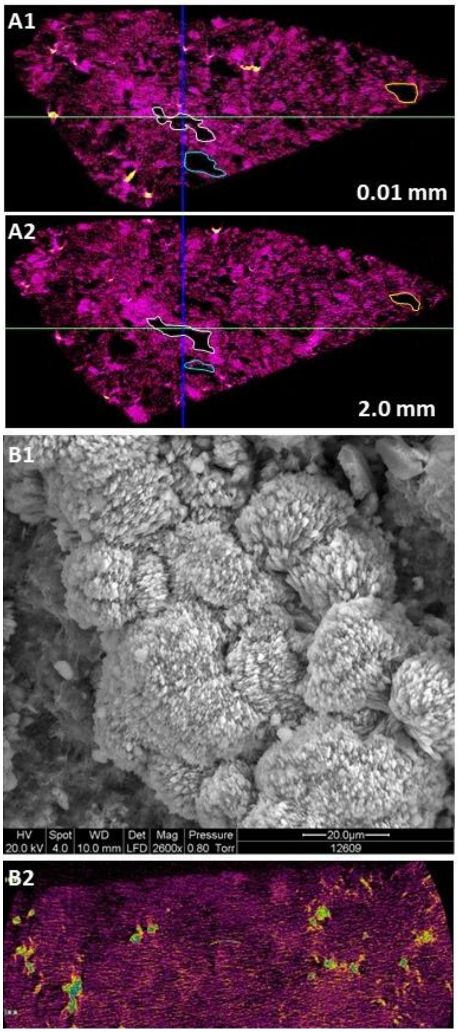

Figure 5: Computerised Tomography (CT) scans of core from a TVZ geothermal field. (A1 - A2): CT scans track void connectivity and dimensions with depth. (B1-B2): Paired Scanning Electron Microscope image (B1) and CT scan (B2) of same cored sample shows platy calcite correlated to the higher density areas shown on the CT image (green and yellow areas; Lynne, 2015).

CONCLUSIONS

We will design and simulate experiments for investigating and ensuring delivery of industry-facing science, including:

- Enhancing dissolution of GHG in geothermal wastewater through pH modification
- Developing efficient chemical processes for mineral entrapment mechanisms within geothermal reservoirs.

This will enhance our understanding fluid-rock interactions and allow us to identify the specific minerals formed based on the rock compositions present in NZ’s geothermal fields.

The numerical simulations we set up will mirror experimental configurations to investigate the reaction mechanisms. Subsequently, we will construct models for large-scale production/injection trials and future scenarios.

Given the distinct mineral composition of New Zealand's rocks, the addition of compounds such as calcium hydroxide and iron oxide to injected water before injection may be necessary. These compounds would react with dissolved CO2 and H2S, respectively, forming solid precipitates. This requires extensive laboratory studies to:

1. carefully select the best materials that won't adversely affect the well,

2. establish reaction kinetics to control entrapment in rock formations.

Samples from fluid-rock interaction experiments will be analysed at UoA laboratories to identify minerals formed during the reactions. This analysis will help in optimizing GHG entrapment technology and uncover secondary minerals, which will feed into reactive transport modeling.

Results from laboratory experiments from will be numerically modelled (data matched) using the TOUGHReact software (Xu et al. 2008). The complex numerical modelling will allow further fine-tune the reactions for eventual implementation in the full scale reservoir predictive scenarios to give more confidence in the modelling results.

We will collaborate with our industry partners on laboratory and field-scale tests. The utilisation of large-scale field data will validate and enhance our research on the influence of GHG-rock-geothermal wastewater interactions, assess the short- and long-term impacts of GHG reinjection, and identify potential risks to the environment and geothermal development operations. Concurrently, we will quantify the benefits of reservoir pressure support resulting from the injected GHG, ultimately leading to higher generation efficiency.

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