Proceedings of the
Latin-American Geothermal Congress 2025
LGC 2025
San Salvador, El Salvador
22–26 Sept. 2025

LATAM GEOTHERMAL CONGRESS

Multicomponent Thermodynamic Geothermometry of Submarine Hot Springs in Northern Dominica

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Keywords: Multicomponent thermodynamic geothermometry, empirical geothermometry, submarine sampling, Dominica

Abstract

Geothermometry, a relatively low-cost exploration technique, is commonly used to estimate geothermal reservoir temperatures prior to drilling. This approach provides insight into deep reservoir temperatures without the logistical and financial requirements associated with drilling. In the early exploration stage, it enables the distinction between more and less attractive prospects.

Empirical geothermometry (EG), also known as 'traditional' or 'classical', has been widely used in geothermal exploration due to its simplicity. However, each empirical geothermometer has its own specific nuances and is relatively imprecise. In contrast, multicomponent thermodynamic geothermometry (MTG) offers increased precision, providing deeper insights into geologic and hydrologic conditions that may influence the results. Moreover, MTG allows for testing of these conditions, thereby enhancing confidence in the results.

For the Picard River geothermal system in northern Dominica, where previous studies focused on the onshore hot springs, we collected water samples from two submarine hot springs located a few hundred meters offshore. The high pressures associated with the submarine springs make them essentially comparable to in situ samples collected from a geothermal borehole. In addition, we chose to apply MTG to our geochemical analysis. These two factors provided us with more precise temperature estimates and increased confidence that we were adequately addressing potential geologic and hydrologic complications.

MTG of the submarine hot springs yielded a significantly narrower range of estimated reservoir temperatures compared to earlier empirical geothermometry (~75% improvement). This enhanced precision gives us much better confidence in the deep reservoir temperature estimate of the geothermal system, providing a more realistic estimate of its limits, thus significantly reducing development risk.

This paper presents our methodology and findings from northern Dominica and outlines the business case for employing MTG as a key technique for geothermal resource assessments in diverse geological settings, ranging from high-temperature hydrothermal systems to low-temperature direct use applications.

Introduction

EG, though invaluable, has several limitations. Some inherent limitations include scattered data, resulting in a ±50°C precision (Fowler et al., 2013). Multiple authors developed EG in distinct geologic settings using different data, introducing variation among similar geothermometers. Many empirical geothermometers have limited calibrated temperature or valid TDS ranges. Geologic conditions and reservoir processes can also affect the accuracy and precision of EG. For instance, fluids not in equilibrium with the mineral, fluids modified after equilibrium due to mixing, boiling, or precipitated solute, varying minerals in equations (especially in low temperature systems), and geologic conditions affecting constituents can all impact accuracy. Historically, EG has been analyzed in the context of local geology, leading to interpretations that are often based on the geochemist's experience and judgment.

Unlike EG, MTG uses thermodynamic models and mathematical equations to describe the relationship between temperature, pressure, and the chemical composition of fluids and minerals. MTG employs comprehensive analyses to simultaneously solve multiple distinct thermodynamic mineral geothermometers that converge around a central value (Spycher et al., 2014). This internal consistency enhances the precision of predicted temperatures, allowing results to be plotted on a single graph that highlights outlying results. This helps geochemists identify the minerals and elements influencing geologic conditions and reservoir processes that may be causing the outliers, enabling them to investigate further and explain the confounding results.

Methodology

In May 2024, the authors led a geochemical survey of the Picard River Geothermal System (PRGS) in northern Dominica. Our work built on previous work done by Dr. Erouscilla "Pat" Joseph 2000-2019, Dr. Alan Smith and his students from 2004-2009, Dr. Dave Rohrs in 2009, and Jacobs in 2020-23.

The PRGS has various surface geothermal features, both onshore and offshore. Due to the limited availability of onshore springs for sampling during our field visit, the high quality of previous EG on the onshore springs (Rohrs, 2009), and our desire to add additional value, we chose to resample only two onshore springs for comparison and focused the majority of our sampling efforts on the submarine hot springs located in Portsmouth Bay. Our rationale was that the submarine springs discharge at higher temperatures, as evidenced by historic data indicating temperatures of 124°C and 128°C. The pressures associated with their depths, ranging from 25 m (3.5 atm) to 28 m (3.8 atm), contribute to the higher temperatures. The submarine samples are mixed with seawater, whose composition is well constrained and can be removed using geochemical modelling. Given the high pressures of the submarine hot springs, the resulting modelled fluid is akin to reservoir fluids from a 30+ m-deep borehole that follows the boiling-with-depth curve (Fowler et al., 2019).

Our field geochemist (Mr. Herman), equipped with sampling equipment he designed and built, collected the submarine samples by SCUBA diving (Figure 1). These samples were subsequently analyzed by GNS Science in New Zealand. Charge balance and other QA/QC indicators indicated excellent sample and analytical quality. Our senior geochemist (Dr. Fowler) performed geochemical modelling of the results using Geochemists Workbench™. To remove the seawater component from the sample, we prepared a Mg regression, and the resulting modelled reservoir fluid was subjected to MTG.

Figure 1: Mr. Herman, SCUBA sampling submarine hot springs.

Results

The MTG curves from the submarine springs (Figure 2) converged neatly, resulting in an estimated temperature range from 218-240°C (229±11°C) for the submarine hot springs.

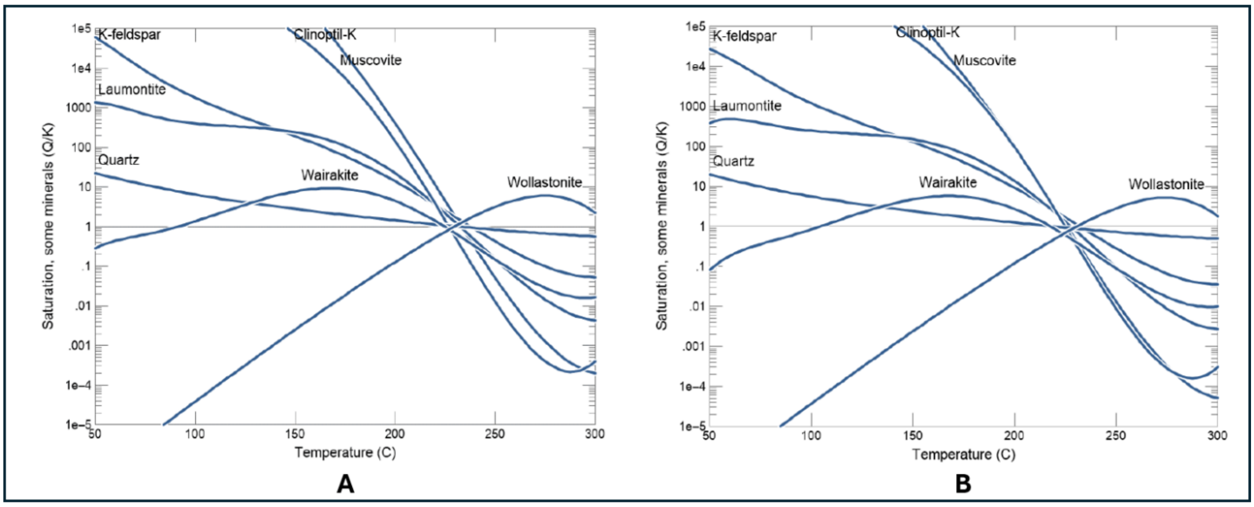

Figure 2: MTG Results from Submarine Springs in PRGS, Dominica A) Volcano B) Hot Sophia

Discussion

Our MTG results appear to be much more precise than those presented by Rohrs (2009), who reported a temperature range of 163-270°C (216±54°C). While the accuracy of the MTG method does not significantly differ (only 13°C), the improvement in precision from 107°C to 22°C is notable. This reduction in uncertainty around deep reservoir temperatures is substantial, exceeding 75%. The absence of outlier curves suggests that there are unlikely to be any unaccounted-for geologic conditions or reservoir processes affecting the results.

These techniques are particularly suitable for submarine geothermal features because it’s relatively straightforward to constrain seawater composition and remove it through geochemical modeling. However, they can also be applied to onshore geothermal features. Samples of local meteoric groundwater from nearby drinking water or agricultural wells could be used to eliminate the groundwater signature and model a theoretical reservoir fluid. This model can then be subjected to MTG for precise geothermometric results (Pfieffer et al., 2014; Fowler et al., 2018).

Conclusion

Geochemical modelling and MTG significantly reduce uncertainty in deep reservoir temperatures and processes during early exploration. For the PRGS, MTG reduces uncertainty in deep reservoir temps by over 75%, reducing risk in estimating reservoir capacity, where temperature is a crucial factor.

MTG enhances confidence that the reservoir temperatures at PRGS are above the pump gap (190-220°C), increasing the likelihood of self-flowing wells. EG results ranged from 163-270°C, encompassing the pump gap, while MTG results only range from 218-240°C, barely overlapping the upper end of the pump gap.

Developers can significantly reduce reservoir temperature risks during early exploration with minimal cost increase by utilizing MTG. However, this method necessitates a more comprehensive laboratory analytical suite, incurring an additional few hundred dollars per sample. It also requires the Geochemists Workbench™ software and an experienced geochemist to perform 3-5 days of additional analysis.

Acknowledgements

This work is part of several programs funded by the Aotearoa New Zealand – Caribbean Facility for Renewable Energy (FRENZ), which is supported by the Ministry of Foreign Affairs (MFAT). FRENZ is delivered by Cowater International in association with JRG Energy. We also acknowledge the Green Climate Fund and the Government of the Commonwealth of Dominica for sharing their IP. Additionally, we are indebted to Kyle Edwards, Virginie and Rémi Granger of Cabrits Dive Center, Davitia James, Aminah Shillingford, Dave Rohrs, and Alan Smith and his former students for their assistance.

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