Proceedings World Geothermal Congress 2026
Calgary, Canada, June 8 – 11, 2026

# Multicomponent Thermodynamic Geothermometry and Geochemical Modeling of Submarine Hot Springs in Northern Dominica

Scott W. Herman[1]*, Andrew P.G. Fowler[2], and Kenneth Alexander[3]
Vulcan Geoscience LLC[1]*, EHS-Support[2], JRG Energy[3]
scottwherman@vulcangeoscience.com

**Keywords:** Geothermal geochemistry, empirical geothermometry, multicomponent thermodynamic geothermometry, submarine hot springs, geochemical modeling, Dominica, Picard River Geothermal System

**ABSTRACT**

Geothermometry, a low-cost exploration technique, estimates geothermal reservoir temperatures before drilling, providing insights into deep reservoir temperatures without drilling logistics and financial requirements. In the early exploration stage, it distinguishes between attractive and less attractive prospects. Empirical geothermometry, also known as 'traditional' or 'classical,' has been widely used for decades due to its simplicity, but it results in relatively imprecise reservoir temperature estimates (typically ±50°C) and offers limited insights into reservoir processes. Multicomponent thermodynamic geothermometry (MTG) combined with geochemical modeling offers improved accuracy and substantially increased precision in temperature estimates, as well as additional insight into geologic/hydrologic conditions and reservoir processes that may affect our geochemical understanding of the geothermal system, thereby significantly increasing confidence in geochemical assessments. This can be critical to reducing risk and identifying the most attractive geothermal prospects for various development scenarios.

As a case study to demonstrate the value of MTG and improved geochemical modeling, we present here the results of a 2024 exploration project in the Caribbean. At the Picard River Geothermal System (PRGS) in northern Dominica, we applied three independent and unrelated methods to improve upon previous geochemical assessments of the system:

1. **Submarine Hot Springs:** Sampling efforts were focused on two submarine hot springs just offshore of Portsmouth. The increased pressure and corresponding increased temperature of the 25-28m deep springs meant that the fluids sampled from these manifestations have undergone less modification (cooling & degassing) between the deep reservoir and the sampling point and are therefore more representative of the deep geothermal reservoir fluids, comparable to in situ samples from 30m onshore boreholes.
2. **Geochemical Modeling:** By taking multiple samples of mixed geothermal fluids and seawater at each hot spring, as well as a blank seawater sample from about a kilometer out in the bay, we were able to use geochemical modeling software (Geochemist's Workbench) to perform a magnesium regression analysis to remove the seawater component of the samples, resulting in a theoretical modeled reservoir fluid that is even more representative of deep reservoir fluids than the sampled submarine hot spring fluids.
3. **Multicomponent thermodynamic geothermometry (MTG):** Applying MTG to the samples enhanced the precision of the temperature estimates, narrowing the range of the reservoir temperature from ±54°C to ±11°C and also offered increased insight into potentially complicating reservoir processes, providing greater confidence in the deep reservoir temperature estimates and thereby reducing development risk.

This paper presents the basic theory behind these improved geochemical techniques, our methodology and findings from northern Dominica where we employed them, and outlines the business case for employing geochemical modeling and MTG more broadly in geothermal exploration as a key technique for geothermal resource assessments in diverse geological settings, from high-temperature hydrothermal systems to low-temperature direct use applications. In this case, the application of these various methods gives us significant confidence that the geothermal reservoir temperatures for the PRGS are above the pump gap (190-220°C). This can significantly reduce development risks and has positive implications for the potential of the project, as wells above 220°C avoid the limited production associated with wells within the pump gap.

## 1 INTRODUCTION

JRG Energy, contracted through Cowater International as part of the FRENZ program, completed a supplemental geothermal resource assessment of the Picard River Geothermal System (PRGS) on Morne Diablotins' NW flank. Our work built on previous research by Dr. Pat Joseph (2000-2019), Dr. Alan Smith and his students (2004-2009), Dr. Dave Rohrs (2009), and Jacobs (2020-23). We evaluated the existing geochemistry work and collected new water samples, both onshore and offshore, for geothermometry and geochemical analysis. The work detailed in this paper is focused on the geochemistry of the PRGS system, but this work was performed as part of a broader geoscientific assessment which has been detailed in several recent papers due for publication (Aguilera et al. LATAMGC, 2025; Alexander et al. GRC, 2025; Herman et al. LATAMGC, 2025).

The PRGS can broadly be described as a classic volcano-hosted geothermal system, where the main geothermal upwelling appears to be located somewhere under the peak of the volcano (SE of Upper Picard Hot Springs) and the system outflows down the NW flank of the volcano into Portsmouth Bay. The distribution of the thermal manifestations appears to be controlled by faulting along and under a flank collapse feature associated with the most recent ignimbrite eruption (~100ka), with thermal manifestations primarily located along the N boundary of the flank collapse and likely resulting from the underlying listric-normal faulting associated with the slumping volcano flank.

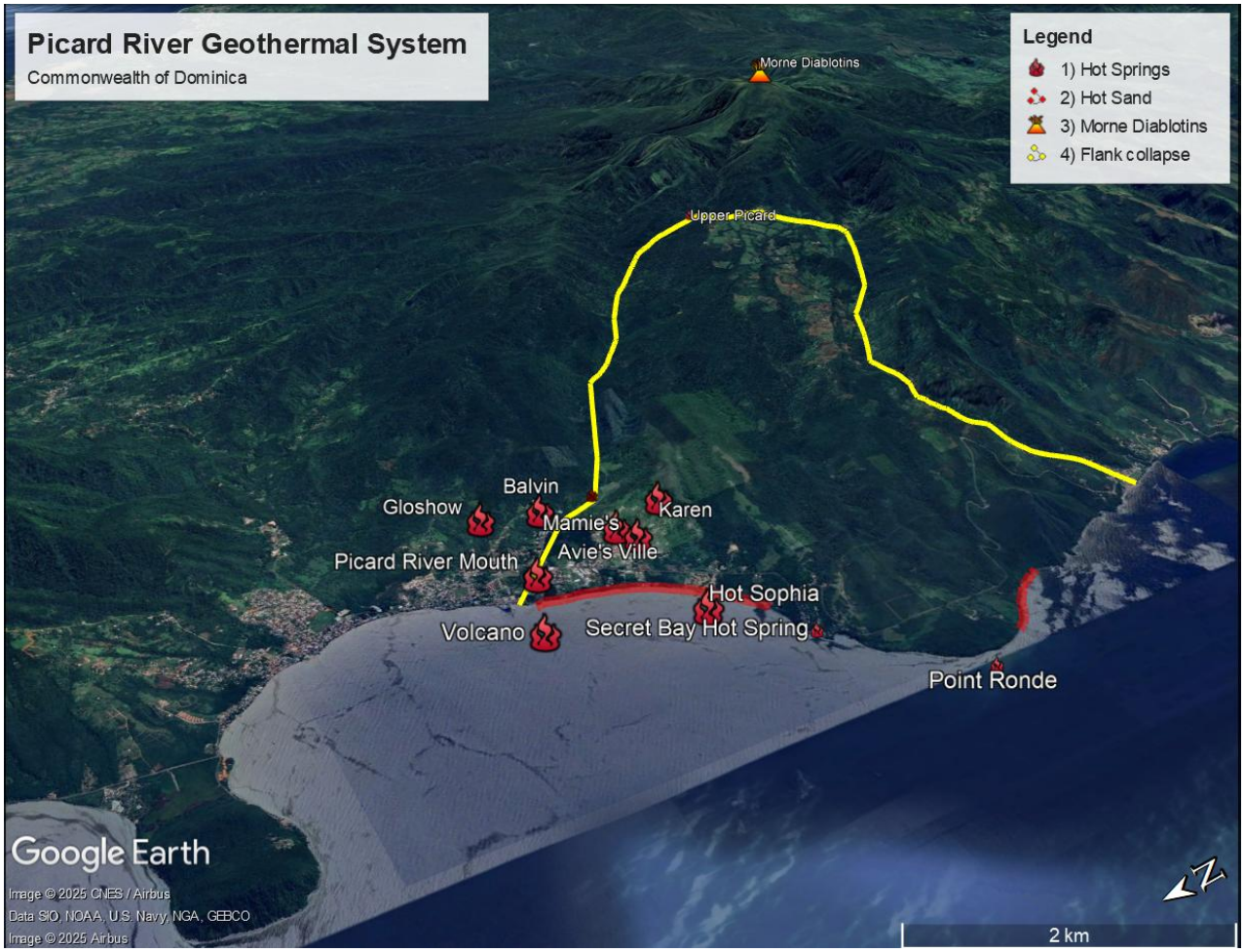



**Figure 1: Map of Picard River Geothermal System**

The PRGS has various historic surface geothermal manifestations, which can be viewed in Figure 1 above:

- 8 terrestrial thermal manifestations:
  - 1 acid sulfate warm spring on Morne Diablotins' upper flank (Upper Picard)
  - 7 thermal features in and around Picard, including several neutral chloride hot springs, one bicarbonate hot spring (Gloshow), and one acid sulfate fumarole (Balvin)
- 2 stretches of beach with hot sand, where shifting hot seeps move along the beach over time (weekly to seasonally) within the intertidal zone.
- Up to 4 submarine hot springs:

- 2 known submarine hot springs in Portsmouth Bay (Volcano, 25 m depth and Hot Sophia, 28 m depth)
- 2 historic submarine hot springs in Secret Bay and off Point Ronde (unconfirmed, listed by previous researchers)

Not all historic thermal features were accessible to sample due to additional development, a low seasonal water table, and the aftermath of Hurricane Maria (2017), which significantly reworked the local landscape, most notably the acid sulfate springs on Morne Diablotins. In addition, two of the historic offshore springs reported in the literature, near Secret Bay and Point Ronde, had imprecise locations and none of the current dive shops in Portsmouth knew about them.

## 2 THEORY

We were initially contracted to repeat the previous geochemical analysis performed by Rohrs (2009) as part of a broader update of the regional geothermal assessment by FRENZ, but upon review of the 2009 work, we concluded that it had been well done by Rohrs and simply repeating it would have added minimal additional value to our understanding of the geothermal system. Because of this, we made the case for focusing on the submarine hot springs and for employing two methods that have been well established for decades in academic geothermal research but have thus far not been widely adopted by the geothermal industry: geochemical modeling of sample fluids and MTG. It was our hope that the improvements/advances in sampling and geochemical modeling would significantly improve the accuracy of our geothermometers, and the improvements in geothermometry methods would significantly improve the precision and confidence in those results, thus furthering our understanding of the PRGS using tools and methods that are proven in research circles but have yet to make the leap to industry standard procedures. FRENZ agreed with our proposal, and we got approval to implement these novel approaches.

### 2.1 Sampling Submarine Hot Springs

Due to limited availability of historical onshore springs and our desire to add further value, we resampled a few onshore springs for comparison and primarily focused on getting high-quality samples from the submarine hot springs in Portsmouth Bay. These were the only submarine hot springs we could reliably locate, and in the case of Volcano Hot Spring we still had to swim a grid based on the description of a former diving guide before we were able to locate and sample that spring, as current dive shops in the area no longer run dives to that location.

The reason we chose to focus our efforts on sampling the Volcano and Hot Sophia submarine hot springs is that they discharge at higher temperatures (124°C and 128°C, respectively) and pressures (3.5 atm and 3.8 atm, respectively) associated with their respective depths (25 m and 28 m) compared to the onshore springs, which discharge at temperatures up to 100°C and at 1 atm. This means that the fluids discharging from the submarine hot springs have undergone less cooling and degassing than their terrestrial counterparts, and make them roughly comparable to reservoir fluids from a 30+ m borehole following the boiling-with-depth curve (e.g., Fowler et al., 2019). Depending on local conditions, the modeled fluid might be representative of even deeper conditions up to 100 m due to the significant density difference between the hot water and the overlying cold seawater. All of this adds together to give us a sample that is more representative of deep reservoir fluids than would typically be obtained from sampling a surface hot spring, and is therefore likely to result in more accurate geothermometry.

### 2.2 Advances in Geochemical Modeling

In addition to the pressure and temperature advantages, the submarine hot springs are mostly mixed with seawater rather than meteoric water, which makes the geochemical modeling to remove the co-mingled seawater component fairly straightforward, as the composition of seawater is much easier to constrain (it tends to be consistent over local and regional distances) and the geochemical modeling methods for removing it to arrive at a theoretical reservoir fluid (magnesium regression) are well established and reliable (Fowler et al., 2019).

It should be noted that this method is not limited to submarine hot springs and can also be applied to terrestrial systems. In particular, hot springs that emerge within rivers, streams, lakes and ponds are often avoided or deprioritized during geochemical exploration because they are thought to be more complicated to analyze. However, when properly sampled along with local meteoric and groundwater samples from nearby sources (such as water wells, streams/rivers, ponds/lakes, etc.), these can constrain the chemistry of any surface or groundwater that has been mixing with the geothermal fluids. This allows for their removal using geochemical modeling resulting in modeled geothermal fluids that better represent the deep reservoir geothermal fluids and

allow us to apply geothermometry to those modeled fluids, giving more accurate geothermometry results, as well as significant additional insight into the reservoir processes affecting the system.

### 2.3 Advances in Geothermometry Analysis

Solute (liquid) geothermometers rely on the temperature-dependent solubility of minerals. Hot fluids quickly reach equilibrium, while cooler ones take longer. As a hot fluid cools, it retains a "memory" of its equilibrium temperature. Consequently, dissolved concentrations vary predictably by temperature, allowing us to estimate reservoir temperature.

#### 2.3.1 Empirical Geothermometry

Empirical geothermometry, also known as traditional or classical geothermometry, has been the most widely used type of geothermometry in geothermal exploration for decades. Developed in the 1970s and '80s by various researchers (included in References), the most commonly employed empirical geothermometers include:

- Silica ($SiO_2$)
- Sodium-Potassium (Na-K)
- Sodium-Potassium-Calcium (Na-K-Ca)
- Potassium-Magnesium (K-Mg)
- Sodium Lithium

These geothermometers assume equilibrium between the sampled fluid and a mineral or solid solution series. We measure dissolved species in a water sample and use simple empirically derived equations to relate them to an equilibration temperature.

Today, most geothermal industry professionals use Powell & Cumming's Spreadsheets for Geothermal Water and Gas Geochemistry to calculate geothermal geothermometers. This comprehensive application compiles the most useful and reliable empirical geothermometers into a free and easy-to-use tool (Powell and Cumming, 2010). These spreadsheets have been invaluable to the industry, making geothermometry more accessible to a broader group of people. However, the downside to the ready accessibility of these geothermometry tools is that they are often implemented by non-geochemists who don't have a thorough understanding of the limitations of the various geothermometers.

While empirical geothermometers have been invaluable, they have limitations. Each solute geothermometer has specific nuances, such as its calibrated temperature range or valid total dissolved solids range. Other factors can affect results, including:

- Water may not have reached equilibrium with the mineral used.
- Water may have been modified after equilibrium due to mixing, boiling, or precipitated solute.
- Empirical solute geothermometers may have slight variations because they were developed by multiple authors in different settings.
- Some constituents are affected by different geologic conditions, so they should be interpreted together.
- Specific minerals assumed in the equation may vary in composition or be absent, especially in lower temperature systems.

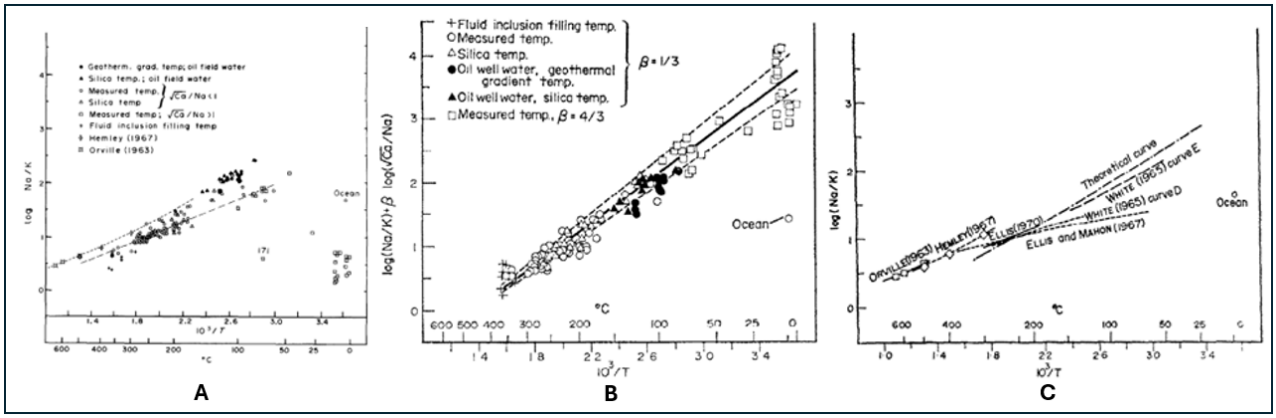



**Figure 2: Examples of Historical Empirical Geothermometers (Fournier and Truesdell, 1973)**

The above figures (Figure 2A, B, & C) show examples of data used to formulate various empirical geothermometers. Note the substantial spread present in the data sets used; the data scatter indicates that each single geothermometer's precision should be considered no greater than roughly ±50°C (Fowler et al., 2013).

In addition, many geothermometers are biased toward specific geothermal areas (e.g., White, 1956; Arnorson, 1975). Historically, these geothermometers are compared in the context of local geology, but many interpretations are based on geochemists' experience. Experienced geochemists (such as Powell) will calculate the various geothermometers, examine the geological conditions of the system to see if there are valid reasons to eliminate or ignore certain geothermometers in certain settings, and then compile the remaining geothermometers into a table of results with various overlapping temperature ranges, and give their best estimate, based in part on their personal experience of the reliability of different geothermometers in varying settings. This method relies heavily on the experience and expertise of the geochemist doing the interpretation. In addition, inexperienced practitioners often simply plug their geochemical analyses into the Powell & Cummings spreadsheets as if they were a black box, and report an average of the resulting outputs, with little to no consideration or understanding of the real-world conditions that can affect the accuracy and precision of the different geothermometers. This is not how the spreadsheets were intended to be used, but it has become relatively common practice within the industry.

### 2.3.2 Multicomponent Thermodynamic Geothermometry

Advancements in computing power and thermodynamics over the last several decades have led to improved geochemical modeling software, enhancing geothermometry and insights into reservoir processes. Multicomponent Thermodynamic Geothermometry (MTG), developed in the 1980s and '90s (Reed and Spycher, 1984; Pang and Reed, 1998), has gained popularity in academic geothermal resource assessments in recent decades (Palandri and Reed, 2001; Spycher et al., 2014; Fowler et al., 2018; Olguín-Martínez et al., 2022).

Thermodynamic geothermometers estimate past rock or fluid temperatures based on chemical reaction equilibrium relationships between minerals and fluids. They use mathematical equations (thermodynamic models) describing temperature, pressure, and mineral/fluid chemical composition, governed by thermodynamic laws (Spycher et al., 2014). These thermodynamic models of mineral saturation have been rigorously tested by many labs all over the world in tightly controlled laboratory experiments, resulting in numerous robust thermodynamic data sets that confirm the thermodynamic models, with very minimal error when compared to the datasets used to calculate the empirical geothermometers, greatly enhancing their precision.

Unlike empirical geothermometers, which rely on different geographical datasets, MTG uses a comprehensive water analysis to simultaneously solve multiple distinct thermodynamic mineral geothermometers. This internal consistency further enhances the precision of predicted temperatures compared to empirical geothermometry.

MTG identifies chemistry affected by mineral composition, water types, and steam/gas loss. Comparing multiple geothermometers in a graph helps identify outliers and examine potential geologic reasons for exclusion or modification (e.g., mineral absence in host rocks). While MTG doesn't specify processes, it identifies minerals (such as Ca and S) involved, guiding geochemists to account for confounding results.

As an example, Figure 3 shows two multicomponent geothermometer outputs:

- Figure 3A: Minerals largely converge on 120±4°C. Chalcedony is an outlier, while Quartz clusters with others, suggesting Quartz is the appropriate silica geothermometer.
- Figure 3B: Calcite and Anhydrite plot outside the 8 other geothermometers, suggesting a reaction causing them to disagree.

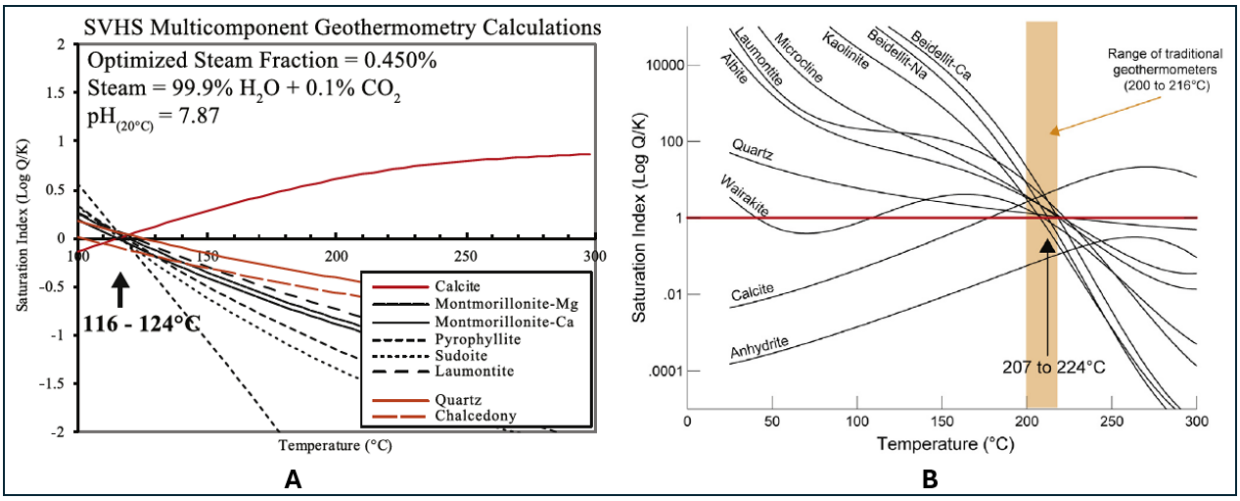



**Figure 3: Examples of MTG results (A – Fowler et al., 2014; B – Fowler et al., 2018)**

In cases such as those illustrated by Figure 3B we know that outlying Calcite ($CaCO_3$) and Anhydrite ($CaSO_4$) curves often result from degassing processes involving $CO_2$ and $H_2S$ or $SO_2$. While the outlying curves don't necessarily identify the exact reservoir process at play, they give a reliable indicator of where to start an investigation and the minerals and elements that are likely involved. Conversely, when all the mineral saturation curves are in tight agreement, this gives you additional confidence that there aren't any extraneous reservoir processes distorting the results that you have failed to account for or examine.

It should be noted that MTG does not typically entirely replace empirical geothermometry. It is common practice to calculate both, as once the samples have been collected and analyzed in the lab, it is minimal additional work to also calculate the empirical geothermometers and they can be valuable for comparison to previous results and additional insights into reservoir processes.

## 3 METHODOLOGY

We collected a suite of 3 samples from each submarine hot spring (approximately 1.25 km apart) and a sample of raw seawater from about a kilometer offshore to account for mixing. Each submarine hot spring location had several vents dispersed over an area 10-20 meters in diameter, and each of the 3 samples per location was taken from a different vent to sample various mixing ratios and improve quality control.

Our field geologist/geochemist (Mr. Herman) sampled the submarine springs using self-designed and custom-built sampling equipment (Figure 4). He placed a weighted funnel over the hot water vent and pumped the water into a 10-liter collapsible water bag with a hand-powered peristaltic pump. The water bag was brought to the surface, and the sample was partitioned on the dive boat into raw, acidized, and diluted/acidized portions for analysis. This process took about 30-60 minutes. GNS Science, a well-respected geothermal laboratory in New Zealand, analyzed the samples and provided excellent results.



**Figure 4: Submarine Geochemical Sampling**

Once the analytical results were verified, our senior geochemist (Dr. Andrew Fowler) input them into Geochemist's Workbench and applied a magnesium regression to remove seawater from the samples,

resulting in a modeled reservoir fluid that is much more representative of deep geothermal fluids. The excellent sampling and analytical results, indicated by an R2 value approaching 1, gives us high confidence in the composition of the modeled fluid (Figure 4).

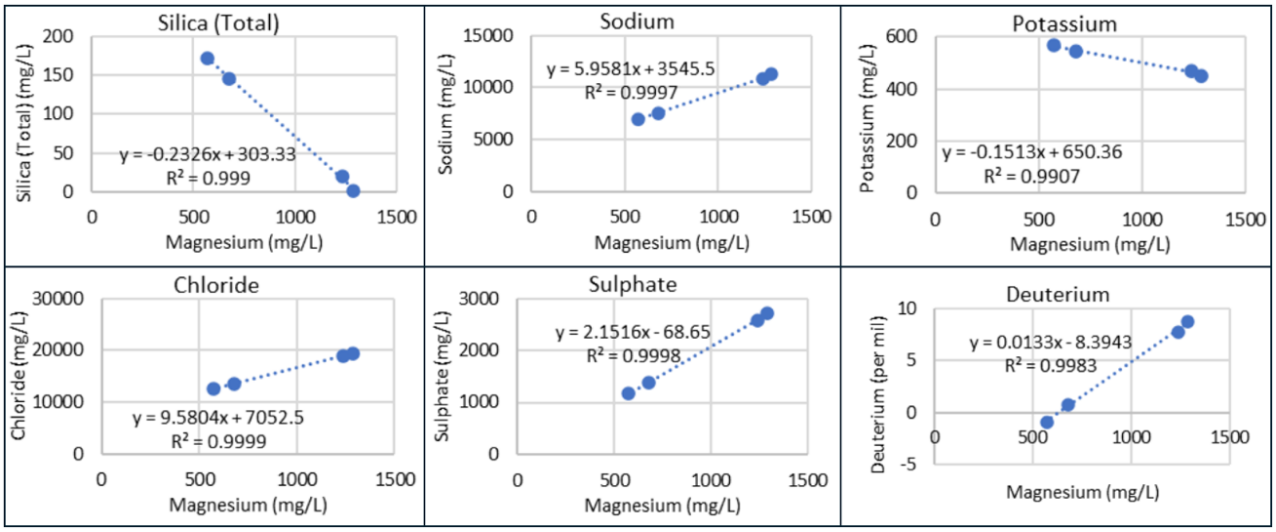



**Figure 5: Magnesium Regression Modeling**

## 4 RESULTS

We applied Multicomponent Thermodynamic Geothermometry to the modeled reservoir fluids and obtained an average result (between the two springs) of 229±11°C (218-240°C) (Figure 6A & B). This compares favorably with Rohrs' (2009) empirical geothermometry results, 216±54°C (163-270°C) and our own empirical geothermometry calculations (225±62°C, 163-286°C).

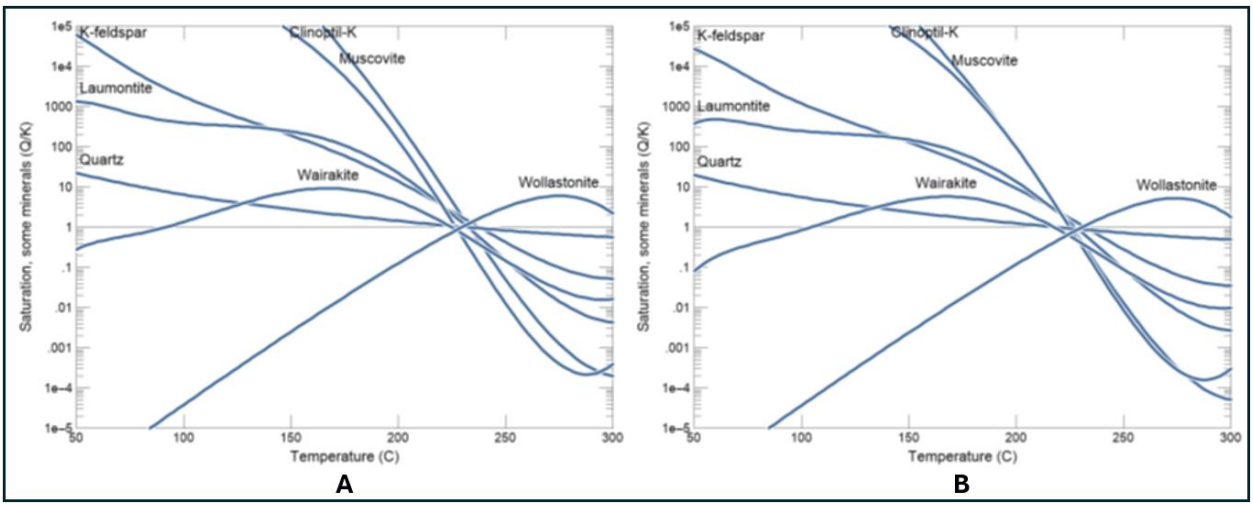



**Figure 6: MTG results for PRGS submarine hot springs A) Volcano and B) Hot Sophia**

## 5 DISCUSSION:

The choice of focusing on the submarine samples, combined with the application of geochemical modeling, yielded an empirical geothermometry result of 9°C higher than previous estimates, which, while valuable, isn't a large difference. While we believe our results (225±62°C, 163-286°C) are likely to be more accurate for the reasons outlined in the theory section- that is, that the sampled/modeled fluids are more likely to be representative of deep geothermal fluids than those sampled by Rohrs 2009 in the terrestrial springs- this improvement is not likely to have a major influence on the resource estimates, development plans, and financial modeling for the PRGS, especially considering that the precision is no better than Rohrs'.

The most notable improvement comes from applying MTG to the new samples. While the MTG estimate of geothermal reservoir temperatures only goes up another 4°C compared to the empirical geothermometers (from 225°C to 229°C), there is a very significant improvement in precision, from ±54°C and ±62°C from the empirical

geothermometers, to only ±11°C. Moreover, the convergence of seven distinct geothermometers based on different minerals around 229°C with minimal variation (Figure 6) and no outliers (such as those illustrated in Figure 2) enhances our confidence that confounding reservoir processes have been adequately addressed.

This improvement in precision is so significant because it gives us a lot more confidence in what the system can produce, and in the case of the PRGS shows us that the reservoir temperatures are almost certainly above the pump gap (190-220°C), the temperature interval where geothermal wells have a significant dip in power production per well due to the temperature limitations of existing pump technology. This has serious positive implications for the development plans and financial models of any planned project involving this resource.

### 5.1 Applications to Onshore Systems

While submarine hot springs at depths deep enough to get significant pressure and temperature sampling benefits (while simultaneously being shallow enough to access with SCUBA gear) are uncommon, domestic or agricultural water wells in the vicinity of the exploration area can be quite common depending on where the system is. Water wells are typically between 30-150 m and access is often simply a matter of getting permission from local landowners to sample them. Depending on the depth of the well and the accessible sampling depth (can it be sampled at depth or only at the surface?) you can sample fluids that have been less affected by changes in temperature and pressure.

Regardless of the presence or absence of local water wells, you can always sample local meteoric fluids and use geochemical modeling to "undo" potential mixing processes, resulting in a more representative sample that can have MTG applied to it. These methods are in no way reliant on the presence of submarine hot springs and can be applied to any geothermal system in the world.

## 6 CONCLUSIONS:

Geochemical modeling and MTG significantly reduces uncertainty in deep reservoir temperatures and processes during the early exploration phase. In the Picard River Geothermal System, these methods combined with sampling the submarine springs reduced deep reservoir temperature uncertainty by over 80%, enhancing reservoir capacity estimation.

The application of MTG and geochemical modeling also significantly increases confidence that PRGS reservoir temperatures lie above the pump gap (190-220°C), increasing the likelihood of self-flowing wells. Empirical geothermometry results ranged from 163-286°C, fully encompassing the pump gap, while MTG results only range from 218-233°C, barely overlapping the upper end of the pump gap.

### 6.1 Business case for application of geochemical modeling and MTG

One of the principal arguments for the increased application of meteoric/groundwater sampling, geochemical modeling and MTG in the geothermal geochemical exploration stage is that it is only minimally more expensive than traditional empirical geothermometry. All that is needed is a somewhat more comprehensive chemical analysis for each sample, a few extra "background" meteoric/groundwater samples, and 40-60 hrs of time from a geochemist well-schooled in these techniques with the proper software. The application of these techniques is likely to increase your exploration geochemistry budget by less than 50%, providing a lot of value for little additional cost, because developers can significantly reduce the risk associated with imprecise reservoir temperatures in the early exploration stages.

### Acknowledgements

This work is part of several programs funded by the Aotearoa New Zealand – Caribbean Facility for Renewable Energy (FRENZ), 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.

We also thank Dr. Alan Smith, his former students, and Dr. Dave Rohrs for discussing their work, providing field notes, and clarifying spring locations and descriptions. Their help was invaluable in sorting through conflicting naming conventions and site descriptions from multiple generations of researchers.

**REFERENCES**

Aguilera, P., Alexander, K., Joubert, C., Herman, S., Fowler, A., Steven, D., and Gilliland, J. In progress. Advanced Geoscientific Studies and Comprehensive Resource Assessment in Geothermal Exploration. *Proceedings* First Latin American Geothermal Congress, San Salvador, El Salvador (September 22-25, 2025).

Alexander, K., Aguilera, P., Steven, D., Gilliland, J., Herman, S., and Fowler, A. In progress. Resource Assessment of the Picard River Geothermal Prospect in Northern Dominica. *Proceedings* Geothermal Rising Conference, Reno, Nevada (October 26-29, 2025).

Arnorsson, S., 1975. Application of the silica geothermometer in low temperature hydrothermal areas in Iceland. Am. J. Sci.; (United States), 275(7).

Fournier, R.O. and Rowe, J.J., 1966. The deposition of silica in hot springs. Bulletin Volcanologique, 29, pp.585-587.

Fouillac, C., Michard, G., 1981. Sodium/lithium ratio in water applied to geothermometryof geothermal reservoirs. Geothermics 10 (1), 55–70.

Fournier, R.O. and Truesdell, A.H., 1973. An empirical Na- K-Ca geothermometer for natural waters. Geochimica et Cosmochimica acta, 37(5), pp.1255-1275.

Fournier, R.O., 1977. Chemical geothermometers and mixing models for geothermal systems. Geothermics 5, 41–50.

Fournier, R.O., 1979. A revised equation for the Na/K geothermometer. Geotherm. Resour. Council Trans. 3, 221–224.

Fournier, R. O., & Potter, R. W. (1979). Magnesium correction to the Na-K-Ca chemical geothermometer. Geochimica et Coemochimica Acta, 43, 1543-1550

Fowler, A.P.G., Hackett, L.B. and Klein, C.W., 2013. Reformulation and performance evaluation of the sulfate-water oxygen isotope geothermometer. GRC Transactions, 37, pp.393-401.

Fowler, A.P., Ferguson, C., Cantwell, C.A., Zierenberg, R.A., McClain, J., Spycher, N. and Dobson, P., 2018. A conceptual geochemical model of the geothermal system at Surprise Valley, CA. Journal of Volcanology and Geothermal Research, 353, pp.132-148.

Fowler, A.P., Tan, C., Luttrell, K., Tudor, A., Scheuermann, P., Shanks III, W.P. and Seyfried Jr, W.E., 2019. Geochemical heterogeneity of sublacustrine hydrothermal vents in Yellowstone Lake, Wyoming. Journal of Volcanology and Geothermal Research, 386, p.106677.

Giggenbach, W.F., 1988. Geothermal solute equilibria. derivation of Na-K-Mg-Ca geoindicators. Geochimica et cosmochimica acta, 52(12), pp.2749-2765.

Herman, S., Fowler, A., and Alexander, K. In Progress. Multicomponent Thermodynamic Geothermometry of Submarine Hot Springs in Northern Dominica. Poster presented at First Latin American Geothermal Congress, San Salvador, El Salvador (September 22-25, 2025).

Peiffer, L., Wanner, C., Spycher, N., Sonnenthal, E.L., Kennedy, B.M. and Iovenitti, J., 2014. Optimized multicomponent vs. classical geothermometry: insights from modeling studies at the Dixie Valley geothermal area. Geothermics, 51, pp.154-169.

Powell, T. and Cumming, W., 2010, February. Spreadsheets for geothermal water and gas geochemistry. In Proceedings (pp. 4-6).

Reed, M., Spycher, N., 1984. Calculation of pH and mineral equilibria in hydrothermal waters with application to geothermometry and studies of boiling and dilution. Geochim. Cosmochim. Acta 48, 1479–1492.

Spycher, N., Peiffer, L., Sonnenthal, E.L., Saldi, G., Reed, M.H., Kennedy, B.M., 2014. Integrated multicomponent solute geothermometry. Geothermics 51, 113–123.

Spycher, N., Finsterle, S., Dobson, P.F., 2016. New developments in multicomponent geothermometry. Proceedings, 41st Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California (February 22–24, 2016).

White, D.E., Brannock, W.W., Murata, K.J., 1956. Silica in hot-spring waters. Geochim. Cosmochim. Acta 10, 27–59.