Improved Geothermometry through Multivariate Reaction-path Modeling and Evaluation of Geomicrobiological Influences on Geochemical Temperature Indicators

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INTRODUCTION

A major barrier to the deployment of geothermal energy is the financial risk associated with geothermal prospecting. One means to reduce such financial risk is to improve the accuracy of geothermometry by taking advantage of recent advances in geochemical analyses and modeling.

The overall project goal was to develop knowledge and methods to improve estimates of reservoir temperatures, which have traditionally been calculated using simple chemical geothermometers.

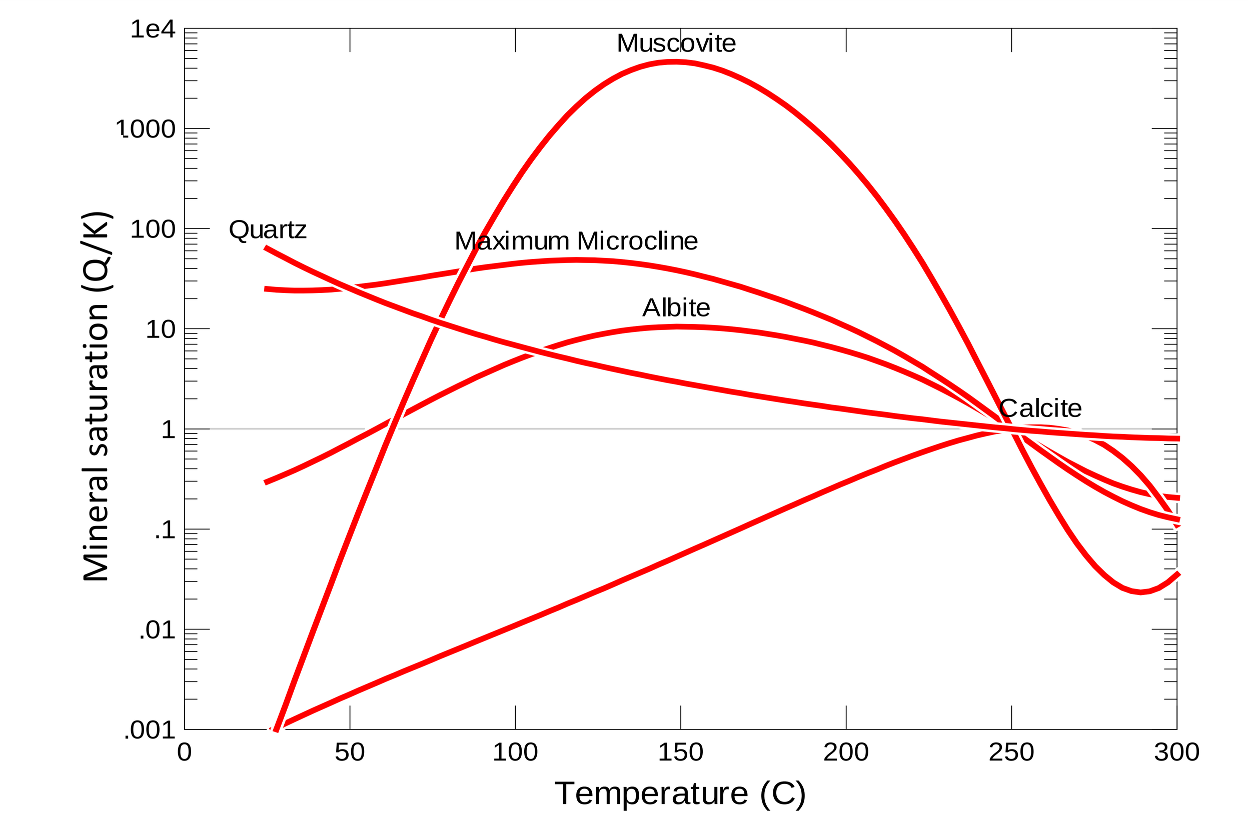
Specific project objectives were to:

- develop knowledge required to use geothermometry to predict reservoir temperature to within ±30 °C,
- advance the scientific state of the art through developing methods to identify samples that may not be amenable to geothermometry due to microbiological activity,
- develop an associated geothermometry software technology product that could be commercialized.

APPROACH

Geothermometry estimates reservoir temperature from the geochemical composition of water/gas samples collected from thermal features. Many of the traditional geothermometry methods rely on empirical correlations between water temperatures and concentration of a subset (e.g., silica, cations or cation ratios) of the dissolved constituents in water.

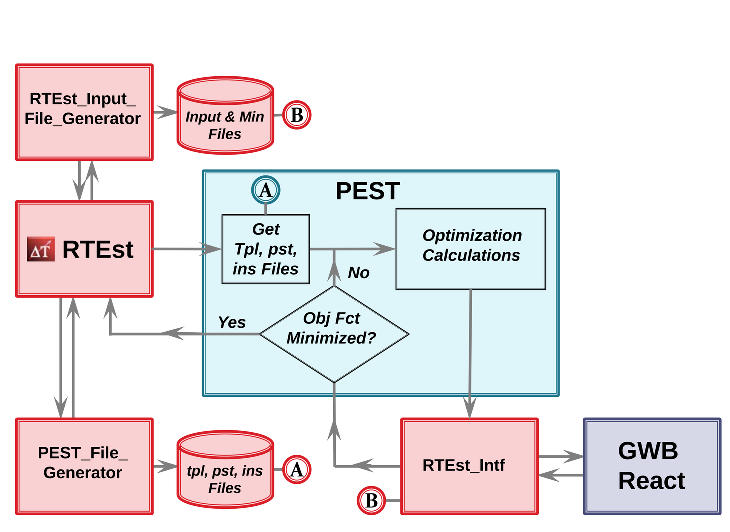
Multicomponent equilibrium geothermometry is an alternative approach for geothermometry. The common intersection of the saturation indices for multiple reservoir minerals with the zero (equilibrium) line is used to estimate reservoir temperature. In the figure shown below the estimated reservoir temperature for a synthetic water sample is 250 °C.



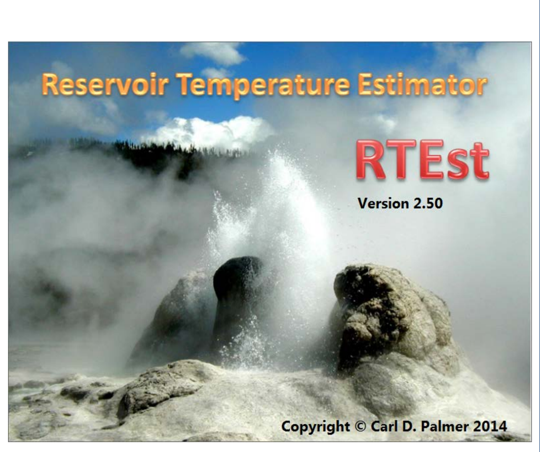
Saturation indices of minerals for a cooled (25 °C) water sample that was previously equilibrated at 250 °C with albite, calcite, maximum microcline, muscovite, and quartz.

RTEst

The **Reservoir Temperature Estimator (RTEst)** is a geothermometry tool. It uses a multicomponent optimization approach that takes into account the steam phase, loss of volatile components (e.g., CO_2), and mixing with other waters to reconstruct reservoir fluid and estimate temperature. RTEst minimizes a weighted sum of squares of the SI values of a user-selected set of minerals believed to be at equilibrium within the reservoir by adjusting the temperature, fugacity of CO_2, and mixing fraction with another water. RTEst uses the React module in The Geochemist's Workbench (GWB) and PEST to perform geochemical modeling and optimization calculations, respectively (see figure).



General flow chart of RTEst



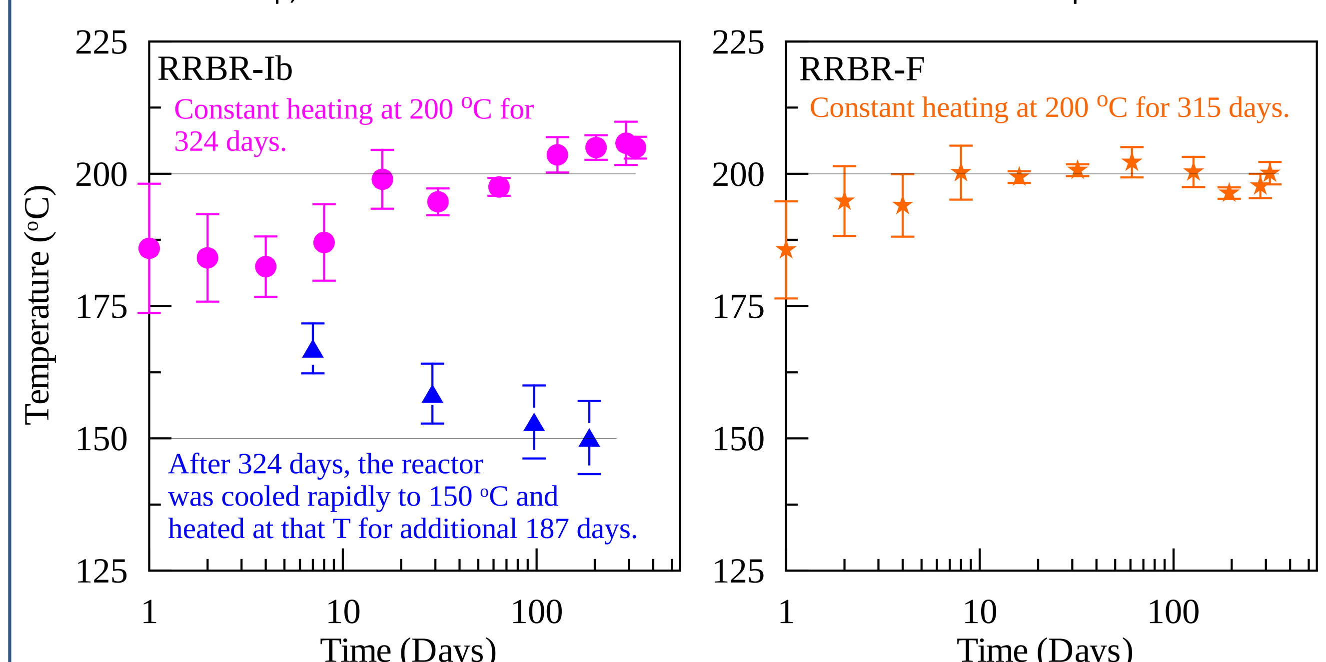
RTEst start up window

VALIDATION

Experimental

The validity of RTEst as a geothermometry tool was tested with batch water-rock interaction laboratory experiments (Figure below). Metamorphosed quartz monzonite was reacted with synthetic geothermal water at 200 °C for more than 10 months. Multiple water samples were collected at various times for chemical analysis and used to evaluate the effect of disequilibrium on temperature estimates. After 324 days at 200 °C, an experimental set was cooled to 150 °C to determine if RTEst would estimate the initial temperature or the cooled temperature. In both the heating and cooling stages of the experiments, RTEst is capable of estimating the temperature to within 5°C.

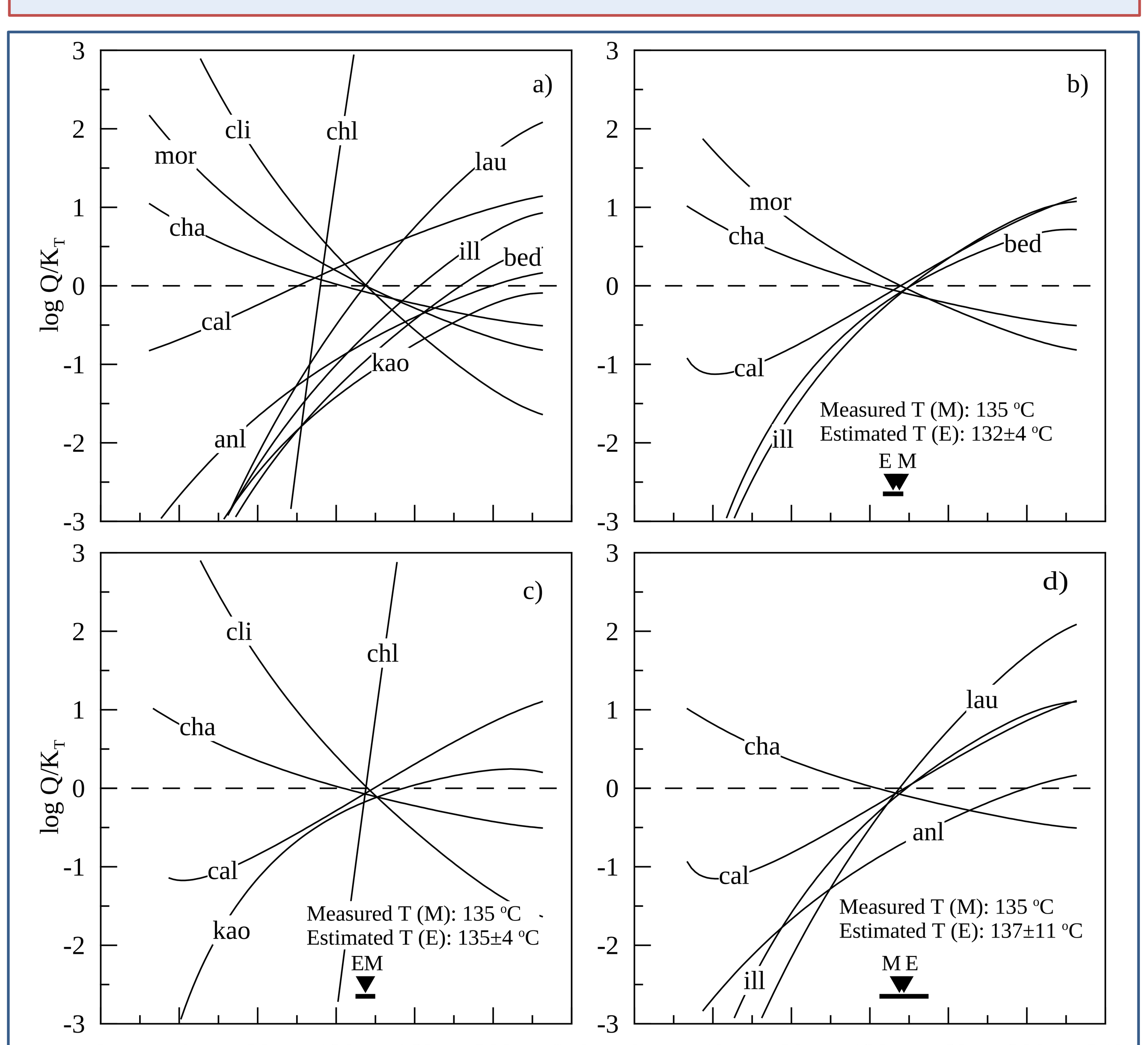
Bench-top, 1-L Parr stirrer reactor set used for Water-rock interaction experiments



Temperature estimates for experimental waters with RTEst. The error bars represent one standard deviation in each direction. RTEst is able to predict experimental temperature during heating to 200°C after two to three weeks of water-rock interaction experiments. However, a much longer (>3 months) time was needed to re-equilibrate the system to cooler temperature.

Raft River Geothermal

The RRG field in south-central Idaho is a designated Known Geothermal Resource Area (KGRA) with a highest measured bottom-hole temperature of 149 ºC. Published water compositions of multiple RRG wells were used to evaluate RTEst. The RRG waters are near-neutral in pH and dominated by sodium and chloride ions.



MEG temperature estimate for RRG1. (a) The log (Q/KT) curves for minerals calculated using original water chemistry with K-feldspar used for FixAl, (b-d) optimized log (Q/KT) curves for three different RMAs. (Minerals used in figures - anl: analcime; bed: beidelite-Mg; cal: calcite; cha: chalcedony; chl: chlorite; cli-clinoptilolite-K; ill: illite; kao: kaolinite; lau: laumontite; mor: mordenite-K).

BIOTIC INFLUENCE

The objective of the microbial component of this project was to provide an initial evaluation of whether microbial activity could alter the geochemical composition of a prospecting sample and bias geothermometric predictions. If so, approaches could be developed in the future to "correct" or account for the influence of microorganisms.

We developed and applied methods for detecting and estimating the potential extent of past or present sulfate reducing or sulfur oxidizing activity in a given sample derived from geothermal waters. These methods rely on quantitative polymerase chain reaction (qPCR) to quantify microbial genes associated with these functional activities in environmental samples. We applied these qPCR assay tools to several thermal expressions in the Soda Springs, Idaho area and the Ojo Caliente hot springs in Yellowstone National Park, Wyoming.

Sampling sites

Cell counts and dsrB and soxB gene estimates at thermal expressions (BDL: below detection limit). dsrB is the gene associated with dissimilatory sulfate reducing activities and soxB is the gene associated with sulfur oxidation activities.

Location	Cells (ml^{-1})	*dsrB* copies (ml^{-1})	*soxB* copies (ml^{-1})	RTEst T ±σ (°C)
Hooper Spring	4.9(1.6)E+4	1.9(1.3)E+1	2.4(1.0)E+2	97±2.5
Soda Geyser	9.3(3.1)E+4	3.1(2.6)E+1	1.9(2.1)E+3	60±5.6
Sulphur Springs	8.5(3.4)E+7	9.0(3.4)E+5	2.6(0.58)E+7	40±6.1
Ojo Caliente (0.3 m)	BDL	BDL	BDL	199±1.3

CONCLUSIONS

We have developed and implemented an approach based on multicomponent equilibrium geothermometry into a reservoir temperature estimation software tool called RTEst. RTEst minimizes the weighted sum of squares of the saturation indices of multiple selected minerals by adjusting the temperature, fugacity of CO_2, and mixing fraction with another water. The software features include several weighting methods and an algorithm to assist users in selecting potential reservoir mineral assemblages given the rock type, water type, and estimated temperature.

RTEst has been tested against hypothetical scenarios, laboratory experiments, and data from geothermal fields. RTEst has consistently shown that it is capable of predicting reservoir temperature to within ±30 °C under a variety of conditions.

We have developed and tested an approach for identifying waters where biological activity may make geothermometric calculations problematic. Microbial alteration of water chemistry can lead to violation of the assumption that fluids have not re-equilibrated from reservoir conditions, making suspect the temperatures predicted by geothermometry. In particular, we applied qPCR assay tools to quantify microbial genes associated with past or present sulfur redox activity in surface thermal expressions.

We have produced a geothermometry software product called RTEst that is being commercialized. BEA is in the final process of completing copyright assignment and licensing agreements to distribute the RTEst software tool to the public. Currently, two Geothermal Technology Office research projects are examining RTEst's utility for more accurate estimation of potential geothermal reservoir temperatures and consequent reduction in the risk of geothermal prospecting.

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