

Optimized multicomponent vs. classical geothermometry: Insights from modeling studies at the Dixie Valley geothermal area

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ABSTRACT

A new geothermometry approach is explored, incorporating multicomponent geothermometry coupled with numerical optimization to provide more confident estimates of geothermal reservoir temperatures when results of classical geothermometers are inconsistent. This approach is applied to geothermal well and spring waters from the Dixie Valley geothermal area (Nevada), to evaluate the influence of salt brines mixing and dilution of geothermal fluids on calculated temperatures. The main advantage of the optimized multicomponent method over classical geothermometers is its ability to quantify the extent of dilution and gas loss experienced by a geothermal fluid, and to optimize other poorly constrained or unknown parameters (such as Al and Mg concentrations), allowing the reconstruction of the deep reservoir fluid composition and therefore gaining confidence in reservoir temperatures estimations. Because the chemical evolution of deep geothermal fluids is a combination of multiple time-dependent processes that take place when these fluids ascend to the surface, reactive transport modeling is used to assess constraints on the application of solute geothermometers. Simulation results reveal that Al and Mg concentrations of ascending fluids are sensitive to mineral precipitation–dissolution affecting reservoir temperatures inferred with multicomponent geothermometry. In contrast, simulations show that the concentrations of major elements such as Na, K, and SiO₂ are less sensitive to re-equilibration. Geothermometers based on these elements give reasonable reservoir temperatures in many cases, except when dilution or mixing with saline waters has taken place. Optimized multicomponent geothermometry yields more representative temperatures for such cases. Taking into account differences in estimated temperatures, and chemical compositions of the Dixie Valley thermal waters, a conceptual model of two main geothermal reservoirs is proposed. The first reservoir is located along the Stillwater range normal fault system and has an estimated temperature of 240–260 °C. It covers the area corresponding to the geothermal field but could extend towards the south-west where deep temperatures of 200–225 °C are estimated. The second reservoir has an estimated temperature of 175–190 °C and extends from well 62-21 to northeastern Hyder, Lower Ranch, Fault Line, and Jersey springs.

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1. Introduction

Solute geothermometers have been applied during the last decades as an exploration tool for inferring geothermal reservoir temperatures. The most widely used are the ‘classical’ geothermometers, which are either based on an absolute concentration like dissolved SiO₂ or on a ratio between dissolved elements such as Na–K, Na–K–Ca, or K–Mg (Fournier and Truesdell, 1973;

Fournier, 1979; Fournier and Potter, 1982; Giggenbach, 1988). Another approach presented by Reed and Spycher (1984) involves the computing of saturation indices (log(Q/K)) of potential reservoir minerals over a range of temperatures, given a full thermal water analysis, then estimating the reservoir temperature by the clustering of saturation indices near zero. This multicomponent geothermometry approach was recently formulated into a computer program (GeoT) that automatically estimates reservoir temperatures (Spycher et al., 2011, 2014). As a stand-alone program, GeoT can be coupled with existing parameter estimation software such as iTOUGH2 (Finsterle and Zhang, 2011) to allow numerical optimization of unknown or poorly constrained input parameters that may adversely affect temperature estimations. This new integrated multicomponent approach is tested here in context with results of numerical simulations, fluid analyses and

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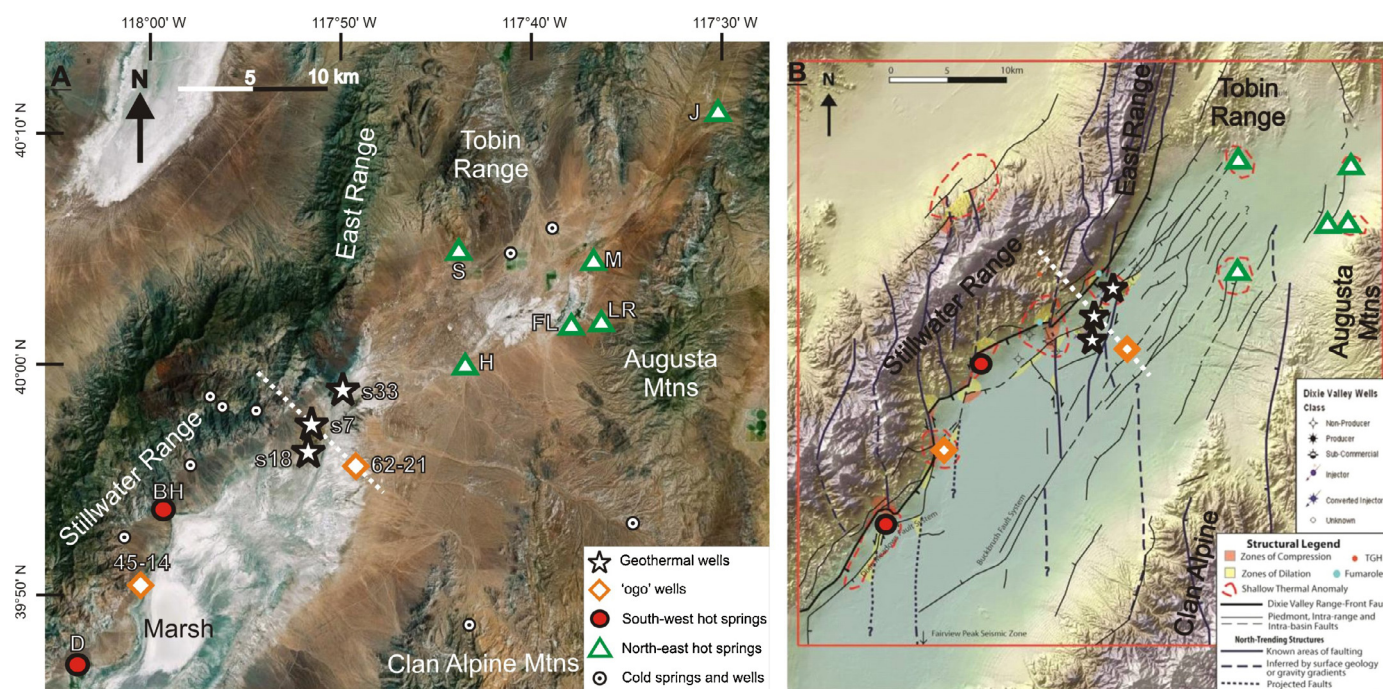


Fig. 1. (A) Aerial view of the Dixie Valley geothermal area and surroundings with locations of wells and springs (Google Earth image). Wells: s33 – Section 33, s7 – Section 7, s18 – Section 18. Springs: D – Dixie, B – Big Horn, S – Sou, H – Hyder, FL – Fault Line, LR – Lower Ranch, M – McCoy, J – Jersey. All waters were sampled by Goff et al. (2002). (B) Structural map of the Dixie Valley (modified from Iovenitti et al., 2012). Note that Jersey springs are off-map. The dashed white line on both maps corresponds to the cross-section shown in Fig. 2.

mineralogical data from the Dixie Valley geothermal system, and classical geothermometry.

All solute geothermometry methods present advantages and disadvantages. All approaches rely on the assumption that the deep reservoir fluid is unmodified by physical (e.g., mixing, dilution, and boiling) or chemical processes during ascent to the surface and that the chemical composition sampled at the surface reflects chemical equilibrium (or near-equilibrium) with reservoir minerals over some narrow range of temperature. When re-equilibration has taken place upon cooling and/or boiling, geothermometers typically miscalculate reservoir temperatures. A detailed discussion on the application range of classical solute geothermometers was presented by Gigenbach (1988). The Na/K geothermometer, based on the equilibrium of geothermal fluids with Na and K feldspars, has been shown to be the least affected by re-equilibration processes due to the slow response of the Na/K ratio to re-equilibration. Therefore, this geothermometer is typically assumed to reflect the deepest equilibration temperature. On the opposite side, the K/Mg geothermometer, based on the fluid equilibration with muscovite, clinocllore and K-feldspar, re-equilibrates much faster and has been used to infer the temperature of last equilibrium. The Na–K–Ca geothermometer is also widely used, however it is known to be sensitive to calcite precipitation and thus to the CO₂ content of geothermal fluids. The mineral saturation index approach presented by Reed and Spycher (1984) is more integral because it is truly multicomponent and based on any number of minerals. However, the fact that this method relies on complete analyses of thermal waters, and requires numerical computations, can be viewed as a significant practical disadvantage compared to classical geothermometry. Also, by searching for the convergence (near zero) of saturation indices of multiple minerals, the method assumes that these minerals are all at or near equilibrium with the deep fluid, which may not always be the case for the all minerals considered. This multicomponent approach is also known to be sensitive to Al concentrations (Pang and Reed, 1998), and our own efforts have shown that this method can be quite sensitive to Mg

concentrations as well, as discussed later in this paper. This can present difficulties because Al analyses are often missing in geochemical studies, or are easily affected by errors because of typically low Al concentrations in geothermal waters.

In this work, the effect of reactive processes such as mineral precipitation and dissolution affecting deep geothermal fluids as they ascend to the ground surface is investigated, and specific cases of reliable and unreliable geothermometry results are presented. This is achieved by running reactive transport simulations and applying both classical and multicomponent geothermometry to different groups of thermal waters (wells and springs) from Dixie Valley, Nevada. Optimized multicomponent geothermometry computations (Spycher et al., 2011, 2014) are applied to reconstitute the deep original geothermal fluid composition in order to estimate the deep reservoir temperature. Groups of waters are processed simultaneously to better constrain the optimization process, under the assumption that waters in these groups originate from a common location. The grouping of these waters is established using standard hydrogeochemical analyses such as elemental and isotopic correlation plots.

The effect of Al and Mg concentrations on chemical geothermometry is also investigated, as well as the impact of dilution and mixing with saline brines. This study is augmented by a more comprehensive modeling investigation of Dixie Valley presented by Wanner et al. (2013, 2014), who developed a two-dimensional reactive transport model across the valley to investigate deep fluid and heat flow patterns, as well as reactive processes affecting solute geothermometry.

Dixie Valley was selected as an area of study not only because of the large number of water chemistry analyses available for this geothermal area (Goff et al., 2002), but also because it includes a diversity of waters with different chemical compositions, and for which classical geothermometers yield a large range of reservoir temperatures, especially when applied to thermal springs. This area has also been the subject of numerous investigations, including a large synthesis report by Blackwell et al. (2007a), summarized in

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