ONE SOURCE OR TWO? IMPLICATIONS FOR INTERPRETING HYDROTHERMAL FLUIDS AT THE FIELD AND REGIONAL SCALE IN THE TAUPO VOLCANIC ZONE, NEW ZEALAND

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ABSTRACT

B, Cl, Cs and Li are commonly used in hydrothermal fluid studies as they are assumed to generally behave conservatively along complex flow paths. Over the past half-century, geothermal systems in the Taupo Volcanic Zone, New Zealand (TVZ) have been extensively studied and numerous inferences have been put forth describing the origin and flow paths through fluid geochemistry. Several studies in the TVZ have used elemental ratios (e.g. B/Cl and Li/Cs) to argue that hydrothermal fluids in the TVZ are derived from two spatially discrete sources: an arc-type fluid in the eastern TVZ and a rift-type fluid in the western TVZ. We reviewed selected geochemical data for hydrothermal fluids in the TVZ to date and show that two distinct B/Cl ratios are present in TVZ fluids. However, contrary to earlier work, our results do not exhibit an east-west spatial distribution of fluid chemistry. Rather, higher B/Cl ratios occur on both the eastern and western margins of the TVZ. We also observe that fluids in local fields (in both the eastern and western TVZ) can switch between the different B/Cl ratio types through time. This discrepancy most likely indicates that B is not behaving conservatively and B/Cl ratios of hydrothermal fluids in the TVZ are not directly linked to the current tectonomagmatic setting. Unlike the B/Cl ratios, the Li/Cs ratios of the same fluids are similar, irrespective of their geographical location, implying a similar parent-fluid across the TVZ. We suggest that ascending fluids in the TVZ hydrothermal systems originate from a geochemically similar parent-fluid at depth as indicated by Li/Cs ratios and through varying contributions of B from water-rock interaction, two B/Cl groups arise. Previous water-rock interaction studies of geologic formations in the TVZ and recent geophysical imaging of hydrothermal plumes in the TVZ support these interpretations.

1. INTRODUCTION

1.1 B, Cl, Cs, and Li in hydrothermal fluids

B, Cl, Cs, and Li and their respective ratios are generally used to delineate end-member 'parent-fluid(s)' in hydrothermal systems due to their generally 'conservative' nature (Arnórsson and Andrésdóttir, 1995; Giggenbach, 1995; Shaw and Sturchio, 1992). The 'conservative', or incompatible, nature refers to their relative preference to remaining dissolved in hydrothermal solutions at elevated temperatures. The most conservative of these elements is Cl, while conservative behavior is not always observed for B, Cs, and Li as has been shown by previous authors from field and lab experiments demonstrating that these elements may be taken up to varying degrees in the mineral phase due to hydrothermal alteration (Goguel, 1983; Arnórsson and Andrésdóttir, 1995; Giggenbach, 1995; Reyes and Trompetter, 2012 and references therein).

2. ARC- AND RIFT-TYPE FLUID MODELS OF THE TVZ

Giggenbach (1995) classified hydrothermal fluids for the Taupo Volcanic Zone (TVZ) (Figure 1) from well discharges for six geothermal fields in the TVZ based on CO_2/Cl ratios and saw that for these fields of study; an east-west trend was exhibited. As sampling of Cl and CO_2 in springs is technically challenging, Giggenbach compared the CO_2/Cl ratios to those of dissolved B/Cl and Li/Cs B, Cs, and Li as they are generally dissolved in the liquid phase at high temperatures (Ellis and Sewell, 1969). A positive relationship was observed between the CO_2/Cl and the respective ratios of B/Cl and Li/Cs for the six fields.

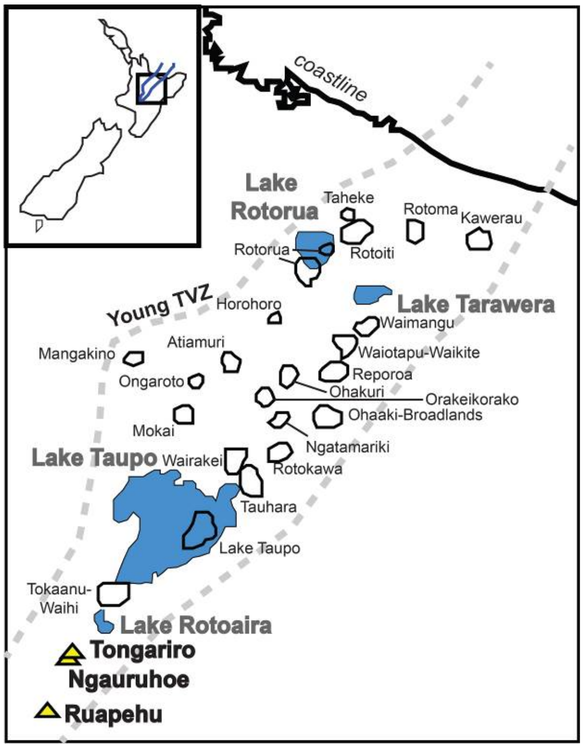

Figure 1: Major geothermal fields of the TVZ from Bibby et al. (1995) and young TVZ from Wilson et al. (1995)

Based on relative B/Cl and Li/Cs ratios from the six fields, Giggenbach showed an east-west trend was apparent to which higher B, B/Cl, and higher Cs/Li ratios were observed on the eastern fields and these compositions were attributed to a combination of "leaching" and "degassing" at sub-solidus temperatures associated with an andesitic lithology (i.e. arc-, or “andesitic water”). Conversely, lower B, B/Cl, and lower Li/Cs ratios observed on the western fields were resultant from similarly inferred interactions with a rhyolitic lithology (i.e. rift-, or “rhyolitic water”). The ratios observed in these systems corresponded well with previous experimental work by Ellis and Mahon (1967) investigating water-rock interactions between andesitic and rhyolitic rock-types. This ‘arc-‘ and ‘rift-type’ classification has been used by subsequent authors in further classifying other geothermal fields in the TVZ as associated with their tectonomagmatic setting (Christenson et al., 2002; Reyes and Trompetter, 2010; Reyes and Trompetter, 2012).

3. DATA SOURCES

Geochemical data used in this study was sourced primarily from the Environment Waikato Regional Environmental Geo Monitoring Program (REGEMP) (Huser and Jenkinson, 1996; Luketina, 2007; Webster-Brown and Brown, 2008; 2012) and from previously published work (Ellis and Mahon, 1967; Giggenbach, 1995).

4. SPATIOTEMPORAL ANALYSIS

4.1 B/Cl and Li/Cs ratios

Bi-variate plots of B-Cl and Li-Cs are presented in Figures 2 and 3, respectively. Examination of B and Cl for samples across the TVZ shows two distinct groups based on their respective ratios. These systems will be referred to as the higher B group (HBG) and lower B group (LBG) for the remainder of this paper. The relationships between these groups individually are significantly high exhibiting R^2 values of 0.97 and 0.93 for HBG and LBG, respectively.

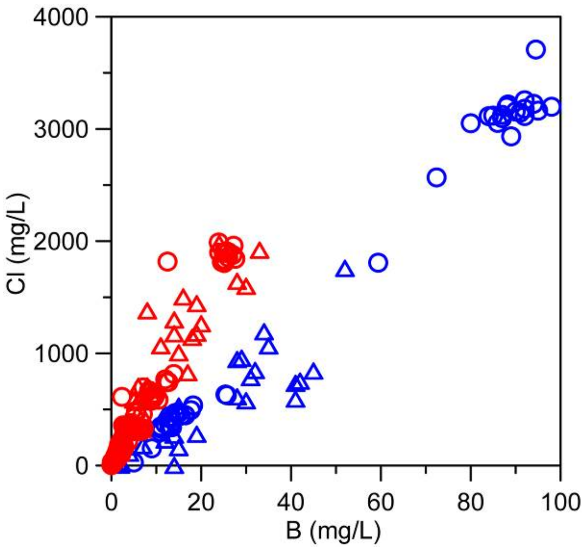

Figure 2: Plot of B and Cl for samples collected in the TVZ liquid-dominated geothermal systems. Circles indicate REGEMP data and triangles indicate data from Giggenbach (1995).

For Li and Cs, two groups are not readily observable in their distributions, albeit with some variation. Classifying the Li vs Cs values based on the corresponding HBG and LBG groupings showed no significant difference between Li/Cs ratios of the associated HBG and LBG groupings.

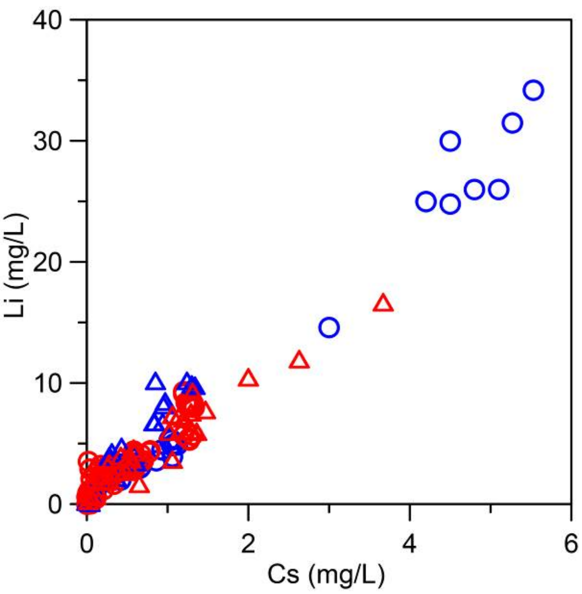

Figure 3: Plot of Li and Cs for samples collected in the TVZ liquid-dominated geothermal systems. Circles indicate REGEMP data and triangles indicate data from Giggenbach (1995).

4.2 Spatial distributions of B/Cl groups

Figure 4 shows the spatial distribution of HBG and LBG in the TVZ. These distributions of HBG and LBG do not exhibit an east-west trend. Rather, HBG groups are generally distributed along the margins of the TVZ with a small number of HBG samples in the central portion of the TVZ, while LBG samples dominate the central portion of the TVZ. Notably, HBG and LBG values may both be present in a single geothermal field (e.g. Rotokawa and Ohaaki-Broadlands).

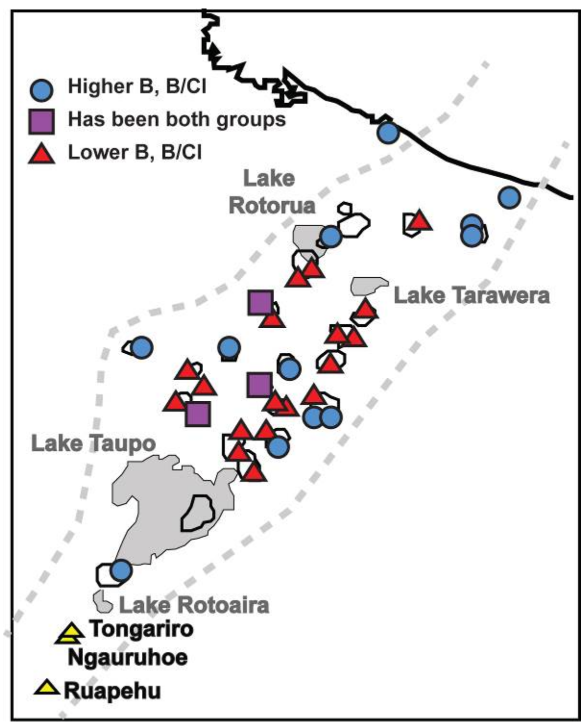

Figure 4: Spatial distribution of B/Cl ratio groups (HBG and LBG). Purple squares indicate sites where both HBG and LBG ratios have been observed.

5. ONE SOURCE, NOT TWO

We explain the variation of B/Cl ratios for HBG and LBG values as a result of water-rock interaction in the upper portion of the geothermal system (< 3 km) as evidenced by the correlation of HBG and LBG to specific water-rock ratios shown in Ellis and Mahon (1967). It is not apparent from these data that magmatic 'degassing' is a significant factor in the observed ratios (see section 5.2).

5.1 Rock leaching

HBG values are inferred to originate from primarily water-rock interaction with an andesitic lithology and conversely, LBG values to be derived from primary water-rock interaction with a rhyolitic lithology. Higher B may result from interaction with greywackes, but Reyes and Trompetter (2012) show from experimental work that B released from greywackes is readily taken into alteration mineral assemblages and is not likely to contribute significantly to B content in TVZ hydrothermal fluids.

5.2. Sources to the TVZ geothermal systems

The fluids contributing to the TVZ hydrothermal systems are ultimately a mixture of meteoric, magmatic, and "leached" components from host rocks. Although, the presence of a HBG and LBG could suggest two end-member fluids contributing to these geothermal systems as has been interpreted by previous studies, we show that a single ratio is dominant throughout the TVZ for Li/Cs ratios, which is indicating a singular distinct parent fluid. Identifying specific ratios as end-member compositions (i.e. magmatic end-member) is troublesome and is likely not reflecting the physiochemical processes occurring deep in the geothermal system.

What the data indicate is a relatively homogenous parentfluid at depth, which represents a culmination of inputs from magmatic, meteoric, and rock-leaching sources as evidenced by the similar Li/Cs ratios and similar observed relationships between Rb, Cs, Ar, and Cl from Webster-Brown and Brown (2008). If B/Cl ratios were indicative of a purely magmatic 'degassing' signature, it would need to be assumed that the other elements being degassed and exhibiting a single ratio (i.e. Li, Cs, Rb) were being degassed from the andesite and rhyolite with similar ratios, which is fundamentally contrary to distinguishing an arc- and rift-type end-member. It seems more plausible that a geochemically similar parent fluid ascends from deep in the TVZ geothermal systems and upon interaction with andesite and rhyolite host rocks in the shallower portion of the geothermal system, becomes distinguishable by B/Cl ratios.

6. APPLICATIONS TO INTERPRETING FLUIDS AT OHAAKI-BROADLANDS

Recent magneto-telluric (MT) imaging and inversions done in the central TVZ by Bertrand et al. (2012) show distinct "plumes" rising from approximately 7-10 km at depth underneath the TVZ and most likely plumes predicted by Bibby et al. (1995). At the Ohaaki-Broadlands field (OB), a 3D inversion of the MT data exhibit a localized, singular plume, which represents the upflow zone in the hydrothermal convection cell feeding OB.

A previous model presented in Christenson et al. (2002) inferred that OB was fed by two distinct fluids, however, we argue that the geochemical work presented in this paper and MT work by Bertrand et al. allow for a single fluid similar in its B, Cl, Cs, and Li content to arise at OB. The differences in host-rock lithology at OB field (Grimes et al., 2000) allow for the rising fluid to interact with a more rhyolitic lithology in the west and more andesitic and greywacke lithology in the east, thus explaining the occurrence of the two B/Cl groups. It is possible that the B could be sourced from the greywacke in the east, but its ratio from Ellis and Mahon (1967) is not observed. Our model, however, is not at this time intended to further explain the gas differences and associated isotopic values, as this is the subject of future study.

7. CONCLUSIONS

Difficulty arises in the quantification of source end-member contributions in hydrothermal systems as each element has a unique evolutionary history (Lowenstern et al., 2012). As in the case of B, Cl, Cs, and Li in the TVZ, the relationships observed are more likely a reflection of fluid evolution relative to flow paths. Li/Cs along with other reported relationships of dissolved solutes (i.e. Rb, As, Cl) from Webster-Browne and Brown (2008) indicate a similar parent fluid in the TVZ while the B/Cl ratios indicate specific interaction with host andesitic and rhyolitic lithology. B, Cl, Cs, and Li in hydrothermal fluids of the TVZ are not a function of the tectonomagmatic setting proposed by Giggenbach (1995). Further understanding the gas component of these fluids is the subject of future research.

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