He Isotopic Evidence for Undiscovered Geothermal Systems in the Snake River Plain

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ABSTRACT

The Snake River Plain is an area characterized by high heat flow and abundant Quaternary volcanism. While USGS assessments indicate that significant undiscovered geothermal resources are likely to be present in this region, no commercial geothermal development in this region has occurred. Elevated ³⁷He/³²He values reflect crustal input of mantle volatiles and may serve as a geochemical indicator of hidden geothermal systems that are masked by the presence of shallow cold water aquifers.

This study is part of an integrated geochemical investigation of thermal features in the central and eastern Snake River Plain region. Our project started by compiling existing He isotope data, regional heat flow data, and the locations of thermal wells and springs to develop compositional trends and identify new sampling opportunities where data gaps exist. Our initial field work has resulted in the highest ³⁷He/³²He measurements ever reported for the Snake River Plain, with three locations having Rc/Ra values greater than 2.0, suggesting that we can see through the effects of shallow cold water aquifers to indicate the presence of mantle-derived fluid and heat input into the shallow crust. Our new He isotopic results and previously reported data for the Snake River Plain range from 0.05 to 2.36 Rc/Ra. These results will be evaluated in conjunction with the results of conventional, isotopic, and multicomponent geothermometry studies.

1. INTRODUCTION

One of the key R&D challenges for the DOE Geothermal Technologies Office Hydrothermal program is to develop techniques that can be used to identify undiscovered geothermal resources in the US, which the USGS has estimated as having a mean power production potential of 30 GWe (Williams et al., 2008). One of the main areas with elevated heat flow in the US, the Snake River Plain (Figure 1), has no geothermal systems that have been commercially developed for energy generation. This area is characterized by abundant Quaternary volcanism associated with the migration of the Yellowstone hotspot, but in a large portion of this region there are shallow cold water aquifers that mask the presence of higher temperatures at depth.

Much of the volcanism in the Snake River Plain is associated with the migration of the Yellowstone hotspot (Pierce and Morgan, 2009), and consists of bimodal basalts and rhyolites that have been erupted over the past 17 Ma. The rhyolites were derived from a sequence of progressively younger to the east silicic volcanic centers (Morgan et al., 1984; Leeman et al., 2008). Voluminous basalt flows range in age from Tertiary to Holocene, and are found throughout both the Eastern and Western Snake River Plain. A small subset of these basalts are late Quaternary to Holocene in age, and form 8 distinct eruptive centers (Kuntz et al., 1992; Hughes et al., 2002), including the Craters of the Moon. A number of Quaternary rhyolitic domes and cryptodomes are located in the Eastern Snake River Plain – these are thought to have evolved from differentiation of basalt (McCurry et al., 2008).

While low enthalpy geothermal fluids have been harnessed for direct use in Idaho for more than a century, geothermal exploration activity in the Snake River Plain for high-enthalpy systems has been carried out sporadically over the past 50 years (Ross, 1970; Young and Mitchell, 1973; Partlman and Young, 1992), and has not yet resulted in the discovery and development of a commercial geothermal system in the area. One recent research study, Project Hotspot, drilled three deep (~2 km) wells in three different regions of the Snake River Plain (Nielson et al., 2012; Shervais et al., 2013). One of these wells (Kimama) intersected a thick (~900 m) cold water aquifer before encountering an elevated thermal gradient, while a second well (Kimberley) encountered a thick (~1500m) reservoir of 55-60°C water in rhyolitic lavas and tuffs. The third well (Mountain Home) discovered a high temperature (~150°C) geothermal system with artesian flow. None of these locations had any surface thermal features that could be used to predict the varying thermal conditions that were encountered.

With the exception of active rift zones (such as Iceland) and hot spots (Hawaii), basaltic dominated volcanic provinces are often neglected as possible hosts for productive geothermal systems (Nielson et al., 2015). This is in part due to the lack of shallow, long-
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lived magma chambers that would provide a sustained source of heat to the shallow crust. However, as evidenced by the elevated heat flow, volcanic activity in the Snake River Plain region appears to be associated with magmatic intrusions in the crust that do provide a viable source of heat based on crustal models (Peng and Humphreys, 1998; DeNosaquo et al., 2009). McCurry and Welhan (2012), Nielson and Shervais (2014), and McLing et al. (2014) all postulate that basaltic sill complexes associated with these volcanic features could serve as the heat source for geothermal systems in the Snake River Plain region. However, such subsurface features are difficult to detect using standard exploration techniques. One possible way to detect such features is to use a tracer that would be present in geothermal fluids that would identify the presence of a magmatic component. Helium isotopes may serve as such a tracer for geothermal fluids in the Snake River Plain region.

Figure 1: Heat flow map of Idaho and the surrounding region, showing elevated values in the Snake River Plain (Blackwell et al., 2011).

2. FIELD AND LABORATORY METHODS

Helium samples were collected during three field campaigns: September 2003, March 2014, and June 2014. Samples collected in 2014 were obtained from thermal springs and wells as part of a coordinated geochemical study of these features for multicomponent and isotopic geothermometry (McLing et al., 2014; Cannon et al., 2014). A type-K thermocouple was used to measure the temperature of the thermal features. Gas samples for noble gas analyses were collected from bubbling hot springs using an inverted plastic funnel that was connected with Tygon tubing to a copper tube. Gas was bubbled through the system to purge any atmospheric contamination, and the gas samples were then trapped in the copper tube using cold seal weld clamps, resulting in a gas sample volume of ~9.8 cm$^3$. For water samples without a gas phase, water was collected in copper tubes to trap dissolved gases for analysis. The samples were then analyzed with a noble gas mass spectrometer at the Center for Isotope Geochemistry at LBNL using the methods described in Kennedy and van Soest (2006). Helium isotopic compositions have been corrected for air contamination (Re) using the He/Ar and Ne/Ar ratios by assuming all of the Ne and Ar were derived from air or air saturated water.

3. RESULTS

There are very few published He isotope values for thermal waters in the Snake River Plain region. Welhan et al. (1988) reported He isotope values ranging from 0.14 to 0.51 R/Ra for four thermal springs in the Snake River Plain region. A more comprehensive unpublished study of He isotopic variations for 19 thermal springs and wells in southern Idaho was conducted by Jenkins (1979); he reported R/Ra values ranging from 0.1 to 1.56, with all but two samples having values less than 1.

The initial results of this study provide He isotope data from a wide range of thermal springs and wells in the Snake River Plain and neighboring areas. A total of 11 He samples were collected during the 2003 field season, and an additional 21 He samples were
collected in 2014. Three of the areas that were sampled in 2003 were resampled in 2014 as a check on the reproducibility of the analyses. In all cases, the Rc/Ra values for the resampled features are within 0.2 Rc/Ra of each other.

He isotope values for the features sampled thus far in this study range from a low of 0.05 Rc/Ra (for Lidy Hot Springs) up to a high value of 2.36 for the Barron’s (Camas Creek Ranch) well (Figures 2 & 3). A total of eight features had Rc/Ra values greater than 1.5, with three of these having values greater than 2. The elevated (Rc/Ra>1.5) values cluster in three distinct regions: one near Craters of the Moon (Green House well), a second in the Twin Falls area (Miracle HS, Banbury HS and well, and Sligers well), and a third located on the northern margin of the Snake River Plain north of Twin Falls (White Arrow HS, Magic Reservoir HS well, and Barron’s well).

Figure 2: He isotopic values for the Snake River Plain superimposed on a digital elevation map with locations of latest Pleistocene-Holocene basalts (Kuntz et al., 1992; Hughes et al., 2002), Quaternary rhyolites (McCurry et al., 2008), and the outlines of major Tertiary silicic volcanic centers (Leeman et al., 2008). Symbol size and number indicates Rc/Ra He value, and symbol color indicates the measured surface temperature of spring or well.
4. DISCUSSION

Helium isotopes can be used to identify the source of the helium (Ballentine et al., 2002; Graham, 2002), thus facilitating its use as a tracer for the origin of geothermal fluids. There are three major reservoirs of helium: the mantle, the crust, and the atmosphere. The $^3$He/$^4$He of air is $1.4 \times 10^{-6}$, and is defined as Ra. Mantle (magmatic) He values are typically enriched in $^3$He, with $^3$He/$^4$He ratios 7 to 9 times that of atmosphere (7-9 R/Ra). Because $^4$He is produced by radiogenic decay of Th and U, crustal He ratios are typically ~ 0.02 R/Ra.

Kennedy and van Soest (2007) conducted a detailed study of He isotopic compositions of thermal features across the Basin and Range. They observed that fluids from geothermal systems located on the western margin of the Great Basin that were associated a volcanic heat source had elevated $^3$He/$^4$He values (Re/Ra >3). In contrast, amagmatic geothermal systems in the Basin and Range Province had significantly lower values (Re/Ra from ~0.2 to 2); however, these values are considerably above crustal values (~0.02). They interpreted the slightly elevated values for the nonvolcanic systems to reflect amagmatic flow of mantle fluids through the ductile lower crust. The values increased systematically from east to west, correlating with an east-west increase in crustal strain rate suggesting a concurrent east-west increase in deep crustal permeability, enhancing fluid flow to the surface. Several regions were found to have anomalously high R/Ra values with respect to the general trend. Siler et al. (2014) looked to correlate the occurrence of major structural features in these regions to see if they might serve as localized zones of higher permeability that would further facilitate deep crustal circulation of fluids and heat.

While the Snake River Plain has a clear association with young volcanism (Figure 2), the thermal effects of this magmatic activity in the shallow crust are often masked by a thick cold water aquifer that overlies much of the Eastern Snake River Plain region (McLing et al., 2014). This cold water aquifer has a thickness reaching up to more than 900 m in places (Nielson et al., 2012; Shervais et al., 2013). Another challenge is that most of the thermal features encountered in the Snake River Plain are located along its margins. Fluids sampled from these features may have undergone cooling and mixing, thus making interpretation of fluid geothermometry challenging. Multicomponent geothermometry has been employed to better constrain the source temperatures of these complex fluids (Neupane et al., 2014; Cannon et al., 2014).

During the preliminary phase of this project, we examined the three regions with elevated He isotopic ratios to see if they coincide with areas that have evidence of young volcanism (Figure 2) or high heat flow (Figure 3). Only one of the areas (Green House well – Rc/Ra = 2.23, by Arco) is near young (< 15 Ka) volcanic rocks (Craters of the Moon). This well is quite unremarkable in terms of its flowing temperature (36.3°C), and multicomponent geothermometry yields a source temperature estimate of only 67±15°C (Cannon et al., 2014). The other two high He isotope clusters (the Twin Falls area and the area near Magic Reservoir HS) are in areas with Miocene rhyolites and Plio-Pleistocene basalts (Leeman et al., 1982; Whitehead, 1992; Ellis et al., 2010) but are generally associated with higher temperature thermal features and/or wells. These clusters are located in areas with high heat flow (Figure 3).

One area that warrants future study is the region around Mountain Home, where drilling has revealed the existence of a hidden 150°C geothermal reservoir (Shervais et al., 2013). Unfortunately this well was plugged and abandoned before it could be sampled for He isotopes, but other wells in the region might contain geochemical signatures related to this system. While this area does not have Holocene volcanism, it does host Quaternary basalts (Shervais et al., 2002) and may be underlain by younger basaltic sills (Nielson and Shervais, 2014).

4. CONCLUSIONS

New helium isotope data for thermal waters in the Snake River Plain has revealed a number of elevated (Re/Ra>1.5) He isotope values that are higher than previously reported data for this region. These values suggest a significant mantle helium component. These elevated values have been observed thus far in three different areas within the Snake River Plain. There is not a clear correlation between these elevated $^3$He/$^4$He values and young (< 15 Ka) volcanic features. However, this He signature may be related to basaltic intrusions that are thought to sustain the high heat flow in this region. Future work will include integration of the He data with isotope and multicomponent geothermometry and collection of additional samples in areas such as Mountain Home, where a hidden geothermal system has been discovered. Such sampling will help test whether He isotopes can help identify systems that have no surface manifestations in the Snake River Plain region.

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Figure 3: He isotopic values for the Snake River Plain superimposed on USGS heat flow map of the Snake River Plain (Williams and DeAngelo, 2011). Map depicts inferred heat flow below the groundwater flow system. Map was generated to identify regional-scale variations, so high heat flow in geothermal regions was capped at 120 mW/m². Outline of the Snake River Plain province from Payne et al. (2012). Symbol size and number indicates Ro/Ra He value, and symbol color indicates measured surface temperature of spring or well. The three Project Hotspot wells, depicted as stars, are (from west to east) Mountain Home, Kimberly, and Kimama (Shervais et al., 2013).

REFERENCES


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