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Applications of Geothermometers to Hydrology Assessment

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ABSTRACT

This article presents a conversion method to assess hydrology of a geothermal system using aqueous geothermometers. In this study, considering the applications and limitations of some aqueous geothermometers, Quartz (maximum steam loss), Na-K and K-Mg geothermometers are used synthetically, together with Na-K-Mg ternary plot, to assess the hydrology of Kuirau park thermal area, Rotorua, New Zealand. Reservoir temperatures, fluid speed and the characteristics of reservoir permeability, characteristics of faults or fractures are deduced. This method is practical and reliable when enough representative samples are available.

1. INTRODUCTION

Aqueous geothermometers are widely used to calculate geothermal reservoir temperatures. But care must be taken. The calculated temperature represents the true deep reservoir temperature only when its specific hydrological application requirements are satisfied. Due to the close relationship between the reliability of a geothermometer and the hydrological conditions of a geothermal system, geothermometers can be used to assess the hydrology by analyzing the temperatures calculated by different geothermometers in theory. Accordingly, the main idea of this study is that the hydrological conditions of a geothermal field can be deduced by comparing the temperatures given by different geothermometers using a reverse method.

Kuirau Park, Rotorua, New Zealand is a thermal active area famous for its hot springs. This paper takes Kuirau Park as an example to discuss the method to assessing geothermal reservoir hydrology conditions using aqueous geothermometers. A number of hot springs make it possible to qualify the research results.

2. HYDROGEOLOGY BACKGROUND

Rotorua Geothermal Field (RGF) is the southern part of the Rotorua caldera covering about $12km^2$. Based on the drillhole information, the stratigraphic succession in the RGF comprises Mamaku ignimbrite, Rotorua rhyolite and lacustrine sediments from bottom to the top. The Mamaku ignimbrite and Rotorua rhyolite form aquifers and sedimentary rocks act as an aquitard (Wood, C. P. 1992).

The older Mamaku ignimbrite is porous and permeable. It contains the hottest fluid, which flows upwards from the southern and eastern parts of the RGF and outflows to the north and west (Technical report of the geothermal monitoring programme, 1982-1985). Hot fluids enter the Rotorua rhyolite from the ignimbrite in the east and in the north near Kuirau Park (Rotorua geothermal regional plan, 1999). The Rotorua rhyolite has good fracture permeability. The hot water migrates horizontally to the west and north under the Rotorua city (Wood, C. P. 1992). Mixing of geothermal water and groundwater takes place in the upper part of the geothermal aquifer (Rotorua geothermal regional plan, 1999).

The zoned distribution of thermal manifestations shows they are likely controlled by faults. The faults provide channels for both hot and cold waters to move vertically. But till now, no borehole data prove the existence of faults. The influence of structure on hydrology is speculative (Wood, C. P. 1992).

Kuirau Park is located in the city of Rotorua, in the northern part of RGF, covering an area of approximately $1km^2$. The underlying strata consist of Rotorua rhyolite (aquifer) and lacustrine sediments (aquitard). Two directions of spring alignments (NNW trending and NW trending) suggest the presence of two fault structures which control the hydrology in Kuirau Park. The hot water coming from Mamaku ignimbrite enters into Rotorua rhyolite from the east and outflows westward horizontally beneath Kuirau Park. It rises along faults up to the surface and forms hot springs.

In eastern sector (NNW trending), the springs include clear springs, milky springs and mud pools that vary from stagnant to discharging. In contrast, most of the springs in the western sector (NW trending) are clear with neutral pH. CO_2 gas bubbles and silica sinter can be seen in most of the discharging or stagnant clear spring. Water level is variable changes with time.

3. SPRINGS CHEMISTRY

The authors (Hu and Zhao) observed almost all the springs in Kuirau Park and sampled 23 of them in September, 2002. Twelve samples were taken from eastern sector, 11 from western sector. Sampling covered the whole area and all feature types. Laboratory analysis were conducted in Oct. Ion balance was used to check the analyses results and it showed that the species analyzed were complete and the results were reliable.

The Cl-SO4-HCO3 classification plot (Fig. 1) shows that most of the springs are near neutral chloride-bicarbonate water, which suggests the water in these springs are a mixture of deep water and shallow ground water.

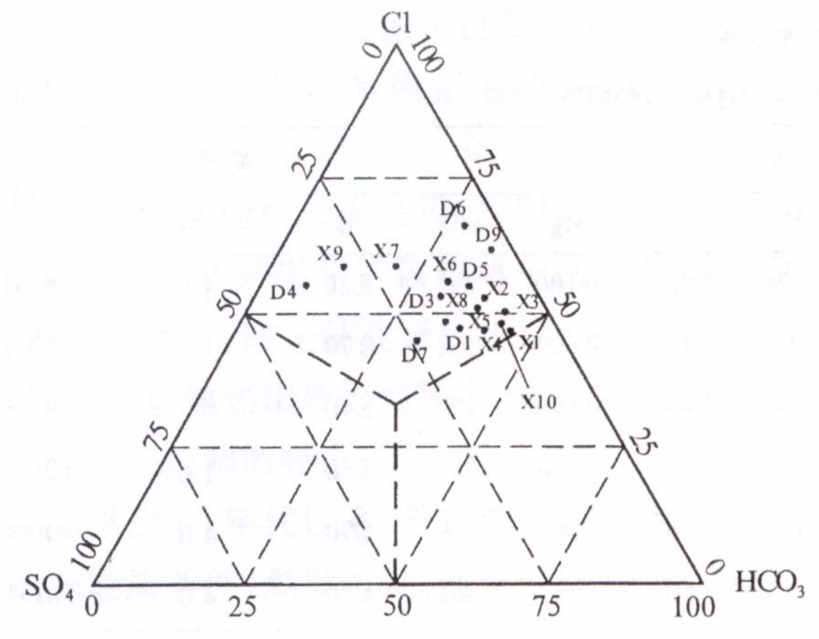

Figure 1: Cl-SO_4-HCO_3 Classification Plot (Hu, 2003)

4. GEOTHERMOMETERS

One geothermometer gives near true temperature of a reservoir when the hydrological conditions are suitable. Geothermometer calculation formula involve ion content which is influenced by reaction temperature, rock type and input fluid. So the characters of ion content have strong links with the character of the reservoir hydrogeological conditions. Namely geothermometer ion content, calculated temperature and hydrogeological conditions connect and influence one another. Every bad temperature given by a geothermometer can find one or several reasons from the above mentioned factors. This is the theoretical foundation for a reverse method used in this study.

Several basic conditions are required for a reaction to become a good geothermometer. When a suitable geothermometer is set, the others can be used as tools to assess the reservoir conditions.

For a good geothermometer, the basic requirement is equilibrium. Hence, in this study, rock-fluid reaction equilibrium conditions is studied to help assess.

The aquifers of RGF are volcanic rocks. Beneath Kuirau Park Rotorua rhyolite is the main aquifer. 3 reactions involved in the deep reservoir can act as geothermometers. They are:

$SiO_2 + 2H_2O = H_4SiO_4$

Na-feldspar + K^+ = K-feldspar + Na^+

2.8K-feldspar + $1.6H_2O$ + Mg^{++} + 0.8K-mica + 0.2chlorite + $5.4SiO_2$ + $2K^+$

During the hot fluid ascent along fractures, boiling and mixing happen. Steam loss occurs. Accordingly, we use quartz-maximum steam loss geothermometer (Giggenbach), Na-K geothermometers (Founier, Giggenbach) and K-Mg geothermometer (Giggenbach) to assess the hydrology of Kuirau Park thermal area.

Table 1 shows the general requirements of these geothermometers.

Table 1 The application requirements for Quarta, Na-K and K-Mg geothermometers

Geothermometers	Applications
Quartz (maximum steam loss)(Fournier,)	1.ReservoirT>180□
	2.Discharge rate >2l/s
	3.Springs or pools with silica sinter
Na-K (Fournier, Giggenbach)	1.Reservoir T>180□
	2.near neutral pH chloride waters
	3.Ca concentration is low (no travertine deposit)
K-Mg (Giggenbach)	Chloride water only

Na-K geothermometers are more reliable in the condition of mixture than quartz and K-Mg geothermometers due to the characteristics of the water type of this area. Considering the possibility of re-equilibrium, quartz (maximum steam loss) and K-Mg geothermometers may tell the true temperatures when re-equilibrium reaches. Meanwhile, they act as analyzing tools to understand the hydrology conditions at depth when equilibrium is unreachable.

K-Mg geothermometers only can be used for chloride waters. It is sensitive to mixing. When the deep chloride water mixes with the shallow groundwater, it gives lower temperature. Also mixing which dilutes the silica concentrations makes quartz geothermometer gives lower temperature than the true equilibrium temperature in the deep reservoir.

Table 2 shows the calculation results of the reservoir temperatures.

Table 2 Calculation results of reservoir T (□)

Sam.	SiO2	Na-K		K-Mg
	F	F	G	G
D1	178	210	226	170
D3	188	205	221	163
D4	184	179	197	155
D5	205	205	221	
D6	204	204	220	
D7	213	233	248	
D9	200	205	221	
X1	183	213	229	152
X2	198	217	233	
X3	201	221	236	253
X4	200	224	239	224
X5	197	223	238	225
X6	187	188	205	135
X7	171	210	226	164
X8	181	216	232	181
X9	173	206	222	165
X10	195	218	233	202

Where F stands for Fournier, G stands for Giggenbach.

5. DATA ANALYSIS

As the underpinning principle for geothermometers is that the fluid is in full equilibrium conditions. Here, Na-K-Mg ternary plot is used (Fig 2) to determine the fluid equilibrium status.

From Fig 2, we can see X4 and X5 are near the full equilibrium line. Since only full equilibrium reactions reflect the reservoir temperature, so temperatures of 224□ (Fournier) - 239□(Giggenbach) which X4 and X5 give reflect the reservoir temperature. Na-K and K-Mg geothermometers give similar temperatures indicate the deep hot water in these two springs is not much diluted and double confirm the temperatures.

D5 and D6 are not put into this plot because their Mg concentrations are below detective. But from table 2, we can see that silica and Na-K (Fournier) temperatures of D5 and D6 give the same temperatures but lower than those of X4 and X5. From Fig.1 we can see these two samples fall in the area which concentrations of Cl^- and HCO_3^- are high and concentration of SO_4^{2-} is low. It can be deduced that hot fluid in these two springs are mature but re-equilibrated.

For the other samples put on this plot fall in the partial equibrium area and show a mixing trend. Silica, K-Mg geothermometers give lower temperatures than that of Na-K geothermometer (see table 2) indicating mixing is a significant process beneath Kuirau Park.

X3's K-Mg temperature is higher than its Na-K temperature. This result is not reliable because the analyzed concentration of Mg^{++} is too low to be detected accurately by ICP-AES.

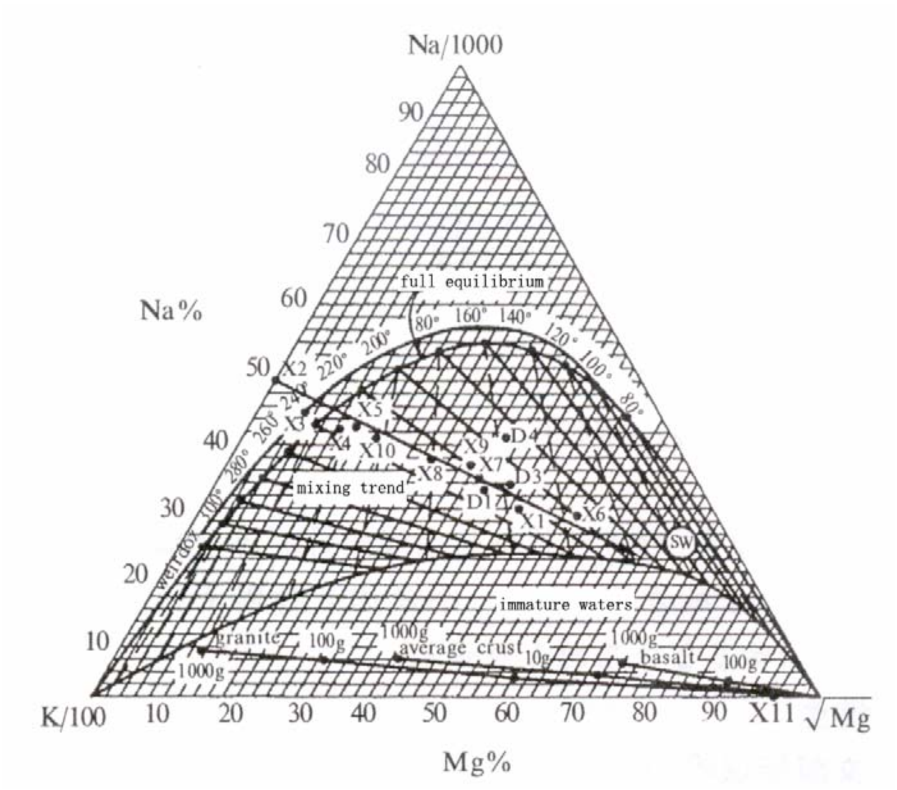

Figure 2: Na-K-Mg ternary plot (Giggenbach) (Hu, 2003)

6. CONCLUSIONS

1. It is practical to use different geothermometers to deduce hydrology conditions of a geothermal field when representative samples are enough for obtaining an all-around understanding of a geothermal field.

2. The deduceed results will be reliable when temperatures given by different geothermometers can test and prove each other.

3. Equilibrated fluid or mature fluid samples are a must for a conversion method. This kind of samples act as a standard for analyses and comparison.

4. The hydrological characteristics of Kuirau Park thermal area are deduced as follows: (1)Aquifer beneath Kuirau Park is not even in permeability. Fractures in upper part and eastern sector are less developed than those in lower part and western sector. Fractures in lower part and western sector are wider and more developed. Hence, the permeability is better. (2) Equilibrium is broken due to dilution and temperature drops. (3)In some places, re-equilibrium reaches at a relatively lower temperature due to less fractured rock and slower speed of fluid. (4) Connection among fractures are not even. A mixing trend is obvious. (5) In eastern sector, hot water re-equilibrates. Reservoir temperatures are about 204℃-221℃. In western sector, the Na-K and K-Mg geothermometers show the deep reservoir temperature is about 223℃-239℃.

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