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The Flow Path of Geothermal Fluid Identification and the Reservoir Temperature Evaluation in Geothermal Area of Ilan, Taiwan

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ABSTRACT

It is a well-known fact that the geochemical modeling is a useful tool for geothermal exploration. In Taiwan, four higher geothermal potential areas, including Tatun, Ilan, Lushan and Hwa-Tung, have been identified based on the data of reservoir temperature and geothermal gradient by silica geothermometer and the temperature profile of drill wells. This is the first application of the multicomponent geothermometer in geothermal area to understand the flow path of fluid from reservoir to surface and evaluate the reservoir temperature in Taiwan. We collected groundwater and hot spring samples from the southern foothill area of Ilan Plain and Chingshui geothermal area for chemical and isotopic analysis. The estimated reservoir temperatures are 31-96 ˚C, 31-91 ˚C and 151-248˚C in the southern foothill of Ilan Plain and Chingshui geothermal area, respectively. Isotopic results show that water samples taken for this study are above the local meteoric line. However, isotopic values of the foothill area are much scatter than that of Chingshui geothermal area indicating various sources of precipitation. On the other hand, isotopic values of the Chingshui geothermal area are much more influenced by heat. The results of the multicomponent geothermometer of this study with chemical analysis demonstrate that this geothermometer not only can estimate the reservoir temperature but also may implicate the fluid flow path.

1. Introduction

One should always keep in mind that the geothermal fluids are coming from the deep reservoir where the most important geothermal processes took place by water-rock interactions, which is dependent mainly on temperature. Two common ways of estimating reservoir temperature are direct measure well borehole temperature and geothermometry which is the most extensively used to estimate the geothermal reservoir temperature before and during exploration and exploitation of geothermal systems (Fournier, 1979; Fournier and Potter, 1979; Karingithi, 2009; Reed and Spycher, 1984).

Enormous contributions have been made on the geothermometers to estimate reservoir temperature. Among them are (1) silica geothermometers, Na-K geothermometer, (3) Na-K-Ca geothermometer, (4) Na-Li geothermometer, (5) K-Mg geothermometer, and (6) multicomponent geothermometer. All estimations are based on the equilibrium between water and rock and most importantly, no additional water is added to the equilibrium equation as it ascends to the surface. (Fournier and Rowe, 1966; White et al., 1956; Fournier and Rowe, 1966; Verma, 2000; Karingithi, 2009; Reed, 1982; Reed and Spycher, 1984). The multicomponent geothermometer is considered to estimate reservoir temperature better than other methods.

Taiwan is located in the ring of fire, circum-Pacific belt, with high potential for geothermal exploration. The Chingshui geothermal field, is located in the north eastern Taiwan, and is one of the oldest renowned geothermal fields in Taiwan and it was the 14th geothermal power plant as it built in 1981 with 3MWe (Liu and Song, 2012). The potential geothermal was estimated as 33.64GWe in 4 different areas (Liu and Song, 2012)

This paper is aimed to first apply the multicomponent geothermometer to the Ilan geothermal area, Taiwan to better estimate its reservoir temperature and attempt to understand the possible variations of its

2. GEOLOGICAL SETTING

Taiwan is located in the ring of fire, circum-Pacific belt, with high potential for geothermal exploration. The study area, the Ilan geothermal field, is located in the northeastern Taiwan with a triangular in shape (Figure 1). The Hsuehshan Range belt lies in the north of the plain and the south is situated the Backbone Range belt. The upper most part of the plain is covered by Holocene alluvium sediments ranging from 100 to1000 meters including gravel, sand and mud. A volcanic intrusion inferred by magnetic anomaly could

be the heat source of the study area (Chiang, et al. 2008). The Backbone Range belt is composed of mainly slate with a well-developed cleavage, and argillite and sandstones (Ho, 1975).

27 samples were taken and analyzed for this paper. 11 samples are taken from the Ilan plain (IP 01, 02, 03, 04, 05, 06, 07, 08, 09, 10, and 12) ranging from 35 meters to 179 meters; 8 samples are taken from the mountain foothill (IF 03, 04, 05, 06, 07, 08, 09 and 12) and another 8 samples from the Chingshui geothermal field (ICd、ICe、ICf、ICg and ICh) with 3 spring samples (Figure 1).

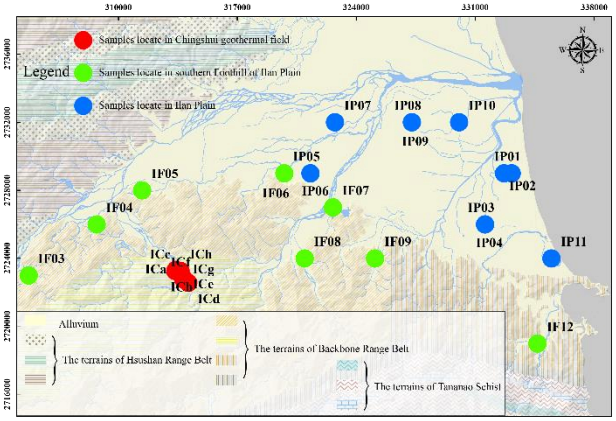

Figure 1. The location maps and sampling sites. Blue dots are located in the plain area, green ones are in the mountain foothill and red ones are in the Chingshui geothermal field.

3. METHODS

3.1 The measurements in field

In situ water temperature, pH values, conductivity and total dissolved solids of waters were measured by handheld instrument (Type Myron L Company ULTRAMETER).

3.2 The analysis in laboratory

All samples were filtered through 0.22-μm cellulose filters in the field and stored in high-density polyethylene (HDPE). An ultra-pure HNO3 added to water samples for cation analysis to prevent precipitation. In laboratory, the Yttrium is added in samples as the internal standard.

The anions and cations were measured using an ion chromatograph (IC, Type Met Rohm) and an inductively coupled plasma-atomic emission spectrometer (ICP-AES, Type Jobin-Yvon ULTIMA2), respectively. The stable isotopes were analyzed by PICARRO L2130-I. The analysis of mineral assemblage of the country rock by X-ray Diffraction (XRD, Type Shimadzu XRD-6000).

3.3 The simulation by Geochemist's Workbench

This study calculates the reservoir temperature and discusses the flow path of different geological terrain by Geochemist's Workbench software. The figure 2 displays the principle of simulation.

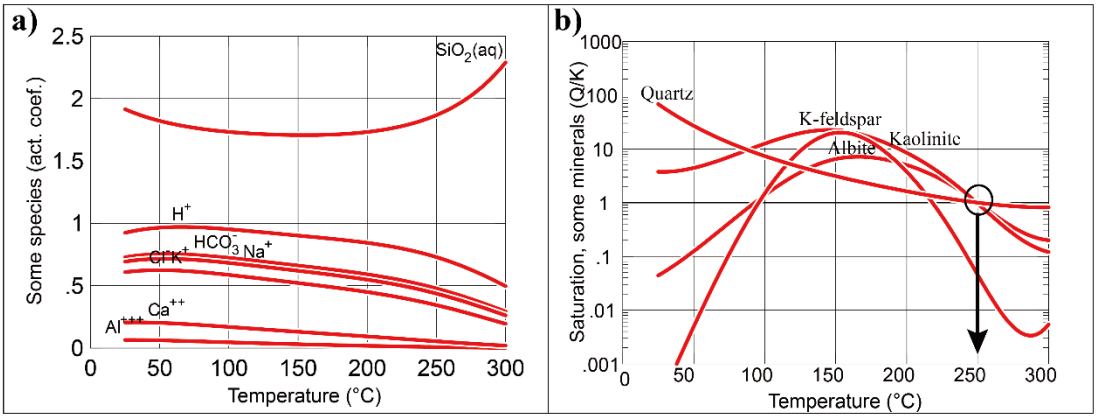

Figure 2. An example of Geochemist's Workbench. a). activities of species with different temperatures; b). The potential temperature was indicated as saturation (Q/K) of mineral assemblage at the same spot.

4. RESULTS

4.1 The measurements in field

In Ilan Plain, the in situ pH and temperature values of water samples are 6.15-8.1 and 21℃-25.9℃, respectively. In southern foothill area of Ilan Plain, the pH values and temperature values of in situ of water samples are 6.47-7.37 and 8.9℃-35.9℃, respectively. In the Chingshui geothermal field, the pH values and temperature values of in situ of water samples are 6.14-9.2 and 63.2℃-96.4℃, respectively (Figure 3).

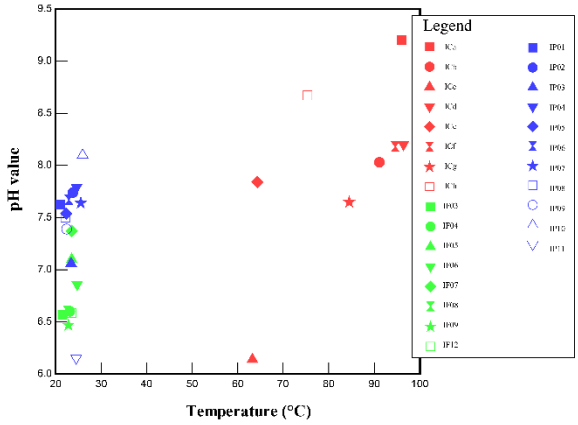

Figure 3. In situ water temperatures and pH. Blue dots are located in the plain area, green ones are in the mountain foothill and red ones are in the Chingshui geothermal field.

4.2 The chemical characteristics of water samples

Based on the major elements concentration, the waters of western Ilan Plain belong to Ca-HCO_3 type, the waters of eastern Ilan Plain are characterized as Na-HCO_3 type; the waters of southern foothill of Ilan Plain are characterized as Na-Ca- HCO_3 type; and the waters of Chingshui geothermal field belong to Na-HCO_3 type (Figure 4).

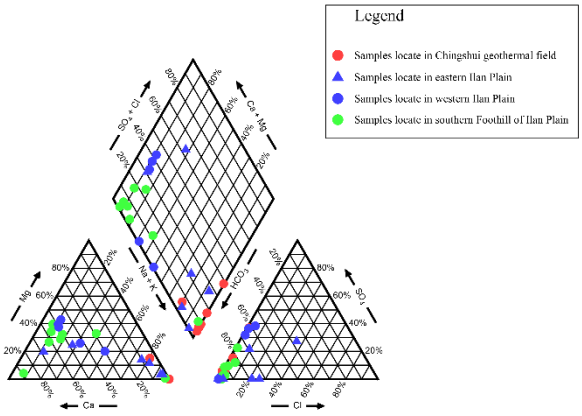

Figure 4. Piper diagrams of major elements of water samples. Blue dots are located in the plain area, green ones are in the mountain foothill and red ones are in the Chinshui geothermal area.

4.3 The stable isotopic characteristics of water samples

In Ilan Plain, the oxygen and hydrogen stable isotopic values of water samples are ranging from -7.1846‰ to -5.1944‰ and -34.6765‰ to -17.5781‰, respectively. In the mountain foothill area, the oxygen and hydrogen stable isotopic values of water samples are -6.3722‰ ~ -4.7036‰ and -34.6775‰ ~ -18.3266‰, respectively. In the Chingshui geothermal field, the oxygen and hydrogen stable isotopic values of water samples are -6.56‰ ~ -4.66‰ and -54.1‰ ~ -40.3‰, respectively (Figure 5). The stable isotopes of Ilan Plain and mountain foothill are located along the Meteoric line but the Chingshui geothermal field.

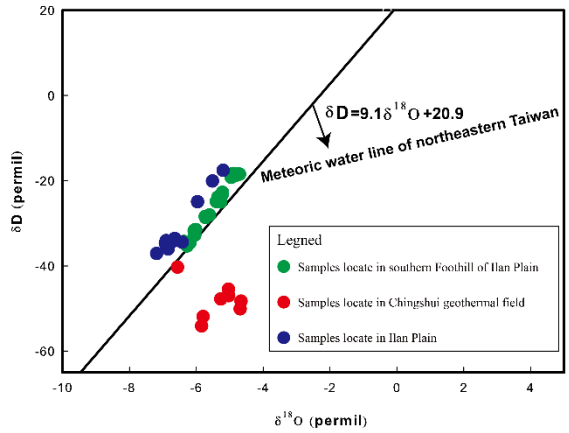

Figure 5. Stable isotopes results of water samples. Blue dots are located in the plain area, green ones are in the mountain foothill and red ones are in the Chingshui geothermal area.

4.4 The mineral assemblages in Ilan area

The mineral assemblages of country rock, cutting and core by XRD showed quartz (49%), illite (28%), kaolinite+chlorite (18%) and feldspar (5%) in Ilan area (Figure 6).

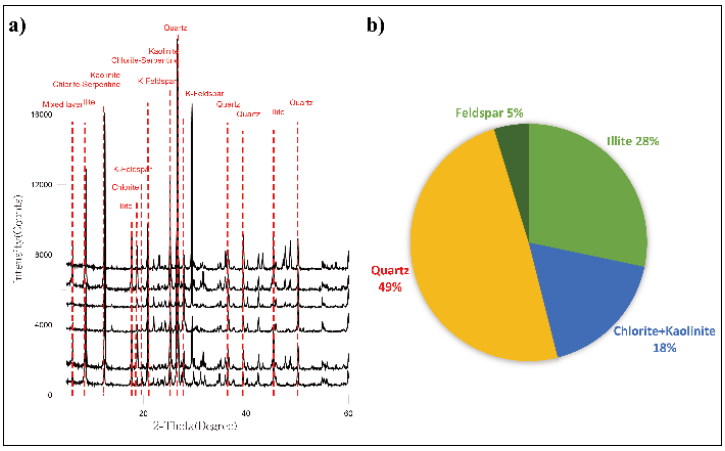

Figure 6. (a) The XRD pattern of mineral. (b) The percentage of mineral assemblages in Ilan area.

4.5 The reservoir temperature evaluation by Geochemist's Workbench software

The reservoir temperature values of Ilan Plain, southern foothill area of Ilan Plain and Chingshui geothermal field are 31℃-96℃, 31℃-91℃ and 151℃-248℃ (Figure 7).

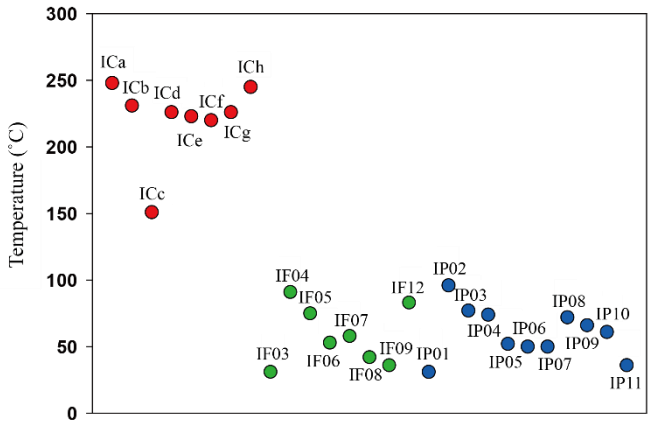

Figure 7. The reservoir temperature in the study area. Blue dots are located in the plain area, green ones are in the mountain foothill and red ones are in the Chingshui geothermal area.

5. DISCCUSSION

5.1 Comparison the geochemical and stable isotopic characteristics in different terrain

Piper diagrams of major element of Ilan plain area show a wide range distribution (Figure 4) indicating that the equilibrium between water and rock has not yet reached. Water samples were collected around 100m mostly in depth where is covered by Holocene alluvium sediments with rapid groundwater flow. On the other hand, piper diagrams of major element of mountain foothill display much less wide spread than that of the plain area indicating much less other water influence even samples were collected at the relatively same depth. Piper diagrams of major element of the Chingshui geothermal field show a much concentrated pattern indicating the equilibrium has been reached. The values of stable isotopes show the same indications. Water samples taken from the Ilan Plain and mountain foothill are located along the Meteoric line indicating severe recent water influence whereas samples from the Chingshui geothermal filed are away from the Meteoric line.

5.2 The geothermal flow path of Ilan area

Figure 8 shows the distribution of gravel and mud in the Ilan plain area. General speaking, it is less sediment cover in the southwest area of the plain where is mainly composed of gravel and higher values of tritium. On the other hand, the southeastern area of the Plain is mainly composed of thicker mud coverage with lower values of tritium isotopes. This indicates that the more rapid recharge in the southwestern area than that of the southeastern area. However, as water heated in the Chingshui geothermal field, it accretes the reaction and keeps the rock signals in water (Savin and Epstein, 1970; Lawrence and Taylor, 1972; Criss, 1999; Hoefs, 2004) and keep the values of stable isotopes off the Meteoric line.

Figure 9 shows the results of applications of the multicomponent geothermometer for three locations in the study area. The more influence of recent meteoric water, the wider intersection area of Q/K indicating the poor correlation between temperature estimation and saturation index. Figure 9a and b represent the Ilan plain and mountain foothill areas with poor relationship whereas 9c represents the Chingshui geothermal field with a highly concentrated intersection area indicating the well relationship between Q/K and temperature. In fact, sample C from the Chingshui geothermal field, exhibit a bit different from the rest of the group indicating it has been influenced by the recent meteoric water as it ascends to the surface. This demonstrates that this method can estimate reservoir temperature and indicates the possible influence as the geothermal fluid ascends along the flow path.

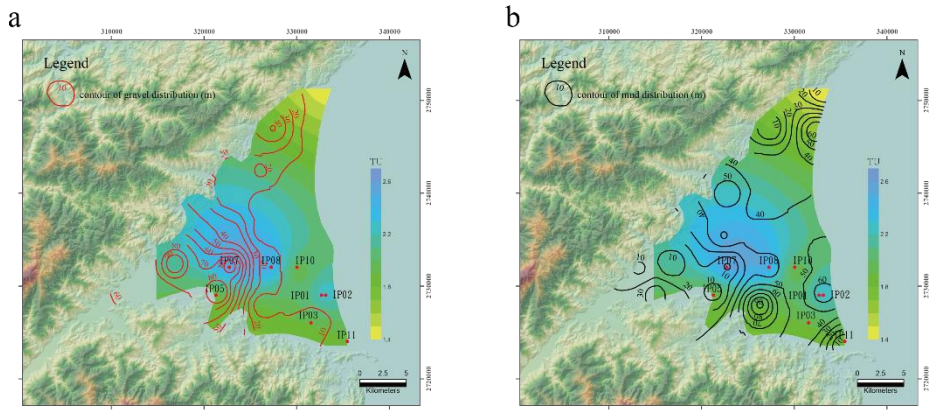

Figure 8. (a) the contours of gravel distribution with tritium isotopes. (b) the contours of mud distribution with tritium isotopes (Taken from MOEA，2014)。

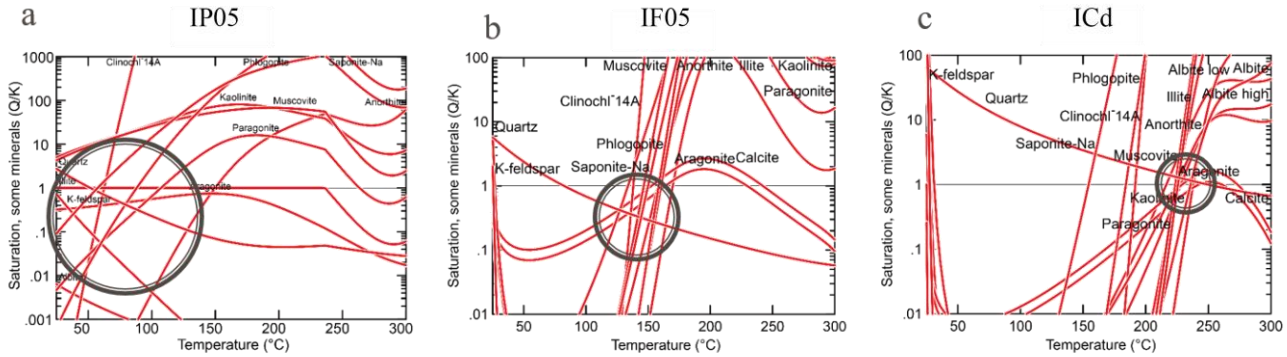

Figure 9. The relationship between saturation index (Q/K) and temperature of the study area. (a) Ilan Plain，(b) Mountain foothill , and (c) the Chingshui geothermal field.

6. CONCLUSION

(1). Waters are rich in Ca-HCO3 in the western are of the Ilan plain and rich in Na- HCO3 in the eastern area; while waters in mountain foothill are rich in Na-Ca- HCO3 and waters in the Chingshui Geothermal field are rich in Sodium bicarbonate.

(2). The major minerals of the study area are quartz, Illite, kaolinite, chlorite and feldspar.

(3). The estimated reservoir temperatures by the multicomponent geothermometer are 31°C-96°C for the Ilan plain area, 31°C-91°C for the mountain foothill area and 151°C-248°C.

(4). There are two distinctive groups of stable isotopes. Ilan plain are and mountain foothill areas are distributed along the Meteoric line and the Chingshui geothermal field is off the Meteoric line indicating the influence of groundwater recharge and equilibrium condition.

(5). The multicomponent geotherometer can apply to estimate reservoir temperature of the study area and indicating the influence of meteoric water as the geothermal fluid ascends along the flow path.

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