FLUID AND HEAT SOURCES IN THE CHINGSHUI GEOTHERMAL SYSTEM

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ABSTRACT

The Chingshui geothermal field is located in the valley of Chingshui stream, southwest of Ilan Plain, northeast Taiwan. The rock hosting the geothermal field is the Miocene Lushan Formation, consisting dominantly of argillite/slate with intercalated thin meta-sandstones. Several hot springs with minor hydrothermal alterations are the important thermal manifestations, which they crop out along the river bed and rock cliffs in this area. In this study, we combined the clumped isotopes with carbon and oxygen isotopic compositions of calcite scaling and veins from geothermal wells and outcrops, respectively, and geophysical information. Two hydrothermal reservoirs at different depths have been identified. The shallow reservoir provides the fluid from meteoric water for the scaling sampled from wells dominantly, while the deep reservoir provides magmatic fluid with deep marble decarbonization recorded in outcropping calcite veins.

Keywords: The Chingshui Geothermal field, clumped isotopes, calcite veins, magmatic fluid

1. INTRODUCTION

Taiwan belongs to the Ring of Fire and is famous for active orogeny (Fig. 1). Presently, the Philippine Sea plate is moving towards WNW at about 70 mm/yr (Seno and Maruyama, 1984), and it is believed the mountain-building process is still on-going (Tsai et al., 1981; Yu and Chen, 1994). The Okinawa Trough is a back-arc basin, which extends from southwest Kyushu Island (Japan) to the Ilan Plain, where is the southwest-most tip of it. The Chingshui geothermal field is located in the valley of Chingshui stream, southwest of Ilan Plain, northeast Taiwan (Fig. 1). The rock hosting the geothermal field is the Miocene Lushan Formation, consisting dominantly of argillite/slate with intercalated thin meta-sandstones (Hsiao and Chiang, 1979; Tseng, 1978). Several hot springs with minor hydrothermal alterations are the important thermal manifestations, which they crop out along the river bed and rock cliffs in this area. More than 20 wells have been drilled since 1970s, and got high geothermal gradient. Abundant geochemical data, including water chemistry, isotopes of fluids and calcite veins have been done. Meanwhile, a 3MW pilot geothermal power plant has been constructed and operated 12.5 years. The aim, therefore, of this article is to study what the heat and fluid sources are from, based on the geochemical information with geophysical surveys.

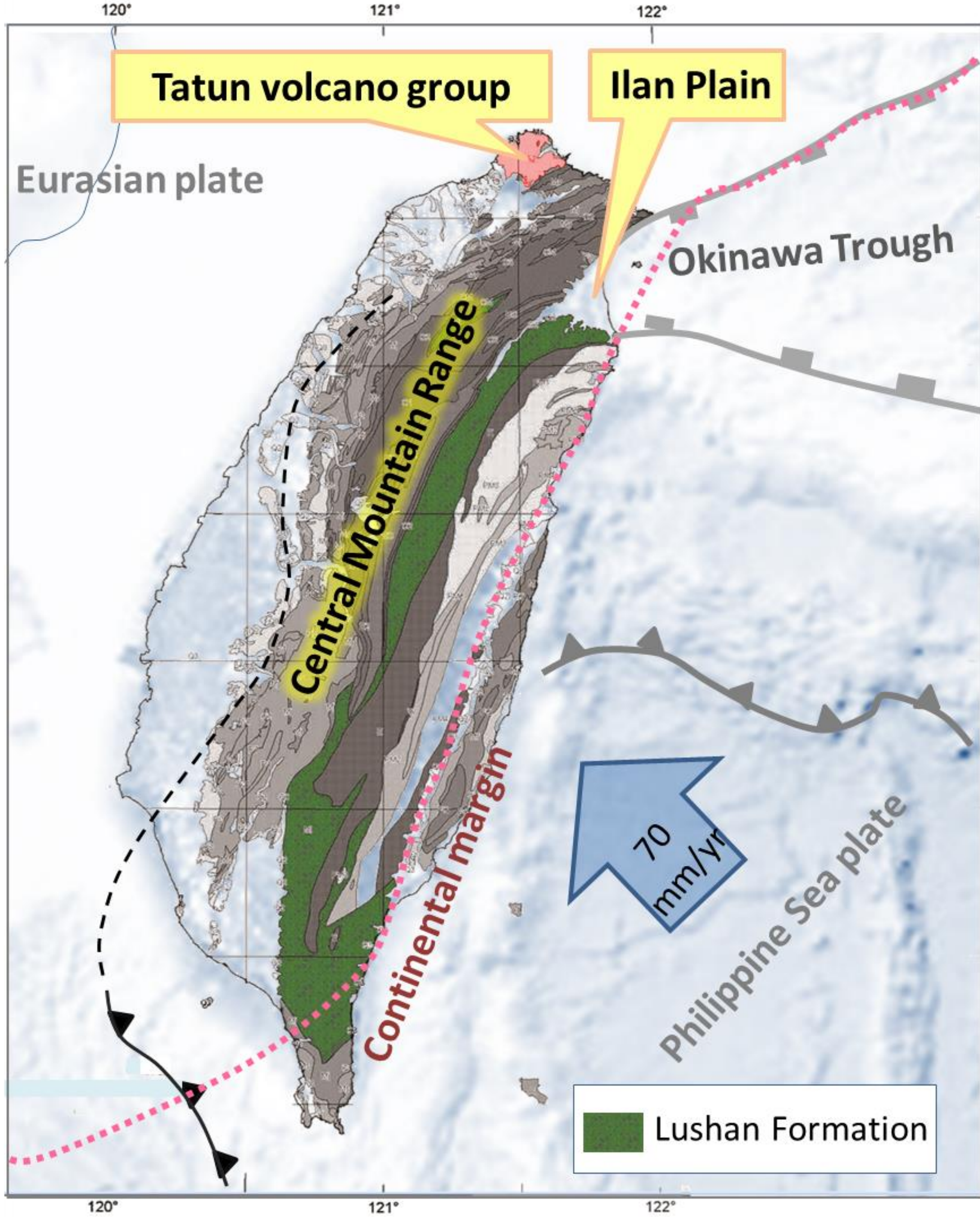

Figure 1: The tectonic framework of Taiwan.

2. GEOCHEMISTRY OF FLUIDS

Several hot springs cropped out on the surface and 21 exploring and production wells have been drilled in the Chingshui geothermal field. The temperatures and pH of springs and wells range from 48℃ to 99℃ and 6.4 to 9.7, and from 180℃ to 230℃ and 6.3 to 8.9, respectively (MRSO, 1978). The major gases of geothermal steam being about 20% in the Chingshui area are CO2, H2S and others. Carbon dioxide is generally the major gas component often comprising more than 97% of all non-condensable gases and its concentration increases with reservoir temperature. Hydrogen sulfide concentration is about 1 % and commonly decreases as steam ascends to the surface due to reaction with wall rock, dissociation to sulfur or oxidation to SO4(MRSO, 1978).

Chemical compositions of cations and anions in the Chingshui geothermal fluids are pretty variable. Bicarbonate ([HCO_3^-] = 500-3,200 ppm) is the major anion in most geothermal waters, and being with lower chloride ([Cl^-]= 6.5~23.4 ppm) and sulfate ([SO_4^{2-}]= 29-72 ppm), which are the bicarbonate fluid type based on Piper diagram (Fig. 2) (Piper, 1953). Sodium ([Na^+] = 35-1,235 ppm) is the major cation in most geothermal fluids, and being with pretty lower calcium and magnesium (both few ppm). Based on the Na-K-Ca geothermometer, the temperatures of thermal fluids in reservoirs range from 137℃ to 205℃. Silica (SiO_2) compositions of thermal fluids range from 83 ppm to 413 ppm, which are correlated to the temperature from 127℃ to 214℃, respectively, by silica geothermometry (MRSO, 1978). However, the SiO_2 geothermometer is a more reasonable and suitable method than Na-K-Ca one for assessing reservoir fluid temperatures in the slate region in Taiwan in terms of experimental fluid-rock interactions on laboratory (Huang et al., 2018).

Hydrogen and oxygen isotopic compositions for meteoric water along Langyong River (the mainstream of Chingshui River) were -70~+10 ‰ and -11 to 0 ‰, which may due to rapid topographic change and the strong monsoon effect in winter (Liu et al., 1990) (Fig.3). For the hot springs and thermal water, the δD and $\delta^{18}O$ values are -67~-32 ‰ and -9.2 to -4.4 ‰, and -57~-24 ‰ and -6.7 to -4.0 ‰, respectively. The wide ranges of isotopic compositions in hot springs may be partly attributed to wider geographic distributions of them and mixing of thermal water with meteoric water (Liu et al., 1990). Plots of H- and O- isotopic compositions of thermal water on the local Meteoric Water Line (MWL) show that close relationship with the meteoric water (Fig.3). Isotopic changes of geothermal water due to fluid-rock interaction were small with a maximum δ18O shift of about 3‰ from the MWL. This small shift may reflect the slow fluid-rock interaction in terms of low permeability of the slate host rocks (Liu et al., 1990).

3. ISOTOPES OF CARVONATE VEINS AND SCALING

The hot fluids in Chingshui geothermal field are characteristic of high concentration of HCO_3^-. When the geothermal reservoir is breached by tectonic activities or drilling for geothermal exploitation, CO_2 is oversaturated and can be released quickly by depressurization causing the bicarbonate solution to oversaturate rapidly with pH increase and to precipitate carbonate minerals from thermal water immediately. The isotopic data from fracture-filling carbonate minerals have been found to be particularly useful to constrain the geochemical characteristics of fluid reservoirs and possible post-depositional and syntectonic fluid processes (Iwatsuki et al., 2002; Li et al., 2013; Luetkemeyer et al., 2016; Wallin and Peterman, 1999; Wang et al., 2010).

Two populations of $\delta^{18}O$ values were recognized: -5.8±0.8 ‰ VSMOW from scaling in the wells and -1.0±1.6 ‰ to 10.0±1.3 ‰ VSMOW from the calcite veins of outcrops, which are indicative of meteoric and magmatic fluid sources, respectively (Fig. 4) (Lu et al., 2017). Meanwhile, two hydrothermal reservoirs at different depths have been identified by magnetotelluric (MT) imaging with micro-seismicity underneath this area (Chiang et al., 2014; Liu, 2013). Two-reservoir model has been proposed: One is the shallow reservoir with fluids from meteoric water to provide the thermal water for scaling depositions inside the production wells, while the deep one supplies magmatic fluids mixing with deep marble decarbonization to precipitate the calcite veins near fault zones (Lu et al., 2017). Helium isotope data from Cheng (2014) also provided strong evidence of magmatic fluids from the deeper reservoir in the Chingshui geothermal field. The ratios of $^{3}He/^{4}He$ were 3.8–4.0 RA and 0.8 RA for the samples. These lines of evidence indicated the existence of a mantle-derived component in the Chingshui area, which may be derived from magmatic degassing; however, the lower helium isotope ratio of the other sample also implied a mixing between such a deeper, magmatic-related reservoir and a shallower, crustal-related one (Cheng, 2014; Lu et al., 2017).

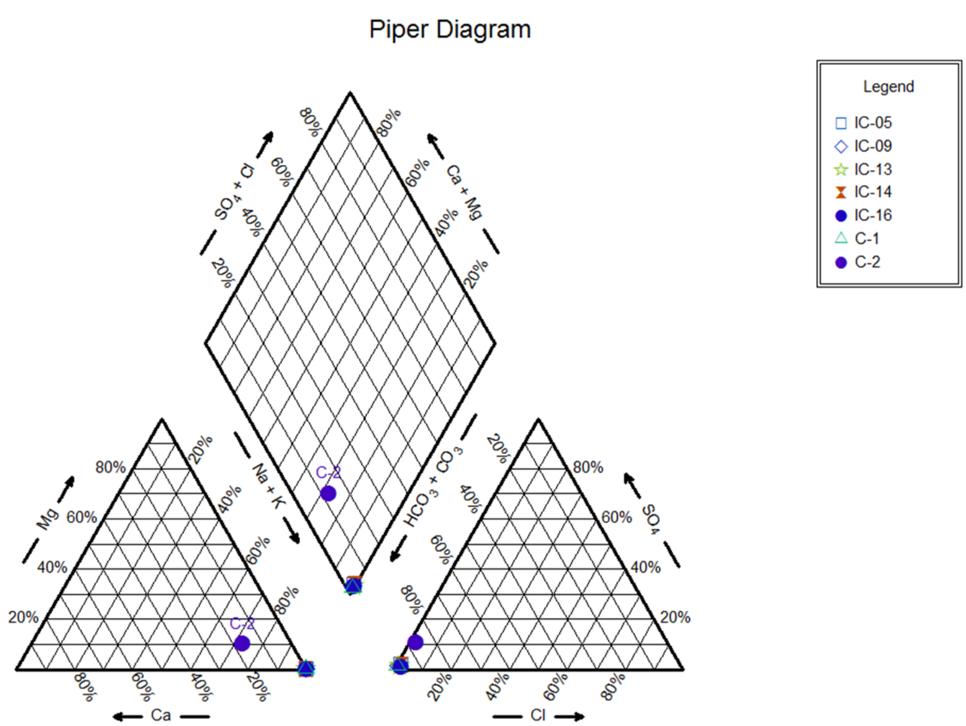

Figure 2. The water compositions of Chingshui area are plotted on the Piper diagram showing the typical Na-bicarbonate fluid type.

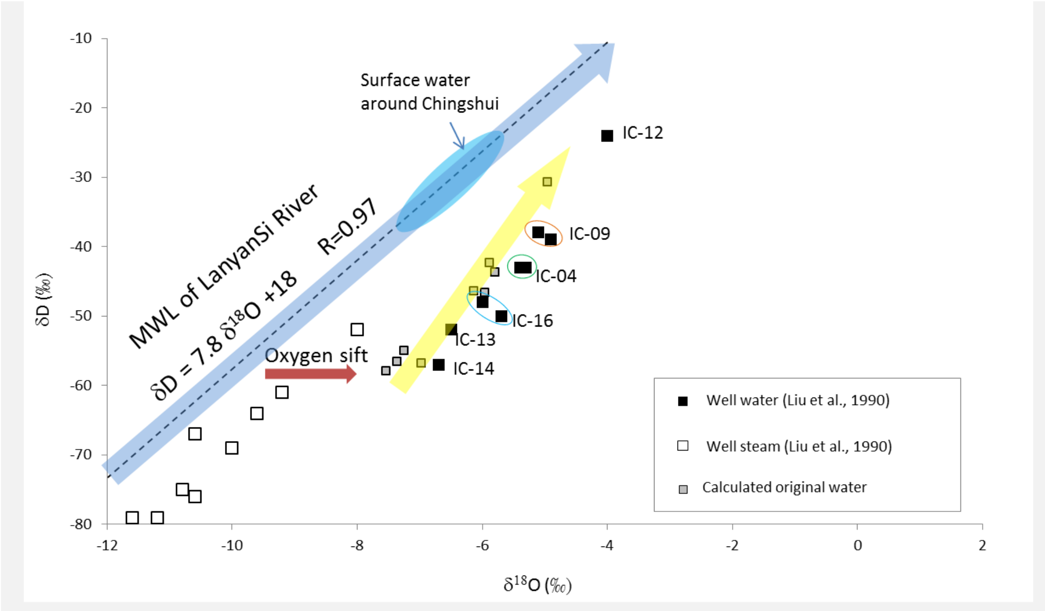

Figure 3. Plots of H- and O- isotopic compositions of thermal water on the local Meteoric Water Line (MWL) show that close relationship with the meteoric water.

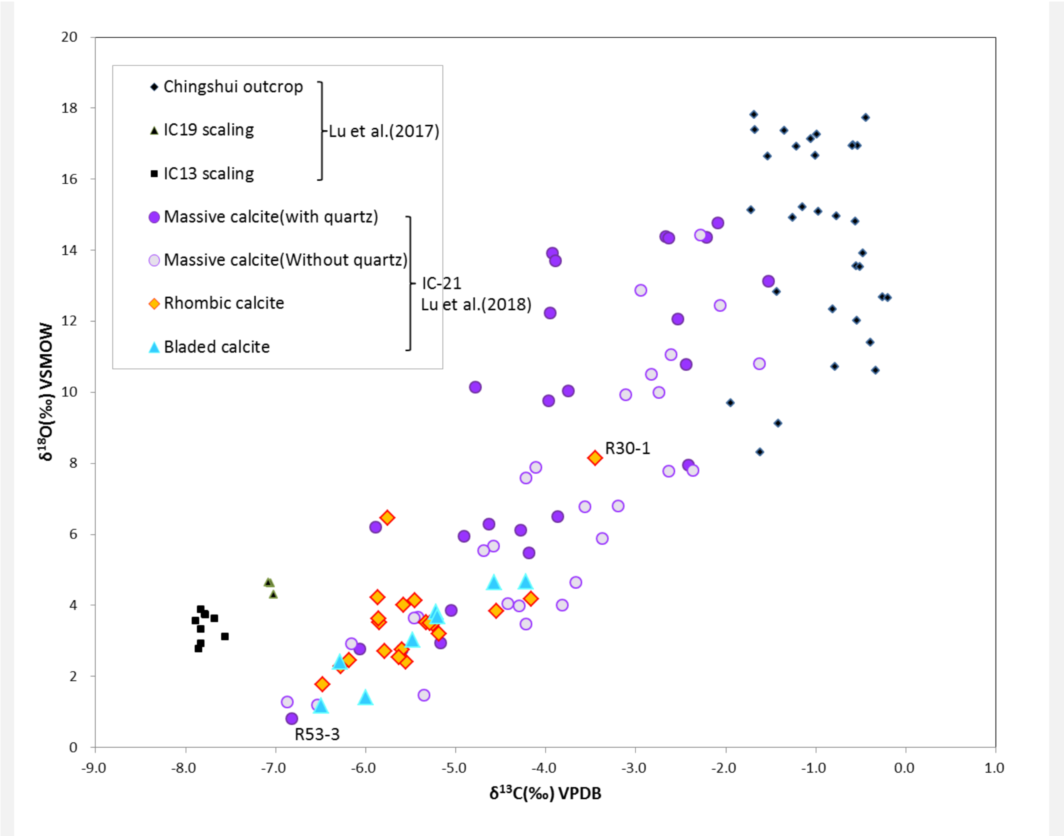

Figure 4. Plots of carbon and oxygen isotope values of calcite veins and scaling from outcrops, IC-21 and wells in the Chingshui geothermal field.

The well IC-21 commenced drilling at May, 2010. Upper 600 m was drilled into the hole and didn't take any cores, just a cutting per 10 meters. Whole coring raised 200 m in length between 600 m to 800 m in depth and got over 95% core recovery. Lithologically, the 200 m cores are predominantly composed of dark-gray to black slates occasionally intercalated with argillites or meta-sandstones. There are many deformation structures, fractured systems and veins in the cores. It is characteristic that many scaling minerals are irregularly filled up in the fractures, veins and open cracks.

Three types of calcite crystal morphologies have been identified in the veins of the cores: bladed, rhombic and massive crystals. Bladed calcites are generated via degassing under boiling conditions with a precipitation temperature of ~165℃ and calculated δ18O value of -6.8 ‰ to -10.2 ‰ VSMOW for the thermal water (Lu et al., 2018). Rhombic calcites grow in low concentration Ca^{2+} and CO_3^{2-} (Domingo et al., 2006; Lahann, 1978; Moore and Wade, 2013) meteoric fluids and precipitate at approximately ~180℃ (Lu et al., 2018). Finally, massive calcites co-precipitated with quartz in the mixing zone of meteoric water and magmatic or metamorphic fluids with calculated $\delta^{18}O$ value of up to 1.5±0.7 ‰ VSMOW. Furthermore, the scaling and hot fluids at a nearby pilot geothermal power plant confirm a meteoric origin. It indicates the current orientations of the main conduits for geothermal fluids are oriented at N10°E with a dip of 70°E (Lu et al., 2018).

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