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Evolution of deep parent fluids of geothermal fields in the Nimu–Nagchu geothermal belt, Tibet, China

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ABSTRACT

This study defines reasonable reservoir temperatures and cooling processes for geothermal fluids in three representative high temperature geothermal fields – Yangyi, Yangbajing, and Gulu – distributed along the active geothermal belt of Nimu–Nagchu in south-central Tibet. It uses a combined analysis of hydrochemical compositions, chemical geothermometers, and multicomponent chemical equilibrium analyses of geothermal fluid with an enthalpy vs. chloride plot. There are two geothermal reservoirs in Yangyi and Yangbajing, and both the intermediate and high temperature reservoirs of any one geothermal field are essentially within the same hydrothermal system. The subsurface geothermal fluids from Yangyi cooled mainly by mixing with abundant cold water in the intermediate (163–172 °C) and high temperature (192–200 °C) reservoir. The subsurface geothermal fluids from Yangbajing experienced adiabatic cooling and mixing with colder water, which formed the high temperature reservoir ZK4001 (255 °C) and intermediate temperature reservoirs (164–177 °C), respectively, and then emerged on the surface with adiabatic cooling during the ascent. The subsurface geothermal fluids from Gulu ascended to high temperature geothermal reservoirs (211–234 °C) mainly cooled by adiabatic boiling or mixing with cooler water. Most of the high temperature fluids mixed with colder water (mixing temperatures range from 149 °C to 176 °C) during the ascent, and then emerged on the surface as hot springs mainly cooled by conduction. The deep parent fluid of Yangbajing is calculated to have a Cl^- concentration of 767 mg L^{-1} and enthalpy of 1350 J g^{-1} (water temperature of 321 °C), which agrees well with the maximum temperature measured in well ZK4002 (329 °C). The deep parent fluid of Gulu is calculated to have a Cl^- concentration of 845 mg L^{-1} and enthalpy of 1290 J g^{-1} (water temperature of 307 °C).

1. Introduction

As part of the Mediterranean-Himalayas geothermal belt, Tibet possesses abundant geothermal resources. The research area is located in the Nimu–Nagchu geothermal belt of south-central Tibet. Geothermal resources in this area occur mainly along the NE-trending active fault belt of Damxung–Yangbajing–Duoqingcuo, which holds one of the most concentrated geothermal reserves with the greatest geothermal potential in Tibet (Geothermal Geological Team of Tibet, 1991; Liu et al., 2014). Based on the hydrochemistry and isotopic composition of geothermal fluids and gases, as well as stratigraphic, tectonic, and geophysical data, previous researchers have investigated the origin of the geothermal fluids, distribution of heat sources, and genesis of geothermal fields in the research area, particularly the Yangbajing geothermal field (Tong et al., 1981; Zhao et al., 1998, 2002; Guo et al., 2007, 2009, 2012, 2014; Yuan et al., 2014; Hochstein and Regenauer-Lieb, 1998; Newell et al., 2008). However, there is relatively little research into the cooling processes of the geothermal fluids and temperature of the deep parent water in the research area.

The heat source for the high temperature geothermal system in the research area is a partially melted crustal layer, as is seen in most high temperature geothermal fields (Zhao et al., 1993; Brown et al., 1996; Hoke et al., 2000; Hou et al., 2001; Guo, 2012; Liu et al., 2014). A high temperature geothermal system with a magmatic heat source usually hosts deep parent water that remains in equilibrium with surrounding rock. The pH of these waters is near neutral, the principal anion is Cl^-, and the principal cation is Na^+ (Li et al., 2015). This type of deep geothermal fluid ascending in a geothermal system may cool by conduction of heat to the surrounding rock, by adiabatic boiling, by mixing with cooler water, or by a combination of these processes (Fournier, 1979; Giggenbach, 1988; Afsin et al., 2013).

The purpose of this study is to analyze the cooling processes of the geothermal fluid and discuss the conditions of the deep parent water in the research area. We used chemical geothermometers to estimate the

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temperature of the geothermal reservoir, including a silica geothermometer and cation geothermometer. However, since these classical geothermometers can fail to predict subsurface temperatures in geothermal systems if the assumptions on which they are based are not met in the specific system (Spycher et al., 2014; Wanner et al., 2014), we should keep in mind the various assumptions implicit in the methods and the hydrologic complexities that are commonly present in hot spring systems (Fournier, 1979; Arnórsson, 1983). To verify the reliability of the chemical geothermometers at this site, we made multicomponent chemical equilibrium analyses of the geothermal waters from the intermediate and high temperature reservoirs of the Yangyi and Yangbajing geothermal fields. After identifying the applicable chemical geothermometer and the temperatures of the corresponding reservoirs for each geothermal field, we considered different cooling processes for the ascending geothermal fluids in these three representative geothermal fields and estimated the temperature of the deep parent waters of Yangbajing and Gulu by integrating the hydrochemical characteristics with an enthalpy–chloride graph. We determined that this method could provide valuable guidance for the assessment, exploitation, and utilization of geothermal resources.

2. Geological setting

The research area lies in the Lhasa–Gangdise block between the Yarlung Zangbo River suture belt and Pangong Tso-Nu River suture belt, largely bounded by the Pangong Tso-Nu River deep fracture in the north and the Yaluzangbu River deep fracture in the south, both of which trend approximately east – west, and the northeast-trending western Nyainqentanglha fracture (Wu et al., 2005; Liu et al., 2014) (Fig. 1). The major structure in the research area is the Damxung–Yangbajing–Duoqingcuo active tectonic zone, which can be divided into three NS-trending fault zones: Jidaguo–Nimu, Jiuzila–Sangxiong, and north of Sangxiong, according to the different characteristics and controlling effects of geothermal activity in each zone (Han, 1987). The high temperature geothermal fields of Yangbajing, Yangyi, and Gulu described in this study are distributed in the Jidaguo–Nimu and Jiuzila–Sangxiong extensional fault zones (Fig. 2).

The rocks exposed in the research area span from the Proterozoic to Cenozoic, mainly comprising Carboniferous, Permian, Jurassic, Paleogene, and Quaternary units. Carboniferous rocks are distributed in the area of Damxung–Jiuzila and include fine-grained clastic rocks, conglomerate, schist, gneiss, migmatite, limestone, and argillaceous limestone. Permian strata also occur in Damxung–Jiuzila, and these mainly consist of limestone, siliceous rock, and interbedded sandstone and shale with intercalations of limestone. Jurassic rocks distributed to the north of Jiuzila include slate, foraminiferous limestone, volcanic rocks, and thin-bedded limestone. Paleogene strata occur along Yangbajing–Yangyi and include pyroclastic rocks, basalt, trachyte, and limited conglomerate, with intercalations of argillaceous conglomerates. Quaternary unconsolidated sediments are found in all the basins (Geothermal Geological Team of Tibet, 1991).

The magmatic rocks exposed in the research area are primarily granite, monzonite granite, syenogranite, granodiorite and, more rarely, gabbro and porphyritic diorite (Liu et al., 2014).

MQS-Middle Qilian Suture zone; SQS-South Qilian Suture zone; SKS-South Kunlun Suture zone; HJS-Hoh Xil–Jinsha River Suture zone;

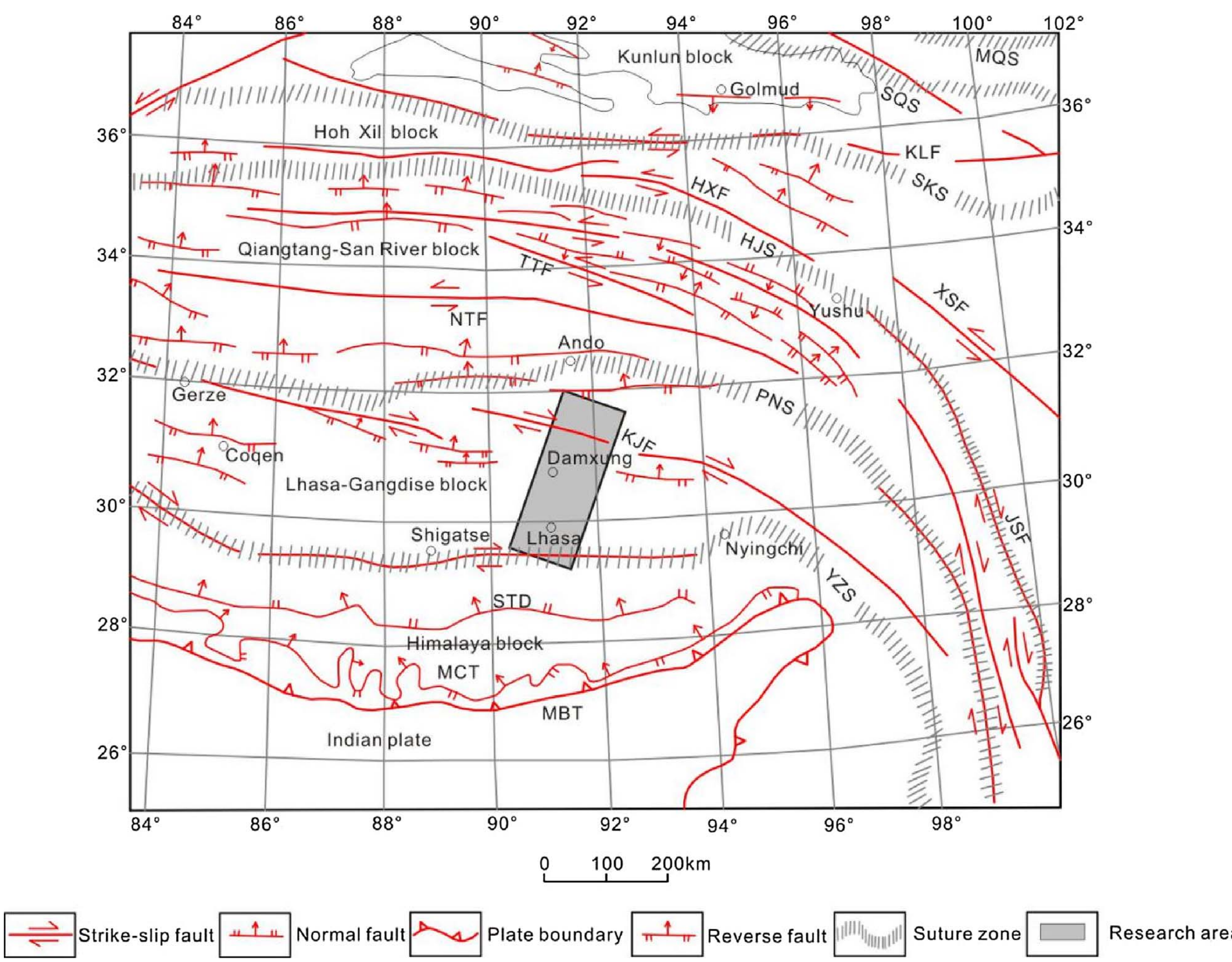

Fig. 1. Tectonic units of the Tibetan Plateau (Wu et al., 2005; Liu et al., 2014).