Geothermics 74 (2018) 92–105

Contents lists available at ScienceDirect

Geothermics

journal homepage: www.elsevier.com/locate/geothermics

# Geochemistry of geothermal fluids with implications on the sources of water and heat recharge to the Rekeng high-temperature geothermal system in the Eastern Himalayan Syntax

Jiao Tian[a,b,c], Zhonghe Pang[a,b,c,*], Qi Guo[a,d], Yingchun Wang[a,b,c], Jie Li[a,b,c], Tianming Huang[a,b,c], Yanlong Kong[a,b,c]

[a] Key Laboratory of Shale Gas and Geoengineering, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China
[b] Institutions of Earth Science, Chinese Academy of Sciences, Beijing 100029, China
[c] University of Chinese Academy of Sciences, Beijing 100029, China
[d] China Minmetals Corporation, Beijing 10010, China

ARTICLE INFO

*Keywords:*
Eastern Himalayan syntax
Hydrogeochemistry
Geothermal gas
Heat source
Isotope
Rekeng geothermal system

ABSTRACT

Rekeng geothermal system in Eastern Himalayan syntax is found to exhibit the strongest surface manifestations in the western Sichuan plateau, with numerous boiling springs, fumeroles and geysers. What is the heat source of such a high temperature system? Is there a magmatic heat source to support it? In this study we have attempted to seek clues from the isotope geochemistry of geothermal fluids. The stable isotope $\delta^2H$ and $\delta^{18}O$ composition of geothermal water suggests that it is recharged by precipitation and snow melt of the surrounding mountains. The chemical type of the geothermal water is alkaline $HCO_3$-Na as a result of water-$CO_2$-rock interaction. Geothermal reservoir temperature in the fractured metamorphic rock is estimated to be between 200 °C–225 °C, using the chemical geothermometers and the chemical thermodynamic modeling approach. During the degassing process upon rising, 0.05 mol/L $CO_2$ has escaped from the geothermal fluid. Evidence from the relationships among major ions and geothermal suite (Li, B, F, As) indicate that the hot springs shared the same parent source fluid and they mixed with cold groundwater to different levels in the subsidiary fractures near surface. Carbon isotope signatures show that the $CO_2$ enriched geothermal gas is 95% of crustal metamorphic origin. Additionally, based on helium isotope analysis, the mantle magmatic $^3He$ signatures have been largely obliterated since it accounts for no more than 5%, implying there is no underlying mantle-derived magma chamber acting as heat source. Therefore, a significant portion of heat is likely converted from crustal deformation in view of the regional tectonic background as Eastern Himalayan syntax.

## 1. Introduction

The most important factor in the formation of a high temperature geothermal system is the heat source. Usually it is necessary to have a magmatic heat source in order for a high temperature geothermal system (> 150 °C) to be formed. In addition to the island arc type geothermal systems along the circum-Pacific ring of fire, for example, the Tatun Volcano Group in northern Taiwan, where high heat flow is fostered by subsurface arc magmas (Christenson et al., 2002; Liu et al., 2011), hydrothermal systems developed in young igneous environments derive their heat from intruding or residual magma in the upper crust. For example, a residual magma chamber was recognized as the heat source for the Rehai geothermal system in Yunnan Province of China (Zhang et al., 2016a,b), and the existence of molten granite has been verified to be the heat source for the Yangbajing geothermal system in Tibet (Nelson et al., 1996; Zhao et al., 2002). Generally speaking, the geothermal systems developed in non-volcanic regions are partly heated from the decay of heat-producing radioactive elements (e.g., $^{238}U$, $^{232}Th$, $^{40}K$) (Karakuş, 2015). Moreover, another heat source of particular interest is frictional heat along the interface between overlapping sections within the lithosphere. The relative motion between the lithospheric sectors is resisted by friction or viscous shearing force along the boundary and converted into heat (Wang et al., 2013). Local temperatures could be as high as 800 °C to 1000 °C with sufficient friction to melt the rocks (Tang et al., 2017). The thermal energy generated by mechanical friction along the strike-slip faults during transpressional deformation can also serve as a heat source for the high-temperature geothermal systems. Therefore, the tectonic

* Corresponding author at: Institute of Geology and Geophysics, Chinese Academy of Sciences.No.19, Beituchengxilu, Chaoyang district Beijing, 100029, China.
*E-mail address:* z.pang@mail.iggcas.ac.cn (Z. Pang).

https://doi.org/10.1016/j.geothermics.2018.02.006
Received 13 July 2017; Received in revised form 16 November 2017; Accepted 7 February 2018
0375-6505/ 

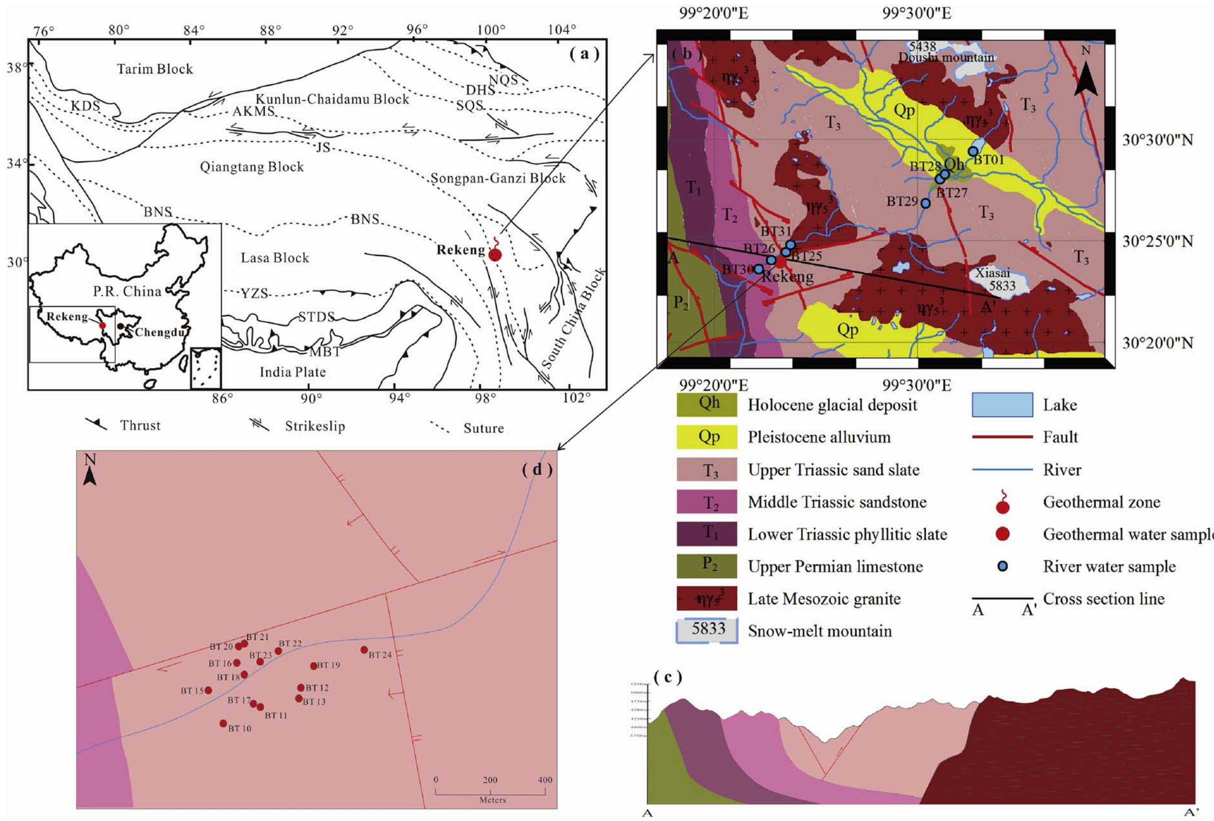


**Fig. 1.** (a) Simplified tectonic map of the Himalayan-Tibetan Orogen(from Yin and Harrison, 2000; Li et al., 2009). NQS-North Qilian suture; DHS-Danghe Nan Shan suture; KDS-Kudi suture; SQS-South Qilian suture; AKMS–Ayimaqin–Kunlun-Mutztagh suture; JS-Jinshajiang Suture; BNS–Bangong-Nujiang suture; YZS-YanglungZangbo suture; STDS-South Tibet Detachment System; MCT-Main Central Thrust; MBT-Main Boundary Thrust; LTB-Longmen Shan Thrust Belt. (b) Simplified geological map ofRekeng geothermal system. (c) Cross section A-A' of the Kangding region. (d) Sampling locations of geothermal water fluids.

frictional heat characterized by numerous faults could also be recognized as a supplementary heat source to the geothermal systems (Mase and Smith, 1987; Zhu, 2016). In continental high temperature geothermal systems, the geochemical characteristics of hydrothermal fluids carry key information of the property and evolution in mass and energy deep within the earth. Understanding the sources of geothermal fluids (including water and gas) and the geochemical processes they are involved is one of the most effective methods of identifying possible heat sources.

Located in the eastern margin of the Tibetan Plateau as part of the Mediterranean-Himalayan geothermal belt, the Rekeng geothermal system in southwestern China is not only marked with numerous and widespread boiling springs but also exhibits many other typical surface manifestations of high-temperature hydrothermal systems, such as fumaroles, geysers, steaming ground and large scale of geothermal sinters. From a tectonic point of view, the Rekeng system is located in the core of Eastern Himalayan syntax where the crust is undergoing strong deformation accompanied by structures changing directions sharply, crustal mass escaping laterally and blocks being limited by faults and other structures (Fig. 1). However, little is known on the genesis of the high-temperature geothermal systems in the Rekeng area especially about the heat source. What the reservoir temperature is and whether magma or heated rocks act as the heat source in this area are still significant scientific issues remained to be solved. Since very little data about the hydrothermal fluid of the Rekeng geothermal system is available in literatures, in this study, we carried out hydrochemical and isotopic investigations on both of geothermal water and gases from the system. These data are discussed in the context of the geological setting to characterize the origin of the geothermal fluid, to delineate their possible variations in compositions as a function of tectonic setting and to investigate the heat sources for this geothermal system.

## 2. Geological setting

The tectonic collision between the Indian and Eurasian continents in the Cenozoic and the continuous compression thereafter has created the Tibetan-Himalayan orogen, which is one of the largest orogens in the world (Tapponnier et al., 2001; Yin and Harrison, 2000). The Tibetan Plateau is characterized by a large but nearly flat-lying orogenic uplift in its central part, side escape in the eastern region, and two tectonic syntaxes in the west and east of the Himalayan Mountain belt (Ding et al., 2001). Near the eastern Himalayan syntax, the trend of the mountains and rivers transitions from nearly east-west to a north-south direction towards India (Zhang et al., 2012; Tang et al., 2017). The Rekeng geothermal system is in the northeast of this region, 480 km to the west of Chengdu, the capital city of Sichuan Province (Fig. 1).

The topography of the study area is a plateau with high altitudes mostly greater than 3000 m and snow-capped mountains with elevations of around 5500 m. The major river in this area is the Maqu, which winds to the southwest and flows into the river Jinsha, into which other tributaries converge. As recorded, its average runoff in October is 62.6 $m^3$/s. The air temperature can range from over 35 °C to below −10 °C, with the rainy season lasting from June to September. The local boiling point is approximately 88 °C.

Overlying the Permian limestone within this region are phyllite and other metamorphic rocks. The surface rocks are mostly upper Triassic strata, which consist of altered sandstone and sand slate, indicating neritic and littoral sedimentary environments in this area after the late Triassic. Quaternary sediment is narrowly distributed in the piedmont south of the snow-capped mountains. The sediments are mainly Holocene alluvium, proluvium, deluvium and glacial deposits of Pleistocene. The Late Mesozoic volcanism was the only stage of volcanic activity identified during the late Yanshanian Tectonic Period (71–119