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# Assessment of Geothermal Resources in Xizang (Tibet), China

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**ABSTRACT**

Xizang (Tibet) Autonomous Region is located in the southwest of China. There are 672 hot springs in Tibet, amongst which the temperatures of 43 hot springs are equal or over the local boiling point. It is estimated that the generation potential of 350 geothermal fields is over 800 MW.

## 1. INTRODUCTION

In 2013, the investigation of geothermal resources in Tibet had been carried out. The main purpose of this project was to investigate the distribution status and hosting conditions of geothermal resources in Tibet, and to assess the potential geothermal resources and to build the database.

There are 672 geothermal systems in Tibet, including hydrothermal explosion systems, geysers, boiling springs, hot springs, warm springs, steaming grounds, sinters. Field investigation has been completed in 209 geothermal systems involving most regions except Qamdo district in the east of Tibet and Ngari district in the west of Tibet.

Based on the assessment of geothermal resources in Tibet, the total volume of geothermal fluid is about $8.4\times10^7$ $m^3/a$, and the total mineable volume of geothermal energy is about $1879.84\times10^{13}$ J/a.

## 2. GEOLOGICAL SETTING

As the main part of Qinghai-Tibet Plateau, Tibetan Plateau is the outgrowth result of series of diastrophism. Since the Mesozoic, spreading of the Indian Ocean, decomposition and northward drift of Gondwanaland, plates collision and amalgamation of Indian Ocean plate and Eurasian plate caused the formation and uplift of Tibetan Plateau. These tectonic movements continue at the present. Tibet is located in the east of Mediterranean-Himalayan geothermal belt and is rich in geothermal resources.

## 3. ASSESSMENT OF GEOTHERMAL RESOURCE AND POTENTIAL

In Tibet, geothermal activities are strictly controlled by the scale, strength and composition of geological structures, and have close relationship with magmatic activities, climates, river systems. Geological tectonic activities provide favorable conditions for the geothermal systems.

According to the investigations and statistics, there are 672 geothermal systems in Tibet. The distribution of thermal springs is concentrated between Himalaya orogenic belt and Bangong-Nujiang tectonic zone, where the NE, NW and NS activity tectonic zones basically control the spatial distribution of geothermal systems. (Hu, 2013).

Hu (2002) mentioned that there are 706 geothermal convection systems in Tibet. However, Liao (2010a) stated as 709, and 644 (Liao, 2010b) (Excluding the spring vestiges and the 'toxic spring' that unknown temperature). Although the statistics of different authors are a little bit different, the data are acceptable.

The main type of geothermal resources in Tibet is uplift-type. The geothermal systems are deep-circulating convection with geothermal reservoir hosting in the fractured bedrock. The bedrocks are granite and diorite.

The geothermal activities are stronger in the southern Tibet than that in the northern, and stronger in the central Tibet than that in the eastern and western. Based on types, distributions of geothermal activity areas and the scale of geological fractures, it is divided into 4 regions by the boundary of Bangong-Nujiang tectonic zone and Gangdese-Nyainqentanglha tectonic zone: (I) Southern Tibet high-temperature geothermal region, (II) Central Tibet middle-temperature geothermal region, (III) Northern Tibet low-temperature geothermal region, and (IV) Eastern Tibet low-middle temperature geothermal region (Figure 1).

### 3.1 Assessment Methods

3.1.1 Subsurface Thermal Flux Method

Actually, it is difficult to survey the subsurface thermal flux except the thermal springs. From the experiences, the subsurface thermal flux is more than 10 times of hot springs. Thus, 10 times of hot springs thermal flux is taken to represent the subsurface thermal flux. The formula for geothermal fluid (hot spring) thermal flux is:

$$Q_p = Q_{WK} C \rho \left( T_1 - T_0 \right) \quad (1)$$

Where: $Q_P$— geothermal fluid thermal flux, kJ

$Q_{WK}$—volume of hot spring, $m^3/d$

$C$—specific heat capacity of thermal water, kJ/kg·°C

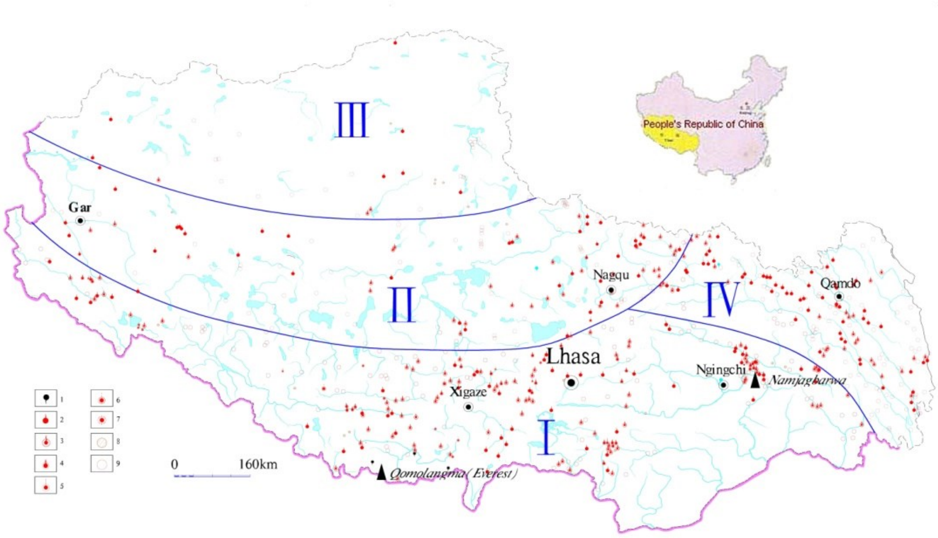
$\rho$—density of thermal water, kg/m$^3$
$T_1$—temperature of thermal water, °C
$T_0$—temperature of constant temperature zone, °C

3.1.2 Volume Method

According to the temperature in the boreholes, the silica geothermometer is more approachable to the basic temperature of the geothermal reservoir. Thus, we choose the silica geothermometer to represent the basic temperature of the geothermal reservoir. The formula is:

$$Q = C_r \rho_r (1 - \varphi) V (T_1 - T_0) + C_w \rho_w q_w (T_1 - T_0) \quad (2)$$

Where: $Q$—reservoir thermal energy, kJ
$C_r$, $C_w$ —specific heat capacity of rock and thermal water, kJ/kg· °C
$\rho_r$, $\rho_w$—density of rock and thermal water, kg/m$^3$
$\varphi$- porosity of reservoir rock
$q_w$—volume of fluid, m$^3$
$T_1$—temperature of reservoir, °C
$T_0$—temperature of constant temperature zone, °C
$V$—volume of reservoir, m$^3$




**1-Cold spring; 2-Warm spring; 3-Hot spring; 4-Boiling spring; 5-Boiling fountain; 6-Geyser; 7-Hydrothermal explosion; 8-hydrothermal vestige; 9-Hydrothermal active area with no measured data; I- Southern Tibet high temperature geothermal region; II- Central Tibet middle temperature geothermal region; III- Northern Tibet low temperature geothermal region; IV- Eastern Tibet low-middle temperature geothermal region**

**Figure 1: Thermal Springs Distribution in Tibet.**

### 3.2 Assessment and Divisions of Potential of Geothermal Resources

There are significantly zoning characteristics according to the thermal springs with different temperature levels. The high-temperature springs are concentrated along EW Yarlung-Zangbo fault zone and Nagqu-Cona fault zone, especially in the intersection parts of the SN or NW activity tectonic and the above-mentioned two fault zones. Geothermal activities are more dynamic and the temperatures of thermal springs are higher, e.g. Yangbajain. Yangyi high temperature geothermal systems are distributed along the Nagqu-Yangbajain-Dorqentso activity tectonic zone.

3.2.1 Southern Tibet High Temperature Geothermal Region (I)

This region is surrounded by an area of about 40.5x10$^4$ km$^2$. The southern boundary is along Himalayas ridge, the northern is Gangdese-nyainqentanglha tectonic belt, and the eastern is Samxung-Guyu activity tectonic zone. The main structure is EW Yarlung-Zangbo fault zone as well as the NW and NE fault zones.

This is the region that has the largest number and most intense geothermal active areas in Tibet. The main type of geothermal activity is hot springs, followed by warm springs, while there are numerous geysers, boiling fountains, hydrothermal alteration, and hydrothermal explosions as well, e.g. Tagejia geyser (photo 1), Chab geyser (photo 2) and Golug geyser.

There are 312 geothermal active areas in this region, 204 of them have the measured data. There are 84 hot springs with an average temperature of 69 °C, 62 warm springs with an average temperature of 30 °C, 35 boiling springs with temperatures between 78 °C and 96 °C, 3 geysers with temperatures between 85 °C and 88 °C, 11 hydrothermal explosions with temperatures between 78 °C and 86 °C, and 5 boiling fountains with temperatures between 85 °C and 88 °C. There are 65 geothermal active areas whose reservoir temperatures are higher than 150 $^oC$, accounting for 34.76%. 106 areas with the reservoir temperatures are between 90 $^oC$ and 150$^oC$, accounting for 56.68%. 13 areas with reservoir temperatures are lower than 90 $^oC$, accounting for 7%.

**Photo 1: Tagejia geyser.**

**Photo 2: Chab geyser.**

It is estimated that the geothermal resources for 43 geothermal active areas, the total thermal water flow is about 3.65x$10^7$ $m^3$/a, and the amount of recoverable resources is about 948.48x$10^{13}$ J/a.

3.2.2 Central Tibet Middle Temperature Geothermal Region (II)

This region is located in the central Tibet. The northern boundary is along the western part of Bangong-Nujiang tectonic zone, and the southern is Gangdese-nyainqentanglha tectonic belt, while the eastern is the connection line of Samxung, Nagqu and Nyairong. The basic structural framework is EW fault zones, which superimposed NS extension fractures and faults, causing mesh active tectonic systems.

There are 88 geothermal active areas in this region, 32 of them have the measured data. There are 21 hot springs with an average temperature of 61 $^oC$, 10 warm springs with an average temperature of 25 $^oC$, 1 boiling springs with an average temperature 82 $^oC$. The average temperature of geothermal reservoir is about 120 $^oC$.

It is estimated that the geothermal resources for the 15 geothermal active areas, the total thermal water flow is about 3.32x$10^7$$m^3$/a, and the amount of recoverable resources is about 614.77x$10^{13}$ J/a.

3.2.3 Northern Tibet Low Temperature Geothermal Region (III)

This region is surrounded by an area of about 25.8x$10^4$ $km^2$ that is located in the northern area of western part of Bangong-Nujiang tectonic zone. The tectonic active period is archaic Yanshanian movement and tectonic activity during neoid is week, thus the activity tectonic movement and geothermal active are undeveloped, but the sinters are developed in this region, e.g., sinter of Nyima geothermal active area in Nyairong county (Photo 3) covered an area of several square kilometers and several meters high.

No survey has been taken in this region, instead of data collection. There are 52 geothermal active areas in this region, 32 of them were investigated by previous surveyors. There are 26 warm springs with an average temperature of 33 $^oC$, and the thermal fluid flows are between 15 and 80 l/s.

It is estimated that the total thermal water flow is about 81.3x$10^4$ $m^3$/a, and the amount of recoverable resources is about 122.36x$10^{13}$ J/a.

**Photo 3: Sinter of Nyima geothermal active area (5m high), Nyairong County.**

3.2.4 Eastern Tibet Low-Middle Temperature Geothermal Region (IV)

This region is surrounded by an area of about $15.2x10^4$ $km^2$ which is located in the eastern Tibet. The southern boundary is Samxung-Guyu activity tectonic zone.

No survey has been taken in this region, instead of data collection. There are 220 geothermal active areas in this region, 100 of them were investigated by previous surveyors. There are 62 warm springs with an average temperature of 30 $^oC$, and the average fluid flow is 68 l/s. There are 40 hot springs with an average temperature of 60 $^oC$ and an average fluid flow of 10 l/s.

It is estimated that the total thermal water flow is about $1.35x10^7$ $m^3/a$ and the amount of recoverable resources is about $194.23x10^{13}$ J/a.

### 3.3 Hot Dry Rock Resources

The basis temperatures of geothermal reservoirs have been measured by geochemical geothermometer. There are 38 geothermal fields whose basis temperatures are higher than 150 $^oC$. The geophysical exploration results show that there is part of molten magma deep in the high temperature geothermal fields, like Yangbajain geothermal field. The depth of the molten magma is 5~10km. Therefore, we believe that in Tibet, there are hot dry rock resources. It is estimated that 22 geothermal systems whose basis temperatures are higher than 150 $^oC$, and the accumulation of heat at the depth of 3~5 km is $1.7x10^{20}$ J.

## 4. CONCLUSIONS

The assessment results by two different methods are shown in table 1. The geothermal resources is about $3.17x10^{20}$ J/a by volume method while $1.88x10^{16}$ J/a by subsurface thermal flux method. The result of flux method is based on hot springs thermal flux. We took 10 times of flux method to represent the final result from the experiences. Thus, the geothermal resources of flux method is about $1.88x10^{17}$ J/a.

**Table 1: Tibetan Geothermal Resources.**

| Division | Volume Method（J/a） | Flux method（J/a） |
|---|---|---|
| Southern Tibet region (I) | $234244.12x10^{15}$ | $948.48x10^{13}$ |
| Central Tibet region (II) | $37828.78x10^{15}$ | $614.77x10^{13}$ |
| Northern Tibet region (III) | $1128.38x10^{15}$ | $122.36x10^{13}$ |
| Eastern Tibet region (IV) | $43670.4x10^{15}$ | $194.23x10^{13}$ |
| Total | $316871.68x10^{15}$ | $1879.84x10^{13}$ |

Assessment of HDR resources is initial and part estimated, which is only within 22 geothermal fields and the depths are between 3~5km. Comparing the assessment results with other regions and nation, the evaluation value of HDR is too few.

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