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Evaluation of Geothermal Resources Potential in China

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ABSTRACT

China is located at the intersection of the Western Pacific island-arc plate margin geothermal belt and the Mediterranean Himalayan continental collision plate margin geothermal belt. Geothermal resources are controlled by tectonic activities and abundant in China, but the geothermal display of different tectonic parts is very different. Based on the geotectonic pattern and the systematic analysis of the distribution and characteristics of geothermal resources in China, this paper has carried out the potential evaluation of hydrothermal geothermal resources. The amount of hydrothermal geothermal resources is equivalent to 1250 billion tons of standard coal, the annual recoverable amount is equivalent to 1.865 billion tons of standard coal, the amount of hydrothermal medium-low temperature geothermal resources is equivalent to 1230 billion tons of standard coal, and the annual recoverable amount of geothermal resources is equivalent to 1.85 billion tons of standard coal; The power generation potential of hydrothermal high-temperature geothermal resources is 8.46 million kW.

1. INTRODUCTION

Geothermal resource is a special fluid mineral resource, which is not only one of green, low-carbon, recyclable renewable energy, but also a rare resource for medical, tourism, chemical and agricultural production. China's geothermal resources are rich and widely distributed. Vigorously promoting the development and utilization of geothermal resources and improving the energy structure are important measures to cope with global climate change and carry out energy conservation and emission reduction, and are of great significance to solve the increasingly serious global environmental problems. The unclear status of geothermal resources has seriously affected the formulation of geothermal resources exploration and development planning and the development of geothermal industry. During the "12th Five-Year Plan" period, China has completed the survey of geothermal water resources in 31 provinces (regions and cities), and basically identified the occurrence conditions, distribution characteristics and development and utilization status of geothermal resources in China. Based on the survey results of geothermal resources in China during the "12th Five-Year Plan" period, and on the basis of systematic analysis of the distribution and characteristics of geothermal resources in China, this paper carried out a potential evaluation of hydrothermal geothermal resources, providing technical support for the sustainable and scientific development and utilization of geothermal resources.

2. DISTRIBUTION LAWS AND CHARACTERISTICS OF GEOTHERMAL RESOURCES

Geothermal resources refer to geothermal resources inside the Earth that can be economically exploited and utilized by human in the foreseeable future. Geothermal resources include geothermal fluids and their useful components.Geothermal resources include shallow geothermal energy, geothermal resources of hydrogeothermal type and hot dry rock resources. Geothermal resources in this paper refer to geothermal resources of hydrogeothermal type, whose geothermal fluid is a general term for geothermal water, geothermal steam and hot gas with temperatures over 25℃.

Geothermal resources can be divided into different types by geothermal reservoir media, geological genesis and water and heat transmission. By geothermal reservoir media, geothermal resources can be divided into porous type, fractured type and karst type; by geological genesis, geothermal resources can be divided into geothermal resources in major sedimentary basins and geothermal resources in major uplift mountain geothermal fields; by heat transmission, geothermal resources can be divided into conductive type and convective type. By temperature levels, geothermal resources can be divided into 3 levels: high temperature (temperature≥150℃), moderate temperature (temperature ≥ 90℃ and <150℃) and low temperature (temperature <90℃). By geological genesis, geothermal resources in this map are divided into sedimentary basin geothermal resources and geothermal resources in major uplift mountain geothermal fields. In addition, sedimentary basin geothermal resources can be divided into cold basin (≤50mW/m^2), warm basin (50-65mW/m^2) and hot basin (≥65mW/m^2) by heat flow measure value. By geothermal reservoir media, geothermal reservoirs can be divided into porous type, fractured type and karst type reservoirs. By spatial distribution, geothermal reservoirs can be divided into layered reservoir and banded reservoir.

2.1 Distribution of geothermal resources in China

The hydrothermal geothermal resources in China are of high regularity and zone-related, unevenly distributed due to some factors as geological features, magmatic action, lithology and hydrogeological conditions. There are some high-temperature geothermal resources in China, but moderate- and low-temperature geothermal resources constitute a major part. The high-temperature geothermal resources are mainly found in Southern Tibet, Western Yunnan, Western Sichuan and Taiwan, where more than 200 high-temperature geothermal systems have been found(Liao zhijie, Zhao ping, 1999). The moderate- and low-temperature geothermal resources are mainly found in large sedimentary basins and fractures in mountain areas. The geothermal resources in the mountain areas are mostly small, the geothermal resources in basins, especially large sedimentary basins are featured by their favorable reservation conditions, numbers of formations, large thickness and broad distribution. The temperature of geothermal reservoir increases along with depth. Since geothermal resources in basins have considerable resources, these basins should be the regions where geothermal resources have the highest potentials for exploitation.

Geothermal resources in major sedimentary basin in China are mainly distributed in North China Plain, Huanghe and Huaihe Plain, Songliao Basin, Xialiaohe Plain, Sichuan Basin, Jianghan Basin and Fenwei Basin. These geothermal resources can all be categorized as the moderate- and low-temperature geothermal resources. Geothermal resources in major sedimentary basin vary in the east and west: in North China Plain, Songliao Basin, Northern Jiangsu Plain, Xialiaohe Plain, Huanghe and Huaihe Plain and northeastern part of Fenwei Basin in the east, asthenosphere swells, leading to thinning crust, solid sedimentation and development of multi-layer geothermal reservoir systems. The major geothermal reservoir layers lie in Mesozoic sandstone porous type geothermal reservoirs and Paleozoic and middle-upper Proterozoic carbonate rock karst type geothermal reservoirs. Basins have high heat flow, around 60-83mW/m^2 , and temperature of geothermal reservoirs is 35-120℃. These basins are hot basins. In Sichuan Basin and Ordos Basin and Jianghan Plain, where crust is thick, terrestrial heat flow is relatively low, around 40-60mW/m^2 . The major geothermal reservoir layers lie in Mesozoic sandstone porous type geothermal reservoir and Paleozoic carbonate rock karst fractured type geothermal reservoirs. These reservoirs usually have low temperature hot water and warm brine in deep depression belt occurrence, thus these basins are warm basins. In Tarim Basin, Qaidam Basin and Junggar Basin in the west, where crust is thick, heat flow value is low (34-51mW/m^2); the major geothermal reservoir layers lie in Tertiary gravel porous type geothermal reservoir and Paleozoic carbonate rock karst fractured type geothermal reservoirs. These reservoirs are usually mineralized greatly and have brine, thus these basins are cold basins.

Geothermal resources in major uplift mountain geothermal fields are mainly distributed in Southeast coastal area, Taiwan, southern Xizang, western Sichuan, western Yunnan and Peninsula of Jiaodong and Liaodong.(Cheng moxiang, et al, 1994; Chen moxiang, Wang jiyang, et al, 1994). Geothermal resources in major uplift mountain geothermal fields are mainly distributed in 4 hydrogeothermal activity intensive belts: southern Xizang- western Sichuan western Yunnan hydrogeothermal activity intensive belt, Taiwan hydrogeothermal activity intensive belt, hydrogeothermal activity intensive belt in Southeast coastal areas and Peninsula of Jiaodong and Liaodong hydrogeothermal activity intensive belt; of which, the first two are high temperature geothermal belt while the second two are low moderate temperature geothermal belt.

Porous type geothermal reservoirs are usually Quaternary loose rocks, Neogene and Paleogene sandstones and Mesozoic sedimentary rocks; karst type geothermal reservoirs are carbonate rocks; fractured type geothermal reservoirs are sedimentary rocks, metamorphic rocks, granite and volcanic rocks. Porous type geothermal reservoirs are usually distributed in the upper part of sedimentary basins; karst type geothermal reservoirs are mainly distributed in mountainous areas with karst development and the bottom of sedimentary basins with hidden karst development; and fractured type geothermal reservoirs in mountainous areas and the bottom of sedimentary basins with fractures development. Porous type geothermal reservoirs are mainly distributed in Songliao Basin, North China Plain, Huanghe and Huaihe Plain, Northern Jiangsu Plain, Yinchuan Plain, Ordos Basin, Qaidam Basin, Xining Basin and so on. Karst type geothermal reservoirs are mainly distributed in eastward to Ordos, karst areas in Weibei, karst areas in Shandong, karst areas in Qinghai, Southwestern karst areas, karst areas along middle reaches of the Changjiang. Fractured type geothermal reservoirs are mainly distributed in Himalayan collision belt, Taiwan, Southeast coastal area, Peninsula of Jiaodong and Liaodong and mountainous areas in Qinghai and Hebei.

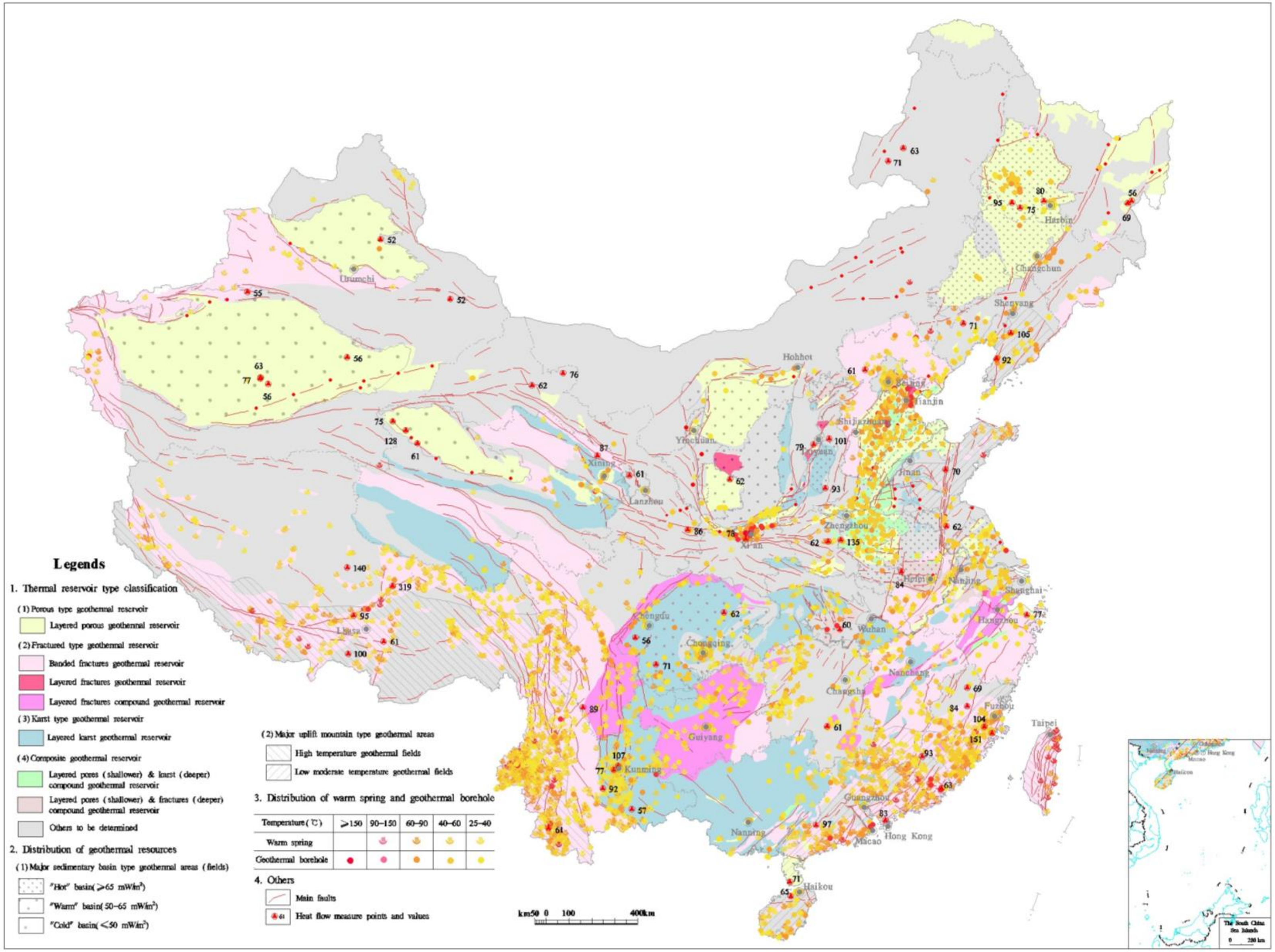

Figure 1: Distribution of geothermal resources in China.

2.2 Characteristics of geothermal resources in China

Based on terrestrial heat flow, earth temperature gradient and ground surface temperature, it is possible to estimate temperature profiles of geothermal reservoir within the certain depth. In general, the regions with stronger tectonic activity or more recent tectonic-thermal events usually have higher heat flow rates, ancient plates with steady structure have lower heat flow rates. According to the collected and measured heat flow data in China , heat flow rates is unevenly distributed in China. Generally, Southern Tibet, Western Yunnan and the eastern coast have the highest value with the average of 90～150mW/m^2, and even up to 304 mW/m^2 in some regions. Then, Northern Tibet and Taiwan have an average value of 80～90mW/m^2. Erdos Basin and Sichuan Basin in the center of China, the coastal basin in the south of China, the southern North China, northern Songliao Basin, northern Jiangsu, Bohai Bay Basin in the east of China, and Haier Basin in the north of China have average values of 55～80mW/m^2. Tarim Basin and Junggar Basin in Xinjiang, northern Sichuan Basin and Songliao Basin, and Sanjiang Basin have average values of 30～50 mW/m^2. These basins could be categorized as cool basin(Hu shengbiao, et al, 2001; Gong yuling, et al, 2003; Wang liangshu, et al, 2005;Duo ji, et al, 2003; Liao zhijie, et al, 1985).

In sedimentary basins of China, the temperature gradient ranges 1.5～4.0℃/m, and the average value is about 3.2℃/m. The temperature gradient is controlled by centrospheric thermal condition and thermal conductivity of geological media. Compared with, heat flow, temperature gradient is affected by the geotectonic structures and highly related to lithological structures. As a result, the temperature gradient and heat flow show different patterns. The highest value of temperature gradients in sedimentary basin range 3.0～4.0℃/m, are mainly found in Tengzhong (Yunnan), North Bay Basin, Xiamen, Shantou, most southern areas of North China Plain, the southmost tip of Bohai and Tianjin, Hailaer Basin, the west of Tsaidam Basin and Songliao Basin. These regions account for 1/10 of all the sedimentary basins of the world. most regions in sedimentary basin have the value range of 2.0～3.0℃/m. Other regions with the value less than 2.0℃/m mainly cover parts of Tarim Basin, Junggar Nasin, and the northwestern part of Sichuan Basin.

3. POTENTIALS OF GEOTHERMAL RESOURCES IN CHINA

3.1 Assessment methodology of the potentials of geothermal resources

Reservoir heat capacity method is used for the hydrothermal geothermal resources assessment. For the sedimentary basin-type geothermal resources, the areas of heat reservoir is determined as formations shallower than 4000m, whose temperature is,higher than 25℃, water yield is over 20m^3/h per well, and average temperature gradient is over 2.5℃/100m in caprock. The border line between local thermal fields and geothermal abnormal areas, the contours of geothermal reservoir temperature and thickness are digitalized,to calculate the area of each sub-regions, and the geothermal reservoir thickness can be calculated according to sand thickness ratio. For apophysis mountain geothermal resources, the areas are calculated for individual geothermal formations in regions with enough geological survey data, such as Shanxi, Inner Mongolia, Shandong, Jiangsu, Zhejiang, Chongqing and Guizhou. In other provinces, the assessment of geothermal resources is conducted for every individual hot spring and geothermal well. If the volume of geothermal reservoirs can be encircled by the heat controlling fracture, the results could be determined by the geological and tectonic information . If the line of geothermal reservoir area is indistinct, the volume for the geothermal reservoir is assigned as one cubic kilometer of every abnormal geothermal point(Muffler and Cataldi, 1978). For hydrothermal geothermal resources, the allowable exploitation can be based on the allowable exploitation of geothermal fluids with the condition of reinjection(Lin wenjing, et al, 2012, 2013). For the moderate- and low-temperature geothermal resources, assuming that the sedimentary basins-type geothermal resources are exploited for 100 years under the condition of reinjection, 15% geothermal reservoir is consumed, and then thermal balance is calculated. For apophysis mountain geothermal resources, the allowable exploitation of geothermal fluids is assigned as twice of the corresponding quantity calculated according to spring(well) fluid method. For the high temperature geothermal resources, the allowable exploitation is assigned as twice of the volume of geothermal fluids that have been determined by geological explorations.

3.2 Potentials of geothermal resources in China

China enjoys abundant hydrothermal geothermal resources, including 2334 hot springs and 5818 geothermal exploitation wells. The hydrothermal geothermal resources can be converted into 1250 billion tons of standard coal, indicating an annual allowable exploitation of 1.865 billion tons of standard coal. There are high-temperature geothermal resources (≥150℃), but the moderate - temperature geothermal resources（90℃-150℃）and low-temperature geothermal resources（<90℃）play a dominant role. The moderate- and low-temperature hydrothermal resources can be converted into 1230 billion tons of standard coal, and the annual allowable exploitation can be converted into 1.85 billion tons of standard coal, indicating the power generation of 1.5 million kW. Hydrothermal high-temperature geothermal resources can be converted into 1.41 billion tons of standard coal, and the annual allowable exploitation can be converted into 18 million tons of standard coal, equaling the power generation of 8.46 million kW.

Table 1:Evaluation table of geothermal resources in China

Cities	Reserve of geothermal resources		Heat of hydrothermal fluid available for exploitation in case of recharge	
	Reserve of geothermal resources（kJ）	Standard coal（t）	Heat of hydrothermal fluid available for exploitation in case of recharge（kJ/a）	Standard coal（t/a）
Beijing	9.94E+16	3.39E+09	1.23E+15	4.21E+07

Cities	Reserve of geothermal resources		Heat of hydrothermal fluid available for exploitation in case of recharge	
	Reserve of geothermal resources（kJ）	Standard coal（t）	Heat of hydrothermal fluid available for exploitation in case of recharge（kJ/a）	Standard coal（t/a）
Tianjin	8.98E+17	3.07E+10	1.48E+15	5.06E+07
Hebei	3.06E+18	1.04E+11	4.63E+15	1.58E+08
Shandong	2.03E+18	6.93E+10	3.39E+15	1.16E+08
Henan	7.73E+18	2.64E+11	1.30E+16	4.44E+08
Anhui	6.03E+16	2.06E+09	1.76E+14	6.01E+06
Jiangsu	6.91E+17	2.36E+10	9.55E+14	3.26E+07
Heilongjiang	1.24E+18	4.22E+10	2.01E+15	6.86E+07
Jilin	1.02E+17	3.48E+09	1.64E+14	5.61E+06
Liaoning	4.37E+16	1.49E+09	8.13E+13	2.77E+06
Sichuan	9.78E+18	3.34E+11	1.61E+16	5.50E+08
Hubei	2.56E+17	8.75E+09	3.77E+14	1.29E+07
Xinjiang	9.76E+17	3.33E+10	5.18E+13	1.77E+06
Shanxi	8.95E+17	3.05E+10	1.67E+15	5.69E+07
Shaanxi	1.43E+18	4.88E+10	2.43E+15	8.29E+07
Inner Mongolia	1.77E+18	6.04E+10	2.95E+15	1.01E+08
Qinghai	1.42E+17	4.86E+09	2.14E+14	7.32E+06
Gansu	4.11E+17	1.40E+10	7.19E+14	2.45E+07
Ningxia	9.37E+17	3.20E+10	1.43E+15	4.88E+07
Zhejiang	1.13E+17	3.87E+09	1.65E+14	5.64E+06
Jiangxi	8.18E+16	2.79E+09	1.40E+14	4.79E+06
Fujian	4.49E+16	1.53E+09	1.85E+13	6.30E+05
Hunan	1.05E+16	3.57E+08	1.09E+13	3.71E+05
Guangdong	2.52E+17	8.59E+09	2.27E+14	7.74E+06
Hainan	1.12E+17	3.81E+09	1.48E+14	5.05E+06
Guangxi	2.58E+17	8.81E+09	3.70E+14	1.26E+07
Chongqing	1.27E+18	4.33E+10	3.23E+13	1.10E+06
Shanghai	3.06E+15	1.04E+08	9.28E+12	3.17E+05
Guizhou	1.33E+18	4.55E+10	4.74E+13	1.62E+06
Yunnan	2.95E+17	1.01E+10	2.28E+14	7.80E+06
Tibet	2.74E+17	9.34E+09	1.76E+14	6.02E+06
Total	3.66E+19	1.25E+12	5.47E+16	1.865E+09

The moderate- and low-temperature hydrothermal resources are mainly distributed in 15 large and medium-sized sedimentary plains including the North China Plain, Hehuai Plain, Northern Jiangsu Plain, Songliao Plain, Lower Liaohe Plain, Fengwei Plain, and mountain faults. Specifically, the geothermal resources in mountain faults are usually of small size, but the geothermal resources in the plains and especially the large sedimentary plains are featured by satisfactory reservoir conditions, , considerable thickness and wide-spread distribution. The temperature of geothermal resources grows as the depth increases, indicating the largest potentials of geothermal resources development. In the 15 large and medium-sized sedimentary plains, geothermal resources can be converted into 1060 billion tons of standard coal, and the annual allowable exploitation can be converted into 1.7 billion tons of standard coal. In the Sichuan Basin, the allowable exploitation of geothermal resources is the highest, which can be converted into 544 million tons of standard coal, and next comes the North China Plain, where the allowable exploitation of geothermal resources can be converted into 422 million tons of standard coal, demonstrating the abundant moderate- and low-temperature geothermal resources in the sedimentary plains in Shandong and Hebei Province.

Table 2:Evaluation table of moderate- and low-temperature geothermal resources of main sedimentary basins

Name of basin	Reserve of geothermal resources		Heat of hydrothermal fluid available for exploitation in case of recharge	
	Reserve of geothermal resources（kJ）	Standard coal（t）	Heat of hydrothermal fluid available for exploitation in case of recharge（kJ/a）	Standard coal（t/a）
North China Plain	7.23E+18	2.47E+11	1.24E+16	4.22E+08
Hehuai Plain	5.33E+18	1.82E+11	9.02E+15	3.08E+08
Northern Jiangsu Plain	6.75E+17	2.30E+10	9.20E+14	3.14E+07
Songliao Plain	1.24E+18	4.22E+10	2.01E+15	6.87E+07
Lower Liaohe Plain	3.95E+16	1.35E+09	7.52E+13	2.56E+06
Fengwei Basin	2.20E+18	7.49E+10	3.86E+15	1.32E+08
Erdos Basin	1.48E+18	5.03E+10	2.68E+15	9.15E+07
Sichuan Basin	9.62E+18	3.28E+11	1.59E+16	5.44E+08
Jianghan Basin	2.49E+17	8.51E+09	3.64E+14	1.24E+07
Hetao Basin	6.61E+17	2.25E+10	9.59E+14	3.27E+07
Yinchuan Plain	9.37E+17	3.20E+10	1.43E+15	4.88E+07
Xining Basin	1.34E+17	4.57E+09	2.09E+14	7.12E+06
Junggar Basin	4.78E+17	1.63E+10	-	-
Tarim Basin	4.83E+17	1.65E+10	-	-
Tsaidam Basin	3.04E+17	1.04E+10	-	-
Total	3.11E+19	1.06E+12	4.98E+16	1.70E+09

The high-temperature geothermal resources are distributed along the Southern Tibet-Western Sichuan-Western Yunnan region with intensive hydrothermal activities, indicating the power generation of 7.12 million kW, 84.1% of the national total. There are 139 hydrothermal zones exceeding 150℃, including 34 in Southern Tibet, 56 in Western Sichuan and 49 in Western Yunnan. The possible generation of high-temperature hydrothermal resources in the coastal areas of Southeast China can reach 0.70million kW, 8.27% of the national total. There are 14 hydrothermal zones exceeding 150℃ in this area. The high-temperature hydrothermal system is also found in the Guanzhong Basin, Xinjiang Taxkorgan region and Changbai Mountain region in Jilin Province. As a crucial renewable energy, it’s of importance to fully develop high-temperature geothermal resources, promote electricity generation by high-temperature geothermal resources in the Southwestern part of China, and build a multipurpose and complementary power development pattern, which can meet the demand of the national energy restructuring polices.

Table 3: Evaluation table of moderate- and low-temperature geothermal resources in the main hydrothermal activity zones of apophysis mountains

Main hydrothermal activity zones	Moderate- and low-temperature geothermal resources					High-temperature geothermal resources	
	Geothermal resources		Allowable exploitation of hydrothermal fluid（m3/a）	Heat of hydrothermal fluid available for exploitation		Reserve of geothermal resources（kJ）	Power generation potential（million kW）
	Reserve of geothermal resources（kJ）	Standard coal（t）		Heat of hydrothermal fluid available for exploitation（kJ/a）	Standard coal（t/a）		
Southern Tibet——Western Sichuan——Western Yunnan	3.16E+17	1.08E+10	2.26E+08	3.61E+13	1.23E+06	3.37E+17	7.12
Coastal areas in Southeast China	1.71E+17	5.85E+09	2.04E+08	3.22E+13	1.10E+06	3.56E+16	0.70
Jiaoliao Peninsular	2.69E+14	9.18E+06	5.37E+06	1.27E+12	4.34E+04		
Taiwan			3.78E+07	9.40E+12	3.21E+05		
Total	4.88E+17	1.67E+10	4.73E+08	7.90E+13	2.70E+06	3.72E+17	7.82

4. CONCLUSIONS

1. The hydrothermal geothermal resources in China are widely distributed and highly diverse. They are very regular and zone-related, but are unevenly distributed due to such factors as geological features, magmatic action, lithology and hydrogeological conditions. There are high-temperature geothermal resources (≥150℃), but the moderate -temperature geothermal resources（90℃-150℃）and low-temperature geothermal resources（<90℃）are dominant. The high-temperature geothermal resources are mainly found in Southern Tibet, Western Yunnan, Western Sichuan and Taiwan. The moderate- and low-temperature geothermal resources are mainly found in large sedimentary basins and mountain fractures.

2. Porous type geothermal reservoirs are mainly distributed in Songliao Basin, North China Plain, Huanghe and Huaihe Plain, Northern Jiangsu Plain, Yinchuan Plain, Ordos Basin, Qaidam Basin, Xining Basin and so on. Karst type geothermal reservoirs are mainly distributed in eastward to Ordos, karst areas in Weibei, karst areas in Shandong, karst areas in Qinghai, Southwestern karst areas, karst areas along middle reaches of the Changjiang. Fractured type geothermal reservoirs are mainly distributed in Himalayan collision belt, Taiwan, Southeast coastal area, Peninsula of Jiaodong and Liaodong and mountainous areas in Qinghai and Hebei.

3. China enjoys very abundant geothermal resources, including 2334 hot springs and 5818 geothermal exploitation wells. The hydrothermal geothermal resources can be converted into 1250 billion tons of standard coal, indicating an annual allowable exploitation of 1.865 billion tons of standard coal. The moderate- and low-temperature hydrothermal resources can be converted into 1230 billion tons of standard coal, and the annual allowable exploitation can be converted into 1.85 billion tons of standard coal, indicating the power generation of 1.5 million kW. Hydrothermal high-temperature geothermal resources can be converted into 1.41 billion tons of standard coal, and the annual allowable exploitation can be converted into 18 million tons of standard coal, equaling the power generation of 8.46 million kW.

REFERENCES

[1]Ji DUO. 2003.Typical High Temperature Geothermal Systems, Yangbajing Thermal Field Basic Characteristics. China Engineering Science, 2003,01:42-47(in Chinese and with English abstract).

[2]Chen Moxiang, Wang Jiyang. Review and prospect on geothermal studies in China [J]. Chinese Journal of Geophysics, 1994, 37 (Supp. I): 320-338 (in Chinese and with English abstract).

[3]Moxiang CHEN, Jiyang WANG, Xiao DENG, 1994 China's Geothermal Resources, the Characteristics and Potential Evaluation. Beijing: Science Press(in Chinese).

[4]Gan Haonan, Wang Guiling, Lin Wenjing, et al. Major Reservation Types and Forming Mechanism of HDR Resources in China [J] . Science & Technology Review, 2015(19):22-27.

[5]Gong Yuling, Wang Liangshu, Liu Shaowen, et al. Terrestrial heat flow distribution in Jiyang Depression [J]. Science in China, (Series D: Earth Sciences), 2003, 33 (4): 384-391 (in Chinese).

[6]Hu Shengbiao, He Lijuan, Wang Jiyang. Compilation of heat flow data in the China continental area (3rd edition) [J]. Chinese Journal of Geophysics. 2001, 44 (5): 611-626 (in Chinese with English abstract).

[7]Zhijie LIAO. 1985. Taiwan province geothermal development history, Geological review. 31（3）：285-288 (in Chinese).

[8]Zhijie LIAO, Ping ZHAO, 1999, the Sichuan-Tibet tropical Belt, Geothermal Resources and Typical Geothermal System. Beijing: Science Press (in Chinese).

[9]Wenjing LIN, Zhiming LIU, Wanli WANG, Guiling WANG, 2013, The assessment of geothermal resources potential of China. GEOLOGY IN CHINA, 40(1) : 312-321 (in Chinese with English abstract).

[10]Wenjing LIN, Zhiming LIU, Feng MA, Chunlei LIU, Guiling WANG, 2012 Estimates of China's Land Area Hot Dry Rock Resource Potential. Journal of Earth, 33 (5) : 807-811 (in Chinese with English abstract).

[11]Guiling WANG, Fawang ZHANG, Zhiming LIU, 2000. Development and Utilization of Geothermal Resources at Home and Abroad Present Situation and Prospect Analysis. Earth Science, 2：134-139 (in Chinese with English abstract).

[12]Liangshu Wang, Cheng Li, Shaowen Liu, Hua Li, Mingjie Xu, Dayong YU, 2005, Terrestrial heat flow distribution in Kuqa foreland basin, Tarim, NW China (in Chinese with English abstract).

[13]Institute of Hydrogeology and Environmental Geology Chinese Academy of Geological Sciences. 2015. National Geothermal Resources Investigation and Assessment Program and Research Outcome Report (in Chinese).

[14]Institute of Hydrogeology and Environmental Geology Chinese Academy of Geological Sciences. 2015. National Geothermal Resources Investigation and Assessment and Regional Outcome Report (in Chinese).

[15]D.V. Duchane. 1996. Geothermal Energy from hot dry rock: A Renewable Energy Technology Moving Towards Practical Implementation. Renewable Energy, Volume 9, Issues 1–4, September–December 1996, Pages 1246-1249.

[16]John W. Lund, Tonya L. Boyd. 2016. Direct Utilization of Geothermal Energy 2015 Worldwide Review, Geothermics, Volume 60, March, Pages 66-93.

[17]P Muffler, R Cataldi. 1978. Methods for regional assessment of geothermal resources. Geothermics, Volume 7, Issues 2–4, Pages 53-89.