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ADVANCES IN STUDIES ON GEOTHERMAL RESOURCES IN CHINA

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ABSTRACT: Based on recent year's advances in geothermal resources studies and explorations in China, this paper reviews the basic distributive characteristics of hot springs in the uplifted area and geothermal water in the Meso–Cenozoic sedimentary basins, suggests that two hydrothermal activity concentrated zones (South Tibet Autonomous Region — West Sichuan Province — West Yunnan Province and coastal area of Southeast China), one large basin(North China Basin) and two smaller basins (Weihe Basin and Leiqiong Basin) are major areas of study and exploration of geothermal resources in China continent, considers that geothermal resources in China have certain potential of exploitation and should be used, but the scale of exploitation seems to be limited, they cannot occupy an important position in energy supply and can only be regarded as a supplementary energy source.
KEY WORDS: geothermal resources, potential of exploitation, Review, China.

I. GEOTHERMAL RESOURCE REGIONS WITH NATURAL MANIFESTATIONS IN TECTONIC UPLIFTS

This type of geothermal resource regions is featured by hot springs and other manifestations which may appear in the form of single–spring or group–spring. Various types of manifestations may coexist in a hydrothermal area. The manifestations in China are dominantly hot springs whose temperatures are less than 80℃. The strong hydrothermal activities, such as boiling springs, boiling–gushing springs, exhalation pores, steaming ground, geysers, hydrothermal explosions and so on whose temperatures are up to or higher than their local boiling points, are only seen in some areas in the Qinghai–Xizang (Tibet) Plateau, West Yunnan Province, West Sichuan Province and Taiwan Province.

1. Geographical Distribution of Hydrothermal Areas and Heat Discharge from Hot Springs

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According to updated statistics[1], 2,200 hot springs with temperatures greater than or equal to 25℃ appear in China, of which 859 with 25–40 ℃ , 807 with 40–60 ℃ , 398 with 60–80 ℃, and 136 with > 80 ℃, respectively occupying 39%, 37%, 18%, and 6% of the total hot springs in the whole nation. The total heat quantity discharge from hot springs is 101.9 PJ/ a, the heat quantities of above four temperature grades are 31.98, 21.49, 28.86, and 19.57 PJ/ a, occupying 32%, 21%, 28% and 19% of the total amount respectively. The annual quantity of heat brought out by the hot springs in China can be converted into standard coal of the 3.54 million tons.

According to statistics on hot springs distribution in executive regions, with exception of Heilongjiang Province and The Ningxia Hui Autonomous Region without hot springs of temperature higher than 25℃, and Shanghai and Tianjin cities without hot springs, there are different numbers of hot springs in other provinces and Beijing City. The provinces or regions with most spring–number in China are Yunnan (603), Tibet (283), Guangdong (275), Sichuan (220) and Fujian (174), the number of springs in those five provinces is approximately 70% of that of China. Five provinces, with spring densities greater than 10/ 10,000 km^2,are respectively Taiwan (19.2), Yunnan (15.9), Guangdong (14.3), Fujian (14.1), and Hainan (10). The 10 provinces with the springs exothermic quantity greater than 3 PJ/ a are consequently Tibet (36.4), Yunnan (19.30), Shaanxi (7.62), Sichuan (5.53), Guangdong (5.01), Fujian (3.98), Shanxi (7.26), Taiwan (3.37), Hubei (3.30) and Hunan (3.14). Those ten provinces possess 89% of the total exothermic quantity of the whole nation. It is worth to mention that the cases of Shaanxi and Shanxi provinces are extremely particular, although there are only 13 and 6 springs, the exothermic quantities rank the 3rd and 7th respectively. This fact results from karst springs of big water discharge (the biggest, 1–2 m^3/ s, water temperature,25–30 ℃) distributed along a northern boundary of Weihe Basin, and boundaries of Datong Basin and Linfen Basin.

2. Major Concentrated Zones of Hydrothermal Activities

The following prospective zones of geothermal resources are identified according to distribution characteristics of hot springs and geothermo–geological backgrounds.

2.1 Concentrated zone of hydrothermal activities along South Tibet–West Sichuan–West Yunnan

It consists of an important part of the Mediterranean geothermal zone, one of the global geothermal zones. Tong Wei et al.[2] calls it Himalayan geothermal zone. There are 772 springs in this zone, approximately 33% of the total number of the nation, among them, 221 with temperature of 25–40℃, 282 of 40–60℃, 139 of 60–80℃ and 80 of > 80℃. The exothermic quantities of four temperature grades are 3.92, 8.44, 6.28, and 14.98PJ/ a respectively, and totally 33.62PJ/ a, they also share 33% of the total amount of the whole nation. Of the springs of temperature higher than 80℃, 41 occur in south Tibet, at least 5 in

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west Sichuan Province, and 34 in west Yunnan Province. The recorded highest temperature of hot springs is 98–100℃. There are about 60 springs with temperature reaching or a little higher than the local boiling points, becoming boiling springs, among them, 37 in south Tibet, at least 4 in west Sichuan Province, and 17 in west Yunnan Province. Besides the boiling springs, the high temperature manifestations such as geysers, exhalation pores, boiling mud pots and hydrothermal explosions and so on, also appear along this zone[2,3]. It is the biggest potential zone of geothermal exploration in the land area in China. The potential in geothermal power generation in south Tibet is the order of magnitude of several hundreds to one thousand MW, simultaneously the direct utilization of geothermal resources approximately reach several thousand MW[4]. Yangbajing field in Tibet is the first high–temperature geothermal field verified and industrially exploited in China, its temperature of geothermal reservoir in shallow part (Quaternary) is 150–170℃. Of a bore hole drilled a depth of 1,003 m, the highest temperature in it is up to 202.2℃, the area of thermal water of high temperature suitable for generating electricity is 5.3 km^2, approximately the Quaternary geothermal reservoir possesses a electric–generating potential of 19–23 MW[5].

2.2 Concentrated zone of hydrothermal activities of Taiwan

It is a part of circling Pacific geothermal zone. Of the hot springs in Taiwan, 69 springs have temperature and water flow rate records[6]. Among them, 8 with temperature of 25–40℃, 18 of 40–60℃, 25 of 60–80℃, 18 of > 80℃, the exothermic quantities in different temperature grades are 0.02, 0.15, 1.48 and 17.33 PJ/ a, respectively, and total quantity of 33.79 PJ/ a. Of the springs with temperature higher than 80℃, there are 8 with temperatures up to or little higher than their local boiling points, becoming boiling springs. The extremely strong modern hydrothermal activities appear in the Pleistocene volcanic area of Datun Bear Beitou, north end of Taiwan, besides the boiling springs, there are also manifestations of high temperature like exhalation pores (the highest temperature up to 120℃), and hydrothermal explosions there. The highest temperatures of two boreholes of the depths of 900 m and 1,500 m in Machao near Seven Star Hill are 186℃ and 293℃ respectively. The area of Datun volcanic geothermal field is 36 km^2, approximately electric potential of installed capacity of 100–500 MW.[6]. However, the geothermal fluid with high degree of mineralization (5–12 g/ L) and intensified causticity (pH< 3), is extremely unfavorable to exploitation. Of the more than twenty nonvolcanic geothermal fields located on Central Mountain of Taiwan, such as Qingshui, Tuchang and Lushan, and so on, the temperatures at the depths of 500–2,000 m are 173–215℃, and the degrees of mineralization are 1–3 g/ L, pH are about 7.0[7]. This zone is the area with the most potential of exploitation of geothermal energy on the east part of China.

The two zones of hydrothermal activities are of anomalously high heat flow, which has been verified by the observed data of terrestrial heat flow①[8,9]. They have 76 hydrothermal

① Lee Qing– and Cheng Weng–Tse, Heat Flow Map of Taiwan, China, 1986.

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systems of high temperature (> 150℃). The background value of regional heat flow is about 100 mW / m^2, it is the a important geophysical background of modern intensified hydrothermal activities. The anomalous high heat flow and intensified hydrothermal activity resulted from heat sources of recent magnetic activity with crustal granite magma intruding up to depth of 10–12 km (South Tibet) and the pocket of magma remained in shallow part during the recent volcanic activities (Datun, Taiwan). Of plate tectonic locations of the two above–mentioned geothermal zones, the former, located on the boundary of Indian–Eurasian plate, belongs to the type of hydrothermal system of land–land collision, and is a typical geothermal zone with blind volcanoes. The latter, located on the boundary of Eurasian–Philippine Sea plate, belongs to the hydrothermal system of plate margin of island–arc type, and is the geothermal zone of volcanic type. Generally thinking, the potential of exploitation of the hydrothermal systems of plate margin is greatly superior to that of in–plate systems, and lower than that of plate margin of island–arc type.

2.3 Concentrated zone of hydrothermal activities in coastal regions of Southeast China

Here it refers to Guangdong, Fujian and Hainan provinces adjacent to the East China Sea and the South China Sea. The region is influenced by both the eastward subduction of the plate of the South China Sea along Manila Trench and the collision of Philippine Sea and Eurasian plate. It is in the extensional condition, and develops a series of intermittent active fault zones dominantly with NNE–NE striking and NW striking in coastal area, which favors the formation of hot springs. It is an area of the most concentrated hot springs on the east part of the continental area of China. There are 461 hot springs with temperature higher than 25℃, approximately 25% of the total of hot springs in China. Among them, 108 with temperature of 25–40℃, 210 of 40–60℃, 119 of 60–80℃ and 24 of > 80℃. The exothermic quantities of four temperature grades are respectively 0.72, 2.69, 4.94 and 1.38 PJ / a, totally 9.73 PJ / a, about 10% of the quantity of the whole country. The highest temperature of natural exposure geothermal water in this zone is 97℃ (Xinzhou Field, Guangdong), approaching but not reach the local boiling point. Zhangzhou Field in Fujian Province is one of the highest temperature observed in this zone, in which there is a well to a depth of 90 m. Its bottom hole temperature is 121.5℃, and the water temperature at well head is 106℃.

With regard to the nature of hydrothermal systems in this region, there are different ideas among Chinese and foreign scholars, and persons in industrial circles. Puvilon and Rose thought it was possible to find geothermal water with temperature greater than 150℃ in Fuzhou and Zhangzhou of Fujian (cited from Fujian Geological News and China Geological News, respectively). Dr. Kappelmeyer thought that a deep hot dry rock was probably found in Boting, Wenchang and Zhan counties in Hainan Island, and geothermal resources of high temperature is possibly found in the Quaternary volcanic areas in north Hainan Island and Leizhou Peninsula[10]. A few years ago, Professor Chen Zhongji of China also held this idea. However, after studying regional heat flow pattern and analyzing

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typical geothermal fields of this region of China in recent years, many geothermics scientists have put forward contrary ideas. Wan Tianfeng et al.[11] thought that Fujian Province didn't have geotectonic conditions to form different geothermal systems of high temperature. Wang Jiyang et al.[12] judged that Zhangzhou Field was a hydrothermal system of middle temperature. Chen Moxiang et al.[13] affirmed that Leiqiong Basin is a distributive area of geothermal resources of low temperature. The author of this paper thinks that the background value of heat flow in this zone is about 75 mW / m^2, a little higher than normal value, heat flow in this zone is not so high as that in South Tibet and Taiwan. Taiwan is a part of island–arc of West Pacific during the history of its evolution, the continental plate underthrusts eastwards oceanic plate, which is very different from the Mesozoic westwards underthrust of oceanic plate. Under this tectonic frame, hydrothermal systems of high temperature can't appear in the coastal area of Fujian and Guangdong provinces. The temperature of geothermal reservoirs in this zone will be less than 140℃, the depth of underground water circulation is within 3.5–4 km, the hydrothermal systems are of middle–low temperature (< 150℃) of in–plate type, most of them are of low temperature (< 90℃). Nature of hydrothermal systems is very important and is the basis of assessing the potential of geothermal resources and choosing directions of utilization. The geothermal water with middle–low temperature is fit for direct use.

II. BURIED GEOTHERMAL RESOURCES REGIONS IN TECTONIC DEPRESSION

Here, it refers to thermal water resources deeply buried in sedimentary basins without surface manifestations. This type of resources has a close relationship with the type of basin origin, main period of basin development, and stratigraphic combination. Thus, according to these major characteristics, following concise descriptions are made about accumulation conditions and exploitative potentials of thermal water in major large and middle sedimentary basins in China.

1. Geothermal Resources of Fault–Depressed Basins

The major phases of development of North China Basin, Northern Jiangsu Basin, Songliao Basin, Xialiaohe Basin, Weihe Basin and Leiqiong Basin have properties of fault–depression, thus some persons call them ancient rift basins, in which the Cenozoic and Mesozoic sedimentary layers are very thick, normally 3,000–6,000 m, the thickest layer is up to 10,000 m. North China Basin and Northern Jiangsu Basin are taken as examples of analysis[14,15,16]. Geotectonically, the two basins are Meso–Cenozoic sedimentary basins developed on North China and Yangtze paraplatforms, controlled by several groups of faults. On these two basins, there exist a series of fault uplifts and depressions and the secondary

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tectonic units, thereby, they are expressed by the structures of Paleozoic and Pre-paleozoic basic rocks in a pattern of many uplifts and depressions, many sedimentary centers, and uplift changing depression alternatively, under a cover of Cenozoic or Meso-Cenozoic groups. Under the control of this kind of tectonic pattern, geotemperature is clearly featured by high and low ones in turn, and by belt appearance. On the basis of analyses of geotemperature data of some 4,000 wells and factories influencing geothermal pattern, 44 local geothermal anomalies are delineated, their geotemperature gradients are greater than 4℃ / 100 m, and heat flow are greater than 65 mW / m^2. This kind of anomaly is mainly caused by inhomogeneities of thermal properties of shallow crustal rocks horizontally and vertically, and results from the redistribution in shallow crust of regionally relatively uniform heat flow in deep crust during the process of upward conduction. Some faults controlling boundaries of uplifts are open ones, where thermal water goes up from the deep part. The partial water-heat convections take place in the fault fracture zones and their surrounding sections. Convection heat transfer superimposes on conduction heat transfer, therefore thermal anomalies are apparently developed. Of the Niutuozhen uplift in central Hebei Province, Shuangyao and Xiaohanzhuang uplifts in the suburb of Tianjin, geothermal water respectively goes upwards from Niutuozhen, Baitangkou and Changzhou fault belts, which results in the geothermal gradients in the covers near the fault belts and their surrounding areas up to 5-7℃ / 100m, the biggest up to 9-10℃ / 100m. In the geothermal anomalous areas above-mentioned geothermal resources are probably used in the depth of 700-2,000m, thermal water reserved in two groups of strata, one upper Tertiary, another Paleozoic and middle-upper Proterozoic. The depth of upper Tertiary is 700-2,500 m, the biggest thickness of the upper Tertiary is 1,200-2,200 m, among which the thickness of sandstone is 400-800m. In some wells with a depth of 700-1,200 m, there may be obtained water of 400-2,000 m^3/ d with 40-60℃, which is of good quality with the degree of mineralization mainly in 1-2 g / L. Thermal water is buried in carbonate rock under Meso-Cenozoic cover of uplifts and is strong capable of blowing, quantity discharge of a single well is generally higher than 400 m^3/ d, and the biggest can be up to 2,000-4,000 m^3/ d. The water temperature at well head is 50-80℃. The degree of mineralization is generally lower than 3 g / L. As reservoirs are stratabound ones, they are widely distributed. It is confirmed that North China and Northern Jiangsu Province Basins are most potential for the use of geothermal water of low temperature in all basins in China.

2. Geothermal Water of Meso-Cenozoic Depressed Basins

They are represented by Junggar Basin and Tarim Basin in W China. This kind of basins is mainly featured by stable downgoing and accepting sediments. The depths of Meso-Cenozoic strata are 2,000-5,000 m or greater. The terrestrial heat flow values, geothermal gradients and temperatures of this kind basin are lower than those of the

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fault–depressed basins, heat flows are less than 50 mW / m², geothermal gradients are generally 2–3℃ / 100m, and the temperatures at the depth of 1,000 m are less than 40℃, so this kind of basin belongs to cold basin[17]. The salinity at the depth lower than 2,000 m is 10–30 g / L, and has an increasing tendency with the increase of depth. The underground water in the very thick mullite formation of piedmont geotectogene probably has low degree of mineralization. It is unfavorable for forming thermal water under the strong influences of cold water flow in foreland. This kind of basins is located on arid area. Fresh water resources is precious, salty thermal water did not has generally real significance.

3. Geothermal Water of Mesozoic Depressed Basins

They are represented by Erdos Basin and Sichuan Basin in central China. This kind of basins is mainly featured by stable Mesozoic downgoing. The Cenozoic sediments in the basins are thin or absence, which means the basins in Pre–Cenozoic have entered the phase of stable development. Geotectonically, Mesozoic strata in Sichuan Basin formed wide and gentle anticlines and synclines, but in Erdos Basin the Mesozoic strata are represented by small–sized uplifts and depressions, and the faults aren't active. The two basins are cold basins indicated by low heat flow (about 50 mW / m²) and low geothermal gradients (2–2.5℃ / 100m)[17]. The Geothermal water be served in Mesozoic sandstone is featured by high salinity, especially in Sichuan Basin, brine with temperature less than 80℃ is dominant in the depth less than 2,000 m. The geothermal water with low temperature and high mineralization has not real significance. Therefore, with regard to Sichuan Basin, most generally realistic and most valuable geothermal water utilized as energy resources and health resort is batch of hot springs distributed in the basin. The temperature of hot springs is not high (< 50℃), but the springs are mostly distributed in Chongqing City and its surrounding area, thus all these conditions are favorable for exploitation.

The geothermal resources of above–mentioned basins are developed in geothermal areas of low temperature at the normal geothermal background of dominant heat conduction. As basins are the areas of water accumulation, they become major distributive areas of geothermal water resources. Many basins are normally the areas of exploration and exploitation of oil–gas. A batch wells without oil only producing thermal water are remained during the exploration and exploitation of oil–gas. It is most realistic way to use geothermal energy in extensive rural areas to make use of these wells recently and in considerably long period of time.

III. CONCLUDING REMARKS

1) The most potential areas of geothermal resources in China continent: two zones (Himalayan geothermal zone and concentrated zone of hydrothermal activities in southeast

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coastal region), one large block (the North China Plain) and two small blocks (Weihe Basin and Leiqiong Basin), should be major areas of study, exploration and exploitation of geothermal energy in China.

2) In the areas with geothermal energy in outlying districts, the area extremely short of conventional energy (such as Tibet), urban and suburban areas of large and middle-sized cities (such as Beijing, Tianjin and Xi'an), and the coastal economic open areas (such as Fuzhou, Xiamen, Zhangzhou, Zhongshan, Zhuhai, Zhanjiang cities ect., Hainan Island and Shandong and Liaodong peninsulas), the geothermal energy with good conditions of production should be actively exploited.

3) Geothermal energy is a new energy source, which plays an important role in some countries and some areas. In generally, with exception of a few countries, the geothermal energy can't take the place of conventional energy in a long period of time, and it can't occupy the majority in energy structure either. The geothermal energy of thermal water type in China is widely scattered, and has a certain exploitative potential, but it isn't abundant. As exploitative scale will be limited, it is an auxiliary energy, and only can become a major energy only in some areas during a certain period of time.

4) Experience of international and national exploitation of geothermal energy shows that geothermal fluid with high temperature is mainly used to generate electricity, geothermal water with middle or low temperature should hold the direction of comprehensive non-electrical utilization. It should take warning that a great upsurge of generating electricity with thermal water of low temperature ever raised in the 1970s in China, brought about an extremely unworthy outcome.

REFERENCES

[1] Chen Moxiang. A new map of hot springs in China and its explanation, Scientia Geologica Sinica (English edition), 2(1), 1993 (in press).

[2] 佟伟、章铭陶编.西藏地热.北京:科学出版社, 1981.

[3] 佟伟,章铭陶编.腾冲地热.北京:科学出版社, 1989.

[4] Shen Xianjie. An order of magnitude estimation of geothermal resources of the Himalayan geothermal belt, Tibet, SGS (English edition), 1(1/2); 107-117, 1992.

[5] 沈显杰.我国第一个高温地热田的地热资源评价.科学通报, 1985, 30 (15): 1171-1174.

[6] 张宝堂.台湾地热征兆分布之特性.能源季刊, 1979, (4) :75-84.

[7] Cheng Weng-Tse, Geothermal update report Taiwan, China, 1985 International Symposium on Geothermal Energy, Hawaii, International Volume, 191-195, 1985.

[8] 沈显杰.青藏高原南北地体壳幔热结构差异的大地热流证据.中国地质科学院院报, 1990, (21): 202-214.

[9] 汪缉安、徐青、张文仁.云南大地热流及地热地质问题.地震地质, 1990, 12 (4): 367-378.

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[10] Kapplemeryer, O., Erkundung and nutzung geothermisher energin in provinz Guangdong, Volksrepublik China, Bundestal fur geowissenschaften und rohstofft, Hannover, 1982.

[11] 方天卡, 褚明记, 陈明佑. 福建省岩石圈热状态及地热资源远景评价. 地质学报, 1988, 61 (2) : 178-189.

[12] Wang Jiyang, Pang Zhonghe, Xiong Liangping, Fan Zhicheng, Jiang Zhenyang and Zhang Qingxiang, Genesis analysis of Zhangzhou Basin geothermal system, Advances in Geoscience, (1), 409-417, China Ocean Press, 1989.

[13] 陈墨香, 夏斯高, 杨淑贞. 雷州半岛局部地热异常及其形成机制. 地质科学, 1991, (4) : 369-383.

[14] 陈墨香主编. 华北地热. 北京: 科学出版社, 1988.

[15] 陈墨香, 邓孝. 华北平原新生界盖层地温梯度图及其简要说明. 地质科学, 1990, (3): 247-255.

[16] Chen Moxiang, Wang Jiyang, Wang Ji'an, Deng Xiao, Yang Shuzhen, Xiong Liangping and Zhang Juming. Characteristics and formation mechanism of the geothermal field in the North China down faulted basin. Acta Geologica Sinica (English edition), 1990, 3(3): 329-343.

[17] 王钧, 黄尚瑶, 黄歌山, 等. 中国地温分布的基本特征, 北京: 地震出版社, 1990.

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