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Geothermal Gradient in the Oilfields in China

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ABSTRACT

Geothermal temperature and its gradient, as a function of depth, is a very important parameter in evaluating geothermal resources. There are many factors affecting geothermal temperature and gradient. These include rock type, contents and categories of radioactive elements, types of heat transfer (convection or conduction), etc. The geothermal potential in oilfields in China is huge. However, the geothermal temperature and gradient data are not available in many oilfields. In some cases, the oil companies have the data but do not provide them to the geothermal users, which causes a lot of difficulties in estimating the geothermal potential in oilfields. To this end, the geothermal temperature data were collected and analyzed in this paper. Using these data, contour map of geothermal gradient and temperature-depth were plotted for the major oilfields in China.

1. INTRODUCTION

Most oilfields in China are located in big sedimentary basins. The present studies show that the basins are not only rich in oil and gas, the traditional fossil resources, but also rich in renewable geothermal resources. However, fossil resources are the most important energy in China, they provide more than 80 percent of total energy needs. Therefore, most people and companies focus on the fossil energy and ignore the geothermal resources that exist in these basins. In addition, the rapid development of solar and wind utilization will shift people's attention away from geothermal resources.

Recently, the national energy structure adjustment in China has accelerated the exploitation of geothermal resources in oilfields and other areas (Wang et al., 2005). Numerous oilfields in China enter the high water cut stage, the average water cut is more than 95%, most oil wells are no longer suitable for further production economically, with large quantities of oil unrecovered (Gong et al., 2013). How to increase the benefit of such oilfields is a significant research subject. Generally, the hot water associated in oilfields is for direct use, like water heating, oil tube cleaning, etc. Deep and high temperature geothermal resources are often used for power generation. Geothermal utilization in oilfields is a good approach offseting the loss of oil production and energy self-consumption (Wang and Wang, 2009).

Some geothermal investigation in oilfields have been conducted in China (Shi et al., 1998; Xu et al., 2002; Wang, 2003; Deng, 2008; Deng, 2009; Lin and Gong, 2005; Wang et al., 2005; Tian, 2009; Liu, 2010; Wang, 2011; Zhao, 2011; Shi, 2013), but the geothermal temperature and gradient data are not systematic and not analyzed in details. Most of them just focused on a specific area, or some hotspots. Sometimes the oil companies have the data but do not provide them to the geothermal users.

The geothermal temperature data were collected and investigated in this paper. Using these data, contour maps of geothermal gradient and temperature-depth were plotted for the major oilfields in China.

2. CONTOUR MAPS OF GEOTHERMAL GRADIENT

1) DQ oilfield

DQ oilfield is located in the middle-south part of Heilongjiang Province of Northeast China. DQ exploration area is also located in the complex structural evolution belt between Siberia plate and China-Korea plate. Folds inside the basin are arranged alternatively with arrested NNE anticlines and synclines. Among them, DQ oilfield is a structural oil and gas field formed on the anticline belt of central depression. Daqing Petroleum Administrative Bureau has explored 14 basins, including Songliao basin. Twenty oilfields and ten gas fields are discovered, and among them DQ oilfield is one of the largest continental oilfield in the world (Zhu, 2011).

Figure 1 shows the contour map of geothermal gradient for DQ oilfield. It can be clearly observed that the geothermal gradient varies from region to region. The geothermal gradient of this oilfield ranges from 2.8 to 3.7^{o}C/100m. Low gradient is basically observed in central part like DQ, eastern part like Mudanjiang, and the southwestern part of the oilfield. Relative high gradient regions lie in the western peripheral area and the southeastern area. In the central part, the gradient decreases from outside (3.3^{o}C/100m) to inside (2.8^{o}C/100m). As for the southeastern part, the gradient increases from the outside (3.15^{o}C/100m) to the inside (3.4^{o}C/100m or so).

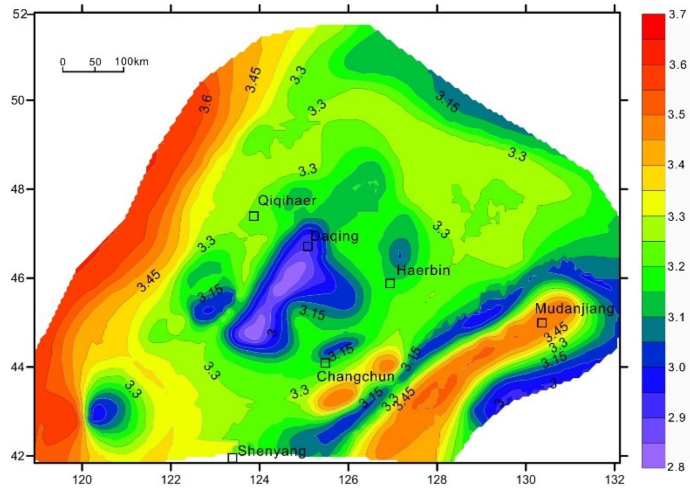

Figure 1: Contour map of geothermal gradient for DQ oilfield.

2) XN oilfield

XN oilfield is located in Sichuan Basin, in Sichuan Province of East China, with an area of approximately190,000 km^2, is a large cratonic basin, containing up to 6–12km of Sinian to Quaternary sediments. Based on the basement structure, sedimentary covers, and petroleum occurrence, the Sichuan Basin can be divided into four oil and gas accumulation districts (i.e. the Eastern, Southern, Western and Central oil districts). Several potential petroleum source rocks occur in northeastern Sichuan Basin, including the Lower Cambrian Jiulaodong Formation, the Lower Silurian Longmaxi Formation and the Upper Permian Longtan Formation. The gas pools in the Southern part are generally small in size and the Eastern part has most of the known large and medium gas fields.

The contour map of geothermal gradient in XN oilfield is depicted in **Figure 2**. As can be seen in the map, the geothermal gradient varies from region to region and ranges from 1.6 to 3.4^{o}C/100m. Low gradient regions basically lie in northwestern part, southeastern part, and northeastern part of the Sichuan Basin. Typically, the geothermal gradient of the central area increases from the outside (2^{o}C/100m) to the inside (3.4^{o}C/100m).

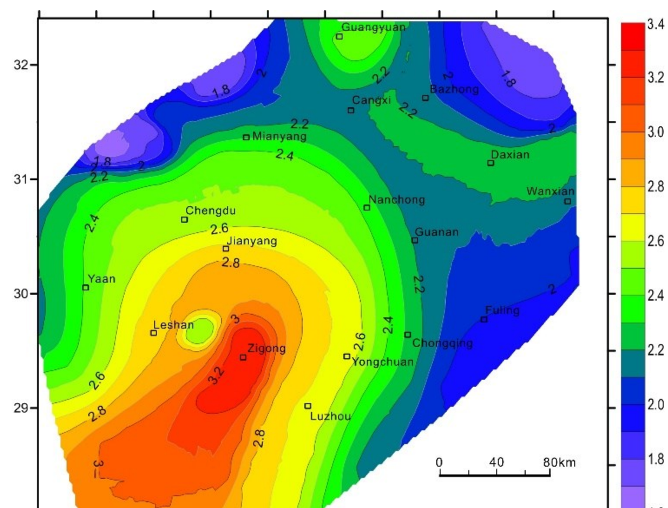

Figure 2: Contour map of geothermal gradient for XN oilfield.

3) HB, SL and LH oilfields

HB, SL and LH oilfields all lie in Bohai Bay Basin, a Meso-Cenozoic basin containing 65 depressions in the eastern part of the North China Block (Wu, 1990; Lin, 2005; Deng, 2008; Deng,2009). The basin was formed at the convergence of the Pacific Plate, the Indian Ocean Plate and the Siberia Plate. In the Bohai Bay Basin, the structures and sedimentary sequences of the depressions are controlled by northwest-trending faults and northeast-trending faults. The hydrocarbon resources and geological structures differ significantly between different depressions.

The contour map of geothermal gradient for HB, SL and LH oilfields is shown in **Figure 3**. The geothermal gradient varies very largely in different areas, with a range from 0.5°C to 9°C/100m. From this map, the low gradient regions distribute randomly. The gradients in Shandong Province present relatively high values than other parts of these oilfields. And the gradients in peripheral northwestern part are very low (less than 2.0°C/100m), which also indicates the low geothermal potential in this area.

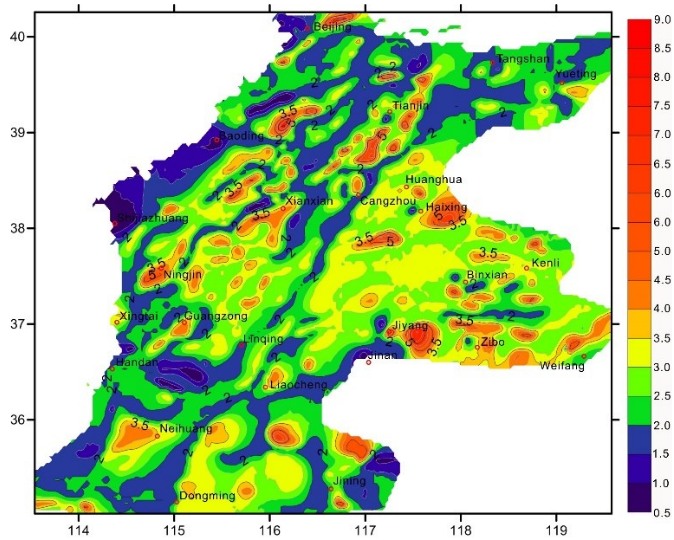

Figure 3: Contour map of geothermal gradient for HB, SL and LH oilfields.

4) CQ oilfield

CQ oilfield lies in Ordos Basin, China's second largest sedimentary basin, which stretches from Lvliang Mountains in the east to Helan Mountains in the west. It has an area of 250,000 km^2, spans 5 provinces and autonomous regions in China (i.e. Shaanxi Province, Gansu Province, Ningxia Hui Autonomous Region, Inner Mongolia Autonomous Region, and Shanxi Province). The Ordos Basin is divided into six tectonic units. Currently, most oil and gas reserves distributed in this area are in the Yishaan Slope (Ren et al., 2007).

The contour map of geothermal gradient for CQ oilfield is depicted in **Figure 4**. The geothermal gradient varies from region to region and ranges from 2.0 to 3.4°C/100m. The west part of the CQ oilfield presents lower gradient than the east part. The central part shows higher gradient than its surroundings, which also indicates higher geothermal potential in this area. Besides, the highest geothermal gradient area lies in the north part of the oilfield.

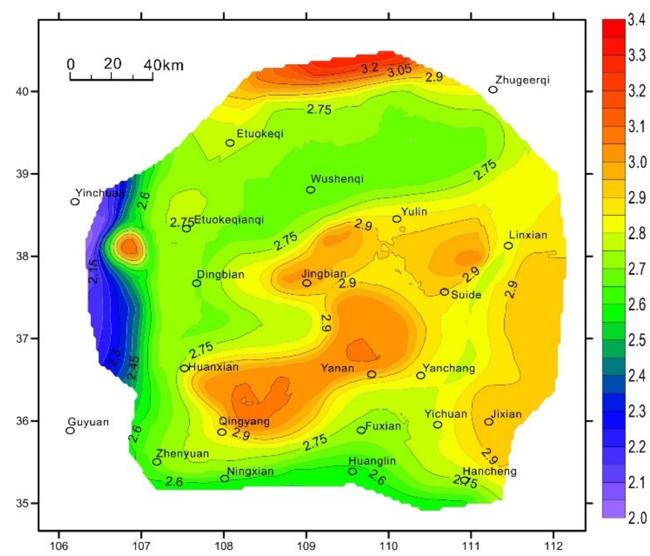

Figure 4: Contour map of geothermal gradient for CQ oilfield.

5) HN oilfield

HN oilfield is located in Dongpu depression along the Yellow River, a small depression in a series of Genozoic rift valley basin on North China Tectonic Plate in East China. With the strike of NNE, the depression is lute shaped, narrow (14-16km) in the north and wide (65km) in the south, covering an exploratory area of 5300km^2. The structural framework of Dongpu depression presents an uplift in central and depression in two sides. More than 95% oil reserves occur in continental strata in this oilfield (Wang, 2011).

Figure 5 shows the contour map of geothermal gradient for HN oilfield. It can be seen that the gradient in this oil field is different from region to region, with a large range from 1.2 to 3.9^{o}C/100m. There is a low temperature gradient belt in the southwestern part of the oilfield. The high gradient regions distribute in many parts. Besides, the geothermal gradient in east part increases from the outside (2.8^{o}C/100m) to the inside (3.9^{o}C/100m). The gradients in most area in the oilfield are about 2.4^{o}C/100m.

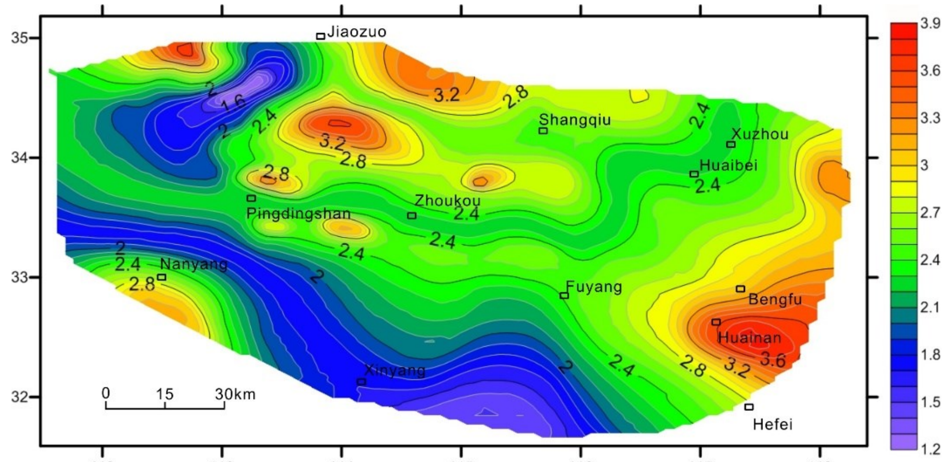

Figure 5: Contour map of geothermal gradient for HN oilfield.

3. GEOTHERMAL TEMPERATUE VS DEPTH

The relationship between geothermal temperature and depth is the key point to evaluate geothermal potential. Economic analysis by other researchers (Allis et al., 2015), like levelized cost of energy (LCoE) evaluation method, divided geothermal temperature-depth graph into five applicable parts; geothermal direct use area, moderate temperature hydrothermal reservoirs area (pumped wells), high temperature hydrothermal reservoirs area (self-discharging wells), stratigraphic geothermal reservoirs (SGR) area, traditional petroleum reservoir (TPR) area and high pressure and high temperature (HPHT) petroleum reservoir area. It is noted that geothermal resources from moderate temperature hydrothermal reservoirs, high temperature hydrothermal reservoirs, and stratigraphic geothermal reservoirs are in good favor of power generation.

Temperature-depth data can show the geothermal potential straightforward. We collected and organized the data from papers and other publications. We then used these data to plot the temperature-depth figures. **Figures 6** to **12** show the data from major oilfields in China. The data reported by Wu (1990), Zhu (2011) and Zhai (2011) in DQ oilfield were used to plot **Figure 6.** The data collected from the wells mostly lie in “traditional petroleum reservoirs”. Generally, the data collected from DQ oilfield have relative higher geothermal gradient values. It should be noted that the data from well Pu No.1 and other fields indicate that DQ oilfield may have the potential to be SGR, which means it has the potential for power generation.

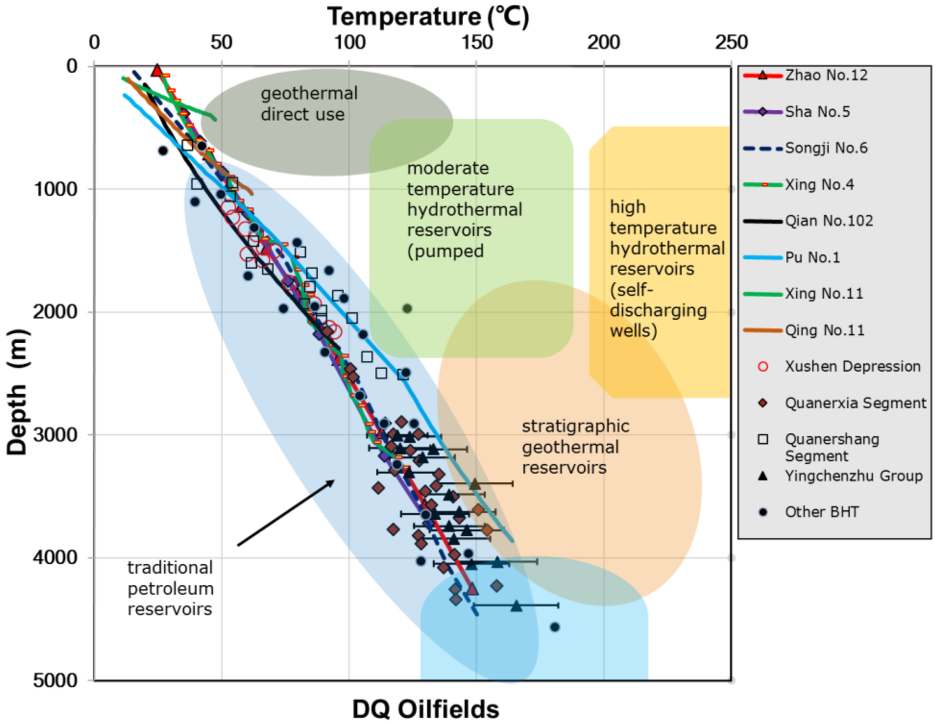

Figure 6: Geothermal temperature vs depth based on data from DQ oilfields

As for LH oilfield, the data reported in these papers (Deng, 2008; Deng, 2009; Wu, 2011; Zhao 2002 and 2011) were collected and used to plot **Figure 7**. Geothermal gradients are typically high in LH oilfield. It can be noted that the regions where four wells lie may have the potential to be SGR.

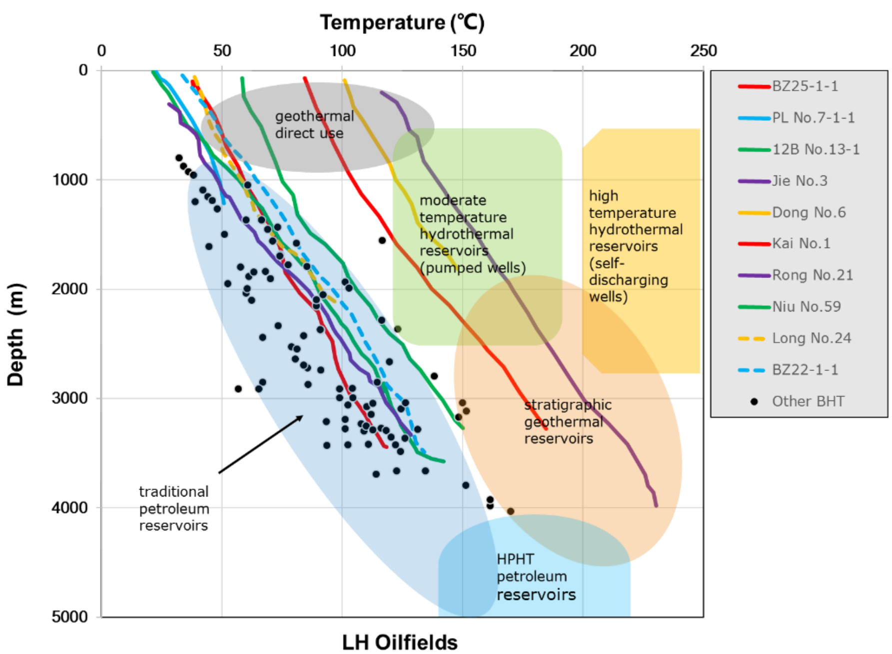

Figure 7: Geothermal temperature vs depth based on the data from LH oilfields

It can be seen from **Figure 8** that the data collected from HB oilfield generally lie in “traditional petroleum reservoirs”. Regions where Xiong No.101 and Xiong No.104 lie have the potential to be direct use, and even SGR.

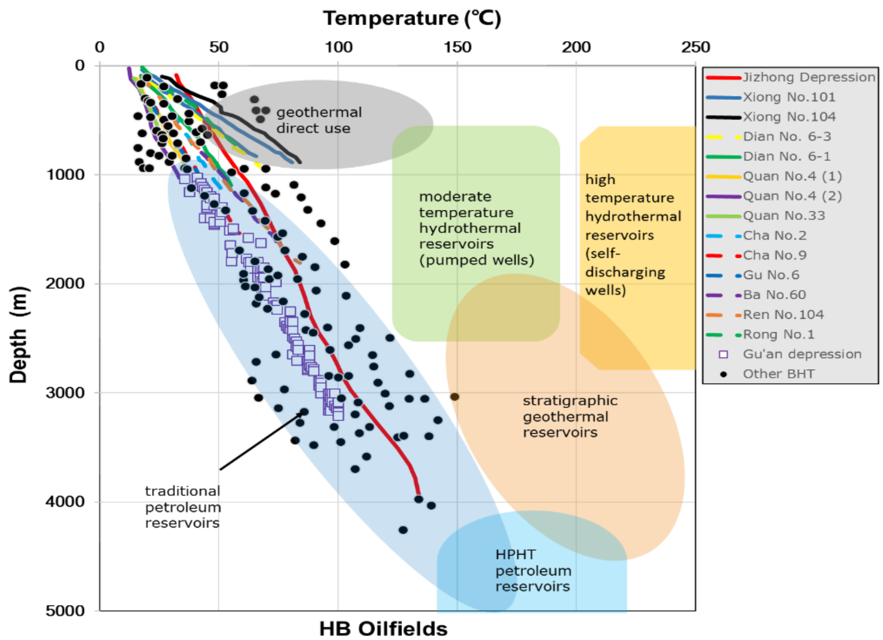

Figure 8: Geothermal temperature vs depth based on data from HB oilfields

(Data from Lin et al., 2005; Xiao, 2001; Zhang et al, 2007)

Figure 9 illustrates that SL oilfield is a typical traditional petroleum reservoir with relatively low geothermal gradient. Data collected from the oil wells in this oilfield even do not lie in the "geothermal direct use" part. However, the data from Dongying No.2 at 4000-meter depth is very close to the SGR area. So the geothermal potential in SL oilfield is worthy of further study, especially in the area more than 3000 m depth.

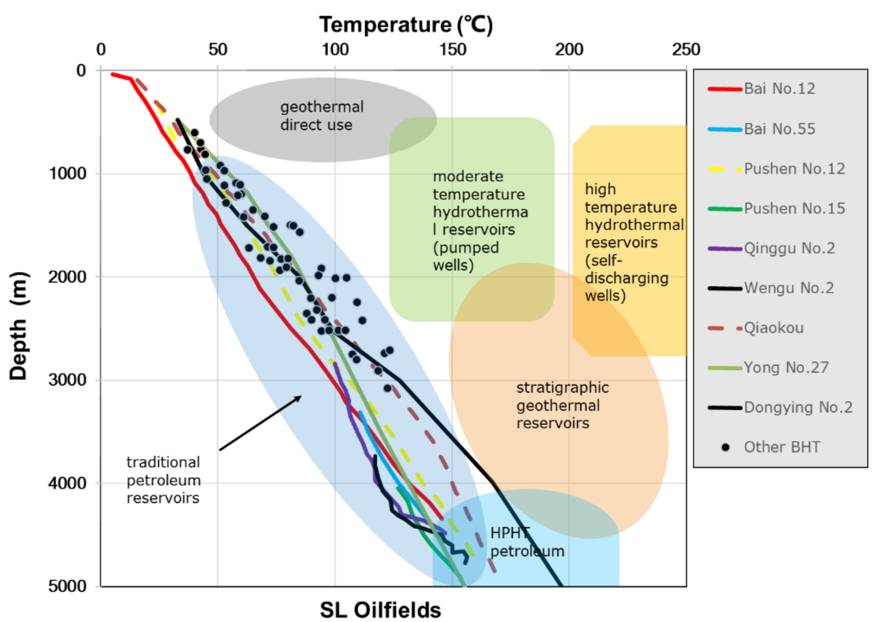

Figure 9: Geothermal temperature vs depth based on data from SL oilfields

(Data from Xu et al., 2002)

The data collected from most of the wells in HN oilfield (**Figure 10**) indicate that this oilfield is a traditional petroleum reservoir. It can also be observed that the regions where wells Taishen No.1 and Ancan No.11 lie have the ability for geothermal direct use. It can also be noted that the region where well Taishen No.1 lies has the potential for SGR.

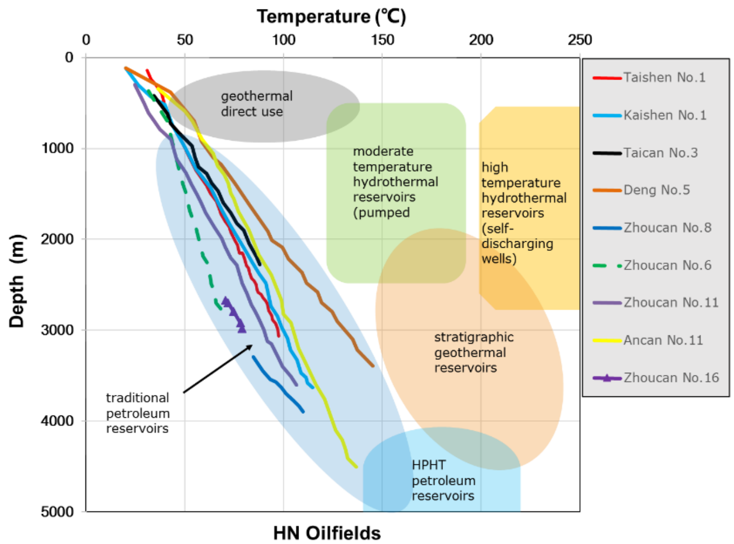

Figure 10: Geothermal temperature vs depth based on data from HN oilfields

(Data from Wang, 2011)

As for XN oilfield (**Figure 11**), most of the data collected from the wells in Sichuan Basin lie in "traditional petroleum reservoirs". Data collected from well Chuanshi No.55 and well Dingshan No.1 demonstrate that the regions may have geothermal direct use potential. Generally, geothermal gradients of oilfield are typically low, geothermal potential needs further evaluation.

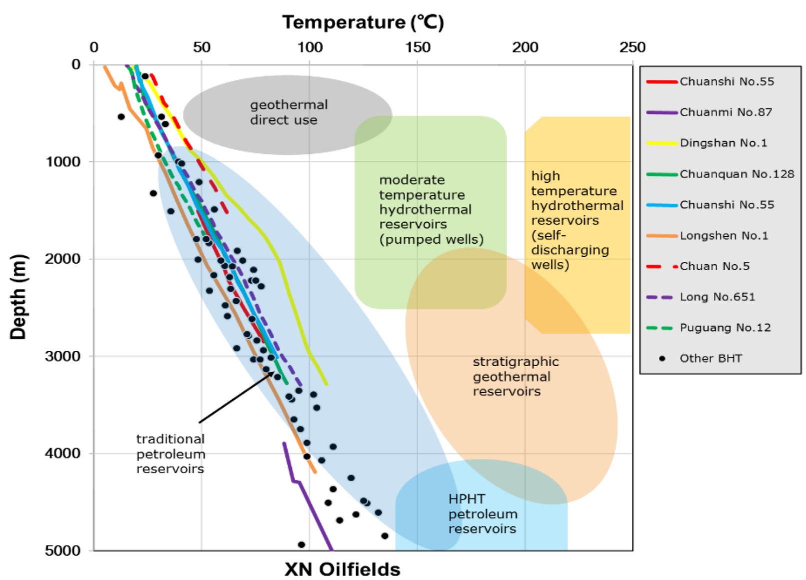

Figure 11: Geothermal temperature vs depth based on data from XN oilfields

(Data from Xie, 1988)

Similarly, all the bottom hole temperature data from CQ oilfield (**Figure 12**) were TPR area. Both of CQ and XN oilfields primarily produced natural gas.

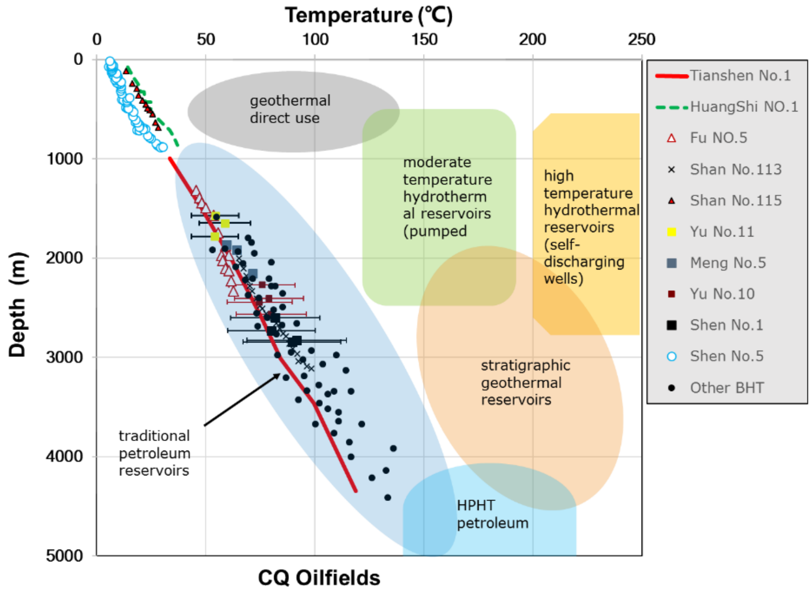

Figure 12: Geothermal temperature vs depth based on data from CQ oilfields

(Data from Wang et al.,2003; Ren et al 2007)

4. CONCLUSIONS

(1) HB oilfield has the highest geothermal gradient, ranging from 3 to 4.8^{o}C/100 meter. The temperatures of the produced water in some oil wells were about 120^{o}C. Many areas in the oilfield could be the stratigraphic geothermal reservoirs targets.

(2) DQ and LH oilfield has the second highest geothermal gradient, with a range from 3 to 4^{o}C/100 meter. Some of the areas in the oilfields could be the stratigraphic geothermal reservoirs targets.

(3) The geothermal gradients in most of the oilfields in China are less than 4^{o}C/100 meter. The temperatures of the produced water in some oil wells were about 60^{o}C.

(4) In most of the oilfields investigated in this study, the geothermal gradients do not vary with depth significantly. This may be one of the unique features in depositional basins.

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