

## The Geothermal Resources and Development Plan in the Olympic Green, Beijing, China

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### ABSTRACT

Beijing will host the Summer Olympic Games in 2008, and the Olympic Green, where the most important facilities for the great event is to be built, will be in the northern part of the city. A few geothermal wells have been drilled around the Olympic Green, which indicate that there is rather good geothermal potential in the area. The geothermal energy will be used for the space heating and bathing in the sports' village that will be more than 29 hectare in area, and its floor area of the department buildings is planned to be 360,000m<sup>2</sup>. According to the planning, 10 geothermal wells, including 6 production wells and 4 reinjection wells, will be drilled for the project. Recently, a geothermal resource assessment project has just been carried out for the area of the Olympic Green, and the result shows that the reservoir to be exploited is the limestone layer of Ordovician and Cambrian Systems, the geothermal wells will be as deep as 3000 to 4000m deep. The geothermal resource assessment and the rapid declining of the reservoir pressure in the wells in the vicinity of the Olympic Green may indicate that the water recharge of the geothermal system in the area is likely rather limited, and reinjection will be an essential part of the geothermal project so as to ensure the sustainability of geothermal energy production.

### 1. INTRODUCTION

Beijing is rich with low-temperature geothermal, and the area identified with geothermal potential is over 2,300 km<sup>2</sup>. The geothermal water in the area of Beijing that is 40 to 88 °C mostly, is used for various direct purposes, including space heating, bathing, greenhouse, fish farming, swimming pool and recreation etc. With the rapid development of the city, the geothermal development was rather fast and 20-40 geothermal wells were drilled each year recently. At present, there have been over 200 geothermal wells producing around 10 million m<sup>3</sup>/a of geothermal water.

The City of Beijing will hold the 2008 Summer Olympic Games, and the Olympic Green (Olympic Park), including a few stadiums and gyms, the Olympic Village, some forest areas and other related facilities will be built in the northern part of the city, about 10 km from the center of the city (Figure 1).

Coal is the dominant energy source of Beijing, causing serious air pollution. In the past several years, measures of curing the air pollution, including the promotion of geothermal utilization, have been taken. The Olympic Games in Beijing will be featured as Green Olympics, and geothermal has been planned to use for space heating and domestic hot water supply for the sports village.

The area of the Olympic Green is with positive geothermal potential according to the geological exploration in the area, and successful geothermal wells have been drilled nearby. The target geothermal reservoirs are limestone and dolomite aquifers buried more than 2000m deep. The geothermal water around the area is 55-75 °C, containing components that are good for human health when used for bathing (HSiO<sub>2</sub>, F, Sr etc.). In relation to the geothermal development for the Olympic Green, some geothermal scientists (Cappetti, 2002; Fridleifsson, 2002; Lund, 2002; Rybach, 2002; Axelsson, 2002; Erlingsson, 2002) have put forward a wealth of suggestions.

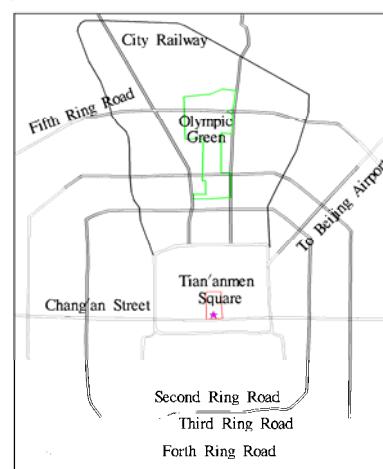


Figure 1: Map of location of the Olympic Green

There have been a lot of geological explorations for ground water purpose in the area of the Olympic Green, allowing for a basic understanding to the geological conditions. But there are a few important faults going through the area, which make the geological condition extremely complicated. Two geothermal wells have been drilled for further investigations of the geothermal condition in the area, and geothermal resources assessment has been carried out accordingly.

In the paper, the geothermal explorations, geological and geothermal conditions, the result of geothermal resources assessment and the geothermal development plan for the area of the Olympic Green will be introduced.

### 2.GEOTHERMAL EXPLORATION

Geological explorations in the area of the Olympic Green were mostly for groundwater purpose, which allow for a basic understanding to the geological conditions (Yang et al., 1980; Liu et al., 2003). In 2002, it was decided that geothermal be used for the Olympic Green, and related

geothermal exploration was carried out, including geophysical, geochemical surveys and drilling of two wells.

It was found out that there is a geothermal anomaly in shallow aquifers around the area of the Olympic Green by a geothermal survey carried out in early 1980's (Li et al., 1983). Later drilling showed that this anomaly is not related to a geothermal reservoir, but to a locally distributed thick cold water aquifer composed of loosely cemented conglomerate, which may be more than 1500m thick.

The geophysical surveys conducted in the area include controlled source audio magneto-telluric method (CSAMT), distributed passive electromagnetic method (DPEM), micro-vibration method, DC sounding, magnetic survey, gravity survey. The purpose of these surveys is to locate the position of the faults and the depth and thickness of the geothermal reservoirs around the area (Xu, 2002; Chen et al., 2003). A geochemistry study in the area of the Olympic Green was carried out by Zheng (2002), considered the chemical composition of geothermal water and cold groundwater from both shallow and deep aquifers. These surveys and the two geothermal wells, plus other wells around the area allow for a better understanding to the occurrence and potential of geothermal around the Olympic Green.

### 3. GEOLOGICAL SETTING

Geologically, the area of Beijing is featured by a series of grabens and horsts bounded by faults, running from SW to NE in parallel. These faults spreading in the same direction with the primary stress of the current tectonics, are mostly conduits of underground water, and are closely related to geothermal (Fang and Zhu, 2002).

The Olympic Green is located near one of the faults mentioned above, H-G Fault (F1). This fault is a regional fault, reaching to about 35 km into the crust. There are also a few other faults (F2 and F3), going through the area. These faults are all rather important to the occurrence of geothermal in the area (Figure 2). The area of the Olympic Green is inside the Beijing Plains, which is located in a sediment basin, and the formations around the area of Olympic Green include:

- Quaternary (Q): unconsolidated sediments
- Tertiary (R): shale, mudstone and basalt
- Cretaceous (K): mudstone and conglomerate
- Jurassic (J): andesite, tuff and mudstone
- Carboniferous-Permian (C-P): sandstone and shale
- Ordovician-Cambrian (O-□): limestone
- Qingbaikou (Qn): shale, sandstone and marlstone

-Jixian (Jx):

Tieling Group (Jxt), dolomite

Hongshuizhuang Group (Jxh), shale

Wumishan Group (Jxw), dolomite

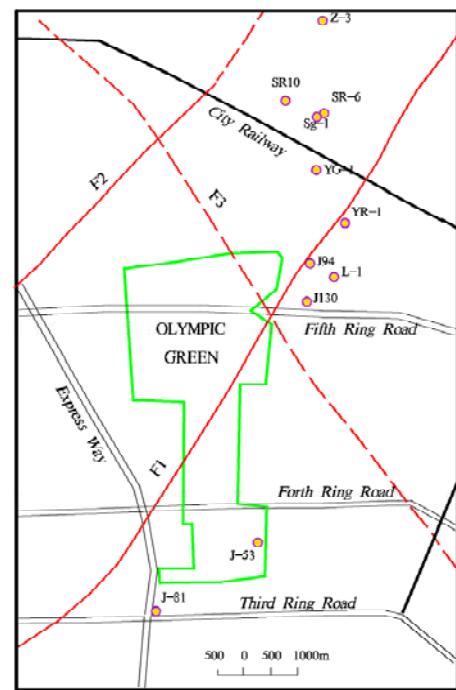


Figure 2: A sketch map of geological structure in the area of the Olympic Green

### 4. GEOTHERMAL OCCURENCE

According to the results of the geological exploration in the area of the Olympic Green in Beijing, a model of the geological structure is put forward (Figure 3), although there are still not enough geological exploration data, considering the complexity of the geological structure in the area. There are two geothermal reservoirs in the area, i.e. the limestone aquifer of Ordovician and Cambrian Systems in the northwest part of the area, the dolomite aquifer of the Wumishan Group in the southeast part of the area.

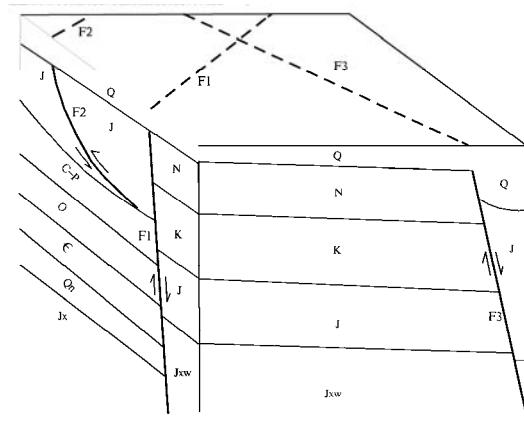


Figure 3: Geological structure model in the area of the Olympic Green

The buried depth of the geothermal reservoir in the northwest part of the Olympic Green (limestone) is from 2000 to 3000 m, deeper to the southwest. And the depth of the geothermal reservoir (dolomite) in the southeast part of the Olympic Green is about 3000 m. The water-bearing nature of the reservoirs is closely related to the karstification of the limestone and dolomite. Generally, the formations are more fractured and permeable near the faults.

The geothermal gradient of the caprock in the area is as low as  $1.4^{\circ}\text{C}/100\text{m}$  mostly, higher only in some area close to fault, such as Well SR-6, which is about 2700 m north of the Olympic Green (Bin et al., 2002). The reservoir temperature in the area is around  $70^{\circ}\text{C}$ .

The geothermal water in the area of Beijing is originally from infiltration of precipitation. Generally, the recharge area is in the mountains in the north and west of the Beijing Plains. The faults play a very important role in the transmission of water from the mountain area to the geothermal fields (Liu et al., 2000). The H-G Fault is a key element of the geothermal system, in both heat and water conduction, in the area of the Olympic Green.

## 5. GEOTHERMAL ASSESSMENT

A geothermal resources assessment was carried out in 2003 (Liu et al.), for the detailed planning of the geothermal project of the Olympic Green in Beijing. The result shows that the geothermal reserve in the area is rather big, but the allowable production, which is closely related to the water recharge of the geothermal system, is quite small.

It was estimated by volumetric method that the geothermal reserve in a  $49\text{km}^2$  area around the Olympic Green was  $7.34006 \times 10^{18}\text{J}$ , and the water storage in the geothermal reservoir is  $2.511 \times 10^8\text{m}^3$ .

An important thing is to estimate the allowable production from the reservoir in a sustainable basis. A simple way is analogous method that is to make use of the result from a similar geothermal reservoir to the reservoir under study. Liu et al. (2001) calculated that the annual allowable production for the Urban Geothermal Field in Beijing accounts for 3.13% of the total water reserve in the geothermal reservoir. If this is used in the area of the Olympic Green, the annual allowable production is  $78.59 \times 10^4\text{m}^3/\text{a}$ . This means that if the net water lose from the geothermal reservoir is not more than  $78.59 \times 10^4\text{m}^3/\text{a}$ , the reservoir pressure will not decline fast over a long period of time. Of course, this is only a simple estimation, considering that there is still not proper monitoring data under production status inside the Olympic Green.

## 6. GEOTHERMAL DEVELOPMENT PLAN

It is planned that geothermal be used for the space heating (supplemented by heat pump system) and bathing for the Sports Village that the floor area will be  $36 \times 10^4\text{m}^2$ . If the temperature of geothermal water is assumed as  $65^{\circ}\text{C}$ , the annual hot water need is  $134 \times 10^4\text{m}^3$ , of which  $78 \times 10^4\text{m}^3$  for space heating in about 150 days per year, and  $56 \times 10^4\text{m}^3$  for bathing.

It is clear that the allowable production of geothermal water for the area ( $78.59 \times 10^4\text{m}^3/\text{a}$ ) is smaller than the total amount of hot water need ( $134 \times 10^4\text{m}^3$ ). Therefore, it is essential to reinject the tail water from the heating system. It is planned that the temperature of the tail water is  $22^{\circ}\text{C}$ .

It is planned that 10 geothermal wells around 3000m deep will be drilled, consisted of two groups. Each group will be drilled in a small surface area, composed of 3 production wells and two reinjection wells. Most of them will be directional wells. The production capacity of each well is estimated as  $60\text{ m}^3/\text{h}$  ( $1440\text{m}^3/\text{d}$ ).

## 7. RECOMMENDATIONS

Considering that there is abundant heat in place in the geothermal reservoir, while the water recharge is very

limited, it is essential to reinject the used geothermal water from the space heating system, so as to support the reservoir pressure and use the geothermal in a sustainable manner. Of course, reinjection is a kind of complicated technique related to the management of the geothermal reservoir, and careful experiments including tracer tests have to be carried out, so as to avoid premature thermal breakthrough. Axelsson (2002) suggested that the spacing of reinjection and production wells be more than 1 km for the area of the Olympic Green. Considering the rather good connection between geothermal wells in the area, this should be kept in mind in the designing of the wells.

Considering the limited time left for the construction of the geothermal project for the Olympic Green (less than 4 years), a detailed plan should be put forward as soon as possible. Since the geological structure in the area is still not very clear and the geothermal potential is still not fully understand, the geothermal development should be in a step-wised manner. And geophysical explorations of different methods should be carried out in sitting the wells.

It is essential to carry out proper management of the geothermal reservoir for the sustainable use of the precious resources. This calls for careful reservoir engineering study from the beginning of the geothermal development, taking all the geothermal wells around the area into consideration. Especially, a proper monitoring program should be set up for the geothermal reservoir in the area of the Olympic Green.

## 8. CONCLUDING REMARKS

The City of Beijing will hold the 2008 Summer Olympic Games. The Olympic village will be build in the northern part of the city, where has been proved with geothermal potential. The geothermal reservoir consists of limestone or dolomite about 2000-3500 m underground. This geothermal can be used for the space heating and domestic hot water supply for the Olympic Green. It has been planned that 10 geothermal wells, including reinjection wells, be drilled for the project. It is suggested to use heat pumps that abstract energy from shallow groundwater for the peak load of the space heating, and also for the cooling of the Olympic facilities and the Sports village. The geothermal reserve in a  $49\text{km}^2$  area around the Olympic Green is calculated as  $7.34006 \times 10^{18}\text{J}$ , and the water storage in the geothermal reservoir is  $2.511 \times 10^8\text{m}^3$ . The annual allowable production from the area is estimated as  $78.59 \times 10^4\text{m}^3/\text{a}$ . It is essential to reinject the tail geothermal water from the heating system for the sustainable use of the geothermal energy in the Olympic Green, because that the water recharge of the geothermal system is rather limited. Owing to the complexity of the geological structure in the area, step-wised development is suggested

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