Proceedings Ninth Workshop Geothermal Reservoir Engineering
Stanford University, Stanford, California, December 1983
SGP-TR-74

GEOTHERMAL ENERGY DEVELOPMENT IN CHINA

Xin Kuide Yang Qilong

Bureau of Hydrogeology and Engineering Geology,
Ministry of Geology and Mineral Resources,
Beijing, China

INTRODUCTION

China's geothermal resources are mainly of low - medium temperature. More than 30 geothermal areas have been or are being explorated. According to the geology, economy and technology of geothermal energy development main efforts are concentrated in some places with better conditions and can be exploited effectively in the near future, such as low temperature geothermal fields in Beijing and Tianjin, Yangbajain and Dengchong high temperature geothermal fields respectively in Tibet and Yunnan province.

In Beijing and Tianjin the geothermal water is used for space heating, bathing, medical treatment, greenhouse, raising tropical fish, industry and so on. In Beijing now more than 200 thousand sq. m. of indoor floor is being heated with geothermal water and about 50 thousand persons per day use it to take bath. In future, the low temperature geothermal water utilization in these big cities would flourish.

In 1970 the first experimental geothermal power plant using the flashing method was built in Dengwu, Guangdong province. In 1977 one MW experimental wet steam power plant was built in Yangbajain, Tibet, and a 6 MW power plant in 1981 (Photo 1). And another 3 MW generator is expected to complete in 1985.

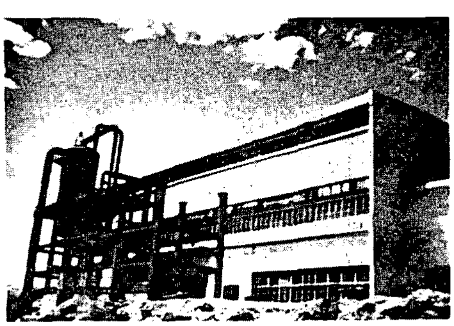


Photo 1: The 6 MW Experimental Power Plant at Yangbajain

This paper is intended to summarize some important results of exploration, particuraly in the geothermal reservoir engineering.

GEOLOGICAL CHARACTERISTICS OF GEOTHERMAL RESOURCES (Fig. 1)

The distribution of geothermal fields in China is closely related to the geotectonic feature, the magma and earthquake activities. The high temperature geothermal fields (> 150°C) are mainly situated in southern Tibet, western Yunnan and Taiwan. The west-southern China is effected by Indian Plate. The Himalayan tectonic zone is located in the collision zone between Eurasian and Indian Plates and Taiwan - between Eurasian and Pacific Plates - is at the same time subjected to the northwestward compression of the Philippine Plate (Luo Huanyan, 1979). In all these areas the plate movement, magma and earthquake activities are quite strong and have no doubt provided the conditions for intense hydrothermal activity.

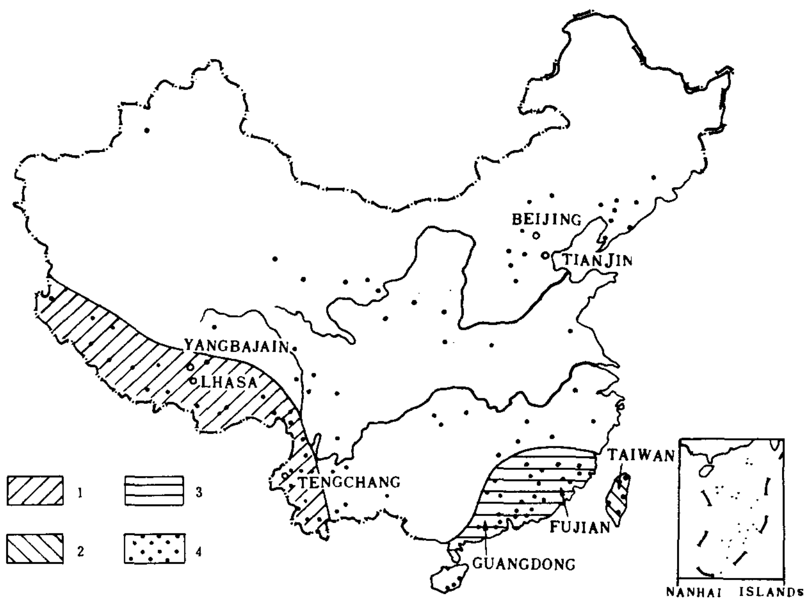
The medium- and low- temperature geothermal fields (< 150°C) are mainly distributed in the coastal region in East China, including Fujian, Guangdong and Hunan provinces, in which the Yanshanin movement since the Mesozoic gave a great influences, The geothermal fluid is contained in the granite with strong silicified alteration.

The low temperature geothermal fields (< 100°C) are distributed almost all over the country, notably the Songliao Plain, North China Plain, Liaodong Peninsula and other areas. The geothermal water is related to faults, magma activities and basement uplift.

BEIJING AND TAINJIN LOW TEMPERATURE GEOTHERMAL FIELDS

1. Regional geology and geothermal feature

Beijing and Tainjin geothermal fields are situated in North China Plain and face the Bohai Gulf on the east. There are a series of deep faults with NE - SW directions between grabens and horsts (Fig. 2). The geothermal fields coincide with the local uplifts within the grabens, but the place with the maximum geothermal gradient in cap



(1) Southern Xizang (Tibet) - Western Yunnan High Temperature Geothermal Zone (2) Taiwan High Temperature Geothermal Zone (3) Southeast Coast Medium Temperature Geothermal Zone (4) Main Geothermal Fields

Fig. 1: The distribution of geothermal resources in China

rock is not at the top of the local uplift, but at the steep fault zone between the uplift and centre of graben.

The geotectonic and geothermal activities in the east is stronger than in the west - the main feature of geotectonic and geothermal condition in North ChinaPlain. For instance, the temperature of basement aquifer in Tainjin is 58 - 96 °C and in Beijing - 40 - 79 °C.

According to the seismic record and observation data of artificial earthquake, the crust thickness of North China Plain is approximately 30 - 45 km, with the trend generally being thin in the east and relatively thick in the west. The neighbourhood of Tainjin, having a Conrad and a Moho respectively of about 17 and 32 - 33 km, is a region which is relatively thinner in the North China Plain (Qin Jiafa and Gu Datong 1981).

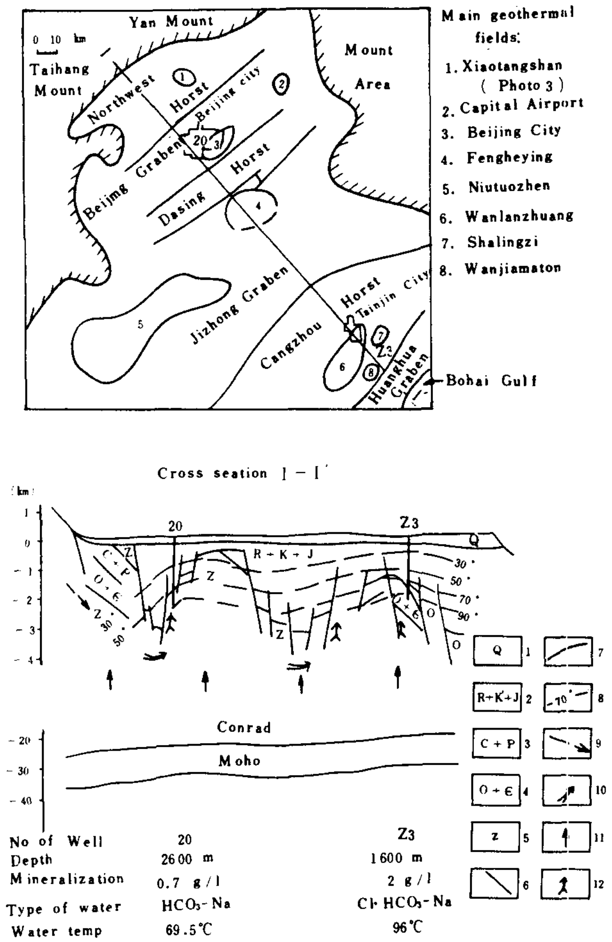
From Isotope data the geothermal fields are recharged by precipitation in the mountain areas, circulated through the basement aquifers and faults. Measured in a bore located in the NW side of Beijing Graben (near the mountain) at depth of 1 km, the temperature only reached 19 °C. It shows the precipitation recharge sweeps the heat from this part of sediment and makes it cooler. The deep water circulation can also be determined by the analyses of the chemical content of geothermal fluids. In Beijing area the mineralization of geothermal water from basement aquifers is low (0.4 - 0.7 g/l), the type of it - HCO_3 - Na. But in Tainjin area the mineralization is high (1.58 - 4.4 g/l), the type - Cl·HCO_3 - Na. It appeared that groundwater runoff and recharge in Tainjin is even smaller compared with Beijing.

2. Reservoir characteristics

The dolomite or limestone basement of Paleozoic and Proterezoic era in North China Plain is characterised by many fissures, fractures and karst. For example,in wells 5 and 7 in Beijing city, the karst caves have been found at depth of 938.6 - 939.3 m and 730 - 735 m respectively. And the fissure with width of 1 cm at depth of 721.9 m in well 32 have been seen by the downhole TV (Photo 2). And in Tianjin while drilling wells 2 and 4 in the limestones, the bits were dropped several times.

Fig. 3 shows the distribution of two aquifers (Tieling and Wumishan groups, Z_{jt} and Z_{jw}), their top depth, the water temperature at wellhead and specific capacities for each well. The basement structure is a monoclinal stratum with dip angle about 10° towards south. It is clear that the dolomite of Tieling group (about 300 m in thickness) distributes only in the south part of the geothermal field with top depth of 587 m in well3 in the east to 1200 m in well R1 in the west, and the water temperature rises with increase of top depth from 39.2 °C in well 3 to 53 °C in well R1. The dolomite of the Wumishan group distributes in all area. The thickness of it may reach several km and is the main reservoir in Beijing. The shollowest top of it (517 m in well 21) is in the central part of the field and it increases rapidly towards the NW direction (in well 20 2456 m). The water temperature rises also with increase of the top depth of the dolomite reaching 69 °C in well 20 at wellhead and 79.6 °C at the bottom of well 38 (2600 m). The well production varies from 30 to 96 m^3/hr and specific capacities - from 0.2 to 3.4 kg/s.m.

Between these two dolomite aquifers and above Tieling dolomite there are the shales of Hongshaizhuang (about 300 m in thickness) and Xiamaling (about 90 m) groups (Z_{jx} and Z_{jh}) respectively. And the basement is overlaid with formations of Mesozoic and Cenozoic era. Since the shales have low resistivity (< 150 om.m.) and high radiativity (3000 - 15000 *n/m*), the



(1) Quaternary system (2) Tertiary and Mesozoic system (3) Permian and Carboniferous system (4) Ordovician and Cambriam system (5) Proterozoic system (6) Fault (7) Geological line (8) Isotherm line (°C) (9) Cold recharge water (10) Deep circular hot water (11) Terrestrial heat flow (12) Upflow along faults

Fig. 2: Schematic of hydrogeology features of North China Plain

Photo 2: The fissure in dolomite (bore 32, depth of 721.9 m), Scale 1:1.1 (TV sereen)
Photo 3 (left): The artesian well 7 (depth of 500 m and temp. of 62°) in Xiaotangshan, Beijing

border of them can be determined clearly by logging.

To determine the parameters of aquifers 3 sets of interference pumping tests have been done in Beijing. The data from an interference well test are shown in Table 1 The water table was recorded in well T2 while well T1 was flowing at a rate of 95.5 m^3/hr. A log-log graph of the drawdown pressures in well T2 versus time was analyzed by type curve matching with the line source solution, as shown in Fig. 4. From the pressure match, the permeability (k) is estimated at 3.06 Darcy (the thickness is 100 m). The time match gives a porosity of 1.6 %, which results in an estimate of 4.5×10^{-5}(kg/cm^2)$^{-1}$for the compressibility.

Table 1
Pressure interference data between wells T1 and T2 (1983)

T (day)	S(m)/P(psig)	T(day)	S(m)/P(psig)
0	0 / 0	0.42	0.24/0.341
0.04	0 / 0	0.50	0.28/0.398
0.08	0.02/0.028	0.58	0.37/0.526
0.125	0.03/0.043	0.67	0.40/0.569
0.17	0.06/0.085	0.75	0.41/0.583
0.21	0.09/0.128	0.92	0.43/0.612
0.25	0.11/0.156	1.08	0.49/0.697
0.29	0.14/0.199	1.25	0.51/0.725
0.33	0.17/0.242	1.42	0.55/0.782
0.38	0.20/0.284	1.67	0.60/0.853

Distance between wells = 230 m
Water viscosity = 0.6 cp

Other methods are also used to determine the porosity of aquifers. For instance, 1.78 - 3.6 % has been calculated by soundwave logging in 6 wells at depth of 705 - 1575 m. In addition, the porosity of 7 dolomite cores collected from a well were measured in lab to be 0.4 - 6 % (av. 2.77%). And Prof. Bodvarsson estimated the porosity to be 3 %, assuming the resistivity of dolomite aquifer and local water 400 and 12 om.m. respectively.

The fact that the results of the interference test agree with other data suggests that the dolomite or limestone aquifers in Beijing, or even in North China Plain, has high permeability (k about 3 Darcy) and low porosity (about 2.5 %), indicating a fractured and/or solution opening situation. Finally it should be noted that besides basement aquifer there are some aquifers in Tertiary and Jurassic sedimentary or volcanic rocks, but their temperature is low. Particularly in Tianjin, the sediment aquifer now is the main geothermal production aquifer.

3. The long-term observed water level and geothermal resource assessment

The drawdown on wells during the exploitation depends on the well production. The

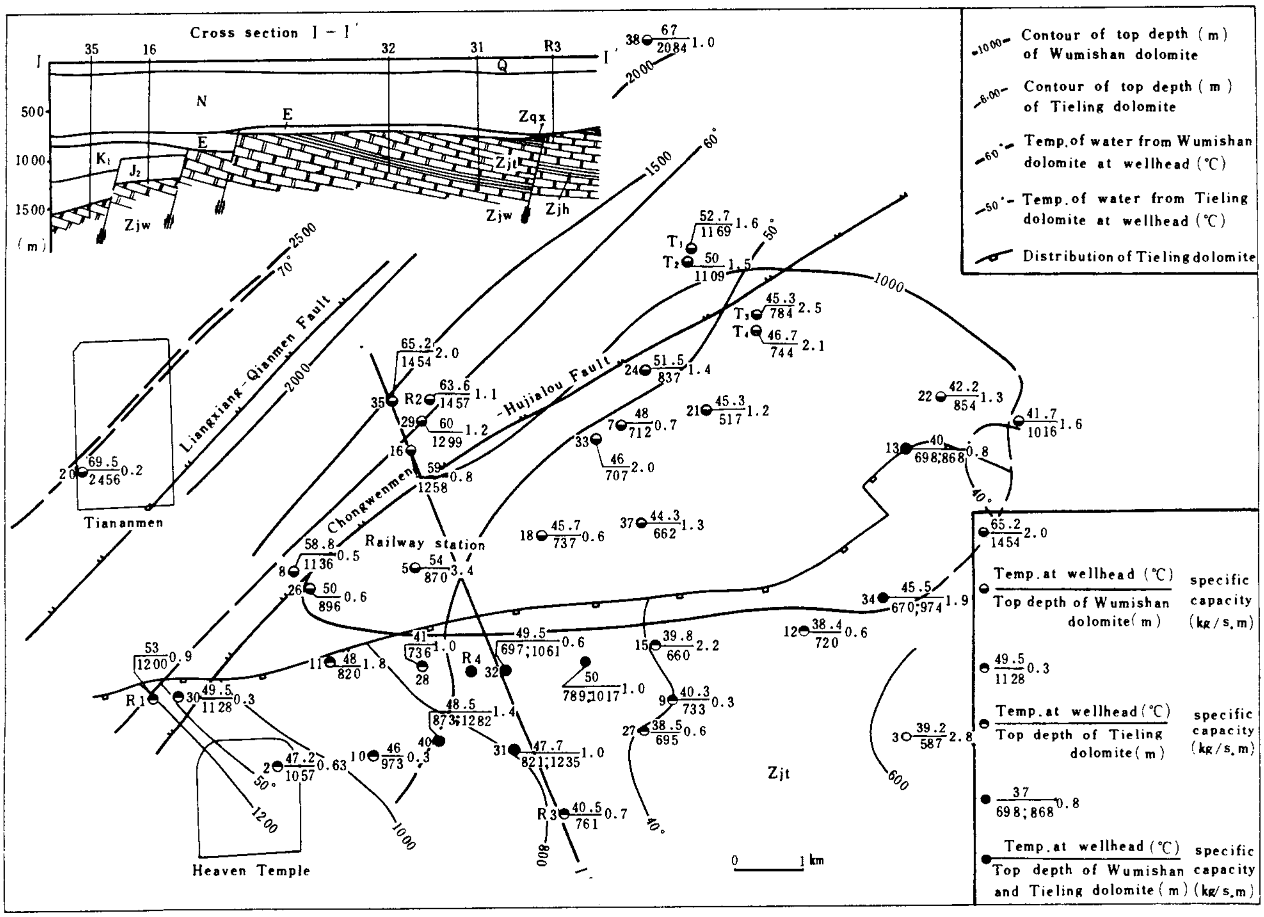


Fig. 3: Distribution of aguifers, their top depth and water temperature by Daofu, Yang Qilong and Bai Tieshan

drawdown curves of 4 typical wells in the city of Beijing, their production increased from $4.9\times10^5 m^3$ in 1971 to $3.3\times10^6 m^3$ in 1981, are shown in Fig 5. And in the city of Tianjin, 259 wells have been drilled since 1970. The water level has dropped to 40 - 60 m below surface (Fig. 6). The basement limestone water is still artesian, because the production rate is limited.

3.1. Estimation of maximum well production

The exploitation period from 1971 to 1981 was divided into four stages (Fig. 5). Based on the functional relationship between specific production rate in whole area and drawdown of water level (from original static water level) the maximum production was estimated. The specific yield (q) and depth of water table[6] for each stage were $3.2\cdot10^5$, 6.9×10^5, 1.3×10^6, $1.9\times10^6 m^3$ and 11.3, 15.1, 18.9, 22.9 m respectively. After distinguishing the relationship between q and s in various way, the power functional equation $Lg\ q = -1.05 + 2.44 Lg s$ has been got (Fig. 6). If the drowdown rate is 1.5 m/yr, the water table would be increased from 22.9 m at the end of 1981 to 35 m in 1990 (dynamic table may reach 60 - 80 m), the production being $7.7\times10^6 m^3/yr$.

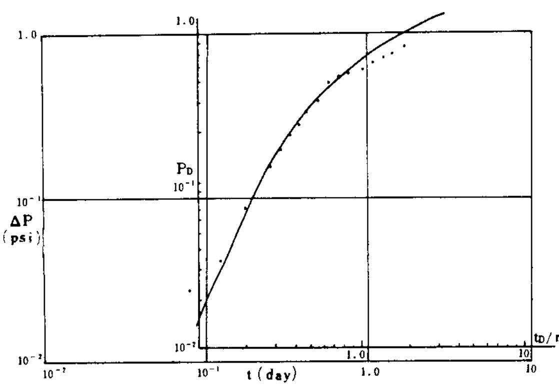


Fig. 4: Type-curve matching of the pressure interference data between wells T_1 and T_2

Prof. Bodvarsson wrote in his consult report:" Based on the data from observation well 3, the equilibrium dynamic drawdown at constant total pumping rate of 6500 m^3/d is about 10 m, that is 18 m below ground surface. Without difficulty, the drawdown could be increased by a factor 6 to 10. It is prudent to limit the estimate to a factor of 5 such that without fluid reinjection the yearly average total pumping rate could be increased to $3\times10\ m^4/d$" ($1.1\times10^7 m^3/yr.$).

3.2. Estimation of total energy reserves

Assuming that the thickness of aquifer is 300 m, temperature at wellhead and for waste water - 55 and 35°C respectively, volumetric specific heat of rock/water - 0.5 cal/cm·°C, recovery factor - 0.2, the energy reserves of 3×10^{13} kcal was estimated for 50 km^2, where the exploitation depth is less than 1.5 km. And the heat energy for an other 50 km^2 (depth of 1500 - 2500 m) is 9×10^{13} kcal (500 m in thickness of aquifer and 70°C of temperature at wellhead are adopted). So the total heat energy inthe geothermal area of 100 km^2 in the city of Beijing could reach 1.2×10^{14} kcal(equals to the energy released by burning 1.7×10^7 tons of coal). Assuming active reservoir life to be 25 yr., heat energy of 4.8×10^{12} kcal/yr can be extracted. If 2/3 of the hot water is used for space heating, the floor area would reach 2.6×10^7 sq.m. (Assuming the heating period is 3 months and heat standard - 40 kcal/sq.m·hr).

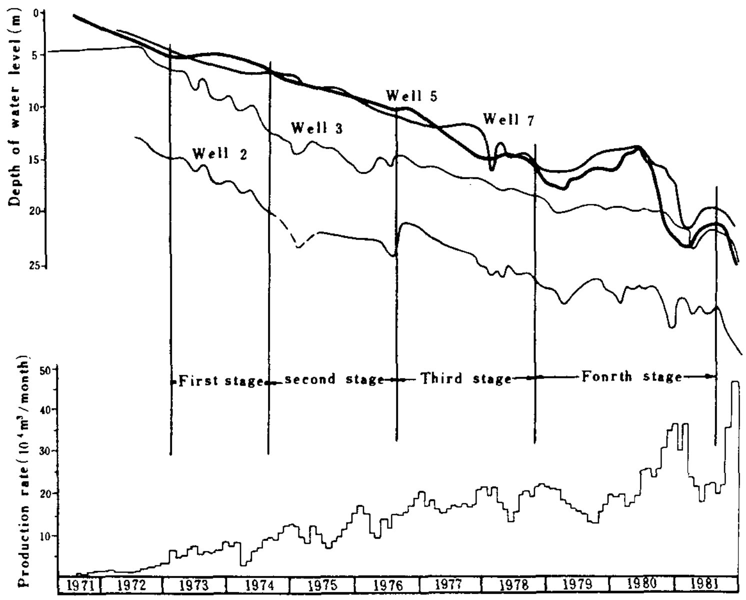


Fig. 5: Drawdown curves of water level in 4 typical wells (1971-1981) by Liu Shufang

In the city of Tianjin the geothermal field (about 100 km^2) has the total energy of 1.4 10^{14} kcal, if the thickness and temperature of basement aquifer assumed to be 400 m and 70°C, and other parameters are the same as mentioned above.

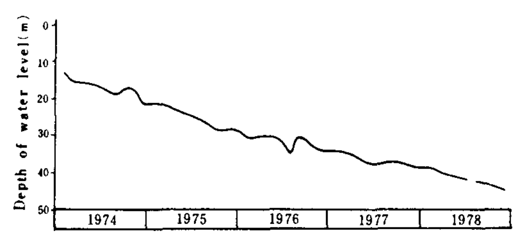


Fig. 6: Variations of underground water level of one geothermal well in Tianjin

It is clear that a sufficient degree of heat sweeping from aquifer can be obtained only by successful reinjection. In Beijing city well R4 (depth of 1274 m) has been used for reinjection of waste water (at the end of heating system) for two years. The production well 32 (depth of 1151 m) at a distance of 200 m from well R4, had a rate of 36 m^3/hr with temperature of 49°C at wellhead, providing a heating floor area of 11,000 sq.m. After the waste water with temp. of 38°C was reinjected into well R4 the water table rised only by 2.8 m. After stopping reinjection of 1.2×10^4 m into R4 for 8 months, the water temperature in the dolomite recovered to 49.5°C (the original temp. was 52°C). Since the heating period in North China lasts only 4 months, the water temperature can recover in an other 8 months. Up to now, no temp. drop in surrounding wells has been observed yet.

HIGH TEMPERATURE GEOTHERMAL FIELD IN YANGBAJAIN, TIBET (Fig. 8)

1. Regional and field geology feature

Just an hour's drive northwest of Lhasa, the capital of Tibet, is the Yangbajain Geothermal Field, located in the elongate basin about 5 km wide and 100 km long at the foot of Mt. Nyaigentanglha. Here there are many geothermal fields and new tectonic movement and earthquake are very active. Folds and faults can be seen in Quaternary layers. The main rocks in Yangbajain and the surrounding area are gneiss, slate, tuff and granite.

In the southern part of the field there are many hot or boiling springs (Photo 4), boiling mud pools, silica sinters, hot water lake and so on. The northern part of the field is an alteration area (about 4 km^2). Here, due to intense thermo-chemical action, the colorful rock has been reduced to white, powdery kaolin. In some places, just a few centimeters beneath the

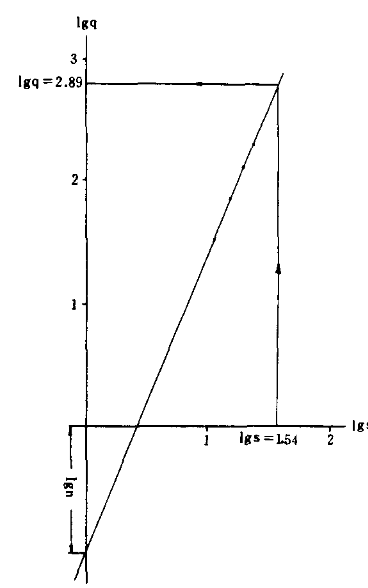


Fig. 7: The line shows the equation of lgq=f (lgs)

ground, the temperature exceeds the local boiling point of 86°C (4300 m above sea level). And sulphur is also being mined. Based on data from wells, the vertical zonation of sulphur and sulphide has been found. At depth of 20 m the Quaternary layers content pyrite (FeS_2). And semi-transparent sulphur crystals (S) appeared at crack from surface to 10 m. In more oxidation condition, sulphate occurred and the layers became kaolinized and alunitized.

2. Temperature and pressure of geothermal fluid (Fig. 9 and 10)

The maximum temperature of geothermal fluid changes from 172°C in the northern part of the field to 160°C in the southern part. On the other two sides, the temperature reduces to 112 - 142°C. Well 19 shows a trend toward a maximum temp. of 152°C at depth of 140 m, followed by a geothermal gradient of 3.1°C/100 m that was recorded from 810 m down to 1000 m. The geothermal gradient of well 7 is 4°C/100 m. So far only these two wells, 19 (1000 m) and 7 (603 m), are deep enough to determine the geothermal gradient at depth, showing temp. trends that would intersect at 178.4 °C at depth of 2600 m (the method provided by Michel J. Economides, etc. 1982). It should be noted that this source temperature is lower than that of 207 - 222°C estimated by geothermometers, so the real source depth might be deeper.

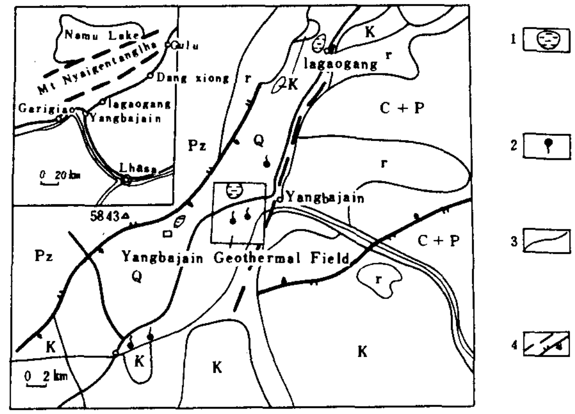
The begining point of increased geothermal gradient changes from 810 m(122.9°C) in well 19 to 460 m (92°C) in well 7. After expanding the gradient to surface the temp. of 97.7°C and 74.4°C (much higher than local average atmospheric temp. of 11°C) have been got.

Depending on the drilling stabilized mud density, Mr. Wang Zongying calculated the downhole water pressure. The altitude of the zero pressure in wells decreases from NW to SE, having the same tendency as the temperature and relief changes (Fig. 9).

3. The geothermal system model

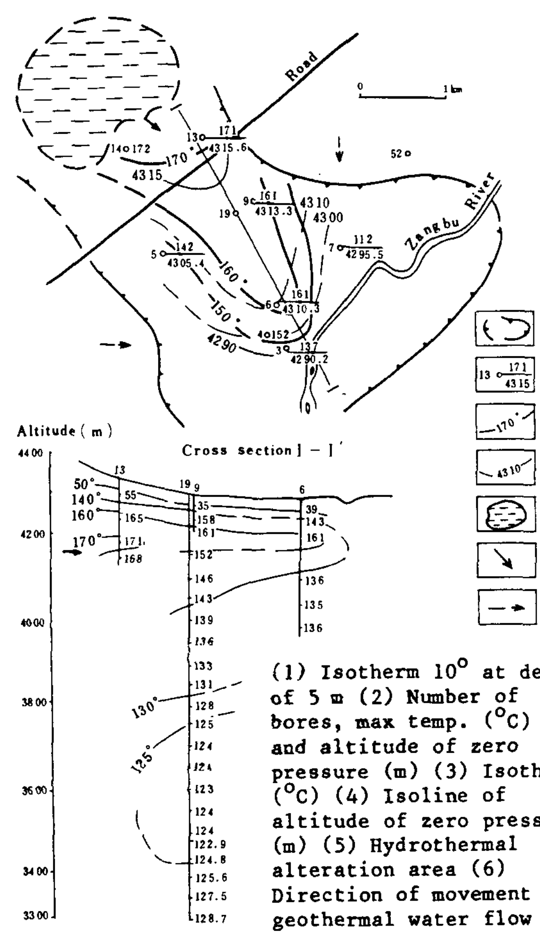
The silicified sandstone distribution and chemical content of geothermal fluid are also important to prove the lateral water flow in Yangbajain Geothermal Field.

Fig. 11 shows the relation of temp. of fluid with silicified sandstone. The highest temp. are recorded all in the silicified sandstones, which have high resistivity. The silicified sandstone appears in a form of "tongue", that is, the top of it varies from a depth 150 m in north to a depth of 70 m in south, and in thickness from 250 to 100 m. As there are a lot of fractures in it, the permeability is high. For instance, well 9 has the best parameters: depth 89.3 m, 169 tons of water and 21 tons of steam per hour at a wellhead



(Q) Quaternary sand and till; (K) Cretaceous tuff, C + P - Carboniferus and Permian slate; (Pz) Pareozoic gneiss, (r) Granite; (1) Hydorthermal alteration area; (2) Hot and boiling springs; (3) Geological line; (4) Fault

Fig. 8: Geology may Yangbajain and surrounding area



(1) Isotherm 10° at depth of 5 m (2) Number of bores, max temp. (°C) and altitude of zero pressure (m) (3) Isotherm (°C) (4) Isoline of altitude of zero pressure (m) (5) Hydrothermal alteration area (6) Direction of movement of geothermal water flow (7) Direction of movement of cold water

Fig. 9: Temperature and pressure distribution in Yangbajain

temp. of 148°C and pressure of 4.7 atm. The estimated electricity potential is 1978 kw (Photo 5).

Fig. 12 shows the mineralization and ion content of fluid in wells are proportional. They decrease from NW To SE and from the "tongue" to surrounding area. The fluid collected from well 13 contains mineralization (2.2 g/l), Cl (651 mg/l) and HBO_2(298 mg/l), the highest among all existing wells. This kind of water mixes cold water with low mineralization and high HCO_3 from outside the field and Cl - HCO_3 mixed water is formed.

Accordingly, it is presumed that the present activity of the field is the post-intrusive action magma. Cold recharge water(1) passes a nearby heating volume beneath the sulphur deposit or even farther and mixes with juvenile water from cooling magma, rising in temp.,decreasing in density, and forming a deep thermal fluid(2), which rises along the fault. Due to pressure reduction and changes in the oxide-reductive conditions, sulphur steam(3),mercury,etc. are separated and produce hydrothermal alteration and sulphur deposit. Then as it is pushed by cold water at the foot of Mt. Nyaingentanglha(4), the deep thermal fluid turns to the horizontal movement to be mixed-thermal fluid(5), Fig. 13.

4. Reservoir parameters and resource assessment (Fig. 14)

Thirteen geothermal wells have been drilled here up to 1980. They have the parameters: depth 68 - 1000 m, total flowrate 82 - 191 tons/hr at a wellhead temperature of 120 - 148°C and pressure of 2.3 - 4.7 atm. The total estimated electricity potential is 15.3 MW.

The energy reserves are estimated to be 4.5×10^{15}kcal for the Quaternary aquifer, as the geothermal area is 10 km^2(the maximum temp. in wells is higher than 150°C). This area consists of 6 km^2 in the north of the road(the thickness of 300 m and temp. of 170°C) and 4 km^2 in the south (150 m and 160 °C). The waste water temp. is 90°C, the specific volume of rock/water - 0.6 cal/cm^3·°C the heat recovery - 0.2. If the pipe and power plant efficiency is 0.1, the electricity potential - 65.4 MW. If the exploitation period covers 25 years, the electric potential of 26 MW is estimated.

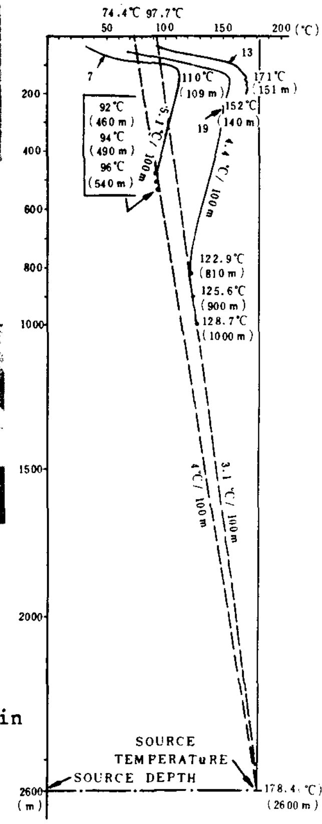
The fact,that the Yangbajain Geothermal Field has the lateral water flow,can not be negleted in its resource assessment. The following equations were used to determine reservoir permeability(k) in well 13.

$$K = \frac{QLgR/r}{2.73MS} \qquad S = 2.32\times10^{5}\,\frac{QV_w\mu^{0.15}}{t^{3}\times10^{9}\,d^{0.85}}$$

Put Q = 141 m^3/hr, R = 400 m, r = 0.2, M = 58 m, μ= 0.09 cp, t = 3 mm(width of fissure determined from core) and V_w= 1.125

Photo 4: Morning in Yangbajain

Fig. 10 (right): The shallow reservoir and source temp. at Yangbajain Geothermal Field



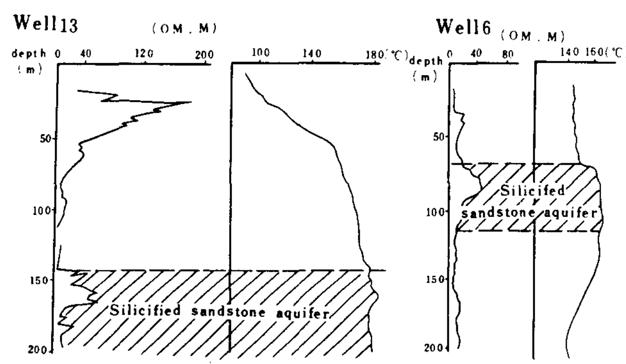


Fig. 11: Relation of temp. and resistivity with silicified sandstone

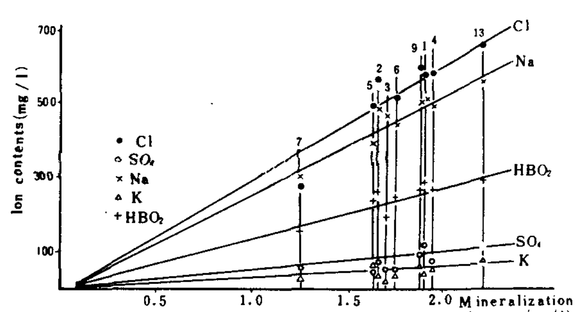


Fig. 12: Relation between mineralization and ion contents of geothermal fluids sampled from bores in Yangbajain

cm³/g into the equations, we got S = 5.1 m and K = 14.3 m/day for well 13. Adopting the width of the cross section I - I' of 2 km, the thickness of aquifer 300 m, water level gradient of 1.5 % (calculated from isoline of altitude of zero pressure) - the cross section water flow of 5363 m^3/hr has been obtained. In Yangbajain a water flowrate of 100 m^3/hr can produce 1 MW, so 54 MW might be produced by using above mentioned flowrate. Finally, the total electricity potential of the Quaternary aquifer in Yangbajain is estimated to be 80 MW.

SUMMARY

Geothermal energy is one of the important new energy resources in China. In Beijing, Tainjin, Tibet, Yunnan, Fujian, Guangdong and many other places it is under exploration and utilization. The preliminary resource assessment in this paper shows the promising prospects of production of geothermal energy in Beijing, Tainjin and Yangbajain.

In North China the dolomite or limestone of Paleozoic and Proterezoic era has higher temp. and good permeability. Important thing is to find and explorate more new geothermal fields in local uplift within grabens. In Yangbajain the silicified sandstone or conglomerate controls the Quaternary aquifer. The most improtant task is to find the high temperature geothermal fluid in the basement.

ACKNOWLEDGEMENTS

Thanks are given to the Beijing Hydrogeology Company, the Geothermal Geology Team in Tibet, and Mr. Zhang Hongren, Mrs. Shen Minzi, Mr. Bai Tieshan and Mrs. Gong Meizhen for their invaluable help in making this manuscript possible.

REFERENCES

Bodvarsson, G.S. (1982) Technical Evaluation of Geothermal Resources and their Development in Beijing Area of the People's Republic of China, Report on a Misson as a Consult in Reservoir Engineering.

Gin Jiafa and Gu Datong, (1981) Prospecting and Utilization of the geothermal Resource of Tainjin, Paper on the Sino/US Geothermal Resources Conference.

Michel J. Economides, Christine A. Ehlig Economides, Jay F, Kunze, Ben Lofgren (1982) A Fieldwide Reservoir Engineering Analysis of the Pilgrim Springs, Alaska, Geothermal Reservoir, Proceedings, Eighth Workshop on Geothermal Reservoir Engineering, pp. 25-30

Xin Kuide and Zhang Xigen, (1982) Geothermal Resources in China, GEOTHERMICS, V. 11, No. 4, pp. 281-187.

Yang Qilong. (1982) Geotemperature Measurement in Geothermal Exploration, Proceedings Pacific Geothermal Conference 1982 and 4th New Zealand Geothermal Workshop, Part 2, pp. 485-489.

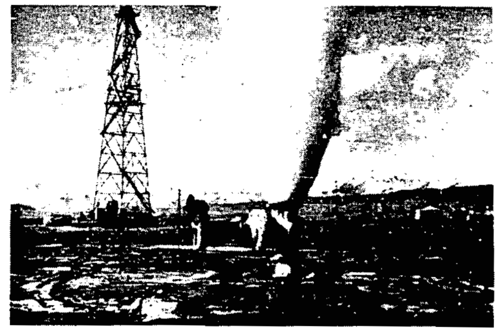
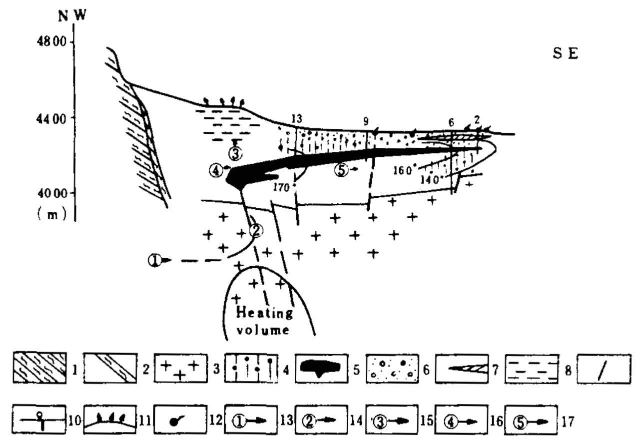


Photo 5: The well 9 spouts



(1) Gneiss of Paleozoic era (2) Breccia
(3) Granite (4) Till of Quaternary
(5) Silicified grit controlled aquifer
(6) Grit (7) Clay (8) Alteration area
(9) Fault (10) Wells (11) Steam ground
(12) Hot or boiling springs (13) Cold recharge water (14) Deep thermal water flow (15) Sulfur steam (16) Cold water at the foot of Mt. Nyaingentanglha (17) Mixed geothermal water flow

Fig. 13: Geothermal system model of Yangbajain Geothermal Field

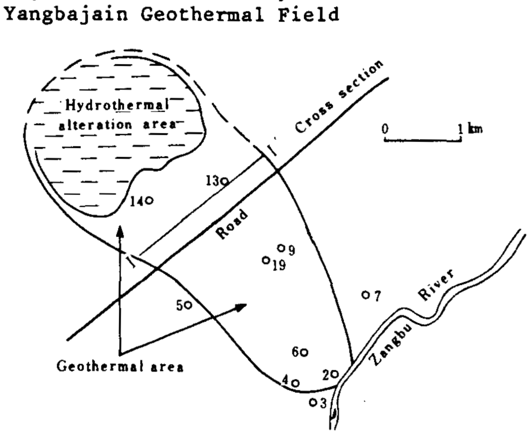


Fig 14: Map shows the geothermal area and cross section for reservoir assessment