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ASSESSMENT OF THE BEIJING GEOTHERMAL PROSPECT (P R CHINA)

M P Hochstein[1], R McKibbin[1], Yang Yutang[2]

[1]Geothermal Institute, University of Auckland
[2]Beijing Bureau of Geology, Beijing

ABSTRACT

Warm water (40 to 70°C) is produced from two deep dolomite aquifers (500-2500m depth) beneath the city of Beijing; the aquifers occur near the top of the Sinian basement which forms a 3.5 km deep and about *50* km wide depression (Beijing Graben). The aquifers have been explored by *45* deep wells covering an area of about 100 km^2; one aquifer is probably coherent throughout the whole prospect. The transmissivity of the aquifers is high (about 150 to 300 darcymeters).

About 4 x 10^6 m^3 of water is presently abstracted per year. Since no re-injection takes place, there is a continuous pressure drop in the aquifers (total drop up to 2 to 3 bars over the last 10 yrs). The warm water is being used in a few industrial and heating pilot schemes.

Analysis of simple reservoir models has shown that the energy potential of the resource is limited (about 2.5 to 10 $MW(thermal)/km^2$ for a 25 yr period) but pressure drops can be stablised by reinjection; natural recharge is also limited.

If geothermal fluids are to be used in future heating schemes, the annual heat load curve and economic considerations indicate that boosting by existing boilers has to be considered. Overall heating costs are comparable with present-day heating costs using coal. The reservoir could also be used for injection of waste heat during the summer, thus increasing its production potential for space heating in the winter.

INTRODUCTION

Slightly anomalous temperatures were detected as early as 1970 at the bottom of shallow (< 100m) groundwater wells in the SE sector of the City of Beijing (Yang Qilong, 1982). Deeper exploratory wells encountered aquifers with temperatures between *40* and 50°C near the top of the Sinian (dolomite) basement at depths of 500 to 800m. Drilling was shifted to the central and NE part of the city where the Sinian basement was encountered at greater depths, although the bottom temperature did not increase significantly below about 1400m depth (average temperature about 70°C). Until 1983, a total of 45 deep exploratory wells had been drilled by the Beijing Bureau of Geology; the well sites cover an area of about 100 km^2.

Abstraction of warm water started in 1973 and the total annual production has increased ever since, reaching about 4 x $10^6 m^3$ in 1983. The water is being used in a few heating and industrial schemes. As a result of this production, the piezometric level has continuously decreased in all wells pointing to a total pressure drop of about 2 to 3 bars in the main aquifer over a period of 10 yrs throughout the whole prospect. Although the experience gained from the pilot schemes encouraged further development of the resource, there were uncertainties as to the overall structure of the reservoir, its potential, and the feasibility of large scale developments.

In 1980 UNDP offered assistance to the project. A review was held in 1983 to find out whether the accumulated data were sufficient for aa overall assessment of the prospect. The findings of the review have been compiled (Hochstein, 1983) and are presented here in a condensed form because exploration and assessment of large low-temperature prospects have not often been discussed in the literature.

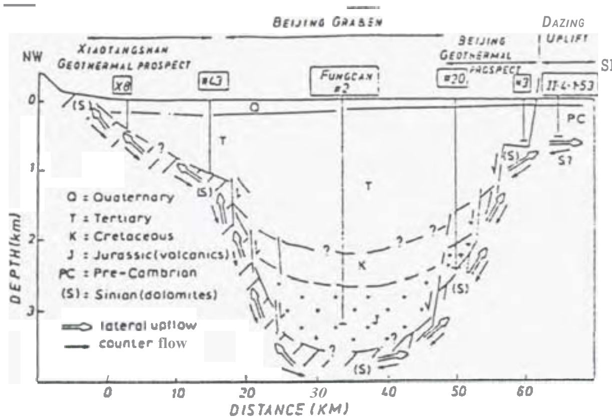


Fig 1: Schematic section of Beijing Graben showing simplified geological structure and inferred circulation of fluids in Sinian basement.

Geological and hydrological setting of the Beijing geothermal prospect

The prospect lies in the SE part of the Beijing Graben. A schematic geological section of the graben is shown in Fig 1. Sinian dolomites outcrop in the NW part of the section where natural warm springs occured until recently at Xiaotangshan. The Sinian basement does not come to the surface *SE* of Beijing where it is concealed by a rather impermeable Precambrian sequence which outcrops in the Daxing Horst structure (see Fig 1). The Sinian basement descends into a set of large basins further to the south. The Beijing Graben is infilled by an up to 3.5 km thick sequence of almost impermeable Tertiary rocks, underlain by Cretaceous sediments and Jurassic volcanics (see Fig 1). The Tertiary sequence effectively seals all deeper formations; wells which bottomed in the Tertiary remained dry even after long standing time, i.e. no vertical infiltration occurs within the graben. The only permeable structures are the thin Quaternary sediments at the surface and the deep aquifers near the top of the Sinian dolomites.

From stable temperature measurements in deer, drill-holes and from thermal conductivity measurements obtained from cores, the heat flux at the contact of the Sinian basement can be estimated. Here a significant change in the temperature gradient occurs caused by the change of the thermal conductivity of the Sinian limestones (mean about 4 W/m°C) to that of the younger Cretaceous and Tertiary sediments (mean about 2 W/m°C). These data indicate that the actual heat flow over both flanks of the Beijing Graben is significantly higher ($\geq$8 mW/m^2) than the regional mean heat flux (6.5 ± 0.5 mW/m^2) observed over North China basins; the heat flov in the centre of the Beijing Graben, however, appears to be lower than the regional mean heatflow (see Fig 2). This distribution of heatflow can be explained by a model where heat in the central part of the graben is transferred by convection in a thin layer associated with the aquifers near the top of the Sinian basement and where thermal fluids move slowly upwards along an inclined path from the floor of the graben to the higher standing flanks. In this case, the deficiency in heat over the graben should balance the excess heat over the flanks; Fig 2 indicates that such balance has probably occurred.

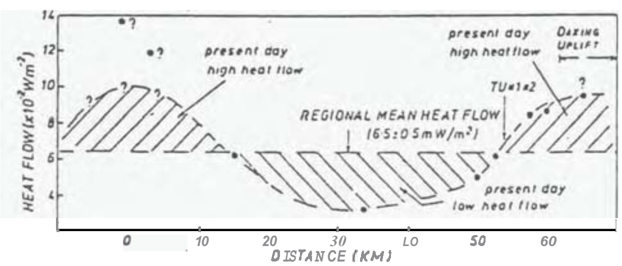


Fig 2: Inferred heatflow on top of Sinian basement across the Beijing Graben (section is the same as that shown in Fig 1).

Since natural discharge by warm springs over the flanks is almost nil, conservation of mass requires a small counter flow as indicated in Fig 1. The readjustment of the temperatures within the graben was dominantly by conduction, i.e. the temperatures in the deepest part of the graben decreased continously until the present equilibrium was established, whereas temperatures over the flanks Increased somewhat as a result of the sheet flow confined to the aquifers near the top of the Sinian basement. Using a simple diffusion model (Hochstein, et al., 1983) it was estimated that this process took at least 0.5 x 10^6 yr to produce the present-day temperature field. If one uses this model, one can also predict the average temperatures at the top of the Sinian basement beneath Beijing (see Fig 3), which shows that temperatures do not increase significantly where the contact lies at depths greater than about 1500m.

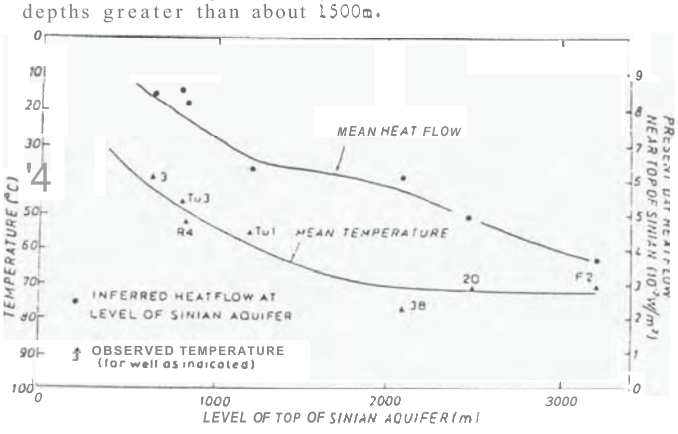


Fig 3: Mean heatflow and temperature near top of Sinian basement beneath the Beijing prospect (central area only).

Additional information about the overall hydrological structure of the Beijing prospect is provided by geochemistry and isotope data. Published δD and δ^{18}O measurements indicate that the fluids in the Sinian basement originate from meteoric waters which infiltrated the Sinian basement outcropping in the mountain ranges lying more than 60 km to the NW from the NW edge of the Beijing Graben shown in Fig 1 (Zheng et al., 1982). The isotope data allow the interpretation that deep waters beneath the Beijing Graben move slowly further to the SE into the Tianjing Basin. This secular movement presumably occurs at great depths, i.e. below the level of the Sinian aquifers. If natural recharge is limited to deep secular flow, one could expect that the tritium content of the waters in the Sinian aquifers should be nil. Some tritium, however, has been found in these waters (average 2.5 tritium units) and further studies are required to check whether these waters have been contaminated by drilling fluids. Geochemical data indicate that the aquifer fluids encountered in wells standing over the SE and NW flank of the Beijing Graben are similar in composition, although the waters beneath the NW flank are more affected by mixing with some groundwater.

Simple reservoir models of the Beijing prospect

Borehole logging data and standard pumping tests have shown that there are two aquifers in the Sinian basement beneath the SE part of the City, namely an upper aquifer (50 ± 25m thick) in the Tieling Croup (Ti aquifer) and a lover, main aquifer (70 ± 35m thick) in the Wumishan Group (Wu aquifer). Both aquifers are separated by a 100m thick sequence of shales. The Wu-aquifer appears to extend throughout the whole prospect. The Sinian basement beneath Beijing is down faulted by a few major NE-trending normal faults with throws between 150 to 300m (see Fig 1). Each aquifer can be clearly recognlsed in temperature logs, run immediately after completion and which show a small temperature inversion in the aquifers reflecting penetration of colder drilling fluids. Pumping tests using nearby observation vells and the Theis method have shown that the average transmissivity of the Ti aquifer is of the order of 150 darcymeter, that of the Wu aquifer about 300 darcymeter.

Interference tests indicate that the aquifers exhibit block structure vhich is probably controlled by a few major NE trending faults and the Daxing uplift in the SE. The approximate extent of basement blocks with coherent aquifers is still not known, but one block extends at least 10 km in NE direction.

To understand the phenomenon of pressure drop, even with low production, ve used a model which consists of a single, equivalent aquifer with a transmissivity of 600 darcymeter (av. porosity: 0.03; av. density: 2.7x10^3kg/m^3; av. thermal conductivity: 4W/m°C, av. thermal capacity: 1 kJ/kg°C) which was bounded above and below by impermeable strata; no reinjection was considered. The aquifer in the model extends from the Daxing Uplift in the SE to a major fault (Liangxiang-Qianmen Fault) in the NW. The model was defined as a 2 dimensional structure by placing fictltious pumping wells to either side at 2 km intervals with a total discharge which was equal to the annual production as in 1983. Temperatures and pressures in the central, 2 km wide strip were computed for 200m wide blocks; one production well (22 l/s) was placed in the centre of the strip. A finite difference technique (Zyvlovskl et al., 1979) was used to compute theoretical temperatures and pressures as a function of time. Initially it was assumed that the permeable layer was infinite to the SE. The model calculations showed that in this case a pressure drop of only 0.2 bar occurs throughout the aquifer which stabilised quickly. Since the observed pressure drop is one order of magnitude greater, the model was then modified by reducing the permeability of the aquifer beneath the Daxing Uplift. Theoretical pressure drops similar to those observed were obtained when the permeability of the blocks beneath the Daxing Uplift was reduced to about 20 millidarcy ($2 \times 10^{-14} m^2$). Natural recharge is therefore limited and it vas concluded that any significant production of fluids from the Beijing aquifers requires reinjection to stabilise pressure drops in the aquifer.

The model was then modified by limiting the recharge both from the SE and the NW and by considering only the Wu aquifer which appears to be coherent throughout the prospect- Reinjection was achieved by placing reinjection wells 1 km updip from production wells. Production and reinjection wells were spaced laterally 1 km apart. Minor flow in a 230m thick layer below the Wu aquifer was also considered where some minor permeability exists ($3 \times 10^{-13} m^2$ was assumed) as indicated by temperature logs. Pumping rates equalled reinjection rates (22 l/s for each well). The original temperature at production well and reinjection wells were 58 and 53°C respectively. The temperature of the reinjected fluids was taken as 30°C. The computed temperature and pressure changes for production and reinjection wells, again using 200m blocks, are listed in Table 1 which shows that there is no pressure drop neat the production well and that the fluid temperatures slowly decrease during production time as the reinjected fluids move towards the production well. The drop in temperature after 19 yrs production, however, is still small (-3°C). The effect of a fault displacing the Vu-aquifer between production and reinjection well was also analysed. The throw was assumed to be greater than the thickness of the Wu aquifer, but less than 300m so that some fluid movement could still occur across the fault in the less permeable layer beneath the aquifer. Results listed in Table 1 indicate that some pressure drop (about 2 bar) will be noticeable in the production well; the long term temperature changes affecting the well are similar to those computed by the model with a coherent aquifer structure between production and reinjection well, except that long term temperature changes are somewhat smaller.

These models have shown that under moderate production, long term exploitation of hot water from deep aquifers beneath the City of Beijing is possible if fluids are reinjected. The path length between production and reinjection wells was kept to a distance of 1 km. If the distance were shorter, interference by reinjected fluids would be noticeable at an earlier stage. Assuming therefore that production coupled with reinjection is feasible, the likely energy potential of the resource can be assessed.

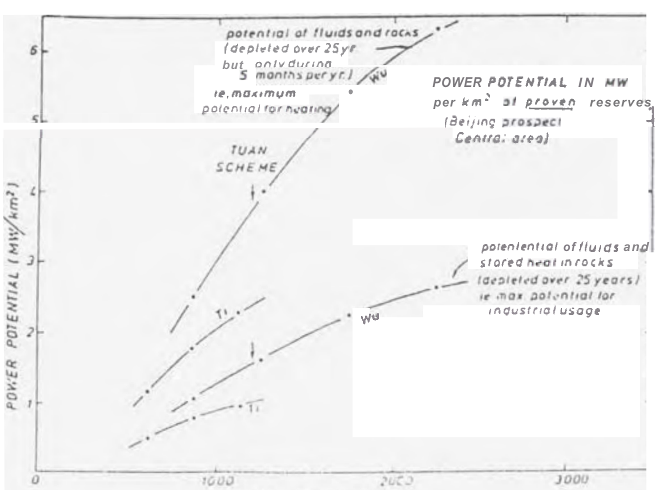


Fig 4a: Power potential in MW/km² of proven geothermal reserves of Beijing prospect versus depth of aquifer.

Table 1: Theoretical temperature and pressure changes in the Wu-aquifer under continuous production and reinjection

time (yr)	0.5	5	19	48
production well				
ΔT(°C)	0 [0]*	-0.6 [-0.6]	-3.0 [-2.2]	-14 [-4]
Δp(bars)	-0.1 [-2.0]	-0.1 [-2.0]	± 0 [-2.0]	±0 [-2.1]
reinjection well				
ΔT(°C)	-1.4 [-1.4]	-10.7 [-10.2]	-20.9 [-20.8]	-23 [-23]
Δp(bars)	+0.6 [+0.2]	M.6 [+0.2]	+0.7 [+0.2]	+0.7 [0.2]

*) The first figure in each column refers to a model where the aquifer is coherent between production and reinjection well; the second figure in brackets refers to a model where this aquifer has been displaced by a fault running between the two wells.

Energy potential of the Beijing prospect

Since the resource is of large extent, we restricted the assessment to blocks of 1 km² size beneath the City of Beijing. The assessment covered both the potential of the well defined two aquifers (proven reserves) as well as the possible potential of a layer beneath the lower aquifer which appears to be permeable, as indicated by temperature logs (probable reserves). The temperature of the fluids, and the energy potential increases with depth; this was allowed for by retaining the depth of the reservoir as parameter. It was assumed that all energy can be extracted from produced fluids down to a cut-gff value of 35°C. It was also assumed that the overall efficiency of extracting heat stored in the aquifers is about 0.25 and that the economic life of any utilisation scheme is about 25 years. The physical constants of the productive reservoir were the same as used in the models discussed previously.

The results of this assessment are shown in Fig 4a (proven reserves) and Fig 4b (proven and probable reserves). It can be seen from Pig 4a that the energy potential of the Beijing resource lies between 1.3 to 2.5 MW (thermal) per km² if fluids are produced from depths between 1000 and 2000m from the Wu-aquifer (continuous production); if fluids vere produced for space beating during a 5 month period, this potential increases by a factor of 2.4. The potential is also

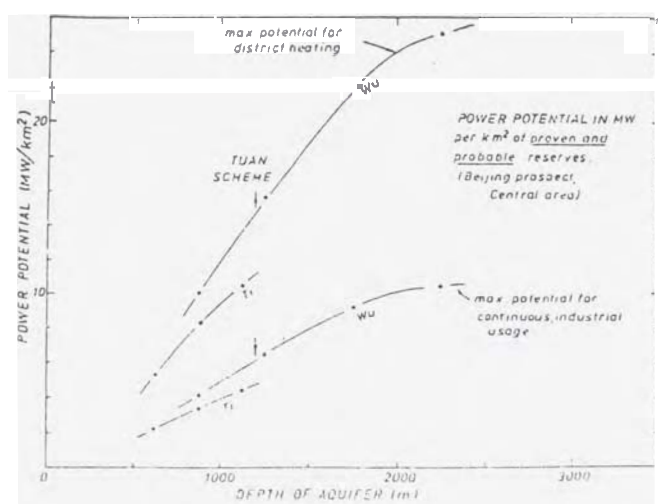


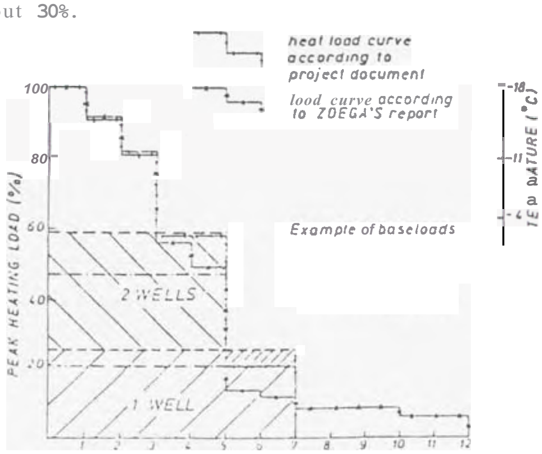
Fig 4b: Power potential in MW/km² of proven and probable geothermal reserves of Beijing prospect versus depth of aquifer.

greater where both the Wu and Ti aquifers occur together although the Ti aquifer does not extend to depths greater than about 1000m. If heat can be extracted from the probable reserves, the potential would increase by a factor of 2 (see Fig 4b). The likely energy potential of the Beijing prospect lies therefore in the range of 2.5 to 10 MW (thermal) per km^2 where aquifers lie at depths greater than 1000m.

Utilisation

With the information as to the likely potential of the resource, one has to assess whether the energy can be used economically. Geothermal energy could be used in Beijing for district heating, as bulk heat for industrial processes, and for public baths. In the first two cases it has to compete with other sources of energy, mainly coal. The basic costs of geothermal energy were estimated using simple schemes consisting of 1 to 2 production wells, 1 reinjection well, heat exchangers and heat boosting units in the form of existing coal fired boiler plants. These costs were then compared with the basic costs of energy delivered by coal fired district heating schemes and industrial plants. Interest for investment costs and returns for investments were not considered for the basic costs.

Two hypothetical district heating schemes were considered, pilot schemes for both types already exist in Beijing. The first type, we called a modified Reykjavik Scheme (R-scheme) where thermal waters directly enter the reticulation system and provide baseload heating; peak load heating can be provided by existing coal fired boilers by means of heat exchangers. Maintenance costs are significant. The scheme has similarities to that described by Einarsson (1976). The second type of heating scheme is a modified scheme which is similar to that described by Lienau (1981) for Klamath Falls (K-scheme). In this scheme non-corrosive surface water is heated by heat exchangers near the well head, peak loading is again provided by existing coal fired boilers; maintenance costs are small. The possibility of providing peak load heating by geothermal energy from additional wells was also considered, but found to be uneconomic. The annual heat load curve for district heating in Beijing usfng one or two geothermal wells and the heat delivered by the R-scheme and the K-scheme are shown in Fig 5. The computations are based on a reservoir structure as it exists in the vicinity of the Tuanjiehue pilot heating scheme. It was found that the basic costs of geothermal energy delivered by the modified R-scheme are slightly lower than the costs of heating by coal only, whereas the costs of the K-scheme are slightly higher. The difference in costs between the two schemes appears to be no greater than about 30%.



It was inferred that the costs of bulk heat provided for industrial usage either by the K-scheme or the R-scheme would be similar to the energy costs of district heating. The study indicates that even under optimum conditions the costs of geothermal energy are not lower than the costs of the most economic alternative energy (i.e. coal). The reasons for this are the rather low temperature of the produced fluids and the additional costs incurred by reinjection and pipelines. It was also found that the costs of geothermal energy increase significantly if fluids are produced from depths greater than 1500m (additional drilling costs) or less than 800m (smaller useable temperature interval).

Present day space heating in Beijing requires at least 2000 MW peak heat load to heat about $40 \times 10^6 m^2$ floor area in the more densely occupied part of the city. About one third of this floor space is associated with high rise housing complexes. All space heating is presently provided by coal, causing significant air pollution during the winter months. It was estimated that the city area lying over the reservoir where geothermal fluids can be produced economically (i.e. aquifer depths between 800 to 1500m) is of the order of 50 km^2. Using the lower value of proven energy potential of 2.5 MW (thermal) per km^2, it can be inferred that at least 125 MW heating power can be provided for mixed district heating schemes by geothermal energy which, however, is no more than about 6% of the total peak heat load required by the city. The contribution of geothermal energy might be greater, but should not exceed 500 MW. Use of geothermal energy for space heating of part of Beijing appears therefore to be feasible, but it cannot provide more than a fraction of the present heat load; the pollution problem would not be solved by large scale geothermal district heating schemes.

On the other hand, a heated reservoir with excellent transmissivity and good storage facility exists beneath the City of Beijing. If waste heat produced by numerous industrial plants during the summer months could, be reinjected in the form of heated, non-corrosive surface waters into the reservoir and be extracted during the winter months, a pollution free district heating scheme could evolve which might solve the heating problems of the city. The scheme appears to be attractive since the economics of the scheme can be optimised as the temperature of the injected vaste heat can be controlled, which in turn controls the temperature of the fluids to be produced during the winter months. The waste heat scheme can be extended to the shallower parts of the reservoir as well. Expertise in' cyclic waste heat storage is already available and efficiencies of better than 80% have been achieved under test conditions (Chin Fu Tsang and Hopkins, 1982). Further studies are required to assess whether waste heat storage in the deep Beijing aquifers is feasible.

ACKNOWLEDGEMENTS

Mr S Einarsson (UN/DTCD New York) was a member of the Technical Review Mission and his expertise in district heating has been fundamental in analysing the economics of hypothetical utilisation schemes suitable for Beijing. All members of the Beijing Hydrological Bureau involved in the Beijing geothermal project contributed to the review; models of the Beijing reservoir presented in a summarised form in this paper are based on their data.

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