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THE BEIJING GEOTHERMAL SYSTEM, P R CHINA: NATURAL STATE AND EXPLOITATION MODELLING STUDY OF A LOW TEMPERATURE BASEMENT AQUIFER SYSTEM

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Introduction

An extensive (>800 km^2) basement aquifer confined to the top 300m of Sinian dolomites occurs beneath the Beijing Graben at 300m to 3000m depth (Fig. 1). The Beijing Geothermal Field is associated with a broad horst structure (called from now on the Beijing sub-uplift) under the SE flank where the aquifer lies typically between 600 to 1200m depth covering an area of about 70 km^2 (Fig. 2). Most of the 44 wells drilled between 1971 and 1982 were brought down on this structure and produce thermal waters at wellhead temperatures between 45 to 55°C; a few wells also produce from the deeper part of the Beijing Graben with wellhead temperatures of up to 70°C from 2600m depth. Fluid production began in 1972 and was increased to about 130 kg/s in 1985; the production rate varies significantly during the year as about 40% of the produced water is used for heating and about 60% for baths and industrial purposes (base load). As a result of this abstraction the reservoir pressure has decreased by about 3 bars. In terms of total production the Beijing Field ranks as the third largest low temperature field presently exploited in China; higher production rates are documented only for the Tianjin Field (Ouyang et al., 1986) and the Fuzhou fracture zone reservoir in Fujian Province (Huang and Goff, 1986).

A summary description of the characteristics of the Beijing Field and its utilization has been given by Zhang, Z.G. (1981), Hochstein et al. (1984), and in the final technical report of a UNDP-sponsored project (UNDP-Ministry of Geology, 1984). There was great uncertainty as to the origins of the thermal anomaly of the Beijing Field. Most of the sediments which infill the Beijing Graben have a very low permeability; temperature gradients in wells are almost linear for the sedimentary section. If one plots the temperature in the basement aquifer and the heat flow in the sediments above versus basement level, one finds that there is a higher than normal heatflow (80-90 mW/m^2) over the sub-uplift and a lower than normal flux (less than 45 mW/m^2) in the deepest part of the graben (see Fig. 3); the heat flux changes by more than a factor of two over a distance of less than 8 km (Hochstein et al., 1984). The thermal waters are of meteoric origin (Zheng, K., 1981; Zheng, K. et al., 1982).

There is still some uncertainty about management of the resource. Although the production has been moderate, the resulting pressure drop in the basement aquifer has been noticed throughout the whole production area. The permeability of the aquifer is very high as indicated by the immediate response to seasonal variations in production noticed in wells throughout the whole sub-uplift area (see Fig. 4). For economic production expensive deep well pumps cannot be used, and the presently installed shaft pumps have a lifting capacity of only about 50-60m. If production increases at the rate as measured during the period 1982-85 (i.e. from 3.5 Mt/yr to 5 Mt/yr), the data in Fig. 4 indicate that some production problems will probably be encountered when the total pressure drop reaches, say, 6 bars in the aquifer. It was uncertain whether significant natural recharge had occurred, whether re-injection was required on a larger scale to stabilize the existing pressure drop, and whether colder fluids from shallower levels were moving into the reservoir.

Some reservoir modelling was therefore required to obtain a better understanding as to which processes in the past caused the thermal anomaly of the Beijing Field and to analyze heat and mass transfer induced by past production.

Earlier models of the Beijing system

In the 1970s it was assumed that the anomalous temperatures in the basement aquifer beneath the sub-uplift were caused by some crustal hot granitic body and that deeper thermal waters ascended along deep-reaching, NE trending faults and entered the aquifer (Zheng, K., 1981). Although this simple model explains the anomalous temperatures in the uplift it does not explain the observation that the temperature in the deepest part of the graben are anomalously low (Hochstein and Caldwell, 1985); the role of deeper fracture zones was also open to criticism since anomalous temperatures near major faults, such as the Liangxiang-Qianmen Fault (see Fig. 1), had not been found.

The role of conductive heat transfer has been studied in more detail by Hochstein and Caldwell (1985). Since the thermal conductivity of the basement rocks is about 2 times greater than that of the sedimentary infill, the Beijing Graben causes a large heat flux anomaly. Detailed 2D modelling showed that about half of the anomalous increase in heat flux over the flanks (and about half the decrease in flux over the graben) could be explained by the divergence of the deep crustal heat flux. Hochstein and Caldwell inferred therefore that some additional heat transfer by secular convection is required. The temperature field of the Beijing Graben has also been modelled by members of the Institute of Geology, Academia Sinica (the study referred to in Xiong and Zhang (1986); this study also reproduced the anomalously low heat flux values over the centre of the graben using a conductive model.

Simple reservoir engineering methods have been used to assess the production potential of the Beijing Geothermal Field. Plotting observed drawdown versus accumulated production, the likely total fluid volume was estimated which could be produced for an assumed economic cut-off limit of 100m drawdown in piezometric level. For the main basement aquifer (Wumishan or Wu aquifer) this value was found to be

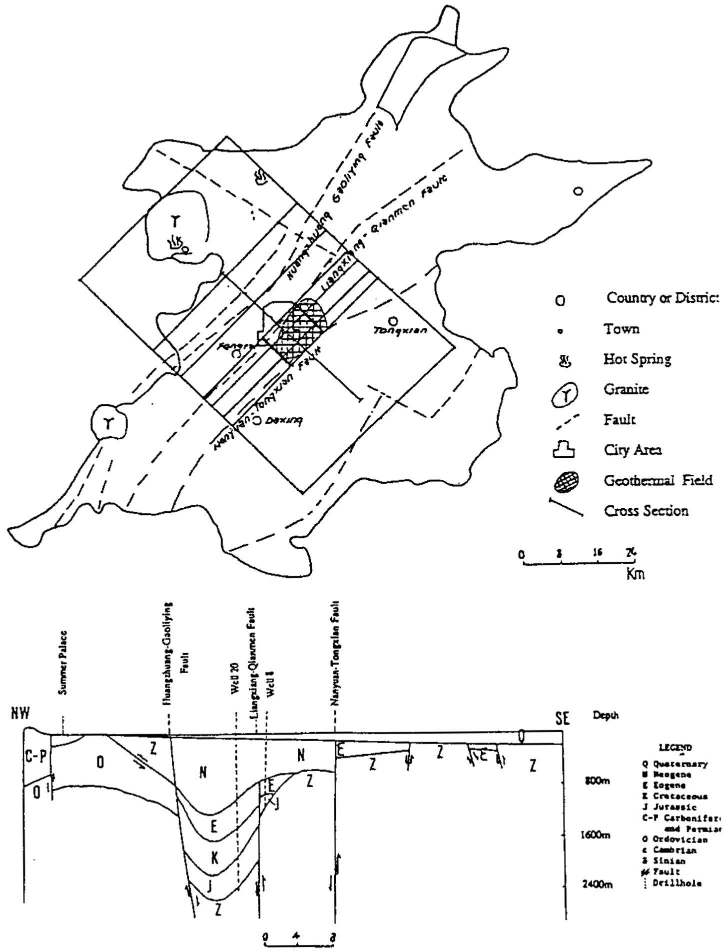

Fig. 1: Structural map and cross-section of Beijing Graben. The cross-section is perpendicular to the axis of the graben and runs through the central part of the Beijing geothermal field.

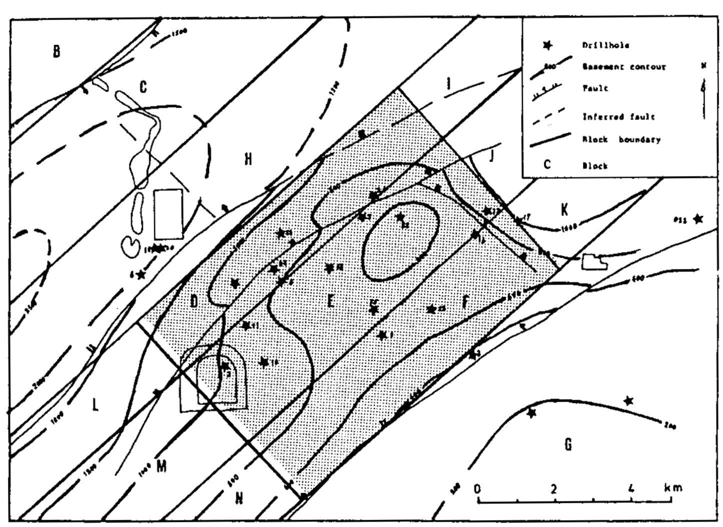

Fig. 2: Basement contour map of the Beijing sub-uplift (contour interval for stippled area is 200m; contour interval for the deeper graben shown by dashed contours is 500m). Most of the production comes from the sub-uplift (stippled pattern) covered by blocks D, E, and F; only half of the productive wells are shown.

about 350 Mt (Beijing Hydrogeological Bureau, 1984); about 10% of this inferred reserve had been produced by 1985. There is also a second basement aquifer (Tieling or Ti aquifer) at the SE margin of the sub-uplift (block F) which overlies the Wu aquifer. The total reserves of the Ti aquifer for a 100m drawdown were estimated to be 46 Mt (Beijing Hydrogeological Bureau, 1984) of which about 20% had been produced by 1985.

A stored mass-energy assessment (Hochstein, 1984) gave somewhat different figures. Considering the actual wellhead temperatures and the efficiency of existing utilization schemes (average reject temperature of 35°C), it was found that the energy potential of the Wu aquifer beneath the sub-uplift is probably no greater than 1 to 1.7 MW_{th}/km^2 for continuous load. This potential is subject to use of re-injection to stabilize reservoir pressure; a mass flow potential of 0.57 $Mt/km^2/yr$ (for 25 yr production) was inferred for the Wu aquifer.

A mass balance approach was used by Kuo (1981) to estimate the likely recharge for 1980 which was found to be about 2/3 of the total annual production of 3.55 Mt. Since it can be inferred that the permeability structure in the direction of the graben axis might not vary significantly for individual units, a simple 2D reservoir model was constructed to assess the permeability of the SE recharge block (Daxing uplift; i.e. the block to the SE of the Nanyuan-Tongxian Fault in Fig. 1) which seem to control the pressure drop for any 2D model of the sub-uplift. The permeability of the Wu and Ti aquifers had been determined by pumping tests and was known to be of the order of 1 Darcy, i.e. 1E-12m^2 (Beijing Hydrogeological Bureau, 1984). Assuming that the permeability of the rocks above and below the basement aquifer is very small (≤ 1mD), and using realistic abstraction rates (22 kg/s for a 2 km wide strip), it was found that the average permeability of the recharge block was of the order of 4E-14 (i.e. 40 mD) by comparing observed and computed pressure drops in the reservoir (Hochstein, 1984); for simulation a modified SHAFT 79 program (O'Sullivan et al., 1983) was used. This simple reservoir model was also used to assess the likely pressure and temperature changes in the aquifer for an idealised "doublet scheme" where production and re-injection wells were separated by 1 km distance (Hochstein et al., 1984) and the previously cited energy potential of 1 to 1.7 Mt/km^2 was based on such "doublet schemes".

However, none of these models could explain adequately the natural heat and mass transfer in the reservoir nor could it predict actual changes in mass transfer and induced recharge inside and outside the production area. For this more detailed modelling was required.

The first conceptual model of the Beijing system (natural state)

The data described so far constitute a good data set for simulation of the Beijing system in its natural state. Such study was recently undertaken by Yang, Z. (1987). Available were the steady state temperatures in the basement aquifer for a depth range of 500 to 2600m covering almost 2/3 of the central strip of the Beijing Graben in which the sub-uplift is located; in addition, some temperature data were also available for a well on the Daxing uplift and a deep (3000m) well in the deepest part of the graben. Since temperatures vary slightly for the same level in each block, a mean temperature from all wells in each block was used as observed temperature (see Table 2). Representative values were also available for rock properties (i.e. saturated density, porosity, thermal conductivity) of the major lithostratigraphic units from cores and well logs. The geological structure was known (see Fig. 1).

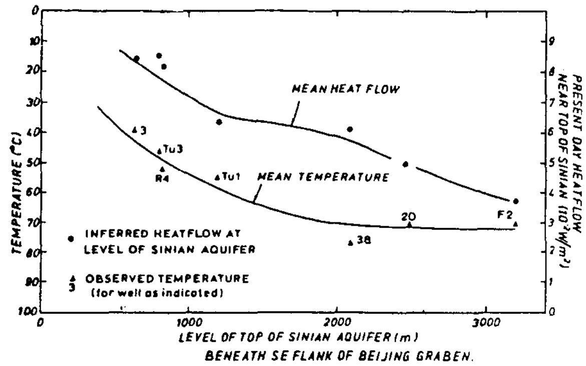

Fig. 3: Temperature at top of basement aquifer and apparent heatflow in sediments versus level of basement aquifer (Beijing Graben).

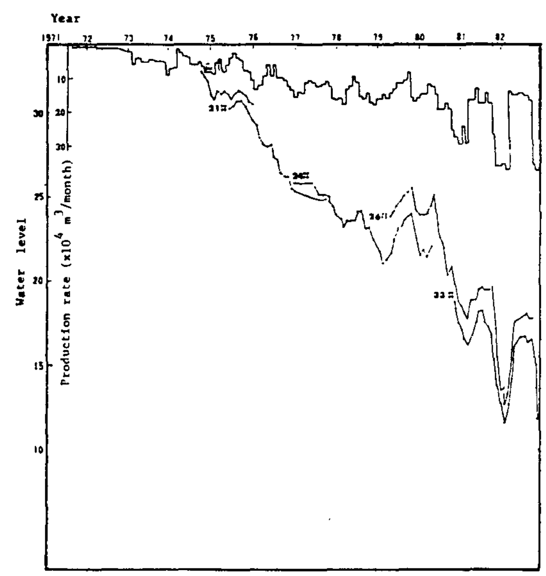

Fig. 4: Monthly production of thermal water from D and E block (see Fig. 2) and water level drawdown in selected wells of E block for period Jan. 1971 to Dec. 1982. (Note parallel tracking of WL in wells 26 and 33 which are about 5 km apart).

The permeability structure as well as the magnitude of the undisturbed heat flux at greater depths beneath the graben were poorly known; paleo-heat studies, however, indicate that the heat flux in the Neogene was probably close to 62 mW/m^2 (Prof. Wang, pers.comm.). There were, however, important constraints. The average transmissivity of the basement aquifers was known to be 300 Dm for the Wu aquifer and about 150 Dm for the Ti aquifer; both aquifers are 200 to 300m thick. The average permeability of the Jurassic and Cretaceous sediments is ≤ 1 mD as indicated by the observation that an uncased well which bottomed in these sediments in the centre of the graben did not fill up with water over several years. A somewhat exponential decrease in permeability was assumed for all deep rocks lying beneath the basement aquifer. The likely permeability range for rocks in the Daxing uplift (block G in Fig. 5) was known from earlier modelling (Hochstein, 1984).

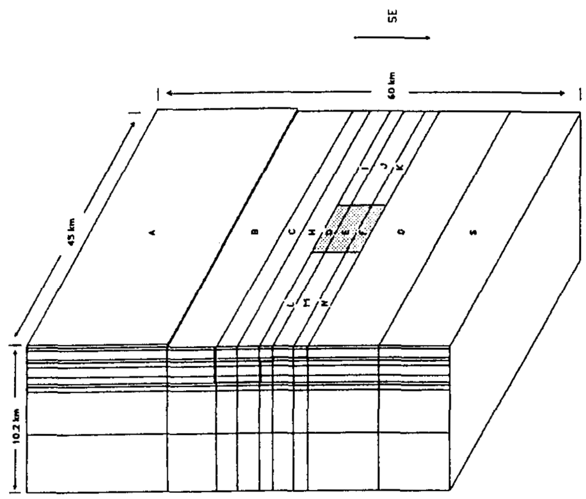

Fig. 5: Quasi 3-dimensional model of the Beijing geothermal system. Strip A represents the Yanshan mountain area where most infiltration of meteoric water occurs; strip B represents the Beijing W Rise; C and H lie over the deepest part of the Beijing Graben, the stippled blocks D,E,F define the Beijing sub-uplift, strips L,M,N and I,J,K represent the SE flank of the graben to the SW and NE respectively, strips G and S outline the Daxing uplift. The thick solid line in the section represents the Beijing Graben.

The aim of the first model study (Yang, Z., 1987) was to simulate a natural mass transfer pattern where infiltrating meteoric waters from the recharge blocks A,B as well as G and S (Fig. 5) penetrate deeply into the crust to depths greater than 5 km, where they sweep out some heat and ascend beneath the graben and the flanks into the basement aquifer. A temperature field given by the normal heatflux was used to define the initial condition; a modified SHAFT 79 program (O'Sullivan et al., 1983) was used to simulate convection until steady state conditions were reached. Matching parameter was the temperature observed in various blocks of the basement aquifer and the overlying sediments.

The first model already gave acceptable fits; simulation had to be run for a period of about $6x10^6$ yr to obtain steady state conditions. Matching of observed and computed temperatures was improved by a trial and error approach during which the initial permeability structure was changed sequentially. Modelling confirmed that the vertical permeability (k_z) of the highly permeable layers had to be about one order of magnitude lower than the horizontal permeability (k_x); this phenomenon has also been inferred from modelling of high temperature systems (O'Sullivan , 1985). For the top layers a ratio of k_x/k_z of 100:1 had to be used to avoid significant cooling. The permeability structure of the best fit model (model 1) is similar to that listed in Table 1, although the data of this table describe the permeability structure of a revised model described in the next paragraph.

Tha main outcome of the simulation was that the temperature structure of the Beijing geothermal system can be explained by secular convection involving a mass transfer of only about 13 kg/s of deeper fluids which ascend into the basement aquifer beneath the sub-uplift; about half of this flow ascends to the surface and is discharged into the groundwater; the other portion constitutes a lateral outflow. Because of the high permeability of the basement aquifers, additional heat is thus transferred from the graben to the flanks. The setting-up time to reach steady state convection is of the order of 6 Mill yrs, i.e. minimum geological lifetime of the system. The observed temperatures within the graben and over the flanks can be reproduced with an error which for most blocks is less than ±2°C. The best fit model requires a natural heatflux of 56 mW/m^2 at 10 km depth; the heat-generating capacity of rocks above this level was neglected.

To test the pressure response of the model to actual production, the width in N-S extension of the model was reduced to that of the Beijing sub-uplift (i.e. about 10 km, see Fig. 2) thus neglecting any lateral flow within the graben. The model was subjected to actual abstraction rates as documented for the period 1971-1982. The overall pattern of the pressure drop as shown in Fig. 4 could be reproduced without any further changes of the model (Yang, Z., 1987).

Revised conceptual model of the Beijing system (natural state and production simulation

Although the first conceptual model could reproduce the natural state situation and thus became the first model describing the likely heat and mass transfer for the whole Beijing basement aquifer system, it could not be used for detailed reservoir modelling since it was essentially a two-dimensional model. The model was therefore revised by considering likely three-dimensional effects related to horizontal anisotropy of permeability and the geometry of the sub-uplift.

For models 3, 4, 7 and 8, separate blocks D, E and F were created which coincide with the Beijing sub-uplift (Fig. 5); for model 3, horiziontal anisotropy was neglected, otherwise its permeability structure is the same as that listed in Table 1. Model 4 was similar to that of model 3 except that horizontal permeability for all basement rocks was reduced by a factor of two in x-direction (perpendicular to the axis of the graben). The direction of the main faults running parallel to the axis of the graben indicates that jointing of the basement rocks could be significant in NE direction (y-axis of the model); minor faulting in NW direction (x-direction of model) also exists (see Fig. 1). For models 7 and 8 the geometry of the uplift was taken into account by moving the level of the top of the basement in columns D, E and F by 200m above that of the basement in the adjacent blocks I, J, K and L, M, N. The geometry of models 7 and 8 is shown in the form of sliced sections in Fig. 6. For model 7, horizontal anisotropy was neglected; for model 8, pressure interference in the basement aquifer in columns E and F was decoupled by assuming that the permeability in x-direction is 10 times less than that in y-direction (for layers SNW and SNT in Table 1 only). The natural heatflow at 10 km depth was kept constant for all 4 models (54 mW/m^2).

The computed and observed temperatures for the central strip with drillhole control, i.e. for columns H, D, E and F, are shown in Fig. 7a,b,c, and d respectively. It can be seen that except for model 4 in H-block, all other models produce quite acceptable fits to observed temperatures. Even the fit of model 4 for H-block could be acceptable if one allows for the fact that the observed temperature profile for this block is based on one well only. The pressure response of each model to actual abstraction scenarios (abstraction by means of a fictitious well intersecting the basement aquifer in the centre of columns H, D, E and F), however, allowed better discrimination. Here model 8, i.e. the model with pronounced fracture permeability in the aquifer for colums E and F, produced the best fit between observed and computed pressure drop (see Fig. 8a, b for model 8 in comparison to Fig. 8c, d for the other

TABLE 1: Rock properties of model 7.

(for location of layers listed under rock types refer to Fig. 6).

ROCK TYPE	DENSITY (kg/m3)	POROSITY	PERMEABILITY (md) HORI.	VERTI.	THERMAL COND. (mW/Deg.C m)	THERMAL CAPACITY (kJ/ C kg)
QUA	2700	0.20	1000	10	1.7	900
QU1	2000	0.20	300	3	1.7	900
CE1	2000	0.12	50	0.5	1.8	900
CE2	2000	0.10	10	0.1	1.9	900
CE3	2000	0.09	7.5	0.1	1.9	900
CRE	2450	0.05	1.0	0.1	2.0	900
JUR	2520	0.04	0.5	0.05	2.4	900
YX1	2650	0.04	100	10	3.0	900
YX2	2650	0.03	80	8	3.0	900
DX1	2650	0.02	80	8	3.5	900
DX2	2650	0.01	60	6	3.5	900
DSN	2700	0.01	60	6	4.0	900
SN1	2700	0.01	100	10	4.0	900
SN2	2700	0.01	20	2	4.0	900
SN3	2700	0.01	0.2	0.02	4.0	900
SNW	2700	0.03	1000	100	4.0	900
SNT	2700	0.03	500	50	4.0	900
SWT	2700	0.01	300	30	4.0	900
GRA	2700	0.01	0.05	0.05	2.6	900

Note: For model 3 the same properties were used as in Table 1, except that horizontal permeability for layer DX2 and DSN was taken as 50 mD. For model 4 the same properties were used as for model 3, except that the horizontal permeability in x-direction (see text) was half that of the horizontal permeability for model 1 for layers YX1, YX2, DX1, DX2, DSN, SN1, SN2, SN3, SNW, SNT, SWT. For model 8 the same properties were used as for model 7, except that the horizontal permeability in x-direction (see text) was 1/10th of that listed in Table 1 for layers SNW and SNT (i.e. the productive horizons).

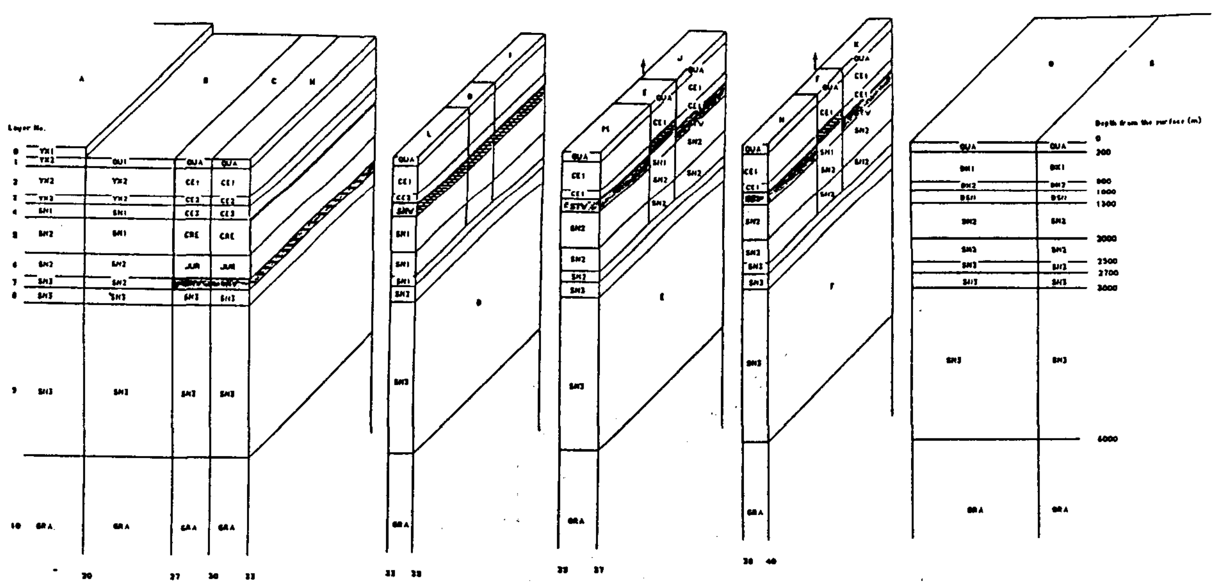

Fig. 6: Sliced 3-dimensional model of Beijing system; the structure shown was used for best fit models No. 7 and 8 referred to in the text. The darker shaded band outlines the highly permeable layers SNT, STW, and SNW coinciding with a thick karst layer at the top of the Sinian basement. The main production comes from two bl[illegible] F3 and F3.

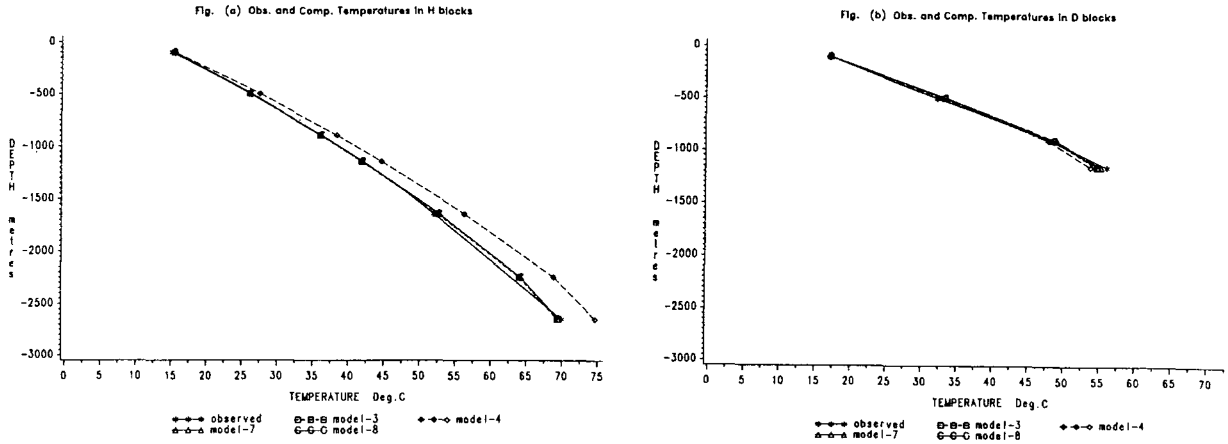

Fig. 7a,b: Observed and computed temperatures for revised models 3,4,7 and 8 of the Beijing geothermal system. Temperatures for models 7 and 8 are listed also in Table 2. Fig. 7a shows temperatures for H-block (deepest part of Beijing Graben), Figs. 7b,c,d show temperatures for D,E and F blocks respectively which are located over the Beijing sub-uplift (refer to Fig. 2).

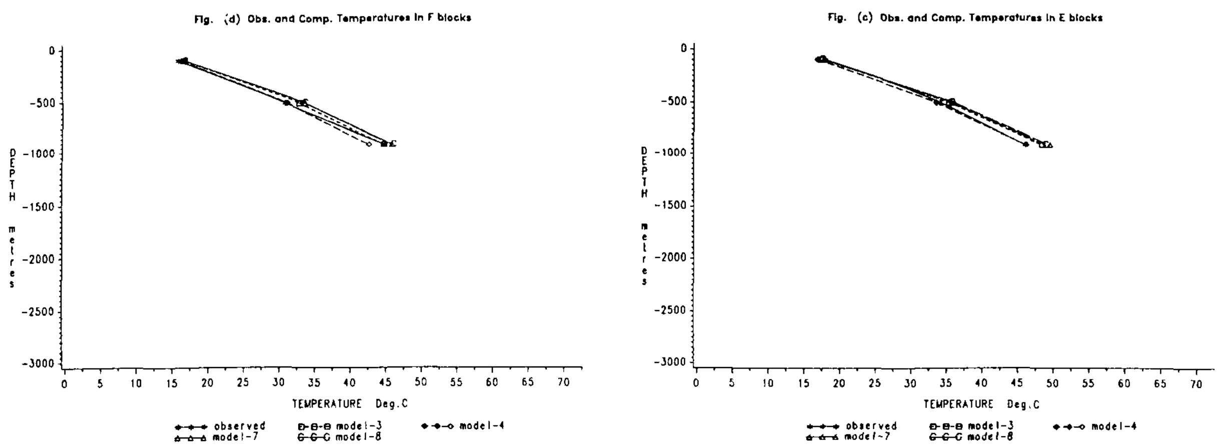

Fig. 7c,d: Observed and computed temperatures for revised models 3,4,7 and 8; for details refer to caption for Fig. 7a,b.

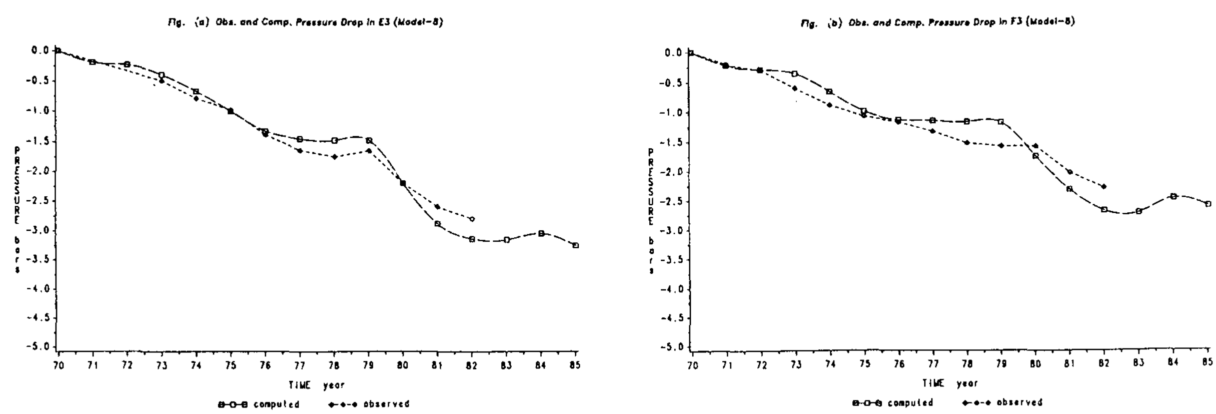

Fig. 8a,b: Observed and computed pressure drop for best fit model 8 caused by production from basement aquifer beneath Beijing sub-uplift between 1971 and 1985. Fig. 8a shows situation for production from E3 block (Wu aquifer only); Fig. 8b refers to F3 blocks (mainly Ti aquifer). For structure of E3 and F3 blocks refer to Fig. 6.

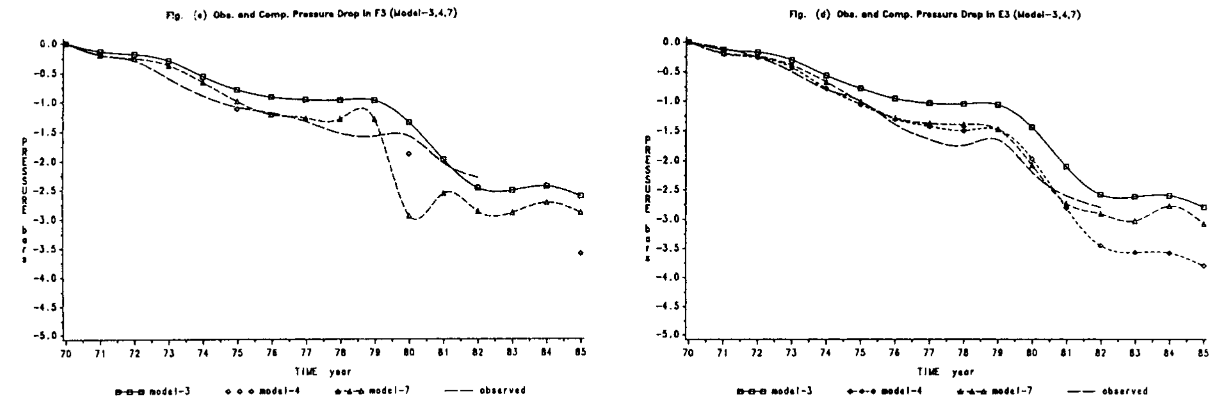

Fig. 8c,d: Observed and computed pressure drop for models 3,4 and 7 (refer to text) caused by production fror basement aquifer beneath Beijing sub-uplift between 1971 and 1985. Fig. 8c depicts scenario for E3 block (Wu aquifer only). Fig. 8d refers to F3 block (mainly Ti aquifer).

models). Observed and computed temperatures of models 7 and 8 for natural state conditions are listed separately in Table 2.

The role of recharge in the revised conceptual model and implications

After obtaining a model which explains in a satisfactory way both heat and mass transfer in the natural and the dynamic stage, we can now look at the role of recharge as predicted by the best fit models (Nos. 7 and 8). By comparing net inflow rates and production rates for each productive block it was found that after one year of production almost all the produced fluids were recharged (total net imbalance was on average only about -0.2% of total production). Most of the induced recharge occurred through the bottom of the basement aquifer block (between 65 to 80% of total induced net recharge). As a result, the temperature of the produced fluids remained almost constant; the model indicates temperature changes of less than -0.1°C for a production period of 15 years, which agrees with observed data. Because of the high permeability of the basement aquifer the trend in the observed pressure drop can be explained simply in terms of increases in the average rate of production. If production remained constant at the 1985 level, pressures would stabilize within one year. The observed plateau in the pressure drop curves in Figs. 8a,b is the result of rather constant production which took place during 1977 to 1979.

The simulation has various implications for the reservoir management of the Beijing basement aquifer. Re-injection of waste fluids into the aquifer is obviously not required to achieve stabilization of reservoir pressure since such stabilization can be brought about by maintaining constant production rates. In view of the almost perfect recharge indicated by the revised reservoir model, the mass flow potential for a given pressure drop at constant production rates appears to be almost unlimited. The long term mass flow potential of the Beijing reservoir appears therefore to be limited only by the characteristics of the installed pumps. For the presently installed shaft pumps it is likely that the long term mass flow potential is reached when the pressure in the basement aquifer has dropped by about 5 to 6 bars, which implies that the annual production of about 5 Mt in 1985 can probably be increased by a factor of 2 (i.e. about 10 Mt/yr), although the yield of individual wells would decrease.

TABLE 2: Observed (T_{obs}) and computed (T_{comp}) natural state temperatures for best fit model 7 for columns H,D,E,F and G; (for position of columns refer to Fig. 6).

H

Depth (m)	T.obs (Deg.C)	T.comp (Deg.C)
100	15	15.4
500	26	26.6 (-0.4)
900	36	36,2
1150	42	42.0
1650	52	52.8
2250		64.3
2650	70	69.6

D

Depth (m)	T.obs (Deg.C)	T.comp (Deg.C)
100	17±1	17.0
500	32±2	33.4 (-0.2)
900	48±1	49.0 (-0.3)
1150	57±3	55.2
* 1162+178	** 56±5	

E

Depth (m)	T.obs (Deg.C)	T.comp (Deg.C)
100	18±2	17.7 (-0.1)
500	34±4	36.0 (-0.2)
900	46±4	49.5 (-0.6)
* 799+126	** 45±4	

F

Depth (m)	T.obs (Deg.C)	T.comp (Deg.C)
100	16±1	17.0
500	31±3	33.8
900	44±6	46.0 (+0.2)
* 871+183	** 44±5	

G

Depth (m)	T.obs (Deg.C)	T.comp (Deg.C)
100		16.9
500	28	27.0

N.B.: * depths of the last entry in D,E, F refer to average depth of production wells in each block; ** temperatures are average wellhead temperatures.

Note: Temperature differences (°C) between model 8 and model 7 (natural state) are listed in parentheses in the T.comp column.

Summary discussion

Computer modelling of the Beijing low temperature, basement aquifer system has shown that secular natural convection of meteoric waters down to depths greater than 5 km can produce a temperature field which is similar to that observed in deep wells. Secular convection occurs within a crustal block with the approximate dimensions of 45 x 60 x 10 km; the Beijing system is probably one of the largest secular convecting systems described so far. It is driven entirely by the crustal heatflow which appears to be slightly lower (i.e. 54 mW/m^2) than the average continental heat flux. The study has several geophysical implications:

(1) The apparent natural heatflow inferred from linear temperature gradients in deep wells over large basins underlain by permeable basement aquifers is not representative for the actual crustal heatflow which probably can only be assessed from natural state modelling studies.

(2) Thermal anomalies associated with large sedimentary basins underlain by basement aquifers involve deeply penetrating meteoric waters. Although the maximum depth of penetration cannot be estimated with confidence for the Beijing system (because of uncertainties in the deeper permeability structure), it is likely that meteoric waters descend to at least 5 km depth beneath the Beijing Graben.

(3) Natural flowrates beneath the basement aquifer are very small (of the order of mm/yr), hence all water in the basement aquifer is very old water. Cation species in the thermal fluids should therefore be re-equilibrated with respect to aquifer temperature. Apparent higher equilibria temperatures, which have been associated with "deeper upflows" and the concept of mixing of deeper upflows (Beijing Hydrogeological Bureau, 1984) are open to criticism. Published high equilibrium temperatures are based on geothermometers involving sodium (Na) which might not re-equilibrate because of the absence of sodium-bearing minerals in the thick dolomite sequence.

Modelling of the observed temperatures in the natural state allows an approximate definition of the permeability structure of the Beijing system, but matching of observed and computed steady state temperatures is not sufficient to define details of the reservoir. For this, modelling of the pressure response of the reservoir under production has to be used. Although the area of the production blocks of good fit models is still very large (between 20 and 25 km^2) thus preventing any precise fits, the modelling of heat and mass transfer of the Beijing reservoir under

steady temperatures is not sufficient to define details of the reservoir. For this, modelling of the pressure response of the reservoir under production has to be used. Although the area of the production blocks of good fit models is still very large (between 20 and 25 km^2) thus preventing any precise fits, the modelling of heat and mass transfer of the Beijing reservoir under exploitation provides valuable information for the management of the resource.

(4) Over most of the Beijing sub-uplift, the basement aquifer is very homogeneous although some inhomogeneity occurs in block F; this probably also applies to other parts of the Beijing Graben.

Anisotropic flow associated with pronounced fracture permeability is probably not as significant as previously thought. High vertical permeability previously associated with inferred upflows along deep-reaching NE-trending major faults is also not significant since modelling showed that temperatures near such faults are significantly elevated in the natural state model - such higher temperatures, however, have not been observed. *Estimation of average transmissivity* from pump tests using line source solutions give almost the same permeability as pressure response modelling.

(5) Pressure response modelling has shown that induced recharge almost balances production ($\geq$99.7%). Most of the induced recharge (>70% by mass) enters the production blocks through the bottom; changes in temperature (enthalpy) of the produced fluids is therefore almost nil (<0.1 °C for a 15 yr period). For present-day production, stabilization of pressure drop by re-injection of colder waste fluids is not required since such stabilization can be brought about by constant production rates. If colder waste fluids are not re-injected, this also avoids cooling of the reservoir.

(6) Since induced recharge of the Beijing aquifer practically balances production, the concept of a finite mass production potential has to be revised. The final production potential is that given by the lifting capacity of the pumps at the wellhead which allow economic production of fluids for a given drawdown which, in turn, can be predicted by the reservoir model for each production block.

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