PRELIMINARY INTERPRETATION OF ISOTOPIC STUDIES OF GEOTHERMAL WATERS FROM THE BEIJING REGION (P.R. CHINA)

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ABSTRACT

Isotopic studies of thermal and cold surface waters sampled in the Beijing Region have shown that the thermal waters are meteoric waters which have been precipitated in the mountainous area lying to the NW of Beijing. δD and $\delta^{18}O$ data indicate that these waters move laterally in SE direction over distances of more than 150 km in Sinian basement rocks which are uplifted in the NW but occur at depths of 3 to 5 km in the SE sector of the region. Significant ^{18}O exchange with basement rocks occurs in the Jizhong Depression about 60 km to the SE of Beijing. On a smaller scale, a SE flow of thermal waters in basement rocks is corroborated by $\delta^{34}S$ data for the Beijing area and the Beijing geothermal field. The Beijing geothermal field and other geothermal fields in the SE sector of the Beijing Region are an example for low temperature systems where the heat is derived from a normal or slightly greater than normal, terrestrial heatflow.

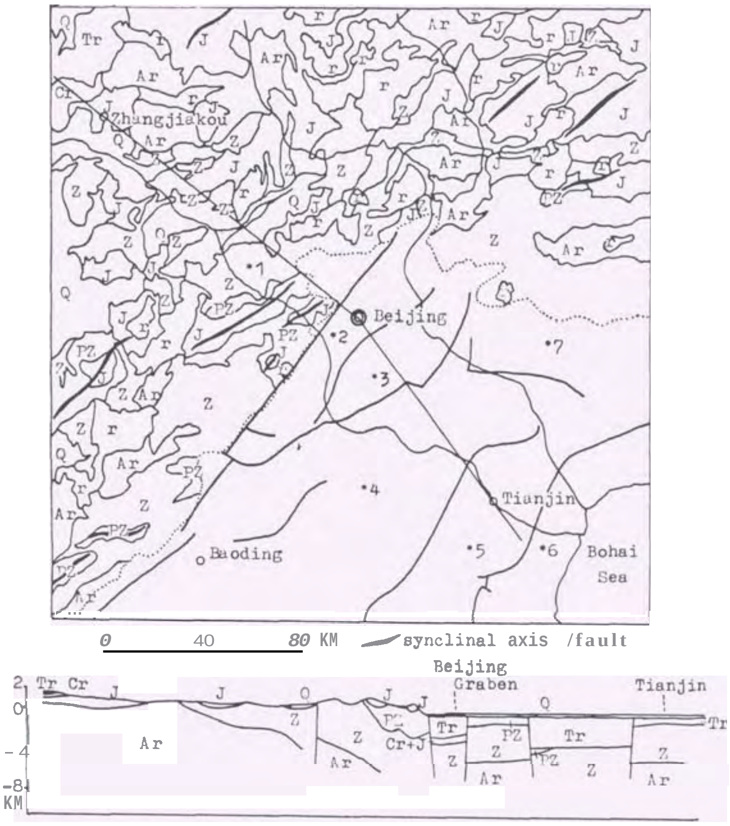

Fig. 1. Geological map and geological profile of Beijing and its surrounding area.

(1* Uplift of north-west Beijing; 2* Beijing Graben; *3 Daxing Uplift; 4* Depression of Jizhong; *5 Uplift of Cangxian; 6* Depression of Huanghua; *7 Tangshan Uplift. Q-Quaternary, Tr-Tertiary, Cr-Cretaceous, J-Jurassic, PZ-Palaeozoic, Z-Sinian, Ar-Archaeozoic, r-Granite).

INTRODUCTION

The Beijing geothermal field occurs beneath the SE urban area of Beijing and lies within the Beijing Graben, a depression infilled by an about 3000 m thick sequence of rather impermeable Cenozoic and Mesozoic

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sediments. The sediments, are underlain by permeable Sinian siliceous dolomites which form the basement for most of the area shown in Fig. 1. Thermal water occurs in vugs, fractures and joints of the basement and which can ascend along secondary faults causing thermal anomalies in the sediments where temperature gradients of up to 6 C/100 m have been measured. There are 42 geothermal wells in the Beijing geothermal field, most of which produce thermal water with temperatures between 38 and 70°C at the wellhead with mass flow rates of more than 10 ℓ/s (i.e. more than 1000 to/d). The thermal water produced contains about 500 mg/ℓ total solids and belongs to the $Na-HCO_3$ type of thermal water and which can be classified as mineral water because of its rich content of fluorine, radon, and radium. The water is also used for balneological and medical treatment.

The Sinian basement rocks are unlifted to the NW of the Beijing Graben (see Fig.1). Numerous thermal springs occur in this area, for example, the Fuyukou warm springs and the thermal springs in the Xiaotangshan area. Recently, thermal waters with temperatures between 38 and 60°C at the wellhead and mass flow rates similar to those in the Beijing geothermal field have been encountered in drill holes. The thermal waters in this area belong to the $Na-SO_4$ type of thermal waters. The thermal springs occur along basement faults or in the foothill region.

Going to the south-east from Beijing, one encounters the Daxing Horst structure (see Fig. 1) where no thermal waters have been found yet. But further south-east in the Jizhong Depression, thermal water has been found beneath a 2000 m thick sequence of sediments in Ordovician limestone. This thermal water can be produced with temperatures between 50 to 73°C at the wellhead (wellhead pressure : 2 bar gauge). The waters belong to the Na-Cl type of thermal waters.

This summary has shown that thermal waters occur in the basement over a large region around Beijing; the chemistry of the water changes slightly from area to area. The question arises whether waters are of local origin or whether they are related to the same type of water which has infiltrated the basement rocks outcropping in the mountainous area to the NW of Beijing and which is the only natural recharge area for the whole region since the sediments-which cover the basement rocks in the Beijing area, but also the SE sector of the region shown in Fig. 1, are practically impermeable. To find an answer to this question, we investigated the isotopic composition of thermal and non-thermal waters, since studies elsewhere have indicated that information about origin and flow mechanism of deeper waters can often be obtained from isotope data (Arnarson, 1976; Downing et al, 1979; Fritz and Fontes, 1980; Truesdell et al, 1979).

OXYGEN -18 AND DEUTERIUM CONTENTS

Deuterium, tritium, ^{18}O, ^{14}C, and ^{34}S isotope concentrations of thermal waters from the Beijing Region, and of meteoric waters (groundwater, cold springs, and surface water) from the surrounding area have been analysed. Although the studies are not complete, some important conclusions can already be drawn from these data.

The ^{18}O and D contents of cold surface waters and of thermal waters expressed in terms of $\delta^{18}O$ and D values in ‰ (with respect to SMOW) for the greater Beijing area, are shown in Fig.2. This figure shows that all thermal waters are depleted in ^{18}O and D with respect to those of cold surface waters. The values plot in most cases along the meteoric water line of Craig (Craig, 1961). Deviations, however, occur for both types of waters. Whereas the ^{18}O and D values of cold springs plot along the meteoric waterline, the values of cold groundwater flowing in solid rocks and of surface water in lakes (reservoirs) lie below this line pointing to an evaporation effect. The enrichment in ^{18}O of some thermal waters indicates that some ^{18}O exchange between thermal waters and the reservoir rocks has taken place. Since all meteoric waters which precipitate at lower temperatures, i.e. higher altitudes and higher latitudes, are depleted in ^{18}O and D, the data in Fig. 2 already indicate that the thermal waters in the greater Beijing Region are derived from surface waters which precipitated at higher altitudes, i.e. in the mountainous region to the NW of Beijing.

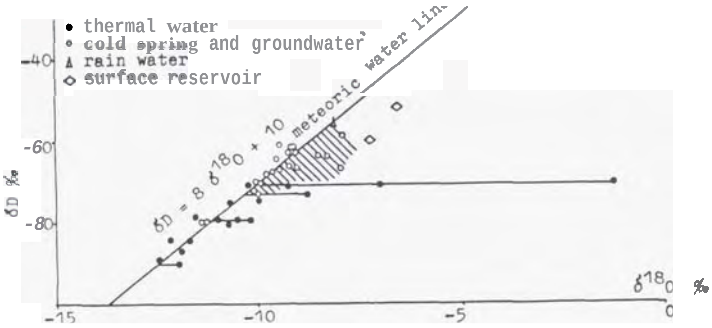

Fig. 2. δD versus $\delta^{18}O$ plot of cold surface and deeper thermal waters from the Beijing Region. (The shaded area outlines the data field for groundwater in solid rocks, data from cold springs all plot along the meteoric water line).

The pattern of regional distribution of $\delta^{18}O$ and δD values for thermal waters and cold surface waters for the greater Beijing Region is shown in Fig. 3. The area covered is the same as that shown in Fig. 1; the Beijing geothermal field is located in the centre of each sketch map shown in Fig. 3. The regional variation of δD of thermal waters is shown in Fig. 3a which indicates a trend in enrichment of D values from the high terrain in the NW (with δD values between -84 to -88°/oo) to the concealed deeper basins in the SE (with δD values between -72 to -76°/oo). A somewhat similar trend is indicated by the δD values of cold surface waters (Fig. 3c) where the enrichment in D, increasing from NW to SE, is controlled by the decrease in mean surface elevation (i.e. increase in mean annual temperature of precipitation). The average δD value of cold surface water at Beijing is about -60°/oo whereas the mean δD value of deep thermal waters from the Beijing geothermal field is about -76°/oo. The $\delta^{18}O$ values of thermal waters (Fig. 3b) show also a NW to SE enrichment trend although some local enrichment of thermal waters in the Jizhong Depression ($\delta^{18}O \simeq -5$°/oo in Fig. 3b) is caused by some exchange with basement rocks. In the extreme case, a $\delta^{18}O$ shift of +9°/oo was observed for thermal waters in Ordovician Limestone in an over 4000 m deep well (Jing -6) in the Jizhong Depression.

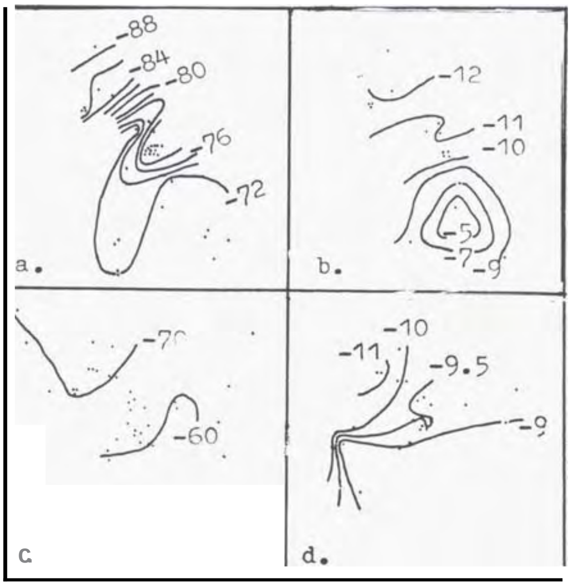

Fig. 3. Sketch map showing the distribution of δD and $\delta^{18}O$ data of thermal and cold surface waters in the Beijing Region.

a. δD values of thermal waters;

b. $\delta^{18}O$ values of thermal waters;

c. δD values of cold surface waters (springs and groundwater);

d. $\delta^{18}O$ values of cold surface waters.

Allowing for the regional trend in δD and $\delta^{18}O$ values as shown in Fig. 3b and Fig. 3d and by extrapolating these data, it can be inferred that all thermal waters, encountered in various geothermal fields lying in the SE sector of the Beijing Region, originate from surface waters which precipitated an Archaeozoic gneisses and granites in the highstanding mountainous terrain lying to the NW of Beijing (see Fig.1). These waters move then to the SE and infiltrate the Sinian basement rocks in which significant lateral movement (in SE direction) must take place over distances of more than 150 km so that these waters can reach, for example, the Jizhong Depression. Deep thermal waters in the Beijing geothermal field might originate from the Dahaituo mountainous area (mean elevation of 1200 m).

^{34}S ISOTOPE DISTRIBUTION

The ^{34}S isotope distribution of thermal waters of the Beijing geothermal field and of thermal waters discharged over the uplifted basement in the NW part of Beijing also shows an increase in ^{34}S concentration from NW to SE (see Fig.4). This indicates that an enrichment in ^{34}S concentration takes place at a deeper level as deeper waters move gradually to the SE.

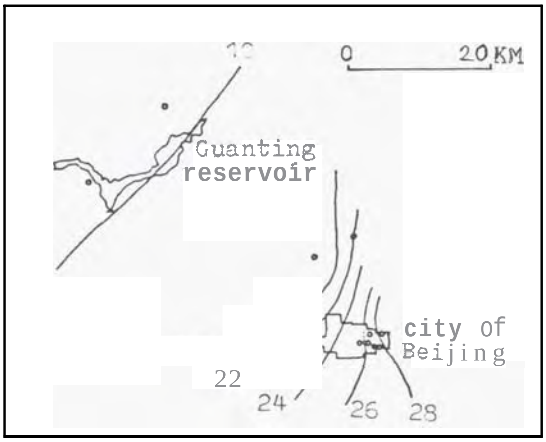

Fig. 4. Sketch map showing the distribution of $\delta^{34}S$ values (°/oo) of thermal waters in the greater Beijing Area.

A deeper origin of sulphates is also indicated in Fig. 5 where the $\delta^{34}S$ concentration of the thermal waters in the Greater Beijing Area has been plotted versus the Cl/SO_4 ratio, The results indicate that sulphates with low $\delta^{34}S$ values and low Cl/SO_4 molecular ratios occur in thermal waters discharged over the uplifted basement to the NW of Beijing. These sulphates originate from surface oxydization of ascending H_2S. The sulphates with high $\delta^{34}S$ values and high Cl/SO_4 ratios, which are encoutered in the basement beneath the Beijing Graben, however, originate from the deep reservoir. Intermediate values indicate mixing between the two sulphate species which, in turn, is indirect evidence for lateral recharge of the deep thermal fluids in the Beijing geothermal field. The results are similar to those obtained by Truesdell *et al*, (1978) for Yellowstone Park (USA).

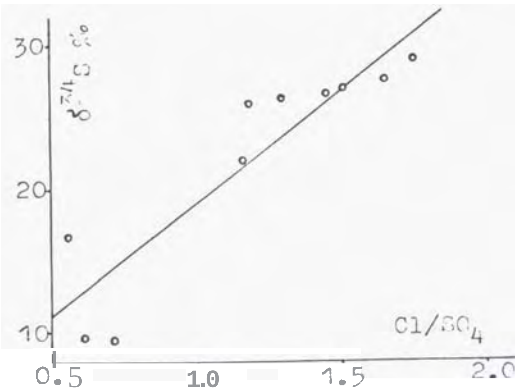

Fig. 5. $\delta^{34}S$ values versus Cl/SO_4 ratio of thermal waters in the greater Beijing Area (samples are the same as those for Fig. 4).

AGE OF THERMAL WATERS

The results presented so far indicate that the thermal waters encountered at depth in the Beijing Region originate from surface waters which infiltrated the high-standing mountainous terrain to the NW of Beijing and moved laterally in the basement over distances of more than 150 km to the SE. This implies a large residence time between precipitation and discharge. Determination of the radiometric age of thermal waters is a problem if mixing occurs (Ellis and Mahon, 1977). Determination of tritium content gives usually only a minimum age because of the short half-life of tritium, although it can be used to detect mixing with tritium enriched surface waters (Pearson and Truesdell, 1978). Radiometric dating using the ^{14}C as an indicator suffers from the problem that the proportion of ^{14}C derived from the atmosphere (and soils) and, the proportion lost through precipitation are unknown; nevertheless, an order of magnitude estimate can beobtained (Pearson and Hanshaw, 1970).

Table 1: Tritium content of thermal and cold surface waters in the greater Beijing Area (figures give content in tritium units, i.e. TU).

Location	April 1979	August 1979	June 1980
a) Thermal waters from wells in Beijing geothermal field.			
well 2	0.3	0.7	-
" 5	-	0.7	-
" 7	-	0.7	-
" 8	5.5	1.4	-
" 9	4.0	2.45	-
" 10	-	3.35	-
" 11	-	4.45	-
" 15	5.85	1.65	-
" 16	7.95	6.85	-
" 17	5.05	0.8	-
" 22	-	1.35	-
" 24	6.25	1.15	-
" Zheno -1	-	1.35	
" Zha -1	0.7	1.35	
b) Thermal waters from warm springs (NW from Beijing).			
Xiaotangshan	7.35	-	-
Liangxiang	15.5	-	-
Tongwuliying	-	-	11.9
c) Cold surface waters (groundwater and reservoir lakes).			
Tapwater	140	-	
Miyun reservoir	122	-	
Shisanling reservoir	96.5		-
Niangniangfeng	-		19.7

We determined the tritium content of thermal waters from wells in the Beijing geothermal field, as well as that of thermal springs from the uplifted basement in the NW and of cold surface waters. The results are listed in Table 1. It can he seen from these data that the tritium content of thermal waters from wells in the Beijing geothermal field is significantly lower than that of thermal springs which, in turn, is much lower than the tritium content of cold surface waters. Some "contamination" of the deeper thermal water with surface water, however, is indicated since the tritium content of deep thermal waters should be < 0.7TU if their radiometric age would be greater than 50 yrs (assuming a mean value of 10 TU for older waters which infiltrated the recharge area prior to thermonuclear explosions in the 1950's). Waters from some wells exhibit indeed such low values (refer to wells 2, 5, 7.). We estimated the effect of complete mixing (dispersion) of deep and surface waters which indicates a mean residence time of more than 10^3 yr for waters with < 0.7TU.

An attempt was made to determine the ^{14}C age of carbonates of deep thermal water which were precipitated in an airproof setting at one wellsite using barium chloride. This sample gave a radiometric ^{14}C age of about 17 x 10^3 yr, although this might be a minimum age since no correction for deeper precipitation and ^{13}C was made.

CONCLUSION

Taking into account the geological and hydrological setting, isotopic studies of thermal waters and cold surface waters in the Beijing region have shown that:

1. Thermal waters occur dominantly in the Sinian siliceous dolomite basement which underlies most of the region (i.e. the region shown in Fig. 1) and which outcrops in the mountainous terrain NW of Beijing.

2. Thermal water moves laterally through this basement which exhibits good permeability and constitutes a coherent (?) aquifer. The Tertiary to Mesozoic sediments which cover this aquifer in the SE sector (see Fig. 1) are rather impermeable.

3. The basement and the sedimentary cover rocks are cut by faults and fractures which formed in response to NW-SE oriented compressive stress fields. In the basement composite folds and compressive faults with NE-SW strike and tensional faults and fractures with NW-SE strike are dominant; the latter ones appear to be associated with lateral flow of thermal waters.

4, The thermal waters of the Beijing geothermal field belong to the Na-HCO_3 type of waters. Its chemical composition can be explained by a mixing model where Ca-HCO_3 surface waters precipitated in the mountainous area NK of Beijing (recharge area), infiltrates the deeper basement and mixes with deeper Na-SO_4 thermal waters which is discharged at the surface by thermal springs over the uplifted basement NW of Beijing.
The composition of the constituents in the deep thermal water from the Beijing geothermal field lies between the two types of water.

5. δD and $\delta^{18}O$ values of deep thermal waters obtained from wells in the SE sector of the Beijing Region indicate that these waters originate from the mountainous region NW of Beijing and which move laterally in the basement towards the SE over distances of more than 150 km.

6. Such lateral SE flow is also indicated for the smaller Beijing area by the distribution pattern of $\delta^{34}S$ data.

7. A large residence time (between >50 to several 10,000 yr) is indicated for the thermal waters by tritium values and ^{14}C data.

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