WERE THERMAL WATERS PRESENT BENEATH THE TIANJIN THERMAL AREA DERIVED DURING A GLACIAL PERIOD?

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SUMMARY - This paper is divided into two parts. The first part deals with the 'piston' mechanism for the origin of thermal water. The second part discusses the relationship between thermal water and a glacial period, and the concept that the isotopic shift of oxygen is not caused by the isotopic exchange between water and rock, but is controlled by climate.

1. THE AGE OF THERMAL WATER

The Tianjin geothermal field is a warm-water system, which is one of numerous thermal areas in northern China. The basement reservoir consists of Pre-Tertiary carbonates saturated with 90°C thermal water in karst-fissures . The overlying Tertiary sandstone and siltstone contain 50°C thermal water in the pores and fissures (Fig. 1)

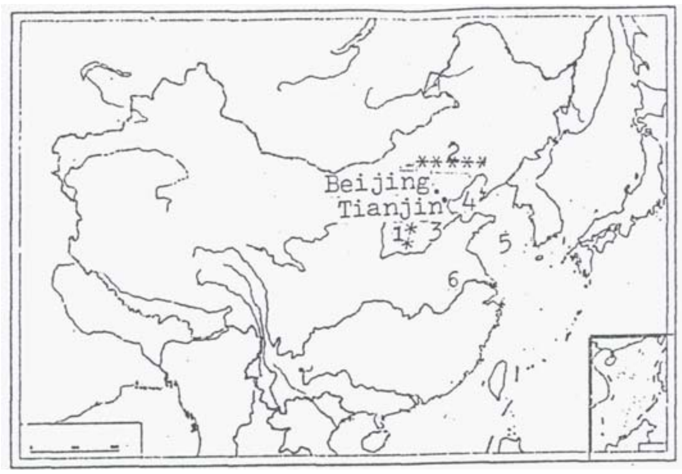

Figure 1. Location of Tianjin warm-water system. 1. Taihang Mountains, 2. Yanshan Mountains, 3, North China Plain, 4, Po Hai Sea, 5, East China Sea, 6, Yangtze River.

The age of the reservoir water is the elapsed time that meteoric water is retained beneath the surface. The age of Tianjin's thermal water has been obtained from the analysis of tritium and carbon 14. The results are shown in Table 1.

The tritium contents of Tianjin's thermal water are usually less than 5 TU representative of rain that fell before 1953. An accurate age of thermal water can also be determined using the carbon 14 dating method. The measured ages determined from carbon 14, corrected with reference to the accompanying 13C value, are between 6 to 27 thousand years, i.e. Late Pleistocene.

Table 1. The ages of ^{14}C and tritium values of thermal waters beneath Tianjin

No.	Aquifer	T(TU)	^{14}C age (corr.)
005	Nm	1.0	16034
054	Nm	1.2	26841
057	Nm	2.5	
SR-3	Ng	0.3	6155
SR-2	E		18474
SR-8	E		23836
SR-1	Pt2-3	1.1	13305
076033	N	1.0	
416082	Q	2.0±0.8	
R1409	N	1.4	
R0618	N	6.9±1.0	
w-2	Pt	2.83	18540
2 3	N	1.79	29310
Z-4	Pt	1.8±0.9	
R-1	O	1.75	
J-9	O	1.7±0.9	
Zh-3	Pt	0.7	26310
w-3	Pt	1.26	
wR-4	O		22520
R0615	Ng		23790

N - Neogene, Nm - Minghuazheng Formation of Neogene, Ng - Guantao Formation of Neogene, Q - *Quaternary*, O - Ordovician, E - Cambrian Pt - Proterozoic group.

The helium-argon age of thermal waters beneath Tianjin has been determined by Zhang (1986) who inferred that it is the true *age;* the ^{14}C age is an upper limit for *the* age of thermal waters. The He-Ar ages range from 1 to 3.5 Ma (Zhang, 1986).

We ma& the following deductions from Table 1:

1. The age of thermal water beneath Tianjin is younger than that of the reservoir rock. Thus, the thermal water is not the stored water. This is supported by hydrochemical and oxygen isotope data.

2. The thermal water in the Tertiary and basement rocks *are* identical in age. Some Tertiary thermal waters are older or younger than that of the basement rocks because of the different hydrological conditions in different places.

It was thought that the thermal water was contained in the reservoir **rock** when it was deposited (connate) but now the consensus view is that the thermal water is meteoric. The flow of water *can* be understood in terms of a "piston" mechanism. The throw of the aquifer between the North China plain and the surrounding mountains is more than 7000 m. The mountains therefore provide an impermeable barrier to the north and west. They surround the plain and thus become the recharge area for the aquifer. Meteoric water seeps in and eventually fills up in the aquifer. There are two source areas: one recharge area overlies the Tertiary aquifer and supplies water, along a fault under hydrostatic pressure, that mixes with Tertiary water; the other source area lies to the east of the aquifer, namely the Po Hai Sea. This hydrogeology-structural system has persisted since the Pleistocene (Shi Yafeng, et al., 1989).

2. THERMAL WATER ASSOCIATED WITH GLACIAL EPOCH

Based on age data, thermal waters beneath Tianjin entered the reservoir from the late Pliocene to the end of the Pleistocene. The Pleistocene was associated with four glacial epochs. The youngest water probably entered the reservoir at the height of Würm Glaciation. At that time, there was no ice sheet on the North China Plain, but there were periglacial features. According to glaciology studies; most of North China was an arid prairie while the most northern part of North China was tundra during the height of Würm glaciation. The ancient Beijing Plain was arid grassland. The climate was *dry* and cold; the annual temperature was 8°C lower than today, and precipitation was a 1/3 of the present rainfall. The largest regression during the late Pleistocene occurred before 25 thousand years. The sea shore was 600 km east of the modern line and the Yangtze river meandered over the shelf of the East China Sea. Over most of North China, northerly winds blew and deposited loess.

This paper discusses the relationship between thermal water and glaciation using hydrogen and oxygen stable isotope data. Table 2 shows representative isotopic water compositions in northeastern Tianjin.

A study of world-wide fresh water samples by H. Craig (1963) showed that the isotopic compositions of cold meteoric waters were related by the equation $6D = 8\ 6^{18}O + 10$. Their straight line, commonly referred to as the meteoric water line, is shown in Fig. 2. A plot of stable isotope data in standard 6 value (‰) relative to SMOW is also shown. The isotopic values of 6D and $8^{18}O$ for the Quaternary water (No.4) at the boundary of the Tianjin field are -66.5 ‰ and -9.37 ‰ respectively; the values are close to those of precipitation in the northern mountains (-9.78 ‰ for $\delta^{18}O$ and -68.1 ‰ for δD, respectively). Depletion of δD value and enrichment of $\delta^{18}O$ affected the others.

Table 2 The δD and $\delta^{18}0$ values of water from thermal wells of NE Tianjin (in ‰). Key Same as Table 1.

No.	Depth of exposed pipe(m)	Aquifer	δD	$\delta^{18}0$
1	261	Q	-9.24	-71.4
2	400	Q	-9.55	-71.3
3	418.34	Q	-8.77	-67.8
4	446.6	Q	-9.37	-66.5
6	548.32	Nm	-8.79	-71.3
7	616.1	Nm	-8.55	-72.6
8	640	Nm	-8.95	-67.8
10	699.4	Nm	-8.92	-80.4
11	716.1	Nm	-8.88	-67.3
12	791.2	Nm	-8.84	-80.1
13	916.13	Nm	-9.30	-67.7
14	1008	Nm	-8.75	-81.3
15	1183.7	Nm	-9.52	-80.7
16	1200.51	Nm	-9.24	-75.5
17	1250	Ng	-8.56	-64.8
18	1348.94	Ng	-8.75	-72.9
19	1170	E	-9 05	-75.1
20	1445	E	-9.06	-74.6
21	1673	Pt3	-9.00	-72.0

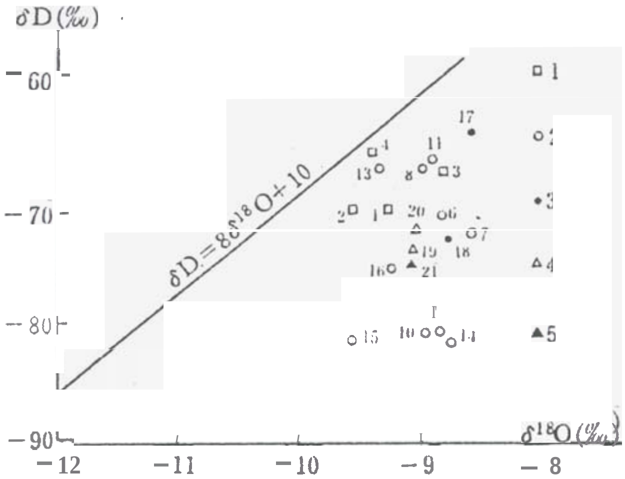

Fig. 2. Relationship between concentrations of deuterium and oxygen-18. Reference symbols refer to wells listed in Table 2.
1. Quaternary aquifer, 2. Minghuazheng Formation (Neogene), 3. Guanto Formation (Neogene), 4. Cambrian aquifer, 5. Proterozoic aquifer.

The depletion relative to present-day cold water might have occurred at a higher altitude, or in the past when the climate was colder. If we can affirm that the thermal water is related to Holocene precipitation, we *can* compare our data with the meteoric water line and then discuss the recharge and reservoir processes. If the thermal waters are older than Holocene, the present-day meteoric water line cannot be used. The thermal waters beneath Tianjin are Pleistocene (Table 1) so that the present-day meteoric water line is unsuitable for discussion of recharge.

The annual temperature in the height of Würm glaciation around Tianjin might have been 3.7°C (i.e. subtract 8°C from the present 11.7°C). If we use the equation which links the annual temperature (ta) and isotopic compositions of meteoric waters (Zhang Ligang, 1985): $\delta^{18}O = 0.35$ ta - 13‰ and $\delta D = 2.8$ ta - 94‰, the isotopic values of δD and $\delta^{18}O$ in late Pleistocene might have been -83.64% and -11.7980, respectively. If we compare these with average values of thermal waters in the basement ($\delta^{18}O$ - -9.03‰, δD - -73.9‰) and in the Tertiary system ($\delta^{18}O$ - -8.92 ‰, δD - -33.53‰) beneath Tianjin, the latter shows obvious enrichment. How did recharge occur in the late Pleistocene?

With regard to the oxygen shift or enrichment of ^{18}O common to many geothermal systems, the conventional explanation is that oxygen isotopes in geothermal systems are exchanged between hot rocks and deeply circulating meteoric waters. But isotope exchange reactions between water and rock occur slowly at temperatures below 150°C (Hobba and others, 1979) and generally occurs only in systems having reservoir temperatures equal to, or *greater* than, about 100°C (Ellis and Mahon, 1977). The 'oxygen isotopic shift ' in Tianjin warm-water system cannot be explained by use of isotopic exchange between water and rock.

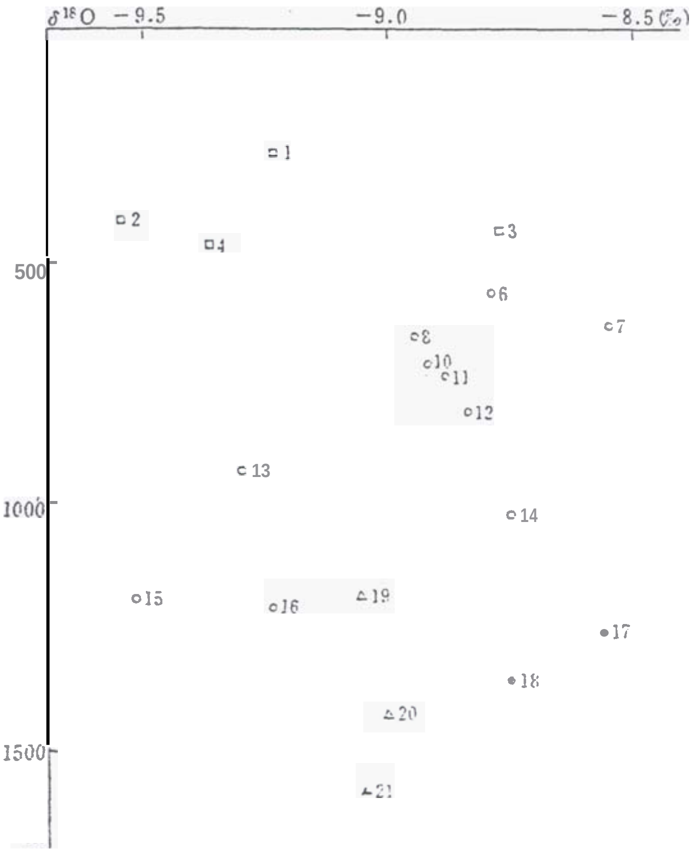

Fig. 3. Relationship between depth of exposed pipe in drillhole and the concentration of O^{18}. (for number and symbol, refer to Fig. 2).

Fig. 3 shows the relationship between $\delta^{18}O$ values and well depth in northeastern Tianjin. Note that

1) the lowest $\delta^{18}O$ values, with average of -9.23% occurs in the Quaternary aquifer, which is close to that of present-day meteoric water. One higher value is interpreted as Tertiary thermal water flowing along the Haihe Fault;

2) the $\delta^{18}O$ values for thermal water in the basement reservoir are -9.0 ‰ which is close to that of the Quaternary thennal waters. Thus present-day meteoric water is recharging basement rock

3) The Tertiary thermal waters have heavy $\delta^{18}O$ values ranging from -8.5 to -9.0‰ and their average is -8.92‰. Some well waters at the margin of thermal field have light $\delta^{18}O$ values.

How does one explain the enrichment of ^{18}O in the Tertiary aquifer? The oxygen and hydrogen isotope compositions should be low for meteoric water because of the low temperatures in the glacial epoch. But the North China Plain was an arid area in the Würm glaciation. *Dry* condition and strong evaporation would have produced higher δ values in precipitation in the late Pleistocene. Furthermore, the thermal water in the Tertiary aquifer is a mixture of glaciation and interglacial period water. Thus a low δ value of thermal water in the Tertiary aquifer beneath Tianjin is not possible because of the many influences of climate and the altitude effects at that time.

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