ENVIRONMENTAL ISOTOPE STUDY RELATED TO GROUNDWATER AGE, FLOW SYSTEM AND SALINE WATER ORIGIN IN QUATERNARY AQUIFERS OF NORTH CHINA PLAIN

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Abstract

An isotopic hydrology section across the North China Plain has been studied to investigate problems of groundwater age, flow system and saline water origin in a semi-arid pre-mountain artesian basin. Two local and one regional flow systems along the section have been recognized. Turnover time of water for alluvial fan, shallow and regional systems are estimated to be the order of 10^2, 10^3, and 10^4 years respectively. Specific flow rates for the three systems have been calculated. Only less than 5 percent of flow from alluvial fan is drained by the regional flow system and the rest, in natural conditions, discharges at surface in the front edge of a alluvial fan and forms a groundwater discharge belt at a good distance away from the mountain foot. Developed in the alluvial plain and coastal plain areas the shallow flow system embraces a series of small local systems. Groundwater in these systems appears to be the salt carrier during continental salinization. It washes salt out of recharge area and deep-occured strata by circulating and carries it upto surface in lowland areas. Consequently, in parallel with salinization at surface a desalinization process occurs at depth, which provides an additional explanation for existing of a thick deep fresh water zone in most arid and semi-arid regions, where continental salting process is in progress.

Introduction

The study area is located in the northern part of the North China Plain, between 37° and 39° north latitude and 114° and 118° east longitude (Fig. 1). It covers an area of about 60,000 km^2 between Bohai Bay in the east and the Taihang mountains in the west. The topography rises up gradually from the coast to about 100 m at a distance of 300 km, after which the gradient becomes steeper with the maximum elevation at the crest of the Taihang mountains being 3.5 km.

The area covers part of the Haihe river basin. Five of its tributaries pass through the region, among them the Hutuo and the South Canal rivers are the largest with catchment areas of 18,000 and 25,000 km^2 respectively. The climate is essentially semi-arid with annual precipitation of 500-600 mm, two thirds of which occur in the July- September period, and it is used to cause frequent waterlogging in the terrain. The rest of the year is extremely dry. Most of streams are seasonal with occasional flood discharge upto some 10^3 m^3/s in summer months. During the last 20 years a series of reservoirs were built in the Taihang mountains and piedmont areas for the stream flow controlling.

1. Hydrogeology

The North China Plain is underlain by 3-10 km thick Cenozoic terrigenous deposits with Quaternary part of 400-600 m thick. It represents a typical semi-arid pre-mountain artesian basin, hydrogeologically, it is characterized by marked horizontal and vertical zonations. Laterally, from the piedmont toward the seacoast 3 belts can be recognized (Fig. 2): the alluvio-diluvial fan of Hutuo river (belt I); the alluvial plain of Haihe and Old Yellow rivers (belt II), and the coastal plain along Bohai Bay (belt III). In this direction grain size and permeability of sediments decrease, portion of impermeable layers and salinity of water increase[1].

Another important characterestic is development of vertical hydrochemical zonation different from that in humid terrains. It has been noted that a saline water zone is commonly formed, resulting from continental salting process in the top part of artesian basins in arid and semi-arid regions. On the top of this zone float a limited number of fresh water lenses. The saline water zone itself is underlain by a deep fresh water zone hundreds and even thousands of meters thick. It is believed also that such a deep fresh water zone is formed due to the pressure head of water developed in the elevated piedmont area in front of folded mountains, which forces fresh water to 'intrude' into the deep part of artesian basin. In the study area the thickness of saline water zone (the second aquifer) is estimated as 50-100 m for its most part, increasing seaward upto 300 m at sea coast (Fig. 2). The top fresh water lenses (the first aquifer) are commonly of 10-50 m thick and 10-30 km in diameter, while the deep fresh water zone (the third aquifer) reaches a depth of more than 1000 m beneath the surface with a Quaternary fresh warwe zone of 400-500 m thick. Deep fresh water, in turn, is underlain by oil field water.

North China Plain is one of the most economically developed areas in the country. However, limited water resources can not meet the growing demand. Therefore, rational use of water resources is crucial in economic development of the region. Groundwater investigation has been carried out at an increasing rate over the last 30 years. It was suggested that an environmental isotope study might shed light on the problems of groundwater age, flow system and saline water origin in the area. The study is still in progress and this paper is a presentation of preliminary results of the investigation.

2. Sampling and isotope data

Water was sampled from 62 locations, lined up along Shijiazhuang-Shulu-Hengshui-Cangzhou so as to get whole picture of an isotope hydrology section across the Plain (Fig. 1). All samples have been analysed for stable isotope composition, of them 9 for carbon-14 and carbon-13, and 32 for tritium. All samples except one (NC-3) were collected from groundwater and were rather equally distributed among different aquifers and hydrogeological belts. All groundwater samples were collected from either open wells or boreholes. The sampling was made in April/May 1985, i.e. towards the end of the dry season. Two sets of samples were collected simultaneously. One of them was sent to the IAEA laboratory, while the other to the laboratory at Zhengding (the Institute of Hydrogeology and Engineering Geology). The results from two laboratories were in good consistence (Table I).

A parallel hydrochemical survey was also done in order to obtain a better understanding of hydrogeochmical and isotope geochemical processes existing in this area. The results are presented in Table I.

3. Groundwater age

Tritium

Tritium contents vary from about 90 to 0 TU. The third or deep fresh water aquifer contains no significant tritium, nor does the second or saline water aquifer except one (NC-52), which must be pointed as a result of some trouble with sampling techniques. The high contents are all in the first or shallow fresh water aquifers, no matter which belt they are from. This indicates that this water was recharged during the last few decades since the commencement of atmospheric testing in early 1950s or its age is younger than 30 years.

Carbon-14

The small number of carbon-14 samples range from 4.5 to 93.5 pmc. In all cases the absence of tritium coincides with the lower carbon-14 values. It is well known that uncertainty in water ages derived from carbon-14 measurements comes mainly from models adjusting for dilution by dead carbon. In this study 3 models[3,4,5] were used for calculation (Table II). Because of lack of actually measured values of ^{13}C in soil CO_2 and carbonate minerals for the area, the commonly accepted values, i.e. -25‰ and 0‰, were used in the calculation instead. Water ages derived from different models differ from each other no more than 3,000-6000 years (Fig. 4).

Quaternary water in Hutuo alluvial fan (the first aquifer)

9 samples were collected for tritium analyses. 8 of them were taken from depth less than 110 m. All of them contain significant amounts of bomb tritium. Only one (NC-18) taken from depth of 250 m contains 1.5 TU tritium, which indicates that water contained bomb tritium is presumably penetrating down to 200-250 m beneath the surface. Carbon-14 measurements (No-14 and No-18) support the same conclusion.

Saline water (the second aquifer)

Three saline water samples collected from depths 40-60 m beneath the land surface were submitted for carbon-14 analyses. The results show that all of them are younger than 1,000-2,000 years, i.e. beyond the upper limit of carbon-14 dating of water. This strongly suggests that most part of saline water must be younger than 1,000-2,000 years. However, because of lack of the data problem of saline water age in the coastal plain area is still open.

Deep fresh water (the third aquifer)

4 carbon-14 samples were collected for determining deep fresh water age. As mentioned above, carbone-14 ages derived

from three models differ from each other no more than 3,000-6,000 years. Inasmuch as the water ages determined range from 10,000 to 25,000 years BP, the difference in dating is only about ±30%. This should be quite acceptable for ordinary hydrogeological investigations.

Close examination of isochrones on the hydrogeological section (Fig. 3) makes it evident that the recharge rate in cold period (from 20,000 to 10,000 years BP) was several times larger than in warm period (from 10,000 to 1,000 years BP). A possible explanation for this is the descent of sea level during the glacial period, which would cause in artesian basin much steeper hydraulic gradients to occur. The fact that all samples dated older than 10,000 years BP show values 1.5-2‰ more depleted than those of recently recharged water is a weighty evidence verifying the feasibility of carbon-14 method for groundwater dating in the project area.

4. Groundwater flow systems

Analysing regional groundwater flow J.Toth[5] introduced a flow system model, according to which three types of flow systems can be commonly determined: local, intermediate and regional. The environmental isotope techniques have been particularly useful in studying groundwater flow system. Along the hydrogeological section studied two local and one regional flow systems have been recognized (Fig.3 and Table III), which exert major control of water resource distribution and salt migration in the area.

Alluvial fan flow system

This is a phreatic and partially confined aquifer system. Turnover time of water is estimated as 100-200 years. Because of intensive circulation of water there is no saline water zone here. Stable isotope composition of groundwater is quite uniform ($\delta^{18}O$=-8.4‰ in average) and show no significant evaporation effect probably besause the groundwater level occurs at a great depth (usually >10 m) (Fig. 3 and Table IV).

Shallow flow system

Developed in the alluvial plain and coastal plain belts (II and III) it embraces a series of small local systems. Each local system represents itself an individual phreatic aquifer system lying above the first regional aquitard and consists of saline water body with small fresh water lenses floating on the top. Lower boundary of local systems occurs at a depth of 50-100 m.

When considered as a whole, that is over all three belts, in reference to Fig. 5 the isotope composition of groundwater demonstrates that all samples from the first aquifer (shallow fresh water) tend to show an evaporation effect in comparision with the samples from the second (saline water) and third (deep fresh water) aquifers. The regression line 1, computed on the basis of samples from saline water and deep fresh water aquifers is:

$$\delta D=(7.40\pm0.36)\delta^{18}O-0.4\pm3.5 \qquad r=0.971$$

Regression line 2, computed on the basis of all samples from the shallow fresh water aquifer is:

$$\delta D=(5.22\pm0.29)\delta^{18}O-18.3\pm2.4 \qquad r=0.955$$

These lines intersect at about the stable isotopic composition estimated for local recharge, i.e.

$$\delta^{18}O=-8.2\sim-8.4‰$$

The sample from Huang Bi Zhuang Reservoir (NC-3) provides an example of a sample which is clearly evaporated (Table I). Reference to Fig.6 shows the groundwater evaporation process is mainly controlled by the depth of the groundwater level. Isotopic evidences show that groundwater evaporates only in the case, if water level occurs less than 2-3 m deep. which is fully consistent with the results derived from ordinary hydrogeological investigations.

Samples from the middle (saline water) aquifer also exhibit a range of stable isotope composition (e.g. from -8 to -10 per mil in Oxygen-18) which is indicated that the saline waters should not originate from a common source. In fact, it is conceivable that the variation in stable isotope composition of saline water samples results from the mixing with the much more depleted water in the third aquifer and the more recent water in the first aquifer. Based on the tritium and carbon-14 data, the turnover time for the system is estimated to be about 1,000-2,000 years.

Regional flow system

Beneath two local systems there is a regional flow system extending throughout the area in a distance of more than 300 km. It is essentially a confined artesian aquifer system with recharge area at the rear of Hutuo alluvial fan. Under a hydraulic pressure of 40-50 m, formed in elevated piedmont area, recharge water is injected into the artesian system. Furthermore, stable isotopic data indicate that this water should pass through the aquitards above and discharge upward into the shallow aquifers and mix with saline water. The typical shape of water salinity curves, which demonstrate a maximum in the middle part of profile, also strongly supports the above suggestion.

Carbon-14 data show the turnover time is about 20,000 years.

5. Saline water origin

Preliminary examination of hydrogeological situation in the study area leads to three hypotheses on saline water origin: i.e. mixing with sea water, enrichment by evaporation, and leaching from basement rocks. It is well known that stable isotopes are a useful tool for solving such a problem[6]. In Fig. 7 salinity of water is plotted vs. its $\delta^{18}O$ value. Line 1 stands for evaporation trend while line 2 shows the trend of leaching process. It can be seen from Fig. 7 that five out of seven saline water samples show clearly the leaching effect. Another is not quite indicative because of low salinity and the rest can be interpreted as a mixture of both leaching and evaporated waters.

6. Shallow flow system and continental salinization

Fig. 8 summarizes certain chemical and isotopical data from shallow flow system showing some characteristics of salt distribution and ground water flow pattern. Close examination of those data suggests that ground water in the shallow system appears to be the salt carrier during continental salinization .

Circulating, it washes salt out of recharge area and deep occured strata and carries it up to the surface in lowland areas, where groundwater discharges in the form of evaporation and salt accumulates immediatly beneath the land surface. Therefore pedological salinization is a process of salt accumulation in soil, but for hydrogeologist it must consist of two parallel processes: accumulation of salt in upper young sediments and desalination of deep-occured rocks. The deeper the sediments occur, the longer they should have affected by desalination process. Thus desalination of deep-occured strata may provide an additional explanation for the existence of a thick deep fresh water zone in most arid and semi-arid region, where continental salting process is in progress.

References

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Table I. Chemical and environmental isotopic composition of the surface water and groundwater

Serial No.	Ele. of well (m)	Deep of well (m)	Area & aquifer	Static water level (m)	D (‰)	^{18}O (‰)	d (‰)	T (TU)	^{13}C (‰)	^{14}C (pmc)	Water chemistry analysis								
											C_a^{++} (mg/l)	M_g^{++} (mg/l)	$N_a^{+}+K^{+}$ (mg/l)	HCO_3^{-} (mg/l)	$SO_4^{=}$ (mg/l)	Cl^{-} (mg/l)	M (g/l)	pH	T (°C)
Nc-1	80	60	I_1^1	24.92	-61.10	-8.39	6.02	96.04*			96.	25.	30.	305.	107.	31.	0.600	7.46	15.
Nc-2	85	50	I_1^1	14.05	-61.00	-8.27	5.16				103.	25.	27.	300.	108.	31.	0.614	7.94	15.
Nc-3	115		I_1^1		-55.50	-7.25	2.50	71.05*											
Nc-4	105	45	I_1^1	9.5	-61.30	-8.20	4.30	73.40	-9.56	93.50	152.	30.	24.	354.	156.	45.	0.804	7.33	15.
Nc-5		30	I_1^1	10.5	-61.25	-8.09	3.47												
Nc-6	88	16	I_1^1	10.92	-60.60	-8.10	4.20				98.	25.	21.	283.	95.	33.	0.572	7.39	15.
Nc-7	80	50	I_1^1	24.5	-62.80	-8.50	5.20	95.99*			98.	24.	22.	300.	88.	33.	0.576	8.06	15.
Nc-8	65		I_1^1	17.7	-62.50	-8.49	5.42				122.	29.	51.	288.	147.	94.	0.745	7.73	15.
Nc-9	65	31	I_1^1	17.00	-61.30	-8.53	6.94	89.10			88.	24.	32.	254.	104.	48.	0.553	7.66	15.5
Nc-10	85	20	I_1^1	11.	-59.40	-7.58	1.24				138.	34.	48.	366.	202.	52.	0.842	7.83	15.
Nc-11	73	84	I_1^1	27.66	-63.60	-8.61	5.28	26.28*			95.	24.	28.	268.	96.	47.	0.568	7.42	16.5
Nc-12	70	110	I_1^1	25.5	-66.40	-9.07	6.16	9.60			88.	21.	22.	295.	44.	34.	0.529	8.09	17.
Nc-13		40	I_1^1	20.	-62.90	-8.21	2.78	68.70			369.	56.	90.	312.	102.	670.	1.647	7.35	16.5
Nc-14			I_1^1	15.	-62.60	-8.40	4.60				62.	29.	34.	247.	46.	57.	0.494	7.72	15.5
Nc-15		30	I_1^1	11.	-63.30	-8.44	4.22												
Nc-16		30	I_1^1	9.5	-63.40	-8.72	6.36	12.65*			82.	60.	60.	383.	48.	146.	0.790	7.26	15.
Nc-17		60	I^1	12.04	-62.40	-8.38	4.64				88.	35.	23.	278.	42.	94.	0.577	7.30	15.
Nc-18		250	I^2	13.36	-65.60	-9.00	6.40	1.50	-9.22	67.50	68.	19.	20.	234.	65.	21.	0.429	7.58	16.
Nc-19	2	560	III^3	60.	-68.80	-9.11	4.08	0.50	-12.18	7.50	11.4	18.	566.	351.5	175.8	602.	1.558	7.98	
Nc-20	3	132	III^3		-70.80	-9.44	4.72				22.	14.6	438.2	341.6	146.5	446.7	1.242	8.	24.
Nc-21	3	<10	III^1	1.5	-49.70	-6.13	-0.66	62.95*			114.2	104.6	616.4	768.9	115.3	925.2	2.26	7.3	11.
Nc-22	4	481.2	III^3	37.	-71.40	-9.51	4.68	6.93*			16.	13.4	439.3	335.4	148.9	432.5	1.224	8.	24.
Nc-23	5	4	III^1	1.5	-50.60	-6.11	-1.72	41.20			114.2	104.6	616.4	768.9	115.3	925.2	2.26	7.3	11.
Nc-24	5	400	III^3	40.	-71.60	-9.83	7.04				15.	6.1	391.1	317.2	168.1	327.9	1.085	8.2	19.
Nc-25	6	4	III^1	1.5	-55.40	-6.87	-0.44				196.4	248.1	746.4	680.4	153.7	1712.2	3.397	7.5	12.
Nc-26	7.3	354	III^3	40.	-75.30	-10.09	5.42				14.	9.7	323.4	335.3	204.1	196.7	0.925	8.4	22.
Nc-27	10	105.5	III^2		-68.50	-9.21	5.19				100.2	190.9	1491.5	735.2	1354.4	1598.8	5.122	7.7	15.
Nc-28	10	818.9	III^3		-71.40	-9.50	4.60				10.	3.7	526.8	365.8	170.5	489.2	1.411	8.2	25.
Nc-29	10	350	III^3	60.	-74.70	-9.93	4.74				11.	10.3	308.2	356.7	184.9	163.1	1.04	8.	19.
Nc-30	11.7	307	III^3		-64.00	-8.75	6.00				9.	7.9	285.2	371.9	151.3	140.	0.788	8.3	18.

See Next Page

Table I -- Continued

Nc-31	12	300	III^{3}	40.	-75.40	-10.09	5.32				12.0	9.1	270.3	350.9	136.9	145.4	0.761	8.2	
Nc-32	12	10	III^{1}	4.	-58.90	- 7.79	3.42				111.2	123.4	686.5	622.4	571.6	522.9	2.127	7.4	13.
Nc-33	11	>10	III^{1}	4.	-61.60	- 8.40	5.60				24.1	28.	269.1	451.5	172.9	147.1	0.869	7.8	14.
Nc-34	10	9.5	III^{1}	4.	-60.10	- 7.94	3.42				24.1	28.	269.1	451.5	172.9	147.1	0.869	7.8	14.
Nc-35	13	220	III^{3}		-75.10	-10.14	6.02				6.	3.7	222.	283.5	120.1	102.8	0.602	8.1	20.
Nc-36	14	9	III^{1}	4.	-62.70	- 8.41	4.58				64.1	74.2	216.2	585.8	216.1	163.1	1.027	7.5	14.
Nc-37	15	9	III^{1}		-63.00	- 8.36	3.88				92.2	149.6	351.9	610.2	494.7	421.9	1.815	7.6	12.
Nc-38	10	350	III^{3}		-74.70	- 9.98	5.14	0.10	- 9.53	6.40	15.2	14.5	281.9	377.9	175.8	151.	0.82	7.87	
Nc-39	10	10	III^{1}		-60.90	- 7.84	1.82	20.40*			30.1	58.2	190.9	890.9	7.2	81.5	0.834	7.5	14.5
Nc-40	10	58.2	III^{2}		-70.60	- 9.20	3.00	1.47*	- 6.38	40.80	190.8	405.	2140.	484.9	2547.	2650.	8.181	7.7	
Nc-41	13	350	II^{3}		-78.00	-10.28	4.24	0.00*			8.	3.6	261.1	298.5	180.1	104.6	0.72	8.1	25.
Nc-42	15	9	II^{1}		-61.90	- 8.29	4.42	12.30			108.2	86.9	174.8	418.	302.6	248.2	1.13	7.5	15.
Nc-43	16	267	II^{3}	20.	-77.50	-10.55	6.90	0.00*			9.	1.2	167.9	158.4	96.1	106.4	0.467	8.1	24.
Nc-44	18	300	II^{3}	20.	-79.50	-10.49	4.42				6.	6.1	181.7	143.1	129.7	120.5	0.523	8.2	
Nc-45	19	15	II^{1}	3.	-60.50	- 8.36	6.38				334.	229.	405.	482.	963.	912.	3.057	7.3	16.
Nc-46	20	300	II^{3}		-78.00	-10.37	4.96	0.40			8.	7.	235.	259.	161.	128.	0.67	8.2	21.
Nc-47	20	10	II^{1}	4.	-61.10	- 8.08	3.54	7.40											
Nc-48	21	230	II^{3}		-80.30	-10.77	5.86				9.	5.	199.	168.	127.	142.	0.569	8.3	22.
Nc-49	22	15	II^{1}	2.	-60.70	- 8.18	4.74	37.46*			128.6	94.2	115.9	499.1	141.2	286.8	1.017	7.5	
Nc-50	22	472.03	II^{3}		-76.30	-10.35	6.50	0.70	-10.37	4.50	10.4	4.6	255.4	201.4	153.2	195.7	0.72	6.5	
Nc-51	23	54.5	II^{2}		-69.10	- 8.98	3.74	0.00*	- 8.38	52.20	362.5	873.8	2498.	544.9	3020.	4495.	11.5	7.	
Nc-52	24	50	II^{2}		-69.80	- 9.24	5.12	24.22*											
Nc-53	24	270	II^{3}		-80.60	-10.94	6.92	0.00			62.	34.	175.	88.	204.	275.	0.794	7.9	20
Nc-54	24	36	II^{2}	6.	-58.90	- 7.88	4.14	0.50	- 9.05	62.20	324.4	572.8	1247.	450.3	2284.	2220.	6.873	7.	
Nc-55	22	270	II^{3}	6.	-78.10	-10.52	6.06				19.	10.	176.	156.	154.	130.	0.567	8.1	22.
Nc-56	22	47.2	II^{2}		-71.40	- 9.75	6.60				176.	325.7	1223.8	524.6	1891.2	1441.3	5.337	7.4	14.5
Nc-57	25	30	II^{2}		-67.80	- 9.25	5.88				380.	1067.5	3364.2	61.	4440.	5768.8	15.15	6.	15.
Nc-58	26	4	II^{1}	1.2	-54.10	- 7.30	4.30	46.37*			402.	145.	437.	525.	595.	1065.	2.906	7.3	14.5
Nc-59	27	4	II^{1}	2.	-57.10	- 7.93	6.34				402.	145.	437.	525.	595.	1065.	2.906	7.3	14.5
Nc-60	35	260	II^{3}	30.	-67.60	- 9.68	9.84	0.20	- 8.99	16.10	9.6	26.	75.9	281.9	52.4	7.4	0.312	7.6	
Nc-61	67	100	I^{1}	17.82	-58.90	- 8.07	5.66				66.	18.	15.	215.	61.	20.	0.397	7.74	16.
Nc-62	70	97	I^{1}		-61.70	- 8.44	5.82												

Data of Sampling: Nc-1 to Nc-7 85-04-26; Nc-8 to Nc-18 85-04-27; Nc-19 to Nc-26 85-05-05; Nc-27 to Nc-40 85-05-06;
Nc-41 to Nc-50 85-05-07; Nc-51 to Nc-55 85-05-08; Nc-56 to Nc-60 85-05-09; Nc-61 to Nc-62 85-05-14
Note: Analysed in IHEG Laboratory

Table II. Calculation of ^{14}C Age of Groundwater

No.	$\delta^{13}C$ (‰)	$A^{14}C$ (pmc)	T (TU)	Pearson model		IAEA model		Fontes model	
				A_s(pmc)	Age (ka)	A_s(pmc)	Age (ka)	A_s(pmc)	Age (ka)
NC−4	−9.56	93.5	73.4	38.2	A.N.	91.8	A.N.	34.7	A.N.
NC−18	−9.22	67.5	1.5	36.9	R	73.8	<0.1	34.5	R
NC−19	−12.18	7.5	0.5	48.7	15.5	97.4	18.8	60.7	17.3
NC−38	−9.53	6.4	0.1	38.1	14.8	76.2	18.1	38.9	15.0
NC−40	−6.38	40.8	1.5	25.5	R	51.0	<0.2	13.1	R
NC−50	−10.37	4.5	0.7	41.5	18.4	83.0	21.7	30.0	15.7
NC−51	−8.38	52.2	0	33.5	R	67.0	<0.2	23.2	R
NC−54	−9.05	62.2	0.5	36.2	R	72.4	<0.2	28.7	R
NC−60	−8.99	16.1	0.2	36.0	6.5	71.9	10.0	32.7	5.9

R—Recent　　A.N.—After thermal nuclear test

Table III. Flow systems in Quaternary Aquifers, North China Plain

Nomenclature	No. of systems	Geometry		Recharge-discharge pattern		Groundwater age (a)	Specific rate of flow (m^3/day)	
		Horizontal (km)	Vertical (m)	Recharge	Discharge		Isotopic method	Hydrodynamic method
Local alluvial fan flow system	1	100	300	Infiltration of rain and surface water at the rear of piedmont alluvial fans	In the forms of springs swamps and marshland in the front of alluvial fans	$<2\cdot10^2$	>30	1.0-3.0
Local shallow flow system	2	10-30	50-100	Infiltration of rain and surface water in present and old river bed belts	Evaporation in the interstream lowland and coastal plain areas	$<2\cdot10^3$	>0.2	0.01-0.1
Regional flow system	3	300	500	Infiltration at the rear of piedmont alluvial fans and deep lateral groundwater flow	Upward discharge into the phreatic aquifers	$<2\cdot10^4$	Present period 0.2-0.5 ------ Glacial period 1-2	0.05-0.1

Table IV. Isotopic Composition Averaged for Different Groundwater Groups

Hydrogeological area		Aquifer		n	δD ‰		$\delta^{18}O$ ‰	
					$\bar{x}$	σ_x	$\bar{x}$	σ_x
Alluvial fan of Hutuo river	I	1	Shallow fresh water	18	−62.0	1.66	−8.4	0.30
		3	Deep fresh water	1	−65.6	—	−9.0	—
Alluvial plain	II	1	Shallow fresh water	13	−60.5	2.52	−8.1	0.35
		2	Saline water	7	−67.7	3.81	−9.1	0.35
		3	Deep fresh water	15	−76.1	3.30	−10.3	0.38
Coastal plain	III	1	Shallow fresh water	3	−51.9	2.50	−6.4	0.35
		3	Deep fresh water	4	−70.7	1.11	−9.5	0.25

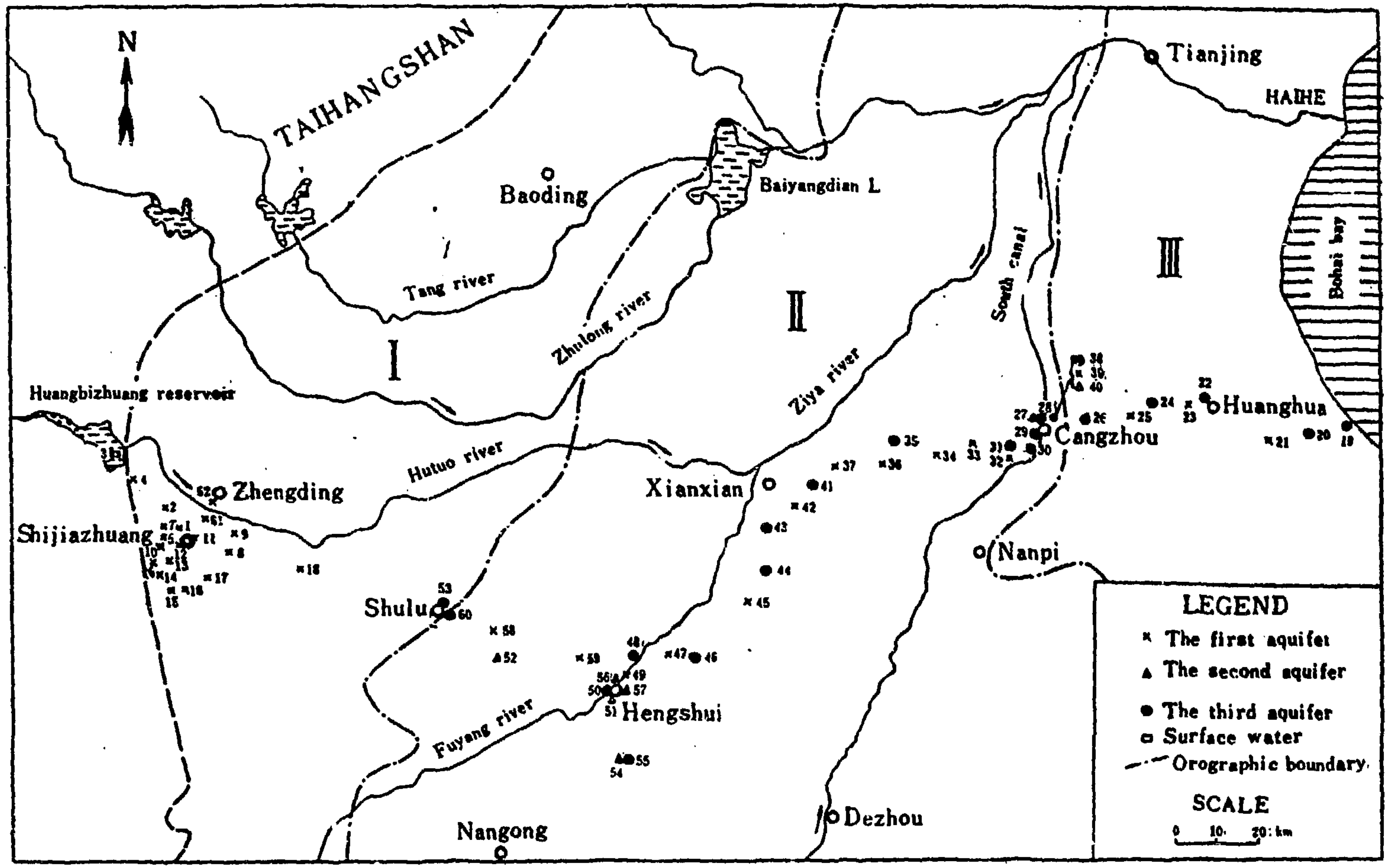

Fig. 1 Location of sampling points

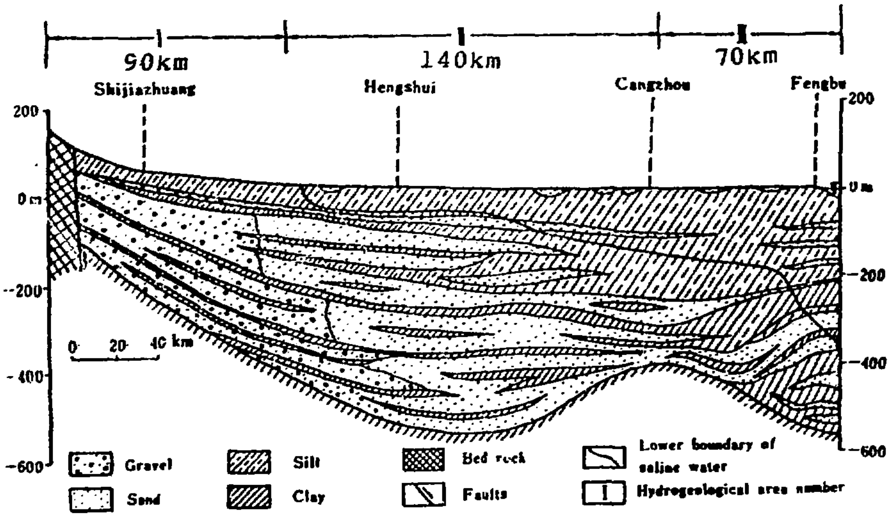

Fig. 2 Hydrogeological section across N.C. Plain

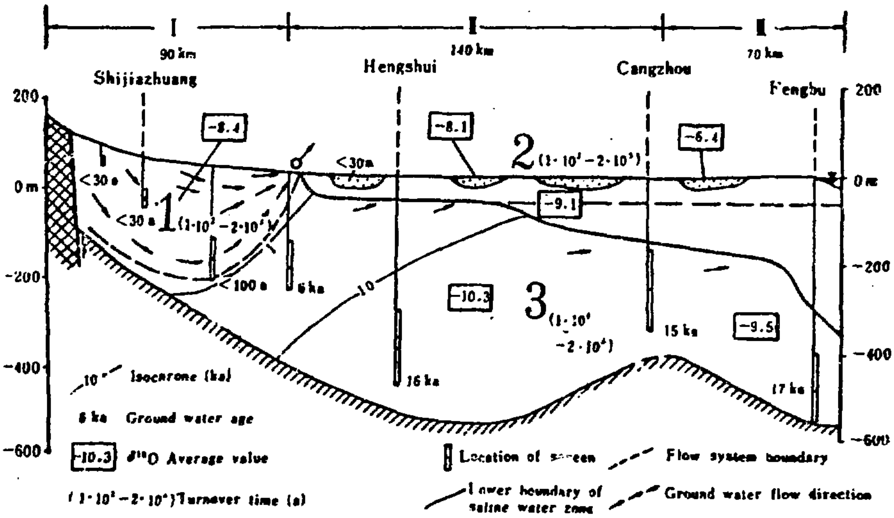

Fig. 3 schematic profile of groundwater flow systems

1. Local alluvial Fan system; 2. Local shallow flow system; 3. Regional flow system

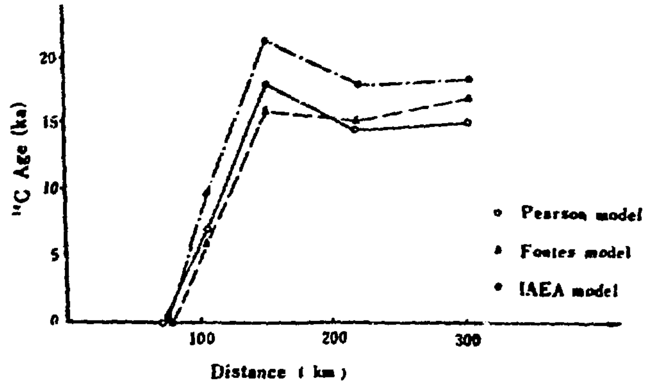

Fig. 4 Comparison of ^{14}C ages derived from different models correcting for "dead carbon"

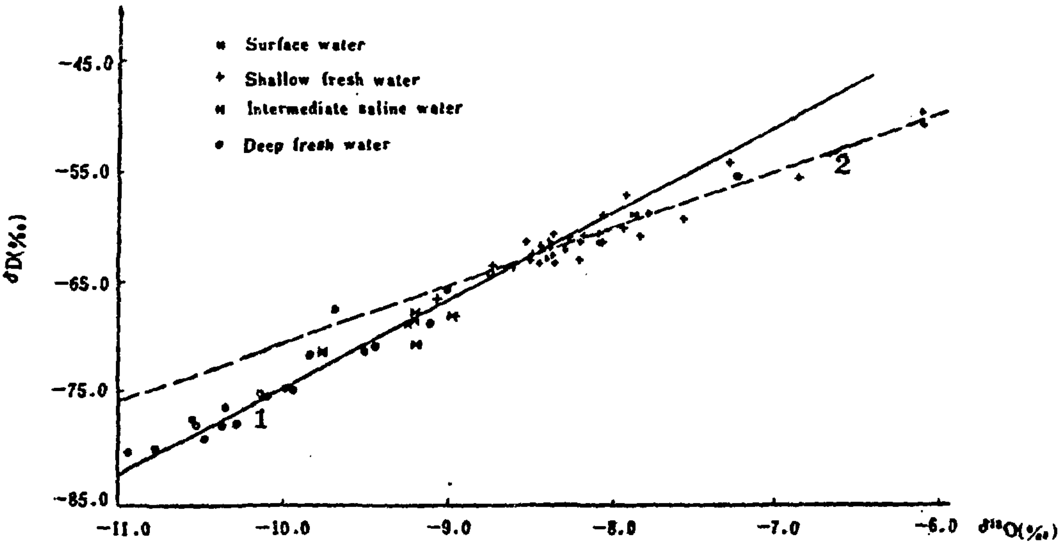

Fig. 5 Isotope composition of groundwater in N.C. Plain region

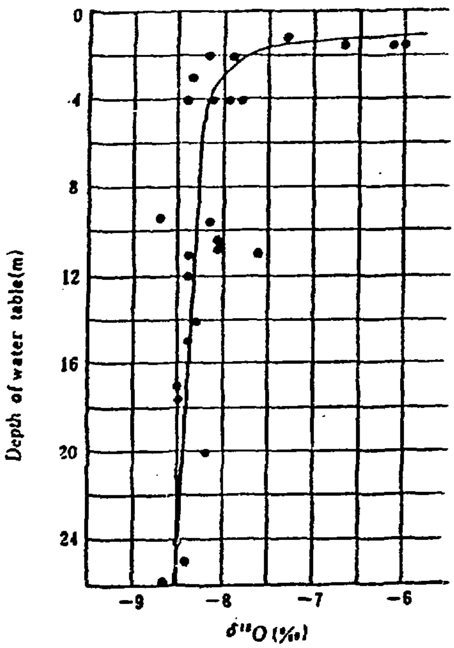

Fig. 6 The depth of phreatic water table plotted versus $\delta^{18}O$ values. Active evaporation occurs only in the zone when phreatic water table lies at depth less than 2 - 3m

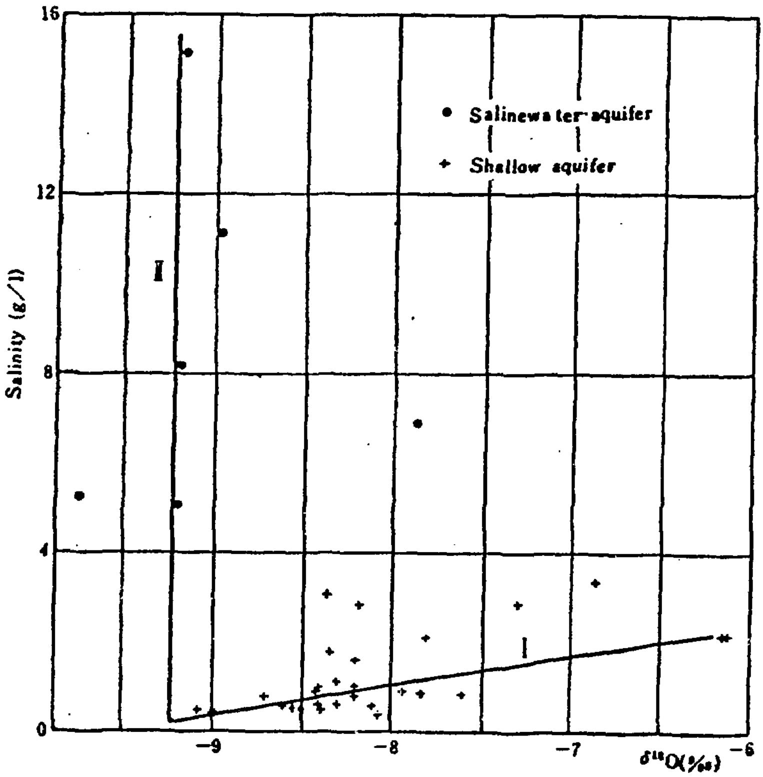

Fig. 7 Salinity of shallow and saline water plotted versus $\delta^{18}O$ values. Line 1 shows an evaporation line and line 1 corresponds to a trend of leaching of process

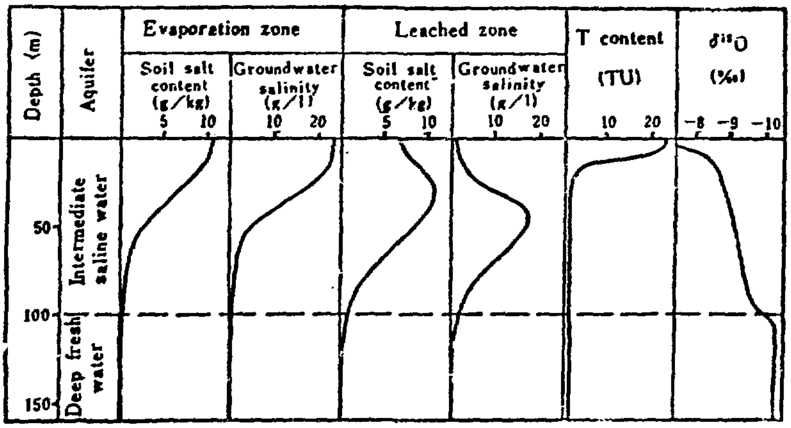

Fig. 8 Variation of salt content in soil, groundwater salinity and isotopic composition with depth in modern zone of salinization