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THE DISCOVERED DEEP-BURIED LAKE ICE IN SOURCE REGION OF THE HUANGHE RIVER

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ABSTRACT: The 4.45 m-thick pure ice lens have been discovered firstly at depth from 19.81–24.26 m in the bore No.6, which locates in north bank of the Ngoring Lake. In source region of the Huanghe (Yellow) River, ^{14}C dating, X-ray diffraction, pollen analysis, micropalaeontology, chemical components, environmental isotope ^{2}H, ^{3}H, ^{18}O and freezing point of the ice and water samples from the bore have been tested and microorganism in the ice have been also appraised with microscope. Combined with the research on geomorphy and Quaternary around the lake, the ice lens are determined as a kind of deep-buried lake ice, formed in 35,030–45,209 yr.B.P., and annual mean air temperature was about −10℃ during that time.

KEY WORDS: source region of the Huanghe River, deep-buried lake ice, palaeoclimate

During investigation and exploration about freeze ground and hydrogeology in the source region of the Huanghe River, the 4.45 m pure ice lens have been discovered in depths from 19.81–24.26 m of the bore No.6 in north bank of the Ngoring Lake. ^{14}C dating, X-ray diffraction, pollen analys is, micro-palaeontology, chemical components, environmental isotope ^{2}H, ^{3}H, ^{18}O and freezing point of the ice and water samples from the bore have been tested, and microorganism in the ice have been also appraised with microscope, combined with the research on geomorphy and Quaternary around the lake, the ice lens are determined as a kind of deep-buriedlake ice, formed in 35,030–45,209 yr.B.P., and annual mean air temperature was about −10℃ during that time. The discovery have pro-

important evidence for the Quaternary development and the changes of palaeoclimate and palaeogeography environment.

I. INTRODUCTION OF GEOLOGY AND GEOGRAPHY

Ngoring Lake in the source region of the Huanghe River is a fault basin, with an elevation of 4,270–4,300 m and an annual mean air temperature of –4.2℃, which is located in a patches of continuous permafrost region with 15–20 m of permafrost (Fig.1). Ngoring Lake is one of the largest outflow lakes in the source region of the Huanghe River, with 618 km^3 of water area, 17.6 m of water depth on an average. The lake water is frozen in the middle ten days of October every year, is thawed in the early April the next year, with 70–80 cm thick lake ice. The bore No.6 is located in the east side of the fishery in the north bank of the Ngoring Lake, 123.9 m to the terrace on the north bank. The bore elevation is 4,271.59 m, 3.54 m over the lake water level, and the bore depth is 200.8 m (Fig.2). The lithology mainly consists of clayey soil and sandy loam of lacustrine or gravel layer of lacustrine and alluvion of the middle and upper Pleistocene series of the Quaternany, ground surface is covered by a thin layer of sand blow by the wind of the Holocene series. According to the boring log, the thickness of the Quaternary stratum is over 200 m. The bore is situated in permafrost region, with 1.5 m of permafrost table, permafrost layer is in the depth of 1.5–8.0 m, unfrozen layer is in the depth of 8.0–19.81 m, with "high-mineralized" intrapermafrost water, 0.3℃ of water temperature. Thick ice lens were buried in the depth of 19.81–24.26 m. It is very pure and transparen , no air bubbles and impurity, 4.45 m thick. There is unfrozen layer in the depth of 24.26–200.8 m, with rich subpermafrost water, 9.1 L/ S of well gush water, 3.1℃ of water temperature.

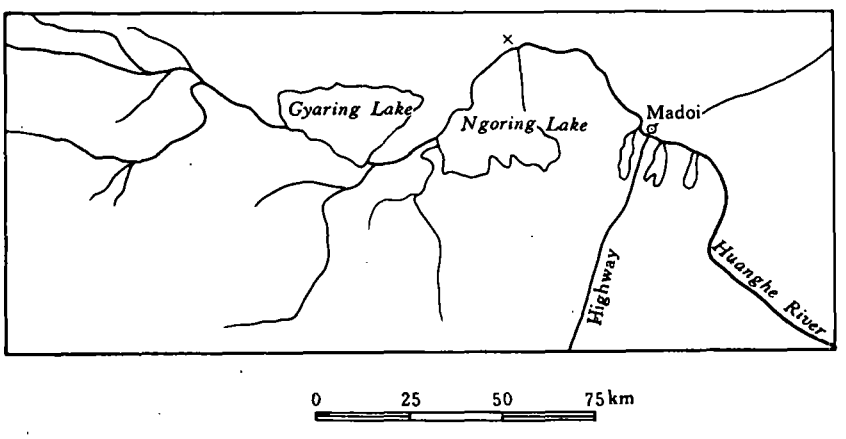

Fig.1 Location of the studied area. x: location of the bore No.6

According to temperature data of the bore, the layers both on and below the thick ice

lens are positive temperat ure, coinciding with the thickness of permafrost of boring log. The thick ice lens were buried very deeply, thickly, keeping lonely in the layers with positive temperature. This case was also firstly found in the Qinghai–Xizang (Tibet) Plateau. It is necessary to find out the formation, time and preservative condition of the thick ice lens.

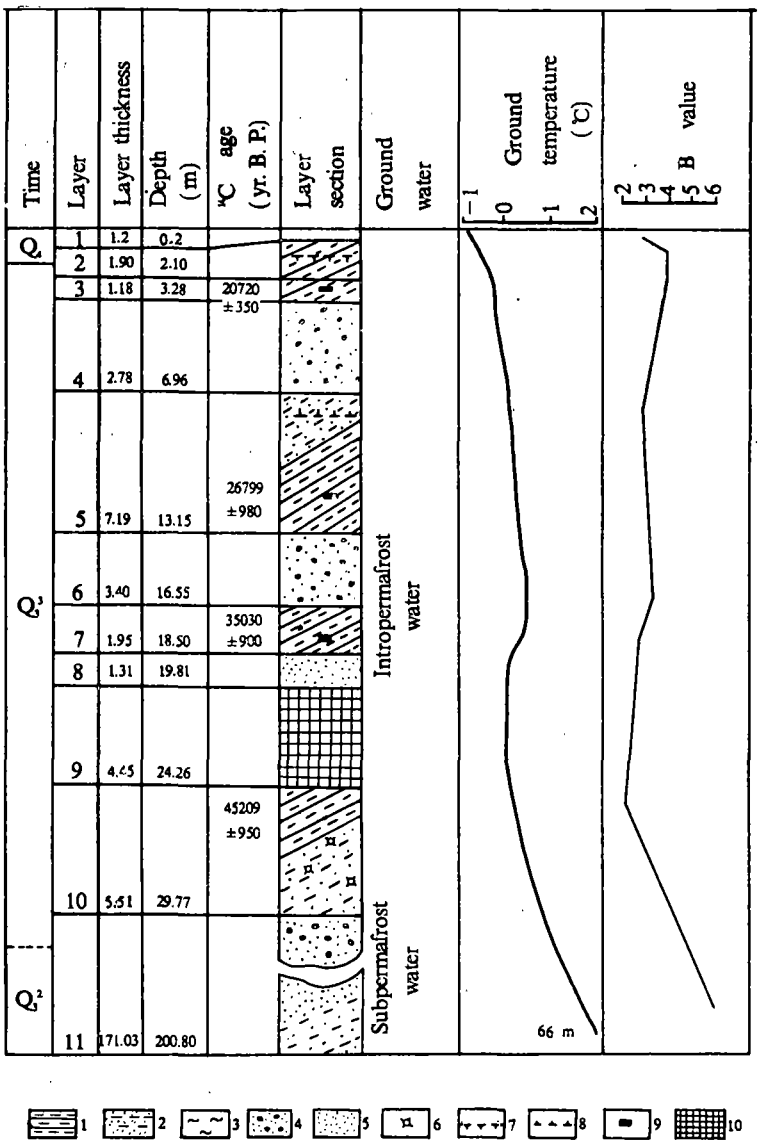

Fig.2 Schematic profile diagram of the bore No.6 (Ground temperature was determined on May 1st, 1988)

1. clayey soil; 2. sandy loam; 3. silt; 4. gravel; 5. sand; 6. fossils of snail; 7. permafrost table; 8. permafrost base; 9. sampling sites of ^{14}C; 10. thick ice lens

II. THICK ICE LENS ARE BURIED LAKE ICE

According to the tested results of the thick ice lens, soil and water samples from the bore No.6 (Fig.1, tables 1–3), the moisture source of formed thick ice lens and the ice types are recognized as follow:

1) The layers both on and under the thick ice lens consist of clayed soil, sandy loam, fine sand and gravel, are dark grey. Fine grained soil layer possesses bedding densely horizontal, humus and stink. Gravels possess sub–corners, good classification, and 0.4–1.4 cm of grain size. ^{14}C ages is 20,720± 350–45,209± 905 yr.B.P. Ten pollen and micro–palaeontology samples in different depths were analyzed, the results are shown in Table 1. 451 grain pollens are found in the samples No.1–No.3, pollen types rich. Herb pollen is dominant, chiefly consisting of Chenopodiaceae, *Artemisia* sp. compositae, Leguminosae. Xylophyta types mainly consist of *Pinus* sp., *Larix* sp., *Picea* sp; pteridophytes are mainly pteris. The compose types are *Pinus* sp.–*Larix sp.*–*Picea* sp.–Chenopodiaceae–*Artemisia* sp., representing a Conophorium vegetation landscape, herbs growing luxuriantly under conophorium.Micro–palaeontogy samples have many mussel–shrimp fossils which is dominated by *Condoniella albicans,* and have many fresh water snail, addoninal fossil pieces and plant pieces, showing cold–wet climate and fresh water lacustrine environment during that time.

2. The old sandbanks and palaeo–shallows in north side of the bore and the parallel the lake terraces show that the Ngoring Lake has been shrinking continuously. Lacustrine layers in the boring log proves that the region around the bore was lake area in the Late Pleistocene.

3. There are not glacial morphology around the bore and tills in rock cores in the depth of 0.55–63.5 m of the bore, proving that thick ice lens are not buried glacial ice.

4. After the water melted from the ice was kept indoor for several months, many algea grow. The algae were determined by microscope as blue algaeand green algae. They are obviously different from microoganism in thecontemporary lake. Because only monocell algae can live a long time in the ice lens in low temperature environment, so the thick ice lens can be proved palaeo–lake ice lens.

5. The thick ice lens are dense in stucture, no air bubbles, with horizontal bedding. It is different from the intrusive ice with rich air bubbles and vertical ice crystals.

6. ^{3}H content of the ice lens is only 7± 5 T.U., obviously lower than that of contemporary lake water and the ground water and ice lens near permafrost table (122–22 T.U.)[1].

7. Chemical compositions of water in the ice lens differ obviously from the contemporary lake water and subpermafrost water beneath the ice lens. The latter is mainly Cl^- anion. Cl^- anion content is the highest in intrapermafrost water, 83.07%, the mineralizity is over 10g. The chemical compositions of water in the ice lens are mainly

Sample numbers	Lithology	Sampling depth (m)	Layer time (yr. B. P.)	Spore-pollen sum				Woody plant pollen												Herb pollen							Pterodphyto			
				Woody plant	Herb	*Pteridophyto*	Sum	*Picea* sp.	*Arix*	*Pinus* sp.	*Corylus* sp.	*Betula* sp.	*Quercus* sp.	*Liqudamber*	*Tamarix*	*Polygonum*	*Fraxinus*	*Ilex*	*Ephedra* sp.	Gramineae	Chenopodiaceae	Cruciferae	Leguminosae	Compositae	*Artemisia* sp.	Polypodiaceae	Pteridaceae	Sinopteridaceae	Drgopteridaceae
1	Clayey soil	0.55—0.60		2	6		8						2						1		2			3				
2	Clayey soil	0.85—1.00		3	5		8			3									1	3				1				
3	Silty clayey soil	2.5—2.8	20720±350	15	63		78					1	8		3	2	1		2		31	3			28				
4	Sandy loam	7.9—8.0		1	1		2			1											1								
5	Silty sandy loam	11.5-12.0	26799±980	6	27	2	35			2			2	2					1	7	8		2	3	6	1		1	
6	Gravel	15.0—16.0		40	71	1	112			21		2	16					1			50		3	4	14				1
7	Silty clayey soil	17.0—17.5	35030±900	38	10	3	51	9		26			3								2		4	2	2		2	1	
8	Sandy loam	25.5—26.0	45209±950	4	22		26	1		1	2										15			1	6				
9	Gravel fine sand	41.5—42.0		39	89	3	131	4	15	16	1		2				1		2	1	60			3	22		3		
10	Gravel	63.0—63.5			6		6														2				4				

Table 1 Statistical results of the pollen analysis in the samples from the bore No.6 (in 0–63.5m)

Table 2 Results of the chemical and isotope analysis of ground water, ice lens and lake water samples of the bore No.6

Water samples types	Sampling depth (m)	Chemical types	Freezing point temperature of water (℃)	^2H value (T.U)	$\delta\,^8O$ value (‰)	^2H value (‰)
Ngoring Lake water	0.10–0.20	$M_{0.23}\ \frac{HCO_{3\ 64.01}\ \ Cl_{29.16}}{Na_{34.62}\ \ Mg_{33.94}\ \ Ca_{31.44}}$	–0.04	183 ± 7		
Introper mafrost water	13.15–16.55	$M_{10.06}\ \frac{Cl_{183.07}}{Na_{60.68}\ \ Mg^{35.81}}$	–0.65	39 ± 10		
Thick ice lens	21.0–22.0	$M_{0.02}\ \frac{HCO_3}{Ca_{47.83}\ \ Na_{41.30}}$	–0.1	7 ± 5	–11.6	–77.9
Subpermafrost water	46.70–176.40	$M_{0.87}\ \frac{Cl_{141.63}\ \ HCO_{3\ 34.68}\ \ SO_{4\ 22.91}}{Na_{44.97}\ \ Ca_{25.44}\ \ Mg_{23.48}}$	–0.15	39 ± 10		

Table 3 Results the X diffracted ray determination in soil samples from the bore No.6

Sample numbers	Lithology	Sampleing depth (m)	Stratum time (yr.B.P.)	$B=\frac{mica}{chlorit.+koolinie}$
1	Clayey soil	0.55–0.60		2.96
2	Clayey soil	0.85–1.00		3.94
3	Silty clayey soil	2.5–2.8	20720 ± 350	3.84
4	Sandy loam	7.9–8.0		3.00
5	Silty clayey soil	11.5–12.0	26799 ± 980	3.10
6	Gravel	15.0–16.0		3.29
7	Silty clayey soil	17.0–17.5	35030 ± 900	2.96
8	Sandy loam	25.5–26.0	45209 ± 950	2.43
9	Gravel fine sand	41.5–42.0		5.85
10	Gravel	63.0–63.5		5.76

HCO_3^- anion, making up 73.1%. The chemical compositions of the two kinds of water are different obviously, so the thick ice lens do not relate with the kinds of water over-sub the ice lens.

8. According to the analysis data of geologic structure, the Ngoring Lake is a fault lake, lacustrine sediments of 27 m were deposited around the bore during 20,720-45,209 yr.B.P. Depositional rhythm is layered structure alternating coarse grain with fine grain of lacustrine, showing the lake subsidence speed was slow and alternated fast, which provided a favourable condition for the quick bural and presercation of the thick ice.

On the basis of palaeogeographical environment, feature of lithofacies and sedimentary structure in the thick ice lens distribution area, combined with the physical and chemical character of the ice lens and so on, the thick ice lens are determined as a kind of deep-buried lake ice.

III. THE FORMATION TIME OF THE DEEP-BURIED LAKE ICE

It is difficult that the formation time of the ice lens is determined only by itself. The deep-buried lake ice and the lacustrine sediments of its over-sub layers are paragenesis, according to formed time of the sediments so formed time of the thick ice lens are determined, formed in 35,030-45,209 yr.B.P., belongs to the Late Pleistocene.

IV. PALAEOCLIMATE SIGNIFICANCE

Based on the fact that the thick ice lens were frozen and quick buried and kept to today, combined with feature of lithofacies and sedimentary structure around the bore and permafrost data, the palaeogeographical environment and climatic changes inthe source region of the Huanghe River were reconstructed.

At present the lake ice of the Ngoring Lake frozen in winter is 70-80 cm thick, is thawed completely in April, so the climate in the formation period of thick ice lens was colder than that of today.

The formation time of the thick ice lens was in a climax stage of late glacial epoch in the Qinghai-Xizang Plateau. Cold-wet climate during that time made lake water area much larger than that of today. The lake water depth around the bore No.6 was over 4.45 m. The lake water was frozen gradually into ice in cold climate condition. Middle-fine sand lacustrine sediments with fast speed deposition were covered on the ice lens. Permafrost was formed with the gradual increase of sediments. The thick ice lens wwas kept in permafrost. The lake area had retreated to the south of the bore in 20,720 yr.B.P. Spore pollen from samples No.1 and No.2 in alluvial sandy loam mainly consist of Chenopodiaceae, Cruciferae and *Arternisia* sp., showing vegetation landscape of herbaceous steppe, and the climate getting arid-cold. During hypsithermal interval air temperature rose to make

permafrost thaw. Because cold storage capacity of thick ice lens was so that the big thick ice lens was not thawed completely. During Neoglaciation new permafrost was formed in the depth of 1.0–8.0 m, resulting in the thick ice lens keeping still today. Thus it can be seen that the region is still at a periglacial climate, even during hypsithermal interral air temperature went up little, the climate was still arid–cold. Sand layer by wind covering surface widespreadly is evidences.

$\delta^{18}O$ of the ice lens is −11.16–11.70‰. It is close to $\delta^{18}O$ (average is −11.22‰) of snow samples in Urumqi glacier firn basin of the Tianshan Mountain and $\delta^{18}O$ (−10.0—12.1‰) of snow samples in firn line of south side of the west Kunlun Mountain[2]. Annual mean air temperature in the two sampling sites are −10℃ and −10 to −11℃ respectively. So we consider, the ice annual mean air temperature during forming the the thick ice lens was about −10℃, being 5–6℃ lower than that of today.

B value in Table 3 shows the changing law of climate since the Late Pleistocene. Samples No.9 and No.10 were sedimented 45,209 ago, so *B* value of the samples is twice as that of samples No.1–No.8, showing that climate was arid and warm, violent weathering during that time. *B* values of samples of No.7 and No.8 on and below the ice lens are the lowest, showing that climate was very cold and wet during that time. *B* values of samples No.4–No.6 are higher than those of No.7 and No.8, but are lower than those of No.9 and No.10, showing that cold and wet climate was dominant, *B* values of samples No.2 and No.3 rise slightly, showing that climate got cold and arid. *B* value of sample No.1 is low, showing it may be the product of Neoglaciation. The Change law of *B* values coincide with analytic results of lithofacies, sediment construction, pollen and microorganism.

To sum up, the discovery of the deep–bruied lake ice shows that the region has been in a periglacial climate since the Late Pleistocene. Even if air temperature in hypsipidly, the range of temperature rise again reduced, resulting in ranges of that is too small to thaw thick ice lens completely, keeping to now.

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