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泥河湾盆地第四纪古湖最终消亡过程研究

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泥河湾盆地位于河北省西北部和山西省东北部, 行政区划隶属河北省张家口市阳原县和山西省大同市大同县及天镇县。盆地西至阳原县东井集乡, 东至石匣以东的桑干河峡谷, 北界为熊耳山, 南界为六棱山和凤凰山; 盆地东西长约 80 km, 南北宽约 15~20 km, 大致位于北纬 39°55′—40°25′, 东经 113°50′—114°50′, 面积达 4 500 km^2, 与阳原盆地的范围大致相同。盆地边缘是洪积扇和洪积平原, 中部是湖积冲积平原, 桑干河自西南向东北流经整个盆地。

泥河湾盆地是一个新生代断陷盆地, 盆地内堆积的巨厚河湖相地层从上新世晚期延续到更新世晚期, 以其沉积连续、富含哺乳动物化石和古人类遗存等得天独厚的地质条件, 在我国第四纪地质研究中占有重要地位。长达百年之久的研究表明, 第四纪早、中期泥河湾盆地发育较广阔的湖泊, 向南可延伸至蔚县盆地, 向西可延伸至大同、朔县一带, 在第四纪期间盆地曾长期被湖泊所占据, 该湖泊被称为泥河湾古湖。

泥河湾古湖的演变过程是泥河湾研究的重要内容之一, 前人对此已经做过大量的工作, 并取得丰硕的成果。但是, 由于受测年手段限制、样品分析数量较少和分辨率低等原因, 泥河湾古湖的消亡过程一直缺乏深入的研究。这给泥河湾盆地中—晚更新世的地层对比、古地理和古环境研究、考古学和古人类研究等, 都带来了不少困难。因此, 开展本研究具有重要意义。

本研究在泥河湾盆地自东向西分别在后沟、小渡口、虎头梁、井儿洼、北梁、侯家窑、梨益沟等地选择了 7 个代表性的中—晚更新世沉积剖面, 并对剖面进行了详细地地层描述和样品采集。对剖面样品进行了光释光、古地磁及 U 系年代测定, 和孢粉、粒度、磁化率、色度、元素等环境指标测试。通过地层对比、年代测定和多种古气候代用指标测试, 建立了区域中—晚更新世地层的年代框架, 恢复了古气候与古环境演变过程, 并据此探讨了泥河湾盆地第四纪古湖最终消亡的时间、过程和原因。

本研究取得的主要进展和创新研究成果有:

(1)确定了泥河湾古湖消亡的年代框架。泥河湾古湖的萎缩和消亡从 266 ka 前后开始, 一直延续到 30 ka 前后。受所处古地貌部位的影响, 盆地中不同地区古湖消亡的时间有早晚差异。

中更新世晚期, 大致在 266 ka 以后, 泥河湾古湖大规模收缩, 盆地东南部的大田洼—郝家台地区湖泊消亡, 仅局部还保留有一些残留湖。小渡口和东目连湖相层顶部有叠层石分布, 其时代分别为 20 多万年和 220 ka; 北梁地区湖积层顶部有文石沉淀, 其时代为 270 ka 左右。叠层石主要生活在半咸水湖、滨湖浅水环境, 文石等化学沉积在半咸水湖, 水深较浅环境沉淀生成, 它们的出现表明这些地区当时十分接近湖岸线。

泥河湾古湖大规模收缩后期, 除大田洼—郝家台地区外, 其他地区仍然有湖泊发育。北梁地区湖泊最先于 190 ka 左右消亡。进入晚更新世之后, 泥河湾古湖又发生了一次小规模的扩张, 这次扩张在虎头梁一带表现最为明显, 虎头梁剖面地层呈湖侵沉积序列。此次湖泊扩张之后, 泥河湾古湖进入了逐步消亡阶段。110 ka 前后, 梨益沟附近湖泊和大田洼—郝家台地区残留湖消亡, 之后湖泊退缩六棱山山前湖泊消失, 80 ka 前后上回村—东目连地区和侯家窑—强家营一带湖泊消亡, 53 ka 前后虎头梁地区湖泊消亡, 30 ka 前后盆地中部的井儿洼地区和化稍营东部一带的湖泊消亡。

(2)建立了泥河湾古湖的消亡模式。在一定的气候和构造背景下, 统一的泥河湾大湖开始收缩, 并逐渐解体为若干个大小不一的残留湖, 如大田洼—郝家台地区官厅附近的残留湖等。这些残留湖在气候的影响下, 不断萎缩并最终消亡。

(3)建立了泥河湾古湖最终消亡的三种过程模式。模式 I: 大量黄土降尘进入湖泊, 造成湖泊最终

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消亡。见于化稍营地区和东井集地区的梨益沟—侯家窑一带。化稍营地区湖相地层顶部覆盖有马兰黄土堆积，黄土与湖相地层之间为渐变过渡关系，不存在明显的界线。东井集地区的梨益沟—侯家窑一带，湖相地层顶部沉积物中黄土含量明显大量增加。这些现象表明，这些地区湖泊的最终消亡与大规模的黄土沉降有关，湖泊因黄土的逐渐填埋而最终消亡；模式 II: 强烈的蒸发作用使得湖水咸化，直至湖泊最终消亡。见于大田洼—郝家台一带和井儿洼地区。在大田洼—郝家台地区、北梁地区和井儿洼地区，湖相地层顶部夹有文石和铁白云石等盐类沉积。这些盐类物质是强烈的蒸发作用下湖水咸化的产物。这表明，这些地区湖泊的最终消亡过程伴随着湖水的蒸发、咸化和化学沉积的形成。模式 III: 冲积扇入湖，导致湖泊最终消亡的。见于东井集地区的强家营一带。东井集地区的强家营一带，山前冲积扇入湖，受到湖水改造，使得沉积物增加，导致湖泊最终消亡。

(4)探讨了古湖消亡过程中的气候因素和构造背景。不同地区泥河湾古湖的消亡时间大致对应于280~30 ka 期间气候相对比较干旱的时段。构造运动导致泥河湾盆地地貌格局发生改变，在气候变干的条件下，泥河湾古湖的最终消亡。泥河湾古湖的消亡过程是构造运动和气候变干共同作用的结果，气候因素是影响泥河湾古湖发展和消亡的主要因素。

泥河湾盆地 280 ka 以来的气候表现为暖湿—冷干—暖偏干—暖偏湿—温干的变化特征。研究区气候变化与深海氧同位素反映的气候阶段和黄土—古土壤沉积序列具有很好的对比性，与全球变化具有一致性的同时也存在明显的区域特征。研究区为新生代断陷盆地，新构造运动活跃，进而也影响着盆地中湖泊的发育。泥河湾盆地东端的构造活动控制着整个盆地的湖泊出口。泥河湾古湖是由中更新世大湖面逐渐经中更新世末大规模收缩等一系列过程，最终走向消亡的。

中更新世晚期 380 ka 左右和 330 ka 左右，气候干旱，湖水浓缩，湖泊中有铁白云石等盐类物质析出，相距时间较近的两次气候干旱时段使得古湖水位变浅。200~300 ka 期间油坊断层的强烈活动造成大田洼—郝家台地区抬升，该地区湖泊无法接受来自北西方向的流水补给，最终导致台地上的湖泊大范围消失。残留在台儿沟等地的湖泊则是在晚更新世 110 ka 左右的干旱气候下逐渐萎缩，最终消亡的。同样于 110 ka 左右消亡的还有梨益沟附近的湖泊。

中更新世中晚期，砂板梁凸起上隆引起六棱山山前断裂产生活动，活动产生的掀斜式抬升可能是造成北梁地区湖泊消亡的原因之一。190 ka 前后，气候变冷干，黄土降尘量加大，北梁地区湖泊最终消失。在晚更新世早期或更晚些，六棱山山前断层活动，使得山前台地被抬高，加之气候干旱使得湖泊收缩，湖泊从山前后退至盆地中心位置。晚更新世后期，气候变冷变干，盆地内的湖泊相继萎缩消亡。70~80 ka 期间上回村—东目连地区和侯家窑—强家营一带湖泊消亡，53 ka 左右虎头梁附近湖泊消亡，30 ka 左右井儿洼附近和化稍营地区湖泊消亡。晚更新世末，造成桑干河两侧湖积台地抬升的构造运动，同时也促使了桑干河的下切。桑干河形成于30~27 ka期间，在 27~13.7 ka 之间和 2.1 ka 之后，桑干河分别发生了一次下切，随后大致形成了现在的河谷和阶地地貌。

(5)首次在泥河湾盆地发现中更新世晚期化学沉积：第四纪河湖相地层中夹有多层化学沉积，前人研究结果显示发现的化学沉积其时代为晚更新世晚期。此次发现的分布于泥河湾层顶部的白色化学沉积层，位于阳原盆地西端东井集乡北梁村一带，具有分布面积广、层位稳定、厚度较大、质地纯正等特征。通过野外调查和年代测试、电子显微镜扫描观察、X 射线粉晶衍射、常量和微量元素分析，以及硅藻和介形类化石鉴定等一系列实验手段，确认该化学沉积主要由文石组成，其形成时代大致在270 ka 前后，属中更新世晚期，是在当时比较温干的气候环境下，湖泊逐渐萎缩，湖水不断咸化，文石类矿物大量析出的结果。此次研究首次发现的中更新世晚期化学沉积，为阳原盆地第四纪河湖相地层格架的建立，提供了直接的地层学和年代学依据；为阳原盆地古气候古环境变化提供了地层沉积新资料，对深入探讨泥河湾古湖消亡的时间、演化过程和原因具有重要意义。同时，中更新世晚期湖泊化学沉积层的发现对于重建我国北方中更新世晚期的古环境也具有重要的科学意义。

关键词： 泥河湾盆地；中—晚更新世；古气候；古环境；古湖演化；消亡模式

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Final Disappearing Process of Ancient Lake during Quaternary in Nihewan Basin

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Nihewan Basin located in the northwestern of Hebei Province and northeastern of Shanxi Province. The administrative division of Nihewan Basin belongs to Yangyuan County Zhangjiakou Hebei Province and Datong County - Tianzhen County Datong City Shanxi Province. The extent of the basin is west to Dongjingji rural area Yangyuan County, east to the Sanggan river valley-east of Shixia, north to Bear mountain, south to the Liuleng mountain and Phoenix mountain. Nihewan Basin is about 80 km long from east to west and 15 ~ 20 km wide from north to south, which generally located N39°55′–40°25′ and E113°50′–114°50′, with an area of 4 500 km^2. The scope of Nihewan Basin was roughly the same scope of Yangyuan Basin. Pluvial fan and diluvial plain were developed along the basin edge and lacustrine and alluvial plain covered the central part of the basin. The Sanggan River flowed through the basin from southwest to northeast.

Nihewan Basin is a Cenozoic rift basin and it was occupied by a thick succession of lacustrine and fluvial sediments which were formed from the late Pliocene the Late Pleistocene. Due to its advantaged geological characteristics, such as continuous sedimentation, rich of fossil and relics of ancient human beings, etc. Nihewan Basin plays an important role in Quaternary geological research in China. Previous studies, over nearly one hundred years, suggested that during the Early and Middle Quarternary, Nihewan Basin was a great lake, which extent was from north to Yuxian Basin and west the region of Datong, Shuoxian County. Nihewan Basin was occupied by lake for a long time during Quaternary. The palaeolake was named ancient Nihewan Lake.

One of the important study contents about the Nihewan Basin is the evolution of ancient Nihewan Lake, about which researchers have done a lot and obtained fruitful achivements. However, the extinction process of ancient Nihewan Lake hasn't been studied deeply, because of limitations of the dating methods, few of anylysis samples and lack of resolution, which brought many difficulties on the study of stratum comparison of Middle–Late Pleistocene, palaeogeography and palaeoenvironment, as well as Archaeology and palaeoanthropology. Therefore, this study is important and necessary.

In this study, seven typical Middle–Late Pleistocene deposit sections were sampled throughout the Nihewan Basin from east to west, including Hougou, Xiaodukou, Hutouliang, Jing'erwa, Beiliang, Houjiayao and Liyigou. Detailed strata description and samples collection were done on each typical section. These deposit sections were firstly well dated, measured for multiple climate proxies, and compared about lithology among each other. Dating method including OSL, Paleomagnetism and U-series, climate proxies including pollen analysis, grain-size, magnetic susceptibility, Chromaticity, chemical elements and so on. Thus, timing framework during Middle–Late Pleistocene of the study area was established, and palaeoclimate and palaeoenvironment evolution were uncovered. At last, periods, processes and causes about the extinction of ancient Nihewan Lake were discussed.

The main advance and innovation results of this study are as follows:

(1) Timing framework of the extinction process of the ancient Nihewan Lake was established. Since ~266 ka, the ancient Nihewan Lake started to shrink and it was extinct at ~30 ka. However, it should be noted that influenced by the palaeogeomorphological place, the extinction time of ancient Nihwan Lake were different in different palces of the basin.

In late Middle Pleistocene, after ~266 ka, the Nihewan Lake shank widely. At the Datianwa–Haojiatai area in southeast of Nihewan Basin, the lake extinct and left residual lake in some places. Ages of stromatolites developed on the top of lacustrine sediments in Xiaodukou and Dongmulian were older than 200 ka and 220 ka respectively. The age of Aragonite deposition on the top of lacustrine sediments in Beiliang area is about 270 ka. Stromatolite mainly lived in the area of semi-salty lake and shore lake, chemical depositions like Aragonite formed in semi-salty lake with a shallow water. There appearance showed that those places where they lived/deposited were close to the lake shoreline.

In the late period of widely shank of Nihewan Lake, lake still developed in same places except Datianwa – Haojiatai area. And then, in Beiliang area around Dongjingji area in the eastern part of Nihewan Basin, the lake became extinct around 190 ka. In early late pleistocene, ancient Nihewan Lake had an expension in small-scale, which can be seen obviously in Hutouliang area. The strata of Hutouliang section showed a lake transgression sedimentary sequence.

After this lake transgression, ancient Nihewan Lake began to extinct gradually. Around 110 ka, lake in the north of Liyigou area near and the residual lake at Datianwa–Haojiatai area extinct, and after that lake shank from Liuleng mountain front. Around Shanghuicun–Dongmulian area in the southwest of Nihewan Basin, and Houjiayao- Qiangjiaying area in the northwest of Nihewan Basin, lakes became extinct around 80 ka. Extinction of lake in Hutouliang area happened around 53 ka. In the Jing'erwa area where near the center of basin, as well as the east part of Huashaoying area, lakes became extinct around 30 ka.

(2)Extinction pattern of the ancient Nihewan Lake was established. Under certain climatic and tectonic situations, the uniform big ancient Nihewan Lake began to shrink and gradually broke up into several residual lake with different sizes, such as residual lake near Guanting at Datianwa–Haojiatai area. Those residual lakes were effected by climate changes, and hence shrank and disappeared.

(3)There were three process patterns about the finally died out of ancient Nihewan Lake. Pattern I: lots of loess deposited into lake, and caused the extinction of the lake, which can be seen in the vicinity of Huashaoying, as well as Liyigou–Houjiayao in Dongjingji area. In Huashaoying area, lacustrine strata were covered by Malan loess, and they were gradual transition deposition relationship without obviously boundary line. Around Liyigou–Houjiayao in Dongjingji area, loess content in the sediment top of the lacustrine sediments increased obviously. Those phenomenons showed that the final extinction of lake in those area had relation with the massive loess deposition, and under the gradually landfill of lake by loess, extinction happened. Pattern II: strong evaporation led to a salt lake, and finally caused the extinction of the lake, which can be seen in the vicinity of Datianwa–Haojiatai and Jing'erwa area. In Datianwa–Haojiatai area, Beiliang area, as well as Jingerwa area, salt deposit such as Aragonite and Ankerite were widely distributed in the top of lacustrine and fluvial sediments, which were formed under a strong evaporation and salty lake environment. Those showed that the final extinction of lake in those area were accompanied with the evaporation and salty of lake water and deposition of chemical sediments. Pattern III: alluvial fan extended into lake and quickly filled up, finally caused the extinction of the lake, which can be seen around Qiangjiaying in Dongjingji area. Around Qiangjiaying in Dongjingji area, alluvial fan in the mountain front brought massive substances in lake, and finally caused the final extinction of lake.

(4)The role that climatic and tectonic activities played in the extinction of the ancient Nihewan Lake was discussed. Ancient Nihewan Lake in different places died out concurrently with the relatively dry period between 280~30 ka. Tectonic activities changed the landscape in Nihewan Basin, and ancient Nihewan Lake finally extincted under the drier climate. The extinction processes of the Nihewan Lake had close relationship with the tectonic activities, as well as raletively dry climate conditions, but the later was the main factor.

Climate evolution of Nihewan Basin since 280 ka had a vary characteristic like warm and wet- cool and dry-dry warn-wet warm-warm and dry, which has good comparation with that of oxygen isotope phases of deep sea as well as loess-paleosoil deposition sequence. The climate change in Nihewan Basin is consistent with the global change, but had obvious regional features. Being a Cenozoic rift basin, neotectonics are active, which controlled the development of lakes in the basin. Tectonic activity in the eastern part of Nihewan Basin controlled the discharge of the lake in the basin. Ancient Nihewan Lake finally extinced after a serial process from wide lake in middle Pleistocene to widely shank in later Middle Pleistocene.

Around 380 ka and 330 ka, under drought climate, lake water concentrated, salt deposit like Ankerite separated out, which caused the shallow lake. Strong activities of Youfang Fault during 200~300 ka caused the uplift in Datianwa–Haojiatai area, and forbad the water supply of this area from northeast, which finally caused the widely disappearance of lake. Residential lake of this area such as that in Taiergou gradually shrank under drought climate around 110 ka, and finally extinct. The same thing happed on the lake near Liyigou.

In late Middle Pleistocene, uplift of Shabanliang caused the activity of fault along the Liuleng mountain, and tilt uplift by the fault activity maight be one of the reasons why the lake in Beiliang area disappeared. Around 190 ka, under the cold and dry climate, loess deposition increased, and lake in Beiliang area finally extincted. In early Late Pleistocene or later, pediment platform uplifted by the activity of fault along the Liuleng mountain, and under the drought climate, the lake shank and with drawed to the middle of the basin. In later period of late Pleistocene, climate changed cold and dry, lakes in basin shrank and extinct one after anothere. During 70~80 ka, lakes in Shanghuicun-Dongmulian area and Houjiayao–Qiangjiaying area extincted. Lake near Hutouliang disappeared around 53 ka, and lakes near Jingerwa and in Huashaoying area disappeared around 30 ka. At the end of Late Pleistocene, tectonic activity caused the lacustrine platform on the each side of sanggan river uplifted, which also prompted the undercut of sanggan river. Sanggan River was formed during 30~27 ka, and undercut two times during 27~13.7 ka and after 2.1 ka respectively, where after river valley and terrace like present were formed basiclly.

(5) For the first time found the late Middle Pleistocene chemical sediment in Nihewan Basin. In Quaternary lacustrine and fluvial sediments, several

chemical sedimentary layers in the basin had been found previously and the chronologic results suggested that they belonged to the Late Pleistocene. A new chemical sedimentary layer was found in Beiliang area southwest of Yangyuan County by field investigation, which widely distributed in the top of lacustrine and fluvial sediments in western basin. In order to discuss the sedimentary processes and environmental history of the palaeolake Nihewan, this section was sampled in detail and analyzed by OSL dating, U-series dating, SEM, XRD, XRF, and diatom, ostracoda. Its U-series dating shows that the age of grayish white chemical sedimentary layer is about 270 ka, much older than that of the chemical sediments found before. Mineralogical data of this grayish white chemical layer reveal that it was mainly composed of Aragonite(71%) and Ankerite(12%). Ostracoda identification shows very low diversity (only two ostracod species) and very high abundance. These evidences suggest that the chemical sedimentary layer was formed under a relatively warmer and dryer climate. The palaeolake had shrank rapidly and become a salt lake during that stage, which led a large number of minerals like Aragonite to be precipitated. The disappearance of the palaeolake Nihewan was during the late middle Pleistocene at Beiliang area. This result would be of an important significance for reconstruction of paleoenvirenment in northern China during the late Middle Pleistocene.

Key words: Nihewan Basin; Middle–Late Pleistocene; Palaeoclimate; palaeoenvironment; ancient lake revolution; extinction pattern

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