

Quaternary Sedimentary Stratigraphic Sequence of Changzhou and Its Significance

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Abstract. All manuscripts must be in English, also the table and figure texts, otherwise we cannot publish your paper. Please keep a second copy of your manuscript in your office. When receiving the paper, we assume that the corresponding authors grant us the copyright to use the paper for the book or journal in question. Should authors use tables or figures from other Publications, they must ask the corresponding publishers to grant them the right to publish this material in their paper. The paper made a descriptive record on the drill core BK1 located at east of BenNiu town and the drill core BK2 located at Tangcun in the Changzhou suburbs by lithologic descriptions, lithofacies, age of stratigraphy, analysis of sporopollen and stratigraphic correlation. Combined with previous research results in the area, we drew conclusions that the two drilling cores revealed the Holocene Rudong formation with the thickness of 2m in the study area, the Upper Pleistocene Gehu formation with the thickness of 22 m and the Upper Pleistocene Kunhan formation with the thickness of 47 m and the Middle Pleistocene Qidong formation with the thickness of 113m and the lower Pleistocene Haimen formation with the thickness of 154m. The two standard boreholes reveal the sedimentary response characteristics of the quaternary sedimentary environment in Changzhou and the sedimentary response characteristics of 4 transgression. There are two depocenter in the northeast in the target area where the Suzhou-Wuxi-Changzhou fault passed. According to the age of Suzhou-Wuxi-Changzhou fault activities, inferring that the fault infected stratum of Qp2q and others on it.

Keywords: Changzhou, Quaternary, core; sporopollen; stratigraphic correlation, dating.

1. Introduction

Based on the surveying of active fault in Changzhou with standard boreholes in new tectonic unit, this paper combines the systematic studies on the stratigraphic section of boreholes from the approaches of lithology, paleobiology, paleoclimatology and chronostratigraphy, with the achievements in the quaternary studies, to put forward the reasonable division and correlation scheme for the quaternary formation in Changzhou, so as to provide an effective yardstick for further explaining the data from cross-fault borehole surveying and geophysical surveying.





Fig. 1. Geotectonic location of Changzhou

(Source: Chen H.S. et al., 1999; Cheng Y.Q., 1994; Jiangsu Institute of Geological Survey, 2003)

(1) Tanlu fault zone; (2) Jiashan-Xiangshui fault; (3) Queshan-Feidong fault; (4) Xiangfan-Guangji fault; (5) Liuhe-Jiangpu fault; (6) Jiangnan fault; (7) Jintan-Rugao fault; (8) Xiuning fault; (9) Husu fault; (10) Dexing-Shexian fault; (11) Jiangshan-Shaoxing fault; (12) Suzhou-Wuxi-Changzhou fault.

2. Standard Boreholes BK1 and BK2 in Changzhou

In the “Surveying on Active Faults in Changzhou and Seismic Hazard Assessment” program during the “Tenth Five-year Plan” period, a special task for the surveying with standard boreholes and the creation of the quaternary stratigraphic section was implemented to make 2 boreholes numbered BK1 and BK2 in Changzhou. Two standard boreholes (BK1 and BK2) represented two different sedimentary positions and controlled different breaking positions. BK1 locates to the west of the target area, in the middle of the Benniu sag, and to the west of the position where the Suzhou-Wuxi-Changzhou fault (F1) and the Houyu-Xinqiao fault (F2) intersect, while BK1 is made to the northeast of the target area, in the shallow position of the quaternary formation in the target area, and to the east of the Suzhou-Wuxi-Changzhou fault (F1) (Fig. 2).

BK1 locates in the east of Benniu Town, to the northeast of the crossing of Yunhe Road and Tenglong Road (X210 County Highway) and near Chenxiang Village, and its GPS coordinates are N31°50'55.52" and E119°49'50.42". It belongs to the thickest central zone of quaternary sediments inside the Benniu sag. BK2 exists near Wantang Village in the north of Dongqing Township, to the south of Shanghai-Nanjing Freeway, in the farmland to the east of Changzheng Road (X303 County Highway), and around 700m away from Dongqing Township, and its GPS coordinates are N31°47'59.38" and E120°03'20.76". N+Q is around 160m.



Fig. 2. Layout plan of standard boreholes BK1 and BK2

3. Chronostratigraphic Test

3.1. Sample Test

The cores from the above two boreholes were used in dating as well as its data analysis and chronostratigraphic study on the quaternary strata. The results of dating are as follows:

Table 1. Results of radiocarbon (^{14}C) dating with borehole BK1

Sample ID	Depth/m	Age/ (a B.P.)
BK1C1	4.0	20540±90
BK1C2	4.9	21590±80
BK1C3	6.0	34390±290

Table 2. Results of optically stimulated luminescence (OSL) dating with boreholes BK1 and BK2

SN	Sample No.	Depth (m)	Lithology	U ($\mu\text{g/g}$)	Th ($\mu\text{g/g}$)	K (%)	Water Content	Equivalent Dose (Gy)	Age (ka)
1	BK102	10.0	Muddy silt	1.87	10.9	1.58	24.38%	120	33.2 \pm 3.1
2	BK105	21.6	Mucky clay	3.16	16.4	1.86	33.84%	278	58.9 \pm 5.9
3	BK107	27.8	Clay	3.00	17.0	1.79	24.06%	420	83.5 \pm 8.2
4	BK108	31.6	Silty clay	2.49	14.1	1.34	22.07%	370	89.4 \pm 8.9
5	BK1011	46.3	Muddy silt	5.50	12.2	1.64	29.40%	500	96.9 \pm 9.7
6	BK1012	49.6	Fine silty sand	2.38	12.3	1.51	22.63%	500	115.5 \pm 11.6
7	BK1013	56.2	Clay	3.13	18.2	1.43	20.65%	>480	>12.8
8	BK1015	71.8	Muddy silt	2.40	13.1	1.73	23.57%	>500	>13.1
9	BK1017	83.6	Moderately fine sand	2.26	7.48	1.56	24.52%	>500	>12.9
10	BK201	3.5	Silty clay	2.91	15.7	1.54	23.14%	160	34.4 \pm 3.4
11	BK202	9.0	Silt	1.61	8.88	1.61	33.93%	240	78.6 \pm 7.9
12	BK203	19.8	Clay	2.97	17.7	1.76	20.93%	440	84.3 \pm 8.4
13	BK206	42.5	Muddy silt	2.62	14.2	1.83	32.97%	450	105.7 \pm 10.6
14	BK207	49.9	Clay	2.66	14.4	1.33	21.62%	500	127.1 \pm 12.7
15	BK209	56.2	Muddy silt	1.98	13.0	1.65	27.08%	>490	>13.2
16	BK2010	62.0	Silty clay	2.21	16.6	0.93	24.80%	>510	>13.5

Note: The test was performed by the Qingdao Marine Geology Test Center of Ministry of Land and Resources.

Table 3. Results of electron spin resonance (ESR) dating with boreholes BK1 and BK2

SN	Sample No.	Laboratory No.	Depth (m)	Lithology	Paleodose (Gy)	Annual Dose (mGy)	Age (ka)
1	BK1O14	X9	65.5m	Muddy silt	1278.9	4.366	293.0 \pm 25.0
2	BK1O16	X10	81.6m	Fine silty sand	1614.7	4.108	393.0 \pm 35.0
3	BK1O18	A26	101.7m	Clay	2437.5	3.250	750.0 \pm 75.0
4	BK1O19+a	G12	119.8m	Clay	2717.3	2.986	910.0 \pm 90.0
5	BK1O21	X13	144.9m	Moderately coarse sand	8070.0	2.486	3246.0 \pm 320.0
6	BK1O24	X14	172.3m	Silty clay			Insufficient quartz content
7	BK1O27	X15	192.4m	Silt	11167.0	3.144	3556.0 \pm 350.0
8	BK2O8	X16	54.5m	Silty clay	1937.5	3.065	632.0 \pm 60.0
9	BK2O11	X17	66.5m	Silty clay			Insufficient quartz content
10	BK2O12	D23	76.0m	Silty clay	2461.3	2.862	851.0 \pm 85.0
11	BK2O16	X19	105m	Moderately fine sand	1800.0	2.453	733.0 \pm 70.0
12	BK2O19	X20	123.8m	Fine sand	1989.3	2.403	828.0 \pm 80.0
13	BK2O23	X21	147.5m	Moderately coarse sand	3766.9	3.225	1168.0 \pm 110.0

Note: The test was performed by Chengdu University of Technology, Institute of Applied Nuclear Technology.

3.2. Sporopollen Analysis

Sporopollen analysis was conducted carefully with standard boreholes for the quaternary strata in BK1. In this process, 220 sporopollen samples were analyzed, and their sampling depth ranged 0.2-136.6m (including all the quaternary horizons, i.e. Qh, Qp3, Qp2 and Qp1). Among 220 samples, 9,278 sporopollens were recorded, 42 per sample on average. The upper part contained a plenty of sporopollens, and the average sporopollen concentration of sample was 132 pieces per gram, but the lower part was deficient in sporopollens. These sporopollens were classified into 105 types, and composed of 54% arboreal pollens, 31% herbaceous pollens, 15% fern spores, and a few aquatic plant pollens, pediastrum, and concentricystes cysts.

The frequent fluctuation of climate is one of the important quaternary characteristics. The combination of sporopollens can reflect how the change of climatic conditions causes the migration of plant communities and the variation of sedimentary environment and has been widely applied in the quaternary stratigraphic subdivision and correlation. In addition to the analysis of sporopollen spectra, it is generally revealed that the study area experienced the evolution as follows: cold and dry in the early Pleistocene→warm and humid in the early Middle Pleistocene→cool but dry and warm in the late Middle Pleistocene→warm and humid in the early Late Pleistocene→cold and dry in the late period of the Late Pleistocene→warm but humid in the Holocene.

4. Comparison of Standard Boreholes and Quaternary Stratigraphic Framework in Changzhou

4.1. Comparison of Boreholes BK1 and BK2 with Main Boreholes in Vicinal Area

Boreholes BK1 and BK2 were compared with representative boreholes including deep borehole (Mahang deep borehole), Caoqiao ZK04 borehole, cross-fault combined section Yunhe Road yard (CZ3-1), Huayang Road yard (CZ2-3) and Chaoyang Road yard (CZ1-1), so as to accurately and clearly understand the quaternary subdivision and correlation in Changzhou.

Holocene Rudong formation (QhR): thin, 0.5-3.0m thick, 1.49m average.

Upper Pleistocene Gehu formation (Qp3G): It is thicker than the Rudong formation, but still thinner than others. The bottom boundary depth is 15.4-33.0m, 22.96m average, so the thickness varies significantly. However, it can be still internally divided into 2 cycles.

Upper Pleistocene Kunshan formation (Qp3K): Generally, its characteristics are similar to those of the Gehu formation, but it is thicker than the Gehu formation, and much thinner than the underlying Qidong formation (1/2). The bottom boundary depth is 43.5-65.9m, 51.63m average, indicating the dramatic variation of thickness. Internally, it can be divided into 2 cycles (Qp3K-1 and Qp3K-2). In the Mahang deep borehole, the bottom boundary depth of the Kunshan formation is 65.9m. In the Caoqiao ZK04 borehole, the Holocene bottom boundary depth is 43.9m.

Middle Pleistocene Qidong formation (Qp2Q): Its characteristics are clearly different from those of the Gehu formation and the Kunshan formation, which are dominated by fluvial and lacustrine facies or lagoonal facies, and equally divided into sand and clay strata. Differently, the Qidong formation was mainly composed of flood plain facies and estuarine facies and dominated by sand strata (especially the lower part). The bottom boundary depth is 81.5-132.0m, 109.56m average. The thickness varies significantly, and the internal cycles are not clearly divided, but there are around 4 cycles. In the Mahang deep borehole, the bottom boundary depth of the Qidong formation is 105.0m. In the Caoqiao ZK04 borehole, the Holocene bottom boundary depth is 81.5m.

Lower Pleistocene Haimen formation (Qp1H): Its characteristics are clearly different from those of the Qidong formation. The Haimen formation mainly contains the sediments of fluvial facies and pluvial facies. The sediments are mostly formed by clay strata, and the sand strata are not steadily distributed. The bottom boundary depth is 149.0-174.0m, 162.03m average, so the thickness does not vary

dramatically. Internally, it can be roughly divided into 2 cycles. In the Mahang deep borehole, the bottom boundary depth of the Haimen formation is 168.4m.

As shown in Table 4, the thickness of stratigraphic units decreases from old to new and from bottom to top. In the early Pleistocene, a gentle slope exists with the increasing depth from northwest to southeast. However, the terrain is relatively flat in the middle and late Pleistocene, and the thickness and depth of strata vary insignificantly but noticeably. However, the sections have satisfying subdivision and correlation of lithologic features

Table 4. Depth and thickness of strata in boreholes BK1 and BK2

Stratigraphic Unit	Stratum No.	Benniu Town BK1	Yunhe Road CZ3-1	Mahang Standard Borehole	Caoqiao ZK04	Huayang Road CZ2-3	Dongqing BK2	Chaoyang Road CZ1-1	Average
Holocene Rudong formation	QhR	3.0	1.2	1.0	0.5	1.8	0.8	2.1	1.49
Upper Pleistocene Gehu formation	Qp3G-2	21.5	20.9	11.6	16.6	14.2	11.0	10.4	15.17
	Qp3G-1	28.0	25.9	20.1	33.0	22.3	16.0	15.4	22.96
Middle Pleistocene Qidong formation	Qp3K-3+2	33.5	35.2	35.0	39.1	30.4	35.5	40.0	35.53
	Qp3K-1	50.5	59.1	65.9	43.9	50.0	43.5	48.5	51.63
Middle Pleistocene Qidong formation	Qp2Q-4	67.7	70.0	70.0	50.3	63.2	61.0	61.7	63.41
	Qp2Q-3	75.5	80.8	82.1	56.8	74.5	71.0	71.0	73.1
	Qp2Q-2	84.0	94.2	96.0	68.7	97.7	96.0	94.9	90.21
	Qp2Q-1	107.5	104.4	105.0	81.5	121.3	118.0	132.0	109.56
Lower Pleistocene Haimen formation	Qp1H-2	123.3	130.5	136.8	92.4	151.3	136.3	157.0	132.51
	Qp1H-1	149.0	155.0	168.4		166.8	159	174.0	162.03

4.2. Characteristics of the Quaternary Transgressions

Based on the quaternary transgressions in South Jiangsu and Shanghai and their sedimentary response, 4 large-scale transgressions have basically happened since the middle Pleistocene. Chronographically, they occurred in the following sequence: Shanghai transgression in the mid-early period of the middle Pleistocene, Taihu transgression in the early period of the late Pleistocene, Gehu transgression in the mid-late period of the late Pleistocene, and Zhenjiang transgression in the mid-early period of the Holocene. Correspondingly, 4 transgressive strata and relatively warm and humid climatic sediments were formed. The lithology, color, and type of climate of sporopollen plants in borehole BK1 are shown in Table 5.

Table 5. Response of lithology, color, and type of climate in borehole BK1 to transgressions

Transgression	Period	Color and Lithologic Characteristics	Sporopollen Zone and Climate
Zhejiang transgression (4 th)	Mid-early period of the Holocene	Dark gray carbon clay and muddy silt of flood plain facies	VI-warm and humid
Gehu transgression (3 rd)	Mid-late period of the late Pleistocene	Gray, dark gray silt, and muddy silt of lagoonal facies	VA-warm, cool but dry
Taihu transgression (2 nd)	Early period of the late Pleistocene	Gray, dark gray silt, fine sand and muddy silt of shallow lake-lagoonal facies	IVa-warm and humid
Shanghai transgression (1 st)	Mid-early period of the middle Pleistocene	Gray moderately fine sand, gravel-contained moderately fine sand of estuarine facies	II-warm and humid

5. Conclusion

The borehole BK1 to the northeast of the intersection with X210 county highway in the east of Benniu Town, and borehole BK2 near Wantang Village in the north of Dongqing Township, Changzhou, Jiangsu, are used together with the existing research achievements. By employing such methods as lithologic description, division of lithic facies, stratigraphic dating, analysis of paleoclimatic sporopollen samples, and stratigraphic correlation between boreholes, it is found that:

(1) The quaternary strata in Changzhou are divided from top to bottom as follows: the Holocene Rudong formation with the thickness of 2m, the Upper Pleistocene Gehu formation with the thickness of 22m, the Upper Pleistocene Kunhan formation with the thickness of 47m, the Middle Pleistocene Qidong formation with the thickness of 113m, and the lower Pleistocene Haimen formation with the thickness of 154m.

(2) As revealed by two standard boreholes, the evolution of the quaternary sedimentary environment in Changzhou corresponds roughly to the sedimentary response characteristics of 4 transgressions in the area, i.e. dry lakes and pluvial sediments in the early Pleistocene→lakes and estuaries in the early period of the middle Pleistocene→lakes in the late period of the middle Pleistocene → lakes and lagoons in the late Pleistocene→pluvial and alluvial sediments in the Holocene. The strata responding to these transgressions generate lakes, lagoons and estuaries, and are dominated by gray and dark gray silt, fine sand, and carbon clay. They contain fragments of bivalves and gastropods, and plant stems in cross beddings. The climates reflected in these plants include warm and humid—warm but dry—mild but dry.

(3) Relying on lithostratigraphy and chrono stratigraphy and following the comprehensive subdivision principle of combining climatic stratification and macroscopic characteristics with microscopic indications, multiple drill cores reveal that the thickness of sections in the study area and their bottom boundary depth have not varied dramatically since the late Qp2, and there is not abrupt variation in the thickness and bottom boundary depth of strata. In other words, there were not significant fault activities or basin fluctuation. As revealed in the comparison of boreholes and the tectonic analysis inside the comprehensive area, the Suzhou-Wuxi-Changzhou fault and the Houyu-Xinqiao fault mainly affected the strata in the Middle Pleistocene Qidong formation and others formed before the period, which is reflected in the thickest sediments in the Qidong formation. However, they did not exert a significant effect on the upper Pleistocene strata, but mainly caused the sedimentary filling, while the strata were steadily distributed.

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