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Article *in* Journal of Geographical Sciences · December 2009

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J. Geogr. Sci. (2009) 19: 671-680
DOI: 10.1007/s11442-009-0671-2

Evidence for marine transgression between 7500–5400BC at the Luotuodun Site in Yixing, Jiangsu Province

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Abstract: Based on archaeological excavations, 217 samples were collected from the Luotuodun Site. Of them 63 samples from the section plane of the site layer were used for identification analysis of foraminifera, plant debris and seed fossils, and four samples were used for ^{14}C dating and relevant analysis. Through many kinds of experiments, we have drawn some conclusions. Firstly, benthic foraminifera, such as *Ammonia compressiuscula* and *Ammonia cff. sobrina*, are found in the 10th layer, indicating that between 7500 and 5400 BC, i.e. before the emergence of the Majiabang Culture, Luotuodun Site and its nearby regions had ever experienced a marine transgression event. Secondly, we have found 450 plant fossils in this site, such as *Polygonum sp*., *Scripus sp*., *Najas sp*., *Physalis sp*., which indicated lacustrine or swamp environment.

Keywords: Luotuodun Site; Foraminifera; transgression event; plant fossils

The relationship between man and environment is one of the most important research fields of the past global changes. But without any written records, it is difficult to evaluate the influences of environmental change on human societies in the prehistoric times. Cultural sites are the perfect research materials for the interactions between environmental change and human civilization. Therefore, environmental archaeology on the cultural sites during the Neolithic Age is important to address this issue.

The area surrounding Taihu Lake is one of the important cradles of ancient culture in China, as revealed by accumulated lines of archaeological data. In this region, the distribution of Neolithic cultural sites is excessive and concentrated. Cultural layers, cultural inter-

Received: 2009-02-14 **Accepted:** 2009-05-21

Foundation: National Science and Technology Project, No.2006BAK21B02; The Open Foundation of the State Key Laboratory of Loess and Quaternary Geology from the Institute of Earth Environment, CAS, No.SKLLQG0817; The Training Foundation of National Basis of Talents, No.J0630535; Foundation of Doctoral Program, No.20050284011; Test Foundation of Modern Analyses Center of Nanjing University, No.0209001309

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ruptions, marine and fluvial sediments, including buried trees, are abundant and typical. The archaeological culture in the Yangtze Delta from 7 ka BP can also be divided into four periods. They are Majiabang Culture (7000–5800 a BP), Songze Culture (5800–5000 a BP), Liangzhu Culture (5000–4000 a BP) and culture of each historical period (An, 1981; Chen *et al.*, 1997; Zhou *et al.*, 2000). So this region is ideal for prehistoric environmental archeological research.

In the distribution of archaeological culture in areas around the Taihu Lake is a relatively independent region, as mentioned above, it plays an important role in the origin and evolution of the civilization. The Neolithic archaeological culture of this region has gone through Majiabang Culture, Songze Culture and Liangzhu Culture, from 5300 BC to 2100 BC, almost experiencing more than 3000 years. During the late stage of the Songze and Liangzhu cultural periods, archaeological culture around the Taihu Lake shows a high degree of identity, but the research about the region's early stage that shows the richness and diversity has been ignored, the major discovery of the Luotuodun Site fills the gap of this research, being successful in connecting the missing links of the culture around the Taihu Lake. It also gives an important clue for the reason why Neolithic sites before 7000 a BP cannot be found easily in the northern Jiangsu region.

1 Introduction

Located at the Tangnan Village Xinjie Town in Yixing City, Luotuodun Site is 10 km away from the Yixing City to the east, and 25 km away from the Liyang City to the west. It lies on the transitional zone from the Yili low mountains to the deltaic plains with a geographical coordinate of 119º42′E, 31º11′N, and an altitude of about 3–5 m above sea level (Figure 1) (Lin *et al.*, 2002; AINM, 2003). The total area of the site is 25×10^4 m^2, of which 1309 m^2 have been excavated.

2 Stratigraphy, field sampling and radiocarbon dating

From November 2001 to July 2002, the archaeology team, which consists of the Archaeological Institute of the Nanjing Museum and the Heritage Management Committee of Yixing City, carried out the first large-scale excavation to the Luotuodun Site and confirmed that it was a settlement center site in the western part of the Taihu Lake region, representing the period from the Majiabang Culture to the Songze Culture between 7000–5500 a BP.

The archaeological stratum of the Luotuodun Site with the history of 7 ka BP can be divided into layers of Majiabang Culture, Songze Culture, Liangzhu Culture, Guangfulin Culture, the Spring and Autumn Period culture, the culture of the Tang–Song dynasties, as well as the layers of shell, buried ancient trees and the natural alluvium among the cultural layers.

The authors carried on investigation and sampling to the site in September, 2007. Field samples were collected from the bottom to the top of the sections in sequence, and a total of 217 samples from the T5033 excavation section were obtained. Figure 2 is the photo showing the T5033 excavation section taken at the Luotuodun Site. From this photo, turf layer of 50 cm can be seen at the lower part of the Majiabang Culture. Table 1 is the characteristic description of the T5033 excavation stratum.

Based on the archaeological age offered by the excavation team, 4 samples are chosen for

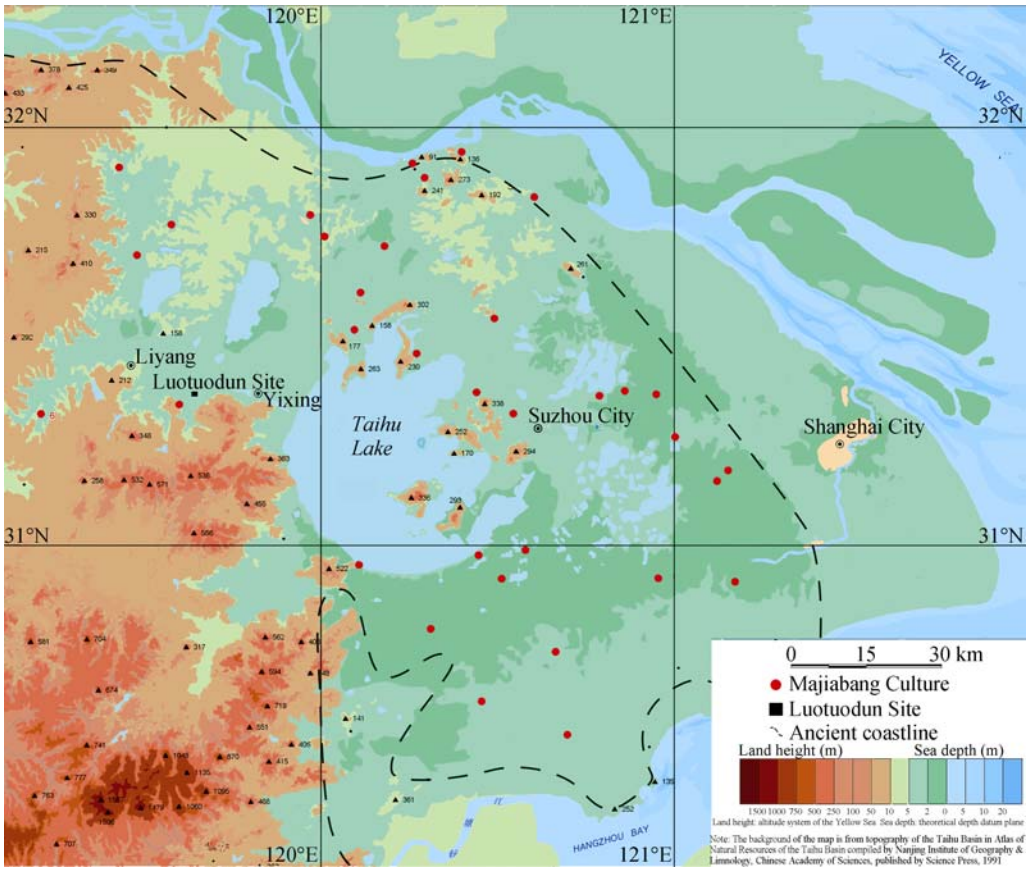


Figure 1 Location of the Luotuodun Site, Yixing, Jiangsu Province

Figure 2 Photo showing the T5003 excavation stratum section at the Luotuodun Site (below the red line is turf layer)

Table 1 Description of the T5033 excavation stratum at the Luotuodun Site

Layer No.	Thickness (cm)	Archaeological age	Layer features	Excavation relics
1	38	Latter-day	Cultivated horizon	Sundries, plant roots
2A	36	The cultures of Western Zhou, The Spring and Autumn Period	Pure yellowish-gray soil	Pottery
2B	25	Guangfulin Culture	Dust-colour soil	Pottery
3	30	Liangzhu Culture	Brown-gray soil with rust spots	Pottery
4	30	Majiabang Culture	Deep brown gray soil with rust spots	Lots of animal bones; pottery
5	19	Majiabang Culture	Gray dark soil with yellow spot, sintering soil	Animal bones, pottery fragments, shell, mussel
6	18	Majiabang Culture	Gray soil with yellow spot, sintering soil	Animal bones, pottery fragments, shell, mussel, carbonized rice
7	21	Majiabang Culture	Steel-gray soil, sintering soil	Animal bones, pottery fragments, shell, mussel
8	19	Majiabang Culture	Steel gray soil with charcoal	Animal bones, carbonized rice, pottery fragments with mussel and fine sand
9	19	Dark turf layer	Dark turf	Animal bones, fragments with mussel and fine sand
10	24	Dark turf	Dark turf	Animal bones, plant roots
11	10	Natural layer	Yellow soil	Plant roots

Table 2 ^{14}C dating and calibration

Laboratory No.	Sample No.	Sample name	Material for dating	^{14}C age (a BP)	Calibrated age (Cal. a BC)
KF071204	T5033(8)-29	Sludge	Organic carbon	5281±175	4100±400
KF071205	T5033(9)-19	Turf	Organic carbon	5464±165	4325±375
KF071206	T5033(10)-24	Turf	Organic carbon	6016±200	4925±475
KF071202	T5033(10)-1	Turf	Organic carbon	8036±190	7000±500

^{14}C dating in the State Key Laboratory of Lake Science and Environment (LLSE), Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences (CAS) (Table 2).

On the basis of the relevant ages and the age sequence of testing the layers offered by the LLSE, we think that four data such as KF071204, KF071205, KF071206 and KF071202 are reliable which means that the age of the layers below the 9th layer must be earlier than 7000 a BP.

3 Laboratory analyses

Based on investigation, excavation, and sampling to this site, 63 samples are selected from the 217 samples for identification of foraminifera and plant macrofossils (Table 3).

Table 3 shows the result of identification, from which it can be seen that lots of plant fossils, plant roots, charcoal and plant debris are found in samples from the 11th, 10th and 9th layers of the T5033 stratum. Also, there are amounts of debris of animal bones in the 5th and 6th layers, lots of charcoal debris and mineral crystal in the 8th layer. From Table 4, we can see that there are at least 450 plant fossils in samples, an indication of a kind of terrestrial environment.

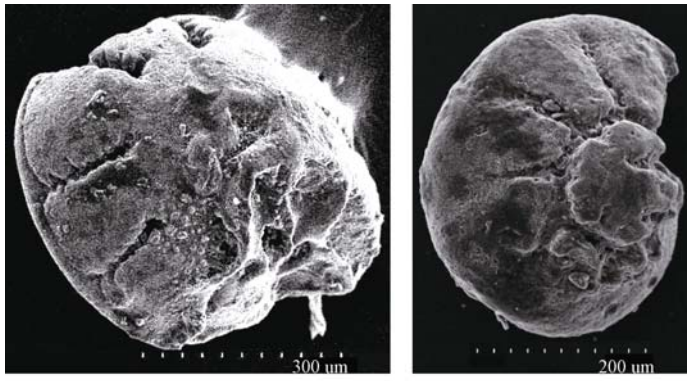
Table 3 Inclusions of the laboratory samples from the T5033 excavation stratum

Laboratory No.	Depth (cm)	Layer	Inclusions of the Laboratory samples
1–6	298–288	11	Mainly plant debris, including some plant microfossils
7–18	287–265	10	Charcoal debris, plant debris, lots of plant fossils, thin silt
19–28	263–245	9	Plant debris, charcoal debris, plant fossils
29–32	244–216	8	Lots of charcoal debris, sandstone with quartz, quartzite, hornblende, biotite, feldspar, little silt
33	213	7	Have the same inclusions with the 8th layer
34	197	7	Materials in white powder
35	193	6	Debris of animal bones, with some sandstone grains
36	177	6	Have the same inclusions with the 7th layer
37–38	173, 161	5	Debris of animal bones
39	157	4	Argillaceous siltstone, white cement
40, 41	143, 131	4	Argillaceous siltstone with some charcoal debris, sintering soil, quartz
42–44	127, 113 101	3	Argillaceous silt, quartz
45–57	98–74	2	Argillaceous silt, quartz
58–61	72, 65 52, 39	2	Argillaceous silt, quartz, some plant roots
62–63	37, 1	1	Argillaceous silt, quartz

3.1 Foraminifera

The foraminifera and ostracode were identified in the Regional Environmental Evolution Institute of Nanjing University. By the pretreatment with sieve, samples are divided into two groups, and then use the JSZ6 binocular stereomicroscope to identify. The identified result shows that there are two species of benthic foraminifera, *Ammonia compressiuscula* (Figure 3a) and *Ammonia cff. sobrina* (Figure 3b), which are found in the samples of the 10th layer. Figure 3 is the SEM photo of the foraminifera scanned by the S-3400N II, which is produced by the Japanese Hitachi Company in the Modern Analyses Center of Nanjing University.

As is well-known, *Ammonia* is a kind of benthic foraminifera with a living environment of euryhaline and brackish seawater in the modern coastal beach (Wang *et al.*, 1988). By the benthic foraminifera in the stratum of the Luotuodun Site, we can speculate that before the appearance of the Majiabang Culture, that the Luotuodun Site and its nearby regions had experienced a marine transgression between 7500BC–5400BC.



(a) *Ammonia compressiuscula* (b) *Ammonia cff. sobrina*

Figure 3 SEM photo of the foraminifera in the 10th layer of the stratum, Luotuodun Site

3.2 Plant macrofossil

The authors identified the 63 samples from the Luotuodun Site for a micro-paleontological analysis (Figure 4 and Table 4). By the identification, a total of 450 plant fossils are found in these samples, mainly distributed in the 2nd, 9th, 10th and 11th layers, especially in the 9th and 10th layers, which accounts for 29.8% and 62% respectively of the whole stratum. Basically, the plant fossils are black, presenting the serious carbonization phenomenon.

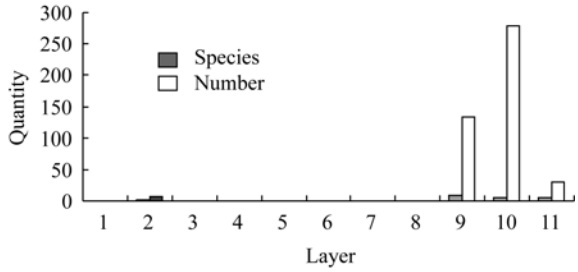


Figure 4 Distribution of the plant macrofossils from the Luotuodun Site

Table 4 Distribution of plant macrofossils from the Luotuodun Site

Laboratory No.	Depth (cm)	Layer	Fossils (Number)	Species
1–6	298–288	11	30	5
7–18	287–265	10	279	6
19–28	263–245	9	134	8
45–57	98–74	2A	3	1
58–61	72–39	2B	4	
62, 63	37, 1	1	0	
Total			450	

Note: Nos. 29–44 are the samples of the 8th to the 3rd layers. No plant fossils are found.

The Taihu Lake region looks like a dish-shaped terrain. It is several tens of kilometers from the Nanjing–Zhenjiang hilly areas to the northwest, and to the southwest is the Yixing–Liyang mountainous area. Luotuodun Site lies on the western side of the Taihu Lake. The plant fossils are found in the 9th and 10th layers of the T5033 excavation stratum should be autochthonous or the deposition transported from the northwest and southwest highland by rain water and surface runoff.

In the species of the discovered plant fossils, usually three kinds of plant seeds fossil can be found in the stratum of the Luotuodun Site (Figure 5). Long shape plant seeds fossil with brownish-black color is from the sample 10-3 of the 10th layer (Figure 5a). Round-spherical plant seeds fossil with red color is from the sample 2A-22 of the second layer (Figure 5b), the same species have been found in the Tenghualuo Site (Li *et al*., 2008), which implies that the distribution of the red spherical plant seeds is prevalent at that time. Furthermore, prolate-shaped plant seeds fossil with brown color is from the sample 10-5 of the 10th layer (Figure 5c); and spherical plant seeds fossil with white color is from sample 10-23 of the 10th layer (Figure 5d). The plant fossils above mentioned shown in Figures 5a, 5c and 5d were found in the stratum containing seeds of 241, 70 and 53 in sequence.

On the basis of the above experiment, the selected plant macrofossils were identified in the Nanjing Institute of Geology and Palaeontology. The result shows that there are 4 species, i.e., *Polygonum sp.* (Figure 6a), *Scripus sp.* (Figure 6b), *Najas sp.* (Figure 6c) and *Physalis sp.* (Figure 6d).

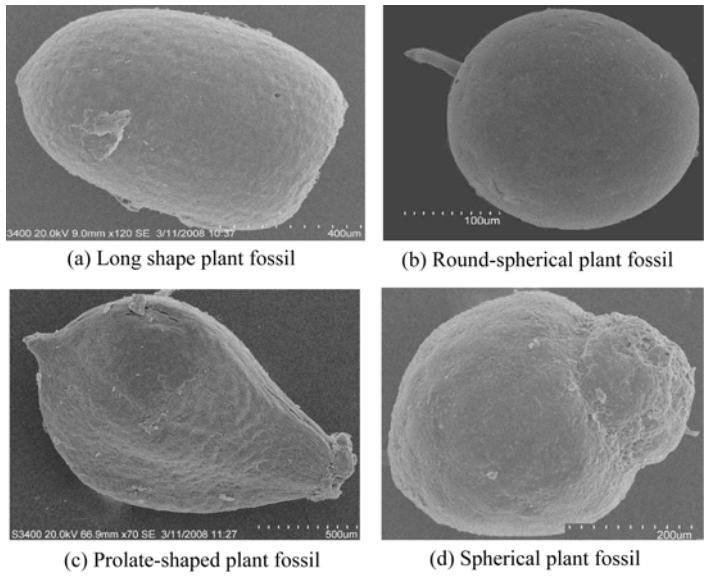


Figure 5 Typical plant macrofossils from the Luotuodun Site

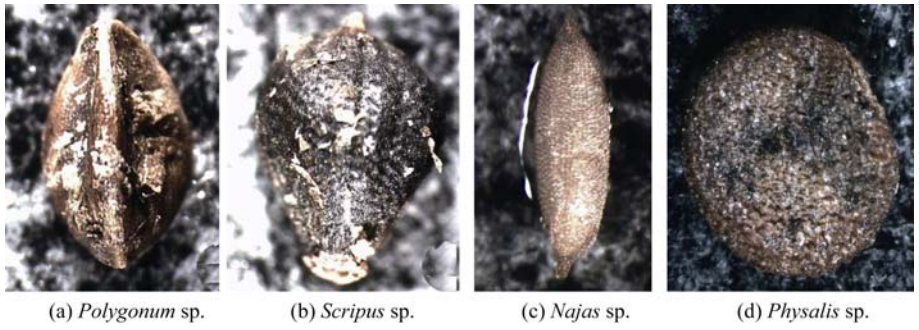


Figure 6 Specimens of the plant fossils that have been identified

It is well-known that *Polygonum* is an annual or perennial herbaceous plant, distributed in the world, mainly in North Temperate Zone; and it also can be found in various provinces of South and North China. *Scripus* is bushy or scattered herbaceous plant, being distributed in whole China, mainly being planted in the humid or swampy environment. *Najas* is an annual submerged plant living in the paddy field with fresh water or salt water, pond and lake. *Physalis* is an annual or perennial herbaceous plant living in the tropic and temperate zones of America, also can be found in the Eurasia and Southeast Asia. These four plants mentioned above are all herbaceous plants. Especially *Scripus* is hygrophytes and *Najas* is hydrophytes, which reflect the sampling place possessing an aquatic environment with lakes, swamps and others.

3.3 Inclusions of the other layers

There are large number of animal bones and their debris in the 5th and 6th layers in the T5033 excavation stratum. Huang *et al.* (2005) has found abundant fossil specimens of mollusc living in rivers and lakes in this site. There are lots of charcoal debris, mineral crystals and sintering soils in the 7th and 8th layers (Tables 1 and 3), which are the signs of fire use. All the above indicate that this area maybe one of the central human habitations.

Comprehensive analysis on the inclusions and signs of the 6th, 7th and 8th layers illustrates that the site was an important settlement site in the Majiabang Culture. There is no plant macrofossil found in 3 layers indicating that, because of the concentrative living areas and low productivity, people had to depend on deforestation, which caused the environmental deterioration in this region.

4 Discussion and conclusions

4.1 Discussion

Generally speaking, it is warm in the Holocene up to its Holocene Maximum between 7000 and 4000 a BP. According to the research (Xu, 1992; Xu *et al.*, 1996), the past 11,000 years can be defined to three major periods using the sporo-pollen assemblages from the sediment profiles of the Taihu Lake Basin. First, from 11,000 to 9000 a BP, broad-leaved deciduous species especially Fagaceae predominated, while conifer species mainly *Pinus* had a strong presence. The Taihu Lake Basin was already dominated by the subtropical evergreen broad leaved deciduous species, but the presence of *Abies* and *Picea* indicated that the temperatures were lower than the present ones. Second, during the period from 9000 to 5000 (5400) a BP, the temperature was about 1–2℃ higher than the present. It is a peak period for evergreen broad-leaved plant to grow. The climate, warm and wet, is suitable for plant growth and human civilization development. Third, from 5000 a BP to now, the subtropical broad-leaved plants obviously declined, while the conifer species and warm-temperate species increased. This reflects lower temperatures and the increasing impacts of human activities.

In the Neolithic Age, the climate and sedimentary environment had great influence on the development of human civilization because human capability was limited to withstand the natural hazard. The Holocene Megathermal Period had provided a good climatic background for the development of human civilization, especially in the Megathermal Maximum when the climate was most appropriate and laid a natural environmental foundation for the emergence of the Neolithic civilizations. Warm and humid climate was conducive to the growth of crops and the development of human civilization. A number of plant fossils found in the 11th, 10th and 9th layers of the Luotuodun Site indicated good vegetation cover.

By the analysis of isotope records of Greenland ice core, the global surface air temperature had changed over the past 18,000 years (Houghton *et al*., 1990, 2001). The result of the research seems to support Fairbridge's idea of high sea level event. As the temperature rose, the glacier melted rapidly, which speeded up the appearance of the high sea level in the Holocene.

Previously, there were lots of discussions about the high sea level in the Holocene and sea transgression (Chen *et al.*, 1959; Zhang *et al.*, 1983; Yang *et al.*, 1985; Shao, 1987; Sun, 1987, 1992; Yan *et al*., 1987, 1993; Jing *et al.*, 1989; Zheng *et al.*, 1994; Stanley *et al.*, 1996; Yu *et al.*, 1999; Jiang *et al.*, 2001; Shen *et al.*, 2003; Zhu *et al.*, 2003; Wang *et al.*, 2004; Xin *et al.*, 2006). For example, Yang *et al.* (1985) thinks that the largest postglacial transgression happened about 7 ka BP when sea water had reached to the hills of Danyang–Liyang–Wuxing; Shao *et al.* (1987) thinks that because of the mid-Holocene marine transgression (7.0–6.5 ka BP), lots of platform in the Taihu plain was submerged to tidal flats with shallow

lagoon environment; Yan *et al.*(1993) thinks that northwestern part of the Taihu Lake plain was a gulf and the central part was plain in the early Holocene (10,000–7500 a BP), and marine transgression influenced this plain in the mid-Holocene (7000–6500 a BP); Zhu *et al.* (2003) thinks that the high sea level might appear in the early Holocene (before 7 ka BP). Most of the conclusions come from the adoption of testing data and analysis of historical documents. There are few practical evidences from the cultural sites.

According to dating and foraminifera identification of the samples from the Luotuodun Site, the authors prove again that this region had experienced marine transgression between 7500BC to 5400BC. It gives the scientific explanation of the problems that why Neolithic sites before 7000 a BP cannot be found easily in the northern Jiangsu region, and also provides the latest scientific evidence for the Holocene sea level change and marine transgression.

4.2 Conclusions

(1) Benthic foraminifera relevant to the marine environment found in the 10th layer of the Luotuodun Site suggested that the Luotuodun Site had experienced marine transgression event between 7500BC to 5400 BC. It is perhaps the real reason why Neolithic sites before 7000 a BP cannot be found easily in the northern Jiangsu region.

(2) Plant macrofossils discovered in the samples of the Luotudun Site are mainly concentrated in the 9th, 10th and 11th layers. The number of the plant macrofossils is reduced gradually from the bottom to the top of the samples. The vertical distribution shows that this region had good vegetation cover and excellent ecological environment in the early Neolithic period; because of the concentrative living areas and low productivity, people had to live on a gathering economy, which induced to the environmental deterioration.

(3) The Luotuodun Site is located at the west side of the Taihu Lake, where fresh water for vegetation growth could be found after the marine transgression event between 7500BC to 5400BC with hot and humid climate. The plant fossils found in the 9th and 10th layers should be autochthonous or the deposition transported from the hills of the northwest and southwest by rain water and surface runoff.

(4) The validation of plant macrofossils as a new evidence or indication of the stratum and regional environment needs more exploration and research.

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