Approaching the Forming Environment of Shelly Chenier in the West Coast of Bohai Bay: exemplified by Chenier III in Yucenzi site

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Abstract. In order to explore the causes of formation of the cheniers on the west coast of Bohai Bay, the Yucenzi chenier near the third chenier on the West Coast Plain of Bohai Bay is taken as the research object, and drilling investigations of the sediment under the Yucenzi chenier was conducted to measure the conductivity of the slime turbid water and identify the foraminifera of the drilling samples. The results showed that the underlying sediments of Yucenzi chenier are formed by a 534m thick continental sedimentary layer, and the chenier does not contact with the marine or transitional sedimentary layer directly. It can be inferred that the Yucenzi chenier belonging to the third chenier is formed through shells accumulated on the supratidal zone during storm tide or spring tide.

1. Introduction

The chenier on the west coast of Bohai Bay in China, the ancient chenier in St. Louisiana and the ancient chenier in Suriname in South America are called the three largest ancient cheniers in the world. In the west plain of Bohai Bay, there are five cheniers which are roughly parallel to the modern coast, the formation ages are 0.9 cal.ka BP for the first chenier, 2.4-2 cal.ka BP for the second chenier, 4.24-3.37 cal.ka BP for the third chenier, 5.65-4.67 cal.ka BP for the fourth chenier and 7.3-6.13 cal.ka BP13-2 for the fifth chenier. According to the different angles and methods of the research, different researchers have come to various conclusions on the causes of the chenier and its accumulation environment, and the representative viewpoints are summarized as follows: (1) Zhao Xitao et al. (1986) thought that the cheniers developing near the mean high tide line or intertidal zone could represent the position of the ancient coastline13. (2) Xu Jiasheng (1994) believed that the cheniers were formed at the position of the high tide line, and it was caused by waves carrying a large number of shells and debris to the high tide line13. (3) Cai Mingli (1993) thought that the ancient cheniers were developed in the edge of the splash zone, and the upper part of the intertidal zone was rich in shells but unable to form the chenier, basing on field observation and analysis of the modern chenier along the coast of Jiangsu Province. Generally speaking, the spring tide was below the bottom of the chenier, and the elevation of the bottom of the chenier was higher than the average high tide line13. (4) Wang Hong et al. (2000) suggested that the lower part and bottom of the ancient chenier can be formed in the underwater
environment of the intertidal zone and the upper part of subtidal zone\textsuperscript{(6)}, (5) Ren Meie (1983) proposed that the formation of ancient cheniers were the results of storm deposition, undering the action of storm, several coastal cheniers were formed near the high tide line, and the cheniers could not represent the ancient coastline\textsuperscript{(7)}, (6) Saito and Xue Hunting (2000) thought that the formation of the cheniers were the results of the diversion of the Yellow River. Because of the southern migration of the Yellow River Estuary, the sedimentation of Tianjin plain stopped, and the coastline was in a long-term stable state since then. In such circumstances, the cheniers are developed\textsuperscript{(8)}. (7) Wang Guanmin (2006) believed that the formation of ancient cheniers was the results of multiple roles. The deposition of shells could be related to both wave impact and tidal impact, especially the rising tide during storm tide\textsuperscript{(9)}. Li Xuening (2009) believed that the main dynamic factors for the migration of biodetritus of the cheniers are the floodcurrent and the wind driven current\textsuperscript{(10)}.

The key to judge the cause of the chenier is to rebuild the sedimentary environment of the sediments under the chenier and distinguish between the marine stratum and the continental strata. To differentiate marine strata and continental strata, the methods of micropaleontology analysis and shell identification are widely used. In some specific areas or horizons, the contents of ancient extinct life and shell are less or poorly preserved, and there are problems of sediment transportation between different places, which lead to misjudgment. In recent years, the Electric Conductivity of the Turbid Clay Water (EC) is a simple method to judge the depositional environment of coastal plain in foreign countries, and it is also widely used\textsuperscript{(11-13)}. In this paper, the authors have measured the conductivity of turbid clay water of the drill-hole samples of the third chenier, Yucenzi chenier, to determine whether the underlying sediments are marine deposit or continental deposit, and find out the paleoenvironment of chenier development, so as to provide new evidence for the causes of the chenier.

2. Geological setting and methods
The region lies to the south of the Yanshan Mountain Range, east of the North China Plain hinterland, north of the hills of Shandong, west of the Bohai Sea. Located in the mid-latitudes of the northern hemisphere, this area is a famous depressed area in China, and the atmospheric circulation is dominated by the subpolar westerlies and subtropical pressure system, thus this area belongs to the Monsoon Climate of Medium Latitudes. The Yellow River and the Haihe River system play an important role in the formation and evolution of the regional landform. Historically speaking, the Yellow River carried lots of sediment to this area, which was the main geological driving force for the land formation on the west coast of the Bohai Bay.

Yucenzi chenier was first discovered by the Coastal Zone Research Center of Tianjin Geological Survey Center in 2011. The chenier is located in the inner side of the third chenier in Tianjin plain, 1.5km southwest of Jygezhuang, Jinnan District, Tianjin (Figure 1).
The author used Dutch slot sampler, Eijkelkamp, to drill a hole with a depth of 9.5 m in the west bank of Bohai Bay, named YC hole. Total station was used to measure orifice elevation of YC hole basing on known elevation point. The YC core of the chenier was measured by the method EC to distinguish the marine and continental strata. Turbid Clay Water is grinding the clay sample into a powder of less than 31 mesh, weighing 10g, and adding 120ml distilled water after drying the sample for 48h in a drying oven at 110°C. The principle of distinguishing marine and continental strata is that the measured value of the EC is positively correlated with the amount of sulfate ion and sulfate. The sediment has the characteristics of low conductivity in fresh water environment and high conductivity in sea water environment, so it can be judged from the conductivity of clay sediment whether it is in water environment or in sea water environment. The conductivity of turbid clay water is less than 0.40 mS/cm in common continental sediments, 0.40-1.20 mS/cm in transitional faces, and more than 1.20 mS/cm in marine sediments. The specific steps: (1) core sample is sampled at an interval of about 20cm and put the samples into a drying oven at 110°C for 48 hours; (2) the powder is grinded to less than 31 mesh, weighed 10g and put into a 130ml long plastic bottle, added with 120mg distilled water; (3) the first conductivity measurement is carried out after stirring for 3min and placing for 1h; (4) After 5 days, stir again for 3 min and place for 1 h, and then conduct a conductivity measurement; (5) if the values of the two measurements are close to each other, take the latter value; if the values of the two measurements differ greatly, it is necessary to measure again [14].

Shell samples collected from Yucenzi chenier profile were sent to US Bata Laboratory for AMS 14C dating, the results are shown in Table 1.

| Lab code   | Sampling elevation | Material dated          | Conventional age (a BP) | Calibrated age (cal BP) |
|------------|--------------------|-------------------------|-------------------------|-------------------------|
| BA110861   | +1.34--+1.44       | Ostrea pestigris         | 4370±35                 | 4743 (4675–4831)        |
| BA110862   | +1.04--+1.14       | Nassarius variciferus    | 4480±40                 | 4892 (4814–4916)        |
| BA110863   | +1.04--+1.14       | mbionium thomasi (crosse)| 4500±40                 | 4914 (4824–4978)        |
| BA110865   | +0.34--+0.44       | Ostrea pestigris         | 4415±35                 | 4808 (4707–4876)        |

### 3. Descriptions of core lithology and results of the EC

#### 3.1. Description of Yucenzi chenier and core lithology
The top elevation of Yucenzi chenier is 1.44 m above sea level. The chenier is about 500 m long, trending NNW-SSE, nearly paralleling to Jygezhuang III chenier. The outcropping thickness is about 1 m. Topsoil can be found from the surface to an elevation of 1.34 m (depth 0.30 m); the chenier is at an elevation of 1.34 m (depth 0.30 m) ~ 0.88 m (depth 0.56 m); the mixture of shell debris and mud can be found at an elevation of 0.88 m (depth 0.56 m) ~ 0.64 m (depth 0.80 m); brown silt is at an elevation of 0.64 m (depth 0.80 m) ~ 0.64 m (depth 0.44 m). According to AMS $^{14}$C dating, the chenier with a thickness of about 26 cm was formed at 3417 cal. BP [15].

Fig. 2 Section photo of Yucenzi shelly chenier.

The YC hole (38°57’51.9”N, 117°18’21.0”E) was drilled at about 2.5 m in front of the chenier profile. The elevation of YC hole orifice is 0.44 m. Brown silt with shell debris can be found from the surface to an elevation of 0.19 m (depth 0.25 m); brown clay with shell debris is at an elevation of 0.19 m (depth 0.25 m) ~ -0.46 (depth 0.90 m); brown-grey clay interbedded with silt is at an elevation of -0.46 m (depth 0.90 m) ~ -2.06 m (depth 2.50 m); dark-grey silty clay is at an elevation of -2.06 m (depth 2.50 m) ~ -8.26 m (depth 8.70 m); grey clay is at an elevation of -8.26 (depth 8.70 m) ~ -9.06 m (depth 9.50 m).

3.2. The EC results of YC core

The EC determination was measured by sampling from YC core at 20 cm interval. According to the results of EC, YC core was divided into three zones (I, II, III). Zone I: -9.06 ~ -4.46 m. The EC value is 0.36 ~ 1.03 mS/cm, in the range of 0.40 ~ 1.20 mS/cm. The result varies greatly, and the decrease trend is obvious from the bottom to the top. The result shows that the sea-land transitional phase deposit is gradually shallower. Zone II: -4.46 ~ -2.26 m. The EC value is 0.24 ~ 0.36 mS/cm, less than 0.40 mS/cm, the boundary value of continental and the transition phase, suggesting a continental deposit environment. Zone III: -2.26 ~ -0.44 m. The EC value is 0.29 ~ 0.44 mS/cm, which is generally larger than that of zone II. Most data are less than 0.40 mS/cm (two data more than 0.40 mS/cm), but Zone III still belongs to continental deposit environment (see Figure 3).
4. Discussions and Conclusion

The results of EC show that the depositional environment of YC hole, located next to the profile of the chenier, is divided into three zones from the bottom to the top: sea-land transition phase (Zone I) → land environment after regression (Zone II) → splash zone (Zone III). Zone III was identified with foraminifera to restore its ancient environment more precisely. The results indicate that there were many foraminifera in Zone I, mainly composed of *Ammonia beccar* vars—*Elphidium nakanokawanse*—*Nonionellina labradorica*. According to Li Jianfen’s (2010) research on the distribution characteristics of modern foraminifera in the west of Bohai Bay and the geological environment records,[15] these foraminifera are common species in the intertidal zone and offshore shallow sea area of the west coast of Bohai Bay. No foraminifera were found in Zone II or Zone III. The bottom of the Yucenzi chenier is 0.88 m above sea level, and the boundary between the underlying transitional faces (zone III) and the continental facies (zone II) beneath the chenier is at an elevation of -4.46 m. Therefore, between the chenier and transitional facies (zone I) under the action of sea water, there is a 5.34 m thick continental facies layer (zone L and zone III). Which indicates that after the exiting of the sea water at the location of Yucenzi profile, there was a deposition of more than 5m thick continental facies. Yucenzi chenier is directly formed on the continental layer, because the chenier was not formed in the intertidal zone or the coastline nearby the average high tide line, but in the land with a certain distance from the coastline.

Therefore, it can be speculated that during the formation of the chenier, shells were brought to the land with a certain distance from the coast by a huge force, which may be a storm tide or a strong wave in spring tide. Because Tianjin plain is located in the middle latitude coastal area, it is easy to form storm tide under the influence of meteorological factors, astronomical factors, geographical factors, hydrology and other factors. According to the records of flood and drought disasters in Tianjin, there were 43 storm tides in Tianjin coastal area from 1644 to 1990 A.D., and the largest storm tide in recent years occurred in 2003.[16]
Therefore, storm tide as a dynamic interaction between ocean and Tianjin plain cannot be ignored. However, in terms of its size, this chenier is rather small, with a shell layer of only 26cm in thickness and 1.20m in width, so the development process of the chenier lasted for a short time, and its size is smaller than that of other large cheniers. Therefore, this is also in line with the short-term severe weather phenomenon of storm tide, which could promote the formation of cheniers.

Basing on the field investigation of Yucenzi chenier, and the results of EC and the identification of foraminifera, the conclusions are as follows. 1) The underlying sediments of Yucenzi chenier have experienced a downward trend in the sea level, which forms transition phase (zone I) → land environment after regression (zone II) → splash zone (zone III). It indicates the trend that the land completely separated from the sea after the sea level dropping and then slightly rose to form the splash zone. 2) Yucenzi chenier doesn’t cover directly on the marine layer or the transitional layer. Instead, it covers on the splash zone of the continental layer. The formation of the chenier should be due to the action of the tide or storm tide, bringing the shells to splash zone—a certain distance from the intertidal land. Yucenzi chenier is the result of strong wave action during storm tide or spring tide. This paper provides new evidences for the former theory of "the origin of storm tide".

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