Late Holocene Coastal and Estuarine Environments of the Shanghai Area, People's Republic of China

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ABSTRACT

Four major sedimentary environments have been identified in the Shanghai area which were deposited over the past 7,000 years, 3 to 20 meters above a Pleistocene basal clay. These are marsh, lagoon, recurved spit and tidal flat. The morphology west of Shanghai is a fresh water marsh since it was not transgressed by rising Holocene sea levels. In the central area, a recurved spit and lagoon had developed from 6,500 years B.P. to 3,500 years B.P. However, the tidal flat has characterized coastal sedimentation in the eastern part of Shanghai since 3,000 years B.P.

KEY WORDS: geomorphology, sediments, recurved spit, coast, People's Republic of China.

Shanghai is located on the delta plain of the Yangtze River (Fig. 1). The study area covers 6,340 square kilometers and includes Shanghai proper and its 10 adjacent counties. The ground surface is approximately four meters above mean sea level and has low relief. This investigation examines, discusses and compares four shallow sections which represent various sedimentary environments. Specifically, the study analyzes sedimentary textures, structures, micropaleontology and heavy minerals. Supplemented with radiocarbon dates and geoarchaeology, the development of the coastal setting is analyzed.

EARLY HOLOCENE FRAMEWORK

During the onset of the last glacial advance in the later Quaternary, the level of the sea dropped. In coastal China the shoreline was displaced seaward onto the continental shelf for a distance of more than several hundred kilometers east of Shanghai. The exposed Shanghai region was covered by a layer of hard clay, dark green in color. This clay layer not only exists in the Shanghai area but also can be traced to the north and southwest parts of Yangtze Deltaic Plain (Fong Mingzhang, 1980). Furthermore, it is acceptably described as hard dark green clay (HDGC). On the basis of carbon dating, it was deposited during the Pleis-
Figure 1. The Yangtze Deltaic Plain and the study area.

tocene Epoch when sea levels were eustatically lower. Deposition occurred in a fluvial and limnological environment and the surface of the HDGC represents the boundary between Pleistocene and Holocene Epochs (Yan Qinshang and Huang Shan, 1987).

The HDGC was deposited over a large area and underlies much of the Yangtze River Delta. It averages 5-10 meters in thickness, however, its depth increases from west to east in the Shanghai study area. Generally, west of Shanghai (e.g. Qinpu County), the depth to its surface is only 3-5 meters while in the eastern part of Shanghai it is 20-30 meters deep.

Therefore, before the Holocene, the ground surface sloped eastward and rivers eroded to base level which was approximately 130 meters lower than the present sea level. As a result, the HDGC was deposited. Therefore, the post-Pleistocene transgressive sediments were deposited on the HDGC unevenly. In fact, at some sites in the western part of Shanghai no marine deposition occurred.

SEDIMENTARY ENVIRONMENTS

Since the rise of Holocene sea level and the transgression of the East China Sea, two well defined marine landforms were deposited (Fig. 2). These landforms represent prominent shoreline features which were deposited within last 7,000 years. Furthermore, the shorelines form boundaries between adjacent features.
Premodern Holocene Shoreline

During the period between 6,500 and 7,000 years before the present (B.P.), the rising sea level during the Holocene transgression was close to its maximum landward extent on east China's coast. (Yan Qingshang and Hong Xueqing, 1987). Based on an analysis of core data and cross sections in Qinpu County, the area west of Shanghai, was above the tidal level and not inundated by the sea at that time. In Qinpu County and its adjacent county, Shongjiang, there are clusters low rocky mountains such as Fenghuangshan, Sheshan, Chenshan, Xiaohunshan, which are distributed in a line stretching roughly north and south. On the west side of these mountains, the depth of HDGC is shallow and no marine deposits occur above the HDGC. However, on the east side the depth of HDGC increases very rapidly and reaches more than 24 meters in depth within one kilometer from the mountain front. This clearly suggests that the HDGC east of
the mountains were buried by Holocene transgressive sediments. In some places the HDGC has dissected by rivers during lower stillstands of the sea. Based on this fact and bore data in adjacent localities, it is estimated that an ancient Holocene shoreline 7,000 years ago ran north to south generally along the line of Xianghuaqiao, Fenghuangshan, Sheshan, Chenshan, Tainmashan, Xiaokunshan, and Xingtga mountain ridges (Fig. 2).

Ancient Recurved Spit

In the central part of the Shanghai area, there is a series of cheniers which extend from the northwest to the southeast and curve landward. The cheniers are composed of sand and shell debris within a mudflat environment and represent barriers deposited during coastal regression. The cheniers concentrated on the coastal plain form belted ridges, which are 4 to 8 kilometers wide and 130 kilometers long and stand slightly above adjacent flats. The belt land is known as "Gangshen" meaning "high land" by the locals. Many studies about "Gangshen" have been published. Chen Jie-yu et al. (1959) suggested that "Gangshen" represented an ancient spit and a salient geomorphological feature in the Yangtze Delta. Liu Cangzhi et al. (1985) and Zhang Shenming et al. (1982) suggested that the cheniers were formed at the mean high tidal level. Therefore, the elevation of the cheniers are above mean sea level and the time of the chenier formation must have been very early. The oldest and the most western ridge is 6,500 years old (Liu Cangzhi et al. 1985 and Zhang Shenming et al. 1982). By studying the current river system on the southern Yangtze Delta, Yan Qinshang and Sho Xusheng (1987) made a suggestion that "Gangshen" was a recurved spit complex which hooked to the northwest at Caojing and Chaishan. Our detail research, on the sedimentary feature of "Gangshen," particularly at its southern recurved end, supports the idea that "Gangshen" is a recurved spit. Additionally, it is realized that the creation of the recurved spit resulted in the sedimentary environment quite different from the areas on both sides of the spit.

The 7,000 year old shoreline and the recurved spit are two important linear features which divide the Shanghai area into three distinct depositional zones as noted on Figure 2: the first is the western fresh water marsh district located landward of the ancient shoreline; the second is the central district consisting of lagoonal and recurved spit sedimentary environments which were deposited between the ancient shoreline and the eastern edge of the recurved spit; and the third zone is the eastern tidal flat district seaward of the recurved spit.

SEDIMENTARY CHARACTERISTICS

In the three depositional areas identified above, there are four main sedimentary types: fresh water marsh, lagoonal sediments, recurved spit and tidal flat.

Fresh Water Marsh

The principal characteristics and the sedimentary succession on the west side of the 7,000 year B.P. shoreline are illustrated in Table 1 which documents a typical section at Jinzhe, Qinpu County. Stratigraphically, the marsh sedimentation may be divided into three sections. These are the lower, middle and upper sections.

Lower Section

There is a layer of gray silt or clay, 1.5 to 3 meters thick, which is 1.5 meters beneath the ground surface. The average sediment size decreases upward. The grain size of the sediment or phi value ranges from 5.70 to 8.05 (medium to fine silt), while the sediment is more poorly sorted near the top of the subsection. This suggests that the ability of currents to sort sediments decreases as the water body becomes shallower. No obvious bedding structure is noted in this subsection. However, numerous holes made by plant roots can be observed in this layer. The heavy mineral suite includes pyrite, hematite, limonite, epidote, apatite, mica and hornblende, however, the mica and hornblende are dominant (20%) as is pyrite (4.6%).

Middle Section

This subsection is a layer of black peat normally from 1.20 to 1.50 meters be-
Table 1
Section of fresh water marsh at Jinzhe, west of Shanghai area.

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Depth (m)</th>
<th>Sedimentary texture</th>
<th>Sedimentary feature</th>
<th>Heavy minerals</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper section</td>
<td>1.25</td>
<td>7.30 2.05 0.00 0.58</td>
<td>Yellow-brown clay with black spots</td>
<td>Limonite, hematite, hornblende</td>
<td>Peat C14 1530 ± 140 years B.P.</td>
</tr>
<tr>
<td>Middle section</td>
<td>1.40</td>
<td>8.01 2.15 0.32 0.78</td>
<td>Peat with numerous plant remains</td>
<td>Pyrite, hornblende</td>
<td></td>
</tr>
<tr>
<td>Lower section</td>
<td>3.00</td>
<td>5.79 1.32 0.10 0.54</td>
<td>Gray fine silt in upper part and gray clay in lower part</td>
<td>Pyrite, mica, hornblende</td>
<td></td>
</tr>
<tr>
<td>Pleistocene</td>
<td>3.50</td>
<td>2.06 0.15 0.65</td>
<td>HDGC Siderite</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1 continues the analysis of its spore and pollen content, it is made up of oak (Quercus ssp.), elm (Ulmus ssp.), pine (Pinus ssp.), grass (Gramineae ssp.) and wall fern. This suggests that the peat was formed and accumulated in a warm and humid climate. In addition to this, the boundary between the peat layer and the lower surface is transitional since many plant roots in the peat have penetrated into the subsurface. This also suggest that the peat is in situ and was not transported and deposited in the area.

**Upper Section**

Within 1.5 meters beneath the ground surface, the sediment is brown-yellow clay devoid of any bedding structure. Hornblende, epidote, pyrite, limonite and hematite make the main component of heavy mineral fraction. This upper section represents a marsh sedimentation the same as the lower subsection. A light color of the upper sediments is due to oxidation at or near the ground surface.

Generally, 7,000 years B.P., the western area of Shanghai was above the sea level. This fact accounts for the absence of marine life or the lack of fossil evidence in the sediments. However, the rising sea level created a high groundwater table and poor drainage in the lowlands. The western area thus appeared as a marsh area with an abundance of aquatic emergent wetlands. The sediments deposited during river flooding are fine with a high frequency of pyrite. In time, the wetland became more shallow as layers of peat accumulated. Based on a C14 date, the peat is about 1530 years old. During the past 1,500 years, the western Shanghai area was dominated by a fresh water marsh environment.

**Lagoonal Sediments**

In the central part of the Shanghai area, a lagoon had existed. This ancient lagoon extended and widened from north to south. The 0.5 meter top layer is a fresh water marsh deposit, whereas, almost all of the remainder 5 meters beneath the ground surface is a clay deposit. A shallow section located in Shongjiang County has been studied in detail (Table 2) and several sedimentary features have been identified:

1. **Sediment color.** The color of sediment changes from dark gray color to light yellow color towards the surface. This indicates a less reduced and a more oxidized sedimentary environment towards the surface.
2. **Sediment texture.** The sediment is
### TABLE 2

Section of lagoon at Songjiang, central part of Shanghai area.

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Sedimentary texture</th>
<th>Sediment feature</th>
<th>Foraminifera assemblage</th>
<th>Organisms in Sediment (%)</th>
<th>Plant remains</th>
<th>Heavy minerals</th>
<th>Date of radiocarbon</th>
<th>Sedimentary facies</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.55</td>
<td>6.8 2.38 0.45 1.28</td>
<td>Brown clay</td>
<td>No</td>
<td>2.278</td>
<td>No</td>
<td>Pyrite: 5.7 -7.7%, hornblende 4.1-8.6%</td>
<td>2950 ± 50</td>
<td>Marsh deposit</td>
</tr>
<tr>
<td>0.60</td>
<td>7.9 2.48 0.54 1.65</td>
<td>Peat</td>
<td>No</td>
<td>22.057</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.50</td>
<td>7.3 2.54 0.31 0.67</td>
<td>Yellow-Brown clay</td>
<td>Mostly <em>Ammonia beccarii</em>, less <em>Ephedriella kiangsuensis</em>, with some deformed foraminifera</td>
<td>0.747</td>
<td>Holes of plant in upper part, unrotted plants in lower part</td>
<td>Pyrite: 53-86%, mica: 3-17%, hornblende less than 2%</td>
<td>5160 ± 110</td>
<td>Lagoonal deposit</td>
</tr>
<tr>
<td>1.90</td>
<td></td>
<td>Gray Clay</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.58</td>
<td></td>
<td>Black clay</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.37</td>
<td>8.5 3.04 0.72 1.14</td>
<td>Shells</td>
<td></td>
<td>1.044</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Black clay</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
fine silt and clay. Its average grain-size ranges between 7.3 phi and 8.5 phi. No obvious change of sediment size appears upward and downward. Clay represents 49.2 percent of the total sediment volume. Such a fine sediment fraction is uncommon and is rarely distributed in other sedimentary environments. It is evident that the current velocity in the lagoon was very low.

3. Microfauna. Foraminifera can be found throughout the shallow section. But the species of foraminifera are fewer. The most abundant is Ammonia beccarii (95%). Other species include Ephphidiella kiang-suesis, Rectoelphididle aplata and Pseudonomionlla variabilis. Some foraminifera are deformed, which suggests that the assemblage occupied a low salt environment.

4. Heavy minerals. Between 53.4 to 53.8 percent of the heavy mineral content is pyrite. Most of the pyrite crystals exhibit a texture similar to fish eggs. Some foraminifera shells are coated with pyrite crystals. Also included are small percentages of mica (3.1% to 16.5%) and hornblende (0.2% to 1.4%). The mineral suite of heavy minerals also reveal that the deposition environment was highly reduced and low current energy prevailed.

5. Shell. A shell layer, 5 to 10 centimeters thick, is buried 2.5 meters below the surface. Although, the fauna are distributed randomly, the majority of them open upward. Some have two petals which are still connected revealing that the mollusks were not moved from other areas but grew in situ and were eventually buried. Basically, the shell assemblage consist of different species: 85 percent are Clementia vatheleti, Cerithidea obtusa are 10 percent; The remaining 5 percent is composed of razor clams (Ensis silqua) which are often distributed concentrically. Currently, some of these organisms live in an intertidal environment which has a low salinity. Carbon 14 analysis indicates that the buried marine organisms were active some 5,100 years ago. In contrast, the cheniers which are located on the east side of the lagoon were deposited some 6,500 years ago. By 5,000 year B.P., two or perhaps three chenier ridges had been formed. Therefore, the C14 dating supports the idea that a lagoon had existed several thousand years before.

6. Plant remains. In the lower part of the section in Shongjiang County, many yellow dead plant remains have been discovered. The diameter of the plant stems is about 3 mm, but in the upper part of the section, only cavities without plant were observed. These voids were made by grasses which had decomposed.

As a whole, the ancient lagoon is characterized by dark colored, fine sediment, devoided of any bedding structure. Also occurring are fewer foraminifera species, mostly pyrite, simple mollusk species and numerous dead plants and plant borrows. Furthermore, above the lagoonal sediments is a layer of peat which is overlaid by fresh water marsh sediments which are similar to the marsh sediments in the western part of the Shanghai area. This layer of peat is 10 or more centimeters thick and is 2,950 years in age on the basis of C14 testing.

Recurved Spit

Much field research has been done on the character of the sediment of the recurved spit (Chen Jie-yu et al. 1959; Liu Cangzhi et al. 1985 and Zhang Shen-ming et al. 1982). However, most investigations concentrated on the main part of the spit, not on the sediment characteristics at the recurved or southern part of the spit. Differences between the main part and the recurved part of the spit are very evident. A comparison
between the two units is outlined in Table 3.

Because the Yangtze River is the most significant sediment source in the Shanghai area, the farther the deposition site is from the ancient mouth of Yangtze River, the finer is the sediment. Consequently, the grain size becomes smaller from the main body of the spit to the recurved part in the south. The average grain size is 2 phi to 3 phi in the main body of the feature but only 7 phi to 9 phi at the recurved part. The medio sand-size sediments along most of the spit are much coarser than the sediment in the lagoon and the marsh areas west of the spit.

Vertically, the sediments consist of a coarse silt in contrast to a underlaying deeper layer of gray clay indicating a shallow sea deposit. Table 3 clearly reveals grain size contrasts between the coarser spit deposit and the shallow sea layer. As shown in Table 3, there is still an upward decrease of grain size at the recurved part of the spit. The explana-

### Table 3
Comparison between the major and end parts of the recurved spit.

<table>
<thead>
<tr>
<th>Section (Depth in meter)</th>
<th>Horizon</th>
<th>Sedimentary texture</th>
<th>Sedimentary Structure</th>
<th>Animal remains</th>
<th>Plant remains</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Soil Shells</td>
<td>Chenier</td>
<td>parallel bedding</td>
<td>Sea shells</td>
<td>None</td>
</tr>
<tr>
<td>2</td>
<td>Fine silt with shells</td>
<td></td>
<td>with disrupted bottom</td>
<td>Blue clam</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shells</td>
<td></td>
<td>surface</td>
<td>Snails, Razor clam</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Clay &amp; silt</td>
<td>Tidal flat</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Clay</td>
<td>Shallow sea</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Section (Depth in meter)</th>
<th>Horizon</th>
<th>Sedimentary texture</th>
<th>Sedimentary Structure</th>
<th>Animal remains</th>
<th>Plant remains</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Coastal storm &amp; marsh</td>
<td>Mz=7.2–8.7 phi</td>
<td>Massive structure, no obvious beds, having with disrupted bottom surface</td>
<td>Ammonia beccari, Echinodema Kiangsuensis, Pseudomonita variabilis, Crinronion porisuturali, Rectoelphi-dilla aplata, Rectoelphi-dilla lepida</td>
<td>Nervous holes made by plant, there are 30 holes in 100 square centimeters</td>
</tr>
<tr>
<td>2</td>
<td>Silty clay</td>
<td>01=1.6–2.3 phi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fine silt Peat</td>
<td>Sk1=1.1–1.45</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Clay silt</td>
<td>Kg=55–86</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Silty clay</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clay &amp; silt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Clay</td>
<td>Shallow sea</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
tion for this change is that, as the spit hooked northwestward, the incoming sediments became finer inside of the spit. The contrast occurs because at the recurved end, wave action is not as significant as tide action. Thus, the deposition is similar to a tidal flat deposit.

In the main part of the spit, there are bedding structures evident which slope seaward. The beds are composed of marine shell fragments and sands, and have an irregular contact at the bottom of the section. In contrast, the recurved part of the spit has no obvious bedding and a massive structure is very common.

The biological feature of the spit is also different between the main part and the recurved part of the spit. In the recurved part of the spit, there are few shells or shell fragments. The faunal assemblages in the sediments at the recurved part of the spit represents a broad saline environment. The dominant foraminifera is *Ammonia beccarii* associated with *Pseudomoniala variabilis*, *Ephidiella kiangsuesis*, *Cribrononion porisuturalis*, *Rectoelphidilla aplata*, and *Rectoelphidiella lepida*.

Mineralogically, the heavy minerals reveal that the sedimentary environment of the recurved part was subjected to more reduction than the main part of the spit. At the recurved part, the most common heavy mineral is pyrite. However, in the main part, hornblende is the principal heavy mineral type.

Shallow borings reveal that the recurved part of the spit becomes thinner and is eventually covered by the marsh sediments. At Chaishan, it is 1.2 meters thick and its buried depth is 2.8 meters. But at Chinyu, northwest of the Chais­han, it is 0.8 meter thick and its buried depth is 5 meters. Therefore, the area at the recurved part of the spit was transforming itself from a depositional barrier feature into a lagoonal deposit.

**Tidal Flat**

During the period between 6,500 years B.P. and 3,000 years B.P., the shoreline had prograded very slowly and extended seaward at a rate of 1 to 2.4 meters annually. During this time, the subtidal slope became less steep and spit development was initiated. Consequently, the lower slope angle of the sea floor resulted in even more rapid shoreline progradation during the past 3,000 years. The average rate of shoreline accretion was about 12 meters annually. The sedimentary environment at the high tide mark is salt marsh and becomes intertidal flat and shallow sea seaward. The tidal flat is about 2 meters in thickness and has a sedimentary character similar to the modern tidal flat (Xu Shi yuan et al. 1984; Shao Xusheng and Yan Qingshag 1982). Based on the typical section in Shanghi proper (Table 4), the recent tidal flat has the following features:

1. **Sediment color.** From the top to the bottom in the tidal flat layer, the color changes from brown-yellow to yellow and finally appears gray. The color variation is a product of an oxidizing environment at the surface which becomes more reduced with increasing depth.

2. **Sediment size.** The sediment of the tidal flat becomes coarser downward. From the top to the bottom, the fine silt is replaced by a medium silt while the amount of the clay in the sediment decreases from 15 percent to 9 percent. Also the sediment is better sorted in the bottom than in the top and the average standard difference of the sediment size is 1.5 phi.

3. **Sediment structures.** It is quite evident that in the vertical profile sediment structure changes. There are silt beds, small cross beds and deformed beds in the low intertidal flat; cross beds and sand lens bedding in the middle intertidal flat deposit; and horizontal bedding in the upper intertidal flat deposit. Such a variable sediment structure resulted from changing current velocity. As current velocity decreased, sediment transport process changed from the bedload transport to suspended load transport.

4. **Plant remains.** Evidence of plant roots appear as brown-yellow belts or circular stains on the sediments. The average diameter of the

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TABLE 4
Section of tidal flat in Shanghai proper, east of Shanghai area.

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Horizon</th>
<th>Sedimentary texture</th>
<th>Sedimentary Structure</th>
<th>Foraminifera assemblages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>mu (phi)</td>
<td>phi</td>
<td>SKI</td>
</tr>
<tr>
<td>Supratidal flat</td>
<td>0.76</td>
<td>6.29</td>
<td>1.64</td>
<td>0.48</td>
</tr>
<tr>
<td>Intertidal flat</td>
<td>6.28</td>
<td>6.28</td>
<td>1.61</td>
<td>0.45</td>
</tr>
<tr>
<td>Intertidal flat</td>
<td>6.05</td>
<td>6.05</td>
<td>1.52</td>
<td>0.45</td>
</tr>
<tr>
<td>Subtidal flat</td>
<td>5.28</td>
<td>5.28</td>
<td>1.32</td>
<td>0.41</td>
</tr>
<tr>
<td>Subtidal flat</td>
<td>5.59</td>
<td>5.59</td>
<td>1.48</td>
<td>0.38</td>
</tr>
</tbody>
</table>

stains is two cm and, however, larger ones may be four cm across. The middle part of the intertidal flat layer is where the root remains are dense, while both the upper part and the lower part have fewer remains.

5. Microfauna. The major kinds of microfauna are foraminifera. Present in this tidal flat are Ammonia beccarii, Epistominella naraensis, Ammonia convexidorsa, Elphidium magellancium, Nonionella jacksonensis and Cribrononion porisuturalis which are species similar to the modern tidal foraminifera but are much different from that in the ancient lagoon and spit sediments. Also several types of plankton occur such as Globigerina spp., Guembelitria vians, Hopkinsina pacifica and Lagena substratiab.

6. Heavy minerals. Mica is a dominant mineral in the intertidal flat sediment, varying from 83.7 percent in the upper layer to 60.4 percent in the lower part of the tidal flat. Conversely, hornblende increases from 4.4 percent to 26.6 percent with depth. Other heavy minerals include limonite, hematite, epidote and zircon.

SEDIMENTARY ENVIRONMENT EVOLUTION

The sedimentary environmental history in the Shanghai area during the past 7,000 years may be subdivided into four sequential stages (Fig. 3). About 7,000 years ago, sea level eustatically rose to or near its present level. At that time the mouth of the Yangtze River was a funnel shaped bay. Most of the sediments from the Yangtze River were deposited near the mouth of the river (Wang Qingtai et al. 1981) and in the adjacent sea bottom. As submarine deposition continued, the nearshore slope became less steep and water depths decreased. A shallow, low angle sea floor is an optimum environment for subsequent rapid shoreline accretion. In Shanghai, from the west to the east 6,500 years ago, the sedimen-
tary environment had a simple sequence of fresh water marsh and an intertidal zone adjacent to a shallow sea (Fig. 3a). West of Shanghai was higher land on which the fresh water marsh developed. At the nearshore zone, the base of the recurved spit began to form.

About 6,500 years ago, the deposition of the recurved spit began and an isolated lagoon began forming landward of this barrier. The sedimentary environmental sequence eastward consisted of fresh water marsh, lagoon, recurved spit, intertidal flat and shallow nearshore deposit from west to east (Fig. 3b). West of Shanghai and the northwestern part of the ancient lagoon, there are a dozen places where ancient camp sites and culture relics have been noted. Ancient artifacts such as pottery had been create-
ated between 6,000 and 4,000 years ago (Huang Xianpei 1982). Consequently, the west and northwestern part of the lagoon was occupied by people where the land had been formed. However, the lagoon still existed and a layer of shell was deposited 5,000 years ago.

By 1,000 B.C., some 3,000 years ago, the ancient lagoon was colonized by a fresh water marsh which was connected with the western fresh water marsh (Fig. 3c). The sedimentary environment at present consists of fresh water marsh, intertidal flat and shallow sea deposits from west to east. This distribution has changed little over the past 7,000 years.

After 3,000 years B.P., the shoreline prograded seaward rapidly and tidal flat sedimentation occurred (Fig. 3d). During the last 2,000 years, the progradation of the shoreline has continued. Three younger seaward strandlines have been identified and dated: 1,200 years B.P., the shoreline along the settlement of Shengqiao-Yuepu-Zhoupu; 800 years B.P., along the line from Heqing, Yancang to Situan; and 600 years B.P. from Bailonggang to Laogang.

Recently, human impact on the sedimentary environment has occurred. At present, the influence of human beings is probably the most important factor controlling the sedimentary environment in the Shanghai area.

CONCLUSIONS

Four points may be concluded based on this research:

1. The boundary between Holocene and Pleistocene is the Hard Dark Green Clay layer which is buried 3 to 5 meters beneath the Holocene sediments in the western part of Shanghai and 20 to 30 meters in depth in the eastern part of Shanghai.
2. Four major sedimentary environments have been identified: fresh water marsh, lagoon, recurved spit and tidal flat.
3. The ancient shoreline 7,000 years ago and the ancient recurved spit are the two important linear features which divide the Shanghai area into three distinct sedimentary district: the western, central and eastern areas.
4. Since the deposition of the recurved spit, there were additional shorelines deposited. Between 6,500 years B.P. and 3,000 years B.P. Progradation was at a rate of 1 to 2.4 m per year. The coast built out at a rate of 12 m per year during the past 3,000 years.

REFERENCES