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ENVIRONMENTAL CHANGES SINCE LATE PLEISTOCENE IN ESTUARINE PLAIN OF JIULONG RIVER, FUJIAN PROVINCE①

Chen Wenrui(陈文瑞)[1] Lan Dongzhao(蓝东兆)[2]
Chen Chenghui(陈承惠)[2] Zhu Dakui(朱大奎)[1]
1 *State Pilot Laboratory of Coast & Island Exploitation, Nanjing University, Nanjing 210093, P.R. China*
2 *Third Institute of Oceanography, National Bureau of Oceanography, Xiamen* 361005, *P.R. China*
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ABSTRACT: Based on the evidences of lithostratigraphy, palynology, micropaleontology and geochronology, paleoenvironments since the Late Pleistocene in the study area have been reconstructed. One of the most important inferences is that two marine transgressions have occurred, one in Wurm Sub-interglacial and the other Postglacial. The former had caused the study area to be in an estuary-bay environment over the transgression maximum, with a sea level of no less than 10 m below present; the latter reached its maximum over the Atlantic stage, with sedimentary environments of estuary-bay, bay or shallow sea, and the sea level arrived at the highest elevation in about 6－5 ka B.P. Furthermore, it is notable that, during the Late Wurm Glacial, the study area had principally been in an estuary-bay environment, although the climate, like many other areas, turned cold and dry, it reflects a general trend of crustal subduction in Jiulong Estuarine Plain over this period.
KEY WORDS: environmental change, Late Pleistocene, Jiulong Estuarine Plain, Fujian Province

The estuarine plain of the Jiulong River, which is the second largest river next to the Minjiang River in Fujian Province, intervenes between Xiamen and Zhangzhou cities in the south of the province. The plain consists of three parts: the northern plain, the southern plain and Zini Isles. With southern-subtropic oceanic monsoon climate, it develops a regional vegetation type of evergreen broad-leaved forest, of which, however, most has been destroyed by human being. Nowadays, shrub or grassland vegetation can be seen on the hills in the vicinity of this area, small stretches of mangrove on the inter-tidal zone.

During last several decades, a lot of hydrogeological and engineering geological surveys

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have been undertaken and many boreholes drilled(Fig. 1), which facilitate the Quaternary research. This paper intends to explore the environmental changes taking place over the Late Pleistocene and Holocene.

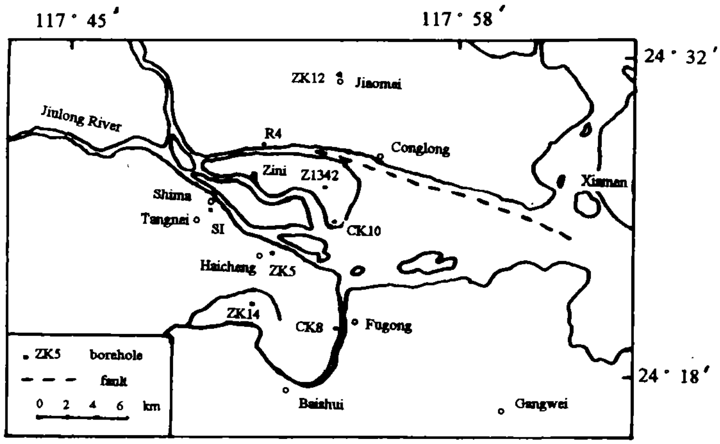


Fig. 1 The distribution of main boreholes in the study area

I. STRATIGRAPHICAL DIVISION

In accordance with lithology, palynology, micropaleontology and age determinations, Late Quaternary strata in the study area can be divided into the following formations in age sequence (Fig. 2).

1. The Upper Pleistocene (Q_3)

This is the lowest of the Late Quaternary strata in the study area. It can be subdivided into the lower, the middle and the upper members, the first two have not been preserved in the northern plain and the edge of the southern plain.

1.1 The lower member ($Q_3^{1al\text{-}pl}$)

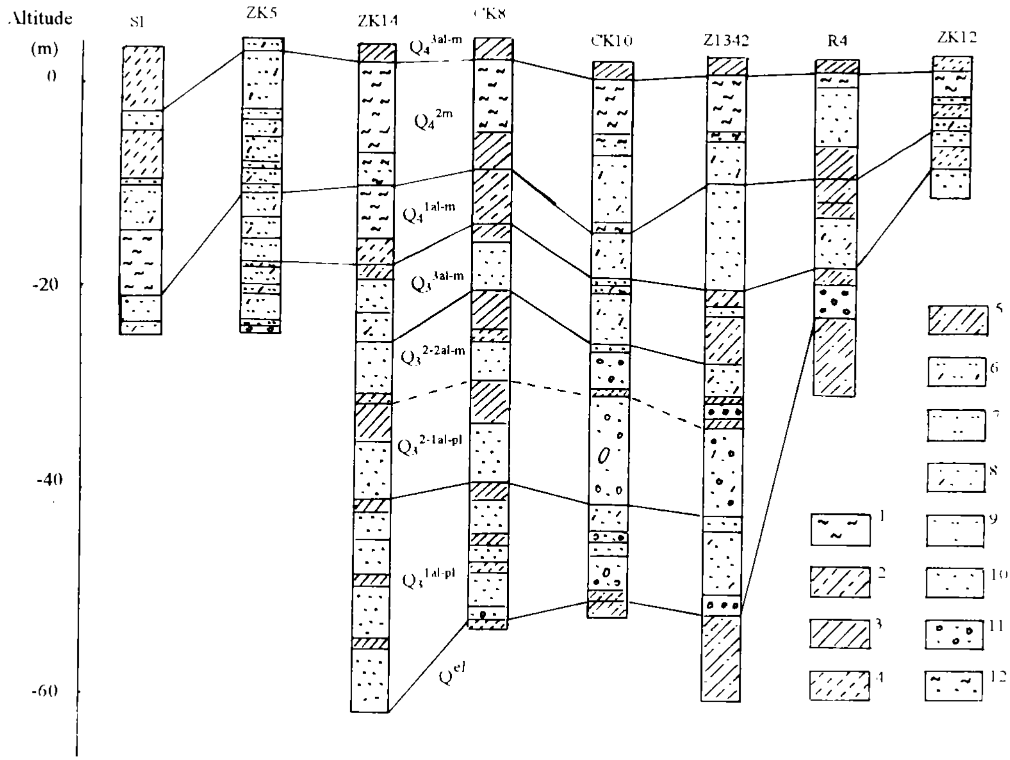
In terms of lithology, it consists of clay, clayey sand, sandy gravel, gravel, sandy-gravelly and gravelly pebble, whose colors are yellow, dark grey or grayish white. It contains practically no microfossil, and is of fluvial origin. Sediment of its middle part in ZK14 borehole has been dated to 97200 ± 2400 a B. P. by thermoluminescene, which indicates that this member was deposited in the early Late Pleistocene, 125.0 – 70.0 ka B. P.

1.2 The middle member (Q_3^2)

In this sequence, two sub-members can be discerned, with substantially different lithology and micropaleontology from each other.

(1) $Q_3^{2\text{-}1al\text{-}pl}$

It is composed of clay, sandy clay, clayey sand, sand gravel and sandy-gravelly pebble, which are dark grey, grayish yellow or yellow. Containing no microfossil, it is probably of fluvial origin, having been deposited during *circa* 70.0 – 42.0 ka B.P., inferred from its context.



1. mud 2. muddy clay 3. clay 4. silty clay 5. sandy clay 6. clayey silt 7. sandy silt 8. clayey sand 9. silty sand 10. sand 11. sandy gravel 12. alternate layers of mud and sand

Fig. 2 Correlation of the typical cores in the study area

(2) $Q_3^{2-2al-m}$

Grey, dark grey, grayish yellow or tan muddy clay, clay, sandy clay, sand, clayey sand and sandy gravel make up this member. Spores and pollen of *Castanopsis*, *Fagus*, *Pinus*, *Quercus*, Polypodiaceae and *Carpinus* have been identified in ZK14, CK8 and CK10 boreholes, where marine diatom and foraminiferal remains have also been seen. In CK8 borehole, the lower sediment of this sequence has given a radiocarbon date of more than 40 000 a B.P. Thus, this sub-member can be assumed to be developed during about 42.0 – 30.0 ka B.P.

1.3 The upper member (Q_3^{3al-m})

It is distributed all over the plain, except for the edge. It is made up of muddy or silty clay, clayey silt, clayey sand, sandy gravel and gravel, which are of grey, dark grey, grayish green, grayish yellow or tan. This member contains two sporo-pollen assemblage zones, the lower is *Hicriopteris*-*Pinus*-Gramineae-*Artemisia*-Polypodiaceae-*Pteridium*, and the other

Hicriopteris-Pteris-Cibotium-Castanopsis-Elaeocarpus-Pinus-Castanea. Referable to this sequence in ZK5 borehole, there are 13 diatom zones indicative of alternating sedimentary environments of river, estuary, estuary-bay and bay (or shallow sea). Therefore, the upper member of the Late Pleistocene is of alluvial-marine origin. In addition, its top layer in ZK5 borehole has been dated to 16 335 ± 150 a B.P. by ^{14}C, and its bottom in CK8 29 290 ± 489 a B.P., so it may have been deposited during 30.0 – 12.0 ka B.P.

2. Holocene(Q_4)

With reference to the work by Chen Chenghui *et al*., (1983), the Holocene strata in the study area can be subdivided into 3 formations, namely the lower, the middle and the upper members, corresponding to Gaobiantou, Xulintou and Tangnei formations, respectively.

2.1 The lower member ($Q_4^{1al\text{-}m}$)

It is extensively distributed in the plain, however, its thickness and buried depth in the northern plain are smaller. It comprises mainly dark grey, grayish white, grayish yellow or yellowish brown mud, muddy clay, clay, clayey silt, clayey sand, sand. Two sporo-pollen zones referable to it have been discerned, the lower one is *Casstanopsis-Cyclobalanopsis*-Polypodiaceae-*Hicriopteris-Pinus*, and the other *Quercus-Castanea-Lourus*-Gramineae-*Osmunda*-Polypodiaceae-*Artemisia*. In terms of micropaleontology, it contains 6 diatom assemblage zones in ZK5 borehole, and some diatom, foraminiferal and ostracoda remains in CK8 and ZK14 boreholes, they are indicative of estuarine, estuary-bay or bay facies. In ZK14 and CK8 boreholes, its mid parts have given radiocarbon ages of 9395 ± 130 and 9823 ± 385 a B.P., respectively, and it can be said that they were deposited during 12.0 – 8.5 ka B.P.

2.2 The middle member (Q_4^{2m})

It is composed of mud, muddy clay, clay, clayey silt or sand, with colors of grayish black, greyish white, dark grey and grey. It contains two sporo-pollen zones, namely *Castonopsis-Quercus-Lithocarpus-Cyclobalanopsis*-Polypodiaceae-*Hicriopteris*-Rhizophoraceae *and Polypodiaceae*-Hicriopteris-Quercusdiatom, foraminiferal and ostracoda fossils, showing that they were of marine origin, developed in the environments of estuary-bay, bay or shallow sea. The lower deposits of the relevant stratum in CK10 borehole, the middle in ZK5 and the peat of Tangnei have been dated to 7154 ± 162, 5740 ± 120 and 2760 ± 150 a B.P. (Chen *et al*., 1983) by ^{14}C respectively, so this member may be formed during about 8.5 – 2.5 ka B.P.

2.3 The upper member ($Q_4^{3al\text{-}m}$)

This member consists mainly of brown or light yellow clay, largely with a top layer of cultivated soil that is around 50 cm thick. Two sporo-pollen zones have been found, the lower one is *Quercus championii-Lithocarpus-Elaeocarpus* and the other *Hicriopteris*-Gramineae-*Pinus-Pteridium-Artemisia*-Polypodiaceae. Additionally, some diatoms, diagnostic of estuarine environment, have been recorded in the relevant deposits of ZK5 borehole. In Tangnei profile of peat, the bottom of this member has been dated at 2450 ± 120 a B. P. by ^{14}C (Chen *et al.*, 1983). The member may be deposited since 2.5 ka B. P.

II. ENVIRONMENTAL CHANGES

During the early and middle Pleistocene, due to tectonic uplift, the study area underwent intensive abrasions by river and sea waters, which resulted in the loss of the Lower and Middle Pleistocene.

1. Late Pleistocene

In the Late Pleistocene, the study area chiefly underwent tectonic subduction and consequent sedimentation. Nevertheless, due to the fault, extending from northern Jiulong River to southern Xiamen, the northern plain has been relatively uplifted and its lower and mid Pleistocene formations eroded.

It was warm and humid in the study area over the early stage of the Late Pleistocene, named Riss-Wurm Interglacial in Europe. Here, the sea level situated from 50 to 30 m below present, and the deposition is attributable to the Jiulong River.

As the Early Wurm Glacial began, the climate turned cold and dry. Consequently, the sea level fell, with the lowest level of more than 50 m below present, and the study area still underwent fluvial deposition.

In Wurm Sub-interglacial, it was again warm and humid and developed evergreen mixed forest, of which the principal genera were *Castanopsis*, *Fagus*, *Quercus*, *Carpinus* and *Pinus*. In this stage, the sea level rose again, and an intrusion of sea water occurred, which has also been recorded in Fuzhou Plain, East China Sea, Yellow Sea and Bohai Sea, and named Xianxian Transgression or Fuzhou Transgression (Lan *et al.*, 1993)

In the study area, the relevant deposits are grey or grayish yellow clay, sand and sandy gravel, which contain microfossils such as *Cyclotella comta*, *Hyalodiscus radiatus*, *Coscinodiscus and Ammonia beccarii*, *Quinqueloculina lamarckiana*, and fish teeth or bones and carbonized wood have also been found. Overall, the fossils are less diversified, however. The study area has been in an estuary-bay environment over the transgression maximum, with a sea level of no less than 10 m below present.

Following the warm stage is the Late Wurm Glacial Maximum, with a pronounced climate of very cold and dry. Accordingly, coniferous forest-grassland vegetation has been developed. In the succeeding Late Glacial, it was comparatively cool and slightly humid, and consequently an evergreen mixed forest developed, containing some deciduous broad-leaved trees. In Core ZK5, 13 diatom zones are referable to this period. They are: (1) *Cyclotella stylorum-Melosira sulcata-Actinocyclus ehrenbergii*, (2) *Melosira sulcata-Cyclotella striata*, (3) *Actinocyclus ehrenbergii-Coscinodiscus*, (4) *Rhicosphenia cruvuta-Coscinodiscus*, (5) *Rhizosolenia cras-*

sispina-Thalassionema nitzschioides-Rhicosphenia cruvuta, (6) *Rhicosphenia cruvuta*, (7) *Cyclotella stylorum-Coscinodiscus*, (8) *Actinocyclus ehrenbergii-Cyclotella striata-Coscinodiscus oculatus*, (9) *Melosira sulcata-Cyclotella stylorum-Coscinodiscus blandus*, (10) *Rhicosphenia cruvuta-Coscinodiscus jonensianus*, (11) *Campylodiscus echeneis* (12) *Melosira sulcata-Coscinodiscus*, (13) *Rhicosphenia cruvuta*. The alternating of marine and freshwater microfissils in the relevant deposits of the study area indicates that the environment underwent frequent changes as: terrene – estuary-bay – bay(or shallow-sea) – estuary – estuary-bay – terrene-bay – shallow sea(or bay) – estuary – terrene – estuary-bay – terrene, but the principal environment was estuary-bay.

2. Holocene

During this epoch, the crustal movement was less active. None the less, the influence of the northern Jiulong River-southern Xiamen Fault, the Holocene series in the northern plain is thinner than those of the southern plain. Being postglacial, the sea level rose again, and transgression occurred due to global warming.

The marine intrusion along the coast of Fujian Province at this time was called Changle Transgression by Lin Jingxing *et al*., (Lin, 1979).

It was temperate and slightly dry in the Pre-Boreal stage, and evergreen mixed forest developed, with dominant species of *Castanopsis*, *Cyclobalanopsis* and *Pinus*. It turned warm and slightly dry when the Boreal began, and its vegetation type was evergreen and deciduous broad-leaved mixed forest-grassland. These two stages, making up Early Holocene, are the initial epoch of the sea level transgression, during which the sea level has been fluctuating. In Core ZK5, the relevant sediments of this period contain such diatom zones as: (1) *Melosira sulcata-Coscinodiscus*, (2) *Rhicosphenia cruvuta*, (3) *Actinocyclus ehrenbergii-Melosira sulcata-Cyclotella stylorum*, (4) *Melosira islandica-Cyclotella striata*, (5) *Actinocyclus ehrenbergii-Cyclotella striata*, (6) *Melosira islandica-Gomphinema olivaceum-Coscinodiscus*. Thus, the sedimentary environments may change as: terrene – estuary-bay – terrene – shallow sea (bay) – estuary – estuary-bay – terrene.

While the Atlantic stage came, the climate became hot and humid, accordingly evergreen broad-leaved forest developed, amongst which *Castanopsis*, *Quercus*, *Cyclobalanopsis*, *Hicriopteris* and Polypodiaceae were of the most importance, in addition, small streches of mangrove grew on the inter-tidal zone. In the subsequent Sub-Boreal stage, the climate was warm and slightly humid, and the regional vegetation was evergreen-deciduous broad-leaved mixed forest, containing some coniferous trees. In the middle Holocene Epoch, including above two stages, the marine transgression reached its maximum, and deposited such formations as grey, dark grey, greyish black or white mud, muddy clay, clay, silty clay, clayey silt and clayey sand, in which abundant microfossils were identified, dominated by *Melosira sulcata*, *Actinocyclus ehrenbergii*, *Thalassionema nitzschioides*, *Cyclotella stylorum*, *C. striata*, *Rhizosolenia crassispia*, *Coscinodiscus*, *Triceratium* and *Ammonia*, *Elphidium*, *Sinocytheridea*, *Neomonoceratina dongtaiensis*. All of these are indicative of estuary-bay – bay (or shallow sea) environment. According to the microfossil analyses, the highest content of marine and planktonic species was found in the mid part of the Middle Holocene Series, deposited over about 6 – 5 ka B. P. It demonstrates that the marine transgression reached its peak in *circa* 6 – 5 ka B. P., which is the timespan when Huanghua Transgression took place along the west coast of Bohai Gulf. At that time, sea water made an intrusion into the Jiulong River and reached Tianbao, Zhangzhou City, let the whole Zhangzhou Basin be inundated, and formed fairly thick marine mud in the study area and first marine abrasion terraces with elevations of 5 – 10 m in the vicinity. In the following stage, the sea level tended to fall gradually, with fluctuations, resulting in the formation of the lower part of Chonglong Chenier, oyster remains in Gaobiantou and Xulintou, and muds of lagoon facies in Tangnei.

Over the earlier part of the Late Holocene, it was warm and humid, developed evergreen broad-leaved forest, dominated by *Quercus championii*, *Lithocarpus* and *Elaeocarpus*, while in the later part, under the influence of human activities, the climate became drier, and the natural flora has largely undergone a replacement by secondary or artificial vegetation, that is, coniferous forest grassland. During the Late Holocene, sea water retreated, and as the sea level gradually fell, the mid and upper parts of Chonglong Chenier and the peat formation in Tangnei were formed. The prevailing diatom species, identified in the relevant deposits of Core ZK5, are *Cyclotella stylorum*, *C. striata* and *Trachyneis antillarum*, which shows an estuarine environment.

In 687 A.D., when Chen Yuanguang stationed troops at Liuyingjiang (now called Jiangdongqiao), the boundless sea just lay to the east (Chen, 1986), as shown that the plain had not been developed then. Since around 1000 a B. P., the sea level have been somewhat fixed at present elevation, leading to accretion in the river mouth, forming and enlarging the plain. The lower part of cultivated soil in CK10 borehole was dated to 602 ± 50 a B. P. by ^{14}C, demonstrating that not until some 600 a B. P. had Zini Isles been exploited.

III. DISCUSSION

Over the Late Pleistocene and Holocene, on account of climatic changes, tectonic activities and sea level fluctuations, different environments were discerned in the study area.

The northern plain misses the Lower and Middle Pleistocene Series, and its Holocene, in general, is thinner than that of other parts of Jiulong Estuarine Plain, showing that, under the influence of the northern Jiulong River–southern Xiamen Fault, the northern plain has been uplifted since the Late Pleistocene. This fault was very intensive in the Late Pleistocene but comparatively inactive in the Holocene.

Two sea level transgressions have taken place, one in Wurm Sub-interglacial and the other Postglacial. In the Minjiang River mouth (Langqi Isle), a set of transgression deposits of 70 –

60 ka B. P. has been identified, and in Xiapu Plain, located in the northeastern Fujian, there are transgression deposits of 90 – 80 ka B. P. This may indicate that the crustal subsidence in Fujian coast since the Late Pleistocene is not homogeneous, it fell slower in the south, while comparatively fast in the north (Zeng, 1993). Nevertheless, the case may also be that earlier transgression sediments in the south, due to succeeding strong tectonic uplift, underwent thorough erosion, and the later ones have been accepted and preserved, owing to the following trend of tectonic subduction.

Over late Wurm Glacial, glaciers and ice sheets all over the world expanded and thus resulted in massive global sea level falls. The sporo-pollen assemblages show the climate of the study area, like other areas, turned colder and drier. Nonetheless, its principal sedimentary environment was estuary-bay, which reflects a general trend of crustal subduction. As for the repeated changes of environment, fluctuations of sea level resulted from oscillatory tectonic movement, with intercated episodes of uplift in the subduction trend, may account for it, rainstorms, waterfloods and storm tides, which are easy to break out in cold climate and deteriorative environment, can form some foreign facies among the estuary-bay sediments, and that also can account for the records of frequent changes.

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