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STUDIES ON HOLOCENE GEOCHRONOLOGY OF THE COASTAL REGION OF SOUTHERN FUJIAN, CHINA

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ABSTRACT. Our studies on ^{14}C chronology and palynology of Holocene sediments in southern Fujian along the western coast of the Taiwan Straits show that the natural environment has undergone three stages of development during the Holocene. From Early Holocene (ca 10,000-8000 yr ago) to Middle Holocene (8000-2500 yr ago) and then to Late Holocene (2500 yr ago), sediments varied from land-sea transitional to marine and then to terrigenous; vegetation altered from mixed forest to evergreen broad-leaf forest and then steppe; climate fluctuated from temperate to hot and then to warm. The sea-level maximum in the post-glacial period occurred at 5000-6000 yr ago, at 5 to 10m elevation. During the subsequent regression, two stable stages of sea-level dated at >3000 and ca 2000 yr ago. The climatic drying and eolian sand deposit began at 700 yr ago. The results agree with our previous studies in southern Liaoning.

INTRODUCTION

The history of climatic fluctuation, land-sea change, and sedimentary development since Late Glaciation can be explained as well as geologic events chronologized and stratigraphic subdivisions and correlations made by ^{14}C dating and palynologic analysis of sediments. These are important aspects of Quaternary and especially of Holocene research. Some significant results of Holocene geochronologic studies on the coastal region of China have been obtained. A Holocene geologic time scale has been established for southern Liaoning (Chen, Lu, and Shen, 1978). The marine strata and shell banks along the western coast of the Pohai Sea (Lab Quaternary Geol, 1980; Zhao et al, 1978), as well as the continental sediments in the Yellow Sea and East China Sea (Geng, 1981) have also been chronologically studied.

Holocene sediments in the coastal region of southern Fujian are well-developed and mainly distributed on coastal and esturine plains, in which marine, alluvial, and eolian deposits predominate. They commonly contain materials suitable for ^{14}C

dating such as shells, peat, wood, and mud, and are rich in pollen and spores all of which are advantageous for Holocene geochronologic study.

Based on a geologic survey of the adjacent area of Xiamen (Amoy) Harbor made by the Third Institute of Oceanography during 1978-79, further studies of several sedimentary profiles in the Longhai estuarine plain and Zhangpu coastal plain were made. More than a dozen ^{14}C dates were determined and palynologic associations of three profiles were analyzed. Thus, a fundamental outline of the history of Holocene environmental evolution of the coastal region of southern Fujian was tentatively drawn.

PROFILES AND ^{14}C DATES

Seven sedimentary profiles were studied (fig 1,2). ^{14}C dates were determined at The Institute of Geochemistry by the liquid-scintillation counter technique. The half-life of ^{14}C used was 5568 years and the ages given are before AD 1950. Table 1 lists the ^{14}C dates.

TABLE 1. ^{14}C dates from the coastal region of southern Fujian

Site	Sample No.	Depth (m)	Sample	^{14}C date (yr BP)
Gaobiantou, Longhai	GC-310	2.8	Shell	3150±150
Xulintou, Longhai	GC-376	1.2	Shell	3330±150
Chonglong, Longhai	GC-313	0.6	Shell	1870±100
	GC-314	1.3	Shell	2350±120
	GC-315	1.6	Shell	3800±150
Tangnei, Longhai	GC-305	0.9-1.0	Mud	2000±120
	GC-308	1.3	Peat	2450±120
	GC-307	1.45	Mud	2760±150
Xiacai, Zhangpu	GC-316	1.0-1.2	Peat	700±50
You'ao, Zhangpu	GC-318	0.5-0.6	Shell	1400±90
	GC-319	2.6-2.7	Shell	1980±100
	GC-320	2.8-3.0	Shell	2600±120
	GC-321	3.5-3.8	Shell	3100±150
Tangbian, Xiamen (Amoy)	GC-369	2.2	Mud	>35,000

THE GAOBIANTOU MARINE-ALLUVIAL PROFILE IN LONGHAI PLAIN. Longhai Plain, ca 300km^2, is an estuarine plain formed by the comprehensive action of the dynamics of the Jiulongjiang River and sea waters. The Quaternary sediments, 81m in maximum thickness, mainly belong to the Late Pleistocene and Holocene. The Upper Pleistocene series is pluvial-alluvial and consists of interbedding yellow or gray-white clay and sand-gravel, 10 to 58m thick. The Holocene series is marine-alluvial, 10 to 20m

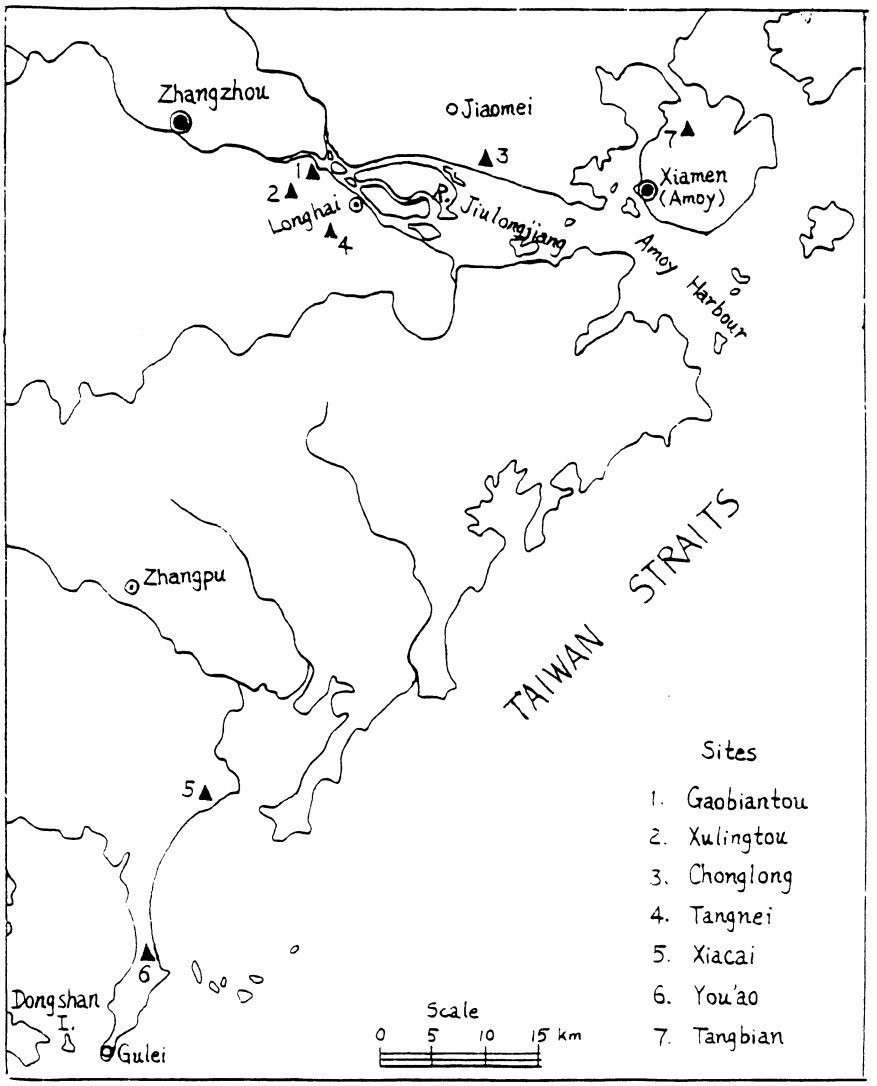

Fig 1. Sampling site for ^{14}C dating of southern Fujian

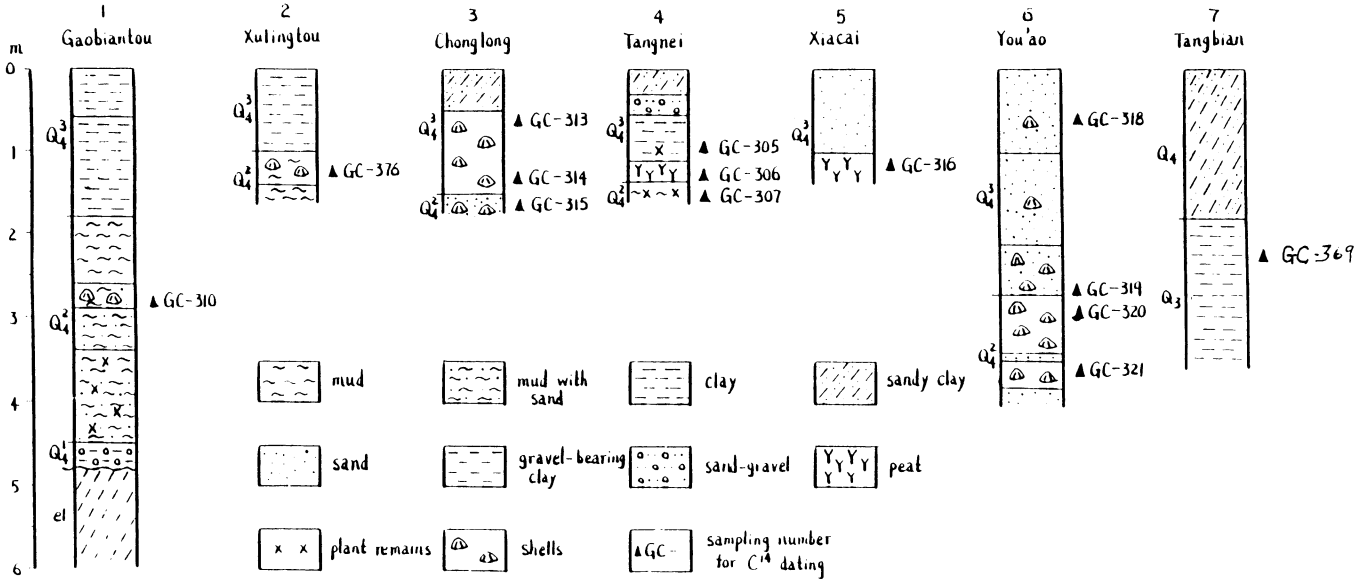

Fig 2. Diagrams of sampling profiles of southern Fujian

thick, and can be divided into three parts. The lower part is land-sea transitional deposits, consisting of gray sand with thin mud beds. The Middle part is marine, consisting of dark gray mud with many shells and plant remains, with a layer of oyster shells at 1 to 3m depth. The upper part is alluvial, consisting of yellow-gray clay.

The Gaobiantou profile is from the eastern side of Guanyin Hill in the western part of Longhai Plain. Holocene sediments, 4.8m thick, overlying the weathering crust of Upper Jurassic Changlin sandstone, from the top downwards (at +5m) are as follows: 0 to 1.8m, yellow-gray to gray clay; 1.8 to 4.5m, dark-gray mud with shells and plant remains, thin layers of fine sand, interbedded in the middle with a layer of abundant oyster shells at 2.6 to 2.9m depth dated at 3150±150 yr ago; 4.5 to 4.8m, gray gravel-bearing clay with plant remains. This profile is roughly the same as the three parts of the Holocene mentioned above, but the lower part here is thinner and shows different lithologic characteristics.

XULINTOU MARINE-ALLUVIAL PROFILE IN LONGHAI PLAIN. The profile is at the northwest side of Xulintou hillock in the western part of Longhai Plain. The sediments, from the top downwards (at ca +4m) are as follows: 0 to 2m, gray clay; 1 to 1.6m (basal), dark-gray to gray-black mud with shells, with a layer of oyster shells at 1 to 1.4m depth dated at 3330±150 yr ago.

This profile corresponds to the upper and middle parts of the Gaobiantou profile. The oyster beds of both profiles, the dates of which are quite close, corresponding to the later Middle Holocene, can be considered diagnostic of Holocene stratigraphic subdivision and correlation.

THE CHONGLONG SHELL BANK PROFILE IN LONGHAI PLAIN. This shell bank is at the northern border of Longhai Plain, 1km from the northern bank of the Jiulongjiang River to the south, >10km from the coastline to the east. It extends in a NE-SW direction, 180m long, 50 to 60m wide, ca +5m. On the southeast or seaward side, is a cliff 2 to 3m above the plain with abundant shells. On the northwest is a smooth slope consisting mainly of sandy loam without shells, 1.5m above the ancient bay surface. Sediments of the cliff profile from the top downwards are as follows: 0 to 0.5m, yellow-brown sandy loam with shell debris; 0.5 to 1.5m, semi-consolidated shell layer, dated at 1870±100 for its upper part and 2350±120 yr ago for its lower part; 1.5 to 1.8m (basal), loose shelly sand bed, with mixed shell debris and fine sand dated at 3800±150 yr ago. The shelly sand bed in the lower part of the profile may be beach deposit below the high-tide line, the formative age of which is a little earlier than the oyster bed in the plain and corresponds to the later Middle Holocene. The shell bed in the upper part

is shell-bank deposit that accumulated at a constant rate around the high-tide line through wave and tide action during a period of little change in sea level and coastline, the formative age of which corresponds to an earlier stage of the Late Holocene. A sedimentary interruption between the layers represents an interval of regression.

TANGNEI PEAT PROFILE IN LONGHAI PLAIN. This profile is in the foothills of the western border of Longhai Plain. The sediments, from the top (+7m) downwards are as follows: 0 to 0.55m, gray-yellow sandy clay and yellow-brown clayey sand-gravel; 0.55 to 1.1m, gray to dark-gray muddy clay with abundant plant remains, dated at 2000±120 yr ago at its base; 1.1 to 1.35m, yellow-brown peat of low decomposition, dated at 2450±120 yr ago at its base; 1.35 to 1.5m (basal), brown-gray mud with abundant plant remains, dated at 2760±150 yr ago. The brown-gray mud below the peat is dated between the lower and middle parts of Chonglong shell bank, corresponding to the latest stage of the Middle Holocene, and belongs to the lagoonal deposit laid down during the regression process. The peat and muddy clay are products of swamping of the lagoon and are contemporary with the upper part of Chonglong shell bank, the earlier stage of the Late Holocene. The sand-gravel and sandy clay are alluvial-pluvial deposits of a rivulet and belong to the later stage of the Late Holocene.

THE XIACAI PEAT PROFILE OF THE ZHANGPU COAST. The peat beds of Zhangpu coast, commonly underlie eolian sand, with maximum thickness reaching 1.5m. The peat is gray-brown, highly decomposed, and dated at 700±50 at the top. In the vicinity, the peat bed is gradually thinned out and embedded in eolian sand. In view of its greater thickness, the peat may have accumulated from the formation of Tangnei peat 700 years ago, covering the whole earlier and middle Late Holocene. The different decomposition of the peat beds is due to the diverse overlying sediments. Tangnei peat, underlying the muddy clay, is basically sealed off which is unfavorable for peat composition. Xiacai peat, underlying the loose permeable eolian sand, is subjected to oxidation and decomposition.

THE YOU'AO BEACH ROCK PROFILE IN GULEI PENINSULA, ZHANGPU. The beach rocks of Gulei Peninsula extend in a NE-SW direction, and consist mainly of consolidated to semi-consolidated shelly sand beds. Eolian sand is also widely distributed over the peninsula, overlying the marine sediments and reaching a height of 20 to 30m. The sediments of the You'ao profile, from the top (+4m) downwards are as follows: 0 to 1m, loose gray-yellow middle to fine sand with shell debris; the surface layer is wind-blown and reworked; the shells are dated at 1400±90 yr ago;

1 to 2.1m, consolidated to semi-consolidated gray-yellow middle to coarse sand with shell debris; 2.1 to 2.7m, loose gray-yellow shelly sand, consisting of middle to fine sand and varied shells such as clam and oyster, dated at 1980±100 yr ago at its base; 2.7 to 3.4m, consolidated gray-white shell layer, dated at 2600±120 yr ago at its top; 3.4 to 3.5m, loose brown-yellow fine sand without shells; 3.5 to 3.8m, loose to semi-consolidated gray-yellow shell bed, dated at 3100±150 yr ago; from 3.8m downwards, loose fine sand without shells. The lower gray-yellow shell bed is contemporary with the oyster bed in Longhai Plain, formed in the later stage of the Middle Holocene. There is a sedimentary interruption of ca 600 years between the top of the middle gray-white shell bed and the bottom of the upper gray-yellow shelly sand, corresponding to the boundary of the Middle and Late Holocene. The upper part of the profile is contemporary with the upper part of the Chonglong shell bank, deposited in the Late Holocene.

THE TANGBIAN SEDIMENTARY PROFILE IN XIAMEN (AMOY) ISLAND. Abrasion-denudation terraces, on which alluvial laterite develops, are widely distributed along the coast of southern Fujian. The three terraces of Xiamen (Amoy) Island are 5 to 10m, 10 to 20m, and 30 to 45m in elevation. The lacustrine deposit filled in the depression on the third terrace at ca 30m elevation near Tangbian is gray-black muddy clay, dated at >35,000 yr ago. The age cannot be exactly determined as it is older than our dating limit. Since the sediments of the Middle Pleistocene are generally laterized, the lacustrine deposit may be of the Late Pleistocene and the third terrace may have been formed in the Middle Pleistocene. The overlying gray-yellow sandy clay, 1.8m thick, is a Holocene alluvial-pluvial deposit.

VEGETATION ALTERNATION AND CLIMATIC FLUCTUATION

The samples from Gaobiantou, Tangnei, and Xiacai profiles were palynologically analyzed. Six sporo-pollen zones can be distinguished (Chen, 1982) (fig 3), representing the different stages of vegetation alternation and climatic fluctuation during the Holocene correlated to the climatic periods of Scandinavia. The palynologic composition of the earliest postglacial stage, the Pre-boreal, was not found. According to the characteristics of the subsequent zone VI of the Boreal, the Pre-boreal vegetation can be interpreted to be mainly coniferous and deciduous broad leaf trees, and the climate to be rather cool.

The VI Castanopsis-Castanea zone of arboreal palynologic association found in gravel-bearing clay in the lower part of the Gaobiantou profile shows deciduous and evergreen broad-leaf mixed forest which was quite open with poor development of

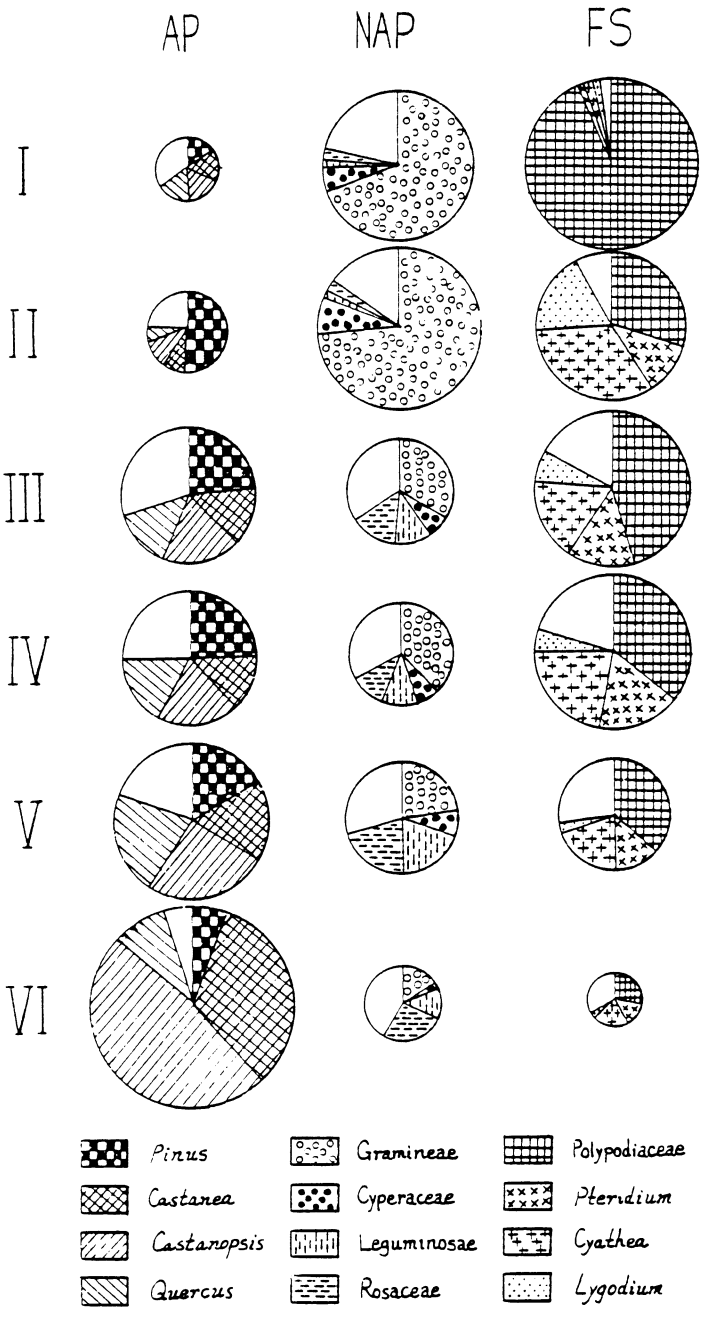

Fig 3. Schematic sporo-pollen diagram of Holocene sediments of southern Fujian

plant cover. The climate was temperate and dry, corresponding to the Boreal.

The V Castanopsis, Quercus- Polypodiaceae zone of arboreal palynologic composition found in dark-gray in the lower-middle part of the Gaobiantou profile shows evergreen broad-leaf forest which flourished with abundant shrubs and herbs. The climate was wettest and hottest then, a little more than at present, corresponding to the postglacial climatic optimum, the Atlantic.

The IV Polypodiaceae, Cyathea-Pinus, Castanopsis, Quercus zone of fern-aboreal palynologic composition found in dark-gray mud with sand in the upper-middle part of Gaobiantou profile and in brown-gray mud in the lower part of Tangnei profile shows evergreen broad-leaf forest with some coniferous and deciduous broad-leaf trees. The forest and plant cover flourished less than in the preceding stage. The climate was still hot, but much drier, corresponding to the Sub-boreal.

The III Polypodiaceae- Pinus, Castanopsis zone of fern-arboreal palynologic composition in gray clay in the upper part of the Gaobiantou profile and in peat and dark-gray muddy clay in the middle part of the Tangnei profile shows coniferous and broad-leaf mixed forest. In view of the increase of the coniferous and deciduous broad-leaf components and the development of peat, the temperature was lower and the humidity higher than in the preceding stage. This indicates warm and wet climate, corresponding to the Sub-atlantic.

The II Gramineae- Cyathea, Polypodiaceae- Pinus zone of nonarboreal-fern palynologic composition found in yellow-gray clay of the uppermost part of the Gaobiantou profile and gray clay of the upper part of the Tangnei profile shows forested steppe. The expansion of newly deposited land and effects of human activities facilitated the alteration of vegetation from forest to steppe. A small number of trees, in which coniferous were more abundant than broad-leaf, were distributed on the border of or scattered on the plain, forming sparse forested steppe landscape. Herbage was mostly Gramineae, a large portion of which might have been cultivated. This implies that cultivation of the region began at this stage. The climate was the same as the preceding stage, warm and wet, with slight fluctuation in temperature and humidity, corresponding to "Scandic" and "New-Atlantic" stage (Wendland and Bryson, 1974).

The I Polypodiaceae-Gramineae zone of the fern-nonarboreal palynologic composition found in the uppermost part of Xiacai peat shows steppe-type vegetation. The trees are mainly broad-leaf and scattered. The climate turned dry and warm, corresponding to the "Pacific" stage. The forest retreated, the steppe cultivated. swamps dried, and native vegetation transformed into planted crops on fields and herbs on wasteland because of the drier climate and the effects of human activities. Eolian

sand prevailed along the coast. According to the ^{14}C date for the top of the Xiacai peat underlying the sand, drier climate began ca 700 yr ago, which concurs with the results of our previous research in southern Liaoning (Chen, Lu, and Shen, 1978). Arid conditions occurred as a result of both climate change and human activities.

SEA-LEVEL CHANGE AND COASTLINE DISPLACEMENT

Ancient shell banks and beach rocks line the coast and provide records on sea-level change and coastal displacement. Some research has been done on shell banks in Tianjin (Tientsin) (Lab Quaternary Geol, 1980) and southern Liaoning (Chen, Lu, and Shen, 1978) and on beach rocks in the South China Sea (Zeng, 1980). Unlike the parallel shell banks of Tianjin, there is only one aggradational shell bank in southern Fujian. As mentioned above, a sedimentary interruption occurred between the lower and upper parts of the Chonglong shell bank and the You'ao beach rock extending >1000 and ca 600 yr, respectively. They are superimposed sediments of two stages corresponding to both the Jugezhuang-Shajingzi and Nigu-Shanggulin shell banks of Tianjin (Lab Quaternary Geol, 1980).

Holocene sea level changes are global and can be approximately correlated for various regions, although elevations may vary because of neo-tectonic and sedimentation processes. The lowest sea level in the latest stage of the Late Pleistocene is at 150 to 160m below present sea level in the East China Sea. Taiwan was then connected to Fujian. Sea level continuously rose during the Early Holocene, submerging the Taiwan Straits and part of the Jiulongjiang estuary, causing land-sea transitional sedimentation in the Lower Holocene. Transgression reached its maximum during the highest sea level dated at ca 5000-6000 yr ago. The whole Longhai Plain was submerged and a thick layer of marine mud was deposited. The first abrasion terrace, at 5 to 10m elevation, was formed along the coast. Sea level was then located at ca 5 to 10m elevation and water depth was ca 10m. Later sea level fell gradually and regression began. The location of sea level and the coastline were relatively stable 3800-3150 yr ago forming deposits of the lower part of the Chonglong shell bank and oyster bed in the plain. During another stable sea level stage, 2350-1870 yr ago, the upper part of the Chonglong shell bank was deposited. The lowered sea level and aggradation of sediments caused the Longhai Plain to emerge. Sea level has been basically stable, sedimentation in the Jiulongjiang estuary strengthening and the area of the plain expanding rapidly for 700 yr.

As for the Gulei Peninsula, the maximum transgression changed Gulei Hill into an island. During the subsequent

regression two relatively stable stages of sea level dated at 3100-2600 and 1980-1400 years ago, formed a tombalo or bar connecting Gulei Hill with the continent. As the formative dates of cementing materials in the beach rock may be younger than those of the deposits themselves, the ^{14}C dates may be younger than the real ages and the beach rock considered contemporary with the shell bank in the estuarine plain.

STRATIGRAPHICAL SUBDIVISION AND SEDIMENTARY HISTORY

In China, the Holocene is divided into three periods according to palynologic composition, ^{14}C dates, and sedimentary lithofacies. On the coast of China during the Early Holocene (Q_4^1, 10,300-8000 years ago) (table 2) following the end of the Late Plestocene glaciation, the climate gradually warmed, the sea constantly rose from the low level of the Late Glaciation and sediments were generally coarse and terrigenous. The Middle Holocene (Q_4^2, 4000-2500 years ago) experienced climatic optimum and sea-level maximum, in which sediments were generally fine-grained and marine. In the Late Holocene (Q_4^3, for the last 2500 years), the climate turned mild, the sea level fell or was close to present, and sediments were mainly terrigenous.

Holocene sediments of the coastal region of southern Fujian also show the same characteristics. As mentioned above, the Holocene series of the Longhai Plain can be subdivided into three sections, corresponding to Lower, Middle, and Upper Holocene. The Lower Holocene Gaobiantou Formation is characterized by land-sea transitional deposits consisting of gray sand with a thin layer of mud or gravel-bearing clay. With the rise in sea level, the estuary of the Jiulongjiang River was gradually transgressed and the silt washed down by the river was continuously accumulated over the alluvial-pluvial beds of the Upper Pleistocene Longhai Formation.

The Middle Holocene Xulintou Formation marine sediments consist of dark-gray mud and can be further subdivided into two sections, the lower being deposited during the warmest climate, with maximum transgression and highest sea level during the Holocene. Wet, hot climate and flourishing vegetation provided the sediments with abundant plant remains such as the wood in the mud layer from Jiaomei in the northern Longhai Plain dated at 5660±95 yr ago (Zhang, Li, and Zhao, 1980). The upper part was deposited during regression. Because of the aggradation of sediments and the lowered sea level, sea water shallowed and shell deposits developed in a suitable environment such as the lower parts of the Chonglong shell bank and the You 'ao beach rock as well as the oyster layer in the plain.

The Upper Holocene Tangnei Formation is mainly terrigenous. Following the continual fall in sea level, the plain began to

emerge, alluvial clay, 1 to 2m thick, accumulated, and rivulets formed in former tidal channels. Peat developed in ancient bays and lagoons such as the peat beds of Tangnei and Xiacai. The upper parts of the Chonglong shell bank and the You 'ao beach rock were also formed during this stage. According to the ages of the peat and underlying gray-brown mud in the Tangnei profile, the boundary date between the Middle and Upper Holocene is ca 2500 yr ago. As the age of the top of the Xiacai peat bed is 700 years old and it lies under eolian sand, the Upper Holocene can be subdivided into two sections: the clay, peat, and shell deposits mentioned above belong to the lower part, and the overlying eolian sand, alluvial-pluvial deposit on the border of the plain as well as the present valley and shoal deposits belong to the upper part.

CONCLUSION

Our studies on the ^{14}C chronology and palynology of Holocene sediments of the coastal region of southern Fujian indicate the following (table 2):

1) The natural environment underwent three stages of development during the postglacial; thus the Holocene can be divided into three stages: Early Holocene, ca 10,000-8000 yr ago, Middle Holocene, 8000-2500 yr ago, and Late Holocene, from 2500 yr ago.

2) The Holocene series can be divided into three parts: the Lower Holocene Gaobiantou Formation (land-sea transition), the Middle Holocene Xulintou Formation (marine), and the Upper Holocene Tangnei Formation (terrigenous).

3) From Early to Middle and then to Late Holocene, ancient vegetation changed from mixed forest to evergreen broad leaf forest and then to mixed forest and steppe; ancient climate changed from temperate to hot and then to warm. The earlier stage of the Middle Holocene, the Atlantic, had the hottest and wettest climate of the postglacial. During the later stage of the Late Holocene, the "Pacific," the climate dried and eolian sands developed.

4) The highest sea level of the postglacial period occurred at ca 6000-5000 yr ago, at 5 to 10m elevation. During the subsequent regression, two relatively stable stages of sea level occurred at >3000 and ca 2000 yr ago.

Our studies of the Middle and Late Holocene are detailed, but we lack ^{14}C dates of the Early Holocene.

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TABLE 2. Outline of Holocene geochronology of the coastal region of southern Fujian, China

Geologic age	Stratigraphy	Sediment	Palynologic Composition	Vegetation	Climate	Sea Level	Correlation: Tiajin coastline (2)	Correlation: S Liaoning stratigraphy (1)	Correlation: Scandinavian climatic period (6)	Boundary date (yr ago)
Late Holocene Q_4^3	Upper Tangnei Formation	Eolian sand, fluvial deposit	I zone FS-NAP	Steppe	Warm-dry	Basically stable	Basically stable	Upper Zhuanghe Formation	Pacific	
	Lower Tangnei Formation	Alluvial clay and peat	II zone NAP-FS	Forested steppe	Mild-wet	Fall	Shell bank I	Lower Zhuanghe Formation	Scandic New-Atlantic	700
			III zone FS-AP	Mixed forest	Warm-wet	Stable (upper shells)	Regression			
						Fall	Shell bank II		Sub-atlantic	1600
Middle Holocene Q_4^2	Upper Xulintou Formation	Marine mud with sand and peat	IV zone FS-AP	Evergreen broad leaf forest	Hot-dry	Stable (lower shells)	Regression	Upper Dagushan Formation	Sub-boreal	2500
						Fall	Shell bank III			
	Lower Xulintou Formation	Marine mud	V zone AP	Evergreen broad leaf forest	Hot-wet	Highest (5-10m) (I marine terrace)	Regression			
							Huanghua transgression	Lower Dagushan Formation	Atlantic	5000
Early Holocene Q_4^1	Gaobiantou Formation	Marine-alluvial, clayey sand-gravel	VI zone AP	Deciduous evergreen broad leaf forest	Mild-dry	Rise		Pulandian Formation	Boreal	8000
					Cool				Pre-boreal	9500
Late Pleistocene	Longhai Formation	Alluvial-pluvial			Cold	Lowest (-150-160m)			Late Glaciation	10,300

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