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THE HOLOCENE ALONG THE COAST OF HAINAN ISLAND, CHINA

Zhang Zhongying (张仲英) Liu Ruihua (刘瑞华)
(Guangzhou Institute of Geography, Guangzhou 510070, PRC)

ABSTRACT: Based on the new data of the Quaternary along the coast of Hainan Island, China, this paper puts forward that the Holocene in Hainan Island can be divided into four formations: Wanning formation (Q_4^1), Sanya formation (Q_4^{2-1}), Qiongshan formation (Q_4^{2-2}) and Ledong formation (Q_4^3). Spore–pollen analysis shows that there are 6 spore–pollen zones existed, reflecting two cycles of climatic fluctuation from warm–dry to hot–humid. The climax of hot–humid period occurred 6,000–5,000 years B.P.. Based on the ^{14}C dating data of the 38 samples representing the positions of ancient sea level, a breakthrough curve representing the sea level change during the Holocene is obtained, in which , a sea level change caused by tectonic movement is subtracted. Two cycles of rise–drop of sea level with three periods of high sea level were found. The period with the highest sea level is some 6,000–5,000 years B.P.. According to the rise–drop rate of sea level, four periods of the sea level change can be distinguished in the Holocene. The amplitude of the sea flunctuation is about ± 6m over the past 6,000 years.

KEY WORDS: Hainan Island, coast zone, Holocene

Hainan Island is located at 18° 10′ — 20° 09′ N and 108° 36′ — 110° 2′ E. It is the second largest island in China. It covers an area of 34,380 sq.km with 1,528 km length of coastline. The Qauternary of the island has been studied formerly in detail while research on the Holocene is rather weak.

I. THE HOLOCENE

The Holocene is most developed in the delta and the coastal plain of the Hainan Island. They lie on the upper Pleistocene Basuo formation and can be distinguished by the sand–gravels plus red midcoarse sand, as the marber bed. They lie mostly unconformably on the pre–Basuo formation. In the Nandujiang Delta where the Holocene is well developed it overlays the Pliocene Haikou formation or directly the base rock as in Lingshui area. Thickness of the Holocene on the average is 23.0 m. The maximum thickness is 33m. The sediments of the Holocene get fine from bottom to top, i.e., from sand–gravels to sandy clay, indicating two deposition cycles (Fig.1). Analysis of 6 representative sections of bore–holes shows that the sand–gravels at the lower part are alluvial deposits while the fine materials at the upper part are marine deposits—especially the clay and mud at the first deposition cycle show clearly that they are maritime. There are 61 ^{14}C dating data of the Holocene in this area (Fig. 2). On this basis, the Holocene are divided into the following 4 formations:

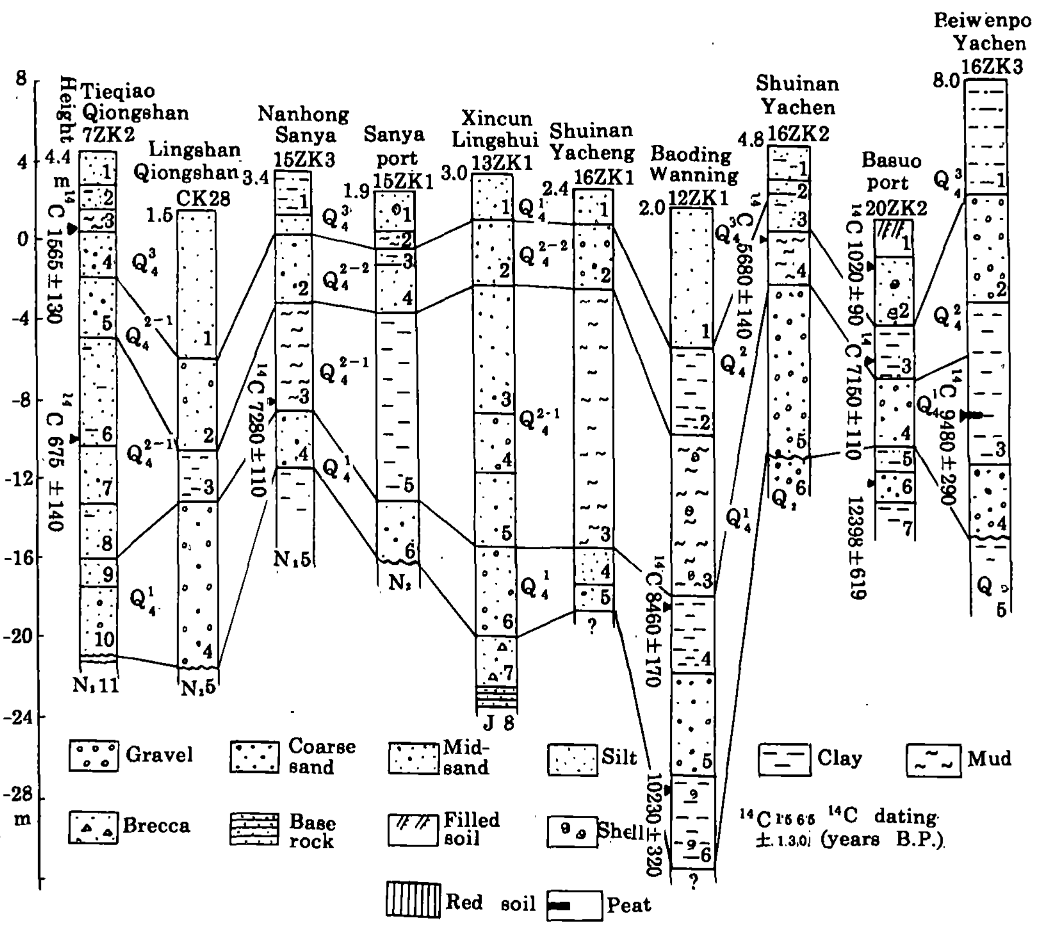

Fig. 1 Bore–hole profile of Holocene series in Hainan Island

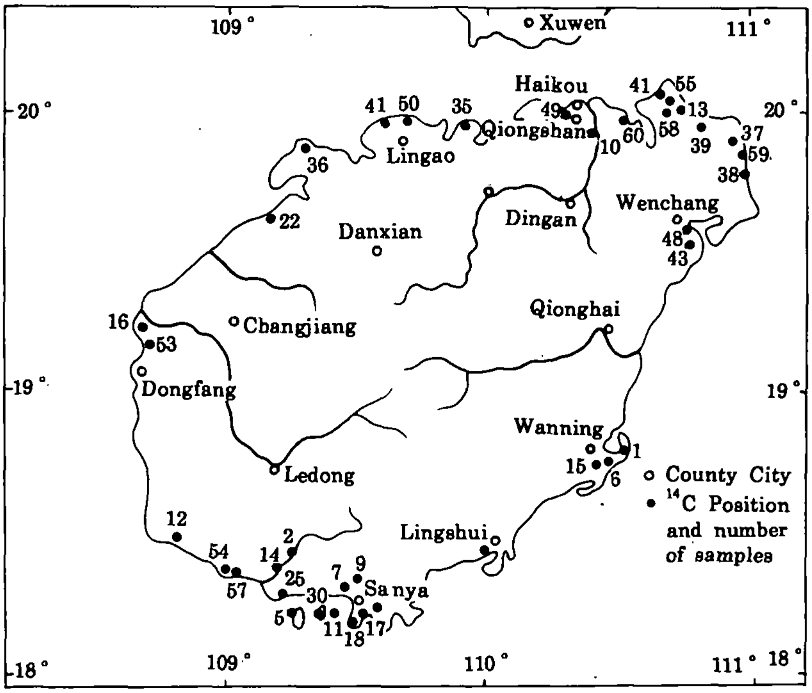

Fig. 2 Distribution of ^{14}C dating samples in Hainan Island

1. Wanning Formation at the Lower Holocene (Q_4^1)

Wanning formation (Q_4^1) consists mainly of gravelly mid–course sand and clay with bore–hole 12ZK as a representative. It contains oysters at the depth of 30.6m, whose age is 10,230± 320 years according to the ^{14}C dating of the samples. Wanning formation is the interactive sedimentation between marine facies and river facies as shown in Fig.1. Wanning formation is widely distributed over this area. The average thickness is 5.7m with 11.9m as its maximum value.

2. Sanya Formation at the Lower–Middle Holocene (Q_4^{2-1})

Sanya formation, represented by bore–hole 15ZK3, is composed mainly of sandy clay and mud. It is widely distributed over the area along the coast with an average thickness of 7.3m. The ^{14}C dating data show that this formation was deposited 7,280± 140 years B.P. It belongs to shallow sea or shoresea facies and contains a large amount of fossils of foraminifera and mussel–shrimp, in cluding 21 different species, mainly *Quinqueloculina, Triloculina, Ammonia tepida,* Elphidium etc. reflecting a transgressive period.

3. Qiongshan Formation at the Upper–Middle Holocene (Q_4^{2-2})

The lithology of Qiongshan formation is mainly gravelly mid–coarse sand or clayey sand with an average thickness of 3.0 m , and the maximum of 5m. The ^{14}C dating data indicate that it was deposited 4,930 ± 185— 2,500± 100 years B.P.. The formation contains less foraminifera in comparison with Sanya formation but more *Parorotalia inermis, Elphidum, Triloculina* etc., which reflects that the sedimentation ervironment was interactive ones between marine facies and land facies with the latter as a major one.

4. Ledong Formation at the Upper Holocene (Q_4^3)

This formation consists of sandy clay and mud with an average thickness of 3.9 m and the maximum of 7.6 m. It forms the upper part of the coastal plain, the sand barriers and lagoons, and beach rock sequence. The ^{14}C dating data show that it was formed about 2360 ± 90—260 ± 60 years B.P..

II. CLIMATIC FLUCTUATIONS OF THE HOLOCENE

Based on spore–pollen analysis of 11 samples, the Holocene can be divided into 6 spore–pollen zones from botterm to top (Fig. 3):

(1) Gramineae–*Artemisia–Quercus–Liquidambar* zone. The Herbaceous pollen accounts for 88.5% of the total spore–pollen amount, reflecting a warm–dry climate.

(2) Gramineae–Euphorbiaceae–*Artemisia–Liquidambar* zone. In this zone herbaceous pollen, which takes up about 80% of the total amount Xylophyta increases to 18% , including *Liquidambar, Castanea, Quercus* etc. reflecting a warm–dry climate.

(3) *Castanopsis–Dacrydium–Proteaceae–Cyathea* zone. With xylophyta amounting to 54.8% , harbaceae to 16.3% and peteridphyte to 28.9%, this zone reflects a hot–humid climate.

(4) *Proteaceae–Elaeocarpus–Castanopsis–Castacea–Piper* zone. This zone reflects a more hot – humid climate than the 3rd zone. It shows that the plant community is tropical origin.

(5) *Casuarina Equisetifolia–Castanopsis–Pinus–Artemisia* zone. There are 42% of xylophyta, 27% of herbaceous, and 31% of pteridophyte in this zone, which reflects a climatic change to warm–dry.

(6) *Casuarina Equisetifolia–Quercus–Liquidambar* zone. This zone reflects a climatic change to hot–humid.

In summary, there are two cycles of climatic flunctuation during the Holocene. First, the climate changed from warm–dry in $Q_4^1$to hot–humid in earlier Q_4^{2-1}(7,280–6,750 years B.P.). It reached the climax of the hot–humid period in late Q_4^{2-1}—this climate change is comparable with that in the Zhujiang River Delta (6,150—6,300 years B.P.)[3] but the hot–humid period is longer in Hainan Island. Then, the climate turned to warm–dry. The climate was warm–dry in Q_4^{2-2}, and changed to hot–humid in Q_4^3, which is determined by the spore–pollen assemblayes analysis of sapro–wood with ^{14}C dating being 1,565 ± 130 years B.P.. The hot–humid period in Q_4^{2-1}lasted longer with more intersive strength in comparison with that in Q_4^3. This climate change in the Holocene in Hainan Island is different from that in the Zhujiang River Delta but identical with that in North China Plain, Shanghai and Zhejiang[4—6].

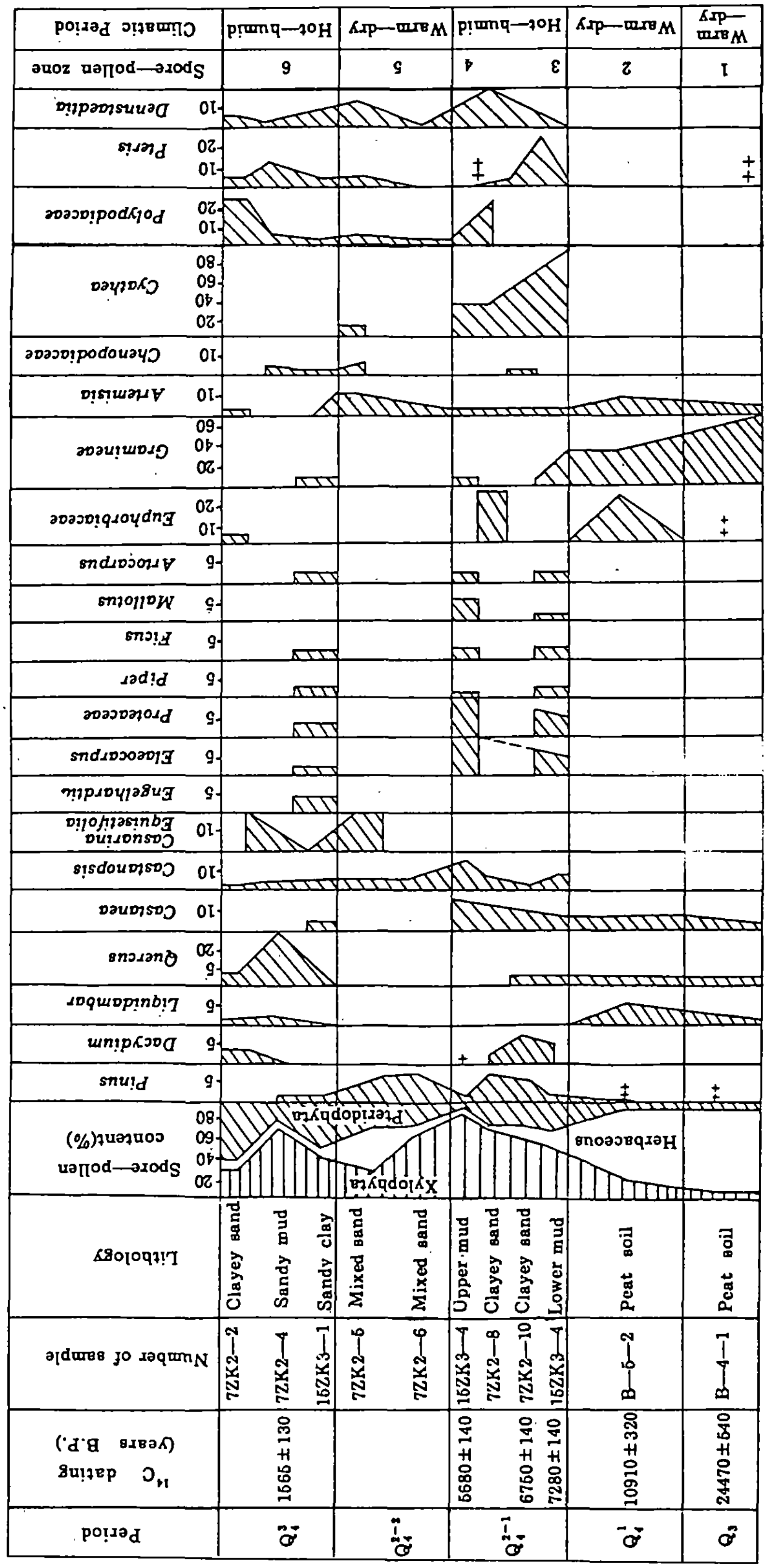

Fig. 3 Spore—pollen diagram of the Holocene series in Hainan Island

III. SEA LEVEL CHANGE IN THE HOLOCENE

There are 38 samples that can be used as indicators of ancient sea level. Obviously, the heights of these samples do not directly represent the real levels of the ancient sea because the positions of sampling sites may change caused by tectonic movements, there fore, need to be corrected. We use the height changes caused by tectonic morement to subtract the herghts of the samples and at the same time consider the deposition positions of the indicators to make some corrections. In this way we can obtain the correct levels of the ancient sea which are characterized by the heights of the indicators.

3. Indicators and Deposition Positions

(1) Beach rock: Beach rock is a kind of clastic rocks deposited in intertidal and / or supratidal zones in tropic or subtropic areas, and cemented by carbonnates. Those deposited in intertidal zone are called beach rock of seashore type , whose deposition depth is 0m. We have 10 samples of this type. Those deposited in supratidal zone are called beach rock of shell—barrier bar type, whose diposition position is 2 m above sea level. For this type, we have 4 samples.

(2) Primary coral reef: The coral reef platforms the lower tital surface as its upper growth limit. Since 1—5m below the water surface is the best growth depth for corals in Hainan Island, we take 5m below the ancient sea level as the deposition depth of primary coral reef. We have 12 samples of this type.

(3) Shell: Shells can be divided into two types: One is formed in supratidal zone and the deposition position is considered to be 2m above seal level; the other is formed in intertidal zone with deposition depth of 0 m. We have 4 samples of shell type in total.

(4) Peat and mud of lagoon facies: There are 3 samples of peat counted at 0m above sea level. Mud of lagoon facies cannot be considered as an indicator of sea level one and all, but mud containing sapro—wood can. The deposition depth is counted at 2m below. We have 2 samples of this type.

(5) Oyster's mud: Oyster grows generally 7—10m below lower tidal surface, thereby we take 7m below sea level as its deposition depth. And we have only one of this type.

2. Tectonic Factors

The change of sea level is a synthetic result of eustasy, crustal movement and static pressure balance of water (or ice) body. At present, there is no a very effective method that can eliminate the influence of crustal movement on the changes of sea level. This paper attempts to eliminate the seal level changes caused by tectonic movement by the modern rate of crustal rise in order to resume height of the ancient sea.

Based on the data of geodetic survey made by Guangdong Provincal Bureau of Seismology, the rate (mm / year) of modern crustal rise in Hainan Island is +3.7 in the area of Haikou, and +1.2 in Wenchang. We take the average of +2.45 as the crustal rising rate for these areas. In the moutainous areas in the west of Wanning and the north of Lingsshui, the rising rate is +3.0 — +3.3. Along the southeast coast, a rising rate of +1.2 is taken. In the subsidence areas along the west coast and in the north Nandu River Delta, we use the crustal rising rates in the Fuzhou Basin (−0.6), the Hanjiang River Delta (−0.71 and −2.27), and the Zhujiang River Delta (−2.0) as references.

3. The Curve of Sea Level Changes

The height of the ancient sea level characterized by 38 indicators can be calculated by equation

$$E = A + M + D$$

where, E: the height of ancient sea level (m);

A: the height of the indicator (m);

M: the subtraction value of the crustal rise (m);

D: the deposition depth of the indicator(m), positive above sea level and negative below sea level.

The oldest age of ^{14}C dating of the 38 samples is 10,230± 320 years B.P., and the youngest 650± 65 years B.P.. The samples are equally distributed in space and can be considered as the representatives of the ancient sea level temporally and spatially. According to the calculated E values and corresponding ^{14}C dating age, a breakthrough curve of the ancient sea level change can be obtained as shown in Fig. 4. Four periods of sea level change in the Holocene in Hainan Island can be found:

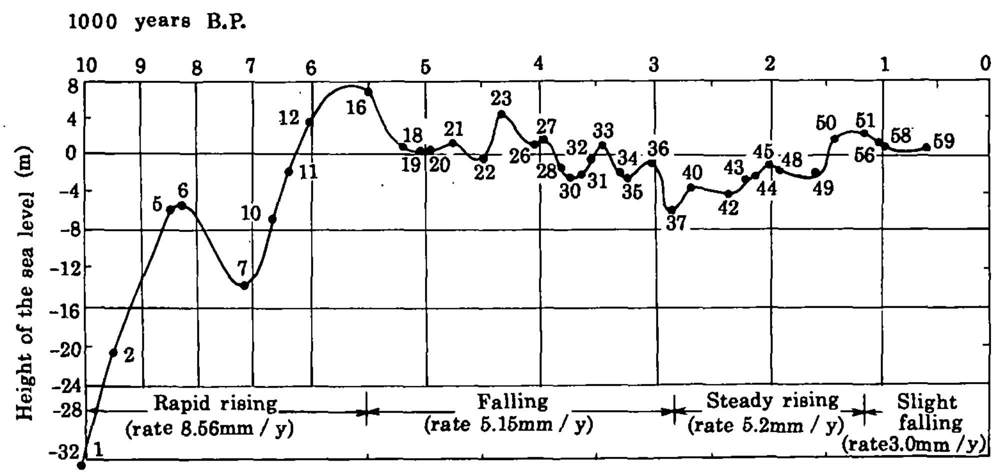

Fig. 4 A curve of sea level change during the Holocene in Hainan Island

(1) The period of rapid rise (10,230— 5,500 years B. P.) : The sea level rose from −32.7m in 10,230 years B.P. to 7.53m in 5,500 years B.P. by a rising rate of 8.56 mm / year, reflecting the rapid rise of sea level during the postglacial period. In the rise process, there

existed an obvious drop of sea level by a rate of 7.30 mm / year, which happened about 8,420— 7,280 years ago. Some 8,000 years ago, sea level was still −5m below. The Wanning formation along the coast was formed at that period. Then sea level started to go up continuously. In 6,000—5,500 years B.P., it was 5.95— 7.5m higher than the present one. This was a period with the higest sea level in the Holocene, having wide−spread marine sedimentation of Sanya formation, and it was also a period in which the primary coral−reef were well developed.

(2) The period of falling (5,500— 2,800 years B.P.): The general trend of the sea level change was going down though there existed 3 times of rising in the falling process. The range of each rising period decreased one after another, and the curve flunctuates above and / or below zero line. The average rate of sea level falling in this period is 5.15 mm / year. The sedimentation enviroment was an interactive one between marine facies and land facies. The Qiongshan formation was formed in this period.

(3) The period of steady rise (2,800— 1,200 years B.P.):This was another period of high sea level in the Holocene. There was a seal level rise from −6.28 m in 2,850 years B.P. to +2.39 m 1,190 years B.P. , having an average rising rate of +5.2 mm / year. There were, however, some fluctuations in the rising process. The Ledong formation was formed in this period, depositing mainly the sediments of sandbarriers—lagoons and beach rock.

(4) The period of slight falling and stability (1,200 years B.P. —present): The sea level went down from +2.39 m to 0.67 m during the period from 1200 to 625 years B.P. The falling rate is about 3.0 mm / year, which is much more slower in comparason with that in the previous three periods, indicating that the sea level has been in a relatively stable state with a slight falling in the last 1,200 years.

To sum up, there are two cycles of rise−falling changes in sea level along the coast of Hainan Island in the Holocene and 3 high sea level periods:the period between 5,995— 5,530 years B.P. (+5.95— +7.55m), the period between 4,365— 4,010 years B.P. (+2.2— +4.36 m), and the period between 1,379— 1,190 years B.P. (+2.35— +2.39 m). The range of sea level fluctuation in the last 6,000 years is ± 6m.

IV. CONCLUSION

On the basis of the newest data of Quaternary geologic investigation along the coast of Hainan, China, this paper puts forward that the Holocene can be divided into four formations: Wanning formation (Q_4^1), Sanya formation (Q_4^{2-1}), Qiongshan formation (Q_4^{2-2}), and Ledong formation (Q_4^3).

The analysis of spore−pollen indicates that the Holocene can be divided into 6 zones, reflecting two cycles of climatic fluctuation from warm−dry to hot−humid. The most hot−humid period occurred 6,000— 5,000 years B.P. Based on the ^{14}C dating data of 38 samples respresenting the positions of ancient sea level, and subtracted the influences of tectonic movement, a curve of sea level change is established. The curve shows that there are two cycles of rise–falling changes of the sea and three high sea level periods. The highest one is 6,000— 5,000 years B.P. According to the rise–falling rate, the change of the sea level can be divided into four periods with a range of flunctuation being about ± 6m in the last 6,000 years.

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