Sedimentary Features and Sea-Level Changes Reflected in Drill Holes in the Zhuhai Area

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Abstract Experimental examinations and analyses have been made of the sediments from drill holes in the Zhuhai area, Guangdong Province. The studies show that there occurred four transgressions in this area over the historical times. The first transgression occurred at 7500 a B.P., with the maxium sea level up to about 1 m above the present level. The second transgression occurred at 5750 a B.P., with the sea level possibly 4 m higher than the present. The third and fourth transgressions took place at 4650 a B.P. and 2600 a B.P. respectively, which lasted for a long time with multiple fluctuations. The fifth transgression is in process. It could be predicted that the sea level at Zhuhai would rise by 15–20 cm in the coming 50 years.

Key words: sedimentary features, sea-level changes, Zhuhai

1 Introduction

Satellite data show that the global sea level is gradually rising in recent years, especially obvious in the Black Sea region. It has caused 27 buildings to be collapsed and over 2000 constructions severely damaged. The environmental variations caused by sea-level changes have direct influences on people's life and development. Decisions on studies of the sea-level changes and their possible effects have been made successively at the 44th United Nations General Assembly, the United Nations Conference on Environment and Development, the United Nations Environment Programme and the Treaty of Government Heads (154 countries). The Chinese government also pays high attention to this issue, and has set up the IGCP 200, 274, 296 and LOICZ (Land and Ocean Interaction of Coast Zone) Chinese working groups for systematical studis of the sea-level changes. Under the sponsorship of the Guangdong Academy of Sciences, the authors have made a study of the sea-level changes in the western bank of the Zhujiang (Pearl River) Mouth.

2 Sea-level Changes

Many studies have been made about the sea-level changes in the South China Sea (Huang Yukun et al., 1982; Huang Zhenguo et al., 1986; Li, 1988; Shi, 1990). In this paper, sea-level changes in the South China Sea are studied based on the examinations and analyses of the sediments collected in the holes. Four holes (ZQ1, ZQ2, ZQ3 and ZQ4) on the nothern shelf of the South China Sea, one (ZK5) in the Xiangzhou Bay and one (ZK42) at Gongbei of Zhuhai were drilled (Fig. 1). According to various indices including the ages, palaeosalinity resulted from sedimentary phosphate measurement, ultramicrofossil species number (simple diversity), diatom abundance and features, abundance and number of species of foraminfera of the sediments from holes ZQ1, ZQ2, ZQ3 and ZQ4, the authors have constructed the eustatic series of the South China Sea since the late Pleistocene (Fig. 2).

The Shenzhen transgression occurred at 128 ka B.P., with the seawater intruding from east to west, during which the sea level reached its maxium at ca. 102 ka B.P., exceeding the present level. It fluctuated at ca. 90 ka B.P., and ended at 80 ka B.P. After that the sea level dropped at a great amplitude.

The Wanshan transgression took place at 61.5 ka B.P., being an adverse transgression during the regression of the Würm glaciation, with the seawater intru ding from southeast to west and north, during which

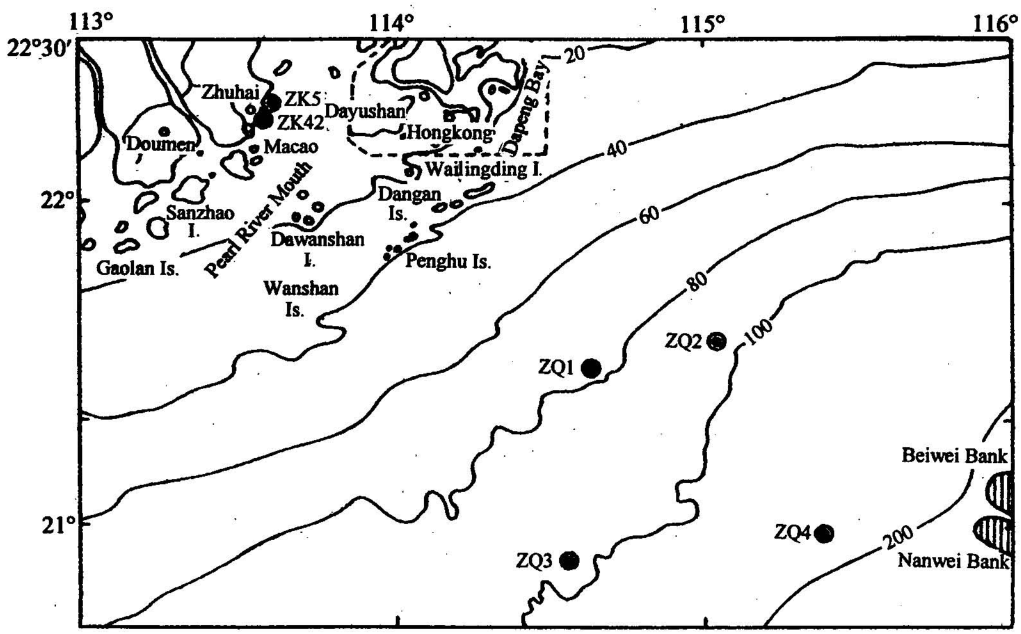


Fig. 1. Location of the major holes for the study of sea-level changes.
⊙–Drill hole.

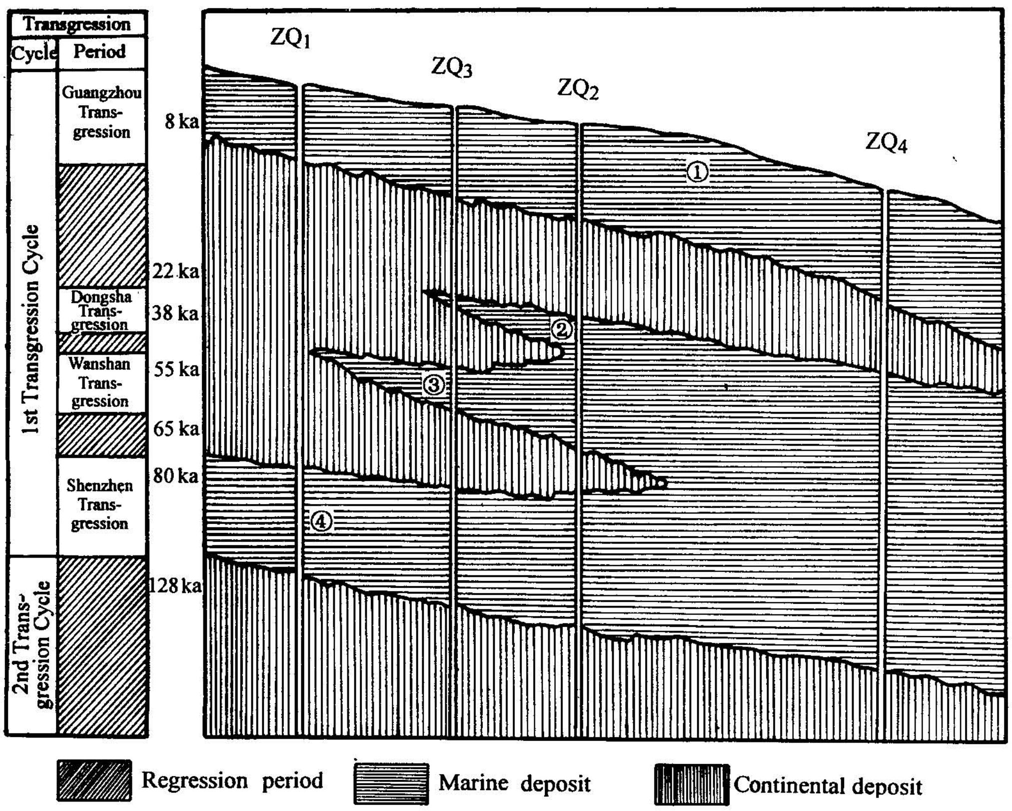
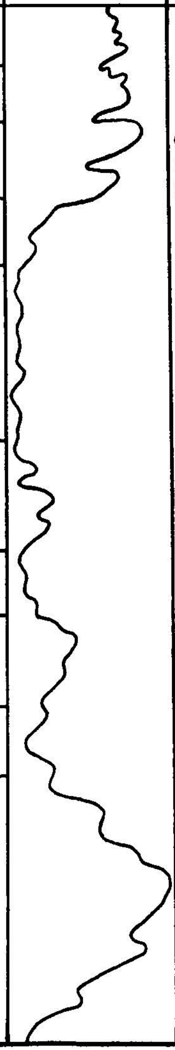


Fig. 2. Transgression series of the northern South China Sea since the late Pleistocene.

Table 1 Transgression series and their correlation in the South China Sea during the Late Pleistocene

Age (ka)				Climatic phase	Sea-level change	Transgression series and their correlation							
						S. China Sea (Chen, 1984)	E. China Sea (I)	E. China Sea (II)	Yellow Sea (Liu Minhou, 1987)	Bohai Sea (Yang Zigeng, 1979)	Bohai Sea (Zhou Mulin, 1983)	Sea of Japan	Sea of Europe
Holocene	L.	2.5		Subatlantic									
Holocene	M.	5.0		Subboreal						Cangdong trans.			
Holocene	M.	7.5		Atlantic		Guangzhou trans. (0-12.0 ka)	Fenghua trans.	Liyang trans.	Jizhoudao trans.		Chunhuazhen trans.	Jomon trans. (6.0-9.0 ka)	Flanderlan
Holocene	E.	12.0		Boreal Preboreal									
Late Pleistocene	L.	14.0, 18.0, 22.0	Würm glaciation	Würm (III)									
Late Pleistocene	M.	34.0	Würm glaciation	Upper sub-interglaciation		Dongsha trans. (26.0-38.0 ka)	Hangzhou trans.	Caojiadu trans.	Lianyungang trans.	Cangxi trans.	Xianxian trans. (23.0-39.0 ka)	Itami trans. (29.8-32.7 ka)	Paudourf (29-32 ka)
Late Pleistocene	M.	42.0	Würm glaciation	Würm (II)									
Late Pleistocene	M.	48.0, 61.5	Würm glaciation	Lower sub-interglaciation		Wanshan trans. (48.0-61.5 ka)	Chuansha trans.		Huanghaicao trans. (55.0-60.0 ka)			Misaki trans. (60.0 ka)	Guttweigh
Late Pleistocene	M.	73.0	Würm glaciation	Würm (I)									
Late Pleistocene	E.	128.	Würm-Riss interglaciation	Upper sub-interglaciation		Shenzhen trans. (80.0-128 ka)	Huangyan trans.	Shanghai trans.	Lingshandao trans. (70.0-114 ka)	Qingxian trans.	Cangzhou trans.	Shimosueyoshi trans. (120-130 ka)	Eemian (130.0 ka)

the sea level reached the maxium at 58–55 ka B.P., but did not exceed the present level. This transgression ended at 53–48 ka B.P.

The Dongsha transgression began at 38 ka B.P. and ended at 23 ka B.P. It was a weak transgression during the late Würm glaciation, with the seawater intruding from south to north and the maxium sea level rising up to near the Dongsha Islands at 28 ka B.P.

The Guangzhou transgression occurred at 12.3 ka B.P. (in eastern Guangdong) and 11.4 ka B.P. (in central Guangdong), with the seawater reaching Gongbei, Zhuhai at ca. 6.89 ka B.P., followed by eustatic fluctuations, and gradually up to the present level.

The sea-level changes of the northern South China Sea could be correlated with those of the East China Sea, the Yellow Sea, Bohai Sea, Sea of Japan and Sea of Europe (Table 1), which shows the existence of global sea-level changes controlled by the Quaternary climate fluctuations since the late Pleistocene (Zhao et al., 1992). It is acknowledged that there has been a 10×10^4a cycle in sea–level changes since the Pleistocene, which is also proved by the above facts, that is, except for the Dongsha and Wanshan transgressions which were minor adverse transgressions during the Würm glaciation, the interval between the Holocene Guangzhou transgression and the Shenzhen transgression was exactly 10×10^4a.

3 Sea-level changes at Zhuhai in historical times

Based on the data of holes ZK5 and ZK42, with special emphasis on ZK42, the authors have made studies of the sea-level changes at Zhuhai in the historical time.

3.1 Sample collection

Hole ZK42 is located at 20°13′22.5″N, 113°33′45″E with a depth of 15.80 m, having terristrial deposits in the lower part, marine deposits in the middle, and artificial landfill in the upper part. Ten (10) samples from the lower part (depths from 7.83 to 15.80 m) and 15 samples from the middle part (depths from 2.20 to 7.83 m) were collected for analyses.

3.2 Sample examination

Different age determination methods were used according to the nature of the samples. The ^{14}C dating method was used for marine deposits of fine-grained composition and high carbon content at a 30 cm interval so as to control the age changes, whereas thermoluminescent dating was used for continental deposits such as brownish red sand or granophyric clayey sand, with 10 samples collected according to the lithologic changes. The results are shown in Table 2.

The palaeosalinity of seawater was calculated through determination of sedimentary phosphate. Based on grain size and composition analyses, the probability cumulative frequency plot, C-M plot and structural parameters scattering plot were made for analyzing the sedimentation environment. For chemical analyses, measurements were made of the most commonly used facies microelements B, Ga, Sr and Ba; the Sr/Ba ratios were calculated; and B/Ga interrupted projection diagrams were plotted. Palaeontological identifications were also made for sporopollen, formaminifera, diatom and nannofossils (unfound). In a word, combined physical, chemical and biological analyses were made to study the sea-level changes in the historical time.

3.3 Sea-level changes

Studies of drilling data of holes ZK5 and ZK42 indicate that it was of a terristrial sedimentary environment in the Zhuhai area at 8000 a B.P. The section at Huaqiao Farm, Haiyan, Taishan County, reveals that the sea level of the South China Sea was −17.3 m at ca. 7340 a B.P., the Nanhong section, at Sanya, Hainan Island shows that the sea level was −10.0 m at ca. 7280 a B.P. After that, four transgressions took place in this area.

The first transgression

The sea level of the South China Sea was −17 m at 7500 a B.P. and after that time the first Transgression occurred. A calculation of the sediment data in ZK42 shows that the sea level rose rapidly at a rate of 8.7 mm/a and the seawater reached Gongbei at 6890 a B.P. with tidal-bank sediments deposited at depths of

Table 2 Dating data of hole ZK42

Serial No.	Sample No.	Depth (m)	Sediment	Sedimentary facies	Dating Method	Age (a B.P.)
3	ct 94003	2.3–2.40	Dark grey clayey silt	Littoral	^{14}C	800±130
4	ct 94004	2.6–2.70	Light grey silty clay	Tidal bank	^{14}C	1110±80
5	ct 94005	2.8–2.90	Dark grey silt	Littoral	^{14}C	1510±130
6	ct 94006	3.0–3.10	Light grey silt	Tidal bank	^{14}C	1880±60
7	ct 94007	3.2–3.30	Dark grey clayey silt	Littoral	^{14}C	2320±80
8	ct 94008	3.6–3.70	Light grey silty sand	Estuary	^{14}C	2730±120
9	ct 94009	3.8–3.90	Light grey silt	Littoral	^{14}C	3110±100
10	ct 940010	4.1–4.20	Grey clay	Littoral	^{14}C	3730±120
11	ct 940011	4.3–4.40	Grey clay	Tidal bank	^{14}C	4140±160
12	ct 940012	4.6–4.70	Light grey silt and sand	Estuary	^{14}C	4530±100
13	ct 940013	4.8–4.90	Light grey silty clay	Littoral	^{14}C	4875±130
14	ct 940025	5.4–5.50	Light grey silt and sand	River bed	Thermoluminescence	5490±250
15	ct 940014	6.2–6.30	Light grey silt	River bed	^{14}C	5810±130
16	ct 940015	6.7–6.80	Light grey clayey silt	Tidal bank	^{14}C	6120±120
17	ct 940016	7.1–7.20	Light grey silty clay	Littoral	^{14}C	6350±175
18	ct 940026	7.4–7.50	Dark grey clay	Littoral	Thermoluminescence	6530±300
19	ct 940017	7.7–7.80	Light grey clay	Tidal bank	^{14}C	6890±180
20	ct 940027	8.2–8.30	Greyish yellow silty clay	Alluvial-pluvial	Thermoluminescence	8690±430
21	ct 940028	8.6–8.70	Brown sandy clay	Alluvial-pluvial	Thermoluminescence	9400±450
22	ct 940029	9.1–9.20	Light grey clayey sand	Swamp	Thermoluminescence	9910±500
23	ct 940030	9.8–9.90	Greyish white clayey sand	Swamp	Thermoluminescence	10200±500
24	ct 940031	10.4–10.5	Granophyric clayey sand	Alluvial-pluvial	Thermoluminescence	11500±600
25	ct 940033	12.6–12.7	Greyish black sandy clay	Swamp	Thermoluminescence	12950±650
26	ct 940034	14.4–14.5	Grey silty clay	Shallow lake	Thermoluminescence	13980±700
27	ct 940035	15.4–15.5	Brown sandy clay	Weathering crust	Thermoluminescence	14750±730

7.7–7.83 m in the hole. The sediments are composed of light grey silty clay, in which the palaeosalinity is 27–30‰. Nọ ultramicrofossils are found, and the abundances (number per gram) and number of species of foraminifera are 2–3 and 25 respectively. The sea level then rose gradually at 2–3 mm/a and reached the highest elevation at ca. 6530 a B.P., 1 m above the present level. The sediments deposited under the high sea level are dark grey clay discovered in hole ZK42 at the depths of 7.3–7.5 m, characterised by palaeosalinities of 30–32‰, abundant foraminifera dominantly composed of *Ammonia tepida, A. beccarii, Protelphidium granosurn* etc. with the abundances being 4–6 and species number 36 respectively. The high sea level sustained only for a short time and dropp-ed at ca. 6120 a B.P. The sediments of that time were found at depths of 6.6–6.8 m from hole ZK42, main-ly consisting of beach and tidal-bank light grey clayey silt and sand with palaeosalinities of 25–30‰, the for aminifera abundances being 4–6 and species number 23 respectively. The sea level dropped at a rate of 7.6 mm/a and reached the lowest level at 5650 a B.P., 3.6 m below the present level. River-bed facies silt and fine-grained sand with muddy gravel deposited can be observed at a depth of 5.6 m from hole ZK42, with palaeosalinities of 5–8‰, and no foraminifera and ultramicrofossils found. The diatoms found belong to the freshwater species and are poorly preserved.

The first transgression in the Zhuhai area began at 7500 a B.P. and terminated at 5650 a B.P., lasting for a period of 1950 a. The highest sea level was 1 m above the present one with 2.2 m-thick sediments deposited. This transgression has experienced the terristrial, tidal bank, littoral, tidal flat and river-bed facies, and belongs to the single transgression characterised by the sea level rising rapidly and dropping with great amplitudes.

The second transgression

The second transgression in the Zhuhai area took place at 5750 a B.P. The sea level rose rapidly and reached Gongbei, Zhuhai at ca. 5350 a B.P. The sediments at depths of 5.2–5.3 m from hole ZK42 consist of tidal-bank clayey silt dominated by silt, which is characterized by a subrounded shape and grain sizes of 0.008–0.050 mm with palaeosalinities of 8–30‰. Most of the foraminifers and diatoms belong to the littoral species. The foraminifera abundance is 8.8 and the species number is 27. After that the sea level continued to rise and reached the maxium at 5100 a B.P., 3.8 m above the present level. The corresponding sediments consist of neritic dark grey clay and silty clay with minor chlorite and glauconite observed at depths of 4.8–5.1 m of the hole ZK42. The silt is characterized by a semi-angular shape, with grain sizes of 0.01–0.05 mm. The palaeosalinities are 34–35‰. Of the total microfossils the foraminifera accounts for 38–91%, and diatoms 6–42%, and there are also minor silicoflagellate, radiolaria and sponge spincule etc. The foraminifera abundances are 32–129 and the species numbers 53–62. These sediments are the most typical marine sediments in the Zhuhai area in history. Subsequently, the sea level began to lower and intertidal sediments appeared at 4750 a B.P. The sediments from hole ZK42 at the depths of 4.75–4.85m are grey silt and sandy silt with palaeosalinities of 30–31‰. There are only a few foraminifers with fragmented tests and their abundance is 9.7 and species number is 38. After 4750 a B.P., the sediments were mainly composed of estuary and river-bed facies dominated by light grey silt and sand with freshwater shells, which could be observed from hole ZK42 at depths of 4.6–4.7 m. The palaeosalinities are 10–17‰. Typical river-bed facies sediments were developed in this area at ca. 4600 a B.P.

The second transgression in the area ended at 4650 a B.P., lasting for a period of 1000 a with about 0.8 m-thick sediments deposited. This transgression is characterized by the sea level rising and dropping rapidly with the highest up to 3.8 m above the present level, called the Holocene high sea level. It caused the whole Zhujiang Delta to be submerged, and 2–3 m-high marine-cut, marine-built terraces formed on both sides of the Zhujiang Mouth. Data from ZK42 reveal that the second transgression is similar to the first one and belongs to the single transgression.

The third transgression

The third trangression occurred at 4650 a B.P. with the sea level up to the present level at ca. 4450 a B.P. During this transgression the sediments contained interbeded tidal flat mud, silt and sand with well-developed stratification, which could be observed from hole ZK42 at the depths of 4.5–4.6 m. There are *Ostrea rivularis* at the bottom and plenty of foraminiferas in the upper part of the transgression stratum. The palaeosalinities are 28–32‰. The foraminifera abundances and species number are 11–13 and 38 respectively. The sea level continued to rise and reached the maxium at ca. 4350 a B.P., 2.6 m above the present level. Littoral and neritic black mud deposits are found in ZK42 at depths of 4.4–4.5 m, which mainly consist of clay and some silt, with minor amounts of pyrite and glauconite. The palaeosalinities are 32–34‰. The foraminfers with abundances of 21–60 and species numbers of 43–63 mainly belong to the benthic species with small and fragmented tests. Regression occurred at ca. 4200 a B.P. and the sediments became coarser at ca. 4050 a B.P., i.e. clayey silt representing a littoral or subtidal environment. At that time the sea level was equivalent to or tens of centimetres higher than the present level. The sea level began to rise at a low speed and small amplitude at 4000 a B.P., probably about 2 m above the present level at ca. 3750 a B.P., which was the second high sea level during the third transgression. The sediments at depths of 4.0–4.2 m of ZK42, composed of silty clay or muddy clay with the palaeosalinities being 30–33‰. Benthic foraminifers increased with an abundance of 16 and species number of 40, suggesting a littoral environment. The sea level dropped at 3700 a B.P. at a low speed and was only tens of centimetres higher than today's level at ca. 3450 a B.P. Interbeded tidal flat and beach grey silt and clayey silt were found from ZK42 at depths of 3.9–4.0 m. The palaeosalinity is 30‰; the foramoinfera abundance is 7 and the species number is 23. The sea level began to rise at 3280 a B.P. and the third high sea level occurred at 3050 a B.P., about 1.5 m above the present level. The silty mud deposited at depths of 3.75–3.85 m are sediments of a littoral environment. The palaeosalinity is 32‰. The foraminifera abundance is 15 and the species number is 36. The diatoms are dominated by salt water species such as *Actinocyclus alienus* and *A. ehrenbergi*. The sea level began to fall slowly from 2950 a B.P., and an estuary environment occurred again at 2650 a B.P. At 3.4–3.6 m of hole ZK42 there is a suite of grey silt and fine-grained sand containing mud. The palaeosalinities are 19–21‰. There are few foraminfers. The diatoms include *Melosira graunulata, A. ehrenbergi var. ralfsii* and *Cyclotella striata*, which belong to a mixture of salt and fresh water species.

The third transgression in the Zhuhai area ended at 2600 a B.P., lasting for a period of 1950 a, with 1.2 m-thick sediments deposited. Analyses of the sediments indicate that there were three highs and three lows during this transgression, with the highest level being about 2.6 m, which was lower than the high sea level of the second transgression. This transgression belongs to a composite oscillatory one.

The fourth transgression

The fourth transgression in the Zhuhai area began at 2600 a B.P. The sea level reached Gongbei at ca. 2450 a B.P. The sediments at depths of 3.3–3.4 m in ZK42 are deposits of this period. They contain tidal-bank black grey and light grey silty clay and sandy clay. The palaeosalinity is 31‰. The feraminifers abundance is 14 and the species number is 30. The sea level rose to the highest level at ca. 2250 a B.P., with dark grey sandy clay deposited and occasionally authigenic spheroidal pyrite found in hole ZK42 at depths of 3.1–3.2 m. The grain sizes of the silt are 0.01–0.07 mm; the palaeosalinity is 32‰. There are abundant foraminiferal tests with the abundance and number of species being 17 and 40 respectively. There are also plenty of salt water diatoms dominated by *Coscinodiscus divisus*. Analyses of the grain size, mineralogical and palaeontological data demonstrate that it was a littoral environment and the sea level was probably 1.5 m higher than the present level. After that time the sea level began to drop. At ca. 1850 a B.P., the sediments under the lower sea level turned lighter in colour and coarser in grain size. At depths of 2.9–3.0 m, the sediments are composed of light grey clayey silt and muddy silt with a palaeosalinity of 30 ‰, foraminfera abundance of 6 and species number of 19. The diatom assemblages consist mainly of *Coscinodiscus divisus-C. blandus*, with 67.3% of salt water species, 30.2% of brackish water species and a few fresh water species. The sea level at that time was as high as the present level or a bit higher. The ^{14}C age for the sediments at the depth of 3.0 m in the hole is 1880 a B.P. Subsequently, the sea level possibly rose; dark grey clay, soft and slippery, was deposited at depths of 2.8–2.9 m (1510 a B.P.). The palaeosalinity is 30‰; the foraminfera abundance is 15 and the species number is 29. The diatoms consist of mainly salt water species (75.45%), some brackish water species (15.85%) and a few fresh water species. Analyses and correlation of data indicate that the sea level was higher than the present level, but no more than 1 m. Then the sea level gradually dropped again, with a suite of tidal-bank clay-silt deposited at 2.6–2.7 m in the hole. The palaeosalinity was 28‰ at 1110 a B.P., and the foraminfera decreased with an abundance of 4 and species number of 28. The diatom assemblages consist mainly of *Coscinodiscus divisus-Cyclotella stylorum*, with 56.7% of salt water species, 41.3% of brackish water species and a few fresh water species. The sea level was equivalent to or a bit higher than today's level with a subsequent rise. Dark grey mud was deposited at 2.3–2.4 m in the hole, corresponding to a higher sea level at 800–1000 a B.P. The palaeosalinity is 30‰. Foraminiferas are very abundant with an abundance of 10 and species number of 25. Diatoms of salt water species increased, mainly consisting of *Coscinodiscus divisus* and *C.curvatulus*. The sea level at that time was at least 0.8–1.0 m higher than the present level. In the past 800 years the sea level has gradually dropped to the present level because of climate cooling, but rising took place again in the recent 100 years, especially rapid in the last decades or so.

4 Future Trends of Sea Level Changes

According to the above analyses, a sea-level curve of Zhuhai in the historical times is plotted (Fig. 3), which shows regular changes with the following characteristics:

- The transgression level tends to be lower and lower.
- The transgression speed becomes smaller and smaller.
- The sea-level changes assume a more and more complexed pattern.

There were four transgressions occurring in the Zhuhai area in the historical times, and the fifth transgression is in progress. From studies of the four transgressions, it is predicted that the fifth one will be a composite transgression.

It is shown in Fig. 3 that the sea level during the third transgression rose from −1.6 m to 2.6 m with an

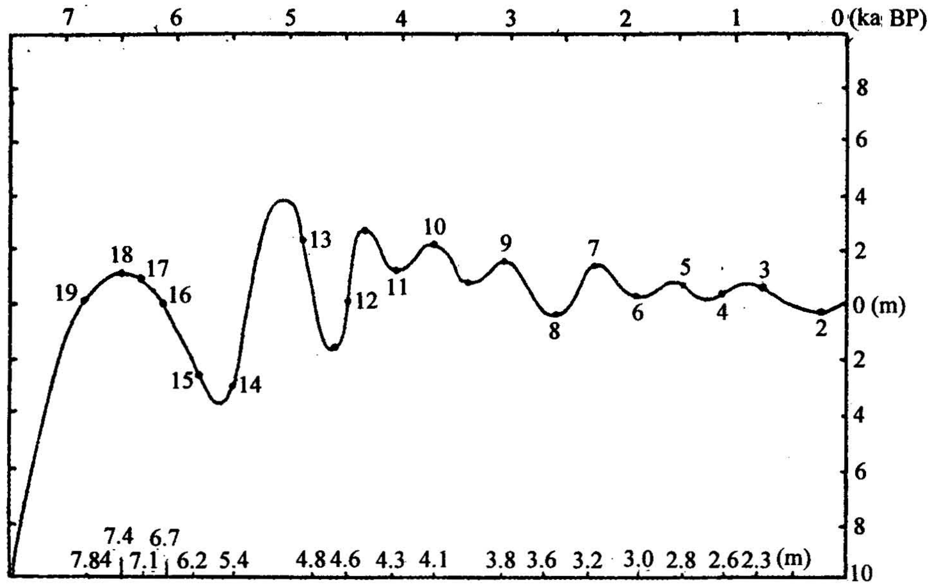


Fig. 3. Typical chart of sea-level changes in Zhuhai.

amplitude of 4.2 m (h_3) and time of 250 a (t_3) at a rate of 16.8 mm/a (f_3). During the fourth transgression the sea level rose from −0.4 m to 1.2 m with an amplitude of 1.6 m (h_4) and time of 350 a (t_4) at a rate of 4.6 mm/a (f_4). Thus, based on the above regularity, the amplitude (h_5), time (t_5) and rate (f_5) of the sea level change during the fifth transgression could be predicted as follows.

According to the equations

$$\frac{h_4}{h_3}=\frac{h_5}{h_4};\frac{t_4}{t_3}=\frac{t_5}{t_4};\frac{f_4}{f_3}=\frac{f_5}{f_4}$$

the amplitude (h_5), time (t_5) and rate (f_5) of the fifth transgression can be calculated as follows: $h_5=(h_4)^2/h_3=1.6^2/4.2=0.609$ m; $t_5=(t_4)^2/t_3=350^2/250=490$ a; and $f_5=(f_4)^2/f_3=4.6^2/16.8=1.26$ mm/a.

According to the above calculated results, it could be forecasted that the sea level at the western Zhujiang Mouth would probably rise 6.3 m in 50 years.

The calculation by the National Bureau of Oceanography based on the data of 48 tidal-gauge stations for over 1200 a in China gives an average rising rate of 1.4 mm/a of the see level in the last hundred years, which is roughly equivalent to our result (only slightly lower). Moreover, the result calculated by Houghton, et al. from the data of large amount of tidal-gauge stations for the last hundred years (1880–1980), with corrections to various factors, also indicates that the global sea level has risen by 14 cm, i.e. 7 cm in 50 years, which is consistent with our result.

Drastic increases in CO_2 and trace gases since the industrialization have resulted in a global greenhouse effect. It was pointed out at the 3rd IPCC (Guangzhou, January 1992) that the greenhouse effect will probably cause the atmospheric temperature to rise by 2.5°C in the coming 40 years. A report made by over 200 meteorologists from more than 200 countries in Marid (November 30, 1995) also showed that the greenhouse effect will lead to major changes in the global climate with a temperature rise of 1–3.5°C before 2100. Scientists have pointed out that thermal expansion of the upper ocean water caused by global surface air temperature rise, say, an average rise of 2.5°C, will possibly result in a sea level rise of 8–14 cm.

Based on the sea level trends and global climate changes, it could be predicted that the sea level will probably rise 15–20 cm in the coming 50 years, not considering abrupt rises that might be caused by rapid collapse of the ice sheet in the Antarctic Pole.

Studies in this paper show that the sea level rise in the Zhuhai area is an inevitable trend, and even a rise of 15 cm in 50 years will be a threat to the development and construction of the Guangdong coastal area, especially the Zhujiang Delta.

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