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Study on the buried oyster reefs and environmental changes with the underlying muddy sediments on the Northwest Coast of Bohai Bay

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Abstract. The Electric Conductivity of Stirred Clayey sediments into Water (EC), pH values and micropalaeontological studies of the underlying muddy sediments of the buried oyster reefs in Dawuzhuang and Airport sites, northwest coastal plain of Bohai Bay revealed a difference of the depositional environments of the underlying mud units in two sites. In Dawuzhuang, from the underlying to the overlying muds, environment changed from subtidal to the lower intertidal zone, which presented a falling tendency of relative sea level. However, the underlying mud in Airport site occurred in the intertidal and changed upwards to the reef body as being lagoonal environment. These indicate that the relative sea level fall resulted in intertidal environment in Dawuzhuang and a change from the open intertidal to relatively isolated intertidal lagoon environment in Airport site as a diatom thriving as well during the mid-Holocene all form the important reasons for the oyster reef development.

1. Introduction

More than 40 sites of the buried oyster reefs have been found in the northwest coast of Bohai Bay. Generally, these buried reef bodies were developed on the muddy sediments while covered by muds. During the recent years, numerous researches, including formation and ecology of the shells, aging of the reefs, palaeoenvironmental correlation of different reefs, relationship between reef building-ups and sea level changes and the cause of the intercalated horizontal layers have been conducted ^[1-6]. Fang studied the environment and turning relation to the overlying muddy sediments for the reefs found in Dawuzhuang and Tianjin Airport^[7]. Evolution from the underlying mud to reef itself and finally to the overlying mud recorded palaeoenvironmental change in the area. Thus, the underlying mud is able to reveal information of the initial stage of the reefs. The environmental difference existing in between the underlying mud and the reef-bottom was significant for reef reconstruction. Therefore, throughout the Electric Conductivity of Stirred Clayey sediments into Water, pH values, and forams and diatom studies, this paper described the palaeoenvironments for both the underlying mud and the initial stage of the reefs and approached the reason of 'the mud-reef conversion'.

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2. General Setting

This study consists of two profiles (1) DW2 Profile, Dawuzhuang site, $117^{\circ}52'25''E$, $39^{\circ}25'08''N$, ground elevation +1.345 m (the Yellow Sea 85 Datum), and top-height of oyster reef -2.0 m and bottom-height -8.21 m, i.e. thickness of reef 6.21 m; (2) DL2D Profile, Airport site, $117^{\circ}23'25''E$, $39^{\circ}08'08''N$, a building-pit unearthed 2.3 m-thick oyster reef.

3. Methods

3.1 Measurements for the Electric Conductivity of Stirred Clayey sediments into Water and pH values The Stirred Clayey sediments into Water is a mixed solution between 10 g clay sample ground after stoving below 110°C and120 ml distilled water. Normally, the Electric Conductivity of Stirred Clayey sediments into Water is less than 0.4 mS/cm for terrestrial sediment, and 0.4~1.2 mS/cm is transitional between land and sea, while the sedimentary environment is marine when the Electric Conductivity is higher than 1.2 mS/cm ^[8]. After 48 h drying under 110°C and ground, the powdered samples were mixed with distilled water. Then, with 3 minutes stirring and an hour static state, the conductivity and pH value can be measured.

3.2 Foraminifera study

Soaked in 10% hydrogen peroxide solution, 20 g dry samples were completely dispersed and then with 0.063 mm sieving. After drying under 50°C in oven, the part larger than 0.063 mm was split and then examined under binocular and statistically studied.

4. Results

4.1 DW2 Profile, Dawuzhuang

The samples were systematically taken with a 25 cm interval from the underlying mud 1m below the reef-bottom upwards. The result shows that the Electric Conductivity of Stirred Clayey sediments into Water (EC) is 1.48~1.85 mS/cm, which is higher than the boundary value of both transitional and marine states. The pH is 8.5~8.9 and belongs to strong alkalinity environment. On the other hand, samples 1, 2 and 3 were taken at 0.025 m, 0.25 m and 0.5 m below the reef bottom, respectively, for foraminifera identification. The dominant species in sample 1 are composed of *Ammonia beccarii* vars. (59.68%) — *Cribrononion* sp. (14.52%) —*Elphidium nakanokawaense* (11.29%). The dominant species in sample 2 are composed of *Ammonia beccarii* vars. (44.36%) —*Elphidium nakanokawaense* (37.35%) —*Cribrononion* sp. (10.89%). The dominant species in sample 3 are composed of *Ammonia beccarii* vars. (50.96%) —*Elphidium nakanokawaense* (19.11%) —*Biloculinella labiata* (16.56%). These infer a subtidal marine sedimentary environment (Fig. 1).



Figure 1. Results of the Electric Conductivity of Stirred Clayey sediments into Water (EC), pH and forams assemblages in Profile DW, Dawuzhuang (a) and Profile DL2D, Airport (b).

4.2 DL2D Profile, Tianjin Airport

We have measured the conductivity and pH of clay water 0.2 m above the reef bottom and the underlying muddy sediments from the reef-bottom downwards to 1.3 m in Profile DL2D, Tianjin Airport. The result shows that the conductivity of the mud fillings into the articulated shell at the lower part of reef body is 1.18 mS/cm, which is closed to but not reach the boundary value of 1.2 mS/cm between the marine and the transitional facies and belonging to lower intertidal deposits. The conductivity values of 7 samples collected from the underlying mud layer are 0.78~0.95 mS/cm, which are all greater than 0.4 mS/cm and less than 1.2 mS/cm and belong to the transitional facies. The changing range of conductivity is small and indicating that the environment was relatively stable. While the pH values of 7 samples collected from the underlying mud layer are in between 9.06 and 9.31, suggesting a strong alkaline environment. Samples 4, 5 and 6 were collected at depths 0.3 m, 0.7 m and 1.3 m from the underlying deposits beneath the oyster reef. Results show that the sample 4 is mainly composed of *Ammonia beccarii* vars. (80%) and other forams are rare such as 6.68% of *Quinqueloculina akneriana rotunda*, 4.44% of *Cribrononion* sp., 4.44% of *Saccammina sphaerica*. The dominant composition of sample 5 is *Ammonia beccarii* vars. (60%) —*Quinqueloculina akneriana rotunda* (22%) —*Triloculina trigonula* (8%). The dominant species of sample 6 is

Ammonia beccarii vars. (63.16%) —*Elphidium nakanokawaense* (15.79%) —*Cribrononion* sp. (13.16%). All these indicate that the underlying deposits beneath the reef shown in Tianjin Airport DL2D section were deposited in the mid–lower part of intertidal environment (Fig. 2).

5. Discussions and Results

The two reefs are mainly composed of *Crassostrea gigas*, which is living in the intertidal zone and growing vertically. The conductivity of muddy samples, taken from inside the articulated shells in Dawuzhuang reef, from the reef bottom to the reef top, is mostly within the 0.40~1.20 mS/cm of the transitional phase, and the lower part of the reef is in the lower intertidal environment, while the upper part of the reef is in the mid-upper intertidal environment ^[4]. The high conductivity of the underlying muds and marine assemblages of forams implied that it was subtidal (the underlying mud) to the lower to mid-upper intertidal (reef body) which means sea water being shallower upwards with relatively falling of sea level.

In DL2D Profile, Airport, the conductivity values of the samples at 0.2 m above the reef bottom is 1.18 mS/cm, which is less than but closed to the boundary value between the transitional and marine facies of 1.2 mS/cm. This shows that the bottom of the oyster reef is in the lower part of the intertidal zone near the average low tide line, while the conductivity values of the 7 samples in the underlying mud layer are all greater than 0.4 mS/cm but less than 1.2 mS/cm and all concentrated in the range of 0.78~ 0.92 mS/cm, belonging to the transitional facies. Foraminifera assemblages of the underlying deposits in Profile DL2D present the dominant species of *Ammonia beccarii* vars. – *Quinqueloculina akneriana rotunda*–*Cribrononion porisuturalis*, featuring strong marine facies, indicating that the underlying sedimentary facies in this site belongs to the mid-lower part of the intertidal zone. It suggests that from the underlying mud to the reef body, sedimentary environment changed from the lower-mid subtidal environment to the lower intertidal environment closing to the mean low tide. This reflects a relative rise of sea level.

The oyster reef in Dawuzhuang belongs to the Reef Group II, with an age of 7170~5652 cal BP^[2]. The reef building-up in this site was formed before 7200 years ago. At that time, Dawuzhuang area was located in the subtidal zone, belonging to the shallow sea environment. The age of oyster reef in Airport is about 6068~3980 cal BP, which belongs to the Oyster Reef Group III. The oyster reef of the Aairport was formed before 6000 years ago and was located in the lower intertidal zone, which belongs to the transitional environment. The formation period of the sediments under the oyster reef in DW2 Profile of Dawuzhuang is earlier than 7200 cal BP, at which the transgression in Bohai Bay reached its maximum extent. Thus these underlying sediments formed when sea level rised. A relative falling led to the transition of Dawuzhuang from the subtidal to the intertidal zone. The sediments under the oyster reefs in the Airport DL2D Profile was formed prior to 6000 cal BP when the mid-lower intertidal zone was altered to a lagoon environment.

In addition, no diatom was found in the mud layers under the oyster reef of both Dawuzhuang and Airport. However, diatoms are greatly abundant in the muddy inclusions of the articulated oyster shells. It suggests that there were less diatoms in the sea water during the deposition of the underlying mud layers. because the shell individuals are being at the upstream of the biological chain, it could grow when there was abundant food supply, such as the diatom. thus, the oyster reefs can build only under these conditions. Thus, we deduce that the development of micro-archaea such as diatoms is an important factor for the growth of oyster reef.

In summary, the following conclusions are drawn.

(1) We have measured the turbid clay water conductivity and pH values and approached the foraminifera assemblages, and reconstructed the depositional environment of underlying sediments of the oyster reefs in Dawuzhuang and in the Airport Logistics Centre, as well as the palaeoenvironment in the early stage of reef construction. These studies allowed us to determine that the underlying sediments beneath the oyster reef in the Dawuzhuang DW2 Profile belong to subtidal environment. At the beginning of its formation, the reef was located in the subtidal zone, then it was transformed to lower intertidal zone because the relative sea level became shallower. The underlying sediments of

oyster reef in the DL2D Profile formed under lower intertidal environment. During its formation, the relative sea level showed a tendency to increase and the closing spit to lagoonal environment.

(2) From the Dawuzhuang oyster reef, we can see that from underlying mud layer to oyster reef itself, the environment changed from subtidal to intertidal and the relative sea level showed a tendency to decrease. The underlying mud layer and oyster reef in this site are both under intertidal environment. However, the bottom of the oyster reef was at the lower interdidal zone, i.e., indicating that the relative sea level showed a tendency to rise because from the underlying mud layer to the oyster reef there was a transition from mid-lower intertidal to lower intertidal zone.

(3) The underlying sediments under the oyster reef in DW2 Profile, Dawuzhuang, was formed in 7200 cal BP, during which the Holocene transgression reached its maximum extent. At that period, the relative sea level turned to stable or was decreasing. The underlying sediments of oyster reef in the Airport DL2D Profile was formed in 6000 cal BP, during which the relative sea level showed a tendency to rise and the closing spit a to forming eventually a lagoon environment.

(4) The salinity and water pH change may result in the emergence and increase of palaeo microbiomass such as diatoms, this change constitutes an important factor to the growth and thriving of oyster reefs. The great abundance of diatom, relatively low pH value and intertidal environment are essential conditions for the development of oyster reefs.

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