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Environmental Evolution and Human Adaption Recorded From a Salt Production Site at the Coastal Plain of Laizhou Bay, China

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The southern coast of the Laizhou Bay is considered as one of important areas for the origin and development of sea salt production in Eastern China. Archaeologists have collected rich materials to better understand history of salt production in the region, but how environmental change influences early salt production is still unknown. Here we collected samples at the Shuangwangcheng (SWC) site in the southern plain of Laizhou Bay. We conducted grain size, mollusk and foraminifera analysis to examine the evolution of sedimentary environment and restored the human adaptions to environmental change. The results showed that the sedimentary environment of study area was lower tidal flat during 6400~5900 yr BP as indicated by coarse and well sorted grain size, high abundance of foraminifera, and the *Ammonia beccarii* vars. - *Quinqueloculina akneriana* foraminifera assemblage. Sedimentary environment changed from intertidal to supratidal flat with decreasing abundance of foraminifera and finer upward grain size at 5900~ 4300 yr BP. After 4300 yr BP, this area was less affected by seawater, which could be reflected by the appearance of freshwater mollusk and rarely discovered foraminifera. Our retrieved environment changes were closely related with ancient human activities. The Holocene transgression constrained the Dawenkou cultural sites within the inland areas with higher altitude. The exposed coast lowlands after sea retreat were initially not suitable for human survival except sporadic salt production sites of the Longshan culture. These conditions were improved during the Shang and Zhou Dynasties when humans widely used the particular natural resources of underground brine for salt production, and then a large number of salt production sites appeared, which made this region develop into an important origin center of salt production. Our research suggests that salt production was an economic activity that was adopted by people to adapt to the harsh environment, which is of great significance for understanding the evolution of the human-environmental relationship in the coastal area.

Keywords: salt production, sedimentary environment, Laizhou Bay, the Shuangwangcheng Site, human-environment relationship

INTRODUCTION

The southern coastal plain of the Laizhou Bay in northern Shandong Province is one of the most important sea salt production areas along the eastern coast of China. This region has a long history of salt production, which can be dated back to the late Neolithic Age (Yan, 2015). Historical documents record that salt production and trade played an important role in economics and politics of this region during 1000 B.C. (Flad et al., 2005). Despite the great importance, early salt production in the southern coast of Laizhou Bay has received less attention in the studies of early civilization. Knowledge was limited to incidental archaeological discoveries and systematic research was lacking for a long time. This situation did not change until the advent of the 21th century when a joint project was carried out to advance the research on the history of salt production throughout the coastal regions of southern Laizhou Bay. There are several excavation activities in this region including the Liwu Site in Yangxin county (Yan et al., 2010b), the Nanheya Site in Guangrao county (Wang et al., 2010), the Huodao-aoli Site in Changyi county (Dang and Li, 2019), the Beiyang site (Wang et al., 2005) and the Shuangwangcheng (SWC) site (Yan et al., 2010a) in Shouguang city, which greatly enriches archaeological materials, especially about salt production during the Shang and Zhou Dynasties. Accordingly, our understanding about salt production has been improved in five aspects, including salt production ceramics, salt production technology and processes, settlement patterns and salt production relations, coastal and inland resource interaction, and the origin and development of salt production (Li, 2009; Wang, 2012; Yan, 2013; Yu, 2014). Due to the rich archaeological materials and important findings about early salt production, the southern plain of Laizhou Bay has attracted much more attention in the field of salt archaeology. However, there is still a lack of knowledge on how environmental changes influenced early salt production, making it difficult to understand human – environment interaction in coastal areas from a more integrated and systematic perspective.

The group of the SWC sites, located in the southern coastal plain of the Laizhou Bay, is one of the largest salt production site clusters discovered in the southern coast of the Bohai Sea. After field surveys, investigation and assessments for seven times in 2003, 2004, 2005 and 2008, a joint project team from the Peking University – Shandong Provincial Institute of Cultural Relics conducted excavations at three locations in the SWC site group. The archaeological excavation of the SWC site covered an area of more than 5,000 square meters. Many remains and relics related to salt production activities in the Shang, Zhou, Song and Yuan dynasties have been discovered, among which several intact salt-making workshop units with clear structures and layouts from the late Yin-Shang to the early Western Zhou period were excavated (Yan et al., 2010a). The excavations of the SWC sites provided valuable information for the study of the development of ancient Chinese salt industry. In this paper, we selected four representative profiles, and collected samples from three of them, which gave us an opportunity to reconstruct environmental evolution, and examine the relationship between salt production and regional environmental changes from the perspective of environmental archaeology. Our research aims to deepen the understanding of the evolution of the relationships between human and environment in coastal areas.

REGIONAL SETTINGS

The southern plain of the Laizhou Bay is located on the south bank of the Bohai Sea. The area extends from the mouth of the Xiaoqing River in the west to the mouth of the Jiaolai River in the east (**Figure 1**). The elevation of the study area is high in the south and low in the north. Accordingly, landforms are composed of the piedmont diluvial tableland, alluvial plains, and marine plains from south to north. This region features the warm temperate monsoon climate, with an average annual temperature of 12.3°C and average annual precipitation of 613.2 mm. The intra-annual distribution of precipitation is uneven, with much more in summer and less in winter. The rivers in this region are short, and flows from south to north.

With the continuous development of archaeological research, the study area has reconstructed a relatively continuous Neolithic to Bronze Age cultural sequence, including the Houli culture (8500-7500 a BP), the Beixin culture (7400-6300 a BP), the Dawenkou culture (6300-4600 a BP), the Longshan Culture (4600~4000 a BP), the Yueshi Culture (3900~3500 a BP) and Shang and Zhou Dynasties Culture (3500~2200 a BP).

MATERIALS AND METHODS

The SWC sites group is located around Shuangwangcheng Reservoir in the north of Shouguang City, Shandong Province, 27 km away from the current coastline (**Figure 1**). The area is flat and low-lying, with only 3 to 4 meters above the sea level. Archaeological survey in 2008 discovered more than 80 locations which were related to salt production. Among them, three locations were excavated in great detail, and two workshops of salt production were unearthed. In addition, some brine wells, evaporation ponds, water storage pits and large stoves boiling for salt were also found. Through field investigations, we selected 4 profiles at the SWC 014 location for stratigraphic division and lithological analysis. We collected 49 sediment samples at 5 cm intervals in the SWC-W profile, 19 samples at 10 cm intervals in the SWC-N profile, and 11 samples at 10-15 cm intervals in the SWC-S profile. We also collected three mollusk samples, one from the depth of 152-156 cm in SWC-N profile and two from the depths of 40~44 cm and 55-60 cm respectively at the SWC-S profile. The SWC-S02 profile was not sampled because its lithological characteristics were very similar to the SWC-S profile.

Grain size analysis of sediment samples were performed at the sedimentary laboratory in Peking University. Samples were preprocessed with H_2O_2 and 10% HCl to remove organic matters and carbonates, and dispersed with a 0.05 mol/L sodium before measured by the Mastersizer 2000 instrument. Grain size composition and parameters such as median size (M_d), Skewness (Sk), Kurtosis (K_G) and standard deviation (SD) were calculated to indicate the diverse deposition environments.

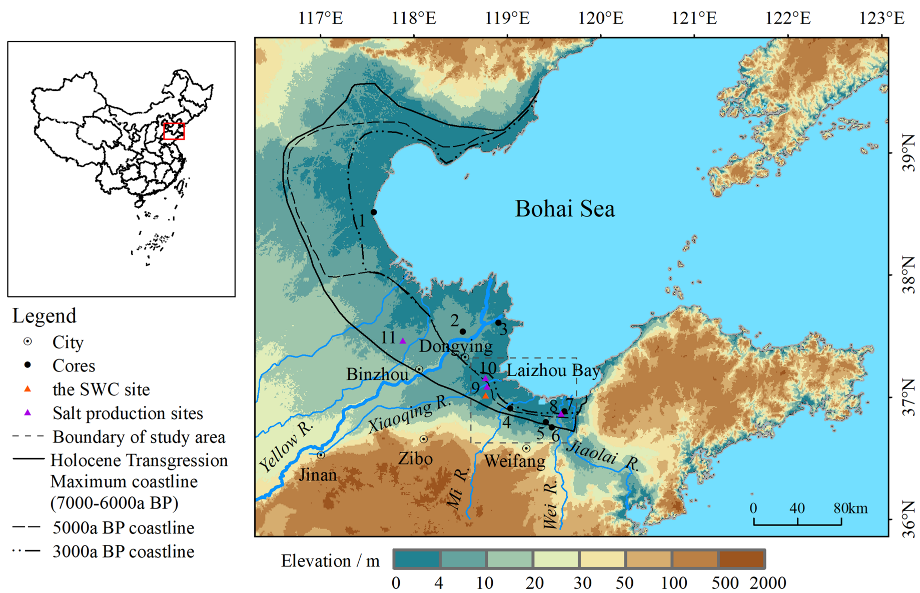

FIGURE 1 | Topographical map and the location of the SWC site, the cores,the excavated salt production sites and coastlines of different period. (1. the BQ1 core, 2. the H9601 core, 3. the H9602 core, 4. the ZK305 core, 5. the A5 core; 6. the A1 core, 7. the ZK303 core, 8. the Huodao-aoli site, 9. the Dahuangbeiyang site, 10. the Nanheya site, 11. the Liwu site).

Mollusk samples were processed and identified at Nanjing Institute of Geology and Paleontology, Chinese Academy of Sciences. Foraminifera analysis were conducted at the Institute of Oceanology, Chinese Academy of Sciences. First, 50 grams of dried sample were filtered with a 63 μm diameter sieve and the left samples on the sieve were collected. Then the samples were dehydrated, and processed with the CCl_4 solution to float, separate and enrich foraminifera. At last, foraminifera were identified and counted under a Zeiss optical stereoscope. Indices were calculated, including the abundance [number of individuals per gram), simple diversity (*S*: number of species), complex diversity (*H(s)*] and percentages of all species of the foraminifera (the proportion of the number of a certain species of foraminifera to the total number of foraminifera in one sample). The complex diversity was reflected by the Shannon-Weiner index (Shannon-Weiner index) whose formula is as follows:

$$H(s) = -\sum_{i=0}^{S} P_i \ln P_i$$

where *H(s)* refers to the complex diversity; *s* refers to the number of species in the sample; P_i is the ratio of the number of the *i*-th species to the total number of all species. The *H(s)* curve can well reflect the changes in paleo-salinity and paleo-sea water depth (Yao et al., 2014). The lower the *H(s)* value, the more the salinity deviates from normal seawater; the lower the *H(s)* value, the generally smaller the sea water depth.

Accelerator mass spectrometry (AMS) ^{14}C dating on mixed benthic foraminifers samples from the SWC-W profile was performed at the AMS^{14}C Dating Laboratory of the Peking University. Radiocarbon ages in **Table 1** were calibrated using CALIB 7.0.2 (Reimer et al., 2013) with ΔR value of −178 ± 50 a (Southon et al., 2002). Based on the dating results, we set up a rough chronological framework to construct the relationship between the cultural layers and the stratigraphic sequence in the profile.

RESULTS AND ANALYSIS

Lithology and Grain Size Composition

The lithological characteristics of the four profiles at the SWC site were consistent with each other (**Figure 2**). From bottom to

TABLE 1 | ^{14}C ages of mixed benthic foraminifera of the SWC-W profile at the SWC site.

Sample No.	Lab No.	Depth/cm	Materials	^{14}C date /BP	Calibrated date / yr BP	
					1σ (68.2%)	2σ (95.4%)
SWC-W-23	BA10366	105-110	foraminifera	5135±60	5630-5490	5660-5370
SWC-W-49	BA10367	233-238	foraminifera	5945±35	6445-4355	6490-6320

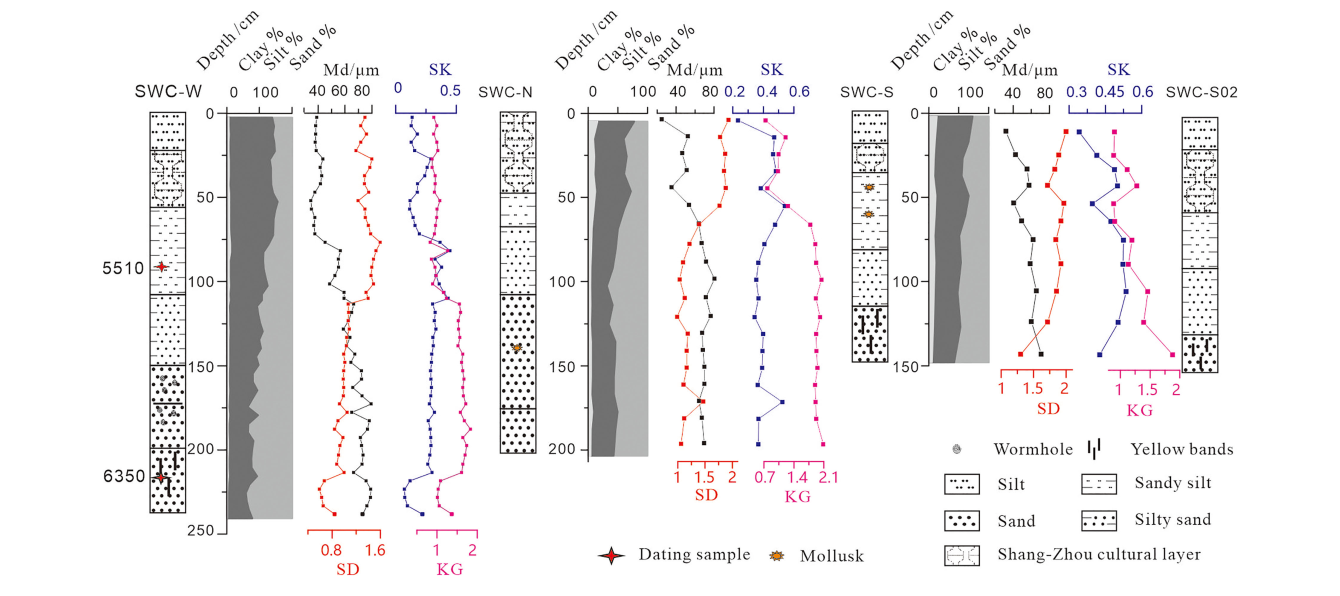

FIGURE 2 | Stratigraphy and curves of grain size parameters of the four profiles at the SWC site.

top, the colors changed from dark to light, while the grain size became finer indicated by the gradually decrease of median grain size (M_d). Sediments at lower part of profiles (150-243cm in SWC-W profile, 110-200 cm in SWC-N profile, 115~150 cm in SWC-S profile, and 135~160cm in SWC-S02 profile) were characterized by a dark gray sand or yellowish gray silty sand with yellow spots or yellow vertical bands. Sediments at the overlying stratum (70-150 cm in SWC-W profile, 60-110 cm in SWC-N profile, 50-115cm in SWC-S profile, and 55-135cm in SWC-S02 profile) featured yellowish gray silty sand or yellow sandy silt. The upper layers (0-70 cm in SWC-W profile, 0-60 cm in SWC-N profile, 0-50 cm in SWC-S profile, and 0-55 cm in SWC-S02 profile) were mainly composed of gray or dark gray sandy silt, and some archaeological remains of Shang and Zhou Dynasties were discovered. Due to the high consistency of the four profiles, we chose the SWC-W profile as the benchmark and the other profiles as a supplement to reveal the changes in grain size distribution properties along the sedimentary layers.

Gain size frequency curves of sediment samples at lower parts of profiles mainly exhibited unimodal distribution (**Figure 3** SWC-W-47, SWC-N-11 and SWC-S-09), probably indicating single and strong hydro dynamics. Sediment samples from overlying stratum showed a typical bimodal pattern with a main peak at 65~75 μm and a secondary peak at 5~10 μm (**Figure 3** SWC-W-22 and SWC-N-05), which indicated that the deposition process might be affected by two forces: rivers and seawater. There were also some samples exhibited the unimodal pattern in the overlying strata with the peak at 70~80 μm (**Figure 3** SWC-N-03 and SWC-S-03). Curves of grain size parameters were shown in **Figure 2**. Sorting values (SD) ranged from 0.59 to 2, suggesting the conversion from well sorting to poor sorting (Folk and Ward, 1957). Specifically, the SD values were relatively lower at the depth of 150~243 cm, then gradually increased at the depth of 70~150 cm, and slightly decreased at the depth of 0~70 cm in SWC-W profile, indicating that the sorting of sediments showed a better-poorer-slightly better trend. Skewness values (Sk) ranged from 0.17 to 0.54, belonging to zero skewness to strongly positive skewness. The kurtosis values (K_G) were between 0.83 and 1.83, indicating the transitions from leptokuitic, mesokurtic to platykurtic. The trend of kurtosis value was opposite to that of SD and Sk in SWC-W profile. Overall, our analysis suggested that from the bottom to the top of the SWC profiles, the grain size composition changed from well sorted sand or silty sand to poorer sorted silty sand or sandy silt. The mean hydrodynamic force weakened with gradually weaker influence of waves and stronger influence of rivers.

Foraminifera Assemblages

We identified a large number of foraminifera from 14 samples of the SWC-W profile which belonged to 24 taxa. The majority were eurythermal and euryhaline forms such as *Ammonia beccarii* vars, *Quinqueloculina akneriana*, *Elphidium magellanicum*, and *Cribrononion incertum* etc. whose variations could well indicate coastal environmental changes. Previous studies have found that *A. beccarii* vars lives in coastal brackish water environments such as intertidal zones, low-salt lagoons, and bays (Wang et al., 1988); *Q. akneriana* mainly lives in the lower intertidal zone and the shallow coastal waters areas at a depth of 50~200 m (Zheng, 1988; Li et al., 2010); *E. magellanicum* often lives in the shallow coastal water at a depth of 5-10m (Wang et al., 1988); and *C. incertum* is mainly distributed in the inland shelf and intertidal zone with a water depth of less than 50 m in the East China Sea (Lin et al., 2005). Based on the chronological framework of profiles and changes of foraminifera assemblage indices, three stages were divided as below (**Figure 4**):

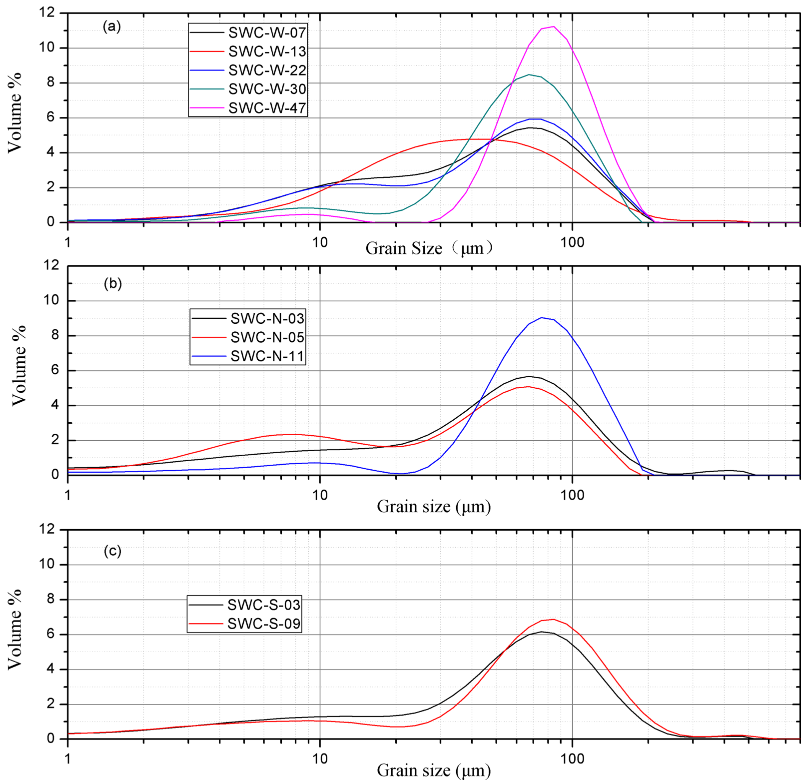

FIGURE 3 | Grain size frequency curves of typical samples. **(A)** SWC-W profile, **(B)** SWC-N profile, **(C)** SWC-S profile.

Stage I (6400~5900 yr BP, 160-243 cm in SWC-W profile): This stage was rich in foraminifera with the abundance values between 70 and 177, the S values between 9 and 13, and the *H(s)* values between 1.52 and 2.07. Foraminifera assemblage was dominated by *A. beccarii* vars. (ranging from 13.8%~39.1%, average 33.8%) and *Q. akneriana* (ranging from 0~38.3%, average 22%), followed by *E. asiaticum* (8.1%), *C. incertum* (8%) and *N. akitaense* (6.1%).

Stage II (5900~4300 yr BP, 70-160cm at SWC-W profile): The abundance of foraminifera ranged from 7 to 20 with an

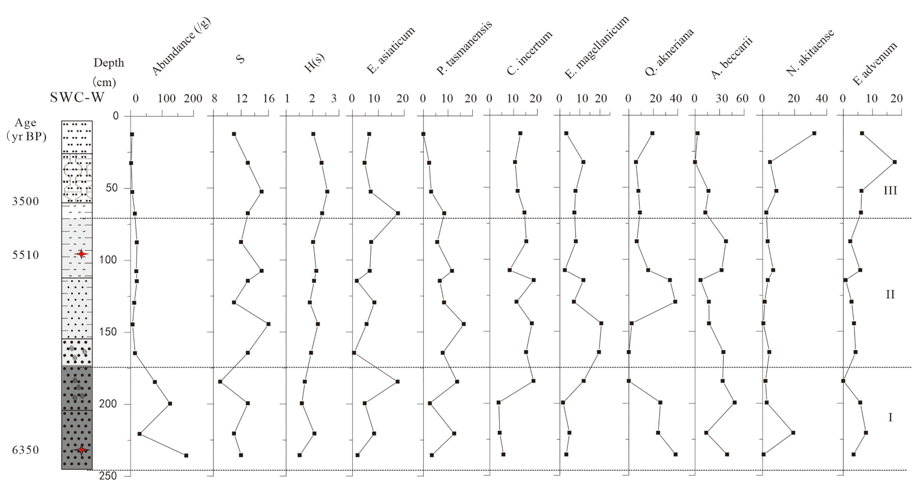

FIGURE 4 | Curves of foraminifera indices and percentage of some typical taxa in SWC-W profile.

average of 15. The values of simple diversity and complex diversity fluctuated obviously with peaks at 16 and 2.36 respectively, suggesting that the sedimentary environment became more unstable. Compared to stage I, the percentages of *E. magellanicum* (11.6%), *C. incertum* (14.4%), and *P. tasmanensis* (9.5%) increased while that of *A. beccarii* vars. (24.3%) and *Q. Akneriana* (16.1%) decreased. Besides, *E. simplex* began to appear in this segment with a proportion of about 3%. Besides, one species of bivalve mollusk, *Sinonovacula constricta* (*Lamarck*), which often lives in the middle and lower areas of the intertidal zone or the inner bay (Xue, 2002), was found at the depth of 152-156 cm in the SWC-N profile. A gastropod species, *Cerithidea sinensis Philippi*, indicative of littoral environment, was found at 72–75 cm in SWC-S profile (An et al., 2008).

Stage III (after 4300 yr BP, 0-70cm in SWC-W profile): Foraminifera fossils were still present in the sediments of stage III in SWC-W profile, but the abundance decreased substantially to 1~4 per gram. The simple diversity and complex diversity were 11~15 and 2.03~2.56 respectively. Foraminifera assemblage were dominated by *C. incertum* (12.44%) and *Q. akneriana* (10.54%). *E. advenum* also appeared with a maximum content (17.65%) at a depth of 30-35 cm in SWC-W profile. Besides, a typical non-marine gastropod species, *Pseudamnicola opima* Yu, was found at 40-44 cm in SWC-S profile.

DISCUSSION

Sedimentary Environment and Coastline Change

Grain size and foraminifera analysis of the SWC profiles revealed clear pattern of sedimentary environment change since the middle Holocene in the southern Laizhou Bay region. The grain size in the four profiles from the SWC site all became finer upwards, changing from well sorted dark grey silty sand in the lower part to the yellowish brown sandy silt or clay silt in the upper part of profiles, which was consistent with the cores of ZK 305, Hsh15 and QSP near the SWC site (Zhang et al., 2004; Xue and Ding, 2008). Studies have reported that grain size in a typical aggradational tidal flat succession tends to be coarser upwards when transited from subtidal to intertidal flat and to be finer upwards when converting from intertidal into supratidal flat, and sediments are generally coarsest in the lower tidal flat (Xue et al., 2001; Fan et al., 2015). Therefore, our profiles indicated the succession from the lower tidal flat to supratidal flat. Mollusk samples at the lower parts of the SWC-N and SWC-S profiles contained species which are typical in intertidal zone, while samples at the upper part of the SWC-S profile contained typical freshwater species. Moreover, the foraminifera assemblage also supported our findings about sedimentary environment. Most species of foraminifera were coastal euryhaline forms, such as *A. beccarii* vars, *Q. akneriana*, *E. asiaticum*, and so forth. The abundance of foraminifera was high at the bottom of profile and decreased substantially at the top of SWC-W profile. Combined with the results of grain size, foraminifera and mollusk assemblages we inferred that the sedimentary environment changed from the lower tidal flat in stage I (6400-5900 yr BP), the intertidal zone in stage II (5900~4300 yr BP) to the supratidal flat in stage III (after 4300 yr BP).

Sedimentary environment evolution reconstructed in our study reflected that the coastline advanced to the SWC site area when maximum Holocene Transgression occurred and then gradually moved seaward during the mid-late Holocene in the southern Laizhou Bay. This is consistent to previous studies that the sea level in the Bohai Sea area rose to the highest at about 6500~7000 yr BP, 2~3m higher than the current level (Liu et al., 2004; Liu et al., 2010). The coastline advanced landward for dozens of kilometers to the coastal plain (**Figure 1**) during the maximum Holocene transgression (Zhuang et al., 1991; Yi et al., 2012; Bradley et al., 2016; Song et al., 2018). The landward movements of coastline can also be supported by the lithological changes (**Figure 5**) of the cores in the west coast of the Bohai Sea (BQ1 core), the Yellow River Delta (H9601 and H9602) (Xue et al., 1995; Yi et al., 2003) and in the southern coastal plain of Laizhou Bay (cores of QSP, Zk 303, ZK305, LZ908 and Hsh15) (Xue and Ding, 2008; Zhang et al., 2004; Yi et al., 2012), which demonstrated the shallow marine facies, tidal flat facies or lagoon facies in the sediments. Sedimentary environment change from the tidal flat to supratidal flat was likely controlled by the seaward retreat of coastline. The records of cores A1 and A5 in Changyi city (**Figures 1** and **5**) supported our finding that the coastline continuously moved seaward from 6000 yr BP (Zhang et al., 2008). Studies showed that the coastline retreated to the north of the Yangzi — Fengtai line in Weifang city at around 3500 yr BP (**Figure 1**) where a shell bank was formed (Zhuang et al., 1991). With the continuous seaward movement of the coastline, several lakes that were formed in the middle Holocene such as Biehua Lake, Judian Lake, and so forth gradually disappeared. The deposition in these areas were characterized by shallow marine facies, lagoon facies, and fluvial facies from bottom to top (Han et al., 2002; Han and Zhang, 2005; Zou et al., 2020).

The Development of Salt Production in Coast Lowlands Due to Environmental Change

Our research highlights the close relationships between environmental evolution and ancient human activity in the coastal areas. Given that the southern plain of Laizhou Bay experienced a large-scale transgression process in the middle of the Holocene, and a large area of land was submerged by seawater, our previous study revealed that the distribution of sites during the Dawenkou Culture period was limited to the inland alluvial plain areas at higher altitudes (Guo et al., 2013) (**Figure 6**). Marine influence terminated after 4300 yr BP, approximately in the Longshan culture period, and the environment around the SWC site hasn't changed a lot since then, which gave more chance for human settlement. Specifically, it was likely that the coastline retreat promoted the early salt production activity in this region during the Longshan culture period. Archaeological studies have reported that ten salt

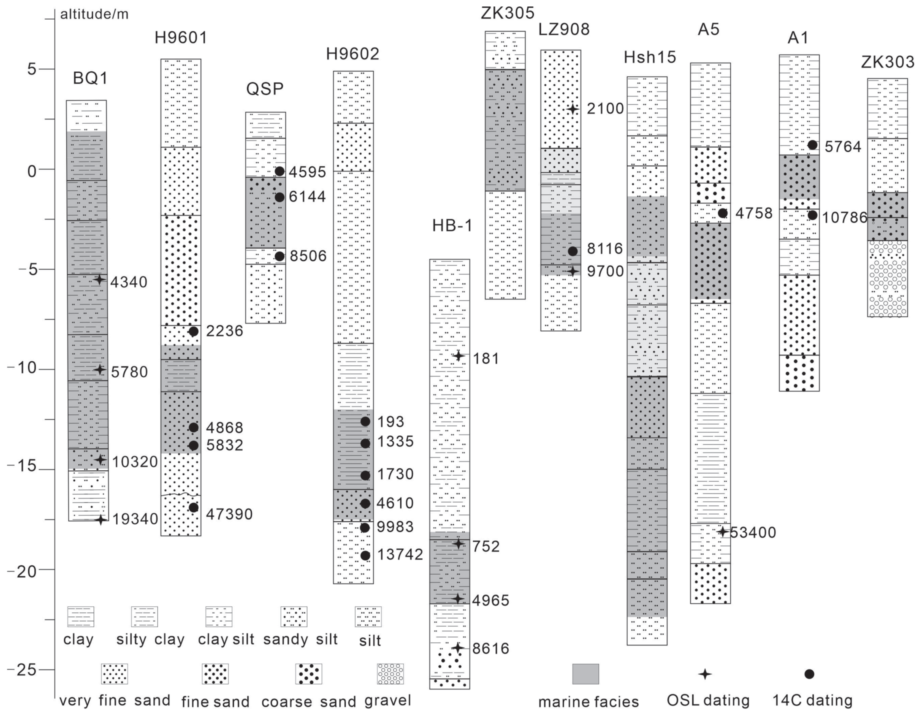

FIGURE 5 | Diagram of sediment cores around the Bohai Sea.

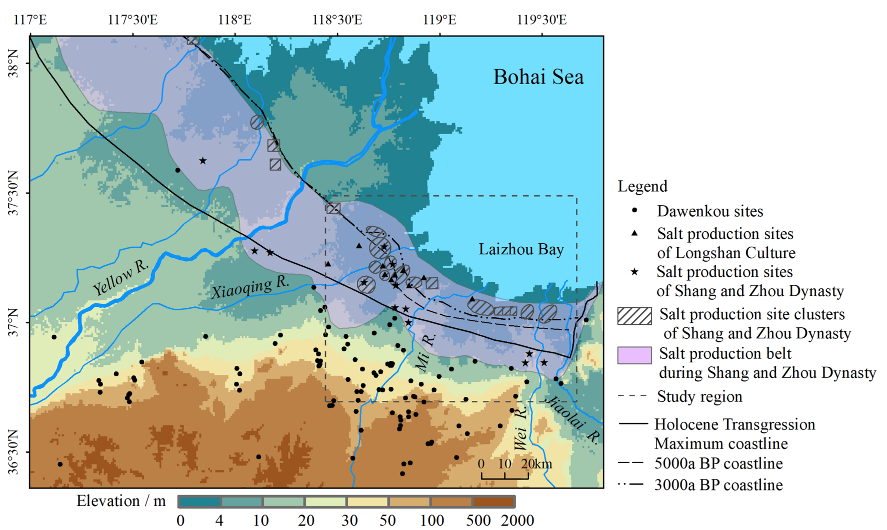

FIGURE 6 | Distribution of the Dawenkou cultural sites, and the salt production sites of the Longshan cultural period and the Shang and Zhou Dynasties.

production sites of the Longshan culture period were discovered sporadically at the coast of the Laizhou Bay (**Figure 6**). However, these sites were small in scale, had short history and the salt production process of this period was at relatively lower level and had no specialized vessels for production (Li and Wang, 2007; Yan, 2015). However, the cultural relics of plant ash, burnt soils and white calcareous remains that were common in salt production sites of the Shang and Zhou Dynasties signified the appearance of early salt production activities in the Longshan culture period.

Our research highlights the great improvement of the salt production technology during the Shang and Zhou Dynasties. There are much convincing evidence supporting our findings.

Specialized helmet-shaped potteries characterized by simple style, thick texture, thick tires, popular shape bottom were used for salt production (**Figure 7**), and this type of potteries for salt production always occupied almost 90% of the unearthed potteries in the salt production sites (Li, 2019). Intact salt production workshop units, including brine wells, salt hearths, hearth shelter, the working rooms, the brine cisterns, groups of settling ponds, evaporating ponds, were restored at the SWC site (Yan et al., 2010a). Stable isotopes (O/C/Sr) analysis on the white calcareous remains (**Figure 7**) collected from salt production potteries demonstrated that raw material was underground brine which had high paleosalinity formed during marine transgression (Cui et al., 2010; Cui, 2011). Brine wells with a depth of 5~10 m (**Figure 8**) often appeared in groups to extract raw materials for salt production (Dang and Li, 2019). The brine layer at the bottom of the brine well found at the SWC site was shown in **Figure 8A**. Salt production sites increased substantially in quantity and scale during the Shang and Zhou Dynasties as indicated by the densely distributed salt-making sites in marine plains (Wang et al., 2006; Ma et al., 2012; Dang and Li, 2019). Charcoal records also revealed frequent anthropogenic biomass burning of large quantities of woods as fuels for salt-making in this area (Tan et al., 2022). In sum, we concluded that salt production in the southern plain of Laizhou Bay during the Shang and Zhou Dynasties became a specialized and large-scale economic activity, and facilitated cultural thriving and prosperity in this region. Therefore, environmental changes provide a favorable and indispensable background for human development in the coastal areas, although technological progress plays an important role in promoting the coordinated development of the ancient human-land relationship.

It is worth mentioning that there may be some connections between salt-making sites in coastal plain of Laizhou Bay and the farming settlements in the inland areas during the Shang and Zhou dynasties. First, the inland areas probably provided coastal salt workers with salt-making tools (Wang, 2012). The specialized salt making tools were found in both the coastal salt production sites and the inland farming sites, but the proportion of *briquetages* in the salt production sites was much higher than that in the inland sites (Wang et al., 2006). Moreover, inland areas are rich in pottery clay suitable for making *briquetages*, and there were pottery kilns found in inland settlements such as the Zhaopu site in Qingzhou city (Wang, 2012). Second, analysis of the animal bones unearthed from coastal salt production sites showed that the domestic mammals mainly consisted of limb bones and mandibles, but very few ribs and no skull and vertebrae were found (Yan, 2013). The evidence might indicate that these mammals were not slaughtered locally in the coastal areas but were transported from inland farming areas. So this could support our finding that inland sites might provide necessities to people in coastal areas. Third, in exchange, the coastal salt-making sites might provide salt products to inland people, because these areas had abundant underground brine

FIGURE 7 | Helmet-shaped potteries and white calcareous remains unearthed in southern plain of Laizhou Bay. **(A)** Helmet-shaped pottery of the Shang Dynasty unearthed at the Huangtuya site in Zibo city (provided by Zimeng Wang), **(B)** Helmet-shaped potteries unearthed at the SWC site, **(C, D)** White calcareous remains adhering to the inner wall of the helmet-shaped pottery at the SWC site (Yan, 2013).

FIGURE 8 | Brine wells discovered in salt production sites. **(A)** Brine well showing the underground brine layer at the SWC site of the Shang and Zhou Dynasties. **(B)** Brine well discovered at the Jixielinchang site of the Eastern Zhou Dynasty (provided by Zimeng Wang).

resources for salt production. Therefore, there might be a trade based on salt between the inland sites and the coastal sites during the Shang and Zhou dynasties. Literature also recorded that during the Eastern Zhou Dynasty, the state of Qi had already implemented the official control on the production and trade of salt to connect with surrounding areas (Fang, 2004). In sum, the development of salt-making activities during the Shang and Zhou Dynasties is a typical example of the comprehensive utilization of regional resources and the adaption to environmental conditions.

CONCLUSION

We reconstructed the sedimentary environments during the middle and late Holocene based on four profiles around the SWC site. Our analysis of the grain size and foraminifera of samples from the SWC site suggests that the stratigraphy was structured by the sea-level changes in the Holocene. The sedimentary environment has undergone changes from lower tidal flat to supratidal flat since 6000 years ago. The landward and seaward movements of coastline during Holocene caused significant changes in the geographical environment of the southern plain of Laizhou Bay, which had a profound impact on the human activities. When the landward movement of the coastline occurred due to the Holocene transgression, human activities were restricted to the inland plains. With the continuous recession of the coastline and the development of salt production especially the use of specialized salt making tools and raw materials of underground brine, the coast plain of the Laizhou Bay became an important center of salt production during the Shang and Zhou Dynasties, which contributed to the social and economic prosperity of the area. Salt production activities indicated the high ability to comprehensively use of resources and environmental conditions in the area, which showed the active adaptation of human beings to the environment.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

YG: Conceptualization, Formal analysis, Investigation, Resources, Writing - original draft, Funding acquisition. LM: Formal analysis, Investigation, Editing, Funding acquisition. LZ: Formal analysis, Editing. DM: Formal analysis, Investigation, Funding acquisition. All authors contributed to the article and approved the submitted version.

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