Introduction

The study area is located in the northern outer shelf of the East China Sea (Figure 1a). As one of the largest river-dominated marginal seas in the world, the East China Sea (ECS) is mainly influenced by a large amount of terrigenous debris, mainly from the Yangtze River, the Yellow River, and surrounding small rivers (Wang et al., 2012; Xu et al., 2016; Wu et al., 2002). The outer shelf in the ECS is a must-go place for the sediments to enter the Okinawa Trough through the continental slope, which has abundant deposit of Cenozoic terrigenous debris. The sedimentary rate during the Quaternary period in the ECS shelf basin is about 300 m/Ma (Liu et al., 2001). The stratigraphic sequence and the development of the sedimentary system on the ECS shelf is primarily affected by sea level changes (Li et al., 2005; Liu et al., 2001).

Materials and methods

The high resolution shallow subsurface seismic profile (Figure 1b) was obtained in 2014 by Qingdao Institute of Marine Geology. The seismic source sinking depth is 1 ± 0.5m, the seismic source energy is 1000J, and the sample rate is 0.2ms. In addition, the AMS 14C dating was completed by the Woods Hole Oceanographic Institute in USA. In this paper, the uncalibrated ages are reported as AMS 14C years BP; the OSL dating was performed by the Qinghai Salt Lake Institute of the Chinese Academy of Sciences.

Correlation between seismic units of shallow subsurface seismic profile and stratigraphic units of borehole SHD-1

Since MIS6, the climate and sea level have changed frequently and the cycle has become longer. The characteristics of the interactive development between the marine and terrestrial environment in the continental shelf are very obvious. Variation in the sedimentary environment has resulted in changes in lithology and structure of the stratum, thus forming different seismic facies characteristics of the stratum. Based on the reflection structure characteristics of the shallow subsurface seismic profile in...
the study area, 7 seismic reflection interfaces were identified, and 7 seismic units were divided from bottom to top: SU7, SU6, SU5, SU4, SU3, SU2, SU1 (Figure 2), and on this basis, the seismic stratigraphic framework was established since MIS6.

The borehole SHD-1 (29°55′16″ N, 126°02′56″ E, 84.1m water depth) was collected from the ESC shelf, with a total of drilling length of 150.4 m. Correlating stratigraphic units (depth) of SHD-1 with the seismic units (TWT), it is concluded that the average velocity of sound waves in this area is about 1580 m/s. Through time-depth conversion, we find that the seismic units are well correlated with stratigraphic units of SHD-1 (Figure 2).

Figure 2 Correlation between the stratigraphic units of the borehole SHD-1 and seismic units of the shallow subsurface seismic profile (See Figure 1 for location of profile a-a′)

DU7 (depth 110–75 m) corresponds to SU7, which is interpreted as estuarine-delta deposits (Figure 2); DU6 (depth 75–63.9 m) corresponds to SU6, which developed shallow marine sediments and typical tidal sand ridge deposits under strong tidal currents on the middle and outer continental shelf. An OSL age at the bottom of the DU6 stratum, is 108.6 ± 11.4 ka B.P. (Figure 2); DU5 (depth 63.9–47 m) corresponds to SU5, which is inferred to represent shallow coastal deposits. Two OSL samples in the stratum were dated, both of which yielding results of ~74.1 ka B.P. (Figure 2); DU4 (depth 47–26 m) corresponds to SU4, which transitioned to delta from shallow marine environment with the sea level drop. The OSL dating datas of the seismic unit SU4 rang from 74.8 to 63.1 ka B.P. (Figure 2); DU3 (depth 26–12.9 m) corresponds to SU3 and developed the delta deposits with continuous decline of sea level. The AMS 14C sample of SU3 is dated at ~43.5 ka B.P. (Figure 2); DU2 (depth 12.9–6.3 m) corresponds to SU2 (Figure 2). With climatic deterioration and lowered sea level, the terrestrial sediment developed during LGM, in which the OSL sample is dated at ~22.5 ka B.P.; DU1 (depth 6.3–0m) corresponds to SU1 (Figure 2), is interpreted as shallow marine deposits on the middle and outer continental shelf, corresponding to high sea level in the Holocene period. The AMS 14C age of SU1 is dated at ~13.09 ka B.P. (Figure 2).

Time series of seismic units and sedimentary environment

SU7 is presumed to be an estuary-delta sedimentary strata formed during the low sea level of MIS6 (Figure 3). Previously, it was generally considered that a regression occurred in MIS6 (Liu et al., 2001; Wellner et al., 2003; Wu et al., 2017), which was universally developed on the ECS, and it was the landmark strata of the ECS shelf. According to the shallow subsurface seismic profile, the unit developed a low-water wedge sedimentary body near the continental slope, and its reflection characteristics are similar to delta front, which is a well progradational reflection (Figure 3).
SU6 developed a set of tidal sand ridges near the borehole SHD-1, with a dating data of 108.6±11.4 ka B.P. (OSL). It is inferred that the tidal sand ridges were formed during the transgression period of MIS5 (Figure 3). MIS5 transgression is the largest transgression in the Late Pleistocene in the ECS (Xu et al., 2016; Yoo et al., 2002), which is equivalent to the Cangzhou transgression in the Bohai Sea (Liu et al., 2007).

SU5 corresponds to the shallow coastal water environment, and both samples at this stage are dated at ~74.1 ka B.P., associated with sea level decline in MIS4. Some negative topographic valleys were found in the SU5 stratum (Figure 3). It is presumed that the tidal trench was formed by eroded underlying strata and then filled with deltaic sediments during the regressive period.

SU4 represented a high-angle progradational reflection structure, well correlated with the characteristics of delta deposits (Figure 3). On the basis of the dating results of 63.1 ~ 74.8 ka B.P., SU4 was probably formed in the late MIS4 (Figure 2) and the sea level was relatively low. At this time, the outer shelf at the SHD-1 hole was not exposed to land, and it was an underwater delta environment during the low sea level period. The area of the underwater delta was still limited. SU3 also showed obvious delta progradational reflection characteristics. The AMS 14C dating result of this unit is ~43.5 ka B.P., which corresponds to MIS3. The delta deposits indicate a lower sea level, and the cover range of the submarine delta is very wide in MIS3. It can be inferred that the delta develops from northwest to southeast, with the maximum thickness more than 60 m.

Borehole SHD-1 reveals that the three dating data of SU2 are concentrated around 22 ka B.P., and the dating results correspond to MIS2 during the sea level decline (Figure 2). Although the stratum of SU2 widely developed, it is relatively thinner, and without any large river channels (Figure 3), indicating that the climate was extremely cold and dry, and the erosion of rivers was also weakened. Therefore, SU2 is the terristrial sediment formed during the last glacial maximum period (LGM) when the sea level of the continental shelf area has declined to the lowest point. It is speculated that the entire ECS shelf is exposed to the seafloor, and the delta deposits underlying suffered the fluvial erosion.

According to the borehole SHD-1 dating data, and compared with the Chappell (1996) curve, it is considered that SU1 represented marine environment during MIS1 and developed tidal sand ridges at local shallow water (Figure 3).

Figure 3 A typical shallow subsurface seismic profile (See Figure1 for location of profile b-b’)

Conclusions

Seven seismic units (SU7–SU1) were divided based on the characteristics of the seismic facies of the shallow subsurface seismic profile. According to time-depth conversion, it shows that the stratigraphic units of SHD-1 well correlated with the seismic units. On the basis of the dating data and seismic
facies characteristics of the borehole SHD-1, the results reveal that SU7 is inferred to be estuary-delta deposits well developed on the outer shelf of the ECS, associated with the low sea level in MIS6. SU6 probably corresponding to MIS5, tidal sand ridges developed in shallow waters at depths of less than 100 m with the sea level rise (Berné et al., 2002; Liu et al., 2001; Wu et al., 2017), and shallow marine environment dominated in other locations of the outer shelf. During MIS4 period (corresponding to SU4), subaqueous delta deposits dominated and widely developed on the outer shelf with the sea level drop. In MIS3 (corresponding to SU3), the climate experienced slight climatic fluctuations, and a brief sea level rise occurred; Generally, sea level were continuously dropped and subaqueous delta expanded. SU2 is associated with MIS2, fluvial deposits dominated and the outer shelf was exposed. In the Holocene (SU1 equivalent to MIS1) shallow marine environment dominated the outer shelf, and tidal sand ridges developed in the northwest near the inner shelf.

References


