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Quaternary high-resolution seismic sequence based on instantaneous phase of single-channel seismic data in the South Yellow Sea, China

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A B S T R A C T S

The South Yellow Sea (SYS) is a semi-closed epicontinental sea with a dense network of seismic reflection profiles, preserving favorable depositional strata. Single-channel seismic has been one of the primary technical methods used to study the characteristics of regional strata sediment since the Neogene period. Based on two cores (CSDP-1 and Qc2) and single-channel seismic data obtained from continental shelf of the SYS in 2013, we present analysis on sequence stratum and evolution environment for the Quaternary around cores CSDP-1 and Qc2 in the Middle and Western sea areas of South Yellow Sea. Identification of instantaneous phase demonstrates more plentiful strata information. Instantaneous phase of marine deposits is seen to continue with horizontal level in most parts, except the areas with some clay and clay silts. Continental units feature poor layering in instantaneous phase profile. Along with the two cores, the result suggests that marine sedimentary time for the core CSDP-1 was longer than that for the core Qc2 since 700 ka, and it may mean the existence of four regressions. Paleo-shoreline lay between cores CSDP-1 and Qc2 during 700–460 ka, 289–270 ka, 75–29 ka, and 13.1–10.3 ka. Different subsidence and climate comprehensively drove the evolution of sedimentation during the Quaternary in SYS.

1. Introduction

South Yellow Sea (SYS) was an integral part of the continental margin in the Pacific rim during the Mesozoic and Cenozoic eras. It is located in the combined region of the Eurasian Plate, Pacific Plate, and Philippine Plate, and features a complicated geological environment (Chen et al., 1999; Wan, 2004; Yao et al., 2008; Zhang et al., 2013, 2014). Since the 1980s, researches on the Quaternary of SYS have been developing rapidly by means of considerable geological surveys. By collecting samples at the bottom of the sea (Zhao et al., 1990; Chen et al., 1994), analyzing the sediment cores (Guan and Qu, 1991; Li et al., 1997; Liu et al., 1999, 2016; Yang et al., 2017) and carrying geophysical exploration (Li et al., 1998; Zhao et al., 2003; Hou, 2006; Zhang et al., 2013; Lim et al., 2004), the researchers have obtained extensive data in the SYS region and conducted many studies on the type of sediment, geochemical characteristics, and Quaternary stratum of the region (Qin et al., 1989; Liu et al., 1999, 2010; Li et al., 2016; Yoo et al., 2016, 2017a, 2017b). Most studies focus on the sediment environment, stratigraphic framework, and changes of sea level (Zheng, 1988, 1989, 1990, 1991; Yang and Lin, 1993, 1996; Kong et al., 2006; Lee et al., 2014; Liu et al., 2015, 2016; Badejo et al., 2016).

Geological core analysis is the most direct and accurate method to identify the strata. A core only manifests the strata information at the hole location. However, the horizontal changes about the stratum cannot be continuously analyzed. Sub-bottom profile and single-channel exploration are the main methods used to study sediment characteristics in a large scale since the Neogene period (Zhao et al., 2003; Lim et al., 2004; Narantsetseg et al., 2014; Li et al., 2016; Feng et al., 2016, 2017; Yoo et al., 2017a, 2017b). These methods feature a relatively high horizontal and longitudinal resolution with wide covering. In the sub-bottom profiles of western SYS, the strata within 80 m depth beneath the seabed are divided as follows: (1) marine strata in Würm-Riss interglacial period of the

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later Middle Pleistocene, (2) early continental stratum in Würm glacial period of Late Pleistocene, (3) marine stratum in the Würm interglacial period of Late Pleistocene, (4) continental stratum in the later Würm glacial period of Late Pleistocene, and (5) marine stratum since the Würm glacial period. Sediments in the area represent transgressions three times and regressions two times since the Late Pleistocene period in the SYS (Song et al., 2005; Hou, 2006), as well as multiple ancient river channels in the continental stratum (Gu and Zhang, 2009; Zhao et al., 2003). Besides, according to theoretical research, conventional seismic data can show various elements only when the thickness of the targeted geological body reaches or exceeds one-fourth of the seismic wave length (Li, 1993). For example, the image of thin sand and mudstone interbedding cannot be achieved in the seismic profile. Some sequence identification of sediment strata in a single-channel seismic profile is missed. Quite a few considerable information is wasted in seismic signals. Utilizing conventional single-channel seismic profile, more detailed researches about strata sequence will not be effectively developed without the calibration of core data. However, the instantaneous phase extracted from seismic data, possesses high resolution for the strata and can be utilized to identify and horizontally track sub-units and micro-units of sediment (Zhao et al., 2016).

In this paper, we developed a study on the division of seismic sequence and corresponding lithology according to the instantaneous phase of single-channel seismic data. Features of instantaneous phase and vertical distribution structure of sediment stratum was summarized. Additionally, sediment environment was analyzed based on the divided strata via the verification and calibration of the cores Qc2 and CSDP-1.

2. Regional setting

South Yellow Sea (Fig. 1), which is located between China's mainland and the Korean Peninsula, is a wide shallow sea plain belonging to one of the epeiric seas in Eastern China (Qin et al., 1989). SYS is adjacent to Shandong and Jiangsu in the West, the Korean Peninsula in the East, and North Yellow Sea in the North, and is separated from East China Sea by the Qidongzui and Jeju Island. Undersea landforms demonstrate an unsymmetrical distribution from East to West. The sea inclines from both sides to the center. Water depth of most continental shelves in SYS measures from 20 m to 80 m, and exceeds 80 m only in the area of “the Yellow Sea channel” (Qin et al., 1989; Liu et al., 1999). The dynamic marine environment of SYS is complex due to a continental margin supply from the Yangtze River, Yellow River, and other small rivers (Milliman et al., 1987; Alexander et al., 1991; Martin et al., 1993; Xu et al., 1997). The sea areas include sediments from the surrounding continent. From north to south, SYS consists of the following tectonic units: Qianliyan Uplift, Northern Depression, Center Uplift, Southern Depression, and Wunansha Uplift (Fig. 1b). The research area in this paper is located at the west of the Center Uplift.

3. Material and methods

3.1. Seismic data

Single-channel seismic lines (Fig. 1b) were collected by Qingdao Institute of Marine Geology in 2013, and the used research vessel was “Ye Zhizheng”. “DelphSeismic” collection system produced by the USA TEI company was used for this single-channel seismic measurement. The work parameters are as follows. Seismic source was the GI gun, and time was counted by GMT, with an excitation of 6 ms. The streamer was AH20/150 hydrophone. Sampling rate was 0.1–0.125 ms, and frequency band was 0–1400 Hz. Line SN3 passed through the studied core CSDP-1, and SN5 passed through core Qc2 (Fig. 1b).

3.2. Core description

Core CSDP-1 (Fig. 1b, obtained by Qingdao Institute of Marine Geology in 2013, with coordinates of 34°18′N, 122°22′E and 300.10 m depth) is a geological whole-core drill hole, which first passed through the bottom of the Quaternary in the CU of SYS. The water depth is ~52.50 m and mean core recovery rate is 80%. The lithology of CSDP-1 is mainly composed of clayey silt, silt and fine sand. And in some of the layers, the lithology is medium and coarse sand. Detailed core description is shown in Fig. 2c. Core Qc2 (Fig. 1b, obtained by Qingdao Institute of Marine Geology in 1984, with coordinates of 34°18′N, 122°16′E and 108.8 m depth) is a detailed core studied for South Yellow Sea, and had indicated a representative transgression event in the Eastern China continental shelf. The water depth is 49.05 m and mean core recovery rate is 90.4%. The lithology of core Qc2 is mainly composed of clayey silt and silt. And in some of the layers, the lithology is fine sand. Detailed core description is shown in Fig. 4c. In the paper, core depth showed in Figs. 2c, 3c and 4c is part of cores CSDP-1 and Qc2, not the whole one.

3.3. Methods

Instantaneous phase is one of three instantaneous attributes for complex seismic trace and is the continuous scale for the events. After using the Hilbert conversion for seismic records, instantaneous phase can be calculated as follows (Tanner et al., 1979):

$$\theta(t) = \tan^{-1}\left[x^{*}(t)/x(t)\right]$$

When signals pass the isotropic medium, they will show a continuous phase event. In the case of anisotropic medium in a signal route, the phase in the anisotropic position will have obvious changes, appearing a discontinuous instantaneous phase in the profile. Instantaneous phase is not related to amplitude and is capable of showing strong or weak signals that will be beneficial to identify the underground abnormal conditions and classify the strata. The instantaneous phase provides an accurate show of contact relationships between the strata, and tracks structures, such as reflection “spot,” “overlap”, and “ending”. Such features of instantaneous phase can be applied to reflect the local changes of the seismic signals.

4. Analysis of instantaneous phase for the seismic strata unit

In the high resolution general single-channel seismic profile, only large seismic strata sequence can be identified, and the sequence of subunits cannot be accurately determined and classified (Figs. 2a, 3a and 4a). In case no information of the core is available to the comparison and calibration, it will be more arduous to accurately identify contact faces in detail (TWT in the paper is short for two-way travel time).

Analysis of instantaneous phase of single-channel seismic data in the SN3 and SN5 lines was conducted after amplitude-preserving processing, increasing frequency, and eliminating noise. Fig. 2 shows the seismic and instantaneous phase profile of the area around core CSDP-1 in SN3 whose analysis time window is from 80 ms to 180 ms. Fig. 3 shows the seismic and instantaneous phase profile whose analysis time window is from 170 ms to 270 ms in SN3. Fig. 4 shows the seismic and instantaneous phase profile of the area around core Qc2 in SN5 whose analysis time window is from 80 ms to 180 ms.

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