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Sedimentary characteristics comparison and genesis analysis of the deepwater channel in the hydrate enrichment zones on the north slope of the South China Sea

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Abstract
Natural gas hydrate (NGH) is one of the important clean energy at present and even in the future. The study of its sedimentary environment and minerogenetic condition has long been a hot issue that has received much concern from geologists all over the world. China has successfully obtained the samples of NGH in Shenhu and Dongsha sea areas in 2007, 2013 and 2015, respectively. From this, the continental slope north of the South China Sea becomes an important test site for the study of NGH sedimentary genesis and minerogenetic condition. NGH has been found in Shenhu, Dongsha and Qiongdongnan areas within the continental slope north of South China Sea, at different depths of water, with different sedimentary characteristics, gas genesis, and minerogenetic conditions. Using a seismic sedimentology theory, combining seismic facies results of each facies, sedimentary facies and evolution of each area are documented in turn establishing a sedimentary model by considering palaeo-geomorphology, sea level change and tectonic movement. The channel system and MTD (Mass Transport Deposition) system among these three areas were compared focusing on the developing position, appearance and controlling factors. Relative location among three areas is firstly defined that Dongsha area in a near-provenance steep upper slope, Shenhu area in a normal gentle slope and Qiongdongnan area in an away-provenance flat plain. Besides, their channel systems are classified into erosional, erosional-aggradational and aggradational channel, and MTD systems into headwall domain, translational domain and toe domain.

Key words: sedimentary characteristics, deep-sea channel, genesis comparison, hydrate enrichment zones

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1 Introduction

Natural gas hydrate (NGH) is a quasi-ice crystal compound composed of water and natural gas in the low temperature and high-pressure environment (Katz, 1959; Sloan, 1998; Milkov, 2004). NGH is in a state of dynamic equilibrium, and its formation process is the result of three-facies equilibrium, i.e., NGH, sea water and gas. Any factor that can impact the formation or decomposition process of NGH, such as the landslide, channel development, canyon activity, etc. (Katz, 1959). As the per document stated, hydrates are mainly distributed in continental permafrost and in the environment along the continental margin 500 m below in water, about 5 000 m below the seabed. Combing the types of hydrate bearing sediment discovered in the world, such as Blake Plateau in North America (Borowski, 2004) and Japan's Nankai Trough (Colwell et al., 2004), coarse-grained sediment are mainly the favorable reservoirs for its accumulation. Especially for the hydrate drilled in the South China Sea have shown the coarse-grained sediment would be the important target for the hydrate exploration (Zhang et al., 2002).

In recent years, the exploration and study of offshore NGH show that the formation, accumulation and distribution of hydrates are often closely related to deep water channel sedimentary bodies and deep channel system, as the main sedimentary system in the deep-water environment, can impact and control the hydrate mineralization to a certain extent (Ginsburg and Soloviev, 1997; Li et al., 2013; Wang et al., 2014; Yu et al., 2013). Channel, as the main passage to transport sediments, can provide coarse sediments with good porosity and permeability to its axial, levee and lobe, thus providing favorable conditions for the storage and migration of free gas and hydrate mineralization (Abreu et al., 2003; Fang et al., 2003; Sylvester et al., 2011). In addition, large hydrocarbon fields have been found in deep channel worldwide, such as Niger Delta (Deptuck et al., 2003), offshore Angola (Beydoun et al., 2002), Gulf of Mexico, and Beibu Gulf (Sawyer, 2008). Through the study of deep channels in different areas, we think that lots of deep channel sediments develop on the passive continental margin, where basin branching sand courses provide a storage space for hydrates (McHargue et al., 2011). Therefore, the channel system becomes the focus in the study of a current deep water sedimentary system. This paper studies the characteristics and compares and analyzes the genesis of the channel system in the hydrate accumulation zones under three different geological backgrounds in the deep-water areas north of the South China Sea, for the purpose of making

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clear of the distribution law and controlling factors of deep channel, and providing scientific basis for knowing the distribution law of hydrate deposits. Through the study of seismic stratigraphy and sedimentology of these three areas since the Pliocene, we make clear of the sedimentary patterns, such as the high-angle dip canyon system in the dongsha drilling area, the low-angle dip channel-levee system in the shenhu drilling area, and debris flow area channel in the prospective area in the Qiongdongnan Basin, and figures out the necessary and sufficient conditions for the hydrate mineralization.

This paper is organized as follows: first, geological settings, methodologies and data preparation are presented to give a background of the study; next, different types of channel are classified and identified through seismic data interpretation; then, impact factors to a deposition model are discussed at the end.

2 Geology of study areas

The formation and evolution of the South China Sea are directly controlled by the Pacific Ocean Plate, Eurasian Plate, and Indo-Australian Plate (Wu et al., 2005). From the report of IODP332 and IODP 333 and Lüdmann (2001) stated, we can see that the South China Sea is formed from the late Mesozoic (Lüdmann et al., 2001). Correspondingly, the South China Sea, on the basis of the original South China Sea platform, transformed from unilateral extension, crust's fault depression, thinning, magmatic intrusion, and twice oceanic crust formation, then, finally formed today's tectonic framework.

The continental slope north of the South China Sea has geological environment and temperature and pressure conditions suitable to the development of hydrates (Zhang et al., 2002), which is thought to have a good NGH resource potential (Wu et al., 2005). Currently, lots of geological, geophysical and geochemical characteristics related to NGH have been identified and four hydrate prospective areas have been divided from west to east in the South China Sea: Shenhu, Dongsha, Qiongdongnan and Xisha sea areas (Fig. 1) (Wang et al., 2006; Zhang et al., 2002; Yu et al., 2014). This study mainly compares the development characteristics of channels in Shenhu, Dongsha and Qiongdongnan areas.

Shenhu sea area is located in the middle of slope break belt north of the South China Sea (Fig. 1), belonging to a part of the Zhujiang (Pearl) River Mouth Basin. It is the first area where the NGH samples are obtained (Yang et al., 2008). In this study area, the submarine topography fluctuates greatly, and the continental slope is complex and changeable in terrain and declines in a ladder form on a whole (Fig. 2). The tectonic landforms are featured by sea troughs, valleys, hills, steep slopes, scarps, submarine plateaus, as well as submarine slumps and submarine fans, which are beneficial to the formation of hydrates (Liu et al., 2012). At the water depth of between 300 and 3 400 m, hydrates occur shallowly and bottom simulating reflectors (BSRs) are found around the slumping blocks that develop widely and often occur in submarine channels (Liu et al., 2012). Dongsha area is located in the east of slope break belt north of the South China Sea, belonging to a part of the southwestern Taiwan Basin. This study area covers an area of about 400 km². The per drilling survey (GMGS-2) revealed that Dongsha drilling area has a great hydrate accumulation potential. The submarine topography in this study area is complex with large changes in slopes, and the water depth ranges from about 1 000 to 2 000 m (Li et al., 2013). The BSR often occurs around the channel accumulation blocks. The Qiongdongnan sea area is located in the south of the slope break belt of Hainan Island (Fig. 1). This study area is 400 km² and distributed in NE-SW trend. The depth of water is high in west and low in east, with the slope of about 0.2°, and the terrain is very gentle. This study area is located in the deep-sea area, with gentle terrain. It is dominated by an abyssal plain, which is relatively single in topographic features (Fig. 2). The hydrates occur very deep in this sea area, and there is no drilling data. The BSRs are wide in area and most near the turbidity channel or on the top of gas chimney.

3 Data and methodology

The pseudo-three-dimensional (3D) survey data was acquired by Guangzhou Marine Geology Survey (GMGS) from 2003 to 2017, indicating a volume with a frequency of 65 Hz and a sampling interval of 1 ms, over an area of approximately 15 km by 25 km. To accurately describe the hydrate-bearing layers, the time windows were set at 3 ms per slice.

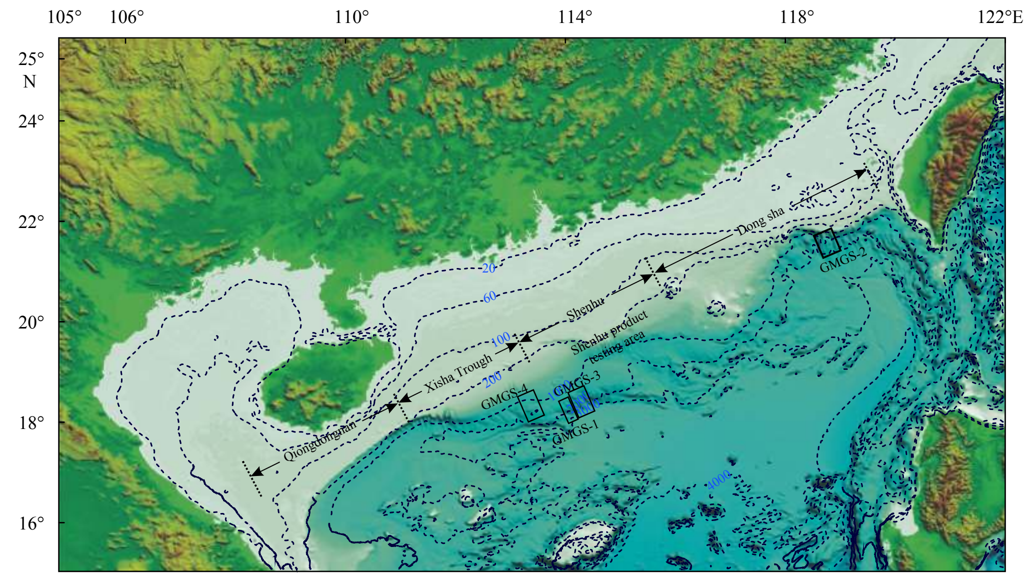


Fig. 1. Locations of the study areas. The base map is the submarine geomorphologic map of continental slope of the South China Sea and three areas in the map are the prospective areas of hydrates.

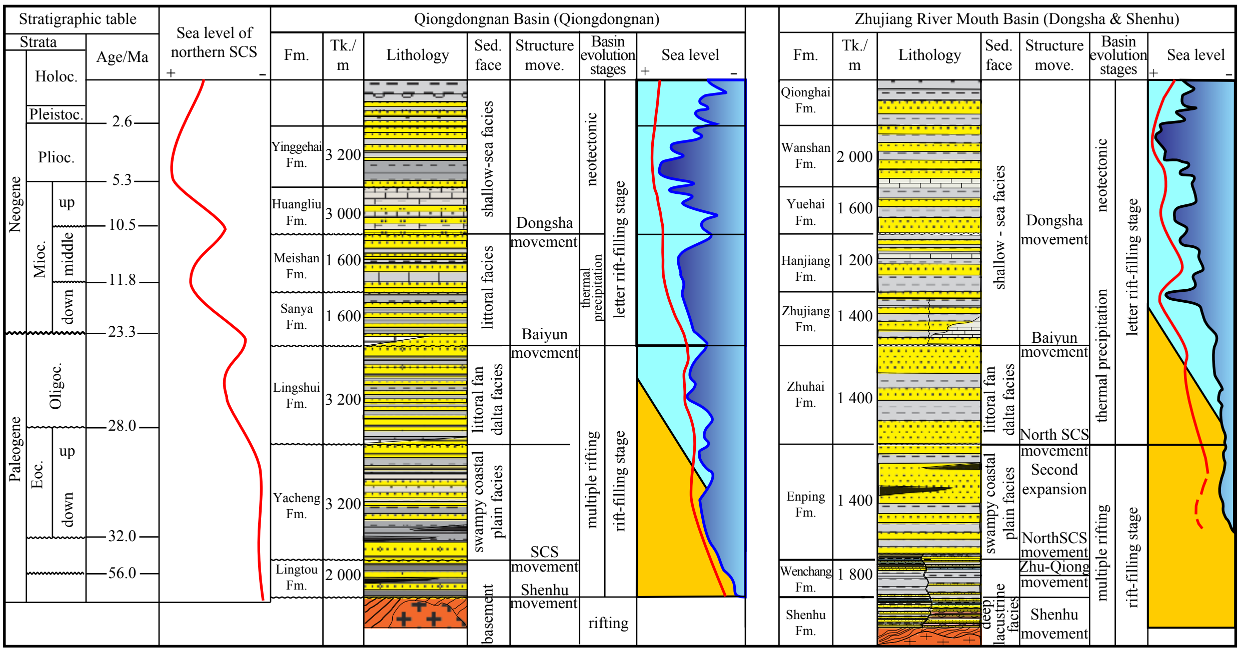


Fig. 2. The composite columnar section of Qiongdongnan area and Shenhu & Dongsha area. From the lift to right is formation, thickness, lithology, responding facies, relative sea level. Fm. represents formation, Tk. thickness, Holoc. Holocene, Pleistoc. Pleistocene, Plioc. Pliocene, Mioc. Miocene, Oligoc. Oligocene, and Eoc. Eocene.

The study of a variable channel development pattern is based on the integration of seismic data, log data and core analysis. As Mitchum and Vail (1977) first put forward the seismic facies analysis methodology, which was based on morphology of a seismic reflectors, reflection of seismic boundary, and contact relation between different seismic facies, to study sedimentary characteristics. In the hydrate enrichment zone on the continental slope north of the South China Sea, five categories, i.e., filling, mound, sheet, lenticular and wedge shape, including 17 seismic facies have been identified (Fig. 3).

4 Results

4.1 *Classification of deep channels*

Deep channels can be divided into several types according to different factors, such as geometric shape, incised type, superposition method, genetic mechanism, and internal reflection. Channels are often studied from four aspects, i.e., geometric shape, superposition method, genetic mechanism, and internal filling (Figs 4 and 5) (Fang et al., 2003; Reesink et al., 2014; Zühlsdorff et al., 2007).

A deep channel, similar to the continental river channel that transforms from a braided shape to meandering shape, changes from straight form to highly tortuous form. A deep channel form is analyzed according to the slope, hydrodynamic conditions and formation environment.

Generally, the straight channel mainly developed at the top of slopes. Increasing of the gradient, the more obvious sediment down cutting shows a V-shape on the seismic section, with lower channel curvature, lower width-to-thickness ratio and straight plane distribution (Fig. 4). At the lower parts of slopes, the decreasing of gradient leads to the sediment down-cutting obviously, showing a U-shape and a standard shape on the seismic section, with higher channel curvature, higher width-to-thickness ratio and meandering channel. In flat-bottomed lands, due to the further weakening of erosion and strengthening of overbank process, the channel is narrowed and the natural levee becomes larger in area, showing a U-shape and disc shape, and the plane bending is obvious. a W-shape channel is generally represented as the superposition of complex channels and affected by erosion.

The evolving process of channel can be determined according to the superposition direction of the channel. Generally, there are two types of the superposition: vertical superposition and lateral superposition. The curvature of laterally superposed channel is larger than that of the vertically superposed channel. The laterally superposed channel is characterized by the lateral migration of channel which has sediment accreting inner-levee and suffers erosion outer-levee, resulting in increasingly larger curvature of the channel.

The superposition mode can also be classified into orderly superposition (unidirectional migration) and disordered superposition (Fig. 4). The development position can be determined according to the direction of aggradation. The orderly one mostly occurs in a restrictive environment, such as canyon; while the disordered is subject to less restrictive factors in the development environment, such as submarine plain.

Fillings in the channel can be classified by property into muddy filling and sandy filling. The muddy filling is formed when the sediment is washed away without any remains under serious down-cutting effect and the channel is subsequently filled by mud; while the sandy filling is formed when the sediment is washed away moderately and some sand is still left in the channel. Generally, most muddy filled channels can be found on upper continental slopes and have larger curvature, while sandy filled channels are mostly developed at the bottom parts of mud filled channels and have smaller curvature.

4.2 *Comparison of channel characteristics*

From the comparison of the deep channels of these three

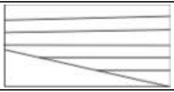
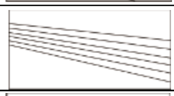
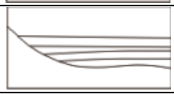
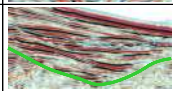
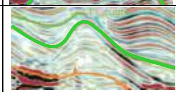
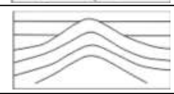
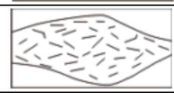
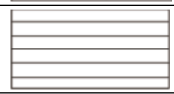
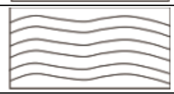
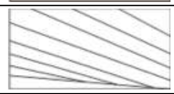
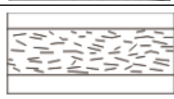
External form	Internal structure	Example	Model diagram	Seismic performance			Sedimentary interpretation
				amplitude	apprent frequency	continuity	
Wedge-shaped	parallel			M	H	H	in the stable hydrodynamic environment, often found in neritic facies or abysmal facies sediments
	wave			M	M	H	differential settlement action of the sedimentary basements or lateral variation of deposition rate
	divergent			M	H	H	delta, turbidite deposit and slope usually develop on the upper continental slope and middle continental slope
Filling	parallel			H	M	M	indicating that submarine canyon or turbidity current channel was formed as the sea level relatively fell
	onlap			H	L	H	nonuniform vertical aggradation
	progradational			H	H	H	filling of the submarine meandering stream
	chaotic			L	L	L	clastic watercourse under various sedimentations
Hummocky	parallel			L	H	L	slumping block
	downlap			L	L	H	slumping block, slope fan
	chaotic			H	L	L	slumping block, turbidite fan
	divergent			L	H	H	sliding block
Lentoid	progradational			H	H	M	indicate the lower fluid force, mainly mud despoliation
	chaotic			L	M	L	MTDs
Sheet-like	parallel			H	M	H	in the stable sedimentary environment such as neritic, bathyal-abysmal sea or unstable sediments such as littoral-neritic sea, delta plain, etc.
	wave			H	M	H	products by sediment migration and nonuniform vertical action
	progradational			H	H	H	deposit on the lobes of the slope or bathyal deposit
	chaotic			M	L	M	hydrodynamic conditions are unstable, and the products formed in the high environment may also be the reaction of original continuous formation after suffering the later reformation and transformation.

Fig. 3. Seismic facies types and genesis analysis, from the left to right is the external forms, internal structure, examples, model diagram, seismic performance and sedimentary interpretation. L represents low, M moderate, and H high.

areas we can see that the slopes in the development zone of the channel have important impact on the channel bodies. Generally speaking, the gradually lowered slope will weaken the down-cutting of sediments and strengthen their overbank process, and thus a single channel system will change into a channel-natural levee system. Meanwhile, the identification feature of a single channel on the seismic section also gradually changes from the V-shape to the U-shape. The channel in the canyon also presents a trend of straight-bend-branching with the increase of curvature. The channel in the canyon is superposed under the action of a bottom current, or disorderly superposed without the action of the bottom current.

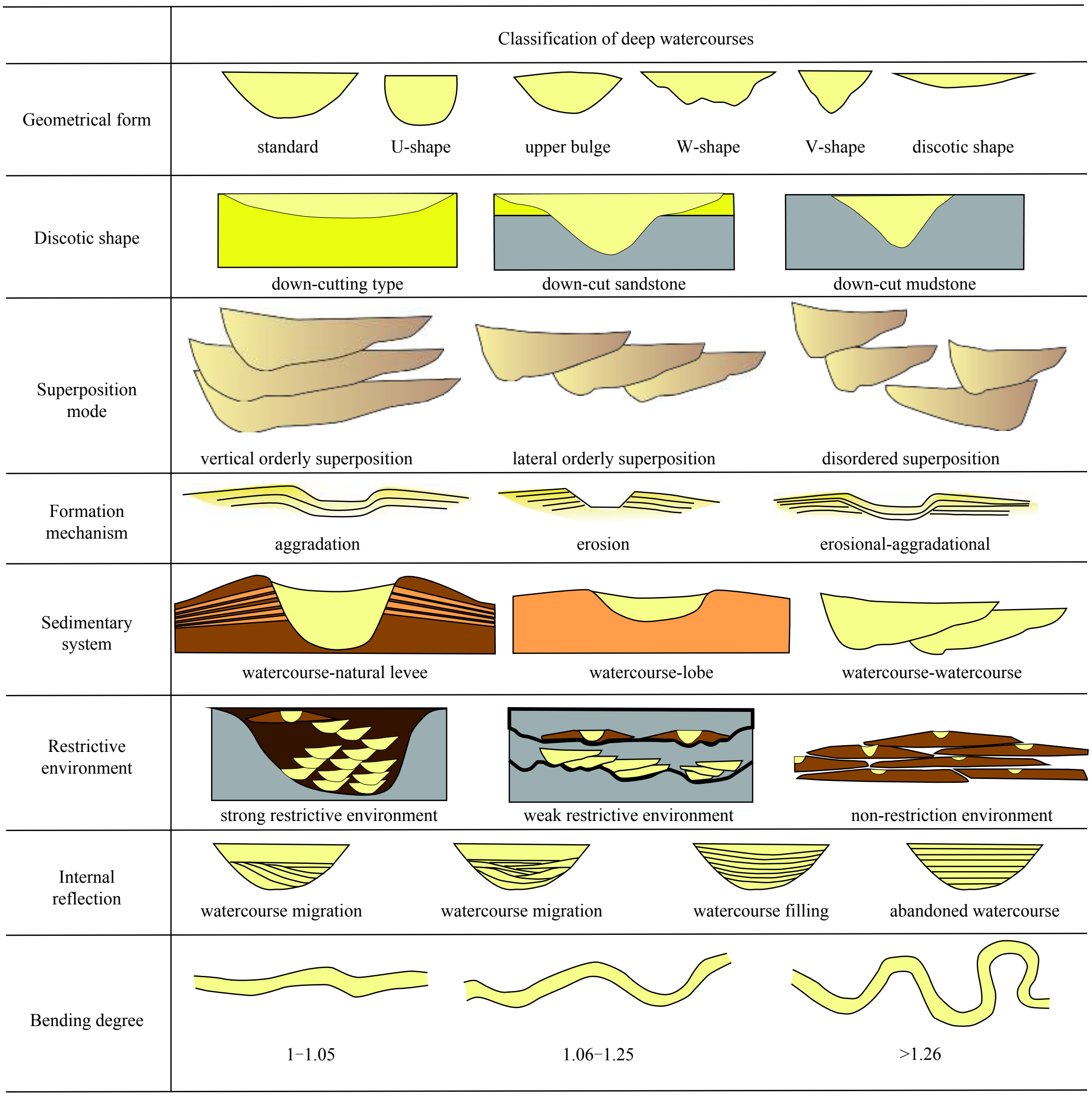


Fig. 4. Classification table of channel, by seismic reflection characteristics, sedimentary configuration, genetic mechanism, etc.

Comparing the channel development characteristics of these three areas, we can see that Shenhu area mainly has unidirectionally migrated erosional/aggradational channels developed in low-confined canyon, with medium plane bending, width slightly less than that of others, and the development of natural levee as the seismic section shown (Fig. 6a); Dongsha area mainly has the straight erosional type channels developed in highly-confined environment, with the strongest down cutting as the seismic section shown (Fig. 7a); the Qiongdongnan area mainly has the highly-bent aggradational channels developed in the unlimited canyon as the seismic section shown (Fig. 8a) setting, developed with overbank levee and turbidity flow, which is caused by the flooding effect.

4.2.1 *Development characteristics of channels in Shenhu drilling area*

From the sedimentary environment of Shenhu area we can see that this area is located in deep water sedimentary environment and the abundant sediments provided in the Zhujiang (Pearl) River system with lots of fragmentary materials, migrating to the Shenhu sea area from the north of the study area, via Zhu I Depression and Panyu Low Uplift, and then develop into shelf slope break belt on the northern slope of the Baiyun depression.

We explain the distribution of the sedimentary system through studying the Neogene and Quaternary strata in the Shenhu sea area.

Canyon and deep-water fan bodies mainly develop in the low stand system tract (LST) in the sequence (Fig. 6). At the early low stand period, a relative sea level fell fast and shelf slope was close to sea level, when the channels strongly down cut the existing continent shelf. After that, the relative sea level began to slowly rise, and sediments carried by the river system started to accumulate through the canyon in the slope zone, thus, and some slope fan bodies are forming. During the development period of the low stand system tract (LST), the relative sea level had a small-scale of shock and the downcutting of river also changed correspondingly, mainly presented as the progradation to the sea basin dominated on a whole.

During the transgressive system tract (TST), the relative sea level rose fast, sea basin expanded, and coastline retreated. The Shenhu sea area was dominated by abysmal deposit, but its north

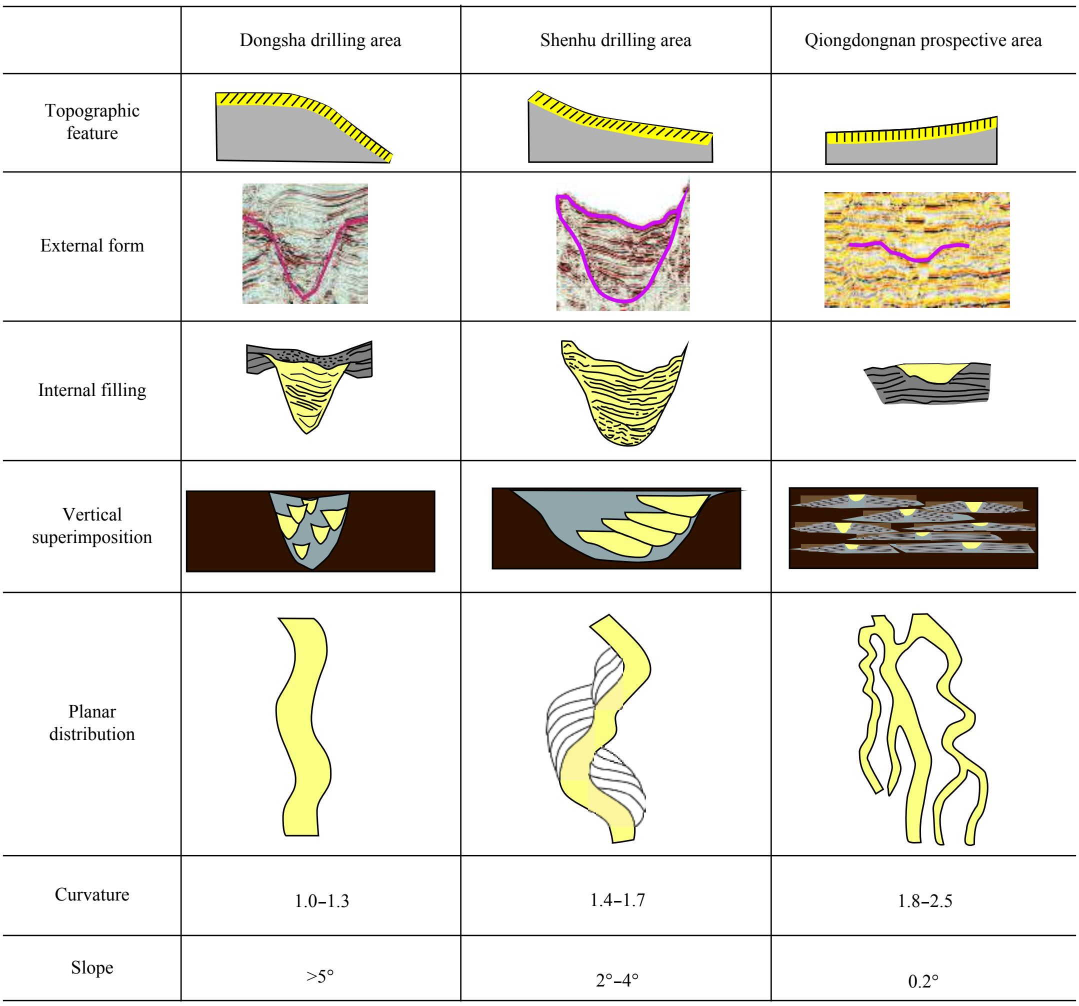


Fig. 5. Comparison of watercourse characteristics (channel are categorized by sedimentary pattern, process, mechanism, etc.).

gradually developed into steep shelf slope break belt due to the continuous supply sediment sources (Fig. 6).

During high stand period (HST), the Zhujiang River Delta continued to advance to the sea basin. Impacted by the relative sea level and the changes of accommodation, local slopes due to the unstable factors may induce the large-scale transport, and the transport of sediments in the high place directly occurred along the slope, thus forming slump fan bodies; another part of the sediments transported along the canyon formed by the LST and provided the sediment sources to the deep-water fans of the abyssal plain at the canyon mouth, in the form of point source. After the channel in the fan flowed out of the canyon, its down-cutting weakened but overbank process strengthened, and the channel was gradually developed into branching channels and lobes of deep-water fans. As an important influence factor in deep-water sedimentary system, bottom current process is very important. The development of the bottom current makes the canyon channel continuous migrate along the east direction on the slope.

Shenhu drilling area is mainly located in the middle of the continental slope, under the slope break belt, with a slope of generally 2°–4°. Therefore, the sediments in this area mainly down cut the continental shelf, but the down-cutting is slightly weaker than that of the Dongsha drilling area. The single channel identified on the seismic section is dominated by a U-shape single channel. The channels in the canyon are mainly superposed laterally and orderly, presenting a unilateral type, which reflects that the development of channels due to the orientation of the bottom current shows the obvious lateral aggradation. As the down cutting of the channel relatively weakened compared with that of Dongsha drilling area, and the limitation of the canyon gradually reduced, the channels in the canyon gradually show sway characteristics, with a curvature of 1.4–1.7. Therefore, the channels in this area are erosional/aggregational-erosional channels laterally and orderly superimposed.

4.2.2 *Development characteristics of channels in Dongsha drilling area*

Taiwan orogenic belt north of the Dongsha drilling area brings lots of terrignous fragmentary materials to the study area, and the characteristics of western slump and eastern channel obviously make the sedimentary characteristics of this area have obvious zoning characteristics. We explain the distribution law of the sedimentary system through studying the Neogene and Quaternary strata in Dongsha sea area.

A western slope and an eastern channel have already existed during the period of the LST. During the LST, the sea level was low and there was no obvious supply of sediment sources. The sediments were thinner, with some slump deposits only in local areas. On the whole, abyssal-bathyal sediments *in situ* domin-

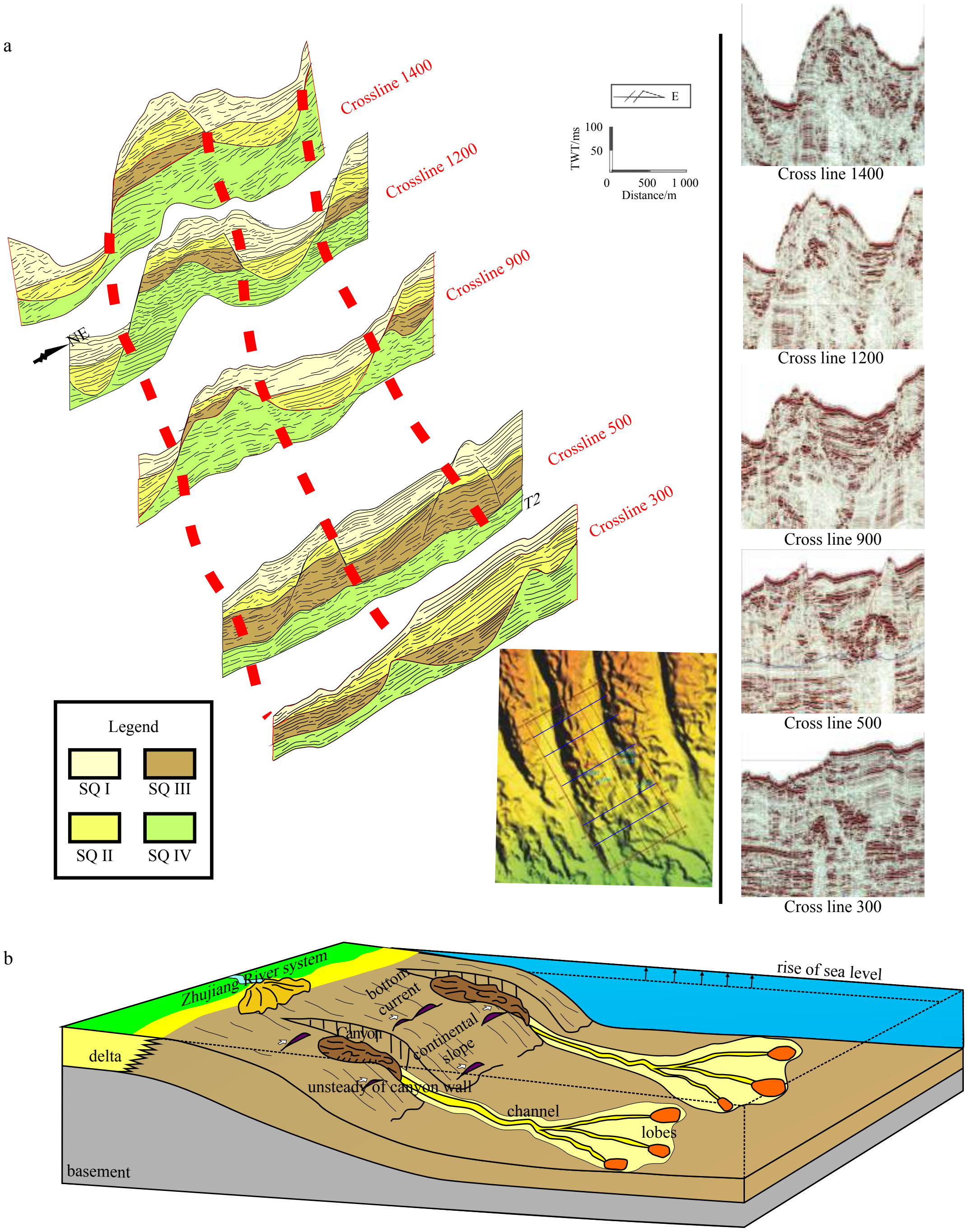


Fig. 6. Series seismic profile and development characteristics of channel in Shenhu drilling area (a) and sedimentary model of Shenhu drilling area (b). The sediments mainly act on the continental shelf with downward erosion, and the impact of the bottom current on watercourse is relatively obvious. TWT represents two-way travel time.

ated.

During the period of the TST, a lake basin area increased, the sea level rose rapidly, and the continental shelf slope break belt migrated to the south due to the intense supply of sediment sources in the north large-scale slumps has developed in the west of the study area, and local sediment sources also were supplied to the submarine basin through the east canyon channels (Fig. 7).

In the HST, the shelf slope break belt continuously advanced to the sea basin. The continuous advancement of the shelf slope break belt and the frequent tectonic movement of the South China Sea made the slumps in the west of the study area developed in a large scale. The slumps were dominated by mass transport sediments, which gradually developed into slump fans on the slope. The fans are dominated by slips, slumps, and debris flow, depositing disorderly, without obvious channel development. Channels in the east of the study area also migrated to the south and converged in the basin plain. The development of the channels made the strata in the thickness in the east of the study area presented strip shape and extended southward.

The Dongsha drilling area is mainly located near the continental slope break belt, with a gradient of over 5°, which is an intense than the other areas (Fig. 1, contour lines shown). There-

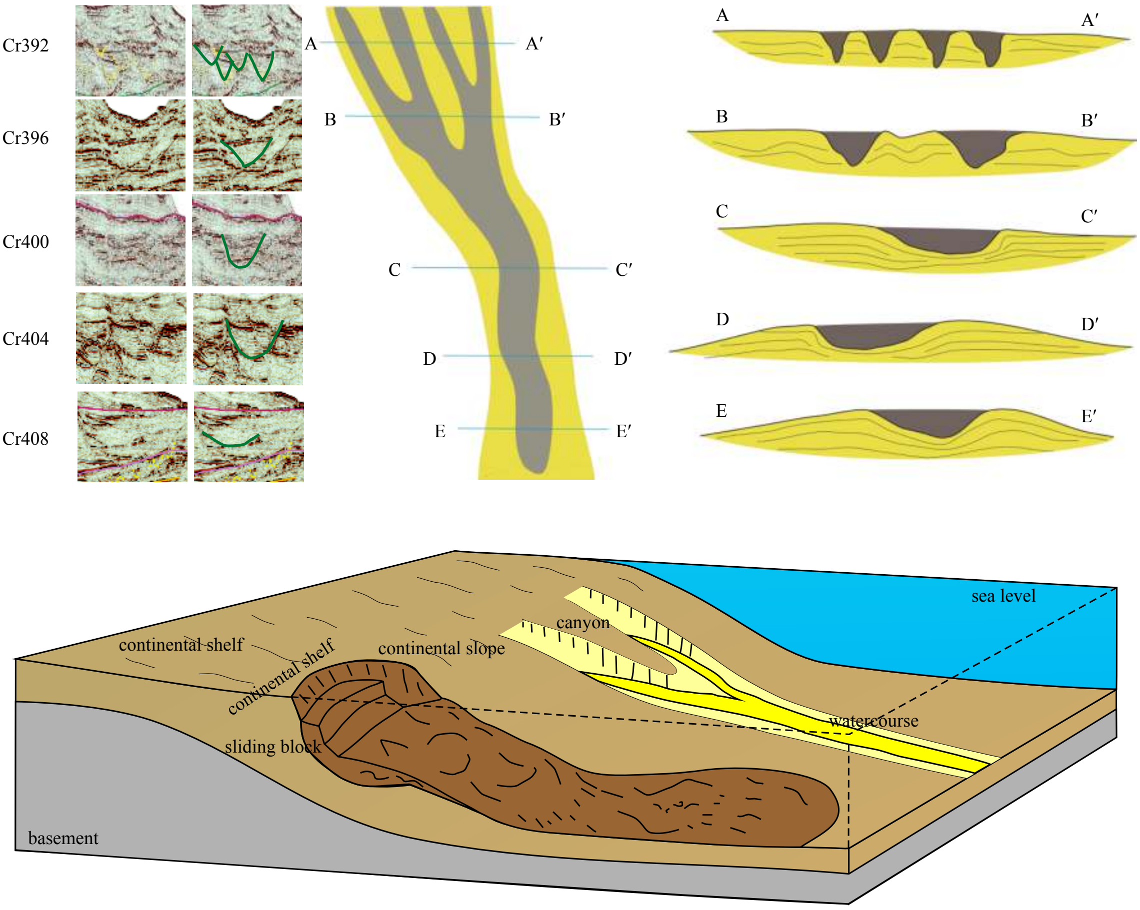


Fig. 7. Series seismic profile and development characteristics of channel in Dongsha drilling area (a), and sedimentary model of Dongsha drilling area (b).

fore, the sediments in this area mainly down cut the continental shelf, and the single channel identified on the seismic section was dominated by a V-shape single channel. From the perspective of superposition method of the channel in canyon, several small channels develop on the bottom of the canyon. Due to the lack of orientation impact such as bottom current, the channels mainly develop vertically, without obvious lateral aggradation development and fixed development sequences. As the overall erosion effect is strong, the channels are relatively straight, with a curvature of 1.0–1.3. The channels in this area are mainly erosional straight channels vertically superposed.

4.2.3 *Development characteristics of the channels in the prospective area in Qiongdongnan prospective area*

According to sedimentary facies analysis results, and combined with the supply of sediment sources, strata isopachous map, and landform features, a sedimentary model of the prospective area in Qiongdongnan prospective area has been established.

Submarine fans develop on the bottom of the Pliocene in the study area. They mainly developed in the LST period with relatively low sea level. At that time, the sea level was low, and the continuous supply of sediment sources to the study area from the northern continental slope break belt formed the submarine fans spreading from the north to south. Obvious progradation configuration can be observed on the profile. Sheet sand bodies in front of the submarine fan lobes also well develop in the study area.

With the gradual rise of sea level, the study area gradually entered into the sedimentary period of the TST. The rise of sea level and the reduction of the northern sediment sources made the submarine fans gradually disappear. The study area was dominated by abysmal-bathyal fine-grained sediments but impacted by the old Red River system in the northwest, a small channel-natural levee sedimentary system developed in the study area. The lateral extension of the natural levee was obvious. The gradual rise of the south also provides some slump deposits for the study area (Fig. 8).

With the further rise and stabilization of the sea level, the study area entered into the HST period. At that time, the structure and the sea level were all relatively stable, and fine-grained sediments developed further. The seismic section is dominated by sheet-like strata, with locally flood fans. The local rise of the south made it possible for the formation of more slump deposits in the study area.

The prospective area in Qiongdongnan prospective area mainly develops in the continental slope area near the submarine plain, with a slope of generally 0.2° and gentle terrain (Fig. 8). Therefore, this area is dominated by the overbank process of sediments, with the gradually weakened downward erosion. The single channel identified on the seismic section is mainly U-shaped, with obvious natural levee development along the flank. Inside the canyon, the channel-natural levee system mainly superposes vertically disorderly, which reflected that the channel gradually diverges on the basin plain, with the development of natural levee. As the limitation of canyon reduced further, the channel started to overflow, with a curvature of 1.8, 2.5. There-

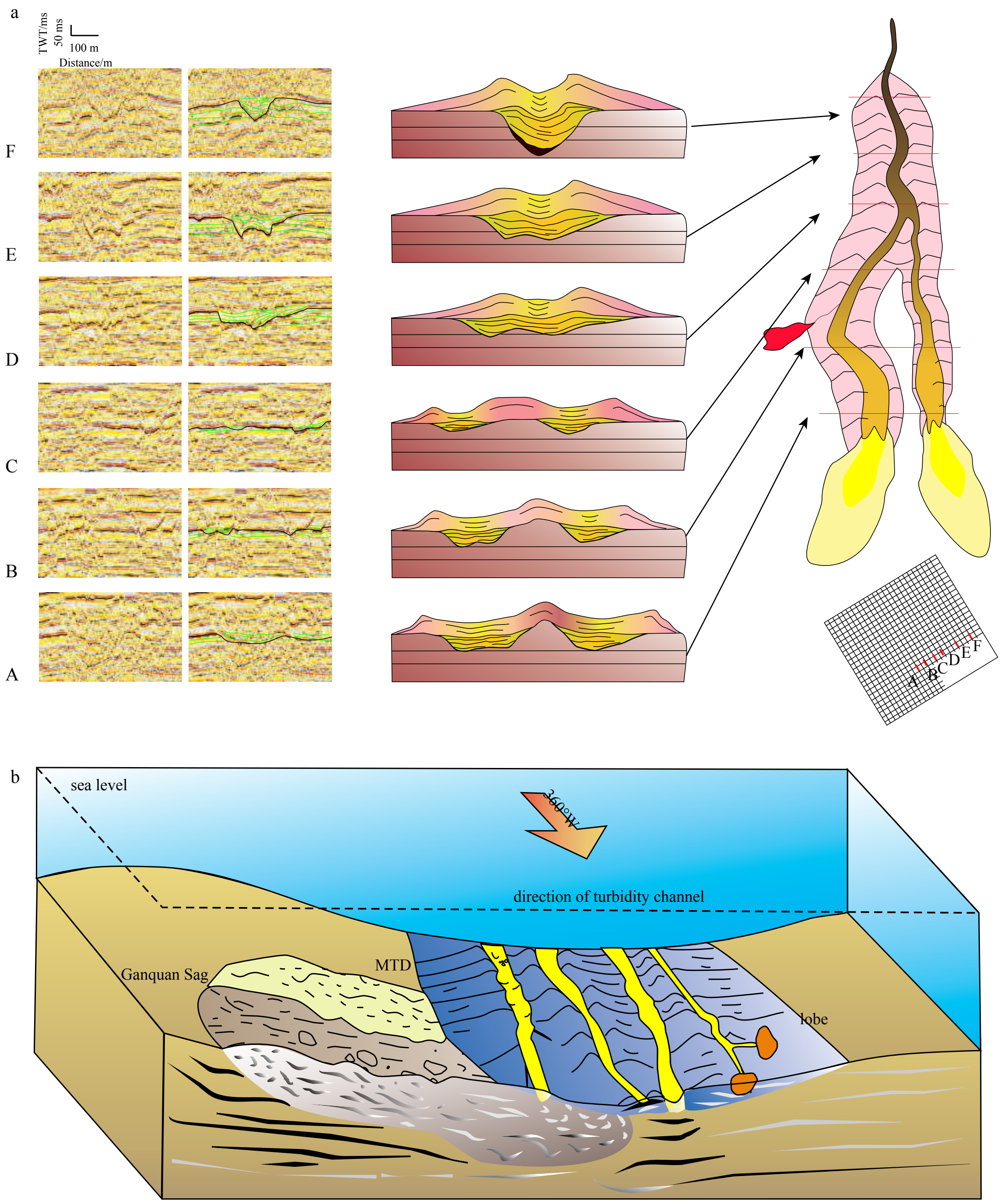


Fig. 8. Series seismic profile and development characteristics of channel in Qiongdongnan sea area (a) and sedimentary model of Qiongdongnan area (b). TWT represents two-way travel time.

fore, this channel is an aggradation channel vertically superposed.

5 Discussion: channel development control factors

5.1 *Characteristics of sediment sources*

The characteristics of sediment sources mainly include the supply volume and the distance from the sediment sources. Taiwan Island directly and continuously delivers the continental fragmentary materials to the north of the Dongsha drilling area. Therefore, the transport distance is relatively short, with the most obviously crumpled and warped strata, and the most sufficient supply of sediment provided. Shenhu drilling area is close to the large ancient Zhujiang River system in the north, and its sediments after a certain distance of transport generally show a parallel stratum with good continuity, and the supply sediment sources are moderate. The sediment sources of the Qiongdongnan sea area are from the Red River Delta in the northwest and the supply volume is the least as the sediment transport takes a longer time than the other blocks.

5.2 *Control by ancient landform*

Terrain and topography are the condition precedent to the formation of channels and determines and affect the development positions and forms of the channels. The Dongsha drilling area has the steepest slope, and the east is dominated by the down-cutting channels that show "V" shapes vertically and intersect at the bottom of the slope. The Shenhu drilling area has a relatively steep topographic slope, and the transport occurs along the several existing canyon channels, indicating that in the areas dominated by sloping ancient landform, lots of eroded canyons develop, the accommodation space is small, the channels are mainly down-cut by erosion, sediments are mostly left when passing by, and the channels are filled by later mud deposition on the whole. The prospective area of Qiongdongnan has relatively wide and gentle slopes. In the study area, not only many deep channels develop, accompanied by relative natural levees nearby, indicating that the weakening of down-cutting and strengthening of overbank process in deep channels. In areas where ancient landform varies intricately, there is certain accommodation space facilitating the development of channel-natural levee.

5.3 *Sea level change*

Frequent sea level changes can affect the supply of sediment sources and result in the frequent migration of the deposition sequence between continental shelf and the continental slope, increasing the instability of the slope break belt. The sea level in the Dongsha drilling area has the most frequent changes, followed by the Shenhu drilling area, and Qiongdongnan sea area has the most stable sea level. The Dongsha drilling area with the most frequent sea level changes is dominated by the down-cut deep channels that are migrating and swinging in the restrictive environment of canyons. In the Shenhu drilling area, the frequent sea level changes and bottom current process in the Quaternary period resulted in many times of migration of the deep channels. The prospective area of the Qiongdongnan sea area has relatively less frequent changes in the seal level. Therefore, smooth deposition dominates here and the channel-natural levee system is developed.

6 Conclusions

(1) By studying and comparing the deep channel systems of the three study areas, it is concluded that the canyon channels in the Dongsha drilling area are mainly affected by the down-cutting erosion and show the V-shape on the seismic section; on the bottom of the canyon, many small channels are vertically and disorderly superposed, leading to wider straight channel on the whole, with the curvature at 1.0, 1.3 and showing typical characteristics of eroded channels. The single channels in the Shenhu drilling area shows in the U-shape, migrates in single direction as affected by underflow, and is developed with obvious lateral aggradation; the channels in the canyon meander to some extent, with the curvature at 1.4–1.7, and are classified as erosional/and aggradational channels. The prospective area of the Qiongdongnan area has flat terrain and weakened down-cutting erosion effect; the single channels mainly show in wide and gentle "U" shape and the disc shape, and the natural levees are developed on flanks and extend in long distance; the vertical aggradation and disordered migration modes coexist, the channels obviously become narrow and extend in shorter distance, with the curvature at 1.8–2.5; and they are classified as aggradational channels.

(2) Deep channels can be classified into many types based on different factors, such as geometry form, down-cutting type, superposition mode, formation mechanism, and internal reflection. Channels can be classified into the straight type and the highly tortuous type by geometry, and into the vertical superposition type and the lateral superposition type by superposition. The factors resulting the diversity of channel development can be summarized as: the supply of sediment source, the distribution of ancient landform, the sea level change and other factors.

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