

# **The Depositional Characteristics and Models and Accumulation of Gas Hydrate in Northern Continental Slope, South China Sea\***

**Jianzhong Wang<sup>1</sup>, Xinghe Yu<sup>1</sup>, Shunli Li<sup>1</sup>, Xiaoming Zeng<sup>1</sup>, and Wen Li<sup>1</sup>**

Search and Discovery Article #50790 (2013)

Posted June 17, 2013

\*Adapted from extended abstract prepared in conjunction with oral presentation at AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania, May 19-22, 2013, AAPG©2013

<sup>1</sup>China University of Geosciences, Beijing, China ([wangjianzhong1010@163.com](mailto:wangjianzhong1010@163.com))

## **Abstract**

South China Sea (SCS) has been confirmed that has favorable deposits accumulation conditions and exploration prospects for gas hydrate. BSR (Bottom Simulating Reflector) was developed and distributed in SCS widely. Under the theory guidance of seismic stratigraphy and sequence stratigraphy, through the methods of detailed interpretation and sequence division of seismic profiles in the SCS, based on a integrated analysis of the depositional conditions (deposition facies, deposition rate, sand content rate, lithologic features, etc.) and special depositional body (structural slope, slump block and sediment waves), combined with the BSR distribution characteristics in each sequence and on the plane, a typical depositional accumulation models has been established by the features of gas hydrate deposition accumulation was systematic analyzed in the northern SCS. This model summarizes the distribution of each depositional system in the continental shelf, continental slope and continental rise and the relationship with BSR and GHSZ (gas hydrate stability zone), which also shows the typical elements for the gas hydrate accumulation. The research shows, BSR has close relationship with slope break zones, deep-water gravity flow and contourites. In the continental shelf, the key to gas hydrate formation and accumulation lies in the transport and migration conditions. In the continental slope, the major BSRs are located in the steep and roughness of relief with long-term successional uplift and subsidence on the seaward side. The rapid sediment unloading area can provide the favorable sedimentary reservoir and cover conditions for gas hydrate. In the continental rise, the critical condition for gas hydrate formation and accumulation is capping conditions.

## **Introduction**

Gas hydrates, also known as methane clathrates or clathrate hydrates, are ice-like solid substance formed by water and gas under the conditions of low temperature and high pressure (Kvenvolden, 1993; Matsumoto et al., 2011). Recent years, many countries have carried out investigation and evaluation programmes on the gas hydrate and a lot of progress achieved (Sain et al., 2012). Through the implementation of the Ocean Drilling Program (ODP) and Deep Sea Drilling Project (DSDP), massive existence signs of gas hydrates have been found in many sea areas (Makogon, 2010). In May 2007, China Geological Survey Bureau drilled at Shenhui district so that gas hydrate cores were successfully recovered ([Figure 1](#) and [Figure 2](#)) (in site A, B, and C), having confirmed the existence of vast gas hydrate resources in South China Sea.

The BSR is a result of an acoustic impedance contrast between gas hydrate-bearing sediments and free gas trapped in the sediments underneath gas hydrates. The zone where gas hydrates are stable is called the gas hydrate stability zone (GHSZ). The sub-bottom depth of the GHSZ depends on the geothermal gradient, bottom water temperature, pressure (water depth), gas composition, and the physical and chemical properties of the host rock. The procedures of formation, evolution and occurrence of gas hydrate in geological history have left many various physical and chemical evidences, therefore, though a variety of minerals, rocks, geochemical and microbiological anomalies are important marks to identify gas hydrate, BSR and GHSZ of them have been becoming the best and most important evidences. However, the presence and location of BSR were spatially controlled by the intersection of geothermal gradients and the stability curve for gas hydrate coincident with the BSR. However, some studies suggested that the base of gas hydrate does not always coincide with the base of the GHSZ (Xu et al., 1999; Diaconescu et al., 2001; Zhang et al., 2011) (Figure 3). Currently there is no effective and reliable method to evaluate the distribution of gas hydrates (Ruppel et al., 2005, 2008; He et al., 2009).

### **Geological Setting**

In Northern Continental Slope of SCS, there are three major basins namely the Southwest Taiwan Basin, Pearl River Mouth Basin and Qiongdongnan Basin. The most of BSR distributory regions of the study area are occurred in the Dongsha, Shenhu, Xisha and Qiondongnan four districts, which is located in the range of eastern longitude of 109°00~121°00, northern latitude of 15°00~23°00, with a north-east trending and its area is about  $27.8 \times 10^4 \text{Km}^2$  (Figure 4).

Subdivision of drilling sequence in Shenhu district indicated that the tectonic movements, which affected relative sea level changes, had occurred in SCS since the Miocene. Three sequence boundaries (T3, T2, and T1) have been identified in the northern continental slope of SCS since the late Miocene. These boundaries correspond to the times of 11.6Ma, 5.33Ma, 1.81Ma. Correspondingly, the three-sequence stratigraphy has been identified as follows: Sequence III, Sequence II, Sequence I (Figure 5).

### **Distribution of Gas Hydrate**

#### ***Thermodynamic and sedimentary conditions***

In the study area, the water depth ranges from 300m to 4400m, and the seafloor temperature is about 1~5°C. The geothermal gradients general between 2.0°C/100m~4.5°C/100m in stratum since the late Miocene. Previous study indicated that the actual gas hydrate distributory region is thinner and falls within GHSZ predicted by thermobaric modeling, but typically at shallower depths and in thinner layers (Diaconescu et al., 2001). As decrease of the geothermal gradients and increase in water depth, both of them result in increasing thickness of the hydrate stability field. The present geothermal field in the deep-water area of the northern SCS is characterized with hot basin (Mi et al., 2009). The heat flow in the BSR distribution range is basically between 65Mw/m<sup>2</sup>~90Mw/m<sup>2</sup>, and the value in the continental slope is relatively high with about 75Mw/m<sup>2</sup>~90Mw/m<sup>2</sup>, whereas in the continental rise and deep sea area the value is slightly lower with about 65Mw/m<sup>2</sup>~80Mw/m<sup>2</sup> (Figure 4).

The sedimentary conditions of the study area are included as follows: (1) the gas hydrate mainly occurred in the relative coarse sediments, which is soft unconsolidated, such as sandy ooze. (2) For the geological era of sediment, most of soft unconsolidated sediments being occurred BSR were formed since Miocene, especially in the Pliocene and Quaternary. (3) Some research results showed that the sediments in GHSZ being contained rich diatom fossils (Su et al., 2005). Therefore, the main sedimentary geological conditions affecting gas hydrate accumulation are as follows: (1) Sediments with medium porosity and low permeability could be favorable to maintain pore water, provide reservoir and easy to form for gas hydrate. (2) The reservoir should have certain thickness. (3) There must be sufficient gas source supply. (4) The low-temperature and high-pressure were external thermal dynamic conditions for its accumulation of gas hydrate; With a high deposition rate, which can not only provide the gas source but also easy to form undercompaction area that may constitute a good fluid migration system. In brief, the key of sedimentary characters for gas hydrate accumulation are moderate sand/mud, relatively high deposition rate and sediments thickness, which was mainly developed in the various fans, deltas, and various gravity flow depositional systems.

### ***BSR distribution***

Based on the recognition of the BSR on the seismic profiles of the study area, 26 BSR distributary regions were identified in the northern continental slope of SCS; those areal sizes are extraordinary disparity, and mostly in shallow to semi-deep sea. There are 17 regions with the water depth less than 2,000m, 7 regions with the water depth between 2,000m and 3,000m, and only two regions with the water depth exceed 3,000m. In the geographical position, the most of BSR distributary regions occurred in Shenhu district with the number about 10. Qiongdongnan and Xisha district each have six BSR distributary regions. In Dongsha district, there were two large BSR distribution regions and both located in the deep-water area of the Taiwan bank slope, where the area is located between the east of Dongsha platform and the west of Taiwan orogenic belt. However, in the vast area of the mainly part of Dongsha district there is no development of BSR. The overwhelming majority of BSR distribution regions are located in the areas with landscape changes steeply, the larger terrain variation, and long-term succession subsidence, such as the upper continental slope of Qiongdongnan district, Xisha district and the east part of Shenhu district. Also there have a small amount of BSR distributed in the regions with relatively simple and flat topography, but the water depth in those places are all over 2,000m ([Figure 6](#)).

### **The Sedimentary Factors Controlling the Distribution of Gas Hydrate and BSR**

The deposition and accumulation conditions to the formation of gas hydrate have been summarized (Yu et al., 2004), this research combined with geologic settings and the distributary characteristics of BSR, and based on sedimentary sequences analysis are as follows:

**Depositional facies.** Other studies have shown that the submarine gravity flow, especially the bathymetric flow and turbidite deposits, and slump fan in delta front as well as the slope fan located in the structure transition are favorable depositional system or facies zone for the development and occurrence of gas hydrate. Gas hydrate mainly concentrated in the front with rapid deposition of each depositional system, such as delta front, the turbidite fan and contour current deposit front. In sequence III, BSR mostly distributed in bathyal facies of Xisha and Shenhu district, indicating that the depositional facies is not the main controlling factors, it is mainly controlled by the temperature and pressure conditions. In sequence II, BSR is widely distributed in Xisha, Shenhu and Dongsha three districts, and mainly occurred in the front of various depositional systems(such as delta, turbidite fan, slope fan). In addition, there are some BSR in the neritic, bathyal and contourite sediments,

showing that in medium burial depth strata, the formation of gas hydrate be obviously controlled by depositional facies. In sequence I, BSR only occurred in the Qiongdongnan district, and almost all of them are located in the delta front and prodelta sediments, suggesting that in the shallow burial depth strata, the requirement for the physical properties of depositional systems is highest, and the controlling factors of depositional facies are more obvious. In brief, the more strata getting shallow, the more obviously BSR be controlled by depositional facies, and the better relationships with high deposition rate of depositional system, especially delta (Figure 7).

**Deposition rate.** The deposition rate is an important factor controlling the gas hydrate accumulation mainly because the coarse-grained clastic sediments with high deposition rate can easy form the undercompaction area, which may constitute a good fluid migration system, and this will be conducive to the formation of gas hydrate. The relationship between the deposition rate and BSR also vary while the strata burial depth changes. The area with high deposition rate due to the impact of undercompaction, generally represents the better reservoir space and strong fluid conduction ability. In sequence II, BSR mainly distributed in the area with high deposition rate (Figure 8), suggesting there need better reservoir space and conducting system. Generally, in the BSR distributary region, the deeper buried depth, the smaller the deposition rate, vice versa.

**Sand content.** The sand content directly influences the development of reservoir space and pore water, thus affecting the development of gas hydrate. In general, the smaller sand content, the less reservoir space and pore water, so that this is not conducive to the formation of gas hydrate. On the contrary, the higher the sand content, the more the reservoir space and pore water, this is favorable to the formation of gas hydrate, but if the sand content is too high, the sealing ability will be getting worse, and this is not conducive to the preservation of the gas hydrate. In sequence II, BSR mainly distributed in the low sand content range in the southern part with the deeper water depth, but in the northern part with the smaller water depth, BSR mainly distributed in the high sand content range (Figure 9 and Table 1). This suggest that for the medium buried depth strata, the requirement for the reservoir physical property of the sediment is not high in the deeper water area, whereas in the shallow water depth area, the requirement for the reservoir space and transport ability of the sediment is relatively high.

**Lithological characters.** At present, the gas hydrate, which has been found in the sea, mainly occurred in the fine-grained sediments with lenticular, nodular, granular or flaky shape. The lithology of the gas hydrate bearing sediments is mostly silt or clay. Grain size analysis of coring interval in Shenhu 2006 3D district suggested that the sediments are homogeneous, and the particle size is fine (Table 2). The gas hydrate bearing layers are mainly composed of clay silts in site A and silts in site C. The lithology components content in the gas hydrate bearing layers have no obvious difference with its above and below layers (Figure 10). It turned out there is no direct relationship between the formation of gas hydrates and sediment grain size fraction component and grain size.

## **The Special Sedimentary Structures Related to the Development of BSR**

### ***Structural slope-break zone***

Studies have shown that the structural slope-break zones are important tectonic units for gas hydrate development and accumulation. The structural slope-break zones generally have the characters of large terrain slope declination and sedimentary thickness. It was also close to the main gas source area, and the faults were relatively developed at its bottom. At the same time, the grain size of sediments was coarser in the

structural slope-break zones and the reservoir was developed widely, which was easy to capture a large number of nature gases. The evolution of northern continental marginal basin of South China Sea underwent two periods of rifting stage and the subsequent thermal subsidence stage. In the rifting stage, a great number of faults were developed, and large scale of syngenetic faults was often developed at the edge of the depression. These faults bounded the basin and ancient landforms. In the subsequent activities, these faults also controlled the fluctuation and evolution of the continental slopes, so that these areas are known as fault slope break. There were favorable conditions for the enrichment of gas hydrate in these fault slope break zones ([Figure 11](#)).

### ***Slump block***

The slump blocks are kind of sediment gravity flow. They were the mass flow and high-density flow induced by the directly or indirectly paroxysmal factors. Submarine slumps were common geological phenomenon on continental margin slopes by gravity flow. Since the late 1970s, scientists have already noticed the gas hydrate occurred in the submarine slumps, and found the slump blocks and BSR on the seismic profiles. Further research showed a close relationship between submarine landslides and the decomposition and formation of gas hydrate. The development of slump blocks provided appropriate temperature and pressure environment for the occurrence of gas hydrate; they were probably induction factors for the slump structures. Moreover, the slump itself may be a structural effect generated due to the decomposition of gas hydrate. BSR were usually presented in the contour current, turbidity current, and slump block depositional systems which with rapid sedimentation rate. These depositional systems were usually the products of the emergency with the bigger deposition rate and thickness. Therefore, they could become the favorable facies for gas hydrate accumulation ([Figure 11](#)).

### ***Sediment waves***

Deepwater sediment waves are one kind of the most distinct and frequently described submarine bedforms. It is been known that deep-water sediment waves are generated mainly by bottom currents (contour current) or turbidity currents ([Figure 12](#)). Since the contourites present coarse grain, good reservoir properties, sufficient gas source and excellent fluid migration condition, they were quite favorable for the formation of gas hydrate. Therefore, the strong contour current sedimentation areas were always the gas hydrate-rich region. The contourites were widely developed within the Pliocene and Quaternary strata at water depth ranging from 500m to 5,000m. There were obvious sheet waveform seismic facies in eastern Dongsha area at water depth of 3,100m to 3,300m, which speculated as the seismic facies response of large contour current migration sediment. The bottom of this sediment has obvious detachment surface, the reason was that when the contour current developed, it had strong erosion ability and jiggling transformation and redeposition to the early sediment. The frequent erosion interface may reflect the pulsation of contour current.

## **Models for Deposition and Accumulation of Gas Hydrate**

A typical gas hydrate deposition and accumulation model was summarized in the northern continental slope of SCS ([Figure 13](#)). Above the continental shelf, there is no BSR for the lack of temperature and pressure conditions of gas hydrates forming and preserving. In the continental shelf, BSR have closely relationship with the high deposition rate delta, and they mainly occurred in the delta front, so the HST formed by HNR is more suitable for the occurrence of gas hydrate compared to the NR and LNR. The source is mainly deep thermogenic gas and

migration vertically through the fault and gas chimney, the key to gas hydrate formation and accumulation lies in the transport and migration conditions. In the continental slope with obviously topographic slope, at the slope break belt, trough and diapirs district, BSR are mainly occurred in the slump body and often show discontinuous distribution topography caused by faults cutting. The sources are the mixed origin gas composed of the deep thermogenic gas and the shallow biogenic gas. In the continental rise and deep-sea area, BSR distributed in the submarine fans, turbidity current and contour current, and the lateral distribution is more continuous due to the smoother topography. For this region is lack of the faults and gas chimneys link the deep thermogenic gas, so the gas source is mainly from the shallow biogenic gas and through the lateral migration, and the critical condition for gas hydrate formation and accumulation is capping conditions.

As a whole, BSR has relationship with high deposition rate delta, slope break zones, deep-water gravity flow and contourite sediments. The rapid sediment unloading area can provide the favorable sedimentary reservoir and cover conditions for gas hydrate, especially the gravity flow below the slope, including slide block, slump block, sandy clastic current and turbidity current. The major BSR are located in the steep and roughness of relief with long-term successional uplift and subsidence on the seaward side. Since the depositional process was regression, it was favorable to the development of gravity-flow deposits in the slope zone, which can provide a suitable reservoir space for the formation of gas hydrates. In addition, a small number of BSR distributed in relatively simple and flat topography areas, where the water was deeper, just with gravity, flow was weak and bottom current was more activity.

### Conclusions

1. There is little inheritance of the BSR plane distribution in three sequences indicates that the BSR is dynamic rather than static, and the hydrates could not save underground for a long time, which is entirely different from the conventional oil and gas reservoirs. The overwhelming majority of BSR distribution regions are located in the areas with landscape changes steeply, the larger terrain variation, and long-term succession subsidence. Also there have a small amount of BSR distributed in the regions with relatively flat topography, but the water depth in these places are all over 2,000m.
2. Gas hydrates are often closely related with gravity flow, which mainly occurred in the contourites, gravity flow, several kinds of fans and the delta front. In the continental shelf, the key controlling gas hydrate formation and accumulation lies in the transport and migration conditions. In the continental slope with obviously topographic slope, at the slope break belt, trough and diapirs district, BSR are mainly occurred in the slump body and often shows discontinuous distribution topography caused by faults cutting. In the continental rise and deep-sea area, BSR distributed in the sediments of submarine fans, turbidity current and contour current, and the lateral distribution is more continuous due to the smoother topography. The critical condition for gas hydrate formation and accumulation is capping conditions.
3. The northern continental slope of SCS with an appropriate temperature and pressure match for the formation and occurrence of gas hydrates. The widely developed faults and diapir structures as gas migration pathways. They are closely related to the special geological bodies such as structural slope-break zone and slump bodies. The heat flow in the BSR distribution range is basically between  $65\text{Mw/m}^2 \sim 90\text{Mw/m}^2$ , and the value in the continental slope is relatively high with about  $75\text{Mw/m}^2 \sim 90\text{Mw/m}^2$ , whereas in the continental rise and deep sea area the value is slightly lower with about  $65\text{Mw/m}^2 \sim 80\text{Mw/m}^2$ .

## Acknowledgements

This work was supported by the National 973 Basic Research Program (Grant No. 2009CB219502), National Natural Science Foundation of China (Grant No. 41072084) and National 127 project (Grant No. GZH201100305-02-02). Thanks for the help from China Geological Survey Bureau, Guangzhou Marine Geological Survey and all the students in our workgroup. Thanks also are extended to all the people who provided us invaluable help.

## References Cited

- Diaconescu, C.C., R.M. Kieckhefer, and J.H. Knapp, 20001, Geophysical evidence for gas hydrates in the deep water of the South Caspian Basin, Azerbaijan: *Marine Petroleum Geology*, v. 18, p. 209-221.
- He, L.J., J.Y. Wang, X. Xu, J. Liang, H. Wang, and G. Zhang, 2009, Disparity between measured and BSR heat flow in the Xisha Trough of the South China Sea and its implications for the methane hydrate: *Journal of Asian Earth Sciences*, v. 34/6, p. 771-780.
- Kvenvolden, K.A., 1993, Gas hydrates, geological perspective and global change: *Reviews of Geophysics*, v. 31/2, p. 173-187.
- Makogon, Y.F., 2010, Natural gas hydrates—A promising source of energy: *Journal of Natural Gas Science and Engineering*, v. 2, p. 49-59.
- Matsumoto, R., B.J. Ryu, S.-R. Lee, S. Lin, S. Wu, K. Sain, I. Pecher, and M. Riedel, 2011, Occurrence and exploration of gas hydrate in the marginal seas and continental margin of the Asia and Oceania region: *Marine Petroleum Geology*, v. 28/10, p. 1751-1767.
- Mi L J, Yuan Y S, Zhang G C, et al. Characteristics and genesis of geothermal field in deep water area of the northern South China Sea. *Acta Petrolei Sinica*, 2009, 30(1): 27-32.
- Ruppel, C., G.R. Dickens, D.G. Castellini, W. Gilhooly, and D. Lizarralde, 2005, Heat and salt inhibition of gas hydrate formation in the northern Gulf of Mexico: *Geophysical Research Letters*, v. 32, p. 1-4.
- Ruppel, C., R. Boswell, and E. Jones, 2008, Scientific results from Gulf of Mexico Gas Hydrates Joint Industry Project Leg 1 drilling: Introduction and overview: *Marine Petroleum Geology*, v. 25/9, p. 819-987.
- Sain, K., and H. Gupta, 2012, Gas hydrates in India: Potential and development, *in* X. Zhao, W. Xiao, R. Hebert, and C. Wang, (eds.), Plate tectonics of Asia; geological and geophysical constraints: *Gondwana Research*, v. 22/2, p. 645-657.
- Su, X., F. Chen, X. Yu, and Y. Huang, 2005, A Pilot Study on Miocene through Holocene Sediments from the Continental Slope of the South China Sea in Correlation with Possible Distribution of Gas Hydrate: *Geoscience*, v. 19/1, p. 1-13.

Xu, W.Y., and C. Ruppel, 1999, Predicting the occurrence, distribution, and evolution of methane gas hydrate in porous marine sediments: *Journal of Geophysical Research*, v. 104/B3, p. 5081-5095.

Yu, X.H., Z.-J. Zhang, S. Su, F. Chen, and Y. Li, 2004, Primary Discussion On Accumulation Conditions For Sedimentation Of Gas Hydrate And Its Distribution In South China Sea: *Earth Science Frontiers*, v. 11/1, p. 311-315.

Zhang, Y., He, L.J., J.Y. Wang, X. Xu, Z. Sha, Y. Gong, H. Wang, and J. Liang, 2011, Heat flow pattern, base of methane hydrates stability zones and BSRs in Shenhu Area, northern South China Sea: *Acta Oceanologica Sinica*, v. 30/1, p. 59-67.



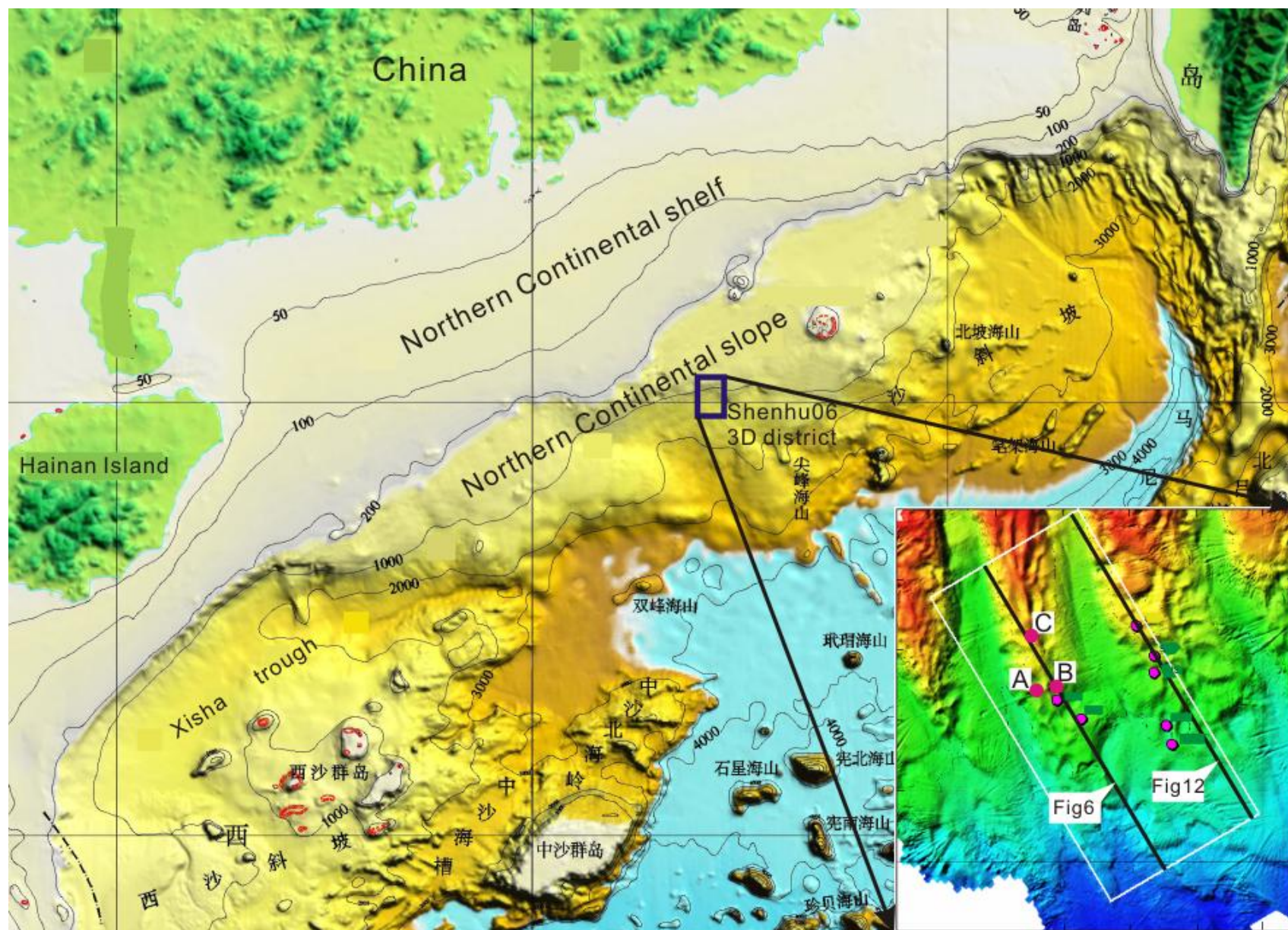


Figure 1. Geologic setting and topography of SCS.



(a)



(b)

Figure 2. Decompose of gas hydrate cores in Shenhu district of SCS: (a) site A, (b) site C.



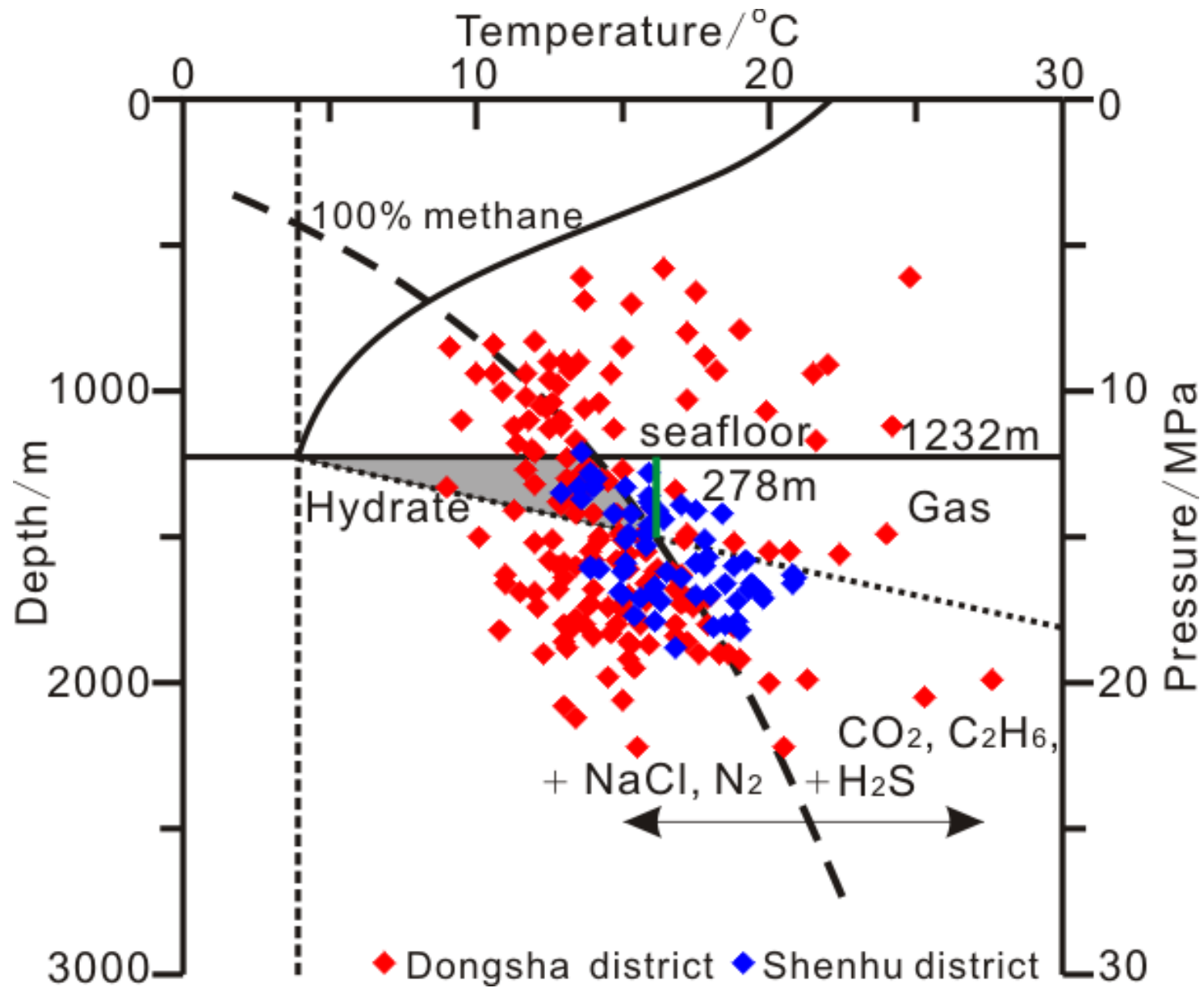


Figure 3. Temperature-pressure scatter diagram and phase equilibrium curve of SCS (The temperature-pressure data provided by Guangzhou Marine Geological Survey Bureau of China Geological Survey).

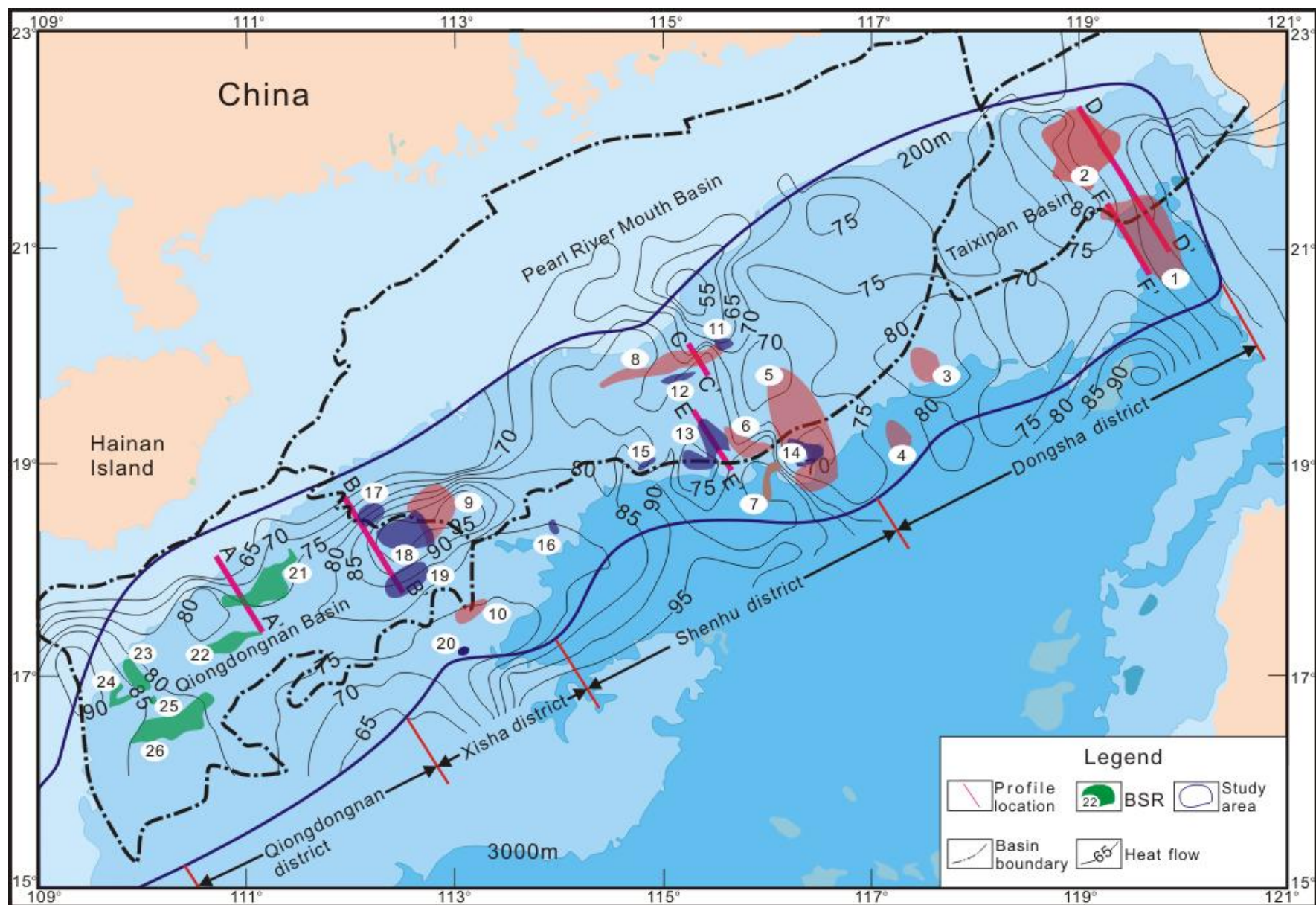


Figure 4. BSR distribution and regional heat flow value in the study area (The contour of heat flow distribution is according Zhang et al., 2011)  
BSR number: 1~10: sequence II; 11~20: sequence III; 21~26: sequence I.

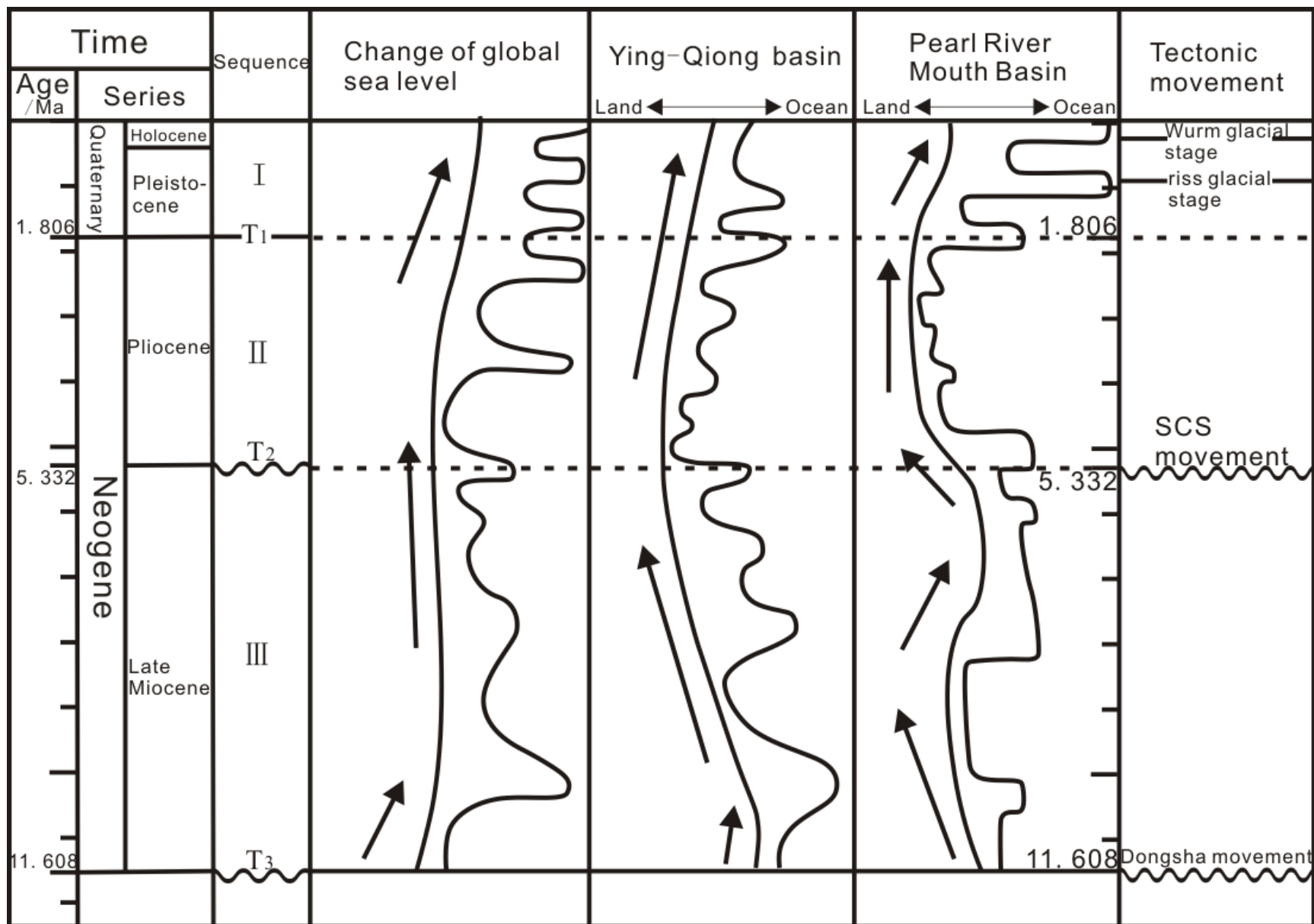


Figure 5. Sequence division of SCS since the Miocene.



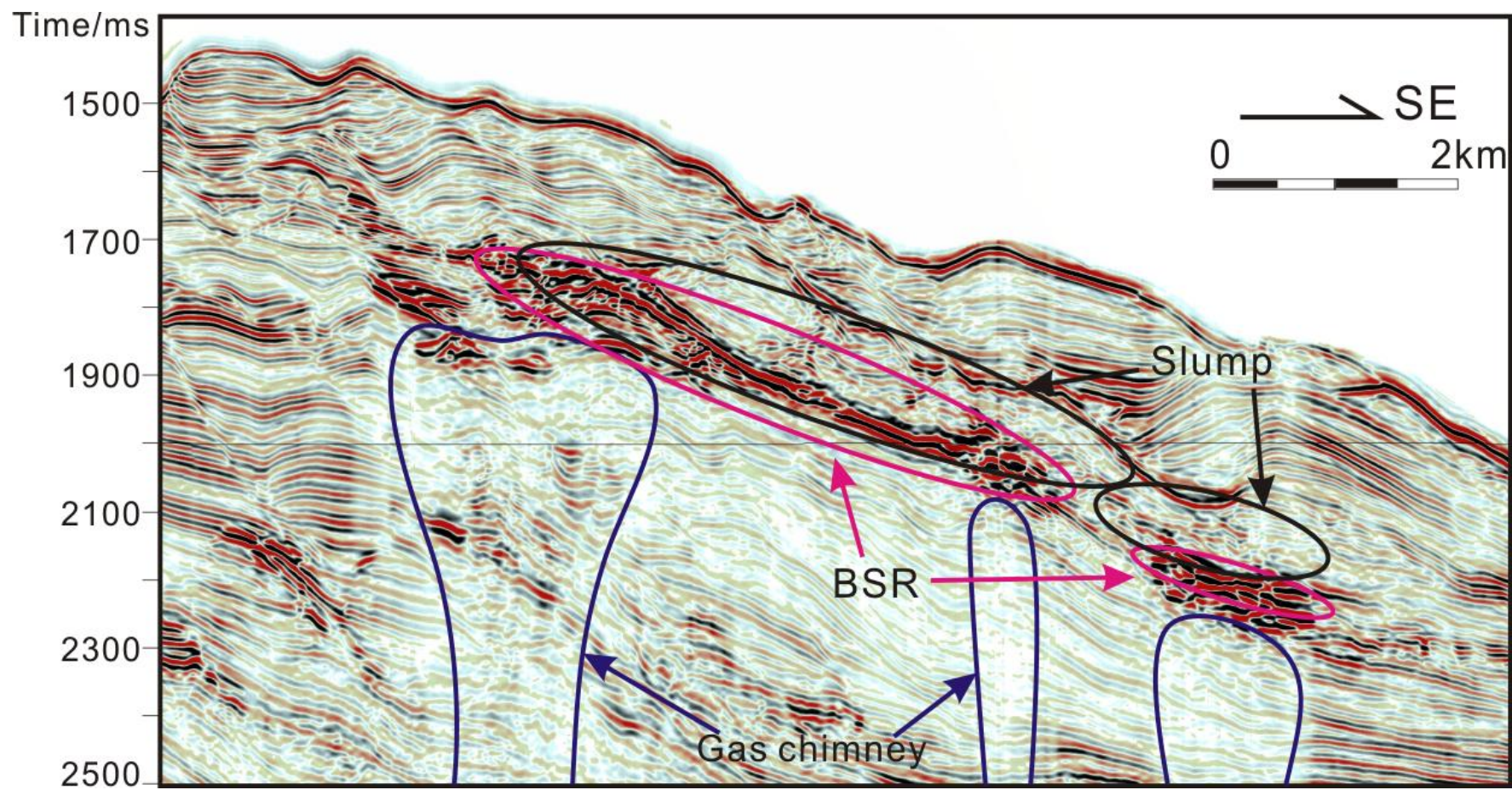


Figure 6. Typical seismic profiles of BSR in Shenhu district of SCS.

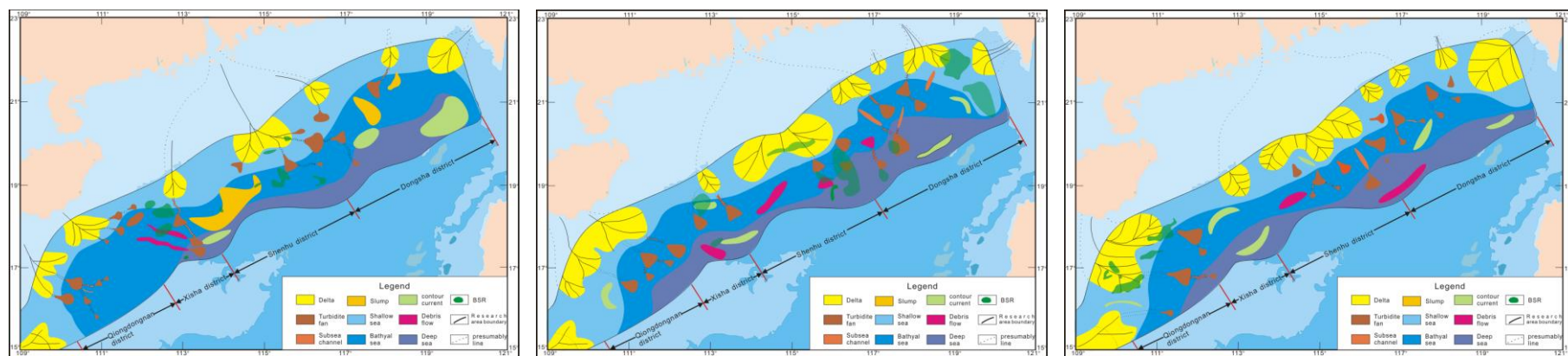


Figure 7. Depositional facies in each sequence of northern slope of SCS.

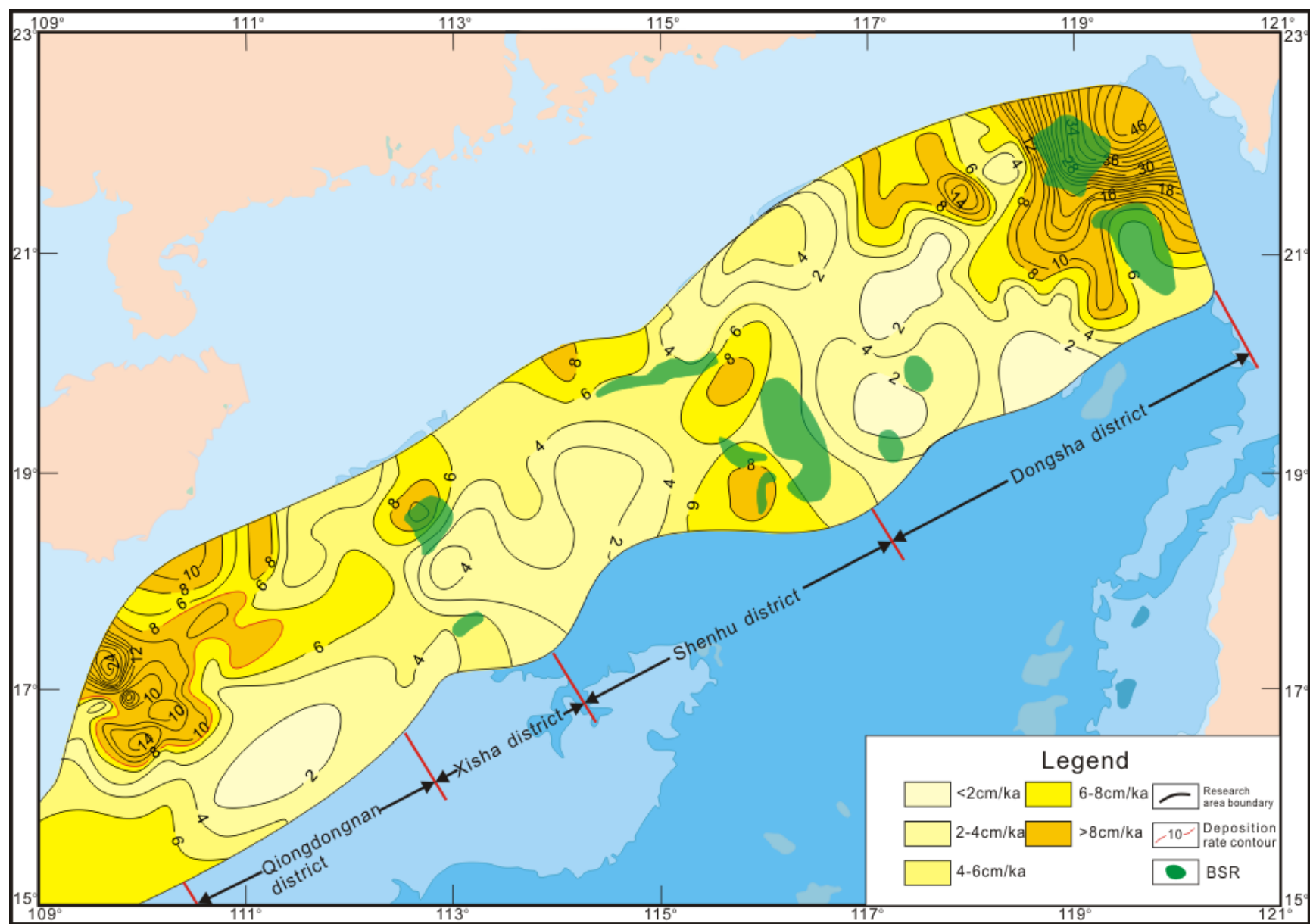


Figure 8. Deposition rate of sequence II.



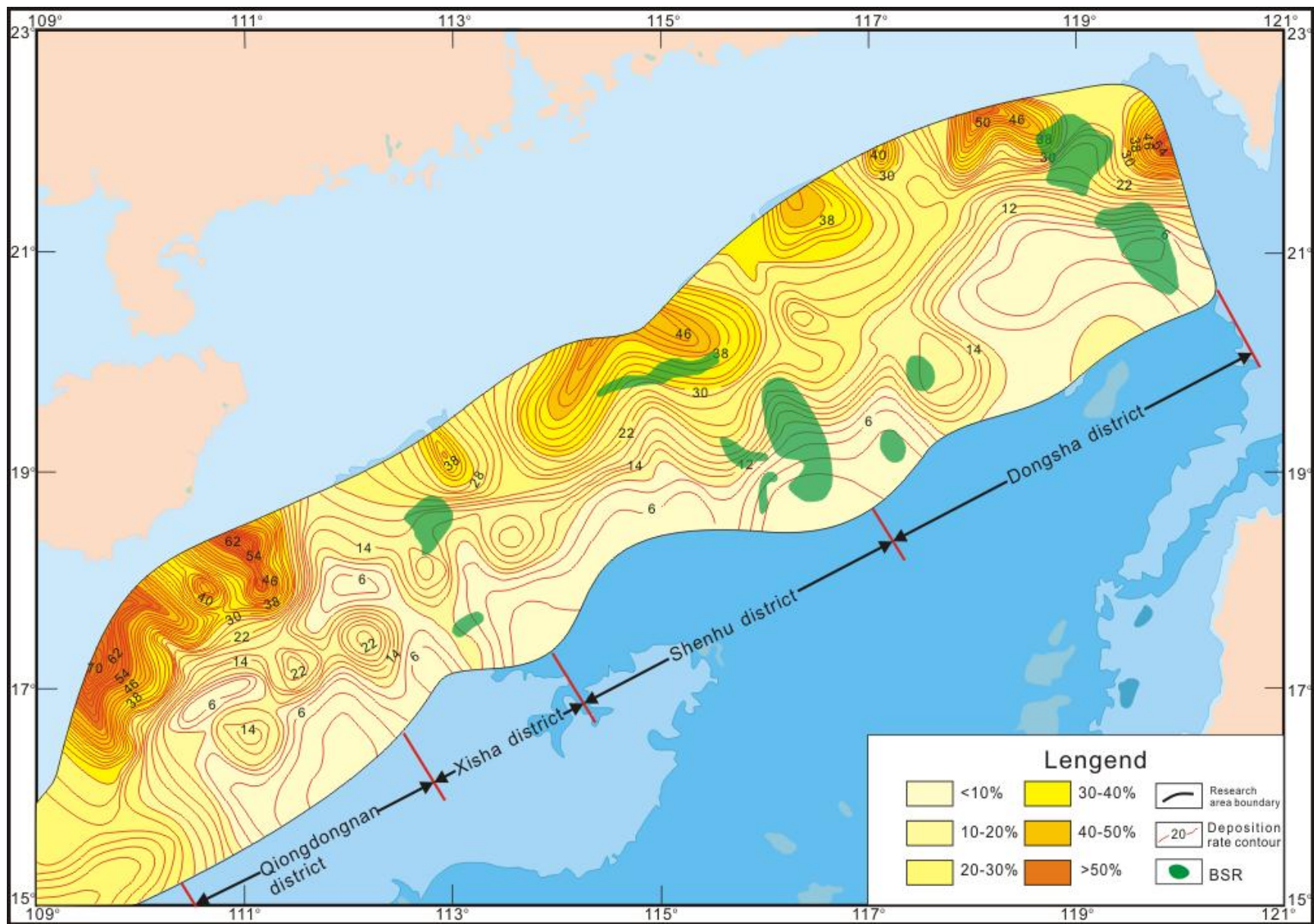
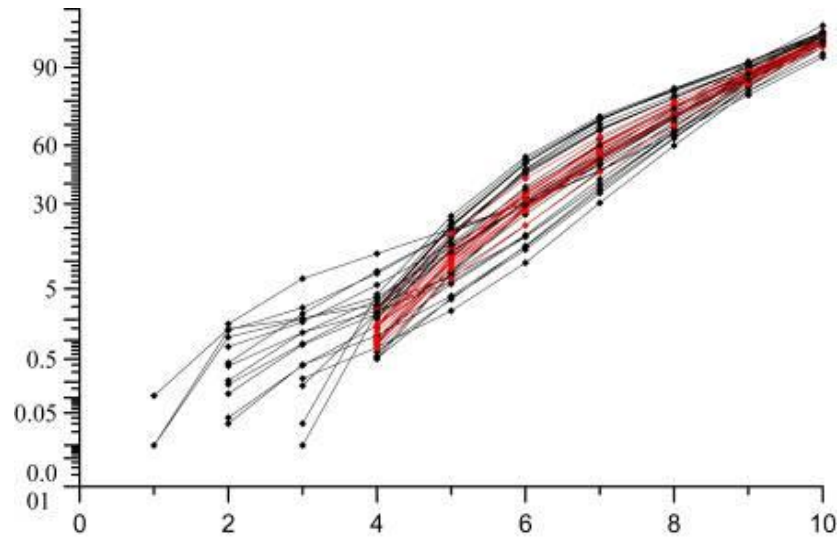
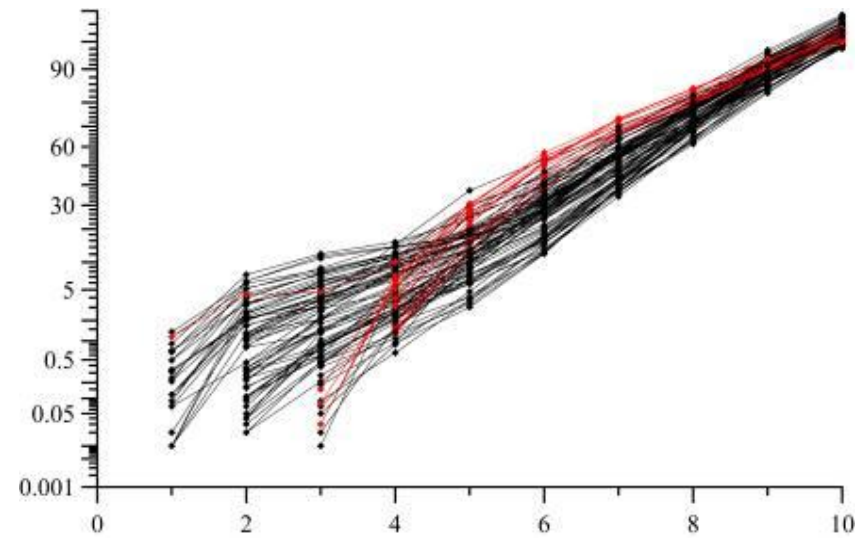


Figure 9. Sand content of sequence II.



(a)



(b)

Figure 10. Grain size probability curve of gas hydrate sites (the red is gas hydrate bearing layers): (a) site A, (b) site C.

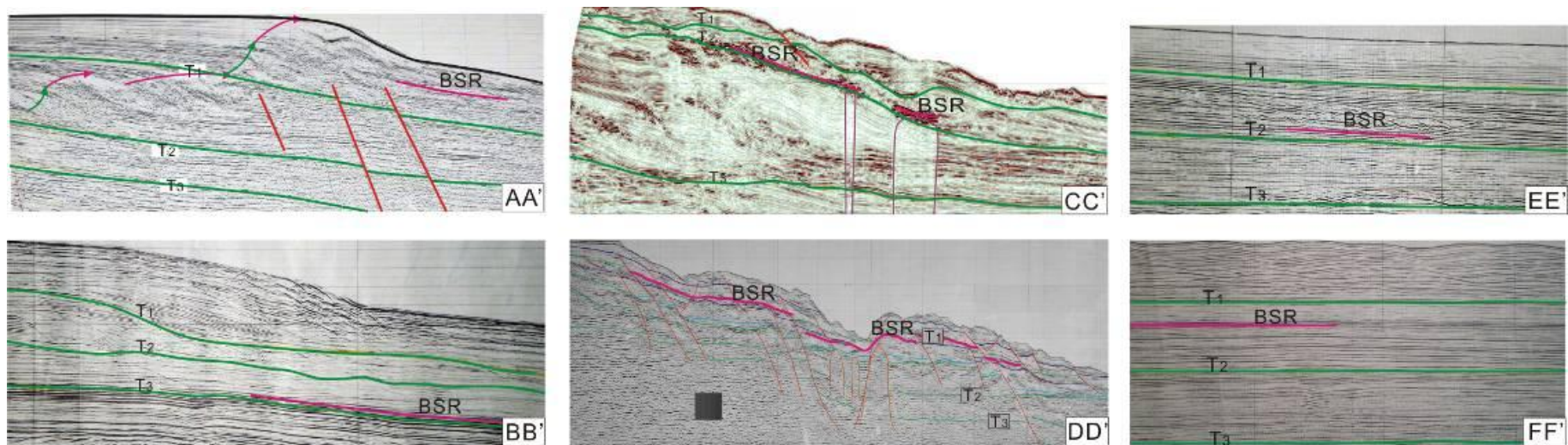


Figure 11. Typical seismic profiles in the northern continental slope of SCS. AA', BB': In the continental shelf, BSR have close relationship with the high deposition rate delta; CC', DD': In the continental slope with obvious topographic slope, BSR are mainly occurred in the slump body and have close relationship with gas chimneys, they often show discontinuous distribution topography caused by faults cutting; EE', FF': In the continental rise and deep sea area, BSR showed a close relationship with turbidity current and contour current.



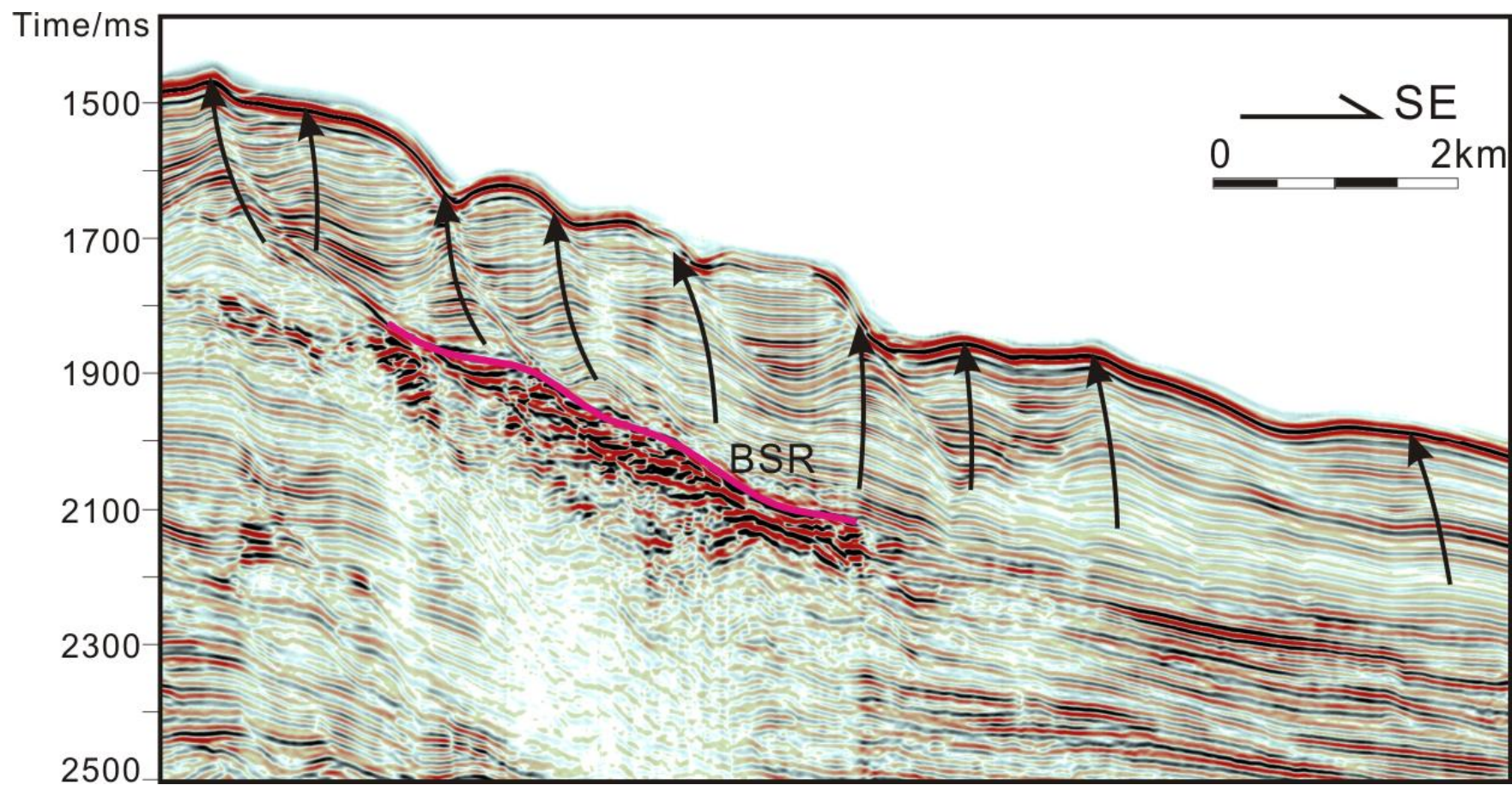


Figure 12. Gravity flow sediment waves in Shenhu district of SCS.

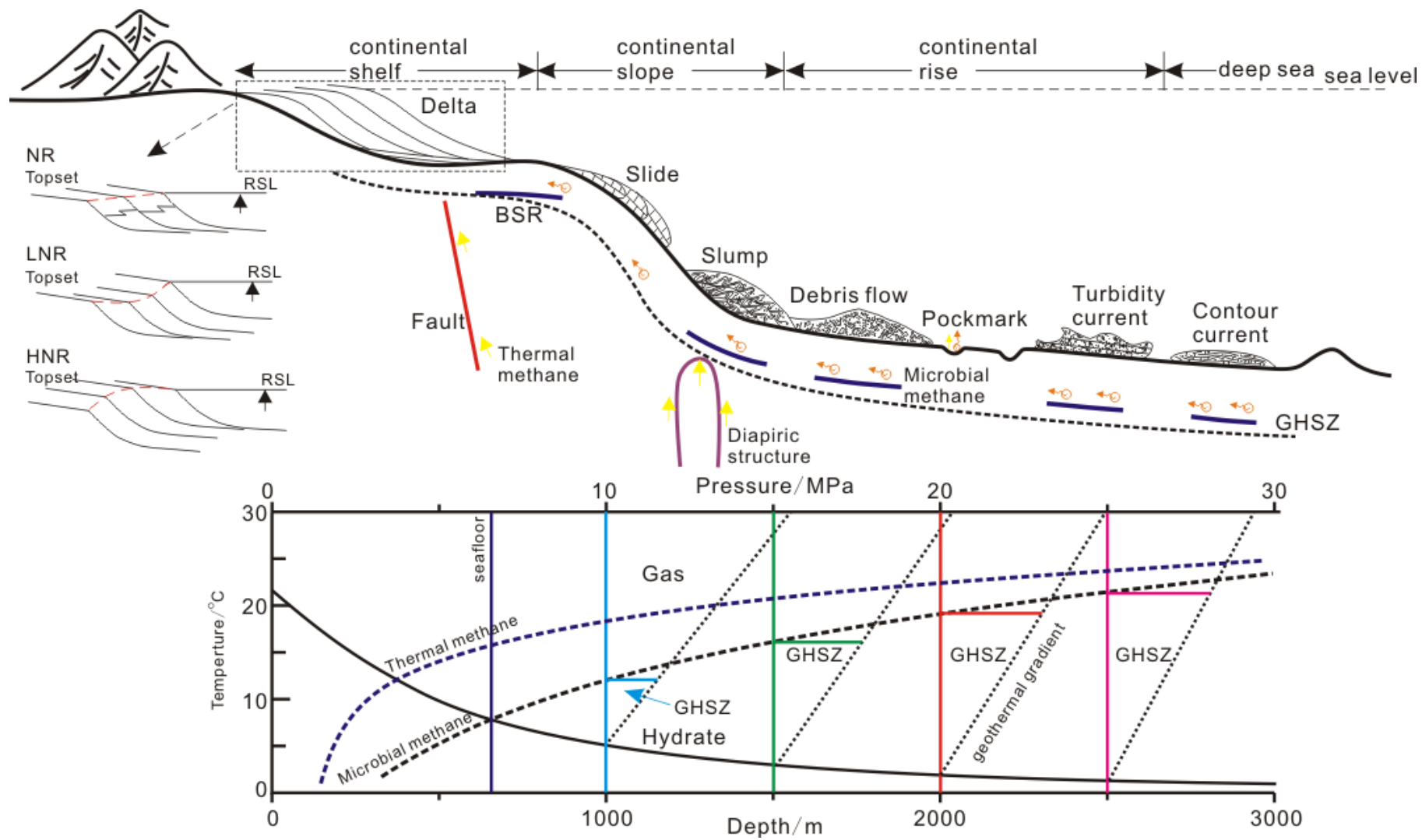


Figure 13. Model of gas hydrate accumulation in the northern continental slope of SCS.

	BSR No.	Depositional facies	Deposition rate (cm/ka)	Sand content (%)
Sequence II	1	Delta	4~12	4~18
	2	Shallow sea	12~44	20~40
	3	Turbidite	2~4	10~12
	4	Deep sea	2~4	2~4
	5	Turbidite	4~6	2~20
	6	Debris flow	6~8	10~22
	7	Deep sea	8~10	2~6
	8	Delta	4~6	28~40
	9	Contour current	2~10	12~24
	10	Deep sea	4~6	6~10
Sequence III	11	Delta	4~6	26~32
	12	Shallow sea	4~12	22~26
	13	Bathyal sea	2~4	10~14
	14	Bathyal sea	2~4	6~10
	15	Slump	1~4	16~18
	16	Slump	2~4	16~18
	17	Shallow sea	4~6	16~20
	18	Bathyal sea	2~4	10~20
	19	Debris flow	2~4	8~12
	20	Deep sea	<2	6~8
Sequence I	21	Delta	6~10	4~46
	22	Shallow sea	8~20	8~24
	23	Delta	18~32	36~46
	24	Delta	22~30	36~46
	25	Delta	16~18	40~48
	26	Delta	12~18	24~48

Table 1. Sedimentary factors of BSR distribution region in each sequence.

Site	Core segment	Grain size fraction component content (%)		
		sand	silt	clay
Site A	upper layers	2.83	71.98	25.19
	gas hydrate bearing layers (191~225m)	1.40	73.94	24.68
	lower layers	2.27	72.76	24.98
Site C	upper layers	5.49	67.76	26.3
	gas hydrate bearing layers (155~177m)	4.24	77.38	18.38
	lower layers	1.56	79.11	19.34

Table 2. Grain size fraction component content of the coring segment.