ZHU Chaoqi, CHENG Sheng, ZHANG Minsheng, DING Dong, CHEN Jiangxin, LU Jing'an, SHAN Hongxian and JIA Yonggang, 2018. Results from Multibeam Survey of the Gas Hydrate Reservoir in the Zhujiang Submarine Canyons. *Acta Geologica Sinica* (English Edition), 92(supp.2):135-138.

Results from Multibeam Survey of the Gas Hydrate Reservoir in the Zhujiang Submarine Canyons

ZHU Chaoqi[1, 2], CHENG Sheng[1], ZHANG Minsheng[1, 2], DING Dong[3], CHEN Jiangxin[4], LU Jing'an[5], SHAN Hongxian[1, 2] and JIA Yonggang[1, 2*]

1 *Shandong Provincial Key Laboratory of Marine Environment and Geological Engineering (Ocean University of China), Qingdao, Shandong 266100,China*
2 *Laboratory for Marine Geology, Qingdao National Laboratory for Marine Science and Technology, Qingdao, Shandong 266061,China*
3 *College of Marine Geosciences, Ocean University of China, Qingdao, Shandong 266100,China*
4 *Qingdao Institute of Marine Geology, China Geological Survey, Qingdao, Shandong 266071,China*
5 *Guangzhou Marine Geological Survey, China Geological Survey, Guangzhou, Guangdong 510075,China*

1 Introduction

Natural gas hydrate is considered a potential source of energy, which formed by methane and water in high pressure and low temperature (Beaudoin et al., 2014; Jia et al., 2016; Zhu et al., 2017a). Global estimates of methane carbon in gas hydrate varies greatly. The median estimate of 5 000 Gigatonnes of carbon in gas hydrate represents a significant fraction of the world's organic carbon, and is of similar magnitude to the combined estimates of carbon in traditional global fossil fuel resources (Beaudoin et al., 2014). In 2007, China's first gas hydrate drilling expedition was carried out in the South China Sea and eight sites were visited in the Zhujiang submarine canyons of Shenhu area, showing a new gas hydrate province (Zhang et al., 2007). Report from China Geological Survey notes the prospect natural gas hydrate resources of more than 1000 million tons of oil equivalent in China. In 2017, the China's first offshore gas hydrate production test in Zhujiang submarine canyons was conducted with total gas production of 3.09×10^5 m^3, making a world record of the longest continuous duration of gas hydrate production and maximal gas yield (Li et al., 2018).

Previous multibeam survey of the gas hydratereservoir in the Zhujiang submarine canyons are common before the gas hydrate production test (Chen et al., 2016; He et al., 2014; Li et al., 2014). However, our survey was conducted in August 2017, just after the production test. In the event of significant change during the production test, it would indicate to some extent.

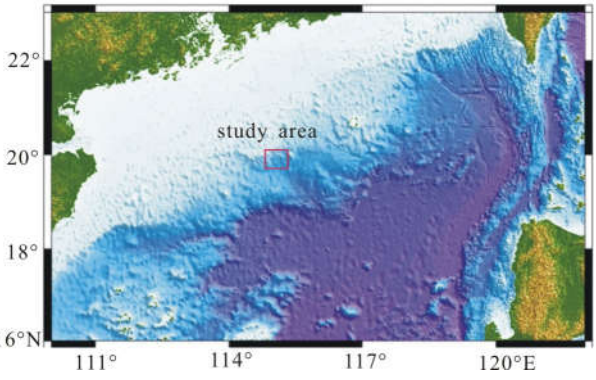

Fig.1 Map showing northern South China Sea and study area

2 Study Area and Methods

2.1 Study area

The study area (115°-115.5°E, 19.7°-20.2°N) covers the major gas hydrate reservoir in the Zhujiang Submarine Canyons, blanketing the China's first gas hydrate drilling sites in 2007 and the first offshore gas hydrate production test site in 2017. The Fig.1 shows the northern South China Sea and the study area.Submarine canyons are located in the Baiyun Sag of the Pearl River Mouth Basin along the northern margin of the South China Sea. Two reversed currents are found here. One is the South China Sea Warm Current (NW-NE), and the

* Corresponding author. E-mail:yonggang@ouc.edu.cn

other is South China Sea Branch of Kuroshio (Zhu et al., 2010).

2.2 Instruments and methods

Data acquisition was supported by NSFC Open Research Cruise in August 2017, funded by Shiptime Sharing Project of NSFC. This cruise was conducted onboard R/V "Dongfanghong 2" by Ocean University of China. Multibeam echosounder EM 122 was used to obtain the seafloor geomorphology and seawater information. The beam angle was set 120°. CARIS HIPS/SIPS was used for post processing in seafloor geomorphology and FMMidwater was used for post processing in seawater information.

3 Results and Discussions

3.1 Canyon geomorphology and inclination

Seven canyons are identified in the bathymetric chart with water depth from 500 m to 1700 m (Fig.2). Cross section of canyons change from V-shape to U-shape. These canyons are more than 25 km long and measures about 6 km in width. Cutting depth of these canyons increases firstly and then decreases, with average of about 180 m and maximum value of 350 m. Accordingly, inclination of valley bottom along the canyons increases firstly and then decreases, with gradient of 2.0-3.5° in the upper part and 1.0-1.5° in the lower part. However, inclination of ridges along the canyons changes little and the gradient is about 1.6-1.8°.

The maximum inclination of side wall is about 20° and the average is about 7.5°. It is worth noting that the gradient of west side is smaller than that of east side for most canyons. The average gradient of west side wall is about 6.6° and the gradient of east side is 8.5°. Canyon wall morphology and sediment draping respond to the currentward or leeward position of each wall (Lastras et al., 2011) and gradient of currentward slope is generally smaller than that of leeward slope. In this way, it is inferred that there is a stronger E-W current. The internal wave and South China Sea Branch of Kuroshio from Luzon Strait are nearly in this direction. If these currents lead to smaller gradient of currentward side, there will be a tendency for canyons to migrate westwards. However, the seismic profiles and borehole information in this area show the northeastward migrating submarine canyons and this migration is attributed to the South China Sea Warm Current (Zhou et al., 2015; Zhu et al., 2010). This contradiction indicates complex mechanism of canyon migration in the Zhujiang Submarine Canyons. The

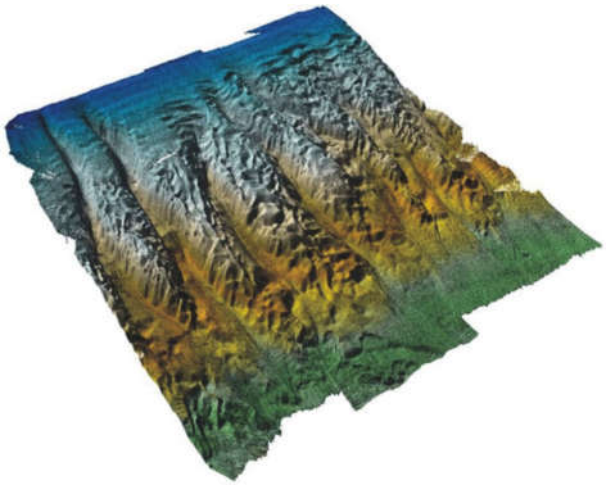

Fig. 2. Bathymetric chart of submarine canyons

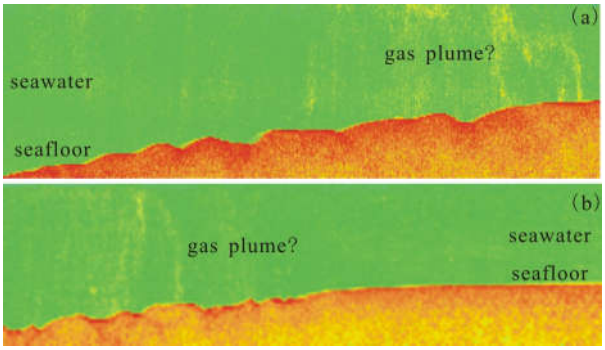

Fig. 3. Suspected gas plumes identified from multibeam survey

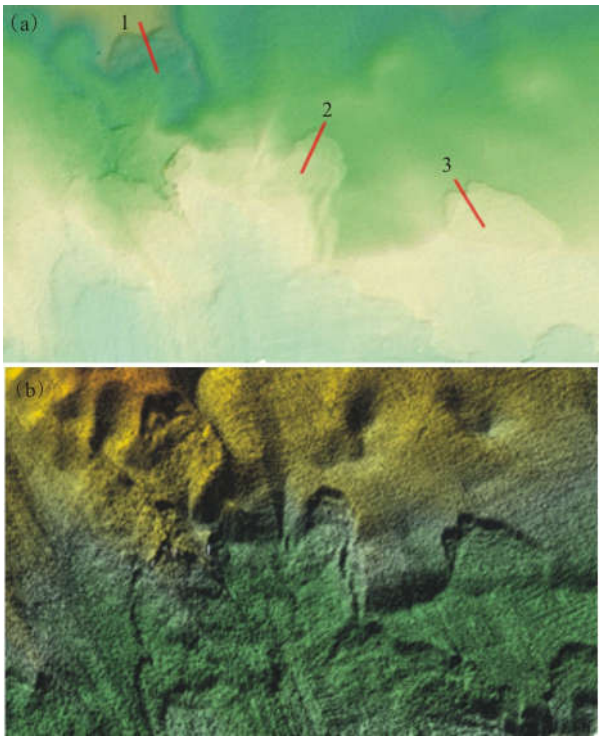

Fig. 4. 2D (a) and 3D (b) bathymetric chart showing the submarine landslid

migration of submarine canyons and evolution of gradients is the comprehensive results from bottom currents (eg. Nanhai warm current and internal wave) and gravity currents (eg. turbidity current), as well as geological conditions.

3.2 Gas plume and submarine landslide

Gas plumes and submarine landslides are also identified from this multibeam survey results. We found two suspected gas plumes (Fig.3). Beams are shown in R-stack mode in the Fig.3 and the yellow part in the seawater may indicate the gas plumes. However, there are more evidences needed to confirm these gas plumes.

Little gas plumes were found before in the gas hydrate reservoirs of the north South China Sea. However, widespread gas plumes were found on the northern US Atlantic margin (Skarke et al., 2014) and Svalbard (Berndt et al., 2014; Wallmann et al., 2018). The difference on gas plumes in different places may due to the geological conditions (e.g. fluid and fault activities) and marine environments (e.g. sea water temperature and pressure).

Submarine landslide is one of most important marine geohazards (Jia et al., 2016; Zhu et al., 2017b). We found submarine landslides on the tails of the canyons (Fig.4), which were already exist before the hydrate production test. Three selected sections cross the scarp (red lines in Fig.4a) show the average wall height of 50-60 m. The slope of the undeformed seafloor here is less than 2° and thus we inferred the landslide slope is about 2° which is much smaller than terrestrial landslides. Three dimensional seismic studies of hazard-related features in this area (Chen et al., 2016) show that buried channel complexes and gas chimneys underlie these slumps. Moreover, abundant fractures (or faults) were found here (Chen et al., 2016). These aforementioned structures and deposits are likely to be linked to the submarine landslides and are considered possible risk factors for seafloor installations.

4 Conclusions

Results from multibeam survey of the gas hydrate reservoir in the Zhujiang Submarine canyons show (1) cross section of canyons change from V-shape to U-shape, with the length of 25-30 km, width of 6 km, and the maximum downcutting depth of about 350 m, (2) Gradient of valley line is 2.0-3.5° in the upper slope and 1.0-1.5° in the lower slope, and gradient of the ridge line is 1.6-1.8°. (3) Maximum gradient, perpendicular to valley line, is 20° and the gradient of the western side wall is smaller than that of eastern side wall. (4) Migration of submarine canyons and evolution of gradients may be the comprehensive results from bottom currents (eg. Nanhai warm current and internal wave) and gravity currents (eg. turbidity current), (5) submarine landslides in the toe of the canyons within gradient 2° and suspected gas plumes are identified.

Acknowledgment

This study was sponsored by the National Natural Science Foundation of China (Grant No. 41831280, 41427803, 41606066, 41606077) and Project for Offshore Production Test of Gas Hydrate (2018C-03-186). The authors were grateful to Song Zhenjie for their great help in this survey.

References

Beaudoin, Y. C., Waite, W., Boswell, R., Dallimore, S. R., 2014, *Frozen Heat - A Global Outlook on Methane Gas Hydrates*. *Volume 1*, Birkeland Trykkeri, Norway, 1-77.

Berndt, C., Feseker, T., Treude, T., Krastel, S., Liebetrau, V., Niemann, H., Bertics, V.J., Dumke, I., Duennbier, K., Ferre, B., Graves, C., Gross, F., Hissmann, K., Huehnerbach, V., Krause, S., Lieser, K., Schauer, J., Steinle, L., 2014. Temporal constraints on hydrate-controlled methane seepage off Svalbard. *Science*, 343(6168): 284-287.

Chen Duanxin, Wang Xiujuan, Völker, D., Wu Shiguo, Wang Lei, Li Wei, Li Qingping, Zhu Zhenyu, Li Cuilin, Qin Zhiliang, Sun Qiliang, 2016. Three dimensional seismic studies of deep-water hazard-related features on the northern slope of South China Sea. *Marine and Petroleum Geology*, 77: 1125-1139.

Jia Yonggang, Zhu Chaoqi, Liu Liping, Wang Dong, 2016. Marine geohazards: review and future perspective. *Acta Geologica Sinica* (English Edition), 90(4): 1455-1470.

Lastras, G., Canals, M., Amblas, D., Lavoie, C., Church, I., De Mol, B., Duran, R., Calafat, A.M., Hughes-Clarke, J.E., Smith, C.J., Heussner, S., 2011. Understanding sediment dynamics of two large submarine valleys from seafloor data: Blanes and La Fonera canyons, northwestern Mediterranean Sea. *Marine Geology*, 280(1-4): 20-39.

Li Jinfa, Ye Jianliang, Qin Xuwen, Qiu Haijun, Wu Nengyou, Lu Hailong, Xie Wenwei, Lu Jingan, Peng Fei, Xu Zhenqiang, Lu Cheng, Kuang Zenggui, Wei Jiangong, Liang Qianyong, Lu Hongfeng, Kou Beibei, 2018, The first offshore natural gas hydrate production test in South China Sea, *China Geology*, 1(1):5-16.

Li Wei, Wu Shiguo, Voelker, D., Zhao Fang, Mi Lijun, Kopf,

A., 2014. Morphology, seismic characterization and sediment dynamics of the Baiyun Slide Complex on the northern South China Sea margin, *Journal of the Geological Society* 171(6):865-877.

Skarke, A., Ruppel, C., Kodis, M., Brothers, D., Lobecker, E., 2014. Widespread methane leakage from the sea floor on the northern US Atlantic margin. *Nature Geoscience*, 7(9): 657-661.

Wallmann, K., Riedel, M., Hong, W. L., Patton, H., Hubbard, A., Pape, T., Hsu, C. W., Schmidt, C., Johnson, J. E., Torres, M. E., Andreassen, K., Berndt, C., Bohrmann, G., 2018. Gas hydrate dissociation off Svalbard induced by isostatic rebound rather than global warming. *Nature Communications*. 9: 83

Zhang Haiqi, Yang Shengxiong, Wu Nengyou, Su Xin, Holland, M., Schultheiss, P., Rose, K., Butler, H., Humphrey, G., Team, G.S., 2007, Successful and surprising results for China's first gas hydrate drilling expedition. *The methane hydrate newsletter, Fire in the Ice*, 7(3): 6–9.

Zhou Wei, Wang Yingmin, Gao Xianzhi, Zhu Weilin, Xu Qiang, Xu Shang, Cao Jianzhi, Wu Jin, 2015. Architecture, evolution history and controlling factors of the Baiyun submarine canyon system from the middle Miocene to Quaternary in the Pearl River Mouth Basin, northern South China Sea. *Marine and Petroleum Geology*, 67: 389-407.

Zhu Chaoqi, Jia Yonggang, 2017a. In-situ observations of engineering geological environment during hydrate production tests in deepwater, *Acta Geologica Sinica* (English Edition), 91(s1):193-194.

Zhu Chaoqi, Zhang Minsheng, Liu Xiaolei, Wang Zhenhao, Shen Zhicong, Zhang Bowen, Zhang Xiatao, Jia Yonggang, 2017b, Gas hydrates: production, geohazards and Monitoring, *Journal of Catastrophology*, 32(3):51-56. (in Chinese)

Zhu Mangzheng, Graham, S., Pang Xiong, McHargue, T., 2010. Characteristics of migrating submarine canyons from the middle Miocene to present: Implications for paleoceanographic circulation, northern South China Sea. *Marine and Petroleum Geology*, 27: 307-319.