Geomorphology and tectonic interpretation of Zhujiang Submarine Canyon, in the northern South China Sea

Xibin Han, Jiabiao Li, Fengyou Chu, Jun Li
Key Laboratory of Submarine Geosciences of SOA
Hangzhou, 310012 China
Email: xibinhan@126.com

Fanlin Yang
Shandong University of Science and Technology
Qingdao, China
Email: yang723@163.com

***Abstract*-Zhujiang Submarine Canyon, a large submarine canyon, is located in the northern South China Sea, extending to 300 km southeastward from the shelf break off Zhujiang River estuary, down to deep-sea basin. Based on the full-coverage multi-beam seabed terrain data, the subtle topographic features of Zhujiang Submarine Canyon are analyzed. According to the morphology, trend, and bottom axial gradient, Zhujiang Submarine Canyon is divided into upper, middle and lower segments and deep-sea fan. On the basis of geomorphology, tectonic interpretation indicates that Zhujiang Submarine Canyon is mainly affected by the northeast-trending faulted basin and northwest-trending fault belt since Mesozoic, followed by the east-west-trending fault belt. Zhujiang Submarine Canyon maybe formed by the continuing thermal subsidence and fault depression of northern South China Sea margin caused by South China Sea spreading based on the collision between India-Australian plate and Eurasian plate. The submarine canyon becomes more narrow and deeper at the entrance because of the submarine volcanoes formed by the volcanic eruptions in Neogene. Zhujiang Submarine Canyon is continual eroded and filled by the cyclical sea level changing and massive sediment carried by Zhujiang River. The thick sediments, slump layer and developed fracture are conducive to migration, aggregation and accumulation of hydrocarbon. And the surface hydrocarbon spill formed the seabed pockmark structure on the north slope of the submarine canyon.**

Keywords- South China Sea; Zhujiang Submarine Canyon; Geomorphology; multi-beam; tectonic interpretation

I. INTRODUCTION

Submarine canyon, the long and narrow seabed negative terrain, greatly reduced the distance and changed the migration modes of the terrigenous sediments transferring from shelf, slope to the deep sea[1]. So they become the important channel and sedimentation areas of rich organic debris flow [2, 3].

Zhujiang Submarine Canyon locates in the northern slope break belt of the northern South China Sea, about 300km long (see Figure 1). It mainly falls on the Baiyun Sag, one of the biggest sags in the Pearl River Mouth Basin. It has huge potential of oil and gas exploration with thick sedimentary body and a number of different geological history low deep-water fan[4]. Zhujiang Submarine Canyon has an important contribution to the hydrocarbon accumulation of the Baiyun Sag. However the canyon itself has not yet been studied systematically. In this paper, the canyon's subtle topographic features are described and its tectonic features are interpreted in order to study the controlling factors on the formation and evolution.

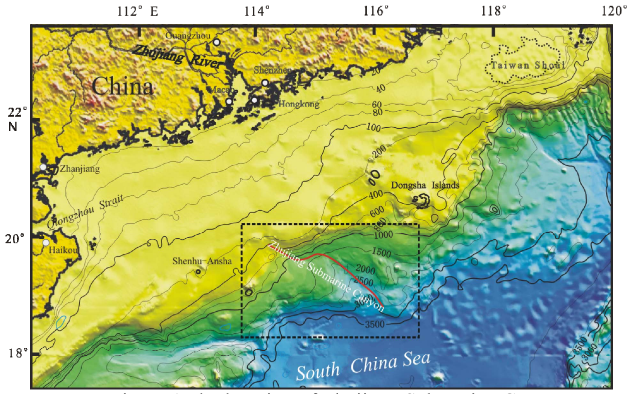

Figure 1. the location of Zhujiang Submarine Canyon

II. Materials and methods

The whole covering precise multi-beam seabed terrain data are acquired at this sea area in 2003 and 2005 surveyed the Second University of Oceanography. The ship borne multi-beam system consists of Elac Bottom Char MKII on the ship "Haijian No.49", SeaBat on the ship "Xiang Yang Hong No. 14," and SeaBeam on the ship "Ocean No.1". In which the operating frequency of the Elac Bottom multi-beam system is 50kHz, each Ping containing 126 beams, beam width of 1.5°×1.5°, the largest sector width of 150 °. The SeaBat operating frequency is 240kHz, each Ping containing 100 beams, beam width of 1.5°×1.5°, the largest sector width of 150 °. SeaBeam multi-beam system operating frequency of 12kHz, each Ping containing 151 beams, beam width of 2°× 2°, the largest sector width of 150°.

After the processing of parameters calibration, data correction and error management, the Multi-beam data are mapped three-dimensional geomorphologic map in the software Surfer version 8.0 (assuming the irradiation light from southeast, 45 ° with horizontal). The profile is cut along the canyon axis direction.

Based on the geomorphologic map, the tectonic map is deciphered referring to the other articles.

III. GEOLOGICAL BACKGROUND

The South China Sea Continental Margin is located at the junction of India-Australia Plate, Europe-Asia Plate and Pacific Plate, gripped in the Tethyan tectonic domain and the Pacific tectonic domain, not only retained the the wealth information from continental margin conjugated rifting to the sea basin spreading, but also experienced the change from the active continental margin to the passive margin. Northern

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South China Sea continental margin is part of it, the underwater extension of the southern China. It is about 1600km long and 300~400km wide, from Taiwan Strait to the Yinggehai Basin southwestern Hainan Island. Many oil and gas wells have been discovered here since 2001. So it is the key natural gas hydrate areas of investigation and research[5].

The study area is mainly affected by the northern South China Sea warm current and the South China Sea branch of Kuroshio, turned to west till 114.5 ° E since 18 ° N, 116 ° E, which maximum flow rate of up to 144cm/s in winter, up to 80cm/s in summer. Under the joint action of wind stress and topography of the northern South China Sea, the South China Sea Warm Current and the Kuroshio branch form a perennial cold cyclonic eddy around Zhujiang Submarine Canyon, accompanied with upwelling[6]. The Zhujiang River is the main river into the northern South China Sea. The Zhujiang River Diluted Water disperses in the surface near the river estuary and spread to the sea as far as up to 21 ° N near the Dongsha Islands carrying large amounts of sediment, nutrients into the northern South China Sea.

IV. RESULTS

A. The overall shape of Zhujiang Submarine Canyon

Zhujiang Submarine Canyon begins at 200m water depths and ends at 3600m water depth (18 ° 42'N, 116 ° E) in the northern slope of South China Sea, 300km long and 20-120m wide, with ensemble direction southeast. At its head many gullies developed on the broad shelf-slope broken belt, two great branches into the valley from two sides at middle (see Figure 2).

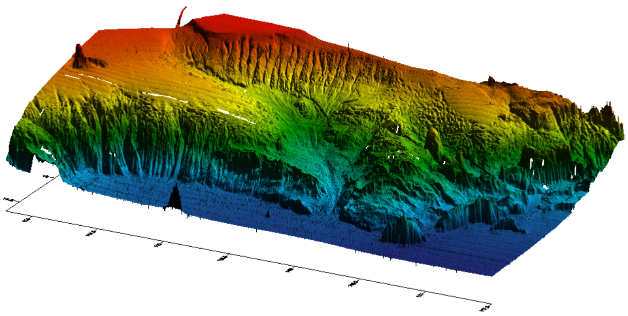

Figure 2. the three-dimensional diagram of Zhujiang Submarine Canyon (assuming the irradiation light from southeast, 45 ° with horizontal, blank areas for vacant data)

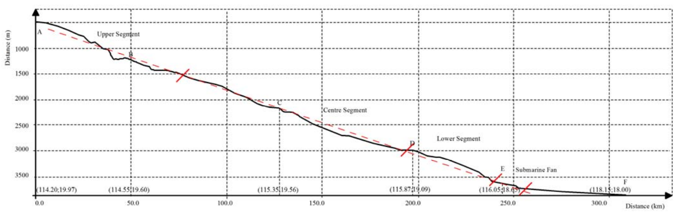

Figure 3. The Axial cross-section of Zhujiang Submarine Canyon

Axial cross-section shows that the overall slope of Zhujiang Submarine Canyon is gentle with 0.6 ° gradient calculated through linear regression method (see Figure 3), which is less than the gradient of San Antonio Submarine Canyon (2-6.3°) and Save Submarine Canyons (1.7°) in active continental margin[7] and more than the gradient of Zaire Submarine Canyon（0.1°-0.5°）in passive continental margin [8].

The overall curvature (the length of the canyon/the length of straight-line from its head to tail) is small bending degree with 1.1 in Zhujiang Submarine Canyon. The geomorphological features in both sides canyon are very different, with steep canyon wall and big gullies on the right side and eroded obvious, while more moderate slope and smaller gullies on the left. Based the morphology, trend and the valley bottom gradient, Zhujiang Submarine Canyon is divided into four segments: upper segment, centre segment, lower segment and submarine fan（see Figure 3）.

B. The upper segment of Zhujiang Submarine Canyon

The upper segment of the Pearl River canyon is situated in the fault shelf-slope broken belt at water depth of 500~1500m. With steep gradient and great throw, the belt trends north-east-east to 160km long. Main deep incised gullies are 17 on the belt with depth of 100m-300m, 6.8° gradient and width of 2km-8km. And new gullies inherit and reworked the old ones. Some slip mass and collapse accumulations obviously exist on the foot of the shelf-slope broken belt (see Figure 2).

The head of the canyon has been eroded to northwest since 1000m water depth till 200m water depth, with the "V"-shaped and a width of 30km. But the both slippery sides walls are asymmetry, less water depth changing on the left, while the changing up to 750m. The bottom terrain irregular with small basins, incised valleys and terraces.

C. The centre segment of Zhujiang Submarine Canyon

Extending southeast 110km from 1500m water depth to 3000m depth, the centre segment becomes widen to 60km, even to 120km wide, formed broader “V” shape section with slow gradient. But the steep scarps developed on the right valley wall and gullies incised on the canyon bottom adjacent with 200m high ridges. A big branch formed between the uplift at the bottom of the shelf-slope broken belt and a submarine terrace in the northwestern canyon, with small gulches. On its complex landform, a lugboss is 100m high. Between the terrace and Jianfeng seamount, a big water channel flows to south with many small gulches incised 300m. It is very interested that many pockmark structure on left valley wall of the centre segment canyon.

D. The lower segment of Zhujiang Submarine Canyon

Initiated from 3000m water depth, the lower segment canyon extends to 40km southeastern into the deep basin. Relative to other submarine canyons, Zhujiang Submarine Canyon suddenly turned narrow with symmetrical “U” shape profile and steep valley walls, incised 600m-700m without incised gullies and ridges on the bottom. It is distinct that a east-west catenarian seamount at the right side of the entrance separated the canyon and deep-sea basin.

E. The submarine fan of Zhujiang Submarine Canyon

The submarine fan is 36km long outside of Zhujiang Submarine Canyon mouth, but its long axis is east to west about 60km long, an area of 1200km^2. At the top of the fan the slope is relatively gentle of 0 ° 19 ' , increasing to 0°31' at its former and flank.

V. DISCUSSIONS

The formation and evolution of submarine canyon is resulted by a series of factors [9]. From the tectonic interpretation map Figure 4, the main influencing factors to Zhujiang Submarine Canyon are structure, sea mounts, natural gas overflow, and turbidity current.

F. *The controlling of structure*

Zhujiang Submarine Canyon lies in the Pearl River Mouth Basin, the basin with unique tectonic pattern of "two depressions and three uplifts, zonations in north-southern, blocks in east-western" for the deep conjugate faults (NEE-NWW faults and NW faults) controlling[10]. The canyon extends along the Huizhou fault (F2) and controlled by it. At upper segment the canyon controlled by Shenhuansha Fault (F1) and turned to nearly east-western from south-eastern at 1500m water depth, and then to northwest at 1000m water depth (see Figure 4).

within the submarine canyon the secondary faults also developed well, and long-term active. Hence they easily led to geological disasters such as landslides and slumps, etc., which can induce turbidity. At the same time, these cracks grow into the passageways for the oil and gas's migration and accumulation because of the pumping mechanism [11].

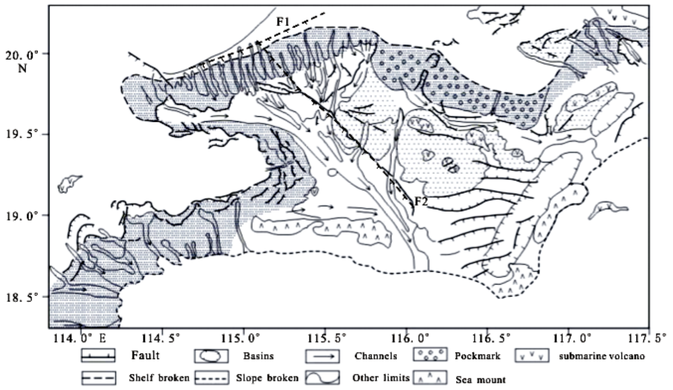

Figure 4 the tectonic interpretation map of Zhujiang Submarine Canyon (F1-Shenhuansha fault, F2-Huizhou fault)

G. *The controlling of sea mounts*

The tectonic movement and fracture re-activities not only caused fault blocks rising, but also caused frequent volcanic and magmatic activity in Northern South China Sea [12]. There were apparent three volcanic eruptions mainly with oceanic basalt in South China Sea since the Oligocene, spreading in the central deep-sea basin and the Pearl River Mouth Basin. That the existence of east-west chainlike sea mounts led to Zhujiang Submarine Canyon suddenly narrowing and deeper at the entrance with "V" shape section. Hence the material can not easy to deposit. The cyclonic cold eddy and powerful South China Sea branch of the Kuroshio delivery materials more far away.

H. *The natural gas overflow and pockmark structure*

The study area is the a natural gas rich region, where the carbonatite were ever found in the union survey in 2004, which formed by the "coldspring" effusion of gas hydrate [13] . Now they are still active, moved upward from fissures and pore spaces and leaked from seabed, which resulted in the breakdown of the hydrate top border and the formation of pockmarks. These also could cause seabed landslides.

I. *The controlling of turbidity current*

The canyon is located out of the great Zhujiang River. The river annually transport more than 8,000 million tons of sediment to the north South China Sea. In late Pleistocene the ancient Pearl River Delta was ever up to the edge of continental shelf. So huge amount of sediment deposited on the slope.

As the sea-level oscillations and the action of earthquakes, volcanism, typhoons, landslides, and natural gas spill results turbidity easily. Many drills located in the submarine appeared dozens of turbidities layers [14]. Moving to the deep basin along the submarine canyon, eroding and filling the seabed and forming incised valley and turbidite accumulation body, The turbidity current becomes the important force of the forming and evolution of the submarine canyon.

VI. CONCLUSION

Zhujiang Submarine Canyon is a big canyon system divided into upper segment, centre segment, lower segment and submarine fan. It is mainly controlled by the Shenhuansha deep fault and Huizhou deep fault. The catenaries sea mounts at left side of the entrance separate the canyon with deep sea basin, narrowed the canyon mouth to carry maters far away. The turbidity current made by landslip and slump shape the morphology of Zhujiang Submarine Canyon. The overflow of natural gas is main reason of the pockmark structure.

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