Study of the types and characteristics of geological hazards in reefs of Nansha Waters, South China Sea

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Abstract. Reports of the 19th National Congress of the Communist Party of China identifies that the construction of islands and reefs in South China Sea (SCS) has been actively promoted. It is of great practical significance to study the types and characteristics of geological hazards in Nansha Islands and reefs, and it is the precondition and guarantees to carry out the construction of islands and reefs. At present, the research on marine geological hazards in China focuses on oil and gas enrichment areas such as Bohai bay, southern Yellow Sea and Northern of South China Sea, and there is little research on southern of South China Sea, especially Nansha Reefs. On the basis of collecting and sorting out previous research achievements, combining with existing geological and geophysical data and drilling data, his paper focuses on analysing two single-channel seismic profiles N01 and N02 collected by "Shiyan 2" of South China Sea institute of Chinese academy of sciences in Nansha Islands and reefs in 2013, and studies the types and characteristics of geological hazards in this area. The study shows that the whole Nansha block belongs to areas with weak seismic activity, most of the faults in the island reef area are weak and micro-active, and the volcanic activity in the island reef area is weak, and the coral reef growth rate is fast, which can be suitable for all kinds of engineering construction projects.

1. Introduction
The report of the 19th National Congress stated that the Reef Construction of the South China Sea (SCS) was actively promoted. It can be seen that the construction of the Reef Project in SCS is undergoing tremendous changes. Located in the southern part of the SCS, the Nansha Islands are the largest islands of the SCS, with nearly 230 coral reefs. Therefore, the construction of the Nansha Reefs is the key point. Furthermore, it can be sure that the definition of the type and characteristics of geological hazards in the reef area is the premise and guarantee for the construction of the reefs.

Meanwhile, marine disaster geology is a discipline that studies the interrelationship between marine geological hazards and human society and its living environment (Yincan Ye, 2012). It is of great significance to the construction of islands and reefs, using the knowledge of marine disaster geology to...
study the types and characteristics of geological disasters in Nansha, SCS, and is conducive to better survival and development of human beings.

Furthermore, the Nansha area and its neighbors are rich in oil and gas resources because of their special location. However, China's research on marine geological hazards focuses on oil and gas enrichment areas such as the Bohai Bay, the South Yellow Sea and the northern SCS. Little research has been done on the southern part of the SCS, especially in the Nansha Waters. At present, it is urgent to strengthen the research and analysis of hazards in areas such as the reef areas in Nansha Waters. Therefore, this paper focuses on the types and characteristics of geological disasters in the reef area of Nansha Waters based on the analysis of previous research results and combined with existing geological and geophysical data with borehole data.

2. Current status of engineering geological survey in Nansha Reefs

2.1. Engineering Geological Survey of Reefs

China's research on modern coral reefs began in the late 1920s and developed rapidly at the end of the last century. In the exploration of coral reefs, the Tertiary reefs were drilled on the Yongxing Reef in Xisha and the Yongshu Reef in Nansha. Since the 1970s, China has gradually carried out engineering construction on the coral reefs in SCS, but the results have been very small. At present, the island reef engineering construction is mainly based on various roads, airports and port projects. In regard to engineering geological research on Nansha Reefs, Xinzhi Wang et al. (2008) have compared and analyzed several coral samples collected from Yongxing Reef in Xisha and Zhubi Reef in Nansha, and combined with laboratory test results for study the engineering geological environment and geotechnical soil of Nansha Reefs. The body structure and the mechanical properties and strength of the main components inside the reef are considered to be a suitable place for the construction of artificial islands, such as airport runways and various engineering facilities. It can be seen that in the future, there will be more China's construction on the reefs of Nansha Waters. Furthermore, it has important scientific and practical meaning to develop the analysis and research on characteristics of geological hazards on reefs.

2.2. Geological hazards investigation

The research and prevention of marine geological hazards in China originated in the 1960s. For the SCS, it is mainly concentrated in the coastal region of South China and the northern seas. The research results of geological hazards in Nansha Reefs are relatively few.

3. Data

The hazard factor of marine geological disasters is geological process. Its activity law is inevitably controlled by geology, natural geography and environmental evolution. According to the principle of cause, marine geological disasters can be divided into natural causes and human causes. Due to the infrequent human activities in the reef area of Nansha Waters, human factors are not considered for the time being. Naturally-oriented geological disasters mainly include earthquakes, volcanoes, active faults, sand liquefaction, landslides, tsunamis, seawater intrusion, and ground subsidence. At present, seismic exploration methods are considered to be the most important detective methods in the field of oil and gas exploration. They are often used in the investigation of deep geological backgrounds, and are rarely used in shallow stratigraphic research, especially for the study of structural features of island reefs. Some scholars have used seismic data to study the geological structures and activity analysis of reefs (Lei Guo et al., 2015). Based on the extensive collection of existing drilling data and seismic profile data at home and abroad (Fig. 1), this paper focuses on the structural interpretation of three single-channel reflection seismic profiles (Line Nan-1, N01 and N02), which was obtained from the “Experiment No.2” survey vessel of the South China Sea Ocean Institute, Chinese Academy of Sciences in 2013. This paper focuses on several major geological hazards such as seismic activity, active faults, volcanic activity and crustal lifting movements in Nansha Reefs.
The drillings in the Nansha sea area are mainly oil exploration wells, and most of them are distributed in the shelf area of the Sunda block in the southwest and the periphery of Palawan and Kalimantan in the east. There is currently no drilling in the Nansha Reefs area. There is only a submarine deep drilling near the Yongshu Reef, the 1143 site of the ODP 184 voyage, and four engineering geological shallow drills on the Yongshu Reef (Nanyong-1, Nanyong-2, Nanyong-3 and Nanyong-4). In order to obtain more accurate results, this paper focused on using several wells on the Yongshu Reef to study the reefs.

4. Types of geological hazards in Nansha Reefs

4.1. Weak seismic activity

There are very few earthquakes in the South China Sea Basin. Most SCS earthquakes occur in the subduction zone or the Asian continental shelf, and earthquakes within the marginal sea basin are very rare (Wang et al., 1979). According to the latest data from the US Geological Survey (USGS) (http://earthquake.usgs.gov/), the largest modern earthquake in the Nansha Waters since 1900 was the earthquake in October 7, 1965, with an epicenter of 12.347°N, 114.485°E, located in the southwest sub-basin, with a magnitude of 5.9 and a focal depth of 20 km. According to relevant research, the 1965 earthquake is the largest earthquake that is currently discovered in the deep sea area and belongs to the intraplate earthquake (Wang et al., 1979). Some other scholars suggested that the location near the Huanglu Reef in the Nansha Islands, 7°N, 114°E, is adjacent to the Nansha Trough. A magnitude 6 earthquake occurred on July 21, 1930 (Yixuan Liu, 1994). According to incomplete statistics, there were 152 earthquakes of magnitude 4 or higher in the Nansha area (3~14°N, 107~120°E) (including earthquakes on the land and nearby seas of Kalimantan Island), including 100 earthquakes of magnitude 4 to 4.9. There were 44 earthquakes of magnitude 5 to 5.9 and 8 earthquakes of magnitude 6 or above (Fig. 2). In addition, there have been only a few small and medium-sized earthquakes in the basin of the Nansha Waters, including 2 earthquakes of magnitude 4.5 or higher, 4 earthquakes of magnitude 3 - 4.4, and 3 earthquakes of magnitude 3 or less. In general, most of the Nansha block is stable or relatively stable, and seismic activity is relatively weak, which is suitable for various types of construction (Ren Wang et al., 1997).
4.2. Faults

This area is mainly based on micro-active faults. Here, we define the active faults in the sea as three types: active faults since the Cenozoic, faults that may be reactivated in the future, and new faults. According to previous studies, the largest principal stress direction in the southern South China Sea is near SN direction, and the active faults in the southern SCS mainly include NE, NW and SN. There is a first-order fault, which is the strike-slip fault of SN and is the transition fault generated when the Yin-A plate is pushed northward. At the same time, there is a set of NW and NE-trending fractures due to SN extrusion, which is a conjugate shear fracture (Xi Wei, 2005; Sanzong Li et al., 2012). As shown in Fig. 3, the NW-trending fault is mainly developed in the western part of the Nansha Waters, while the NE-trending fault is mainly developed in the eastern part, which is consistent with previous research results (Wenhuang Zhan et al., 1993, 1995; Xi Wei et al., 2008).

According to the scale of the fault, the degree of activity, the depth of cutting and its relationship with seismic activity, the active faults in the study area can be divided into five categories: very strong active fault, strong activity fault, medium active fault, weak activity fault and micro-active fault. Generally, the locations with strong fracture activity are mainly concentrated at the intersection of structural inflection points, endpoints or different faults, and the fault activity at other locations is weak or inactive.

Most of the faults in the Nansha Reefs are weak or micro-active faults, which have little impact on the stability of the reef, which is conducive to the development of the island's engineering construction projects. Affected by the multi-phase structure and complex topography of the SCS, the fractures of different structural parts show different occurrences. Seismic profiles of Line N01 and N02 show that the faults in the Nansha area are mainly NE and NW-trending faults (Fig. 4), which are formed in the first submarine expansion of SCS during the Late Yanshan period and have inherited activities since the Late Tertiary. The faults are mainly tensile shear faults with moderate to weak activity. The mid-deep part of the line N02 shows large-wavelength folds, indicating that there has been a record of strong activity in history. The micro-structures such as the paleo-channels shown in the shallow layer indicate that the crust has risen in the block in history.
4.3. Volcanic activity
There is no record of volcanic activity in the reefs. Still, there are some Quaternary volcanic activities in the Nansha Islands, but almost all occur during the interglacial period. They are weak during the glacial period and have not been active since the Holocene (Jiaqi Liu, 1989). According to previous research results, there are few volcanic activities in the reef area of Nansha Waters. There are three Quaternary extinct volcanoes, which are located 5 km north of Xiweitan, 80 km south of Wan’an Bank and near Nantong Reef (Wenhuan Zhan, 1995). As shown in Fig. 5, there are 5 Holocene volcanoes in the Nansha Waters, which are mainly located in the Indo-China peninsula. The volcanic debris of the Nansha Reefs area is mainly derived from the submarine volcanic eruption, and part of the magma activity is reflected in the seismic profiles as the sea-mound or seamount. Some seismic data shows that
there are volcanic activities on the NW side of the Beikang Bank, and the fault has magmatic intrusion. It is inferred that the reef base near it is volcanic rock. In addition, there may be magmatic intrusion along the fault zone and form some small volcanoes, but there is no record.

Figure 5. Volcano distribution in the Nansha area since the Holocene. The data is from NOAA.

4.4. Crustal lifting movement
According to the analysis of coral core data, the Nansha block will have been in a state of structural subsidence for a long time. Ren Wang et al. (1997) pointed out that the data of the well “Sampaquita-1” in the Liyue Bank shows that the Quaternary sediments is all reef limestone with a thickness of 2160m, indicating that the crust of Liyue Bank has settled 2160 m (at least 2110 m) since 27 Ma. The average sedimentation rate is 0.08 mm/a. It indicates that the crust have been settling slowly for a long time. At present, some researches are focused on the Yongshu Reef in the middle of Nansha block. According to the well data of “Nanyong-1” in reef plat, the Nansha Formation of Pleistocene series and the Nanhai Formation of Holocene series are all reef limestones with 152.07 m thick (no penetrating the reef), indicating that the crust has settled 152 m(at least 100 m) since 970 ka. The average sedimentation rate is 0.156 mm/a, indicating that the crust of the Yongshu reef is in a state of slow subsidence. Only when the dynamic type of sea level drops during the world ice age, it will emerge.

5. Conclusion
Seismic activity and active faults are two major geological hazards in Nansha Reefs. Since the 1900s, there have been 8 earthquakes with magnitude 6 or above in the Nansha Waters. The seismic activity is relatively weak. The active faults in Nansha Reefs are mainly NE, NW and SN trending faults. Most of the faults are weak or micro-active faults. Their current activity is moderate or weak, so the overall stability of the area is good. According to the seismic and drilling data, there are large folds in the shallow strata, which can be inferred that there has been an active period of neotectonic activity since the Quaternary. The paleo-channels and shallow gas shown in the profiles reflect the existence of various catastrophic geological factors in the area. The volcanic activity in the area is weak, with five Holocene volcanoes, where mostly are dead volcanoes. During the Late Eocene, large-scale subsidence occurred in the Nansha block, and the sedimentation rate was very large. Since the late Oligocene, the shallow sea has turned into the deep sea, and there has not been any obvious crustal uplift in the area. From the
Late Miocene to the Quaternary, the block has turned to be stable, the fracture activity has obviously weakened or stopped, and the magma activity was partially active. It can be considered that, the Nansha block have been in a relatively stable state and suitable for various reef constructions since the Late Miocene.

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