Analyses of active faults, seismic activities and sea floor
unstable factors of the Zhujiang River Mouth Basin
and its adjacent areas

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(Received February 20, 1988; accepted January 3, 1990)

Abstract — On the basis of the data of geophysics and seismic activities, the analyses of the active faults, seismic activities and the sea floor unstable factors of the Zhujiang River Mouth Basin have been made so as to study the characteristics of the compressional subactive continental margin of Cathaysian system, arc littoral strongly active fracture zone, the division of seismic subzone and seismic zone of the continental margin of northern South China Sea, the potential focal area, and to analyze the regional stability. We consider that the Zhujiang River Mouth Basin belongs to a stable or a moderately stable region.

INTRODUCTION

Regional stability of marine geological environment is determined by seismic hazard and unstable factors of the bottom materials. Both the former and the latter may cause heavy losses to the life and property of the people and offshore projects in a twinkling. Recently, scientists in many countries have paid much attention to the study of geological hazard in the fields of oil prospecting and development. The South China Sea is an important oil explorational area in the offshore field and the stability of the marine geological environment attracts the attention of scientists in China and abroad. On the basis of the data collected from the investigation and study made in many years, the authors try to discuss the regional stability of the Zhujiang River Mouth Basin from the respects of the active faults, seismic activities and sea floor unstable factors.

REGIONAL TECTONIC BACKGROUND

Zhujiang River Mouth Basin lies in northern South China Sea where the Eurasia, Pacific and Indian plates converge and are interacted. So, the geological structure is complicated. Since the Mesozoic, the Pacific Plate compressed and subducted to the continental margin of East Asia, forming the mobilized zone of continental margin (Cathaysian diwa). The geological structure is characterized by

* This study granted by the Scientific Foundation of the China Academy of Sciences, is one of the stage results of the subject (R850835). A symposium of the International Petroleum Geological Conference of Northern South China Sea Continental Shelf, 1987.
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the volcanic arc with thousand km long, the continental diwa basins, and a series of strong compression-shear fractures. The main direction of the tectonic line turns to NE − NNE, named “East Asia Sysyem”. Since Late Cretaceous, a neotectonic framework has occurred in the South China Sea. With the Himalayan compressional uplifting, the continent of East Asia crept to SE, leading to the fracture and dismembering of the continental margin. The small sea floor spreading caused, the large-scale tensinal fault-sags, forming NEE − EW tensional fractures of the “South China Sea System”, an intense basic magma spilling and seismic activities. The northern South China Sea appeared to be a diwa of marginal sea type.

From the analysis of tectonic environment, the Zhujiang River Mouth Basin belonged to a compressional active continental margin during the Mesozoic, and a tensional passive margin during the Cenozoic. During the Quaternary the tectonic activity was characterized by the fault and fault-block differential movement, the basement was broken with strong magma activities. The seismic activities occurred frequently in the westernmost and easternmost parts of the basin and at the joining of the tectonic line of land and sea of northern margin. The data of focal mechanism indicate that the dominant direction of neotectonic stress field in the north continental margin is SEE − SE, NE plane of focal translocation is demonstrated by dextral rotation and NW plane of that is sinistral rotation. This indicates that the recent stress is related to the recent compressional stress in the Philippine Sea. The dominant compressional stress axis mostly in the southern basin tends to be of SEE − SE (Leiqiong) and gradually turns to SE (southern Zhuang Autonomous Region of Guangxi). The NE plane of focal translocation is shown by sinistral rotation and dextral rotation in NW plane, indicating that the present stress is related to the compressional stress of the Indian Plate. Compared with the active continental margin of the Taiwan − Philippine island arc, the tectonic and volcanic activities and seismic and stress intensities are comparatively weak, but more unstable than that of the passive continental margin of the Atlantic type. The stress difference is within the range of 12.5 ～ 25.0 MPa. Therefore, it could not be a stable continental margin, or named subactive continental margin. The subactive continental margin was in the condition of compression-tension stress in the Mesozoic and of compression stress at present, named “Cathaysian type” or “complex type” margin (Liu, 1984).

ACTIVE FAULTS

The fault was still mobile after Late Tertiary, or reached to the seismic reflective sequence T₂ or N₂ - Q shown in the marine seismic profiles, named active fault.

Signs and types of the active faults

The signs of active faults in northern South China Sea are based on the features of geophysics including seismic reflection profiles (cut to N₂-Q), variations of gravity, magnetic and Moho surface, seismic activities and basic volcanic eruption along the fault zone, landform, etc. The factors among those mentioned above are based mainly on the seismic profiles and seismic activities. The active faults in the South China Sea and its vicinity could be divided into five types, namely, intensely active faults, strongly active faults, moderately active faults, weakly active faults and slightly active faults
on the basis of the active fault scale, cutting depth, contrast intensity of landform, geophysical features, and intensity of seismic activity (Liu, 1984). The framework and types of active faults in this region are shown in Fig. 1.

The characteristics of the active faults

The directions of the active faults are NE – NNE, NEE – EW, NW and NNE – SN in the Zhujiang River Mouth Basin and its vicinity.

**NE – NNE fault system.** The NE – NNE faults reaching down to the basement of the crust are situated along the coast of Southeast China, which is the tectonic line formed by the subduction...
of the Pacific Plate into the continental margin of East Asia, named the East Asia System (Liu, 1984). They are strongly active in the Yanshanian period of the Mesozoic. The compression-shear and tension-shear variations of the system occurred in the Mesozoic and Cenozoic, and the closer to the littoral zone, the more strongly active the faults would be. The seismic subzone along the southeast, coast is composed of major active fault system, such as Nan’ao, Shantou, Lufeng, Haifeng, Heyuan, Yangjiang, Wuchuan. Most of these faults belong to moderately or weakly active faults. The strong earthquakes occurred along the coastal zone.

**NEE–EW fault system.** This is the major fault system in the Zhuijiang River Mouth Basin and is developed in the middle and northern waters of the South China Sea as well as reaches down to the basement of the crust. The fault activities in the system started from the Cretaceous, and the strong activities occurred in the period of the Oligocene–Pliocene. The tectonic line was created by the sea floor spreading to the north and south in the Central Sea Basin, named the South China Sea System (Liang, 1982). The system is composed of tensional or tensional-shear faults with the arrangement of echelon, with the length of several hundred to one thousand km and width of several scores of km. The system appears to be staircase towards the basin and controls the distribution of the Cenozoic basin; there is basic magma uplifting along the fault zone, enhancement of heat flow, and the distribution of earthquake epicenter. The features of the system are listed in Table 1. The strong active faults are located in littoral fault zone (Figs 2~4), reaching to the top of N-Q as indicated by seismic profiles. This is a large continental margin fault zone recognized in recent years and is an important fault earthquake zone along the coast and north of the South China Sea.

**NNW–NWW fault system.** This system is characterized by the faults of equidistance echelon arrangement with the length of several hundred km and the width of only several score to one hundred m along the southeast coast. The obvious landform contrast in the fault system and the gravity and magnetic anomaly lineation can be seen from geophysical profiles. The faults cutting the Basin and

<table>
<thead>
<tr>
<th>Name of fault</th>
<th>Littoral</th>
<th>Edge of northern Zhuijiang Basin</th>
<th>Edge of northern slope</th>
<th>Dongsha</th>
<th>Southeast Qionghai</th>
<th>North Qionghai</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strike</td>
<td>N70°E</td>
<td>N70°E</td>
<td>N50°~70°E</td>
<td>N35°~70°E</td>
<td>N30°~40°E</td>
<td>N70°~75°E</td>
</tr>
<tr>
<td>Dip</td>
<td>SE</td>
<td>SE</td>
<td>NW</td>
<td>SE</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Dip angle</td>
<td>70°</td>
<td>65°~70°</td>
<td>60°~70°</td>
<td>60°~70°</td>
<td>65°~70°</td>
<td>62°~70°</td>
</tr>
<tr>
<td>Length (km)</td>
<td>1 000</td>
<td>610</td>
<td>700</td>
<td>350</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Width (km)</td>
<td>40~60</td>
<td>24~40</td>
<td>20~40</td>
<td>20~30</td>
<td>30~40</td>
<td>20</td>
</tr>
<tr>
<td>Type</td>
<td>strongly active</td>
<td>weakly active</td>
<td>moderately active</td>
<td>weakly active</td>
<td>weakly active</td>
<td>strongly active</td>
</tr>
<tr>
<td>Water depth (m)</td>
<td>30~50</td>
<td>50~70</td>
<td>100~150</td>
<td>2 000</td>
<td>200~1 000</td>
<td>along coast</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Features of activity</th>
<th>cut to N2~Q, or Q, &gt; M = 7 earthquake</th>
<th>cut to N2~Q, or Q, &lt; M = 5 earthquake</th>
<th>cut to N2~Q, or Q, &lt; M = 6 earthquake</th>
<th>cut to N2~Q, or Q, &gt; M = 7.5 earthquake</th>
</tr>
</thead>
</table>

Table 1. The features of NEE–NE active faults in the Zhuijiang River Mouth Basin and its adjacent areas.
trending to N35°~50°W are sinistral faults. This system was formed by the subduction of the Philippine Plate and the spreading of the continental margin of the South China Sea, named southeast coast system (Liu, 1984). The system generally cuts NEE–EW faults, the active time is rather late, and it is the major earthquake triggering structure (see Table 2).

**NNE–SN fault system.** This system is located in the Taiwan–Philippine island arc zone with prominent arc to the west. The faults in this system cut down the crust or lithosphere and strong fault activities occurred in the Cenozoic. The island arc had been compressed and subducted by the Philippine Sea plate and crustal block of the South China Sea, forming the high-angle reverse-thrust compressional and compressional-shear fault system, named Island Arc System (Liu, 1984). This main system produces the frequent and strong seismic activities in this region, such as longitudinal valley of Taiwan, coastal mountain, Manila Trench, Luzon Trough and Cordillera Central faults.
Table 2. The basic features of NW active faults in the sea area off the Zhujiang River Mouth Basin

<table>
<thead>
<tr>
<th>Name of fault</th>
<th>Strike</th>
<th>Dip</th>
<th>Dip angle</th>
<th>Length (km)</th>
<th>Type</th>
<th>Features of activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nanpeng</td>
<td>N42°W</td>
<td>W</td>
<td>71°</td>
<td>197</td>
<td>weakly active</td>
<td>gravity &amp; magnetic anomaly, earthquake, hot spring, Cenozoic basalt</td>
</tr>
<tr>
<td>Offshore Shantou</td>
<td>N35°W</td>
<td>E</td>
<td>65°-70°</td>
<td>235</td>
<td>weakly active</td>
<td>gra. &amp; mag. anomaly, hot spring, shatter, difference of Cenozoic thicknesses, Cenozoic basalt, earthquake</td>
</tr>
<tr>
<td>Offshore Lufeng</td>
<td>N33°W</td>
<td>W</td>
<td>65°-70°</td>
<td>135</td>
<td>slightly active</td>
<td>gra. &amp; mag. anomaly, minor earthquake, difference of Moho &amp; Cenozoic thicknesses</td>
</tr>
<tr>
<td>Beilwei Shoal</td>
<td>N38°W</td>
<td>W</td>
<td>80°-85°</td>
<td>370</td>
<td>weakly active</td>
<td>gra. &amp; mag. anomaly, shatter, earthquake, difference of Cenozoic thicknesses</td>
</tr>
<tr>
<td>Guozhou Islands</td>
<td>N30°W</td>
<td>E</td>
<td>&gt;70°</td>
<td>170</td>
<td>weakly active</td>
<td>gra. &amp; mag. anomaly, small earthquake, sharp variations of Moho &amp; Cenozoic surfaces</td>
</tr>
<tr>
<td>Zhujiang River mouth</td>
<td>N40°W</td>
<td>E</td>
<td>&gt;70°</td>
<td>325</td>
<td>weakly active</td>
<td>gra. &amp; mag. anomaly, &lt; M = 5 earthquake, sharp variation of Cenozoic thicknesses</td>
</tr>
<tr>
<td>Shangchuan Island</td>
<td>N33°W</td>
<td>E</td>
<td>&gt;70°</td>
<td>180</td>
<td>weakly active</td>
<td>gra. &amp; mag. anomaly, &lt; M = 5 earthquake, sharp variations of Cenozoic thicknesses</td>
</tr>
<tr>
<td>Hailing Island</td>
<td>N40°- 50°W</td>
<td>E</td>
<td>&gt;70°</td>
<td>390</td>
<td>weakly active</td>
<td>gra. &amp; mag. anomaly, &gt; M = 5 earthquake, sharp variations of Cenozoic thicknesses, Cenozoic basalt</td>
</tr>
<tr>
<td>Shenhui</td>
<td>N35°W</td>
<td>W</td>
<td>65°-75°</td>
<td>200</td>
<td>weakly active</td>
<td>gra. &amp; mag. anomaly, M = 7.1 earthquake, difference of Cenozoic of thicknesses</td>
</tr>
<tr>
<td>Guangzhou Bay</td>
<td>N38°W</td>
<td>E</td>
<td>65°-75°</td>
<td>420</td>
<td>weakly active</td>
<td>gra. &amp; mag. anomaly, strong earthquake, sharp variations of Cenozoic thicknesses</td>
</tr>
<tr>
<td>Tonggu Cape</td>
<td>N48°W</td>
<td>W</td>
<td>65°-75°</td>
<td>160</td>
<td>weakly active</td>
<td>gra. &amp; mag. anomaly, small earthquake, NE fault</td>
</tr>
<tr>
<td>Southeast Qionghai</td>
<td>N45°W</td>
<td>W</td>
<td>65°-75°</td>
<td>200</td>
<td>weakly active</td>
<td>gra. &amp; mag. anomaly, small earthquake, difference of buried depths between Moho &amp; basement</td>
</tr>
</tbody>
</table>

SEISMIC ACTIVITIES

Spatial distribution of the earthquakes

Geographical distribution of the earthquakes. From 1600 to December 1986, 180 times of Ms > 4.5 earthquakes occurred in the South China Sea and its vicinity. The distributions of 3/5 earthquakes occurred along the margin of eastern South China Sea and in the Taiwan — Philippine island arc region in the direction of NNE — SN, and those of 2/5 earthquakes occurred along the continental margin of northern South China Sea in the direction of NEE — NE. Only few of them occurred in the central sea basin of the South China Sea.

Depth distribution of the earthquakes. The strong seismic focal depths are becoming deeper from continent to sea, such as the focal depth was 6 km in the Lingshan, 10 km in Heyuan, 20 ~ 40
km in Shantou, and 40~50 km in the Shallow of Taiwan. Most of the focal depths of strong earthquakes were within the range of 15~25 km in the continental margin of northern South China Sea in which the depth of Conrad discontinuity was within range of 15~25 km and that of the Moho was in the range of 17~35 km, so most of the focal depths of strong earthquakes were in those of the Conrad surface.

Temporal distribution of the earthquakes

Since 1373 earthquakes have been recorded in the continental margin of northern South China Sea and the adjacent areas. The seismic activities recorded may be grouped temporally into two periods, 1373~1693 and 1694~the present, each consisting of tranquil and active subperiods (Fig. 5). In each period there were four active phases, namely, (1) the phase of strain accumulation (\( M_s = 5\sim 5 \frac{1}{2} \)), (2) the phase of premonitory activities (\( M_s = 6\sim 6 \frac{1}{2} \)), (3) the phase of major strain release (\( M_s > 7 \)), and (4) the phase of residual strain release (\( M_s = 4 \frac{3}{4} \sim 5 \frac{3}{4} \)). In the north of the South China Sea, the littoral and Dongsha~Hainan earthquake zone were in the fourth phase of the second active period, except that the Leiqiong earthquake zone was in the second phase of the second active period.

![Fig. 5. Map of historical seismic sequence of seismic subzone in the continental margin of northern South China Sea.](image_url)

Spatial and temporal migration of earthquakes

The migration of earthquakes along the earthquake belts in the continental margin of northern South China Sea is of the type of jumping from one end to another. At the beginning of the 17th century, earthquakes occurred in the offshore Quanzhou (\( M_s = 8, 1604 \)) and the offshore Nanpeng (\( M_s = 7 \frac{1}{4}, 1605 \)) at the west end. At the beginning of the present century, earthquakes occurred in the offshore Jinmen Island (\( M_s = 7 \frac{1}{4}, 1906 \)) and the offshore Nanpeng (\( M_s = 7 \frac{1}{4}, 1918 \)) at the eastern end, and then occurred in Shenuo shoal (\( M_s = 7, 1, 1931 \)) at the western end. These two active periods were characterized by the earthquake occurring 2 times in the east and 1 time in the west.

\( M_s > 7 \) earthquakes did not occur at the same site within a single period, but did occur at the same site in different periods, such as in Nanpeng, \( M_s > 6 \) earthquakes might occur in a single active period within one fault depression, such as in Hanjiang Delta. \( M_s > 6 \) earthquakes were of the nature of neogenesis, for example, the Yitong shoal earthquake (\( M_s = 7, 1, 1931 \)) and the Yangjiang earthquake
There is no record of tsunami caused by great earthquake in the South China Sea. Eight $M_s > 7$ earthquakes occurred in the history in the offshore Quanzhou, Nanpeng, Qiongshan and sea area of eastern South China Sea, but no seismic sea wave was recorded during that time. There is also no effect on the coast and continental margin of northern South China Sea exerted by tsunami coming from outside the South China Sea, because there is a broad shelf in northern South China Sea, submarine plateaus as Dongsha, Zhongsha and Xisha block tsunami from outside of the South China Sea, no trench or trough in the shelf, and weakly recent fault-block differential movement. This is advantageous to oil exploration.

Regionalization of earthquake belts

According to the features of seismic activities and their relationship with geological structures, this area studied belongs to part of the South China Sea earthquake region, and the northern land belongs to the South China earthquake region. According to the size and degree of seismic activities, the area studied may be further divided into the third-order earthquake divisions and earthquake belts: northern continental margin subregion, Central Sea Basin subregion and east continental margin seismic subregion as well as several seismic zones of the South China Sea (Fig. 6).

In the following we briefly discuss characteristics of the earthquake subregion of the continental margin of northern South China Sea.

This subregion extends NEE – NE, parallel to the South China shoreline with the southern border at the northern margin of the South China Sea Basin. The subregion including the continental shelf, slope, Leizhou – Qiongzhou district, and the islands along the coast. The division of this subregion is parallel to the southeast coast earthquake subregion within the South China earthquake region (Liu, 1981).

A. The Fujian – Guangdong littoral earthquake belt in this subregion trends parallel to the shoreline from Nanpeng Islands in the east to Zhanjiang – Guangzhou Bay in the west. To the east the belt may be connected with the southeastern Fujian littoral fault belt. This earthquake belt is controlled by the strongly active fault belt of South China and the weakly active fault belt of the northern Zhujiang River Mouth Basin. Along this belt $M_s > 6$ earthquakes have been recorded 11 times; $M_s > 4 \frac{1}{2}$ earthquakes 57 times. The great earthquakes were the strongest offshore Quanzhou earthquake ($M_s = 8$) in 1604 and the Nanpeng earthquake ($M_s = 7 \frac{1}{4}$) in 1918.

B. The Leizhou – Qiongzhou earthquake belt extending NEE – EW is bordered by the Leibei (Suixi – Potou) fault to the north and the Qiongbei (Changpo – Ding’an) strongly active fault to the south. Along this belt, $M_s > 4 \frac{3}{4}$ earthquakes have been recorded 4 times, with the strong one being the Qiongbei earthquake ($M_s = 7 \frac{1}{2}$) in 1605.
C. The Dongsha–Hainan earthquake belt is the NE-trending, moderately active shelf-margin fault to the north, and is the NEE–EW-trending, weakly active northern Xisha Trench and northern deep-sea basin fault to the south. \( M_s > 4 \frac{1}{2} \) earthquakes occurred 16 times, and the strongest one was the Yitong shoal earthquake (\( M_s = 7.1 \)) in 1931.

**EARTHQUAKE HAZARD ANALYSIS**

*Geological and geophysical features of potential focal regions*

On the basis of the data of geological and geophysical features of strong earthquake zones, the general features are as follows:

A. Sharp changing zone of crustal structure, such as combination of continental and transitional crusts and sharp changing zone of the Conrad and the Moho surface.

B. Geophysical anomaly zone, such as the interchanging zone of gravitational and magnetic anomalies.

C. Deep fracture reaching \( N_2 - Q \) shown on the seismic reflection profiles.

D. Border zones between the uprising and subsiding fault-blocks.

E. Districts with strong modern differential crustal movements.

F. The migration, repetition, gap-filling, and neogenesis of seismic activities.

G. The structural situation of strong earthquakes;

a. Periphery of the Cenozoic basins or that of littoral island-chain uplifts; b. intersections of NEE and NW active faults, or convergent and broken points of several active faults; c. ends of the intensely, strongly and moderately active faults, or both ends of a active fault; d. districts with high relief contrast along both sides of the intensely, strongly and moderately active faults.

In fact, many strong earthquakes do not possess characteristics of a certain type alone, but possess those of several types simultaneously. The specific structural situations are often reliable bases for locating the potential focal regions.

*Correlations between earthquake scales and geological structures*

A. Earthquakes of \( M_s > 7 \frac{1}{4} \) (intensity \( \geq X \)) occurred along the border zones between the Neogene strongly subsiding belts and the uplifting belts, such as the sea area at the east end of littoral strongly-active faults near Jinmen, Nanpeng Islands, and the sea areas at the east end of Qiongbei strongly-active faults and near Manila Trench faults.

B. Earthquakes of scale \( 6 \sim 6 \frac{3}{4} \) (intensity \( VII \sim IX \)) occurred along the border zones between the Cenozoic large-scale fault-depressions and fault-uplifts, or between the secondary depressions and uplifts as well as at the intersections or end points of the active faults, such as Xiongdi Isle to the offshore along the eastern part of littoral fault zone, along the shore from Yangjiang to Dianbai, along the western part of the same fault zone, and along the margin of the Zhangzhou basin, Hanjiang-delta fault depression, and Qionglei basin.
C. Earthquakes of $4 \frac{1}{2} \sim 5 \frac{3}{4}$ (intensity VI ~ VII) occurred at the intersections of NEE faults, NE-NW faults and NW faults, or at their ends or broken points, as well as along the margins of step-fault basins, gulfs, and valleys, which are controlled by NE, NW, or near EW-trending faults.

Potential focal region

Through the analyses of correlations between the extremum theory, Markov model, relation between magnitude - frequency and strain accumulation and release, seismic activity period and the relation between scale and structure, 7 potential focal regions have been divided in the earthquake region of the Zhuijiang River Mouth Basin for the coming 100 a. They are Nanpeng, Dangan Island, Dianyang coast, Qiongbei, south of the Taiwan shoal, Dongsha and Shenu (Fig. 6). The basic characteristics of each potential focal region in northern South China Sea and its adjacent areas are shown in Table 3.

![Sketch map of distribution of the epicenter and potential seismic focus zone in the continental margin of northern South China Sea.](image)

**Legend**

- $M_s \geq 8$
- $M_s = 7 \sim 7.9$
- $M_s = 6 \sim 6.9$
- $M_s = 4.5 \sim 5.9$

**Fig. 6.** Sketch map of distribution of the epicenter and potential seismic focus zone in the continental margin of northern South China Sea. A. Seismic subzone along the coast of southeast China; $A_1$. Quanzhou—Shantou seismic zone. $A_2$. Lianhuaqian seismic auxiliary zone. $A_3$. Heyuan seismic zone. $A_4$. Yangjiang seismic zone. B. Seismic subzone of continental margin of northern South China Sea; $B_1$. littoral seismic zone. $B_2$. Leiqiong seismic zone. $B_3$. Dongsha—Hainan seismic zone. C. Seismic subzone of South China Sea Basin; $C_1$. seismic zone of northern sea basin. D. seismic subzone of continental margin of eastern South China Sea; $D_1$. coastal seismic zone of western Taiwan, $D_2$. Manila Trench seismic zone.
<table>
<thead>
<tr>
<th>Seismic zone</th>
<th>Potential focal region</th>
<th>Position</th>
<th>Controlling earthquake &amp; the fault triggering earthquake</th>
<th>Directions of macro axis &amp; minor axis</th>
<th>Maximum magnitude in history (M,)</th>
<th>Most believable seismic magnitude (M,)</th>
<th>Potential magnitude &amp; intensity for the coming 100 a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Littoral</td>
<td>Nanpeng</td>
<td>22.8°～23.5(^\circ)N 116.9°～117.7(^\circ)E</td>
<td>NEE littoral &amp; NW Hanjiang &amp; offshore Shantou, Huanggang River &amp; NE Nan’ao fault</td>
<td>macro NEE minor NW</td>
<td>7 1/4</td>
<td>7 1/4</td>
<td>6 1/4, VII</td>
</tr>
<tr>
<td></td>
<td></td>
<td>21.6°～22.4(^\circ)N 113.5°～114.5(^\circ)E</td>
<td>NEE littoral &amp; NE Haifeng, Shenzhen &amp; NW Xijiang, Zhujiang mouth, Jianpeng fault</td>
<td>macro NEE minor NW</td>
<td>5 3/4</td>
<td>7</td>
<td>6 1/2～7, VII</td>
</tr>
<tr>
<td></td>
<td></td>
<td>21.0°～21.8(^\circ)N 110.6°～112.0(^\circ)E</td>
<td>EW littoral, NE Yangjiang, Wuchuan, NW Guangzhou Bay, Nanpeng fault</td>
<td>macro NEE minor NW</td>
<td>6 3/4</td>
<td>7</td>
<td>6 1/4～6 1/2, VII</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19.6°～20.1(^\circ)N 110.0°～111.0(^\circ)E</td>
<td>NEE Qiongbei, NW Puqian, Dongying, Tianwei fault</td>
<td>macro NEE minor NW</td>
<td>7 1/2</td>
<td>6 3/4～7, VII</td>
<td>6 1/2～6 3/4, VII</td>
</tr>
<tr>
<td></td>
<td></td>
<td>21.8°～22.7(^\circ)N 117.5°～118.4(^\circ)E</td>
<td>NEE north margin of continental slope NE Dongsha, Nanpeng, offshore Shantou fault</td>
<td>macro NEE minor NW</td>
<td>6 3/4</td>
<td>7</td>
<td>6 1/2～6 3/4, VII</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19.8°～20.6(^\circ)N 116.2°～117.4(^\circ)E</td>
<td>NE north margin of continental slope, NEE north margin of sea basin, NNE Dongsha, NW Beiwei shallow fault</td>
<td>macro EW minor SN</td>
<td>5 1/2</td>
<td>6</td>
<td>5 1/2～5 3/4, VII</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19.2°～20.1(^\circ)N 112.4°～113.5(^\circ)E</td>
<td>NE continental slope NNE southeast Qionghai, NE Nanpeng, Guangzhou Bay fault</td>
<td>macro NEE minor NW</td>
<td>7 1/4</td>
<td>7 1/4</td>
<td>6 1/4～6 1/2, VII</td>
</tr>
</tbody>
</table>
ANALYSIS OF SEA-FLOOR UNSTABLE FACTORS

The slide, collapse, active fault and graben, modern tide, erosional landform, high-rate sedimentation area of the river mouth, buried negative landform and intercalated beds of ooze all belong to the sea-floor unstable factors, which are harmful to the sea-floor engineering.

Sea-floor slide and collapse

Sea-floor slide and collapse tend to occur in the following regions (Fig. 7); A. Steep-slope segments of littoral fault, such as Wanshan - Naozhou Island in the west of the littoral fault zone, Lufeng - Shantou offshore steep-slope and underwater shore-slope; B. in front of the modern underwater deltas of the Zhujiang River and the Hanjiang River as well as their alongshore island and steep-slopes; C. in the sea hill districts formed by structural upwarping in the inner and outer continental shelves; D. in the steep -slope of the continental slope, ridge and sea mountain.

Active faults and grabens

Active faults and grabens provide unstable background. The potential districts include NEE strongly active littoral fault, Zhujiang River Mouth Basin north-border fault, and 10 NW-trending weakly active faults which cut the basin. The locations where faults cut Q or N–Q sequences reflected by the seismic profiles, or fault cliffs and fault steps, are especially hazardous districts.

The landforms resulting from erosion or modern tidal actions are potential unstable districts, such as tidal delta, tidal sandy ridge and dam, erosional valley and platform. They are situated in the following regions. A. Tidal delta in the Qiongzhou Straits, washing valley in the southeast Qionghai and southwest of Naozhou Island. B. Sandy ridges and sandbars in the offshore Gaolan Isles, offshore Yangjiang, offshore Haifeng, and offshore Huilai. C. Large gradient of boundary of terraces (platform) in the inner continental shelf.

A tremendous argillo-arenaceous materials are brought to the river mouths of the Zhujiang River and the Hanjiang River, forming the high-rate sedimentation area. Because of the high content of water in the argillaceous beds, formation in short time, low cementation and load-bearing, it could cause the pipeline and drilling plate deform and subside. The fine-grained sediments of the modern delta above 50 m isobath in the Zhujiang River mouth and the Hanjiang River mouth and Taiwan shoal belong to this kind of area, which are of a certain effective on the oil pipeline and cable.

The buried negative landform

The sea-floor landforms were formed by river, tide, wave and current in a low sea-level condition of the Quaternary glacial stage. These negative topographic units were covered by the post-sediments after the postglacial period, creating the buried ancient delta, river bed, sea valley, low area and lagoon. These may cause unbalanced sinking of constructions because of the large gradient, coarse sediment and fine overlying strata. Potential unstable districts of this type include paleodeltas, paleo-river channels, sea valleys and small sags on the deltas off the Zhujiang River mouth and the Hanjing
River mouth. For the drilling sites near these paleo-landforms, attention should be paid to these unstable factors.

The intercalated beds of ooze or sudden changes in physical properties of sediments are well developed in the Zhujiang River Delta and the Hanjiang River Delta as well as the nearshore areas. The sudden change of the dynamic property of sedimentary sequence reflected in the vertical section and the argillaceous sequence intercalated in the arenite clastic sediments, are the main characteristics.

The waters of drilling sites in the Zhujiang River Mouth Basin generally belong to the scope of outer continental shelf in which the surface sediments are mostly composed of Late Pleistocene coarse-grained sandy materials which are advantageous to the marine engineering. The argillaceous intercalation in the sediments could be generally seen in the inner continental shelf.
The unstable factors that affect the sea floor of the Zhujiang River Mouth Basin are summarized in Table 4.

**Table 4.** Analysis and comment on the unstable factors in the sea bottom of the Zhujiang River Mouth Basin and its adjacent areas

<table>
<thead>
<tr>
<th>Sea region</th>
<th>Inner continental shelf</th>
<th>Outer continental shelf</th>
<th>Continental slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Water depth (m)</td>
<td>0~50(+)</td>
<td>60~200(+)</td>
<td>200~2500(+)</td>
</tr>
<tr>
<td>2 Tectonic unit and active faults</td>
<td>Wanshan faulted upfold zone and coastal upwarped zone, active faults in coastal region and north margin of the Zhujiang River Basin and along the coastal NW fault</td>
<td>active faults in north margins of the Zhujiang River Basin and continental slope, as well as NW faults in separated basins are developed in fault-sag zone</td>
<td>NE and NW faults are developed in Dongsha, north margins of continental slope and sea basin in Dongsha-Hainan eastern extension fault-rise zone</td>
</tr>
<tr>
<td>3 Topography</td>
<td>large gradient of slope, erosional and accumulative landform are developed, large relief in littoral fault zone</td>
<td>rather smooth, with residual landform belt, such as ancient coastal line and ancient delta</td>
<td>large gradient of slope large relief, seamounts, ridges, sea knolls and terraces are developed</td>
</tr>
<tr>
<td>4 Hydrodynamism</td>
<td>high tidal range, strong tidal current, strong wave and longshore current</td>
<td>weakly affected by tidal current, wave and longshore current</td>
<td>affected by Kurushima</td>
</tr>
<tr>
<td>5 Surface sediment and era</td>
<td>Mainly the Holocene fine-grained mud, silt and other clastics</td>
<td>mainly Late Pleistocene coarse-grained silt</td>
<td>Mainly mixed fine sand, silt and mud of Late Pleistocene</td>
</tr>
<tr>
<td>6 Unstable factors in sea bottom</td>
<td>landslide and ebullement, fracture and graben, current and erosion, high-rate sedimentation in river mouth, buried ancient landform, mud intercalation</td>
<td>landslide &amp; ebullement, weakly active fault and graben, fossil river course and sea valley, small depression, sandbar, structural ridge, shallow gas</td>
<td>landslide &amp; ebullement, turbidity current, seamounts, sea ridges, sea knolls, abrupt variation of physical nature of sediments</td>
</tr>
<tr>
<td>Possible engineering facilities in the near future</td>
<td>submarine cables, oil pipeline, harbour engineering dock, nuclear power station</td>
<td>well drilling, oil production platform, oil and gas pipeline</td>
<td>well drilling, oil production platform, oil and gas pipeline</td>
</tr>
</tbody>
</table>

In short, the sea floor in the East Oil Exploration Zone of the Zhujiang River Mouth Basin in northern South China Sea has a good stability. This conclusion is concordant with that derived from seismic hazard analysis and favourable to the oil exploration in the South China Sea.

**PRELIMINARY COMMENT ON THE REGIONAL STABILITY**

Seismic hazard in the Zhujiang River Mouth Basin and its vicinity mainly comes from north NEE
strongly active fault zone, NEE – NE moderately active fault zone to the south in the continental slope and the convergent NW weakly active fault zone. The intensely, strongly, moderately and weakly active faults are corresponding to the capable faults named by the International Atomic Energy Agency (IAEA). This has an important effect on the submarine engineering stability. The intersection between the two NEE moderately or strongly active fault zone and NNE – NE moderately active fault zone, especially in the Nanpeng and Qiongbei districts is the most probable destructive potential earthquake zone. Therefore, the Zhujiang River Mouth Basin is a relatively stable zone between the active zone of littoral and moderately stable zone of northern slope. In other words, Zhujiang Mouth Basin belongs to a relatively seismic tranquil zone, the stress difference is within the range of 12.5 ~ 25.0 MPa (25.0 ~ 50.0 MPa in the Taiwan Strait and > 50.0 MPa in the Taiwan – Philippine island arc and trench), which is situated in the wide continental shelf with submarine plateau in front of the margin to block the effect of tsunami coming from outside of the South China Sea.

From the analysis of the characteristics of the Zhujiang River Mouth Basin, we know that there was no $M_{\geq}6$ earthquake in the history. On the basis of the calculation of diameters of the main and minor axes of the strong earthquake in history, the intensity was within the range of $V \sim VI$ in the Basin and VII in the east of the Zhu-1 depression and local areas in the west of the Zhu-3 depression. The seismic hazard will come mainly from the northeast of Nanpeng and southwest of Qiongbei potential focal zones for the coming 100 a. However, the intensity of the earthquake influence field is with in the range of $V \sim VI$, VII in the east of the Zhu-1 depression and local areas in the southwest of the Zhu-3 depression, and mostly $V$ in the Zhu-2 depression. The analysis of the sea-floor potential unstable factors, shows that most region of the Zhu-1 and Zhu-3 depressions now explored are located in the outer continental shelf (water depth 60 ~ 200 m). The stability of the sea-floor is considered to be moderate or better than moderate. The regional stability could be regarded as a little bad one in the Zhu-2 depression because the water depth in most region is more than 200 m, the sea floor fluctuation is large, and the region is close to the moderately active fault zone in the northern margin of the continental slope. However, the comment on the regional stability concerning the whole region could be stable or moderately stable. It is advantageous to oil exploration and production in the Zhujiang River Mouth Basin.

REFERENCES


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