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Research Article

Analysis of Engineering and Geological Conditions of International Submarine Optical Fiber Cable Routing in the East China Sea Section

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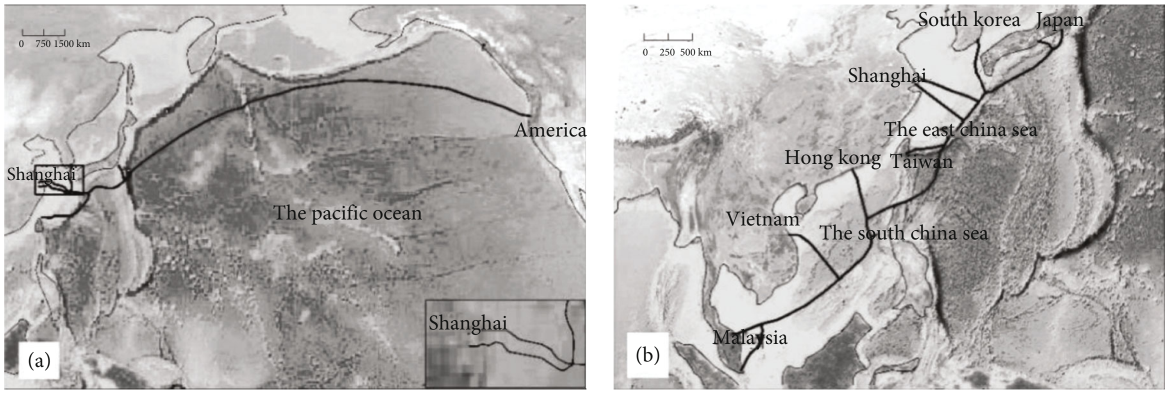
The East China Sea section of the Chinese international submarine optical fiber cable generally starts from the Shanghai coast, crosses the East China Sea shelf and continental slope to the east, and intersects with the international optical fiber cable system in Okinawa Trough. In this paper, the regional tectonic, seismic, and other environmental conditions of the East China Sea section of the international submarine optical cable are briefly described based on the previous data. Additionally, the geological engineering conditions of the international optical cable routing in the East China Sea area will be analyzed based on the field investigation data such as multibeam, side-scan sonar, shallow stratigraphic profile, sediment sampling, and cone penetration test (CPT). It is found that the main geological factors in the East China Sea shelf area are submarine scouring, sandwave, shallow gas, and hard seabed; in the land slope area are steep slope, submarine valley, rock, landslide, and shallow gas (pockmark); and in the Okinawa Trough area are gully, sea mound/seamount, rock, shallow gas, fault, and hard strata outcrop. This paper briefly analyzes the impact of each geological disaster factor on the submarine cable project and proposes solutions for providing essential information and some scientific basis for designing, constructing, operating, and maintaining international submarine optical fiber cables in the East China Sea area.

1. Introduction

As international economic, scientific, educational, and cultural exchanges expand, the demand for international communication capacity and quality in various countries and regions increases [1]. In order to meet the growing demand, coastal countries have been building new high-performance communication cables for efficient information exchange between various countries and regions in recent years. The Chinese mainland's international submarine communication optical fiber cable is primarily landed in Shanghai, including the optical fiber cable system between China and the United States as well as the regional international optical fiber cable system from East Asia to Southeast Asia. After starting from the coast of Shanghai, the optical fiber cable traverses the East China Sea shelf and land slope to the east and intersects with the international optical fiber cable system in the Okinawa Trough, as shown in Figure 1.

Due to the different conditions of the East China Sea shelf [2–4], land slope [5], and Okinawa Trough sea area [6, 7], for example, the international optical fiber cable in the East China Sea shelf area has to cross several sedimentary geomorphological areas such as the Yangtze River subaqueous delta [8, 9], large erosion depression, and shelf residual sand area. Besides those, the land slope and Okinawa Trough have dramatic topographic undulations and their geological conditions are more complex [10–12]. In the past decade, submarine cable damage accidents in the East China Sea area have occurred occasionally, causing interruption of international cables, thereby affecting international communications and leading to significant economic



(a) (b)

Figure 1: Schematic diagram of the completed international submarine optical fiber cable in the East China Sea. (a) New Cross Pacific Cable Network (NCP) and (b) Asia Pacific Gateway (APG).

losses. Therefore, it is essential to study the geological engineering conditions of international submarine cable routing in the East China Sea area [13, 14].

The influence of the damage geology of submarine cable is analyzed mainly from the aspects of topography, shallow stratum's profile, and sediment type. Relevant detection methods mainly include multibeam [15], side-scan sonar [16], shallow stratum profile, sediment sampling, and CPT [17]. For example, Ou et al. [18] used multibeam to detect seabed topography in the South China Sea and analyzed the causes of landform formation. Bryant [19] used side-scan sonar to measure the seaway and evaluate the situation of the sea floor. Li et al. [20] analyzed the role of shallow formation profiler in detecting undesirable seabed geology. Guo et al. [21] studied the undrained shear strength and penetration test of Marine soil, which supply important reference for the construction of marine cable.

In this study, some combined detection methods of multibeam, side-scan sonar, shallow stratigraphic profiler, sediment sampling, and cone penetration test (CPT) were used to obtain the terrain, seafloor condition, shallow stratigraphic profile structure, and seafloor substrate condition in the cable routing area. So that, it is enabled to obtain the geological engineering conditions and adverse geological factors in the East China Sea section of the international submarine optical fiber cable routing. The results provide basic information and some scientific basis for designing and constructing international submarine cables in the East China Sea.

2. Study Area Overview

This paper takes the East China Sea part of the Southeast Asia-Japan No. 2 submarine cable (SJC2 S6) as an example for analysis. SJC2 S6 is located in the northern part of the East China Sea, with Shanghai as the landing point to the southeast to the Okinawa Trough the whole area is around 300 km and 700 km apart from north to south and east to west, respectively, crossing the Yangtze River subaqueous delta, large erosion depressions, accumulation plateaus, ancient delta plains, ancient tidal sand ridge groups, and residual accumulation plains, subsequently, from west to east [22] (Figure 2).

2.1. Regional Structure. There are many geological structures developed in the routing area (East China Sea), which is a tectonic domain of the East Asian continental margin and can be divided into five primary tectonic units of "three uplifts and two basins," with the uplifts and basins in order from west to east, namely, the Zhejiang-Fujian uplift area, the East China Sea shelf basin, the Diaoyu uplift zone, the Okinawa Trough basin, and the Ryukyu uplift area, all of which are NNE trending. The first four units are related to this paper (Figure 2).

The Zhejiang-Fujian uplift zone is adjacent to the Chinese mainland, accompanying abundant sediment sources, and the base is deeply buried into the seafloor. The East China Sea shelf basin owns a large area and has been sedimented for a long time since the Quaternary period [23], which deposited a large amount of ancient Yangtze sediment in the East China Sea basin forming a huge sedimentary stratum and a flat seafloor terrain [24]. The Diaoyu uplift zone is a fault-block uplift bounded by the fault and the basins on both sides. It is located on the outer edge of the shelf, around 1000 km and 5~70 km in length and width, respectively, with well-developed magmatic rocks and thin overburden. Local islands such as Diaoyu Island are exposed to the sea level. The Okinawa Trough is a young postarc rift basin in the tensional (expansion) stage, with intense fault activity and intrusion of magmatic rocks in the trough [25–27].

2.2. Seism. The western part of the routing is located within the middle and lower Yangtze River-South Yellow Sea zone in the North China seismic region. This seismic zone is a moderately strong seismicity area characterized by strong sea and weak land. Modern seismic activity has also been relatively active since 1970, with three earthquakes of magnitude five or higher.

The routing $123°30'$E~$126°30'$E is located within the East China Sea shelf basin, and the seismic activity is relatively quiet, with no historical records of destructive earthquakes and weak modern seismic activity.

The routing $126°30'$E is located on the eastern edge of the East China Sea shelf basin, the East China Sea shelf edge

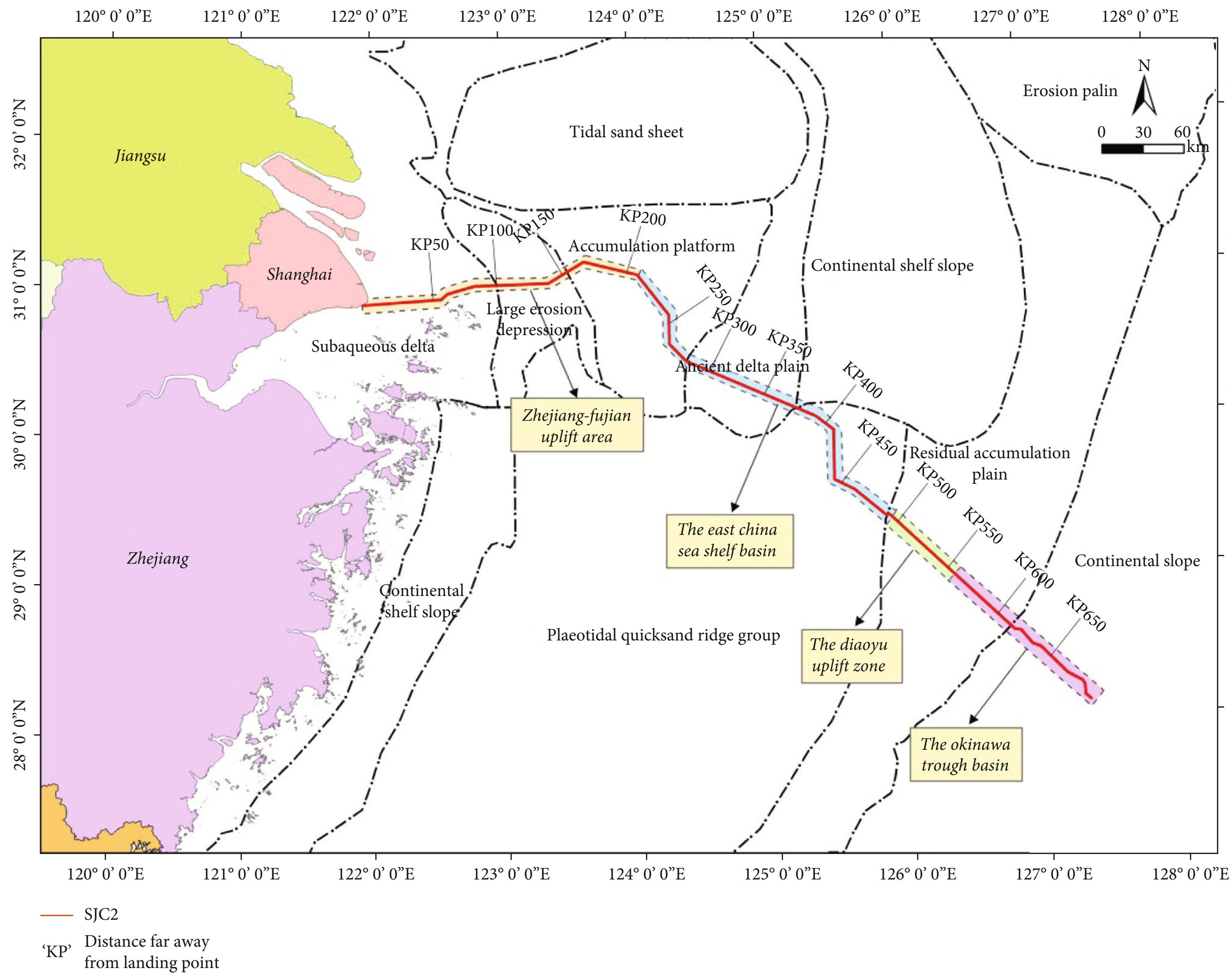


Figure 2: Location of the study area (the figure shows the seabed landform of the East China Sea [22]).

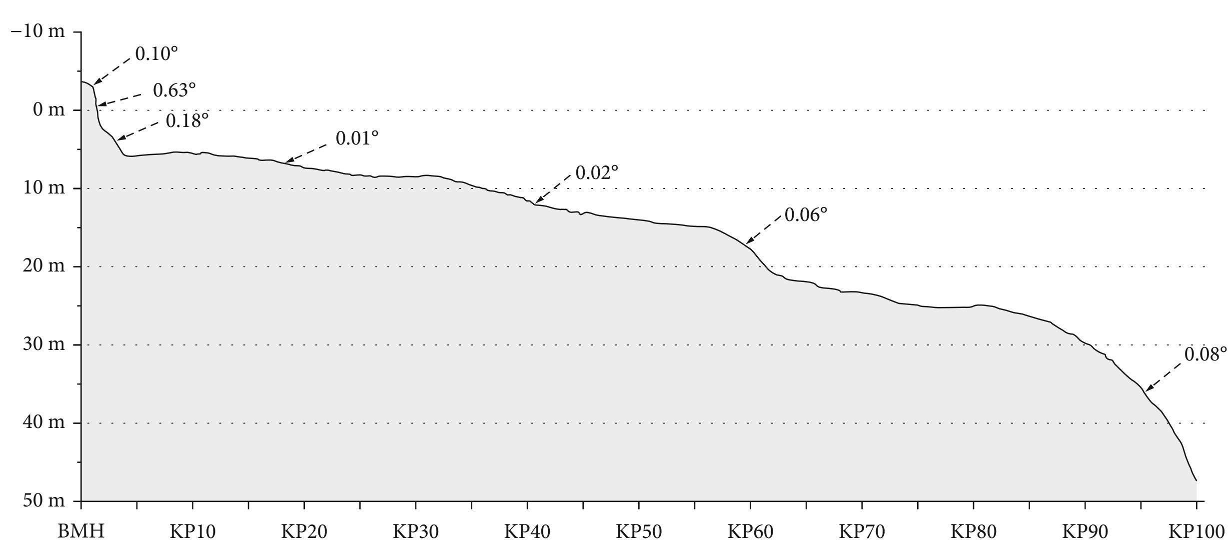


Figure 3: Routing topographic profile (submerged delta portion of the Yangtze River).

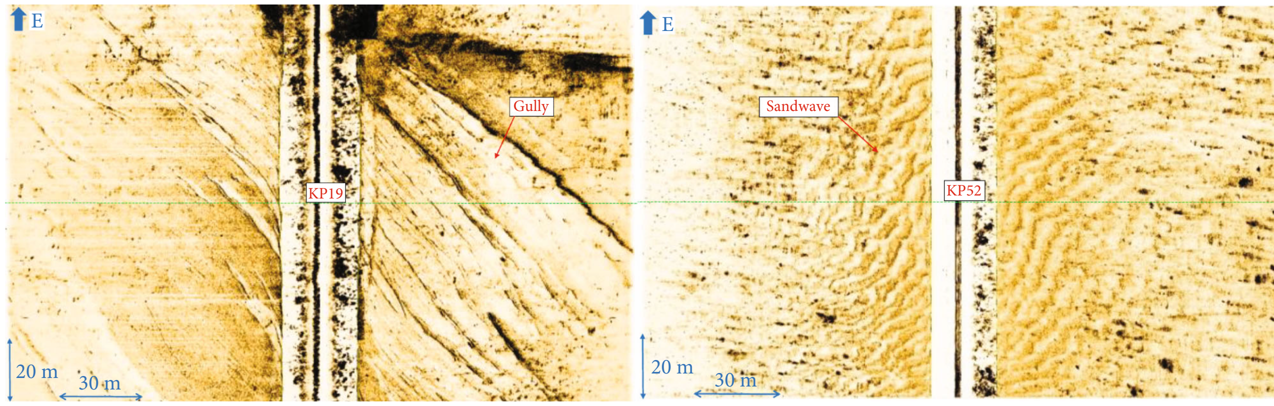


Figure 4: Microscouring and sandwave geomorphology of the Yangtze River subaqueous delta showed by side-scan sonar (left is scouring gully, and right is sandwave).

uplift zone, and the Okinawa Trough, which is flanked by the Okinawa Trough, the Ryukyu Island Arc, and the Ryukyu Trench to the east. This area is the central part of the Ryukyu Island Arc seismic zone in the western Pacific Ocean and is a well-known area of strong earthquakes.

3. Analysis of Engineering Geological Conditions and Impacts in the Routing Area

3.1. Geological Engineering Conditions of the East China Sea Shelf

3.1.1. Terrain of the East China Sea Shelf. Route's KP0-KP10 ("KP" in this essay refers to distance form landing point) is located in the underwater delta of the Yangtze River. According to the multibeam measured data, the seafloor is very flat, the terrain generally slopes from west to east, the water depth changes slowly, the nearshore slope is 0.1°~0.63°, and the average slope of the offshore area is less than 0.05° (Figure 3). Based on the side-scan sonar image data, scour and sandwave induced by waves and tides prevail in this area (Figure 4).

KP100 km~KP165 km is an enormous erosion depression geomorphic area with relatively flat terrain and four apparent sand ridges. The bottom of the sand ridge is 15 km~20 km wide and has a height difference of 10 m~15 m; the slope of both sides of the southeast sand ridges is similar, about 0.2°, and the slope of the northeast flank of the northeast sand ridges is flat, and the height difference is smaller, from southwest to northeast, and the terrain is stepped upward (Figure 5). Based on the side-scan sonar image data, the sandwave microterrain in this area is evident with the 0.6 m height wave, as shown in Figure 6.

KP165 km-KP260 km is a stacked terrace geomorphic area. The terrain slopes to the southeast, and the water depth gradually increases from 35 m to 50 m, with a relatively flat slope (Figure 5). Small sandwave or sand ridges are developed with a 2 m height wave, as shown in Figure 7.

KP260 km~KP380 km is the ancient delta plain (Figure 5), which is mainly related to the ancient Yangtze River during the Late Pleistocene low sea level period in terms of genesis. About 120000 to 15000 years ago, the sea level rose and fell several times, exposing the shelf of the Yellow Sea and the East China Sea into a wide land plain. The Okinawa Trough bordered the coastline and the ancient Yangtze River flowed into the Yellow Sea from near Rudong County, Nantong, Jiangsu Province, forming a multiphase delta. The sea terrain is very flat, and the slope is less than 0.06°.

KP380 km~KP484 km is the ancient tidal sand ridge group (Figure 5), with the terrain sloping to the southeast overall and the water depth gradually deepening from 60 m to 105 m. Among them, the terrain is slightly undulating between KP450~KP460, the relative height difference is about 10 m, and the maximum slope is approximately 0.23°. The development of this sand ridge is related to the Late Quaternary sea level lifting movement. During the terminal low sea level, about 23000 years ago, the sea level began to decline (marine regression), reaching a minimum level (about 150 m lower than the present level) about 15000 years ago, the East China Sea shelf was exposed into a wide land plain, the Okinawa Trough bordered the coastline, and the ancient Yangtze River estuary was extended, bringing a large amount of sediment; the sea level rose during the interglacial period (marine transgression), the shelf was gradually submerged by seawater, and around 7000 years ago, the sea level rose to the present level. In the process of sea level rise, the tide relocated and modified the sediments, moving the sediments in the tidal trench to the top of the ridge, forming a geomorphic pattern of tidal sand ridges and troughs [28–33].

KP484 km~KP610 km is the residual accumulation plain; the water depth is gradually deepened from 105 m to 110 m; the terrain is very flat with a slope less than 0.1°. The east of the residual accumulation plain is the East China Sea land slope, as shown in Figure 6.

In addition, according to the side-scan sonar image data, the seabed surface of the East China Sea shelf from the shore to the outer edge is distributed with anchor marks and obstacles, as shown in Figure 8. Anchor marks are formed when a ship is anchored, which will impact the safety of submarine cables. Obstacles may impact the safety of ships, construction equipment, and submarine cables during submarine cable construction.

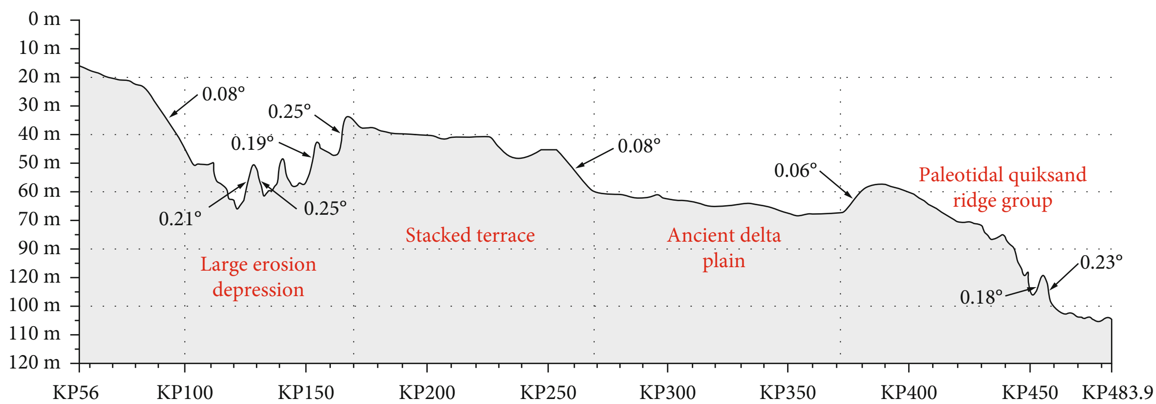


Figure 5: KP56 km~KP484 km topographic profile.

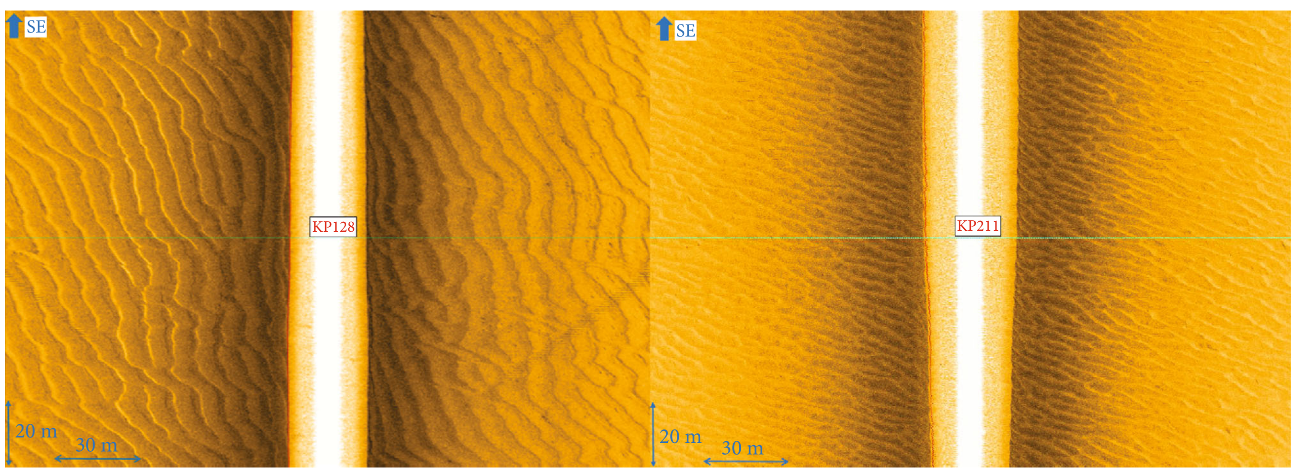


Figure 6: KPKP484 km~KP638 km routing topographic profile.

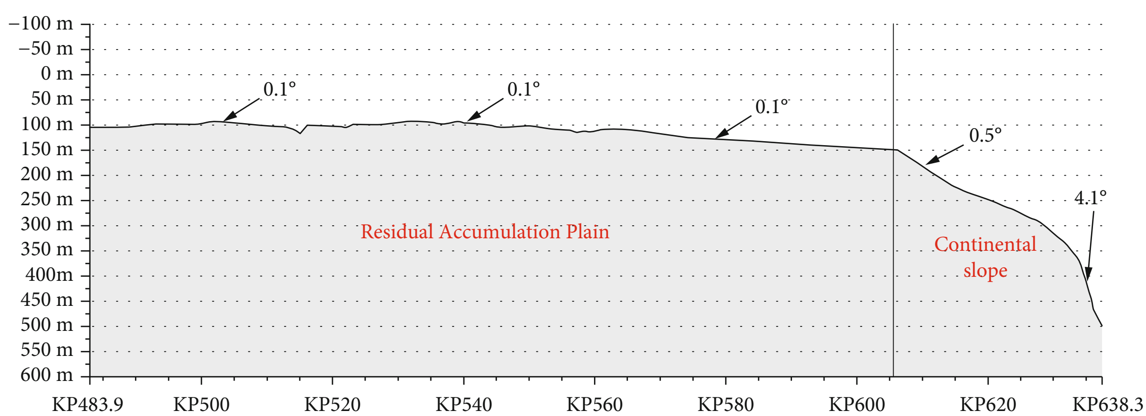


Figure 7: Sandwave images showed by side-scan sonar (the left is located in the large erosion depression landform area, and the right is located in the stacked terrace landform area).

3.1.2. Substrate Type and Shallow Stratigraphic Characteristics of the East China Sea Shelf. In addition to nearshore islands and rocky areas of islands and reefs such as Diaoyu and Suyan on the outer shelf, the East China Sea shelf is covered with sediments, and the substrate is influenced by sand transport from the modern Yangtze River and Zhejiang-Fujian Rivers [34–40].

According to the sediment sampling and shallow stratigraphic survey data, the substrate from KP1.0 to KP56 (Yangtze River subaqueous delta) is variable and complex, among

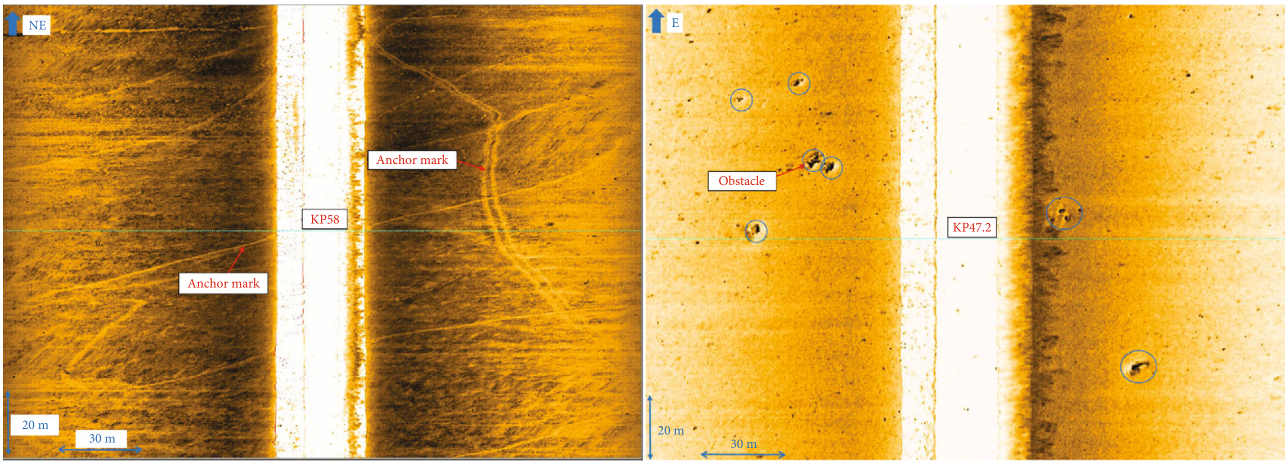


Figure 8: Side-scan sonar shows anchor marks and obstacles distributed on the seabed of the East China Sea shelf.

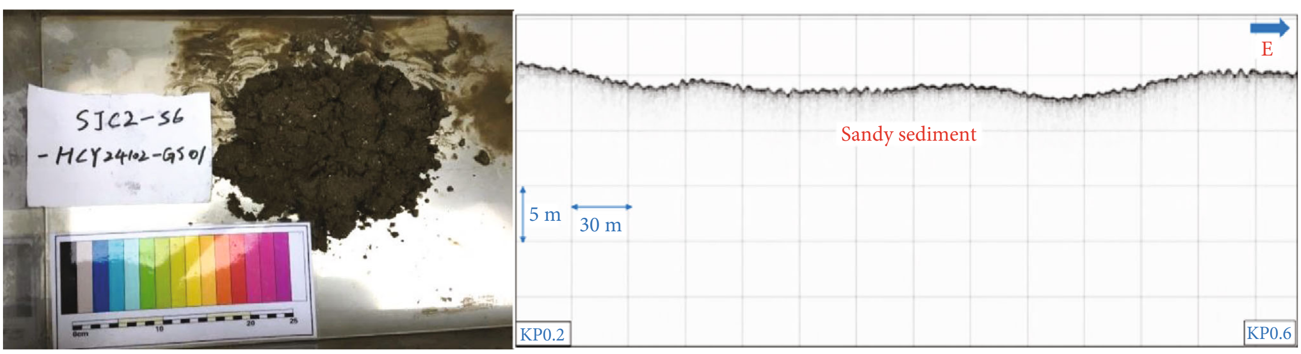


Figure 9: Typical sediment photos and shallow stratigraphic section images of the landing section (left is the sediment photo, and right is the shallow stratigraphic section image).

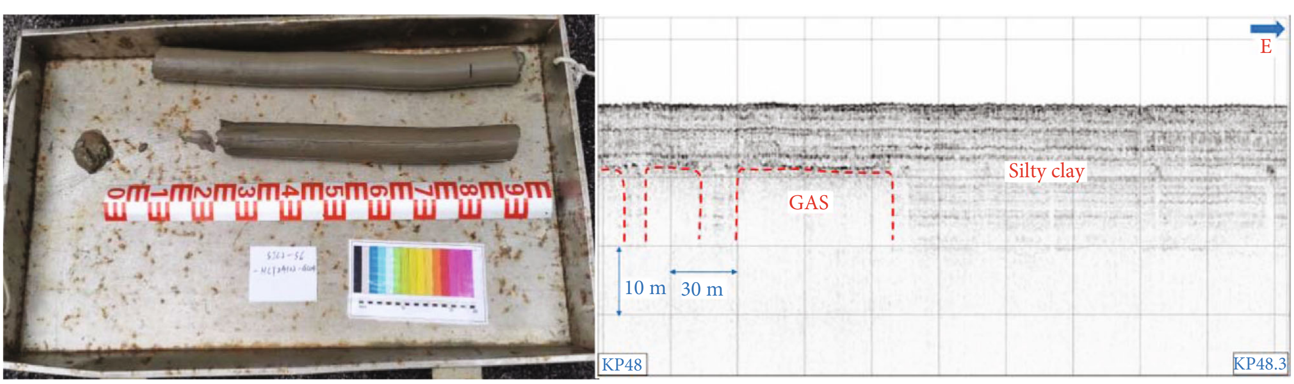


Figure 10: Typical sediment photos and shallow stratigraphic profile images of the nearshore section (left is the sediment photo, and right is the shallow stratigraphic profile image).

which the submarine cable landing section (KP0~KP1.0) has a slightly coarse substrate, dominated by sandy sediments, and the shallow stratigraphic profiler acoustic reflection signal is weak overall (Figure 9). However, in the landing section outward (KP1.0~KP56), the substrate is composed chiefly of gray-black/gray-yellow sandy silt, clayey silt, and silt clay, with a small amount of shell debris and silt (Figure 10). The signal of shallow stratigraphic profiler acoustic reflection is strong, and maximum penetration thickness is more than 20 m; the horizontal bedding is developed, and the homogeneous axis continuity is favorable with large amplitude (Figure 10). Due to the soft substrate, it is conducive to constructing submarine cable excavation. Moreover, shallow gas is well-developed in the Yangtze River subaqueous delta; its burial depth ranges from 2 m to 8 m, and the burial depth of the top of the gas gradually increases from the shore to the outside, and the

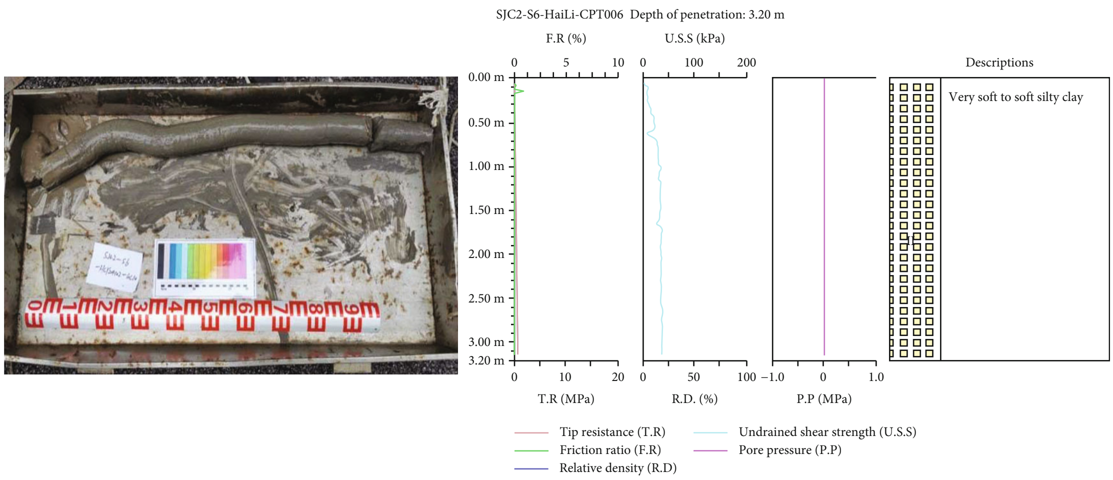


FIGURE 11: Sediment and CPT results in a typical erosion depression geomorphic area.

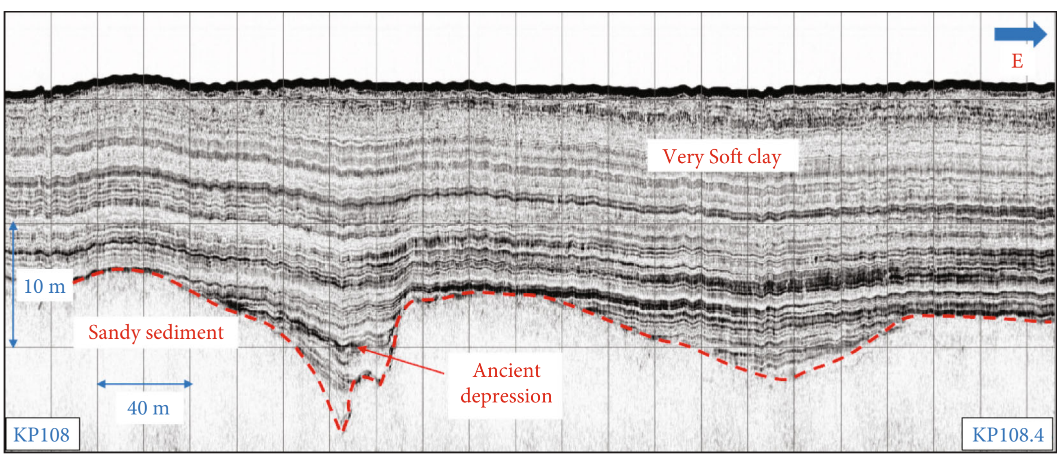


FIGURE 12: Shallow stratigraphic images of a typical erosion depression geomorphic area.

development of shallow gas is relatively weak after KP46 (Figure 10). During the construction of submarine cables, shallow gas may cause high-pressure blowout, endangering the safety of construction personnel. In addition, shallow gas may cause seabed collapse, resulting in the fracture of submarine cables. Therefore, attention should be paid to the influence of shallow gas during the construction of submarine cables.

KP56-KP165 (large erosion depression geomorphic area) generally originates from the southward diffusion of the Yangtze River outlet sediment, the material carried by coastal outlet rivers and the material weathered and denuded by coastal rocks. It is a Late Holocene marine sediment, presenting the feature of the bottom of the sand ridge is fine, and the top of the sand ridge is coarse.

The sediments at the bottom of the sand ridge are generally clayey silt and silty clay (Figure 11), with the color of gray, gray-yellow, and gray-black, locally containing silt and a small amount of fine sand. Also, according to CPT results (Figure 11), the substrate is generally soft, and its cone tip resistance and shear strength are less than 1 MPa and 30 kPa, respectively. Observation from the shallow stratigraphic image, the stratigraphic penetration thickness is about 15 m (Figure 12), the acoustic reflection signal is strong, horizontal laminae are developed, with good continuity of the same phase axis, strong amplitude, and clear laminae, and the lower part usually develops ancient depressions. The sediment at the top of the sand ridge is generally dominated by fine sand and silty sand (Figure 13), with massive results, grayish yellow, and containing a small amount of shell debris. According to the results of the CPT, the cone tip resistance and relative density is high, indicating that the substrate is hard. The stratigraphic penetration thickness is shallow from the shallow stratigraphic image, with obvious sandwave geomorphology (Figure 14).

The seafloor lithology from KP165 to the outer edge of the land shelf (stacked terrace geomorphic area, ancient delta plain, ancient tidal sand ridge group, and residual stacked plain) consists of sandy silt and silty sand, the outer edge of the shelf substrate especially is coarse, and its composition is fine to coarse sand, with loose-dense, gray-black characteristics, containing a small amount of shell debris. These substrates are primarily formed in the Late Pleistocene or Early Holocene. From the CPT results, the cone tip resistance and shear strength of these sediments are high, among which the cone tip resistance is 2Mpa~15Mpa and

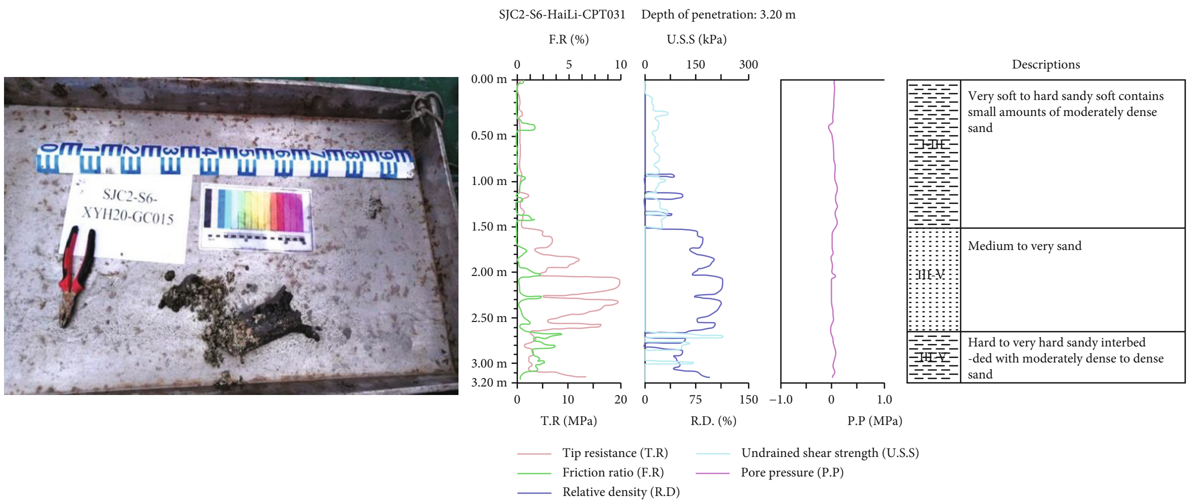


Figure 13: Sediments and CPT results at the top of the sand ridge in a typical erosion depression geomorphic area.

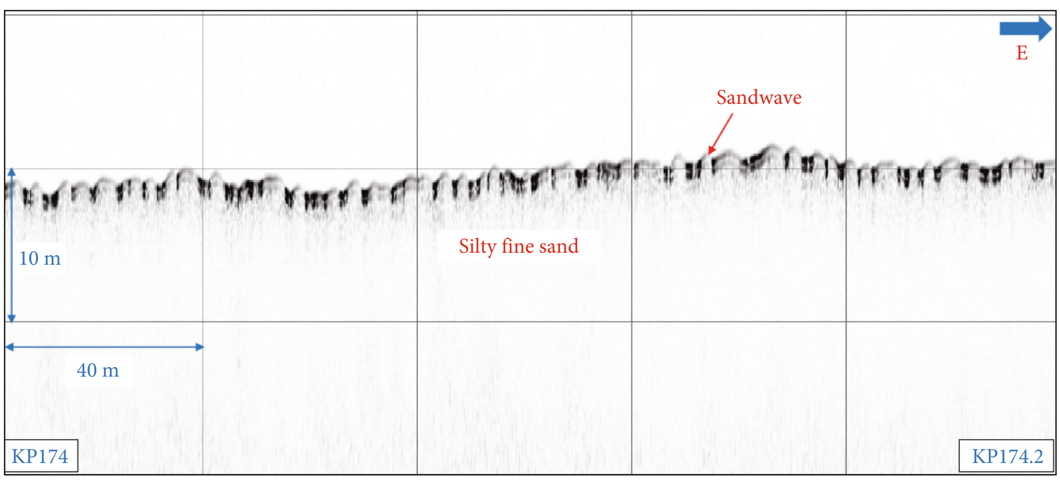


Figure 14: Shallow stratigraphic images at the top of the sand ridge in a typical erosion depression geomorphic area.

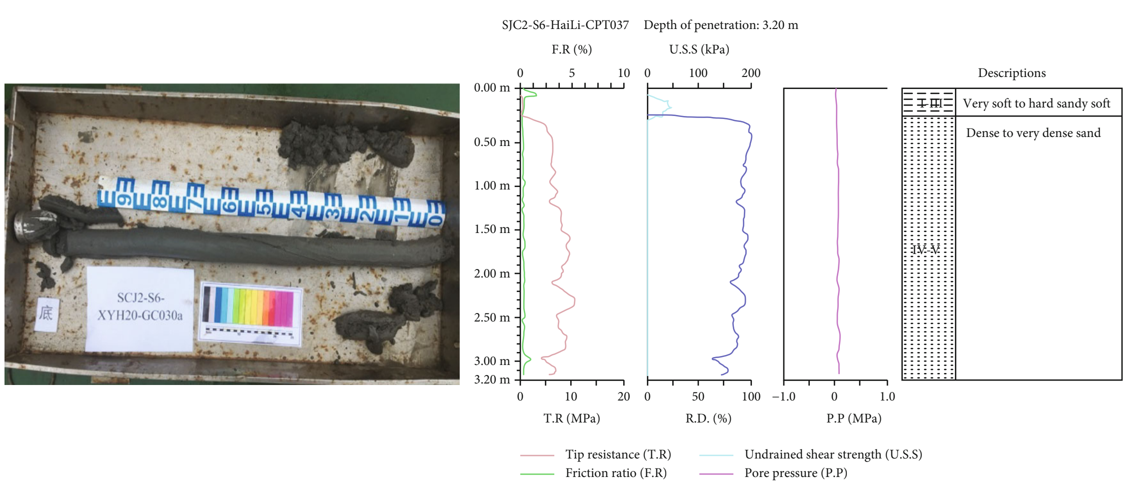


Figure 15: KP165-typical sediments and CPT test results on the outer edge of the continental shelf.

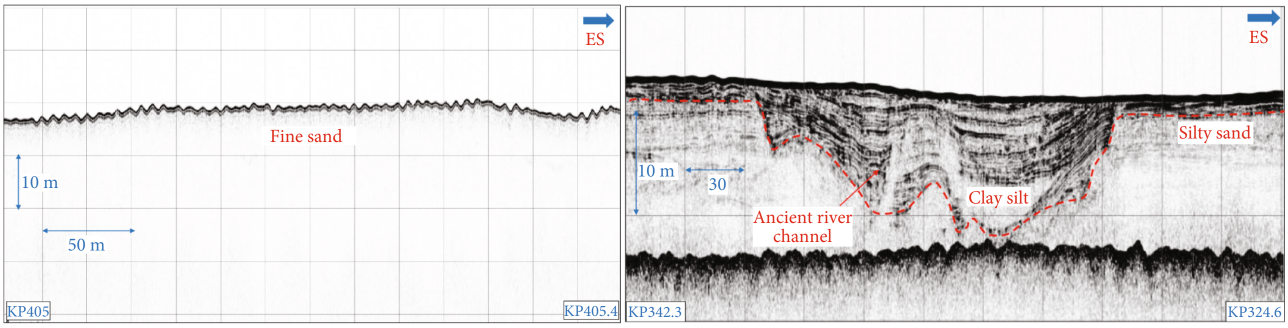


FIGURE 16: KP165-image data of typical shallow strata on the outer edge of continental shelf (sandy area on the left and ancient river channel area on the right).

the shear strength ranges from 20 kPa to 150 kPa in general and up to about 180 kPa in maximum (Figure 15). It is observed from the shallow stratigraphic profile (Figure 16) that this section routing submarine stratigraphic penetration is short; the stratigraphy is underdeveloped; the local sea area develops ancient river channel/ancient lagoon, with undulating reflection bottom boundary, burial depth 2 m~6 m, and bottom burial depth around 6 m~15 m; and filling sediment reflection structure is more complex, generally clayey silt, sand dominant.

3.2. Engineering Geological Conditions of the East China Sea Land Slope

3.2.1. Terrain of the East China Sea Land Slope. The land slope is bounded from the shelf by a distinct change in slope (slope fold). The East China Sea land slope, also known as the western slope of the Okinawa Trough, is 15-70 km wide from the outer edge of the shelf to the foot of the slope, with an average width of about 35 km. This land slope presents a character of wide in the north and narrow in the south, with a narrow NE-SW oriented arc set between the East China Sea shelf and the Okinawa Trough (bottom of the trough), and the slope of the seafloor terrain is large, dropping rapidly from a water depth of around 150-160 m to 1000 m. The land slope is relatively wide and flat in the north of 28°N direction, with a slope of about 1°~14° and a few small-scale canyons. The land slope is narrow and steep in the south of 28°N with a 30° slope. Numerous large-scale (a length of 10~50 km and width of 1~6 km) developed canyons are across the land slope, with a depth of undercutting of 5~500 m, making the terrain of the land slope fragmented and complex as well as a great height difference. The lower part of the land slope is developed with underwater terraces and seamounts. The international submarine optical fiber cables in the East China Sea section all enter the land slope in the north of 28°N.

The historical survey shows that the submarine valleys on the land slope are relatively developed, with "V-" shaped and irregular "U-" shaped cross-sections, with widths of several hundred meters and kilometers to ten kilometers. In the cross-section, the valleys developed on the top of the land slope are small scale, while those in the middle and lower part of the land slope are large scales (at least in the cross-section), and there are also smaller ones with more variable and complex morphology. Figure 17 shows the topographic profile of the submarine gully zone at the top of the land slope, nearly 9 km away from the slope fold. The bottom of the gully is uneven and undulating, with dense potholes in the size of diameter about 100~200 m; some may extend to 500~1000 m along the direction of the gully, forming the structure of a gully within a gully. Figure 17 shows the lower part of the land slope on the southeast side with a water depth of 780~900 m develops three-step terrain, the width of the platform is 500~1000 m locally potholes, and the step drop on the back can reach 50 m with a slope of 14°. The development of this terrain is usually related to the step-like landslide. The SJC2 S6 submarine cable routing has avoided the land slope valley and tertiary terrain areas (stepped landslide areas).

According to the side-scan sonar image data, there are scattered pockmarks on the seabed of the land slope, which are less than 50 m in diameter and 3 m in depth, and locally clustered. Scattered pockmarks may cause construction equipment to capsize and impact construction safety. In addition, the land slope submarine trench area is generally accompanied by the development of submarine rocks, as shown in Figure 18.

3.2.2. Substrate Types and Shallow Stratigraphic Characteristics of the East China Sea Land Slope. The top of the land slope is sand and silty sand, which is continuous with the sandy sediments of the shelf. The lower slope section and the bottom of the slope consist of very soft clay in gray-black as well as locally containing thin layers of silty sand, and the submarine bedrock is generally developed in the submarine trench. Except for the rocks developed in the valley area, the shallow stratum bedding is relatively developed in the land slope area, with a penetration depth of around 30 m. The whole land slope is horizontal and continuous traceability (Figure 19).

3.3. Engineering Geological Conditions of the Okinawa Trough

3.3.1. Terrain of the Okinawa Trough. The Okinawa Trough is located between the land slope of the East China Sea and the western slope of the Ryukyu Island Arc, which is a postarc basin in the "trench-arc-basin" system formed by the subduction of the Pacific plate to the Eurasian

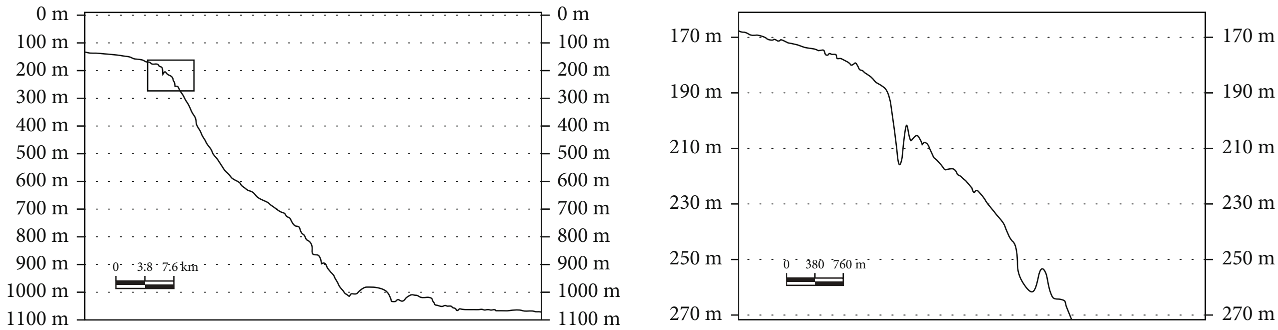


Figure 17: Topographic profile of a typical land slope gully zone (the right figure is a partial enlargement figure of the box in the upper left corner of the left figure).

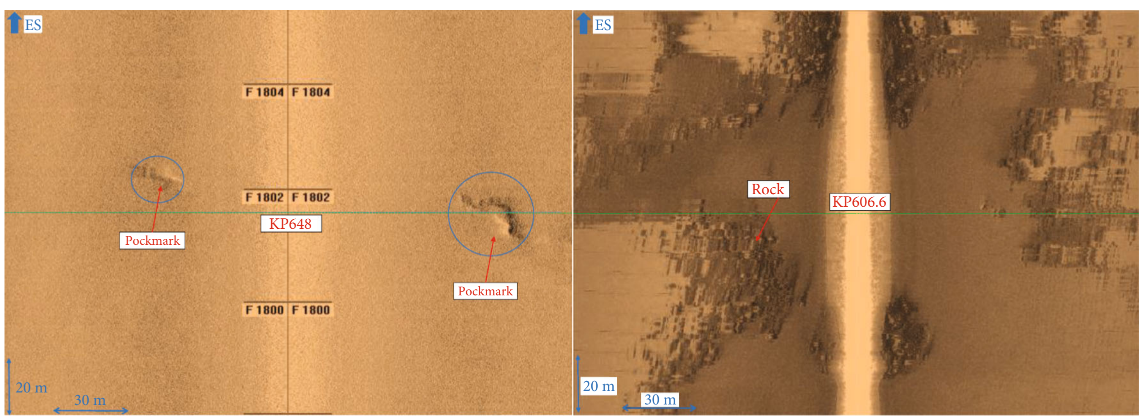


Figure 18: Typical land slope side-scan sonar image (the left is a group of pockmarks, and the right is exposed rock in the submarine trench area).

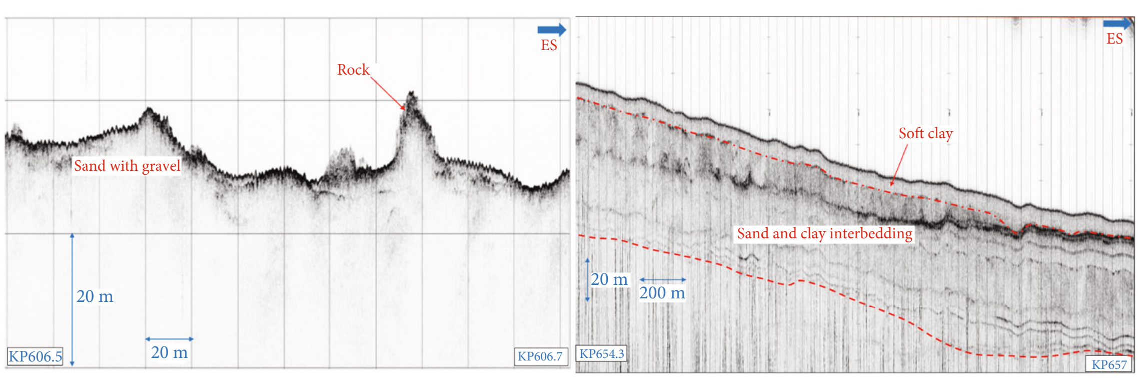


Figure 19: Typical land slope shallow stratigraphic profile (the left figure shows the rocks developed in the land slope gully area, and the right figure shows the land slope stratigraphic developed area).

plate. The features of that are developed fault structures, active submarine volcanoes, and complex sediment types. The overall direction of the trough is the same as the shelf edge, with an average width of 94.7 km in NE-SW, and the basic features of the trough terrain are deepening from north to south, with a water depth 700~1000 m in the north of 30°N. The bottom of the trough is widely distributed with seamount and rugged terrain. The central water depth in 26°30′~30°N is 1000~2000 m, mostly between 1000~1300 m. The submarine landforms are primarily composed of volcanic landforms or tectonic types such as semiapartheid plains, central rift valleys, fractured depressions, volcanic chains, and fractured block uplifts.

Most of the East China Sea submarine optical fiber cable routing enters the trough in 30°N, and the routing length is 50~100 km, which is in the secondary trough of the western trough. The survey data show that the seafloor is undulating, with gullies and abyssal hills/seamounts interspersed, and

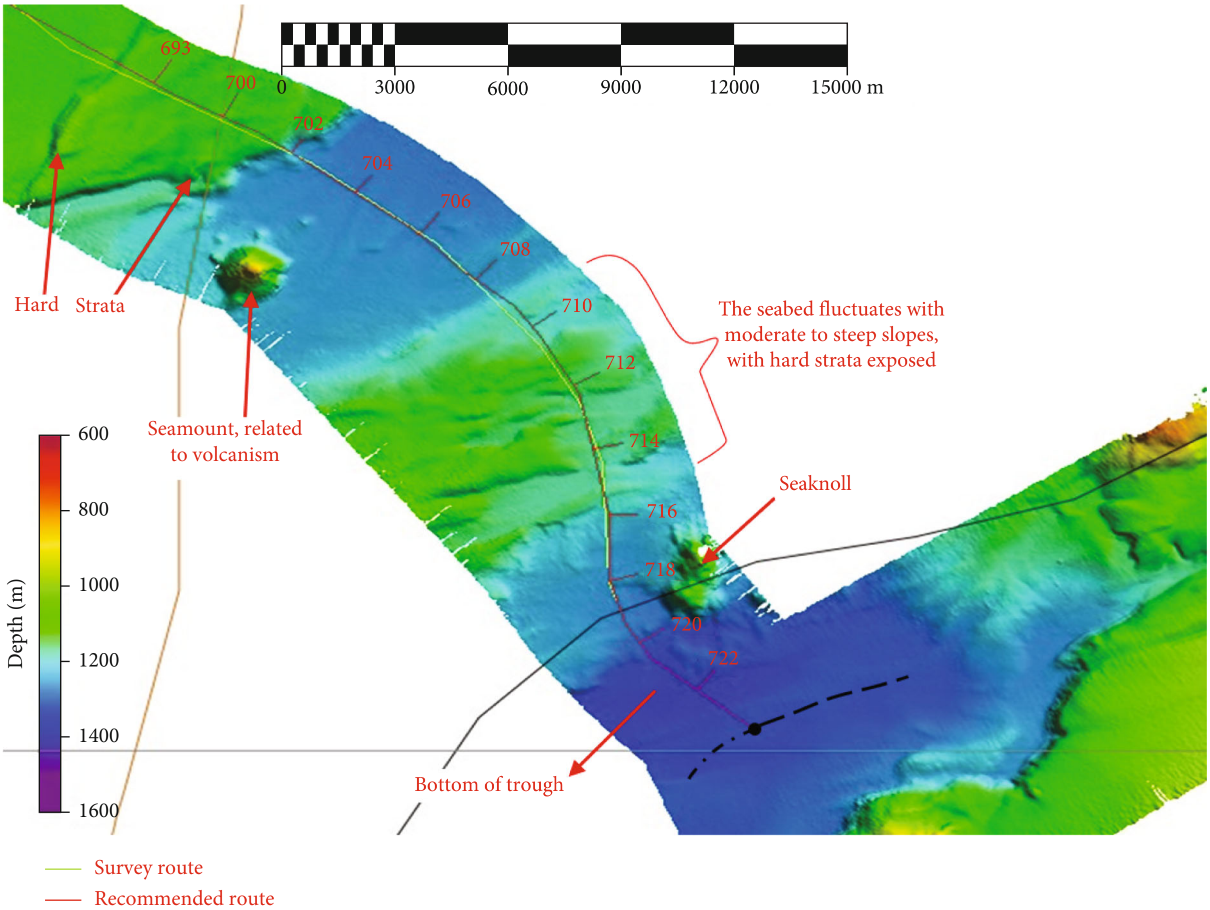


FIGURE 20: Typical Okinawa Trough gullies and abyssal hills/seamounts interspersed as revealed by multibeam.

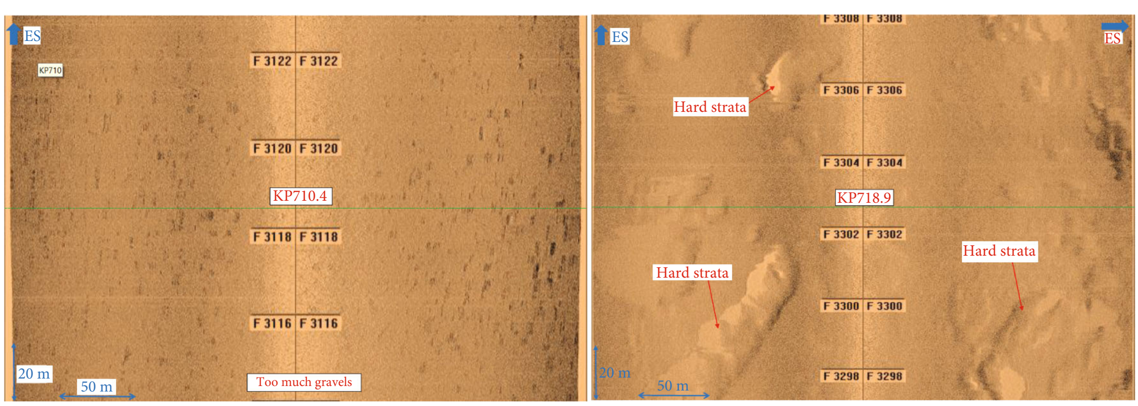


FIGURE 21: Side-scan sonar images showing a large number of gravels and hard strata outcropping in the area of the trench and the accompanying abyssal hills/seamounts in the Okinawa Trough (the left image is a side-scan image of gravels, and the right image is a side-scan image of hard strata outcropping).

the seabed in the survey corridor shows irregular undulations with a maximum slope of 35° (Figure 20). The phenomenon of gullies and abyssal hills/seamounts interspersed may be related to small magmatic activities along the fault in the trough, which also affect the land slope deep water area. In addition, due to the side-scan sonar images, many gravels and hard strata are generally exposed along the trench and mound/seamount seas (Figure 21).

3.3.2. Substrate Type and Shallow Stratigraphic Characteristics of the Okinawa Trough. From the shallow stratigraphic shadow survey data, the shallow stratigraphy

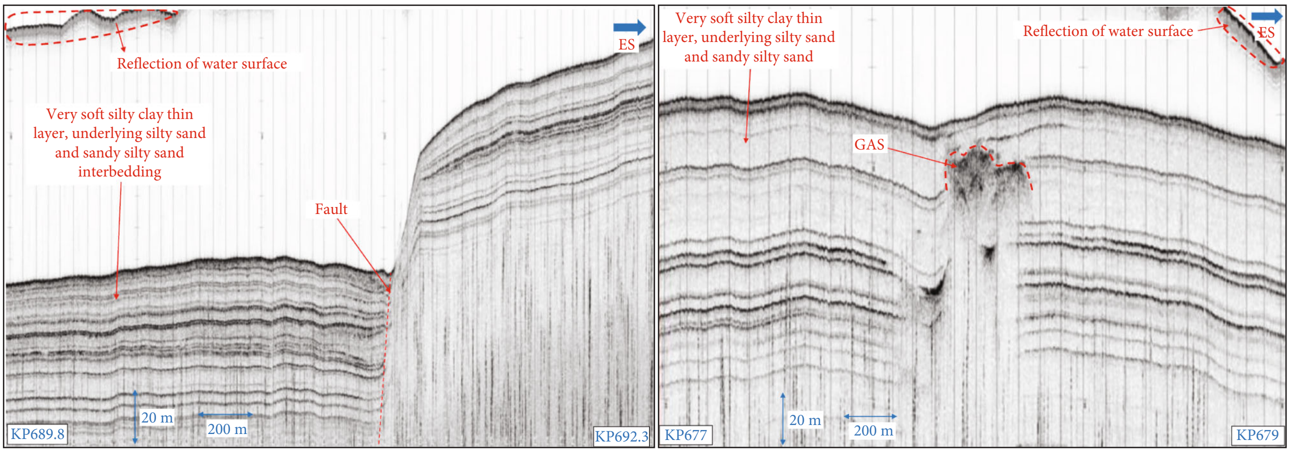


Figure 22: Profile of a shallow stratigraphic of typical Okinawa Trough (left image shows the stratigraphic developed area, and the right image shows the shallow gas area).

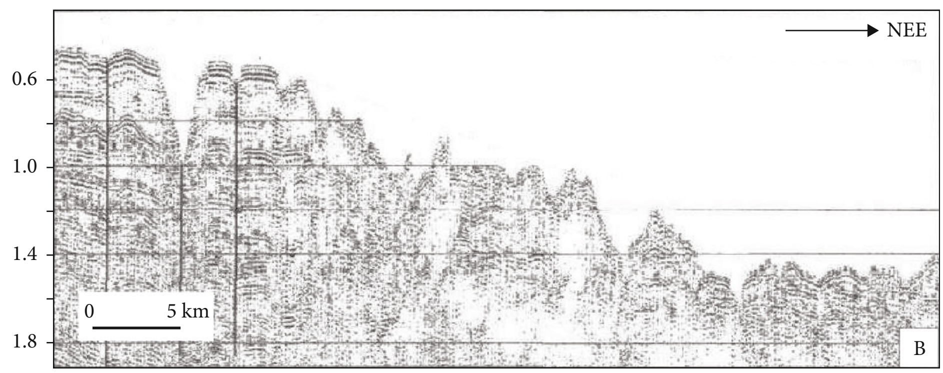


Figure 23: Typical seismic profiles of turbidity in the East China Sea slope area (Zhao et al. [41]).

of Okinawa Trough is relatively well-developed, and the penetration depth reaches 30 m, horizontal and continuous traceable, local development of shallow gas, faults, and hard strata or rock outcrops, which has a significant impact on the construction of submarine cables. The survey found that there are many faults in the trough, indicating that the faults in the trough are developed, which is generally related to seismic activity. The typical fault stratigraphic section is shown in Figure 22. After extensive investigation, the route could not avoid the defect area. Therefore, during the construction of the submarine cable, the length of the submarine cable should be increased in the area where the fault may occur to reduce the probability of damage to the submarine cable.

In addition, there is another potential risk in the slope and Okinawa Trough—high-density turbidity. Although no turbidity was found in this investigation, according to the research of Zhao et al. [41] and Xufeng et al. [42], turbidity has developed in the slope of the East China Sea and Okinawa Trough. The slope area is characterized by steep slopes, large amounts of sediment, and high water content. Turbidity events are triggered when earthquakes or triggering factors are encountered, and it is also the main mode of sediment transport between the East China Sea slope and the Okinawa Trough, which plays an important role in shaping the slope topography. Xufeng et al. [42] studied three columnar cores in the Okinawa Trough and proved that turbidity events in the Okinawa Trough are generally related to volcanic activities, seisms, and storms. Meanwhile, turbulent flow caused by seismic activities generally develops a number of superimposed mound-shaped accumulations, which are formed by the collapse and creep of subsidence deposits under the action of gravity (Figure 23). Turbulence-induced slumps and landslides are also risk factors impacting the safety of submarine cables, which should be avoided in submarine cable routing.

3.4. Evaluation Results of Geological Engineering Conditions. From the above engineering geological conditions of the East China Sea area shelf, land slope, and Okinawa Trough, the international optical fiber cable routing successively crosses the geological conditions of the geological area routing vary. The evaluation results are shown in Table 1.

Table 1: Evaluation results of geological engineering conditions of each geomorphological unit in the routing area.

Geomorphological units		Terrain and landform, substrate, and shallow stratigraphic features	Disaster factors	Countermeasure
Continental shelf	Yangtze River subaqueous delta	The terrain is flat, with microlandforms such as scouring and sandwaves, and there are many obstacles. The sediments are mainly silt and clay, and the buried layer is soft, which is suitable for submarine cable excavation and shallow gas development	(1) Obstacles (2) Scouring (3) Sandwave (4) Shallow gas	(1) Avoid obstacles (2) Scouring- and sandwave-developed area should be buried as deep as possible and increasing the length of the submarine cable appropriately (3) The construction of the submarine cable should take shallow gas preemission measures and increase the length of the cable appropriately
	Large erosion depressions	The terrain is flat with many obstacles, and four obvious sand ridges are developed. The sediment at the top of the sand ridge is mainly fine sand, and the sandwave landform is developed. The sediment at the bottom of sand ridge is mainly silt or clay, and shallow gas is developed	(1) Obstacles (2) Developed shallow gas at the bottom of the sand ridge (3) Hard seabed at the top of the sand ridge, developed sandwave, and hard for deep burial	(1) Avoid obstacles (2) The construction of the submarine cable at the bottom of the sand ridge should take shallow gas preemission measures and increase the length of the cable appropriately (3) The length of the sea cable can be increased appropriately when it is difficult to bury deeply at the top of the sand ridge
	Stacked terrace Ancient Delta plain Ancient trendy sandy ridge group Residual accumulation plain	Flat terrain, development of small sandwave or sandwave, obstacles, and fishing activities The substrate is composed of sandy silt and silty sand, and the local sea area is developing ancient river channel/ ancient lagoon	(1) Occasional obstacles (2) Hard seabed, hard for deep burial	(1) Avoid obstacles (2) Buried as deep as possible otherwise increase the length of the sea cable appropriately
Land slope		Large terrain changes, hard for burial construction, developed submarine valley, developed stepped terrain, abundant pockmarks on the submarine surface, turbidity, and submarine bedrock are developed in submarine trench	(1) Large slope of the terrain, hard for burial construction (2) Submarine trench, rock, stepped terrain, and high-density turbidity (3) Pockmarks	(1) Slow construction; burial operation and properly strengthen the structure and strength of the protective layer of the optical fiber cable (2) Avoid submarine trench, rocky, stepped terrain, and high-density turbidity (3) Avoid pockmarked area
Okinawa trough		Undulating seafloor terrain, with gullies, abyssal hills/seamounts, rocky and hard strata exposed The substrate is composed of clayey silty sand, with shallow stratigraphic layers and locally developed shallow gas, faults and hard strata, or rock outcrops	(1) Gullies, abyssal hills/ seamounts (2) Shallow gas (pockmarks) (3) Fault (4) Hard strata or rock outcrops (5) High-density turbidity	(1) Complex terrain, buried construction is prone to plowing accidents, and it is recommended to lay construction, while avoiding trench valleys, abyssal hills/seamount areas, choose relatively flat terrain area, and properly strengthen the structure and strength of the optical cable protective layer (2) Avoid shallow gas developed area (3) Avoid fault zones as far as possible, and when unavoidable, shall try to choose shallow stratigraphic structure stable area to cross (4) Avoid hard strata or rocky outcrop areas

4. Conclusion

In this paper, we analyzed geological engineering conditions of the East China Sea section through the Southeast Asia-Japan No. 2 submarine cable (SJC2 S6) routing survey project, based on the survey data of multibeam, side-scan sonar, shallow stratigraphic profile, sediment sampling, CPT, etc. Ultimately, we proposed solutions to those typical disaster geological factors that may happen in the East China Sea area.

(1) The main disaster geological factors in the East China Sea continental shelf area are submarine scour, submarine sandwave, shallow gas, and hard seabed. The sediments in the scouring and sandwave areas are moveable, which has a certain impact on the safety of submarine cable operation, and it is generally recommended to bury as deep as possible or increase the length of the cable; the shallow gas developed area is prone to construction safety accidents and sinking of the cable during operation; it is recommended to take predischarge measures during construction and appropriately increase the cable length; the hard seabed area generally has an impact on the deep burial construction of the cable, and it is recommended that the cable should be buried as deep as possible and the length of the cable can be increased appropriately when deep burial is difficult to carry on

(2) The adverse geological factors in the East China Sea land slope area include steep slopes, submarine valley ditches, rocks, landslides, high-density turbidity, and shallow pockmarks, which significantly impact the submarine optical fiber cable project, combined with the regional geological characteristics. It is suggested to avoid those mentioned adverse geological areas during the construction of submarine cables in the East China Sea land slope area and require burial and slow construction as far as possible, while the structure and strength of the cable protective layer should be strengthened

(3) The adverse geological factors in the Okinawa Trough area include gullies, hills/seamounts, rocks, shallow gas, faults, hard strata outcrops, and high-density turbidity. The development of these adverse geological conditions may be the result of the postarc expansion activities of the Okinawa Trough, so the construction of submarine cables should avoid gullies and hills/seamounts and choose relatively flat terrain areas, while the routing should avoid shallow gas developed areas, fault, hard strata, rock outcrops, and high-density turbidity. When it is impossible to avoid the above areas, the structure and strength of optical cable protective layer should be strengthened

The analysis results of this paper can provide a reference for the routing desktop selection as well as submarine cable design, construction, operation, and maintenance of China's international optical fiber cable routing in the East China Sea.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

No potential conflict of interest was reported by the authors.

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References

[1] X. L. Chen, Y. C. Ye, and D. Li, "Analysis and research on fault cause of international submarine optical cable in East China Sea," *Ocean Engineering*, vol. 27, no. 4, pp. 121–125, 2009.

[2] C. F. Chen, K. Zhong, W. L. Zhu, D. H. Xu, J. Wang, and B. C. Zhang, "Provenance of sediments and its effects on reservoir physical properties in Lishui sag, East China Sea shelf basin," *Oil & Gas Geology*, vol. 38, no. 5, pp. 963–972, 2017.

[3] H. Lu, C. Xie, C. Zhang, and J. Zhai, "CMIP5-based projection of decadal and seasonal sea surface temperature variations in East China shelf seas," *Journal of Marine Science and Engineering*, vol. 9, no. 4, p. 367, 2021.

[4] Z. Liu and S. L. Berne, "Paleochannels and paleodelt as in the continentals helf of the East China Sea," *Marine geology & quaternary Geology*, vol. 20, no. 1, pp. 9–14, 2000.

[5] H. Xu, Y. Cai, H. Q. Sun, and G. J. Yan, "The survey status and geological conditions sea," *Journal of Tropical Oceanography*, vol. 32, no. 4, pp. 22–29, 2012.

[6] Y. Zheng, B. Liu, J. Wu, R. Liang, C. Liu, and Z. Zhang, "Structural control of the Gagua "wedge" zone east of Taiwan Island on the southern Okinawa trough," *Science in China Ser: D Earth Sciences*, vol. 48, no. 8, pp. 1165–1174, 2005.

[7] B. Zhu and Z. Zeng, "Detrital zircon provenance in the sediments in the southern Okinawa trough," *Journal of Marine Science and Engineering*, vol. 10, no. 2, p. 142, 2022.

[8] D. B. Simons and E. V. Richardson, "Resistance to flow in alluvial channels," in *Depositional Sedimentary Environments with Reference to Terrigenous Clastics*, p. 1962, Spring Verlag, Berlin, 1973.

[9] R. A. Bagnold, *An Approach to the Sediment Transport Problem from Generalphysics*, Geological Survey, Washington US, 1966.

[10] Z. Zeng, X. Li, Y. Zhang, and H. Qi, "Lithium, oxygen and magnesium isotope systematics of volcanic rocks in the Okinawa trough: implications for plate subduction studies," *Journal of Marine Science and Engineering*, vol. 10, no. 1, p. 40, 2022.

[11] K. Zhong, W. L. Zhu, S. L. Gao, and X. W. Fu, "Formation and evolution of East China Sea shelf basin and key geological issues of oil and gas accumulation," *Journal of Earth Science*, vol. 43, no. 10, pp. 3485–3497, 2018.

[12] Z. G. Zhao, P. Wang, P. Qi, and R. Guo, "Regional geological setting and tectonic evolution of the East China Sea basin," *Journal of Earth Science*, vol. 41, no. 3, pp. 546–554, 2016.

[13] W. Q. Guo, X. X. Chen, J. Z. Tang, and T. Q. Zhang, *Route Survey Report of Shanghai Chongming (S1.1) and Nanhui (S3) Section of New trans-Pacific Ocean (NCP) International Submarine optical Cable Project*, Shanghai Donghai Ocean Engineering Survey and Design Institute, Shanghai, 2016.

[14] X. M. Chen, J. S. Gao, and X. Q. Zhu, “Research on the construction and maintenance of submarine optical cable,” *Information Communication Technology*, vol. 15, no. 4, pp. 79–84, 2021.

[15] J. H. Zhao and J. N. Liu, *Multi-Beam Sounding and Image Data Processing*, Wuhan University Press, Wuhan, 2008.

[16] J. Powers, S. K. Brewer, J. M. Long, and T. Campbell, “Evaluating the use of side-scan sonar for detecting freshwater mussel beds in turbid river environments,” *Hydrobiologia*, vol. 743, no. 1, pp. 127–137, 2015.

[17] Z. Q. Wand, “The Chinese CPT and the prospect of penetration tests,” *Chinese Journal of Geotechnical Engineering*, vol. 22, no. 5, pp. 517–522, 2000.

[18] X. Ou, J. Zhu, S. Li et al., “Submarine geomorphological features and their origins analyzed from multibeam bathymetry data in the South China Sea,” *Journal of Marine Science and Engineering*, vol. 9, no. 12, p. 1419, 2021.

[19] R. Bryant, “Side scan sonar for hydrography: an evaluation by the Canadian hydrographic service,” *The International Hydrographic Review*, vol. 52, no. 1, pp. 43–56, 2015.

[20] Y. B. Li, Y. F. Zhang, Y. L. Liu, and L. Chen, “Application of shallow stratigraphic profiler in ocean engineering,” *Journal of Engineering Geophysics*, vol. 4, no. 1, pp. 4–8, 2007.

[21] X. S. Guo, T. K. Nian, D. Wang, and Z. D. Gu, “Evaluation of undrained shear strength of surficial marine clays using ball penetration-based CFD modelling,” *Acta Geotechnica*, vol. 17, no. 5, pp. 1627–1643, 2022.

[22] Z. Y. Wu, *Marine Geology of China Sea Series Map: Submarine Topography Map of East China Sea*, Science Press, 2019.

[23] A. Fildani and W. R. Normark, “Late Quaternary evolution of channel and lobe complexes of Monterey Fan,” *Marine Geology*, vol. 206, no. 1-4, pp. 199–223, 2004.

[24] D. Jiang, C. An, X. T. Li, S. M. Liu, F. J. Wan, and X. F. Xu, “Holocene climate modulates mud supply, transport, and sedimentation on the East China Sea shelf,” *Journal of Geophysical Research Earth Surface*, vol. 125, no. 10, pp. 52–58, 2020.

[25] Z. Guo, *Analysis of Important Geological Phenomena and their Dynamic Background in the Evolution of East China Sea Shelf Basin*, Northwest University, 2015.

[26] W. R. Li, Z. S. Yang, Y. J. Wang, and B. M. Zhang, “Petrochemical characteristics and geological significance of volcanic rocks in Okinawa trough,” *Acta Petrologica Sinica*, vol. 13, no. 4, pp. 538–550, 1997.

[27] H. Liu, C. H. Xu, W. L. Shen, D. P. Wang, and Y. L. Deng, “Tectonic evolution characteristics of Lishui sag in East China Sea shelf basin,” *Experimental Petroleum Geology*, vol. 43, no. 6, 2021.

[28] Z. G. Guo, Z. S. Yang, Y. H. Qu, and D. J. Fan, “Study on composition sedimentary geochemistry of mud area on East China continental shelf,” *Acta Sedimentologica Sinica*, vol. 18, no. 22, pp. 284–289, 2000.

[29] Q. X. He, *Marine Sedimentary Geology of China*, Beijing Ocean Press, 2006.

[30] D. B. Zhao and S. M. Wan, “Research progress of tracing sediment sources in Okinawa trough,” *Marine Geology Frontiers*, vol. 31, no. 2, pp. 32–41, 2015.

[31] W. Xiaodan, W. Bin, M. Jiang et al., “Distribution, sources and burial flux of sedimentary organic matter in the East China Sea,” *Journal of Oceanology and Limnology*, vol. 38, no. 5, pp. 1488–1501, 2020.

[32] W. Zhong, J. Ouyang, D. Yang, X. Wang, Z. Guo, and K. Hu, “Effect of the in situ leaching solution of ion-absorbed rare earth on the mechanical behavior of basement rock,” *Journal of Rock Mechanics and Geotechnical Engineering*, vol. 8, no. 6, pp. 23–40, 2021.

[33] W. Hao, G. Zhao, and S. Ma, “Failure behavior of horseshoe-shaped tunnel in hard rock under high stress: phenomenon and mechanisms,” *Transactions of Nonferrous Metals Society of China*, vol. 32, no. 2, pp. 639–656, 2022.

[34] M. He, Z. Q. Zhang, J. W. Zhu, N. Li, G. Li, and Y. S. Chen, “Correlation between the rockburst proneness and friction characteristics of rock materials and a new method for rockburst proneness prediction: field demonstration,” *Journal of Petroleum Science and Engineering*, vol. 205, article 108997, 2021.

[35] D. Pan, K. Hong, H. Fu, J. Zhou, N. Zhang, and G. Lu, “Influence characteristics and mechanism of fragmental size of broken coal mass on the injection regularity of silica sol grouting,” *Construction and Building Materials*, vol. 269, article 121251, 2021.

[36] D. Pan, K. Hong, H. Fu, J. Zhou, and N. Zhang, “Experimental study of the mechanism of grouting colloidal nano-silica in over-broken coal mass,” *Quarterly Journal of Engineering Geology and Hydrogeology*, vol. 54, no. 4, pp. qjegh2020–qjegh2161, 2021.

[37] X. L. Li, Z. Y. Cao, and Y. L. Xu, “Characteristics and trends of coal mine safety development,” *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, vol. 23, no. 11, pp. 1–19, 2020.

[38] S. M. Liu, X. L. Li, D. K. Wang, and D. Zhang, “Investigations on the mechanism of the microstructural evolution of different coal ranks under liquid nitrogen cold soaking,” *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, vol. 19, no. 5, pp. 1–17, 2020.

[39] L. Qiu, Y. Zhu, D. Song et al., “Study on the nonlinear characteristics of EMR and AE during coal splitting tests,” *Minerals*, vol. 12, no. 2, p. 108, 2022.

[40] X. L. Li, S. J. Chen, Q. M. Zhang, X. Gao, and F. Feng, “Research on theory, simulation and measurement of stress behavior under regenerated roof condition,” *Geomechanics and Engineering*, vol. 26, no. 1, pp. 49–61, 2021.

[41] Y. Zhao, B. H. Liu, X. S. Li et al., “Sedimentary characters and material transportation of submarine canyon-fan systems in slope of the East China Sea,” *Journal of Palaeogeography*, vol. 13, no. 1, p. Feb, 2011.

[42] Z. Xufeng, L. Anchun, W. Shiming, and Y. Zhaojie, “The turbidity events in okina wa trough during middle holochne and its potential dominating mechanisms,” *Journal of Palaeogeography*, vol. 34, 2014.