

Communication

Morphological Significance and Relation of Ecosystems of Submarine Canyons off SW Taiwan

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Abstract: There are four shelf-incising submarine canyons off SW Taiwan. They are distributed along the active continental margin, which is periodically flushed by gravity flows. Shelf-incising canyons, such as Kaoping Canyon, may not only be affected by oceanographic conditions but also by extreme climate change due to the direct input of river sediment. In the canyons along the SW margin of Taiwan, strong sedimentary flows are reflected in highly abundant nutrient input and physical disturbances. The Kaoping Canyon possesses habitats that promote biodiversity but that are sensitive to environmental change. The aims of this study are to review the canyons along the SW margin of Taiwan and to present their geomorphological features and associated ecosystems.

Keywords: submarine canyon; shelf-incising canyon; Kaoping Canyon; ecosystem



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1. Introduction

Submarine canyons are major geomorphological features that deeply incise into continental slopes and serve as sediment pathways that link shelf areas to the deep sea [1,2]. Submarine canyons may be near or connected to a major river or funnel large amounts of sediment, nutrients, and organic carbon from the continental shelf into deep water [3,4]. In deep seas, benthic microfaunal and macrofaunal assemblages depend on allochthonous organic matter [4–9]. As a result, some shelf-incising canyons have been shown to be associated with high levels of biodiversity [10–12]. Therefore, the sedimentary records of submarine canyons may provide paleo-environmental information for paleo-climate or paleo-oceanographic reconstructions [13].

In terms of its geological setting, Taiwan is characterized by young mountains, in addition to frequent earthquakes, typhoons, and heavy rainfall. The result is large amounts of sediment that are transported to the surrounding seas [14]. Off SW Taiwan, the Kaoping Canyon is shelf-incising. Moreover, it is connected to a small mountain river (i.e., Kaoping River) with extremely high sediment load. Its complex features influence currents, waves, nutrients, and other oceanographic parameters. As a result, there is high diversity of benthic habitats in the region. From the late 1970s, Taiwan became more industrialized and economically prosperous. Unfortunately, its capacity to treat waste and sewage is not as advanced [15]. For example, excrement from pig farms is directly discharged into the Kaoping River and eventually makes its way to the Kaoping Canyon [16]. Such pollution may affect deep-sea ecology. This issue requires urgent attention and action.

1.1. Geological Setting

The island of Taiwan is situated near the junction of the Ryukyu Arc and Luzon Arc along the western boundary of the Philippine Sea plate (Figure 1). Due to ongoing mountain building, there is loading on the Eurasian Plate. The result is a mildly deformed foreland basin located offshore SW of Taiwan [17,18]. The foreland region of the Chinese margin has been flexed downward. This is in response to the topographic loading of the Taiwan orogen with an east-dipping, wedge-shaped foreland basin flanking the Taiwan

orogen [17,19]. In southern Taiwan, there is low and shallow seismicity. This significantly increases at the base of the crust as a result of the orogen [20,21]. Tectonically, the SW Taiwan margin trending NW is an active margin that features numerous thrust faults and mud diapirs, which have come about due to the progression of westward compression induced by oblique collision between the Chinese continental margin and the Luzon arc [22,23]. Along this active margin, the shelf-slope region is structurally dominated by folds, faults, and mud diapirs formed by younger compressions adjacent to the Taiwan Mountain Belt (Figure 2). Diapiric intrusions and thrust faults influence not only the direction but also the intensity of incision and morphology of these canyons [24,25].

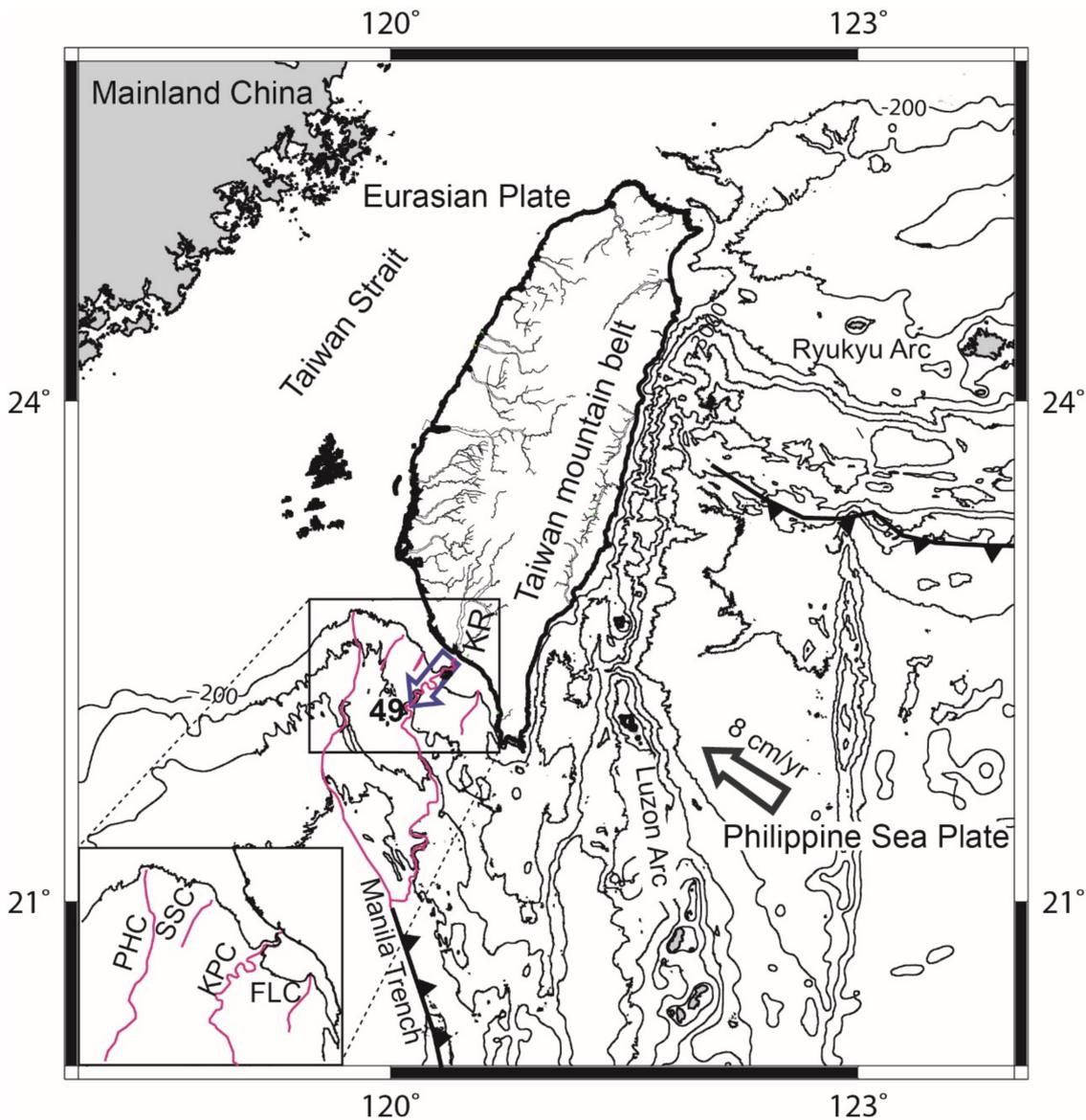


Figure 1. The island of Taiwan is active geologically, as it formed on a complex convergent boundary between the Eurasian Plate and the Philippine Plate to the west and east, respectively. The Kaoping Canyon extends seaward almost immediately from the Kaoping River mouth, incising the shelf and the continental slope, and terminates in the Manila Trench of the South China Sea. An annual sediment load of 49 MT is carried by the Kaoping River (data from [26]). PHC: Penghu Canyon, SSC: Shoushan Canyon, KHC: Kaohsiung Canyon, KPC: Kaoping Canyon, FLC: Fangliao Canyon, KR: Kaoping River.

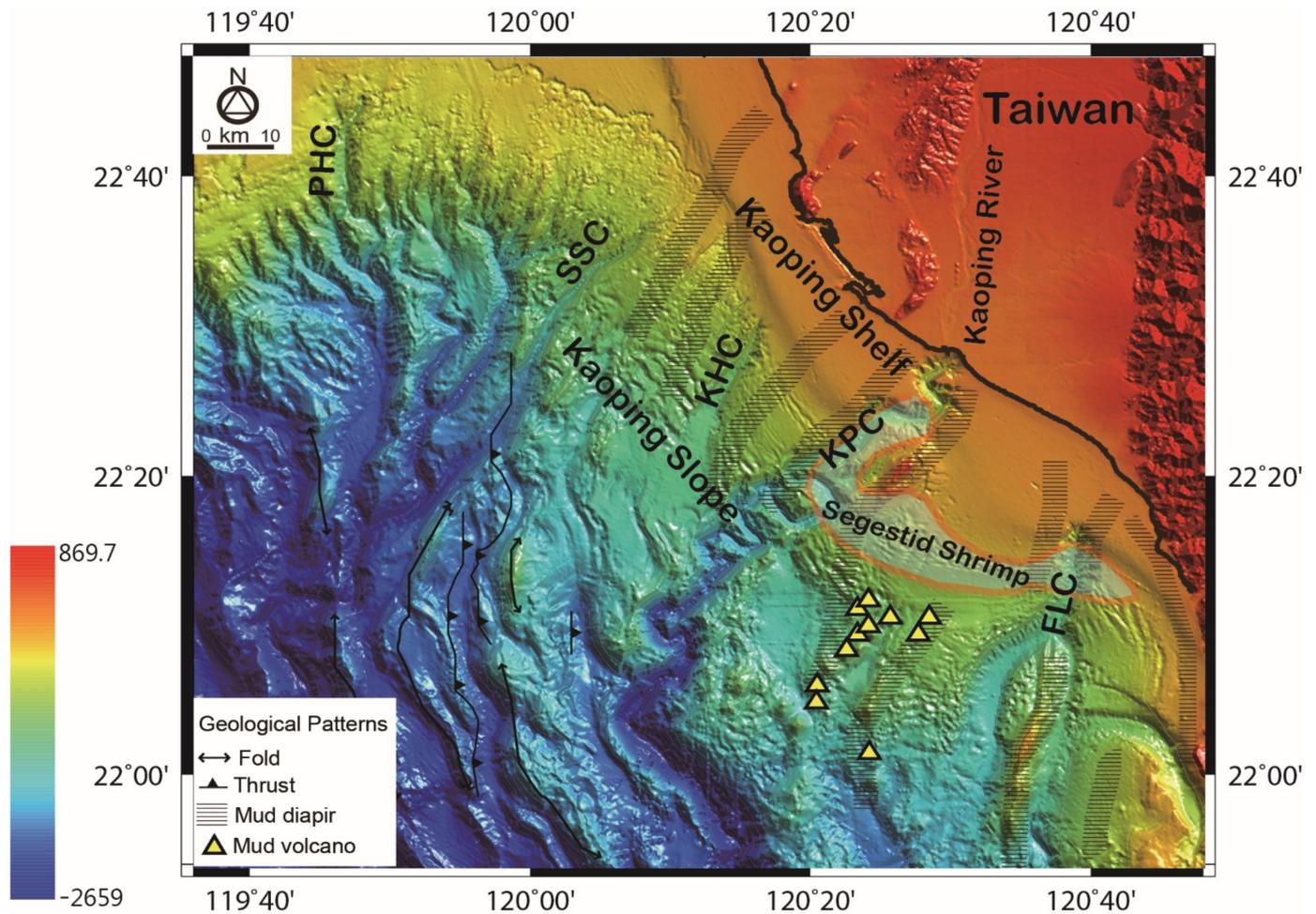


Figure 2. Bathymetric chart showing the five submarine canyons and the geological diversity of landscapes along the SW Taiwan margin with a relatively narrow shelf but a broad and topographically irregular slope (data from [22,23,25]). Sergestid shrimp are distributed between the head of Kaoping Canyon and the head of Fangliao Canyon [27]. PHC: Penghu Canyon, SSC: Shoushan Canyon, KHC: Kaohsiung Canyon, KPC: Kaoping Canyon, FLC: Fangliao Canyon.

1.2. Canyon Setting Offshore SW Taiwan

The submarine canyon distributions off SW Taiwan include a shelf and a slope and follow a 120 km-long margin from NW to SE. The Penghu, Shoushan, Kaohsiung, Kaoping, and Fangliao canyons are named for nearby cities or towns (Figure 1).

In 1928, Yabe and Tayama were the first to describe a canyon offshore from SW Taiwan [28]. Ma (1947) [29] compiled a bathymetric chart of the distribution of submarine valleys around southern Taiwan that was used to discuss their geological significance. Due to limited bathymetric data, it was once thought that there was one submarine canyon around SW Taiwan that ended at the upper Kaoping Slope. Later, other submarine canyons were detected with new bathymetric data and 3.5 kHz and seismic profiles [30], followed by detailed studies of the Kaoping Canyon area with the use of multibeam and seismic profiles [31]. Recent advances in source-to-sink sedimentary research have been mainly driven by studies of sediment dispersal in a small mountain river [32–35]. These have focused on the processes of and sediment routing by submarine canyons. Only recently has more attention been paid to the study of canyons offshore of SW Taiwan.

By definition, geodiversity includes the natural range of geological, geomorphological, soil, and hydrological features, such as rocks, minerals, fossils, landforms, topography, and physical processes, in addition to assemblages, structures, systems, and landscape contributions [36]. Moreover, geodiversity refers to substrates, landform mosaics, and

physical processes required for habitat development and maintenance [37]. Geomorphological diversity refers to the diversity of geological inheritance, landform history, and dynamic geomorphology with assemblages, relationships, properties, interpretations, and systems [38]. The Kaoping Canyon area is a hotspot of geodiversity. Moreover, it is considered a hotspot for biological diversity. Due to the delineation of canyon systems into geofoms that are sinuous, meandering, flat, and sloping, in addition to gullies and valleys, there is a high diversity of benthic habitats. The importance of geodiversity is not confined to geoconservation and its links to biodiversity are fundamental. The conservation of Taiwan margin canyons must be of primary concern to government officials as they possess rich biodiversity and grant insight into deep-ocean ecosystems.

1.3. Canyon Types

Submarine canyons of different types drastically shape the morphology along both active and passive margins. Harris and Whiteway (2011) [39] proposed a useful scheme based on the general geomorphology and location of the canyon head of canyon systems to classify submarine canyons into three types: I—shelf incising (river associated), II—shelf incising, and III—blind or headless. The heads of type I canyons extend landward as shelf valleys with a direct connection to a river mouth. Type II canyons incise the shelf as shelf valleys but do not connect to river systems and type III canyons are confined to the continental slope with heads that terminate below the shelf break [39,40].

From a regional perspective, SE Asian canyons account for 15.7% of the total known canyons with thalweg lengths of 2.9 to 274.9 km, mean canyon spacing of 36.4 km, and low sinuosities (mean = 1.117) [39]. Within SE Asia, only 2.5% of canyons are thought to be directly linked to fluvial sources (type I), while 37.7% incise the continental shelf (type II) and the remaining 59.8% are slope confined (type III). Geographic areas with greater numbers of shelf-incising canyons tend to have relatively high rates of sediment export to continental margins [39]. Along the SW Taiwan margin, five submarine canyons have been documented [41–51]. Recent studies have indicated that SW Taiwan differs from other marine regions ([25]; Table 1) in that it possesses a high proportion of shelf-incising canyons (type I and type II = 80%). The geological setting of Taiwan features young mountains, steep gradients, erodible lithology, frequent earthquakes and typhoons, and heavy rainfall. These result in large amounts of sediment transported to the surrounding seas [14,26,52]. Narrow shelf and abundant sediment supply are two main controls for the occurrences of shelf-incising canyons along the SW Taiwan margin [25]. Overall, there is higher habitat potential for all faunal groups in shelf-incising canyons along the SW Taiwan margin. Therefore, attention is being given to integrated and multidisciplinary studies on submarine canyon processes, productivity, and biodiversity [53].

Table 1. Types of and differences between submarine canyons along the SW Taiwan margin based on previous studies (data from [25]).

Criterion	Penghu Canyon	Shoushan Canyon	Kaohsiung Canyon	Kaoping Canyon	Fangliao Canyon
Type	Shelf-indenting canyon	Slope-confined canyon	Shelf-indenting canyon	River-connected canyon	Shelf-indenting canyon
Canyon head to shelfbreak	2 km	0	1 km	20 km	5 km

2. Oceanographic Conditions and Biological Distributions of Submarine Canyons

In general, submarine canyons are influenced by large changes in topography and differences in depth, in addition to gravity flow and episodic down-canyon flushing events, which result in locally increased nutrient concentrations and food availability [3,54]. Within submarine canyons, ocean currents, tides, and internal waves interact, and the resulting hydrodynamic conditions influence benthic ecosystems and habitats [54]. Shelf-incising canyons are generally larger with better depth-range than blind canyons and are more

likely to have mixed hard and soft substrates. As a result, some shelf-incising canyons in Australia have been shown to harbor high biodiversity [40].

The Kaoping Canyon is characterized by unique environmental conditions, including high sediment loads from a small mountain river, turbidity currents triggered by extreme monsoonal conditions and earthquakes, and strong internal-tide energy that causes swift bottom currents, as well as Kuroshio Current induced by near-bottom flow [32,55–57]. During floods, there is a convergence of tidal currents near the head of the Kaoping Canyon. This may be an important factor in the daily migration of sergestid shrimp, which burrow along the canyon walls [55]. According to the findings of Omori et al. (1998) [27], sergestid shrimp in Japan mostly exist along river estuaries in relatively closed areas of bays and in more complicated sea valleys. Around the Kaoping Canyon is open sea. This submarine canyon is enclosed or semi-enclosed (Figure 3) and its large sediment-yield enables sergestid shrimp to reach it.

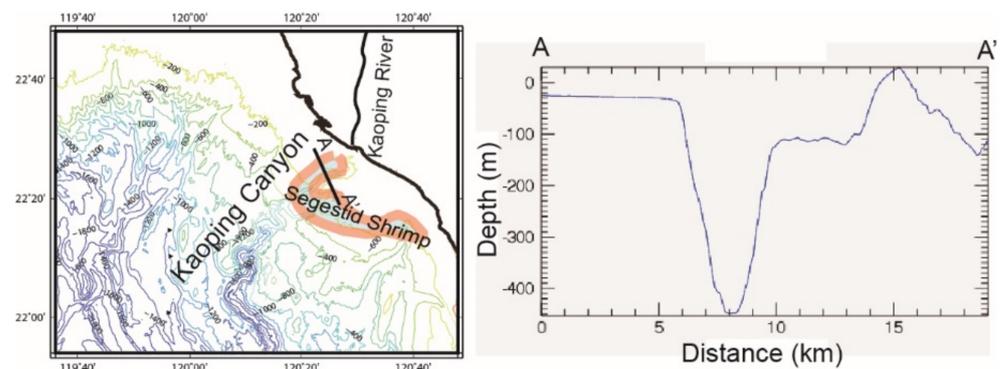


Figure 3. Cross-sectional morphology of the head of the Kaoping Canyon on bathymetric transects. The width of the canyon is about 9 km with a 7° flank slope (profile A-A'). Note the steep and complicated topography of the canyon walls.

Yu et al. (1993) [41] used a remotely operated vehicle (ROV) to observe the high density of burrows along the canyon walls. There were distinctive edges around the openings of most burrows, revealing that they were occupied. The investigation of the upper Kaoping Canyon by Liao et al. (2017) [58] represents the first benthic ecological study of a major submarine canyon associated with high sediment-yield small mountain river along the SW Taiwan margin. The benthic communities in the upper Kaoping Canyon are mainly a nested subset of the adjacent slope assemblages. Meiofaunal (e.g., ostracods) and macrofaunal taxa (e.g., peracarid crustaceans and mollusks) that typically occur on the slope have been lost [58]. According to the findings of Yu et al. (1993) [41], faunal diversity and abundance are extremely low in the Kaoping Canyon head. Taxa on the canyon floor, with the exception of shrimp and flounders, generally utilize some form of shelter. The relatively dense assemblage of emergent fauna (e.g., sea whips, sea fans, soft coral) at the shelf break on the east wall may represent a refuge for species that previously occupied a larger region of the Kaoping Shelf [41]. Surprisingly, total macrofaunal densities increase with depth in the upper Kaoping Canyon. In addition, overall meiofaunal and macrofaunal densities in the canyon are lower than on the adjacent slope [58]. These trends are peculiar, as many benthic studies have suggested that canyon density is several-fold higher than that of slopes at similar depths [3,58]. Moreover, canyon heads, in comparison with major habitats along the continental margins, have the highest benthic standing stocks [58,59]. Physical disturbances (e.g., turbidity currents, bottom currents, and gravity flows) within the Kaoping Canyon substantially suppress vulnerable macrofaunal taxa [58], decreasing the number of species and functional diversity of nematode assemblages [60]. Apparently, the river-connected Kaoping Canyon has more river-borne nutrients than the neighboring shelf-incising Fangliao Canyon and likely greater biodiversity. Thus, a biological investigation with an ROV survey of the Fangliao Canyon can provide valuable

data to compare with that of the Kaoping Canyon to better understand the biodiversity of submarine canyons along the SW Taiwan margin.

3. Conclusions: Trans-Disciplinarity in Geodiversity

Shelf-incising canyons along the SW Taiwan margin are associated with a narrow shelf. The Kaoping Shelf is no more than 20 km wide. This represents a short distance over which a canyon reaches the shoreline and funnels coastal sediment into the canyon head. Other equally important controls such as tectonic forcing (i.e., earthquake) and extreme climate conditions (e.g., typhoon) trigger erosive turbidity currents in the Kaoping Canyon. The influence of turbidity currents triggered by earthquakes and floods on the formation of shelf-incising canyons has been overlooked [22,34]. Shelf-incising canyons, such as Kaoping Canyon, may not only be affected by oceanographic changes but also by extreme climate change due to the direct input of river sediment. Canyons along the Taiwan margin show habitat niches that promote biodiversity but are sensitive to environmental change. These results reveal the need for future studies on the ecological processes and functions of SW Taiwan margin submarine canyons. In particular, the establishment of a hierarchy of canyon types has led to an objective framework for interplay with physical disturbances in submarine canyons and for placing local case studies into a broader context.

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