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Sedimentary erosive processes and sediment dispersal in Kaoping submarine canyon

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The Kaoping submarine canyon, connected to the Kaoping River in the coastal plain in SW Taiwan, continues the dispersal path of modern Kaoping River sediments, from an active small mountainous drain basin to the receiving basin of the South China Sea. Using seismic reflection sections, Chirp sonar profiles, and bathymetric mapping, we reveal characteristic erosive processes responsible for multiple cut-and-fill features, deeply entrenched thalweg, and sediment dispersal that are closely related to turbidity currents in the canyon. The river-canyon connection setting, along with extreme climatic conditions and active tectonism, is favorable for generation of turbidity currents at the canyon head. The upper reach of the Kaoping Canyon is distinguished into three distinct morpho/sedimentary features. The canyon head is characterized by V-shaped axial thalweg erosion. The sinuous segment of the upper reach is dominated by a deeply incised canyon pathway with trough-like morphology. Relatively small-scaled features of cut-and-fill associated with the dominant incision process are commonly along the canyon floor, resulting in a flat-floored pathway. Sliding and slumping dominated the steep canyon walls, producing and transporting sediments to canyon floor and partially filling up canyon thalweg. The meandering segment is characterized by erosive features where deeply down-cutting occurs in the outer bend of the major sea valley, forming V-shaped entrenched thalweg. The recurrences of turbidity currents have allowed continuous incision of the canyon head and have kept the connection between the canyon head and the river mouth during Holocene highstand of sea level. The upper reach of the Kaoping Canyon is linked to drainage area and maintains as a conduit and/or sink for terrigenous and shallow marine material. Sediment-laden river plume operates in the Kaoping River-Canyon system, with turbidity currents flushing river sediments into the canyon head where the canyon thalweg is the most erosive. Presently, the upper reach of the Kaoping Canyon can be considered as a temporal sediment sink.

entrenched thalweg, cut-and-fill, sediment dispersal, active submarine canyon

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Submarine canyons are a prominent erosional feature on the sea floor they not only shape the present morphology of continental margins but also serve as a major sediment conduit delivering terrestrial and shallow marine sediments to the deep sea basins [1–3]. The southwestern Taiwan margin is a growing wedge-top depozone where sediments derived from the Taiwan orogen are prograding seawards to form present-day shelf and slope off the island of Taiwan [4]. The Kaoping submarine canyon, a 260 km long linear feature deeply down-cutting into the shelf and slope off SW Taiwan (Figure 1), is a sediment pathway delivering orogenic sediments of Taiwan to the marginal South China Sea basin [5, 6]. The Kaoping River drainage basin is a small (3250 km^2), tectonically active and overfilled foreland basin,

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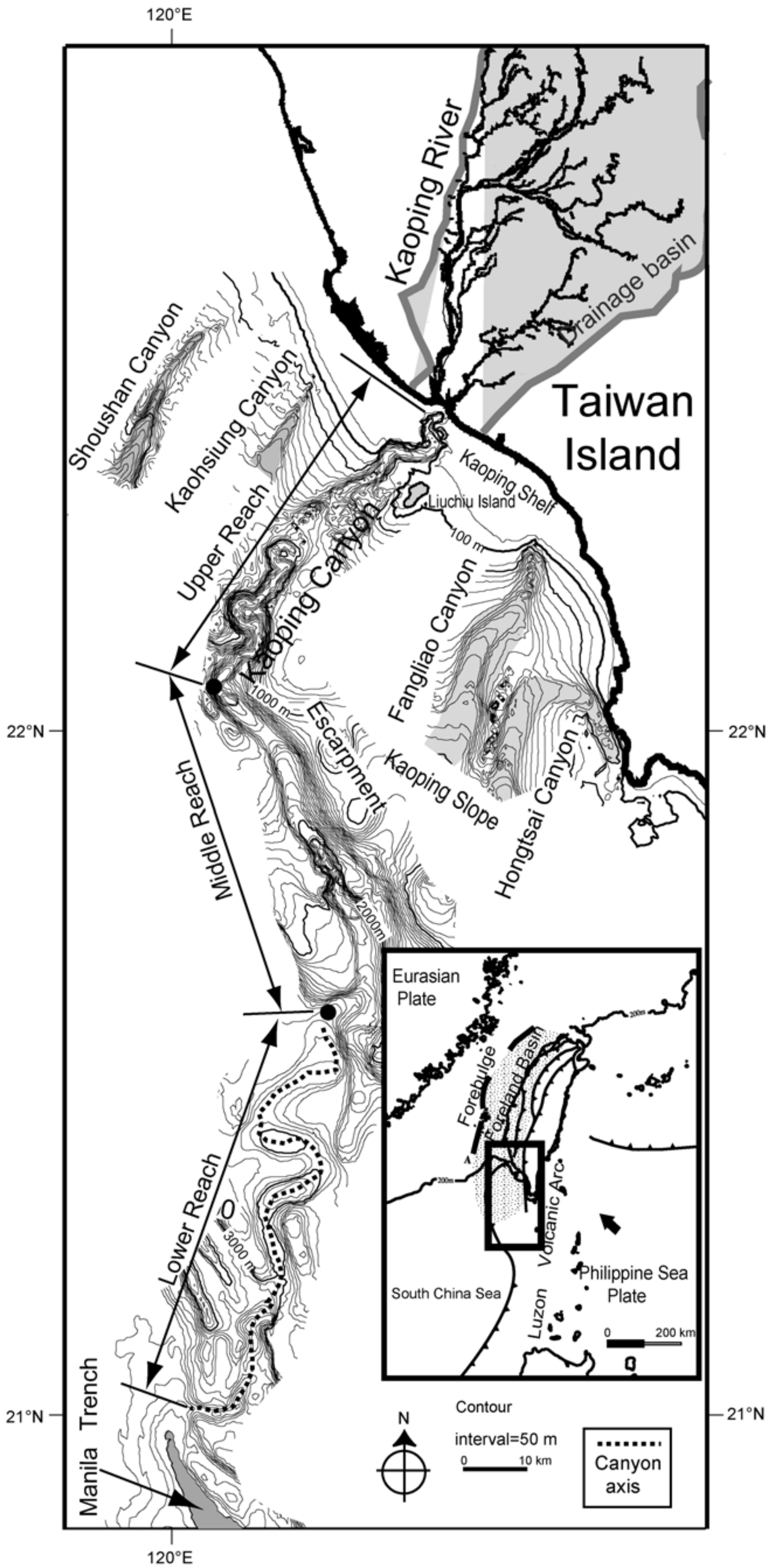

Figure 1 The Kaoping Canyon is directly connected to the Kaoping River characterized by a small mountainous river. The canyon consists of three distinct segments: an upper reach, a middle reach, and a lower reach. The inset at lower right corner shows the plate tectonic setting of Taiwan Island.

receiving a large amount of sediment derived from the uprising Central Range of Taiwan (Figure 1) [7]. The Kaoping River drainage basin is influenced by typhoons and the annual monsoon cycle, which supports an annual river discharge of 8.5×10^9 m^3. More than 70% of the basin's annual rainfall and river discharge occurs during May–September, and is closely linked with the presence of typhoons [8]. The Kaoping River is categorized as a small mountainous river whose high sediment load is capable of triggering turbidity currents, especially during flood seasons or typhoon events [9, 10].

The submarine canyon thalweg is a preferential zone of erosion. Axial thalweg erosion occurs in the canyons during cycles of sea level lowstand when canyon head was connected to river mouth. The direct sediment supply to the canyon head increased the frequency and magnitude of turbidity currents to initiate axial thalweg erosion within the canyon, resulting in a characteristic erosive feature on canyon floor. Close links between axial thalweg erosion, canyon morphology and sediment dispersal were documented in the Capbreton Canyon [11, 12], the Danube Canyon [13], canyons in western Gulf of Lion [14–16], and the Central Portuguese canyons [17]. The controls on the erosive features during highstand conditions are not fully understood. The axial thalweg erosion has a key influence on canyon development because it triggers mass wasting that progressively widen and deepen the canyon [14].

Liu and Lin [6] emphasized the importance of river-sea interaction for the Kaoping River-Canyon system, forming a source to sink scheme. Fine-grained sediments from the Kaoping River are delivered into the Kaoping Canyon by river plume and wind-induced current on the shelf. Coarse-grained Kaoping River sediments are directly delivered into the Kaoping Canyon by river effluent. In other words, relatively large amounts of Kaoping river sediment are transported to the Kaoping Canyon rather than to the Kaoping Shelf. Chiang and Yu [18] suggested that hyperpycnal flows occur in the sinuous (sinuosity=1.3) and meandering (sinuosity=2.02) segments of the Kaoping Canyon. In terms of source to sink, the Kaoping Canyon is considered to be a major sink for receiving terrestrial materials from adjacent land areas, mainly based on analyses of cored sediment [19, 20]. However, other studies showed that sediments derived from terrestrial and shallow shelf are stored temporarily in the upper reach of the canyon, for example, the canyon of Swatch of No Ground off Bangladesh [21] and the Nazare canyon off Portugal [22]. Therefore, it needs further investigation of sediment dispersal in upper reach of the Kaoping Canyon to test the validity of a major sink [19, 20] by using data other than cored sediment such as seismic profiles.

The purpose of this study is to better understand submarine sedimentary features and sediment dispersal of the Kaoping Canyon under highstand of sea level, characterized by a direct sediment source from a small mountainous river with high sediment load. This case study can be compared to that of other submarine canyons on active margin and served as one variant to a general canyon model. In particular, this paper presents modern information on thalweg incision for the broad interest in submarine canyon research. This paper focuses on erosive features and related sedimentary processes and discusses the characteristics of sediment dispersal in upper reach of the active Kaoping Canyon.

1 Materials and methods

Bathymetric transects and seismic reflection profiles across the upper reach of the Kaoping Canyon were acquired using the *R/V Ocean Research I*, National Taiwan University. Bathymetric data are collected by Simrad EK 500 Sonar. Thirteen cross-canyon seismic profiles were collected approximately evenly-spaced along the course of the upper reach of the Kaoping Canyon (Figure 2). Newly acquired bathymetric data were integrated into the bathymetric databank at the National Center of Ocean Research, National Taiwan University (http://www.ncor.ntu.edu.tw/ODBS/MGG/depth/swcoast/swcoast.html). Bathymetric data were then gridded and contoured using a GMT (Generic Mapping Tools) system [23] to generate bathymetric charts showing the Kaoping Canyon and adjacent sea floors. On board the *R/V Ocean Research I*, the seismic energy was an airgun array, and seismic signals were recorded on a 300-m long, 4-channel streamer with a DFS-V floating gain digital system. Seismic reflection data were processed following standard procedures and using the SIOSEIS system and PROMAX software. In addition, Chirp Sonar images (profiles C-1, C-2 and C-3) were collected for the Kaoping River-Canyon sediment dispersal system research, providing high resolution morphology and sedimentary features of the sea floor and up to 100 m. Chirp bandwidth ranges from 3 to 11 kHz and sub-bottom resolution is 8 cm with 100–200 m sub-bottom penetration.

2 Results

Based on the bathymetric map (Figure 3) and cross-sectional geometry (Figures 4 and 5), major morphologic features in the upper reach of the Kaoping Canyon can be divided into three parts (Table 1):

(1) Canyon head. The canyon head is the shallowest part of submarine canyons usually near the river mouth or close to the shelf edge where the initiation of submarine canyons took place. The Kaoping Canyon head is characterized as a relatively small V-shaped trough. The bathymetric map shows that the Kaoping Canyon begins at the Kaoping River mouth and continues seawards, cutting sea floor of the narrow shelf and forming a headward erosive geomorphic feature (Figure 3). Cross section 340-1 close to the

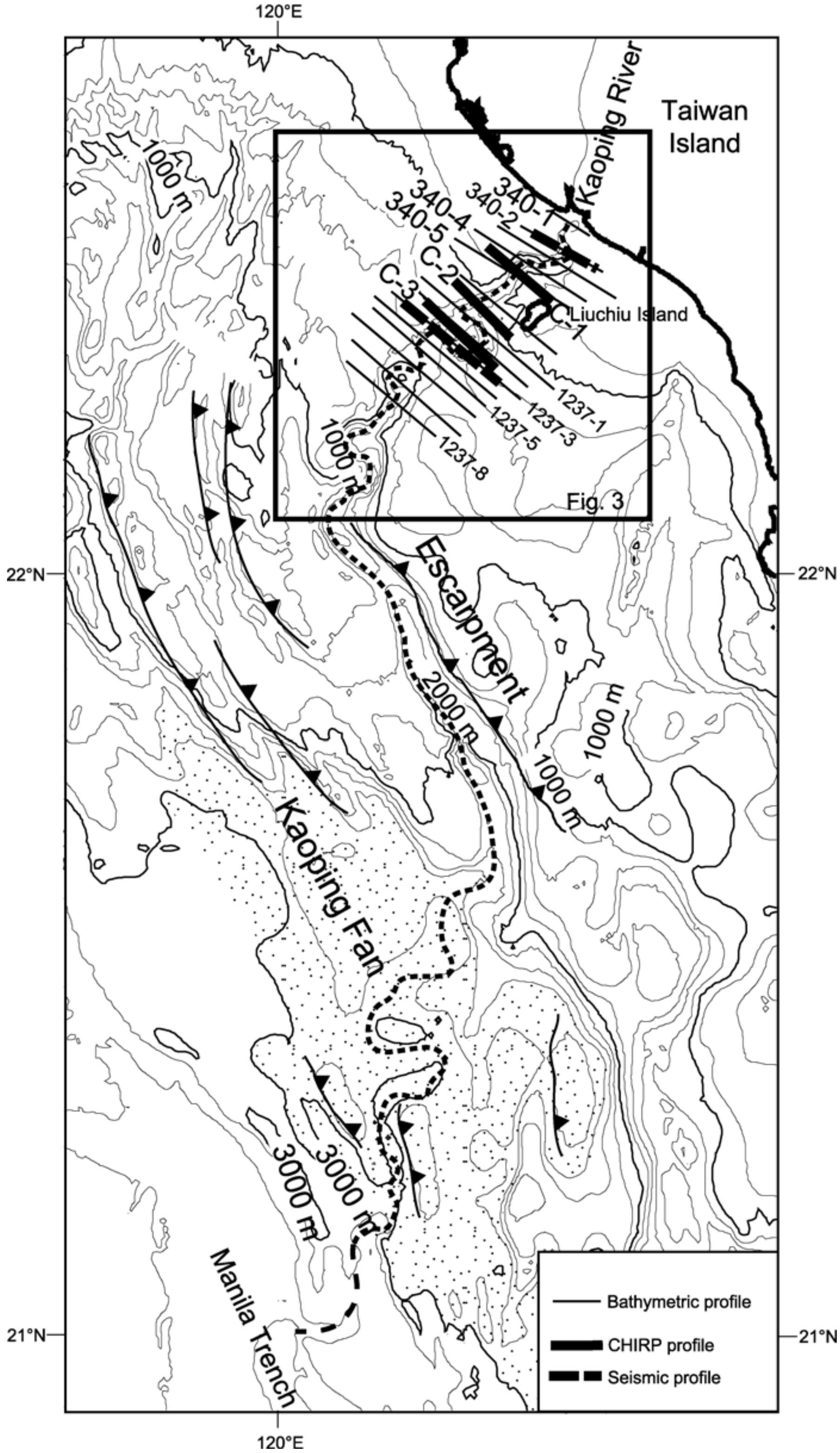

Figure 2 Map showing track lines of bathymetry and four-channel seismic reflection profiles in the upper reach of the Kaoping Canyon in the active margin off southwest Taiwan. Seismic profiles are perpendicular to the upper reach. Three more Chirp profiles (C-1, C-2 and C-3) were collected to reveal fine scales of sedimentary features in the upper reach.

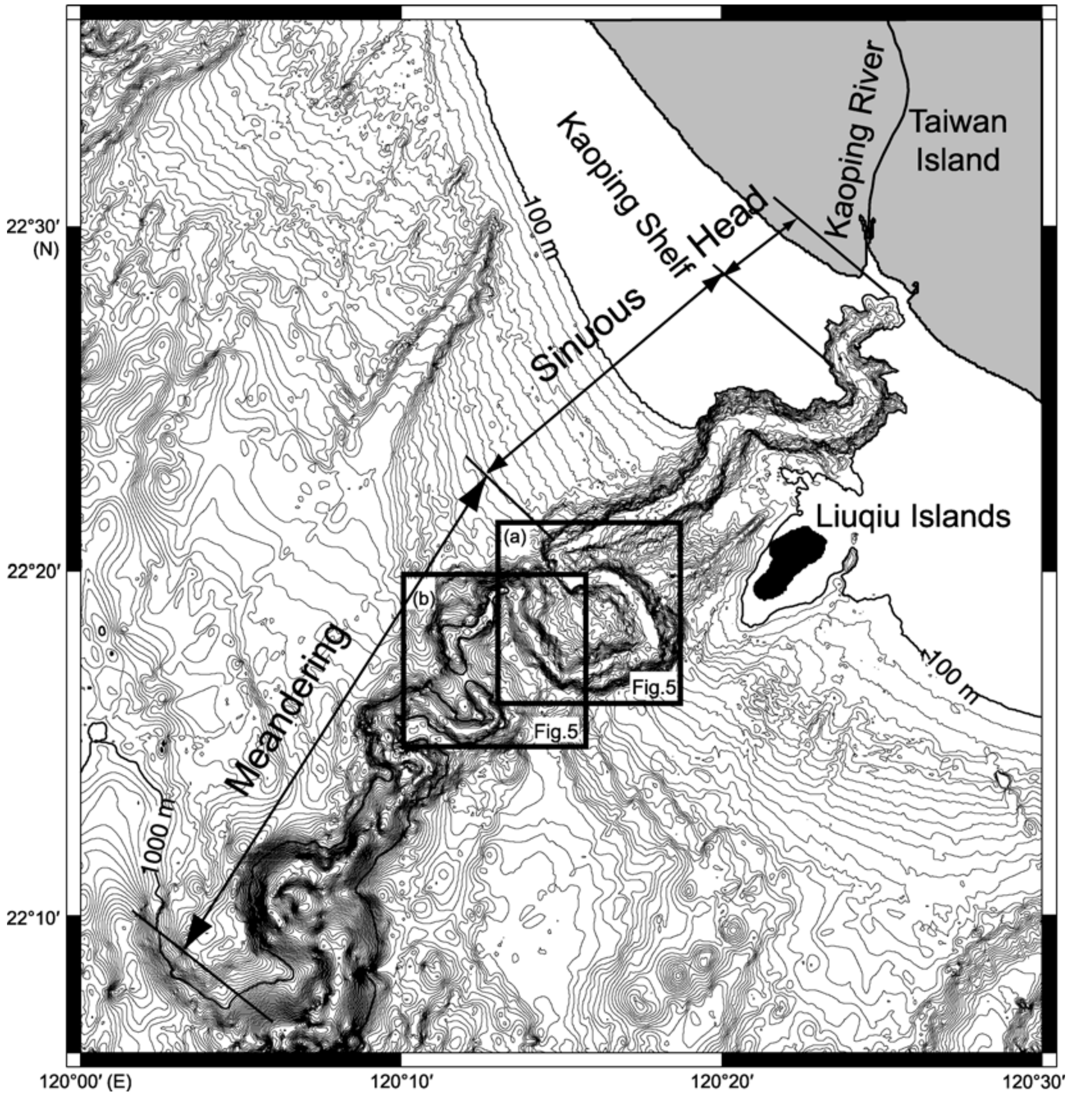

Figure 3 The upper reach of the Kaoping Canyon is deeply incised into the narrow shelf and upper slope off southwestern Taiwan. It shows two distinct segments: a sinuous canyon and a meandering segment.

Table 1 Main morphologic characteristics for the three segments in the upper reach of the Kaoping Canyon

Segment	Thalweg depth (m)	Relief of canyon (m)	Relief of the entrenched thalweg (m)	Width of canyon (km)	Width of the entrenched thalweg (km)	Main geomorphic characteristics
Head	~186	~171	~76	~3.01	~1.09	Axial thalweg erosion
Sinuous segment	186–763	171–442		5.01–6.96		Slumping/sliding U and V shaped valley Flat bottom
Meandering segment	763–1322	442–615	153–341	6.96–11.60	1.78–4.44	Major sea valley, Entrenched thalweg, Terrace, Levee

river mouth shows that the canyon thalweg is a 186 m deep depression with about 4.5° flank slope (Figure 4). The canyon head is 171 m into sea bed of the Kaoping Shelf, at the axial thalweg erosion.

(2) Sinuous segment. This segment is immediately seaward of head region and the thalweg along its length is between 310 and 763 m deep (Figure 4). The width of canyon increases to about 7.1 km wide with 7° flank slope. This sinuous segment incised more than 400 m into sea bed of the Kaoping Shelf (profile 340-4 in Figure 4), displaying a deeply incised pathway characterized by V- or U-shaped cross sections. The canyon floor is either flat-bottomed or

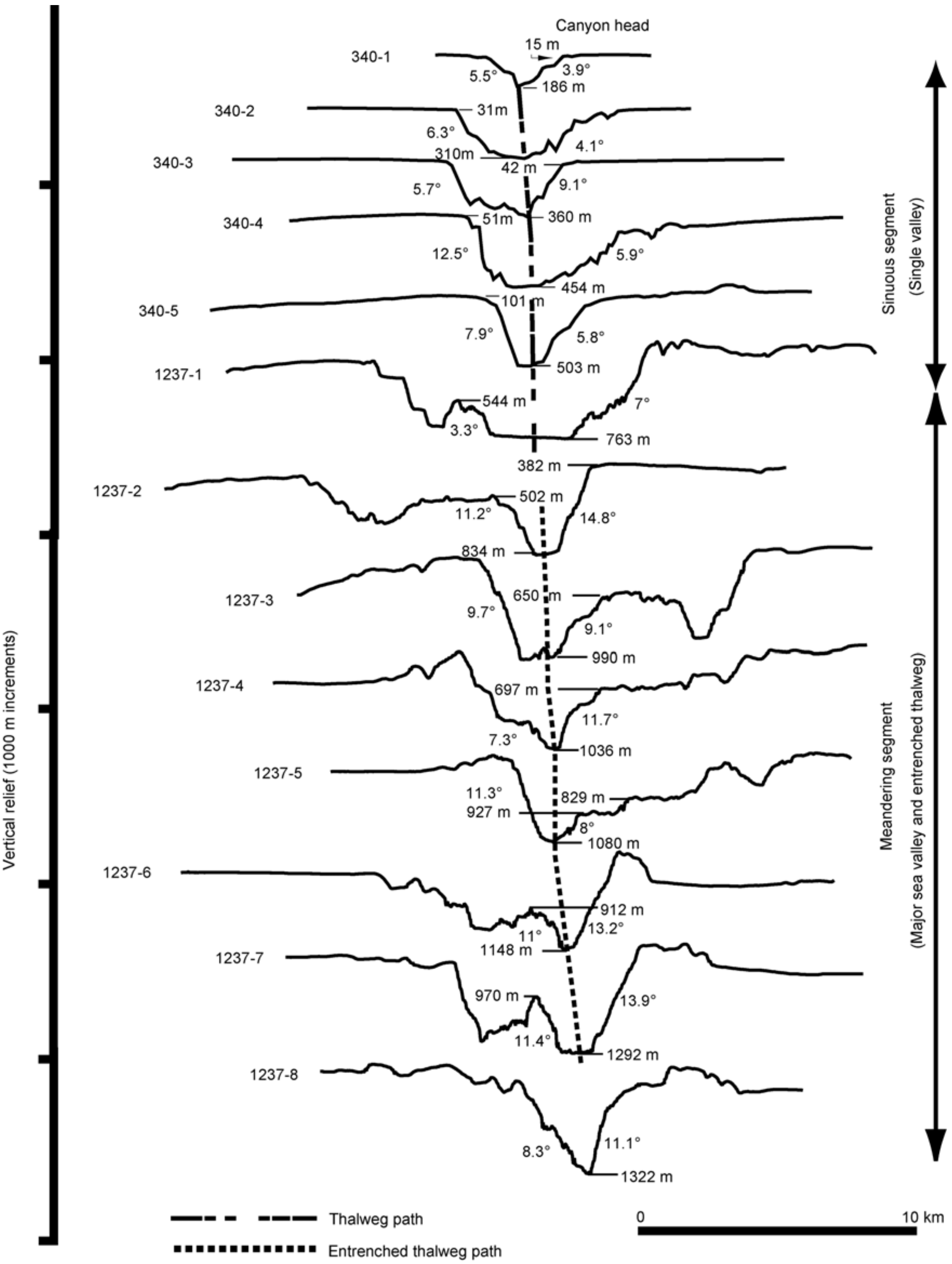

Figure 4 Cross-sectional morphology of the upper reach of the Kaoping Canyon revealed by bathymetric transects. The canyon thalweg pathway is shown by the connected dotted line. Note that entrenched thalweg mainly occurs in the meandering outer bends. Alignment of the locations of thalweg shows a sinuous thalweg pathway rather than an axial thalweg pathway. Locations of bathymetric transects are shown in Figure 2.

with an irregular base.

The seismic facies and internal structure of the canyon are revealed by seismic sections across the sinuous segment (Figure 6). Seismic section in 340-2 shows a relatively irregular surface on the canyon floor. The canyon flanks are also irregular due to numerous sliding and slumping on the canyon walls, resulting in trough morphology rather than a typical V-shaped canyon cross-section. Bedded and chaotic

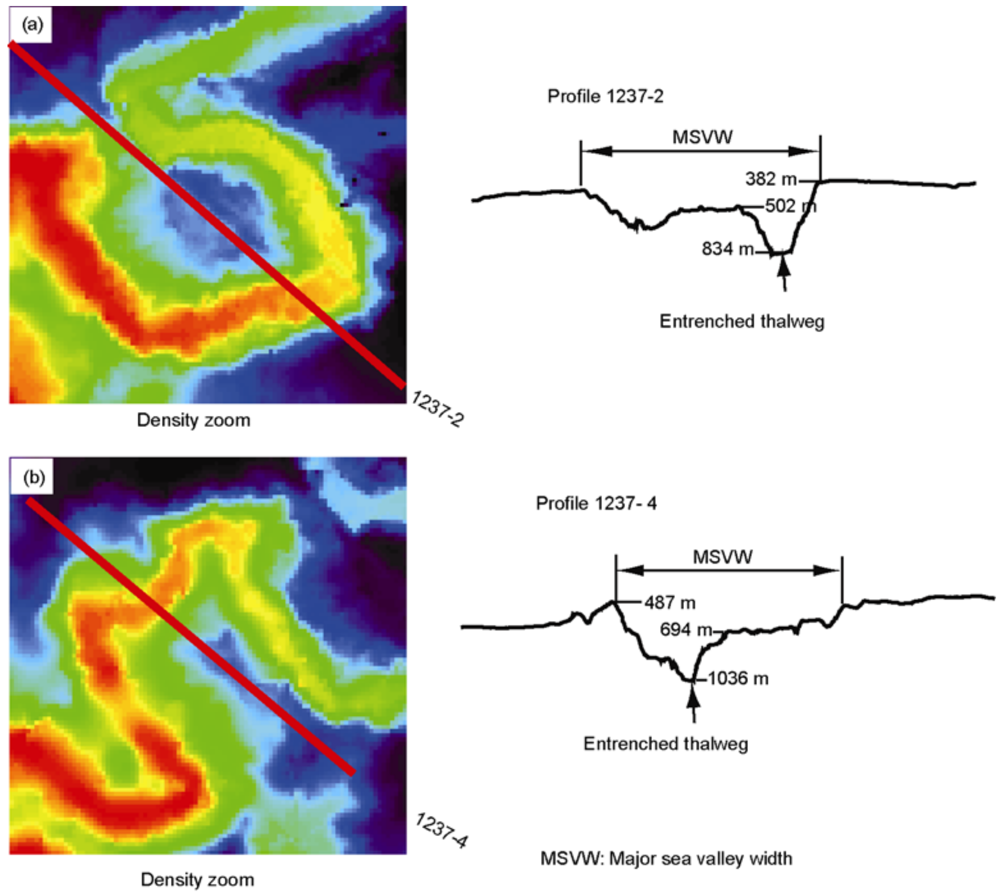

Figure 5 In the bathymetric section across a meandering loop, the meandering canyon with axial thalweg erosion is confined to the outer bend of the loop towards southeast within a large major sea valley (a). Similarly, in the bathymetric section across the next loop, the meandering canyon with entrenched thalweg is confined to the outer bend of the loop towards northwest within a major sea valley as well (b). Locations of meander bends are shown in Figure 3.

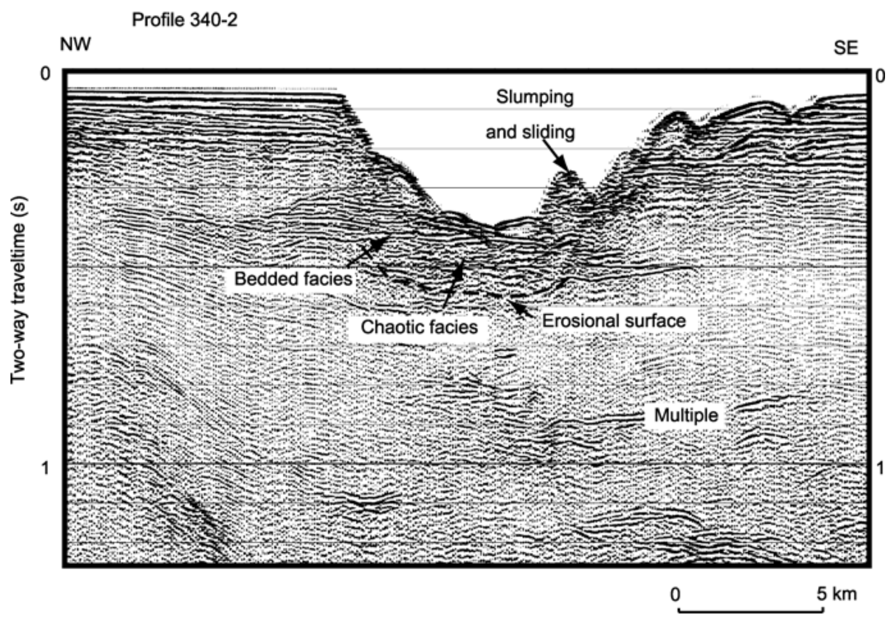

Figure 6 Seismic profile 340-2 across the sinuous canyon segment shows bedded facies and chaotic facies under the canyon bottom, resulting from infilling of sediment of the last event of cut-and-fill. Sliding and slumping on the canyon walls produced sediments that are transported toward the canyon bottom and to fill up the canyon axis, erasing the V-shaped notch morphology. Locations of seismic profiles are shown in Figure 2.

sediments are beneath the irregular canyon flanks and canyon floor overlies unconformably an ancient erosional surface that is in prolongation of the canyon walls. Clearly, the expected small axial erosive pathway incising into the broad canyon floor does not exist.

(3) Meandering segment: the meandering segment begins at about water depth of 763 m, about 25.4 km from the canyon head (Figure 3). At the transition the width of the canyon significantly increases to 11.3 km bathymetric in profile 1237-2 (Figure 4). The meandering segment shows major sea valleys with entrenched thalweg (Figure 4). The meandering segment of canyon begins to swing to southeast and back to southwest laterally and extends down-canyon between 834 m and 1322 m in water (Figures 3 and 4). Distally the canyon course increases in magnitude of lateral migration (swing) and down-slope bend translation (sweep), resulting in bifurcated narrow channels within a major sea valley (Figure 5). In the bathymetric section across a meandering loop (Figure 5(a)), the meandering canyon shows an entrenched thalweg within a deeply incised trough at the outer bend of the loop towards southeast within a large major sea valley. Similarly, in the bathymetric section across the next loop (Figure 5(b)) the meandering canyon characterized by an entrenched thalweg is also confined to the outer bend of the loop towards northwest within a major sea valley.

Seismic profile 1237-3 across the first bend immediately southwest of the transition from sinuous to meandering segment shows an ancient erosional surface in prolongation of the present-day canyon flanks (Figure 7). Canyon walls are characterized by relatively steep and smooth surfaces compared to that shown on seismic profile 340-2 in the sinuous segment. Apparently, common sliding and slumping features on the canyon walls are not preserved. The floor of major canyon is entrenched into thalwegs restricted to the meander bends. The entrenched thalwegs are displayed as asymmetric V-shaped troughs. Note that a terrace is present between entrenched thalwegs.

Three Chirp Sonar profiles (C-1, C-2, and C-3) show the transition from erosion in the sinuous canyon segment to entrenched thalweg erosion in the meandering segment (Figure 8). Profile C-1 across the middle sinuous segment shows deeply incised canyon situated near the shelf break (Figure 8(a)). Profile C-2 at the end of the sinuous segment shows non-visible axial thalweg erosion in canyon floor, characterized by step-like failure scars on both flanks (Figure 8(b)). By contrast, profile C-3 at the beginning of the meandering segment shows sediment accumulation forming terrace at the inner bend while deeply entrenched thalweg erosion at the outer bend of the canyon (Figure 8(c)).

3 Discussion

A schematic representation summarizes the morphological and sedimentary erosive features in upper reach of the Kaoping Canyon (Figure 9). The upper reach of the Kaoping Canyon is distinguished into three distinct morpho/sedimentary features. The canyon head is characterized by V-shaped axial thalweg erosion. The sinuous segment of canyon is dominated by a single valley morphology floored by flat bottom. Entrenched thalweg erosion is well observed

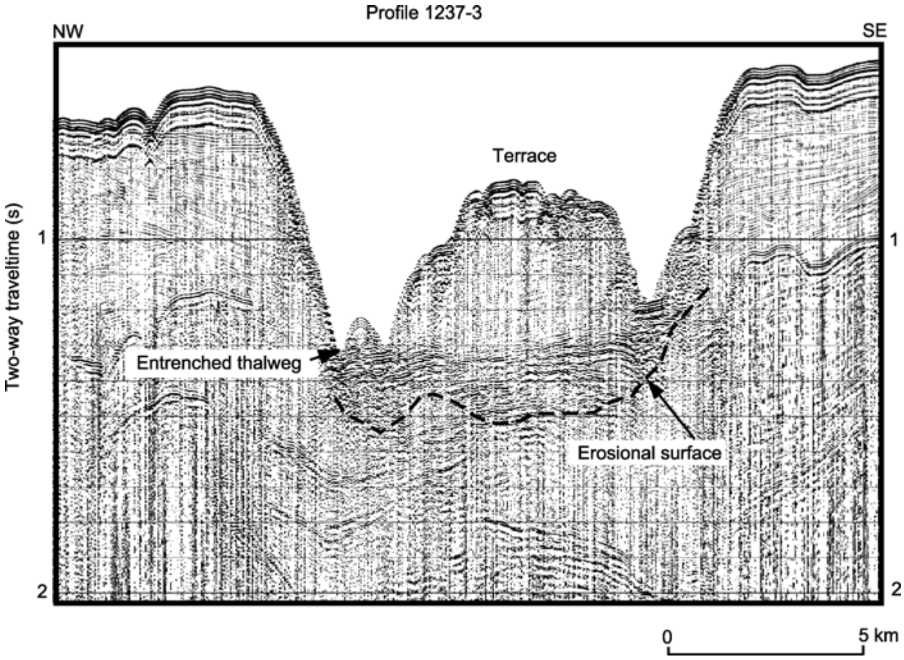

Figure 7 Seismic section 1237-3 across the meandering loop shows that the entrenched thalweg is again focused to the outer bend of the loop towards northwest. Note that the down-cutting of sea floors of the major sea valley is focused to the outer bend, forming the main course of the Kaoping Canyon characterized by entrenched thalweg and a V-shaped cross-section. Location of seismic profile 1237-3 is shown in Figure 2.

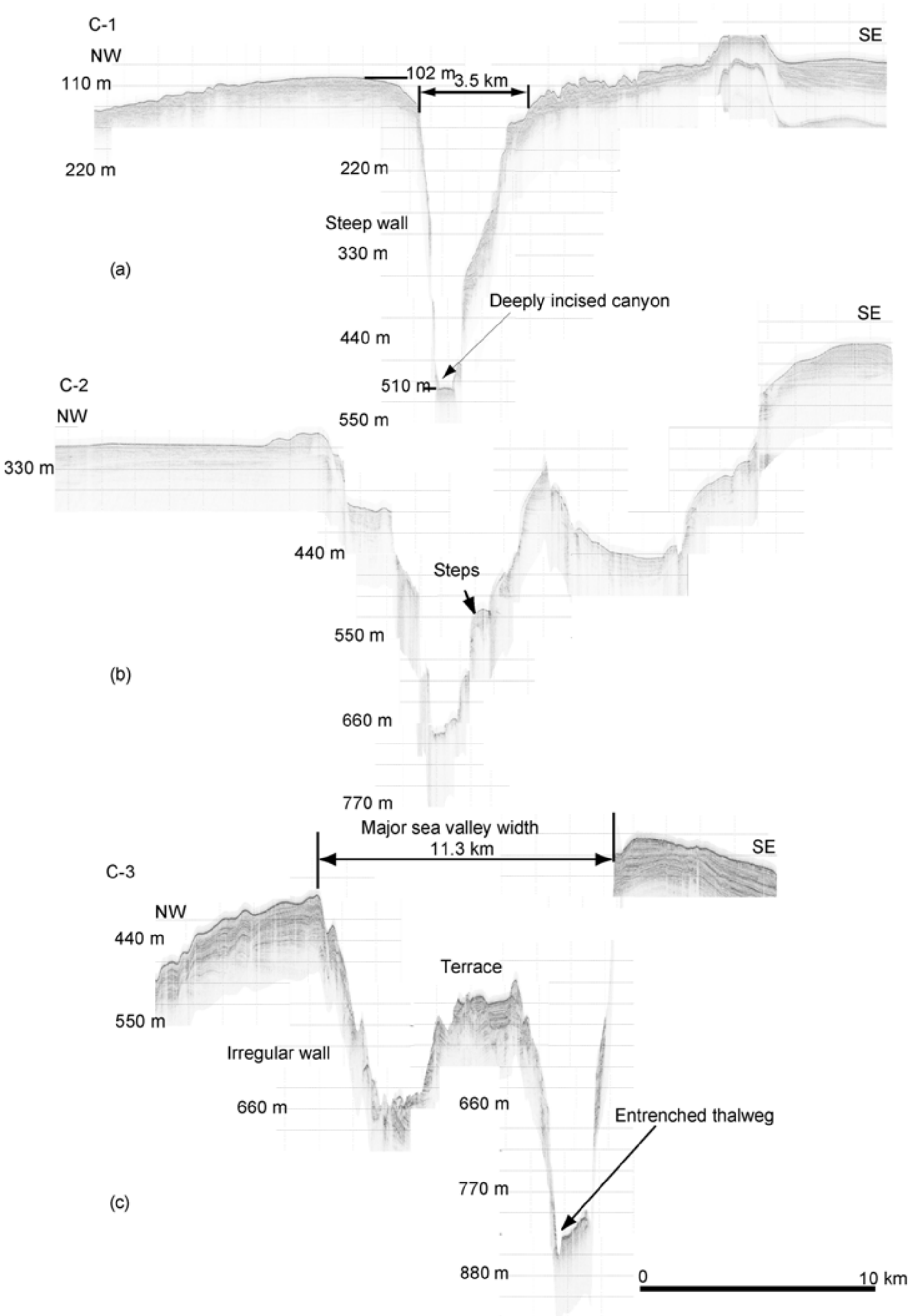

Figure 8 Profile C-1 across the middle sinuous segment shows deeply incised canyon (a). Profile C-2 across the end of sinuous segment shows step-like canyon flanks (b). Profile C-3 shows sediment accumulation forming terrace at the inner bend while entrenched thalweg at the outer bend of the canyon (c). Note that profile C-3 shows entrenched thalweg within a major sea valley. Locations of Chirp Sonar profiles are shown in Figure 2.

in the meandering segment and occurs mainly at outer bends. The detailed discussions of the characteristic of there three morpho/sedimentary features are given below.

3.1 Thalweg erosion

Cross section 340-1 shows the presence of axial thalweg erosion, the deepest incised part of the canyon floor with an incision depth of 171 m into the shelf sediment. The thalweg is referred to as axial thalweg, which is a V-shaped notch or depression located around the central part of canyon floor where there is no sediment accumulation.

During the early stage of canyon development in the head region, flood discharge from the Kaoping River feeds directly into the Canyon head, and enhances down-cutting by erosive turbidity currents along the canyon axis rather than lateral enlargement of the canyon width. Axial thalweg erosion has dominated over erosion of canyon walls and

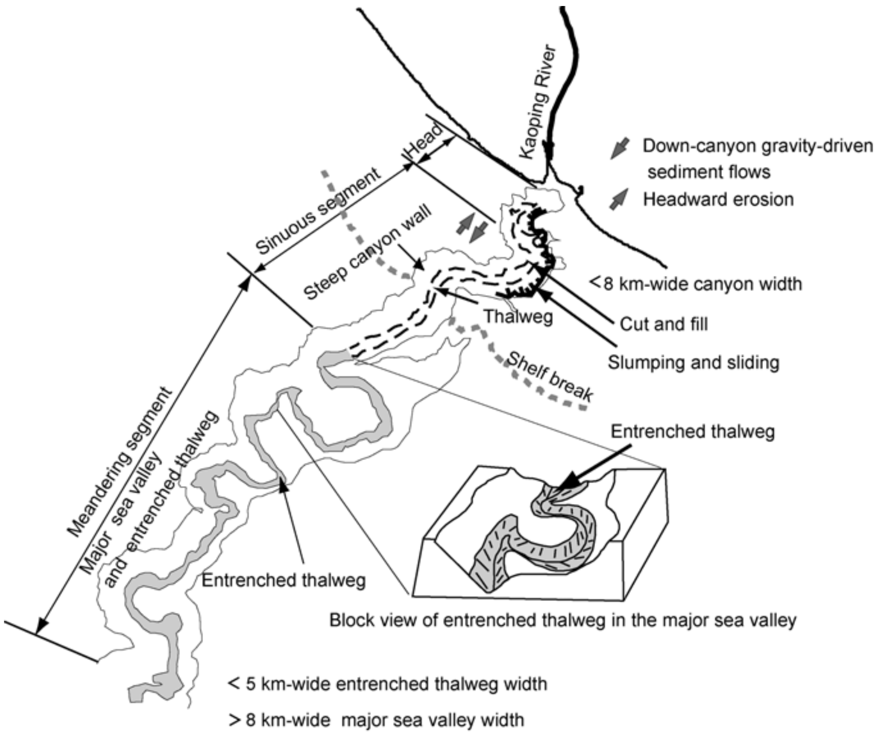

Figure 9 A schematic representation summarizes the morphological and sedimentary erosive features in upper reach of the Kaoping Canyon.

downslope erosion. As long as the Kaoping Canyon head is connected to the Kaoping River mouth by headward erosion, a continuous supply of sediment from the Kaoping River would be entrained within the Kaoping Canyon. Features of axial thalweg erosion occurring around the canyon head suggest that the canyon activity has continued even during a rising sea level stage. It is evident that canyon headward erosion has maintained the sediment supply from the Kaoping River which tends to produce erosive sediment flows. The continued sediment supplies from the Kaoping River to promote the downslope erosion, coupled with progressive upslope slumping, counteract the rate of sea level transgression in the Holocene. The canyon entrains fluvial sediments and funnels them farther down-canyon, excavating the canyon floor enough to maintain their position at the river mouth (Figure 9).

There are no clear indications of axial incision into the canyon floor from the bathymetric map (Figure 3), cross-sectional geometry (Figure 4) and seismic profiles (Figure 6). Three possible explanations are suggested for not having axial thalweg erosion in the sinuous segment. First, mass-wasting sediment from sliding and slumping on the canyon walls partially fills up the canyon floor, and masks the typical V-shaped notch morphology at the axial thalweg (Figure 6). The sediment becomes a new source of sediment-gravity flows that transform into turbidity currents along the course down-canyon. Thus, erosion of canyon walls and resultant sediments provide a new mechanism for canyon erosion and filling. Secondly, repeated strong turbidity currents from the canyon head running down the canyon flush the entire canyon floor, instead of an axial thalweg pathway. Thirdly, processes of sliding and slumping on canyon walls and turbidity currents along canyon course are combined to form present-day erosive features: steep canyon walls characterized by scars mainly due to sliding and slumping and canyon floors characteristic of either irregular or flat surfaces. Apparently, enhanced erosion in the sinuous segment is ascribed to a combination of thalweg down-cutting and mass-wasting processes of canyon flanks.

However, the Kaoping Canyon head is relatively small V-shaped trough with no sediment accumulation. This distinct notch with V-shaped cross section at the canyon head may be formed by axial thalweg erosion induced by turbidity currents. During river floods, a large amount of suspended sediment discharge from the river mouth to the canyon head generated erosive turbidity currents and down-cut the canyon floor. Bathymetric and seismic data indicate that axial thalweg erosion exists only near the canyon head, not further down-canyon.

The cross-sectional areas increase significantly from the sinuous course to the meandering segment, suggesting that increasing lateral erosion of canyon meandering had widen the canyon to form a relatively large sea valley (profiles 1237-2 through 1237-4 in Figure 5). Meanders occur on slopes by erosion of turbidity current maintaining over long periods [24]. The erosive processes in the Kaoping Canyon increase in magnitude of lateral migration (swing) and down-slope bend translation (sweep) to form the entrenched thalweg within a larger major sea valley (Figure 4). Similarly, sinuous channels commonly occur within larger channels/canyons/valleys in submarine environments [25].

Chirp Sonar profiles C-1, C-2 and C-3 (Figure 8) show the features of thalweg incision in the sinuous and meandering segments, respectively. Profile C-1 shows a relatively narrow canyon deeply incised into the underlying shelf strata, forming a V-shaped thalweg. Note that the canyon axis is filled with little sediment. Profile C-2 near the end of the sinuous course displays step-like canyon flanks due to movements of sliding and slumping. Mass-wasting sediments derived from canyon walls are moved toward the canyon floor. Apparently, sediment failures from both flanks have been remobilized on the canyon floor and farther down-canyon, enhancing erosion of the canyon floor and masking previous entrenched thalweg. Profile C-3 across a meander bend (Figure 8(c)) shows a deeply entrenched thalweg at the outer bend within a major sea valley where down-cutting is the most severe.

3.2 Episodes of cutting and filling

Seismic facies and internal structures shown in seismic profile 340-2 in the sinuous segment reveal episodes of cutting and filling during development of the Kaoping Canyon. Liu et al. [5] and Chiang and Yu [26] recognized the multiple cut-and-fill events in the Kaoping Canyon but without discussing the significance in terms of thalweg erosion. The ancient erosional surface indicates the initial phase of canyon erosion and followed by subsequent partial infilling of sediments. Seismic characteristics suggest that multi-phases of cutting and filling and early thalweg erosions with subsequent sediment fills characterize the sinuous segment of the Kaoping Canyon. Seismic characteristics of the canyon walls suggest that major sliding and slumping affect the flanks and that the erosion has erased the imprint of the thalweg erosion in its upper course or strong turbidity currents down-cutting and widening lateral entire canyon floor not restricted to the axial parts of the canyon floor.

Seismic facies shown in seismic profiles 340-2 and 1237-3 reveal basal erosional surfaces during early stage of development of the Kaoping Canyon. These confined basal unconformities of the canyon may be related to the possible role of the sea level change on the evolution of the Kaoping Canyon. According to Vail et al. [27], relative sea level change is the major element responsible for the formation of sequence boundaries in continental margins. A major sea level fall will affect the exposure of the continental shelf and its subsequent erosion. Erosion on the shelf leads to incision of submarine canyons and development of regional unconformities, resulting in the formation of sequence boundaries [28, 29]. During the lowstand of sea level, the Kaoping Canyon was generally active, causing significant erosion and maximum down cutting of the canyon.

Observations of bathymetric maps and seismic profiles across the Kaoping Canyon suggest that incision morphology changes along the course of upper reach of the canyon. The canyon head region is dominated by single valley morphology characterized by cut-and-fill feature. V-shaped and trough-like entrenched thalwegs within a major sea valley occur mainly in the distal meandering segment at the outer bends of the loop. We only found an erosive axial thalweg in the head region of the Kaoping Canyon. Although the mechanism for axial thalweg erosion is the same for the Kaoping Canyon and canyons in the Capbreton Canyon and canyons of western Gulf of Lion (i.e., turbidity currents) but the resulting erosive features are not comparable. The Kaoping Slope region is influenced by the complex plate tectonic history causing the west-vergent fold-and-thrust structures. Turbidity currents are important in modifying and maintaining the course of submarine canyons; however, the distribution of faults may play a more important role in determining the overall morphology of Kaoping Canyon in active collision margin of southwest Taiwan. It implies that sea level, sediment load, climate, tectonics and other factors are responsible for the differences of erosion processes during the canyon evolution.

3.3 Canyon activity

The canyon-river connection plays an important role in the activities of submarine canyons. In active canyons, large amounts of terrestrial sediments are continuously transported to the deep sea [30, 31]. In contrast, inactive canyons act as depocenters where sediments are accumulated within the canyons [32]. Submarine canyons become most active when they are connected to river systems and receive direct supply of terrestrial sediment discharges. For example, the Zaire submarine canyon directly connects with the Zaire River estuary. The canyon activity is evidenced by breaks of submarine cables near the canyon head during the Zaire River flood [33, 34]. In contrast, the Cap-Ferret Canyon (Bay of Biscay), located at the shelf edge without direct terrestrial supply from river, at the present highstand of sea level, is more a trap for sediment [32]. This led Sorbe [32] to conclude that the Cap-Ferret Canyon is inactive at present. Thus, this study considers the Kaoping Canyon active, because it directly receives large amounts of terrestrial sediment even during the present highstand of sea level.

The active Kaoping Canyon is one of five canyons in southwestern Taiwan margin for sediment dispersal seawards. The Taiwan margin has experienced frequent earthquakes. For example, Hsu [35] reported that submarine cable across these canyons were broken as a consequence of submarine landslides and turbidity currents associated with the 2006 Pingtung earthquake offshore SW Taiwan. Turbidity current can be triggered by natural causes in addition to earthquakes, including floods, storms, and rapid sedimentation [36, 37]. Except for the Kaoping Canyon the heads of other four named submarine canyons on the Kaoping Slope begin at shelf break-upper slope areas and their courses end on the upper Kaoping Slope (Figure 1). The lengths of these four canyons are relatively short compared to that of the Kaoping Canyon. We suggest that these four slope canyons do not receive a large amount of sediments in the head areas and in turn have a low capacity of triggering down-slope eroding sediment flows even associated with earthquakes, which are the only mechanism that can erode sea beds intensely and simultaneously transfer sediment in a down-canyon direction for a longer distance. In contrast, the Kaoping Canyon has been eroding sea beds of the contemporaneously formed Kaoping Shelf and Kaoping Slope, removing sediments from the shelf and slope and resulting in a prominent erosional trough of the sea floor. In other words, the sedimentary process of the Kaoping Canyon is mainly erosion, removing sediments away from the Taiwan mountain belt and delivering them to the receiving basin of the South China Sea.

Morphology of the sinuous segment of the Kaoping Canyon indicates that the canyon is largely empty with little sediment accumulation (Figure 4). Cross sections with great relief ranging from 171 to 442 meters strongly imply the time when presumed turbidity currents actively pass through and remove sediments from the canyon floor. The axial thalweg erosion at canyon head means that the turbidity currents produced an axial pathway within the canyon where sediments are either transported down-canyon or bypassed.

Seismic characteristics indicate that deposition of sediments occurs mainly in the meandering segment, forming terraces and levees [18]. However, thalweg erosion at the outer bends is the dominant canyon down-cutting feature in the meandering segment, i.e., erosion is prevalent over deposition within the canyon. In an approach of source to sink the observed morphology and seismic features lead us to conclude that the upper reach of the Kaoping Canyon functions as a sediment conduit or a sediment bypass zone at present. This reasoning is in contradiction to the conclusions that the Kaoping Canyon functions as a major sink receiving terrestrial materials from adjacent land areas [19, 20].

Alternatively, the Kaoping Canyon head region can be considered as a temporary sediment sink rather than a major sink. Data from radioactive dating of sediments in the canyon head segment provide partial evidence supporting this argument. Age of ^{210}Pb dating cannot be determined from core samples located near the canyon head. This suggests that rapid sedimentation and subsequent removal of recent flood sediments in the canyon head region prevented ^{210}Pb ages from being determined [8]. In contrast, ^{210}Pb ages were determined from core samples farther down-canyon away where flood sediments accumulate slowly.

4 Conclusions

The canyon morphology changes along the upper reach of the Kaoping Canyon. Main morphologic characteristics for the three segments in the upper reach are summarized in Table 1. The canyon head segment is characterized by V-shaped axial thalweg erosion. The sinuous segment of canyon is dominated by a single valley morphology floored by flat bottom without an axial thalweg pathway. Entrenched thalweg erosion is well observed in the meandering segment and occurs mainly at outer bends. Exceptional tectonic, climatic and canyon setting generated turbidity currents, flushing sediment down-canyon and eroding most parts of canyon floor rather than the axial thalweg. Repeated canyon cuttings and subsequent partially sediment fillings have resulted in present morphology. Entrenched thalweg ranges from 153–341 m in relief, reflecting the present day conditions of recurrences of cutting events by differing sediment flow processes. A schematic representation summarizes the morphological and sedimentary erosive features in upper reach of the Kaoping Canyon (Figure 9).

Observed morphological and sedimentary features suggest that the Kaoping Canyon is a major link between the Kaoping River drainage basin and the South China Sea basin. Sediment-laden river plume operates in the Kaoping River-Canyon system, with inferred turbidity currents flushing river sediments into the canyon head and the canyon head region functioning as a sediment conduit. Presently, the upper reach of the Kaoping Canyon can be considered as a temporal sediment sink rather than a permanent sink.

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