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Morphology and Geologic Implications of Penghu Channel off south-west Taiwan

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ABSTRACT

Penghu Channel shows submarine valley morphology characterized by relatively shallow and wide elongate depression with gently sloping sides and a continuous bottom gradient. The possibility of being a river valley of the Penghu Channel during Late Pleistocene can not be ruled out. But, modern currents completely overprint the signature of inherited paleo-geomorphology of a river valley. At present, Penghu Channel is considered as a scour furrow of probably erosion origin, mainly by northward tidal currents. It serves as a sediment pathway transporting shelf sediment alongshore and northward on the tide-dominated Taiwan Strait shelf. Penghu channel together with Yunchang Ridge to the north may be considered parts of a modern tidal erosion and deposition system.

Bathymetric data indicate that Penghu Channel may not extend seaward into Penghu Canyon. The head and main course of Penghu Canyon are not aligned with Penghu Channel. They are two different undersea features, not a continuous sea valley. The hypothesis of an ancient Minchiang River flowing from China and extending southward to the sea through a sinuous valley on the exposed Taiwan Strait during Late Pleistocene is not supported by evidence of newly generated bathymetric chart and modern hydrodynamics.

(Key words: Penghu channel, Morphology, Currents, Sediment pathway)

1. INTRODUCTION

1.1 Geological Setting

The island of Taiwan is situated at the junction of the Ryukyu and Luzon Arcs along the

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plate boundary between the Eurasian plate to the west and the Philippine Sea plate to the east in the northwestern Pacific. The collision between the Luzon Arc and the eastern Chinese margin formed the Taiwan orogen during Late Miocene-Early Pliocene (Ho 1986). The Taiwan Strait lies between Taiwan and Mainland China and is about 180 km wide, 350 km long and 60 m deep (Boggs et al. 1979). The Taiwan Strait is floored by a foreland shelf formed by flexural subsidence of the eastern Chinese margin and basin-filling of orogenic sediment from the Taiwan orogen (Covey 1984; Yu and Chou 2001). Off east and south Taiwan, the sea floors show very narrow shelves and steep slopes cut by gullies and canyons with irregular topography (Fig. 1a).

1.2 Topography and Geology

The early investigation of submarine topography and related geology in the Taiwan Strait was carried out by Boggs et al. (1979). Bathymetry data indicate that most of sea floor of the Taiwan Strait is shallower than 60 meters. Despite the small variations of bottom relief of the Taiwan Strait irregular troughs and ridges can be recognized (Fig. 1a). Boggs et al. (1979) pointed out that a large submarine valley exists off southwest Taiwan. This valley extends northward until it reaches a ridge confined by the bathymetric contour of 60 m northeast of the Penghu Islands. It then turns west and passes north of the Penghu Islands and continues northeastward, joining another bathymetric trough confined by the bathymetric contour of 60 meters (Fig. 1a). They suggested that this submarine valley is probably of relict origin because the shape and main course of this valley are not consistent with known current patterns and hydrodynamic regime of the Taiwan Strait. The East China Sea shelf was emergent during low stand in Late Pleistocene when the sea level is assumed to be 140 meters below the present level (Emery et al. 1971). By analogy, Boggs et al. (1979) considered this sea valley to be formed by subaerial erosion about 15,000 years ago when the Taiwan Strait shelf was exposed. Furthermore, they suggested that this sea valley might be part of the ancient Minchiang River System which flowed southward to the sea through this sinuous valley as shown in Fig. 1b. This postulated Late Pleistocene river valley might extend southward and merge seaward with a major submarine canyon.

Later, these troughs and ridges investigated by Boggs et al. (1979) were named with geologic interpretations (Chen 1989; Mao and Hsieh 1989; Yu and Lee 1993; Liu et al. 1998a; Yu and Song 2000). The large submarine valley off the southwest coast of Taiwan was named Penghu Channel (Chen 1989), as shown in Fig. 2. The elongated trough parallel to the China coast located northwest of the Penghu Channel was named Wuchui Trough (Mao and Hsieh 1989). A NW-SE trending trough connecting the Penghu Channel and Wuchu trough is called Southwest Depression (Liu and Cong 1997). Southwest of the Penghu Islands in the southern Taiwan Strait lie the Taiwan Banks, large bathymeric highs, consisting of more than 30 shoals with water depths between 20 to 40 m.

While studying topography of the continental slopes off southwestern Taiwan, Yu and Lee (1993) found that the Penghu Channel extends southward and merges into gullies on the upper slopes, not a major submarine canyon. The major submarine canyon was named by Yu and Lee (1993) the Penghu Canyon, whose tributary canyon heads originate on the upper

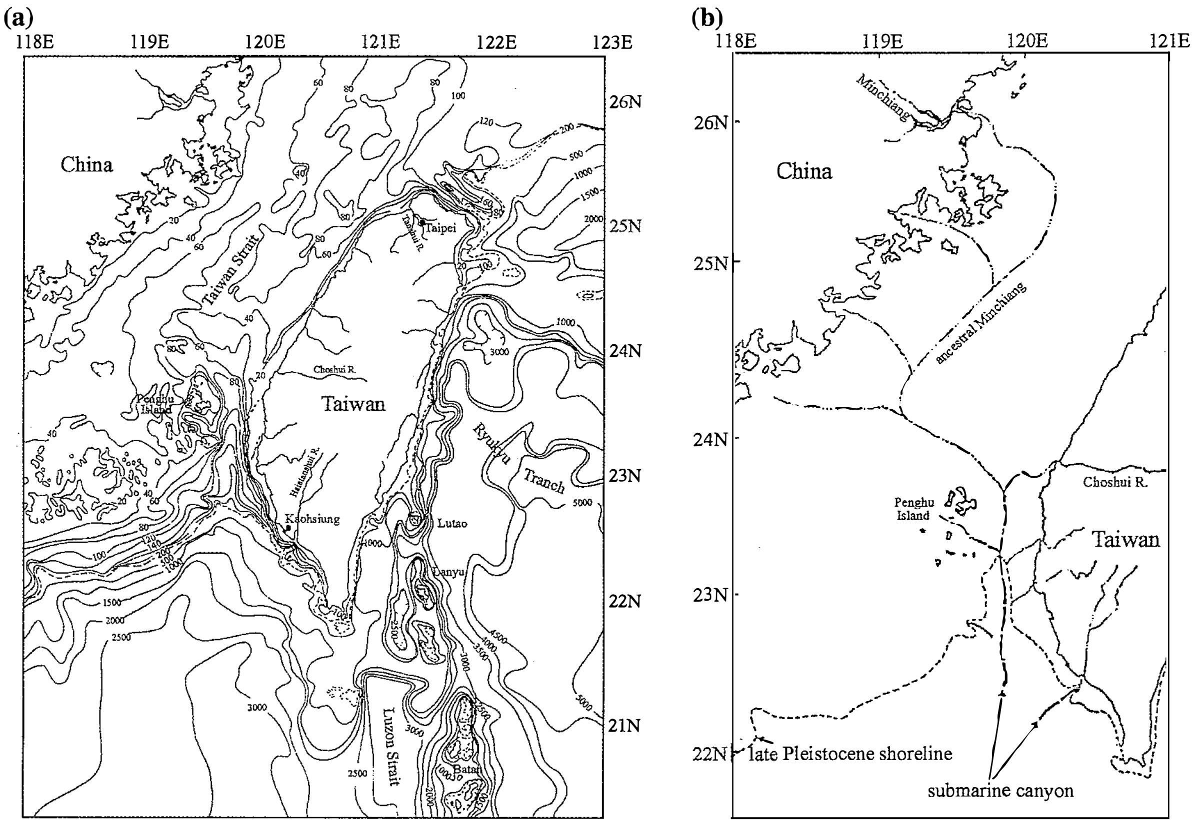


Fig. 1. Most of the sea floor of the Taiwan Strait is shallower than 60 meters. A large submarine valley (now is the Penghu Channel) exists off southwest Taiwan. This valley extends northward until if reaches a ridge confined by the bathymetric contour of 60 m northeast of the Penghu Islands. It then turns west and passes north of the Penghu Islands and continues northeastward joining another bathymetric trough confined by the bathymetric contour of 60 meters (Fig. 1a). This sea valley was formed by subaerial erosion about 15, 000 years ago when the Taiwan Strait shelf was exposed and perhaps might be part of the ancient Minchiang River, as shown in Fig. 1b. This postulated Late Pleistocene river valley might extend southward and merge seaward with a major submarine canyon. After Boggs et al. (1979).

slopes southwest of the Penghu Islands. They suggested that the Penghu Channel and Penghu Canyon are two submarine features and should not be regarded as a single undersea feature. Chen (2001) determined the location and course of the Penghu Canyon. This canyon is a multi-head canyon and originates at the shelf-break off southwest Taiwan. It is probably not connected to the mouth of the Penghu Channel. Later, Chuang and Yu (2002) determined the head of Penghu Canyon to be a small trough on the upper slope with a water depth of about 240 m, not related to the Penghu Channel. The main course of the Penghu Canyon extends from its head near the shelfbreak southwards curve-linearly to the South China Sea (Fig. 2). This canyon is the physiographic boundary separating the South China Sea Slope to the west from the Kaoping Slope to the east. The head and upper reach of the Penghu Canyon were formed by slumping and sliding on the upper slopes (Yu and Lee 1993; Chen 2001; Chuang and Yu 2002).

Liu et al. (1998b) postulated that the Taiwan Strait is a modern tidal deposition system that consists of two tidal erosional and depositional geomorphic units. One is the paired Taiwan Strait scour furrow (Wuchui Depression) and the Taiwan Shoal sand ridges (Taiwan Banks) that exist in the central-southern Taiwan Strait. Mao and Hsieh (1989) postulated that the Wuchui Depression was a fault-controlled trough and modified by present-day erosion of tidal currents. The other tidal erosion and deposition system is the Penghu Channel scour furrow and the Taichung Shoal appearing in the southeastern part of the Taiwan Strait. Apparently, these authors interpreted the submarine topography and related geologic meaning quite differently than did Boggs et al. (1979).

Chen and Lin (1990) and Liu et al. (1998a), however, believed the postulated Late Pleistocene river valleys of the Wuchui Trough and Penghu Channel might extend southward and merge seaward with a major submarine canyon (Penghu Canyon). The nature of the Penghu Channel and adjacent topographic features still remains controversial because of different interpretations using a similar or same marine database (Mao and Hsieh 1989; Chen and Lin 1990; Liu et al. 1998b).

1.3 Hydrography and Topography

Our understanding of hydrography of Taiwan Strait has been improved progressively since late 1970s due to the newly available advanced instruments of hydrographic surveys. A short description of the up-to-date hydrography of the Taiwan Strait is helpful for understanding its effects on the topography of the strait. Jan et al. (2002) gave a summary of seasonal circulation of currents in the Taiwan Strait, showing the close relationship between the topography and hydrography. The northward flowing Kuroshio Branch Water from the South China Sea via the Penghu Channel to the Taiwan Strait is strongly blocked by the northeast monsoon during winter season (Fig. 3a). In the western Taiwan Strait, a portion of the southward flowing China Coastal Water is deflected by the Yunchang Ridge and turns back northeastward. In spring, weak northeast monsoon allows the northward intrusion of the Kuroshio Branch Water passing over the Yunchang Ridge (Fig. 3b). In summer (Fig. 3c), the stratified northward flowing South China Sea Water aided by southwest monsoon easily passes over the Yunchang Ridge; only the bottom flow is deflected anticyclonically. During fall season (Fig. 4d), the

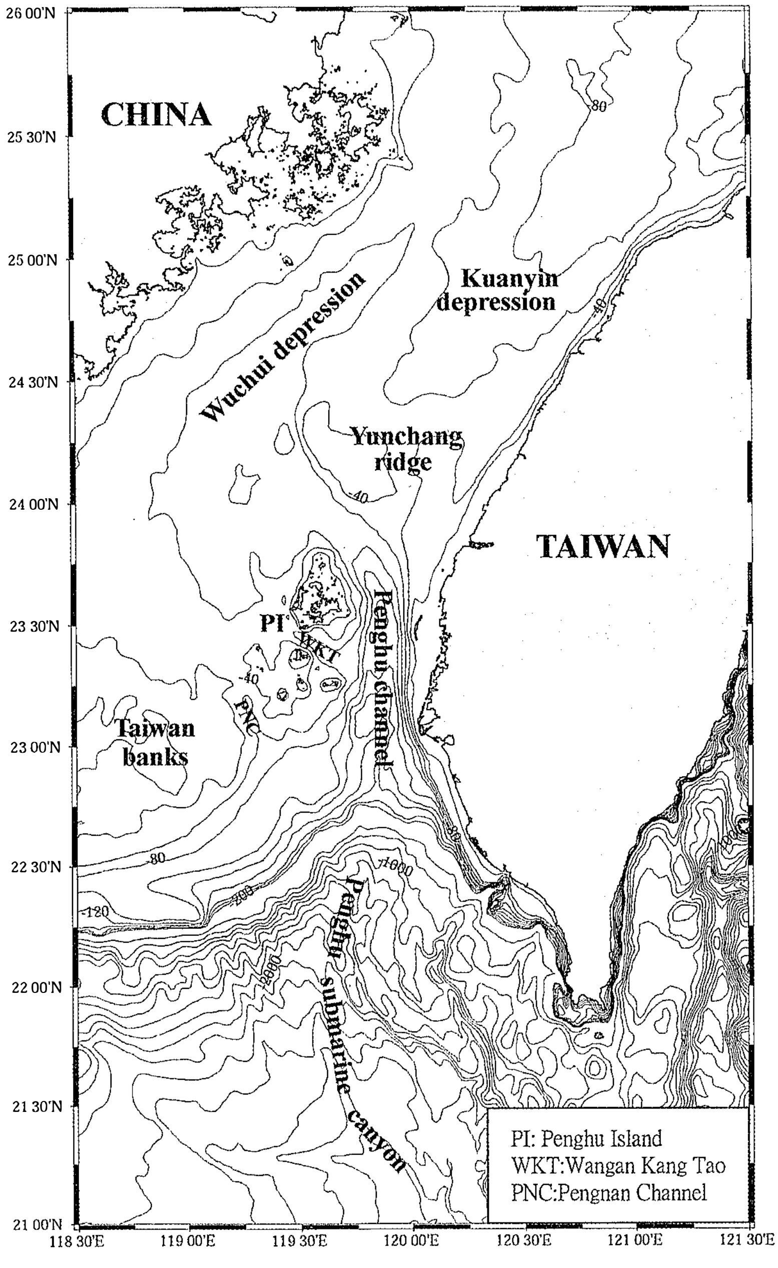


Fig. 2. Bathymetric map showing major topographic units in the Taiwan Strait. The Penghu Channel is located between the Penghu Islands and southwest Taiwan. Secondary topographic units include the Wangan Kang Tao (WKT) Channel and the Pengnan Channel (PNC). The bathymetric chart was made of bathymetric data from the Center for Ocean Research databank in Taiwan.

circulation pattern remains the same, except for the emergence of the China Coastal Water in the northwest part of the strait. It is noted that the Penghu Channel is the waterway for the South China Sea Current and Kuroshio Branch Current flowing from south into the Taiwan Strait.

In addition, the Taiwan Strait shelf is characterized by semidiurnal tides. Wang et al. (2003) pointed out that the yearly average tidal current is 0.46 m s^{-1}, with the maximum amplitude at the northeast and southeast entrances and the minimum amplitude in the middle part of the strait. The Penghu channel is characterized by a waterway passing by strong tidal current with northward net flow.

2. PURPOSE

The purpose of this paper is aimed at discussing the relationship between the submarine topography and geological significance of the Taiwan Strait Shelf. Is the Penghu Channel a relict fluvial valley or a modern tidal channel? Does the Penghu Channel extend southward and merge into the Penghu Canyon? Does the Penghu Channel extend northwestward and continue into the Wuchu Trough? How well justified is the postulated paleo-drainage of the Minchiang River in the Taiwan Strait? This paper intends to answer these questions. Emphases are on the nature of the Penghu Channel and implications for paleo-drainage of the Taiwan Strait 15,000 years ago.

3. DATA AND METHODS

A high frequency (3.5 kHz) sub-bottom seismic survey aboard R/V Ocean Research I in the area between the Penghu Islands and Taiwan was conducted (Fig. 4). The total length of track-lines is about 3000 km, including 33 E-W trending transverse profiles and 2 N-S trending longitudinal sections. Bathymetric data were collected by a Simard EK 500 Sonor. The 3. 5 kHz sub-bottom records were acquired using Ocean Research Equipment transducers. The standard procedures for interpreting micro-topography and sedimentation processes from the 3.5 kHz echograms refer to Damuth (1980), Laine et al. (1986) and Gaullier and Bellaiche (1998). Eight box cores along the axis of the Penghu Channel and Yunchang Ridge were collected to determine the surface sediment type using a standard size-analysis technique.

4. INTERPRETATION

4.1 Morphology

Examining newly acquired bathymetric profiles across the sea valley between the Penghu Islands and Taiwan (Fig. 5), we determine four geomorphic units: (1) deeply cut gullies and canyon-like troughs on the upper slope, (2) the Penghu Channel, (3) a small trough northwest of the Penghu Channel and (4) southern Yunchang Ridge.

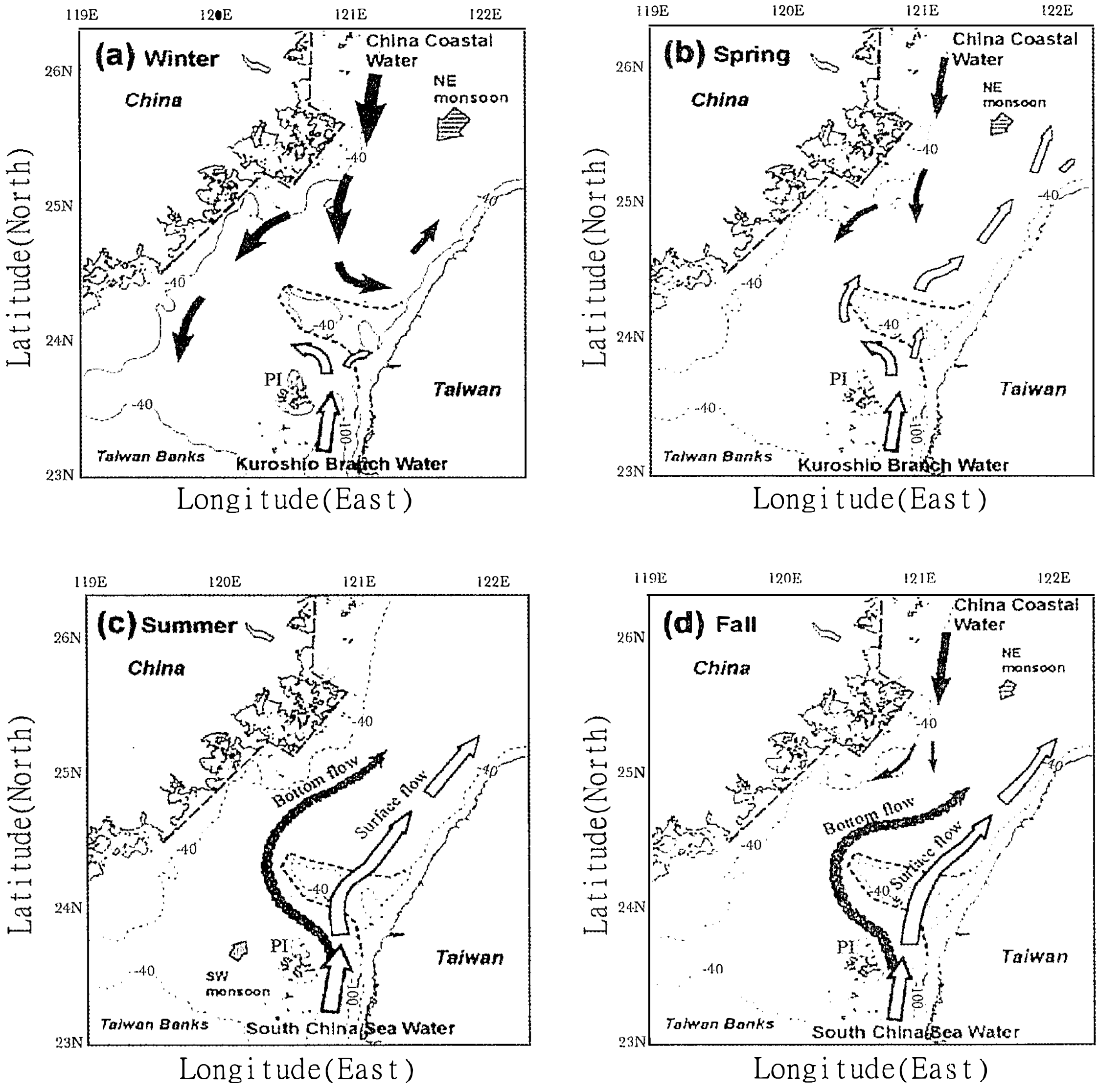


Fig. 3. The seasonal circulation of currents in the Taiwan Strait. After Jan et al. (2002). Note that currents passing through Penghu Channel are affected by the topographic high of the Yunchang Ridge to the north.

4.2 Gullies

Bathymetric profiles 1 through 5 show very irregular sea floor with deep incisions on the upper slopes. They are considered gullies and canyon-like troughs. Gully floors are between 230 m and 668 m in depth. The relief between gully and canyon-like trough edge and floor

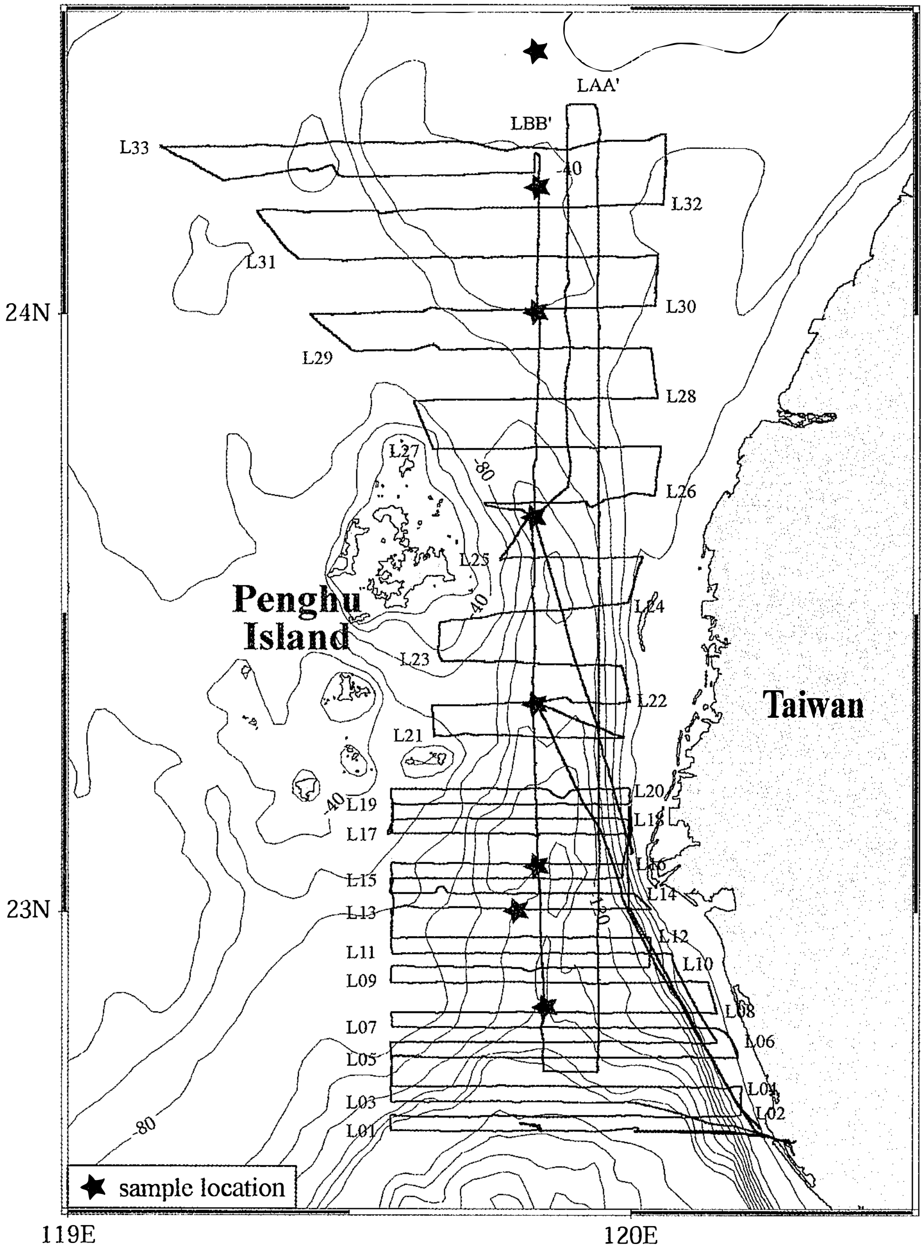


Fig. 4. A high frequency (3.5 kHz) sub-bottom seismic survey aboard R/V Ocean Research I in the area between the Penghu Islands and Taiwan was conducted. The total length of track-lines is about 3000 km, including 33 E-W trending transverse profiles and 2 N-S trending longitudinal sections.

varies greatly from 70 to 600 m.

4.3 Penghu Channel

The N-S trending main course of Penghu Channel can be delineated by trough-like bottom from Profiles 6 through 28. Its depth is between 80 m to 200 m with width ranging from about 30 to 60 km. The Penghu Channel shows two gently sloping banks with sloping angles less than 0.3 degrees. The longitudinal gradient of the Penghu Channel from its head to mouth is about 0.06 degrees, a relatively gentle slope, as determined by two longitudinal profiles of LAA' and LBB' following the channel axis (Fig. 4). Bathymetric measurements indicate that the Penghu Channel is a relatively shallow, wide and low-relief elongate depression with gently sloping sides and its bottom has a continuous gradient, showing a typical sea valley (Bouma 1990).

Examining the bathymetric chart (Fig. 2) and cross sections (Fig. 5), we determine that main course of the Penghu Channel extends southward and merges into gullies on the upper slope, without connecting to the main course of the Penghu Canyon.

4.4 Southern Yunchang Ridge

North of the Penghu Channel lies the Yunchang Ridge which is represented by a bathymetric high between 30 to 50 m of water depth (Profiles 29-33). Surfaces of the southern Yunchang Ridge are relatively flat and smooth without indications of downward cutting of sea floor.

4.5 A small trough northwest of the Penghu Channel

A relatively small trough along the southwestern edge of the Yunchang Ridge is present west of the ridge shown on Profiles 29 through 33 (Fig. 5).

4.6 Tidal Erosion and Deposition

Changes of bottom topography and variations of sediment types along the channel floor and current patterns are used to infer the sedimentary processes of forming the Penghu Channel on the shelf. Judging from variations of relief of the channel bottom, we consider that the Penghu Channel can be divided into two parts: the southern section (Profiles 6 through 18) and the northern section (Profiles 19 through 28). The former shows that the channel floor is irregular with relief between 60-70 m; the latter is characterized by irregular channel floor but with small relief between 25-35 m. Irregular shape of channel floor suggests that the channel has been subjected to erosion. The intensity of erosion in the southern deep segment has been stronger than that in the northern shallow part, as suggested by greater bottom relief. Furthermore, 3.5 kHz echograms suggest that the floors of the Penghu Channel have been eroded into grooves that are highly irregular, with relief between 20-70 m (Fig. 6). The northward flowing tidal currents in the channel rather than waves and storms are considered the major agents for erosion of bottoms of the Penghu Channel. This may account for the southern

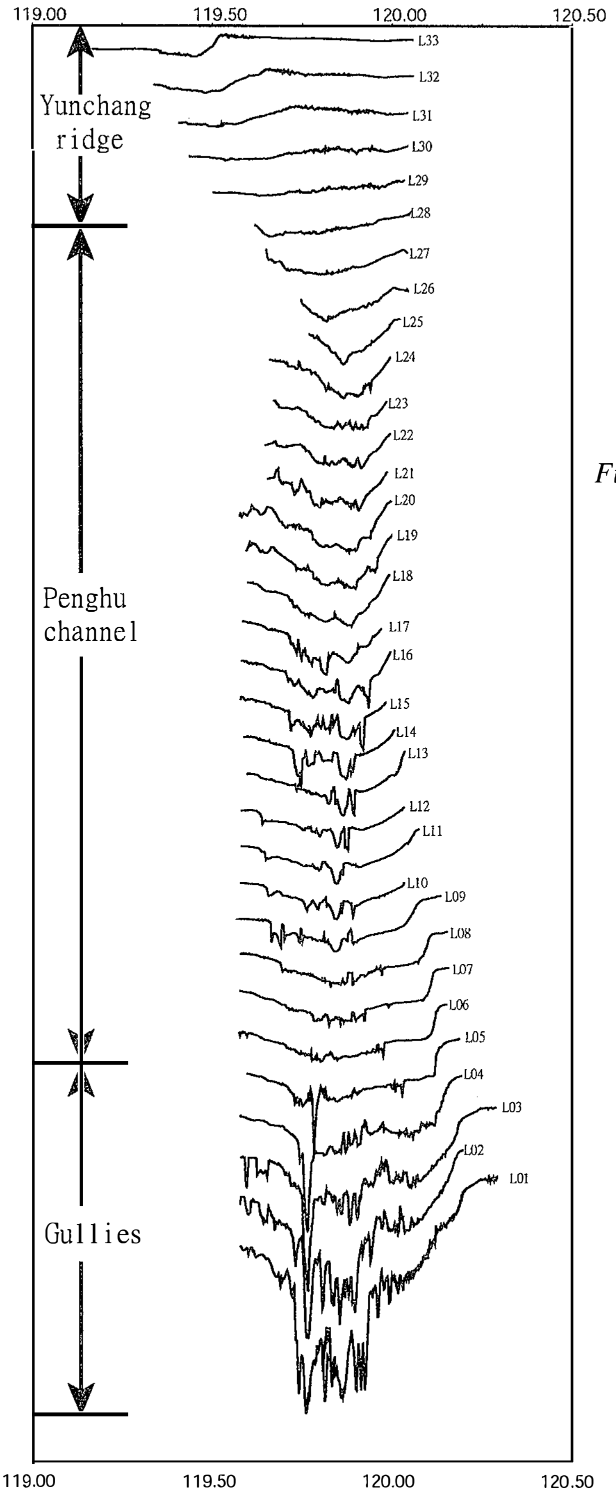


Fig. 5. Thirty three bathymetric profiles show four geomorphic units: (1) deeply cut gullies and canyon-like troughs on the upper slope (profiles 1 through 5), (2) the Penghu Channel (profiles 6 through 28), and (3) southern Yunchang Ridge and a small trough west of the ridge on the shelf (profiles 29-33).

part of the Penghu Channel having greater bottom relief than that of the northern part, responding to northward decreasing velocity of tidal currents. These irregular grooves associated with strong tidal currents can be considered scour furrows, as evidenced by furrow-like shape and truncation of sedimentary layers (Flood 1983).

Bathymetric Profiles 29-33 across the southern Yunchang Ridge show that the surfaces of the Yunchang Ridge are relatively flat and smooth. However, 3.5 kHz echograms show sediment sandwaves with amplitudes from 2 to 10 m (Fig. 7), suggesting movements of sands on the ridge surfaces.

Analyses of eight sediment samples indicate that gravel and sand (> 95 percent) dominate in the Penghu Channel with a minor amount of mud, whereas abundant sands (>90 percent) are present on the Yunchang Ridge. The depression north of Yunchang Ridge is covered by silty mud with about 55 percent silt. Shell fragments are the major component of the gravel found at stations 4 and 5 near the Penghu Islands. Sediments in the channel are mainly composed of fine to medium sands. In contrast, sands on the Yunchang Ridge consist mainly of fine sands (50 to 75 percent). The general trend of decreasing grain size down the tidal currents path along the Penghu Channel is compatible with other tidal transport paths on the tide-dominated shelves (Leeder 1999).

Scour furrows develop in the Penghu Channel and the tidal sand dunes occur on top of the Yunchang Ridge. Furrows of intense erosion are aligned parallel to the northwards direction of tidal current flow. Sediment bedforms on the surface of the Yunchang Ridge are large to very large subaqueous sand dunes, indicating movement and accumulation of sands. Immediately north of Yunchang Ridge lies an unnamed mud patch. The spatial distributions of scour furrow, sand dunes and mud patches follow the northward flowing direction of the tidal currents. The Penghu Channel, Yunchang Ridge and the muddy zone beyond are accompanied by a corresponding trend of decreasing grain size from gravel to mud. The channel-shoal couplet underwent systematic changes in bottom morphology and sediment characteristics, which suggest that the strong tidal currents played an important role in shaping areas between Penghu Islands and Taiwan into distinct sedimentary and geomorphic features. The Penghu Channel and Yunchang Ridge together might be considered a modern tidal deposition system as suggested by Liu et al. (1998b). However, contributions of tidal currents to sedimentary facies on the Penghu Channel floors are not well understood. Sediment source and composition of sediment in the Penghu Channel are not fully documented and need further clarification. Therefore, the conclusion of scour furrow of the Penghu Channel is preliminary.

4.7 Submarine Erosion of Slope Failure

South of the Penghu Channel, gullies and canyon-like troughs occur on the upper slope. These large gullies exhibit much greater relief than does the Penghu Channel on the shallow shelf. Their relief increases down-slope up to more than 200 m, indicating intense down-cutting of the upper slope, typical of erosion of slope sediments (May et al. 1983; Field et al. 1999). During the present sea-level highstand, the Penghu Channel is not a significant source of sediment to the upper slope. The possibility of downslope sediment flows, induced by input of sediment from the Penghu Channel, for erosion of the gullies on the upper slope is relatively

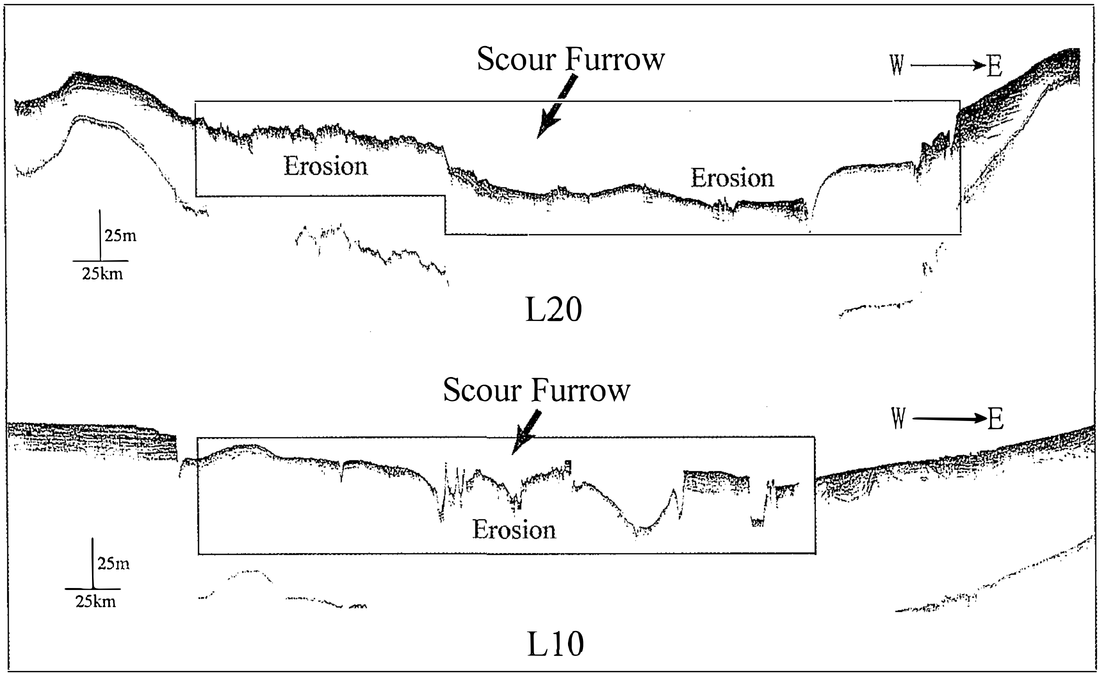


Fig. 6. 3.5 kHz echograms suggest that floors of the Penghu Channel have been eroded by currents into scour furrows that are highly irregular with relief between 10-30 m.

low. Instead, local slope failures along the shelfbreak dominate erosion of gullies on the upper slope. These gullies began about the 200 m isobath and extend down-slope and become tributaries to the Penghu Canyon.

The postulated Late Pleistocene drainage of the Taiwan Strait (Fig. 1b) implies a major canyon is directly connected to the Penghu Channel. Boggs et al. (1979) postulated that fluvial erosion of emergent Taiwan Strait shelf and upper slope during lowered sea-level stand 15, 000 years ago initiated the submarine canyon in southeastern Taiwan Strait. Our new bathymetric data suggest that subaerial erosion may not account for the initiation of the Penghu Canyon. The head and main course of the Penghu Canyon are not aligned with the Penghu Channel (Fig. 8). The mouth of the Penghu Channel on the shelf is about eleven kilometers away from the head of Penghu Canyon located on the upper slope. Instead, gullies on the upper slope east of the head portion of the Penghu Canyon are connected to the mouth of the Penghu Channel. Locations and morphology of these gullies on the upper slope south of the Penghu Channel imply that submarine erosion due to slope failure was mainly responsible for the initiation and development of the Penghu Canyon. Submarine slumping and other down-slope movements extended these gullies seaward and combined axial down-cutting formed the Penghu Canyon with many tributary canyons on the upper slope (Chuang and Yu 2002).

It is likely that the Penghu Channel was formed as a fluvial valley during sea-level lowstand,

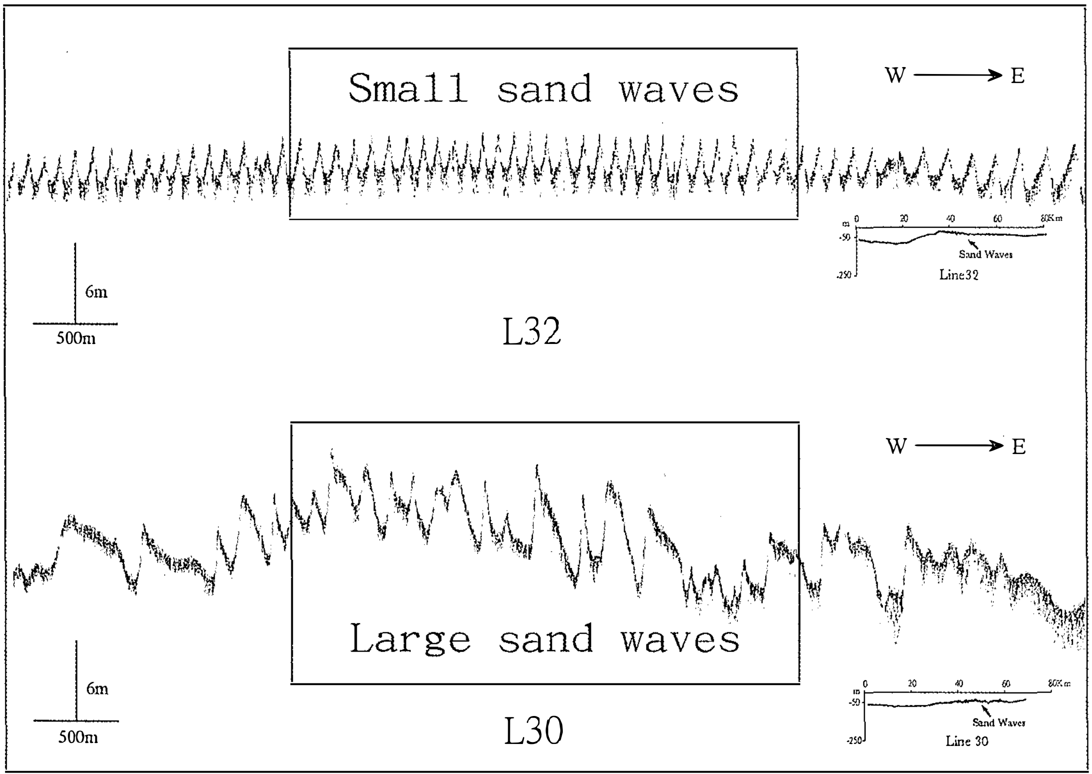
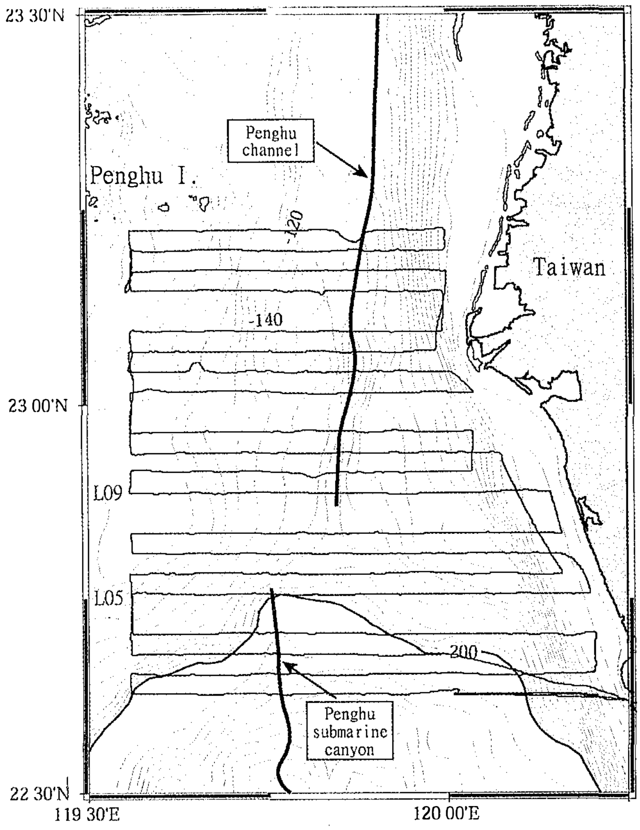


Fig. 7. 3.5 kHz echograms show sediment sandwaves with amplitude of from 2 to 10 m occur on surface of the Yunchang Ridge, suggesting movements and accumulation of sands.

and gullies have formed seaward on the upper slope. Upon subsequent sea transgression, the tidal currents combined with northward flowing currents modified the Penghu Channel into a tidal scour furrow. Meanwhile, submarine erosion of the upper slope occurred south of the Penghu Channel. Large gullies developed south of the Penghu Channel. Erosional gullies southwest of the Penghu Channel continued axial down-cutting into the lower slope and became larger and finally formed the Penghu Submarine Canyon.

4.8 Sediment Pathway

Submarine canyons are active sediment pathways for shallow marine sediments to be transported to deep-sea basins (Shepard 1973). The Penghu Canyon is no exception (Yu and Chang 2002). The Penghu Canyon is an active conduit for transporting orogenic sediments from the Taiwan orogen and sediments from the Chinese margin to the Manila Trench (Yu and Chang 2002). However, this canyon is not a sediment pathway for sediments on the Taiwan Strait shelf via the Penghu Channel. A northward and along-shore transport of sediments rather than a seaward transport occur in the Penghu Channel.



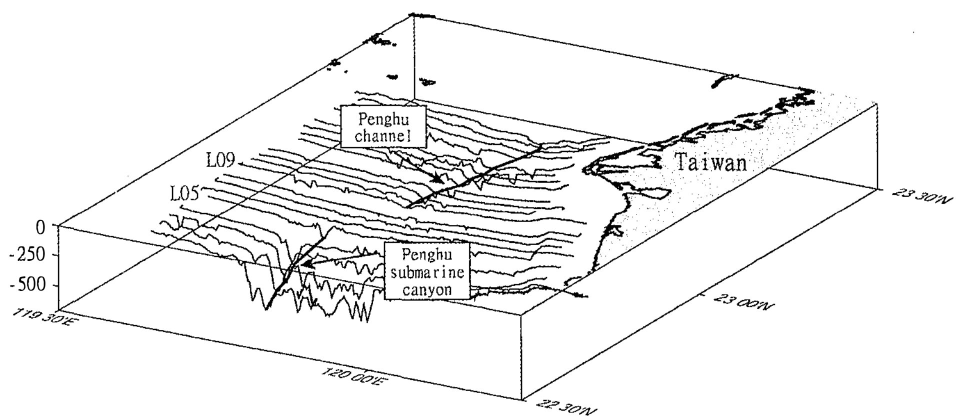


Fig. 8. The mouth of the Penghu Channel on the shelf is about eleven kilometers away from the head of Penghu Canyon located on the upper slope. The head and main course of Penghu Canyon are not aligned with the Penghu Channel (upper panel). Instead, gullies revealed by cross sections on the upper slope east of the head portion of Penghu Canyon are connected to the mouth of the Penghu Channel (lower panel).

Evidences from locations, morphology, origin and sediment transport route indicate that Penghu Channel and Penghu Canyon are two different undersea features, not a continuous sea valley as suggested by Boggs et al. (1979).

5. CONCLUSION

The Penghu Channel is a sea valley characterized by relatively shallow and wide elongate depression with gently sloping sides, and its bottom has a continuous gradient. This sea valley is a waterway for tidal currents with northward net flows of the South China Sea Current and the Kuroshio Branch Current flowing from the south into the Taiwan Strait. The Penghu Channel serves as a sediment pathway transporting shelf sediment along-shore and northward on the tide-dominated Taiwan Strait shelf. The possibility of the Penghu Channel being a river valley during Late Pleistocene can not be ruled out. However, modern tidal currents completely overprint the signature of inherited paleo-geomorphology of a river valley. At present, the Penghu Channel is considered a scour furrow of probably erosion origin, mainly by northward tidal currents.

The hypothesis of the Penghu Channel connecting to a major submarine canyon is not supported by new bathymetric evidence. Bathymetirc data suggest that the Penghu Channel and the Penghu Canyon are two different undersea features and not connected together, as suggested by Boggs et al. (1979).

The small sea trough northwest of the Penghu Channel may be formed by erosion by present-day currents along the southwestern edge the Yucchang Ridge. This implies a combination of effects of inherited topography and modern hydrodynamics.

The hypothesis of an ancient Minchiang River flowing from China and extending southward to the sea through a sinuous valley on the exposed Taiwan Strait during Late Pleistocene is not supported by evidence of newly generated bathymetric chart and modern hydrodynamics.

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