

**OBLIQUE CONVERGENCE BETWEEN TRENCH-ARC SYSTEM
AND CONTINENT-IMPLICATIONS FOR THE FORMATION
OF THE SUBMARINE PHYSIOGRAPHY OFF
SOUTHERN TAIWAN**

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ABSTRACT

The northern Manila Trench-Luzon Arc system and the juxtaposed Asian continental margin were successively deformed by collision which began at about 5 Ma ago and has been propagating southward at a rate of about 9cm/year. As a consequence, folding, thrusting and orogenic sedimentation related to the east-west compressive stress have deformed the Asian continental margin and the trench-arc system into the mountain range (Taiwan) which plunges southward into the sea. Off southern Taiwan the sea floor features several prominent alternating N-S trending linear ridges and troughs.

Beginning about 5 Ma, the northern tip of the Manila Trench has been progressively filled, closed and uplifted from north to south and compressed into the deformation front buried west of Taiwan. The northern portion of the Manila accretionary prism together with the Asian continental margin were deformed into the Central Range and its southern extension of the submarine Hengchun Ridge which ends at about 21°N. The northern segment of the forearc basin of the North Luzon Trough was deformed into the Longitudinal Valley, serving as the boundary between the Eurasian and Philippine Sea plates. The southern extension of the Longitudinal valley is represented by the Southern Longitudinal Trough, Huatung Ridge and Taitung Trough which merge together as the North Luzon Trough south of 21°N. During the last 3 Ma, the volcanic islands north of Lutao-Lanhsu Ridge then collided with the accreted Asian continental margin, resulting in the formation of the Coastal Range, and the Lichi melange accreted into eastern Taiwan.

INTRODUCTION

Taiwan is an island located among the island arcs along the rim of the Western Pacific. It is situated near the junction between the Ryukuu Arc to the northeast and the Luzon Arc to the south (Fig.1). The Philippine Sea plate is moving relative to the Eurasian plate at a rate of 7cm/year (Seno, 1977), resulting in an oblique convergence between the Asian continent and the Philippine Sea plate. The Manila Trench-Luzon Arc system and Asian continental margin were successively deformed by collision which began probably at about 5 Ma ago and has been propagating southward at a rate of about 9cm/year (Suppe, 1981). For the past two decades, the arc-continent collision model has been successfully applied to the tectonic evolution of the island of Taiwan and especially the Coastal Range in eastern Taiwan, which has been well documented to be the product of the collision between the northern extension of the Luzon volcanic islands and the Asian continental margin (Biq, 1972; Chai, 1972; Bowin et al., 1978; Chi et al., 1981; Page and Suppe, 1981; Ho, 1982, 1986; Suppe, 1981, 1984; Stephan et al., 1986; Chen et al., 1990; Teng, 1990; Huang et al., 1992).

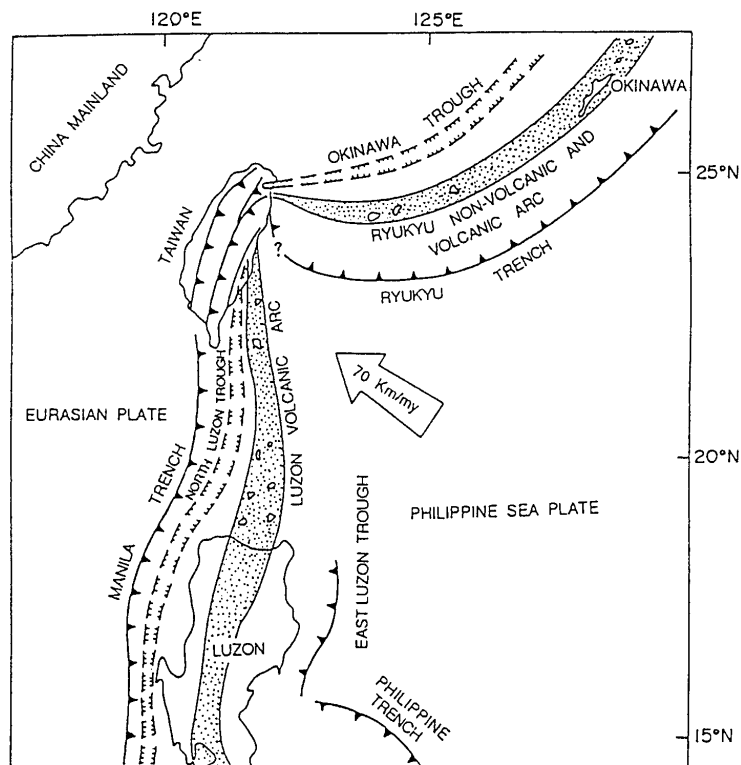


Fig. 1. Cenozoic plate settings of the Asian continental margin near Taiwan (After Shyu and Chen, 1991)

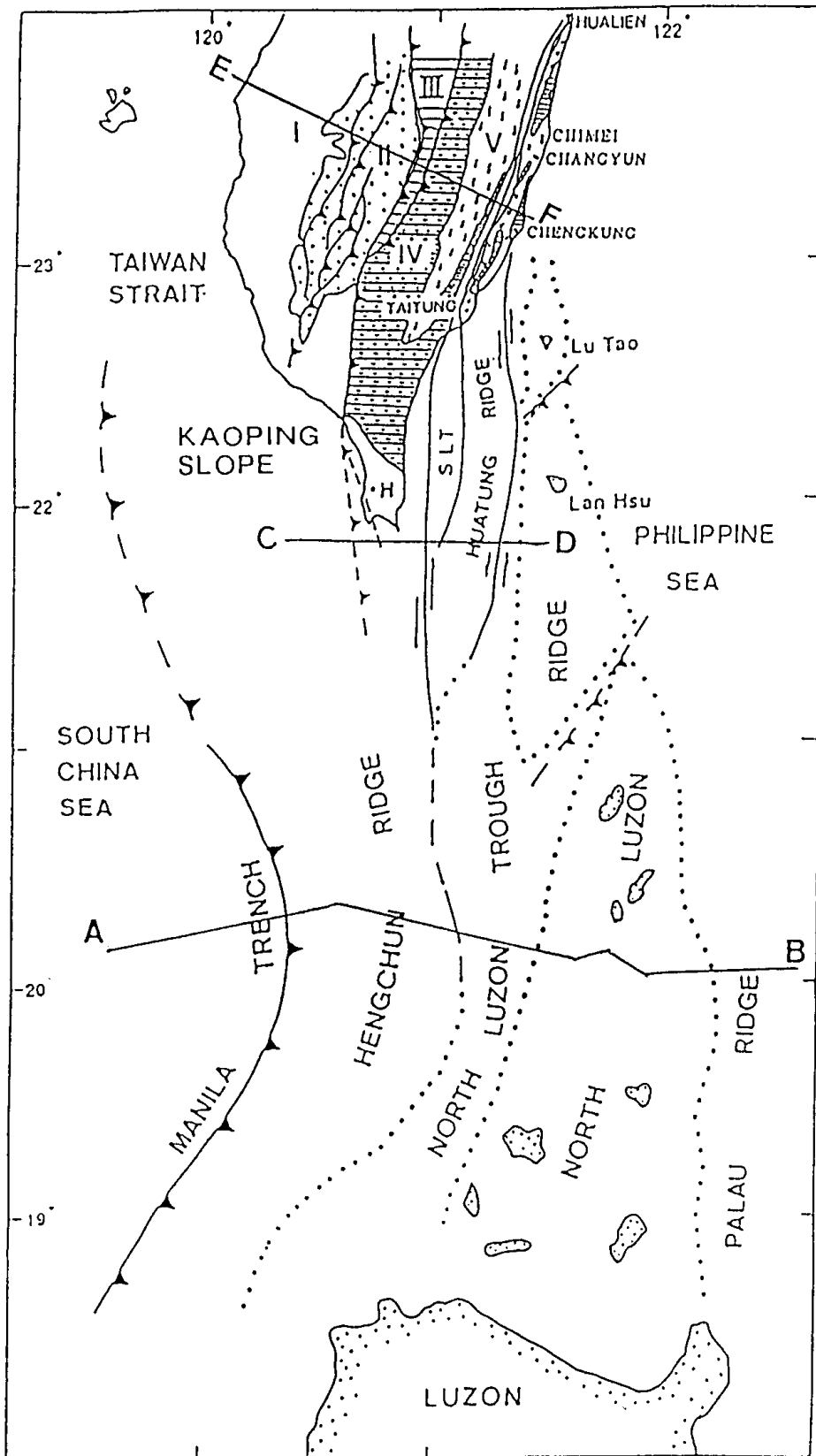


Fig. 2. Major morphotectonic features in the waterway between Taiwan and Luzon.

SLT: Southern Longitudinal Trough (After Shyu and Chen, 1991).

Although the arc-continent collision model adequately accounts for the development of the tectonic features in Taiwan, it has not explained the nature and development of the submarine morphotectonic features between southern Taiwan and northern Luzon. For instance, where is the end of the northern extension of the Manila Trench towards Taiwan? How does the North Luzon Trough extend into the Longitudinal Valley onland Taiwan? Is it appropriate to call collectively the ridges and troughs off southern Taiwan an accretionary prism?

Indeed, the region between southern Taiwan and northern Luzon is a complex convergent zone and led Ho (1982, p.67) to state that "A conclusive solution to this problem may have to await more submarine information derived from marine geology, geophysics, and bathymetry in the waterway between Luzon and Taiwan". Recently the submarine morphotectonic features off southern Taiwan have been mapped (Fig.2) and discussed (Chen and Juang, 1986; Chen et al., 1988; Lundberg, 1988; Huang and Yin, 1990; Chen et al., 1990; Liu et al., 1991; Shyu and Chen, 1991; Chen et al., 1992; Huang et al., 1992; Yu and Wen, 1992). These studies did not reach a consensus about correlating offshore units and geological elements onland Taiwan. However, these additional marine data combined with onland geology of Taiwan can provide critical information on the better understanding of the complex tectonics in Taiwan and its southern submarine region.

We emphasize the contraction rather than collision between trench-arc system and continent to account for the formation of the southern submarine morphotectonic features of Taiwan. This paper addresses the equally important role played by the trench, accretionary prism and forearc basin in addition to the volcanic islands of the arc during the process of convergence between the trench-arc system and the continent. The Manila Trench rather than the volcanic islands of the Luzon Arc was first compressed obliquely with the Asian continent beginning about 5 Ma ago. The significance of the contraction between the Manila Trench and associated accretionary prism and the Asian continent has been noticed but not fully applied to the formation of the morphotectonic features off southern Taiwan (Suppe, 1981, 1984; Barrier and Angelier, 1986 and Pelletier and Stephan, 1986). The purpose of this paper is to call attention to the trench-arc system as a whole being compressed against the Asian continent in the evolution of southern Taiwan submarine region.

This paper presents three schematic E-W trending transects from south to north across the Manila Trench-Luzon Arc system, offshore southern Taiwan and the island of Taiwan to illustrate tectonic processes varying from active subduction in the Manila Trench to active collision along the Coastal Range in eastern Taiwan.

MANILA TRENCH-LUZON ARC SYSTEM

As shown in the transect A-B (Fig.3), the Manila Trench, Manila accretionary prism, North Luzon Trough and the Luzon Volcanic Arc progressing eastward comprise a typical trench-arc system (Karig and Scharman, 1975; Schweller, 1987). The Manila Trench, about 3 to 4km deep in front of the Manila accretionary prism, is partially filled by turbidities derived from the Chinese margin (Hayes and Lewis, 1984). Subduction of the South China Sea oceanic plate underneath the Philippine Sea plate takes place along the Manila Trench. The Manila accretionary prism has been formed at the lower trench slope by the accretion of scraped trench turbidities since late Miocene time (Hayes and Lewis, 1984). The North Luzon Trough represents the forearc basin receiving several kilometers of turbidities derived from the Luzon Arc (Hayes and Lewis, 1984). The North Luzon Trough is also characterized by a negative free-air anomaly (Watts et al., 1978). The Luzon volcanic islands extend northwards into the Lutao-Lanhsu volcanic islands off southeastern Taiwan. Clearly, the deep marine region between 21°N and north of Luzon is represented by an active subduction zone.

RIDGES AND TROUGHS OFF SOUTHERN TAIWAN

This transect C-D shows five morphotectonic units off southern Taiwan which are the Hengchun Ridge (HR), Southern Longitudinal Trough (SLT), Huatung Ridge (HTR), Taitung Trough (TT) and the Lutao-Lanhsu Ridge (LLR) from west to east (Fig.3). Apparently, the Manila Trench loses its identity as a linear deep ocean depression near Taiwan resulting from the compression against the Asian continent. The Kaoping Slope and the Hengchun Ridge can be regarded as deformed accretionary prism of the former Manila accretionary prism. The Southern Longitudinal Trough, Huatung Ridge and Taitung Trough all together can be regarded as parts of the deformed North Luzon Trough, evidenced by both the similar negative free-air anomaly and bathymetric low (Chen et al., 1992).

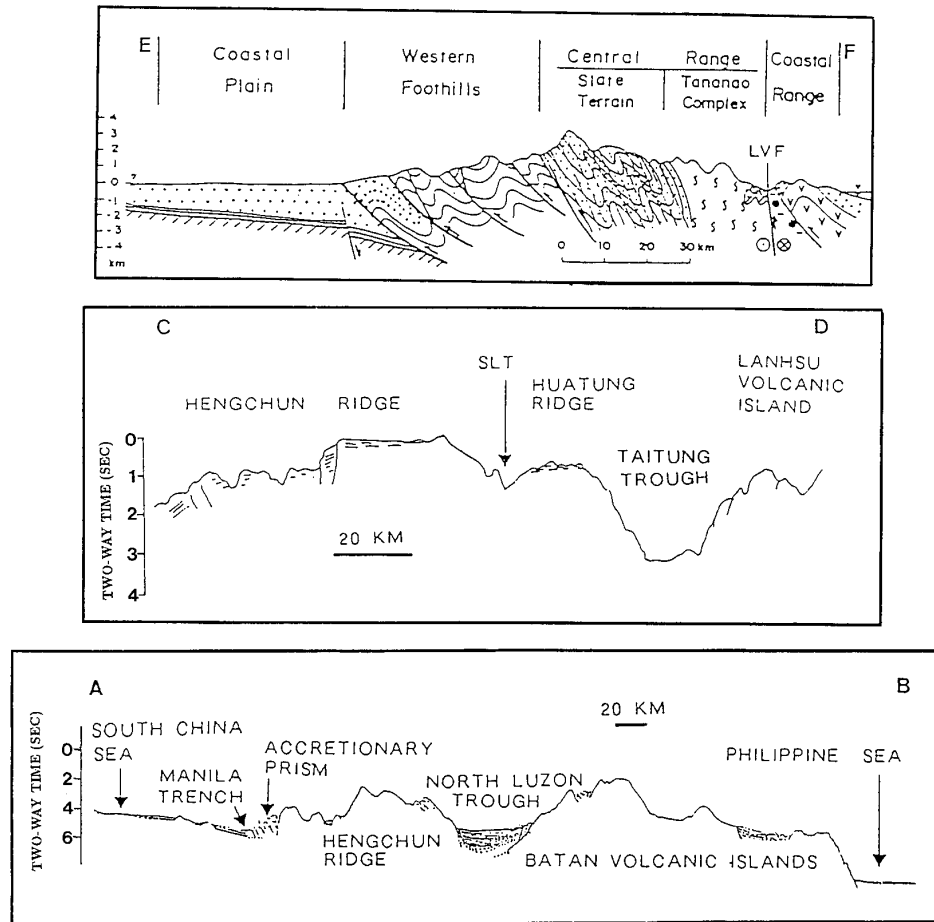


Fig. 3. Geological cross sections through the island of Taiwan and its southern offshore areas. Locations are shown in Fig.2. After Huang et al. (1992) (A-B, C-D) and Teng (1990) (E-F).

The Lutao-Lanhsu Ridge maintains as the undeformed northern extension of the Luzon Arc. The presence of ridges and troughs suggests that the region between southern Taiwan and north of 21°N has been undergone convergence by the process of collision rather than subduction between the Philippine Sea plate and the Eurasian plate. It should be noted that the subduction stopped along this deformed segment of the Manila Trench where it extends northward into Taiwan.

Thus, in the offshore region north of the Manila Trench-Luzon Arc convergent zone it appears that the trench, accretionary prism and the forearc basin were already deformed whereas the volcanic islands of Lutao and Lanhsu have not yet collided with the Asian continent.

THE ISLAND OF TAIWAN

The transect E-F shows five major tectonic units across the island of Taiwan which are the Coastal Plain, Western Foothill, Central Range, the Longitudinal Valley and the Coastal Range from the west to east (Fig.3). Previous studies (Suppe, 1981,1984; Barrier and Angelier, 1986; Pelletier and Stephan, 1986 and Teng, 1990) clearly pointed out that the Coastal Range is the product of the northern extension of the Luzon Arc collided with the Asian continent. The Coastal Range consists mainly of volcanic series of andesites and andesitic breccias and intercalated Lichi melange.

The Longitudinal Valley can be regarded as a sutuae zone at the expense of the close of the northern extension of the North Luzon Trough due to the collision process. The Central Range is the mountain range of almost 4,000m altitude west of the Longitudinal Valley. It can be considered an intensively deformed Manila accretionary prism plus the imbricated and overthrusted Eocene-Oligocene sequence of the Asian continental margin. The Western Foothill represents the imbricated Upper Oligocene to Lower Pleistocene sequences of the Asian continental margin and parts of the deformed Manila accretionary prism. The Coastal Plain is the lowland covered by Quaternary clastics west of the Western Foothill. Bowin et al. (1978) suggested that the surface trace of the completely deformed Manila Trench buried underneath (deformation front) extends along the boundary between the Western Foothill and the Coastal Plain.

TECTONIC EVOLUTION

The tectonic evolution of the island of Taiwan and its southern offshore morphotectonic features can be divided into three stages: (1) Subduction, (2) Trench-continent convergence and (3) Arc-continent collision. The transformation of the northern part of the former Manila Trench-Luzon Arc system into the island of Taiwan including its southern submarine region is summarized in Table 1.

Table 1. Sequential events of oblique convergence between Manila Trench-Luzon Arc System and the Asian continent.

0 Ma					
3 Ma	Collision (Volcanic islands vs. continent)	Tectonic Front (Completely filled by sediments and sealed up by compression)	Western Foothill and Central Range (Deformed & uplifted accretionary prism)	Longitudinal Valley (Deformed and Closed up North Luzon Trough)	Coastal Range (Deformed volcanic islands & Melange)
5 Ma	Compression (Trench, accretionary prism vs. continent)	Deformation Front (Partially filled by sediments)	Bathymetric Ridges and Troughs i.e., KPS, HR SLT, HTR, TR (Deformed accretionary prism and forearc basin)		Lutao-Lanhsu Ridge (Undeformed volcanic islands)
	Subduction (Pre-Collision)	Manila Trench (Trench)	Accretionary Prism	North Luzon Trough (Forearc basin)	Luzon Arc (Volcanic Islands)

Before being compressed against the Asian continental margin, the Manila Trench in the vicinity of today's Taiwan maintained as a deep depression associated with strong seismicity. Beginning in the Late Miocene-Early Pliocene about 5 Ma ago, the Manila Trench-Luzon arc system was compressed against the Asian continent due to the northwestward movement of the Philippine Sea plate relative to the Eurasian plate. Following the convergence, the Manila Trench was changed into the tectonic front (Bowin et al., 1978; Stephan et al., 1986) where the trench was partly filled by sediments and deformed. The subduction along the trench was replaced by compression.

The associated Manila accretionary prism and North Luzon Trough were deformed into N-S trending ridges and troughs. However, the volcanic islands of Lutao and Lanhsu underwent little deformation. During the last 3 Ma, the volcanic islands north of the Lutao and Lanhsu have collided with the accreted Asian continental margin to form the Coastal Range and Lichi Melange in eastern Taiwan (Page and Suppe, 1981; Chi et al., 1981). The linear Longitudinal Valley west of the Coastal Range became the convergent suture zone, serving as the plate boundary between the Eurasian and the Philippine Sea plates at the expense of the close of the northern extension of the North Luzon Trough.

The deformed accretionary prism and modified Asian margin sediments were converted into the Western Foothill and Central Range with numerous thrusts toward the west. The Central Range has been pushed onto the Eurasian plate and elevated to a maximal height of almost 4,000m resulting from the accreted continental margin-arc collision. The western limit of the Western Foothill characterized by westward imbricate thrusts is the surface expression of the deformation front of the former Manila Trench which was completely filled by sediments and sealed up.

CONCLUSIONS

The developments of tectonic features onland Taiwan and the submarine bathymetric features between Taiwan and Luzon can be interpreted in terms of convergence between the Manila Trench-Luzon Arc system and Asian continental margin. The convergence began probably in Miocene-Pliocene time (about 5 Ma), when the Manila Trench was partially filled by continent-derived sediments and partially sealed up, and continued compression changed the Manila accretionary prism and the North Luzon Trough into ridges and troughs. Intense collision probably has taken place from early Late Pliocene to the present (about 3 Ma to 0 Ma), when the volcanic islands of the Luzon Arc collided against the deformed accretionary prism accreted to the Asian continent and caused rapid uplift of the Central Range

accompanied by the formation of the Coastal Range in eastern Taiwan. The Manila Trench west of Taiwan orogen was totally sealed up and no longer can be considered to be a trench. The northern extension of the North Luzon Trough was sandwiched between Central Range and the Coastal Range and was deformed into the Longitudinal Valley, serving as the boundary between the Eurasian and Philippine Sea plates.

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海溝—島弧系統與大陸間的斜向聚合— 臺灣南部海域地形成目的含意

俞何興、宋國士

摘 要

馬尼拉海溝—呂宋島弧系統的北端與歐亞大陸邊緣受連續碰撞作用而變形，碰撞在 5 百萬年前開始，由北而南推進，速率約為 9 厘米/年。與此東西向擠壓力有關的褶皺，逆斷層及山前沉積使得亞洲大陸邊緣形成山脊（臺灣），其南部向海裡延伸。臺灣南部海域其海床呈現著數個明顯的南北方向相間的海脊及海槽。

約在 5 百萬年前，馬尼拉海溝的北端，逐步地被沉積物充填，由北而南，海溝被填滿，抬昇而擠壓成今日的變形前緣，深埋在臺灣西部。馬尼拉增積體及歐亞大陸邊緣同時變形成為中央山脈及其南延海下的恒春海脊。北呂宋海槽的北端受擠壓形成縱谷，可能為菲律賓海及歐亞大陸板塊的界限。陸上縱谷向海南延為南縱海槽，花東海脊及臺東海槽，此三個海槽及海脊在北緯 21 度合併成單一的北呂宋海槽。過去的 3 百萬年內，綠島—蘭嶼海脊北面的火山島嶼與變形的歐亞大陸邊緣碰撞，產生了臺灣東部的海岸山脈及利吉混雜岩。