

Characteristics of the wedge-top depozone of the southern Taiwan foreland basin system

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ABSTRACT

The wedge-top depozone in the southern Taiwan foreland basin system is confined by the topographic front of the Chaochou Fault to the east and by a submarine deformation front to the west. The Pingtung Plain, Kaoping Shelf and Kaoping Slope constitute the main body of the wedge-top depozone. In a subaerial setting, the alluvial and fluvial sediments accumulate on top of the frontal parts of the Taiwan orogenic wedge to form the Pingtung Plain proximal to high topographic relief. In a submarine setting, fine-grained sediments accumulate on the Kaoping Shelf and dominant mass-wasting sediment forms the Kaoping Slope. Wedge-top sediments are deformed into a series of west-vergent imbricated thrusts and folds and associated piggyback basins. A major piggyback basin occurs in the Pingtung Plain. Four smaller piggyback basins appear in the shelf-slope region. Many small-sized piggyback basins developed over ramp folds in the lower slope region. Pliocene–Quaternary deep marine to fluvial sediments about 5000 m thick have been deposited on top of the frontal orogenic wedge in southern Taiwan. Sedimentary facies shows lateral variations from extremely coarse fluvial conglomerates proximal to the topographic front (Chaochou Fault) to fine-grained deep marine mud close to the deformation front near the base of the slope. The stratigraphic column indicates that offshore deep-water mud is gradationally overlain by shallow marine sands and then fluvial deposits. The transverse cross-section of the wedge-top depozone in the southern Taiwan is a doubly tapered prism. The northern boundary of the wedge-top depozone in southern Taiwan is placed along the southern limit of the Western Foothills where the frontal orogenic wedge progressively changes southward to a wedge-top depozone (Pingtung Plain), reflecting ongoing southward oblique collision between the Luzon Arc and the Chinese margin. The wedge-top depozone is bounded to the south by the continent–ocean crust boundary. The deep slope west of the Hengchun Ridge can be viewed as an infant wedge-top depozone, showing initial mountain building and the beginning of wedge-top depozone.

INTRODUCTION

Basin setting and previous studies

Taiwan is located at the junction between the Ryukyu and Luzon Arcs in the northwest Pacific (Fig. 1). The mountain belt of Taiwan was formed by collision between the Luzon Arc and the Chinese margin beginning in Late Miocene–Early Pliocene (Suppe, 1981, 1984; Ho, 1988). The resultant development of the Taiwan Orogen flexed down the foreland region on the eastern edge of Chinese margin to form an east dipping wedge-shaped foreland basin (Fig. 1). More than 5000-m thick Pliocene–Quaternary sediments derived from the Taiwan Orogen have been deposited in the adjacent foreland basin (Covey, 1984, 1986).

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The western Taiwan foreland basin can be classified as a peripheral foreland basin in terms of the classification of Dickinson (1974) or a collisional foredeep (Bradley & Kidd, 1991; Johnson & Beaumont, 1995; Galewsky & Silver, 1997; Sinclair, 1997; Chen *et al.*, 2001; Chou & Yu, 2002). On the basis of lithofacies and depositional environments of the western Taiwan foreland basin, Covey (1984) distinguished a mature foredeep in the north from a youthful one in the south. The former consists mainly of deep marine facies or flysch facies but the latter comprises mainly fluvial–shallow marine facies or molasse facies (Fig. 2). Covey (1986) suggested that the northern mature foredeep in Taiwan has reached a steady state in the evolution of a foreland basin with a balance between sedimentation and subsidence. These two papers about the foreland basin west of Taiwan (Covey, 1984, 1986) have been commonly cited and compared with other foreland basins. For example, Karig *et al.*, (1987) and Galewsky & Silver (1997) compared

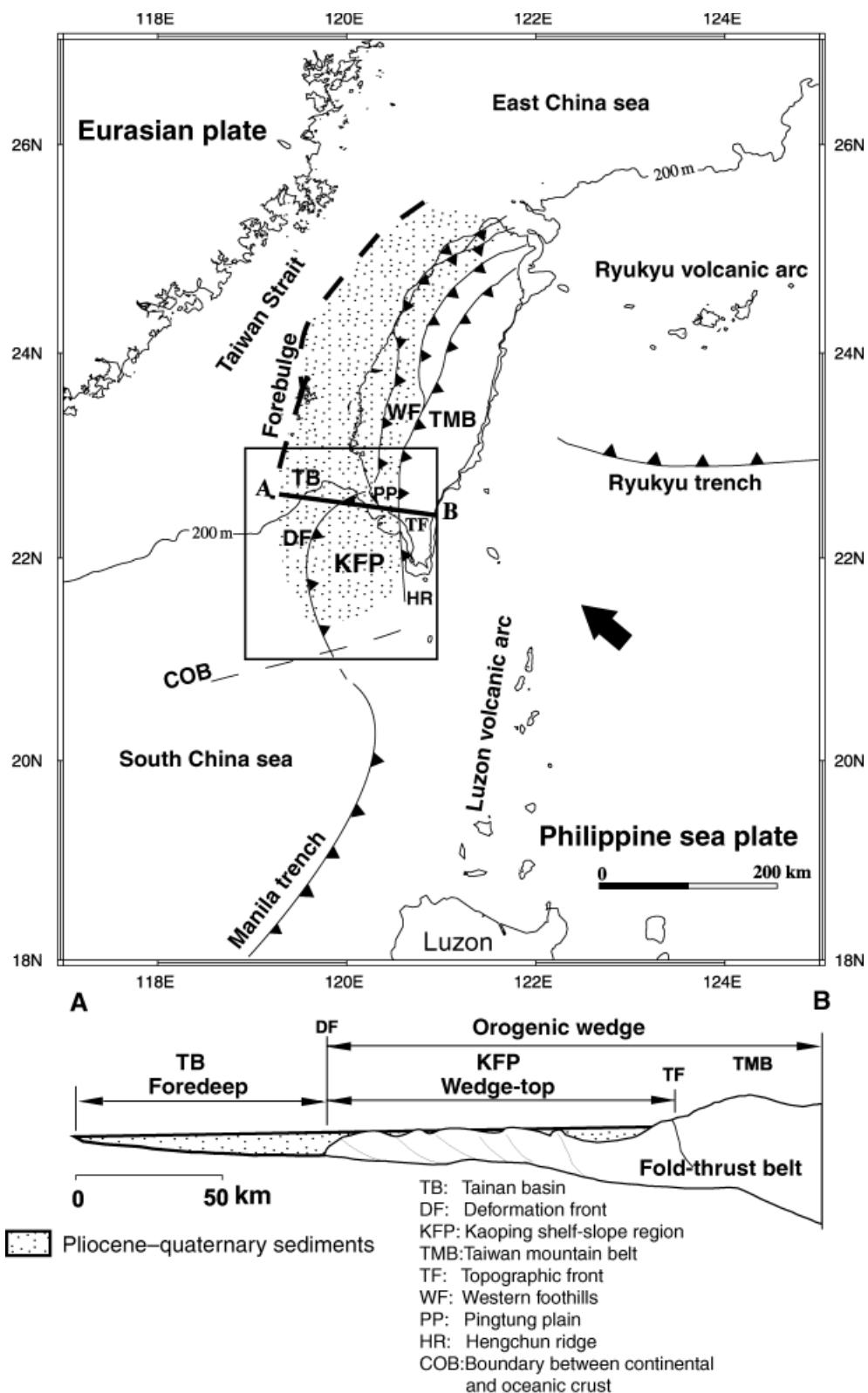


Fig. 1. Geological setting of Taiwan. The mountain belt of Taiwan, resulted from collision between the Luzon Arc and the Chinese margin, is accompanied by a foreland basin on its western side. Pliocene–Quaternary orogenic sediments have filled the basin (upper panel). A nearly east–west cross-section in the southern Taiwan foreland basin shows the prevailing wedge-top depozone proximal to the Taiwan Orogen (lower panel).

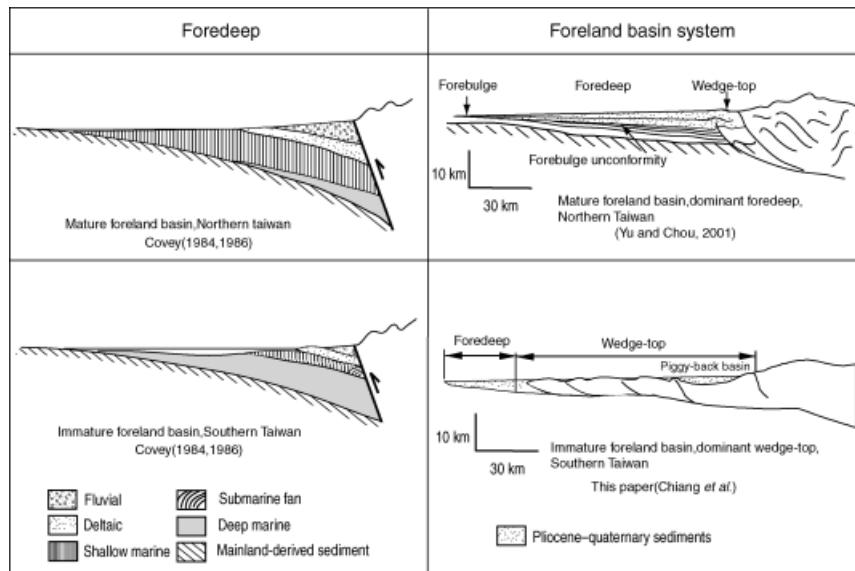


Fig. 2. The western Taiwan foreland basin can be divided into a mature basin in the northern Taiwan and an immature one in the southern Taiwan. In terms of lithofacies, the mature basin consists mainly of shallow marine and fluvial sediment and the immature one is dominated by deep marine fine-grained sediment (left column). Using the foreland basin system nomenclature of DeCelles & Giles (1996), the mature basin consists of distinguished features from east to west: a wedge-top depozone, a dominant foredeep depozone and a forebulge. The immature one is characterized by a dominant wedge-top depozone and an incipient foredeep (right column).

the Timor Trough and the Finisterre Foredeep with the Taiwan foreland basin in detail, respectively. Covey has done important works to build the framework of the western Taiwan foreland basin. However, his studies are confined to land areas of Taiwan.

Fifteen years later, using industrial marine seismic profiles and exploration well data, Yu & Chou (2001) and Chou & Yu (2002) continued and expanded the mature basin in central-north Taiwan to offshore areas and to reveal a larger foreland basin system (Figs 1 and 2). Using the foreland basin system nomenclature of DeCelles & Giles (1996), they determined a foredeep depozone, a sedimentary wedge thickening eastward in the Taiwan Strait distal to the Taiwan Orogen. A prominent flexural forebulge west of the foredeep depozone and a basal flexural unconformity underlying the foredeep are also recognized (Fig. 2). Normal faults related to flexural extension are found in the youngest strata of the foredeep zone (Chou & Yu, 2002). The foreland basin system west of Taiwan occupies the Western Foothills, coastal plain and the eastern Taiwan Strait (Fig. 1).

Significance and purpose

What makes Taiwan interesting is the oblique collision, which allows the foreland basin to be seen at different stages in its evolution at the present day. Northern Taiwan is in a steady state of arc-continent collision (Covey, 1986; Lallemand & Tsien, 1997). West of the Taiwan Orogen, the foreland basin has developed to a mature system comprising a wedge-top depozone, a foredeep depozone and a flexural forebulge from the Western Foothills westward to the middle of the Taiwan Strait. Southern Taiwan and its off-

shore areas are currently undergoing incipient collision (Lallemand & Tsien, 1997). The Pingtung Basin immediately south of the Western Foothills became a large Plio-Pleistocene piggyback basin, receiving sediments derived from the Taiwan Orogen (Wu, 1993). The shelf-slope region west of the Pingtung Basin is considered to be a marine foreland basin distal to the Taiwan Orogen. The sediments are deformed into folds and thrust faults and form part of the wedge-top depozone (Chiang, 1998; Chiang & Yu, 1998). In other words, the mature molasse basin in northern Taiwan has expanded into a foreland basin system including characteristic features of a wedge-top depozone, namely the foredeep depozone, the forebulge and the flexural unconformity. The immature flysch basin in the southern Taiwan consists of a prevalent wedge-top depozone and an incipient foredeep depozone (Figs 1 and 2).

The purpose of this paper is to extend the scope of the immature foreland basin defined by Covey (1984) to the offshore areas in SW Taiwan by combining geological data from on land and offshore areas in southern Taiwan. This paper adds more structural, stratigraphic and morphological information than those presented by Covey (1984, 1986). We propose a wedge-top depozone model to replace the immature basin of Covey (1984, 1986) and define the topographic front and deformation front to refine the extent of the immature basin to a larger basin. The preliminary results of this study indicate that a relatively large piggyback basin is confined by two thrust faults in the Pingtung Basin. Four smaller piggyback basins occur in the shelf and slope regions. The strata of the lower slope are deformed into west-verging folds and thrust faults. Limited sediment has been deposited on these structures. The characteristics of the wedge-top depozone in southern

Taiwan are somewhat different from that of the foreland basin system (DeCelles & Giles, 1996). The wedge-top depozone in southern Taiwan is at an early stage of development. Hence, the wedge-top depozone in southern Taiwan could be considered as one variant of the wedge-top depozone in general. This paper therefore presents a revised view of one component of the foreland basin system. This study of the wedge-top depozone provides a modern analogue for other foreland basin systems (modern or ancient) in a similar geological setting.

Study area and data

Taiwan is one of few places where ongoing processes of mountain building and foreland basin formation can be examined simultaneously. The study area in particular is within the initial arc-continent collision zone in the Taiwan region (Lallemand & Tsien, 1997), demonstrating the formation of the paired wedge-top depozone and proto-orogen system. The study area includes the Pingtung Basin

in southwestern Taiwan and the adjacent offshore shelf-slope region (Fig. 3) where mainly Quaternary sediments derived from the Taiwan Orogen accumulate on top of the underlying orogenic wedge. The study area is bordered to east by the Chaochou Fault, a thrust fault separating the Central Range from the Pingtung Basin, and to the west by the submarine deformation front of the Taiwan Orogen where the westward propagating thrust faults terminate (Fig. 3).

This paper is mainly based on more than 2000 km of marine four-channel seismic reflection profiles distributed mainly in the shelf-upper slope region (Fig. 3). Seismic sections were acquired onboard R/V Ocean Researcher I and processed by the Institute of Oceanography, National Taiwan University from 1992 to 2002. An air gun array was deployed as the seismic source. Seismic reflection data were processed using the SIOSEIS and PROMAX software at the institute. Related data in the areas of the onshore Pingtung Basin and lower slope are derived from the published literature. Two exploration wells drilled by Chinese Petroleum in the Pingtung Basin pro-

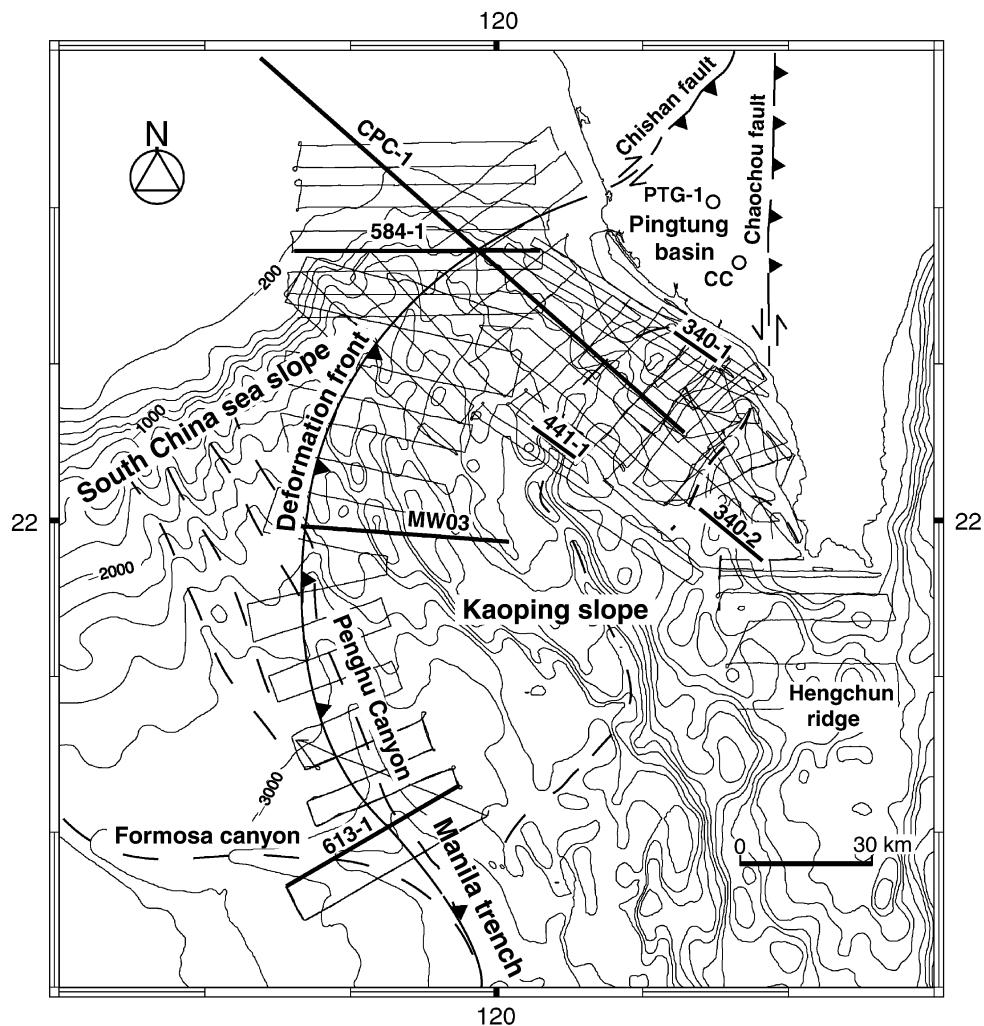


Fig. 3. The study area includes the Pingtung Basin in southwestern Taiwan and adjacent offshore shelf-slope region. The Chaochou Fault (topographic front) is located to the east and the submarine deformation front along the base of the Kaoping Slope is the western boundary. Open circles indicate locations of exploration wells. More than 2000 km of four-channel seismic reflection profiles were collected in the shelf and upper slope. Heavy segments of seismic line show representative structural and stratigraphic features.

vide age information of the foreland basin sediments and allow age calibration of seismic profiles.

Wedge-top depozone

By definition, the wedge-top depozone is a mass of sediments that accumulate on top of the frontal part of an orogenic wedge (DeCelles & Giles, 1996). The frontal edge of a wedge-top depozone is the deformation front in transition to the foredeep. The topographic front flanking the mountain belt is the boundary of the wedge-top depozone in the hinterland.

Deformation front

In southern Taiwan, the submarine deformation front of the Taiwan orogenic wedge is located along the base of the Kaoping Slope and around the Penghu Submarine Canyon (Fig. 3). Seismic profile CPC-1 across the submarine deformation front shows that the submerged Taiwan orogenic wedge with west-verging thrusts is advancing northwestward and overriding the Chinese passive margin (Fig. 4). West of the deformation front lies the Tainan Basin which is a Pliocene–Quaternary foredeep characterized by flexural normal faults (Chou, 1999). Seismic lines 584-1 (Fig. 5a) and 613-1 (Fig. 5c) show that sediments derived from the Taiwan Orogen progressively are transported westward and bury the outermost parts of the Chinese margin. West of the Kaoping Slope is the South China Sea Slope underlain by the passive Chinese margin composed mainly of Tertiary strata. The Penghu Submarine Canyon separates the western front of the Kaoping Slope of the orogenic wedge of Taiwan from the base of the South China Sea Slope of the cratonic margin. Seismic line 584-1 shows that the sediments at base of the Kaoping Slope are characterized by chaotic seismic facies and ruptured by intense erosion. Seismic line 613-1 indicates that westward thrust faults occur at the base of the Kaoping Slope. The deformation front is located along the Penghu Canyon. The interpreted seismic line MW03 (Fig. 5b) shows a series

of west-verging thrust faults. The deformation front is located at the bottom of the Penghu Canyon. The regional distribution of the deformation front follows the structural trend of the frontal deformation of a series of west-verging thrusts in the offshore region of southwestern Taiwan (Reed *et al.*, 1992; Lee *et al.*, 1995; Liu *et al.*, 1997; Yu & Huang, 1998). The submarine deformation front trends NNW–SSE in the lower slope but bends to the northeast at about 22°N, follows an approximately northeast trend and probably can be extended onshore into the Chishan Fault (Fig. 3).

Topographic front

Towards the Taiwan Orogen, the eastern limit of the wedge-top depozone is about 120 km (the maximum cross-sectional width) to the east of the submarine frontal thrust and coincides with the Chaochou Fault (Fig. 3). The Chaochou Fault is an east-dipping high-angle thrust fault and trends north to south along the western flank of the southern Central Range (Yen & Tien, 1986; Ho, 1988). The Chaochou Fault may extend offshore to the south inferred from seismic profiles. Significant topographic relief of about 1000 m of terrace-cliffs has been produced along the trace of the Chaochou Fault (Shih *et al.*, 1984). Streams draining uplifted cliffs along the Chaochou Fault transport sediments towards the west. Many Holocene alluvial fans have developed at the foot of the cliffs (Chang, 1997). The Central Range, east of the Chaochou Fault, is undergoing erosion and is an important sediment source for the wedge-top basin west of the fault.

Main body of wedge-top basin

The wedge-top depozone in the southern Taiwan foreland basin system is confined by the topographic front of the Chaochou Fault to the east and by the submarine deformation front to the west. The Pingtung Plain and the Kaoping Shelf–Slope constitute the main body of the wedge-top depozone.

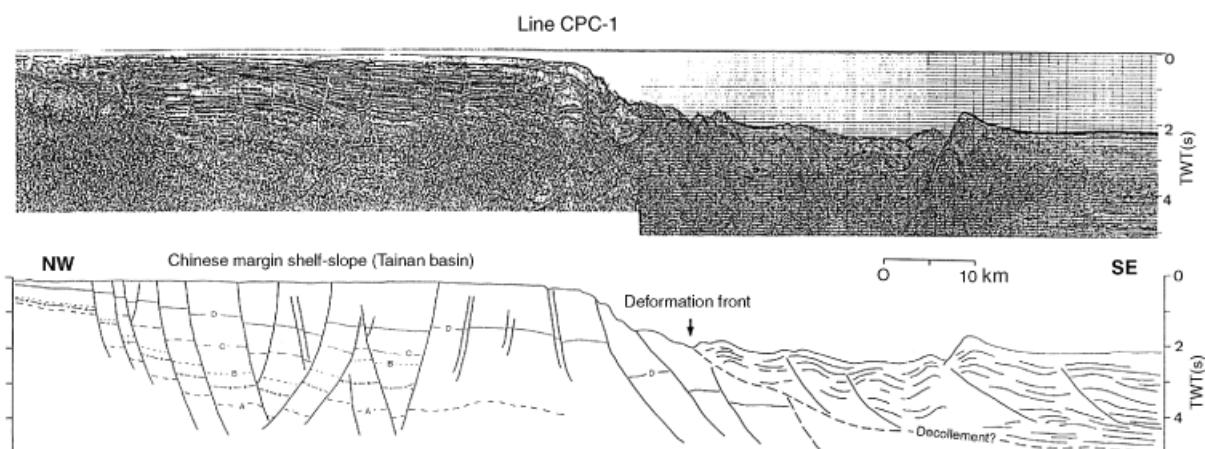


Fig. 4. Seismic profile CPC-1 across the submarine deformation front shows that the submerged Taiwan orogenic wedge with west-verging thrusts is advancing northwestward and overriding the Chinese passive margin. West of the deformation front lies the Tainan Basin, which is a Pliocene–Quaternary foredeep characterized by flexural normal faults. Seismic reflectors are labeled: (A) base of Oligocene; (B) top of middle Miocene; (C) top of upper Miocene; and (D) top Pliocene (after Chou, 1999).

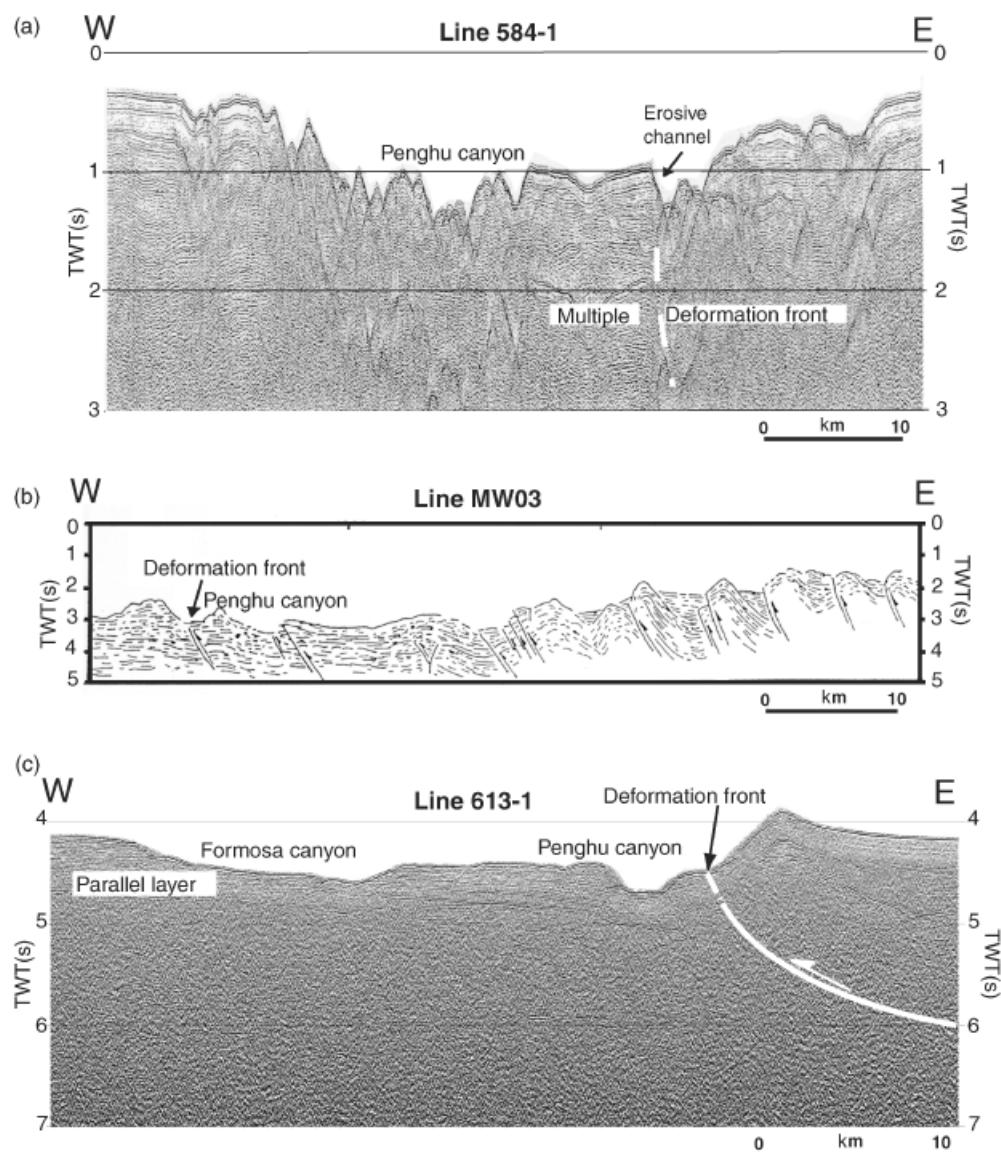


Fig. 5. Seismic lines 584-1 and 613-1 show that orogenic sediments derived from Taiwan progressively onlap westward and bury the outermost parts of the Chinese margin. Seismic line 584-1 shows that the sediments at base of the Kaoping Slope are characterized by chaotic seismic facies and ruptured by intense erosion. Seismic line 613-1 indicates that westward thrust faults occur at the base of the Kaoping Slope. The interpreted seismic line NW03 shows a series of west-verging thrust faults (after Fuh, 1997). The locations of deformation front are along the Penghu Canyon. The alignment of the deformation front shows the structural trend of the frontal deformation of a series of west-verging thrusts in the offshore region of southwestern Taiwan.

The Pingtung Plain lies west of the Chaochou Fault where more than 5000 m thick Plio-Pleistocene sediments derived from southern Central Range are deposited on top of the frontal part of the Taiwan Orogen (Hsieh, 1970). West of the Pingtung Plain is the Kaoping Shelf, a very narrow (10 km wide) and very shallow (40 m deep) island shelf (Yu & Chiang, 1997). Seaward of the Kaoping Shelf, the Kaoping Slope is a broad and deep sloping region and extends to a depth of about 3000 m at the northern limit of the abyssal plain of the South China Sea. The slope is characterized by a very irregular surface (Yu & Song, 2000).

Alluvial sediments accumulate on top of the Taiwan orogenic wedge to form the Pingtung Plain proximal to high topographic relief. In a submarine setting, fine-grained sands accumulate on the shelf and mass-wasting

sediments dominate the Kaoping Slope (Boggs *et al.*, 1979; Chen, 1997; Liu *et al.*, 1997).

STRATIGRAPHY

The wedge-top sediments west of the Chaochou Fault and underlying the Pingtung Plain consist mainly of Pliocene–Quaternary marine to fluvial sediments of more than 5000 m thick (Figs 6 and 7). The basement, overlain unconformably by the wedge-top sediments, is the Wushan Formation, characterized by Upper Miocene shallow marine sediments derived from Mainland China (Fig. 7). Overlying the Wushan Formation, the Kaitzuliao Shale consists mainly of offshore fine-grained mudstone interbedded with some thin layers of sandstone and is Early

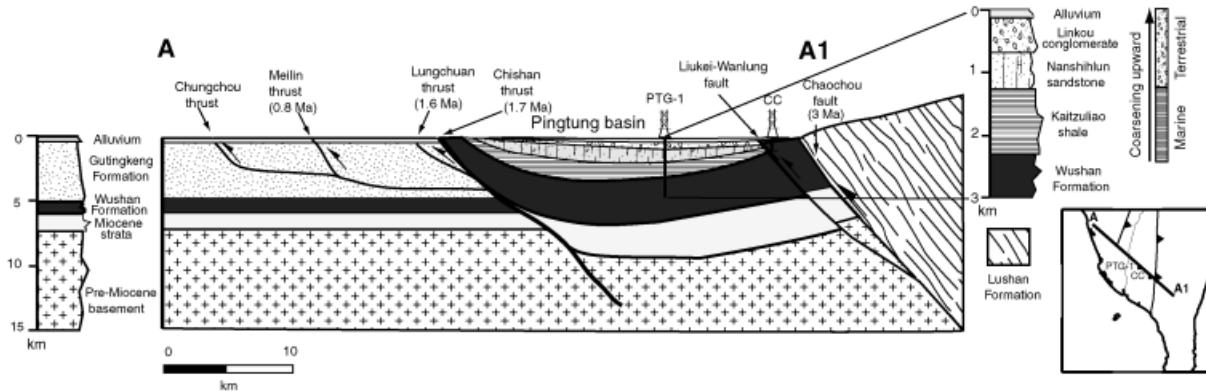


Fig. 6. A NW–SE section in southern Taiwan shows the Pingtung Basin (piggyback basin) is confined by two thrust faults. Basin fills show a coarsening upward sequence and sedimentary facies from deep marine to alluvial, representing flysch–molasse facies change during a late foreland basin filling stage. The westward propagation of folds and thrusts is the dominant structural style evidenced by decreasing age of westward fault movement (modified from Hsieh, 1970; Wu, 1993; Lee *et al.*, 1999; Mouthereau *et al.*, 2001).

Pliocene in age. The thickness of this formation varies from 200 to 1000 m. The Nanshihun Sandstone (Early–Late Pliocene), consists mainly of storm-dominated sandstone and deltaic sandstone, and overlies the Kaitzuliao Shale. The Nanshihun Sandstone is overlain by the fluvial facies of the Linkou Conglomerate (Pleistocene) that in turn is covered by Holocene alluvium. The vertical sequence of strata in the Pingtung Basin indicates a shallowing-up transition from deep-water offshore to fluvial, representing flysch–molasse facies change during a late foreland basin filling stage. The wedge-top strata thin and pinch out towards the flanking thrust faults. Figure 6 shows that east of Chishan Fault near the basin margin, Pliocene–Pleistocene strata are tilted upward and pinch out, resulting in small-scale local unconformities indicating syndepositional tectonism (Bryhni & Skjerlie, 1975).

Along the Chaochou Fault, slates and metamorphosed sandstone of the Lushan Formation (Middle Miocene) are thrusted westward over the Wushan Formation (Fig. 6). Coalesced alluvial fans of Holocene age form a north-south bayada along the topographic front of the Chaochou thrust east of Pingtung Basin (Chang, 1997). West of the Chaochou Fault sediments become progressively finer away from the Taiwan Orogen and are dominated by braided stream deposits (Covey, 1984; Wu, 1993).

The Pingtung Plain, west of the Chishan Fault, comprises mainly thick Plio-Pleistocene sediments (Figs 6 and 7). The Wushan Formation (Upper Miocene) is unconformably overlain by the thick Gutingkeng Formation (Pliocene–Pleistocene), which can be divided into three members. The Lower Gutingkeng Formation consists mainly of marine mud with thin layers of fine-grained sandstone, deposited in bathyal depth about 1000 m during the Early Pliocene (Teng, 1987; Wu, 1993). Its thickness varies from 500 to 1000 m. The Middle Gutingkeng Formation consists mainly of Late Pliocene offshore fine-grained sandstone with thick layers of mudstone, and ranges in thickness from 1600 to 3000 m. The Upper Gutingkeng Formation comprises Early Pleistocene thick mudstone interbedded with coarse-grained sandstone up

to 1400 m thick. Conglomerates occasionally are found in the top of the Lower Gutingkeng Formation. The Middle and Upper Gutingkeng Formation is dominated by mudstone interbedded with thin layers of fine-grained sandstone, showing a coarsening-upward sequence. Clay mineralogy of the Gutingkeng mudstones shows a reverse metamorphic grade, suggesting the sediment sourced from the Central Range to the east (Hsueh & Johns, 1985). The Liushuang Formation (Late Pleistocene) consists mainly of fluvial sandstones with minor conglomerates and mudstones. The contact between the Liushuang and Gutingkeng Formations is generally conformable, but local disconformities are present (Teng, 1987; Wu, 1993).

Farther southwestward and seaward the Pingtung Plain extends into the shelf and slope regions where thick sediments equivalent to Gutingkeng Formation, dominated by offshore muddy sediments are deposited. Seismic profile 340-1 shows that sediments reach a thickness at least of 2500 m (Fig. 8a). However, Sun & Liu (1993) suggested that these Pliocene–Quaternary sediments may reach a maximum thickness of about 10 000 m based on seismic profiles without well control. These sediments deposited in the shelf and upper slope are considered to be paleo-channel deposits confined by NNE–SSW trending mud diapiric structures. We interpreted these depocentres of Late Pliocene–Pleistocene sediments confined by anticlinal structures as piggyback basins.

In the lower slope, sediments derived from the Taiwan Orogen gradually thin and eventually pinch out along the deformation front (Fig. 4). The sedimentary sequences in the lower slope are only mildly deformed into low-relief ramp anticlines. Syntectonic sediments less than 1.5 km thick are deposited behind many of these ramp anticlines. Sediments covering the lower slope are mainly silty clays derived from the Taiwan Orogen (Chen, 1983; Chuang & Yu, 2002).

Clearly, sedimentary facies show lateral variations from extreme coarseness of fluvial conglomerates proximal to the topographic front to fine-grained deep marine mud close to the deformation front. The Pingtung Plain is in a subaerial setting with relatively high topographic relief, al-

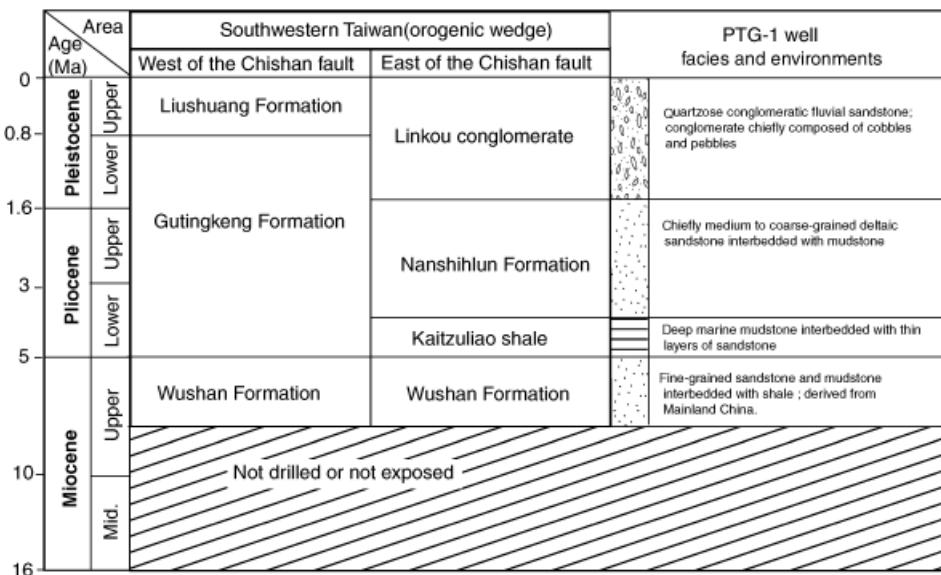


Fig. 7. Stratigraphic columns of the Pingtung Basin and the Pingtung Plain west of the Chishan Fault, respectively, in the southwestern Taiwan. Pliocene–Pleistocene foreland basin sediments show characteristic coarsening upward and shallowing upward sequences. Lithology and time correlations between formations are discussed in the text (modified from Teng, 1987; Ho, 1988; Wu, 1993; Mouthereau *et al.*, 2001).

lowing coarse-grained sediments to prograde into the distal submarine slope. At present, the Kaoping Shelf–Slope region is a site for the deposition of marine sediments, representing the underfilled stage of the foreland basin. In contrast, the Pingtung Basin, filled with fluvial sediments, has reached the overfilled stage in terms of foreland basin development (Sinclair, 1997).

Combining the distribution of sediments in the Pingtung Plain and its offshore Kaoping Slope, the thickest sediments are found in the coastal plain to shelf region and sediments progressively thin towards the topographic front and the deformation front. The transverse cross-section of the sedimentary basin in southern Taiwan and its offshore extension can be viewed a typical cross-section of a wedge-top depozone having the geometric form of a doubly tapered prism (DeCelles & Giles, 1996).

STRUCTURE

Sediments on top of the frontal orogenic wedge onshore in southern Taiwan and offshore are deformed into a series of west-vergent imbricated thrusts and folds (Hsieh, 1970; Reed *et al.*, 1992; Wu, 1993; Liu *et al.*, 1997; Lee *et al.*, 1999). In the proximal wedge-top depozone, westward propagating thrusts are the main structures in the Pingtung Basin (Fig. 6). Structural lows between thrust faults and folds are depocentres for wedge-top sediments, forming piggyback basins. For example, Wu (1993) suggested the Pingtung Basin is a piggyback basin because the sediments are derived from the uplifted region of the Taiwan Orogen and are confined by the Chaochou and Chishan Faults (Fig. 6). Several smaller piggyback basins have been determined west of the Chishan Fault in the coastal plain of the Pingtung Basin (Lee *et al.*, 1999).

In contrast, contractional anticlines, forming NNE–SSW trending ridges, are the most prominent structures in the Kaoping Shelf and upper Kaoping Slope regions (Liu *et al.*, 1997; Chiang, 1998). These folds and thrusts extend continuously to the coastal plain of the Pingtung Basin (Fig. 8a). Wedge-top sediments are generally deformed at or near the syntectonic erosional/depositional surface, resulting in progressive deformation and local unconformity (DeCelles & Giles, 1996). Seismic profile 340–2 (Fig. 8b) shows features of progressive deformation in which parallel-stratified packages of sediments are uplifted and disrupted. Syntectonic features of propagating piggyback thrusts and local unconformity are observed on line 441–1 (Fig. 8c). We propose tentatively that four offshore piggyback basins occur in the shelf and upper slope regions (Fig. 9). Basins A and B are the offshore extension of Pingtung Basin and are separated by thrust faults (Fig. 8a). Basin C is wedge-shaped and confined by a shale ridge to the west and by the offshore extension of the Chaochou Fault to the east (Fig. 8b). Basin D is characterized by syn-deformational features of piggyback thrust propagation (Fig. 8c).

In the distal wedge-top depozone, imbricated thrusts and ramp folds are the main structures distributed in the lower Kaoping Slope east of the deformation front (Fig. 4). Ramps progressively steepen eastward and become tightly spaced (Fig. 5b). Small-sized slope basins developed syntectonically with ramp folds in the lower slope region. Sediments are deposited in the ramp synclines and have a thickness of less than 1500 m to form small-sized slope basins (Liu *et al.*, 1997). We interpret these slope basins between structural highs to be piggyback basins. The overall structural style of the wedge-top depozone from Pingtung Basin to the lower Kaoping Slope is character-

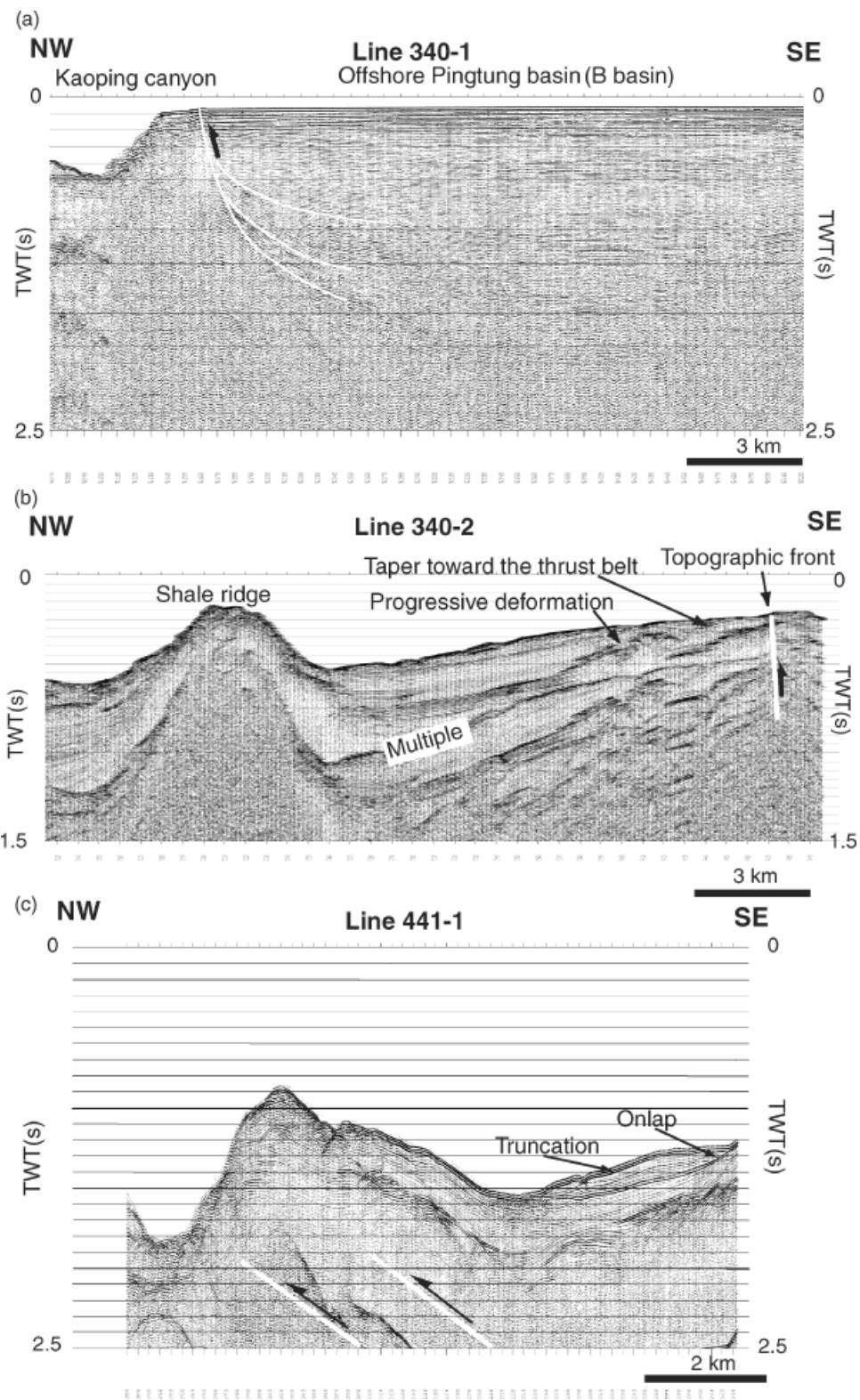


Fig. 8. Thrust faults and anticlines are characteristic of the shelf and upper slope region. Line 340-1 shows that offshore extension of the Pingtung Basin to the shelf is confined by thrust faults at its northwest side. Line 340-2 shows that features of progressive deformation of which some parallel layers of sediments are uplifted and disrupted. Line 441-1 indicates probable syntectonic piggyback thrust propagation and local tilting of strata and truncation. Locations of seismic lines are provided in Fig. 3.

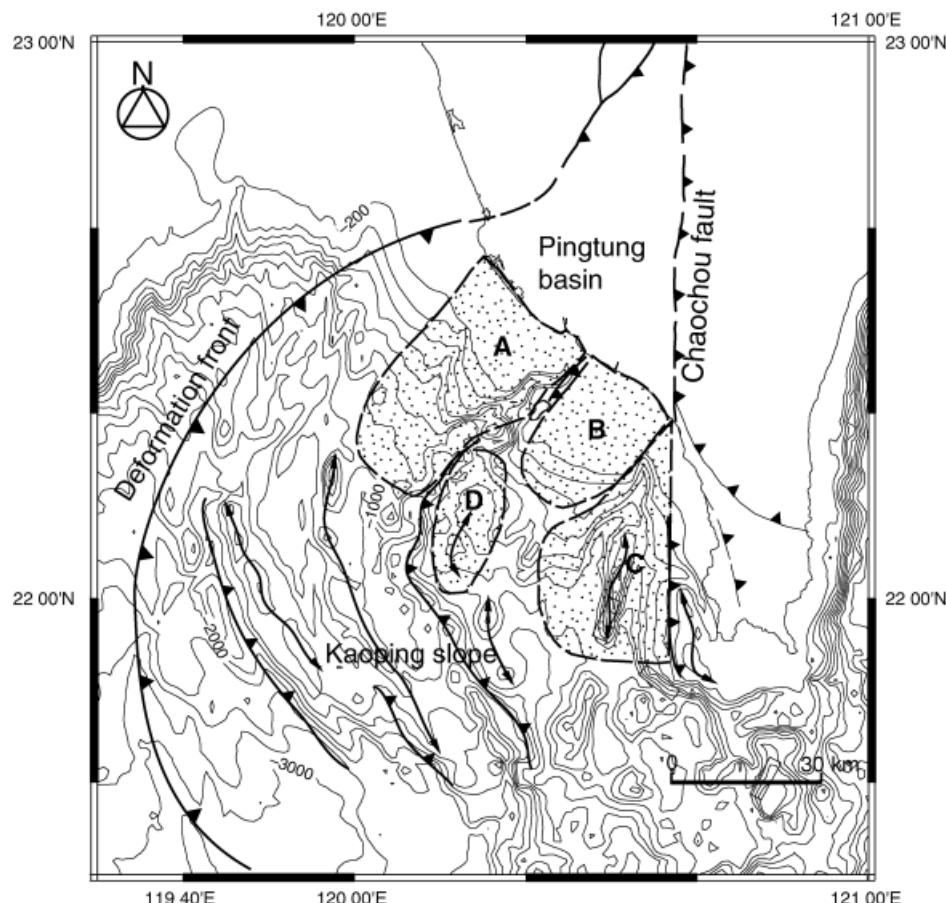


Fig. 9. Four piggyback basins denoted A, B, C and D, respectively, are tentatively proposed in the shelf and upper slope area. These basins are confined by syndepositional thrust faults. Landward lies a relatively large piggyback basin (Pingtung Basin). The lower slope area is dominated by west-verging thrusts and folds. Little sediment is deposited in the structural lows between these structural highs. Folds are indicated by lineaments with arrows on both ends. Thrust faults are marked by solid triangles.

ized by a series of west-verging thrust faults and folds (Figs 4 and 6).

The westward propagation of each thrust/fold of the wedge-top depozone in southern Taiwan can be dated by the age of associated syntectonic sediments (Wu, 1993; Deoramond *et al.*, 1995; Lee *et al.*, 1999; Moutherneau *et al.*, 2001). The Chaochou Fault has formed since about 3 Ma BP and is associated with the syntectonic Linkou conglomerates and Gutingkeng mudstone in the flanking Pingtung Basin (Fig. 6). West of the Chaochou Fault, another east-dipping thrust fault, the Liuwei-Wanlung Fault, displaces the Wushan Formation over the wedge-top sediments of Kaitzuliao shale, Nanshihlun sandstone and Linkou conglomerate. At the western edge of Pingtung Plain the Chishan Fault began to move westward about 1.7 Ma ago and the Wushan Formation was thrusted westward over the lower Gutingkeng Formation. During the period from 1.7 to 0.8 Ma, the thrusting of the Chishan Fault caused the Pingtung Basin to continuously subside, accumulating over 1000 m thick of the Linkou conglomerates (Lee *et al.*, 1999). West of the Chishan Fault, three west-verging thrust faults have formed during Pleistocene to Recent time with decreasing age from east to west. The Lungchuan Fault,

immediately west of the Chishan Fault, initiated about 1.6 Ma ago. Farther to the west, the Meilin thrust fault moved about 0.8 Ma BP and the westernmost Chungchou Fault has formed in the Recent (Lee *et al.*, 1999; Moutherneau *et al.*, 2001). Displacement of these late thrust faults is relatively small compared with that of Chishan and Chaochou Faults. For example, the Meilin thrust fault shows tens of metres of displacement at outcrops. In contrast, the Chaochou Fault has displacement over 2000 m. Note that these younger thrust faults are confined in the Gutingkeng Formation, offshore mudstones over 3000 m thick of Pliocene–Early Pleistocene age (Teng, 1987; Wu, 1993). Relatively thin layers of Liushuang fluvial sandstone above the Gutingkeng Formation are not shown on Fig. 6. It was proposed that onset of tectonic escape in the Pingtung Basin and upper Kaoping Slope occurred in the Late Pleistocene. N/S and NE/SW along-strike motions occur along the Chaochou Fault and Chishan Fault, respectively (Lacombe *et al.*, 2001). However, westward propagation of folds and thrusts is the dominant structural style in the Pingtung Basin and its offshore extension (Fig. 10).

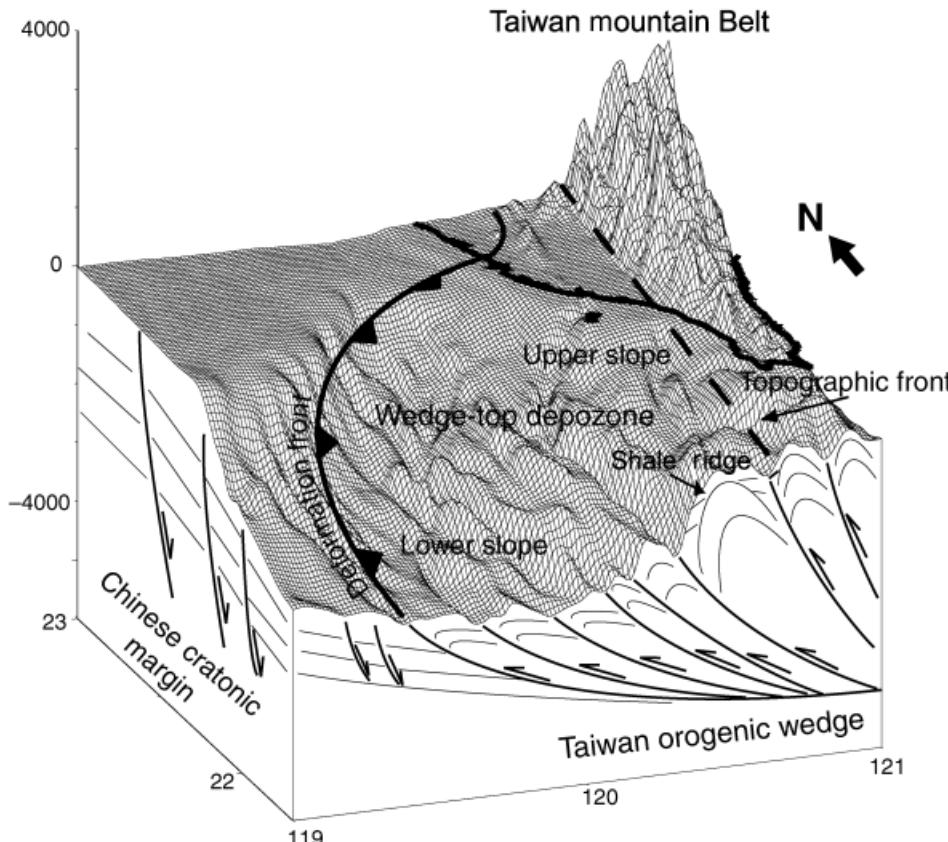


Fig. 10. The overall structural styles of a series of west-verging imbricated thrusts and folds and shale ridges in the wedge-top depozone confined by the topographic front proximal to the Taiwan Orogen and by the distal submarine deformation front transition to the passive Chinese margin (modified from Wu, 1993; Liu *et al.*, 1997; Chiang, 1998).

DISCUSSION

The northern boundary of the wedge-top depozone in southern Taiwan may be placed along the southern limit of the geological province of the Western Foothills (Fig. 11). The Western Foothills are low-relief hills no more than 1000 m high extending in a north–south direction west of the Central Range of Taiwan. This geological unit consists mainly of unmetamorphosed Miocene to Pleistocene rocks, which are deformed into westward propagating thrust faults (Ho, 1988). North of the Pingtung Plain, the Western Foothills province is bounded to the east by the Chaochou Fault and to the west by the fault equivalent to Chishan Fault. Morphologically, Pliocene and Pleistocene strata confined by these two major thrust faults are highly deformed and become tilted, folded and uplifted, forming low-relief hills. Structurally, these deformed Late Cenozoic strata are deformed into fold-and-thrust belts, acting as sources of orogenic sediments. In turn, sediments shed from the Western Foothills are transported partly westward to the coastal plain and partly southward to the Pingtung Plain. Tectonically, the area north of the Pingtung Basin is characterized by uplift, whereas the Pingtung Basin is dominated by subsidence (Chen, 1984).

No piggyback basins are found in the Western Foothills immediately adjacent to the Pingtung Plain. Syntectonic

sediments are not deposited in the structural lows between the folds and thrusts of the Western Foothills, which can therefore be considered as a part of orogenic wedge, not a part of a wedge-top depozone. From north to south, the Western Foothills change to a coastal plain with piggyback basins filled with syntectonic sediments in the Pingtung Basin. In other words, the frontal orogenic wedge (Western Foothills) progressively changes to wedge-top depozone (Pingtung Plain) in a southwest direction, reflecting ongoing southward oblique collision between the Luzon Arc and the Chinese margin (Suppe, 1984).

The submarine wedge-top depozone confined by the deformation front and the Chaochou Fault decreases from 120 km in cross-section width southward to 70 km where the continental crust gradually changes to oceanic crust (Fig. 11). The continent–ocean crust boundary (COB) located in the region of about 21°20'N is likely a transition zone along the inferred boundary (Liu *et al.*, 1992). South of the COB the oceanic crust of South China Sea is subducted eastward beneath the Luzon Arc. The Manila Trench is the surface trace of this subduction zone. The Manila Trench passes northward across the COB and merges into the Penghu Submarine Canyon, indicating a transition from subduction south of COB to collision (Luzon Arc–Chinese margin) north of COB (Yu & Song, 2000; Chuang & Yu, 2002).

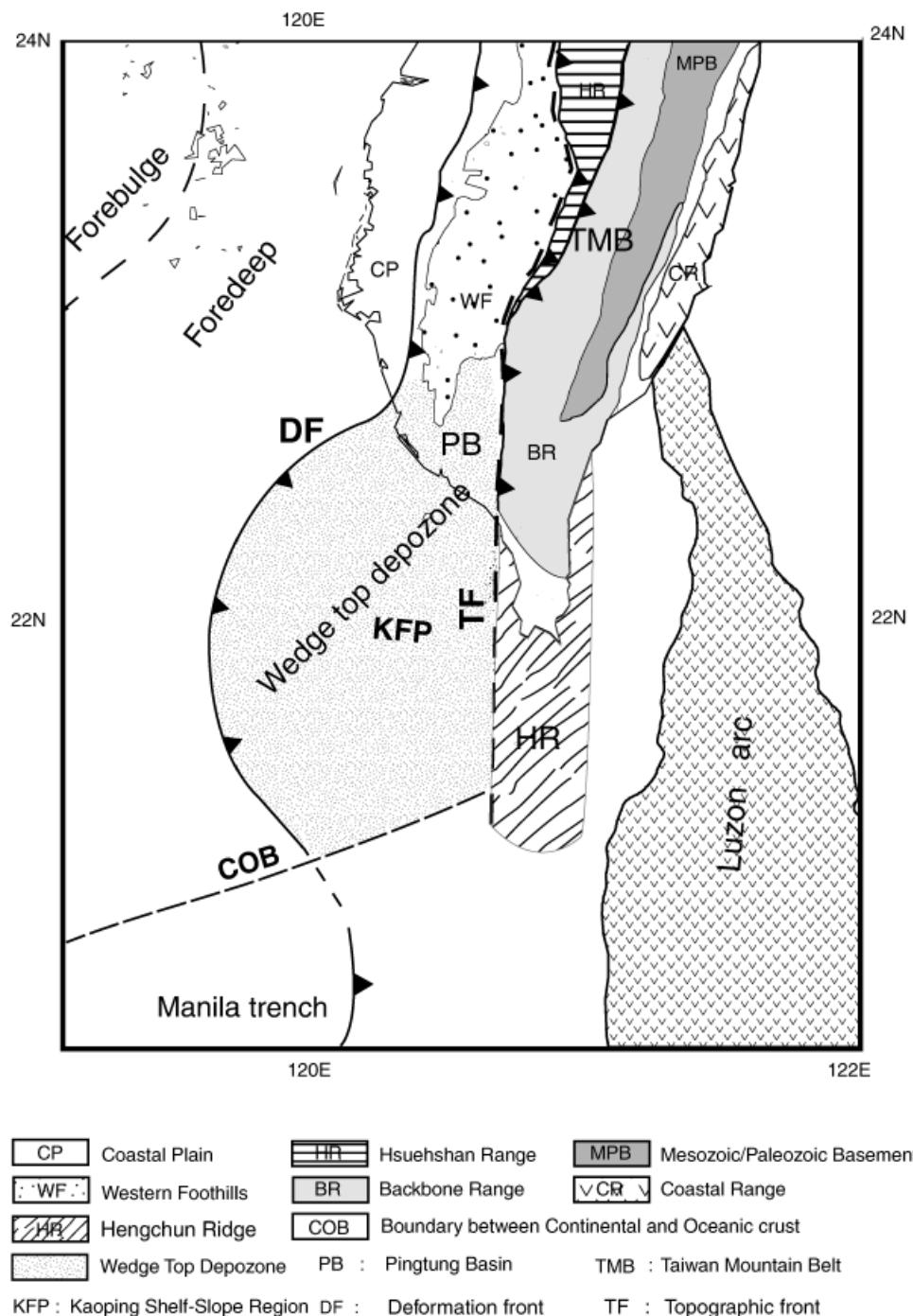


Fig. 11. The areal extent of the wedge-top depozone in southern Taiwan foreland basin system. The northern boundary of the wedge-top depozone in southern Taiwan may be placed along the southern limit of the geological province of the Western Foothills. The continent–ocean crust boundary in the northern South China Sea may be the southern boundary of the wedge-top depozone. Varying characteristics of boundaries reflect incipient collision between the Luzon Arc and the Chinese margin together with syndepositional and syntectonic features.

The submarine Hengchun Ridge (HR) can be considered the submerged proto-Central Range (Fig. 11), resulting from the initial collision between Luzon Arc and Chinese margin. Sediments derived from the HR and on-land Central Range are deep marine facies and are deformed into imbricated thrusts and ramp folds. The deep slope west of the HR can be viewed as an infant wedge-top depozone, showing initial mountain building and the be-

ginning of wedge-top depozone. The COB is tentatively considered the southern boundary of the wedge-top depozone of the southern Taiwan foreland basin system.

CONCLUSIONS

Much sediment derived from the thrust belt in southern Taiwan has been accumulated on top of the frontal oro-

genic wedge, forming a wedge-top depozone. These sediments are referred to as wedge-top sediments and are confined between the Taiwan Orogen and the submarine deformation front distal to the orogen. Syntectonic deformation and deposition are the main characteristics of the wedge-top sediments. Sedimentary facies show lateral variations from extreme coarseness of fluvial conglomerates proximal to the topographic front to fine-grained deep marine mud close to the deformation front. The stratigraphic column indicates a gradual shallowing-up from offshore deep-water mud to shallow marine sands and to fluvial deposits. The transverse cross-section is about 120 km wide and is geometrically a doubly tapered prism.

Westward propagation of thrust faults and folds is the characteristic deformational style in the wedge-top depozone. Accompanying the movements of folds and thrusts, many piggyback basins are formed and are simultaneously filled by syntectonic sediments. Thick sediments in the piggyback basins distinguish wedge-top depozones from the orogenic wedge of the Western Foothills. The COB in the northern South China Sea may be the southern boundary of the wedge-top depozone in southern Taiwan.

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