Journal of Zhejiang University SCIENCE A
ISSN 1673-565X (Print); ISSN 1862-1775 (Online)
www.zju.edu.cn/jzus; www.springerlink.com
E-mail: jzus@zju.edu.cn

A Cenozoic tectono-sedimentary model of the Tainan Basin, the South China Sea: evidence from a multi-channel seismic profile*

Wei-wei DING[†1,2,3], Jia-biao LI[1,2], Ming-bi LI[1,2], Xue-lin QIU[3], Yin-xia FANG[1,2], Yong TANG[1,2]

(*[1]Key Laboratory of Submarine Geoscience, State Oceanic Administration, Hangzhou 310012, China*)

(*[2]Second Institute of Oceanography, State Oceanic Administration, Hangzhou 310012, China*)

(*[3]Key Laboratory of Marginal Sea Geology, South China Sea Institute of Oceanology, Chinese Academy of Sciences, Guangzhou 510301, China*)

[†]E-mail: wwdingsio@yahoo.com.cn

Received Oct. 30, 2007; revision accepted Jan. 7, 2008; published online Apr. 11, 2008

Abstract: The Tainan Basin is one of the set of Cenozoic extensional basins along northern margin of the South China Sea that experienced extension and subsequently thermal subsidence. The Tainan Basin is close to the Taiwan Arc-Trench System and straddles a transition zone between oceanic and continental crust. A new regional multi-channel seismic profile (973-01) across the region of NE South China Sea is introduced in this paper. In seismic stratigraphy and structural geology, a model of Cenozoic tectono-sedimentation of the Tainan Basin is established. The results show that three stages can be suggested in Tainan Basin; In Stage A (Oligocene (?)-Lower Miocene) the stratigraphy shows restricted rifting, indicating crustal extension. Terrestrial sediments mostly filled the faulted sags of the North Depression on the continental shelf. Structural highs, including the Central Uplift, blocked material transportation to the South Depression in abyssal basin. In Stage B the Tainan Basin (Middle-Upper Miocene) exhibits a broad subsidence resulting from the post-rifting thermal cooling. The faulted-sags in North Depression had been filled up. Terrestrial materials were transported over the structural highs and deposited directly in the South Depression through submarine gullies or canyons. This sedimentation resulted in a crucial change in the slope to a modern shape. In Stage C (Latest Miocene-Recent) a phase change from extension to compression took place due to the orogeny caused by the overthrusting of the Luzon volcanic arc. Many inverse structures, such as thrusts, fault bend folds, and a regional unconformity were formed. Forland basin began developing.

Key words: Southwest Tainan Basin, Dual-layered structure, Fault bend fold, Tectono-sedimentary evolution
doi:10.1631/jzus.A071572 **Document code:** A **CLC number:** P5; P7

INTRODUCTION

The Tainan Basin lies in the northeast of the South China Sea (Fig.1). To the east, there is a typical arc-trench system originated from the collision of the Luzon Arc against the Eurasian margin. To the southeast the South China Sea is a subduction zone beneath the Philippine Sea Plate along the Manila Trench. A zone of cooling oceanic crust and the Pearl River Mouth Basin bordered its south and west. The Tainan Basin extends from continental shelf, continental slope, to abyssal basin with three structural units: the North Depression, the Central Uplift and the South Depression (Fig.2) (Lin *et al*., 2003; Li *et al*., 2007). Episodes of rifting, collision, subduction and volcanism have co-shaped the Tainan Basin in current tectonic configuration, making the area an ideal natural geological laboratory with a complete geological spectrum. Great efforts have been made to understand the tectonic history of the area from opening, sedimentation, to deformation, for energy exploration with geological and geophysical data acquired in the past (Yu and Lin, 1992; Zhong *et al*.,

* Projected supported by the National Basic Research Program (973) of China (No. 2007CB411704), the National Natural Science Foundation of China (No. 40676024), and the Key Laboratory of Marginal Sea Geology, the Chinese Academy of Sciences (Nos. KZCX3-SW-234 and MSGL0609)

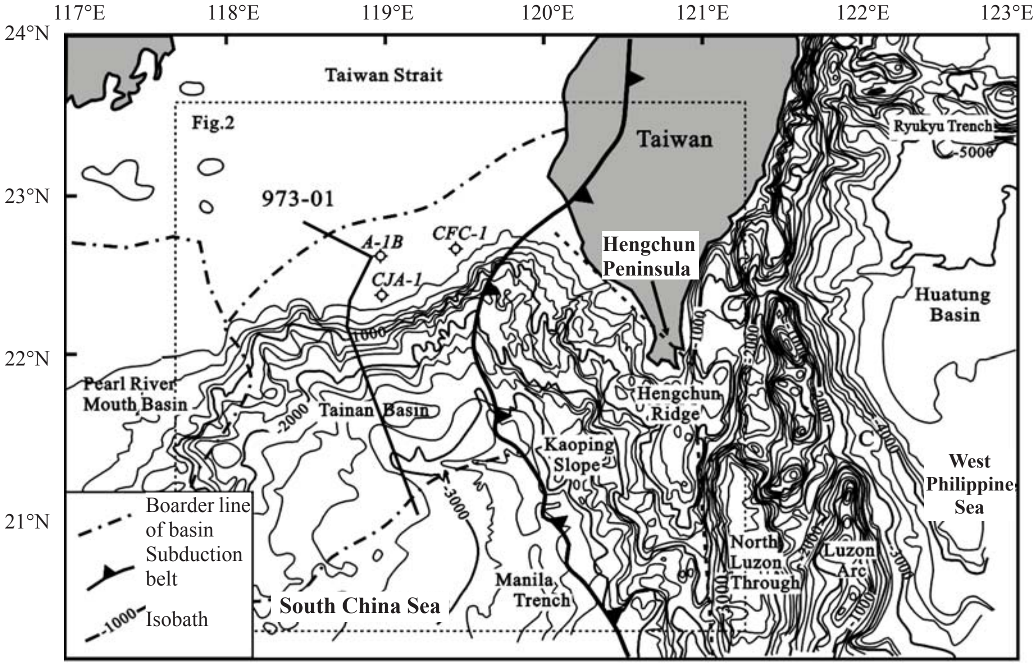


Fig.1 General bathymetric and topographic map of offshore Taiwan Island

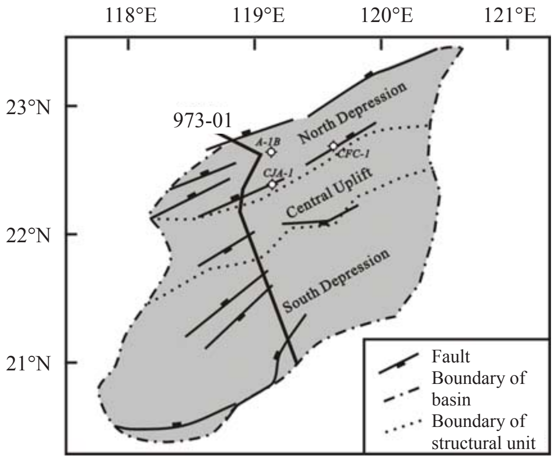


Fig.2 Structural division of the Tainan Basin

1993; Du, 1994; Zhou *et al*., 1995; Lüdmann and Wong, 1999; Huang *et al*., 2001; Ding *et al*., 2004). Zhong *et al*.(1993) considered that the Tainan Basin experienced an active rifting event in the Paleogene-Middle Miocene and a passive rifting one in the Late Miocene-Quaternary. Du (1994) established the tectonic evolution of the Tainan Basin that mainly related to a rifting extension along continental margin of northern South China Sea, and discussed the hydrocarbon potential. Zhou *et al*.(1995) summarized the geological history of continental margin of the South China Sea and concluded that the Tainan Basin was influenced mostly by the third rifting (Late Eocene-Early Miocene) in NNW-SSE direction. Huang *et al*.(2001) believed that the Tainan Basin experienced two stages of normal faulting, one in the Oligocene and the other in the Late Miocene, and no obvious compressive feature is observed. However, the lack of modern high-resolution seismic profiling on the continental-slope area hindered, until now, the study on detailed tectono-stratigraphic pattern. Several issues on the development of the Tainan Basin are still under discussion including: (1) Whether the Tainan Basin has compressive structures? If yes, how did they influence the sedimentation? (2) As the Tainan Basin stretches across continental slope, what is the difference of tectono-sedimentation in the continental-oceanic transition zone between landward and seaward? When did the present style of slope form up?

This paper presents a seismic-stratigraphic analysis of the Tainan Basin. Using a new 2D seismic profile acquired in this area, emphasis is given to place some constraints on our understanding of the Cenozoic tectono-sedimentary evolution and dynamics of the Tainan Basin and adjacent region. Such an approach includes the identifications of the seismic stratigraphic units, the differences of these seismic units between the continental shelf and abyssal basin, and the recognitions of major structures formed during rifting phase and subsequent arc-continent collision related tectonism.

GEOLOGICAL BACKGROUND

In the middle Jurassic, the proto-north South China margin was Andean type convergent margin with the basement of mainly meta-sediments of the Caledonian fold belt in the west and the Hercynian fold belt in the east (Hilde *et al*., 1977; Hamilton, 1979; Taylor and Hayes, 1983; Letouzey *et al*., 1988; Williams *et al*., 1988). The volcanism ceased by approximately 85 Ma. From the middle Jurassic to Cretaceous the subduction of the paleo-Pacific plate beneath the Eurasia plate made a Mesozoic magmatic arc system in the middle-east of the continental margin (Hamilton, 1979; Zhou *et al*., 1996; Lapierre *et al*., 1997; Zhou and Li, 2000; Li *et al*., 2007). Starting from about 50 Ma, the southern Chinese continental margin changed its tectonic regime from subduction to continental stretching and rifting. Rifting with uplifting shoulders in erosion probably began in the Late Cretaceous or Paleogene (Taylor and Hayes, 1980; Chen *et al*., 1987; Clift and Lin, 2001). The beginning of subsequent South China Sea Basin (SCSB) opening in a north-south direction is marked by a major breakup unconformity. By reinterpreting the new magnetic anomalies (11~5d according to (Taylor and Hayes, 1980; 1983; Holloway, 1982)), Briais and Pautot (1990) placed this sea floor spreading phase at from the end of Lower Oligocene to Early Middle Miocene (32~15.5 Ma, anomalies 11~5c). With the cessation of seafloor spreading, the deep SCSB and its adjacent continental margins started to subside because of thermal relaxation of the oceanic crust underneath. In addition, convergence between the Eurasian and the Philippine Sea Plate (68 mm/y toward 305°N) (Seno *et al*., 1993) further leaded to the collision between the Luzon Arc and the Eurasian continent off SE Taiwan. Collision started 5~3 Ma ago by Teng (1990), or 6.5 Ma by Hall (2002). The North Luzon Arc collided against the East China continental margin and formed the Taiwan Accretionary Prism (TAP). From the Late Pliocene to present, the second major collision phase took place, leading to uplift of the mountain ranges in northern Taiwan.

DATA AND METHODS

A multi-channel seismic profile on offshore of the SE China coast, from the Tainan Basin, TAP, and the Huatung Basin, to the West Philippine Sea, was obtained during the Project-973 Cruise from June to Dec., 2001 on Chinese R/V “Tanbao”. The data were acquired through 240 channels in geophone group of 50 m having common midpoint gathers placed every 12.5 m along profile with a 3000 m-long cable, and recorded in SEG-D format in 2 ms sampling interval up to 10 s Two Way Time (TWT). The profile is hereafter named Profile 973-01, which was processed as a standard industrial pre-stack procedure (including amplitude compensation, static correction, gain and mute analysis, predictive deconvolution, multiple attenuation, velocity analysis, residual static corrections and frequency analysis). Post-stack deconvolution, band-pass and coherency filtering were then applied to the stacked data, followed by finite-difference migration.

Data of key wells located near the seismic line, including Well A-1B, Well CJA-1, Well CFC-1 (ECPGC, 1990), and Type Well (Taylor and Hayes, 1980; see Fig.1 for position) were used to interprete seismic sequences against regional litho-stratigraphic units (Fig.3). The analysis on seismic facies is by conventional methods regarding deep-water basins (Shanmugam and Moiola, 1988; Weimer, 1990; Mann *et al*., 1992), and recently published paper on continental shelf (Lu *et al*., 2003) and continental slope (Ercilla *et al*., 2002; Alves *et al*., 2006).

SEISMIC STRATIGRAPHY

The Tainan Basin is mainly composed of Neocene sediments. The Paleogene sediments are relatively thin and even absent in structural highs. Four seismic units are recognized in the North and South Depression featuring particular reflection pattern, geological age and internal structure (Table 1). Subdivision of them has not been attempted because of the lack of adequate sediment indicators from well logs.

Unit T_g-T_6 (the paleocene)

In the study area, Unit T_g-T_6 is the basal seismic-stratigraphic unit covering rotated half-graben

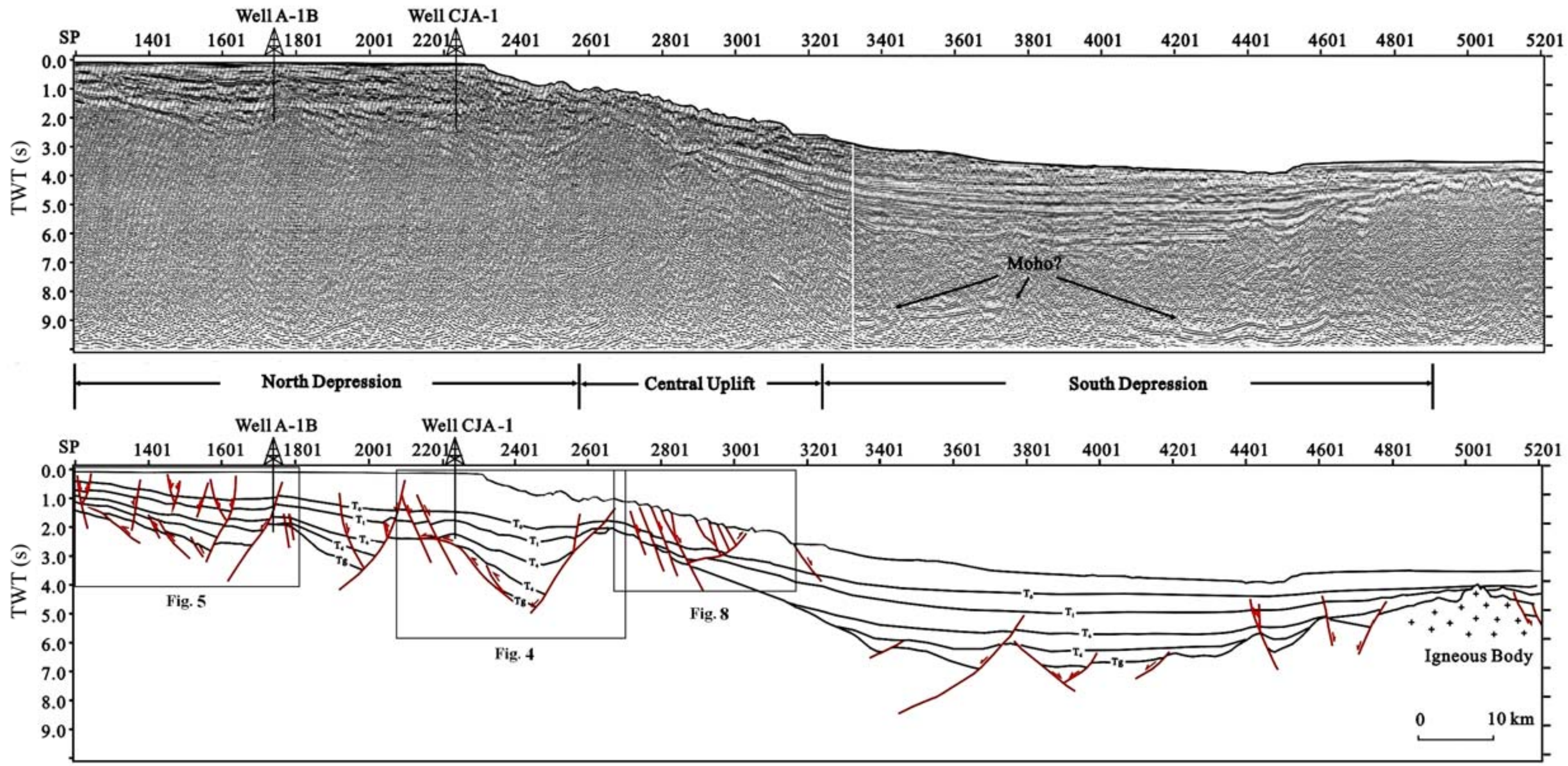
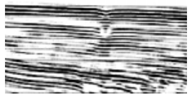
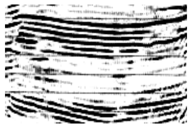
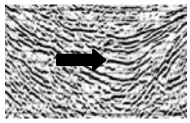
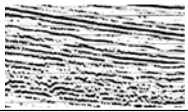
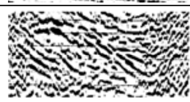
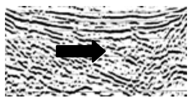
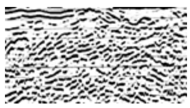


Fig.3 Part of the seismic Profile 973-01 crossing the Tainan Basin (a) and its interpretation (b). See Fig.1 for location. A clear elevation of reflection in depth of 8~10 TWT (two way traveltime) between SP (shoot point) 3001 and 4601 is believed of Moho, suggesting a thinned crust with continental character

Table 1 Seismic facies and sequences in the Tainan Basin

Sequence	Position	Internal reflection pattern	Frequency	Intensity	Continuity	
$Q+N_2$	North Depression	Parallel	Uniform	Low to moderate, locally transparent	High	
	South Depression	Subparallel, locally chaotic	Slightly variable	Low to moderate	Intermediate	
N_1^{2+3}	North Depression	Parallel, locally wavy	Slightly variable	Moderate to local high, locally transparent	High	
	South Depression	Parallel	Uniform	Medium	Intermediate to high	
N_1^1	North Depression	Subparallel, locally chaotic	Variable	Variable	Intermediate	
	South Depression	Parallel	Slightly variable	Low to moderate	High	
E	North Depression	Chaotic	High variable	Variable	Discontinuous	
	South Depression	Chaotic, locally subparallel	High variable	Variable	Discontinuous	
North Depression basement		Hyperbolic to chaotic	Low	High	High laterally, low vertically	
South Depression basement		Chaotic	Low	Medium	Low	

and graben basement blocks. Local coverage over faults was found bounding half-graben and graben tilt blocks (Figs.4 and 5). The bottom boundary (T_g) is coincident with a high-amplitude surface and locally diffractive, marking up the top of acoustic basement of the Tainan Basin. The Paleogene (mainly Oligocene) of the North and South Depressions is characterized by chaotic and discontinuous reflectors in various intensities, indicating rift-filling clastic sediments of mainly fluvial to coastal facies. The Paleogene sequences are topped by an unconformity, which is especially prominent in the South Depression.

Unit T_6-T_4 (the Lower Miocene)

Similarly to Unit T_g-T_6, Unit T_6-T_4 in the North Depression covers rotated half grabens and grabens, characterized by subparallel, intermediate continuity

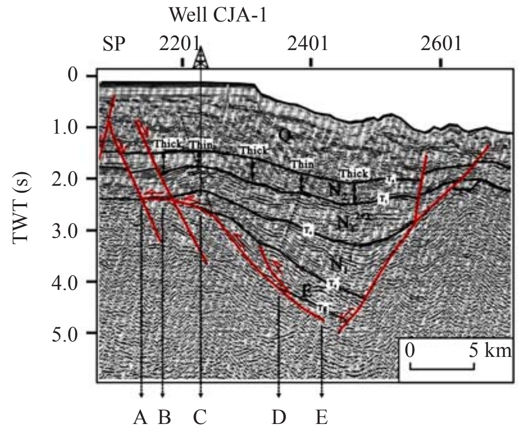


Fig.4 Inverse structures in the faulted-sag (broken line represents the axis direction of the fold. A-B: fault flat; B-C: hanging wall fault ramp; C-D: lying wall fault ramp; D-E: fault flat)

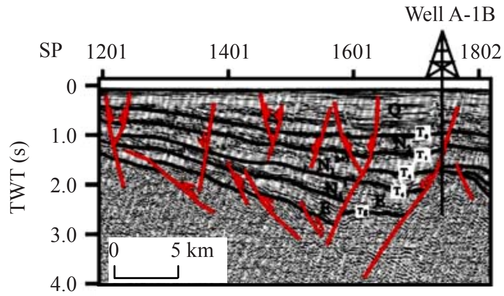


Fig.5 Faulted-sag in the Tainan Basin

reflections in variable amplitude. The lithology differs place-to-place. Well A-1B contains shallow marine facies in alternation of sandstone and mudstone, while well CFC-1 shows semi-abyssal facies of mudstone. The unit is topped in unconformity having its syn-rifting sequence truncated in marginal depression but in conformity in central depression. However, the reflection of the South Depression is totally different, featuring strong, parallel and continuous reflections, indicating of typical deep marine facies. No wells have been drilled in this abyssal deposit. Probably it includes mudstone and siltstone of bathyal facies.

Unit T_4-T_1 (the Middle-Upper Miocene)

Unit T_4-T_1 is the oldest post-rifting strata of the Tainan Basin. The reflections are similar in the North and South Depressions. The internal reflectors are parallel to each other in good continuity, intermediate to locally high intensity and the frequency varies slightly. The sediments involved are siltstone or mudstone of marine facies interbedded with sandstone. Unconformity is observed on top of the unit in the North Depression with the strata truncated by overlying layers. Well logs have proved the sedimentary hiatus, for example, the Upper Miocene is absent in Well CFC-1. The unconformity represents a major change in tectonics and sedimentation. However, no unconformity is observed in the South Depression.

Unit T_1-seabed (the Pliocene-Quaternary)

This unit in the North Depression is characterized by continuous parallel reflectors of low to moderate intensities, dominated by mudstones over siltstones and sandstones (Table 1). On the other hand, near the continental slope, reflections are chaotic resulted from slump deposit or olistostrome by turbidity currents, displaying a progradation upslope pattern. In the South Depression, the internal reflectors are subparallel, locally disordered in intermediate continuity, showing hemipelagite and turbidite nature.

STRUCTURE OF THE TAINAN BASIN

Extensional structure

Similar to other basins of Atlantic-type passive margin, the Tainan Basin shows a structure of graben with numerous extensional faults (Figs.3~5). In general, the deep part of the section displays restricted rifts by crustal extension. The shallower part of the section exhibits broad subsidence took place as the result of thermal cooling of the upper mantle.

The rifting phase in the North Depression mainly occurred from the Oligocene to Early Miocene. The array of half grabens mostly developed on planar faults. The longest and deepest faults developed in margin of the depression. Structural highs have smaller fault thrust and weaker deformation inside than those in nearby sags. Some north-dipping master faults sometimes show listric pattern on seismic profile (Figs.4 and 5). The thickness of sediment changes across syn-sedimentary faults (i.e., growth faults). Active faulting formed a wedge-shaped graben with some secondary faults in the E_3-N_1^1 layer.

In the Middle Miocene, faulting became less active. Sedimentation was not fault-controlled. An overall vast thermal subsidence developed and modern basin initiated with the coverage of the Middle Miocene to Quaternary over the Oligocene-Early Miocene fault sags and related uplift blocks.

In the South Depression, the rifting is different. The depression is mainly filled with Oligocene sediment and the rifting did not cease until the Neocene. In other words, the rifting in the South Depression terminated earlier than that in the north one. No wells have been drilled in the South Depression. The seismic reflections, as discussed in Section "Seismic Stratigraphy", show a quiet deep-water sedimentary environment. After the Early Miocene, the South Depression became a new depo-center for >4400 m sediments in thickness. The N_1^2-Q strata blanket the central uplift. Many seaward dipping normal faults and associating slump structures developed outside the central uplift.

Compressive structure

The Cenozoic Tainan Basin features extensional tectonics, and contains two depositional hiatuses related to tectonic and eustatic events, marked by the Middle Miocene unconformity and the Pliocene unconformity. The former is a "break-up" unconformity separating the rifting phase from post-rifting phase, which underneath no inverse structures indicates eustatic events. However, at the end of the Late Miocene, the Tainan Basin experienced an intensive compression with a series of inverse structures developed.

A typical inverse structure can be seen in the left part of Fig.4, showing that the Miocene sequence was folded into an anticline above a thrust: the area from Points A to B is a fault flat where the fault plane is parallel to the Cenozoic bottom surface. Points B to C represent the hanging wall fault ramp. The fault plane is nearly horizontal over which hanging wall sediments overlap. Section from Points C to D passes from a footwall flat into a fault ramp. A further small thrust and associated fold developed between Points D and E. The whole area was subjected to erosion and the Pliocene sequence draped over the unconformity at a lower angle. The topography formed in compression at the end of the Miocene influenced the overlying sediments that thicken up away from the anticline center. Fig.5 shows some inverse structures although not typical.

CENOZOIC TECONO-SEDIMENTARY EVOLUTION

The Cenozoic structural evolution of the study area is summarized in Fig.6. In overall, three distinct stages can be divided for the Cenozoic evolution of the Tainan Basin. Stage A (the Oligocene (?)-Early Miocene) is rifting phase during which normal fault systems developed. Stage B (the Middle-Upper Miocene) is post-rifting phase during which the present Tainan Basin was shaped by thermal subsidence at Eurasian margin. In Stage C (Latest Miocene-Recent) a phase change from extension to compression took place due to the orogeny caused by the overthrusting of the Luzon volcanic arc.

Stage A (the oligocene (?)-Early Miocene)

In the Paleogene, the north margin of South China Sea was controlled under an extensional stress field. The steepening or eastward retreat of the West Pacific subduction zone triggered large-scale rifting in NE-SW in Late Cretaceous (Holloway, 1982; Zhou *et al*., 1995; Northrup *et al*., 1995) involving most marginal basins, such as the Pearl River Mouth Basin, Beibu Gulf Basin, Qiongdongnan Basin, etc. The collision and northward impinging of the India Plate to Asian continent at Tibet since the Late Eocene squeezed the Indochina Block extruded southeastward, generating a large-scale sinistral movement along the Red River Fault (Tapponnier *et al*., 1982; 1986). This event produced the NNW oriented left-lateral stress in the northern South China Sea, while the clockwise rotation of the Indochina Block superimposed a N-S-oriented and eastward increasing scissors-like tensile stress (Zhou *et al*., 1995; Sun *et al*., 2006). These resulted in another rifting in NNW-SSE direction in the northern margin of the South China Sea. Finally, the SCSB opened up by the end of Late Oligocene ongoing until the Early Miocene.

The Tainan Basin, as one of marginal basins in the rifting scope was also impacted by the rifting. Terrestrial materials were originated from the Eurasian Plate and mainly deposited in rifted-sags that were the depo-centers of the North Depression.

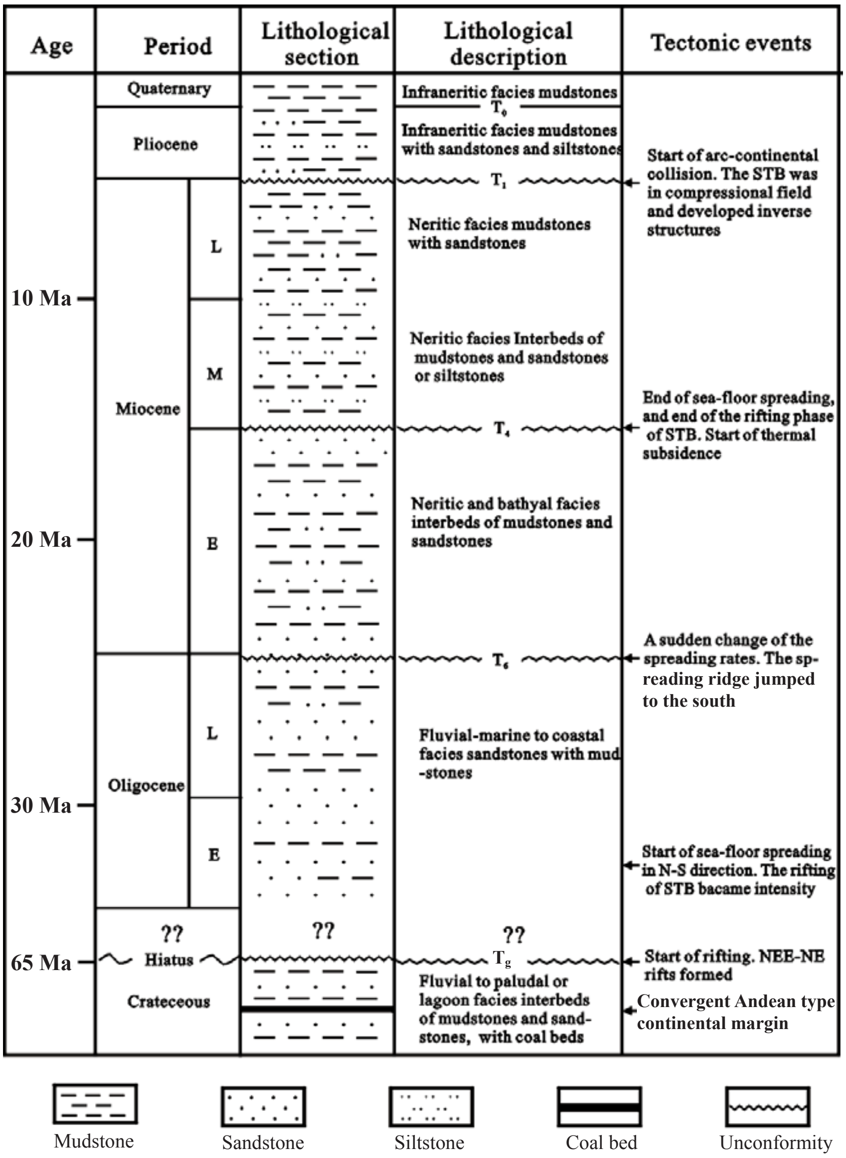


Fig.6 Cenozoic stratigraphy and tectonic events in the Tainan Basin (this study; ECPGC, 1990; Lin *et al*., 2003; Tzeng, 1994)

Structural highs including the Central Uplift clogged sediments from deposition in continental margin, which explained why the South Depression has thinner strata (Fig.7a).

No sediments older than Obligocene have been found in boreholes of the Tainan Basin. Note that all the wells were operated at structural highs or uplifts. Therefore, the older strata existed possibly in deep of sags and certainly was disclosed in adjacent area of the Tainan Basin. In the Penghu Basin, north of the study area, fluvial and lacustrine Eocene sandstones and shale were 1570 m in thickness revealed in Well PA (Zhou, 2002). To the west of the Tainan Basin, the Pearl River Mouth Basin have also >4000 m Paleocene-Eocene fluvial and lacustrine clastic facies (Lüdmann and Wong, 1999). Moreover, the Paleocene-Eocene sediments in onshore Taiwan were also discovered in Wells THS-1 and WG-1 (ECPGC, 1990). It is quite possible that the Eocene and older strata exist in the deeper part of the faulted-sags, and the Tainan Basin may have shared common rifting with the Pearl River Mouth Basin. But the intensity of

Paleogene rift was much weaker than those of other rifting basins in northern margin of the South China Sea.

Stage B (the Middle-Upper Miocene)

Since the Middle Miocene, northward subduction of the India-Australia Block had initiated, which caused northwestward thrusting of Sabah and Palawan. The NWW movement of the Philippine Sea Plate had become decisive force in the South China Sea, terminating finally the seafloor spreading in late Early Miocene (Hinz and Schlünter, 1985; Hinz *et al.*, 1989; Hall *et al.*, 1995; Hall, 2002; Hutchison, 2004). The entire stress regime of the South China Sea region had shifted from extension-wise to compression-wise.

In the Tainan Basin, normal faulting had almost stopped with no control on sedimentation in Middle Miocene. Submarine incised valleys occurred during the Lower Miocene in the depressions on continental shelf, east of the Tainan Basin (Li *et al.*, 2005), and afterwards the depressions have been filled up with terrestrial materials that then overflowed to the abyssal basin through these valleys. Although no clear sign of the valley was shown in seismic Profile 973-01, it is the fact that the South Depression became a depo-center after the Early Miocene, letting us believe that the faulted-sags in the North Depression had been filled since by the time of Middle-Miocene, that terrestrial materials were transported over structural climaxes and shed directly into subsiding South Depression, and that the gradient of the slope become ongoing to the present status (Fig.7b).

Stage C (Latest Miocene-Recent)

As the Philippine Sea Plate kept converging to the Eurasian Plate at 68 mm/y in 305°N (Seno *et al.*, 1993), it obducted onto the South China Sea since Late Miocene generating the Manila Trench (Suppe, 1984; Seno *et al.*, 1993; Li *et al.*, 2002). The front of Luzon Arc collided obliquely to the Eurasian continental margin since 6.5 Ma with the formation of the TAP (Huang *et al.*, 1997; 2001; Hall, 2002), or since 9 Ma (Sibuet and Hsu, 2004). The Tainan Basin evolved into a compression phase as inverse structures including the thrusts and fault related folds formed. Elevation and erosion of the Lower Miocene sequence formed an unconformity finally (Fig.7c). The unconformity is called basal foreland unconformity in the regions near the TAP, as it separates an onlapping foreland basin sequence above from passive margin sequences below and marks the base of the Taiwan foreland sequence (Lin *et al.*, 2003). Rifting ceased and a foreland basin began developing beyond the underlying rifted margin.

In the Pliocene to Quaternary, the continental slope kept developing. Sufficient terrestrial sediments supply caused the pattern of upslope progradation. Many sea-dipping normal faults slumped or slid oceanward, reaching even the seafloor. Thrusts were also formed by mass movement (Fig.8).

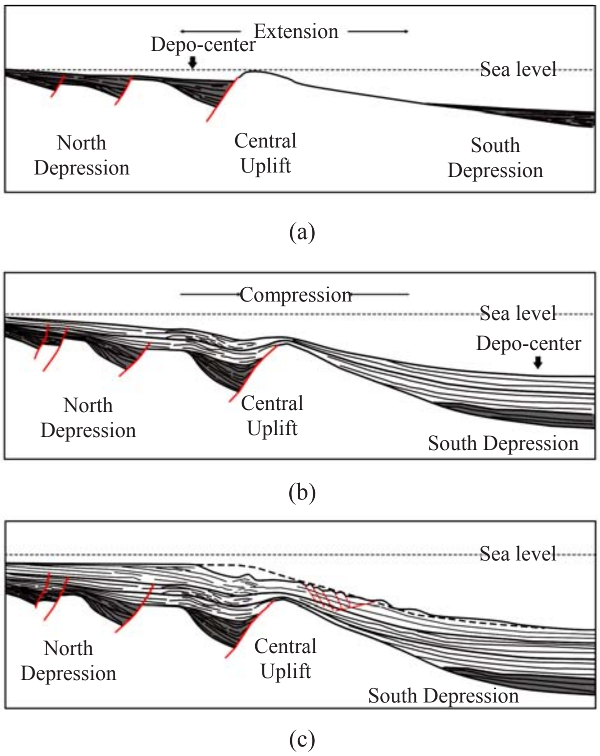


Fig.7 Sedimentary evolution model. (a) Terrestrial materials mainly deposited in the North Depression. The structural highs, including the Central Uplift, blocked the way of the sediments from continental margin, resulting in thinner depositions in the South Depression; (b) As sea level rose, terrestrial materials transported over structural highs and deposited into subsiding South Depression. The infill of depressions during this stage even out the gradient of the slope, leading to present slope formation; (c) Transition zone between shelf and slope shifted seaward. Many sea-dipping normal faults slumped and slid, some even reached the seafloor. The mass movement also yielded thrusts

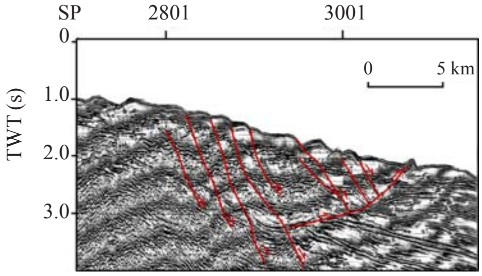


Fig.8 Sea-dipping normal faults and thrusts formed by mass movement in the continental slope (See Fig.3 for position)

CONCLUSION

Similar to north margin of South China Sea, the Tainan Basin experienced rifting in Cenozoic. In Oligocene (?) to Lower Miocene it displays restricted rifts and represents crustal stretching during the rifting. The extension in Paleogene is much weaker than other marginal basins, west of the Tainan Basin, such as the Pearl River Mouth Basin. Different structural unit has different tectono-sedimentary characteristics. The North Depression on continental shelf developed rows of north-dipping faults and half-grabens, and was the depo-center during the rifting phase. However, the South Depression in the abyssal basin had weaker rifting and shorter rifting phase. The sedimentary sequences in the North Depression appeared to be mostly terrestrial and showed land and shallow marine sedimentary environments, while those in the South Depression came partially form the central uplift and depositied fine grained sediment in a deep water environment. At the end of Early Miocene (16.5 Ma) the seafloor-spreading of the South China Sea ceased and the Tainan Basin began the thermal subsidence phase. Rapid thermal subsidence made the Central Uplift buried and the South Depression became the depo-center all the way to the formation of modern slope. In Latest Miocene (6.5 Ma) a change from extensional to compressive regime occurred. The arc-continental collision between the Luzon Arc and the Eurasian continental margin not only formed Taiwan Mountains and offshore Taiwan Accrectionary Prism with intensive thrust folds, but also influenced the Tainan Basin as many inverse structures formed by the end of Miocene together with a regional unconformity. New hydrocarbon exploration at these folds and thrust belts in deep-water continental passive margins can be potential (Heiniö and Dacies, 2006). The Taiwan orogeny has created a foreland basin by loading and flexing the underlying rifted margin.

References

Alves, T.M., Motta, C., Sandnes, F., Cunha, T., Monteiro, J.H. Pinheiro, L.M., 2006. Mesozoic-Cenozoic evolution of North Atlantic continental-slope basins: the Peniche basin, western Iberian margin. *AAPG Bulletin*, **90**(1):31-60. [doi:10.1306/08110504138]

Briais, A., Pautot, G., 1990. Reconstructions of the South China Sea from Structural Data and Magnetic Anomalies. *In*: Jin, X., Kudrass, H.R., Pautot, G. (Eds.), Marine Geology and Geophysics of the South China Sea. Proc. Symp. on Recent Contributions to the Geological History of the South China Sea. China Ocean Press, Hangzhou, p.60-70.

Chen, S., Lei, Z., Zhou, Y., 1987. Major oil accumulation characteristics and exploration direction in the Pearl River Mouth Basin. *China Oil*, Winter, p.17-23.

Clift, P., Lin, J., 2001. Preferential mantle lithospheric extension under the South China margin. *Marine and Petroleum Geology*, **18**(8):929-945. [doi:10.1016/S0264-8172(01)00037-X]

Ding, W.W., Wang, Y.M., Chen, H.L., Yang, S.F., Wu, N.Y., 2004. Deformation characters and its tectonic evolution of the Southwest Taiwan Basin. *Journal of Zhejiang University* (*Science Edition*), **31**(2):216-220 (in Chinese).

Du, D.L., 1994. Tectonic evolution and analysis of oil-gas accumulation in Southwest Taiwan Basin. *Marine Geology and Quaternary Geology*, **14**(3):5-18 (in Chinese).

ECPGC (Editiorial Committee of Petroleum Geology of Oil and Gas Bearing Areas on the Continental Shelf and Its Neighbouring Regions), 1990. Oil and Gas Bearing Areas on the Continental Shelf and Its Neighbouring Regions, Petroleum Geology of China. Petroleum Industry Press, Beijing (in Chinese).

Ercilla, G., Alonso, B., Wynn, R.B., Baraza, J., 2002. Turbidity current sediment waves on irregular slopes: Observations from the Orinoco sediment-wave field. *Marine Geology*, **192**:171-187.

Hall, R., 2002. Cenozoic geological and plate tectonic evolution of SE Asia and the SW Pacific: computer-based reconstructions, model and animations. *Journal of Asian Earth Sciences*, **20**(4):353-431. [doi:10.1016/S1367-9120(01)00069-4]

Hall, R., Ali, J.R., Anderson, C.D., Baker, S.J., 1995. Origin and motion history of the Philippine Sea Plate. *Tectonophysics*, **251**(1-4):229-250. [doi:10.1016/0040-1951(95)00038-0]

Hamilton, W., 1979. Tectonics of the indonesian region. *U.S. Geol. Surv., Prof. Paper*, **1078**:345.

Heiniö, P., Dacies, R.J., 2006. Degradation of compressional fold belt: Deep-water Niger Delta. *AAPG Bulletin*, **90**(5):753-770. [doi:10.1306/11210505090]

Hinz, K., Fritsh, J., Kempter, E.H.K., Mohammad, A.M., Mohamed, D., Vosberg, H., Weber, J., Benavidez, J., 1989. Thrust tectonics along the northwestern continental margin of Sabah/Borneo. *Geologische Rundschau*, **78**(3):705-730. [doi:10.1007/BF01829317]

Hilde, T.W.C., Uyeda, S., Kroenke, L., 1977. Evolution of the western Pacific and its margin. *Tectonophysics*, **38**:145-165. [doi:10.1016/0040-1951(77)90205-0]

Hinz, K., Schlünter, H.U., 1985. Geology of the dangerous grounds, South China Sea, and the continental margin off southwest Palawan: results of SONNE cruises SO-23 and SO-27. *Energy*, **10**:297-315.

Holloway, N.H., 1982. North Palawan block, Philippines—Its relation to Asian mainland and role in evolution of South China Sea. *AAPG Bulletin*, **66** (9):1355-1383.

Huang, C.H., Wu, W.Y., Chang, C.P., 1997. Tectonic evolution of accretionary prism in the arc-continent collision terrane of Taiwan. *Tectonophysics*, **281**(1-2):31-51. [doi:10.1016/S0040-1951(97)00157-1]

Huang, C.H., Xia, K.Y., Perter, B., 2001. Structural evolution from Paleogene extention to Latest Miocene-Recent arc-continent collision offshore Taiwan: comparison with on land geology. *Journal of Asian Earth Sciences*, **19**(5):619-639. [doi:10.1016/S1367-9120(00)00065-1]

Hutchison, C.S., 2004. Marginal basin evolution: the southern South China Sea. *Marine and Petroleum Geology*, **21**(9):1129-1148. [doi:10.1016/j.marpetgeo.2004.07.002]

Lapierre, H., Jahn, B.M., Charvet, J., Yu, Y.W., 1997. Mesozoic felsic arc magmatism and continental olivine tholeiites in Zhejiang Province and their relationship with the tectonic activity in southeastern China. *Tectonophysics*, **274**(4):321-338. [doi:10.1016/S0040-1951(97)00009-7]

Letouzey, J., Sage, L., Müller, C., 1988. Geological and Structural Map of Eastern Asia, 1:2,500,000: Introductory Notes. Am. Assoc. Pet. Geol. Bookstore, USA, p.52.

Li, C.F., Zhou, Z.Y., Li, J.B., Hao, H.J., Geng, J.H., 2007. Structure of the northeasternmost South China Sea continental margin and ocean basin: geophysical constraints and tectonic implications. *Marginal Geophysical Research*, **28**(1):59-79. [doi:10.1007/s11001-007-9014-9]

Li, J.B., Jin, X., Gao, J.Y., 2002. Morpho-tectonic study on late-stage spreading of the eastern subbasin of South China Sea. *Science in China* (*Series D*), **49**(12): 1279-1288.

Li, M.B., Jin, X.L., Li, J.B., Chu, F.Y., Fang, Y.X., Tang, Y., 2005. Miocene deposition and palaeo-slope evolvement of the middle part of northern continental slope in the South China Sea. *Acta Oceanologica Sinaca*, **27**(3):73-79 (in Chinese).

Lin, A.T., Watts, A.B., Hesselbo, S.P., 2003. Cenozoic stratigraphy and subsidence history of the South China Sea margin in the Taiwan region. *Basin Research*, **15**(4):453-478. [doi:10.1046/j.1365-2117.2003.00215.x]

Lu, H., Fulthorpe, C.S., Mann, P., 2003. Three-dimensional architecture of shelf-building sediment drifts in the offshore Canterbury Basin. *New Zealand: Marine Geology*, **193**:19-47.

Lüdmann, T., Wong, H.K. 1999. Neotectonic regime on the passive continental margin of the northern South China Sea. *Tectonophysics*, **311**(1-4):113-138.

Mann, R.G., Bryant, W.R., Rabinowitz, P.D., 1992. Seismic Facies Interpretation of the Northern Green Canyon area, Gulf of Mexico. *In*: Watkins, J.S., Feng, Z.Q., McMillen, K.J. (Eds.), Geology and Geophysics of Continental Margins. AAPG Memoir, **53**:343-360.

Northrup, C.J., Royden, L.H., Burchfiel, B.C., 1995. Motion of the Pacific plate relative to Eurasia and its potential relation to Cenozoic extension along the eastern margin of Eurasia. *Geology*, **23**(8):719-722. [doi:10.1130/0091-7613(1995)023<0719:MOTPPR>2.3.O;2]

Seno, T., Stein, S., Gripp, A.E., 1993. A model for the motion of the Philippine Sea plate consistent with NUVEL-1 and geologic data. *Journal of Geophysical Research*, **98**(B10):17941-17948. [doi:10.1029/93JB00782]

Shanmugam, G., Moiola, R.J., 1988. Submarine fans: Characteristics, models, classification, and reservoir potential: *Earth Science Reviews*, **24**:383-428.

Sibuet, J.C., Hsu, S.K., 2004. How was Taiwan created. *Tectonophysics*, **379**(1-4):159-181. [doi:10.1016/j.tecto.2003.10.022]

Sun, Z., Zhong, Z.H., Zhou, D., Xia, B., Qiu, X.L., Zeng, Z.X., Jiang, J.Q., 2006. Research on the dynamics of the South China Sea opening: Evidence from analogue modeling. *Science in China Series D: Earth Sciences*, **49**(10): 1053-1069.

Suppe, J., 1984. Kinematics of arc-continent collision, flipping of subduction and back-arc spreading near Taiwan. *Mem. Geol. Soc. China*, **6**:21-33.

Tapponnier, P., Peltzer, G.L., le Dain, A.Y., Armijo, R., Cobbold, P., 1982. Propagaring extrusion tectonics in Asia: New insights from simple experiments with plasticine. *Geology*, **10**(12):611-616. [doi:10.1130/0091-7613(1982)10<611:PETIAN>2.0.CO;2]

Tapponnier, P., Peltzer, G., Armijo, R., 1986. On the Mechanics of the Collision between India and Asia. *In*: Coward, M.P., Ries, A.C. (Eds.), Collision Tectonics. Geol. Soc. London Spec., **19**:115-157.

Taylor, B., Hayes, D.E., 1980. The Tectonic Evolution of the South China Basin. *In*: Hayes, D.E. (Ed.), the Tectonic and Geologic Evolution of Southeast Asian Seas and Islands, Part 1. Am. Geophys. Union Geophys. Monogr., **23**:89-104.

Taylor, B., Hayes, D.E., 1983. Origin and History of the South China Sea basin. *In*: Hayes, D.E. (Ed.), the Tectonic and Geologic Evolution of Southeast Asian Seas and Islands, Part 2. Am. Geophys. Union Geophys. Monogr., **27**:23-56.

Teng, L.S., 1990. Geotectonic evolution of late Cenozoic arc-continental collision in Taiwan. *Tectonophysics*, **183**(1-4):57-76. [doi:10.1016/0040-1951(90)90188-E]

Tzeng, J., 1994. Tertiary Seismic Stratigraphic Analysis of the

Tainan Basin. M.S. Thesis, National Taiwan University, p.5-17 (in Chinese).

Weimer, P., 1990. Sequence stratigraphy, facies geometries, and depositional history of the Mississippi Fan, Gulf of Mexico. *AAPG Bulletin*, **74**:425-453.

Williams, P.R., Johnston, C.R., Almond, R.A., Simamora, W.H., 1988. Late Cretaceous to Early Tertiary structural elements of West Kalimantan. *Tectonophysics*, **148**(3-4):279-297. [doi:10.1016/0040-1951(88)90135-7]

Yu, H.X., Lin, X.Z., 1992. The seismic-stratigraphic analysis of the late Cenozoic stratum, Tainan Basin. *Acta Oceanographica Taiwanica*, **9**(2):6-12.

Zhong, J.Q., Huang, C.L., Zang, W.H., 1993. Geologic evolution analyse of Taixinan Basin in late Cenozoic Era. *Marine Sciences*, **12**(4):34-38 (in Chinese).

Zhou, D., 2002. Mesozoic strata and sedimentary environment in SW Taiwan Basin of NE South China Sea and Peikang High of western Taiwan. *Journal of Tropical Oceanography*, **21**(2):50-57 (in Chinese).

Zhou, D., Ru, K., Chen, H.Z., 1995. Kinematics of Cenozoic extension on the South China Sea continental margin and its implications for the tectonic evolution of the region. *Tectonophysics*, **251**(1-4):161-177. [doi:10.1016/0040-1951(95)00018-6]

Zhou, X.M., Li, W.X., 2000. Origin of Late Mesozoic igneous rocks in southeastern China: implications for lithosphere subduction and underplating of mafic magmas. *Tectonophysics*, **326**(3-4):269-287. [doi:10.1016/S0040-1951(00)00120-7]

Zhou, Z., Lao, Q., Chen, H., Ding, S., Liao, Z., 1996. Early Mesozoic Orogeny in Fujian, Southeast China. *In*: Hall, R., Blundell, D. (Eds.), Tectonics Evolution of Southeast Asia. Geol. Soc. Spec. Publ., **106**:549-556.