Terr. Atmos. Ocean. Sci., Vol. 19, No. 3, 257-278, June 2008 doi: 10.3319/TAO.2008.19.3.257(TT)

The Tectono-Thermal Events of Taiwan and Their Relationship with SE China

Ching-Ying Lan[1, *], Chun-Sun Lee[2], Tzen-Fu Yui[1], Hao-Tsu Chu[3], and Bor-Ming Jahn[1]

[1] *Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan, ROC*
[2] *Department of Earth Sciences, National Taiwan Normal University, Taipei, Taiwan, ROC*
[3] *Central Geological Survey, Minister of Economic Affairs, Taipei, Taiwan, ROC*

Received 6 February 2007, accepted 7 August 2007

ABSTRACT

We present a new synthesis of the tectono-thermal events of Taiwan, excluding the Coastal Range, based on existing isotopic, geochemical and geochronological data for granitic, metamorphic, volcanic and sedimentary rocks. Nd model ages (T_{DM}) and the inherited zircon ages consistently yielded Proterozoic ages, suggesting that the source rocks from the exposed rocks in Taiwan were formed in the Proterozoic, starting from about 2 Ga ago. The crustal evolution of Taiwan began in the Late Paleozoic (250 ± 20 Ma). Since then, five tectono-thermal events can be delineated: (I) an Early Jurassic event (200 - 175 Ma) registered in the marble and metapelites of the Tananao metamorphic basement complex of northern Taiwan and crystalline limestone of the basement rocks in western Taiwan; (II) a Late Jurassic event (~153 Ma) revealed by a meta-granite of the Tananao metamorphic basement complex of southern Taiwan; (III) a Late Mesozoic event (97 - 77 Ma) recorded in the rocks of the Tananao metamorphic basement complex and offshore of northern and western Taiwan; (IV) a Cenozoic of pre-Pliocene event (episodic from 56 to 9 Ma) registered in the dikes in the Central Range and the intraplate basalts of mainland Taiwan and offshore of northern and western Taiwan; and (V) an ongoing Late Cenozoic event (since 5 Ma) shown in the recent volcanics of onshore and offshore northern Taiwan and offshore northeastern Taiwan.

In comparison with the Cathysia foldbelts, Taiwan demonstrates similar Paleoproterozoic crustal residence ages, coeval Jurassic magmatism (Early Yanshanian) and Late Cretaceous (Late Yanshanian) orogeny. However, subduction-related magmatism was prevalent in Taiwan in comparison with both extension- and subduction-related magmatism in Cathaysia foldbelts during the Yanshanian orogeny. Rifting-related magmatism has continued in the Cathaysia foldbelts ever since Jurassic. Since Late Cretaceous, rifting-related magmatism migrated from the interior toward the coastal region in the Cathaysia foldbelts but it did not reach Taiwan until Paleogene. Since 5 Ma, subduction-related activity started in northern Taiwan. The volcanism in northern Taiwan was attributed to the Late Pliocene extensional collapse of the northern Taiwan mountain belt in response to the oblique collision of the northern Luzon arc with the Asian continent, but not directly related to the magmatism of the Ryukyu subduction zone. However, volcanism resulting from the spreading of the Okinawa trough manifests in the offshore region of northeastern Taiwan.

Key words: Tectono-thermal event, Taiwan, Tananao basement complex, Cathaysia foldbelts, Yanshanian Orogeny, Luzon arc, Okinawa trough

Citation: Lan, C. Y., C. S. Lee, T. F. Yui, H. T. Chu, and B. M. Jahn, 2008: The tectono-thermal events of Taiwan and their relationship with SE China. Terr. Atmos. Ocean. Sci., 19, 257-278, doi: 10.3319/TAO.2008.19.3.257(TT)

1. INTRODUCTION

Taiwan is composed of two major tectonic units separated by the Longitudinal Valley Fault. The western unit belongs to the continental margin of the Eurasian Plate, while the eastern unit, the Coastal Range, is an island arc of the Philippine Sea Plate. The arc was accreted to the continental margin in the late Tertiary. The previous version of crustal evolution of Taiwan (Jahn et al. 1986, 1992; Lan et al. 1996a) has been established through a series of isotope dating, supplemented by available geologic data up to the

* *Corresponding author*
E-mail: kyanite@earth.sinica.edu.tw

year of 1996. In the last decade, numerous isotopic, geochemical and geochronological data on Taiwan have been obtained. The purpose of this paper is to present a new synthesis of crustal evolution of Taiwan with incorporation of all post-1996 data.

Accordingly, this paper builds on the existing geochronological, Nd isotopic and geochemical literatures up to early 2007. We hope that the paper presented here will be a timely contribution to our understanding of this arealy insignificant but geologically and tectonically important island. The updated crustal evolution scheme is presented in Fig. 1. However, the precise timing of each tectono-thermal event in Taiwan must be refined by further high-precision in-situ geochronology investigation. The available age and Nd isotopic data for granitic, sedimentary and mafic to intermediate rocks (metamorphosed and un-metamorphosed) are given respectively in Appendixes 1, 2, and 3. We emphasize the following addenda:

(1) Confirmation of the Paleoproterozoic crustal residence age of Taiwan;
(2) Revelation of a Late Jurassic intrusive event (II);
(3) Support for the previously established events of crustal evolution of Taiwan for Late Mesozoic (III), Cenozoic of pre-Pliocene (IV) and Late Cenozoic (V) events.

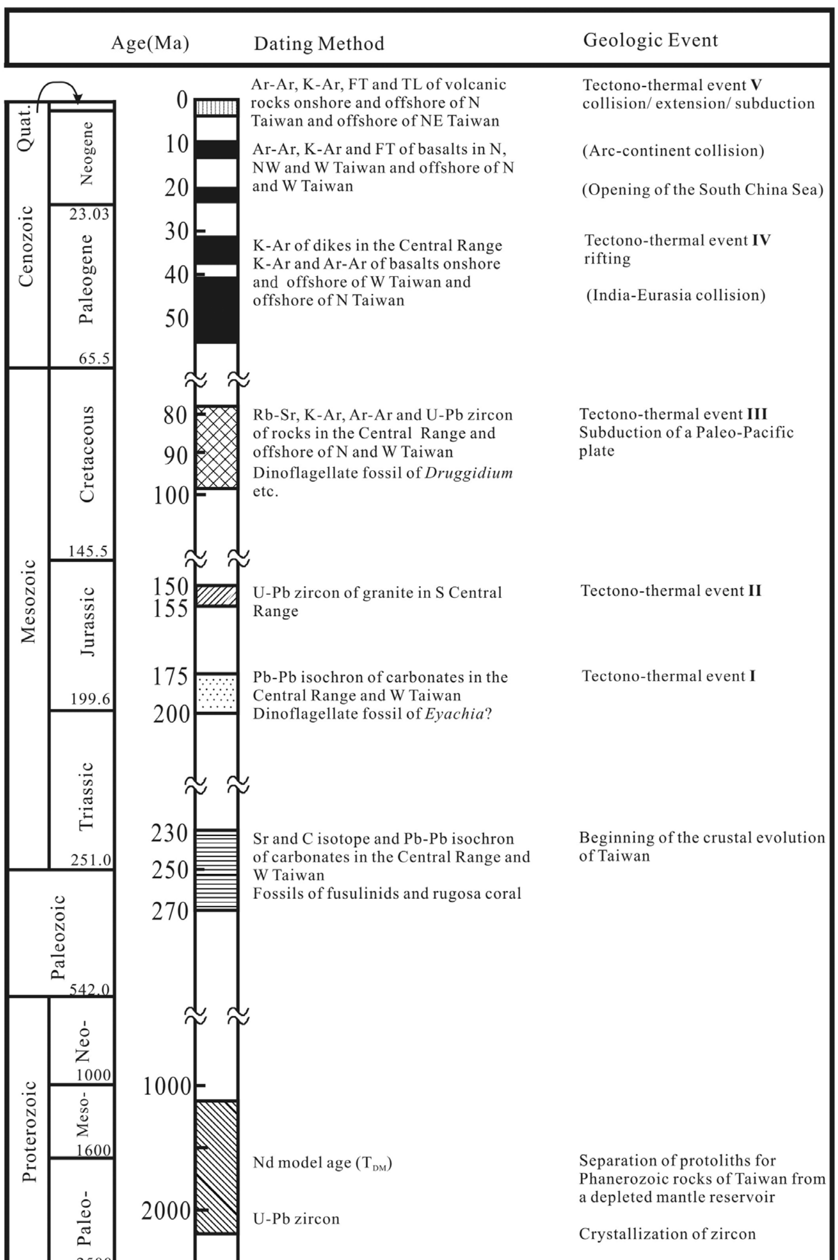

Fig. 1. Summary of geological events including five important tectono-thermal events (I to V) of Taiwan. Age scheme is after Gradstein et al. (2004). FT: fission track dating. TL: thermoluminescence dating. See text for the data sources.

2. CONFIRMATION OF THE PALEOPROTEROZOIC CRUSTAL RESIDENCE AGE OF TAIWAN

The crustal residence age or the pre-crustal history of Taiwan can be recognized through Nd model ages (T_{DM}) and the inherited zircon ages of crustal rocks. Based on the Nd model ages (Figs. 2a, b and Appendixes 1 and 2), the protoliths of the granitoids (Late Jurassic and Late Cretaceous) and sedimentary rocks (metamorphosed and un-metamorphosed) of Taiwan probably had resided in a crustal environment since Paleoproterozoic time, especially those from sedimentary rocks (Fig. 2b). As shown in Fig. 2a and Appendix 1, the Nd model ages of the granitoids (Jahn et al. 1986; Lan et al. 1995b; Yui et al. 1998) of the Tailuko belt of the Tananao metamorphic basement complex show a range from Meso- to Neo-Proterozoic age (1.5 to 0.7 Ga). The youngest T_{DM} age of 0.7 Ga was obtained from a Late Jurassic meta-granite (Yui et al. 1998). In comparison, T_{DM} ages of metamorphosed and un-metamorphose sedimentary rocks (Fig. 2b and Appendix 2) are restricted to Paleo- to Meso-Proterozoic ages from 2.3 to 1.2 Ga (Chen et al. 1990; Lan et al. 1995b, 2002; Sun et al. 1998). The oldest Nd model ages (2.3 Ga) are found from the blackschists of the Yuli belt of the Tananao metamorphic basement complex in the Juisui area (Sun et al. 1998). The younger Nd model ages for the granitoids compared to those of the sedimentary rocks is likely due to the input of the mantle component in the genesis of granitoids, so its ε_{Nd} was raised and the model ages reduced. River sediments in Taiwan could provide a quick way to survey the average composition of the crust exposed in their drainage areas. For example, river sediments collected near the mouths of Lanyangchi and Liwuchi have present day ε_{Nd} values of -11.8 and -10.6 and Nd model ages of 1.7 and 1.6 Ga, respectively (Chu 2005). Consistently, these two river sediments indicate the average crust of their drainage area is Paleoproterozoic, which is comparable with the Nd model ages obtained from the rocks.

Some inherited zircon grains were crystallized in Paleoproterozoic times as sustained by the discordia of U-Pb zircon ages using thermal ionization mass spectrometry method (TIMS), which gives upper intercept ages of 1668 ± 40 Ma (Jahn et al. 1986) and ~2087 Ma (Yui et al. 1996) for Late Cretaceous granitoids, ~1793 Ma for a Late Jurassic meta-granite, and ~2084 Ma for a Late Cretaceous meta-andesite (Appendix 4; Yui et al. 1998). Such Paleoproterozoic zircon grains have survived and been finally incorporated in the young (Late Jurassic and Late Cretaceous) granitic and andesitic (Late Cretaceous) magmas.

Although a middle Proterozoic crustal formation age has been proposed for the Phanerozoic rocks of Taiwan in Jahn et al. (1986, 1990) and Lan et al. (1996a) previously, Paleoproterozoic age is now confirmed to be the crustal formation age for the Phanerozic rocks of Taiwan. Additional supporting evidence comes from the newly revealed CHIME ages (Chen et al. 2006) of detrital monazites from four beach sands (two samples from NW Taiwan, two samples from SW Taiwan) and a sedimentary rock from the Paleogene strata of Taiwan. The relative proportion of monazite age population depicted the presence of Paleoproterozoic age for 43%, 27%, and 13% of the beach sands of NW and SW Taiwan and the Paleogene rock of Taiwan, respectively. All this evidence reinforces a Paleoproterozoic crustal residence age for Taiwan's crustal rocks. Furthermore, the monazites from the washout of the Neogene and Paleogene strata in W

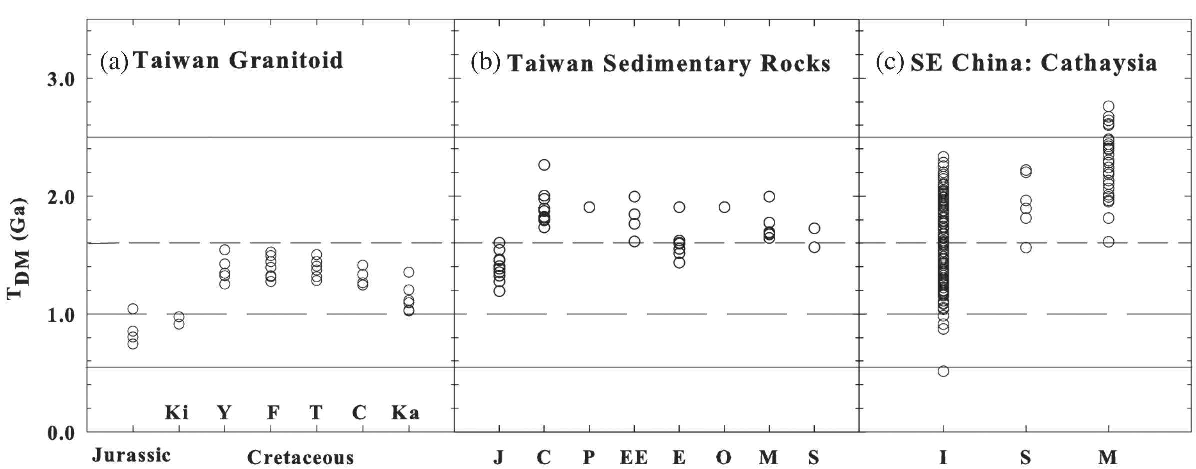

Fig. 2. T_{DM} age variation diagram for: (a) granitoid and (b) sedimentary (and meta-sedimentary) rocks from Taiwan, and (c) igneous (I), sedimentary (S) and metamorphic (M) rocks from Cathaysia foldbelts, SE China (ages limited to $^{147}Sm/^{144}Nd$ ratios between 0.08 and 0.15 in Chen and Jahn 1998). Data sources are: (a) Jahn et al. 1986; Lan et al. 1995b; Yui et al. 1998; (b) Chen et al. 1990; Lan et al. 1995b, 2002; Sun et al. 1998. Abbreviations for Cretaceous granitoid body in (a): C: Chipan; F: Fanpaochienshan; Ka: Kanagan; Ki: Kiyoku; T: Tachoshui; Y: Yuantoushan. Abbreviations in (b) for ages: C: Cretaceous; EE: early Eocene; E: Eocene; J: Jurassic; M: Miocene; O: Oligocene; P: Paleogene. S represents river sediments (Chu 2005).

Taiwan present good age-pattern correlation with those of the Minjiang river mouth sediments of SE China. This implies that the 1.8 Ga monazites of W Taiwan and Minjiang share the similar Wuyishan protolith. Such Paleoproterozoic crustal material of SE China has been incorporated in the generation of the bulk of the Phanerozoic rocks of Taiwan.

3. REVELATION OF A LATE JURASSIC INTRUSIVE EVENT (II) IN TAIWAN

No Late Jurassic tectono-thermal event has previously been recognized in Taiwan; however, its existence has been predicted to have taken place (Jahn et al. 1986). Here we document Late Jurassic meta-granite from southern Taiwan, i.e., Talun meta-granite (Chu 1993; Yui et al. 1998). The Talun meta-granite is located at Long. 121°2'42"E, and Lat. 23°7'35"N and is a plutonic body exposed on the riverbank of the Talunchi, which is a tributary of the Hsinwuluchi in the eastern part of the Southern Cross Island Highway. The rocks of its eastern boundary are greenschist, mica schist, and marble of the Tananao metamorphic complex. From aerial photography, the meta-granite has a distinct circular pattern of approximately one kilometer in diameter.

The discordia of TIMS U-Pb zircon analysis of the Talun meta-granite defines a lower intercept age of 152.6 ± 1.7 Ma and an upper intercept age of ~1793 Ma (Appendix 4a). The lower intercept age of Late Jurassic (152.6 ± 1.7 Ma) is interpreted as the time of the granite emplacement and is clearly distinguished from the Late Cretaceous ages (97 - 77 Ma) of the granitoids from the northern part of the Tananao metamorphic basement complex. Therefore, a new Late Jurassic intrusive event is recognized in Taiwan. Since this is the first report of a Jurassic thermal event in Taiwan, SHRIMP analysis on zircons from this granite body is underway to re-confirm the age.

The Late Jurassic meta-granite is fractionated K-rich I-type granite, with 74 - 78 wt% SiO_2, 12 - 14 wt% Al_2O_3, 4.9 - 5.3 wt% K_2O, and 2.2 - 2.7 wt% Na_2O. It shows moderately enriched light rare earth elements (LREE), relatively unfractionated heavy REE, with La_N = 42 - 90, Lu_N = 14 - 18 and $(La/Lu)_N$ = 2.7 - 6.5 and marked negative Eu anomalies (Eu/Eu* = 0.16 - 0.30). On a primitive mantle normalized trace-element diagram, it shows a significant depletion in Ba, Nb-Ta, Sr-P, and Ti, which is typical of calc-alkaline magmatism and shows close affinity with subduction related Late Cretaceous granitoids on the northern part of the Tananao complex, NE Taiwan (Lan et al. 1996b). The $\varepsilon_{Nd}(T)$ values are higher, ranging from +2.1 to +3.3, than those of Late Cretaceous granitoids. The higher $\varepsilon_{Nd}(T)$ values indicate higher mantle input (depleted oceanic crust) in the generation of Late Jurassic meta-granites relative to Late Cretaceous granitoids. The I_{Sr} values are also high, varying from 0.7084 to 0.7124, and are plotted away from the array set of common Taiwan igneous rocks (including the Miocene to Quaternary volcanics) in Fig. 3. The Miocene to Quaternary volcanic rocks are basaltic to andesitic in composition. They usually involve less crustal material than granitic rocks during their genesis. It is reasonable to see granitic rocks having higher I_{Sr} values than those of basaltic to andesitic rocks. The Late Jurassic meta-granites possess I_{Sr} values higher than that of Late Cretaceous granitoids. High I_{Sr} is caused by alteration and the highly fractionated nature of Late Jurassic meta-granites (Rb/Sr = 1.8 to 3.7) compared to Late Cretaceous granitoids (Rb/Sr = 0.2 to 1.4). Nevertheless, other coeval subduction related rocks, such as depleted oceanic crust, volcanic rocks, and basic intrusive rocks remain to be found.

4. SUPPORT FOR THE PREVIOUSLY ESTABLISHED EVENTS OF CRUSTAL EVOLUTION OF TAIWAN BY NEW DATA

4.1 Late Mesozoic Tectono-Thermal Event (III):

As described by Lan et al. (1996a), the Late Mesozoic event (97 to 77 Ma) is recorded mainly in the granitoids and associated pegmatite and amphibolites in the Tailuko belt of the Tananao complex. This event (ranging from 94 to 78 Ma) is also registered in the epidote amphibolites and omphacite-bearing high-pressure rocks of the Yuli belt of the Tananao complex. Such a coeval event serves as confirmation of the Late Cretaceous paired-metamorphic belts in the Tananao metamorphic basement complex as proposed by Yen (1963).

Coeval volcanic rocks have been confirmed from a meta-andesite in the Tailuko belt of the Tananao complex,

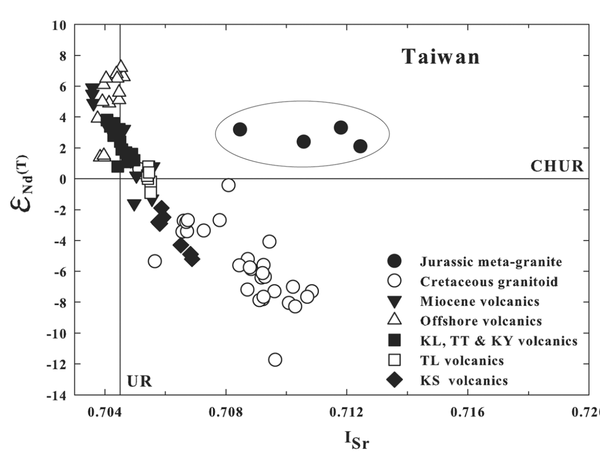

Fig. 3. $\varepsilon_{Nd}(T)$ versus I_{Sr} plot for Jurassic meta-granites in S Taiwan (Yui et al. 1998). For comparison, those of Cretaceous granitoids (Lan et al. 1995b), Miocene volcanics (Chung et al. 1995a), Pliocene-Quaternary offshore volcanics (Sekibisho, Kobisho, Mienhuayu, and Pengchiayu), Keelung (KL) volcanic group, Tatun (TT) volcanic group and Kuanyinshan (KY) volcanics, Tsaolingshan (TL) volcanics (Wang et al. 2004), and Kueishantao (KS) volcanics (Chen et al. 1995) are shown. Abbreviations: CHUR: chondritic uniform reservoir; UR: uniform reservoir.

NE Taiwan. The meta-andesite occurs alongside the Su-Hua highway about 10 km to the south of Suao, or 3 km to the north of Tungao (Lo and Liu 1984; Yui and Wu 1991). It is chemically similar to the modern oceanic island-arc medium-K calc-alkaline andesite. The discordia of TIMS U-Pb zircon analysis (Yui et al. 1998) defines a lower intercept age of 85 ± 2 Ma and an upper intercept age of ~2084 Ma (Appendix 4b). The newly analyzed results give ε_{Nd} and Sr isotopic composition as -2.8 (Appendix 3) and 0.7061, respectively. Such values are within the range for Late Cretaceous granitoids but approach the high ε_{Nd} and low Sr isotopic ratio value. The lower intercept age of 85 ± 2 Ma is interpreted as the best estimate for the andesite emplacement. As a whole, the Tananao metamorphic basement complex may represent a continental margin during Late Mesozoic.

A probably coeval intermediate plutonic rock was found from the offshore drilling of northern Taiwan, near the northern rim of the Kuanyin Uplift (Chen et al. 1997). It is a slightly metamorphosed (zeolites facies burial metamorphism) microdiorite. The whole-rock Ar-Ar plateau date of 71.5 ± 1.0 Ma is regarded as the metamorphic age. The microdiorite reflects the island arc geochemical character by having high Al_2O_3 content and depletion of Ta in the spidergram. It shows an ε_{Nd} of -2.7 (Appendix 1), which is comparable with the ε_{Nd} of -2.2 to -4.4 of Cretaceous volcanic rocks from Fujian (Fong et al. 1991) and the Late Cretaceous granitoids of Taiwan, especially those of the Kanagan gneiss (Lan et al. 1995b). Therefore, Chen et al. (1997) suggested that the microdiorite was emplaced earlier than 71.5 ± 1.0 Ma, and most likely related to the widespread Cretaceous magmatism in the coastal area of SE China.

Huahsu, the southwestern-most island of Penghu, is composed mainly of andesitic lava with subordinate epiclastics and basaltic, dacitic to rhyolitic dikes (Yang 1989). All the rocks have undergone low-grade metamorphism. Chloritization, epidotization and calcitization are common. TiO_2 content and AFM diagram for the whole rock indicate that all rocks belong to the calc-alkaline series of island arc volcanics. Zircon fission track datings gave 65 ± 3, 62 ± 4, and 61 ± 2 Ma for andesitic lava, dacitic dike and rhyolitic dike, respectively. These ages are interpreted as the cooling ages. Yang (1989) concluded that the magmatic age for the Huahsu volcanics should be older than the cooling age and most likely related to the volcanic arc formed in SE China during Mid-Jurassic to Cretaceous (Holloway 1981). The isotopic compositions of the rocks from Huahsu remain to be studied.

4.2 Cenozoic of Pre-Pliocene Tectono-Thermal Event (IV):

The Nd isotopic data for the volcanic rocks related to the Cenozoic of pre-Pliocene tectono-thermal event (IV) are presented in Appendix 3 and Fig. 4. As stated in Lan et al. (1996a), Paleogene basaltic rock (K-Ar whole rock age of 53.5 ± 2.7 Ma) from the drill hole of the Coastal Plain, metabasites from the Eocene and Miocene slate formation of the Central Range, and mafic dikes (K-Ar and Rb-Sr whole rock age of 37 - 32 Ma, and ε_{Nd} value of +1.3) cross-cutting the granitoids of the northern part of Tananao complex show geochemical feature transition from an arc (late Mesozoic subduction) to intraplate (Neogene extension) character. Neogene intraplate alkali and tholeiitic basalts were emplaced in two distinct periods in northwestern Taiwan: Early Miocene Kungkuan stage (23 - 20 Ma) and Late Miocene Chiaopanshan stage (13 - 9 Ma). They are represented by the basalts of the Kungkuan and Kuanhsi-Chutung areas, and on the Penghu Islands. Sr-Nd-Pb isotopic studies indicate the Early Miocene Kungkuan basalts have isotopic compositions (ε_{Nd} = +4.9 to +5.9) comparable with the seamount basalts from the South China Sea, suggesting the involvement of an EM2-type mantle source. By contrast, the Late Miocene Chiaopanshan basalts of Kuanhsi-Chutung area show different isotopic characteristics (ε_{Nd} = -1.3 to +3.6) indicating additional involvement of an EM1-type mantle component (Chung et al. 1995a). Thus, this pre-Pliocene event occurred episodically with ages at 54 Ma, 37 - 32 Ma, 23 - 20 Ma, and 13 - 9 Ma (Lan et al. 1996a).

Paleogene volcanic rocks were further recovered from deep drillings offshore of northern Taiwan and onshore and

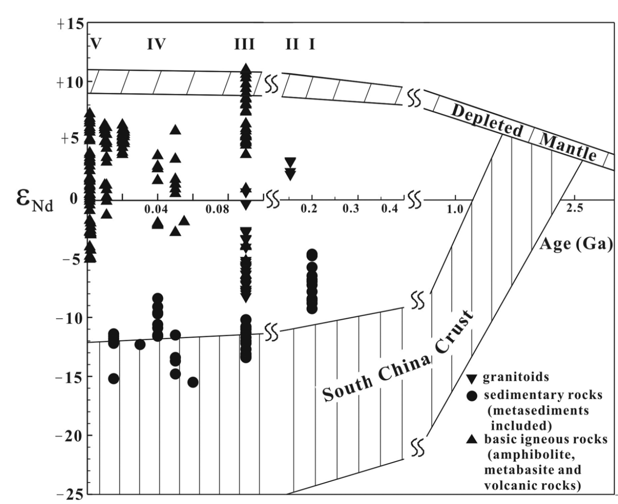

Fig. 4. Nd isotopic evolution diagram for granitoids, sedimentary (and meta-sedimentary) rocks, and basic igneous rocks (amphibolites, metabasites and volcanic rocks) of Taiwan. They represent the products of tectono-thermal events of I (200 - 175 Ma), II (~153 Ma), III (97 - 77 Ma), IV (56 - 41, 37 - 32, 23 - 20, 13 - 9 Ma), and V (< 3 Ma), respectively. The ages of the amphibolites and metabasites are not clear but are tentatively assigned as 90 Ma. The "South China Crust" is the Precambrian basement rocks of the Cathaysia foldbelts in Zhejiang (Badu Group) and Fujian (Mayuan Group) listed in the Table 5 of Chen and Jahn (1998). The data sources include those listed in Appendixes 1, 2, and 3 and Chen (1988), Lee (1994), Lo (2003) and Chu (2005).

offshore of western Taiwan. High-alumina basalts (Chen et al. 1997) with whole-rock Ar-Ar ages of 56 - 53 Ma and ε_{Nd} value of -1.9 were found from the drillings, offshore of northern Taiwan, in Tungyintao Ridge and Pengchiahsu Platform. An enriched magma source of EM2-type is suggested for such high-alumina basalts. However, trachybasalts to trachybasaltic andesites are the major rock types for the deep drillings onshore and offshore of western Taiwan and are distributed in Wangkung, Paochung and Chengan. Whole rock Ar-Ar dating gave an age of 54 - 41 Ma (Lo et al. 2000; Chen 2001). Such Eocene rocks show the enrichment of LREE and the large ion lithophile element (LILE) and the depletion of high field strength (HFS) elements with ε_{Nd} value ranging from -3.2 to +5.6. Together with the Sr-Nd-Pb isotopic data, Paleogene volcanic rocks from the deep inside the drilling site of western Taiwan were derived from a lithospheric mantle source that had been modified by Mesozoic subduction processes (Lo 2003).

Besides northwestern Taiwan, Neogene intraplate basalts and related rocks are reported from deep drillings offshore of northern Taiwan, from onshore of northern Taiwan, from deep drilling onshore and offshore of western Taiwan, and from submarine volcanoes offshore of southwestern Taiwan. One alkali basalt (Chen et al. 1997) recovered from the deep drilling, offshore of northern Taiwan, in the South Pengchiahsu Basin shows an ε_{Nd} value of +4.9 which is similar to that of Neogene Kungkuan basalts of northwestern Taiwan. In northern Taiwan, from Shiting to Yinko area, early Miocene (23 - 20 Ma) alkali basalts and late Miocene (12 - 9 Ma) tholeiites were found (Chen et al. 2001a). Although they appeared to be different rock types and erupted with a gap for about 10 m.y., both Miocene alkali basalts and tholeiites from northern Taiwan display Nd isotopic compositions (ε_{Nd} varying in a narrow range of +4.3 to +6.1) similar to the common Fujian-Taiwan Neogene intraplate basalts except for the Kuanhsi-Chutung volcanics. Deep-drilled core samples from offshore of western Taiwan (Tungliang) and onshore of western Taiwan (Peikang) were composed of basalt, while basanites are the major rock for submarine volcanoes offshore of southwestern Taiwan (Lo 2003). Whole rock Ar-Ar dating gave an age of Late Miocene (11.8 - 11.2 Ma) for the basalts of deep drillings and Early Miocene (22 - 21 Ma) for the basanites of submarine volcanoes (Lo et al. 2000; Chen 2001). The ε_{Nd} values are ~+6 for the former and +3.8 to +5.0 for the latter. Such Miocene volcanic rocks from western and southwestern Taiwan are similar to the ocean island basalts and the basalts from northwestern Taiwan, northern Taiwan and the South China Sea.

In summary, the first sub-episode of the four sub-episodes delineated by Lan et al. (1996a) for the pre-Pliocene tectono-thermal events (IV) should be expanded as 56 - 41 Ma. Hence the time range for the four sub-episodes is revised as Early Eocene (56 - 41 Ma), Late Eocene (37 - 32 Ma), Early Miocene (23 - 20 Ma), and Late Miocene (13 - 9 Ma). The composition of volcanic rocks shifts from a lithospheric mantle source (modified by Mesozoic subduction process) for Paleogene rocks to an asthenospheric mantle source for the Miocene intraplate basalts.

4.3 Ongoing Late Cenozoic Tectono-Thermal Event (V):

The Nd isotopic data for the volcanic rocks related to the Late Cenozoic tectono-thermal event (V) are presented in Appendix 3 and Fig. 4. The Late Cenozoic thermal event is best recorded in the Northern Taiwan Volcanic Zone (NTVZ), which comprises onshore volcanoes (Tsaolingshan, Kuanyinshan, Keelung volcanic group and Tatun volcanic group) and offshore volcanoes (Mienhuayu, Pengchiayu, Kobisho, and Sekibisho). Radiometric age data (Ar-Ar, K-Ar and fission track) show that the volcanism of NTVZ commenced at 2.8 - 2.6 Ma and lasted throughout the Quaternary (Liu et al. 1986; Liu 1987; Juang 1988, 1993; Wang and Chen 1990; Shinjo et al. 1991; Tsao 1994; Lee 1996; Wang et al. 2000; Chung et al. 2001). The NTVZ volcanic rocks consist predominantly of calc-alkaline andesites and basalts, except the low-K magmas of Sekibisho (Shinjo 1998) and Mienhuayu (Wang et al. 2002) and the shoshonitic and ultrapotassic series magma of Tsaolingshan (Chung et al. 2001). They have long been regarded as the westernmost part of the Ryukyu volcanic arc (Chen 1990; Teng et al. 1992; Juang 1993; Chung et al. 1995b; Teng 1996) due to the calc-alkaline geochemical characteristics commonly observed in the convergent-margin lavas.

The basalts and basaltic andesites from Mienhuayu and Pengchiayu present the highest ε_{Nd} value of +5.1 to +7.2 while the basalts from Tsaolingshan have the lowest ε_{Nd} of -0.9 to +0.8. The ε_{Nd} value of the other NTVZ volcanic rocks lies between them. Consequently, two mantle components are involved in the magma generation, the asthenosphere and the metasomatized subcontinental lithospheric mantle, represented by the Mienhuayu high-Mg basaltic andesites and the Tsaolingshan high-Mg potassic lavas, respectively. The overall NTVZ geochemical characteristics can be explained by various degrees of partial melting within a region of the ascending asthenospheric mantle, triggered by the extensional collapse of the northern Taiwan mountain belt, and interaction of these melts with overlying fluid- and the sediment-modified lithospheric mantle (Wang et al. 2004). Therefore, the magmatism of NTVZ resulted from the post-collisional extension related to the Late Pliocene orogenic collapse of the northern Taiwan mountain belt (Chen 1997; Wang et al. 1999, 2004) and is not simply related to the Ryukyu volcanic arc. The views and debates relating to the origin of NTVZ volcanic rocks have been discussed by Wang (2007).

The Late Cenozoic thermal event (V) is also registered in the Kueishantao, an emerged andesitic volcanic islet offshore of the Ilan plain, NE Taiwan. The Kueishantao is located in the western end of the Southernmost Part of Okinawa Trough (SPOT). The main volcanic activity on this islet occurred at 7 ± 0.7 Ka based on the thermoluminescence method (Chen et al. 2001b). The Okinawa Trough, extending from southwestern Kyushu, Japan to northeastern Taiwan, is widely regarded as an intracontinental back arc basin that is situated behind the Ryukyu arc-trench system owing to the subduction of the Philippine Sea plate underneath the Eurasian plate. According to Chen et al. (1995), the andesites from Kueishantao possess low ε_{Nd} values of -5.1 to -1.8, which can be discriminated from those of back arc magmas from the Middle Okinawa Trough (with ε_{Nd} value of +2.3 to +4.7). Hence, the magma from its southwestern tip segment (Kueishantao) is regarded as the product of "the onset of rifting" stage which reflects product of the Ryukyu subduction and it was assimilated with the overlying continental crust when it ascended. In comparison, magmas at the middle of the Okinawa Trough represent a more mature segment and reflect the product of back arc rifting. Chung et al. (2000) studied major and trace element concentrations for dredged volcanic rocks from submarine volcanoes within the SPOT area and andesites from Kueishantao. The rocks show a compositional range from medium-K andesites to rhyolites. Such a compositional range (mafic rocks not been recovered) differs from that delineated by the remainder of the Okinawa Trough, where magmas show bimodal composition (Shinjo et al. 1999). They also present the geochemical character marked by the enriched LREE pattern and the spidergram with the enrichment of LILE and depletion of HFSE, a feature typical of arc magmas from the Ryukyu subduction zone. Chu (2005) further reported major and trace elements and Sr-Nd-Pb isotopic compositions of the andesites from Kueishantao. The results indicate that some of the samples have unexpectedly high magnesium (MgO ≧ 5 wt% and Mg# > 0.5), relative to the silica contents (SiO_2 ~ 60 wt%). Hence the description 'high-Mg andesites' (HMAs) was coined. The HMAs also exhibit enriched LREE pattern and a spidergram of enrichment of LILE and depletion of HFSE, with low ε_{Nd} value (-5.0 to -4.3). More interestingly, the overall geochemical compositions of HMAs are very similar to those of the mean continental crust proposed by Rudnick and Fountain (1995). Such "continental" signatures require complicated magma genesis of the Kueishantao HMAs. Consequently, partial melting of the altered Philippine Sea oceanic crust and overlying subducting sediments, followed by a melt-mantle wedge interaction (Chu 2005) is a likely process for the formation of Kueishantao HMAs. In summary, despite being spatially contiguous with the Okinawa Trough, Kueishantao (and SPOT), which developed in the Quaternary, is not a simple back arc basin but instead an embryonic rift zone in which early arc volcanism occurs as a result of the Ryukyu subduction (Chung et al. 2000).

5. COMPARISON BETWEEN TAIWAN AND SE CHINA

5.1 Similar Paleoproterozoic Crustal Residence Age

The South China Block is tectonically composed of two major units, the Yangtze craton to the northwest and Cathaysia foldbelts (Cathaysia or Huanan block) to the southeast, separated by the Jiangshan-Shaoxing fault. The Yangtze craton has an old Paleoarchean (≧ 3.2 Ga) core in its northern part (Kongling group, Hubei: Qiu et al. 2000; Zhang et al. 2006) and the Archean basement is widespread beneath Proterozoic upper-crustal rocks in Ningxiang, Hunan; Jingshan, Hubei and Zhenyuan, Guizhou (Zheng et al. 2006).

The Cathaysia foldbelts can be further divided into the marginal belt to the southeast and the Caledonian belt to the northwest. The marginal belt is a terrain consisting of the Late Mesozoic intrusive and volcanic rocks while the Caledonian belt is overprinted by Indosinian (Middle Triassic to Middle Jurassic) to Yanshanian (Jurassic to Cretaceous) events. The metamorphic basement rocks recognized in the marginal belt were mainly found in the northeast part (Wuyishan area of southwestern Zhejiang, northwestern Fujian and eastern Jiangxi) and southwestern part (Yunkai area of western Guangdong and eastern Guangxi). The oldest rocks in the Wuyishan area are Paleoproterozoic (2.1 to 1.7 Ga) in age and are limited to the Badu group in southwestern Zhejiang (Hu et al. 1993; Gan et al. 1995; Li et al. 1996) and the Mayuan group in northwestern Fujian (Yuan et al. 1991; Li 1997; Li et al. 2000). Such a Paleoproterozoic age is also supported by the SHRIMP U-Pb zircon age of "Danzhu granite" in southwestern Zhejiang (Li and Li 2007), which gave an upper intercept age of 1832 ± 6 Ma as the best estimate of the magmatic crystallization age. Hong Kong Island also lies within the marginal belt. Upper intercept ages from the discordia of TIMS U-Pb zircon datings (Davis et al. 1997) for the Mesozoic Hong Kong granites range from Neoarchean (3000 ± 700 Ma) to Cambrian (507 ± 70 Ma), with half of them older than Paleoproterozoic (≧ 1845 ± 15 Ma) age. However, no concordant Archean ages have been delineated for rocks in Hong Kong. In contrast, the Yunkai group of the Yunkai area in western Guangdong was formed in Neoproterozoic (1.0 - 0.9 Ga) time (Zhang and Yuan 1997).

The basement beneath the Caledonian belt of the Cathaysia foldbelts is poorly known mainly due to the overprinted Indosinian and Yanshanian events. In situ U-Pb and Hf-isotope analyses (Xu et al. 2005) of zircons from the rocks of the Nanling Mountains reveal the Mesoproterozoic (1.5 - 1.3 Ga) crustal basement, the Paleoproterozoic event (1.8 Ga) and minor Neoarchean component (2.7 - 2.5 Ga). Xu et al. (2005) envisaged that central parts of Cathaysia foldbelts may contain Archean microcontinental fragments. However, the rounded shape and the possible detrital origin of these zircons make the existence of Archean nucleus in the Nanling Mountains questionable. Hainan Island is located in the southwestern Caledonian belt and the Baoban Complex is believed to be the basement rock of the Hainan Island. SHRIMP U-Pb zircons from two granodiorites of Baoban Complex form concordant mean ages of 1436 ± 7 Ma and 1431 ± 5 Ma (Li et al. 2002). These Mesoproterozoic ages are regarded as the minimum age for the basement of Hainan Island.

Chen and Jahn (1998) compiled Nd model ages of Cathaysia foldbelts (Fig. 2c) which gave 2.3 to 0.9 Ga (except Qinghu quartz monzonite of 0.51 Ga) for Phanerozoic granitoids and acidic volcanic rocks; 2.2 to 1.5 Ga for sedimentary rocks; and 2.7 to 1.6 Ga for metamorphic rocks. The oldest T_{DM} age of 2.7 Ga set the upper limit age of the basement rock of the Cathaysia foldbelts. The Neoarchean model ages (> 2.5 Ga) are confined to the metamorphic basement rocks of the Longquan group in SW Zhejiang (Chen and Jahn 1998). The Mesozoic granites (164 to 136 Ma) of Hong Kong have yielded Nd model ages ranging from 2.0 to 1.3 Ga (Darbyshire and Sewell 1997). Shen and Lin (2002) summarized the Nd model ages of metasedimentary and granitic to volcanic rocks of the Cathaysia foldbelts and gave 3.3 to 1.3 Ga and 2.8 to 1.0 Ga, respectively. Although the Nd model ages and zircon upper intercept ages gave the oldest crustal residence age of the Cathaysia foldbelts being Paleoarchean (up to 3.3 Ga), SHRIMP age datings reveal the oldest basement age is Paleoproterozoic (Li 1997; Li and Li 2007). On the whole, the oldest basement in Cathaysia foldbelts is Paleoproterozoic in comparison with the Yangtze craton being Paleoarchean. Thus, the Yangtze craton and the Cathaysia foldbelts have different Precambrian tectonic histories and may have been juxtaposed during the Neoproterozoic continental collision (Li et al. 2002).

As stated in the previous sections, Nd model ages of the metapelites from the Tananao metamorphic basement complex and Tertiary sedimentary rocks of Taiwan (Fig. 2b and T_{DM} in Appendix 2) range from 2.3 to 1.2 Ga. The oldest T_{DM} age of 2.3 Ga sets the upper limit for the crustal residence age of Taiwan. Granitoid and meta-andesite from the Tananao metamorphic basement complex of Taiwan give 2.1 to 1.7 Ga upper intercept ages from the discordia of TIMS U-Pb zircon dating. All these ages suggest Taiwan has a Paleoproterozoic crustal residence age which is comparable with the beginning of the crustal history of the Cathaysia foldbelts in SE China. The difference between them is that Paleoproterozoic basement rocks exist in the Cathaysia foldbelts, while not in Taiwan.

5.2 Coeval Mesozoic Magmatism

The oldest age of the Cathaysia basement is Paleoproterozoic and the crustal evolution of the Cathaysia foldbelts started in Paleoproterozoic time. Principal orogenies in the Cathaysia foldbelts (Li et al. 2002; Li et al. 2005; Xu et al. 2005; Zhou et al. 2006) have been broadly related to 1.4 Ga (Mesoproterozoic Grenvillian orogeny), 1.0 Ga (Neoproterozoic Sibao orogeny), 0.8 Ga (Neoproterozoic Rodinia rifting), 440 - 420 Ma (Caledonian), 280 - 230 Ma (Hercynian), 251 - 205 Ma (Indosinian), and 180 - 67 Ma (Yanshanian). In comparison, the crustal history of Taiwan is short and began in late Paleozoic time (~250 Ma) with the deposition of carbonates and clastic sediments in the Asian continental margin (Jahn et al. 1992). Indosinian magmatism has not been found in Taiwan. The oldest magmatism so far documented in Taiwan is Late Jurassic (~153 Ma) meta-granite (Yui et al. 1998), which cropped out in the Tananao metamorphic complex of southern Taiwan. Such Late Jurassic magmatism can be correlated with Early Yanshanian (180 - 142 Ma) magmatism in the Cathaysia foldbelts (Zhou et al. 2006).

Most of the Early Yanshanian granitoid-volcanic rocks of the Cathaysia foldbelts are distributed in the interior, 250 - 800 km away from the southeast coastline and extend northeastward for about 1000 km. The composition of Early Yanshanian granitoids is dominated by calc-alkaline I-type granites which spatially coexist with minor gabbro-diorite (Zhou et al. 2006) although peraluminous S-type granites are dominant in the western part during 164 - 153 Ma (Li 2000). In the coastal area, Early Yanshanian plutonic and volcanic rocks of Hong Kong have yielded ages ranging from 164 to 136 Ma (Sewell et al. 1992; Davis et al. 1997; Sewell and Campbell 1997). Three isotopic domains for granitic rocks are delineated from northwest to southeast in Hong Kong. Both I- and A-type granites exist in three domains with $\varepsilon_{Nd}(T)$ and initial $^{87}Sr/^{86}Sr$ varying from -12.2 to -9.2 and 0.7104 - 0.7152, -7.0 to -4.2 and 0.7061 - 0.7102, and -6.5 to -5.4 and 0.7067 - 0.7109, respectively (Darbyshire and Sewell 1997). However, in the Cathaysia foldbelts, the occurrences of Early Yanshanian volcanic rocks are far less than those of the granitoids and crop out mainly in southern Hunan to eastern Guangxi, southern Jiangxi and southern Guangdong, and there are a few occurrences in northern Guangdong (Zhou et al. 2006). Three episodes (c.175 Ma, c.160 Ma, and c.150 Ma) of Jurassic magmatism have been delineated from the basalts of southern Hunan and the syenite intrusions of eastern Guangxi (Li et al. 2004). The $\varepsilon_{Nd}(T)$ of the rocks decreases from +5 to -2 with decreasing magmatic age. Trace-element patterns vary from OIB to arc and back to OIB affinity. Such variations are inferred by Li et al. (2004) to have resulted from post-Indosinian orogenic lithosphere extension and thinning. Rift basins distributed mainly in southern Jiangxi and southwestern Fujian are synchronous with the bimodal volcanic rocks of basalts and rhyolites (Zhou et al. 2006). Jurassic (~160 Ma) I- and A-type granites from central Guangdong (Li et al. 2007), having $\varepsilon_{Nd}(T)$ of -12.2 to -4.3 and -2.4 to +0.3, respectively, were interpreted as anorogenic magmatism formed in response to foundering of an early Mesozoic subducted flat-slab beneath continental SE China. In comparison, the Late Jurassic I-type Talun meta-granites (Fig. 3) of southern Taiwan possess $\varepsilon_{Nd}(T)$ values (+2.1 to +3.3) higher than those of the I- and A-type Jurassic granites from central Guangdong and Hong Kong, while the I_{Sr} values of Talun meta-granites are comparable with those of the zone 1 granites of Hong Kong. The high $\varepsilon_{Nd}(T)$ values of Taiwan Late Jurassic meta-granites indicate a prominent mantle component (depleted oceanic crust) during granite genesis via subduction. On the whole, the Early Yanshanian magmatism in Cathaysian foldbelts represents both compression and extension tectonics while that in Taiwan indicate subduction affinity (Yui et al. 1998).

In Taiwan, the Late Jurassic magmatic episode is followed by the Late Cretaceous magmatic event (97 - 77 Ma), which can be correlated with the Late Yanshanian (142 - 67 Ma) magmatism in the Cathaysia foldbelts (Zhou et al. 2006). The Late Yanshanian magmatism in the Cathaysia foldbelts is further divided into four episodes at: 146 - 136 Ma, 129 - 122 Ma, 109 - 101 Ma, and 97 - 87 Ma (Li 2000). Granites (A- and I-type), acidic-intermediate volcanics, mafic dikes and basalts are found for all four episodes. A-type granites of four episodes have $\varepsilon_{Nd}(T)$ of -8 to -3, indicting a mantle-derived magma influenced by different degrees of crustal components. The high-K calc-alkaline I-type granites and acidic-intermediate volcanic rocks show large variation in $\varepsilon_{Nd}(T)$ from -12 to -4 suggesting significant involvement of crustal materials in their origin and indicating these rocks coincide with the syntectonic granites series. The mafic dikes show similarities to within-plate basalts with $\varepsilon_{Nd}(T)$ of +4 to +5. A-type granitic and within-plate basaltic magmatism from 140 - 90 Ma suggests a dominant extensional environment in the region (Li 2000). Zhou et al. (2006) divided the Late Yanshanian magmatism into two stages as early Late Yanshanian (K_1) granitoid-volcanic rocks and late Late Yanshanian (K_2) tholeiitic basalt volcanism. The K_1 basalts show LILE enrichments with Nb-Ta depletion, indicating subduction-related origin, while the K_2 basalts do not show Nb-Ta depletion suggesting back-arc basin origin. Furthermore, three stages were proposed for the Late Yanshanian magmatism distributed along the coastal area of the Cathaysia foldbelts (Chen et al. 2004). They were: (1) syn-orogenic (130 - 110 Ma) high-Al gabbros plus medium-K calc-alkaline tonalite, trondhjemite and granodiorites; (2) post-orogenic (110 - 99 Ma) high-K calc-alkaline I-type granitoids; and (3) an-orogenic (94 - 81 Ma) miarolitic A-type granites plus shoshonitic bimodal rhyolites. Lin (2001) combined the coastal area of the Cathaysia foldbelts (as the inner belt) and Tananao metamorphic belt of Taiwan (as the outer belt) and divided the Late Yanshanian magmatism into three stages; those being: syn-orogenic (130 - 110 Ma), post-orogenic (110 - 80 Ma), and an-orogenic (late Cretaceous to Miocene). They are characterized by low-K high-Al gabbroic to medium-K tonalitic intrusions, high-K calc-alkaline granitic intrusions and bimodal-intraplate magmatism, respectively. Accordingly, the Late Cretaceous granitoids in the Tananao metamorphic belt represents the post-orogenic magmatism of Lin (2001). However, Early Cretaceous syn-orogenic low-K high-Al gabbroic to medium-K tonalitic intrusions and Late Cretaceous post-orogenic bimodal-intraplate magmatism of Lin (2001) are awaiting confirmation in the Tananao metamorphic belt of Taiwan. Thus, the petrological characters of all the Late Yanshanian rocks in the Cathaysia foldbelts suggest both arc (Lan et al. 1997; Zhou and Li 2000; Zhou et al. 2006) and extensional (Li and McCulloch 1998; Li 2000) environments. In comparison, the Late Cretaceous (97 - 77 Ma) magmatism of Taiwan was confined to the K_2 stage and presented by the I-type granitoids (Lan et al. 1996b) and intermediate rocks of meta-andesite in the Tananao metamorphic complex (Lo and Liu 1984; Yui and Wu 1991; Yui et al. 1998), microdiorite in the offshore region of northern Taiwan (Chen et al. 1997) and lava and epiclastics in Huahsu (Yang 1989) without any extensional magmatism. Coeval products of paired metamorphic belts with high-temperature/low-pressure Tailuko belt (pegmatite and granitoid) and high-pressure/low-temperature Yuli belt (epidote amphibolite and omphacite-bearing rock) support the existence of a subduction environment in Taiwan during the K_2 stage.

5.3 Time-Lag in Magmatism from Late Mesozoic to Miocene

Since the Late Cretaceous, the tectonic environment of the continental margin of SE China has changed from compression to a rifting regime (Taylor and Hayes 1983; Ru and Piggot 1986; Qiu et al. 1991), which caused the cessation of the Andean-type magmatism and the subsequent onset of the post-orogenic magmatism. The crustal extension or rifting prevailing in SE China probably migrated from the interior toward the continental margin. Along with the dominant calc-alkaline rocks, Mesozoic to Paleogene mantle-derived magmas with OIB geochemical features form a southward/southeastward younging trend. From inland to the coast, there are Middle Jurassic (~175 Ma) alkali basalts in southern Hunan (Chung et al. 1997), Cretaceous (140 - 90 Ma) mafic dikes in northern Guangdong (Li and McCulloch 1998) and Paleogene (64 - 38 Ma) basalts in the Sanshui basin (Chung et al. 1997; Zhu et al. 2004). Actively bimodal magmatism of the coastal regions of Zhejiang, Guangdong and Fujian (Charvet et al. 1994; Lee 1994; Chung et al. 1997) and the emplacement of abundant mafic and felsic dikes in the coastal area of Fujian (Lee 1994; Lan et al. 1995a; Yang 1998) are the result of such rifting. K-Ar and ^{40}Ar-^{39}Ar age datings gave 90.7 ± 2.0 Ma to 86.3 ± 1.9 Ma (Lee 1994) and 97.0 ± 1.6 Ma to 82.6 ± 1.3 Ma

(Yang 1998) for the mafic dikes from the Chinmen and Liehyu islands and the felsic and mafic dikes from the Pintan-Dongshan metamorphic belt of coastal Fujian, respectively. The mantle component in the magmatic source gradually increased as the eruption ages became younger for the Paleogene basalts from Sanshui basin (ε_{Nd} increases from +3.2 at 56 Ma to +6.4 at 38 Ma; Zhu et al. 2004). The lithospheric extension might not have reached Taiwan until Paleogene when Paleogene mafic dike rocks intruded the Late Cretaceous granitic rocks (Jahn et al. 1986; Juang and Bellon 1986) and the other parts of the Tananao metamorphic basement complex of Taiwan, Paleogene volcanic rocks in the offshore of northern Taiwan (Chen et al. 1997) and on shore and offshore of western Taiwan (Lo et al. 2000; Chen 2001; Lo 2003), and metabasites within the Eocene and Miocene slate formations of Taiwan (Yui et al. 1994). The Late Cretaceous to Paleogene magmatic rocks from both Taiwan and the Cathaysia foldbelts originated from a lithospheric mantle source that has been modified by the subduction process (i.e., depletion of HFSE and ε_{Nd} = -5 to +5.6) (Lan et al. 1995a; Lo 2003).

Cenozoic continental lithospheric extension of Taiwan and the Cathaysia foldbelts has resulted in the Neogene intraplate basaltic volcanism associated with the pull-apart basins in Taiwan, the Taiwan Strait, Zhejiang, Fujian, Guangdong, and the Leiqiong region (Peng et al. 1986; Zhou et al. 1988; Chung et al. 1994; Lan et al. 1994; Ho 1998; Ho et al. 2000, 2003; Zhu et al. 2004). According to the timing of the cessation of the South China Sea floor spreading (~16 Ma, Chung et al. 1997), the Neogene volcanic activity in the Cathaysia foldbelts can be divided into two periods: the first period (> 16 Ma, i.e., 34.3 - 16.3 Ma) being of sparse volcanic activity with small amounts of lava and pyroclastics, and the second period (< 16 Ma) being of active eruption with large amounts of lava and minor pyroclastics. For the Leiqiong area, volcanic activity was most extensive during the Pleistocene. In comparison, the most active volcanism for Taiwan (including northern, northwestern, western and southwestern Taiwan) was in the Oligocene-Early Miocene (23 - 20 Ma) and Late Miocene (13 - 9 Ma), and for the Taiwan Strait in the Miocene (16 - 8 Ma). All the Neogene basaltic rocks from Taiwan (excluding those occurring in the Kuanhsi-Chutung area), the Taiwan Strait, Zhejiang, Fujian, and Leiqiong possess coherent elemental and isotopic characteristics comparable to the seamount basalts of the South China Sea (Tu et al. 1992) with insignificant crustal contamination (Chung et al. 1995a). Their lead isotope ratios display EM-2 type character distinct from those of the Kuanhsi-Chutung basalts, which required additional mixing of an EM-1 type component. The "enriched mantle" components (EM-1 and EM-2) reside in different levels of the continental lithospheric mantle. Reactivation of the unique EM-1 source is ascribed to the collision of the Luzon arc and the Asian continent as early as 12 Ma (Teng 1990), which terminated intraplate volcanism around Taiwan (Chung et al. 1995a, b).

5.4 Unique Magmatism in Taiwan after the Miocene

Starting ~12 Ma, Taiwan became an active mountain belt created by the oblique collision of the Luzon arc and the Eurasian continent (Teng 1990 for review). Despite the ongoing collision in south-central Taiwan, extensional collapse began in northern Taiwan about 5 Ma (Teng 1996). Consequently, a series of onshore and off-shore volcanism occurred in northern Taiwan during the Late Pliocene and Quaternary (~2.8 Ma to recent), which altogether constitute the NTVZ. Most NTVZ volcanics have arc-like geochemical features with significant enrichments in LILE and Pb and depletion in HFSE, which indicate that their mantle source regions must have been modified by processes associated with the adjacent Ryukyu subduction zone. Embryonic rifting associated with arc volcanism occurred in an offshore region of northeastern Taiwan, Kueishantao, as a result of the Ryukyu subduction (Chen et al. 1995; Chung et al. 2000; Chu 2005) no later than 7 ± 0.7 Ka (Chen et al. 2001b). In contrast, the Cathaysia foldbelts have inherited a rift environment and intraplate volcanism since the Jurassic. In other words, for the last 5 m.y. Taiwan has its unique tectono-thermal history, which is distinct from that of the Cathaysia foldbelts.

6. CONCLUDING REMARK

The sequence of tectono-thermal events for Taiwan is established based on the presently available (up to early 2007) geochronological, isotopic, and geochemical literature. It is then compared with that of the Cathaysia foldbelts of SE China. Both Taiwan and the Cathaysia foldbelts share similar Paleoproterozoic crustal residence ages. The Cathaysia foldbelts began its crustal history in Paleoproterozoic time while Taiwan had a much younger crustal history, which started only in Permo-Triassic time. Indosinian magmatism registered in the Cathaysia foldbelts has not been found in Taiwan. The oldest magmatism so far documented in Taiwan is the Late Jurassic I-type meta-granite. This can be correlated with the Early Yanshanian magmatism in the Cathaysia foldbelts. In Taiwan, Late Jurassic magmatism is followed by Late Cretaceous subduction-related magmatism. Such Late Cretaceous magmatism of Taiwan can be correlated with the late Late Yanshanian (K_2) magmatism in the Cathaysia foldbelts, where subduction-related, continental back-arc, and post-collision extensional magmatisms occurred. Since the Late Cretaceous to the present, post-orogenic magmatism, including intraplate basalt, mafic and felsic dikes and bimodal magmatism, has been widespread throughout the Cathaysia foldbelts; and it migrated from the interior toward the continental margin. However, such intraplate magmatism had not reached Taiwan until the Paleogene. Intraplate magmatism was terminated by the collision of the Luzon arc with the Asian continent as early as 12 Ma. Unlike the Cathaysia foldbelts, unique volcanism relating to the Ryukyu subduction zone and the rifting of Okinawa trough occurred in the last 5 Ma along onshore and offshore northern and northeastern Taiwan.

Taiwan is situated in the continental margin of SE China. However, from the Late Jurassic, the tectonic regimes of Taiwan and Cathaysia foldbelts began to differ. The Cathaysia foldbelts involved both post-Indosinian lithospheric extension/thinning and the subduction of the paleo-Pacific plate beneath southern China. Since Late Cretaceous, rifting has been predominant in the Cathaysia foldbelts up to the present. In Taiwan, compression has been dominant due to the subduction of the paleo-Pacific plate beneath southern China since the Late Jurassic. Rifting propagating from the interior of the Cathaysia foldbelts reached Taiwan during the Paleogene. Since the Late Miocene, compression has taken place, followed by rifting for the last 5 m.y. In summary, the magmatism occurring in Taiwan demonstrates a major subduction/accretion process in the continental margin of SE China, while magmatism in the Cathaysia foldbelts manifests the prevalent intraplate extensional tectonism related to continental SE China.

Acknowledgements Part (the tectono-thermal events of Taiwan) of this review paper was presented as a poster during the symposium on "Continental Growth and Orogeny in Asia" held at the Academia Sinica, Taipei, in March, 2006. W. Y. Hsu, Y. S. Chia, F. L. Lee, and T. S. Wu of the Academia Sinica are thanked for their assistance in isotopic analyses and figure drawing. We are grateful to Prof. Cheng-Hong Chen and an anonymous reviewer for their critical and constructive review. This work is supported by the Academia Sinica and the National Science Council of the Republic of China. This is a contribution of the Institute of Earth Sciences, Academia Sinica, IESAS1182.

REFERENCES

Charvet, J., H. Lapierre, and Y. W. Yu, 1994: Geodynamic significance of the Mesozoic volcanism of southeastern China. *J. SE Asian Earth Sci.*, **9**, 387-396.

Chen, C. H., 1989: Nd-Sr-O isotopic study of Cenozoic arc volcanic rocks in Taiwan. Ph.D. Thesis, Inst. Geol., National Taiwan Univ., 198 pp. (in Chinese)

Chen, C. H., 1990: Igneous Rocks of Taiwan. *Central Geol. Surv. Spec. Publ.*, **1**, 137 pp. (in Chinese)

Chen, C. H., 1997: Extensional collapse of the northern Taiwan mountain belt: Comment. *Geology*, **25**, 855-856.

Chen, C. H., B. M. Jahn, T. Lee, C. H. Chen, and J. Cornichet, 1990: Sm-Nd isotopic geochemistry of sediments from Taiwan and implications for the tectonic evolution of southeast China. *Chem. Geol.*, **88**, 317-332.

Chen, C. H., T. Lee, Y. N. Shieh, C. H. Chen, and W. Y. Hsu, 1995: Magmatism at the onset of back-arc basin spreading in the Okinawa Trough. *J. Volcano. Geotherm. Res.*, **69**, 313-322.

Chen, C. H., C. Y. Lee, T. C. Huang, and J. S. Ting, 1997: Radiometric ages and petrological and geochemical aspects of some late Cretaceous and Paleogene volcanic rocks beneath the northern offshore of Taiwan. *Petrol. Geol. Taiwan*, **31**, 61-88.

Chen, C. H., S. H. Chung, H. H. Wang, C. H. Chen, and S. L. Chung, 2001a: Petrology and geochemistry of Neogene continental basalts and related rocks in northern Taiwan (III): Alkali basalts and tholeiites from Shiting-Yinko area. *West. Pac. Earth Sci.*, **1**, 19-46.

Chen, C. H., W. Lin, C. Y. Lan, and C. Y. Lee, 2004: Geochemical, Sr and Nd isotopic characteristics and tectonic implications for three stages of igneous rock in the Late Yanshanian (Cretaceous) orogeny, SE China. *Trans. R. Soc. Edinburgh: Earth Sci.*, **95**, 237-248.

Chen, C. H., H. Y. Lu, W. Lin, and C. Y. Lee, 2006: Thermal event records in SE China coastal areas: Constraints from monazite ages of beach sands from two sides of the Taiwan Strait. *Chem. Geol.*, **231**, 118-134.

Chen, C. N., 2001: Ar-Ar dating and the geochemistry of the volcanic rocks drilled from western central Taiwan. Master Thesis, Inst. Geol., National Taiwan Univ., 63 pp. (in Chinese)

Chen, J. and B. M. Jahn, 1998: Crustal evolution of southeastern China: Nd and Sr isotopic evidence. *Tectonophysics*, **284**, 101-133.

Chen, S. J., 1988: Isotope and trace element geochemistry of Neogene basaltic rocks in western Taiwan. Master Thesis, Inst. Geol., National Taiwan Univ., 80 pp. (in Chinese)

Chen, Y. G., W. S. Wu, C. H. Chen, and T. K. Liu, 2001b: A date for volcanic eruption inferred from a siltstone xenolith. *Quat. Sci. Rev.*, **20**, 869-873.

Chu, C. H., 2005: Generation of high-Mg andesites in the Kueishantao volcano, the southernmost part of the Okinawa Trough. Master Thesis, Inst. Geol., National Taiwan Univ., 98 pp. (in Chinese)

Chu, H. T., 1993: The discovery of granite boulders from the upstream of the Hsinwuluchi, southeastern flank of the Central Range of Taiwan. Program and Abstract Volume, Annual Meeting Geol. Soc. China, 19. (in Chinese)

Chung, S. L., S. S. Sun, K. Tu, C. H. Chen, and C. Y. Lee, 1994: Late Cenozoic basaltic volcanism around the Taiwan Strait, SE China: Product of lithosphere-asthenosphere interaction during continental extension. *Chem. Geol.*, **112**, 1-20.

Chung, S. L., B. M. Jahn, S. J. Chen, T. Lee, and C. H. Chen, 1995a: Miocene basalts in northwestern Taiwan:

Evidence for EM-type mantle sources in the continental lithosphere. *Geochim. Cosmochim. Acta*, **59**, 549-555.

Chung, S. L., T. F. Yang, C. Y. Lee, and C. H. Chen, 1995b: The igneous provinciality in Taiwan: consequence of continental rifting superimposed by Luzon and Ryukyu subduction systems. *J. SE Asian Earth Sci.*, **11**, 73-80.

Chung, S. L., H. Cheng, B. M. Jahn, S. Y. O'Reilly, and B.Q. Zhu, 1997: Major and trace element, and Sr-Nd isotope constrains on the origin of Paleogene volcanism in South China prior to the South China Sea opening. *Lithos*, **40**, 203-220.

Chung, S. L., S. L. Wang, R. Shinjo, C. S. Lee, and C. H. Chen, 2000: Initiation of arc magmatism in an embryonic continental rifting zone of the southernmost part of Okinawa Trough. *Terr. Nova*, **12**, 225-230.

Chung, S. L., K. L. Wang, A. J. Crawford, V. S. Kamenetsky, C. H. Chen, C. Y. Lan, and C. H. Chen, 2001: High-Mg potassic rocks from Taiwan: Implications for the genesis of orogenic potassic lavas. *Lithos*, **59**, 153-170.

Darbyshire, D. P. F. and R. J. Sewell, 1997: Nd and Sr isotope geochemistry of plutonic rocks from Hong Kong: Implications for granite petrogenesis, regional structure and crustal evolution. *Chem. Geol.*, **143**, 81-93.

Davis, D. W., R. J. Sewell, and S. D. G. Campbell, 1997: U-Pb dating of Mesozoic rocks from Hong Kong. *J. Geol. Soc. London*, **154**, 1067-1076.

Fong, Z., S. Huang, J. Li, M. Xe, G. Wang, W. Hei, R. Qi, Y. Zhiou, and Z. Wu, 1991: Mesozoic volcanology and mineralization related to volcanics in Yongtai-Dehua district, Fujian province. *Bull. Nanjing Inst. Min. Res., Supple.*, **9**, 1-100. (in Chinese)

Gan, X., H. Li, D. Sun, W. Jin, and F. Zhao, 1995: A geochronological study on early Proterozoic granitic rocks, southwestern Zhejiang. *Acta Petrol. Mineral.*, **14**, 1-8. (in Chinese)

Gradstein, F. M., J. G. Ogg, A. G. Smith, W. Bleeker, and L. J. Lourens, 2004: A new Geologic Time Scale, with special reference to Precambrian and Neogene. *Episodes*, **27**, 83-100.

Ho, K. S., 1998: Petrology and geochemistry of Cenozoic basalts from southern China. Ph.D. Thesis, Inst. Oceanog., National Taiwan Univ., 580 pp. (in Chinese)

Ho, K. S., J. C. Chen, and W. S. Juang, 2000: Geochronology and geochemistry of late Cenozoic basalts from the Leiqiong area, southern China. *J. Asian Earth Sci.*, **18**, 307-324.

Ho, K. S., J. C. Chen, C. H. Lo, and H. L. Zhao, 2003: ^{40}Ar-^{39}Ar dating and geochemical characteristics of late Cenozoic basaltic rocks from the Zhejiang-Fujian region, SE China: Eruption ages, magma evolution and petrogenesis. *Chem. Geol.*, **197**, 287-318.

Holloway, N. H., 1981: The north Palawan block, Philippines: Its relation to the Asian Mainland and its role in the evolution of the South China Sea. *Geol. Sci. Malaysia Bull.*, **14**, 19-58.

Hu, X., J. Xu, C. Tong, and C. Chen, 1993: The geological characteristics of 1.9 Ga granodiorite in southwestern Zhejiang and its significance. *Geol. Rev.*, **39**, 557-563. (in Chinese)

Jahn, B. M., F. Martineau, J. J. Peucat, and J. Cornichet, 1986: Geochronology of the Tananao Schist Complex, Taiwan, and its regional tectonic significance. *Tectonophysics*, **125**, 103-124.

Jahn, B. M., X. H. Zhou, and J. L. Li, 1990, Formation and tectonic evolution of southeastern China and Taiwan: Isotopic and geochemical constraints. *Tectonophysics*, **183**, 145-160.

Jahn, B. M., W. R. Chi, and T. F. Yui, 1992: A late Permian formation of Taiwan (marbles from Chia-Li well no. 1): Pb-Pb isochron and Sr isotopic evidence and its regional significance. *J. Geol. Soc. China*, **35**, 193-218.

Juang, W. S., 1988: Geochronology and chemical variations of late Cenozoic volcanic rocks in Taiwan. Ph.D. Thesis, Inst. Oceanog., National Taiwan Univ., 231 pp. (in Chinese)

Juang, W. S., 1993: Diversity and origin of Quaternary basaltic magma series in northern Taiwan. *Bull. Natl. Museum Nat. Sci.*, **4**, 125-166.

Juang, W. S. and H. Bellon, 1986: Potassium-argon ages of the Tananao Schist in Taiwan. *Mem. Geol. Soc. China*, **7**, 405-416.

Lan, C. Y., T. Lee, S. A. Mertzman, T. W. Wu, B. M. Jahn, T. F. Yui, and J. J. S. Shen, 1991: Geochemical and isotopic study of gneiss-associated metabasites at the Central Range, Taiwan. *Proc. Geol. Soc. China*, **34**, 233-266.

Lan, C. Y., S. L. Chung, S. A. Mertzman, and W. Y. Hsu, 1994: Petrology, geochemistry and Nd-Sr isotope of late Miocene basalts in Liehyu and Chinmen, Fujian. *J. Geol. Soc. China*, **37**, 309-334.

Lan, C. Y., S. L. Chung, S. A. Mertzman, and C. H. Chen, 1995a: Mafic dikes from Chinmen and Liehyu islands, off SE China: petrochemical characteristics and tectonic implication. *J. Geol. Soc. China*, **38**, 183-214.

Lan, C. Y., T. Lee, B. M. Jahn, and T. F. Yui, 1995b: Taiwan as a witness of repeated mantle inputs - Sr-Nd-O isotopic geochemistry of Taiwan granitoids and metapelites. *Chem. Geol.*, **124**, 287-303.

Lan, C. Y., C. H. Chen, C. H. Chen, S. L. Chung, T. Lee, C. M. Wang Lee, and T. F. Yui, 1996a: The crustal evolution of continental Taiwan. *J. Geol. Soc. China*, **39**, 337-353.

Lan, C. Y., B. M. Jahn, S. A. Mertzman, and T. W. Wu, 1996b: Subduction-related granitic rocks of Taiwan. *J. SE Asian Earth Sci.*, **14**, 11-28.

Lan, C. Y., S. L. Chung, and S. A. Mertzman, 1997: Mineralogy and geochemistry of granitic rocks from Chinmen, Liehyu and Dadan islands, Fujian. *J. Geol. Soc.*

China, **40**, 527-558.

Lan, C. Y., C. S. Lee, J. J. S. Shen, C. Y. Lu, S. A. Mertzman, and T. W. Wu, 2002: Nd-Sr isotopic composition and geochemistry of sediments from Taiwan and their implications. *West. Pac. Earth Sci.*, **2**, 205-222.

Lee, C. Y., 1994: Chronology and geochemistry of basaltic rocks from Penghu islands and mafic dikes from east Fujian: Implications for the mantle evolution of SE China since Late Mesozoic. Ph.D. Thesis, Inst. Geol., National Taiwan Univ., 226 pp. (in Chinese)

Lee, S. F., 1996: Volcanic sequence study of the Tatun volcano group: The Chihsinshan subgroup. Master Thesis, Inst. Geol., National Taiwan Univ., 136 pp. (in Chinese).

Li, S., Y. Chen, N. Ge, X. Hu, and D. Liu, 1996: Isotopic ages of metavolcanic rocks and metacryst mylonite in the Badu group in southwestern Zhejiang province and their implications for tectonics. *Acta Petrol. Sin.*, **12**, 79-87. (in Chinese)

Li, W. X., X. H. Li, and Z. X. Li, 2005: Neoproterozoic bimodal magmatism in the Cathaysia Block of South China and its tectonic significance. *Precam. Res.*, **136**, 51-66.

Li, X. H., 1997: Timing of the Cathaysia Block formation: Constraints from SHRIMP U-Pb zircon geochronology. *Episodes*, **20**, 188-192.

Li, X. H., 2000: Cretaceous magmatism and lithospheric extension in Southeast China. *J. Asian Earth Sci.*, **18**, 293-303.

Li, X. H. and M. T. McCulloch, 1998: Geochemical characteristics of Cretaceous mafic dikes from northern Guangdong, SE China: Age, origin and tectonic significance. In: Martin, F. J. F., S. L. Chung, C. H. Lo, and T. Y. Lee (Eds.), Mantle Dynamics and Plate Interactions in East Asia, AGU Geodynamics Series, 27, 405-419.

Li, X. H., M. Sun, G. J. Wei, Y. Liu, C. Y. Lee, and J. Malpas, 2000: Geochemical and Sm-Nd isotopic study of amphibolites in the Cathaysia Block, southeastern China: evidence for an extremely depleted mantle in the Paleoproterozoic. *Precam. Res.*, **102**, 251-262.

Li, X. H., S. L. Chung, H. Zhou, C. H. Lo, Y. Liu, and C. H. Chen, 2004: Jurassic intraplate magmatism in southern Hunnan-eastern Guangxi: $^{40}Ar/^{39}Ar$ dating, geochemistry, Sr-Nd isotopes and implications for the tectonic evolution of SE China. In: Malpas, J., C. J. N. Fletcher, J. R. Ali, and J. C. Aitchison (Eds.), Aspects of the Tectonic Evolution of China. *Geol. Soc., London, Spec. Publ.*, **226**, 193-215.

Li, X. H., Z. X. Li, W. X. Li, Y. Liu, C. Yuan, G. Wei, and C. Qi, 2007: U-Pb zircon, geochemical and Sr-Nd-Hf isotopic constraints on age and origin of Jurassic I- and A-type granites from central Guangdong, SE China: A major igneous event in response to foundering of a subducted flat-slab? *Lithos*, **96**, 186-204.

Li, Z. X. and X. H. Li, 2007: Formation of the 1300-km-wide intracontinental orogen and postorogenic magmatic province in Mesozoic South China: A flat-slab subduction model. *Geology*, **35**, 179-182.

Li, Z. X., X. H. Li, H. Zhou, and P. D. Kinny, 2002: Grenvillian continental collision in south China: New SHRIMP U-Pb zircon results and implications for the configuration of Rodinia. *Geology*, **30**, 163-166.

Lin, W., 2001: Late Yanshanian intrusive magmatism in coastal region of South China and tectonic implications. Ph.D. Thesis, Inst. Geol., National Taiwan Univ., 237 pp. (in Chinese)

Liu, T. K., 1987: Some new radiometric ages of rocks from Taiwan. Program and Abstract Volume, Annual Meeting Geol. Soc. China, 62.

Liu, T. K., C. H. Chen, and S. H. Jiang, 1986: Fission-track study of igneous rocks from northern Taiwan. Unpublished report to the National Science Council, Taiwan, 7 pp.

Lo, C. H., T. Y. Lee, and S. L. Chung, 2000: The evolution of thermal event and the development of oil basin in Taiwan region (II). Unpublished report to the National Science Council, Taiwan, 192 pp. (in Chinese)

Lo, H. J. and T. K. Liu, 1984: A preliminary study of metamorphosed andesite in the Tananao Schist. *Acta Geol. Taiwan.*, **22**, 189-195.

Lo, Y. M., 2003: Geochemistry and petrogenesis of Cenozoic basaltic rocks drilled from western Taiwan. Master Thesis, Inst. Geol., National Taiwan Univ., 84 pp. (in Chinese)

Peng, Z. C., R. E. Zartman, K. Futa, and D. G. Chen, 1986: Pb-, Sr- and Nd-isotopic systematics and chemical characteristics of Cenozoic basalts, eastern China. *Chem. Geol.*, **59**, 3-33.

Qiu, Y. M., S. Gao, N. J. McNaughton, D. I. Groves, and W. Ling, 2000: First evidence of > 3.2 Ga continental crust in the Yangtze craton of South China and its implications for Archean crustal evolution and Phanerozoic tectonics. *Geology*, **28**, 11-14.

Qiu, Y. X., Q. J. Wu, X. Ji, J. C. Li, H. P. Zhong, and Z. G. Sheng, 1991: Meso-Cenozoic taphrogeny and dispersion in the continental margin of southeast China and adjacent area. *Tectonophysics*, **197**, 257-269.

Ru, K. and J. D. Piggot, 1986: Episodic rifting and subsidence in the South China Sea. *Bull. Am. Assoc. Petrol. Geol.*, **70**, 1136-1155.

Rudnick, R. L. and D. M. Fountain, 1995: Nature and composition of the continental crust: A lower crustal perspective. *Rev. Geophys.*, **33**, 267-309.

Sewell. R. J. and S. D. G. Campbell, 1997: Geochemistry of coeval Mesozoic plutonic and volcanic suites in Hong Kong. *J. Geol. Soc., London*, **154**, 1053-1066.

Sewell, R. J., D. P. F. Darbyshire, R. L. Langford, and P. J.

Strange., 1992: Geochemistry and Rb-Sr geochronology of Mesozoic granites from Hong Kong. *Trans. R. Soc. Edinburgh, Earth Sci.*, **83**, 269-280.

Shen, W. and H. Lin, 2002: Isotope studies of basement metamorphic, granitic and volcanic rocks in SE China and its crust evolution. In: Wang, D. and X. Zhou (Eds.), Genesis of Late Mesozoic Granitic Volcanic-plutonic Complexes in SE China and Crustal Evolution, Chap. 10, Science Press, Beijing, 230-272. (in Chinese)

Shinjo, R., 1998: Petrochemistry and tectonic significance of the emerged late Cenozoic basalts behind the Okinawa trough - Ryukyu arc system. *J. Volcano. Geotherm. Res.*, **80**, 39-53.

Shinjo, R., M. Ban, K. Saito, and Y. Kato, 1991: K-Ar dating of the volcanic rocks in the Ryukyu arc. *J. Japanese Asso. Mineral. Petrol. Econ. Geol.*, **86**, 323-328. (in Japanese)

Shinjo, R., S. L. Chung, Y. Kato, and M. Kimura, 1999: Geochemical and Sr-Nd isotopic characteristics of volcanic rocks from the Okinawa Trough and Ryukyu Arc: Implications for the evolution of a young, intracontinental back arc basin. *J. Geophys. Res.*, **104**, 10591-10608.

Sun, C. H., A. D. Smith, and C. H. Chen, 1998: Nd-Sr isotopic and geochemical evidence on the protoliths of exotic blocks in the Juisui area, Yuli belt, Taiwan. *Int. Geol. Rev.*, **40**, 1076-1087.

Taylor, B. and D. E. Hayes, 1983: Origin and history of the South China Basin. In: Hayes, D. E. (Ed.), Tectonic and Geologic Evolution of Southeast Asian Seas and Islands, Part 2. *AGU Geophy. Monogr.*, **27**, 23-56.

Teng, L. S., 1990: Geotectonic evolution of late Cenozoic arc-continent collision in Taiwan. *Tectonophysics*, **183**, 57-76.

Teng, L. S., 1996: Orogenic collapse of the northern Taiwan mountain belt. *Geology*, **24**, 959-962.

Teng, L. S., C. H. Chen, W. S. Wang, T. K. Liu, W. S. Juang, and J. C. Chen, 1992: Plate kinematic model for late Cenozoic arc magmatism in northern Taiwan. *J. Geol. Soc. China*, **35**, 1-18.

Tsao, S. J., 1994: Potassium-Argon age determination of volcanic rocks from the Tatun volcano group. *Bull. Central Geol. Surv.*, **9**, 137-154. (in Chinese)

Tu, K., M. F. J. Flower, R. W. Carlson, M. Zhang, and G. H. Xie, 1992: Magmatism in the South China basin, I. Isotopic and trace element evidence for an endogenous Dupal mantle component. *Chem. Geol.*, **97**, 47-63.

Wang, K. L., 2007: Origin of the Pliocene-Quaternary magmatism in Northern Taiwan: reviews and debates. Program and Abstract, Annual Meeting Taiwan Geosciences Assembly, T4-3B-04.

Wang, K. L., S. L. Chung, C. H. Chen, R. Shinjo, T. F. Yang, and C. H. Chen, 1999: Post-collisional magmatism around northern Taiwan and its relation with opening of the Okinawa Trough. *Tectonophysics*, **308**, 363-376.

Wang, K. L., C. H. Chen, S. L. Chung, L. H. Lin, C. H. Lo, T. F. Yang, and H. Y. Lee, 2000: Field occurrence, $^{40}Ar/^{39}Ar$ dating and petrochemical features of volcanic rocks in Mienhuayu off NE Taiwan. *J. Geol. Soc. China*, **43**, 247-266.

Wang, K. L., S. L. Chung, C. H. Chen, and C. H. Chen, 2002: Geochemical constraints on the petrogenesis of high-Mg basaltic andesites from the Northern Taiwan Volcanic Zone. *Chem. Geol.*, **182**, 513-528.

Wang, K. L., S. L. Chung, S. Y. O'Reilly, S. S. Sun, R. Shinjo, and C. H. Chen, 2004: Geochemical constraints for the genesis of post-collisional magmatism and the geodynamic evolution of the northern Taiwan region. *J. Petrol.*, **45**, 975-1011.

Wang, W. S. and C. H. Chen, 1990: The volcanology and fission track age dating of pyroclastic deposits in Tatun volcano group, northern Taiwan. *Acta Geol. Taiwan.*, **28**, 1-30.

Xu, X. S., S. Y. O'Reilly, W. L. Griffin, P. Deng, and N. J. Pearson, 2005: Relict Proterozoic basement in the Nanling Mountains (SE China) and its tectonothermal overprinting. *Tectonics*, **24**, doi: 10.1029/2004TC001652.

Yang, H. C., 1989: Geochemistry and fission track studies on the volcanics of Huahsu, Penghu Hsien, Taiwan. Master Thesis, Inst. Geol., National Taiwan Univ., 116 pp. (in Chinese)

Yang, H. C., 1998: ^{40}Ar-^{39}Ar thermochronological study on the Pingtan-Dongshan metamorphic belt, SE China. Ph.D. Thesis, Inst. Geol., National Taiwan Univ., 217 pp. (in Chinese)

Yen, T. P., 1963: The metamorphic belts within the Tananao Schist terrain of Taiwan. *Proc. Geol. Soc. China*, **6**, 72-74.

Yuan, Z. X., L. S. Wu, Z. Q. Zhang, and X. J. Ye, 1991: The Sm-Nd, Rb-Sr isotopic age-dating of Mayuan group in northern Fujian. *Acta Petrol. Mineral.*, **10**, 127-132. (in Chinese)

Yui, T. F. and T. W. Wu, 1991: The geochemical characteristics of the metamorphosed andesite/dacite from the Tananao Schist Complex in the Tungao area, Taiwan. *Proc. Geol. Soc. China*, **34**, 147-162.

Yui, T. F., T. W. Wu, and B. M. Jahn, 1990: Geochemistry and plate-tectonic significance of the metabasites from the Tananao Schist Complex of Taiwan. *J. SE Asian Earth Sci.*, **4**, 357-368.

Yui, T. F., T. W. Wu, and C. Y. Lu, 1994: Geochemical characteristics of metabasites from the slate formations of Taiwan. *J. Geol. Soc. China*, **37**, 53-67.

Yui, T. F., L. Heaman, and C. Y. Lan, 1996: U-Pb and Sr isotopic studies on granitoids from Taiwan and Chinmen-Lieyu and tectonic implication. *Tectonophysics*, **263**, 61-76.

Yui, T. F., C. Y. Lan, L. Heaman, and H. T. Chu, 1998: Late Cretaceous meta-andesite and late Jurassic (meta-) granite in the Tananao basement of Taiwan. Program and Abstract Volume, Annual Meeting Geol. Soc. China, 31.

Zhang, S. B., Y. F. Zheng, Y. B. Wu, Z. F. Zhao, G. Shan, and F. Y. Wu, 2006: Zircon isotope evidence for ≧ 3.5 Ga continental crust in the Yangtze craton of China. *Precam. Res.*, **146**, 16-34.

Zhang, Z. L. and H. H. Yuan, 1997: Dating for Luoxia unit of Yunkai group with zircon grain evaporation method. *Acta Geosci. Sin.*, **18**, 105-107. (in Chinese)

Zheng, J., W. L. Griffin, S. Y. O'Reilly, M. Zhang, N. Pearson, and Y. Pan, 2006: Widespread Archean basement beneath the Yangtze craton. *Geology*, **34**, 417-420.

Zhou, X. H., B. Q. Zhu, R. X. Liu, and W. J. Chen, 1988: Cenozoic basaltic rocks in eastern China. In: Macdougall, J. D. (Ed.), Continental Flood Basalts. Kluwer Academic Publ., 311-330.

Zhou, X. M. and W. X. Li, 2000: Origin of Late Mesozoic igneous rocks in southeastern China: Implication for lithosphere subduction and underplating of mafic magmas. *Tectonophysics*, **326**, 269-287.

Zhou, X. M., T. Sun, W. Z. Shen, L. S. Shu, and Y. L. Niu, 2006: Petrogenesis of Mesozoic granitoids and volcanic rocks in South China: A response to tectonic evolution. *Episodes*, **29**, 26-33.

Zhu, B. Q., H. F. Wang, Y. W. Chen, X. Y. Chang, Y. G. Hu, and J. Xie, 2004: Geochronological and geochemical constraint on the Cenozoic extension of Cathaysian lithosphere and tectonic evolution. *J. Asian Earth Sci.*, **24**, 163-175.

APPENDIX

Appendix 1. Sm-Nd isotopic data of granitoids form Taiwan.

Sample No.	Rock type	Locality	Age (Ma)	[Sm] (ppm)	[Nd] (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	εNd(0)	$^{143}Nd/^{144}Nd(T)$	εNd(T)	T_{DM} (Ga)	Data* source
TL6	meta-granite	Talun River	153	3.02	13.32	0.1371	0.512746	2.1	0.512609	3.3	0.80	6
TL7	meta-granite	Talun River	153	3.75	17.76	0.1277	0.512732	1.8	0.512604	3.2	0.74	6
TL13	meta-granite	Talun River	153	3.51	14.42	0.1472	0.512697	1.2	0.512550	2.1	1.04	6
SC1	meta-granite	Talun River	153	3.09	14.18	0.1317	0.512694	1.1	0.512562	2.4	0.85	6
BJ-132-82	granite	Yuantoushan	85.8	6.43	31.82	0.1221	0.512402	-4.6	0.512330	-3.8	1.25	3
BJ-123-82	granite	Chipan	90.3	5.92	29.52	0.1212	0.512390	-4.8	0.512319	-4.0	1.24	3
BJ-125-82	paragneiss	Chipan	90.3	5.55	27.84	0.1205	0.512333	-5.9	0.512262	-5.1	1.33	3
Ki1	granitoid	Kiyuku		1.98	10.25	0.1168	0.512571	-1.3	0.512502	-0.4	0.91	4
Ki2	granitoid	Kiyuku		2.32	13.7	0.1024	0.512445	-3.8	0.512385	-2.7	0.97	4
Y1	granitoid	Yuantoushan	87.3	0.68	2.12	0.1939	0.512670	0.1	0.512556	0.7		4, 5
Y2	granitoid	Yuantoushan	87.3	6.07	28.19	0.1302	0.512429	-4.2	0.512352	-3.3	1.32	4, 5
Y3	granitoid	Yuantoushan	87.3	5.98	34.7	0.1042	0.512185	-8.9	0.512124	-7.8	1.34	4, 5
Y4	granitoid	Yuantoushan	87.3	5.06	31.1	0.0984	0.511981	-12.9	0.511923	-11.7	1.54	4, 5
Y5	granitoid	Yuantoushan	87.3	6.34	34.8	0.1101	0.512185	-8.9	0.512120	-7.8	1.42	4, 5

Appendix 1. (Continued)

Sample No.	Rock type	Locality	Age (Ma)	[Sm] (ppm)	[Nd] (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	εNd(0)	$^{143}Nd/^{144}Nd(T)$	εNd(T)	T_{DM} (Ga)	Data* source
F3	granitoid	Fanpaochienshan	90	6.63	37.4	0.1072	0.512228	-8.0	0.512165	-7.0	1.32	4, 5
F4	granitoid	Fanpaochienshan	90	5.62	30.5	0.1114	0.512216	-8.3	0.512150	-7.3	1.39	4, 5
F5	granitoid	Fanpaochienshan	90	4.26	25.6	0.1006	0.512209	-8.4	0.512150	-7.3	1.27	4, 5
F6	granitoid	Fanpaochienshan	90	4.7	27.8	0.1022	0.512191	-8.7	0.512131	-7.6	1.31	4, 5
F7	granitoid	Fanpaochienshan	90	3.6	19.2	0.1134	0.512199	-8.6	0.512132	-7.6	1.44	4, 5
F8	granitoid	Fanpaochienshan	90	5.38	28.36	0.1147	0.512179	-9.0	0.512111	-8.0	1.49	4, 5
F9	granitoid	Fanpaochienshan	90	4.75	24.9	0.1153	0.512168	-9.2	0.512100	-8.2	1.52	4, 5
T1	granitoid	Tachoshui	87.3	5.41	27.24	0.1201	0.512266	-7.3	0.512195	-6.4	1.44	4, 5
T2	granitoid	Tachoshui	87.3	5.69	29.9	0.1151	0.512266	-7.3	0.512198	-6.3	1.37	4, 5
T3	granitoid	Tachoshui	87.3	5.55	27.42	0.1224	0.512310	-6.4	0.512238	-5.6	1.40	4, 5
T4	granitoid	Tachoshui	87.3	5.08	25.6	0.1200	0.512226	-8.1	0.512155	-7.2	1.50	4, 5
T5	granitoid	Tachoshui	87.3	6.03	32.8	0.1112	0.512289	-6.9	0.512224	-5.8	1.28	4, 5
T6	granitoid	Tachoshui	87.3	5.91	30.2	0.1183	0.512327	-6.1	0.512257	-5.2	1.31	4, 5
C1	granitoid	Chipan	90.3	5.94	29.26	0.1227	0.512308	-6.5	0.512236	-5.6	1.41	3, 4
C2	granitoid	Chipan	90.3	5.95	30.9	0.1164	0.512298	-6.7	0.512229	-5.7	1.33	3, 4
C3	granitoid	Chipan	90.3	5.54	27.68	0.1210	0.512386	-4.9	0.512315	-4.1	1.26	3, 4
C4	granitoid	Chipan	90.3	5.33	26.97	0.1195	0.512280	-7.0	0.512210	-6.0	1.41	3, 4
Ka1	granitoid	Kanagan	90	5.36	27	0.1200	0.512320	-6.2	0.512249	-5.3	1.35	4, 5
Ka2	granitoid	Kanagan	90	6.36	30.48	0.1262	0.512461	-3.5	0.512387	-2.6	1.20	4, 5
Ka3	granitoid	Kanagan	90	5.83	33.7	0.1046	0.512410	-4.5	0.512348	-3.4	1.03	4, 5
Ka4	granitoid	Kanagan	90	4.91	26.3	0.1129	0.512416	-4.4	0.512350	-3.4	1.11	4, 5
Ka5	granitoid	Kanagan	90	6.12	34.1	0.1085	0.512444	-3.8	0.512380	-2.8	1.02	4, 5
Ka6	granitoid	Kanagan	90	5.02	26	0.1167	0.512455	-3.6	0.512386	-2.7	1.09	4, 5
A-1	microdiorite	Kuanyin Uplift	Cretaceous	3.7			0.512501	-2.7				1, 2

* *1. Cheng-Hong Chen, personal communication 2007; 2. Chen et al. 1997; 3. Jahn et al. 1986; 4. Lan et al. 1995b; 5. Yui et al. 1996; 6. Yui et al. 1998.*

Appendix 2. Sm-Nd isotopic data of meta-sedimentary and sedimentary rocks from Taiwan.

Sample No.	Rock type	Locality	Age (Ma)	[Sm] (ppm)	[Nd] (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	εNd(0)	$^{143}Nd/^{144}Nd_i$	εNd(T)	T_{DM} (Ga)	Data* source
Fm1	qtz mica sch	Fanpaochienshan	Jurassic (195)	5.61	33.25	0.1021	0.512157	-9.4	0.512023	-7.0	1.35	2
Fm2	qtz mica sch	Fanpaochienshan	Jurassic	3.39	23.8	0.0861	0.512042	-11.7	0.511929	-8.8	1.32	2
Fm3	qtz mica sch	Fanpaochienshan	Jurassic	1.53	9.6	0.0964	0.512032	-11.9	0.511906	-9.3	1.45	2
Fm4	qtz mica sch	Fanpaochienshan	Jurassic	5.73	32.1	0.1079	0.512174	-9.1	0.512033	-6.8	1.40	2
Tm1	qtz mica sch	Tachoshui	Jurassic	2.96	15.3	0.1170	0.512133	-9.9	0.511980	-7.8	1.60	2
Tm2	qtz mica sch	Tachoshui	Jurassic	5.30	28.1	0.1140	0.512198	-8.6	0.512049	-6.5	1.45	2
Cm1	qtz mica sch	Tienhsiang	Jurassic	2.67	15.9	0.1015	0.512275	-7.1	0.512142	-4.7	1.19	2
Cm2	qtz mica sch	Tienhsiang	Jurassic	4.61	27.3	0.1021	0.512219	-8.2	0.512085	-5.8	1.27	2
S87-13	blackschist	S. Cross Island Hwy	Jurassic	8.08	48.0	0.1018	0.512075	-11.0	0.511942	-8.6	1.46	1
LIT-10	blackschist	S. Cross Island Hwy	Jurassic	5.10	30.1	0.1024	0.512083	-10.9	0.511949	-8.4	1.46	1
LIT-22	blackschist	S. Cross Island Hwy	Jurassic	5.10	26.7	0.1155	0.512160	-9.4	0.512009	-7.3	1.54	1
S87-107	blackschist	C. Cross Island Hwy	Jurassic	2.61	13.2	0.1195	0.512292	-6.8	0.512136	-4.8	1.38	1
HY-901	blackschist	Juisui	Cretaceous (90)	4.72	23.3	0.1226	0.511968	-13.1	0.511896	-12.2	1.97	4
HY-902	blackschist	Juisui	Cretaceous	6.50	34.5	0.1139	0.511977	-12.9	0.511910	-12.0	1.79	4
HY-1008	blackschist	Juisui	Cretaceous	6.65	30	0.1206	0.511994	-12.6	0.511923	-11.7	1.89	4
HY-1009	blackschist	Juisui	Cretaceous	4.93	27.4	0.1089	0.511906	-14.3	0.511842	-13.3	1.80	4
JU-904	blackschist	Juisui	Cretaceous	11.60	61	0.1148	0.512024	-12.0	0.511956	-11.0	1.73	4
JU-1007	blackschist	Juisui	Cretaceous	5.69	30.7	0.1120	0.511936	-13.7	0.511870	-12.7	1.81	4
JU-4701	blackschist	Juisui	Cretaceous	11.90	55.7	0.1296	0.512043	-11.6	0.511967	-10.8	2.00	4
HO-1006	blackschist	Juisui	Cretaceous	6.66	31.9	0.1263	0.512018	-12.1	0.511944	-11.3	1.97	4
TS-1003	blackschist	Juisui	Cretaceous			0.1418	0.512081	-10.9	0.511998	-10.2	2.26	4
WU-1010	blackschist	Juisui	Cretaceous	5.51	30	0.1111	0.511919	-14.0	0.511854	-13.1	1.82	4
WU-1102	blackschist	Juisui	Cretaceous	6.82	36.8	0.1122	0.511903	-14.3	0.511837	-13.4	1.87	4

Appendix 2. (Continued)

Sample No.	Rock type	Locality	Age (Ma)	[Sm] (ppm)	[Nd] (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	εNd(0)	$^{143}Nd/^{144}Nd_i$	εNd(T)	T_{DM} (Ga)	Data* source
880209-06	Chulai F.	S. Cross Island Hwy	pre-Eocene (60)	5.33	30.24	0.1066	0.511807	-16.2	0.511765	-15.5	1.90	3
LIT-4	blackschist	S. Cross Island Hwy	early Eocene (50)	6.94	34.9	0.1202	0.511924	-14.0	0.511885	-13.4	1.99	1
S87-16	meta s.s.	S. Cross Island Hwy	early Eocene	2.85	16.3	0.1057	0.511904	-14.4	0.511869	-13.7	1.76	1
S87-19	meta s.s.	S. Cross Island Hwy	early Eocene	3.32	18.8	0.1068	0.512018	-12.1	0.511983	-11.5	1.61	1
S87-27	meta s.s.	S. Cross Island Hwy	early Eocene	4.34	24.7	0.1062	0.511849	-15.4	0.511814	-14.8	1.84	1
S87-111	slate	Shuehshan Range	Eocene (40)	6.15	34.7	0.1072	0.512148	-9.6	0.512120	-9.1	1.43	1
S87-112	slate	Shuehshan Range	Eocene	6.90	37.7	0.1107	0.512187	-8.8	0.512158	-8.4	1.43	1
MSE17A	slate	S. Cross Island Hwy	Eocene	5.94	34.0	0.1056	0.512073	-11.1	0.512045	-10.6	1.51	1
S87-06	metasiltstone	S. Cross Island Hwy	Eocene	3.50	16.8	0.1260	0.512060	-11.3	0.512027	-10.9	1.90	1
HSY-1	slate	S. Cross Island Hwy	Eocene	6.77	34.8	0.1176	0.512126	-10.0	0.512095	-9.6	1.62	1
HSY-15	slate	S. Cross Island Hwy	Eocene	7.86	42.5	0.1118	0.512025	-12.0	0.511996	-11.5	1.55	1
5	slate	C. Cross Island Hwy	Eocene	7.58	39.7	0.1154	0.512122	-10.1	0.512092	-9.7	1.59	1
14	phyllite	C. Cross Island Hwy	Eocene	7.64	43.4	0.1064	0.512021	-12.1	0.511993	-11.6	1.60	1
TK2	siltstone	Tsuku	Oligocene (30)	6.70	33.2	0.1220	0.511995	-12.6	0.511971	-12.3	1.90	1
S87-59	shale	S. Coastal Plain	Miocene (15)	6.77	35.2	0.1163	0.512013	-12.2	0.512002	-12.0	1.77	1
S87-60	shale	S. Coastal Plain	Miocene	4.72	23.9	0.1194	0.512013	-12.2	0.512001	-12.0	1.67	1
BJ87-1	slate	Backbone Range	Miocene	6.76	36.2	0.1129	0.512044	-11.6	0.512033	-11.4	1.67	1
MSE1A	shale	S. Cross Island Hwy	Miocene	6.78	36.7	0.1117	0.512025	-12.0	0.512014	-11.8	1.68	1
S87-02	siltstone	S. Cross Island Hwy	Miocene	5.82	30.7	0.1146	0.511851	-15.4	0.511840	-15.2	1.99	1
3	argillite	C. Cross Island Hwy	Miocene	6.85	37.6	0.1101	0.512033	-11.8	0.512022	-11.6	1.64	1
10	argillite	C. Cross Island Hwy	Miocene	7.16	39.0	0.1110	0.512007	-12.3	0.511996	-12.2	1.69	1

** 1. Chen et al. 1990; 2. Lan et al. 1995b; 3. Lan et al. 2002; 4. Sun et al. 1998.*

Appendix 3. Sm-Nd isotopic data of amphibolites, metabasites, meta-andesite, and volcanic rocks from Taiwan.

Sample No.	Rock type	Locality	Age (Ma)	[Sm] (ppm)	[Nd] (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	εNd(0)	Data* source
BJ-137-82	amphibolite (enclave)	Nanao		3.95	11.49	0.2076	0.513150	9.9	9
BJ-138-82	amphibolite	Nanao		2.44	6.70	0.2201	0.513213	11.2	9
BJ-143-82	amphibolite	Nanao		1.68	4.67	0.2175	0.513068	8.3	9
2709	amphibolite	Yuantoushan		2.48	6.92	0.2167	0.513215	11.3	9
T8	amphibolite	Yuantoushan		2.07	7.00	0.1788	0.513172	10.4	10, 15
K21	amphibolite	Fanpaochienshan		2.32	6.26	0.2241	0.513135	9.7	10
TCS52	amphibolite	Fanpaochienshan		2.62	6.68	0.2371	0.513100	9.0	10
TCS58	amphibolite	Fanpaochienshan		2.48	7.54	0.1989	0.513024	7.5	10
TCS95	amphibolite	Fanpaochienshan		1.99	5.58	0.2156	0.513093	8.9	10
TCS97	amphibolite	Fanpaochienshan		1.87	5.18	0.2183	0.513115	9.3	10
HZ7-2	metabasite	Kanagan		5.36	22.40	0.1447	0.512867	4.5	10
KL79-100	metabasite	Tachoshui		5.80	28.7	0.1222	0.512924	5.6	10, 15
TCS4C	metabasite	Tachoshui		10.1	47.6	0.1283	0.512874	4.6	10
TCS6C	metabasite	Tachoshui		7.10	32.3	0.1329	0.512877	4.7	10
TCS9	metabasite	Tachoshui		4.09	12.4	0.1994	0.513141	9.8	10
TCS16A1	metabasite	Tachoshui		3.16	14.2	0.1345	0.512912	5.4	10
CP10	metabasite	Chipan		3.20	13.9	0.1391	0.512856	4.3	10
CP17	metabasite	Chipan		9.27	40.5	0.1384	0.512900	5.1	10
CP18-1	metabasite	Chipan		4.75	18.5	0.1552	0.512860	4.3	10
CP18-3	metabasite	Chipan		4.76	19.6	0.1468	0.512881	4.7	10
LB42	metabasite	Chipan		3.47	14.7	0.1427	0.512842	4.0	10, 15
TA-4601	epidote amphibolite	Tamayen		2.45	6.47	0.2287	0.512706	1.3	12
TA-4603	metabasite	Tamayen		8.44	20.4	0.2503	0.512945	6.0	12
TA-4605	epidote amphibolite	Tamayen		1.99	5.37	0.2011	0.512834	3.8	12
TA-4606	epidote amphibolite	Tamayen		7.15	31.6	0.1369	0.512278	-7.0	12
TA-4607	epidote amphibolite	Tamayen		2.21	6.60	0.2025	0.513169	10.3	12
TA-SF9	glaucophane schist	Tamayen		10.1	41.8	0.1462	0.512408	-4.5	12
TA-SF11	glaucophane schist	Tamayen		9.84	40.2	0.1481	0.512488	-2.9	12
TA-TL3	glaucophane schist	Tamayen		11.1	54.0	0.1240	0.512331	-6.0	12
WU-1103	metabasite	Wuho		4.98	17.7	0.1702	0.512908	5.3	12
WU-1104	epidote amphibolite	Wuho		3.69	14.0	0.1600	0.512891	4.9	12

Appendix 3. (Continued)

Sample No.	Rock type	Locality	Age (Ma)	[Sm] (ppm)	[Nd] (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	εNd(0)	Data* source
TS-1002	epidote amphibolite	Tsunkuanshan		1.35	2.95	0.2769	0.513098	9.0	12
TS-1104	metabasite	Tsunkuanshan		1.83	5.76	0.1630	0.513001	7.1	12
Y80-1	meta-andesite	10 Km south of Suao	85 ± 2				0.512496	-2.8	this study
C-1-02	high-Al basalt	N. Tungyintao Ridge	55.2	7.46	34.70	0.1300	0.512540	-1.9	3, 4
BJ-134-82	diabase	Nanao	37	3.47	14.71	0.1425	0.512709	1.3	9
ST-02	alkali basalt	Shiting	23 - 20	11.1			0.51293	5.7	5
TN-4	alkali basalt	Nanshihchiao	23 - 20	9.0	51.8	0.1050	0.51292	5.5	5, 6, 7
TB-07	alkali basalt	Tucheng	23 - 20	10.2	53.0	0.1164	0.51294	5.9	5, 6, 7
TB-08	alkali basalt	Tucheng	23 - 20				0.51293	5.7	5
TB-11	alkali basalt	Tucheng	23 - 20	10.2	52.0	0.1186	0.51289	4.9	5, 6, 7
L-302	basanite	Kuanhsi-Chutung	13 - 9	10.2	54.9	0.1123	0.51282	3.6	6, 7
M-30	alkali basalt	Kuanhsi-Chutung	13 - 9	11.3	61.0	0.1120	0.51270	1.2	6, 7
N-209	alkali basalt	Kuanhsi-Chutung	13 - 9	10.0	55.1	0.1097	0.51265	0.2	6, 7
M-604	high-K basalt	Kuanhsi-Chutung	13 - 9	10.5	51.6	0.1230	0.51268	0.8	7
S-14	transitional basalt	Kuanhsi-Chutung	13 - 9	6.5	32.2	0.1220	0.51280	3.2	6, 7
S-03	tholeiite	Kuanhsi-Chutung	13 - 9	4.4	17.7	0.1503	0.51263	-0.2	6, 7
W-39	tholeiite	Kuanhsi-Chutung	13 - 9	4.4			0.51257	-1.3	7
D-1-01	dark-colored cutting	S. Pengchiahsu basin	13 - 9				0.51290	4.9	4
TCS-01	tholeiite	Chienshan	13 - 9	5.55	21.95	0.1529	0.512876	4.6	3, 5
TCS-02	tholeiite	Chienshan	13 - 9	7.0			0.512858	4.3	3, 5
CHS-01	tholeiite	Hengchi	13 - 9	5.6			0.51292	5.5	5
CHS-13	tholeiite	Hengchi	13 - 9	4.9			0.512950	6.1	3, 5
SBS-2	high-Al basalt	Sekibisho	2.6 - 0.2	2.52	8.26	0.1845	0.51289	4.9	14
SBS-7	high-Al basalt	Sekibisho	2.6 - 0.2	3.36	12.03	0.1689	0.51284	3.9	14
KBS-1	high-Al basalt	Kobisho	2.6 - 0.2	2.81	10.48	0.1621	0.51271	1.4	11, 14
KBS-3	high-Al basalt	Kobisho	2.6 - 0.2	2.87	10.80	0.1607	0.51271	1.4	11, 14
K-04	high-Al basalt	Kobisho	2.6 - 0.2	2.85	10.66	0.1616	0.512717	1.5	1, 14
MHH-01	high-Mg basaltic andesite	Mienhuayu	2.8 - 0.2	3.15	8.85	0.2152	0.51298	6.6	13, 14
MHY-2	high-Mg basaltic andesite	Mienhuayu	2.6 - 0.4	2.32	7.06	0.1987	0.51301	7.2	13, 14
MHY-3	high-Mg basaltic andesite	Mienhuayu	2.6 - 0.4	3.15	8.25	0.2308	0.51290	5.1	13, 14
MHY-4	high-Mg basaltic andesite	Mienhuayu	2.6 - 0.4	2.96	8.24	0.2172	0.51294	5.9	13, 14

Appendix 3. (Continued)

Sample No.	Rock type	Locality	Age (Ma)	[Sm] (ppm)	[Nd] (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	εNd(0)	Data* source
MHY-7	high-Mg basaltic andesite	Mienhuayu	2.6 - 0.4	3.04	8.05	0.2283	0.51299	6.8	13, 14
MHY-8	high-Mg basaltic andesite	Mienhuayu	2.6 - 0.4	3.09	8.27	0.2259	0.51297	6.5	13, 14
MHY-9	high-Mg basaltic andesite	Mienhuayu	2.6 - 0.4	3.27	9.48	0.2085	0.51293	5.6	13, 14
Pen-20	basalt	Pengchiayu	2.1 - 0.3	4.11	15.15	0.1640	0.512893	5.0	1, 14
PGU-04	basalt	Pengchiayu	2.1 - 0.3	3.93	14.05	0.1691	0.51295	6.1	14
PGU-05	basaltic andesite	Pengchiayu	2.1 - 0.3	3.68	11.79	0.1887	0.51297	6.5	14
CKS5-1	andesite	Keelungshan	1.4 - 0.3	2.92	15.54	0.1136	0.512693	1.1	1, 14
TS-3	andesite	Keelungshan	1.4 - 0.3	3.19	15.54	0.1241	0.51270	1.2	14
GML	andesite	Keelungshan	1.4 - 0.3	3.09	15.51	0.1204	0.51272	1.6	14
L-15	andesite	Keelungshan	1.4 - 0.3	2.77	13.42	0.1248	0.51270	1.2	14
CH-7	andesite	Keelungshan	1.4 - 0.3	2.10	9.22	0.1377	0.51282	3.6	14
A-3	andesite	Tatunshan	2.8 - 0.2	3.28	16.42	0.1208	0.512727	1.7	1, 14
A-10	basaltic andesite	Tatunshan	2.8 - 0.2	2.37	10.35	0.1384	0.512783	2.8	1, 14
A-18	basaltic andesite	Tatunshan	2.8 - 0.2	3.61	16.66	0.1310	0.512733	1.9	1, 14
A-31	basaltic andesite	Tatunshan	2.8 - 0.2	2.76	13.81	0.1208	0.512681	0.8	1, 14
A-129	high-Al basalt	Honglushan	2.8 - 0.2	4.96	23.01	0.1303	0.51280	3.2	14
H-B-1	high-Al basalt	Honglushan	2.8 - 0.2	4.45	20.68	0.1301	0.512763	2.4	1, 14
K-41	basalt	Kyanyinshan	1.1 - 0.2	4.36	24.18	0.1090	0.51284	3.9	14
K-64	basalt	Kyanyinshan	1.1 - 0.2	4.14	20.32	0.1232	0.512833	3.8	1, 14
K-99	andesite	Kyanyinshan	1.1 - 0.2	4.01	29.47	0.0822	0.512805	3.3	1, 14
K-108	dacite	Kyanyinshan	1.1 - 0.2	2.83	21.83	0.0784	0.51281	3.4	14
T-49	absarokite	Tsaolingshan	0.3 - 0.2				0.512662	0.5	1
T-4	absarokite	Tsaolingshan	0.3 - 0.2				0.512614	-0.5	1
TLS-3	absarokite	Tsaolingshan	0.3 - 0.2	4.88	25.63	0.1151	0.51268	0.8	8, 14
TLS-12	absarokite	Tsaolingshan	0.3 - 0.2	4.93	25.98	0.1147	0.51263	-0.2	8, 14
TLS-17	absarokite	Tsaolingshan	0.3 - 0.2	5.00	26.31	0.1149	0.51266	0.4	8, 14
TLS-24	absarokite	Tsaolingshan	0.3 - 0.2	4.37	22.92	0.1153	0.51266	0.4	8, 14
TLS-27	absarokite	Tsaolingshan	0.3 - 0.2	4.36	23.19	0.1137	0.51266	0.4	8, 14
T-20	absarokite	Tsaolingshan	0.3 - 0.2	4.98	26.26	0.1147	0.51264	0.0	8, 14
T-24	absarokite	Tsaolingshan	0.3 - 0.2	4.61	24.10	0.1157	0.51265	0.2	8, 14
T-30	absarokite	Tsaolingshan	0.3 - 0.2	4.57	23.83	0.1159	0.51268	0.8	8, 14

Appendix 3. (Continued)

Sample No.	Rock type	Locality	Age (Ma)	[Sm] (ppm)	[Nd] (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	εNd(0)	Data* source
T-43	absarokite	Tsaolingshan	0.3 - 0.2	4.59	24.48	0.1134	0.51266	0.4	8, 14
T-48	absarokite	Tsaolingshan	0.3 - 0.2	4.62	24.31	0.1149	0.51259	-0.9	8, 14
TLS-8	absarokite	Tsaolingshan	0.3 - 0.2	4.47	23.72	0.1139	0.51268	0.8	14
TLS-18	absarokite	Tsaolingshan	0.3 - 0.2	4.52	23.91	0.1143	0.51263	-0.2	14
TLS-23	absarokite	Tsaolingshan	0.3 - 0.2	4.79	25.40	0.1140	0.51266	0.4	14
T-16	absarokite	Tsaolingshan	0.3 - 0.2	4.40	23.21	0.1146	0.51266	0.4	14
K-A-1	andesite	Kueishantao					0.512391	-4.8	1, 2
K-B-7	andesite	Kueishantao					0.512378	-5.1	1, 2
KS-3	andesite	Kueishantao					0.512495	-2.8	1, 2
KS-5	andesite	Kueishantao					0.512432	-4.0	1, 2
KS-6	andesite	Kueishantao					0.512547	-1.8	1, 2
KS-8	andesite	Kueishantao						-2.5	2
KS-9	andesite	Kueishantao					0.512498	-2.7	1, 2

** 1. Chen 1989; 2. Chen et al. 1995; 3. Cheng-Hong Chen, personal communication 2007; 4. Chen et al. 1997; 5. Chen et al. 2001a; 6. Chen 1988; 7. Chung et al. 1995a; 8. Chung et al. 2001; 9. Jahn et al. 1986; 10. Lan et al. 1991; 11. Shinjo 1998; 12. Sun et al. 1998; 13. Wang et al. 2002; 14. Wang et al. 2004; 15. Yui et al. 1990.*

Appendix 4. U-Pb concordia diagrams for TIMS zircon dating (Yui et al. 1998) of (a) Jurassic Talun meta-granite in S Taiwan and (b) Cretaceous meta-andesite in NE Taiwan.