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Age and Geochemical Features of Dredged Basalts from Offshore SW Taiwan: The Coincidence of Intra-Plate Magmatism with the Spreading South China Sea

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ABSTRACT

This study reports age and geochemical analyses of basaltic rocks dredged from volcanic seamounts offshore SW Taiwan. $^{40}Ar/^{39}Ar$ dating results of these rocks show them to be of the early Miocene age of ~22 - 21 Ma. They are evolved alkali basalts that show OIB-type geochemical features similar to post-spreading seamount basalts (14 - 3.5 Ma) in the South China Sea (SCS) and Miocene intraplate basalts on the Penghu Islands (16 - 8 Ma) and NW Taiwan (23 - 9 Ma). Their Sr-Nd-Pb isotope data plot within the range of the SCS seamount basalts that show an EM2-like component in the mantle source. The age and overall geochemical characteristics of the dredged basalts are comparable to those of the Kungkuan basalts, NW Taiwan and Baolai basalts, SW Taiwan, suggesting an extensive alkali basaltic volcanism along the southeastern Eurasian continental margin during the early Miocene that resulted from regional lithospheric extension in association with seafloor spreading in the South China Sea.

Key words: Miocene, Dredged basalts, Geochemistry, South China Sea spreading, Taiwan, Eurasian continental margin

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1. INTRODUCTION

The southeastern Eurasian continental margin near the Taiwan region evolved from a latest Cretaceous-Paleogene rift into a latest Miocene-Recent foreland basin (Lin et al. 2003; Teng and Lin 2004). This evolution is related to a post-orogenic extension which began within Southeast China (Li and Li 2007 and reference therein) leading to the opening of the South China Sea (SCS), and its subsequent partial closure by the Taiwan orogeny (Teng 1996). Since the late Oligocene, rifting at the outer margin of the SE Eurasian continent caused breakup of the continental margin such that the oceanic SCS basin began to spread. A spreading of SCS was thought to propagate northeastward toward the Taiwan Strait region but since latest Miocene rifting dwindled then continued in the remnant SCS margin which has been smoothly subsiding. A section of the passive margin persists in offshore Guangdong province in China; in Taiwan, it was tectonized by the impinging Luzon Arc (Teng and Lin 2004).

Several models have been proposed to explain the formation of the SCS: (1) the association as a result of the India-Asia collision (Tapponnier et al. 1982; Leloup et al. 1995); (2) a slab pull and subduction of the proto-South China Sea under Sabah/Borneo (Taylor and Hayes 1980, 1983; Holloway 1982; Hall 2002); and, (3) an extension related to an upwelling mantle plume (e.g., Fan and Menzies 1992). The South China Sea consists of three sections, the northern continental margin, oceanic basin and southern

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continental margin. The oceanic basin is divided geographically into the SW sub-basin, NW sub-basin and central sub-basin. These SCS basins opened from NE to SW in a complex tectonic process, starting during the middle Eocene and finishing near 15.5 Ma. According to magnetic lineation analyses, Taylor and Hayes (1980, 1983) suggested that the central sub-basin was formed by the seafloor spreading during 32 - 17 Ma (chron 11 - 5d). Yeh et al. (2010) reported that at the northeastern part of the SCS basin opened from chron C17 (37.8 Ma) to 15.5 Ma (after chron C5c, 16.7 Ma). Ho et al. (2003) proposed that northeastward age-decreasing trend of magmatism shown in the middle of the SCS toward the Taiwan Strait indicates a northeastward migration of the rifting center during the Miocene. Although model of a rift center shifting in SCS has been proposed for rifting in the Taiwan Strait during the Miocene (Lin et al. 2003), no direct evidence has been provided.

A widespread episode of intra-plate volcanism followed the cessation of sea-floor spreading in the South China Basin (SCB; ~32 - 17 Ma) affecting large parts of southern China and Indochina and penetrated the oceanic basement and stranded micro-continent fragments. In the probable absence of a mantle plume beneath this region decompression melting of the subcontinental lithospheric and asthenospheric mantle may have resulted from the lithosphere stretching as a regional response to the Indo-Eurasian collision (Tu et al. 1992). Tu et al. (1992) further documented findings wherein seamount basalts from the SCB are characterized by Dupal-like OIB-type signatures and proposed that the SCB mantle sources comprise both asthenospheric and lithospheric components including a lower region of accreted asthenospheric melt (isotopically resembling Central Indian Ridge MORB) overprinted by radiogenic melts of subducted sediment.

In this study, rare magmatic rocks dredged from seamounts offshore SW Taiwan are studied for their age and geochemical characteristics to decipher the origin of the seamount. This is the first attempt to dredge volcanic rocks among the seamounts near SW Taiwan.

2. SAMPLES AND ANALYTICAL METHODS

Samples were dredged and collected by the R/V Ocean Research I from seamounts offshore SW Taiwan (Fig. 1) located at coordinates 21°10'N and 119°12'E by Yeh et al. (2010) to initiate a detailed geochemical investigation, including whole-rock major- and trace-element, and Sr-Nd-Pb isotope determinations in this study. Geochemical data including seamounts in the SCS basin (SCS seamounts; Tu et al. 1992), the Eocene volcanic rocks drilled in the Taiwan Strait and onland Taiwan (Wang et al. 2012), and Miocene intraplate basalts in the Penghu Islands (Chung et al. 1994, 1995) are also included in this paper for comparison. Three dredged samples are remarkably fresh and all are aphyric basalts. They are porphyritic. The phenocryst includes olivine, augite, plagioclase and opaque iron oxide. The groundmass consists mainly of plagioclase and augite.

2.1 $^{40}Ar/^{39}Ar$ Dating

Two fresh-looking samples were selected for $^{40}Ar/^{39}Ar$ dating using whole-rock chips. Sample preparation and analytical procedures followed those outlined by Lo and Lee (1994) and Lo et al. (2002). Weighted aliquots of the samples were wrapped in aluminum foil packets with the irradiation standard: LP-6 biotite (Odin et al. 1982), and irradiated in the VT-C position of the Tsing-Hua Open-pool Reactor (THOR) at Tsing-Hua University, for 20 hours with a fast neutron flux of 1.566×10^{13} n/cm^2 sec. After irradiation, the samples were degassed in a furnace from 400 to 1200°C in a 30-minute/step heating schedule. The isotopic composition of argon was measured by using a GD150 mass spectrometer at the Department of Geosciences, National Taiwan University.

2.2 Whole-Rock Chemical Analysis

Powder samples were prepared using a jaw crusher and a corundum mill. Major element compositions were determined by X-ray fluorescence (XRF) using a Rigaku® RIX 2000 spectrometer at the Department of Geosciences, National Taiwan University. The analytical uncertainties are generally better than 5% for all elements (Wang et al. 2004). Loss on ignition was determined by routine procedures. Powdered samples weighing about 50 mg were dissolved using a HF/HNO_3 (10:1) mixture in screw-top Teflon Savillex® for 7 days at ~100°C, followed by evaporation to dryness, refluxing in 7N HNO_3 and drying again, and then dissolving the sample cake in 2% HNO_3. An internal standard solution of 10-ppb Re was added and the spiked dissolutions were diluted with 2% HNO_3 to a sample/solution weight ratio of 1/1000. The internal standard was used for monitoring the signal shift during inductively coupled plasma-mass spectrometry (ICP-MS) measurements using a Perkin Elmer® Elan-6000 spectrometer at the Guangzhou Institute of Geochemistry, the Chinese Academy of Sciences, China, which has a good stability range within ~10% variation (Liu et al. 1996; Li 1997).

Values recommended for the USGS rock standard BCR-1, BHVO-1 and AGV-1 (Govindaraju 1994; Eggins et al. 1997; Weyer et al. 2002) were used for data calibrations; the analytical errors are generally better than 5% for most trace elements. All three samples were selected for Sr-Nd isotopic analyses. The Sr and Nd fractions were separated by ion exchange chromatography, and isotopic compositions were measured using a MAT 262 mass spectrometer at the Dept. of Earth Sciences, National Cheng Kung University, Tainan. Procedural blanks for Sr and Nd were < 200 pg. Nd

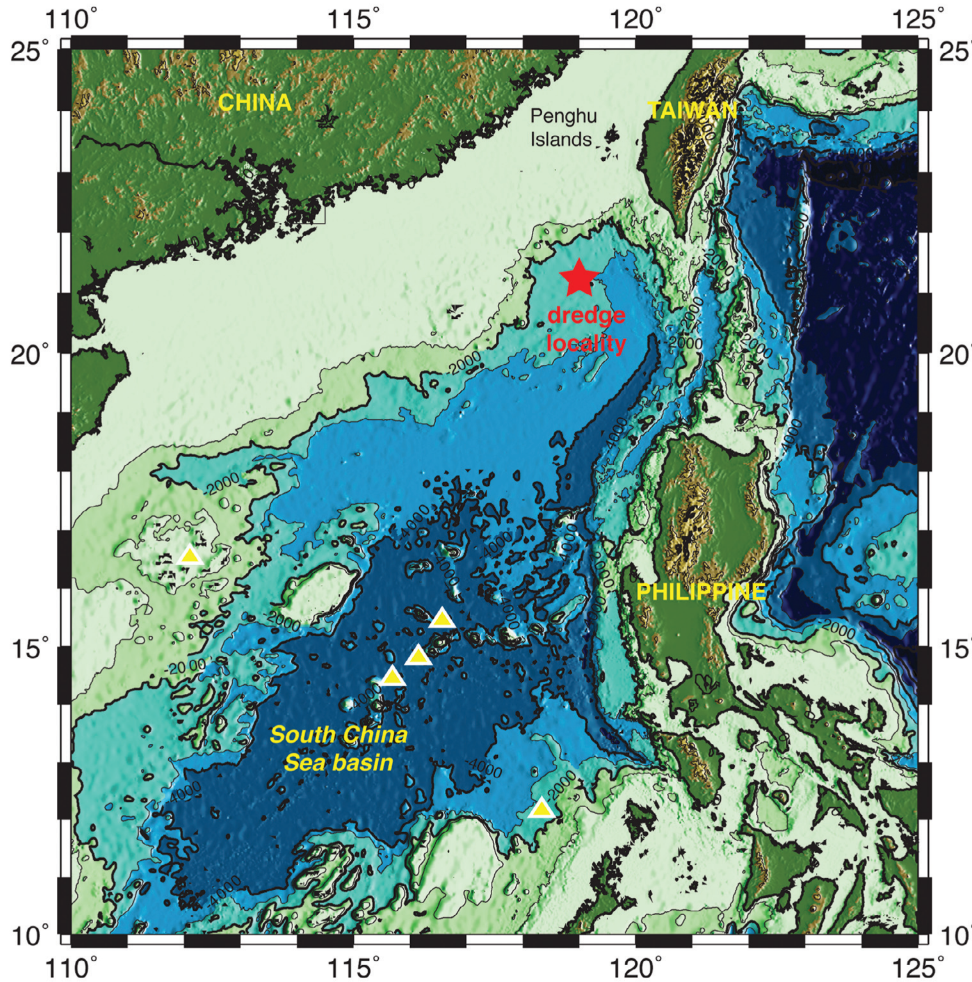

Fig. 1. Bathymetric map (created from the TECDC graphic service at IESAS, Taipei) showing locality of dredged basalts in this study (marked as a red star). Yellow triangles mark localities of the SCS seamounts used to compare their geochemical features with dredged basalts in this study (see the text for details).

isotopic ratios were normalized to $^{146}Nd/^{144}Nd = 0.7219$ and are reported relative to 0.511855 for the La Jolla standard. Sr isotopic ratios were normalized to $^{86}Sr/^{88}Sr = 0.1194$ and are relative to 0.710240 for the SRM987 standard. The precisions of the Nd and Sr isotopic compositions were both better than ±0.000010 (2σ). More analytical details have been described in Liu et al. (2007).

Chemical separation of Pb for isotope analysis was undertaken at the National Taiwan University, Taiwan and the University of the Ryukyus, Japan. The detailed procedure follows, Wang et al. (2004). Rock chips and/or powders were leached with 6N HCl at ~80°C for 30 minutes. The Pb was separated using standard HBr anion exchange procedures in Teflon columns and the sample solution passed through the columns twice for purification. Two small aliquots of the purified Pb sample were loaded on to two single Re filaments to analyze natural and double-spiked samples separately. A small drop of ^{207}Pb-^{204}Pb double spike solution and Pb emitter silica gel-H_3PO_4 solution, prepared according to Gerstenberger and Haase (1997), were then added to the aliquot on the double-spiked filament. Lead isotope measurements were made on a Finigan MAT262® mass spectrometer using a static multi-collectors mode at the University of the Ryukyus, Japan. Lead isotope ratios were corrected for mass fractionation by the use of a ^{207}Pb-^{204}Pb double-spike method. The double-spike calibrated SRM 981 has the following composition: $^{206}Pb/^{204}Pb = 16.9411 \pm 42$, $^{207}Pb/^{204}Pb = 15.4978 \pm 52$ and $^{208}Pb/^{204}Pb = 36.7185 \pm 142$ (2σ), which agrees well with values recently reported by Galer and Abouchami (1998) and Thirlwall (2000) using triple-spike and double-spike methods, respectively. The external reproducibility of the SRM 981 (2sd, 54 analyses in the period of this study) is 124 ppm for $^{206}Pb/^{204}Pb$, 112 ppm for $^{207}Pb/^{204}Pb$ and 96 ppm for $^{208}Pb/^{204}Pb$. The overall blank contributions were 0.4 ng Pb for about 0.2 μg Pb in the samples. The major- and trace-element and Sr-Nd-Pb isotopic compositions of the volcanic rocks are posted in Table 1.

3. RESULTS

3.1 $^{40}Ar/^{39}Ar$ Ages

The age spectra and correlation diagram for samples SCS-1 and SCS-2-3 are shown in Fig. 2. The age spectra display a well-defined plateau providing plateau ages of 21 ± 0.2 and 22.1 ± 0.2 Ma, covering most of the $^{39}Ar_K$ released (~70%). In the correlation diagrams, a least-square regression of the plateau steps yields similar intercept dates of 20.6 ± 2.1 and 22 ± 0.2 Ma, respectively. Such a consisten-

Table 1. WR elemental and isotopic compsotions for dredged basalts at offshore SW Taiwan.

Sample Lithology [a] Age (Ma)	**SCS-1 AB 21 ± 0.2**	**SCS-2-1 AB**	**SCS-2-3 AB 22.1 ± 0.2**	**Sample Lithology [a] Age (Ma)**	**SCS-1 AB 21 ± 0.2**	**SCS-2-1 AB**	**SCS-2-3 AB 22.1 ± 0.2**
SiO_2 (wt.%)	45.29	43.07	44.79	CaO	11.61	13.02	11.75
TiO_2	2.92	2.78	2.93	Na_2O	3.04	2.64	2.9
Al_2O_3	16.07	14.83	16.18	K_2O	1.22	0.98	1.4
tFe_2O_3 [b]	12.05	12.14	12.03	P_2O_5	1.17	2.25	1.35
FeO	9.3267	9.39636	9.31122	L.O.I	1.39	2.19	1.53
MnO	0.18	0.13	0.25	Total	100.2	99.24	98.94
MgO	5.29	5.23	3.85	Mg# [c]	49	48	41
Sc (ppm)	29.2	28.6	29.8	W	0.45	0.41	0.62
V	276	257	298	Pb	4.26	7.66	5.48
Cr	213	225	220	Th	5.25	5.21	5.33
Co	36	29	38	U	1.15	1.39	1.56
Ni	72	83	54	La	40.59	56.12	42.75
Zn	124	130	135	Ce	78.18	78.81	80.18
Ga	20.6	18.1	21.7	Pr	9.25	10.71	9.61
Rb	22.1	19.2	29.6	Nd	37.78	44.14	39.38
Sr	570	596	593	Sm	7.76	8.75	8.06
Y	33.7	63.1	37.6	Eu	2.38	2.6	2.47
Zr	245	229	253	Gd	7.58	9.17	7.96
Nb	52.3	48.8	53.5	Tb	1.13	1.36	1.18
Mo	1.73	1.2	2.12	Dy	5.96	7.52	6.28
Sn	1.15	1.12	1.19	Ho	1.16	1.6	1.24
Sb	0.97	0.83	1.84	Er	3.06	4.47	3.3
Cs	0.26	0.3	0.39	Tm	0.41	0.62	0.45
Ba	403	304	437	Yb	2.57	3.92	2.82
Hf	5.97	5.77	6.07	Lu	0.38	0.62	0.42
Ta	3.46	3.4	3.51				
Isotopc ratios [d]							
$^{86}Sr/^{87}Sr$	0.704181	0.704729	0.704244	$\varepsilon Nd_{(T)}$	5.06	4.5	3.95
$(^{86}Sr/^{87}Sr)_L$	0.703745	0.70377	0.703792	$^{206}Pb/^{204}Pb$	18.842	18.829	18.866
$(^{86}Sr/^{87}Sr)_{(T)}$	0.703733	0.70376	0.703776	$^{207}Pb/^{204}Pb$	15.622	15.652	15.621
$^{144}Nd/^{143}Nd$	0.512892	0.512863	0.512835	$^{208}Pb/^{204}Pb$	39.07	39.104	39.076
εNd [e]	4.95	4.39	3.84				

Note:

[a] *AB: alkali basalts.*

[b] *Total iron.*

[c] *Mg# = atomic 100 $(Mg/Mg + Fe^{2+})$, assuming $Fe_2O_3/FeO = 0.1$.*

[d] *Analytical 2σ errors are: ±0.00001 for $^{87}Sr/^{86}Sr$; ±0.00001 for $^{143}Nd/^{144}Nd$; ±0.004 for $^{206}Pb/^{204}Pb$; ±0.005 for $^{207}Pb/^{204}Pb$ and ±0.014 for $^{208}Pb/^{204}Pb$.*

[e] $\varepsilon Nd = [(^{143}Nd/^{144}Nd)_{sample}/(^{143}Nd/^{144}Nd)_{CHUR}-1] \times 10^4$; $(^{143}Nd/^{144}Nd)_{CHUR} = 0.51264$.

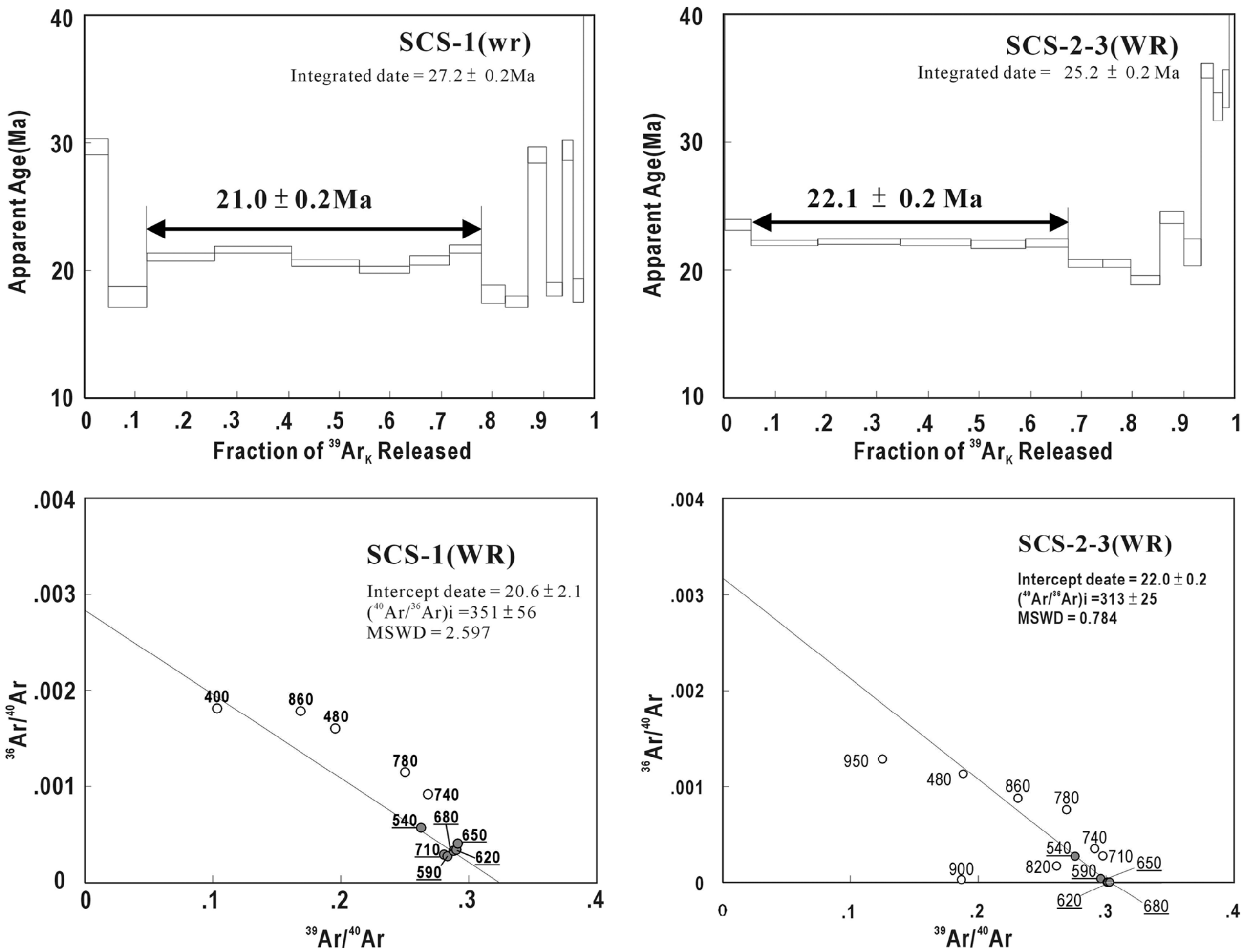

Fig. 2. Whole-rock $^{40}Ar/^{39}Ar$ age spectrum and isotope correlation diagram for dredged basalts SCS-1 and SCS-2-3.

cy indicates that the obtained plateau ages are geologically meaningful, and thus incorporated for discussion later. The ages are younger than the earliest phase of eruption spans (23 - 9 Ma) of Miocene intraplate basalts on northwestern Taiwan (Chung et al. 1994, 1995).

3.2 Major-Element Compositions

On the plot of K_2O+Na_2O versus SiO_2 (Fig. 3), these dredged volcanic rocks were found in the field of alkaline basalts. In terms of the SiO_2 content, these rocks display relatively low Mg (MgO ≈ 3.9 ~ 5.3 wt.%) and Mg-value (≈ 41 ~ 49) in comparison with the Miocene basalts in the Taiwan Strait and NW Taiwan (Fig. 4; Chung et al. 1994, 1995; Wang et al. 2012). They are similar to basalts from the Scarborough Seamounts in the SCS basin (Tu et al. 1992) which have experienced fractional crystallization to a minor extent (Fig. 4). In addition, they show slightly higher Al_2O_3 (≈ 14.8 - 16.2 wt.%) and CaO (≈ 7.7 - 8.5 wt.%) contents than those of Miocene basalts in the Taiwan Strait and NW Taiwan (Fig. 4).

3.3 Trace-Element Compositions

The three dredged basalts are generally homogeneous in trace element composition. In the chondrite-normalized rare earth elements (REEs) diagram, their REE patterns are light REE (LREE) enriched (Fig. 5a). They show similar REE abundance and patterns with basalts from the SCS Seamounts (Tu et al. 1992). In the primitive mantle-normalized element diagram, they show similar patterns with typical oceanic island basalts (OIBs; Fig. 5b; Sun and McDonough 1989). Their patterns are similar with those of the SCS seamounts and Miocene intraplate basalts on the Penghu Islands and NW Taiwan but distinct from Eocene basalts in the Taiwan Strait and western Taiwan, which are depleted in high field strength elements (HFSEs; e.g., Nb, Ta and Ti) and have a pronounced Pb anomaly.

3.4 Nd-Sr-Pb Isotopic Compositions

Nd-Sr isotope ratios of dredged basalts are plotted in the Nd-Sr isotopic diagram with other representative samples for comparison (Fig. 6). They have uniform Sr isotope ratios ($^{87}Sr/^{86}Sr \approx 0.70374$ - 0.70379) and Nd isotope ratios ($^{143}Nd/^{144}Nd \approx 0.51284$ - 0.51289). These ratios are similar to those of the SCS seamounts (Tu et al. 1992) although they are located close to their most radiogenic part in the Nd-Sr isotopic diagram. In comparison with the near-by Miocene intraplate basalts in the Taiwan Strait the dredged basalts are more radiogenic than the least radiogenic Miocene intraplate basalts in the Taiwan Strait. However, they are similar to that of some alkali basalts in the Taiwan Strait and NW Taiwan. The isotopic compositions of the SCS seamounts may represent a composition of the local mantle source of an enriched MORB/OIB component (Tu et al. 1992) as they are more enriched than that of the Eastern Taiwan Ophiolite (ETO) representing the composition of the local mantle source of a depleted MORB (Jahn 1986; Chung and Sun 1992).

Pb isotope ratios of these dredged basalts all lie within the range of the SCS seamounts (Tu et al. 1992) and above the Northern Hemisphere Reference Line (NHRL) of Hart (1984) (Fig. 7). Within the range of the SCS seamounts, these dredged samples are located toward the EM2 mantle component which is apparently apart from the majority of the Miocene intraplate basalts in the Taiwan Strait and NW Taiwan (Chung et al. 1994, 1995). This is similar to their most radiogenic Nd-Sr isotopic characteristic in comparison to the SCS seamounts.

4. DISCUSSION

4.1 Eruption Age of Basalt in the Northeastern Tip of the South China Sea

The SCS spreading was generally believed to rift over ~37 - 15.5 Ma (Yeh et al. 2010). Ho et al. (2003) proposed a northeastward age-decreasing trend of magmatism shown from the middle of SCS toward the Taiwan Strait indicating northeastward migration of the rifting center during the Miocene epoch. A similar model of rift center shifting

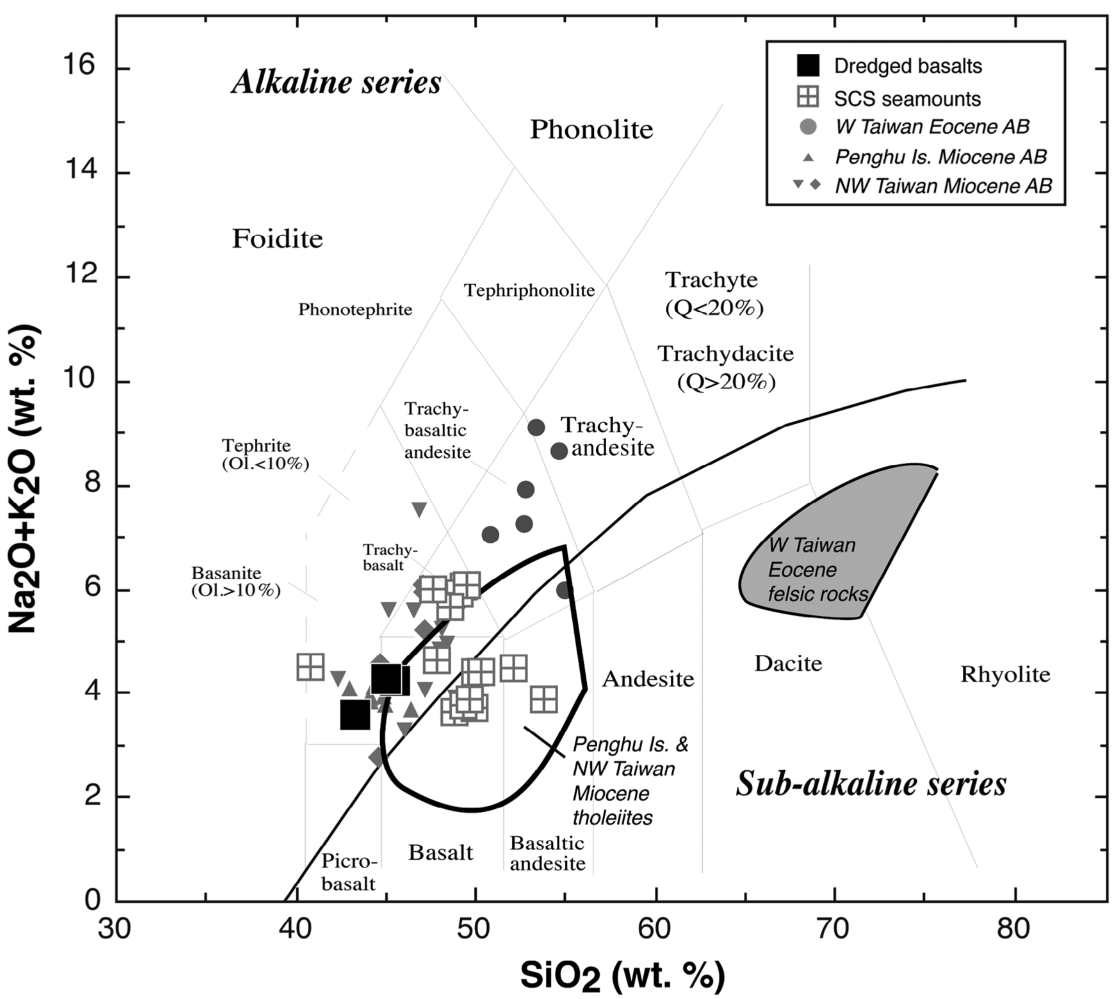

Fig. 3. Diagram of total alkali ($K_2O + Na_2O$) versus SiO_2 for dredged basalts at offshore SW Taiwan. SCS seamounts (Tu et al. 1992), the Eocene volcanic rocks drilled in the Taiwan Strait and onland Taiwan taken from Wang et al. (2012) and Miocene intraplate basalts in the Penghu Islands from Chung et al. (1994, 1995) are also shown for comparison. Rock type boundaries are from Le Maitre et al. (1989).

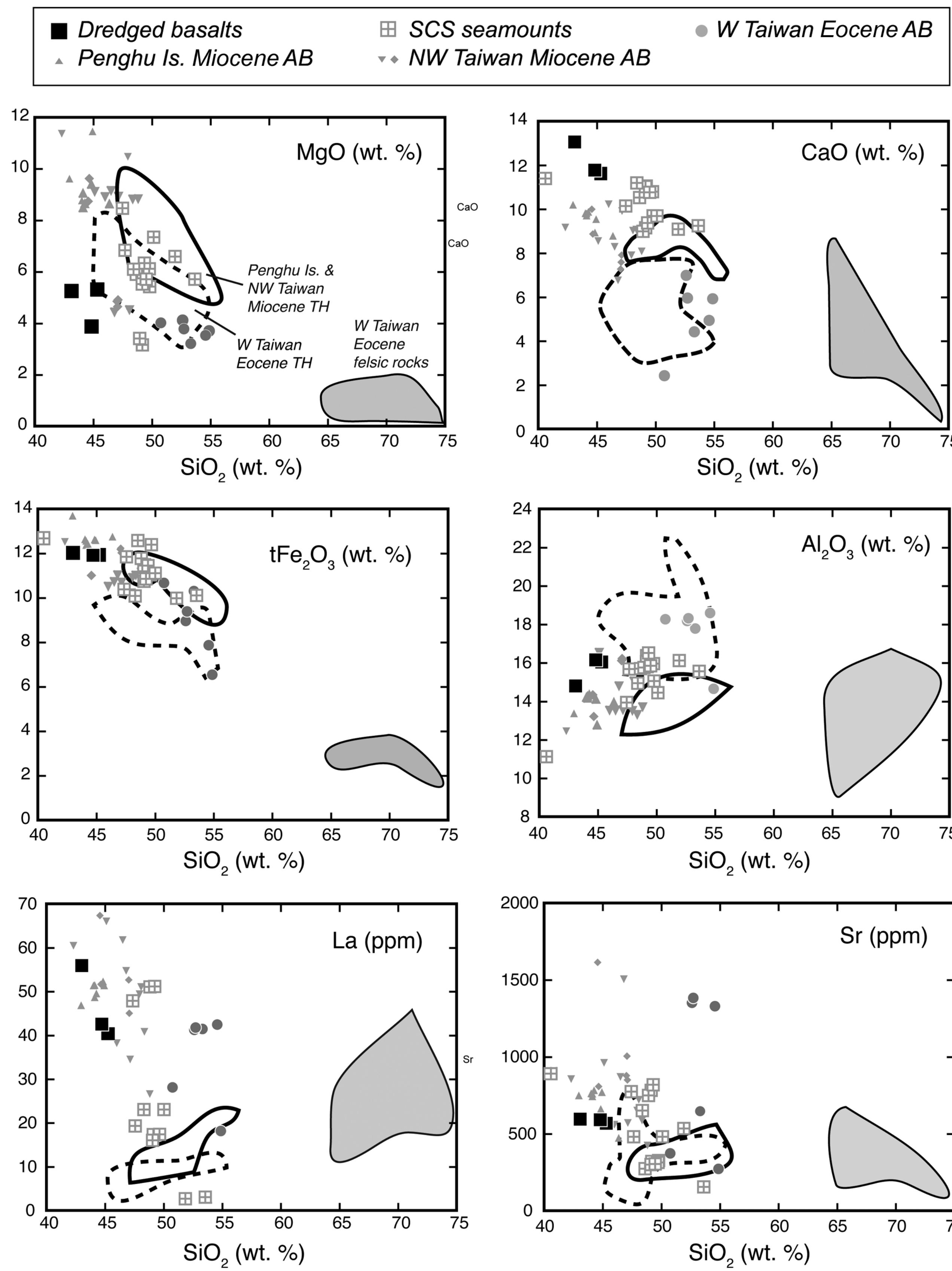

Fig. 4. Variation diagrams of MgO, Fe_2O_{3t}, CaO, Al_2O_3, Sr and La versus SiO_2, respectively, for dredged basalts at offshore SW Taiwan. Data sources and symbols are the same as Fig. 3.

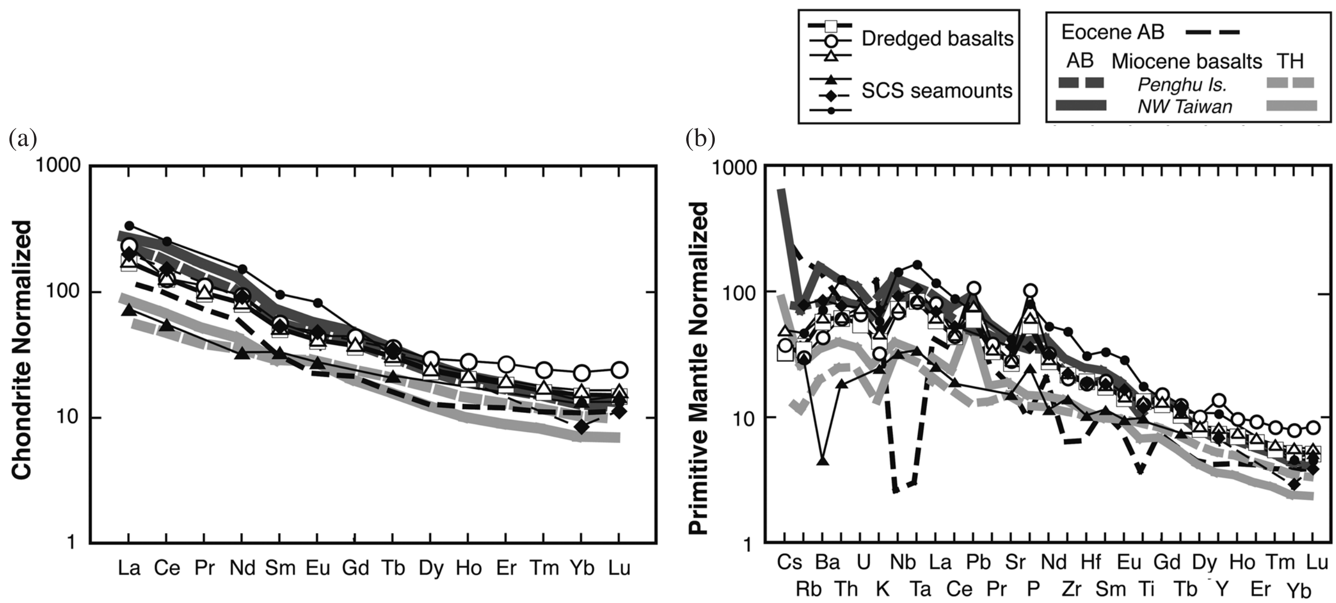

Fig. 5. A Chondrite-normalized REE variation diagram (a) and a primitive mantle-normalized trace element variation diagram (b) for dredged basalts at offshore SW Taiwan. Normalization constants are from Sun and McDonough (1989). Representative SCS seamounts (Tu et al. 1992), the Eocene volcanic rocks drilled in the Taiwan Strait and onland Taiwan from Wang et al. (submitted) and Miocene intraplate basalts in the Penghu Islands from Chung et al. (1994, 1995) are also shown for comparison. The letters in the legend representing the lithology, TH: tholeiite; AB: alkali basalt.

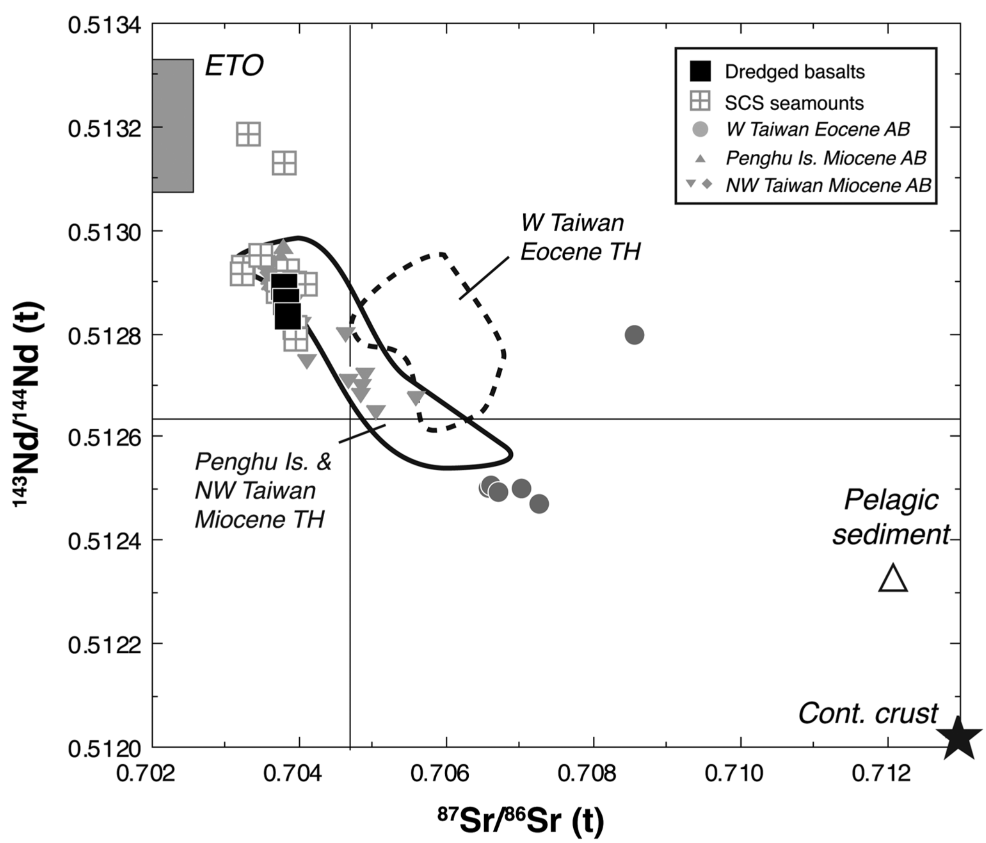

Fig. 6. Variation of $^{87}Sr/^{86}Sr$ (t) versus $^{143}Nd/^{144}Nd$ (t) for dredged basalts at offshore SW Taiwan. Data sources and symbols are the same as Fig. 3. Field of the East Taiwan Ophiolite (ETO) is from Jahn (1986) and Chung and Sun (1992). The composition of average continental crust from Taiwan is from Lan et al. (1990).

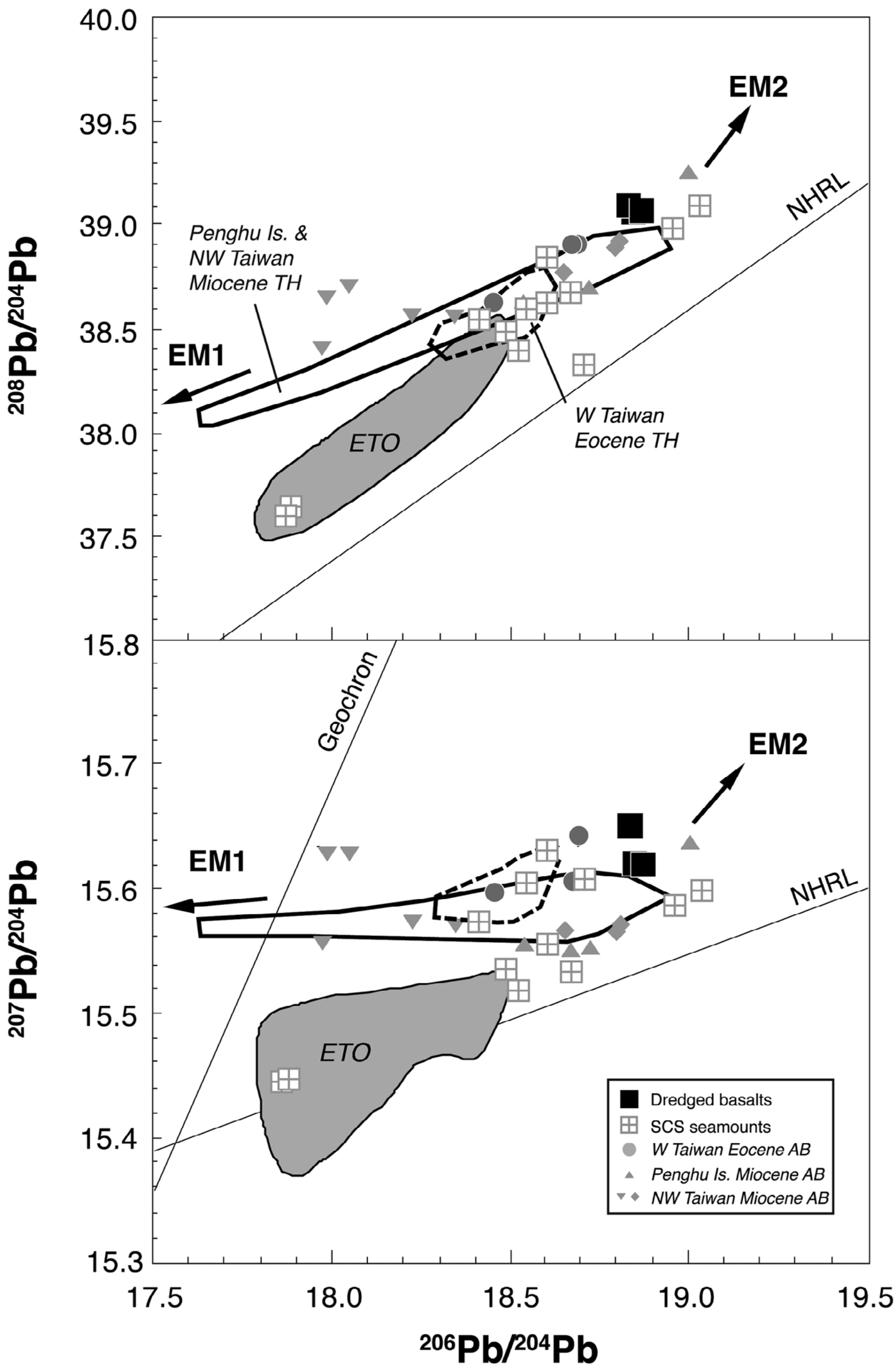

Fig. 7. $^{208}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ diagrams for dredged basalts at offshore SW Taiwan. Data for the ETO are from Sun (1980). The enriched mantle components EM1 and EM2 are from Hart (1988). The NHRL is from Hart (1984). Other data sources are the same as in Fig. 6.

has also been suggested by Lin et al. (2003) based upon tectono-seismic characteristics in the rift basins in the Taiwan Strait.

However, age results of the dredged basalts indicate these magmas were emplaced at about 21 Ma at the northeastern tip of SCS which coincide with the spreading of the SCS basin. It is also older than nearby Miocene intraplate basalts at the Penghu Islands (16 - 8 Ma; Chung et al. 1994), however, slightly younger than those along NW Taiwan (23 - 9 Ma; Chung et al. 1994). Thus, a northeastward migration of the rifting center from the SCS basin cannot explain the older eruption age which occurred at its northeastern tip or even older basaltic magmas erupted to the further northeast in NW Taiwan. Thus, ages of these dredged basalts demonstrate that rifting in NW Taiwan during the Miocene might result from a synchronous regional extension rather than a shifting of a rifting center from the SCS which is consistent with conclusion drawn by Yeh et al. (2010) suggesting that a generalized intraplate magmatic episode occurred at that time with SCS spreading at the SE Eurasian continental margin.

4.2 Petrogenesis of Basalt in the Northeastern Tip of the South China Sea

Low Mg content of these Miocene dredged basalts indicates they have been affected by fractional crystallization; however, its degree should be minor as no substantial Eu negative anomaly has been observed from their REE patterns (Fig. 5a). Influence from crustal contamination is also negligible as a result of no changes in Nd and Sr isotope compositions with increasing SiO_2 content (Fig. 8). Thus, the geochemistry of these dredged basalts can still reflect their mantle source characteristics within the region. Mantle normalized trace-element patterns of the dredged basalts show a typical OIB-type pattern, comparable to those of the SCS seamounts (Tu et al. 1992) and Miocene intraplate alkali basalts on the Penghu Island and NW Taiwan, but have a higher abundance than tholeiites (Chung et al. 1994, 1995; Fig. 5). Further when taking the compositions of the Nd-Sr-Pb isotope into account, these dredged basalts have homogeneous Nd-Sr isotope compositions sharing an indistinguishable range of isotope compositions with that of SCS seamounts and Miocene basalts on the Penghu Islands and NW Taiwan (Figs. 7 and 8). The dredged basalts also show an EM2-like affinity in their Sr-Nd-Pb isotope composition (Castillo et al. 2007) comparable to those of SCS seamounts and Miocene basalts on the Penghu Islands and NW Taiwan. The overall geochemical characteristics of the dredged basalts are similar with that of the early Miocene basalts (23 - 20 Ma) from Kungkuan in the NW Taiwan (Chung et al. 1994, 1995) and Baolai basalts, SW Taiwan (Smith and Lewis 2007).

The SCS seamounts are typical intraplate basalts emplaced on the SCS oceanic basin originated from decompressional melting of upwelling asthenosphere. Thus, the geochemistry of the SCS seamounts reveals characteristics of their source mantle, i.e., decompression melting of the subcontinental lithospheric and asthenospheric mantle (Tu et al. 1992). The dredged basalts have similar elemental and isotopic characteristics with the SCS seamounts, which suggest similar decompression melting of asthenospheric mantle interacted with subcontinental lithospheric mantle might happen beneath offshore SW Taiwan. Their geochemical similarity with the intraplate alkali basalts from Kungkuan at NW Taiwan and Baolai basalts, SW Taiwan also indicates their genetic link.

Chung et al. (1994, 1995) proposed that the early Miocene intraplate basalts at NW Taiwan were typical intraplate basalts originated from decompressional melting of upwelling asthenosphere interacted with the overlying lithospheric mantle. Therefore, extent of the lithospheric extension at the SE Eurasian continental margin in the early Miocene can be extended from northern Taiwan, south-central Taiwan to SW offshore Taiwan. It is indicated that the most northeastern extension of SCS spreading and lithospheric rifting coincided in offshore SW Taiwan. Therefore, the explanation of a synchronously regional lithospheric extension in association with seafloor spreading in the South China Sea, rather than shifting of rifting center from the SCS, is pro-

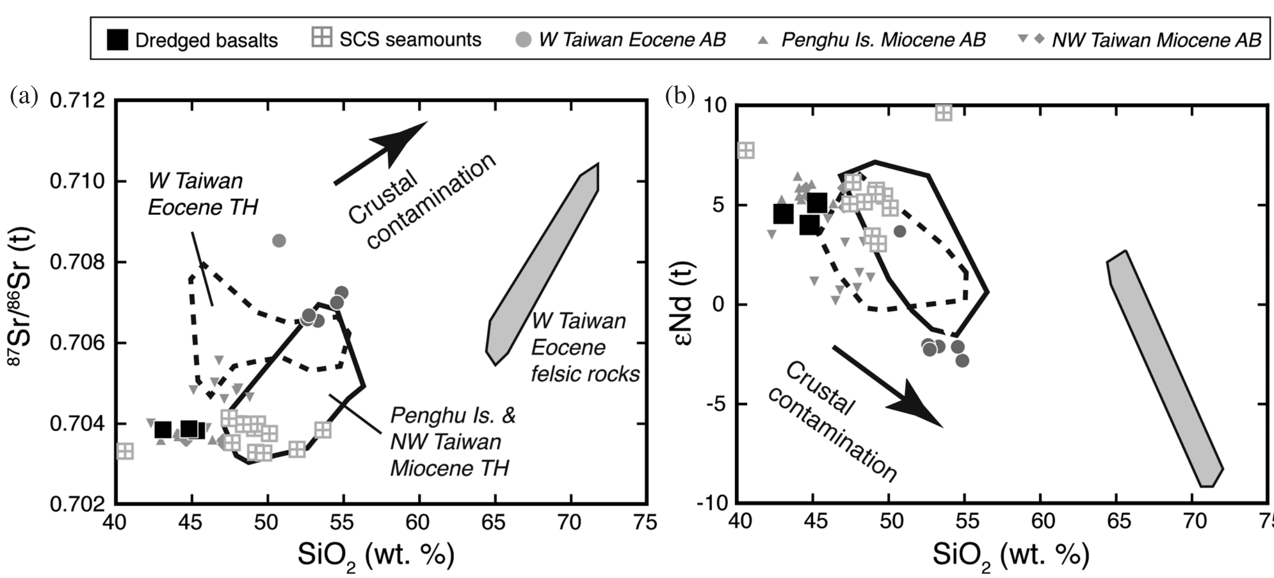

Fig. 8. Diagrams of (a) $^{87}Sr/^{86}Sr$ and (b) $\varepsilon Nd_{(t)}$ versus SiO_2 (wt.%) for dredged basalts at offshore SW Taiwan to show effect of crustal contamination on these rocks. Data sources and symbols are the same as Fig. 3.

posed as a model for the Miocene intraplate magmas in the SE Eurasian continental margin.

5. CONCLUSIONS

1. Volcanic rocks dredged from offshore SW Taiwan reveal another episode of intraplate volcanism postdated commence of the SCS spreading and erupted simultaneously during the spreading at the northeastern tip of SCS basin at the SE Eurasian continental margin around the Taiwan region. $^{40}Ar/^{39}Ar$ dating results of these dredged basalts show ages of ~22 - 21 Ma.
2. Their overall geochemical characteristics, showing typical OIB-type intraplate basaltic features, are similar to that of seamounts in the SCS basin and early Miocene intraplate basalts from Kuankuan at NW Taiwan and Baolai basalts, SW Taiwan.
3. Ages of these dredged basalts (~22 - 21 Ma) demonstrated that the earliest rifting magma (~23 Ma) in NW Taiwan might result from synchronously regional lithospheric extension in association with seafloor spreading in the SCS, rather than shifting of rifting center from the SCS.

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