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The igneous provinciality in Taiwan: consequence of continental rifting superimposed by Luzon and Ryukyu subduction systems

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Abstract—Geochemical characteristics of late Cenozoic volcanics in Taiwan demonstrate that these rocks were produced in diverse tectonic environments. In Taiwan, three igneous provinces, namely, Western, Eastern and Northern, respectively (in order of the initiation of volcanic activities), can be distinguished. The Western Province comprises intraplate basalts, erupted in the rifted continental margin of southeastern China; whereas the Eastern and Northern Provinces are composed of arc volcanics genetically related to the Luzon and the Ryukyu subduction zones, respectively. These volcanic rocks were sequentially emplaced on the island of Taiwan as a result of the collision between the Luzon arc and the Asian continent since about 12 Ma. This collision, likewise, induced westward migration of the Ryukyu Trench system and subsequent opening of the Okinawa Trough. As a consequence, the collision-derived compression diminished in northern Taiwan. A post-collisional extension regime thus formed has generated some recent volcanic rocks in this region.

Introduction

The active mountain belt of Taiwan was created by the collision between the Luzon arc and the Asian continent (Chai, 1972; Bowin *et al.*, 1978; Ho, 1986; Teng, 1990). This collision is the major event in the late Cenozoic geodynamic history of the Ryukyu–Taiwan–Luzon area (Fig. 1). In the Taiwan orogen, late Cenozoic volcanic rocks are widespread and characterized by a great diversity of rock types, presumably generated in different tectonic settings. They include intraplate basalts, island arc andesites, mid-ocean-ridge derived ophiolites and ultrapotassic rocks formed by post-collisional extension.

In Taiwan, three igneous provinces, namely the Western, Eastern and Northern Provinces (Fig. 2), have been recognized by Yen (1958). Liu and Wang (1982) illustrated the geographic distribution of these provinces and discussed general tectonic implications. It was shown that each province reflects a unique tectonic environment around Taiwan (Table 1). In the last decade, numerous geochemical studies of the volcanic rocks have been carried out with the purpose of understanding the processes of magma genesis along with the geodynamic evolution of the island.

In this paper, we first provide a review of the geotectonic framework of Taiwan. Then, a scheme of the igneous provinces will be presented and chemical and isotopic characteristics of the volcanic rocks will be summarized. Finally, following the arc–continent collision model proposed by Teng (1990), we shall discuss the tectonomagmatic evolution in Taiwan with emphasis on the temporal and spatial relationships between the late Cenozoic magmatism and the geotectonic environment.

Geotectonic Framework

The continental margin of southern China has been a rifted margin since the late Cretaceous (Taylor and Hayes, 1980; Ru and Piggot, 1986). This is evidenced by the occurrence of many Tertiary grabens and half-grabens in the Taiwan Strait and western Taiwan, as revealed by studies of seismostratigraphy and deep drilling down to about 6 km depth (Sun, 1985; Sun and Hsu, 1991). The rifting around the Taiwan Strait, which gave rise to episodic emplacement of intraplate basalts (Fig. 1), is generally considered to be related to the opening of the South China Sea. This rifting probably began in the late Eocene and resulted in major subsidence accompanied by graben formation in the early Oligocene (Teng *et al.*, 1991). It ceased due to the westward compression resulting from the arc–continent collision since about 12 Ma (Teng, 1990). This collision has not only created the orogen in Taiwan but also triggered westward encroachment of the Ryukyu Trench system that initiated the arc volcanism in northern Taiwan (Suppe, 1984; Teng *et al.*, 1992).

The Taiwan orogen is sitting on the boundary between the Philippine Sea plate and the Asian plate (Fig. 1). The Longitudinal Valley Fault in eastern Taiwan is believed to be the geologic suture (Fig. 2). To the east, the coastal Range represents the accreted northern tip of the Luzon arc. It consists of arc volcanics and sedimentary sequences; the latter comprise rocks from the pre-collisional Luzon arc–Manila Trench system overlain by syn-collisional orogenic sediments (Teng, 1987). To the west, metamorphic and sedimentary rocks of the deformed southeastern China margin are exposed. The Tananao metamorphic complex of the

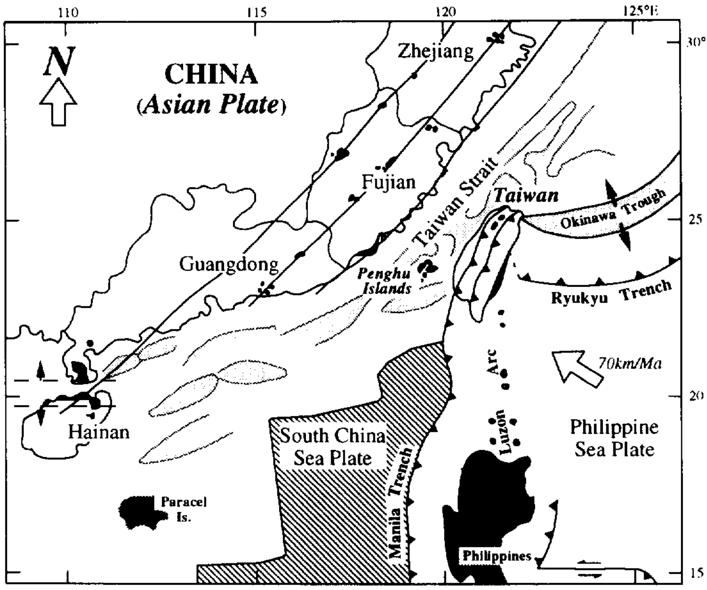

Fig. 1. Generalized map showing the geotectonic framework around Taiwan. Sedimentary basins and intraplate basalts resulting from the Cenozoic extension in the south China continental margin are shown by shaded and black areas, respectively. Modified from Suppe (1981), Ho (1986), Teng (1990) and Chung *et al.* (1994).

Central Range can be regarded as uplifted and unroofed continental basement. The Slate Terrane and the Western Foothills, both composed of Tertiary sequences, represent the overlying sedimentary cover (Chai, 1972; Ho, 1986; Teng, 1990). Further to the west, the Coastal Plain and the Taiwan Strait are underlain mainly by undeformed Cenozoic sedimentary sequences (Sun, 1985).

The Philippine Sea plate is subducting underneath the Asian plate at the Ryukyu Trench and overriding the South China Sea plate at the Manila Trech (Fig. 1). A change of the motion of the Philippine Sea plate at about 5 Ma (Seno and Maruyama, 1984) has been thought to be closely related to the arc–continent collision in Taiwan, and probably has induced westward migration of the subducting boundary of the Philippine Sea plate (Suppe, 1984). As a consequence, the Ryukyu Trench system extended southwards to northeastern Taiwan in association with subsequent backarc spreading (i.e. opening of the Okinawa Trough; Fig. 1). The northeastern part of Taiwan hence has switched from the collisional environment to the Ryukyu subduction scheme in the last 3 million years (Suppe, 1984; Teng *et al.*, 1992). Therefore, Taiwan is not only a collision zone between the Luzon arc and the Asian continent, but also a transitional region between the opposing Ryukyu and Luzon subduction systems.

The Igneous Provinces in Taiwan

Western Province

The Western Province consists of intraplate basalts emplaced in the southeast China rifted margin. The intraplate volcanism probably began in the early Tertiary and was most active in the Miocene time (Zhou and Chen, 1981; Chen, 1990). The early Tertiary volcanics occur sporadically in the sedimentary sequences in the Taiwan Strait (Sun, 1985; Sun and Hsu, 1991). Only late Cenozoic basalts have been exposed on land; as lava flows and pyroclastics in Fujian (mainland China), Penghu Islands (in the Taiwan Strait) and northwestern Taiwan, respectively (Fig. 1). Overall, these basalts display a spatial variation in chemical and isotropic compositions that could be explained as a result of the interaction between the lithosphere and the asthenosphere during continental rifting (Chung *et al.*, 1994).

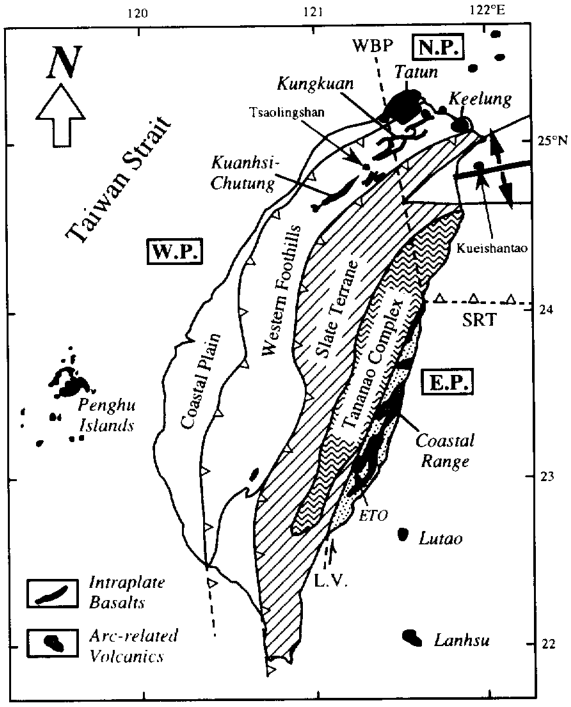

Fig. 2. Igneous provinces and major geotectonic units in Taiwan. W.P. = Western Province; E.P. = Eastern Province; N.P. = Northern Province; ETO = East Taiwan Ophiolite; L.V. = Longitudinal Valley; WBP = western boundary of Philippine Sea plate; SRT = seismological Ryukyu Trench. Summarized from Tsai *et al.* (1977), Bowin *et al.* (1978), Ho (1982) and Liu and Wang (1982).

Table 1. Igneous provinces in Taiwan and their generalized characteristics

Province	Tectonic setting	Major locality	Age (Ma)	Main rock	References
Western	Continental rifting	Penghu Islands	16–8	Basalt	Chen and Chung (1985); Juang (1988); Chen (1990); Lee (1990 and unpublished data); Chung *et al.* (1995a)
		Kungkuan area	23–20	Basalt	
		Kuanhsi–Chutung	13–9	Basalt	
Eastern	Luzon subduction	Coastal Range	>16–4	Andesite	Juang and Bellon (1984); Yang *et al.* (1988, 1992); Yang (1992); Lo *et al.* (1994)
		Lutao and Lanhsu	>3.5–0.5*	Andesite	
	South China Sea spreading	Kuanshan (Lichi Mélange)	~15	Ophiolite	Liou *et al.* (1977); Suppe *et al.* (1981); Jahn (1986); Chung and Sun (1992)
Northern	Ryukyu subduction	Tatun Volcanoes	2.8–0.2	Andesite	Chen (1978); Chen (1989); Juang and Chen (1989); Wang and Chen (1990); Chen (1990)
		Keelung Volcanoes	1.7–0.8	Andesite	
		Offshore Islets	2.1–1.6	Andesite	
Recent	Post-collisional extension	Kueioshantao	<0.1	Andesite	Chang and Chen (1979); Chen (1983); Chen (1989); Juang and Chen (1989)
		Tsaolingshan	≤0.2	Absarokite	

* In Hsiaolanhsu, a small islet near Lanhsu, the volcanism may have lasted until recently (<0.1 Ma; Yang, 1992).

The Penghu Islands are composed of 63 basaltic islets with a total area of about 120 km^2 above the sea level. The basaltic volcanism lasted from 16 to 8 Ma (Table 1) and resulted in alternating flows of alkali basalts and tholeiites in many localities. Generally, tholeiites constitute the bulk of the islands. They all display element abundance patterns typical of OIB (ocean island basalt) (Fig. 3a), resembling other Cenozoic basalts around the South China Sea (Tu *et al.*, 1991, 1992). Likewise, alkali basalts and tholeiites in the Penghu Islands have virtually indistinguishable isotopic compositions (Fig. 4a), suggesting that they originated from a rather homogeneous mantle source through different degrees of melting (Chung *et al.*, 1994).

In NW Taiwan, basalts occur as lenticular bodies in Neogene sedimentary sequences of the Western Foothills (Fig. 2). The sequences, presently constituting a part of the fold-and-thrust belt of Taiwan (Suppe, 1981; Dahlen *et al.*, 1984), have been transported about 200 km northwestly and squeezed up to the present position by the arc–continent collision (Suppe, 1981, 1984; Teng, 1990). Two major stages of basalt emplacement, the Kungkuan

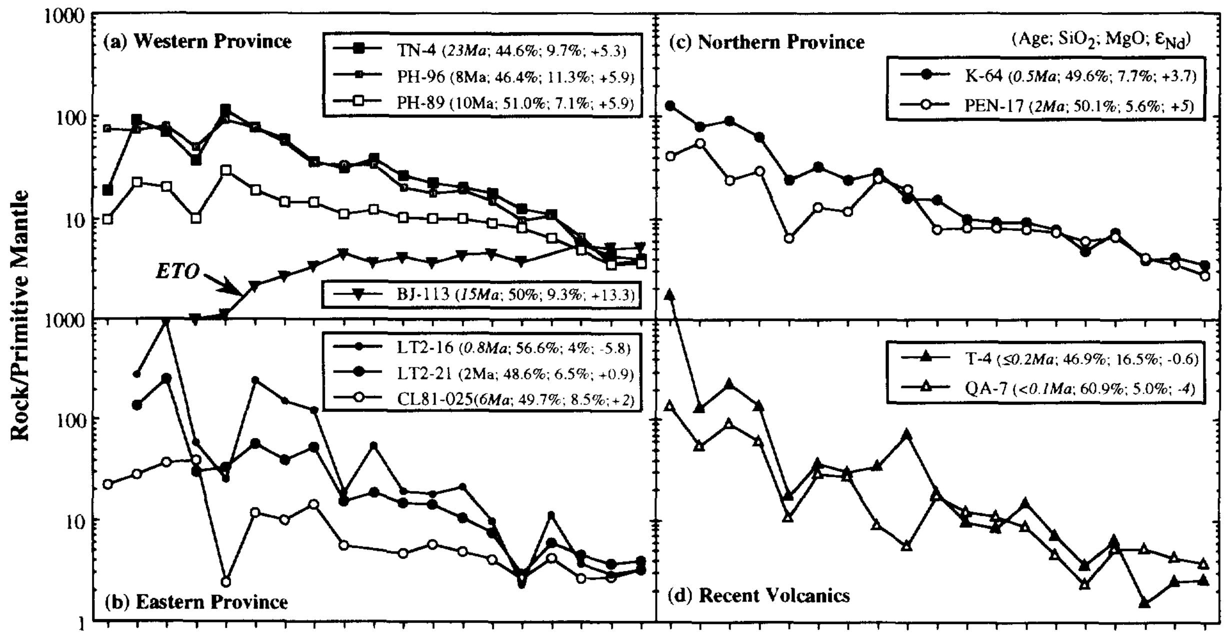

Fig. 3. Spidergrams of the late Cenozoic volcanic rocks in Taiwan. Except for two samples (LT2-16 and QA-7), basaltic rocks from different igneous provinces are shown through the plots. They include: (a) TN-4, alkali basalt from the Kungkuan area; PH-96, alkali basalt from Penghu Islands; PH-89, tholeiite from Penghu Islands; BJ-113, basalt of the East Taiwan Ophiolite; (b) CL81-025, tholeiitic basalt from Wushipi, central Coastal Range; LT2-21, high-Al basalt from Lutao; LT2-16, andesite from Lutao; (c) PEN-17, high-Al basalt from Pengchiahsu (an offshore islet); K-64, cal-alkaline basalt from the Tatun Volcano Group; (d) T-4, absarokite from Tsaolingshan; QA-7, andesite from Kueishantao. Note that the East Taiwan Ophiolite basalt is shown in (a) for clarity. Further chemical data are given in parentheses and italicized if representing synthesized values. Data are from Jahn (1986), Chen (1989), Chen (1990), Chen *et al.* (1990), Yang (1992) and Chung *et al.* (1995; and unpublished data). The primitive mantle normalizing values are taken from Sun and McDonough (1989).

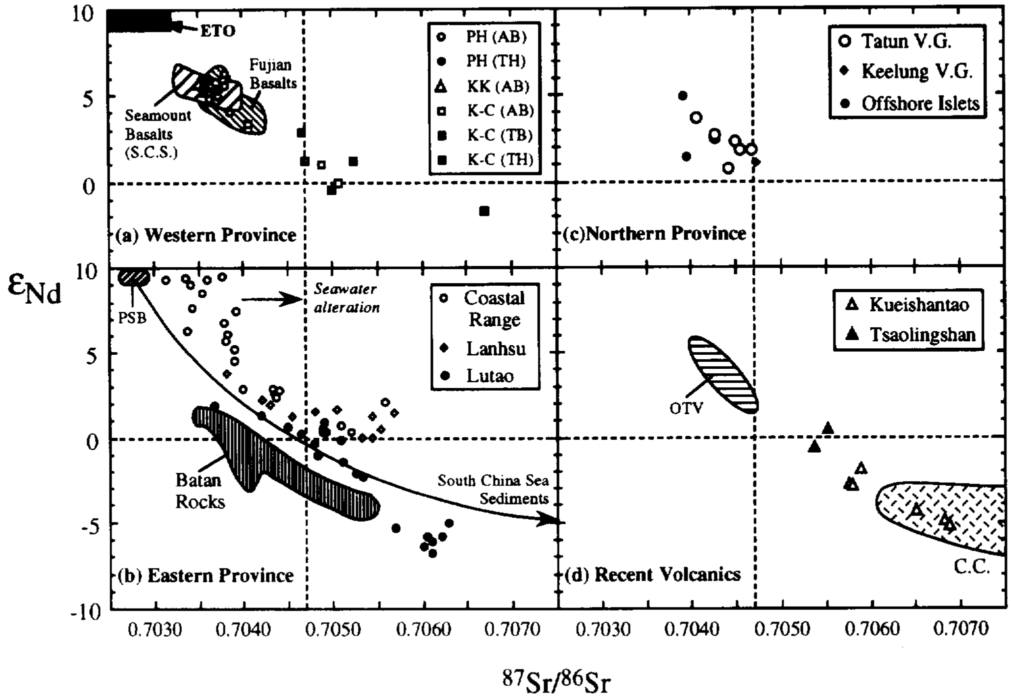

Fig. 4. Sr–Nd isotopic plots of the late Cenozoic volcanic rocks in Taiwan. Data are from Jahn (1986), Chen (1989), Chen *et al.* (1990), Yang (1992) and Chung *et al.* (1995; and unpublished data). Sources for the comparison field are as follows: (a) seamount basalts from the South China Sea—Tu *et al.* (1992), Fujian basalts—Chung *et al.* (1994); (b) PSB (western Philippine Sea basalts)—Hickey-Vargas (1991), Batan volcanics and xenoliths—McDermott *et al.* (1993); (d) OTV (Okinawa Trough volcanics)—Auzende *et al.* (1990), C.C. (continental crust of southeast China)—Lan (1989) and Cheng Hong *et al.* (1990).

Stage and the Chiaopanshan Stage (Yen, 1958), have been proposed. In general, they are represented by the volcanic activities in the Kungkuan (23–30 Ma) and the Kuanhsi–Chutung (13–9 Ma) areas, respectively (Fig. 2 and Table 1). The Kungkuan volcanics comprise overwhelmingly alkali basalts; whilst rocks in the Kuanhsi–Chutung area show a wide range of compositions including basanite, alkali basalt, transitional basalt and tholeiite (Chen and Chung, 1985). All these basalts exhibit coherent OIB-type chemical characteristic (Fig. 3a) but variable isotopic compositions (Fig. 4a). The early Miocene Kungkuan basalts have uniform Sr and Nd isotopic ratios that are identical to those of the Penghu basalts. In Fig. 4a, they plot within the range of the intraplate basalts in Fujian, showing isotopic composition similar to seamount basalts from the South China Sea (Tu *et al.*, 1992). In contrast, the Kuanhsi–Chutung basalts reveal distinct isotope characteristics (Fig. 4a). The significantly higher $^{87}Sr/^{86}Sr$ and lower $^{143}Nd/^{144}Nd$ ratios of these late Miocene basalts indicate that an additional source component is required in the magma genesis. Most recently, based on new Pb isotopic data, Chung *et al.* (1995) document this component to be an EM1-type (as defined by Zindler and Hart, 1986) mantle source. This finding makes the Kuanhsi–Chutung basalts the first convincing group of known volcanics showing EM1 isotope signatures in South China and adjacent areas.

Chung *et al.* (1994) proposed a continental rifting model of lithosphere thinning and asthenosphere upwelling beneath the Taiwan Strait in the Miocene time. According to this model, the "homogeneous" Kungkuan basalts (23–20 Ma) can be interpreted as decompressional partial melts originating from the asthenospheric convecting mantle. On the other hand, the chemically and isotopically heterogeneous basalts in the Kuanhsi–Chutung area (13–9 Ma) may represent contaminated asthenospheric melts that have interacted to various degrees with the overlying lithosphere during ascent (Chung *et al.*, 1995). This secular change of basalt chemistry in NW Taiwan, which was located near the southeasternmost part of the Asian continental margin in the Miocene time, may be attributed to the onset of the arc–continent collision (i.e. at about 12 Ma). Since then, the collision-derived compression may have stagnated the magma ascent that could heat up and trigger melting of the lithosphere. The compression finally terminated the intraplate volcanism.

Eastern Province

The Eastern Province, lying to the east of the Longitudinal Valley Fault, comprises predominantly arc volcanics in the Coastal Range and on the Lutao and Lanhsu islets (Fig. 2). These volcanics were emplaced since at least 16 Ma until the late Quaternary (Table 1). They constitute the backbone of the northern Luzon arc. The most dominant rock type is andesitic pyroclastics with compositions ranging from tholeiitic to high-K calc-alkaline series (Chen, 1990; Yang, 1992). All volcanics in this province, except rocks of the East Taiwan Ophiolite (Fig. 2), show depletion of high field strength elements (HFSE; e.g. Ta, Nb, Ti) indicative of an arc-related origin (Fig. 3b). In addition, they exhibit heterogeneous isotope characteristics with ϵ_{Nd} values varying from +10 to −7 (Fig. 4b). A temporal variation in chemical and isotopic compositions of these arc rocks (i.e. increase of alkalinity and $^{87}Sr/^{86}Sr$ ratios and decrease of $^{143}Nd/^{144}Nd$ ratios) has been documented (Chen, *et al.*, 1990; Defant, *et al.*, 1990; Yang, 1992).

In general, this temporal chemical and isotopic variation can be attributed to involvement of continental sediments in the magma geneses when the Luzon arc progressively approached the Asian continent (Defant *et al.*, 1990). Excluding the effect of seawater alteration, Sr–Nd–O isotope systematics suggest an origin for most rocks via appropriate degrees of mixing between the depleted mantle of the western Philippine Sea and the subducted sediments from the South China Sea (Chen *et al.*, 1990; Yang, 1992). Certain volcanics in the Lutao islet show the highest Sr and the lowest Nd isotopic ratios plotting below the possible mantle–sediment mixing curve (Fig. 4b). Moreover, they have highly enriched LILE (large ion lithophile element; e.g. Ba, Th, U) and LREE (light rare earth element; e.g. La and Ce) abundances (Fig. 3b). Such characteristics indicate incorporation of additional source component(s), rather than the binary mixing, in the magma generation. To explain the unusual Sr–Nd isotopic array defined by these Lutao samples and rocks from the Batan island (Fig. 4b), Chen *et al.* (1990) suggested the involvement of an EM1-type mantle source which has never been found before in a modern island arc setting. However, based mainly on new Pb isotopic evidence, McDermott *et al.* (1993) discard this suggestion and proposed an alternative "subduction component" of slab-derived hydrous fluid. Yang (1992), through a systematic field survey coupled by chronological, chemical and isotopic studies, emphasized the highly LILE-enriched character of the Lutao volcanics (e.g. La and Th reach 300 and 1000 times of the primitive mangle values, respectively; Fig. 3b). He therefore suggested the contribution of low-degree partial melts from the continental lower crust (of mafic granulite composition) to account for the generation of these distinctive arc volcanics. It is further postulated that this enrichment event related to lower crustal melting which took place rather recently (<1 Ma), resulting probably from the particular tectonic position of Lutao islet where the southeastern China lithosphere is likely to have been underthrusted beneath the Luzon arc (Yang, 1992).

The East Taiwan Ophiolite, consisting of glassy basalts, dolerites, gabbros and serpentinized peridotites as blocks in the Neogene mélange in the western part of the Coastal Range (Liou *et al.*, 1977), is an exotic rock suite in the Eastern Province. Since Shih *et al.*, (1972), who first recognized the "oceanic" character of these rocks and suggested a name of "Coast Range Ophiolite of Taiwan", numerous petrological, geochemical and isotopic studies have been carried out (see Chung and Sun, 1992; for a review). Overall geochemical and isotopic characteristics, such as the MORB (mid-oceanic ridge basalt) type elemental abundances (Fig. 3a) and Nd isotope compositions of the glassy basalts ($\epsilon_{Nd} \approx 13$–9; Jahn, 1986), argue for a mid-ocean or marginal basin origin for the East Taiwan Ophiolite. Together with the geotectonic consideration, the ophiolite is widely believed to have originated from the mid-ocean region of the South China Sea. The rocks were incorporated into the Manila Trench–Luzon arc system, through subduction of the South China Sea plate underneath the Philippine Sea plate (Fig. 1), as allochthonous fragments in the mélange; and finally emplaced at their present location as a result of the arc–continent collision (Suppe *et al.*, 1981). Because of lack of drilling projects in the South China Sea, the well-studied East Taiwan Ophiolite is currently the best material for investigating the structure and chemistry of the ocean floor. Moreover, it provides important chemical and isotopic information of the convecting upper mantle in South China, which offers clues for understanding the relationship between Cenozoic continental rifting, mantle dynamics and intraplate volcanism around this region (Chung and Sun, 1992; Tu *et al.*, 1992; Chung *et al.*, 1994).

Northern Province

In the Northern Province, volcanic rocks occur in the northern tip of Taiwan and the offshore region (Fig. 2). The magmatism, as compared to that occurring in the Western and Eastern Provinces, is relatively juvenile and short-lived (2.8–0.2 Ma; Table 1). Two main volcanic fields (namely, the Tatun and the Keelung Volcano Groups), as well as the offshore islets, are composed of andesitic pyroclastics and flows with minor basalts (Chen, 1990; and references therein). These rocks are also characterized by HFSE depletions in spidergrams (Fig. 3c), indicating a subduction-related origin. In contrast to volcanics in the Eastern Province, they show rather restricted Sr and Nd isotopic compositions (Fig. 4c). Besides, the basaltic rocks have generally lower $^{87}Sr/^{86}Sr$ and higher $^{143}Nd/^{144}Nd$ ratios than the andesites (Chen, 1989). The chemical and isotopic data demonstrate that this volcanism evolved in a tectonic environment affiliated with the western Ryukyu subducting system via combined crystal fractionation and assimilation processes (Chen, 1989; Chen, 1990).

Based on integration of available radiometric age data, Teng *et al.* (1992) pointed out a westward-younging character for the carc volcanism in the Northern Province. It appears that both the onset and the cessation of the volcanic activity migrated from the east to the west, hence each volcano was active only for a short period of about 1 million years. These authors proposed that the arc magmatism was initiated by the westerly encroachment of the Ryukyu subduction system, and ceased subsequently as a result of the southwestward propagation of the opening of the Okinawa Trough.

Recent volcanisms in Northern Taiwan

In northern Taiwan, two recent igneous centers provide important information concerning a change in the neotectonism. One is the Kueishantao, an offshore islet in the Okinawa Trough (Fig. 2). It may offer a unique opportunity for studying the initiation of backarc opening. The islet consists entirely of young andesitic rocks (<0.1 Ma; Juang, 1988), which seem to be characterized by similar geochemical features to the arc volcanics in northern Taiwan. They show LILE enrichment and HFSE depletion (Fig. 3d), which may reflect combined effects from subduction-related processes and crustal contamination (Chen, 1989). However, because of their relatively high Sr and low Nd isotopic compositions pointing towards the southeast China continental crust (Fig. 4d), crustal contamination could have played a significant role in magma geneses during the initial stage of opening of the Okinawa Trough. The degrees of crustal contamination may diminish following the establishment of the back-arc spreading, as evidenced by the lower Sr and higher Nd isotopic ratios of dredged volcanics (Fig. 4d) from the well-rifted region in the central Okinawa (Auzende *et al.*, 1990).

The other recent volcanism took place in the Tsaolingshan, an independent volcanic dome sitting on the Pleistocene sediments in northwestern Taiwan (Fig. 2). It consists of mafic ultrapotassic rocks ($K_2O/Na_2O > 2$) extremely enriched in some LILE (Fig. 3d); hence these rocks have been termed "absarokites" (Yen, 1949; Chen, 1983). They used to be regarded as a variety of the arc volcanics in the Northern Province because of showing HFSE depletions (Fig. 3d), however, these magmas have distinctive chemical characteristics (e.g. $MgO \approx 15\%$; $P_2O_5 \approx 1.5\%$; $K_2O \approx 4\%$; $Rb \approx 1000$ ppm) and somewhat higher Sr and lower Nd isotopic ratios (Fig. 4d). Furthermore, they were emplaced more recently ($\leqslant 0.2$ Ma; Juang, 1988), a significant distance away from the arc volcanic fields of the Northern Province.

We note that all of northern Taiwan has been stepping into the Okinawa Trough spreading regime; as evidenced by the Quaternary extensional structure features (Lee and Wang, 1988) and the earthquake focal mechanisms (Tsai *et al.*, 1977; Tsai, 1986). Therefore, the emplacement of the ultrapotassic rocks may have resulted from the onset of this post-collisional extension. A comparable case exists in eastern Indonesia which has also been characterized by arc–continent collision (between the Banda arc and the Australian continent) since at least Pliocene time (Charlton, 1991). In that region, a post-collisional extensional setting has been generally accepted to account for the generation of highly potassic magmas of the late Quaternary age (Stolz *et al.*, 1990; Charlton, 1991; Edwards *et al.*, 1991). In this sense, the chemical and isotopic characteristics of the Tsaolingshan absarokite can be explained to have originated from a refractory and metasomatized (phlogopite and apatite bearing) lithospheric mantle source recently modified by subduction-related processes.

Tectonomagmatic Evolution of Taiwan

Combining information provided by the igneous provinciality and the geotectonic history of Taiwan as discussed in the former sections, the tectonomagmatic evolution in Taiwan can be summarized as follows.

Since the early Tertiary the passive margin of southeastern China has been a rifted continental margin related to the opening of the South China Sea. The rifting lasted at least until the late Miocene and resulted in the formation of many sedimentary basins coupled with episodic intraplate basaltic volcanism (Fig. 5a). The Luzon volcanic arc, resulting from eastward subduction of the South China Sea plate underneath the Philippine Sea plate, did not have any contact with the rifted continent until about 12 Ma. Since then, northwestward motion of the Philippine Sea plate has given rise to the onset of the collision between the Luzon arc and the Asian continent. This collision changed the tectonic environment from dilational to compressional and hence terminated the intraplate basaltic volcanism (Fig. 5b).

The continuing collision resulted in folding and thrusting of the continental margin to form the orogen in Taiwan. At the latest Miocene, the northern tip of the Luzon arc began to encroach upon the southeastern China margin. This may have started the incorporation

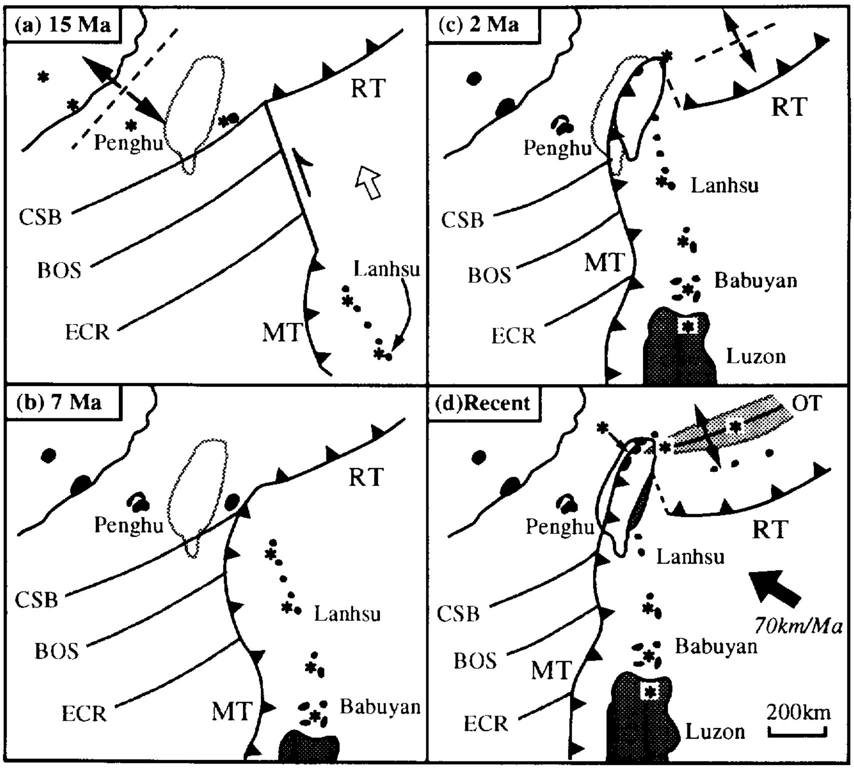

Fig. 5. Integrated maps modified from Teng (1990) showing the late Cenozoic tectonomagmatic evolution of Taiwan. Stars indicate active magmatisms at various ages. CSB = continental shelf break; BOS = base of slope; ECR = edge of continental rise; MT = Manila Trench; OT = Okinawa Trough.

of continental materials into the northern Manila Trench and influenced the arc magma generation, as evidenced by the temporal chemical and isotopic variation observed in the volcanic rocks of the Coastal Range. Following the movement of the overlying Luzon arc, the western boundary of the Phillippine Sea plate propagated to the west. Consequently, the compressional tectonism in the northern orogen ceased and the arc magmatism related to the southwestern Ryukyu Trench took place since about 3 Ma (Fig. 5c). In the meantime, the collision also induced opening of the Okinawa Trough which subsequently obstructed the Ryukyu subduction regime and terminated the nascent arc volcanism (Fig. 5d). Relating to this back-arc opening, a post-collisional extension setting has been initiated most recently in northern Taiwan. It resulted in the Kueishantao volcanism in the southwestern part of the Okinawa Trough and the emplacement of Tsaolingshan ultrapotassic rocks in northwestern Taiwan.

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