FORUM

Extensional collapse of the northern Taiwan mountain belt: Comment and Reply

COMMENT

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In Teng's (1996) published study of an extensional collapse model in the northern Taiwan mountain belt, he claimed that the Okinawa Trough opened up in the middle of the orogen instead of the volcanic arc, and that the southern Okinawa Trough is a fore-arc rift basin. These conclusions need more clarification.

This debate stems from the tectonic definition of the northern Taiwan volcanic zone, which stands on an almost east-west line along the northern wall of the southern Okinawa Trough from Tatunshan to Koibisho (T to K, Fig. 1 in Teng, 1996). This volcanic zone has been considered as a part of the southwestern extension of the Ryukyu island arc (Ho, 1982). However, the submarine volcanic knolls are found (Kimura et al., 1991) a little north of Ishigakijima and Iriomotejima (S and R, Fig. 1 in Teng, 1996). These submarine knolls can be continuously linked to the northern part of the Quaternary Ryukyu volcanic front. Therefore, the geographical observation does not support that the northern Taiwan volcanic zone is a part of the southwestern extension of the Ryukyu volcanic front because there exists a 160 km northward offset between the volcanic zone and the southwestern extension of the volcanic front along 124°E (see D–D′ cross section in Fig. 1 in Teng, 1996).

The geochemical data of the northern Taiwan volcanic zone does not show the "typical" island arc signature. In the Nb/Zr vs. Ba/Zr diagram (Fig. 1), the ratios for basaltic rocks of the northern Ryukyu volcanic front are plotted in the low Nb/Zr and high Ba/Zr corner. This corner represents the typical island arc basalt (IAB) signature (Nb/Zr: IAB < 0.05 < ocean island basalt [OIB]; Perfit et al., 1980; Gill, 1981, Morris and Hart, 1983; Reagan and Gill, 1989). In contrast, Nb/Zr for basaltic rocks of the northern Taiwan volcanic zone are higher than those of the Ryukyu volcanic front and are plotted close to that of the OIB (Sun and McDonough, 1989). Also, the Nb/La ratios of the volcanic zone basalts, which vary from 1.7 to 0.7, are similar to those of OIB and higher than those of IAB (Nb/La: IAB < 0.5 < OIB; Perfit et al., 1980; Gill, 1981; Reagan and Gill, 1989).

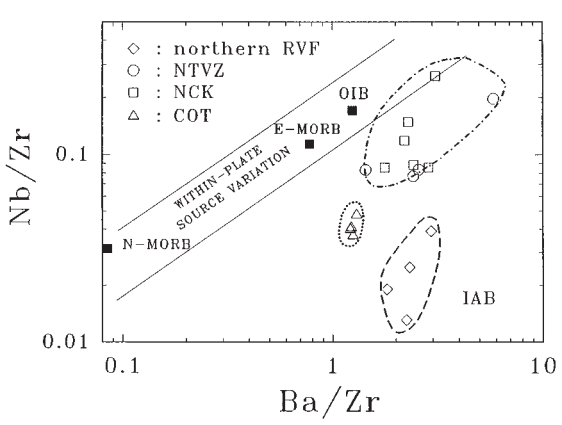

Figure 1. Nb/Zr versus Ba/Zr diagram. Abbreviations are as follows: NTVZ—the northern Taiwan volcanic zone, COT—the central Okinawa Trough, RVF—the Ryukyu volcanic front, IAB—island arc basalt, NCK—the northwestern and central Kyushu, OIB—ocean island basalt, MORB—mid-ocean-ridge basalt. The data of the COT and the NCK as well as the NTVZ are from Ishizuka et al. (1990) and Chen et al. (1996), respectively. The values of OIB, E-MORB, and N-MORB are from Sun and McDonough (1989).

Based on Teng's (1996) model, the termination of magmatism of the northern Taiwan volcanic zone is believed to be related to the opening of the Okinawa Trough, which also propagated westward (Figs. 2 and 4 of Teng, 1996). However, the age data of the northern Taiwan volcanic zone have shown that the westward trend of the cessation times of volcanic activity are not systematical. The young volcanic rocks (<0.5 Ma) can be found along the northern Taiwan volcanic zone not only in the western part, e.g., Meinhuahsu (~122°E) and Kuanyinshan (west of Tatunshan, ~121.5°E), but also in the eastern part, e.g., Kobisho (~123.5°E) (Shinjo et al., 1991; Juang, 1993; Wang and Chen, 1990; Tien et al., 1994). Thus, the magmatic activity of the eastern part of the northern Taiwan volcanic zone is not extinct due to the opening of the Okinawa Trough as suggested by Teng (1996). Moreover, the western propagation of the onset ages of magmatism in the northern Taiwan volcanic zone cannot be verified either, because the volcanic rocks older than 2 Ma can be found in eastern and western parts of the zone, e.g., Sikibisho (east of Kobisho, ~124.5°E), Penchiahsu (~122°E), and Tatunshan (~121.5°E) (Shinjo et al., 1991; Juang, 1993; Wang and Chen, 1990; Tien et al., 1994). All these observations are not consistent with the magmatic activity of the northern Taiwan volcanic zone shown in Figures 2 and 4 of Teng's paper.

In conclusion, the submarine geographical observation near the southern Okinawa Trough and geochemical characteristics of basaltic rocks in the northern Taiwan volcanic zone do not support that the zone is a southwestern extension of the Ryukyu volcanic front. The temporal variations of the onset and the termination of magmatism in the northern Taiwan volcanic zone did not show any trend on the spatial distribution. The interpretation of the southern Okinawa Trough as a fore-arc rift basin is considered fallacious. The volcanic activity of the northern Taiwan volcanic zone was mainly controlled by the postcollision extension in this whole area, and only minorly affected by the opening of the Okinawa back-arc basin and the subduction of the Philippine Sea plate.

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REPLY

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I appreciate Chang-Hwa Chen's comments on the northern Taiwan volcanic zone, which was not the major topic in Teng (1996) and, hence, was not fully discussed. My interpretation of the northern Taiwan volcanic zone as a volcanic arc is based on more than 50 years of field mapping, petrological and geochemical studies, and tectonic analyses accomplished by various workers (for a review, see Chen, 1990; Teng et al., 1992). The northern Taiwan volcanic zone consists of a series of volcanic cones and chonoliths aligned parallel to the Ryukyu Trench and is underlain by a north-dipping Wadatti-Benioff zone. These volcanic bodies predominately contain andesites (>90%), and some of them are capped by minor amounts of basalt. Most of these rocks pertain to the calc-alkaline series, while some fall in the shoshonitic series (Chen, 1982, 1990; Juang and Chen, 1989). Trace element data show that both andesites and basalts are characterized by high large ion lithophile element/rare earth element and high field strength element ratios and a prominent depletion in Ta (Chen, 1982, 1990; Juang and Chen, 1989). Lead isotopic compositions demonstrate a distinct signature of sediment mixing in the source magma (Sun, 1980). All these features indicate a close affiliation of northern Taiwan volcanic zone magmatism with the subduction zone and strongly support the widely accepted notion that the volcanic zone is part of the Ryukyu volcanic arc.

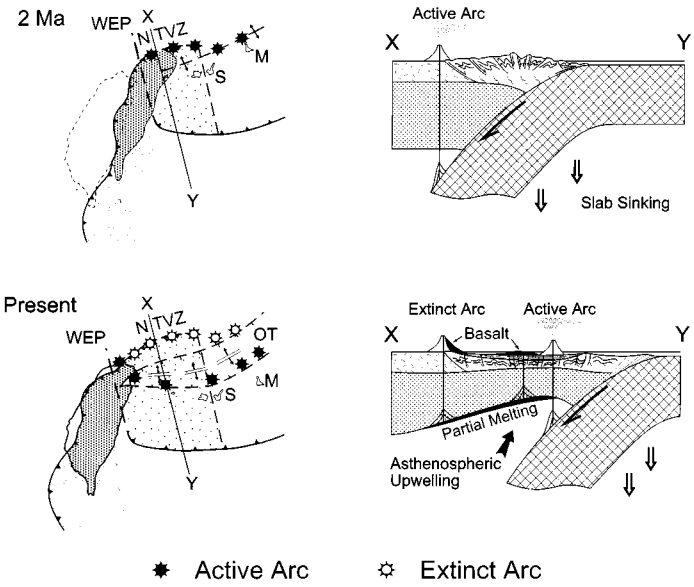

Figure 1. Tectonic evolution of northern Taiwan volcanic zone (NTVZ). Left is the plane views, and right is the corresponding cross sections. Note that arc volcanism was active in NTVZ at 2 Ma but later migrated to the Okinawa Trough. Asthenospheric upwelling induced by lithospheric stretching may trigger partial melting of the decompressed mantle to yield magmas of ocean-island-basalt signature. WEP—western edge of subducting Philippine Sea plate, S—Ishigakijima, M—Miyako-jima, OT—Okinawa Trough (modfied from Fig. 4 of Teng, 1996).

Chen is correct that the present Ryukyu volcanic arc can be linked to a series of submarine volcanoes north of the Ryukyu islands. But he failed to recognize the fact that these submarine volcanoes did not exist before the Okinawa Trough opened up at about 2 Ma. As shown in Figure 1, arc volcanism was active in the northern Taiwan volcanic zone before 2 Ma but later migrated southward to the Okinawa Trough as the subducting slab rolled back. Initiated by the flipping of subduction but terminated by the following slab rollback, arc volcanism in the northern Taiwan volcanic zone has been short lived and propagating westward. A time-space plot of more than 60 available K-Ar and fission track dates indeed show that the northern Taiwan volcanic zone andesites are almost all confined to a narrow westward-younging zone (Teng et al., 1992), which gives additional support to the proposed scenario.

Although misinterpreting the tectonic setting of the northern Taiwan volcanic zone, Chen highlighted an important geochemical feature that has already been demonstrated by previous studies (Chen, 1982, 1990). It appears that some of the basaltic rocks in the zone, which postdate the arc andesites, display a distinct near-ocean-island-basalt (OIB) signature that is anomalous to the overall arc characteristics. This anomaly comes as no surprise but is a corollary in my model. As shown in Figure 1, lithospheric stretching associated with the orogenic collapse in the last 2 m.y. may well have induced asthenospheric upwelling under the northern Taiwan volcanic zone and the Okinawa Trough. Partial melting of these decompressed mantle materials may yield magmas with an OIB signature. Depending on the degree of partial melting and the amount of contribution from the subducting plate, a whole gamut of magmas can be produced with the chemical signature ranging from OIB to the arc. As these magmas rose to the earth's surface, they were capable of forming various types of basalts in the northern Taiwan volcanic zone and neighboring areas, including those Chen described.

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