Origin of the Pliocene-Quaternary magmatism in Northern Taiwan: reviews and debates

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Abstract

Being part of an active mountain belt formed by oblique collision of the Luzon arc with Asia, northern Taiwan and offshore islets are marked by a series of latest Pliocene-Quaternary volcanoes whose eruptions have been conventionally ascribed to westward propagation of the Ryukyu volcanic arc (Chen, 1990; Chung, 1995; Juang, 1993; Teng, 1996). The Northern Taiwan Volcanic Zone (NTVZ) comprises several offshore volcanoes from Sekibisho to Mienhuayu (MHY), two major onland volcanic fields, i.e., the Keelung and Tatun Volcano Groups, and two isolated volcanic domes named Kuanyinshan (KYS) and Tsaolinghsan (TLS). Kueishantao and volcanoes in the Okinawa Trough at the vicinity of Taiwan are not included due to different petrogenesis and tectonic setting. Available age data show that the NTVZ volcanism commenced randomly related to their localities at 2.8-2.6 Ma and lasted throughout the Quaternary (Wang et al., 2004), in contrary to the central Ryukyu volcanic arc volcanism which has existed earlier in 18-6 Ma (Kizaki, 1986; Shinjo, 1999). The NTVZ volcanic rocks consist dominantly of andesites with calc-alkaline geochemical features, similar to that often observed in the convergent-margin lavas (Gill, 1981). Therefore, the NTVZ has been envisaged over decades as the westernmost segment of the Ryukyu volcanic arc and (Teng, 1996), furthermore, postulated a tectonomagmatic model for the northern Taiwan orogenic evolution, in which the NTVZ develops as a result of southwestward flipping of the Ryukyu subduction after Plio-Pleistocene extensional collapse of the northern Taiwan mountain belt.

However, there are problems in considering the NTVZ as part of the Ryukyu volcanic arc. These include (1) the ~150 km horizontal displacement between the NTVZ and the western end of central Ryukyu volcanic arc; (2) parts of the NTVZ (offshore islets) are now sitting ~200-250 km above the north-dipping Benioff zone of Philippine Sea plate (Chou et al., 2006; Kao et al., 1998), distinct from the Ryukyu arc whose volcanic front is essentially located along the 100-km-depth Benioff zone contour; (3) some NTVZ volcanoes (KYS and TLS) located beyond the western boundary of subdcuting Philippine Sea plate beneath northern Taiwan (Kim et al., 2005; Wu et al., 1997); (4) apparent differences in volcanic durations exist between the NTVZ and central Ryukyu arc, as the latter has become dormant since the earliest Pliocene (Shinjo, 1999); (5) The Ryukyu volcanic arc does not show geochemical variation along the trench, whereas the NTVZ volcanics display systematic compositional variations from low-K to calc-alkaline and then shoshonitic along the Trench from northeast to southwest (Wang et al., 1999, 2004). These inconsistencies reflect that the NTVZ should be genetically distinctive from the Ryukyu arc.

The conventional view was first questioned by (Chen, 1997) who suggested an extension rather than subduction regime for magma generation. Based on new geochemical data ((Wang et al., 1999), a unique spatial geochemical variation, characterized by southwesterly increase in potassium and incompatible trace elements, appears to be subparallel to the southwestern part of the modern Ryukyu subduction system, which has never been reported before. Sr-Nd isotope ratios of the NTVZ

volcanic rocks ($^{87}Sr/^{86}Sr \approx 0.70376-0.70551$; $^{143}Nd/^{144}Nd \approx 0.51259-0.51301$) suggest two mantle source components involved in the magma generation, the asthenosphere and metasomatised subcontinental lithospheric mantle. These two components are represented by the 2.6-Ma MHY high-Mg basaltic andesites and the 0.2-Ma TLS high-Mg potassic lavas, respectively. The latter are interpreted to be products of small-degree melting of a phlogopite-bearing harzburgite lithospheric mantle metasomatised recently by the nearby Ryukyu subduction zone processes. The unique spatial geochemical variation of the NTVZ volcanic rocks can be successfully modelled using variable degrees of partial melting of mantle source regions, coupled with mixing of different melt components from depleted asthenospheric and metasomatised lithospheric mantle components beneath individual volcanic fields. It is inferred that mixing of melts from specific mantle components and the degree of partial melting are *spatially* and *temporally* related to tectonic evolution of the northern Taiwan region, and *not* simply due directly to subduction zone processes. The overall NTVZ geochemical characteristics can be explained by various degrees of melting within an ascending asthenospheric mantle, triggered by extensional collapse of the northern Taiwan mountain belt (Teng, 1996), interacting with overlying fluid- and sediment-modified lithospheric mantle. Thus, the “arc signatures” evident in most of the NTVZ volcanic rocks do not mean that the NTVZ is part of the Ryukyu arc as these are not direct melts induced by subduction processes, but extension-induced melts formed significantly after the active subduction and that were contaminated by the overlying subcontinental lithospheric mantle (that had inherited subduction components).

More tectonic models, tear of Eurasia plate with detachment of subducting Eurasia plate (Lallemand et al., 2001; Sibuet and Hsu, 2004) and tear of subducting Philippine Sea plate (Lin et al., 2004a, b) have been recently proposed to accommodate to seismological observation and regional tectonic evolution in northern Taiwan. Together with existing extensional collapse model (Teng 1996), all could provide dynamic explanation of similar post-collisional extension regimes in northern Taiwan and associated NTVZ volcanism. However, a plausible model should be also able to explain the spatially and temporally geochemical variations with the NTVZ and their petrogenesis. The controversy over these issues is likely to be resolved when the so far limited seismic imaging beneath northern Taiwan region (including offshore) becomes sufficient, so that geophysical and geochemical data can be more specifically correlated.

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