

Assuming a protolith age of 300 Ma, initial $^{87}\text{Sr}/^{86}\text{Sr}$ for both amphibolites represent extremely high values (0.7153-0.7315). ϵNd values of Group I amphibolites are very low (-8.9 to -17.0), and those for Group II amphibolites are grouped into two; -13 for a layered amphibolite and +0.2 to +1.1 for a boulder-like amphibolite included in psammitic gneiss. The paragneiss samples have higher $^{87}\text{Sr}/^{86}\text{Sr}$ (0.734-0.789) and lower ϵNd values (-18.3 to -24.6) than those of the amphibolites. Two component mixing calculation between primitive basalt from depleted mantle and upper crust (for paragneisses) requires 50-60 % of crustal component. This result excludes wall rock assimilation as a possible process to account for the extremely high Sr and low ϵNd values. Other processes which are likely to alter the isotope values include element mobilization during regional metamorphism and secondary alteration. However, such isotope exchanges do not likely occur particularly in the Sm-Nd isotope system. The enriched Sr-Nd isotope signatures of Group I and some of the Group II amphibolites are explained by contamination within the mantle source by subducted ancient upper crust. In this process the amount of subducted crustal component is estimated to be 5 %. Similar processes have been proposed for mafic-ultra mafic intrusions in eastern Siberia, Russia (Amelin et al., 1996) and northern Dabie complex, China (Jahn et al., 1999).

Combination of these chemical and isotopic results with previous studies suggest that the majority of the Oki metamorphic

rocks were formed within a continental tectonic environment but not in a continental margin with subduction zone as proposed for the Hida belt, central Japan (Arakawa et al., 2000). The protoliths of some boulder-like amphibolites included in the psammitic gneiss, which have island-arc or MORB characteristics, may have been derived from the provenance region.

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Crustal Evolution of the Tugela Terrane, Natal Belt, South Africa

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The isotopically juvenile Tugela terrane, part of the Grenvillian Natal belt, southeastern Africa consists of a heterogeneous assemblage of regionally metamorphosed (upper amphibolite facies) mafic and felsic rocks (Matthews, 1972). The lack of any older detrital zircons suggests that the Tugela terrane was far-removed from the Archaean Kaapvaal craton during deposition (Johnston et al., 2001). The Tugela terrane is divisible on the basis of lithology and structural style, from east to west, into four major thrust sheets referred to as the Nkomo, Madidima, Mandleni and Tugela sheets, respectively. The Tugela sheet includes the Kotongweni tonalite, a 15km long body of coarsely crystalline garnetiferous hornblende meta-tonalite. Although strongly lineated and foliated, the intrusive contact of the tonalite with its amphibolite wall rocks remains recognizable, as are wall rock xenoliths within the intrusion. Geochemically, the tonalite is extremely depleted with very low abundance of Ta, Nb, rare earth elements (REE) and LIL elements, features considered diagnostic of arc-related igneous rocks. The lithological and geochemical characteristics of the tonalite and its amphibolite wall rocks suggest their formation in an intra-oceanic arc setting comparable to the present day Izu-Bonin

arc. In contrast, amphibolites of the underlying Mandleni sheet are characterized by relatively high abundance of Nb, Ti, LIL and HFS elements more similar to the present day oceanic island basalt.

Johnston et al. (2001) determined SHRIMP and TIMS U-Pb zircon ages of various lithological units of the Tugela terrain. They reported the age of the metasedimentary Dulumbe gneiss to being 1276 ± 10 Ma, the age of the oldest detrital component in the sequence. Intra-oceanic arc development was underway by 1209 ± 5 Ma, the age of the Kotongweni tonalite. Subsequent crustal thickening and tectonic burial of the terrane occurred prior to about 1180 Ma, the age of the late to post-tectonic Mkondene diorite and Mambula massif anorthosite intrusions. Peak metamorphism occurred at 1175 ± 9 Ma, the age of metamorphic zircon, and inherited zircons that had suffered syn-metamorphic Pb-loss in the Dulumbe paragneiss. Subsequent exhumation and northward obduction of the terrane, occurred at around 1155 ± 1 Ma, the age of the syn-tectonic Wosi granitoids.

The Tugela terrane is interpreted to be an accretionary complex consisting of rocks formed at intra-oceanic island arc

and oceanic island (plateau) (Arima et al., 2001). It is likely that thrust faulting and metamorphism occurred during initial collision between the oceanic arc and ocean islands, and subsequently between the imbricated oceanic terranes and the continental margin of the Kaapvaal continent. In this model,

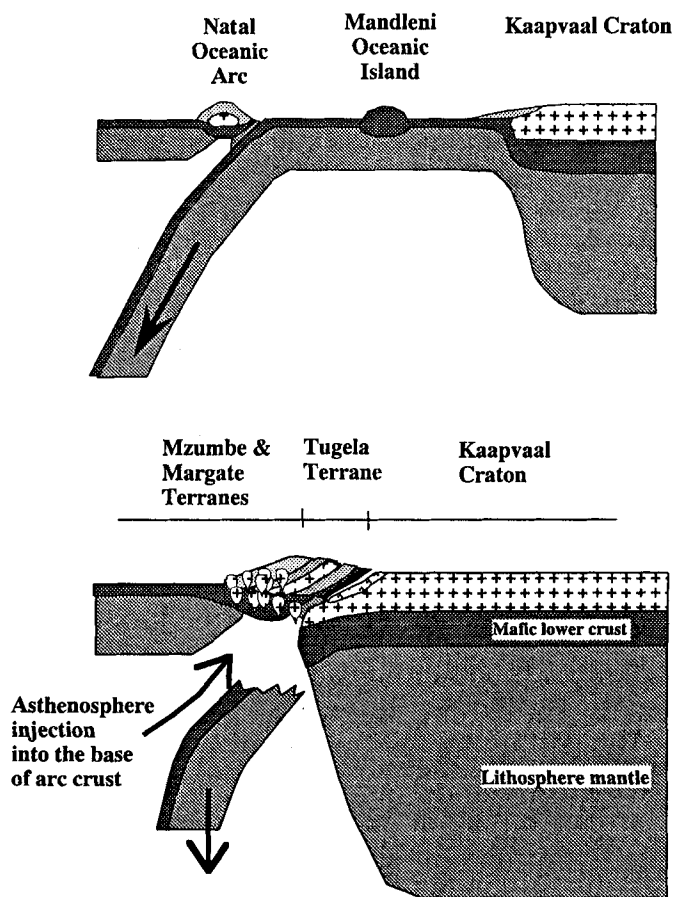


Fig. 1. Schematic sketch illustrating crust formation of the Tugela terrane during Grenvillian continent-arc collision. The Tugela terrane is interpreted as an accretionary complex composed of intra-oceanic "Natal Arc" and accreted "Mandleni Oceanic Island" during closure of the "Tugela Ocean" that once separated the Natal arc from the Kaapvaal continent.

the ultramafic schists widely exposed along the thrust sheet boundaries are interpreted as supra-subduction zone ophiolites. The highly deformed Mfongosi and Ntingwe groups, distributed at the most northern margin of the Tugela terrane, are interpreted as continental shelf deposits formed on the passive margin of the Kaapvaal craton. The Mfongosi and Ntingwe groups were probably incorporated within this accretionary complex during the Grenvillian continental-arc collision.

Combining the present data with data formerly reported (Jacobs and Thomas, 1994, 1996; Thomas et al., 1999), we interpret that the Natal belt, including the Mzumbe and Margate terranes, originated as a single intra-oceanic arc - the Natal Arc. Arc magmatism is inferred to have developed in response to the subduction of oceanic crust of the Tugela Ocean that separated the arc from the Kaapvaal craton. The polarity of subduction would be from the Kaapvaal craton toward the Natal arc (Jacob and Thomas, 1994). The "Mandleni Oceanic Island" or "Plateau" once built on a foundation of oceanic crust of the Tugela Ocean (Jacob and Thomas, 1996) accreted to the Natal arc during closure of the Tugela (Fig. 1).

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Crustal and Mantle Evolution of the Proterozoic Eastern Ghats Belt, India

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Finding of coexisting corundum and quartz from Rayagada in the Proterozoic Eastern Ghats Belt (EGB), one of the well-studied UHT terranes, reveals a dramatically high pressure and ultra-high temperature conditions (Shaw and Arima, 1998). Isothermal decompression from over 1.2 to 0.9 GPa under ultra-high temperatures (~1100°C) followed by nearly isobaric cooling may suggest possible early continent-continent collision

followed by rapid uplift. This extreme high temperature condition further suggests that mantle to crust heat transfer associated with tensional lithosphere collapse during or after crustal thickening might play a major role for the formation of UHT metamorphism. In this context, protolith identification and age relationship of meta-igneous rocks, major lithologic units in many UHT metamorphic terranes are important research