Geochemical and isotopic studies of syenites from the Proterozoic Damara belt (Namibia): Implications for the origin of Pan-African syenites

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Ne- to qtz-normative syenites are rare plutonic rocks within the Proterozoic Damara Belt of Namibia. New U/Pb sphene ages of some Pan-African syenites at Otjimbingwe indicate an age of *c.* 540 Ma for the intrusion of these rocks into a low- to medium grade metamorphic terrain prior to the inferred peak of metamorphism. These new ages are broadly comparable with previous Rb/Sr whole-rock and hornblende-whole-rock ages which indicate an age of either 570 $\pm$ 41 Ma or 524 $\pm$ 7 Ma.

Regardless of minor geochemical variations, all syenites are characterized by high K_2O+Na_2O (9.6–11.4), K_2O/Na_2O (2.2–4.2), Sr (651–1227 ppm), Ba (1167–2732 ppm) and high TiO_2, P_2O_5, Zr, Nb and *LREE* relative to Damaran I-type, S-type and A-type granites. Their mantle-normalized trace element diagrams are characterized by pronounced enrichment in LILE and *REE*, and a depletion of Ba, Nb, Sr, P, and Ti. Depletion of Ba and Sr are typical for rift-related syenites, however, their depletion in Nb, Ti, P indicate some involvement of a subduction-zone component. Initial isotopic composition are characterized by low initital ε Nd values (−4.26 to −5.47) and high Sr_i ratios (0.70706 to 0.70769). The $\delta^{18}O$ values vary between 8.20‰ and 9.39‰. $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ isotope ratios are between 18.95–23.31, 15.73–16.04, and 38.85–40.25, respectively.

Since the syenites are extremely enriched in Sr and Nd, the isotopic composition reflect the nature of the mantle source, rather than significant crustal contamination. The isotopic signatures are distinct from those of rift- or hotspot-related syenites which are thought to be derived from depleted asthenospheric sources. The Damaran syenites have K/Rb relationships similar to those seen in upper mantle phlogopites but unlike those from upper mantle amphiboles. We therefore conclude that the syenites come from an enriched, lithospheric mantle source, probably modified by a subduction zone fluid, containing phlogopite as the major OH-bearing mineral. Ce/Pb ratios are low (< 6) in the most primitive members, further indicating an extremely enriched source for the syenites.

The most fractionated qtz-syenites have higher $\delta^{18}O$ values that are positively correlated with Sr_i isotope values and negatively correlated with εNd values. $^{206}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ ratios are positively correlated with Sr_i isotope values. Some samples have constant $^{206}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ ratios but varying εNd values whereas other samples show a distinct negative correlation of $^{206}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ ratios with ε Nd values. These features indicate (1) that the upper mantle is partly heterogeneous with respect to Sm/Nd ratios and (2) crustal contamination is also monitored by the Pb isotope systematics.

Since the Damaran metasedimentary rocks and most granites have higher oxygen isotope values, higher Sr_i isotope and less negative εNd values, contamination with these upper crustal rocks can be ruled out. Rare Pan-African granites from the high-grade central part of the orogen have low $\varepsilon Nd_{(500\ Ma)}$ values of −12 to −18, typical of lower crustal rocks but inferred 'normal' $\delta^{18}O$ values of > 10‰. Modelling using Nd concentrations and εNd values of the syenites, basement rocks and the inferred enriched upper mantle source indicate that 2–4% contamination with such crustal material can explain the isotopic variation in the most differentiated syenites.

Considering the distinct geochemical and isotopic signatures, it is proposed that the syenites were generated by fractionation from ne-normative mantle magmas and magma mixing with a lower-crustal melt, followed by subsequent crystal fractionation of mainly clinopyroxene, amphibole, biotite, K-feldspar and sphene and cumulate–melt unmixing at upper crustal levels. These crystal fractionation/ cumulate–melt unmixing processes probably took place at extremely shallow levels at pressures < 2.5 kbar and at temperatures of *c*. 900°C as inferred from Al-in-hornblende barometry and Ti-in-hornblende thermometry.

From a plate-tectonic viewpoint there is a correlation between alkaline magmatism and changes in the direction of micro-plate movements between the southern and the central part of the Damara orogen, provoking reactivation of lithospheric shear zones and rifting within these micro plates. If such reactivation caused a reversal in the sense of movement, the associated faults would open and propagate as tensional faults. This would allow fracturing through the continental crust causing pressure release, channeling of volatiles, partial melting and generation of magmas from the subcontinental lithospheric mantle. The Damaran syenites display all features of anorogenic within-plate magmatism, despite their appearance close to the peak of the Damaran high-grade metamorphism and their location along a major suture zone. Tectonically, the syenites intruded along a prominent shear zone, the Okahandja shear zone which is probably one of the oldest shear zones in the Damara belt. The intrusion of the syenites was probably accompanied by a change in the stress field which renewed transcurrent movements along lithospheric mega-shear zones. In this model, access to new mantle sources is explained by the rise of mantle material to shallow depths beneath continental lithosphere after rupture of the cold lithospheric plate. While the source of the alkaline rocks is in the lithospheric mantle, their location is controlled by the structure, composition and dynamics of the overlying continental crust.