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Open vs. closed-system behaviors in granitoid rocks during granulite-facies metamorphism: a case study from the Bulai Pluton (Central Limpopo Belt, South Africa)

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The late-Archaean, high-K calc-alkaline Bulai pluton emplaced within the Central Zone of the Limpopo Belt, a polymetamorphic terrane characterized by at least three granulite-facies events. The youngest, Paleoproterozoic (∼2.0 Ga), D3/M3 structural-metamorphic overprint reached pressure-temperature conditions as high as 9-10 kbar and 830°C. As it post-dates the emplacement of the Bulai magmas (∼ 2.6 Ga), we investigated the textural and geochemical record of this event in the plutonic rocks of the batholith, focusing on chemical and isotopic re-equilibration.

The regional D3/M3 episode is associated with complex strain patterns, including large shear zones, folding and possibly horizontal nappe tectonics. However, in the core of the pluton, there is very little structural field evidence for subsolidus deformation. In addition, no granulite-facies paragenesis developed in the Bulai rocks during the D3/M3 overprint, except in discrete undeformed granulitic veins that are probably related to this event. On the other hand, all rock types display granoblastic polygonal textures, suggesting that the thermal peak induced annealing, almost complete in some cases.
Mineral compositions also show evidence for re-equilibration during the Paleoproterozoic metamorphism. Indeed, plagioclase is systematically unzoned, and its chemical composition is notably constant (An29-33) regardless the whole-rock composition over large ranges of SiO2 (47–75 wt.%), CaO (1.5–8 wt.%) and Na2O (2.5–4 wt.%). Similarly, hornblende and biotite compositions are homogeneous within the whole Bulai suite, and present high Ti contents suggesting equilibration at high temperatures. Furthermore, hornblende-plagioclase thermometry indicates temperatures up to 800-900°C, consistent with the thermal peak of the D3/M3 metamorphic episode. 147Sm/147Nd data on whole-rock and separated minerals provided further evidence for grain-scale equilibration, as internal isochrons of 4 individual samples yield ages close to the assumed age for this metamorphic overprint (∼ 2000-2200 Ma), pointing to a partial resetting of the Sm-Nd system.

On the other hand, there is no evidence for perturbation of bulk rock isotopic compositions, as a well-defined Sm-Nd external isochron established with 16 whole-rock data indicate an age of 2750 ± 200 Ma. Even imprecise, this age is consistent with new U-Pb LA-ICP-MS dating on separated zircons grains from 4 samples, which yielded concordant ages comprised between 2627 ± 18 Ma (granodiorite sample BUL-20 ; MSWD=0.7) and 2593 ± 17 Ma (monzodiorite dyke BUL-14 ; MSWD = 0.34), assumed to represent the timing of emplacement of the Bulai magmas. Moreover, zircons isotopic composition failed to prove any record of the ∼ 2.0 Ga metamorphic event, indicating that they were affected by neither recrystallization, nor isotopic equilibration, and strongly supporting fluid-absent conditions.

These results suggest that the main rock-forming minerals of the Bulai pluton underwent open-system equilibration associated with annealing during the granulite-facies overprint of the D3/M3 Paleoproterozoic event. Nevertheless, this thermal peak did not last long enough to generate large-scale and extensive chemical

and isotopic equilibration, as evidenced by closed-system behavior for individual hand-samples and resistant minerals such as zircons. Consequently, the $\sim$ 2.0 Ga regional granulitic event only led to discrete structural and chemical records within the Bulai pluton, which can be seen as a large refractory body compared with host rocks that accommodated most of the deformation and metamorphism. This conclusion has important implications for geochemical studies, since the whole-rock major-, trace-element and isotopic composition can be used to study the petrogenesis of such granitoids even if they underwent high-grade granulite-facies conditions.