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On Samarium-Neodymium isochron dating of garnet and the role of inclusions

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Garnets are common minerals formed during medium to high-grade metamorphism. They are among the most resistant rock-forming minerals, quite difficult to be chemically modified after their growth. Characteristically, they have very low REE content, and during their formation they fractionate these elements, enhancing the heavy REE and acquiring consequently an increased Sm-Nd ratio. Because of this, garnets have been extensively used to date parts of the prograde thermal histories of metamorphic belts, by means of the Sm-Nd method. Because of the low REE content, the major problem of dating garnets is that the main inventory of REE measured in their crystals may be located in inclusions rather than in the garnet lattice itself. This is why only the cleanest crystals are usually chosen for Sm-Nd dating attempts. Inclusions of different minerals belonging to the same paragenesis, such as biotite, K-feldspar, amphibole, etc. shall not invalidate the age calculation, because all them are supposed to reach isotopic equilibrium during metamorphism. However, even small amounts of REE-rich accessory minerals such as monazite, allanite, apatite or zircon can dominate the elemental budgets of Sm and Nd in garnets. If they are old relict xenocrysts retaining a different Sm-Nd ratio and Nd isotopic composition, the resulting age calculation will be geologically meaningless. Frequently, for a Sm-Nd age determination, a two-point isochron is made, using the analytical points of garnet and whole-rock system for the regression calculation. A straight line always passes perfectly through two points, and consequently the analytical error attributed to such regression only depends on the individual precision of the analyses, because there is no scatter regarding a best-fit line to be considered. This error is then usually very low, unrealistic, and the geological interpretation of the apparent age can be misled. In addition, the whole-rock chemical system is vulnerable to all sorts of fluids and alterations, and later events affecting the rock are likely to modify its Sm/Nd ratio or its Nd isotopic composition, invalidating the calculated garnet-whole rock isochron age. An alternative dating procedure is here proposed, making use of different splits of garnet separates from the same rock, without taking into account the apparent cleanliness of the crystals. The splits are obtained by magnetic separation, in a way analogous to the technique employed to produce different populations of zircon crystals used in U-Pb dating by means of Concordia diagrams. Normally, the cleanest garnets, with less inclusions, will concentrate in the more non-magnetic fraction, and will produce the analytical point in the Sm-Nd isochron diagram with the highest Sm/Nd ratio. Garnet fractions with increasing amounts of inclusions will be more magnetic, and will produce points in the isochron diagram with lower Sm/Nd ratios, and hopefully spanning a range of values that will provide adequate constraints on the slope of the isochron. In our view, the garnet lattice, together with the inclusions within it, is likely to behave as a closed system after the final growth of the host garnet. The small inclusions of the associated metamorphic minerals will tend to reach isotopic equilibrium in respect to the Sm/Nd system, and this is expected to occur also for some of the REE-rich accessories such as apatite, allanite or monazite. A problem is anticipated for those inclusions of accessory minerals that may retain an older age, like zircon, that will not equilibrate during garnet growth.

This procedure was attempted in rocks from the high-grade metamorphic terrain of the Araçuai belt, in the region of Colatina, eastern Brazil. The main petrographic varieties are kinzigitic gneisses exhibiting, in addition to garnet, K-feldspar, cordierite, quartz, plagioclase, biotite, as well as minor amounts of hornblende, sillimanite and orthopyroxene. Zircon, monazite, apatite and opaques are the accessory minerals. The garnet crystals are poikiloblastic, millimetric in size, and exhibit many inclusions of all kinds of associated minerals. Regional metamorphism attained granulite facies (about 800 ^{o}C and 6.5 kbar), and the geochronological evidence obtained by other methods (U-Pb, Rb-Sr and Ar-Ar) indicate that the thermal peak for the metamorphic evolution occurred at about 480-500 Ma. From rocks of this region, a few garnet-whole rock isochron ages were different from each other and all younger than 480 Ma. A Sm-Nd isochron made using only the garnet analytical points from the same rocks produced an apparent age close to 480 Ma. However, for one of these samples, an isochron was obtained from nine splits with different magnetic properties, by the procedure outlined above. Its apparent age was of 482 ± 27 Ma, which we consider a good estimate for the final growth of the garnets within the rock.

In conclusion, in our view, a garnet-only isochron, based on splits with different magnetic behaviour, may indicate with some confidence the time of termination of the metamorphic growth of such minerals. If this actually happens, it means that isotopic equilibrium between the garnet and its inclusions of metamorphic minerals is likely to be reached. Moreover, it also means that the closure of the garnet lattice must occur at high temperature (close to 700-800°C), immediately after the termination of the crystal growth, and finally it means that the garnet crystals are likely to remain closed in relation to possible younger thermal events that may have affected the whole-rock system.