Pb isotope evolution of Archaean granitoids: inferences on world-wide mantle heterogeneity and post-emplacement processes

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The existence of early mantle heterogeneity and its evolution through time is difficult to access because existing early Archaean crust is composed mainly of granitoids which are not derived directly from the mantle. However, their genesis requires a basaltic source which can reflect distinct mantle compositions. Nd isotope systematics have shown short-lived mantle heterogeneity at 2.7 Ga (Blichert-Toft and Albarède, 1994) and by contrast $\varepsilon_{Nd}(T)$ homogeneity for the early and mid-Archaean (Blichert-Toft and Luais, 1994). Because of their half-lives ranging from 0.7 to 4.6 Ga, the U-Pb isotope system is a powerful tool to study the early history of the mantle as it can access the primary signatures through U/Pb parameters. Pb isotope investigations on Archaean granitoids at age T of 3.8–3.9, 3.5, 3.2, 2.9, 2.7 Ga from all over the world have been undertaken, and the calculated apparent μ_1 (4.56 Ga $\rightarrow$ T) and μ_2 (T $\rightarrow$ present) U/Pb parameters are discussed together with the measured $^{206}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ ratios.

An example the $^{207}Pb/^{204}Pb_{meas}$ *vs* μ_1 diagram is given for the 2.9 Ga old samples (Fig.1). This diagram gives information through the parameter μ_1 about processes which take place at the source level, and through the parameter $^{207}Pb/^{204}Pb$meas mostly about post-emplacement processes. The pre-3.2 Ga old samples display significant scatter both at the scale of a craton, and at the world scale. For the 3.2, 2.9, 2.7 Ga old samples, the Pb data define two main trends:

- trend 1 is characterized by large variations of μ_1 from 6.2 to 8.9 associated with a slight increase in $^{207}Pb/^{204}Pb$meas from 14 to 15. It corresponds to a unique trend defined by samples from different cratons (Labrador, Greenland, Scotland, Finland, Zimbabwe, Australia) with proper μ_1 values. This trend is well defined for the 2.9 and 2.7 Ga old samples and, given the limited number of data, probably holds for the 3.2 Ga old samples.

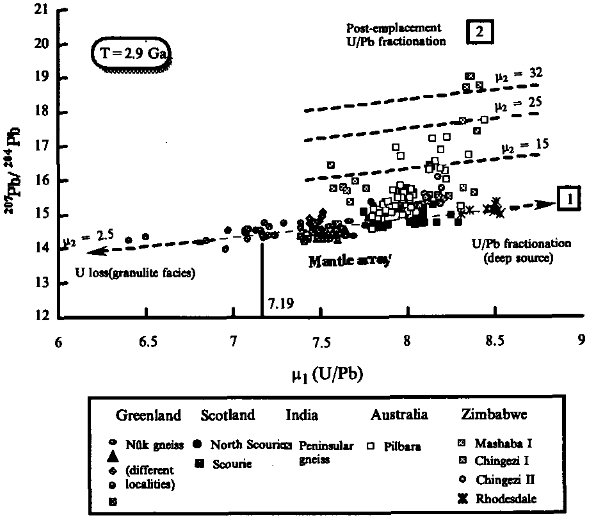

FIG. 1.

- trend 2 corresponds to restricted variations of μ_1 values associated with a nearly vertical shift in $^{207}Pb/^{204}Pb$meas from 14.5 to 19.5. Each craton defines a specific trend characterized by a given μ_1 value of 7.6 for India, 8.1–8.4 for Zimbabwe, and 7.8 → 8.4 for Pilbara. The samples with the lowest $^{207}Pb/^{204}Pb_{meas}$ values lie on the trend 1 curve. Trends 1 and 2 thus define coherent Pb evolution on the world scale. Modelling trend 1 using the two-stage closed-system U–Pb decay equation requires low μ_2 values of 2.5 for the 2.9 Ga old samples and of 1.5 for the 2.7 Ga old samples. Variations in $^{207}Pb/^{204}Pb_{meas}$ depend mainly on the μ_1 parameter, which means that these samples did not suffer significant post-emplacement chemical and isotope changes. The decrease of μ_1 from the initial value of 7.19 to values as low as 6.2 for a restricted number of samples from Greenland and Labrador is explained by U loss during high-grade granulitic metamorphism of the basaltic source. The main part of the trend corresponds to an increase in μ_1 values which may reflect (a) Pb leaching from the basaltic protholith during hydrothermal processes, (b) mixing with a high μ_1 older crust through recycling processes as indicated by Nd isotope systematics from 3.2 Ga, (c) a mantle process. The strong regionality of μ_1 values supports the latter interpretation. The trend 1 can therefore be considered as the mantle array for the Archaean. This explanation emphasizes the contrast between local source homogeneity and global mantle heterogeneity.

Modelling trend 2 can only be achieved for each locality by considering μ_1 values as constant, and μ_2 values varying up to 32. This reflects an increase of the U/Pb ratios subsequent to emplacement, but sufficiently close to it to produce consistent variations in $^{207}Pb/^{204}Pb$ with U/Pb in terms of isochrons. It is unlikely that this increase in μ_2 results from contamination during the intrusion by an old radiogenic Pb with similar μ_1 and higher μ_2 values, because trends formed by each area seem to have similar slope. More likely, it results from selective U/Pb fractionation during alteration or metamorphism.

Pb evolution from 3.9–3.7 to 2.7 Ga indicate that 3.2 Ga times represents a change in the evolution and growth of the continents. From 3.9 to 3.5 Ga, geographically scattered microcontinents or crustal nuclei grow independantly from each other from a basaltic source which composition reflects a chemically and isotopically undefined mantle signature. This leads to Pb isotope compositions with little overlaps between each craton. From 3.2 to 2.7 Ga, mantle composition is well characterized, neighbour continents have been unified, and crustal compositions with no post-emplacement chemical changes defines a main array with a coherent regional distribution of $^{207}Pb/^{204}Pb_{meas}$ and μ_1 values. This demonstrates the existence of mantle heterogeneity early in the history of the earth.

The best-known isotopic anomaly over a world-wide scale is the Dupal anomaly (Hart, 1984). It is based largely on high $^{207}Pb/^{204}Pb$ ratios which therefore hints that it is originated early in the Earth's history. However, comparison of μ_1 values and geographic location of the cratons is not informative, as their relative position in the Archaean is not known. The present study has shown that μ_1 values can also be used to trace mantle heterogeneity back from the ancient times. Nd isotope investigation has demonstrated the existence of strong convective movements in the Archaean, and therefore fast destruction of Nd mantle heterogeneities (Blichert-Toft and Albarède, 1994). By contrast, survival of well-defined U/Pb heterogenities places severe constraints on the origin of U/Pb fractionation and requires that it originated in location protected from dispersal by mantle convection. It can be suggested that μ_1 values trace mantle heterogeneity in the deep mantle or at core-mantle boundary, and therefore the genesis of continents is related to basaltic protholiths with a plume origin.

It is important to emphasize that this age of 3.2 Ga coincide with the beginning of crustal recycling or crustal contamination processes as indicated by Nd isotopes, even if 3.2 Ga age is not a major event for production of juvenile crust.

References

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