On the half-life of mantle evolution models.

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From early accretion on up to recent volcanism, a variety of very complex fractionation processes operated in the Earth, separating geochemically distinct terrestrial reservoirs. Major subdivisions of the solid Earth into core mantle and crust have been made in the early days of seismology. These structural units must not necessarily be identical to geochemical reservoirs, however geochemical models must not be at odds with geophysical findings.

As early as 1932 Holmes suggested the use of the radioactive decay schemes as geochemical tracer for petrogenesis, after Rutherford's proposition of their use as a measure of geological times in 1906, and Soddy coining of the term isotope in 1913. The principal of using radiogenic fingerprints to trace the evolution of rocks and reservoirs is a key area of recent isotope research.

The first significant modelling using the U-Pb system was done - independently - by Houtermans as well as Holmes (1946), with their modelling of the age of the Earth. Stacey & Kramers (1975) proposed a two-stage growth curve for common lead still widely used as a reference for comparison and for common lead corrections as applied in U-Pb-zircon geochronology.

Unfortunately, the dominant reservoir of the silicate Earth, the mantle, is largely inaccessible to direct sampling. Yet it represents 83 % of the total volume of the Earth. Further, terrestrial crust is generated from the convecting mantle. Evolution of the crust and upper mantle have been regarded in two general types of models (Jacobsen & Wasserburg 1979): (1) that continental crust derived from undepleted mantle by melt extraction taking a depleted mantle as the respective residue, or (2) that continental crust formed by repeated extraction from a mantle reservoir which became progressively depleted.

It was not before the late 70ties/early 80ies that the Sm-Nd isotopic system was established and a body of data was produced sufficient to isolate model (2) as appropriate: ε_{Nd} values from various rock types and even Archean ages were mainly positive. However, the properties of the depleted mantle evolution model used for crustal evolution studies are rather controversial. DePaolo (1981) assumed an intra oceanic island arc basalt source as source of the continental crust. Thus, he proposed a present-day ε_{Nd} value of +8.5 for the source of continental crust. Goldstein et al. (1984) proposed a linear evolution model beginning at 4.5 Ga and ending with present-day mean mid-ocean-ridge Nd isotopic composition (ε_{Nd}= +10) as it represented the simplest one consistent with the data available to them. DePaolo's (1981) upwards concave evolution curve implies an increasing depletion in light rare earth elements of the upper mantle with time while other models are either linear or even upwards concave. Liew & McCulloch (1985) preferred to let their depleted mantle evolution model depart at 2.7 Ga, based on the assumption that significant volumes of depleted mantle would only have been stabilized earlier. Several additional models have been proposed until the mid 90ies, but those of DePaolo and Goldstein et al. remained the most often used. Obviously, inverse models, trying to constrain the Nd mantle evolution mainly on Nd data of sample sets do not yield a unique solution. The variability within the available Nd data is just far too large and does not seem to narrow down completely towards the earliest Archean. The latter is partly due to the fact that uncertainties on the Nd initials accumulate from age uncertainties, analytical uncertainties and geological post-rock-formation changes of the Sm-Nd system. Also, it has been shown in some cases, where initial Nd isotope ratios were calculated using zircon U-Pb ages, that the results do not reflect the Nd isotope composition of the mantle (Moorbath et al. 1997). Alternatively, extreme very early Sm/Nd fractionation in the silicate Earth has been postulated from the mid 90ies on to explain strong apparent Nd isotope deviations in some Archean suites (e.g. Bennett et al. 1993). This has in turn given rise to models invoking very rapid continental crust generation during or immediately after Earth accretion (Bowring & Housh 1995) or a depleted upper mantle reservoir which grew in size as the continental crust evolved over geological time (McCulloch & Bennett 1994).

To resolve the terrestrial evolution of the Sm-Nd system, Nägler & Kramers (1998) applied a forward modelling approach to the upper mantle development. Present-day concentrations and Nd isotope ratios of upper mantle and crustal reservoirs were target values of their model. Mass transfer was modelled within the constraints given by siderophile element, noble gas- and Pb isotope data. The shape of the resulting Nd mantle evolution was then compared to a screened Nd database. The model solution shows a steady increase of the ε_{Nd} value of the upper mantle from 3 Ga on to a present day value of +10. In the Early Archean, a constant ε_{Nd} value is seen. The data, however, are generally one ε_{Nd} unit above the accepted chondritic reservoir evolution. Lunar rocks also show this offset and, in particular, appear to indicate its existence since 4.5 Ga ago. This offset partly explains the positive ε_{Nd} data of the Early Earth mantle. This 1998 model is in-between those of Goldstein et al. (1984) and DePaolo (1981), with a concave shape.

In recent years the advances in high-resolution seismic tomography and mantle convection modelling have led to the conclusion of whole-mantle convection. Thus, compositional differences between an upper and lower mantle could not have persisted during Earth history. Still, due to compelling geochemical evidence there hast to be a mantle reservoir isolated from convection mixing. Tolstikhin, Kramers & Hofmann (2006) propose this reservoir to be located in the core–mantle transition (termed DW). It is supposed to have formed during the late stages of Earth accretion via subduction of primitive mafic to ultramafic crust along with a terrestrial regolith. The study showed that this scenario enables to reconcile mass balances with whole mantle convection in the framework of a chondritic Earth model. DW could be an important reservoir containing ~20% of the terrestrial amount of incompatible trace elements. The shape of the resulting Nd mantle evolution curve is quite linear, and thus similar to the model of Goldstein et al. (1984).

Thus, since the development of the Nd isotopic techniques, there is a constant evolution in the understanding of the Earth mantle. In the early 80ies the source of the continental crust has been constrained to a convecting, depleted mantle, the early 90ies saw the discussion and modelling of the Early Archean mantle, forward modelling involving various isotope systems reduced the model uncertainties in the late 90ies, while recent forward models account for the geophysical findings of whole mantle convection. The apparent half live of mantle evolution models is thus in the order of a decade. Combined isotope geochemical methods together with geophysical information will further improve our picture of the Earth.