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^{187}Re -^{187}Os Nuclear Geochronometry: Dating Peridotitic Diamond Sulphide Inclusions

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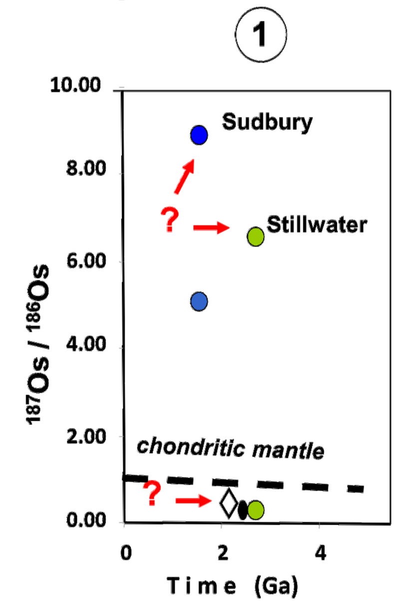
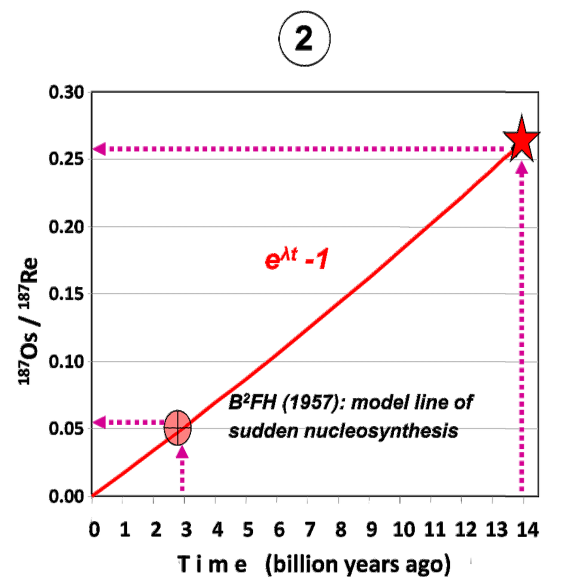
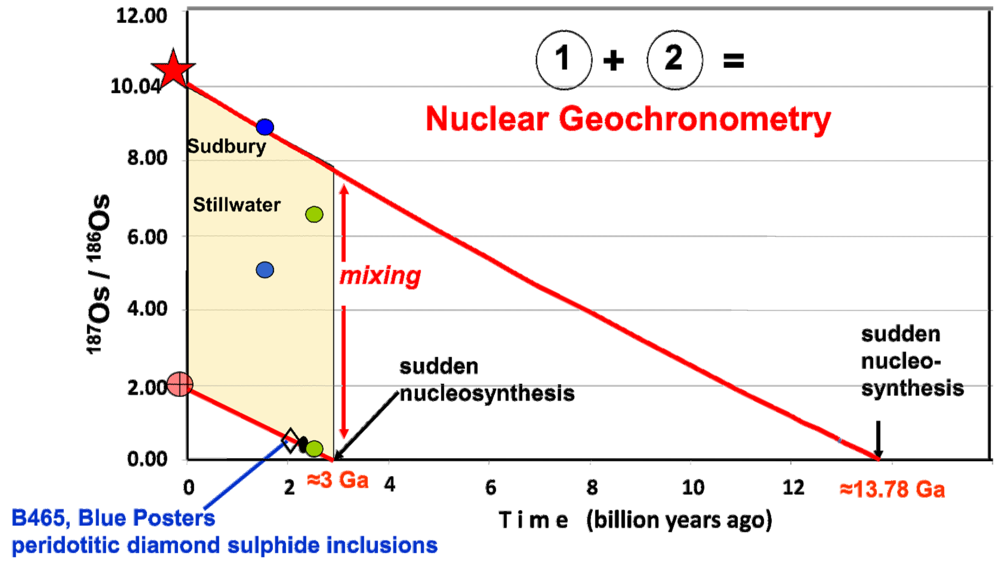
I





^{187}Re -^{187}Os Nuclear Geochronometry

Nuclear geochronometry is a new research field, developed to bridge the gap between geochronology and nuclear astrophysics. It is based upon the discovery of terrestrial signatures from at least two rapid (r-) neutron-capture processes, which plot on the astrophysical model line of sudden nucleosynthesis (see (2) ; Burbidge et al 1957). It aims at dating rocks by means of radioactivity, which makes it a subfield of nuclear chemistry. The dating method is embedded in other scientific fields like cosmology, cosmochemistry and nuclear theory, which impose tight constraints on nuclear geochronometry. Or, in other words: in nuclear geochronometry we start with Becquerel and Curie, move on to Rutherford and Soddy, pass Chadwick and Fermi, and finally end up with Fowler, Mather and Smoot …



II

Let's talk about some basics: Most of the neighbor nuclides of Os (Re, Ir) are created via the r-process and subsequent β-decay. Because of its long half-life of 41.6 Ga, ^{187}Re becomes a powerful cosmic clock to calculate the age of the heavy elements, which is a lower boundary for the age of our Universe. Knowing the nuclear production ratio (PR), it is possible to solve the following equations for t:

$^{187}Re/^{188}Os_{now} = {}^{187}Re/^{188}Os_{PR}\ (e^{-\lambda t})$

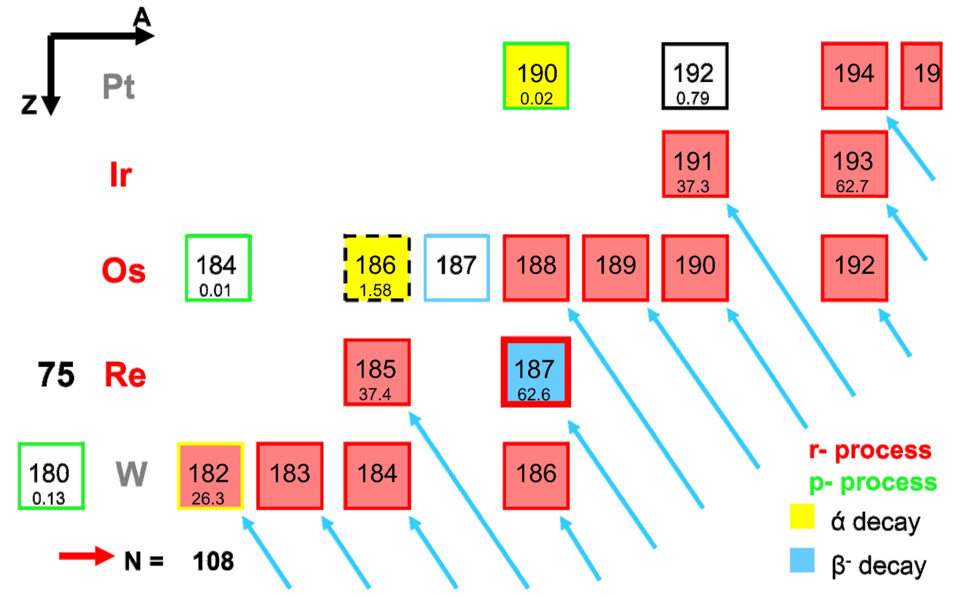
$^{187}Os/^{188}Os_{now} = {}^{187}Re/^{188}Os_{PR}\ (1 - e^{-\lambda t})$

The PR`s may be derived from nuclear theory (which is the normal case in astronomy) or from observation:

Ir/Os = 0.96 ; C I Chondrites; (Lodders et al. (2009), arXiv: 0901.1149)

Ir/Os = 0.96 ; solar photosphere; (Asplund et al. 2009, ARA&A 47. 481)

See the following chart below, which is an excerpt from the chart of nuclides, modified for nuclear geochronometry:



Look at the chart: ^{191}Ir and ^{185}Re as well as ^{193}Ir and ^{187}Re have similar relative abundances (37:63), which could point to the same physics behind the creation of these nuclides! We find Re/Os ≈ Ir/Os ≈ 1.

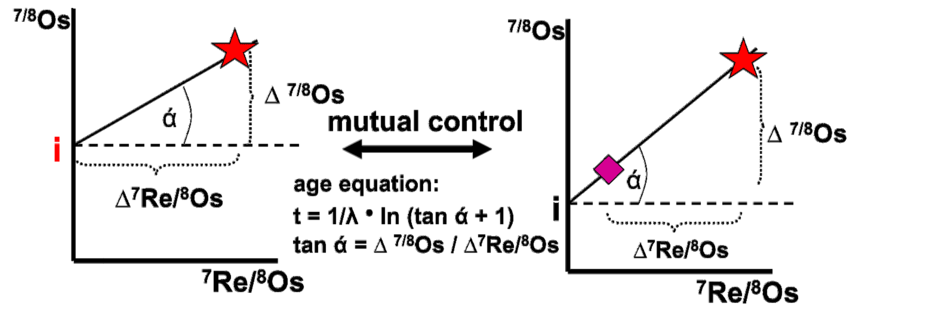
The most powerful nuclear chronometer currently used is ^{187}Re. Five nuclear ^{187}Re chronometers (Re/Os ≈ 1) have been identified so far. There are two age clusters: At T_{NUC} ≈ 13.78 Ga and at T_{NUC} ≈ 3 Ga.

Ref.	Sample / CHRONOMETER	^{187}Os/^{186}Os	^{187}Re/^{186}Os	Re [ppt]	Os [ppt]	Re/Os (≈ Ir/Os)	^{187}Os/^{187}Re	T_{NUC} [Ga]
1	[5085 BasKom] BARBERTON	10.04	38.9	208	245	0.849	0.25809	13.78
2	[R85–62] RONDA	1.97	38	710	740	0.959	0.0518	3.034
3	[Mo369] IVREA	1.9360	39.1	101	106	0.951	0.0495	2.901
(4)	[LA 14] LANZO	1.800	41.5	2.600	2.500	1.04	0.0434	2.549
5	[Cape Smith Sulf.] CAPE SMITH	2.040	40.6	448.000	440.000	1.02	0.0502	2.943

[1] Birck, J.-L. & Allegre, C.-J. (1994) Earth Planet. Sci. Lett. 124, 2139 - 148 (NTIMS) [2] Reisberg, L. C., Allegre, C.-J. & Luck, J. M. (1991) Earth Planet. Sci. Lett. 105, 196 – 213 (SIMS) [3] Roller, G. (1996) RKP Natw. + Techn., Munich. (NTIMS) [4] Roy-Barman, M., Luck, J. M. & Allegre, C.-J. (1996) Chem. Geol. 130, 55 - 64 (SIMS) [5] Luck, J. M. & Allegre, C.-J. (1984) Earth Planet. Sci. Lett. 68, 205 -208 (SIMS)

III

Model Ages and TPI Ages



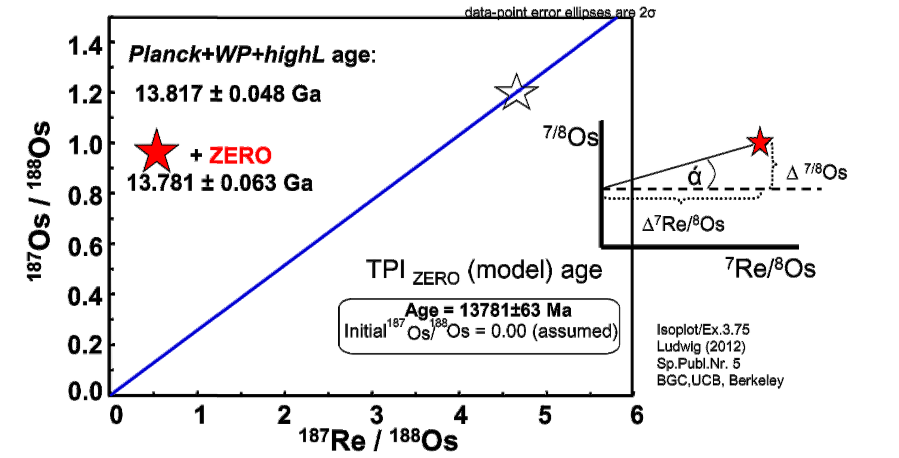
By means of two-point-isochrone (TPI) ages it is possible to question the significance of model ages.

Model ages are based on the assumption, that a sample has a defined initial ratio at a specific time. For an r-process, this initial ratio is assumed to be ZERO.

TPI ages constrain the initial ratio using the BARBERTON etc. chronometer always as the second data point in a TPI diagram.

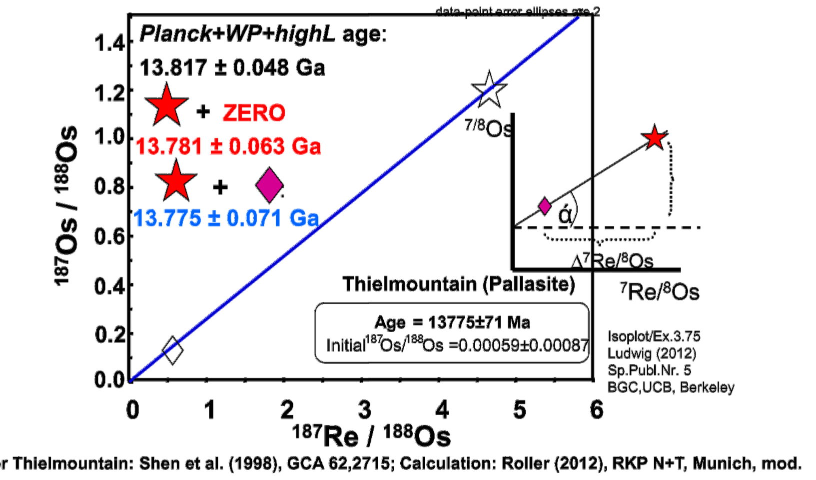
Example: Model age diagram for ★

The initial ratio (i) is assumed to be ZERO, as expected in case of a sudden nucleosynthesis event. The model age is well constrained by the cosmological *Planck-WP-highL* age of the Universe.



Example: TPI age diagram to control the model age

The two data points are the BARBERTON ★ chronometer and the Thielmountain Pallasite ◆. The model age is constrained by this TPI age, which is also a lower boundary for the age of the Universe.

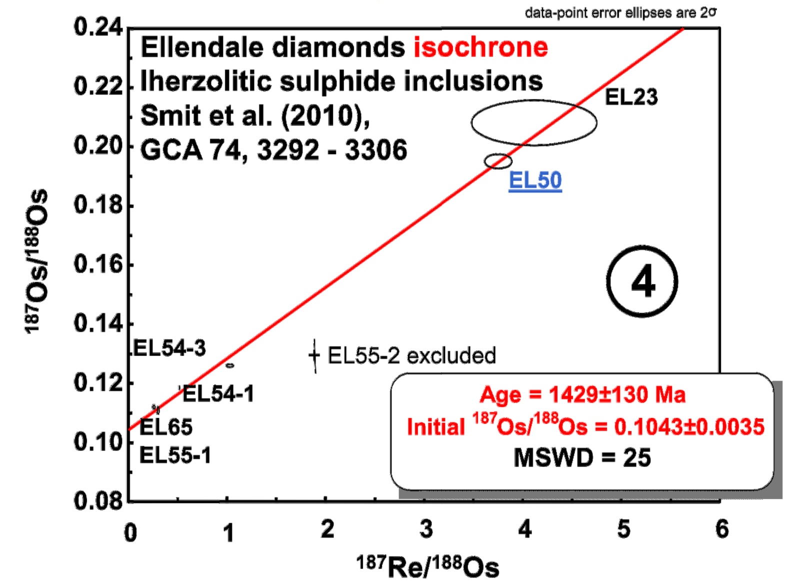


Data for Thielmountain: Shen et al. (1998), GCA 62,2715; Calculation: Roller (2012), RKP N+T, Munich, mod.

IV

Dating Peridotitic Diamond Sulphide Inclusions: The "Fractionated" EL50 ◆ Geochronometer

^{187}Re-^{187}Os nuclear geochronometry can be successfully applied for dating peridotitic diamond sulphide inclusions by means of two-point-isochrones (TPI), using the nuclear geochronometer always as the second data point in a TPI diagram. It turns out that the method may have a huge potential to constrain the chemical evolution of the SCLM. For example, TPI ages for Ellendale (Australia) peridotitic diamond sulphide inclusions reveal at least two main fractionation events. Besides, they prove for the first time that mantle-like Re/Os ratios could indeed have been fractionated from Re/Os PR's between 0.8 and 1.0!



The new TPI – age results agree with the isochrone age. The "fractionated" chronometer EL50 ◆ significantly improves the previously inconsistent model ages:

Isochrone age: 1429 ± 130 Ma , i = 0.104 ± 0.0035

Sample	T_{MA} Smit et al. 2010		TPI ages	TPI initial ratios
(EL23)	1264 ± 100 Ma		2497 ± 2300 Ma	i = 0.03 ± 0.19
EL50 ◆	1171 ± 27 Ma	(5)	2342 ± 300 Ma	i = 0.046 ± 0.025
EL54-1	- 8281 ± 218 Ma		1401 ± 60 Ma	i = 0.10632 ± 0.00078
EL54-3	- 362 ± 22 Ma	(6)	1503 ± 76 Ma	i = 0.0998 ± 0.0018
EL55-1	7973 ± 324 Ma		1445 ± 59 Ma	i = 0.1035 ± 0.0011
EL65	5773 ± 155 Ma		1409 ± 56 Ma	i = 0.10582 ± 0.00070

T_{MA} calculation with primitive upper mantle composition taken from Meisel et al (2001), GCA 65, 1311.

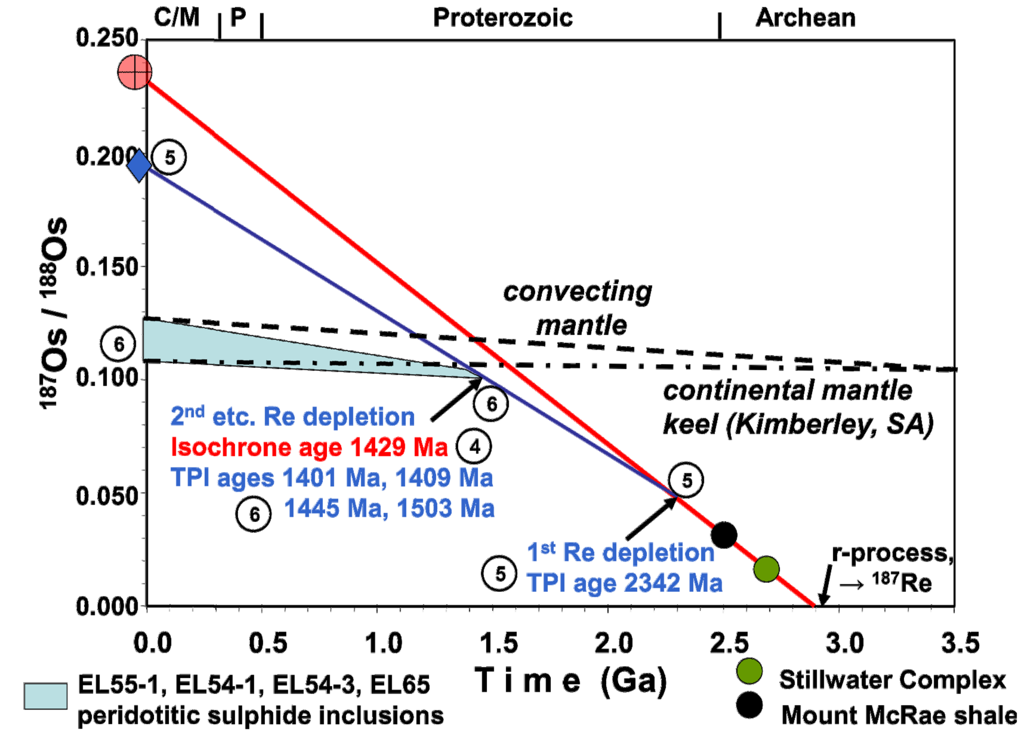
TPI ages for EL23 and EL50 calculated with ⊕

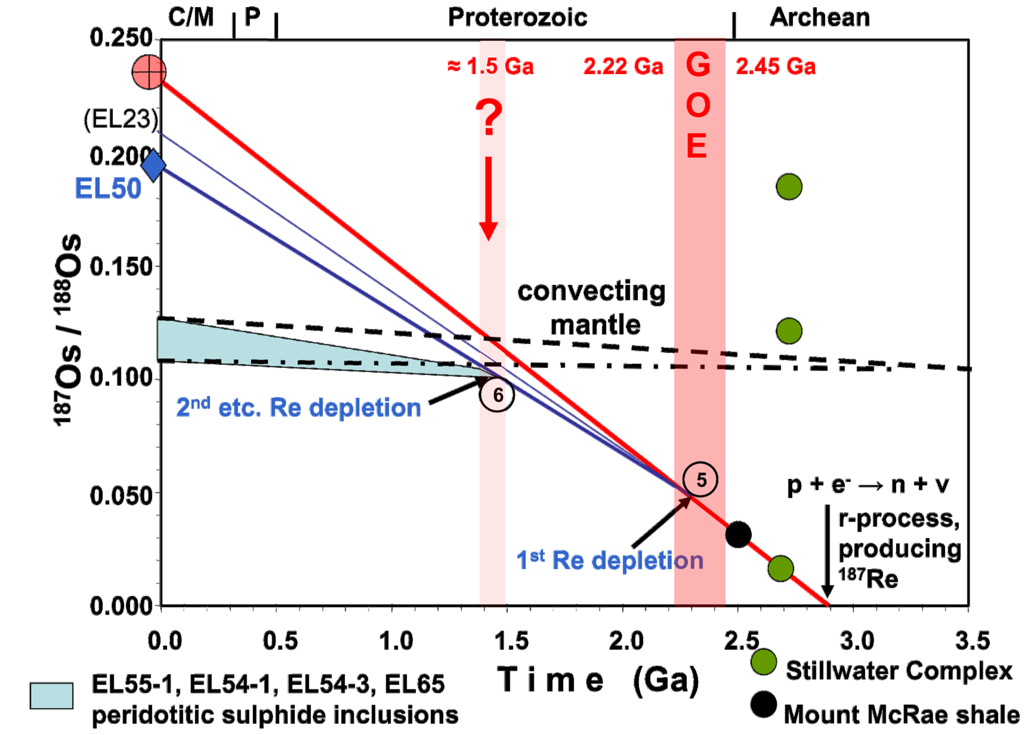
TPI ages for other EL-samples calculated with EL50 chronometer

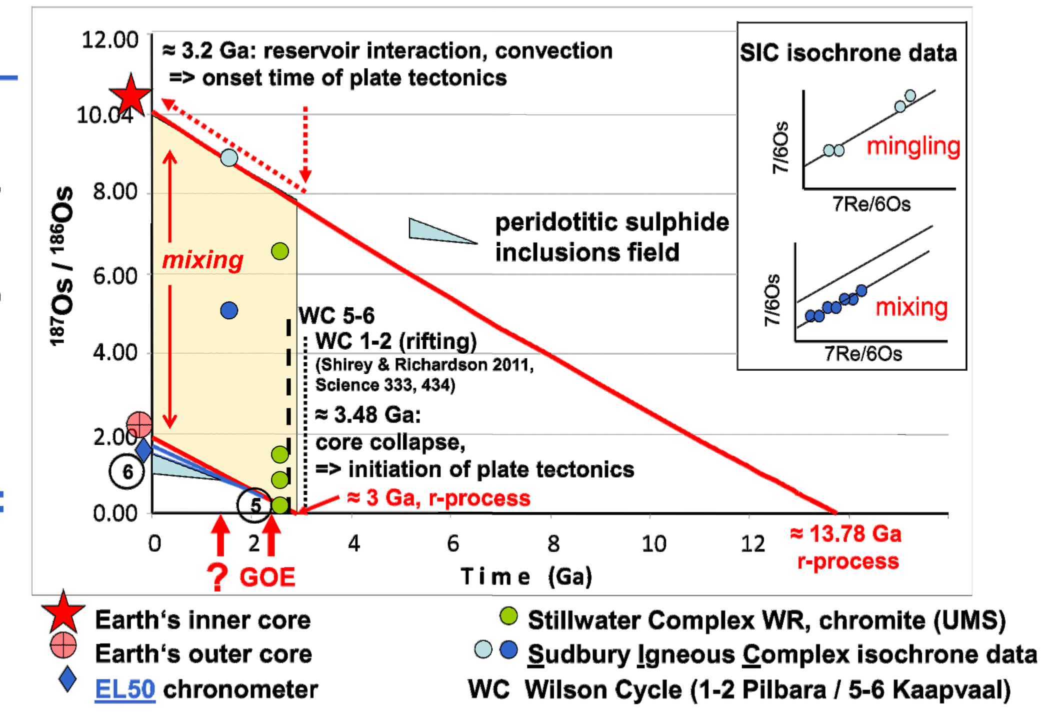
Two-stage-model for Re depletion of the SCLM:

(5) 1st fractionation of EL50 ◆ from ⊕

(6) 2nd fractionation of EL-samples from EL50 ◆







Conclusions

1. TPI ages for Ellendale peridotitic diamond sulphide inclusions reveal at least two fractionation events.
2. The first fractionation event occured ≈ 2.3 ± 0.3 Ga and coincides with the so-called Great Oxidation Event (GOE) between 2.22 Ga and 2.46 Ga. (5)
3. The second event occured ≈ 1.4 Ga and 1.5 Ga (6) and is consistent with a previously reported isochron age. (4)
4. While the first event caused only a minor disturbance of the ^{187}Re/^{188}Os nuclear production ratio assigned to the outer core, the second event leads to fractionation of the ^{187}Re/^{188}Os ratios towards values typical for mantle peridotite.
5. It is suggested that a major change concerning the oxygen/sulphur fugacity across the core-mantle boundary (CMB), coincident with the GOE, is responsible for the first fractionation event. (5)
6. Whether the second fractionation event (6) is due to an even more pronounced change in the oxygen and/or sulphur fugacity across the CMB, within the mantle or, alternatively/additionally, reworking of the mantle because of mantle convection and/or subduction of oceanic crust, remains an open question.

See also Blue Posters B641, Wednesday, 5.30 P.M. ^{187}Re- ^{187}Os Nuclear Geochronometry: Advancing Precambrian Chronostratigraphy

Nucleogeochronometric Evolution of the Earth's Core