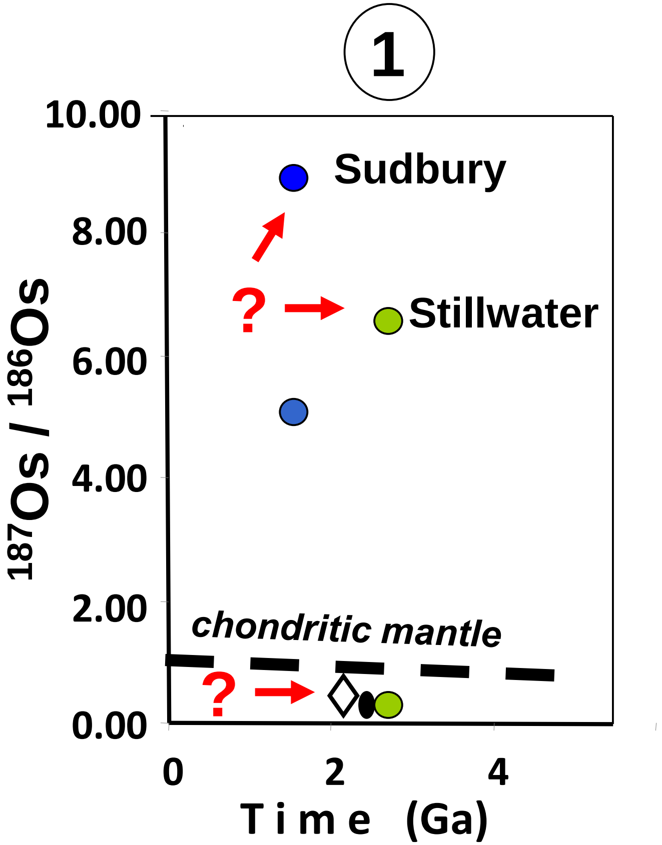
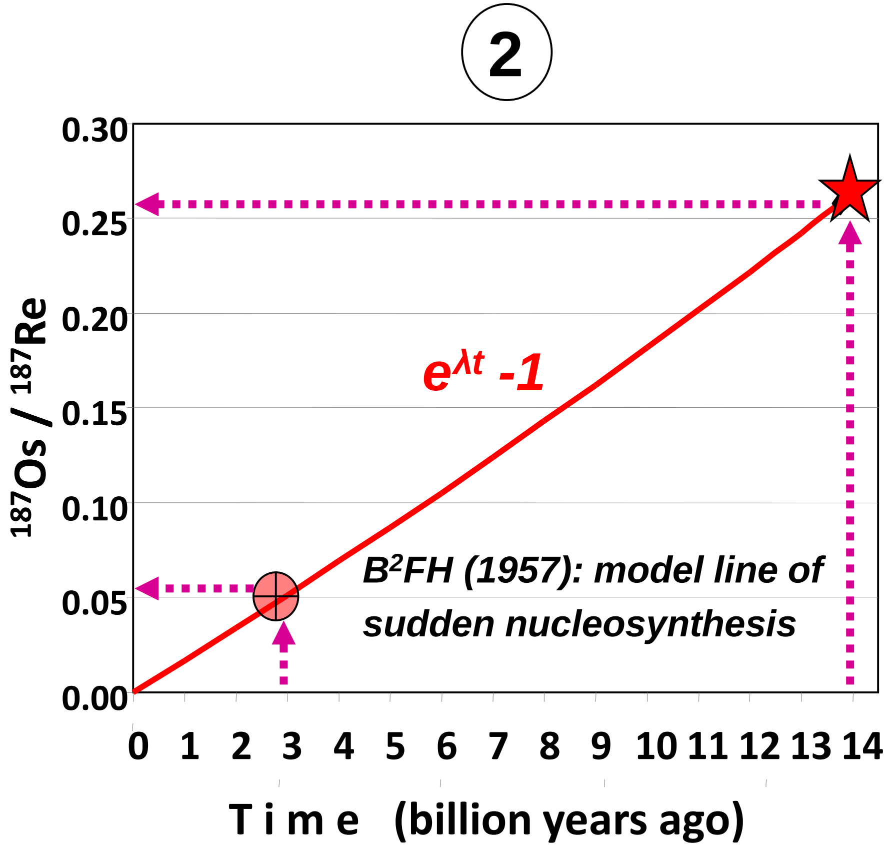
^{187}Re - ^{187}Os Nuclear Geochronometry:

A New Dating Method Applied to Old Ores

Goetz Roller





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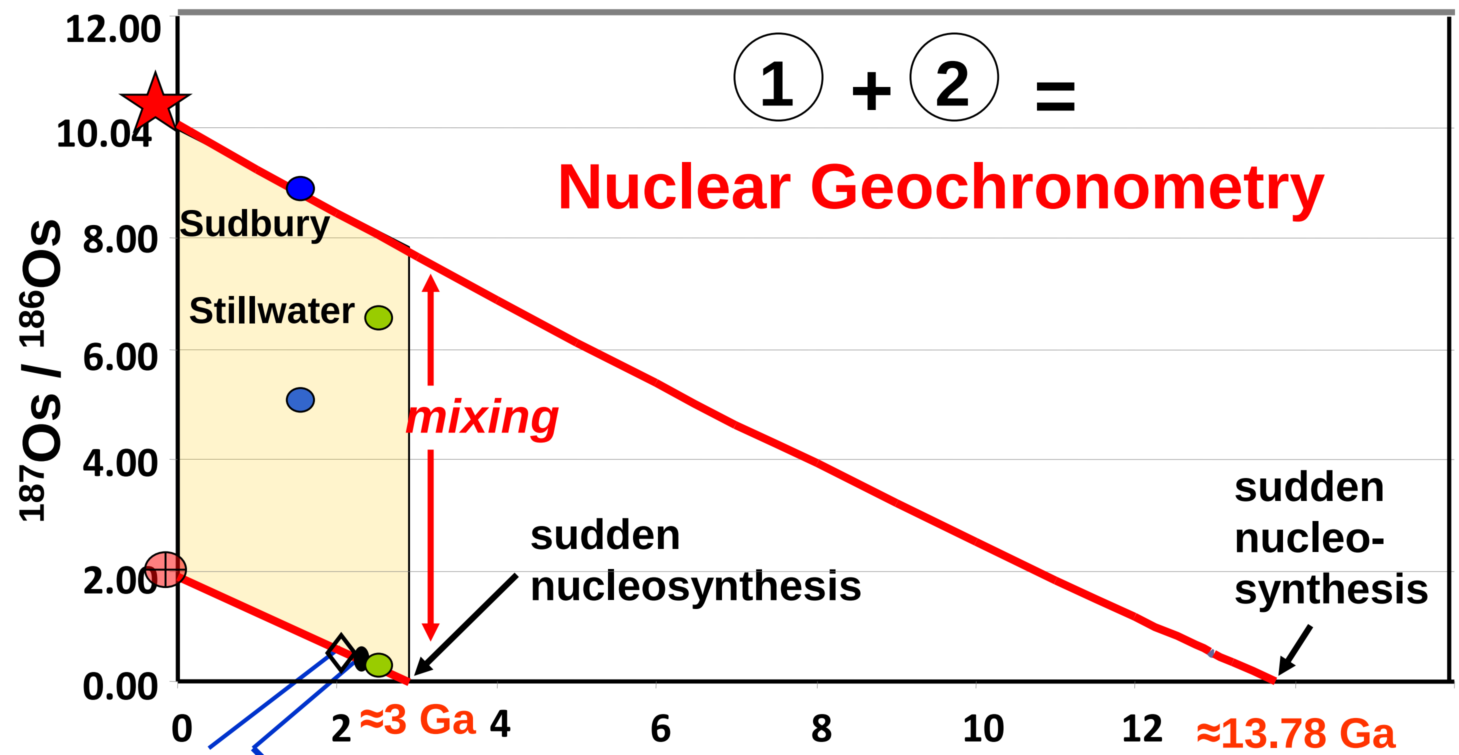


B465, Blue Posters
Tuesday, 5.30 P.M.

B641, Blue Posters
Wednesday, 5.30 P.M.

^{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 …

Let‘s first talk about some basics: most of the neighbour nuclides of Os (Re, Ir) are created via the r-process and subsequent β- decay. Because of its 41.6 Ga half-life, ^{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:

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

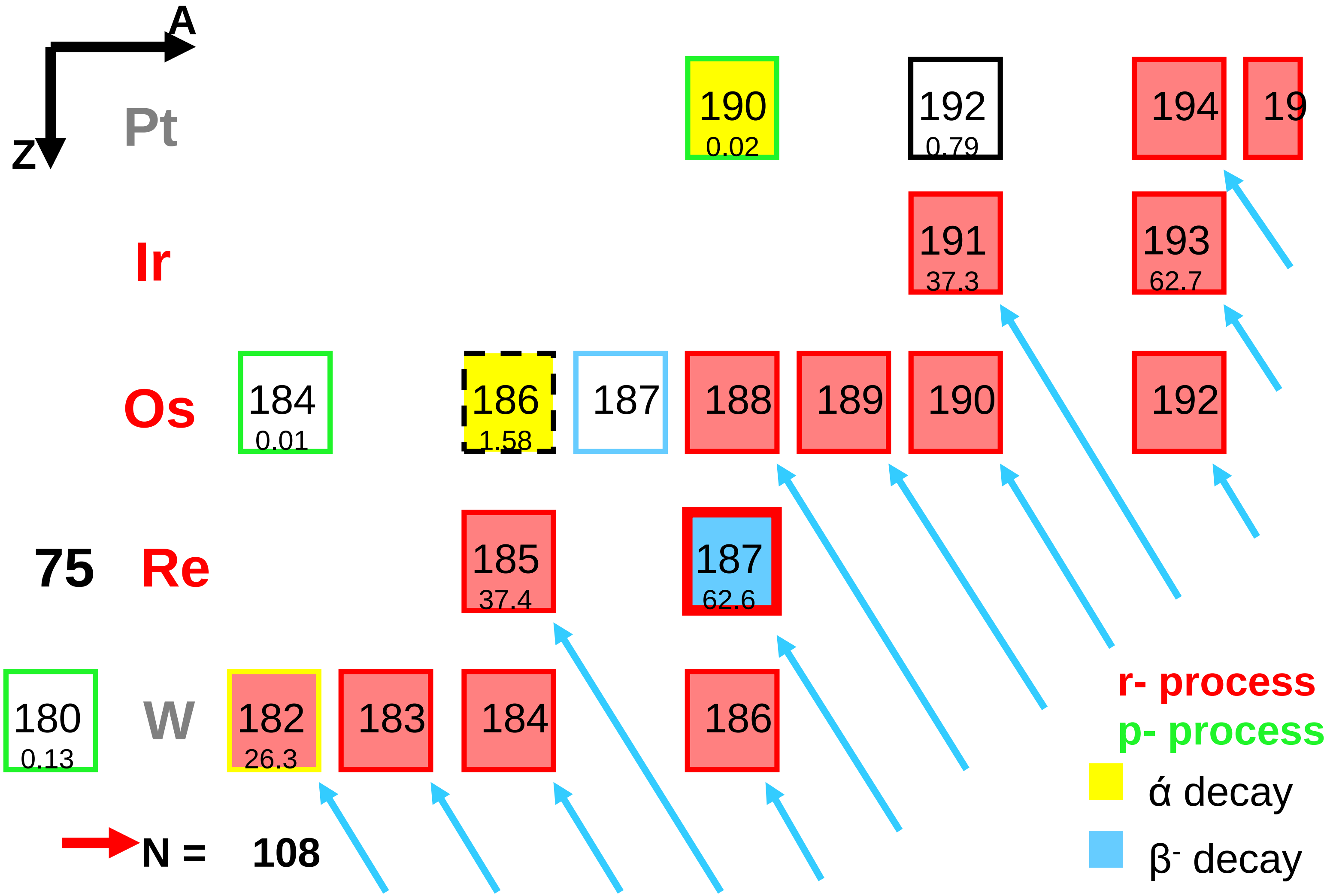
$$^{187}Os/^{188}Os_{now} = {}^{187}Re/^{188}Os_{PR}\,(1 - e^{-\lambda t})$$

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, 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.

≈ Ir/Os

Ref.	Sample / CHRONOMETER	^{187}Os/^{186}Os	^{187}Re/^{186}Os	Re [ppt]	Os [ppt]	Re/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)

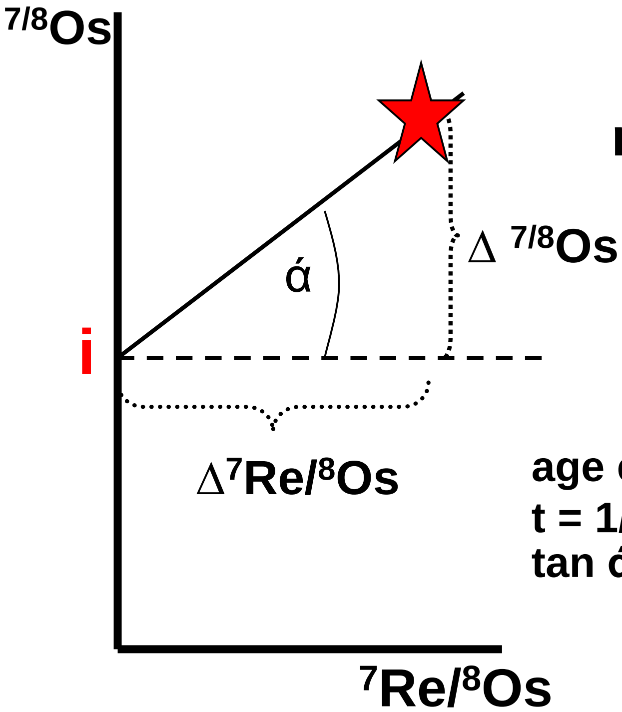
Model Ages and TPI Ages

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**.

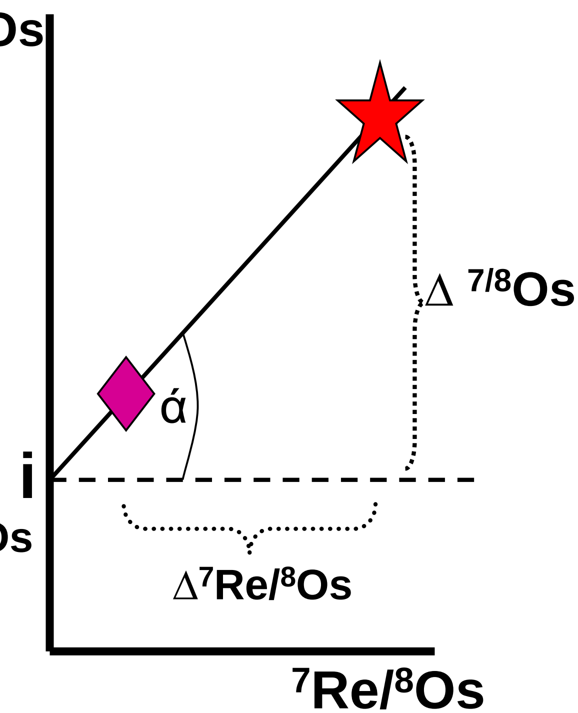
TPI ages constrain the initial ratio using the **BARBERTON** or **IVREA** etc. chronometer always as the second data point in a **TPI diagram**.

Model Age (i = assumed) | **TPI Age (i = derived)**



mutual control

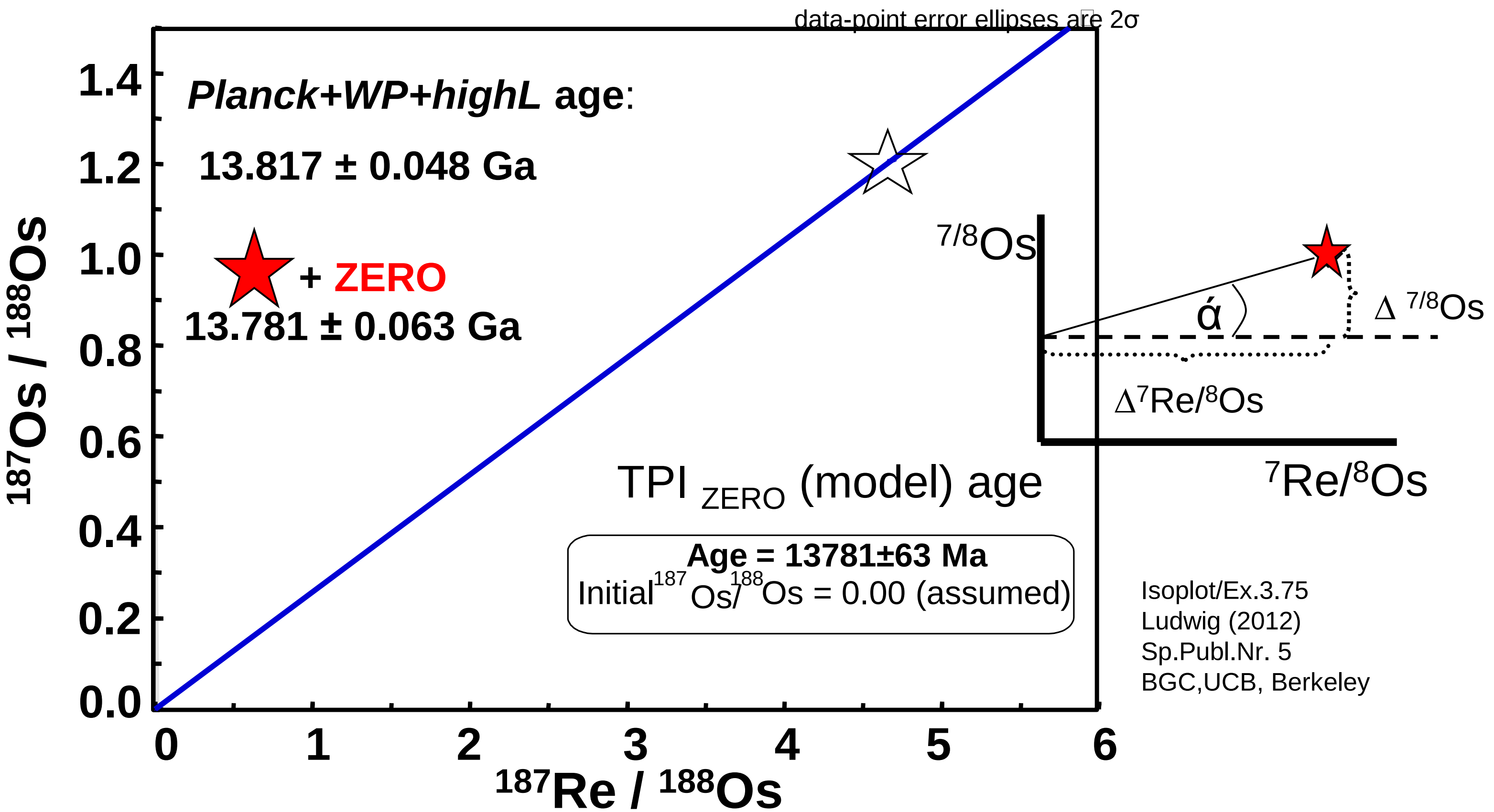
age equation:
$t = 1/\lambda \cdot \ln(\tan ά + 1)$
$\tan ά = \Delta\, ^{7/8}Os \,/\, \Delta ^{7}Re/^{8}Os$



Look at the next charts for an example. You will see these two diagrams attached to the diagrams of the example …

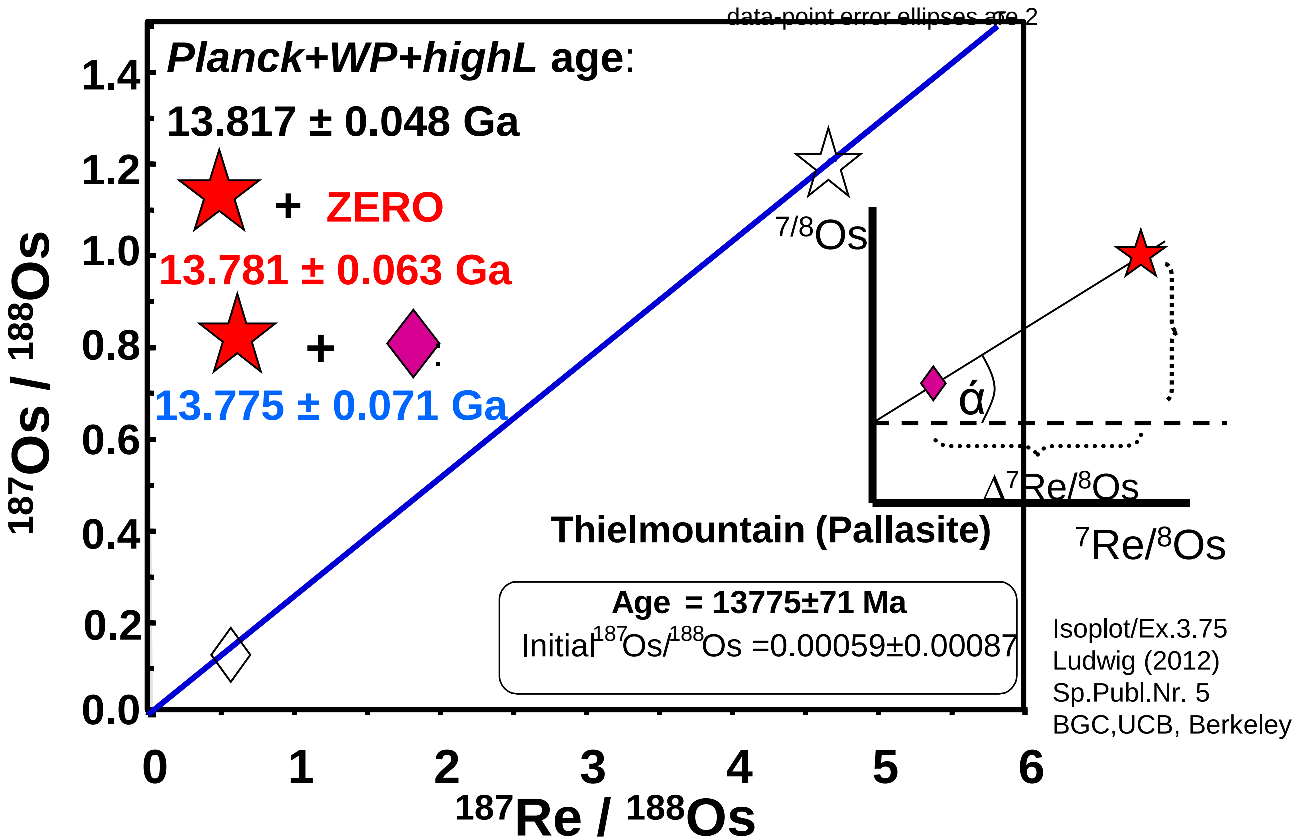
Example: Model age diagram for ★

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

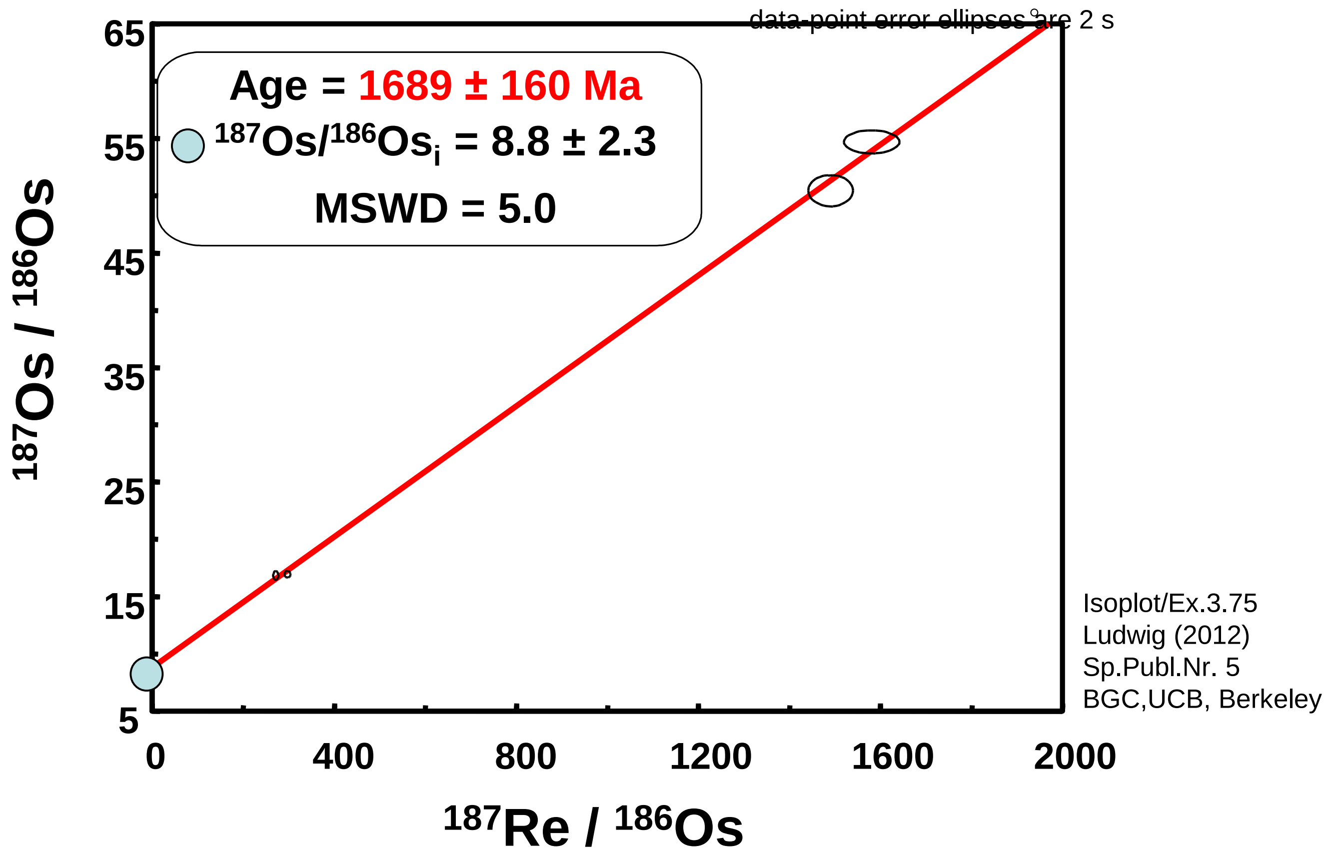
The two data points are the BARBERTON ★ chronometer and the Thielmountain Pallasite ◆. The model age is constrained by this TPI age, which is also a lower boundary for the age of the Universe.



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

Dating the Sudbury ores with the BARBERTON chronometer

Now, let's begin with the PGE ores. Below you see a conventional isochrone calculated with the data of Walker et al. (1991, EPSL 105, 416 - 429) for the Strathcona ores of the Sudbury Igneous Complex:



The nucleogeochronometric TPI ages for these Strathcona ores are in good agreement with the isochrone age of 1689 ± 160 Ma:

★ + PGM-79-126:
1715 ± 62 Ma, $^{187}Os/^{186}Os_i$ = 8.913 ± 0.044 ○

★ + PGM-79-128:
1649 ± 62 Ma, $^{187}Os/^{186}Os_i$ = 8.957 ± 0.044 ○

★ + PGM-79-138:
1733 ± 84 Ma, $^{187}Os/^{186}Os_i$ = 8.901 ± 0.059 ○

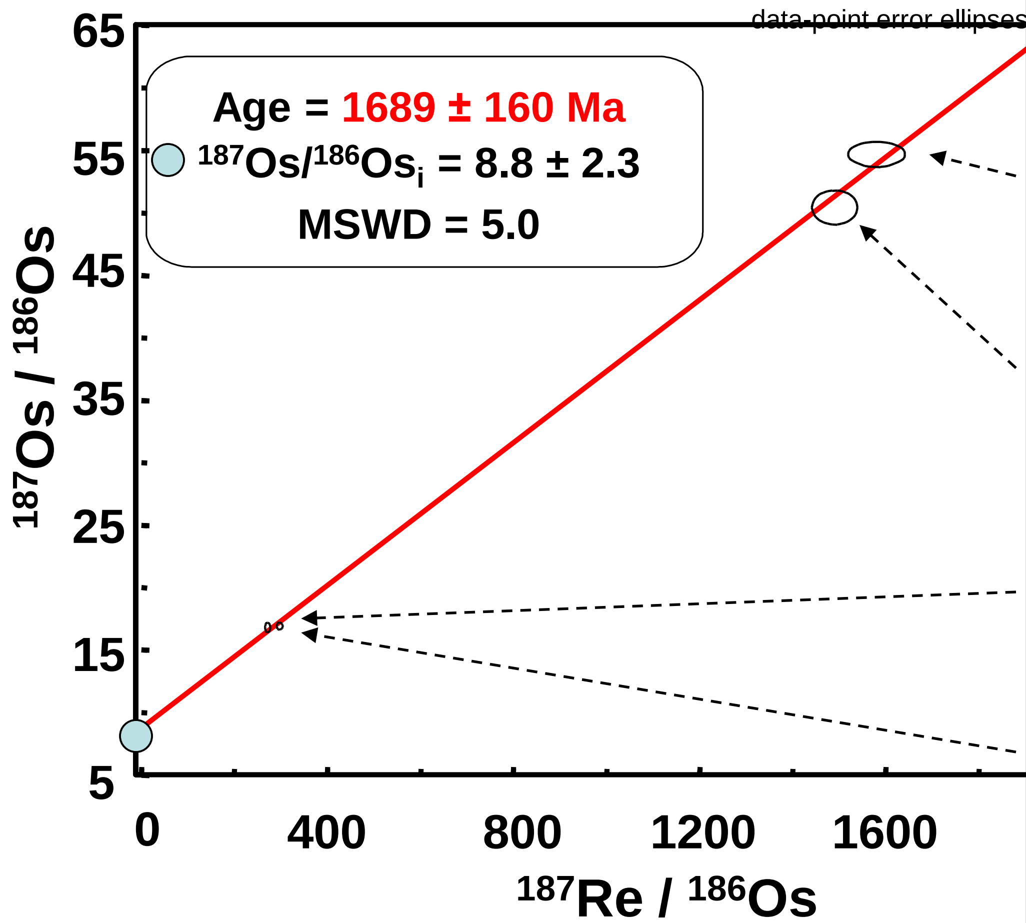
★ + PGM-79-139:
1586 ± 63 Ma, $^{187}Os/^{186}Os_i$ = 8.998 ± 0.045 ○

Look at the improved 2 σ values!

Then, see the next two charts and remember the ○ ○ ○ ○ …

Below, the TPI ages are attatched to the isochrone data points.

Remember the ◯ and see the next chart ….



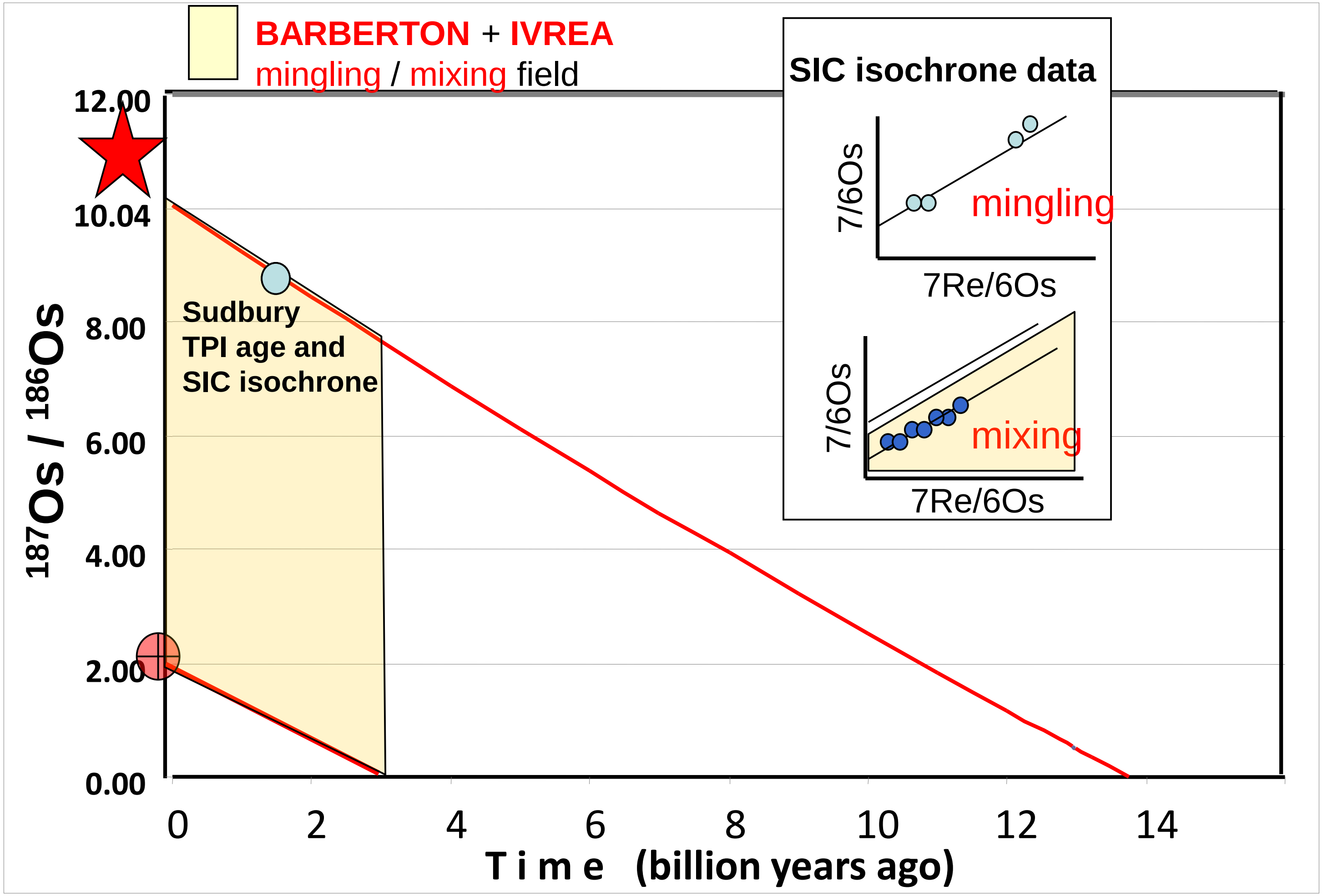
TPI ages

+ PGM-79-126:
1715 ± 62 Ma,
$^{187}Os/^{186}Os_i$ = 8.913 ± 0.044

+ PGM-79-128:
1649 ± 62 Ma,
$^{187}Os/^{186}Os_i$ = 8.957 ± 0.044

+ PGM-79-139:
1586 ± 63 Ma,
$^{187}Os/^{186}Os_i$ = 8.998 ± 0.045

+ PGM-79-138:
1733 ± 84 Ma,
$^{187}Os/^{186}Os_i$ = 8.901 ± 0.059



BARBERTON chronometer

IVREA, RONDA, CAPE SMITH chronometer

= Sudbury SIC

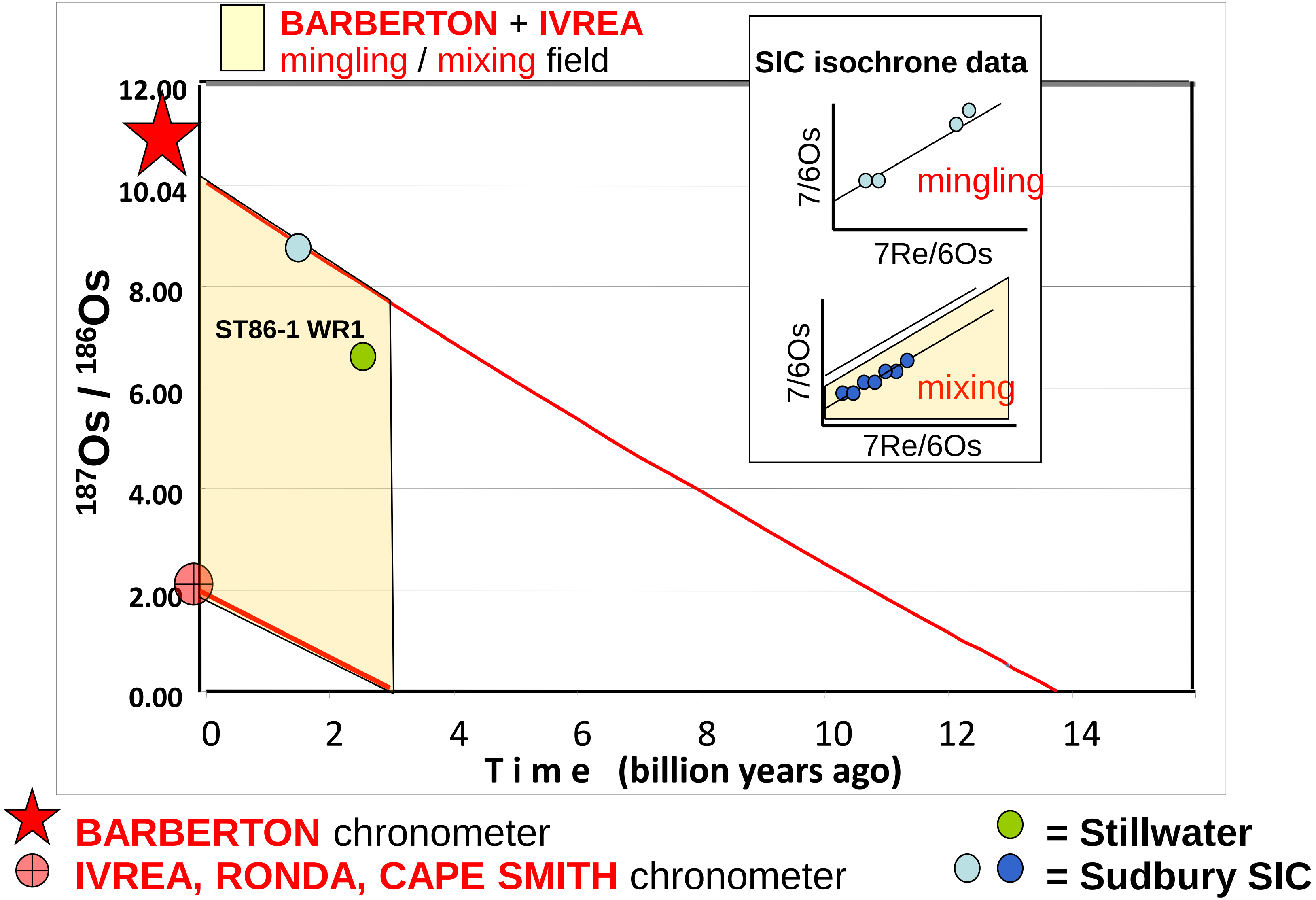
Dating the Stillwater ores by means of the IVREA RONDA or CAPE SMITH chronometer

For the Stillwater Complex (Montana, USA), Marcantonio et al. (1993, GCA 57, 4029 – 4037) report a Molybdenite Re/Os age (ST86-1) from the *G-chromitite* of 2740 ± 80 Ma, consistent with the Sm-Nd age of 2701 Ma (DePaolo & Wasserburg 1979).

For this age, the ST86-1 WR1 sample from the *G-chromitite* shows an extremely high suprachondritic $^{187}Os/^{186}Os_i$ = 6.55. ($^{187}Os/^{188}Os_i \approx 0.786$). [high suprachrondritic = very, very high!]

This is very close to the signature of the BARBERTON chronometer at the same time.

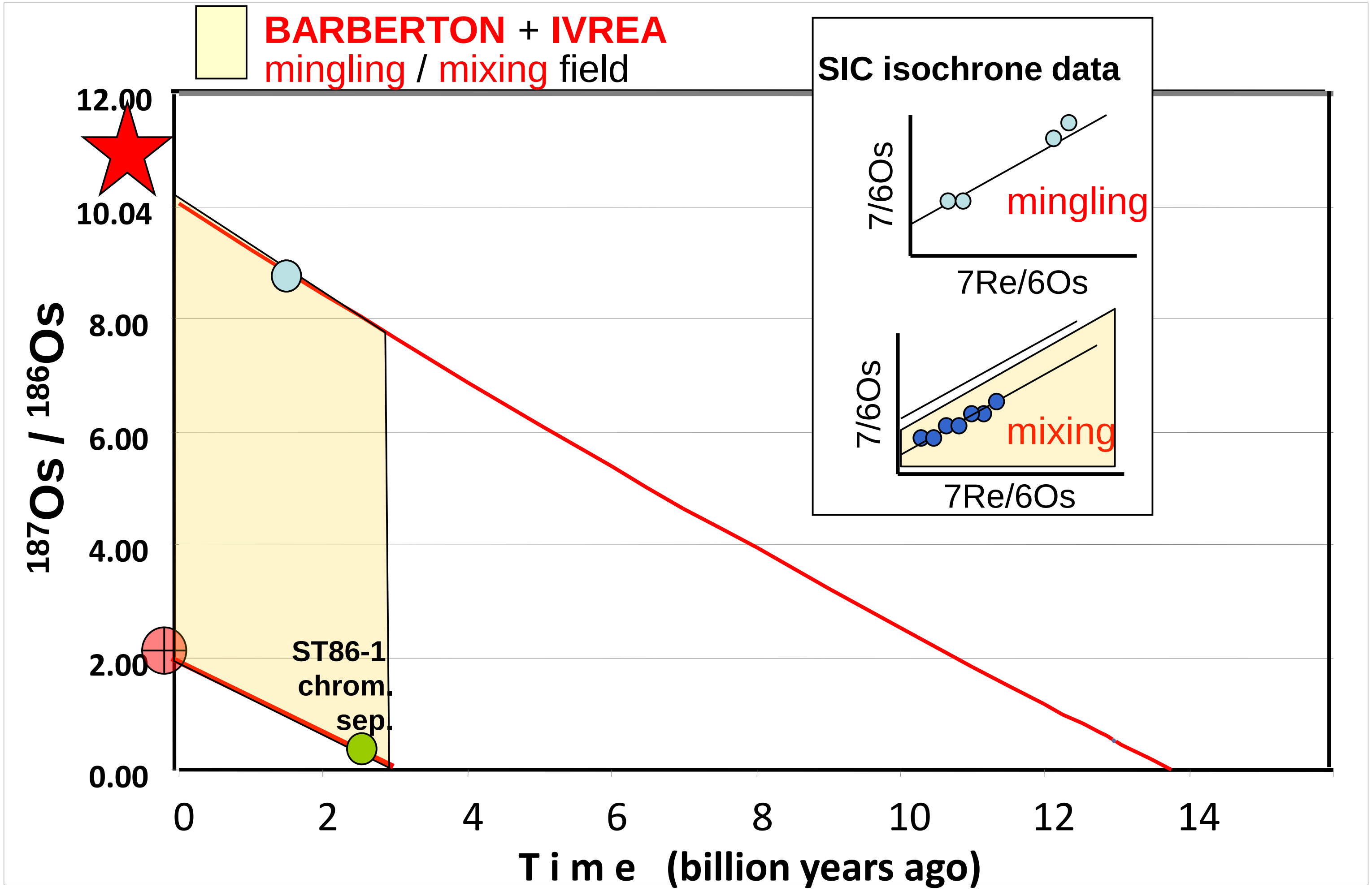
Remember the and see the next chart …


BARBERTON + IVREA
mingling / mixing field
SIC isochrone data
7/6Os
mingling
7Re/6Os
7/6Os
mixing
7Re/6Os
12.00
10.04
8.00
6.00
4.00
2.00
0.00
ST86-1 WR1
^{187}Os / ^{186}Os
0
2
4
6
8
10
12
14
T i m e (billion years ago)
BARBERTON chronometer
IVREA, RONDA, CAPE SMITH chronometer
= Stillwater
= Sudbury SIC

Contrary to that, ST86-1 chromite separate 1 from the same *G-chromitite* (Ultramafic Series) shows an unusual ultra-subchondritic $^{187}Os/^{186}Os_i$ = 0.13 ($^{187}Os/^{188}Os_i \approx 0.0156$). [ultra-subchondritic = very, very low, much lower than the chondritic mantle at 2700 Ma, which shows a $^{187}Os/^{186}Os_i \approx 0.92$ or $^{187}Os/^{188}Os_i \approx 0.11$]

Using the geochronometer, a TPI age of 2717 ± 100 Ma ($^{187}Os/^{186}Os_i = 0.125 \pm 0.067$ or $^{187}Os/^{188}Os_i \approx 0.015$) can be calculated for ST86-1 chromite separate 1 .

Again, keep the in mind and see the next chart …



BARBERTON chronometer

IVREA, RONDA, CAPE SMITH chronometer

= Stillwater

= Sudbury SIC

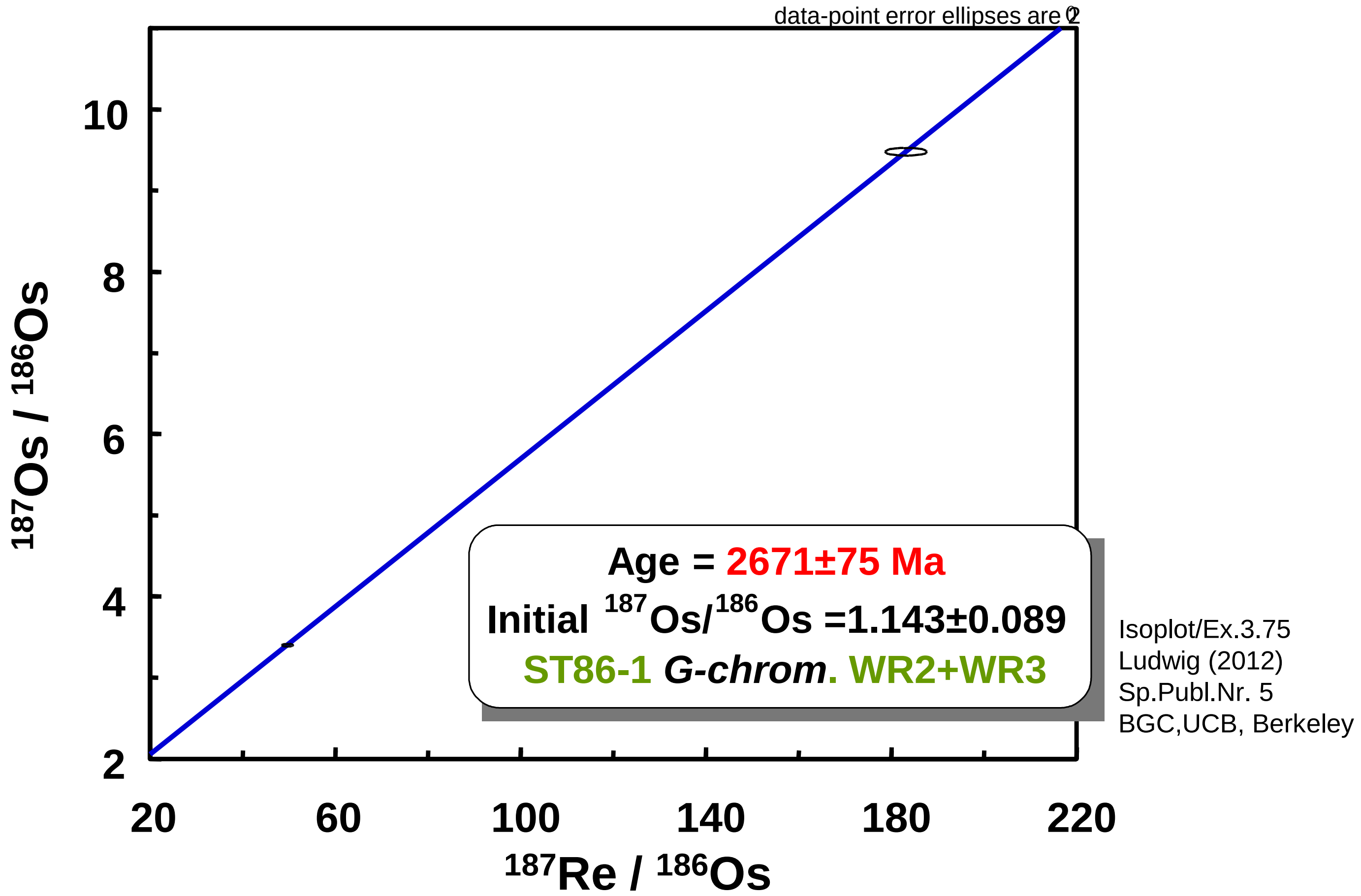
From WR2 and WR3 of the Stillwater Complex *G-chromitite* reported in Marcantonio et al. (1993, GCA 57, 4029), an isochrone age of 2671 ± 75 Ma can be calculated, which confirms the TPI age of 2717 ± 100 Ma and the other ages for the Stillwater Complex (2740 Ma, 2701 Ma). The initial $^{187}Os/^{186}Os$ ratio of the isochrone is 1.143 ± 0.089 ($^{187}Os/^{188}Os$ ≈ 0.1372).

This could be explained by mixing of components from the and geochronometers at ≈ 2671 ± 75 Ma.

Thus, the situation is comparable to the Levack West + Falconbridge isochrone of the Sudbury Igneous Complex.

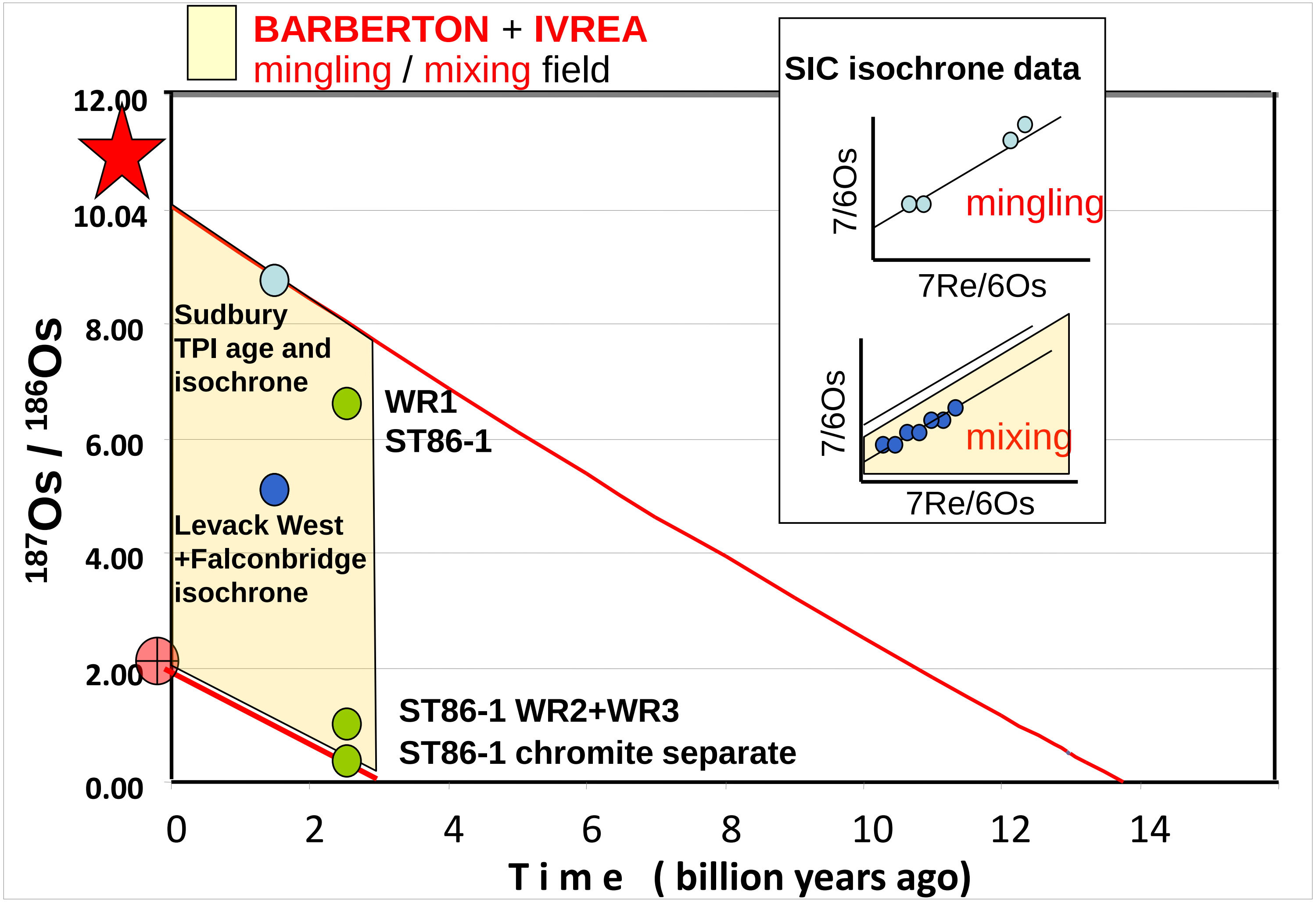
See the isochrone diagram for WR2 and WR3 on the next chart, ...

… and then the nucleogeochronometric summary chart …



Do you remember all the ●, ● and ● you have seen so far?

If not: don't worry! Just look at the following summary chart …



BARBERTON chronometer

IVREA, RONDA, CAPE SMITH chronometer

= Stillwater

= Sudbury SIC

Conclusions

1. **Ultra-suprachrondritic $^{187}Os/^{186}Os$ or $^{187}Os/^{188}Os$ initial ratios in Proterozoic magmatic rocks may be explained as being derived from a magmatic source with a ≈ 13.78 Ga old r-process signature, created in a sudden nucleosynthesis shortly after the Big Bang.**

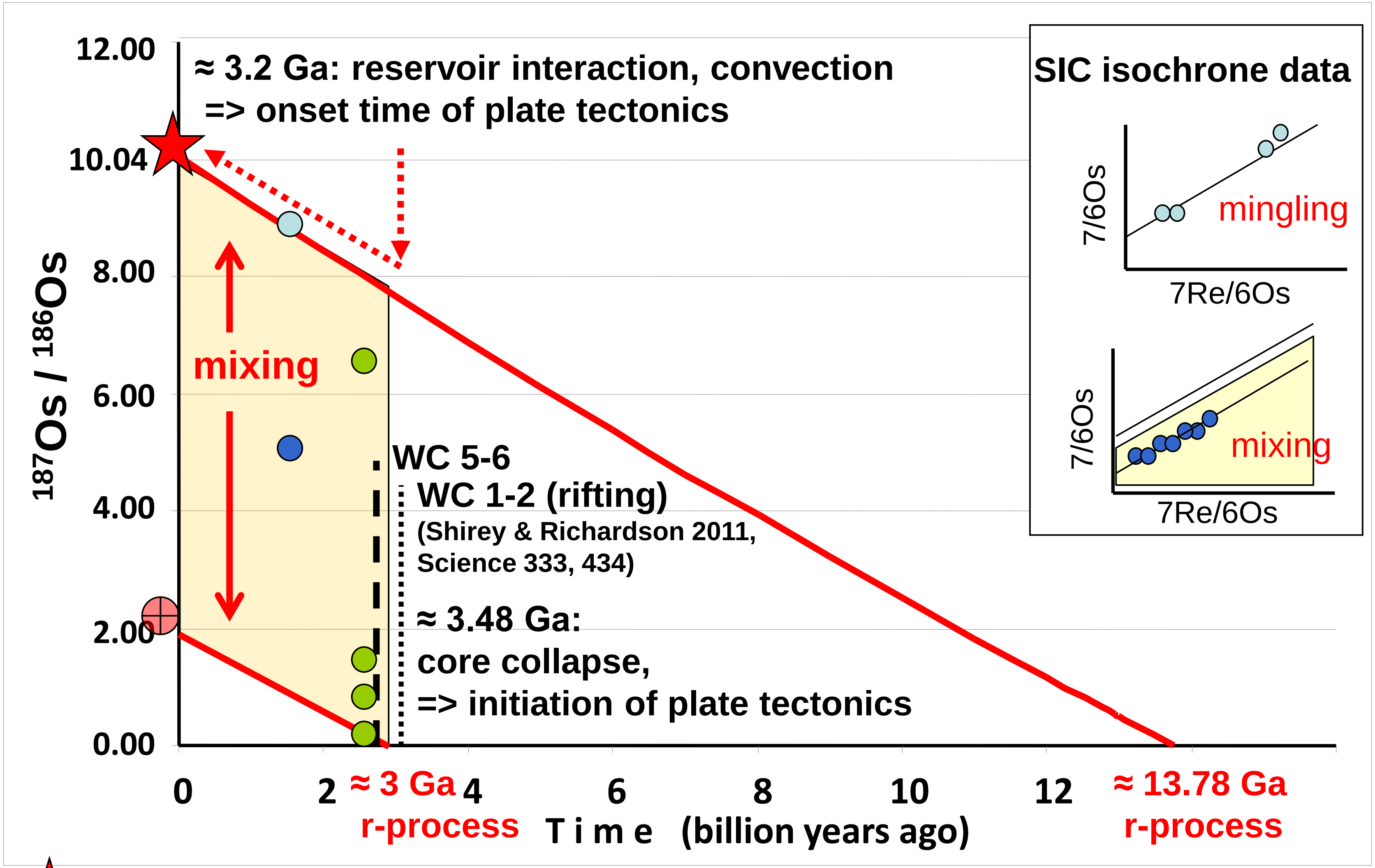
2. **Ultra-subchrondritic $^{187}Os/^{186}Os$ or $^{187}Os/^{188}Os$ initial ratios in Archean magmatic rocks may be explained as being derived from a magmatic source containing a ≈ 3 Ga old r-process signature from a sudden nucleosynthesis event, which might have initiated rifting within the Pilbara Craton and thus plate tectonics on Earth.**

3. **Initial Os isotopic ratios between the ★ and ⊕ evolution lines (as in the case of the Stillwater and the Sudbury Complex) may be explained as a mixture between the two r-process reservoirs and / or the convecting mantle signature.**

4. The interaction of the two reservoirs may be responsible for convection within the Earth`s core, thus being still today's driving force for plate tectonics and the Earth's magnetic field.

5. Nuclear geochronometry favours an endogenic origin for the Sudbury and Stillwater ores, with at least some of the PGE's being genetically related to the Earth's core.

… and since a picture tells more than 1000 words, see the next chart!



Earth‘s inner core

Earth‘s outer core

Stillwater Complex G-chromitite (UMS)

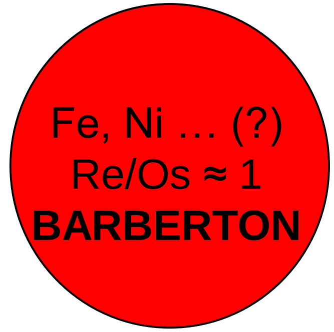
Sudbury Complex, Strathcona, Falconbridge etc

WC Wilson Cycle (1-2 Pilbara / 5-6 Kaapvaal)

See the last chart …

Nucleogeochronometric Evolution of the Earth‘s Core

13.78 Ga → 3.48 Ga
ancient component
weak magnetic field



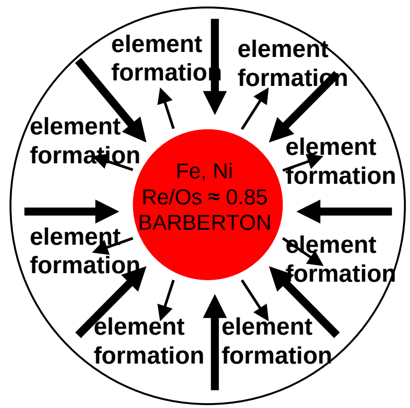
slow cooling
during ≈ 10 Ga

$p_{in} \approx p_{out}$ ↓ T (K) ↓

metastable

$p_{in} \approx/> p_{out}$ ↓ T (K) ↓↓

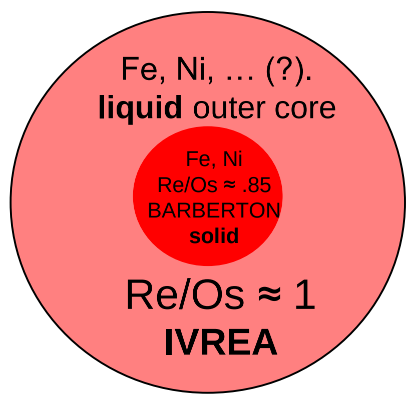
≈ 3.48 Ga core collapse
$p^+ + e^- \rightarrow n + \nu$, r-process
ignition of nuclear processes
nucleosynthesis etc.
suddenly increasing
magnetic field strength



instable
$p_{in} >>>> p_{out}$
→ ←
gravitational collapse
← →
thermal expansion ↑
magnetic pressure ↑

$p_{in} \approx p_{out}$ ↓ T (K) ↓

3 Ga → today
modern Earth,
inner/outer core
convection, pulsation
magnetic field reversals
mantle/crust/plate tectonics



stable
“only“ magmatism,
earthquakes etc.

T = temperature (Kelvin); p = pressure
out = outward, due to thermal expansion etc.
in = inward, due to gravitation etc.
↓ = down, ↑ = up