How to date the subcontinental lithospheric mantle? Methods and applications in the Carpathian-Pannonian region

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Aims of the study

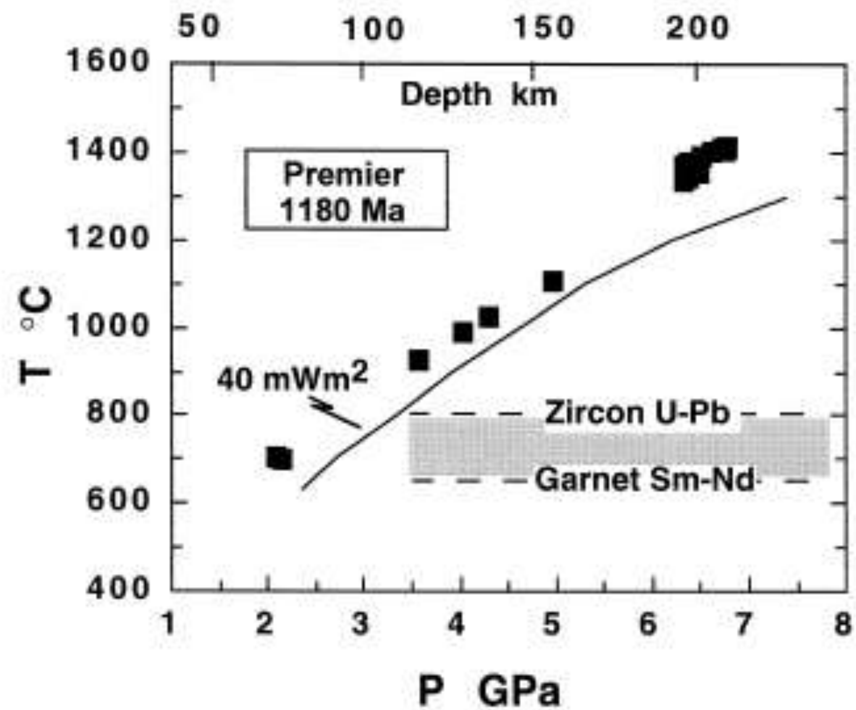
- Determine the age of the subcontinental lithospheric mantle (SCLM) beneath the Carpathian-Pannonian-region (CPR)
- Reveal the connection between the formation of the crust and the lithospheric mantle
- Provide evidence of an ancient, inherited SCLM or a young, „freshly" lithospherized mantle
- Provide additional information to improve the recent geodynamical models of the CPR

Method

- *in-situ* LAM-ICP-MS Re-Os geochronology of sulfides in alkali basalt derived mantle xenoliths

Problems with dating continental roots, especially mantle rocks

- High temperature ↔ low blocking temperatures
- Very low level of elements of interest (sub ppm)
- Absence of minerals which concentrate them (zircon, garnet)
- Long-lasting rocks, infiltrating fluids can easily disturb the isotopic systems of mantle minerals
- The usage of „classical” isotope systems (Sr-Nd-Pb) is very limited



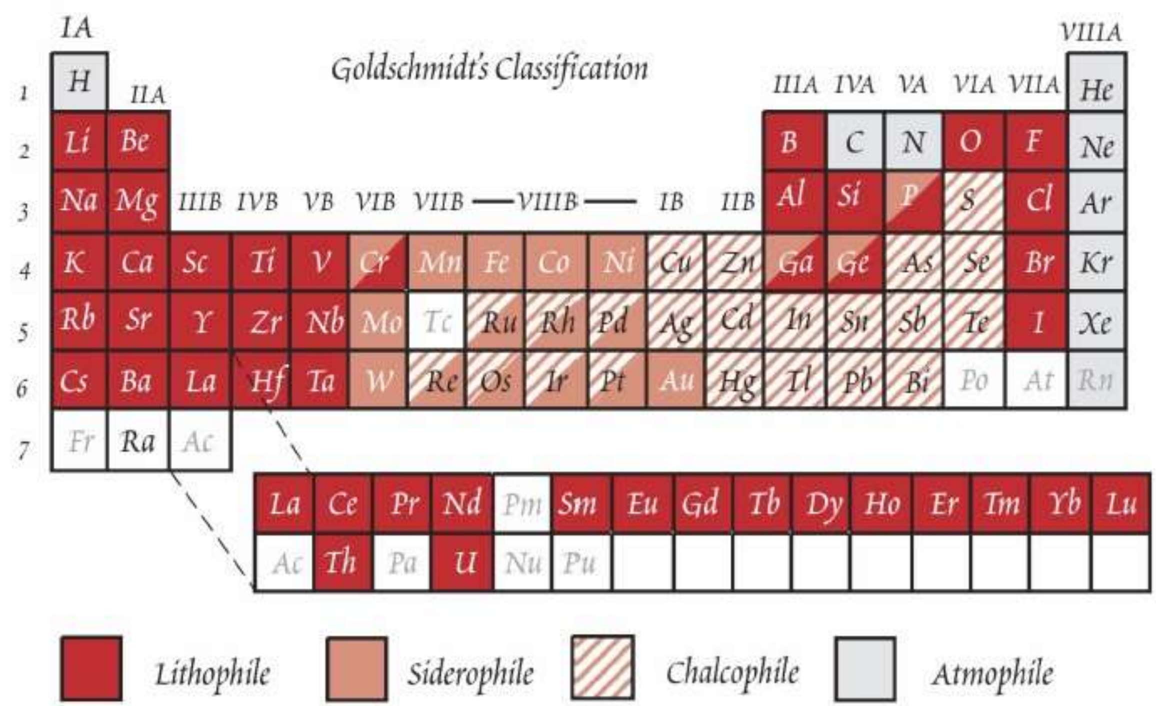
Premier kimberlite, Kaapvaal craton

Pearson, 1999

Re-Os system

- Rhenium: ^{185}Re (37,4%) and ^{187}Re (62,6%)
- $^{187}Re\ \beta^- \rightarrow\ ^{187}Os$, $\lambda=1{,}64\text{-}1{,}66*10^{-11}\ a^{-1}$, $T_{1/2}=41{,}2*10^{9}\ a$
- Os is highly compatible during mantle melting (resides in solid phases), meanwhile Re is moderately incompatible (~Al)

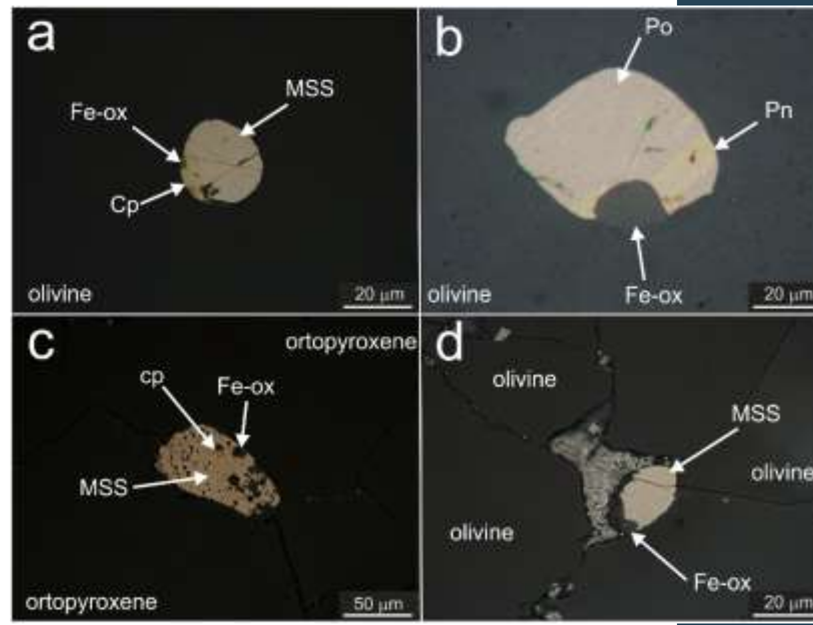
Widely used in geology: event, chemo- and chronostratigraphy, organic geochemistry, geochronology (ore deposits and **igneous/mantle rocks**)



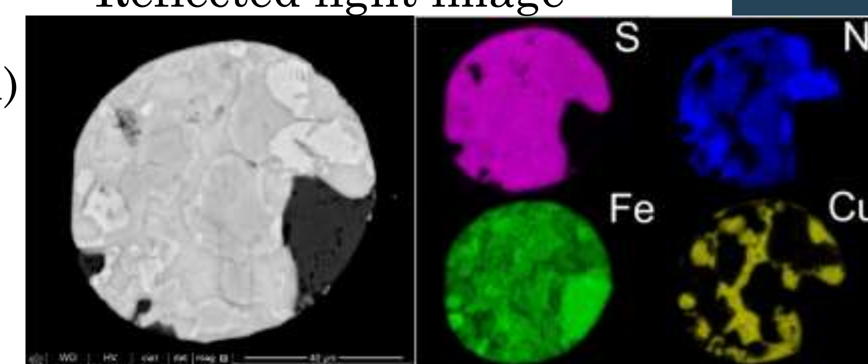
White, 2007

Where does Os (and Re) reside in the mantle?

- 95% of the Platinum-group elements (PGE) reside in sulfide minerals and platinum-group minerals
- Sulfides are quite common in mantle xenoliths, also in the CPR
- Sulfides are mobile in the SCLM, being transported by metasomatic fluids, or being resorbed into percolating silicate melts and subsequently redeposited
- Whole-rock Re-Os ages provide a mixed age, since sulfides in mantle rocks are usually polygenetic, crystallized during different melting and melt-percolation (metasomatism) processes
- *in-situ* LAM-ICP-MS analyses of sulfides provide Re-Os ages for **unique** melting/melt percolation events



Reflected light image



Backscattered electron image

Model age calculations

- Isochron methods cannot be used
- T_{MA}, T_{RD}: time of separation from the primitive mantle, which is modelled with the Enstatite Chondritic Reservoir (ECR)

$$T_{MA} = {}^{1}/_{\lambda} \times ln\left\{\left[\frac{{}^{187}Os/{}^{188}Os_{chon} - {}^{187}Os/{}^{188}Os_{sample}}{{}^{187}Re/{}^{188}Os_{chon} - {}^{187}Re/{}^{188}Os_{sample}}\right] + 1\right\}$$

$$T_{RD} = {}^{1}/_{\lambda} \times ln\left\{\left[\frac{{}^{187}Os/{}^{188}Os_{chon} - {}^{187}Os/{}^{188}Os_{sampleEA}}{{}^{187}Re/{}^{188}Os_{chon}}\right] + 1\right\}$$

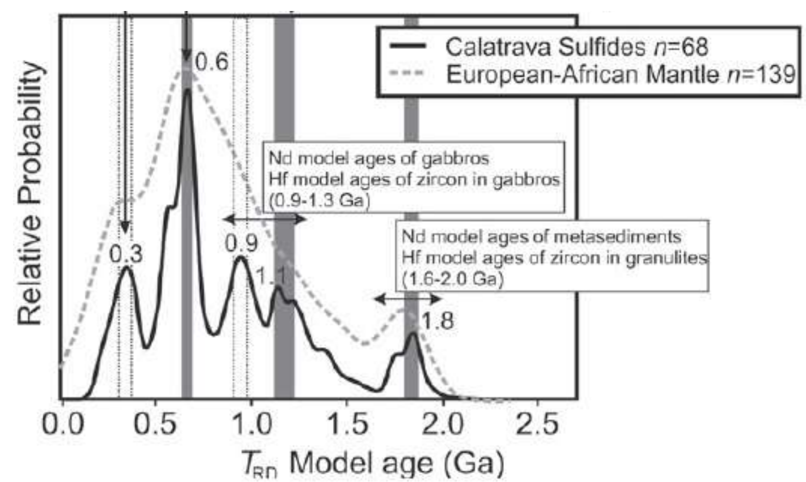
Assuming ${}^{187}Re/{}^{188}Os_{sample}$=0 means all the Re was removed from the sample via melt depletion → **minimum age**

sampleEA: isotope ratio at the time of eruption

Walker et al., 1989

How to interpret Re-Os ages?

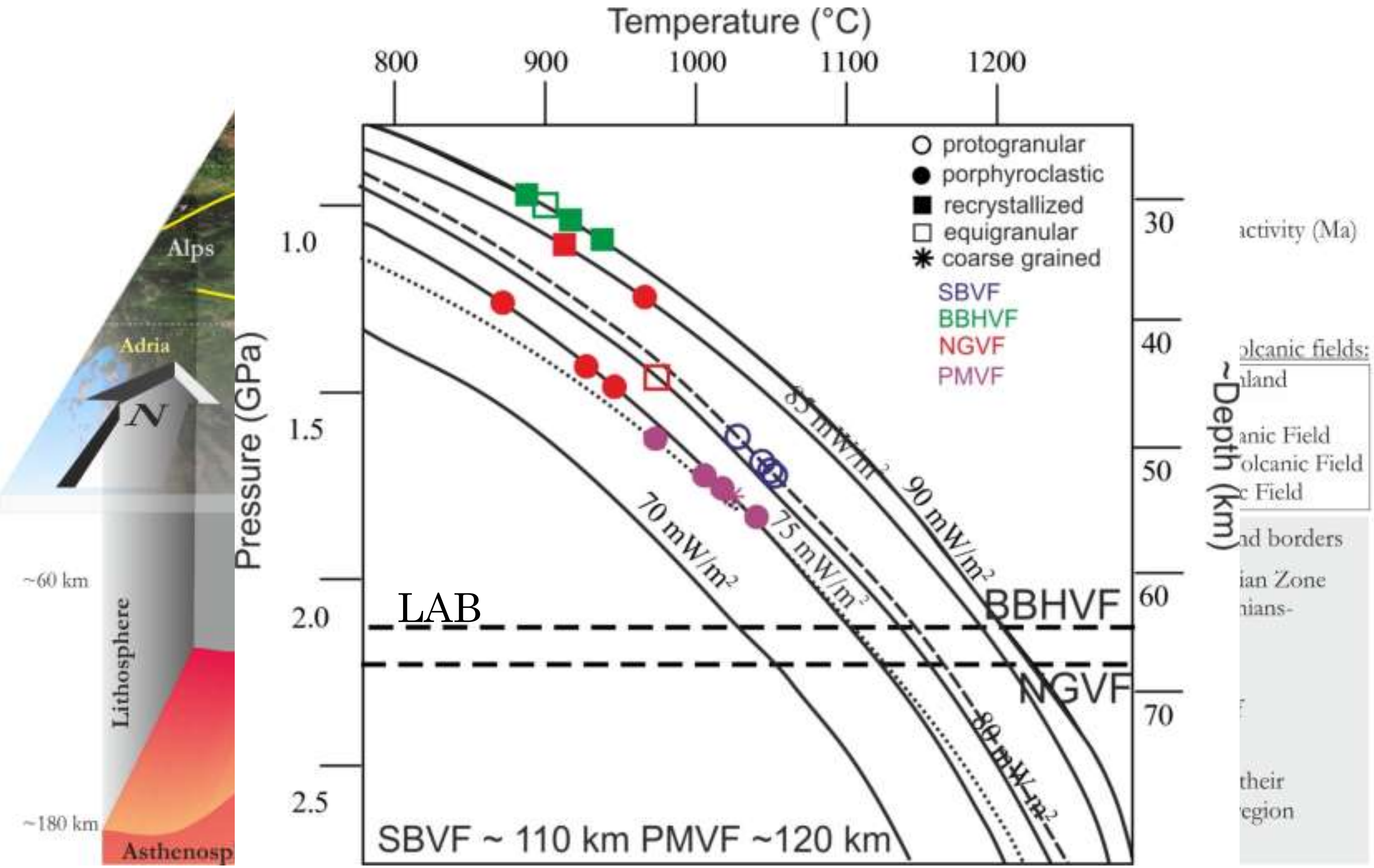
- Lower resolution than crustal ages (2σ<0,2 Ga considered to be precise)
- High degrees of partial melting will remove sulfur from the upper mantle, therefore it is unlikely that several stages of melting will be recorded by sulfide data in cases more than one generation of sulfides
- Different T_{RD} model ages in a single xenolith →**only the oldest generation may approach the original age of lithosphere stabilisation**
- Younger generations may record **episodes of melt infiltration into the lithosphere.**
- Melt extraction → crust formation, link between crustal and mantle ages



Example from the Calatrava Volcanic Field

González-Jiménez et al. (2013), Wang et al. (2013), Griffin et al. (2002)

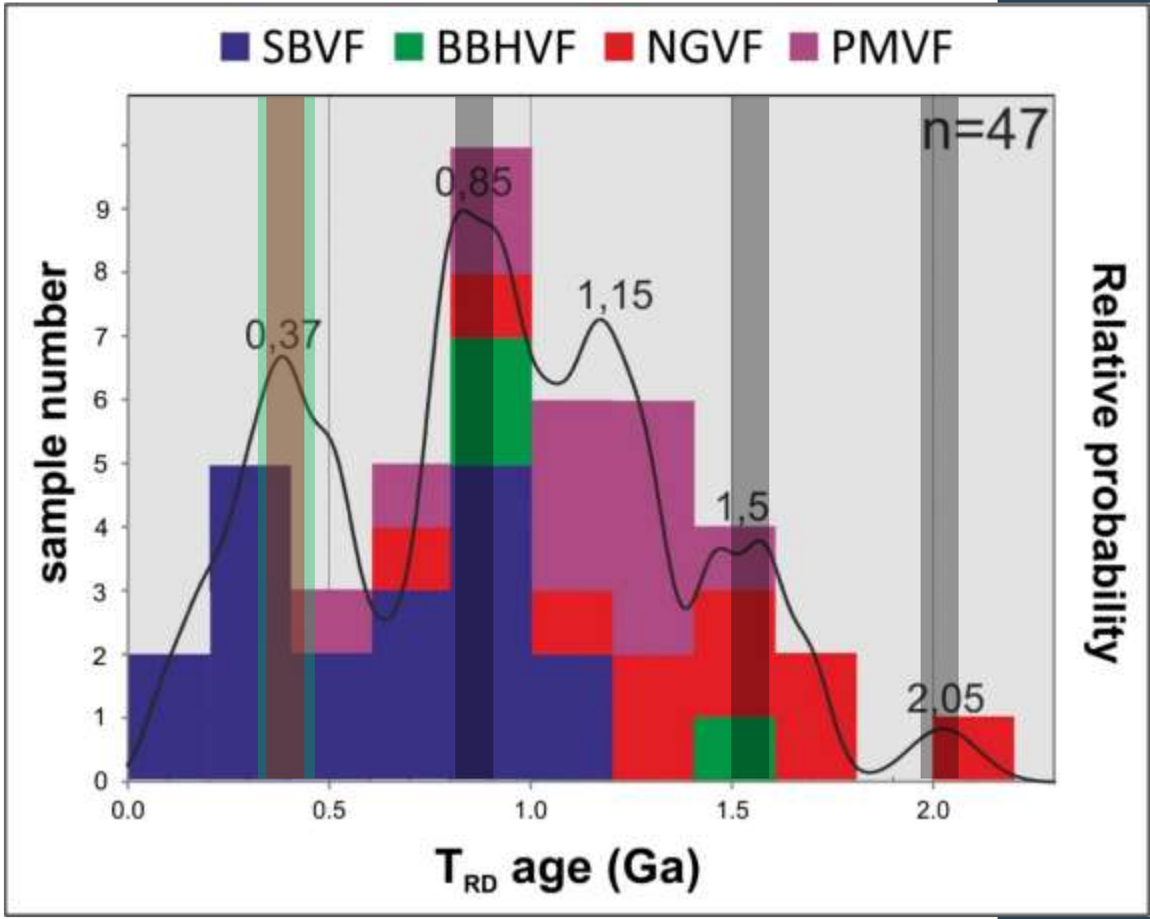
Case study from the CPR



*Lenkey et al. (2002), Artemieva (2009), Lankreijker et al. (1997), Sachsenhofer et al. (1997), Horváth (1993).*Szabó et al., 2010

Results

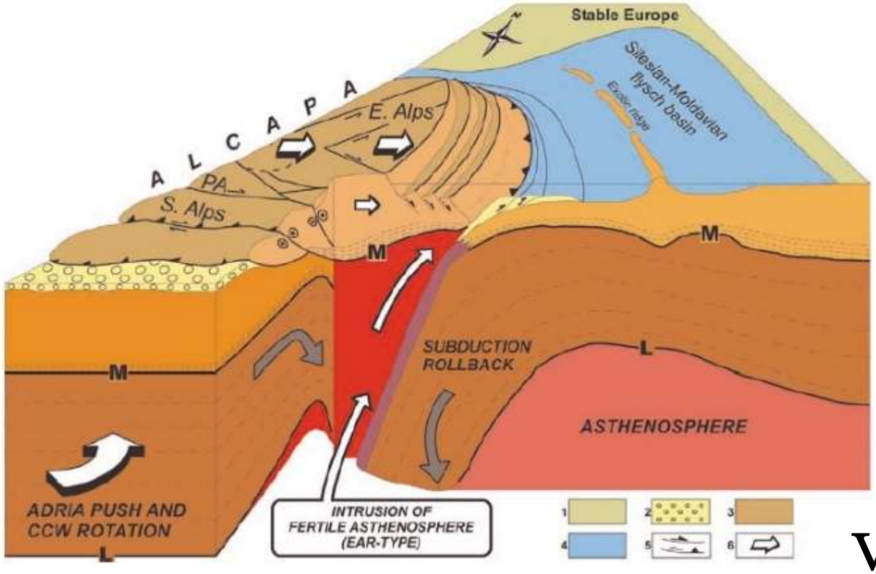
- The SCLM beneath the CPR is much older than the overlying crust
- The oldest T_{RD} ages representing the age of lithospherization:
  - SBVF: 1,12 Ga
  - BBHVF: 1,48 Ga
  - NGVF: 2,05 Ga
  - PMVF: 1,44 Ga
- Regional differences: NGVF is the oldest, SBVF is the youngest
- Pulses of continental crust growth at 0,37, 0,85, 1,15 and 1,5 Ga
- Scarcity of crustal ages (lost during extension?)– the younger peaks are in agreement with lower crustal zircon ages (Hilary Downes, personal comm., 2013), but there is no information about Proterozoic crust beneath the CPR



Related geodynamic events?

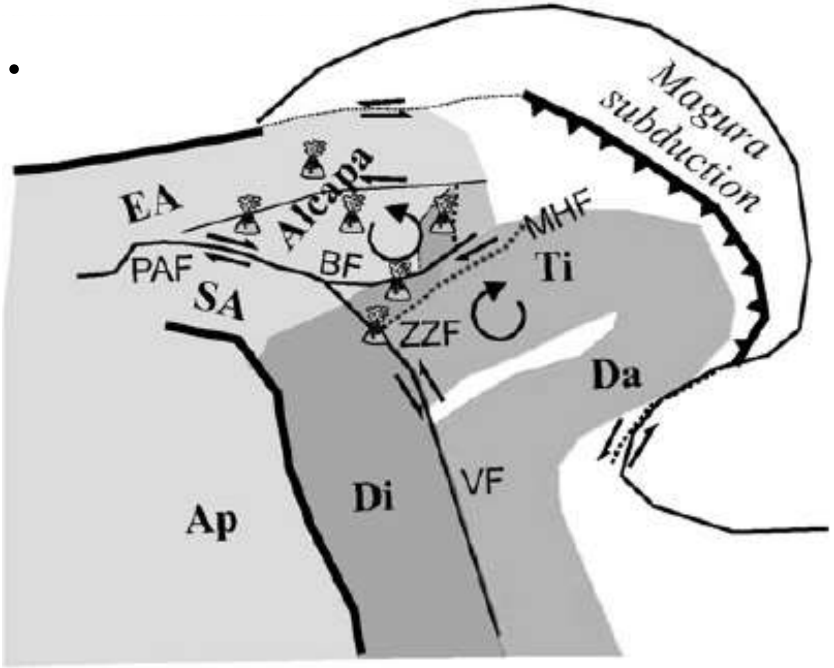
Klötzli et al. (2004), Broska et al. (2013), Balintoni et al (2013)

Geodynamical consequences



Extrusion without the SCLM

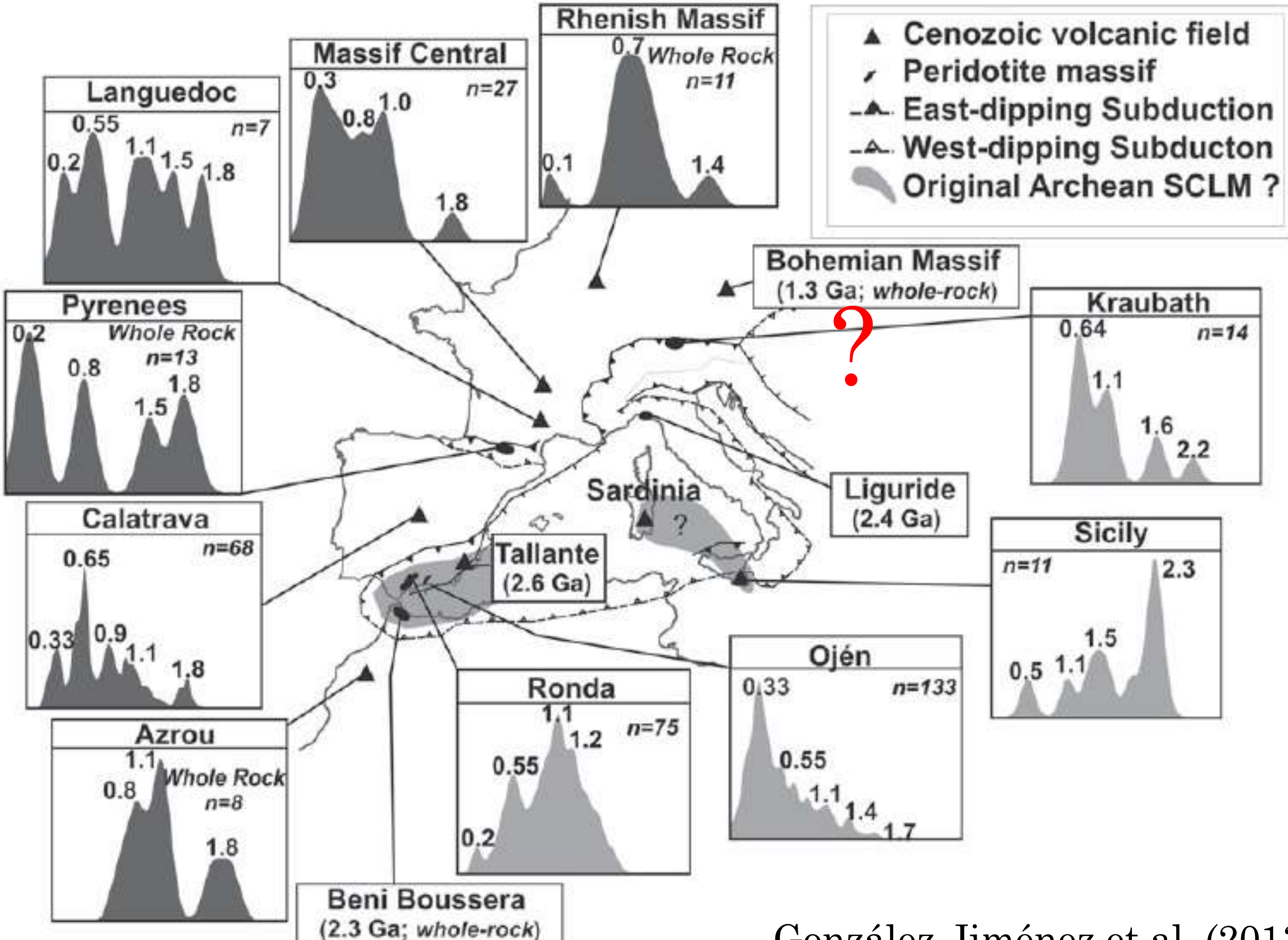
vs.



Extrusion with the SCLM

Horváth et al. (2006), Kovács & Szabó (2008), Kovács et al. (2012)

Interpretations from Re-Os ages



González-Jiménez et al. (2013)

Conclusions

- Detailed *in-situ* Re-Os dating of mantle sulfides from the Carpathian-Pannonian region
- Rhenium depletion ages revealed that the subcontinental lithospheric mantle is much older than the known crust
- We can assume that the SBVF has the youngest, and the NGVF the oldest SCLM, as old as 2,05 Ga
- These data suggest that the SCLM could not be lithospherized after the Miocene extrusion
- The CPR mantle shows ages similar to the Western Mediterranean region

Thank you for your attention!

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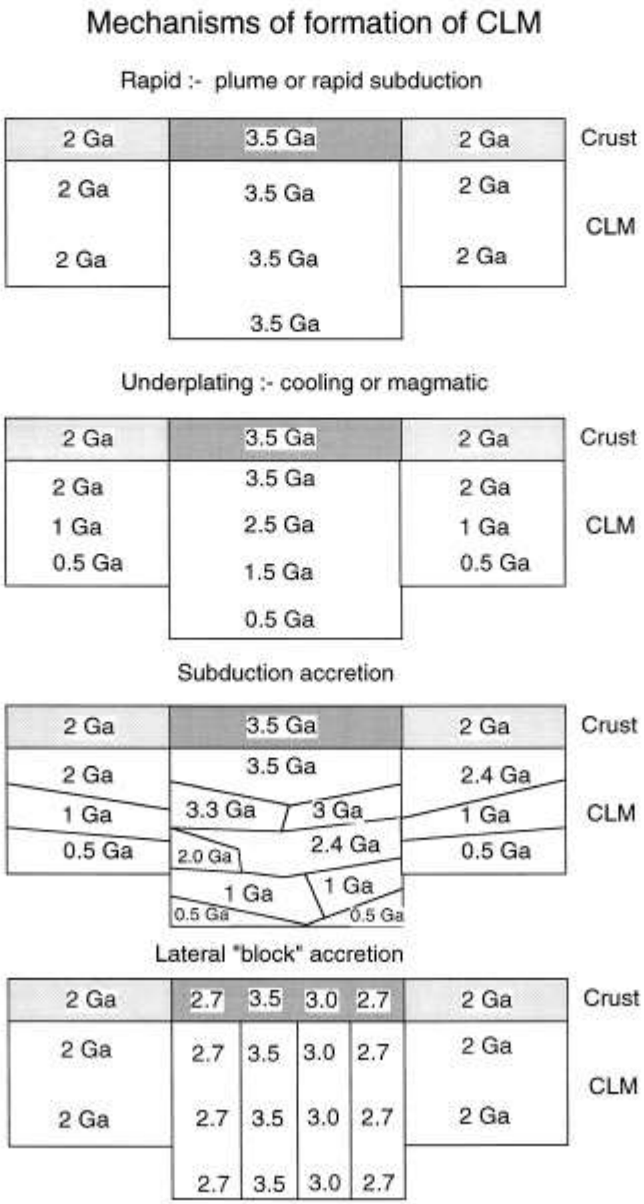
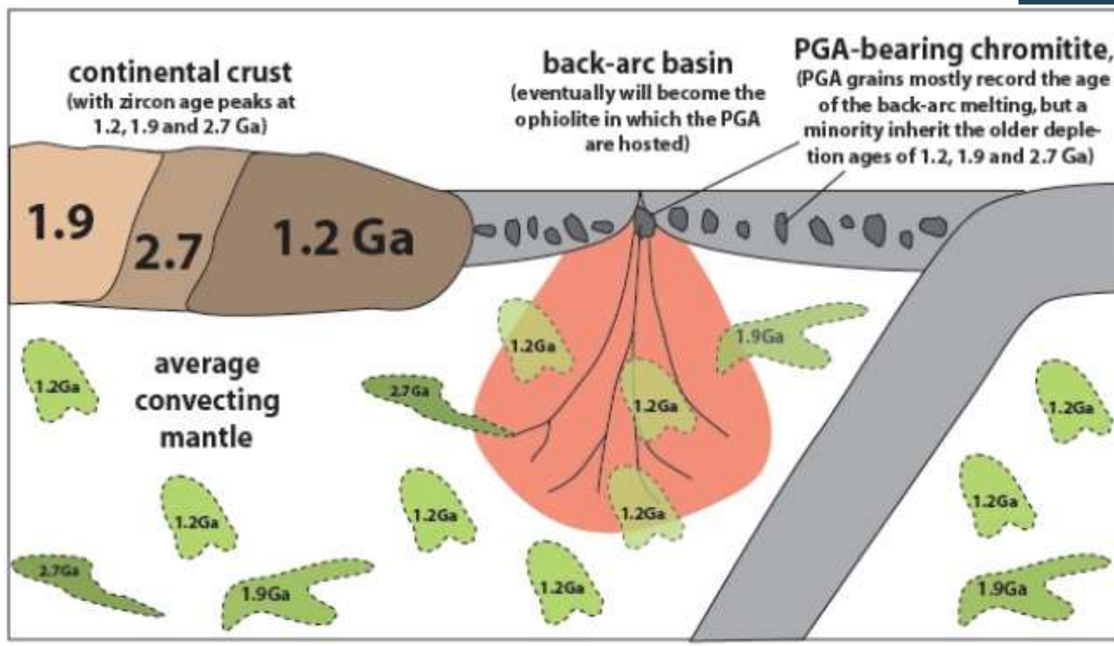
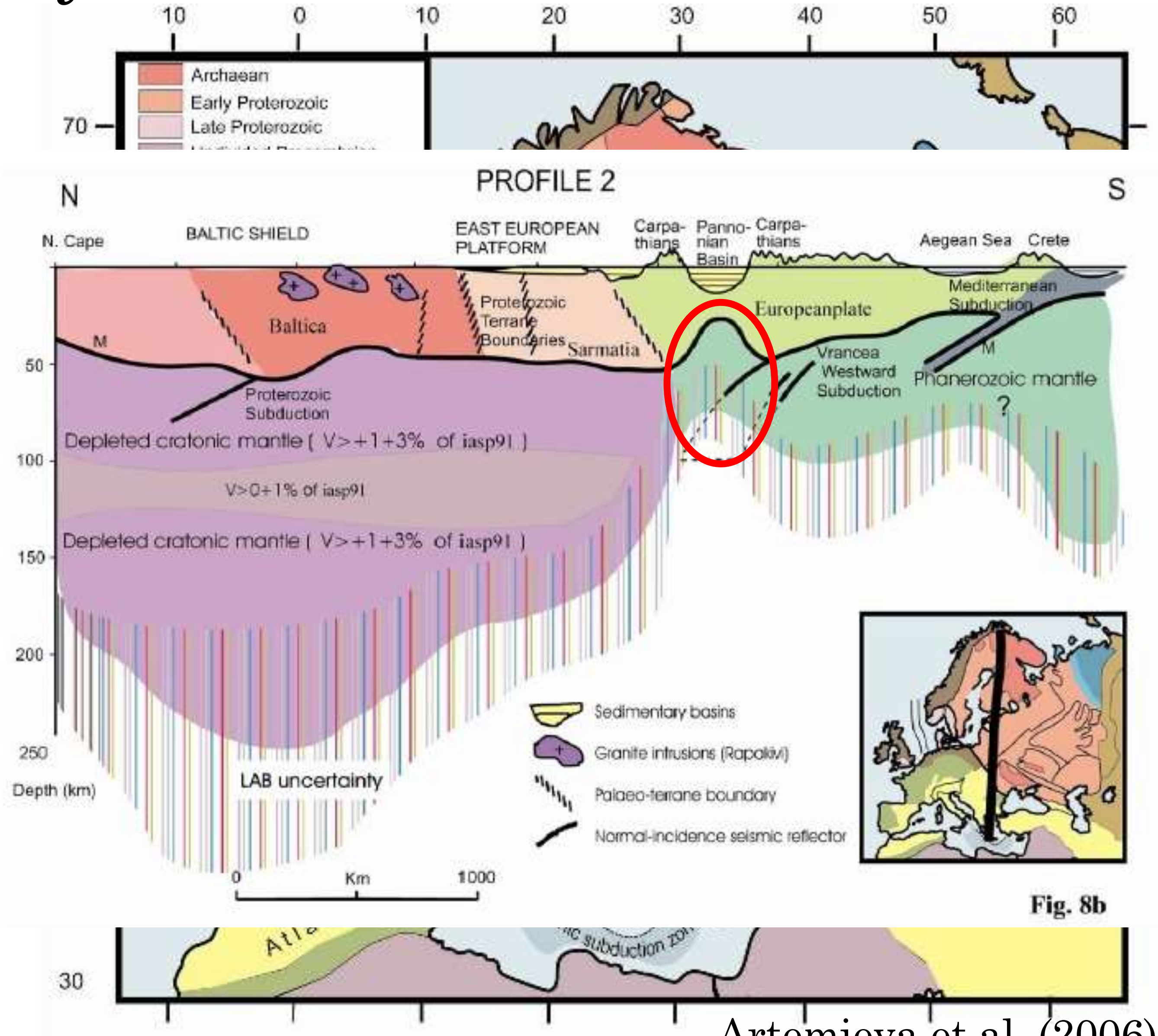




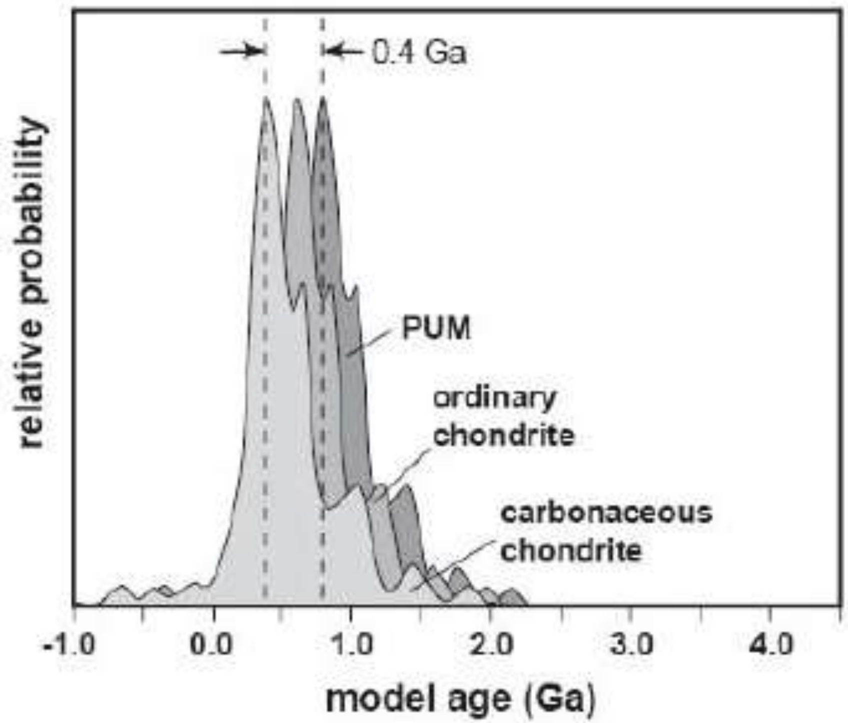
Supplementary Figure 1. Formation of PGA grains. Melting events at 1.2, 1.9 and 2.7 Ga produce highly depleted mantle domains (green areas) and significant volumes of continental crust (brown regions). Convective mixing progressively destroys these heterogeneities and so the older domains are less abundant. The depleted mantle domains have low Re/Os (parent/daughter) ratios and so produce little radiogenic ^{187}Os after the melting events, thus preserving their depletion age. Their high Os concentrations make them highly resistent to resetting by refertilization or metasomatism. A high-degree melting process (red area, here envisioned to be a back-arc basin) scavenges the Os from the mantle. The melts ascend through the mantle and deposit PGA bearing chromitites (dark grey regions) in the oceanic lithosphere (light grey regions). The PGA grains inherit the Os heterogeneity of the mantle from the melts. Most of the mantle sampled by the melting process has 'average mantle' Os isotopic composition, thus most of the PGA grains yield the age of ophiolite formation, while only a few record the earlier depletion events. PGA grains are not thought to be present in the convecting mantle, as none have been found in any abyssal peridotite sample. After the melting process ceases, the chromite bearing crust is obducted onto the continents, forming an ophiolite from which the PGA are concentrated by erosion. Note that the figure is schematic and not to scale.

Pearson (1999); Pearson et al. (2007)

SCLM in Europe, interpretations from geophysical data



Artemieva et al. (2006)



Supplementary Figure 13. Probability density graphs of Re-depletion model ages for the Urals PGA dataset calculated using three different mantle evolution models. PUM = Primitive Upper Mantle (Ref 26), $^{187}Os/^{188}Os$ = 0.1296; $^{187}Re/^{188}Os$ = 0.422. Ordinary chondrites (ref. 19) $^{187}Os/^{188}Os$ = 0.1283; $^{187}Re/^{188}Os$ = 0.422. Carbonaceous chondrites (Ref 19) $^{187}Os/^{188}Os$ = 0.1262; $^{187}Re/^{188}Os$ = 0.392. All internal uncertainties on model ages used to construct the probability density plots are 0.1 Gyr.

- Pearson et al. (2007)