Crystallisation of the upper lunar magma ocean and implications for KREEP and crust formation

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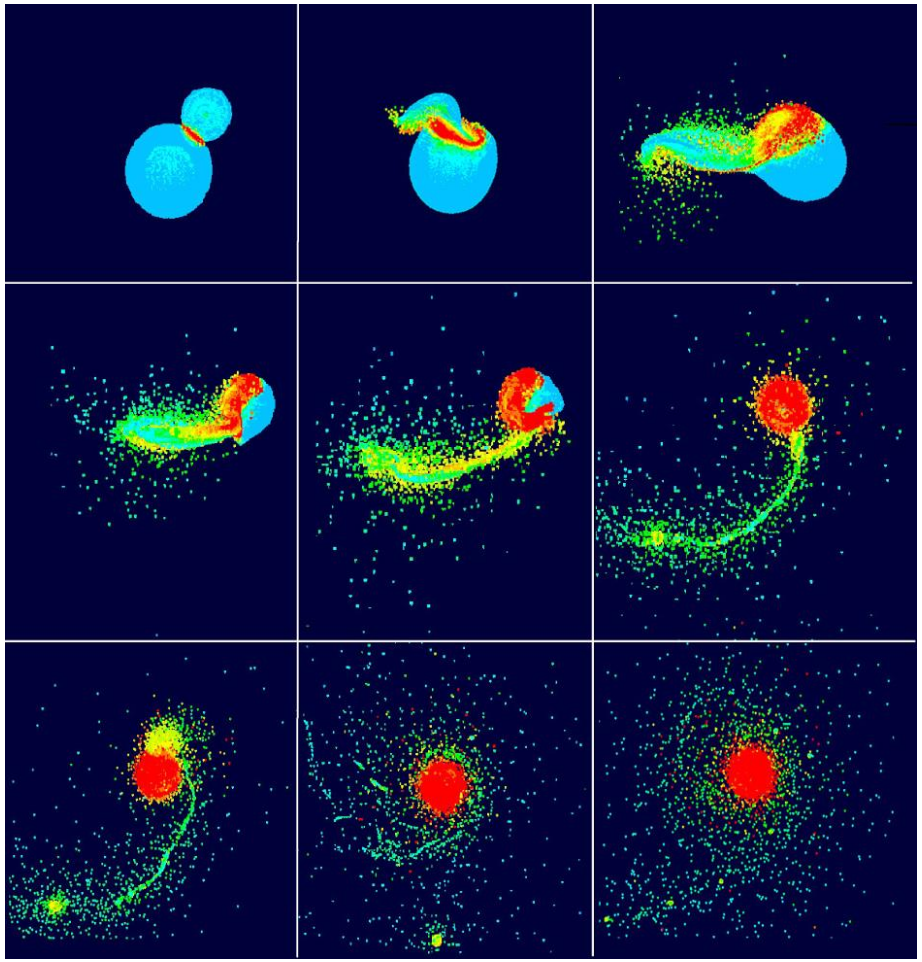
EGU General Assembly 2022

Background



Canup (2004)

Giant impact hypothesis

(Hartmann & Davis, 1975; Cameron & Ward, 1976)

Mars-size impactor struck the proto-Earth and created a disk of debris from which the Moon was accreted.

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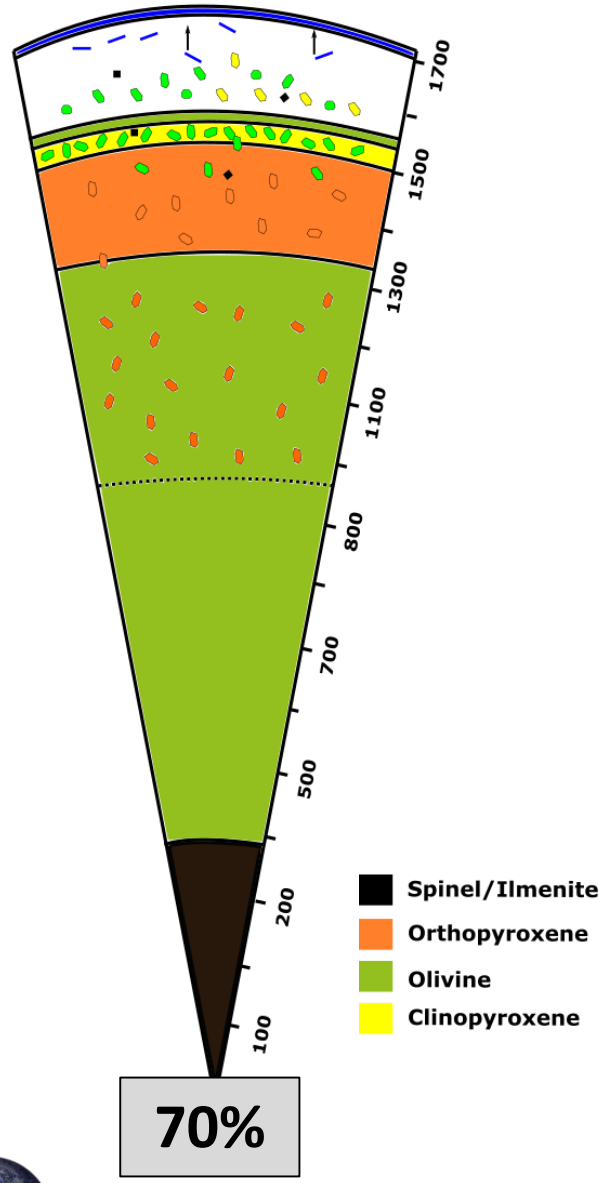

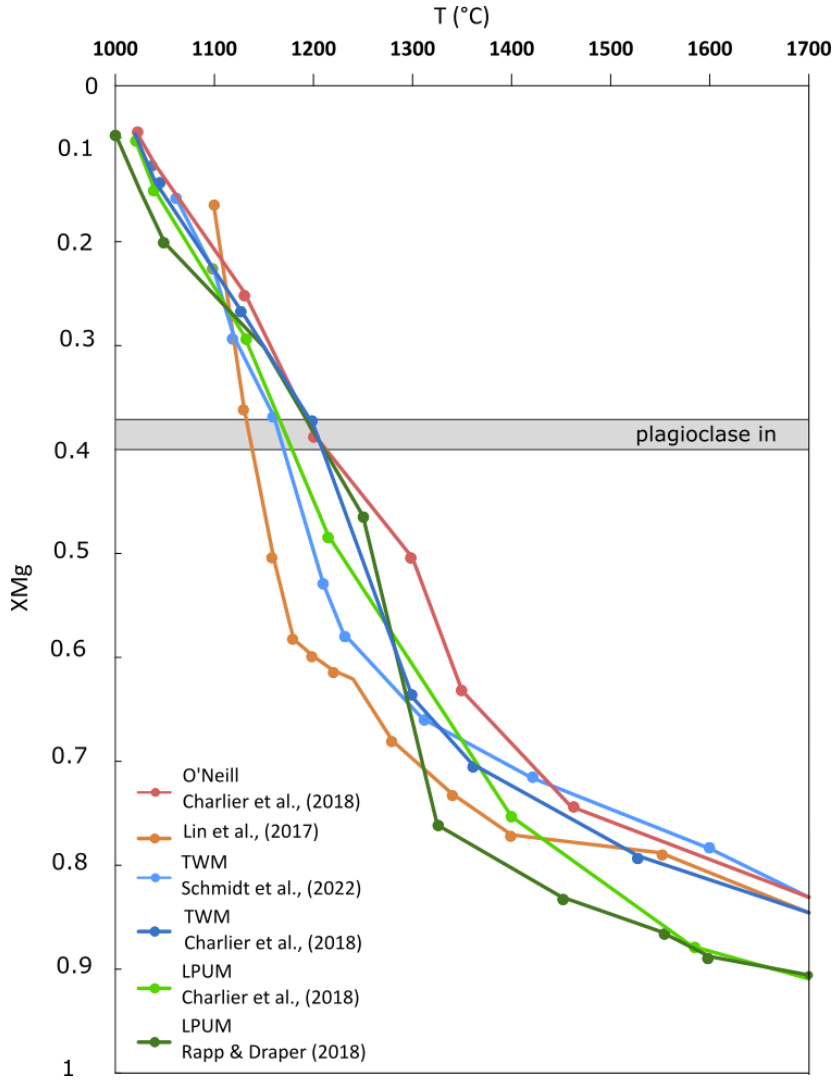

Opx ± Olivine ± Cr-spinel

Olivine ± Opx

Olivine

Johnson et al., (2020)
Longhi et al., (2003)
Snyder et al., (1992, 1995)

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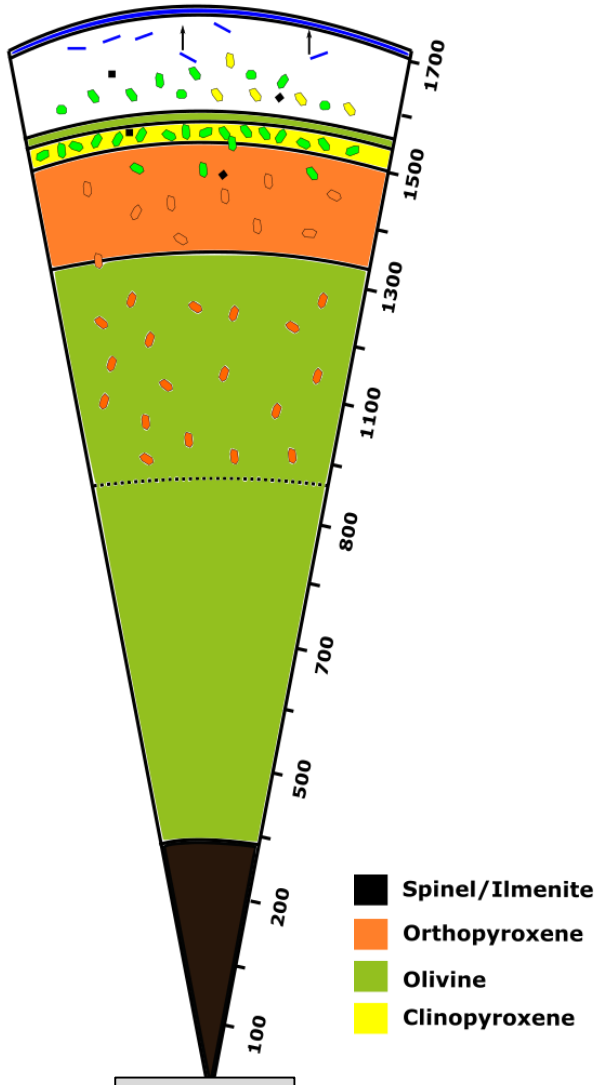
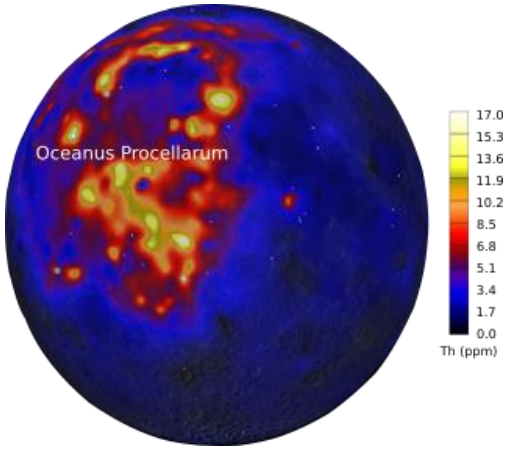
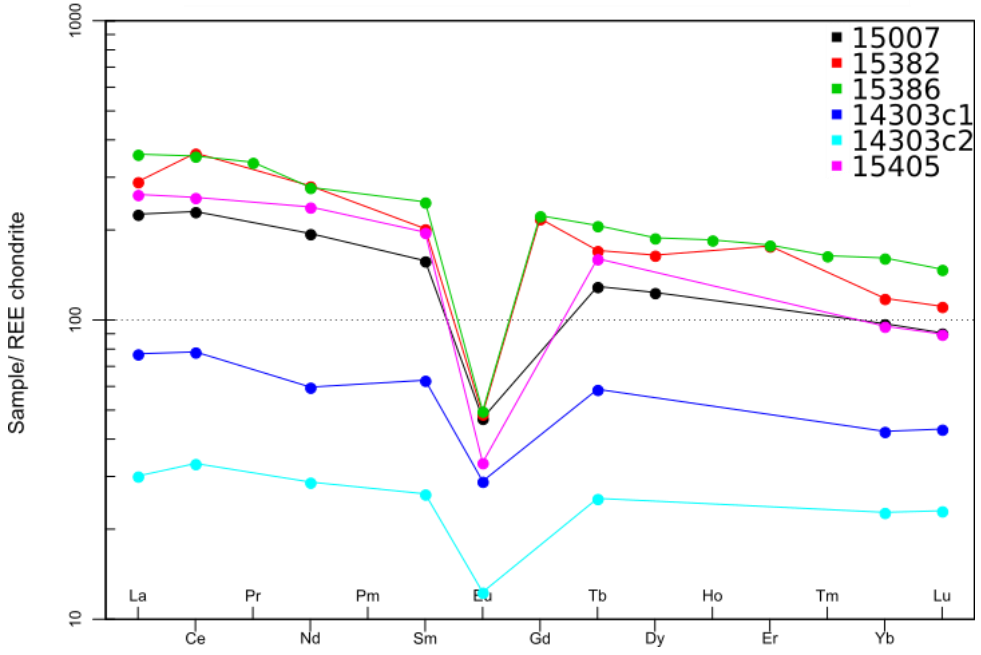
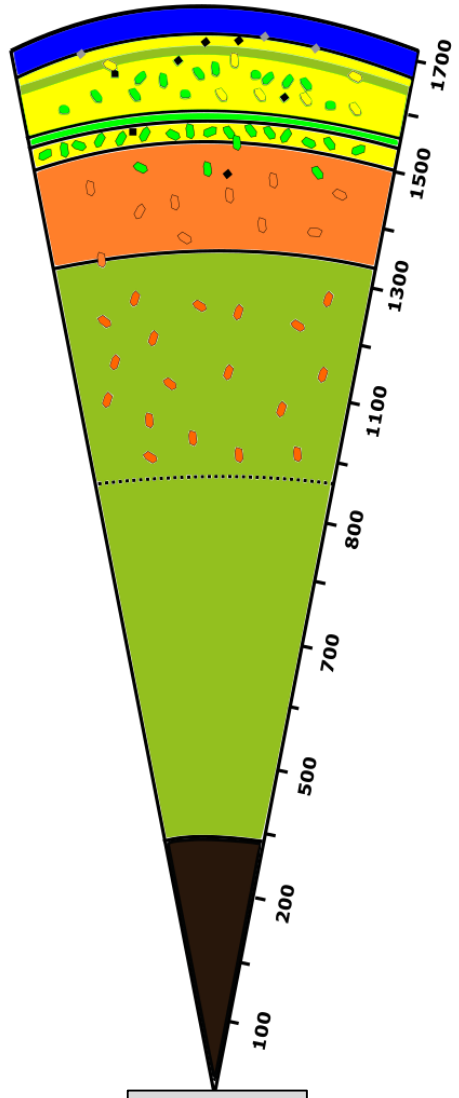


70%



Lawrence et. (2007)





99%

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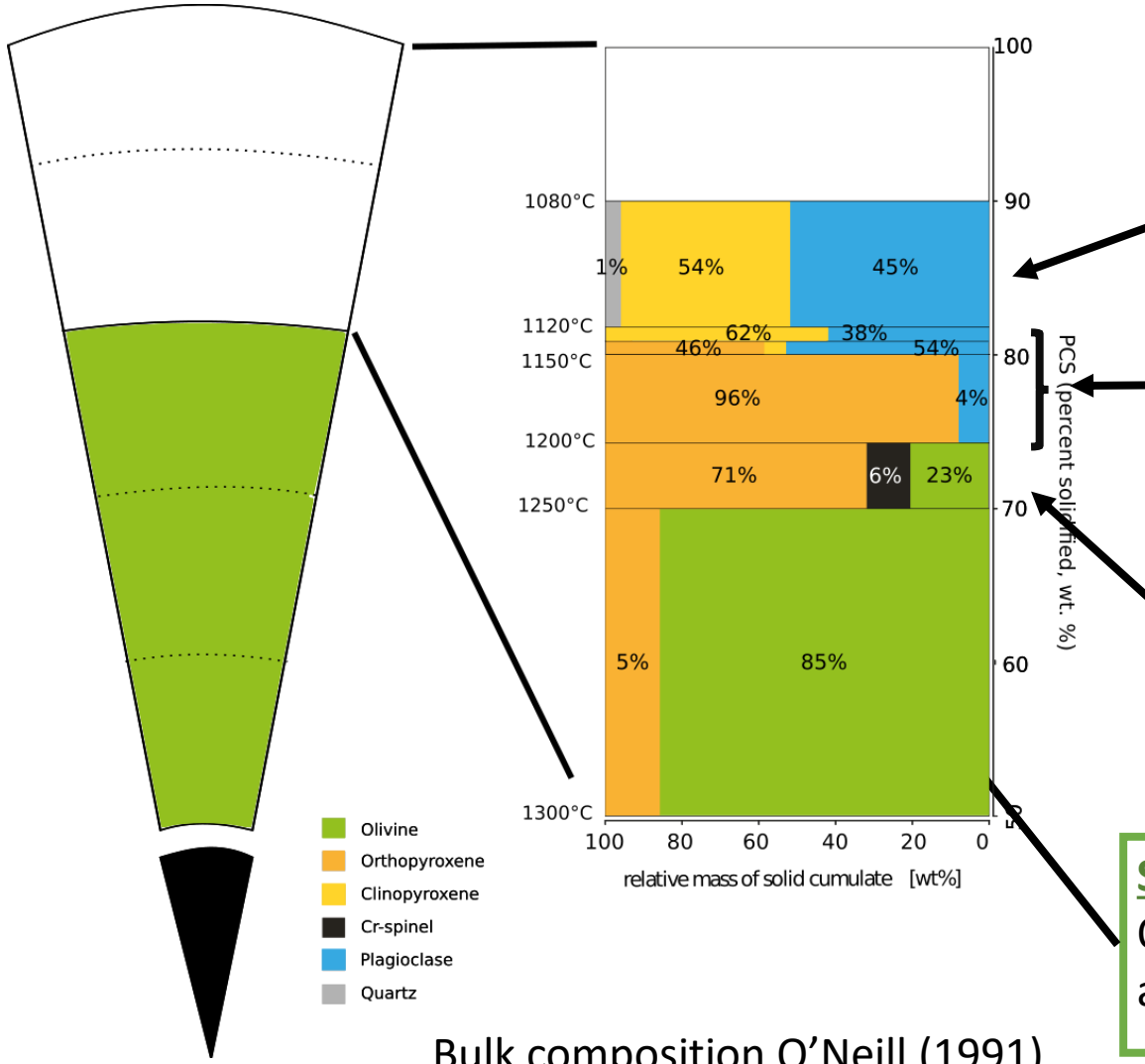
Results/Discussion

6 end load piston cylinder experiments in Ir capsules
Pressure range: 8-5 kbar



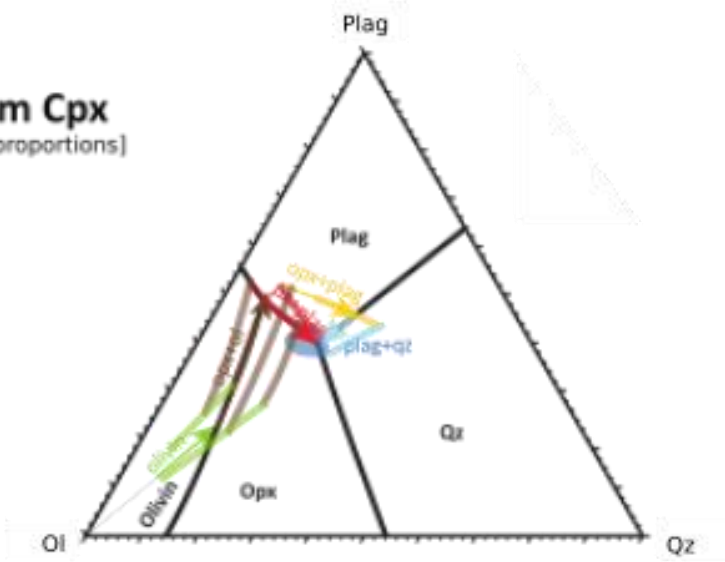
Stage 6
Cpx + plag + Qz

Stage 3-5
Opx ± Cpx + plag

Stage 2
Ol + Opx + magnesiochromite

Stage 1
Olivine with a small amount of Opx

from Cpx
[wt - proportions]



Bulk composition O'Neill (1991)

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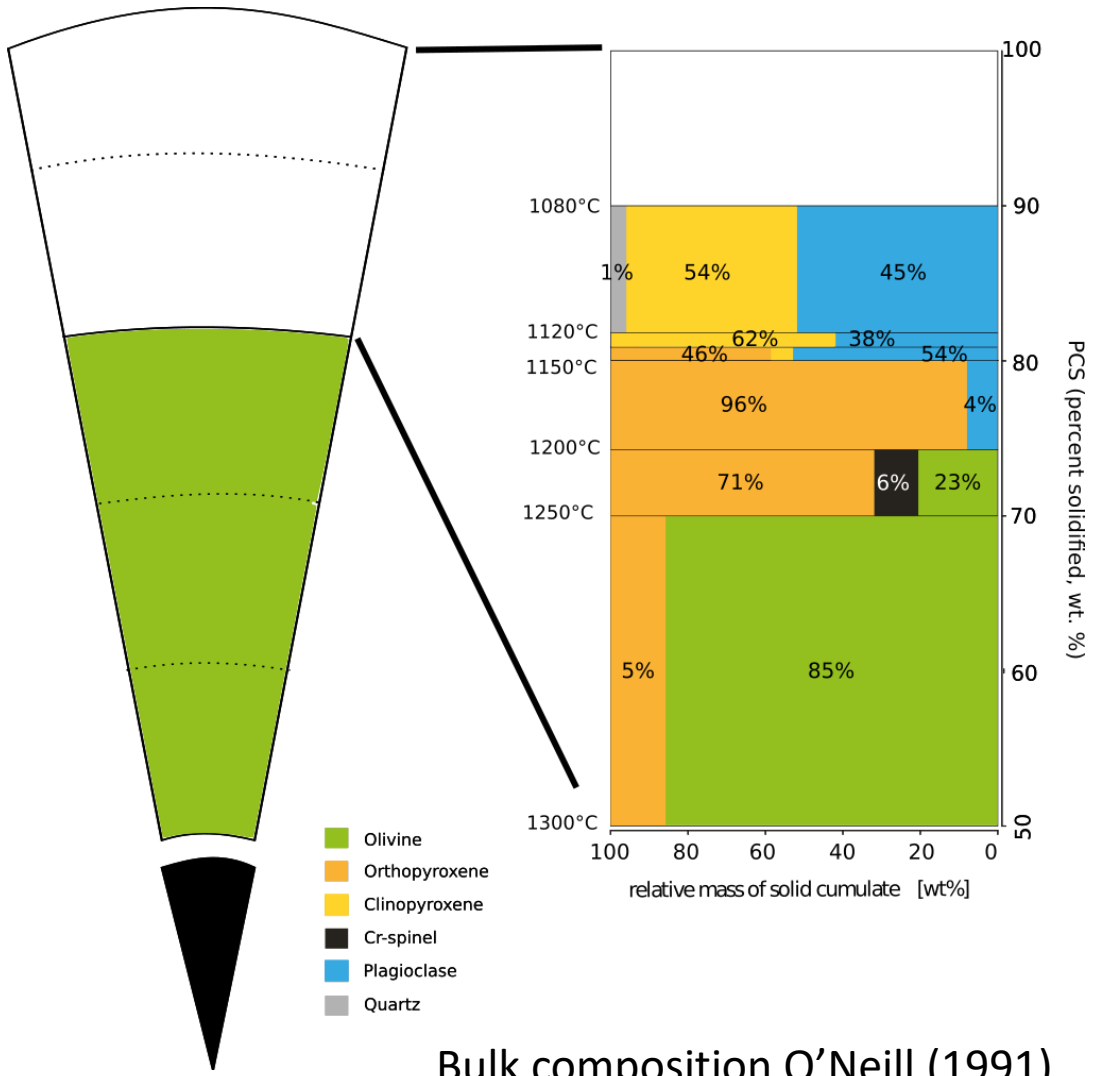
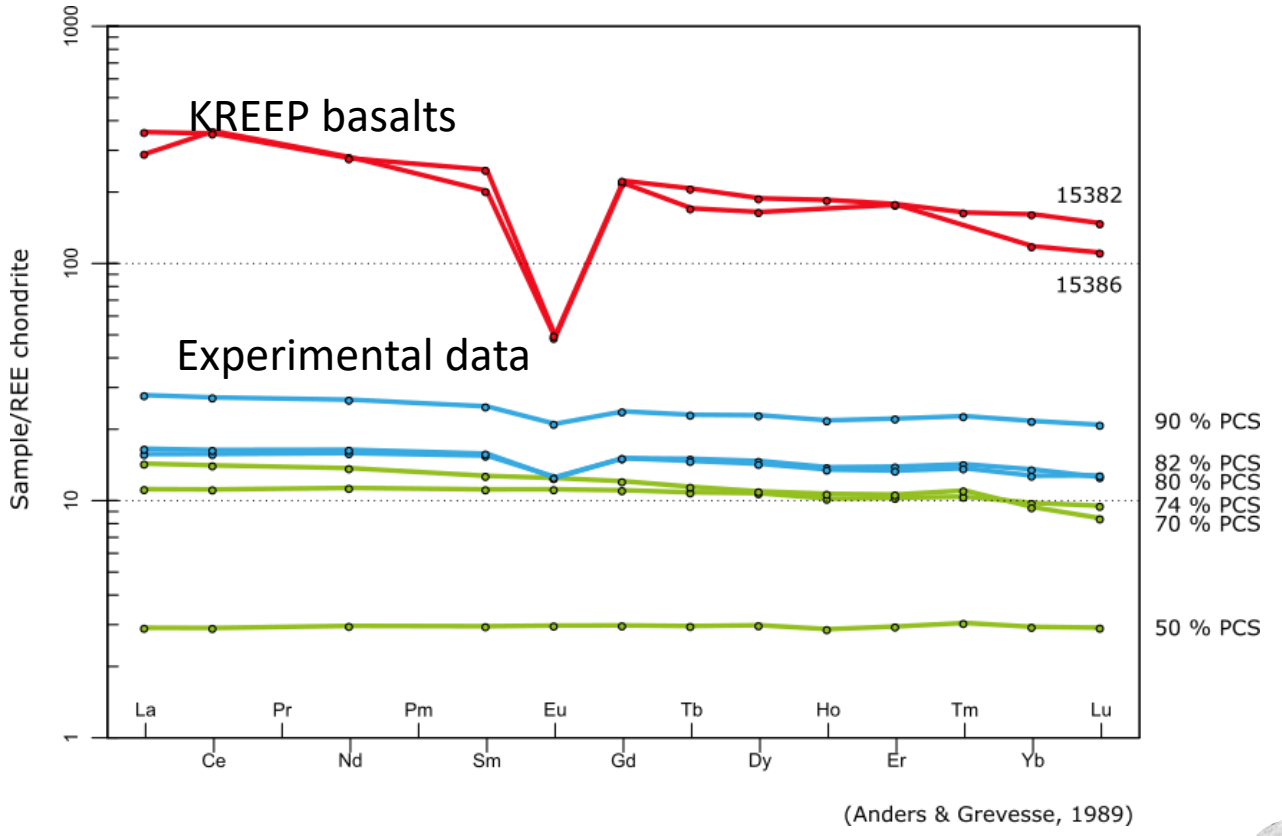
Results/Discussion



Bulk composition O'Neill (1991)

$$D_i = D_0 \exp\left(\frac{-4\pi ENa\left(\frac{r0}{2}(r_i - r_0)^2 + \frac{1}{3}(r_i - r_0)^3\right)}{RT}\right)$$

$$D_i^{\alpha/\beta} = \frac{C_i^{\alpha}}{C_i^{\beta}} \qquad \frac{C_L}{C_0} = F^{(D-1)}$$



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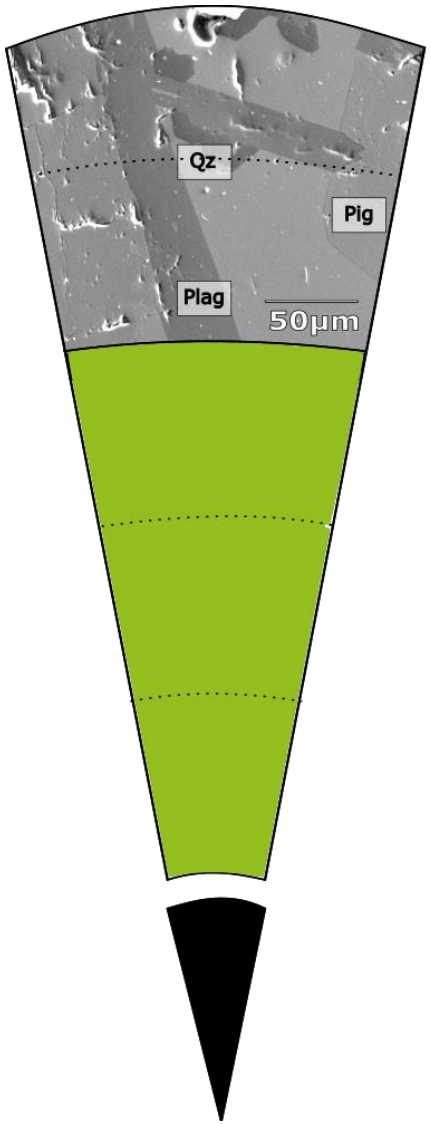
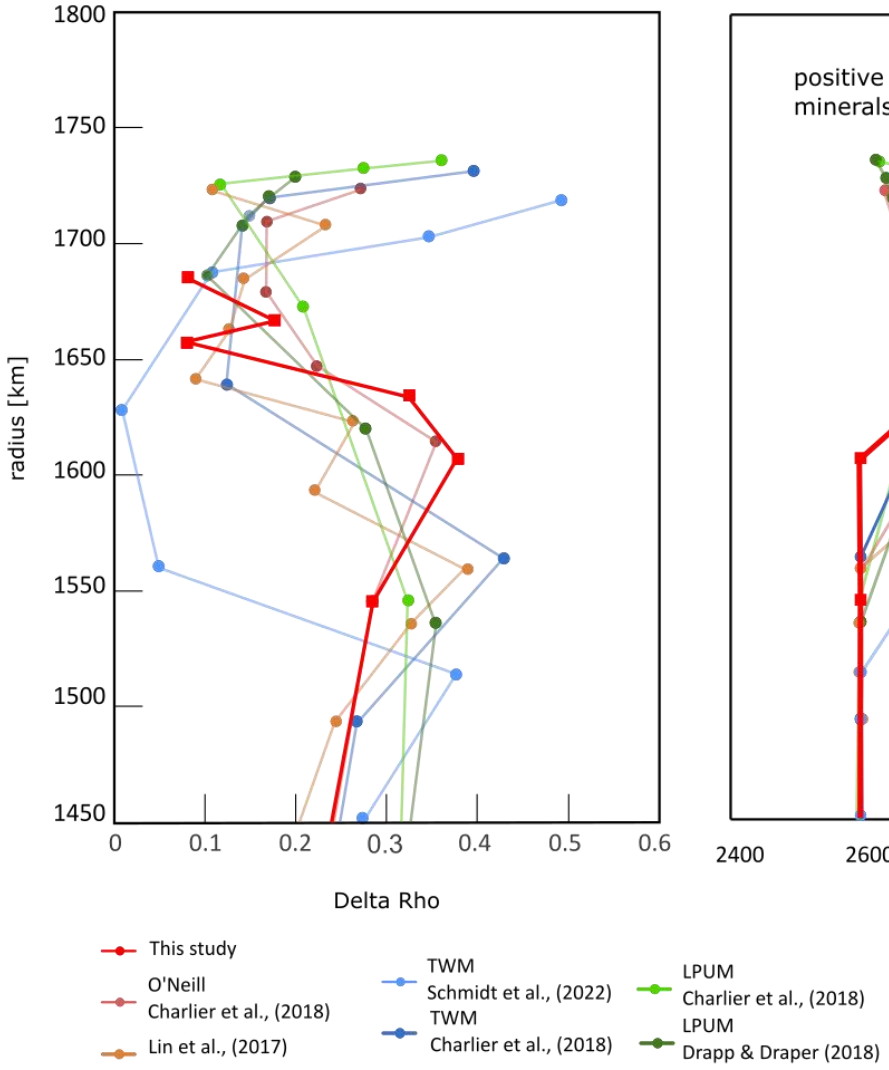
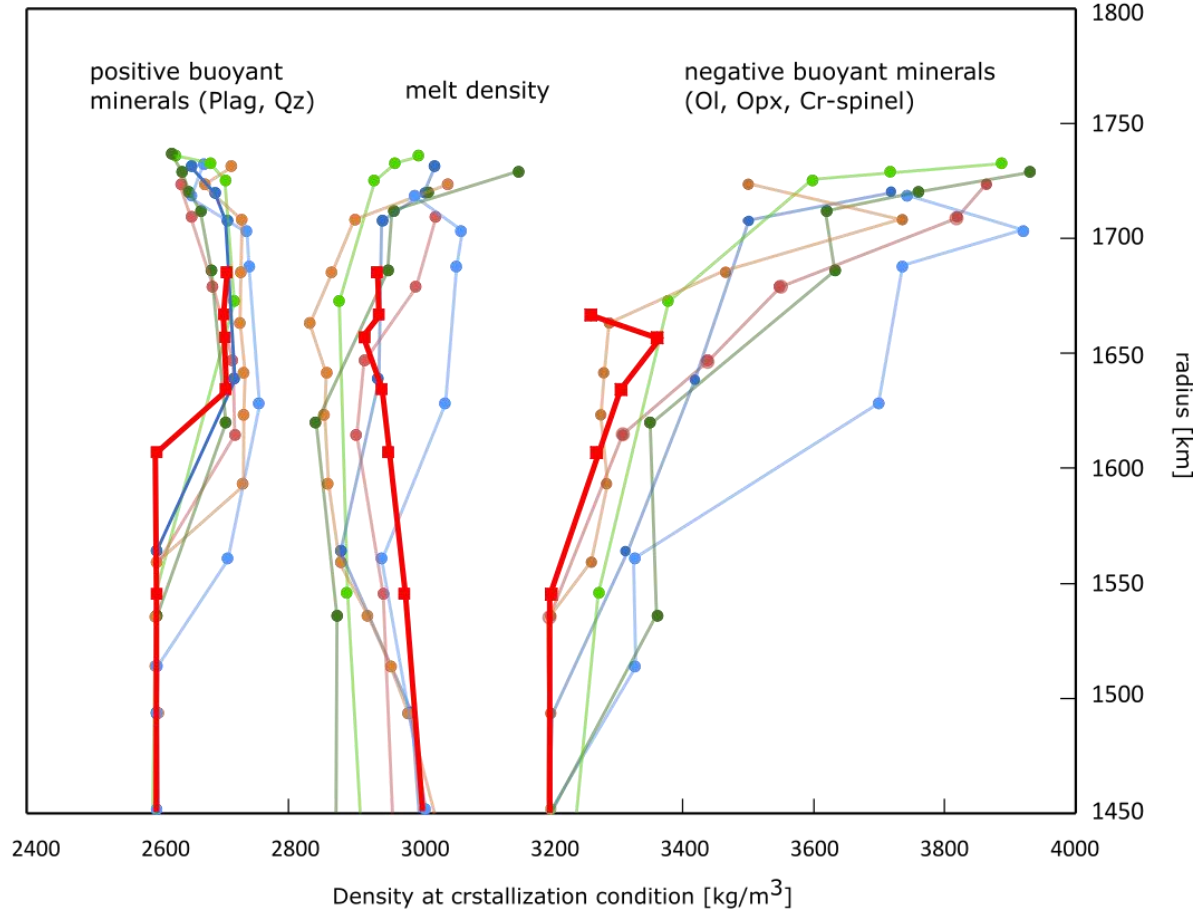
Results/Discussion







Mineral density was calculated using: Albers and Hacker (2016)

Melt density was calculated using: Lange and Carmichael (1990)

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Conclusions

The composition for the lunar mantle goes from **dunitic** to **harzburgitic** to **wehrlitic** to gabbroic mineral assemblages.

The KREEP component REE pattern could be reproduced giving ***substantial*** plagioclase crystallization and/or appropriate fO2 conditions.

The density models should take into account not only perfect fractionation of the crystals but also **clustering** and bulk aggregate densities.

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Thank you!

Any questions?

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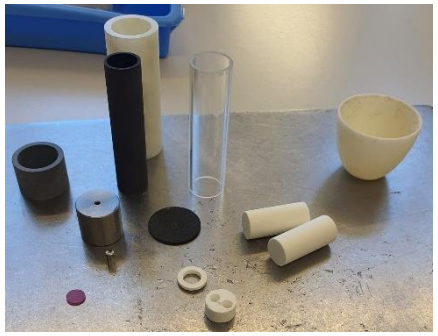
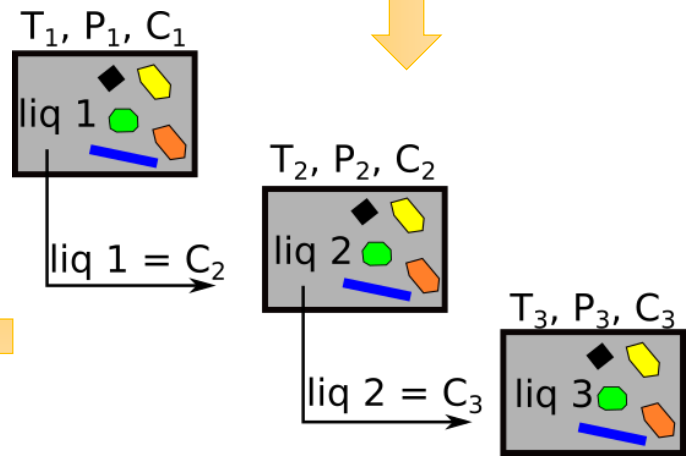
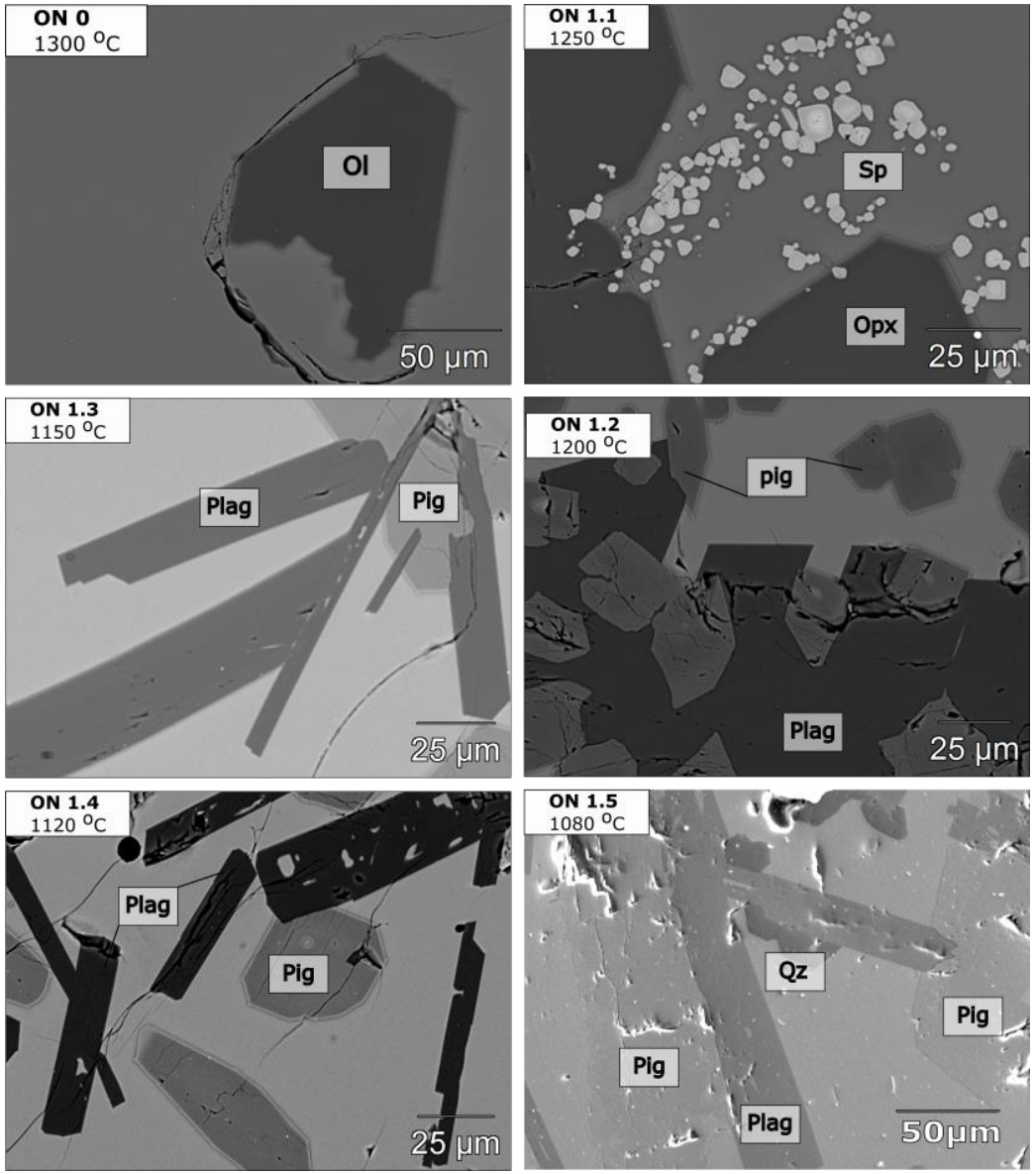
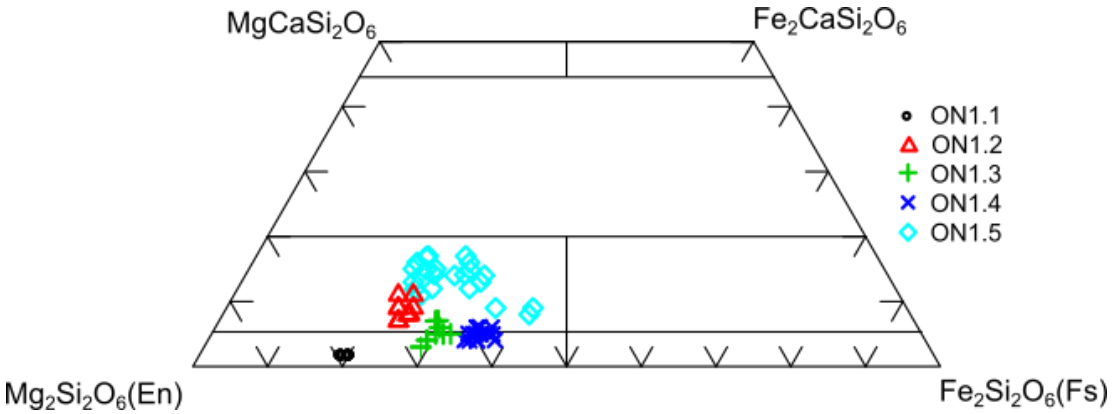
2000µm

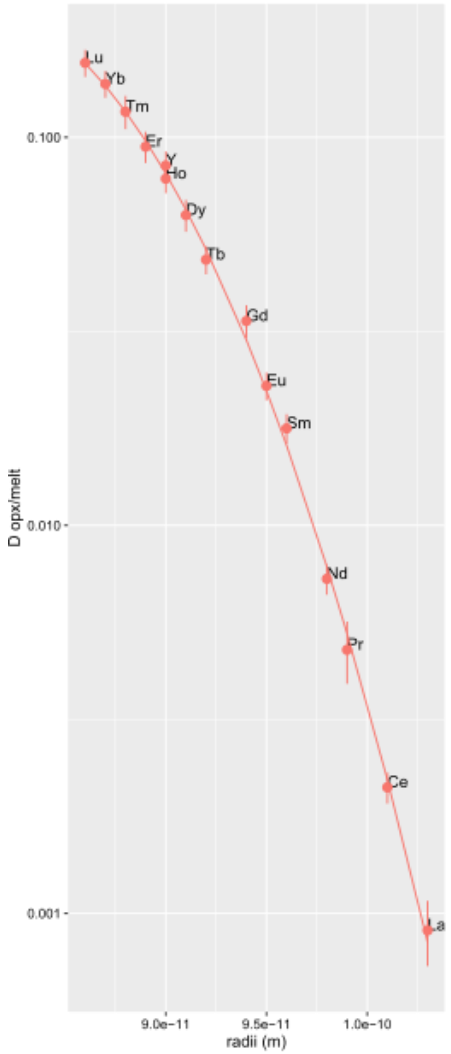
bulk [wt%]	O'N O'Neill 1991
SiO_2	44.5
TiO_2	0.17
Al_2O_3	3.90
Cr_2O_3	0.47
FeO	12.4
MnO	0.17
MgO	35.0
CaO	3.30
Na_2O	0.05
K_2O	0.004
P_2O_5	0.005
total	100.0
X_{Mg}	**0.835**
CaO/Al_2O_3	0.846



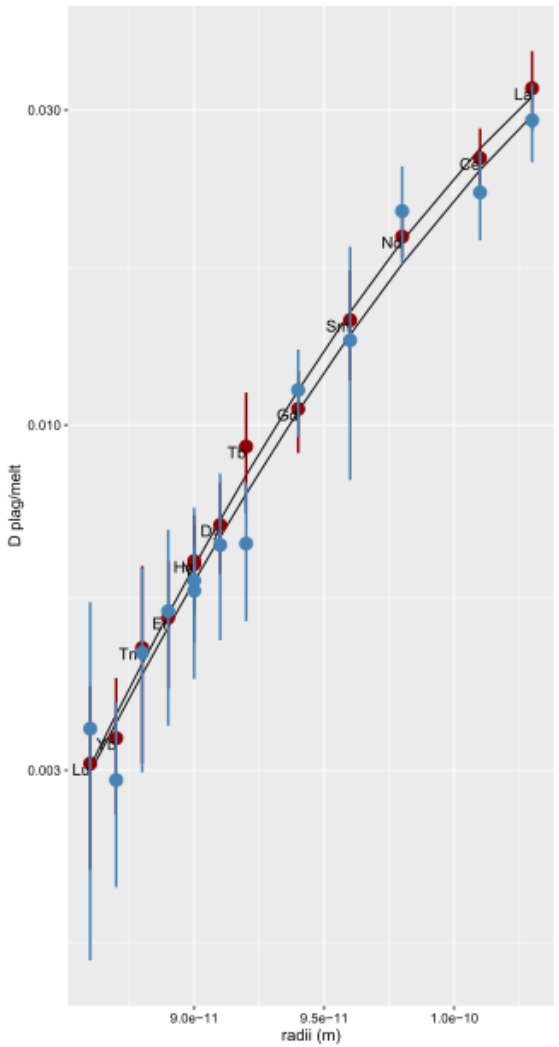



ON 0
1300 °C
Ol
50 µm
ON 1.1
1250 °C
Sp
Opx
25 µm
ON 1.3
1150 °C
Plag
Pig
25 µm
ON 1.2
1200 °C
pig
Plag
25 µm
ON 1.4
1120 °C
Plag
Pig
25 µm
ON 1.5
1080 °C
Qz
Pig
Pig
Plag
50µm

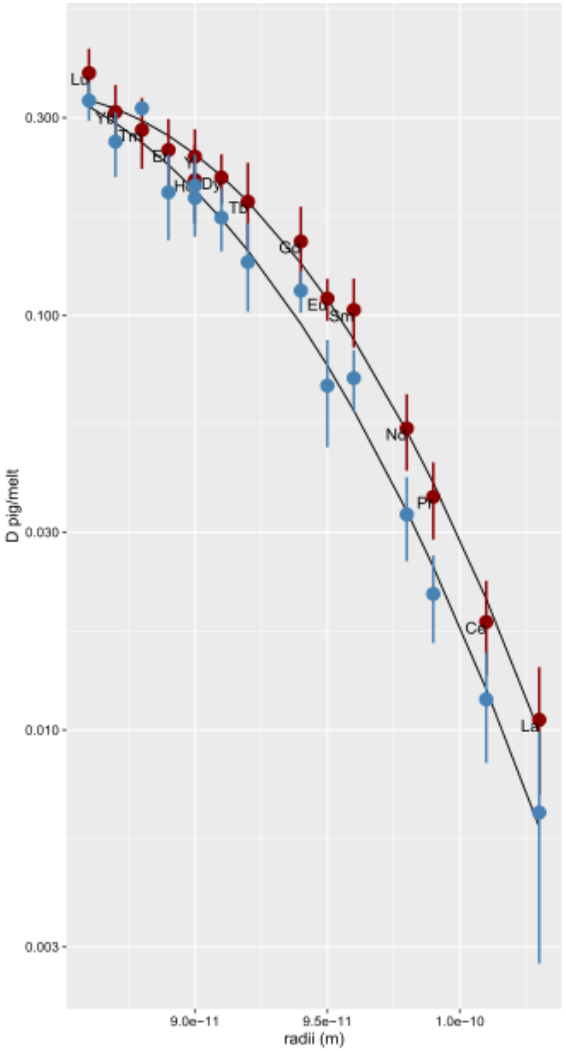

MgCaSi2O6
Fe2CaSi2O6
Mg2Si2O6(En)
Fe2Si2O6(Fs)
ON1.1
ON1.2
ON1.3
ON1.4
ON1.5



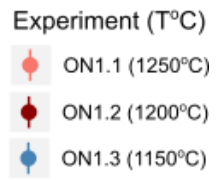
Orthopyroxene	ON1.1
	$D0=2.37*10^{-1}$
	$r0=7.89*10^{-11}$
	$E=3.356*10^{11}$



Plagioclase	ON1.2	ON1.3
	$D0=4.89*10^{-2}$	$D0=5.23*10^{-2}$
	$r0=1.13*10^{-10}$	$r0=1.55*10^{-10}$
	$E=1.27*10^{11}$	$E=1.11*10^{11}$



Pigeonite	ON1.2	ON1.3
	$D0=3.46*10^{-1}$	$D0=4.01*10^{-1}$
	$r0=8.36*10^{-11}$	$r0=8.04*10^{-11}$
	$E=3.21*10^{11}$	$E=2.83*10^{11}$



$$D_i = D_0 \exp\left(\frac{-4\pi E N a\left(\frac{r0}{2}(r_i - r_0)^2 + \frac{1}{3}(r_i - r_0)^3\right)}{RT}\right)$$

D_i - measurements to be fitted,
D_0, r_0, E -> fitting parameters
π, r_i, R, T, Na -> known or constant

The lattice strain model (Blundy & Wood 1994) enables assessment of the quality of fit of the experimentally determined D values.

Useful for highly incompatible elements such as La (very low concentration in px and plag)