Genesis of chromitite ore bodies in ophiolites: problems and (possible) solutions

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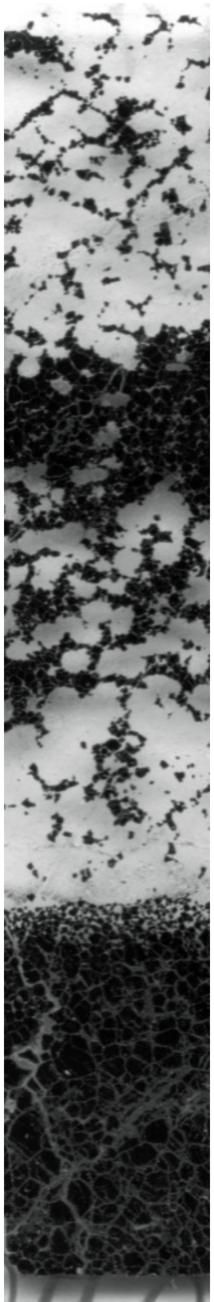
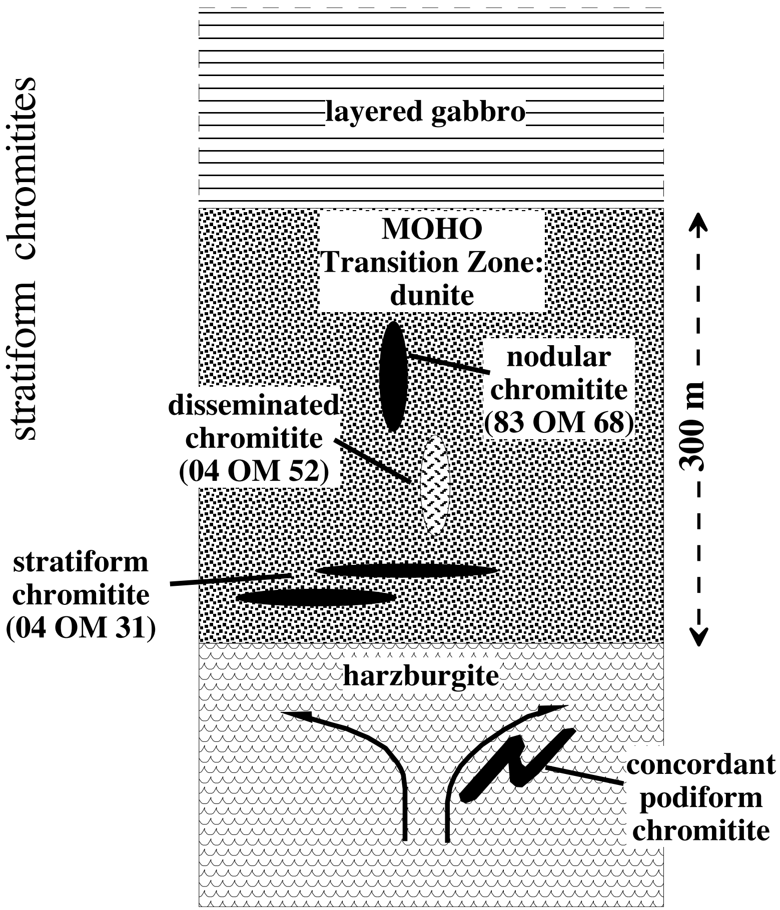
Ecole Thématique du CNRS, INSU, Toulouse, France, 2016

Photo by Nail Zagrtdenov, 2015

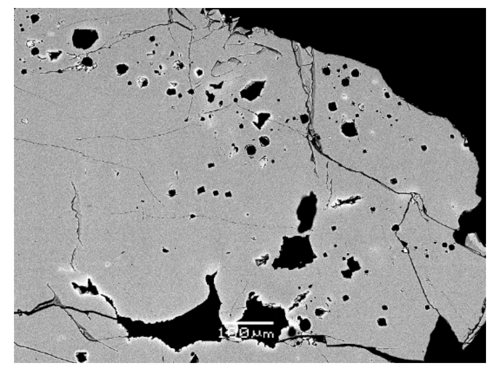
MOHO transition zone (MTZ) of the Oman ophiolite

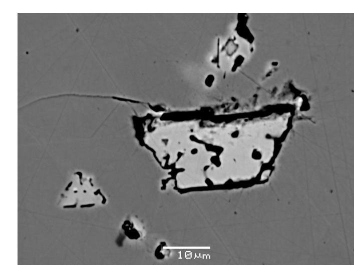


stratiform chromitites



Nodular chromitites





(after Borisova et al., *J. Petrology 2012*)

Chromium geochemistry: siderophile

Cr III – Cr VI
Cr - O

Cr = 35 – 350 ppm in the crust

× 1000 – 10 000

Cr III
Cr - O

Cr_2O_3 ≈ 22 – 59 wt.% in the chromitite ores
Cr ≈ 150 000 – 400 000 ppm

(Salih, 1999)

Cr II

Cr ≈ 1000 - 3000 ppm in the mantle

Cr 0 – Cr II
Cr - Fe

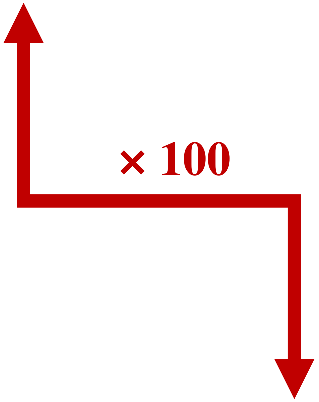
Cr ≈ 60% of the Earth's total Cr in the core

(e.g., Bonnand et al., 2016)

Chromium geochemistry: siderophile

Cr_2O_3 ≈ 22 – 59 wt.% in the chromitite ores
Cr ≈ 150 000 – 400 000 ppm

(Salih, 1999)



Cr ≈ 1000 - 3000 ppm in the mantle

Photo by Nail Zagrtdenov, 2015

$Number_{Models} \approx Number_{Scientists} \times X$

Three problems of the chromitite genesis

(I) Source of chromium for the chromite crystallization

(II) Environment of the chromite and olivine growth

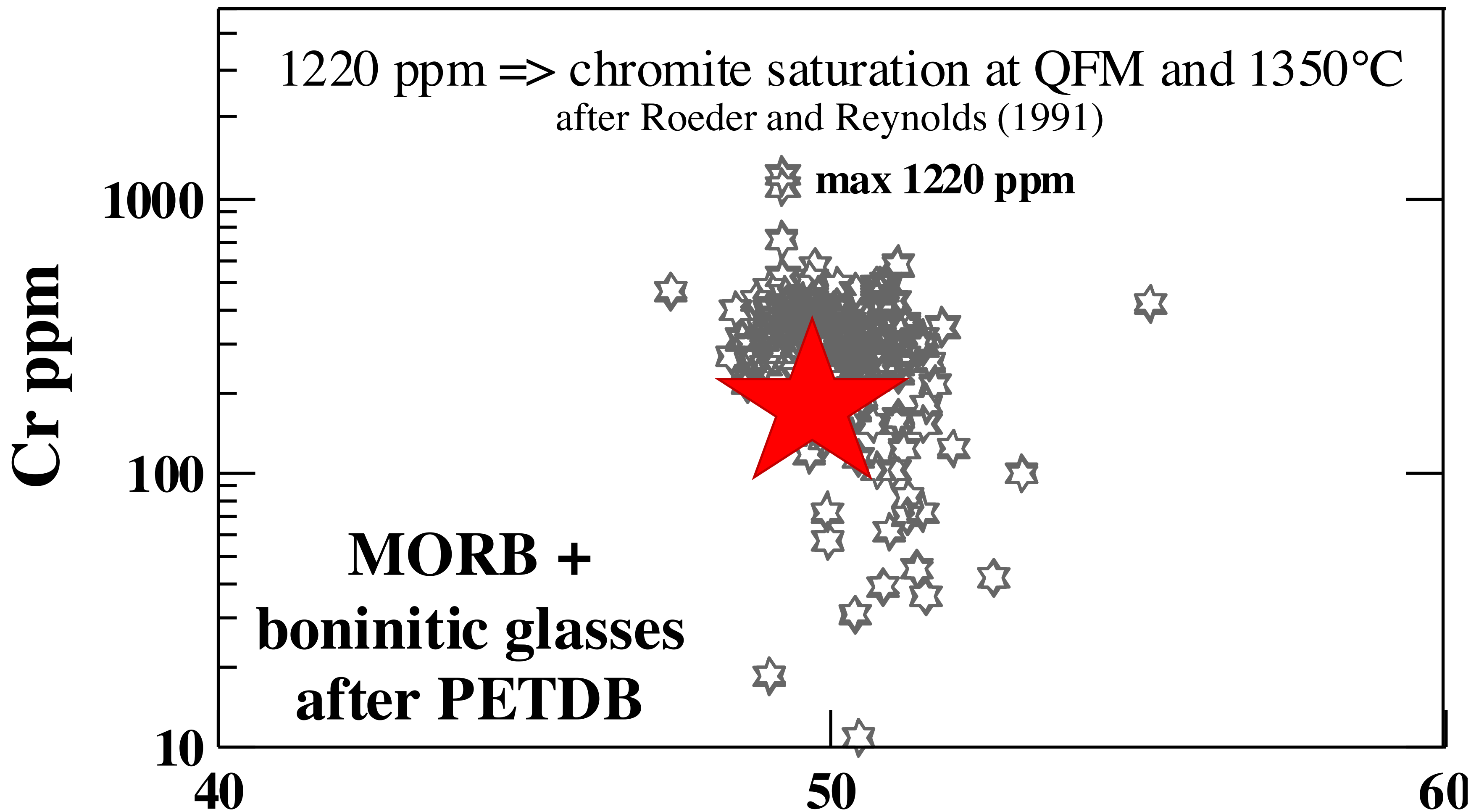
(III) Chromitite genesis as the consequence of chromite concentration

(I)

Source of chromium for the chromite crystallisation

Photo by Nail Zagrtdenov, 2015

Principal source of Cr for the chromitite formation: Cr extraction from mafic melts?



$Fe^{2+}Cr_2O_4$

Principal source of Cr for the chromitite formation

MORB melt:
~ 100 ppm of Cr

V ~ 10^4 km^3
M ~ 10^7 Mt of melt

MOHO chromitites:
~ 400,000 ppm of Cr

V ~ 10 km^3
~ 10^3 Mt of Cr
~ 10^4 Mt of chromitite

Principal source of Cr for the chromitite formation

MORB melt:
~100 ppm of Cr

V ~ 10^4 km^3
M ~ 10^7 Mt of melt

×1000

MOHO chromitites:
~400,000 ppm of Cr

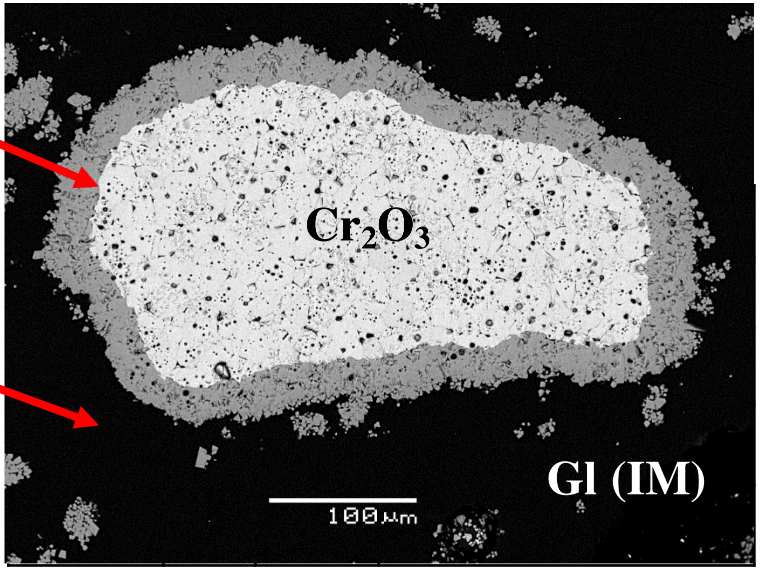
V ~ 10 km^3
~ 10^3 Mt of Cr
~ 10^4 Mt of chromitite

Reaction of Cr_2O_3 with haplobasalt at high temperature (1450°C) and QFM

(Zagrtdenov et al., in preparation)

$MgCr_2O_4$ - magnesiochromite or picrochromite

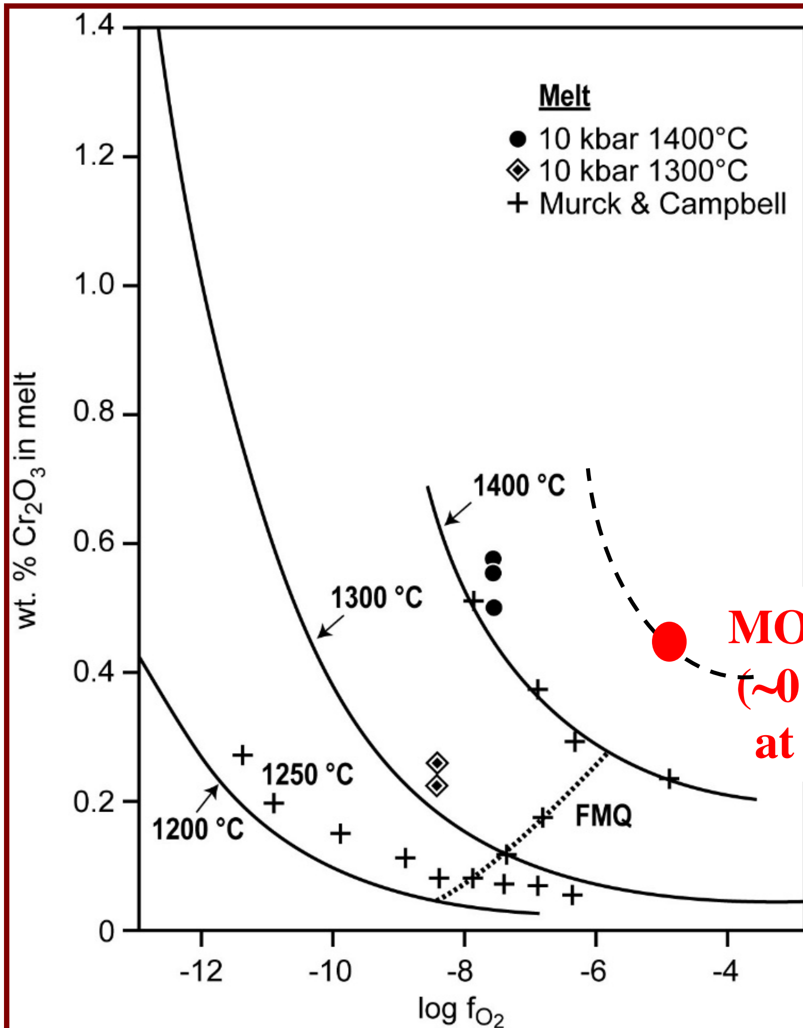
Cr = 7000 ppm
in the interface melt (IM)



$$Cr_2O_3 + L^{\text{haplobasalt}} = MgCr_2O_4 + L'^{\text{Interface melt}}$$

Trigger of chromite crystallization: interface melt at chromite saturation

f_{O2} < QFM
Cr II



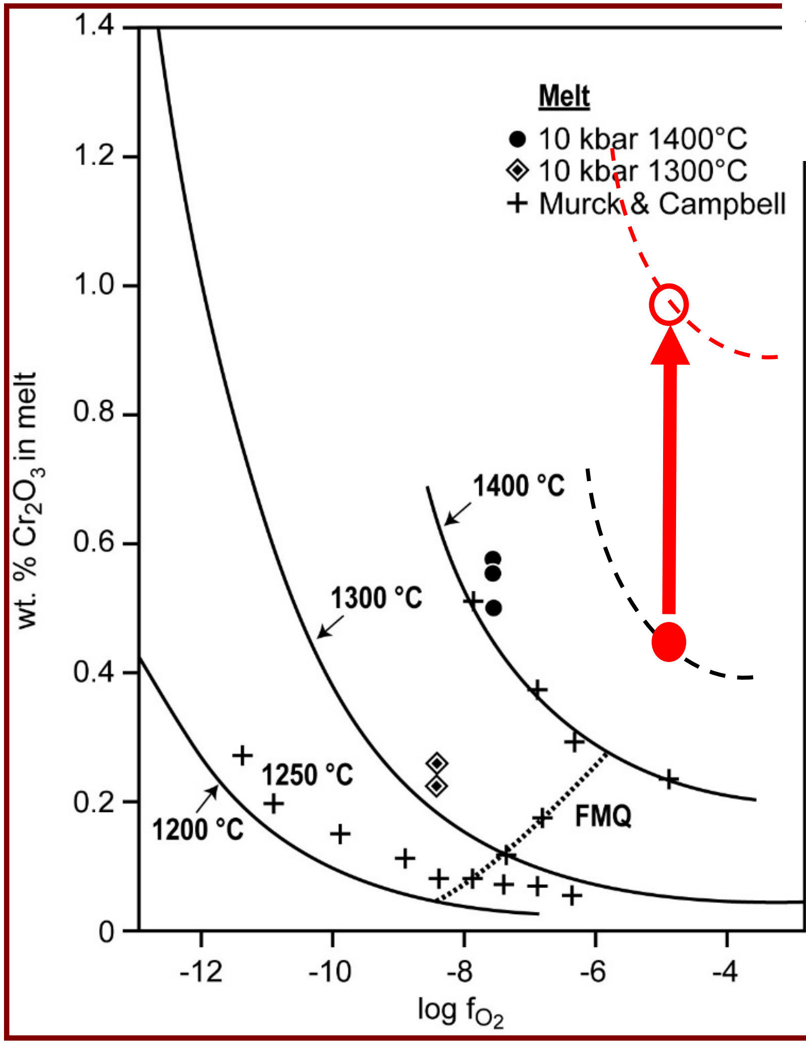
f_{O2} = QFM
Cr III

MORB: 3000 ppm (~0.4 wt.% Cr_2O_3) at 1450°C, QFM

after Roeder and Reynolds (1991) and our new experimental data

$Fe^{2+}Cr_2O_4$

Trigger of chromite crystallization: interface melt at chromite saturation



Interface melt: 7000 ppm (~1 wt.% Cr_2O_3) at 1450°C, QFM

f_{O2} < QFM
Cr II

f_{O2} = QFM
Cr III

after Roeder and Reynolds (1991) and our new experimental data

$MgCr_2O_4$

Principal source of Cr for the chromitite formation

Interface melt:
~7000 ppm of Cr

V ~ 10^3 km^3
M ~ 10^6 Mt of melt

MOHO chromitites:
~400,000 ppm of Cr

V ~ 10 km^3
~ 10^3 Mt of Cr
~ 10^4 Mt of chromitite

Principal source of Cr for the chromitite formation

Interface melt:
~7000 ppm of Cr

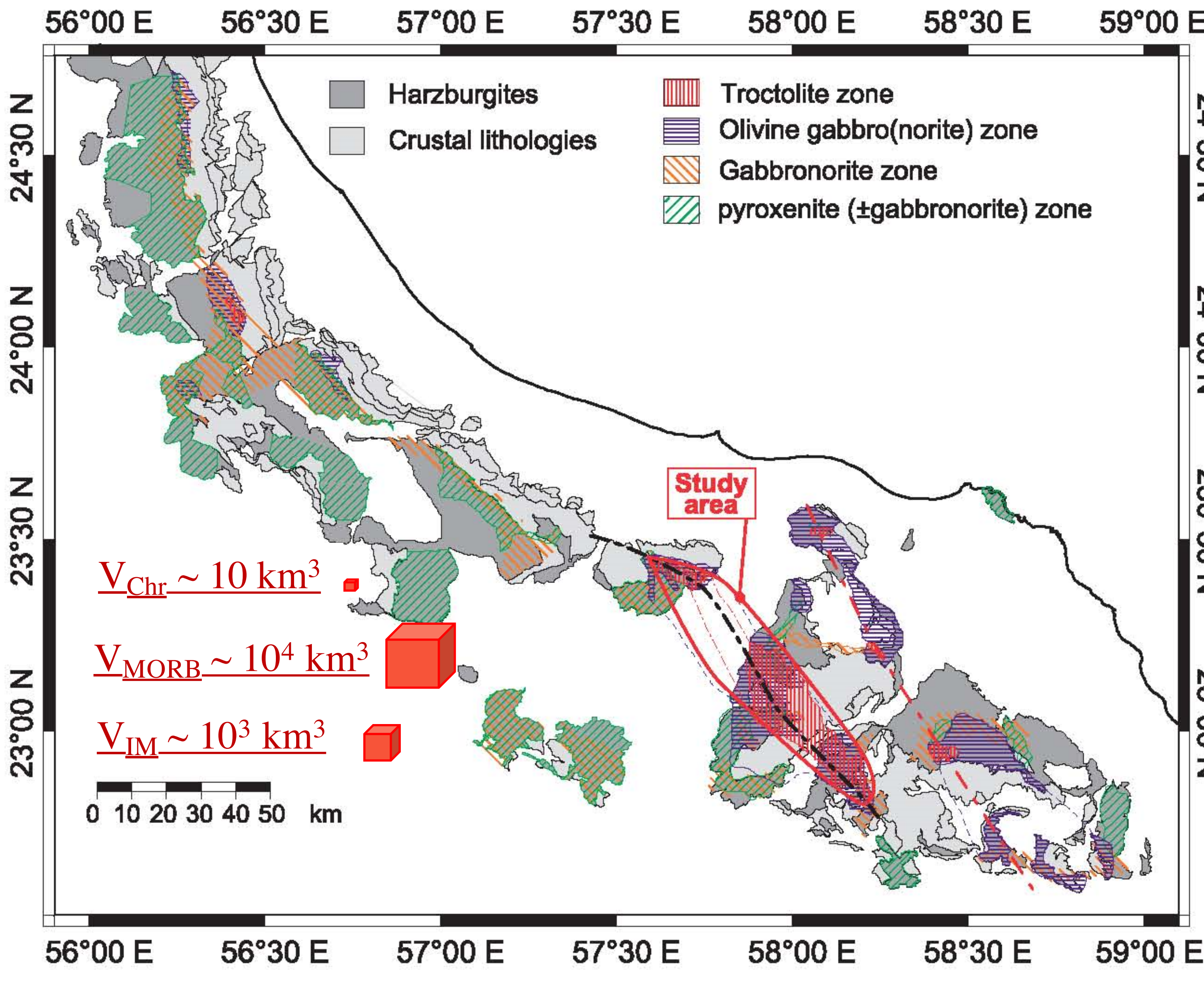
V ~ 10^3 km^3
M ~ 10^6 Mt of melt

×100

MOHO chromitites:
~400,000 ppm of Cr

V ~ 10 km^3
~ 10^3 Mt of Cr
~ 10^4 Mt of chromitite

Study area of the Oman ophiolite



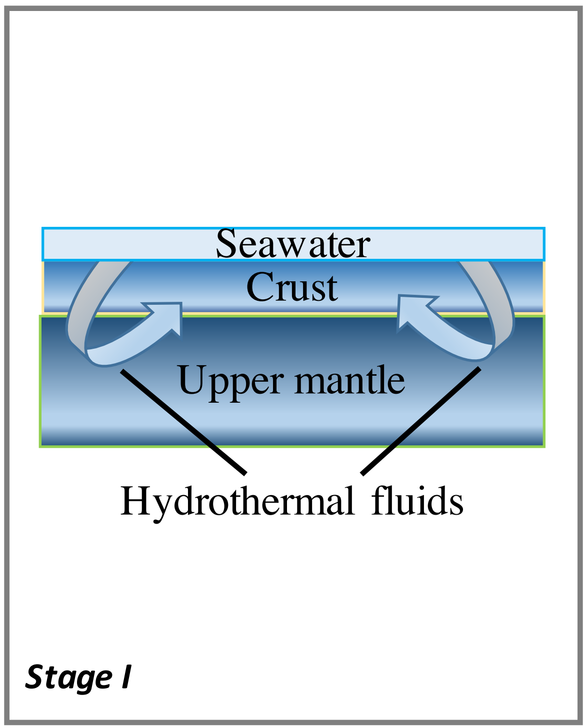
(after Borisova et al., *J. Petrology 2012*)

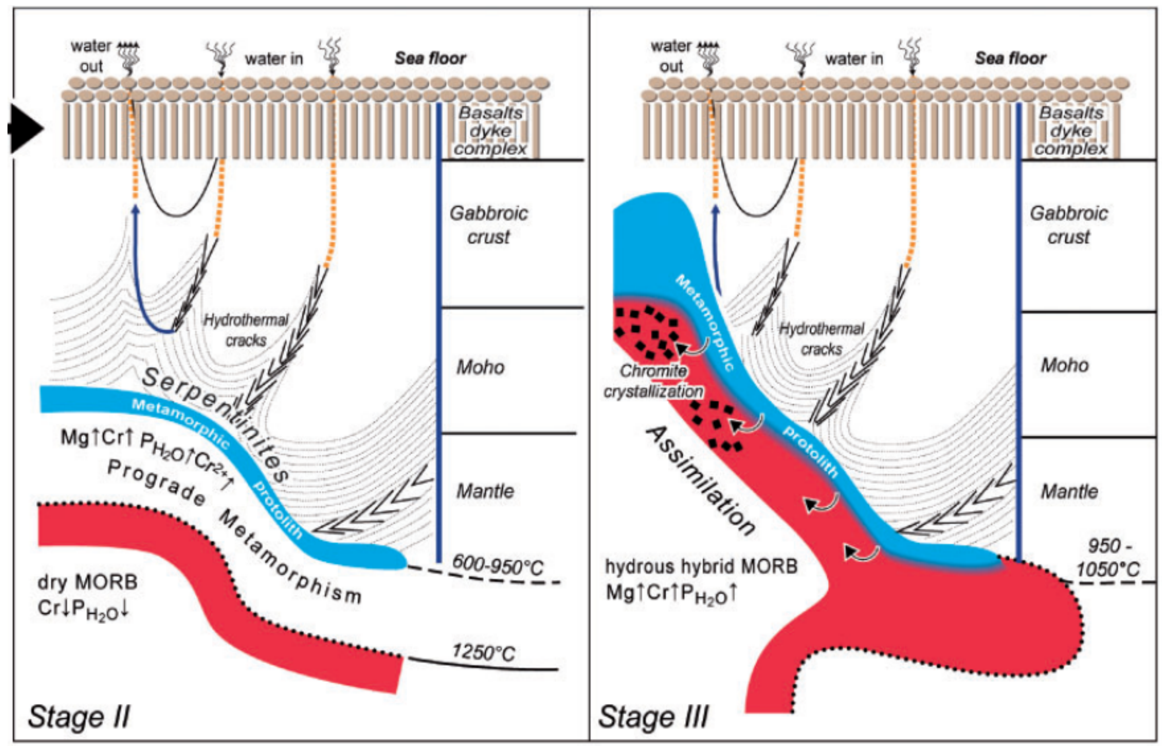
(II)

Environment of the chromite and olivine growth

Photo by Nail Zagrtdenov, 2015

Model of lithospheric assimilation by magma at the MOHO (Borisova et al., *J. Petrology 2012*)



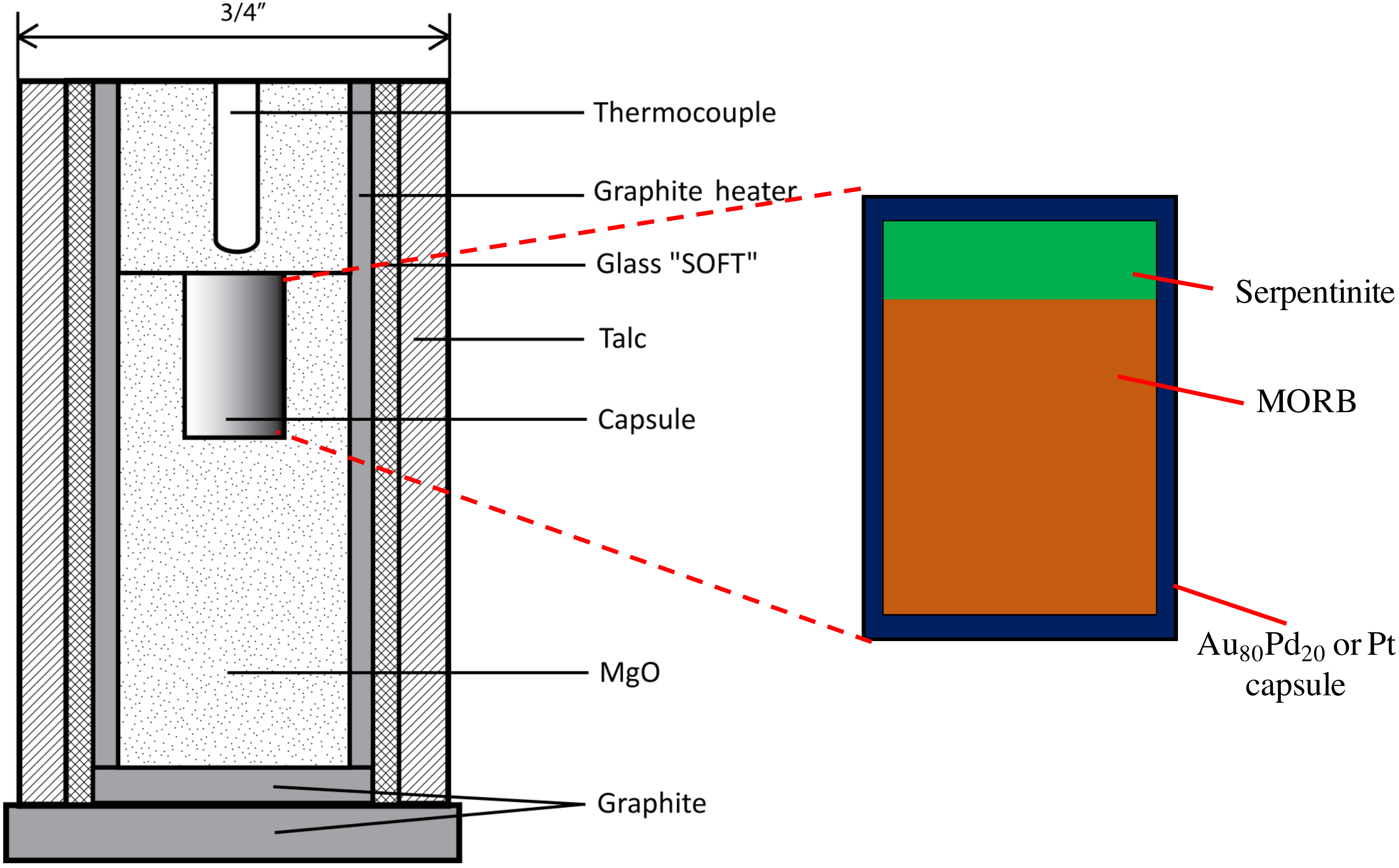


Retrograde metamorphism (serpentinization)

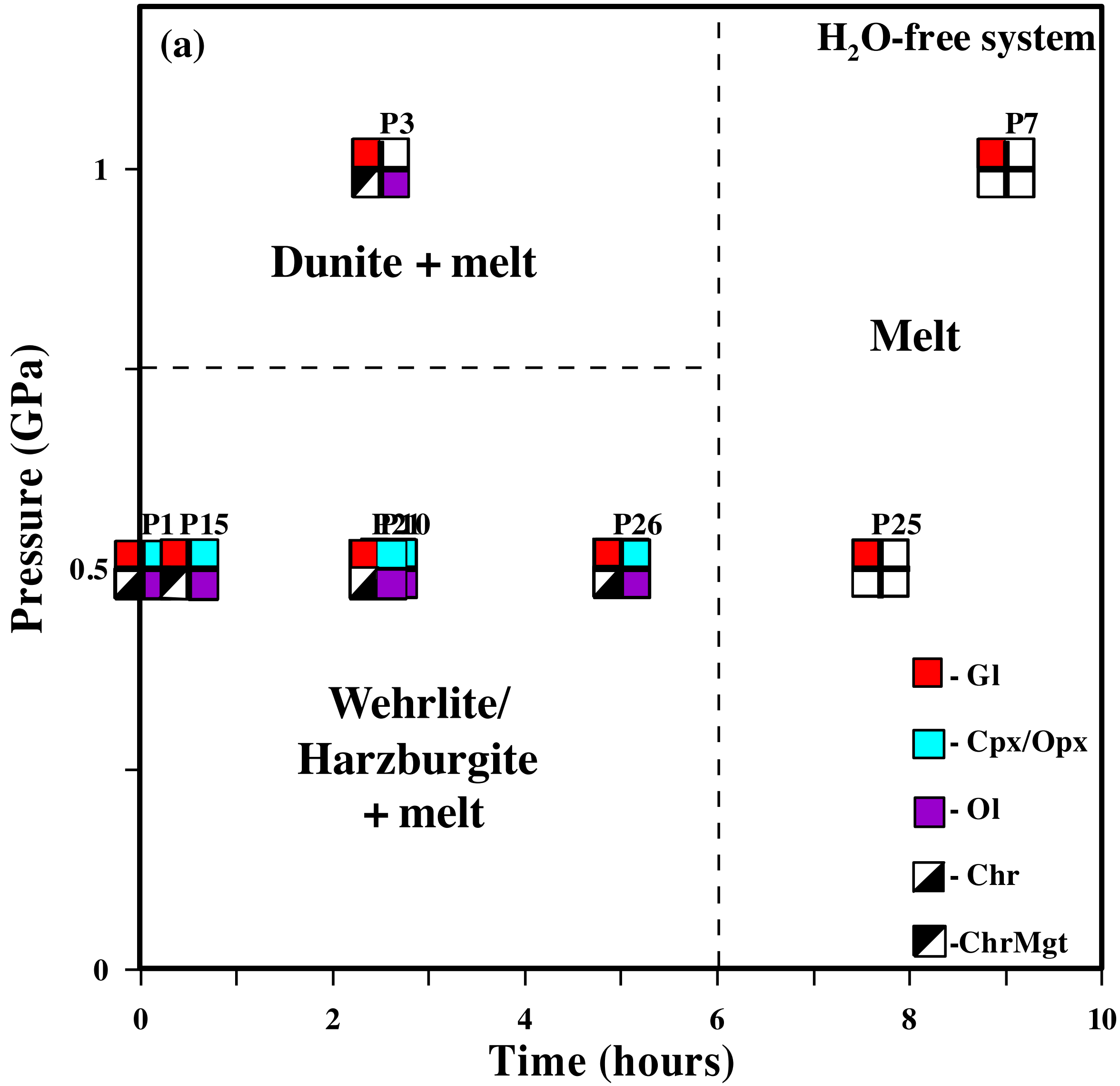
Prograde metamorphism

Assimilation by MORB

Piston-cylinder experiments of serpentinite – MORB interaction (Zagrtdenov et al., *EPSL* in preparation)

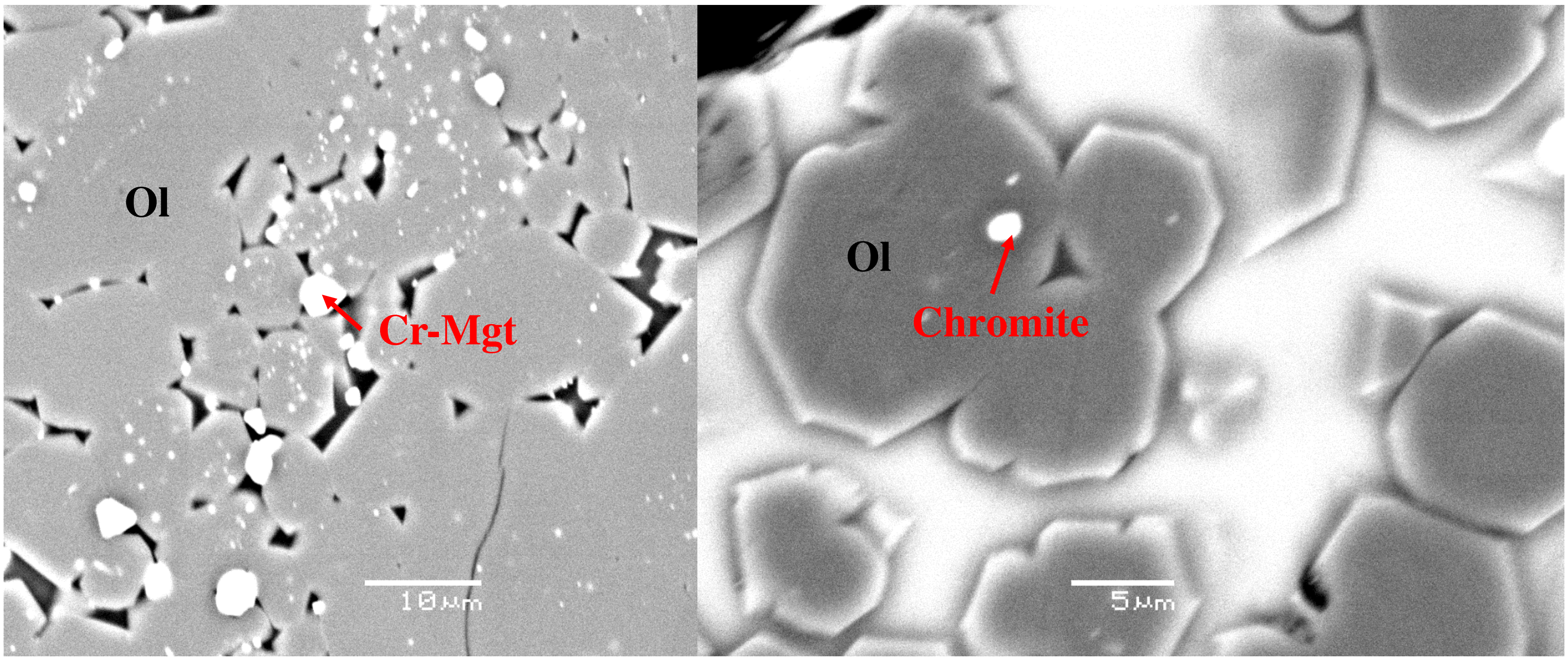


Phase diagram for experiments on reaction of serpentinite with MORB (Zagrtdenov et al., *EPSL* in preparation)



Experiment on serpentinite-MORB reaction at 1300°C and 0.5 GPa (Zagrtdenov et al., *EPSL* in preparation)

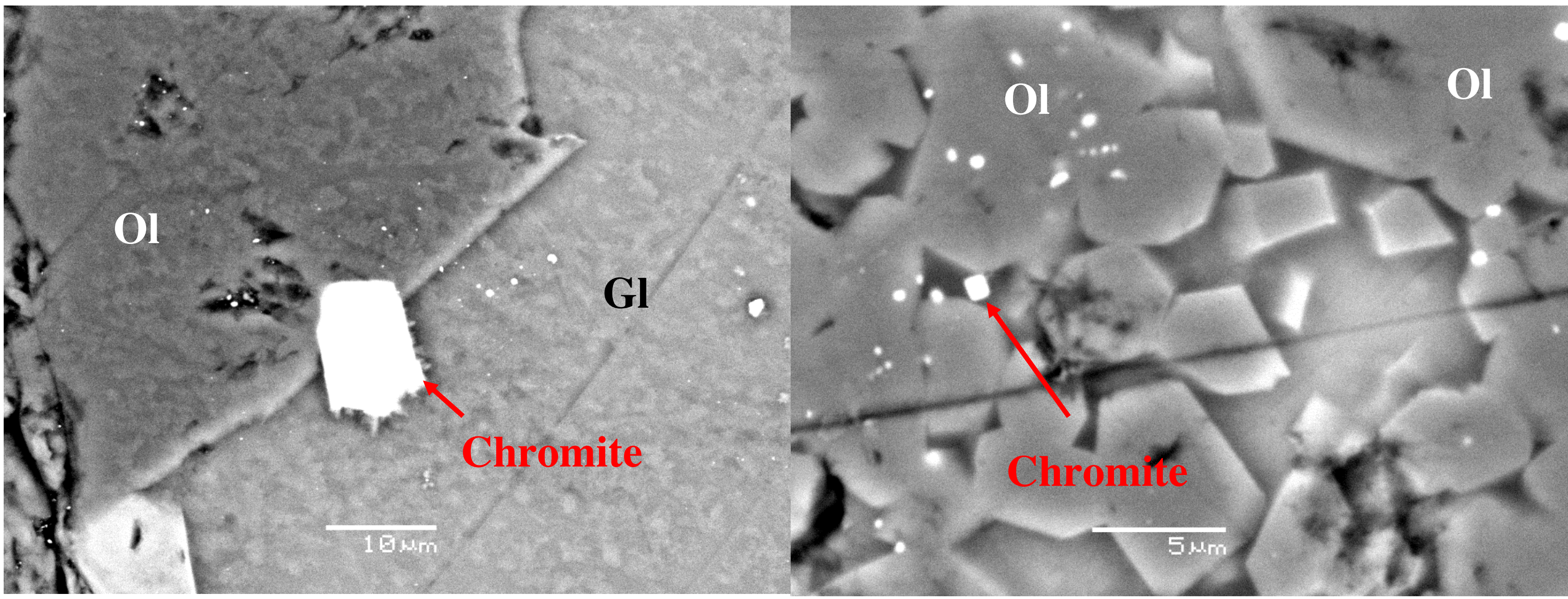
Experimental assemblage of Cr-Mgt/Chr+Ol±Opx±melt (P15, P26)



(1) Prograde metamorphic reaction: Mgt + Antigorite => Cr-Mgt/Chr + Olivine + H_2O

Experiment on serpentinite-MORB reaction at 1300°C and 0.5 GPa (Zagrtdenov et al., *EPSL* in preparation)

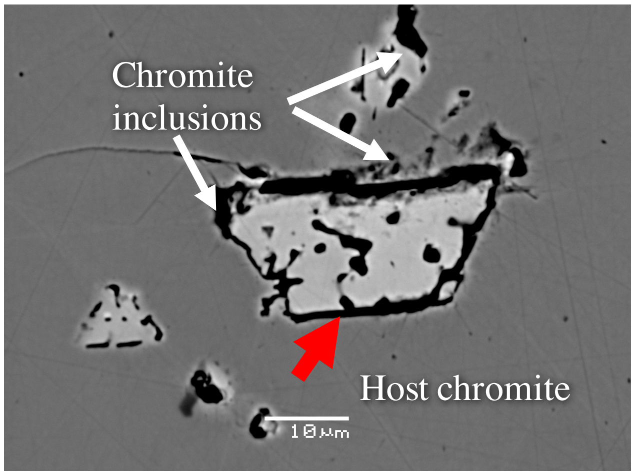
Experimental assemblage of Chr+Ol±Opx±Cpx+melt (P10, P18)

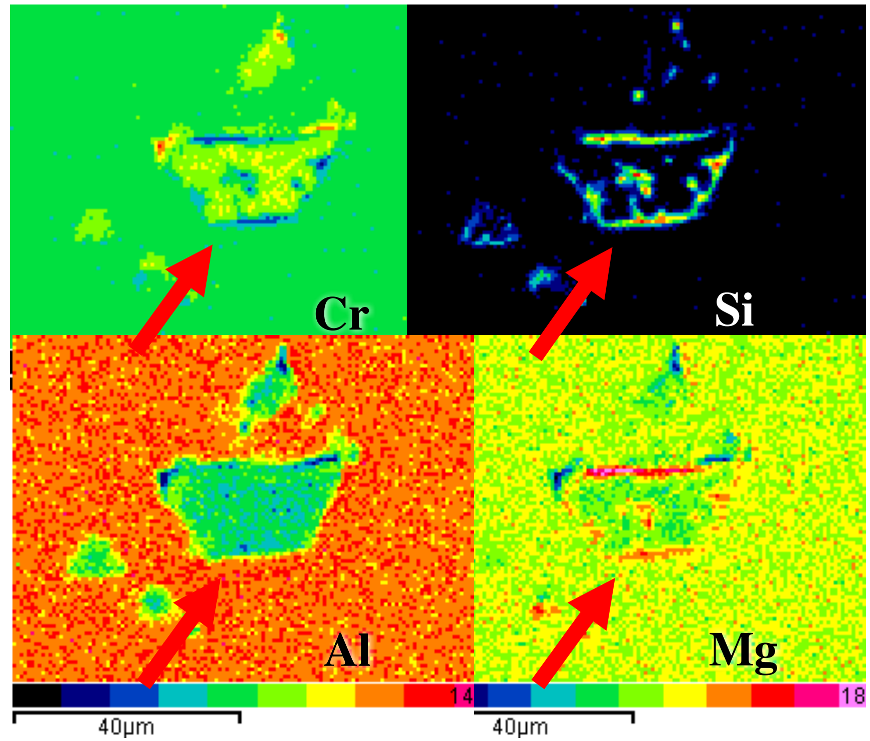


(2) Magmatic reaction: <u>Interface melt</u> => Chromite + Olivine ± Cpx + Hydrous melt

SiO_2-rich phase entrapped between the high-Cr-number chromite and the host chromite (the Oman ophiolites)

(JEOL JSM-6480LV, MSU, Moscow, Russia)





EMPA:
Al_2O_3 = 11.5 – 12.0 wt%
TiO_2 = 0.4 – 0.6 wt%
Mg # = 58 – 66

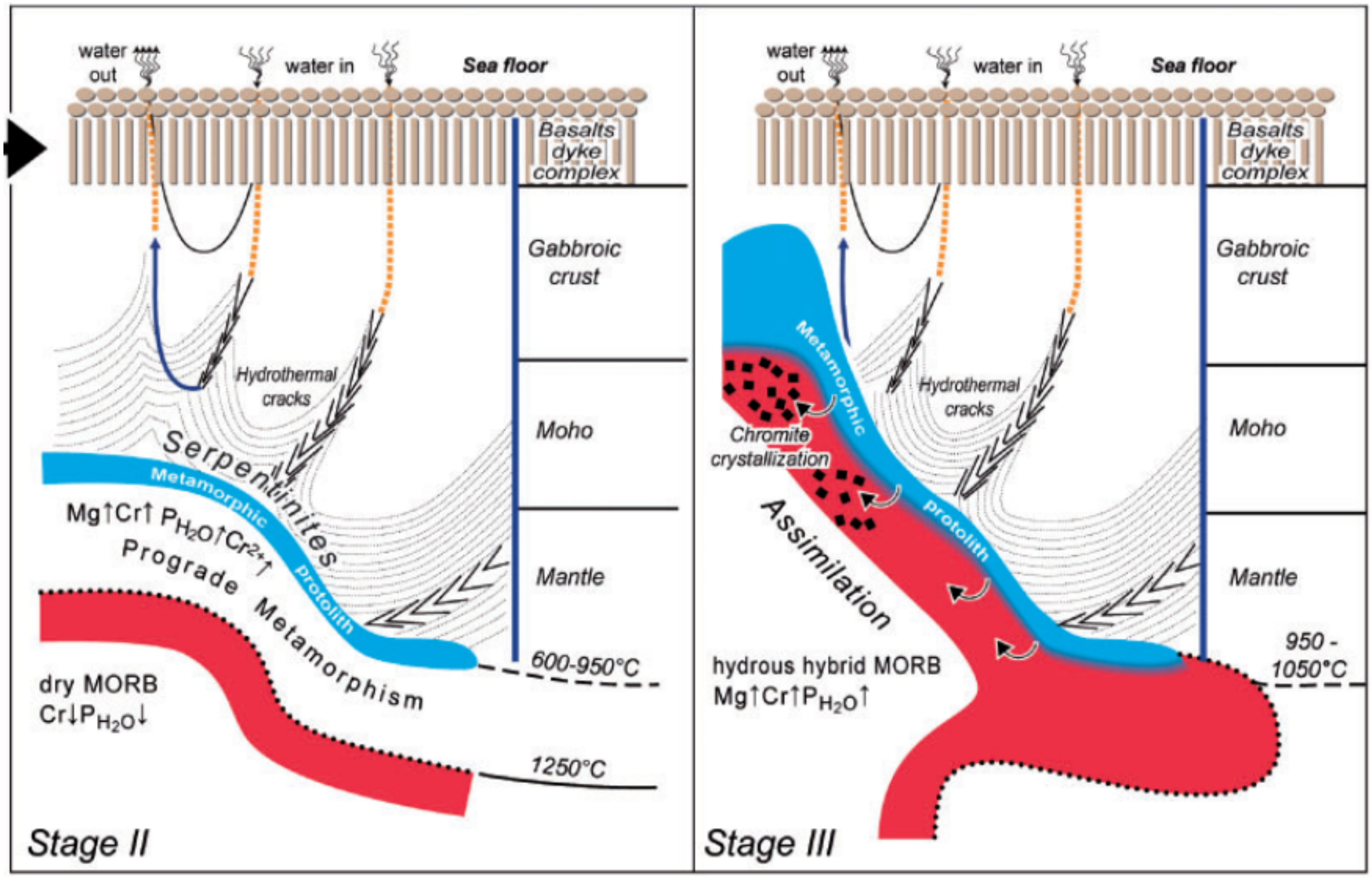
SiO_2-rich phase is a hydrous silicate melt (≤ 1050°C)?

(III)

Chromitite genesis as the consequence of chromite concentration

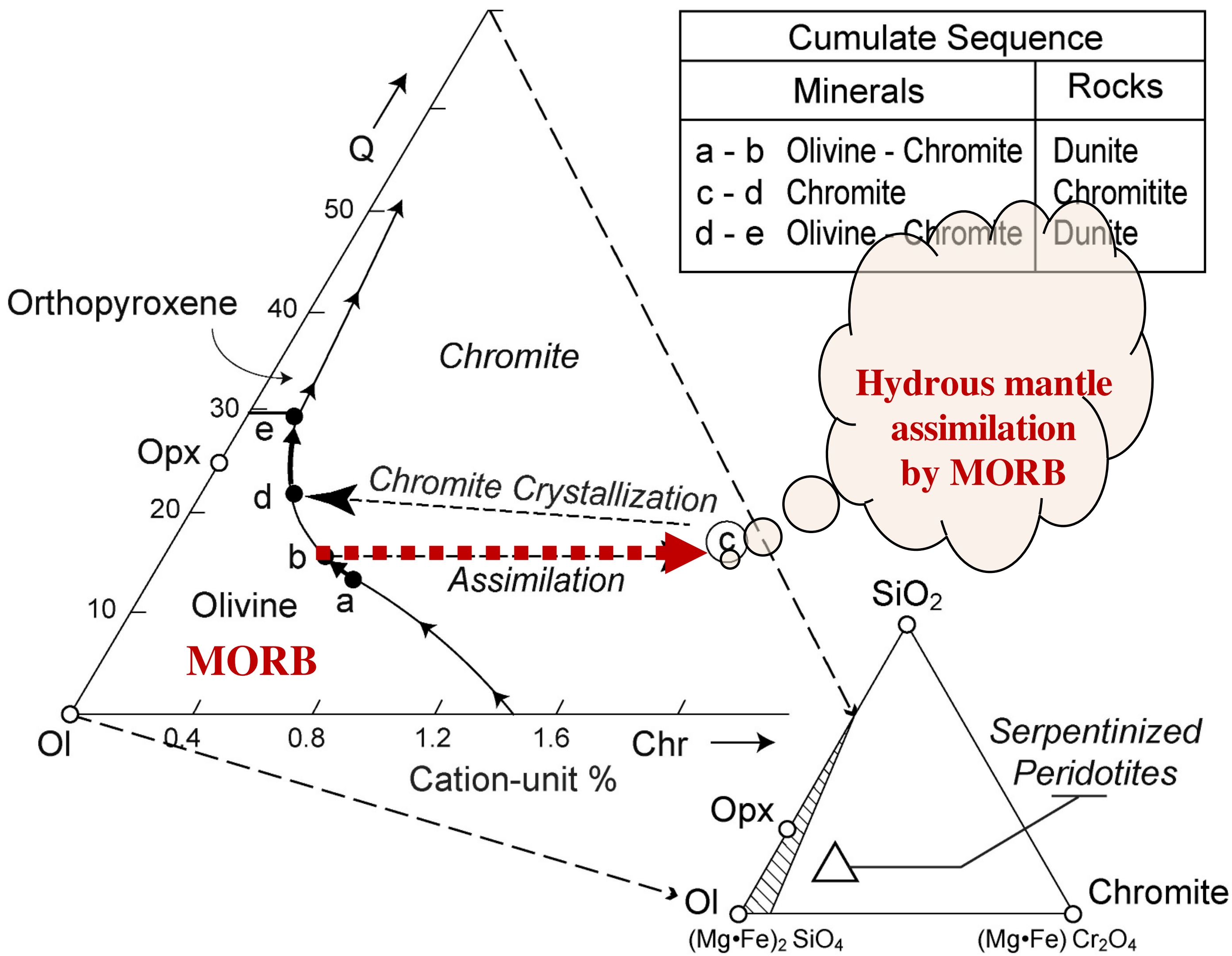
Photo by Nail Zagrtdenov, 2015

Model of lithospheric assimilation by magma at the MOHO (Borisova et al., *J. Petrology 2012*)

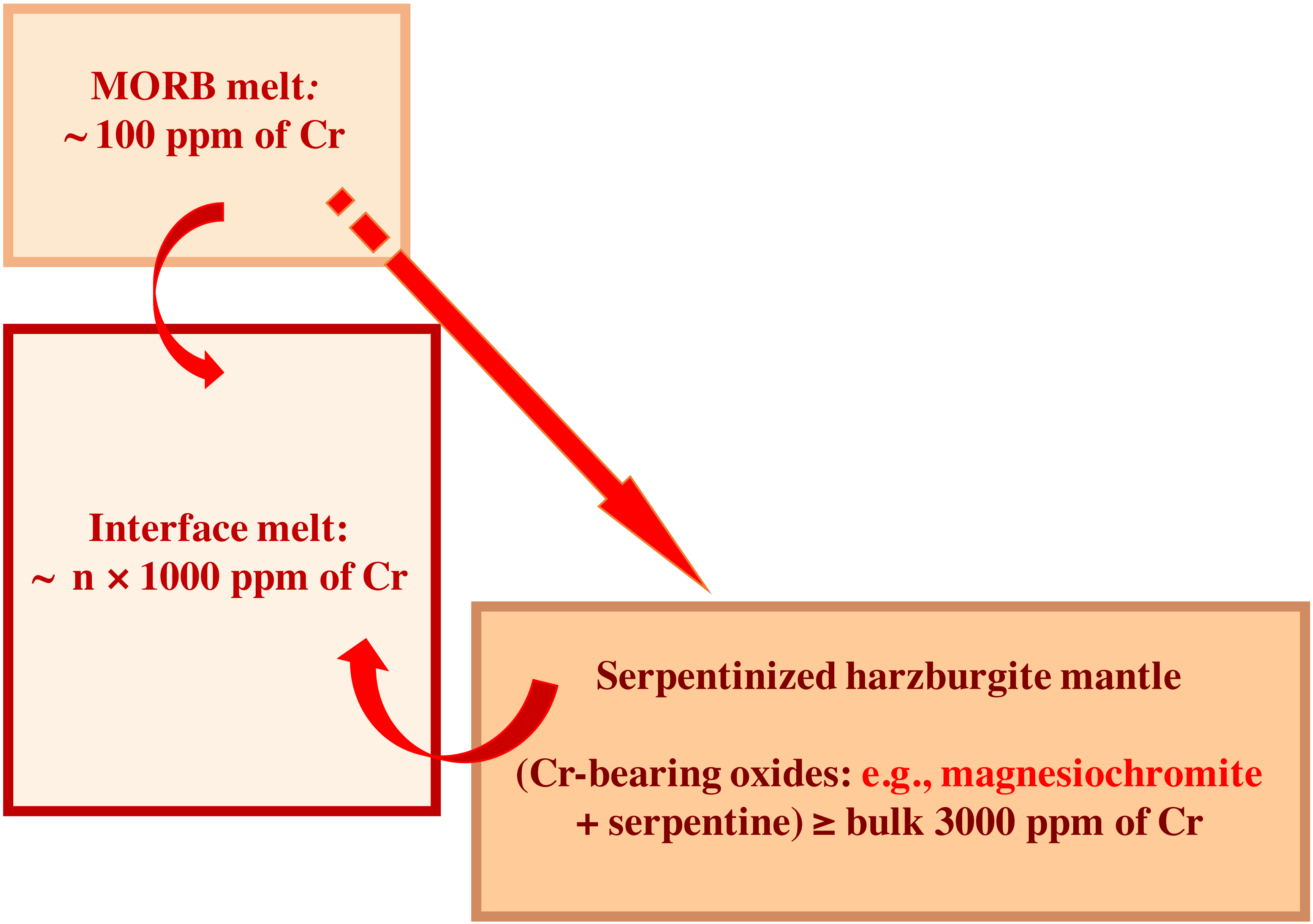


Chromite crystallization is triggered by hydrous mantle assimilation

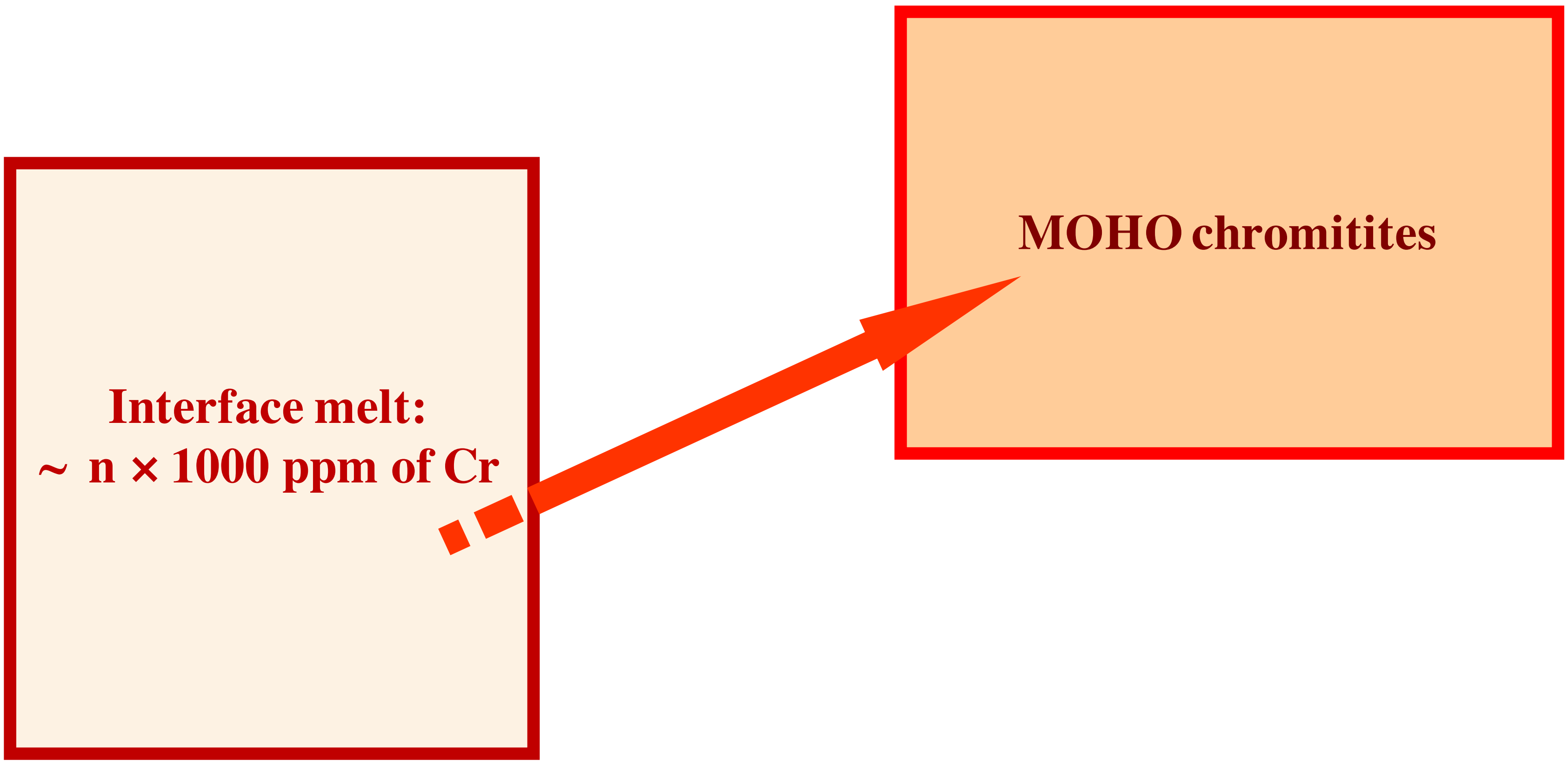
(Borisova et al., *J. Petrology* 2012)



Principal source of Cr for the MOHO chromitite formation



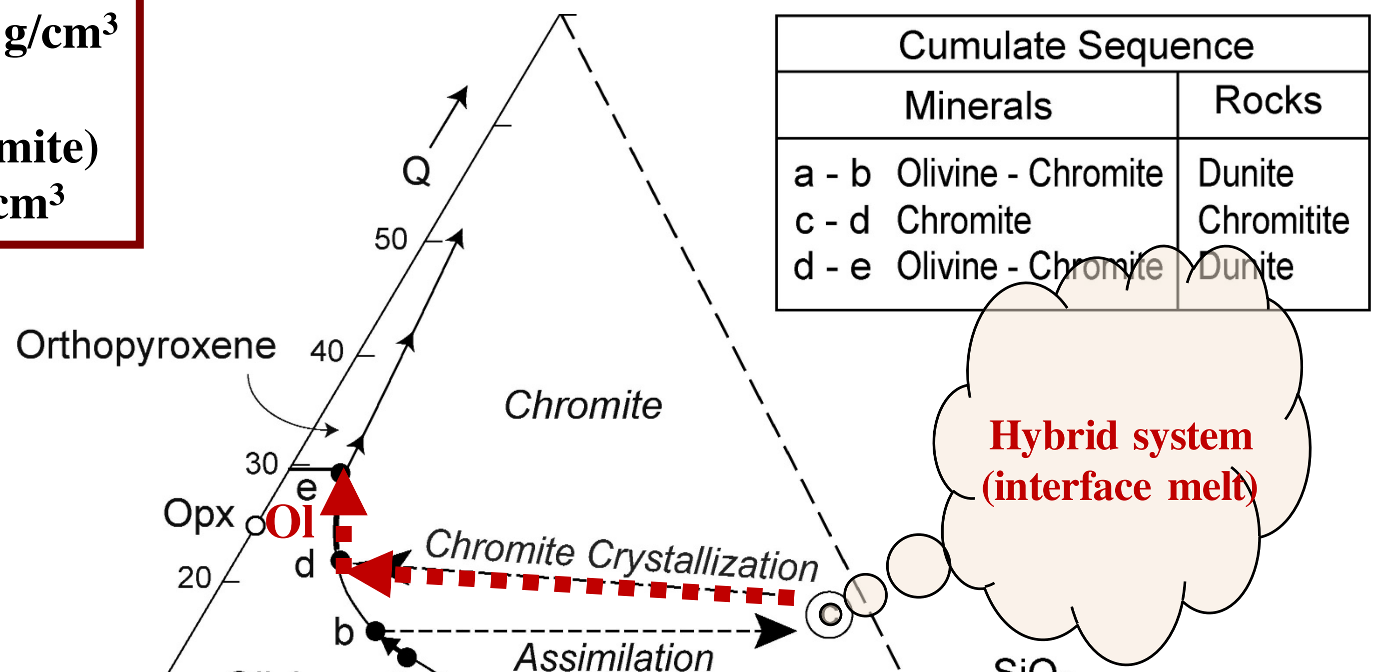
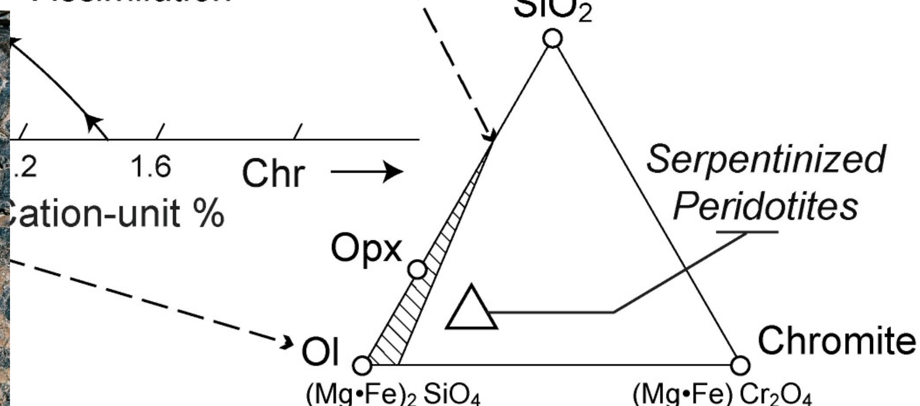
Principal source of Cr for the MOHO chromitite formation



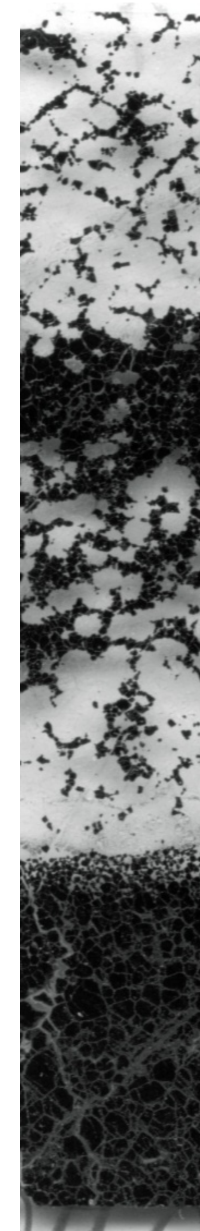
Chromite crystallization is triggered by hydrous mantle assimilation

(Borisova et al., *J. Petrology* 2012)

ϱ (melt):
2.6 – 2.7 g/cm³
<<
ϱ (chromite)
4.5 g/cm³

Cumulate Sequence		
	Minerals	Rocks
a - b	Olivine - Chromite	Dunite
c - d	Chromite	Chromitite
d - e	Olivine - Chromite	Dunite



Conclusions:

(1) Our experiments suggest that assimilation of **magnesiochromite**-bearing mantle by MORB can produce basaltic melts highly enriched in Cr contents (of n $\times 10^3$ ppm).

(2) **The hydrous mantle – MORB reaction** results in metamorphic recrystallization of serpentinite to form Cr-rich-spinel-bearing dunite/harzburgite at short timescales ($\leq$ 6 hours).

(3) Our experiments imply that **assimilation of serpentinized mantle** by MORB melt triggers chromite crystallization in association with dunite/wehrlite $\pm$ hydrous melt at short timescales ($\leq$ 6 hours).

(4) **Our new experimental data are** in accordance to the model of Borisova et al. (2012) developed based on chromite-hosted inclusions in the Oman chromitites (and associated dunites) at the MOHO transition zone.