Using wehrlites to monitor the passage of CO_2-bearing melts in the shallow lithosphere

Sonja Aulbach[1], Abing Lin[1,2], Yaakov Weiss[3], Gregory M. Yaxley[4]

[1]Institut für Geowissenschaften, Goethe-Universität Frankfurt am Main (Germany), [2]State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences, Wuhan (China), [3]The Fredy and Nadine Herrmann Institute of Earth Sciences, The Hebrew University, Jerusalem (Israel), [4]The Australian National University, Canberra (Australia)

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Motivation

- Wehrlitisation (conversion of lherzolite ± harzburgite to orthopyroxene (opx)-poor or -free clinopyroxene (cpx)-rich rock) requires interaction with SiO_2-undersaturated, low-*F* melts
- Low-*F* melts should be carbonated given strong incompatibility of CO_2
- Passage of low-*F* melts through lithospheric mantle typically associated with lithosphere thinning, craton margins, rifting, faulting
- Involves liberation of CO_2 vapour [1], which may contribute to diffuse continental degassing [2,3]

→ Use wehrlite-bearing xenolith suites to monitor CO_2 flux through shallow subcontinental lithospheric mantle (SCLM)

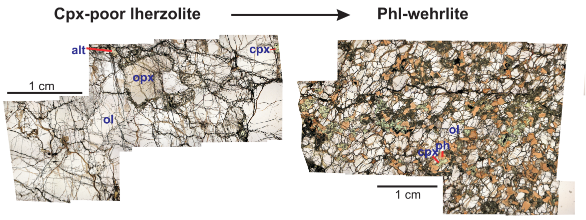


***Figure 1**: Thick section scans (plane-polarised light) showing a cpx-poor lherzolite (assumed protolith) and a phlogopite-bearing wehrlite from E Greenland where repeated rifting facilitated infiltration of carbonated melts leading to oxidation and wehrlitisation in the shallow lithosphere (90-110 km depth) [4]*

Wehrlitisation depth

Proportion of wehrlitic garnet in peridotite xenoliths and included in diamond is minute (<1 and 1%, respectively) (Fig. 2), despite widespread evidence for interaction with kimberlite-like SiO_2-undersaturated melt (xenoliths) and carbonatite (diamond)

→Wehrlitisation not important in garnet- and diamond-stable SCLM

→Interaction with carbonated melt leads to diamond formation (lherzolitic diamond [5]) or diamond resorption [6]

Conversely, xenolith suites sampling shallow (<3-4 GPa) SCLM from rift and palaeo-subduction settings contain significant wehrlite proportions (Table 1).

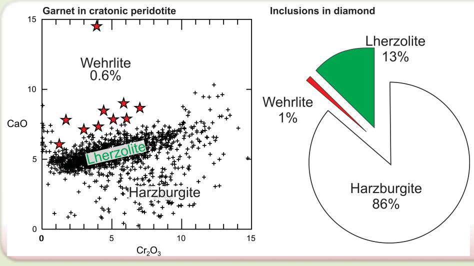


***Figure 2**: Wehrlitic garnet in cratonic peridotite xenoliths (Aulbach, unpubl. database) and included in diamond [7]*

Locality	Ref	Region	Setting	%wehr	total n
Labait, Olmani	1	East African Rift	Rifting	45	40
Tok	2	S. Siberian craton margin	Extension	23	47
Midternaes, Pyramidefjeld	3	NAC in E Greenland	Multiple failed rifting	38	24
TLFB type carb	4	North China craton	Extension	20	234
WEVF	5	Shoulder Rhine Graben	Extension	22	52

Table 1 Wehrlite-bearing xenolith suites from the literature

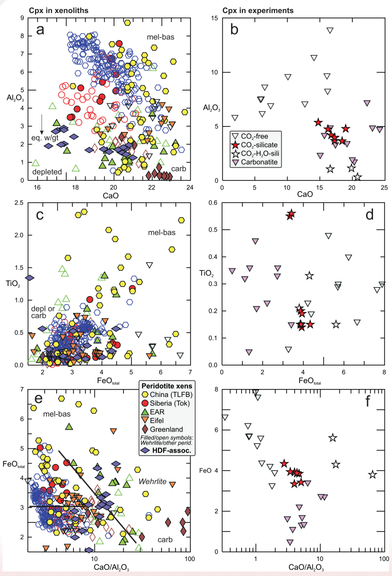
References: (1) Rudnick et al. 1994 5IKC Proc; Lee&Rudnick 1999 7IKC Proc; (2) Ionov et al. 2005a CMP, 2005b CMP, 2006a GCA, 2006b EPSL; (3) Aulbach et al. 2017 JPet; (4) A. Lin unpubl. database; (5) Witt-Eikschen et al. 1998 JPet, 2003 JPet, Shaw et al. 2018 Jpet

TLFB Tan Lu Fault Belt, WEVF West Eifel Volcanic Field, NAC North Atlantic craton, wehr wehrlite (number includes reaction dunite)

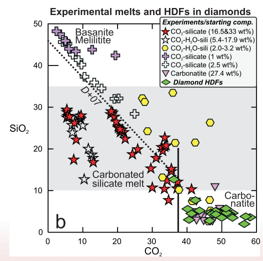
References: [1] Yaxley et al. 1998 JPet,. [2] Brune et al. 2017, [3] Foley and Fischer 2017 Nat Geosci, [4] Aulbach et al. 2017 JPet, [5] Gurney et al. 2010, [6] Fedotchouk et al. 2019, [7] Stachel and Harris 2008, [8] (Klemme et al. 1996 EPSL; Salters and Longhi 1999 EPSL; Dasgupta et al. 2007 JPet, 2009 CG; Foley et al. 2009 Lithos; Girnis et al. 2013 Lithos

Hallmarks and agents of wehrlitisation

Based on reported mineral modes and cpx compositions, wehrlitisation always leads to increased cpx modes and low to absent opx relative to other peridotites. Associated major element effects vary (Fig. 3), depending on the thickness of garnet-bearing SCLM percolated and reflecting the melt fraction and spectrum of SiO_2-undersaturated carbonated melts. The latter range from carbonatite (*c*) to carbonated silicate melt (*cs*) to melilitite-basanite (*mb*) similar to those produced in experiments (Fig. 4).



***← Figure 3**: Major elements in cpx (wt%) from garnet-free xenolith suites (Table 1), occurring with diamond-hosted high-density fluids (HDF; Weiss, unpubl. database) and produced in experiments with varible amounts of CO_2±H_2O [8].*



***→ Figure 4**: Major elements of experimental melts (wt%) with varible amounts of CO_2±H_2O, as well as high-density fluids (HDF) in diamonds (References in Fig. 3).*

Wehrlitisation reaction and CO_2 flux

Based on the reaction in [1]:

$$\textit{enstatite} + CO_3^{2-}\textit{(melt)} = \textit{forsterite} + \textit{diopside} + CO_2\ \textit{(vapour)}$$

and assuming (1) upper and lower bounds of dolomite mole fractions in wehrlitising c (1-0.83), cs (0.63-0.21) and mb (0.10-0.02) melts, (2) median peridotite as protolith to wehrlites, and taking median cpx modes and diopside mole fractions, the melt mass required to convert opx to cpx and of CO_2 transported through the lithosphere is estimated (Table 2).

Locality	Agent[1]	+ wt% cpx[2]	kg liq/100 kg wehr[3]	Kg CO_2/100 kg rock[4]
Labait, Olmani	cs	12	14-43	1.9
Tok	mb	11	68-340	0.8
TLFB	c	9	7-8	0.2
TLFB	cs	14	17-51	0.2
TLFB	mb	13	88-440	0.7
WEVF	cs	10	12-37	0.8

Table 2 Liquid mass needed for wehrlitisation of xenolith suites in Table 1, and mass of CO_2 lost

[1]*cs* carbonated silicate melt, *mb* melilitite-basanite, *c* carbonatite, [2]Difference between median cpx mode in wehrlites and other peridotites, [3]mass of liquid required to generate cpx from opx, forming wehrlite, weighted by X(dolomite) in liquid, [4]mass of CO_2 liberated per 100 kg rock considering wehrlite fraction in rock column (Table 1); X(Dol) in melt assumed to scale with CO_2 (from experiments [8]) anchored to ~pure dolomite melt

Caveats: Only dry experimental melts used for calculation CO_2, effect of H_2O not considered; cpx is only produced through the wehrlitisation reaction, reported volume % modes not converted to wt%; only diopside endmember considered with respect to proportion and molecular wt; mole fraction assumed to equal *a*(CO_2)

Conclusion

Wehrlites are products and monitors of the passage of CO_2-bearing melts in the shallow SCLM. CO_2 released due to wehrlitisation may ultimately lead to diffuse degassing to the atmosphere. The Early-Cretaceous Tan Lu Fault Belt is even more massive (5000 x 800-1000 km) than the EAR, the latter linked to degassing of 28 to 34 Mt C/yr over 40 Ma [3]. If wehrlitisation affected only a 10 km depth interval over a similar time, 12 Mt C/yr is calculated for the TLFB, possibly contributing to the Early-Cretaceous greenhouse climate.