Effect of CO_2 on the partial melting of peridotite: clues from some simple systems

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It is obviously important to study the genesis of magma and the role of CO_2 in that process when you see the things going on in Iceland!

http://news.sciencenet.cn/imgnews.aspx

Outline

- Experimental investigation of effects of CO_2 under dry and hydrous conditions on the partial melting of peridotite in some simple systems
- Comparison of experimental results from simple and natural compositions
- Conclusions

Simulating the melting process of the upper mantle peridotite

Pyrolite model of McDonough & Sun, 1995:

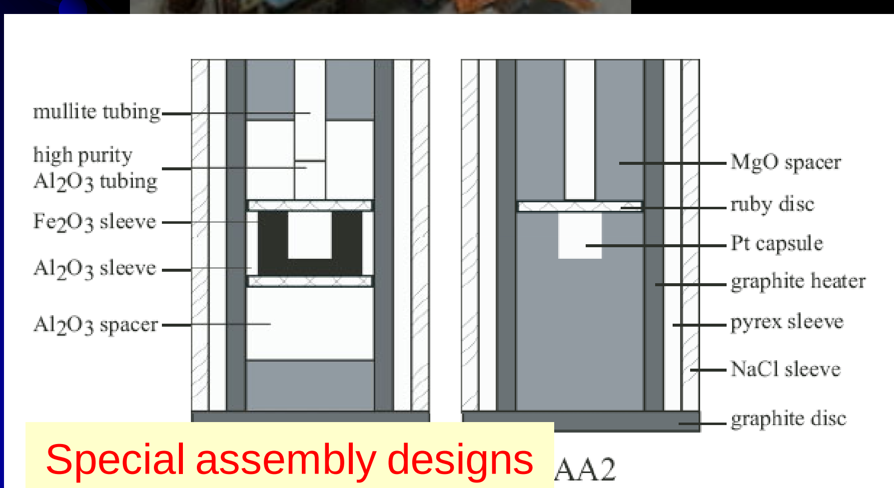
CaO	***3.55***	*FeO*	*8.05*
MgO	***37.80***	Cr_2O_3	*0.38*
Al_2O_3	***4.45***	Na_2O	*0.36*
SiO_2	***45.00***	TiO_2	*0.20*
	91%	K_2O	*0.03*
		MnO	*0.14*
		NiO	*0.25*
		H_2O	*200 ppm?*
		CO_2	*80 ppm?*
		P_2O_5	*?*

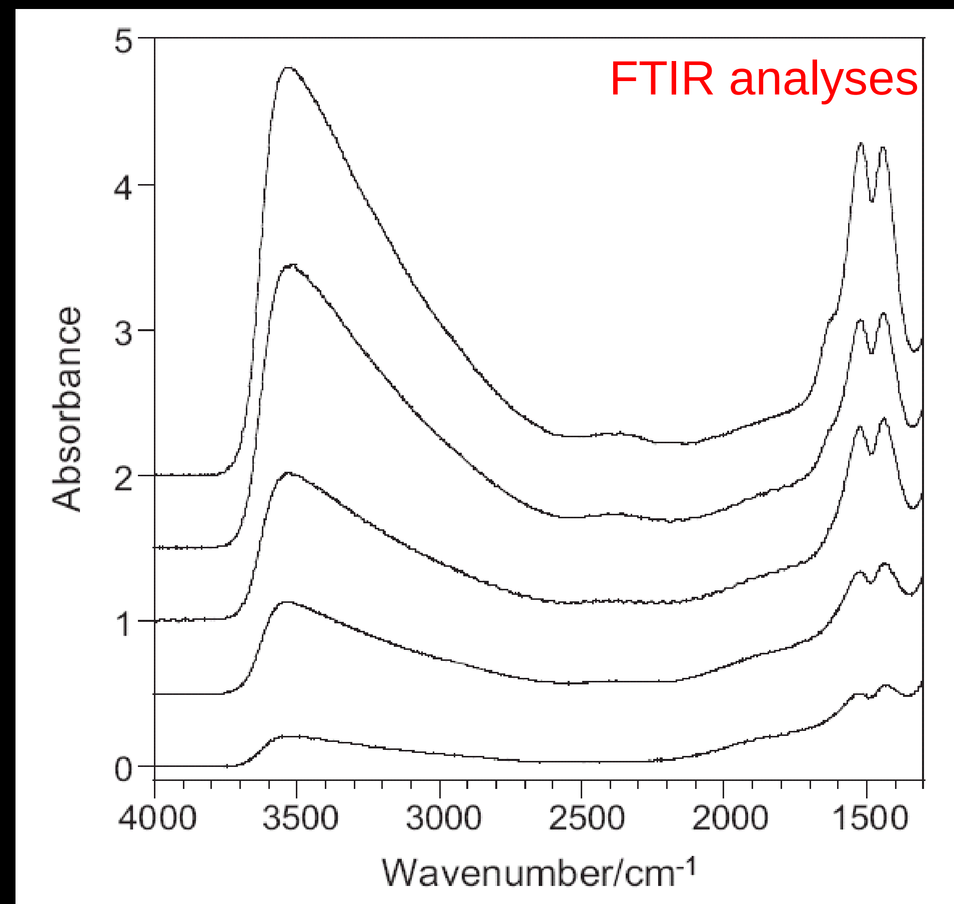
Mineral Phases of melting peridotite:

1. **Ol**
2. **Opx**
3. **Cpx**
4. **Pl (low P)/ Sp (intermediate P)/ Grt (high P)**
5. **Melt (when melting)**

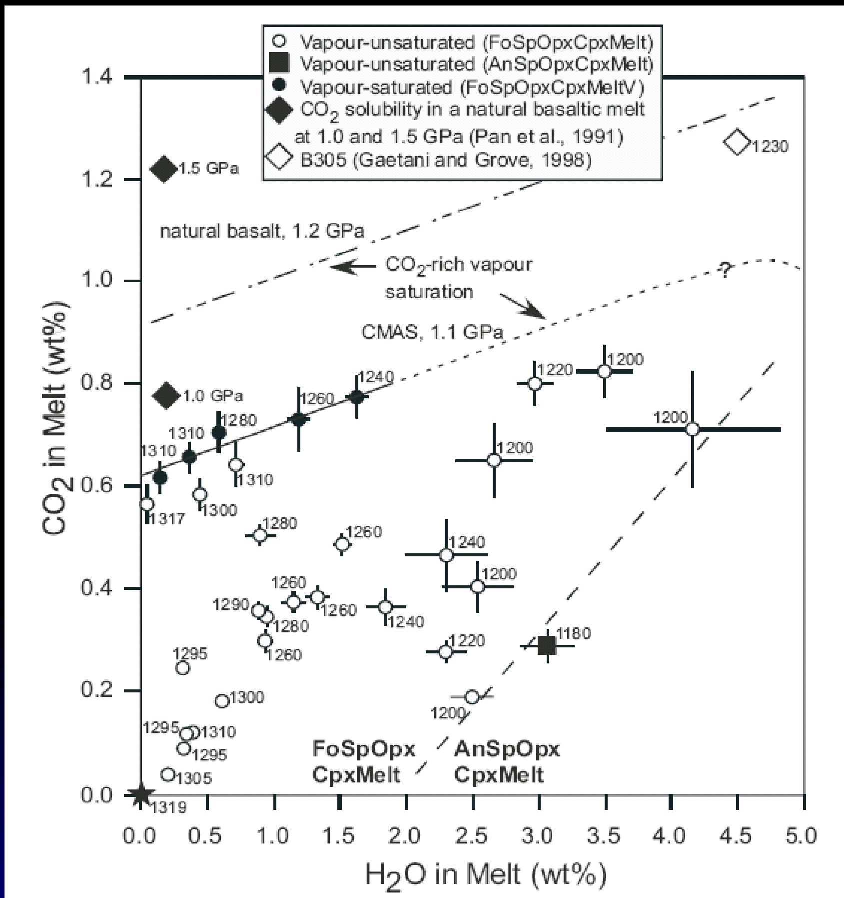
1. **The simplest chemical system for the lherzolite phase assemblage (Ol, Opx, Cpx, and Pl/Sp/Grt) to be stable is CMAS.**
2. **According to the pyrolite model, CaO, MgO, Al_2O_3 and SiO_2 add to 91wt%. CMAS is a perfect starting point for studying of the partial melting process.**
3. **Isobarical phase rule for the CMAS system: P + F = C + 1 (5 + 0 = 4 + 1)**
4. **To investigate the effect of CO_2, the right system is CMAS + CO_2**
5. **To investigate the effect of H_2O, the right system is CMAS + H_2O.**

Experiments in system CMAS+CO_2 under dry and hydrous condition at 1.1 GPa

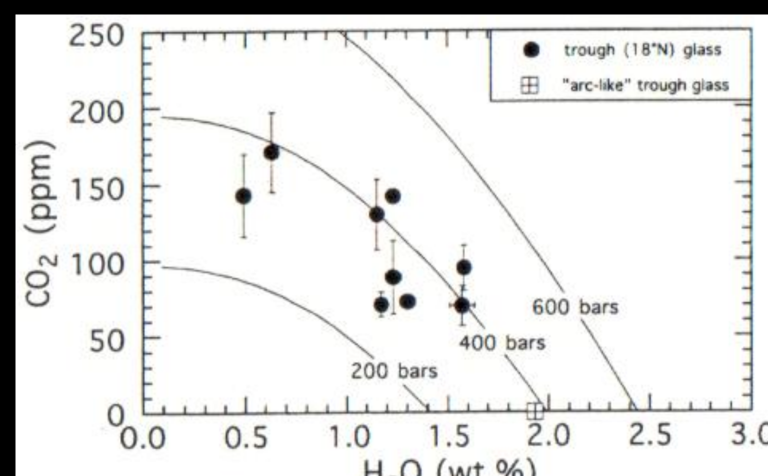




Interaction of H_2O and CO_2 in basaltic melts

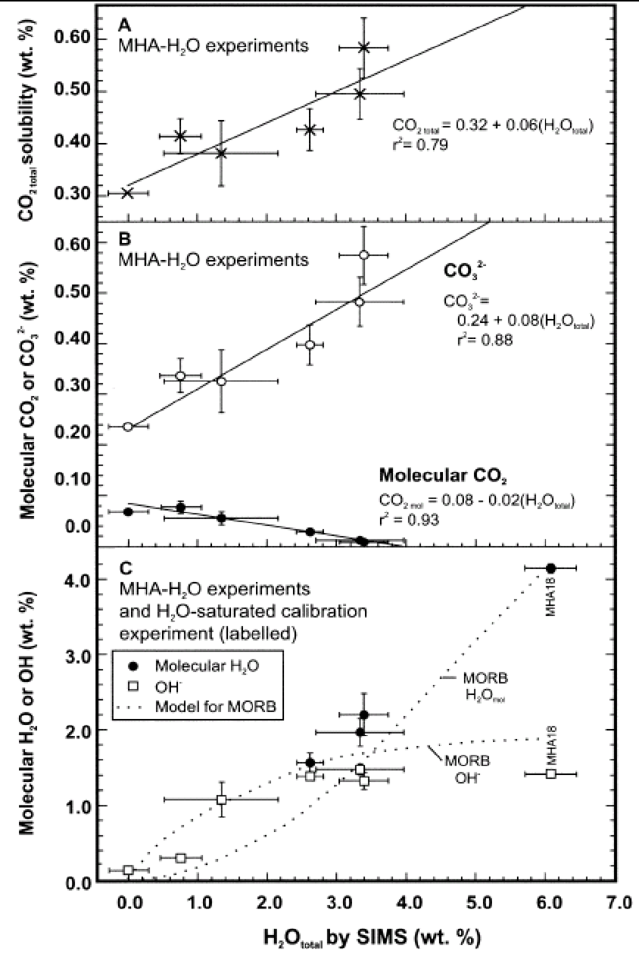


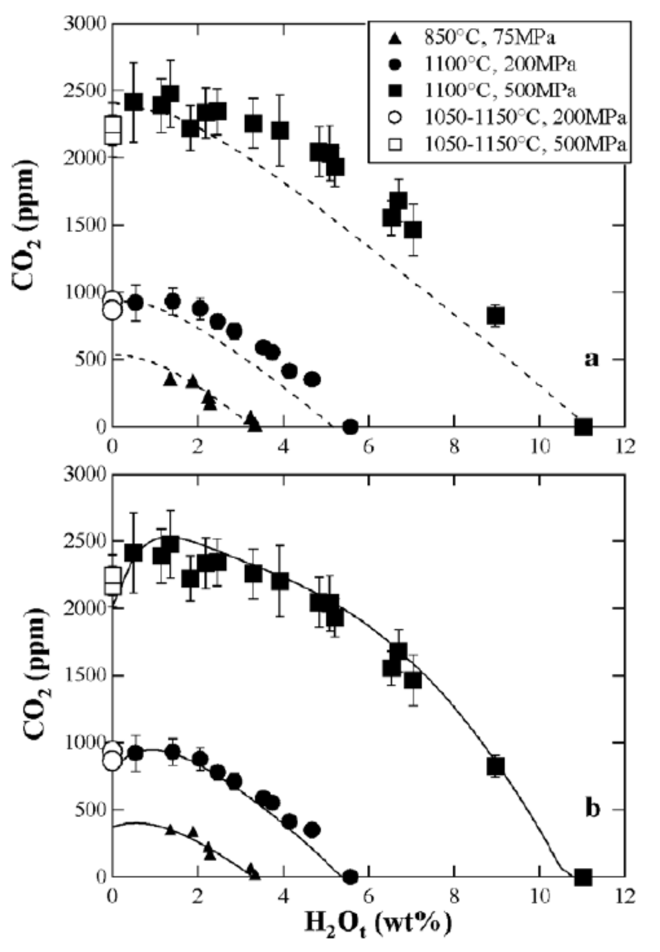
- Over 200 FTIR analyses on 42 samples (the thinnest sample is of 14 micrometers)
- The first data set, the only data set so far, with full quantification of the experimental products of hydrous partial melting.
- Note the interaction of H_2O and CO_2: H_2O increases the solubility of CO_2 in basaltic melts



Stolper & Newman, 1994
Earth Planet Sci Lett

Interaction of H_2O and CO_2 in other melts



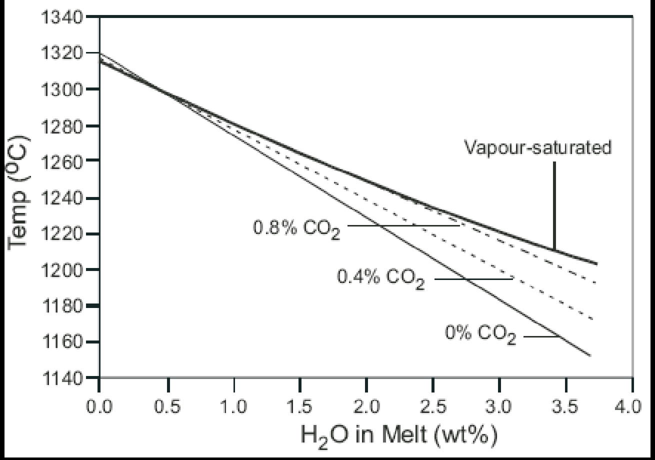


Andesitic melts: King & Holloway, 2002
Geochim. Cosmochim. Acta

Rhyolitic melts: Liu et al., 2004
J. Volcanol. Geoth. Res.

$$[X] = [X]_{\mathrm{CMAS}} + A^X_{\mathrm{Na_2O}}[\mathrm{Na_2O}] + A^X_{\mathrm{H_2O}}[\mathrm{H_2O}] + A^X_{\mathrm{CO_2}}[\mathrm{CO_2}] + A^X_{\mathrm{H_2O/CO_2}}[\mathrm{H_2O}][\mathrm{CO_2}]$$

where the parameter denoted $[X]$ is either temperature (T_{melt}) or melt composition, i.e. $[SiO_2]$, $[Al_2O_3]$, $[CaO]$ and $[MgO]$

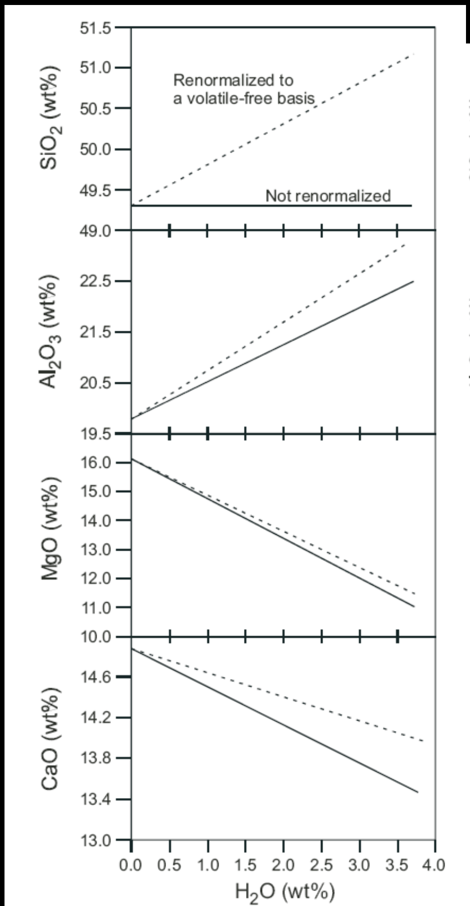


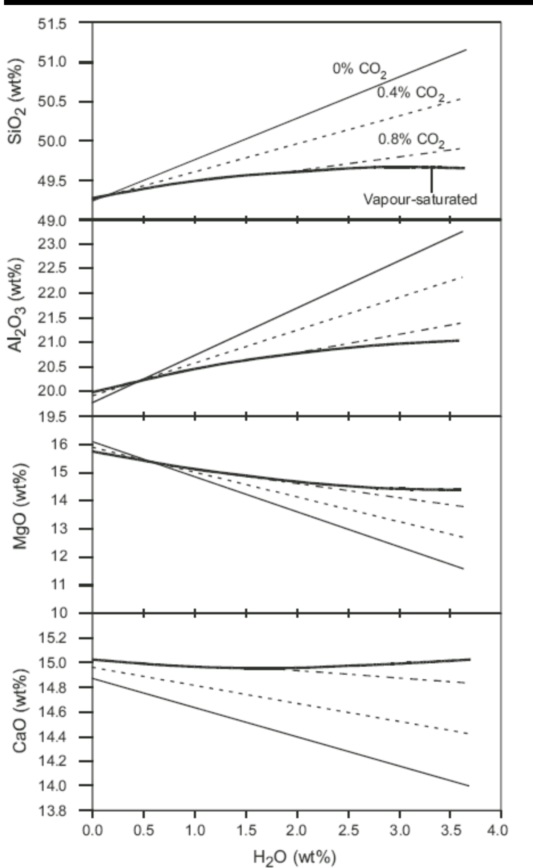
Effect of H_2O, and effect of CO_2 on hydrous melting; Liu et al., 2006, J Petrol

Data-fitting in the system CMAS+H_2O+CO_2

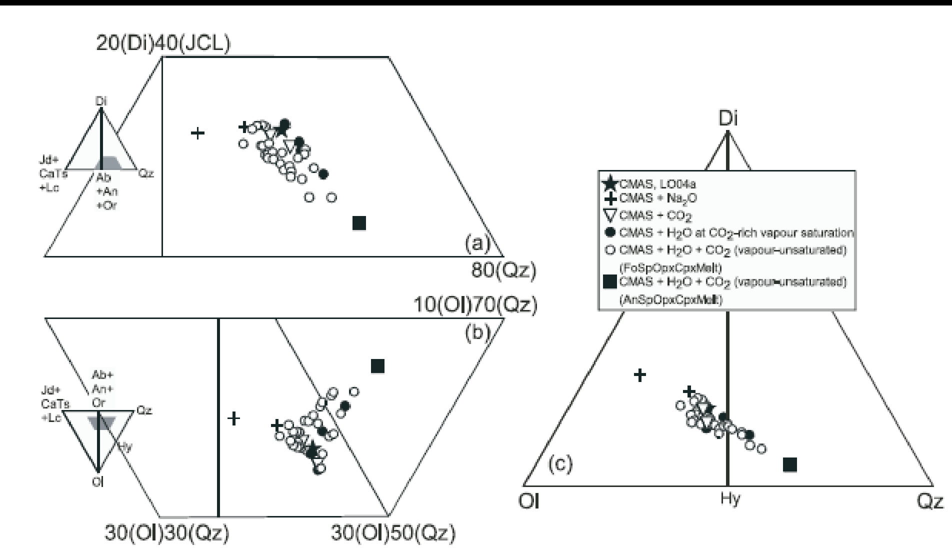
Variable	Constant	$[Na_2O]$	$[H_2O]$	$[CO_2]$	$[H_2O][CO_2]$	χ^2_ν
T	1319	−4·2	−45·4	−7·0	16·0	2·9
$[SiO_2]$	49·30	0·47	—	−0·74	−0·32	1·8
$[SiO_2]$*	49·17	0·52	0·59	—	−0·48	1·8
$[Al_2O_3]$	19·81	0·48	0·72	—	−0·66	4·1
$[Al_2O_3]$*	19·80	0·44	0·86	—	−0·52	3·8
$[MgO]$	16·13	−0·98	−1·37	−0·85	0·95	8·3
$[MgO]$*	16·14	−0·97	−1·29	−0·69	1·00	9·1
$[CaO]$	14·89	−0·65	−0·38	—	0·24	5·4
$[CaO]$*	14·96	−0·70	−0·26	—	0·31	5·5

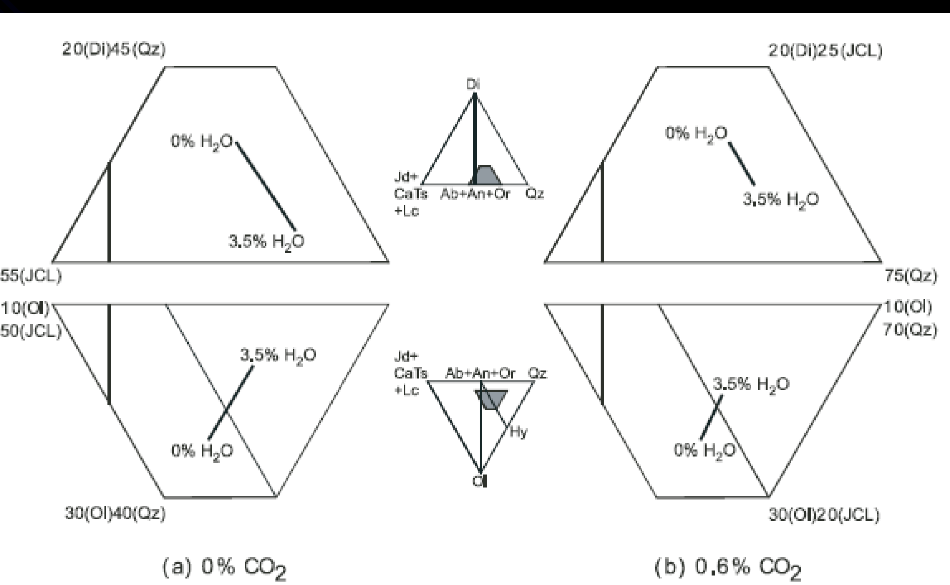
*Oxides recalculated by normalizing $[SiO_2]$ + $[Al_2O_3]$ + $[MgO]$ + $[CaO]$ + $[Na_2O]$ to 100% on a volatile-free basis.

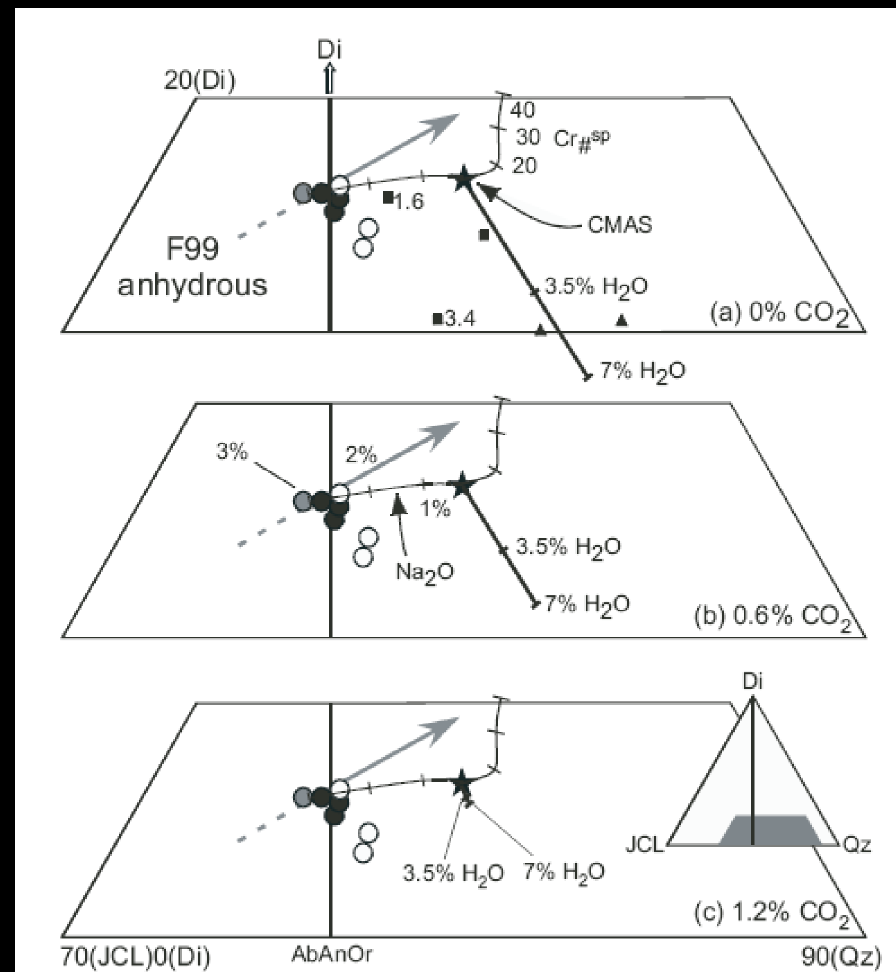




Effects of H_2O and CO_2 on the melt composition







Application of these coefficients by Wood and Turner (2009, Earth Planet Sci Lett)

In contrast to H_2O, the other major fluid component in mantle-derived magmas, CO_2, decreases the SiO_2 contents of equilibrium melts of peridotite (e.g. Brey and Green, 1975). Thus, in nature, H_2O and CO_2 probably counteract one another to some extent, as demonstrated by Liu et al. (2006). The latter authors determined the effects of CO_2 and H_2O on the compositions of melts produced in equilibrium with spinel lherzolite in the model system CaO–MgO–Al_2O_3–SiO_2 at 1.1 GPa. They found, as anticipated, that addition of H_2O increases the SiO_2 content of the melt, calculated on an H_2O-free basis, by about 0.6% and decreases the MgO content by about 1.3% (on an anhydrous basis) for every percent of H_2O added. Addition of CO_2 in the form of mixed H_2O–CO_2 fluids partially counteracts the effect of H_2O, reducing the increase in SiO_2 and decrease in MgO contents

The experiments of Hirose and Kawamoto (1995), Hirose (1997) and Gaetani and Grove (1998) provide the potential for quantification of the effects of H_2O on SiO_2 and MgO contents of melts of natural lherzolite. The most complete set of experiments, that of Gaetani and Grove, was performed in the presence of CO_2 as well as H_2O, but fortunately these authors determined the CO_2 contents of some of their product glasses. They found that their product melts had CO_2 contents of approximately 1.25% for 3 liquids containing 4.5–5.3% H_2O and <0.07% for H_2O contents of <1%. Given these measurements, we corrected their results for SiO_2 and MgO contents using the correction factors of Liu et al. (2006) which were determined for the analogous lherzolite assemblage in the iron-free system. Our correction assumed 1.25% CO_2 for all melts containing 3.3–7.9% H_2O, and was made as follows:

$$SiO_2 = SiO_2(\text{anhydr}) + 0.48[H_2O][CO_2] \quad (3a)$$

$$MgO = MgO(\text{anhydr}) + 0.69[CO_2] - 1.00[H_2O][CO_2] \quad (3b)$$

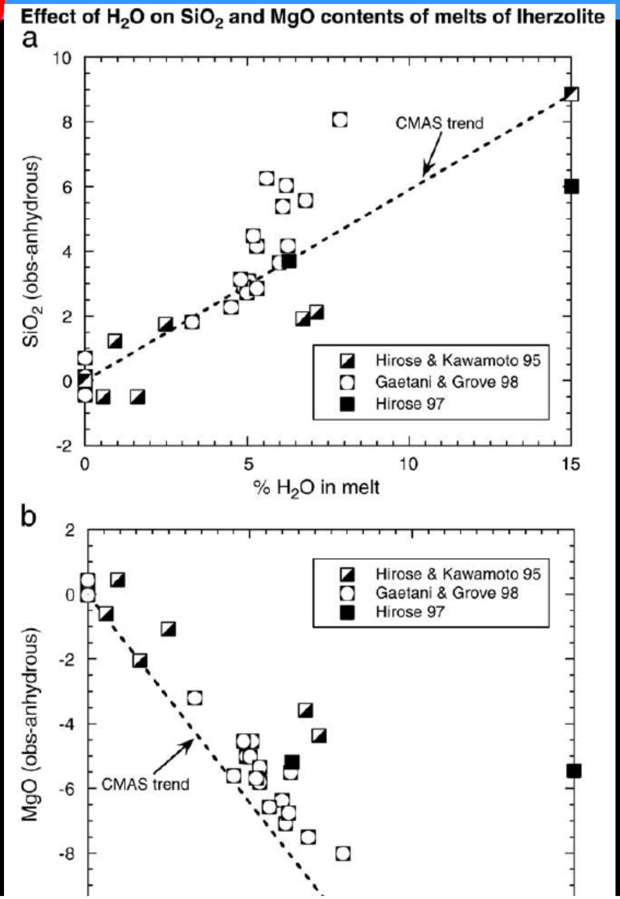


Fig. 5 shows the effects of H_2O on compositions of melts from experiments on natural compositions saturated in lherzolite residue from the experimental studies discussed above. As can be seen the data are consistent with the observations of Liu et al. (2006) in that, on an anhydrous basis, SiO_2 content increases and MgO decreases as H_2O is added to the melt. The effect of H_2O was quantified by least squares fitting to obtain (on an anhydrous basis):

$$SiO_2 = SiO_2(\text{anhydr}) + 0.6[H_2O] \quad (4a)$$

$$MgO = MgO(\text{anhydr}) - 1.0[H_2O] \quad (4b)$$

$$[X] = [X]_{CMAS} + A^{X}_{Na_2O}[Na_2O] + A^{X}_{H_2O}[H_2O] + A^{X}_{CO_2}[CO_2] + A^{X}_{H_2O/CO_2}[H_2O][CO_2]$$

where the parameter denoted $[X]$ is either temperature (T_{melt}) or melt composition, i.e. $[SiO_2]$, $[Al_2O_3]$, $[CaO]$

and $[MgO]$

Data-fitting in the system $CMAS+H_2O+CO_2$

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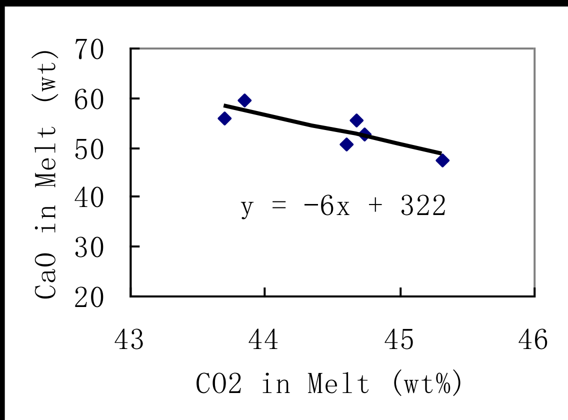
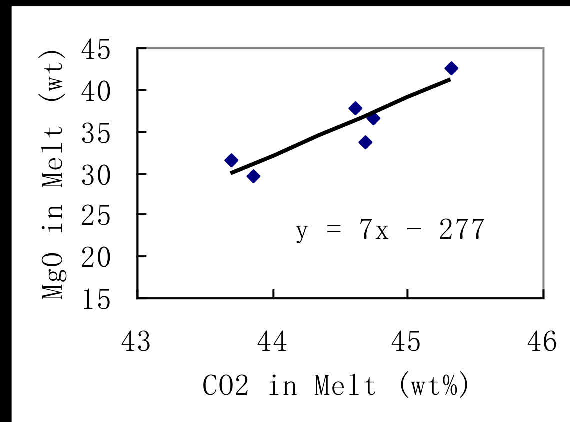
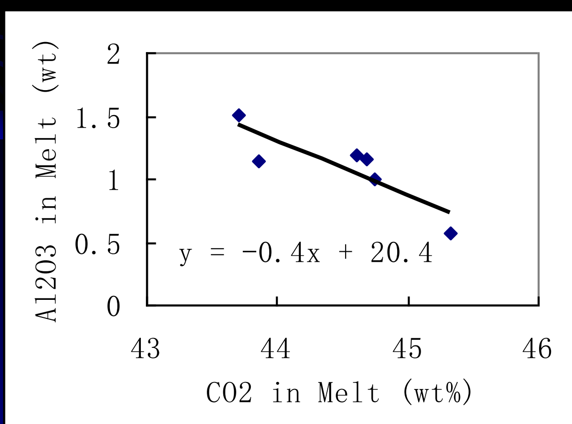
*Oxides recalculated by normalizing $[SiO_2]$ + $[Al_2O_3]$ + [MgO] + [CaO] + $[Na_2O]$ to 100% on a volatile-free basis.

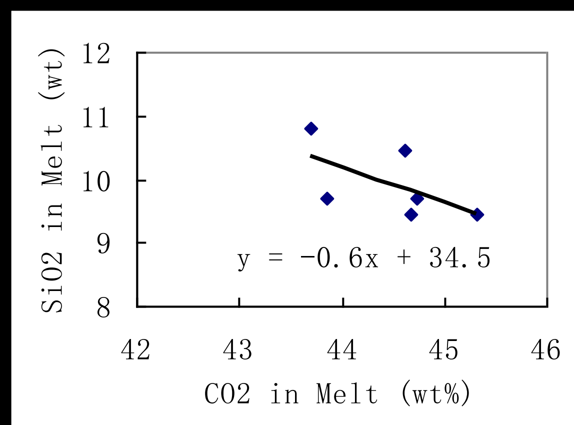
The effects of CO_2 and H_2O on the partial melting process of the carbonated peridotite can be extracted as well!!!

Effect of pressure on the melt composition for the partial melting of the phase assemblage of solid carbonate phase + peridotite









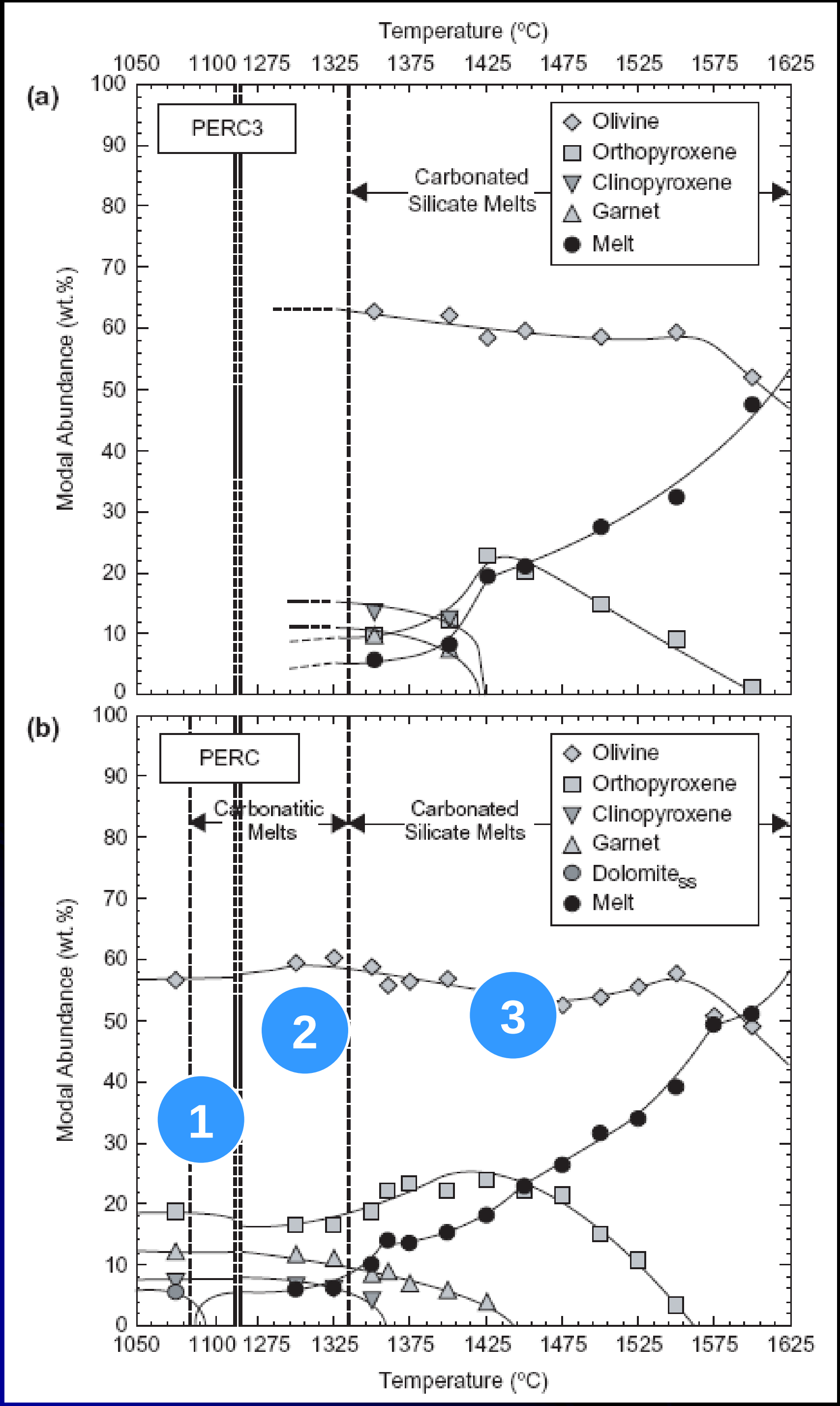
As P increases:
CO_2 increases,
CaO decreases,
MgO increases,
Al_2O_3 decreases,
SiO_2 decreases.

Obviously, the effect of pressure is more or less just diluting the melts by dissolving more CO_2.

No comparison can be made between the model system and the natural rock system.

Dalton & Presnall, 1998, Contrib Mineral Petrol (3-7 GPa/CMAS+CO_2)

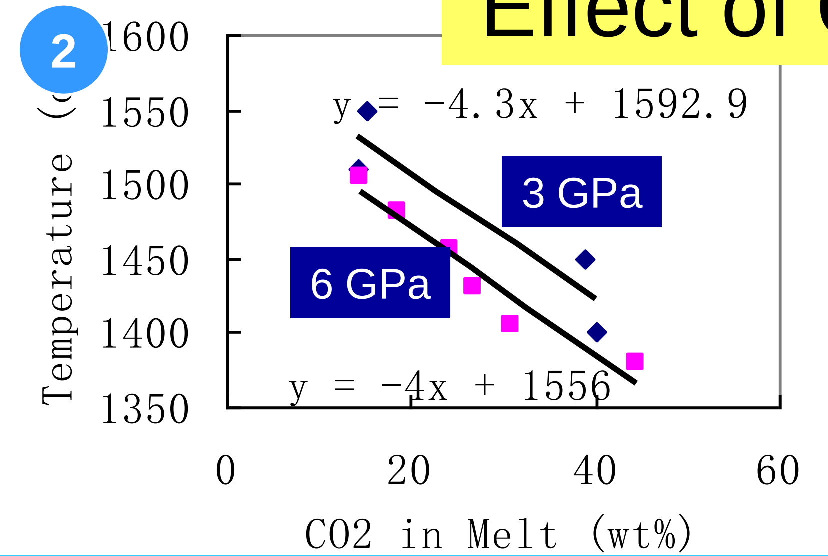
Effect of CO_2 on the melting process of the carbonated peridotite



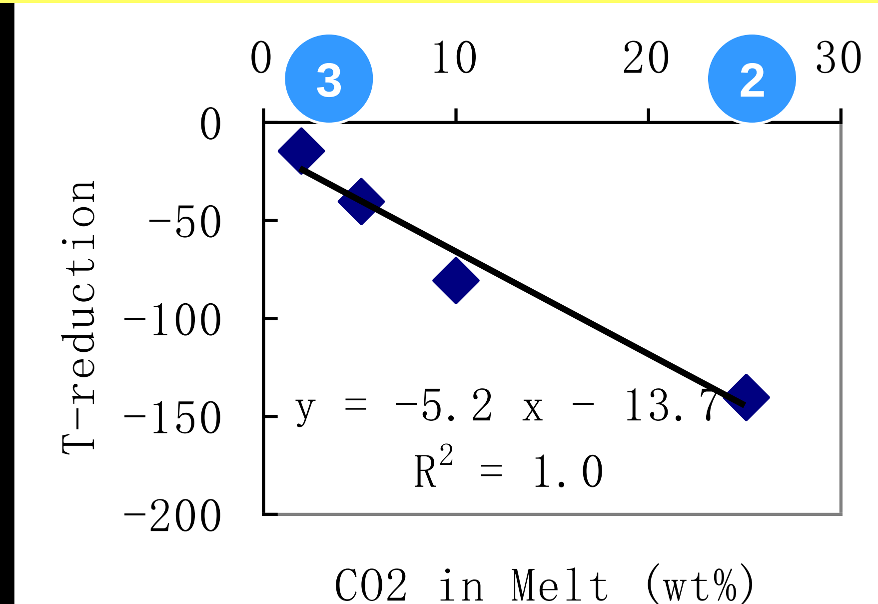
Three major steps of the partial melting process of the carbonated peridotite at 3.0 GPa (Dasgupta et al., 2007, J Petrol):

1. Dolomite/magnesite-buffered melting at very low temperatures;
2. Melting at generally low temperatures to produce carbonatitic melts;
3. Melting at generally high temperatures to produce carbonated silicate melts.

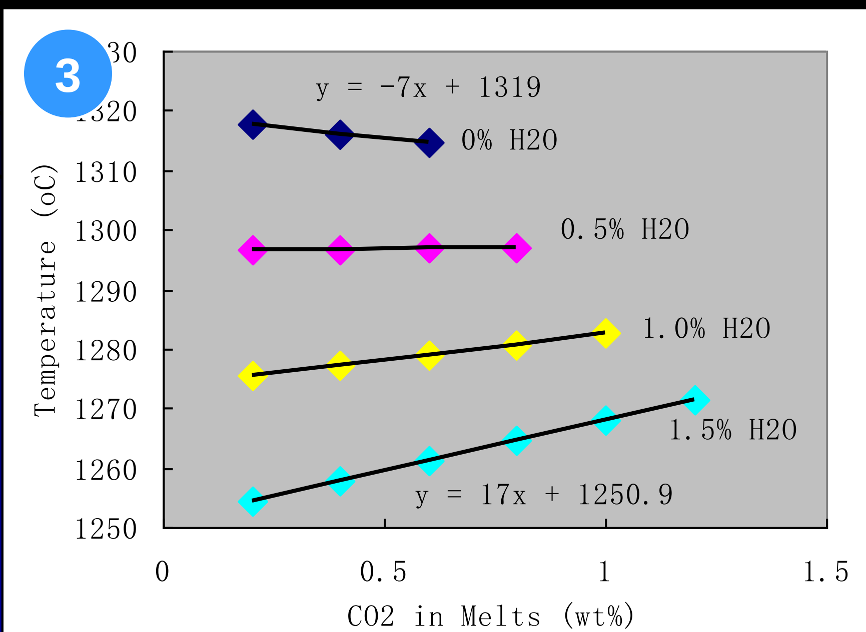
Effect of CO_2 on melting temperature



Gudfinnsson & Presnall, 2005, J Petrol (3 GPa/CMAS+CO_2)
Dalton & Presnall, 1998, J Petrol (6 GPa/CMAS+CO_2)



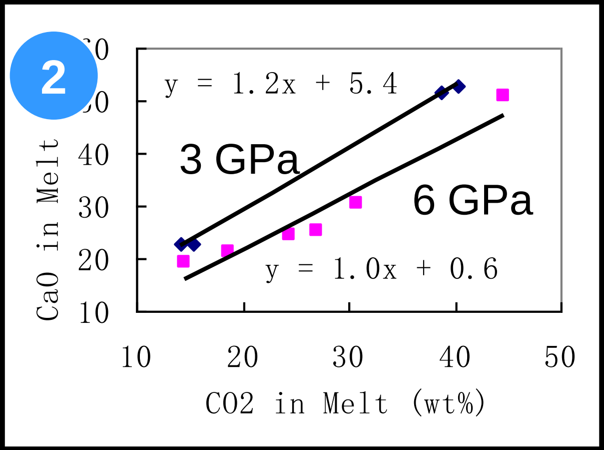
Dasgupta et al., 2007, Geology (3 GPa/natural



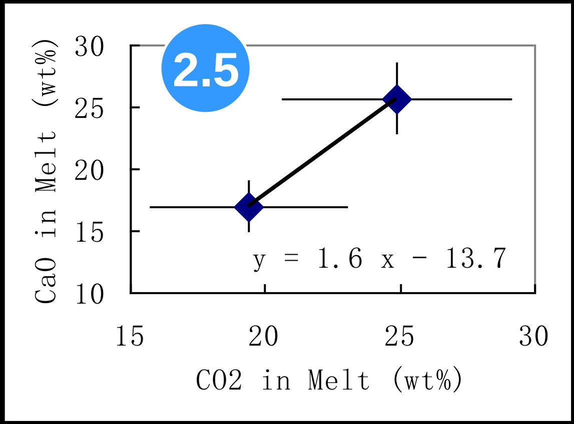
This Study (1.1 GPa/CMAS+CO_2+H_2O)

1. CO_2 decreases the melting temperature under dry condition; but this effect can be altered under hydrous condition;
2. Pressure does not strongly influence the effect of CO_2;
3. Other components probably have very limited influence as well;
4. The experiments in Dasgupta et al. (2007) had little water (<<0.5%?).

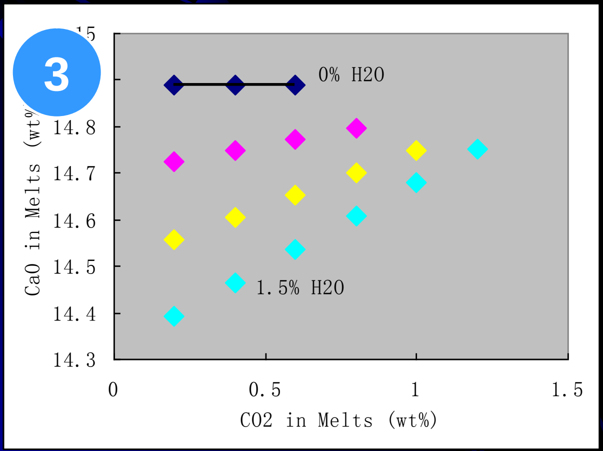
Effect of CO_2 on melt composition --CaO



Gudfinnsson & Presnall, 2005, J Petrol (3 GPa/CMAS+CO_2)
Dalton & Presnall, 1998, J Petrol (6 GPa/CMAS+CO_2)



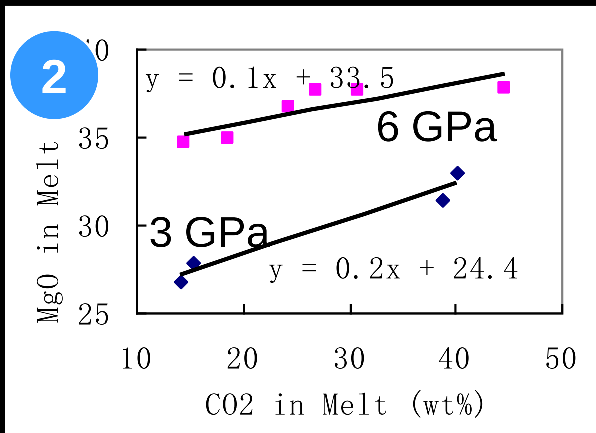
Dasgupta et al., 2007, J Petrol (3GPa/1350°C/natural compositions)



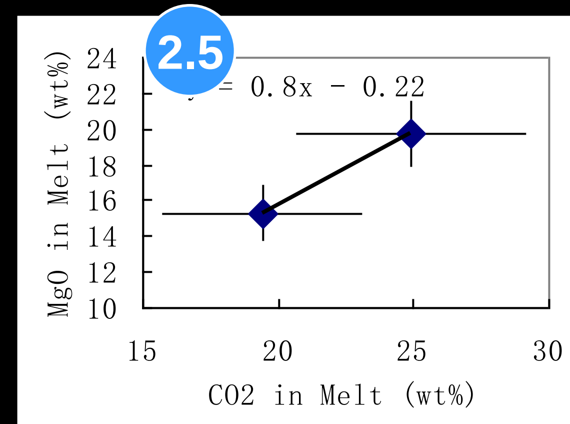
This Study (1.1 GPa/CMAS+CO_2+H_2O)

1. CO_2 mostly likely increases the CaO content, especially under wet condition;
2. Pressure appears to have little influence on the effect of CO_2 on the CaO content;
3. Other components, excluding water, might have negligible effect as well;
4. The effects of CO_2 on the CaO content might be different for carbonated-spinel

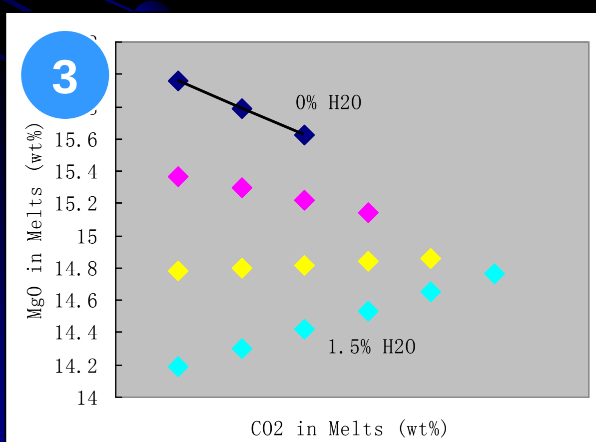
Effect of CO_2 on melt composition --MgO



Gudfinnsson & Presnall, 2005, J Petrol (3 GPa/CMAS+CO_2)
Dalton & Presnall, 1998, J Petrol (6 GPa/CMAS+CO_2)



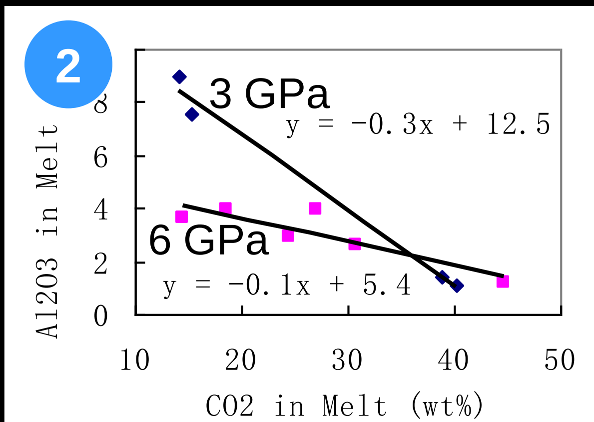
Dasgupta et al., 2007, J Petrol
(3GPa/1350ºC/natural compositions)



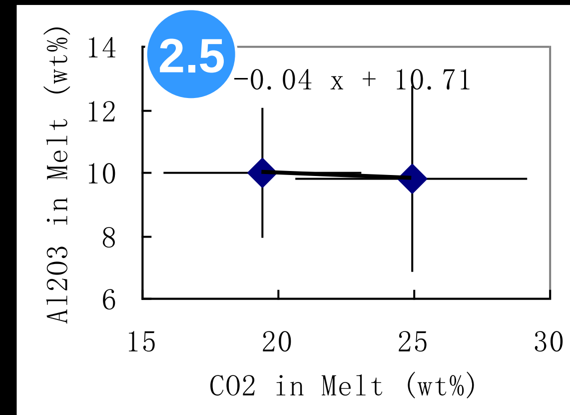
This Study (1.1 GPa/CMAS+CO_2+H_2O)

1. CO_2 mostly likely increases the MgO content;
2. Pressure appears to have small influence on the effect of CO_2;
3. Other components might have strong effect;
4. The effects of CO_2 on the MgO content might be different for carbonated-spinel lherzolite and carbonated-garnet lherzolite.

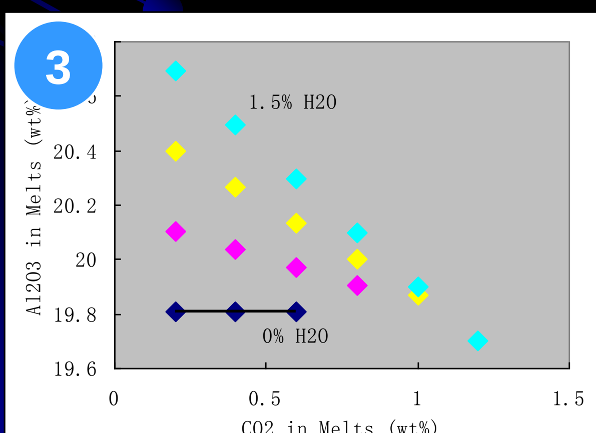
Effect of CO_2 on melt composition --Al_2O_3



Gudfinnsson & Presnall, 2005, J Petrol (3 GPa/CMAS+CO_2)
Dalton & Presnall, 1998, J Petrol (6 GPa/CMAS+CO_2)



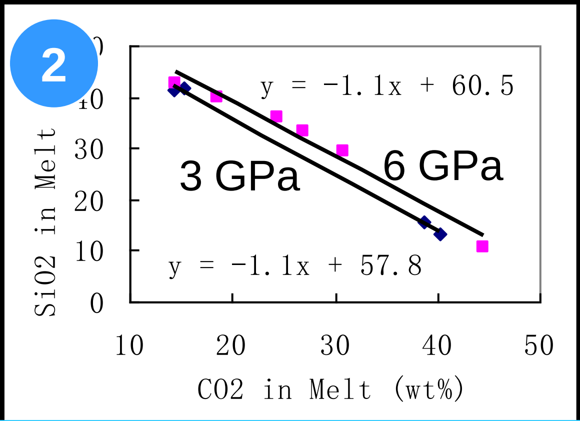
Dasgupta et al., 2007, J Petrol
(3GPa/1350ºC/natural compositions)



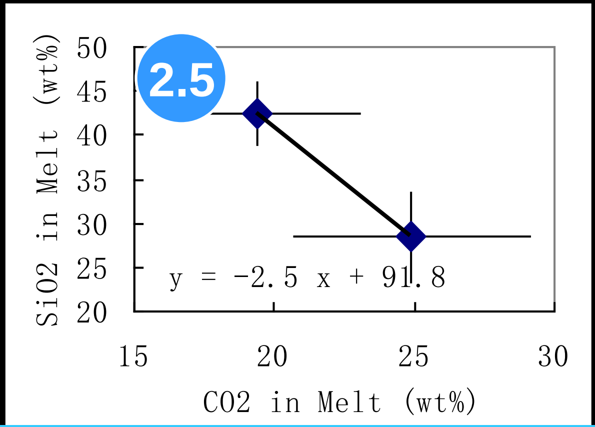
This Study (1.1 GPa/CMAS+CO_2+H_2O)

1. CO_2 mostly likely decreases the Al_2O_3 content, especially under wet condition;
2. Pressure appears to have significant influence on the effect of CO_2;
3. Other components might have strong influence too;
4. The effects of CO_2 on the Al_2O_3 content might be very different for carbonated-spinel lherzolite and carbonated-garnet lherzolite.

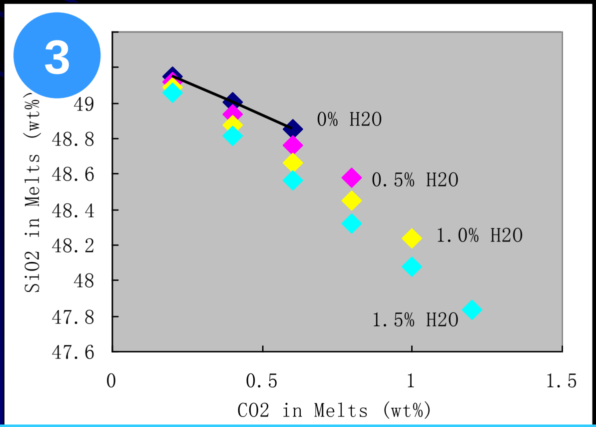
Effect of CO_2 on melt composition --SiO_2



Gudfinnsson & Presnall, 2005, J Petrol (3 GPa/CMAS+CO_2)
Dalton & Presnall, 1998, J Petrol (6 GPa/CMAS+CO_2)

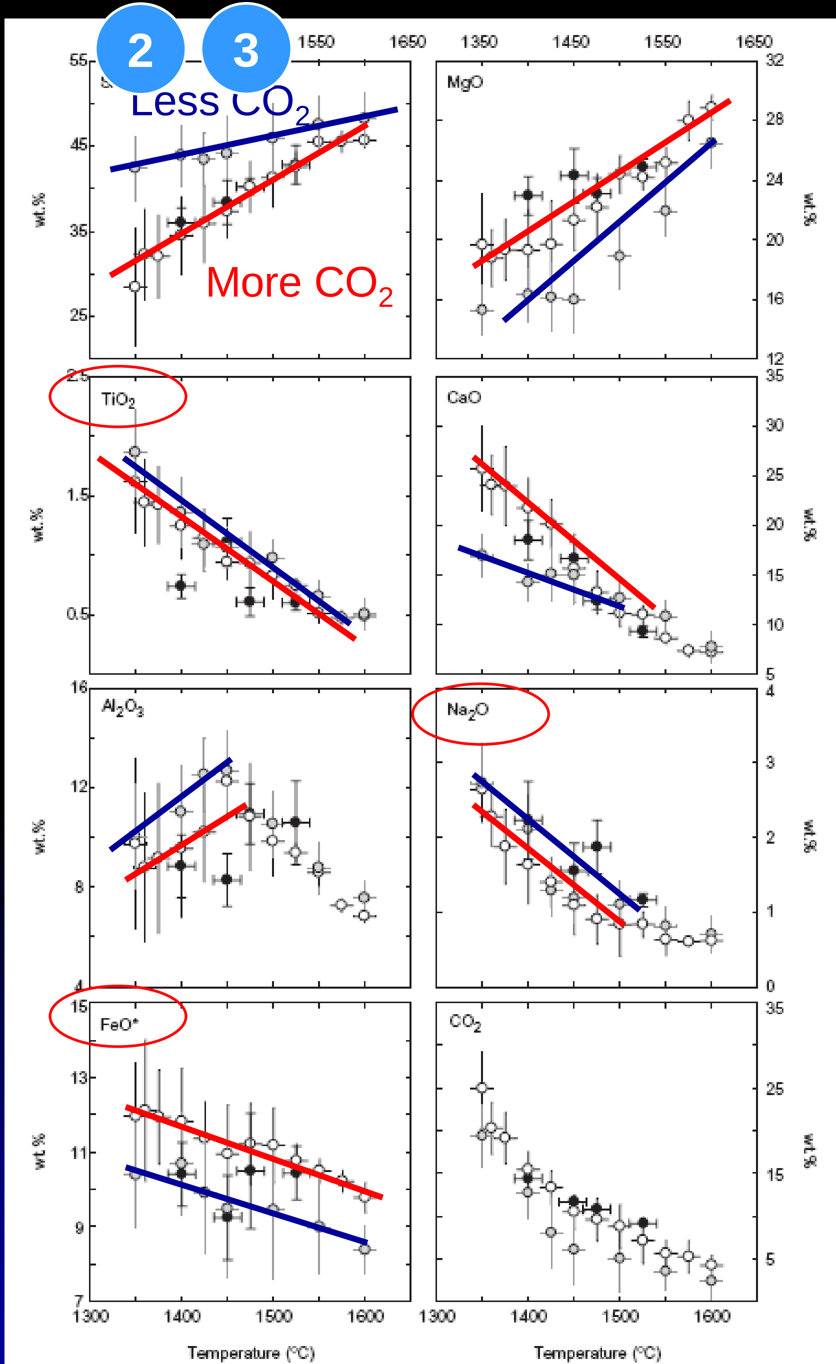


Dasgupta et al., 2007, J Petrol (3GPa/1350ºC/natural compositions)



This Study (1.1 GPa/CMAS+CO_2+H_2O)

1. CO_2 certainly decreases the SiO_2 content;
2. Pressure appears to have little effect on the effect of CO_2 on the SiO_2 content;
3. Other components might have strong effect;
4. The effects of CO_2 on the SiO_2 content might be very similar for carbonated-spinel lherzolite and carbonated-garnet lherzolite.



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Partial Melting Experiments of Peridotite + CO_2 at 3 GPa and Genesis of Alkalic Ocean Island Basalts

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Potential effects of CO_2 on other components:

TiO_2: negligible
Na_2O: very small
FeO*: potentially large

Conclusions:

1. The potential role of CO_2 in the partial melting process of the carbonated peridotite at dry condition is to decrease the melting temperature, and to increase the CaO and MgO content but decrease the Al_2O_3 and SiO_2 content of the melts; but the effect of CO_2 on the melting temperature and MgO content might be completely different with the presence of a small amount of H_2O;
2. The potential role of CO_2 on the content of TiO_2, Na_2O and FeO* might be negligible, small, large, respectively, according to the experimental data with the natural rock composition;
3. We still do not have any data in the natural rock composition system about the magnesite/dolomite-buffered partial melting of peridotite (stage 1); Nor do we have any data in the simple composition system;
4. The effects of CO_2, other components, phase assemblages, temperatures, and pressures on the partial melting of carbonated peridotite are still at large; more experiments at high pressures are necessary.

Thank you for your attention!