Thermodynamic constraints on assimilation of silicic crust by primitive magmas

EGU General Assembly 2021
vEGU21: Gather Online | 19–30 April 2021
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Jussi S. Heinonen, *University of Helsinki;* Frank J. Spera, *University of California Santa Barbara;* Wendy A. Bohrson, *Colorado School of Mines*

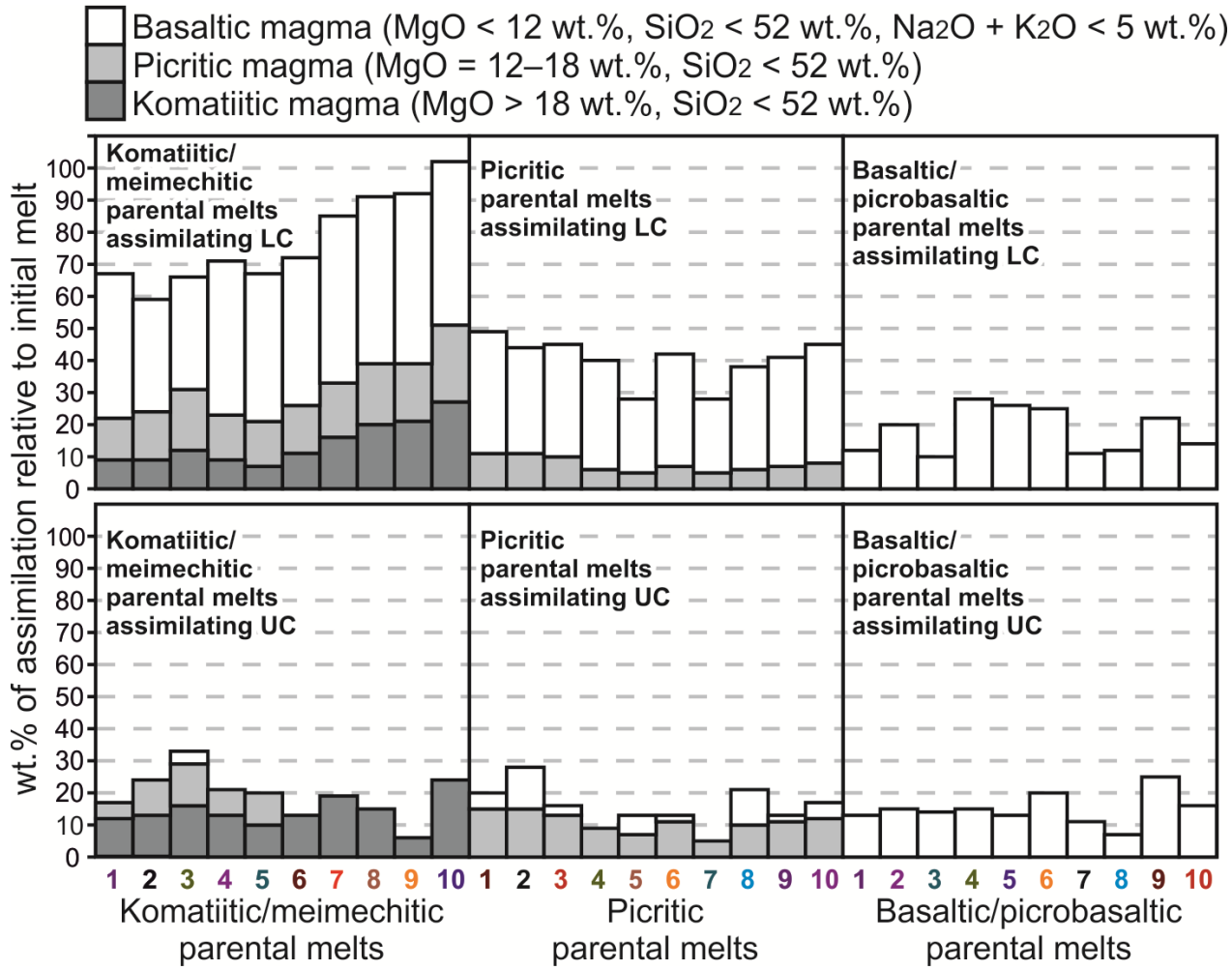
Question:
How much assimilation of silicate crust is possible by primitive magmas until they are not "primitive" anymore?

Study method:
Thermodynamic and geochemical modeling using the Magma Chamber Simulator

Models:
Parental melts of different composition (komatiitic, picritic, basaltic), age, and tectonic environment assimilate maximum amounts of average crustal materials.

Answer:

1. **Upper (or middle) crust: not much, 20–30 wt.%.**
2. **Lower crust: A LOT, up to their weight, i.e. ~100 wt.%.**



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MAGMA CHAMBER SIMULATOR

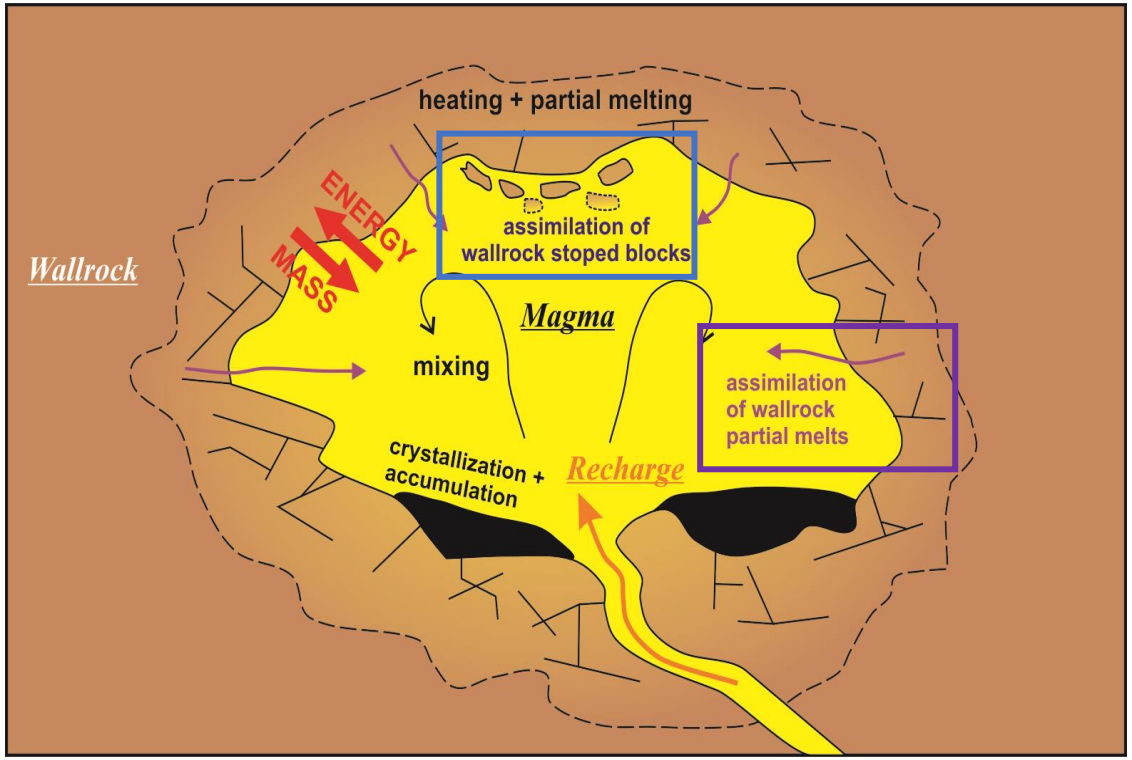
The Magma Chamber Simulator (**MCS**) is a numerical code that quantifies the **thermodynamic** and **geochemical** effects of magma **Recharge**, **Assimilation of partial melts** and/or **Stoped blocks**, and **Fractional Crystallization** (**RASFC**) on the evolution of a magma body and surrounding wallrock.

To maximize potential for assimilation:

- **Wallrock preheated above solidus but below percolation threshold (10 wt.% of melt) temperature**
  - **LC = 1060 °C @ 800 MPa**
  - **MC = 880 °C @ 500 MPa**
  - **UC = 700 °C @ 200 MPa**

Assimilation by stoping (bulk) vs. wallrock partial melting (selective)

- **Stoped blocks are heat sinks that substantially increase the crystallinity in the resident magma**
- **Assimilation of wallrock partial melts energetically favorable (crystallinity in all presented models below 50 wt.%)**



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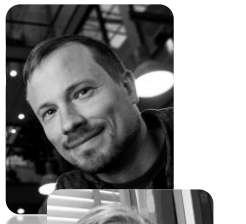

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Parental melts (SiO_2 < 52 wt.%):

Komatiitic/meimechitic (MgO > 18 wt.%)	Picritic (MgO = 12–18 wt.%)	Basaltic/picrobasaltic (MgO = <12 wt.%)
Etendeka LIP	Gorgona Island	Vanuatu arc
Karoo LIP (MEI)	Grassy Portage Bay GB	Early Central American arc
Siberian Traps (MEI)	NAIP	Kurile-Kamchatka arc
Gorgona Island	Hawaii	Iceland
Emeishan LIP	Karoo LIP	SWIR MORB
Belingwe GB	Ontong Java Plateau	Hawaii tholeiite
Abitibi GB	Ferrar LIP	Pyrolite model melt
Barberton GB	Deccan LIP	Aleutian arc
Commondale GB	Siberian Traps	Karoo LIP picrobasalt
Norseman-Wiluna GB	Siberian Traps 2	Ethiopian-Yemeni CFB

Wallrocks

Lower crust (avg)
basaltic andesitic
SiO_2 = 53 wt.%
at 800 MPa

Middle crust (avg)
dacitic
SiO_2 = 63 wt.%
at 500 MPa

Upper crust (avg)
dacitic
SiO_2 = 66 wt.%
at 200 MPa

Rudnick & Gao (2003), Treatise on Geochemistry 3, 1-64.

30 x 3 models = 90 altogether

Thermodynamic constraints on assimilation of lower crust by primitive magmas

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Komatiitic/meimechitic
1 Etendeka LIP
2 Karoo LIP (MEI)
3 Siberian Traps (MEI)
4 Gorgona
5 Emeishan LIP
6 Belingwe GB
7 Abitibi GB
8 Barberton GB
9 Commondale GB
10 Norseman-Wiluna GB

Picritic
1 Gorgona
2 Grassy Portage Bay GB (FP)
3 North Atlantic Igneous Province
4 Hawaii
5 Karoo LIP
6 Ontong Java Plateau
7 Ferrar LIP
8 Deccan LIP
9 Siberian Traps
10 Siberian Traps (FP)

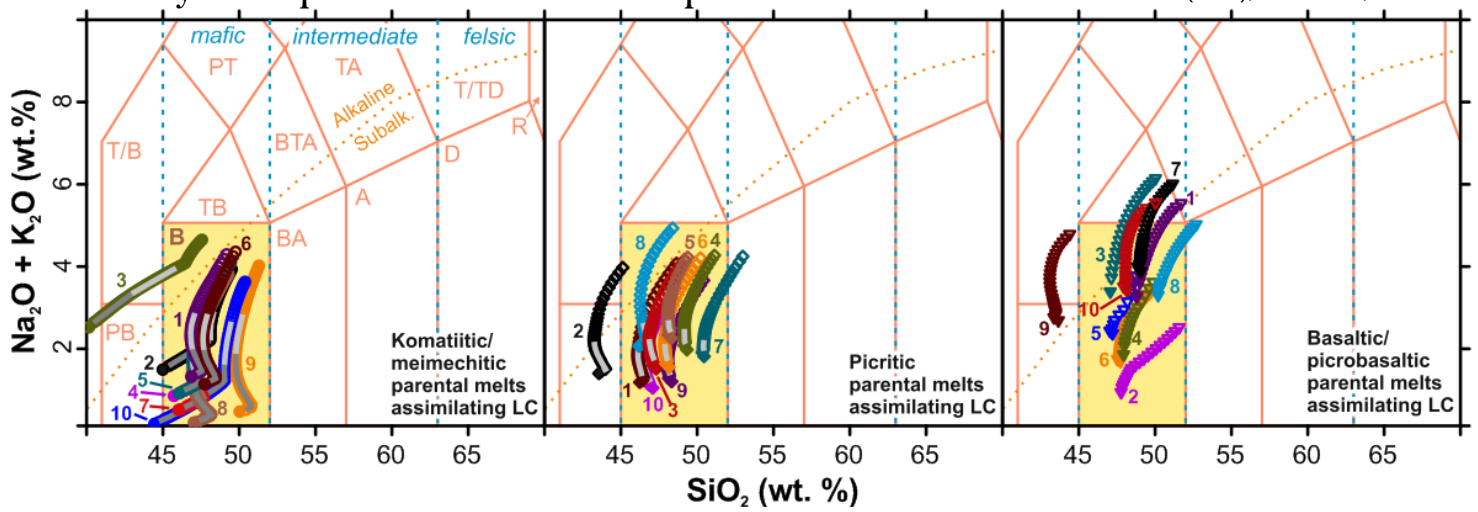
Basaltic/picrobasaltic
1 Vanuatu arc
2 Early Central American arc
3 Kurile-Kamchatka arc
4 Iceland
5 Southwest Indian Ridge MORB
6 Hawaii tholeiite
7 Pyrolite model melt
8 Aleutian arc
9 Karoo LIP picrobasalt
10 Ethiopian-Yemeni CFB

MgO > 18 wt.%

MgO = 12–18 wt.%

Each symbol represents an assimilation step

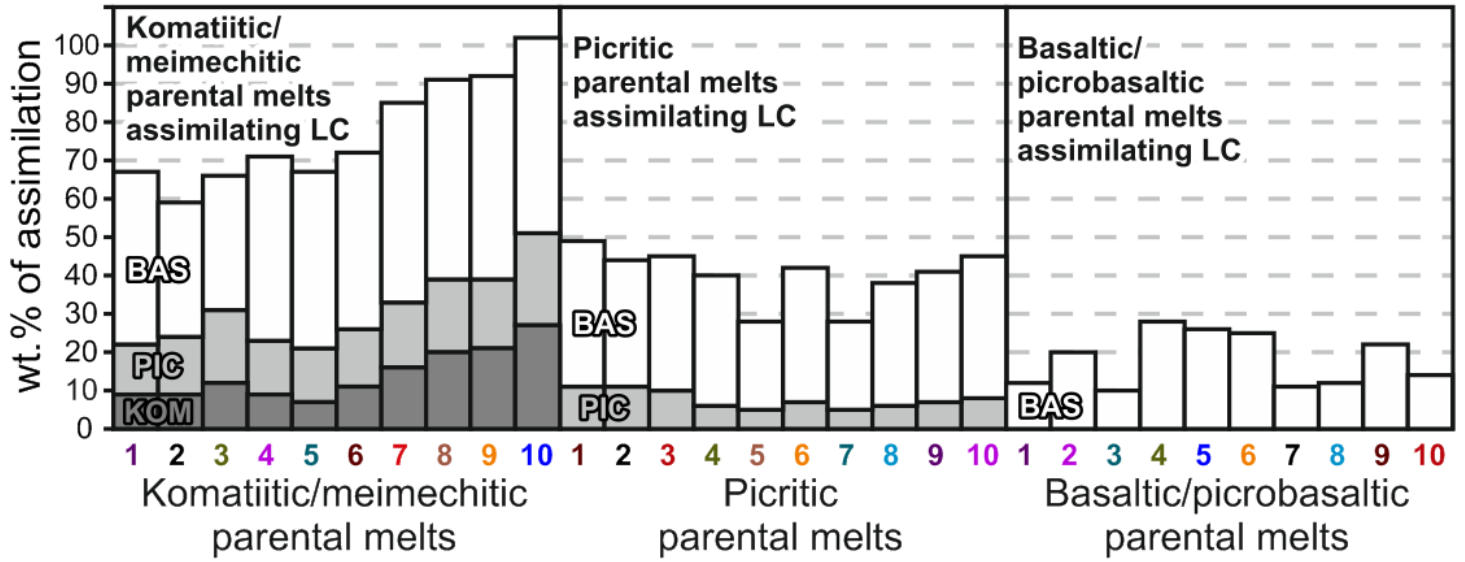
TAS classification: Le Bas et al. (1986), J Petrol 27, 745-750



OBSERVATIONS:

Slight increase in alkalinity

Considerable potential for assimilating LC and remaining below 52 wt.% of SiO2 in komatiitic and picritic melts



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Thermodynamic constraints on assimilation of upper crust by primitive magmas

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Komatiitic/meimechitic
1 Etendeka LIP
2 Karoo LIP (MEI)
3 Siberian Traps (MEI)
4 Gorgona
5 Emeishan LIP
6 Belingwe GB
7 Abitibi GB
8 Barberton GB
9 Commondale GB
10 Norseman-Wiluna GB

Basaltic/picrobasaltic
1 Vanuatu arc
2 Early Central American arc
3 Kurile-Kamchatka arc
4 Iceland
5 Southwest Indian Ridge MORB
6 Hawaii tholeiite
7 Pyrolite model melt
8 Aleutian arc
9 Karoo LIP picrobasalt
10 Ethiopian-Yemeni CFB

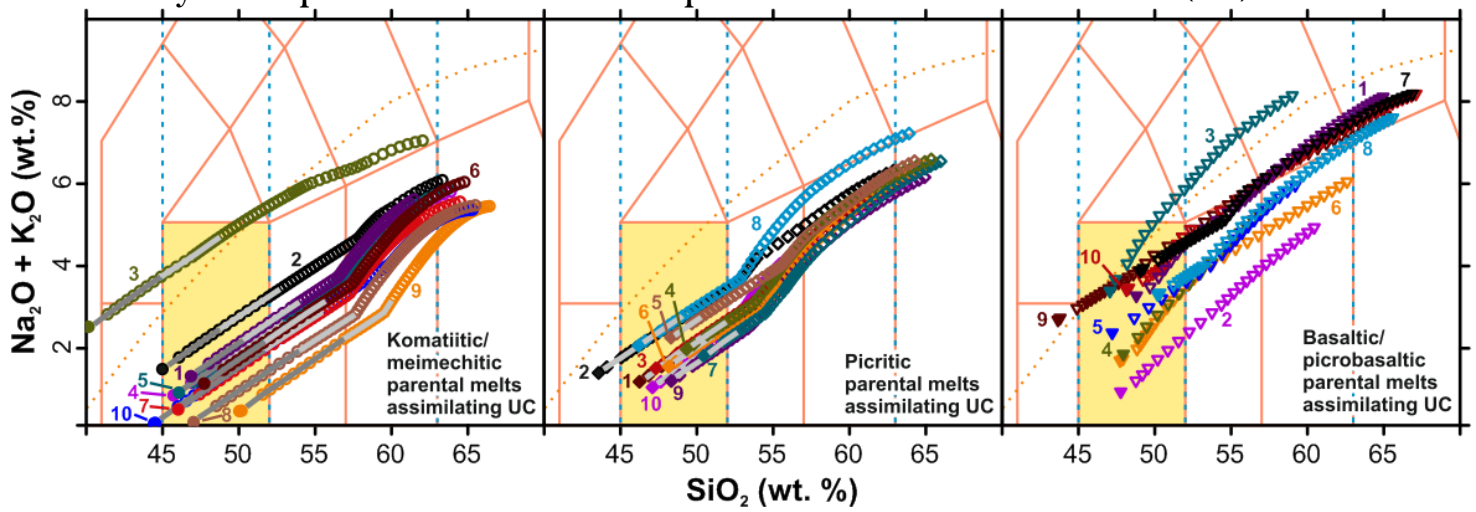
Picritic
1 Gorgona
2 Grassy Portage Bay GB (FP)
3 North Atlantic Igneous Province
4 Hawaii
5 Karoo LIP
6 Ontong Java Plateau
7 Ferrar LIP
8 Deccan LIP
9 Siberian Traps
10 Siberian Traps (FP)

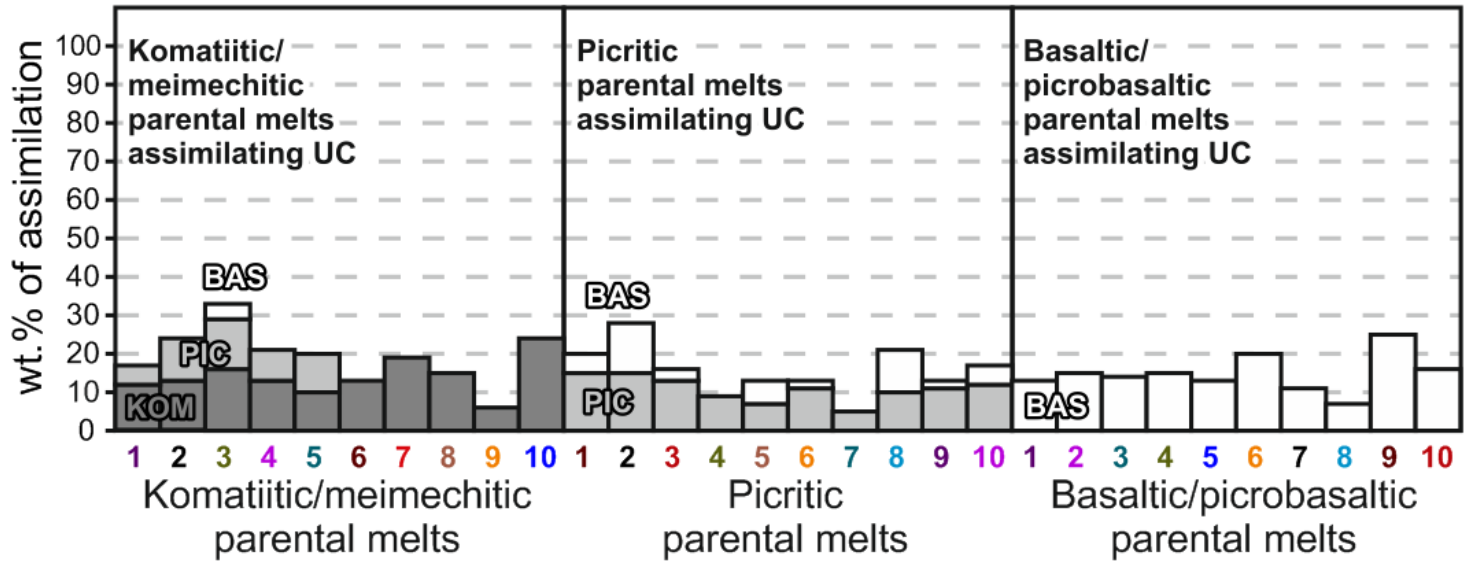
MgO > 18 wt.%

MgO = 12–18 wt.%

Each symbol represents an assimilation step

TAS classification: Le Bas et al. (1986), J Petrol 27, 745-750





OBSERVATIONS:

Considerable increase in SiO_2

Very low potential for assimilating UC and SiO_2 remaining below 52 wt.% for any parental melt

Thermodynamic constraints on assimilation of middle crust by primitive magmas

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Komatiitic/meimechitic
1 Etendeka LIP
2 Karoo LIP (MEI)
3 Siberian Traps (MEI)
4 Gorgona
5 Emeishan LIP
6 Belingwe GB
7 Abitibi GB
8 Barberton GB
9 Commondale GB
10 Norseman-Wiluna GB

Picritic
1 Gorgona
2 Grassy Portage Bay GB (FP)
3 North Atlantic Igneous Province
4 Hawaii
5 Karoo LIP
6 Ontong Java Plateau
7 Ferrar LIP
8 Deccan LIP
9 Siberian Traps
10 Siberian Traps (FP)

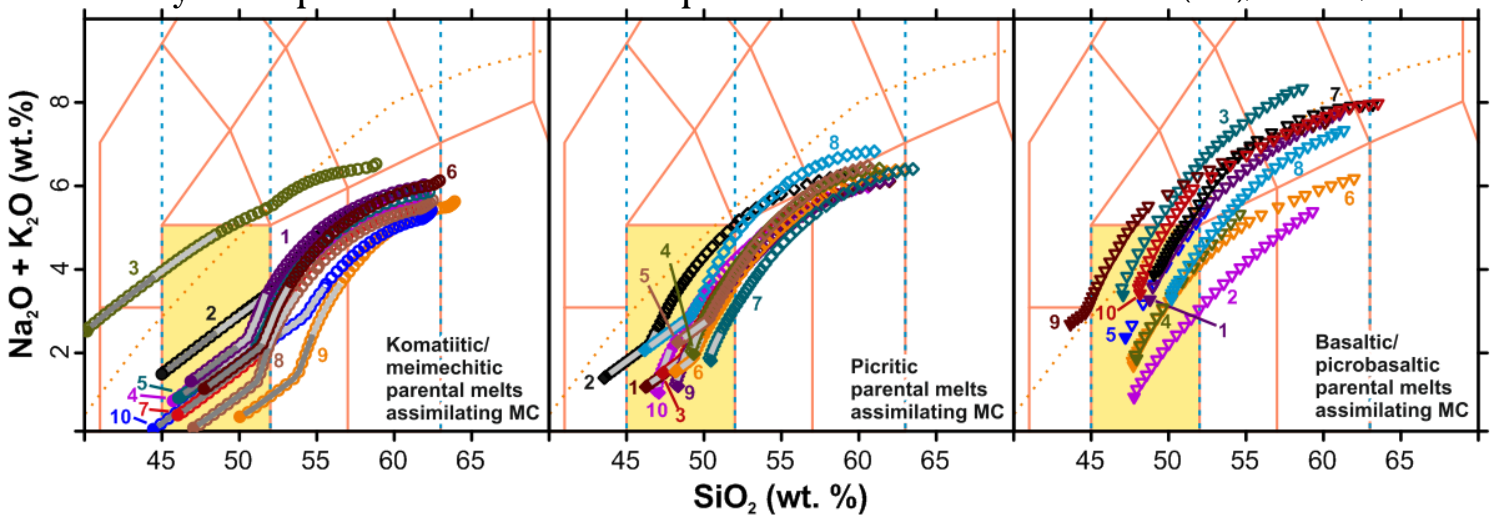
Basaltic/picrobasaltic
1 Vanuatu arc
2 Early Central American arc
3 Kurile-Kamchatka arc
4 Iceland
5 Southwest Indian Ridge MORB
6 Hawaii tholeiite
7 Pyrolite model melt
8 Aleutian arc
9 Karoo LIP picrobasalt
10 Ethiopian-Yemeni CFB

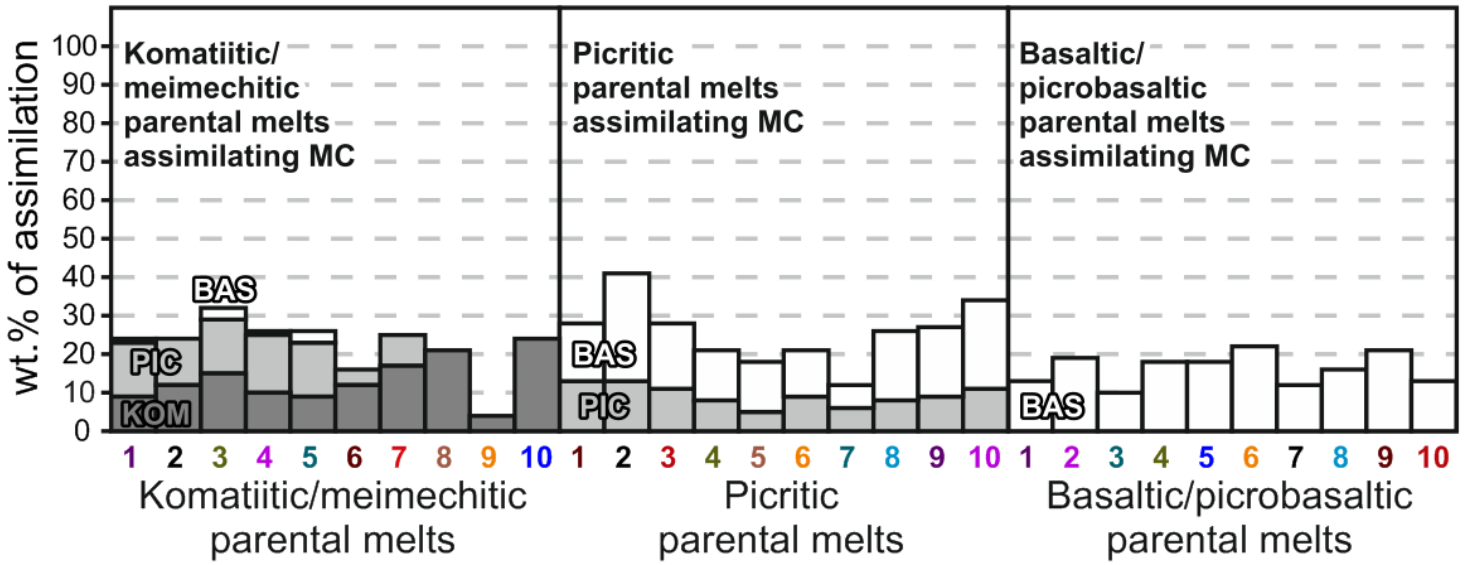
MgO > 18 wt.%

MgO = 12–18 wt.%

Each symbol represents an assimilation step

TAS classification: Le Bas et al. (1986), J Petrol 27, 745-750





OBSERVATIONS:

Transitional between models of LC and UC assimilation, but more similar to the latter

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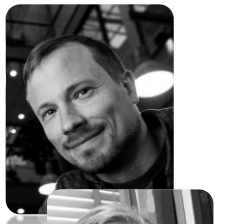

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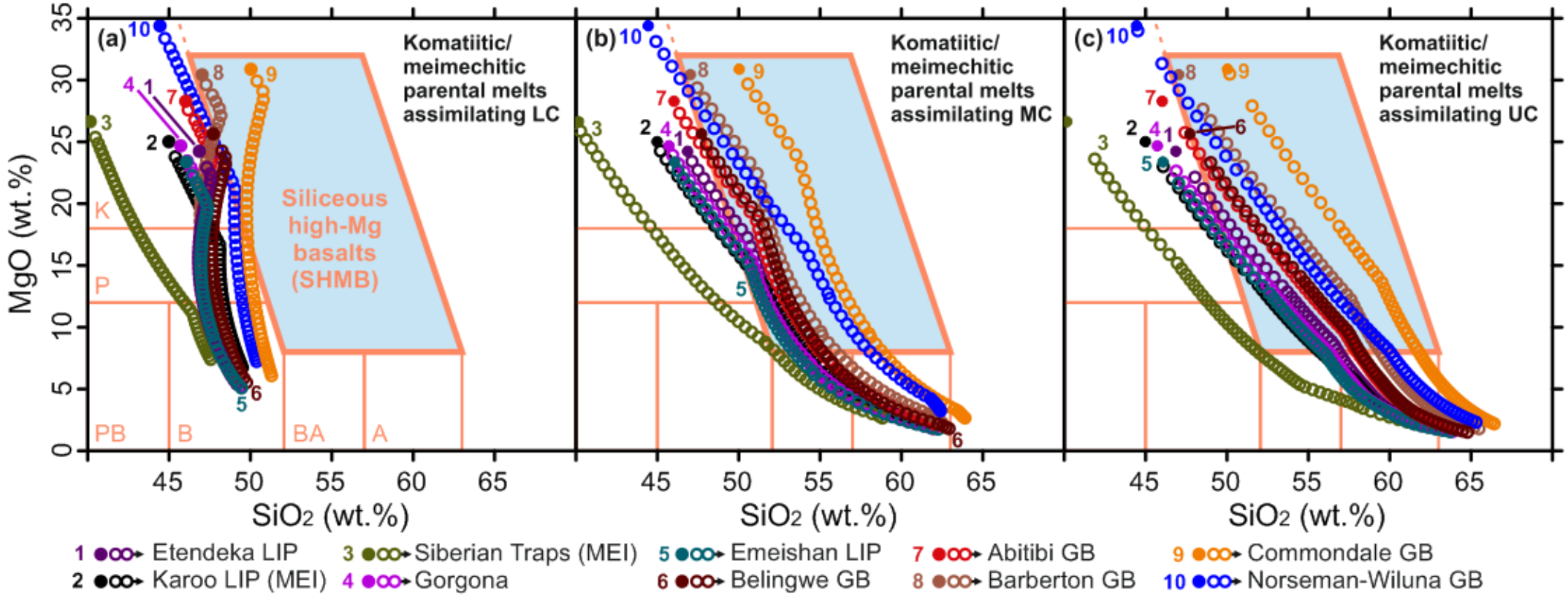
An additional look on the models in SiO2 vs. MgO space and implications for the generation of siliceous high-Mg basalts (SHMB)



SHMB classification: Pearce & Reagan (2019), Geosphere 15, 1008-1037.

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CONCLUSIONS

- It is difficult for any subalkaline primitive magma to assimilate more than 20–30 wt.% of UC or MC before evolving to compositions with higher SiO2 than a basaltic magma (52 wt.%).
  - Basaltic magmas cannot assimilate any silicate crustal materials in excess of 20–30 wt.% and remain basaltic
  - SHMBs generated by assimilation of UC/MC by komatiitic magma
- Typical komatiitic and picritic magmas have thermodynamic potential to assimilate considerable amounts (60–100 wt.% and 30–50 wt.%, respectively) of LC and retain a basaltic composition.
  - Generation of basaltic magmas with considerable crustal overprint (e.g., massif-type anorthosites)?
  - Generation of large-scale mineralization fronts related to mafic magmas in lower crust?
  - Crustal growth vs. crustal recycling!
- **Thermodynamic models, as presented here, provide a framework over which additional kinetic and dynamic constraints can be placed to study natural systems in more detail.**

Publicly available for Mac and PC: https://mcs.geol.ucsb.edu/code
(or google "Magma Chamber Simulator")

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MCS presentations in this conference:

SC5.20 EDI
Showcasing the Magma Chamber Simulator
Co-organized by GMPV
Convener: Jussi Heinonen | Co-conveners: Wendy Bohrson, Riikka Fred[ECS], Frank Spera, Ville Virtanen[ECS]
Tue, 27 Apr, 16:00–17:00 (CEST)

Short course

EGU21-6922 | vPICO presentations | GMPV8.1/EMRP1.10/NH2.8
The Origin and Melt Evolution of Massif-type Anorthosite Parental Magmas: Thermodynamically Controlled Major Element Constraints
Riikka Fred, Aku Heinonen, and Jussi S. Heinonen
Mon, 26 Apr, 11:16–11:18

EGU21-2570 | vPICO presentations | GMPV8.1/EMRP1.10/NH2.8
Modelling the production of linear trends in granitoids using the Magma Chamber Simulator: a case study of the Jindabyne Suite from the Lachlan Fold Belt, Australia
Kieran Iles and Jussi Heinonen
Mon, 26 Apr, 11:14–11:16

EGU21-7903 | vPICO presentations | GMPV5.2/ERE5.5
Modeling the sulfide saturation in continuously assimilating magmatic systems with the Magma Chamber Simulator
Ville Virtanen, Jussi Heinonen, Nicholas Barber, and Ferenc Molnár
Thu, 29 Apr, 15:35–15:37

Thank you!

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