The Origin and Melt Evolution of Massif-type Anthorthosite Parental Magmas: Thermodynamically Controlled Major Element Constraints

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PROBLEM

What is the source, composition, and crystallization history of massif-type anorthosite parental magmas?

THERMODYNAMIC MODELING

- Magma Chamber Simulator
- rhyolite-MELTS

MODELS

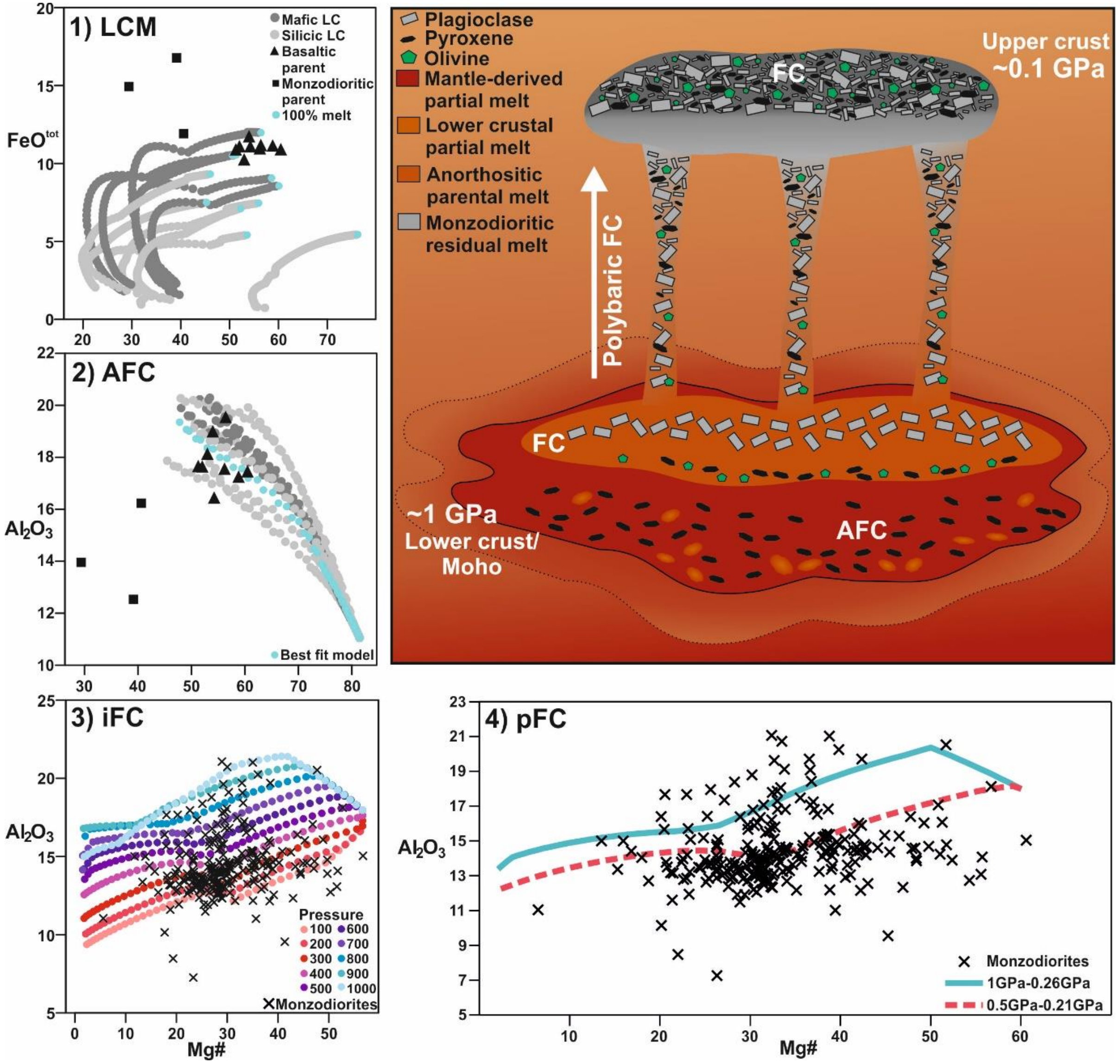
1. Lower crustal melts (LCM)
2. Assimilation-fractional crystallization (AFC)
3. Isobaric fractional crystallization after AFC (iFC)
4. Polybaric fractional crystallization after AFC (pFC)

COMPARISON DATA

- Suggested parental melt compositions (high-Al basaltic and monzodioritic)
- Suggested residual melt compositions (monzodioritic)

OUTCOME

- Mantle-derived magma assimilated mafic lower crustal material leading to production of basaltic massif-type anorthosite parental magmas
- Further fractional crystallization of the basaltic parental melts gives similar melt evolution trends to those shown by the monzodioritic rocks



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Massif-type anorthosite problematics

- What is the composition of the parental magmas?
    - High-Al basaltic (e.g., Ashwal and Bybee 2017) vs. monzodioritic (jotunitic; e.g., Duchesne et al. 1999) compositions parental magma compositions
- What is the source for the parental magmas?
    - mantle-derived melts with crustal contamination (e.g., Bybee et al. 2014) vs. lower crustal melts (e.g., Duchesne et al. 1999)
- Polybaric fractional crystallization from lower crustal levels (~1000 MPa) to upper crustal emplacement levels (~100 MPa; e.g. Bybee et al. 2014, Heinonen et al. 2020)
- Several suggestions for the origin of the related monzodioritic rocks, but they rather represent residual melt than parental melt compositions (Fred et al. 2020)
- **Here we use thermodynamic major element modeling to shed light on the remaining questions concerning the petrogenesis of massif-type anorthosites**

Ashwal & Bybee 2017, Earth-Sci Rev 173; Duchesne et al. 1999, Terra Nova 11; Bybee et al. 2014, Earth Plan Sci Let 389; Heinonen et al. 2020, Contr to Min Pet 175; Fred et al. 2020, Contr to Min Pet 75.

Rhyolite-MELTS and Magma Chamber Simulator (MCS)

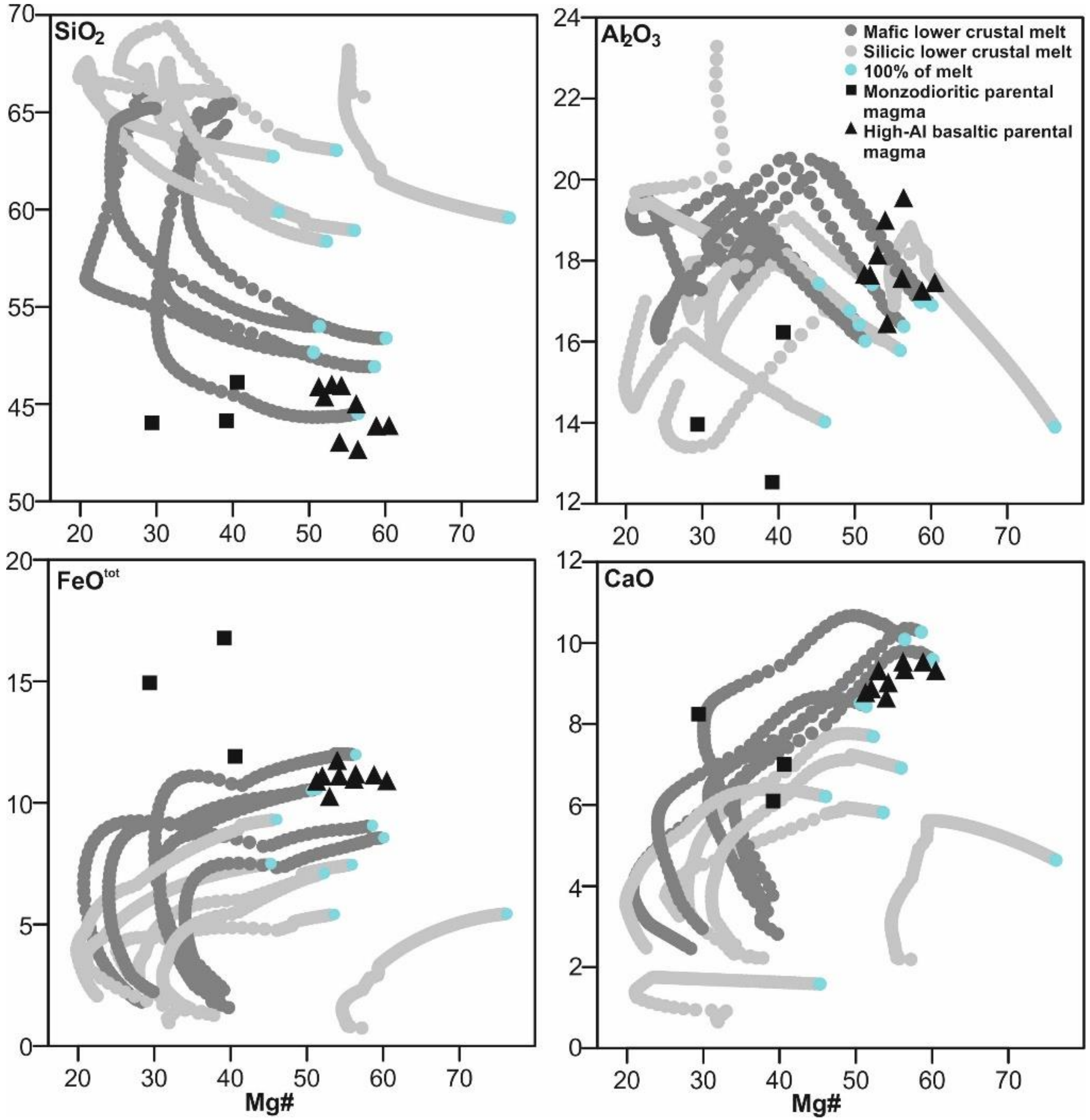
- Rhyolite-MELTS is a code that can be used to facilitate thermodynamic modeling of phase equilibria in magmatic systems (Gualda et al. 2012) http://melts.ofm-research.org/

- The MCS is a thermodynamic modeling tool that can be used to model simultaneous magma crystallization, recharge, and assimilation in an evolving multicomponent-multiphase open magmatic system (Bohrson et al. 2014) https://mcs.geol.ucsb.edu/

Gualda et al. 2012, J Pet 53; Bohrson et al. 2014, J Pet 55.

Lower crustal melts

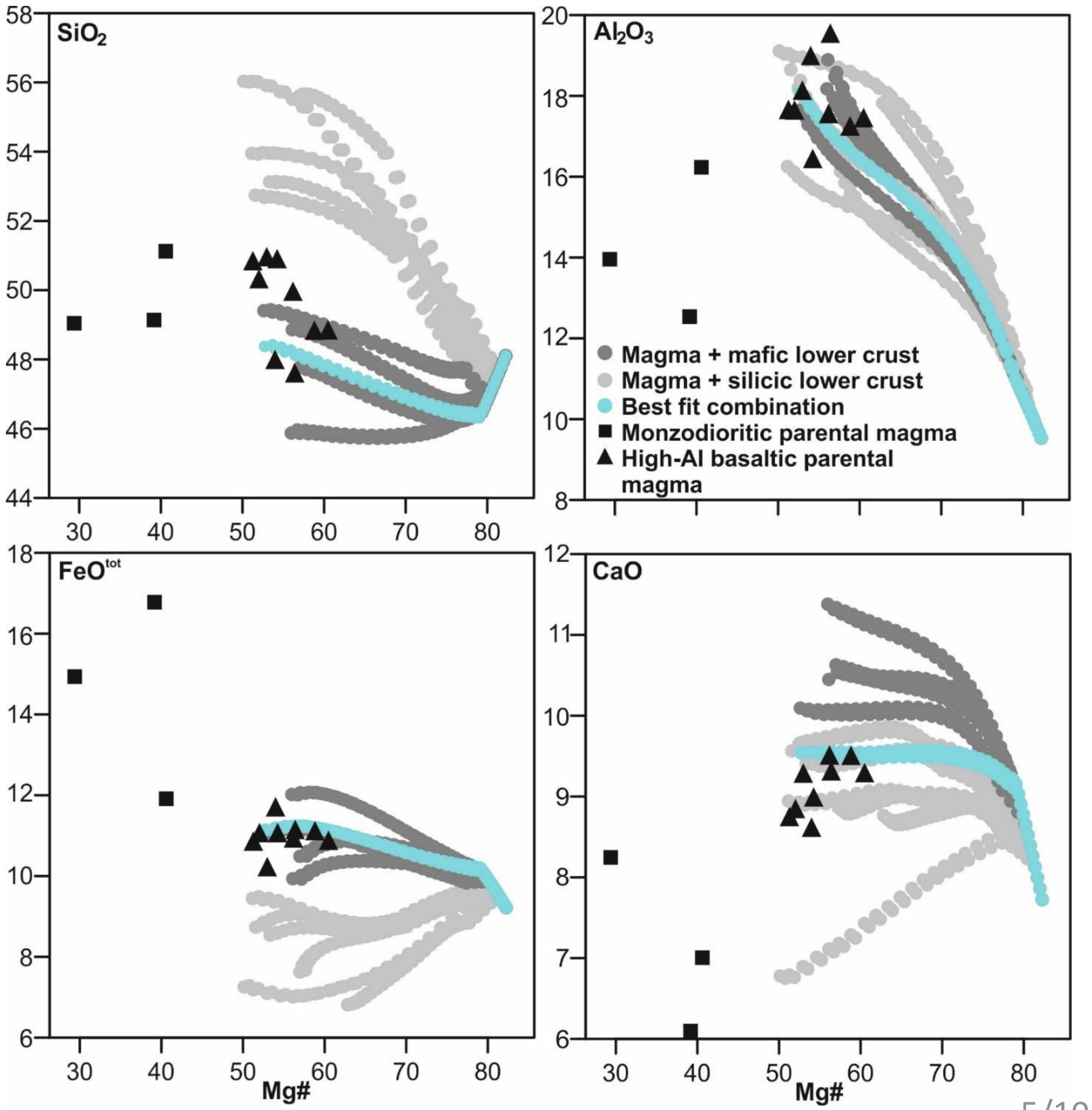
- 11 lower crustal compositions compiled in Rudnick and Gao (2003)
- Equilibrium melting using rhyolite-MELTS at 1000 MPa
- Comparison data: suggested high-Al basaltic and monzodioritic parental melt compositions (Berg 1980, Demaiffe and Hertogen 1981, Morse 1981, Mitchell et al. 1996, Charlier et al. 2010)
- Melts similar to basaltic parental melt compositions can be produced, but not with monzodioritic parental melts
- Requires the crust to melt completely



Rudnick & Gao 2003, Treatise on Geochemistry 3, 1-64; Berg 1980, Contr to Min Pet 72; Demaiffe and Hertogen 1981, Geohem Cosmochin Acta 45; Morse 1981, Geohem Cosmochim Acta 45; Mitchell et al. 1996, J Pet 37; Charlier et al. 2010, J Pet 51.

Assimilation-fractional crystallization

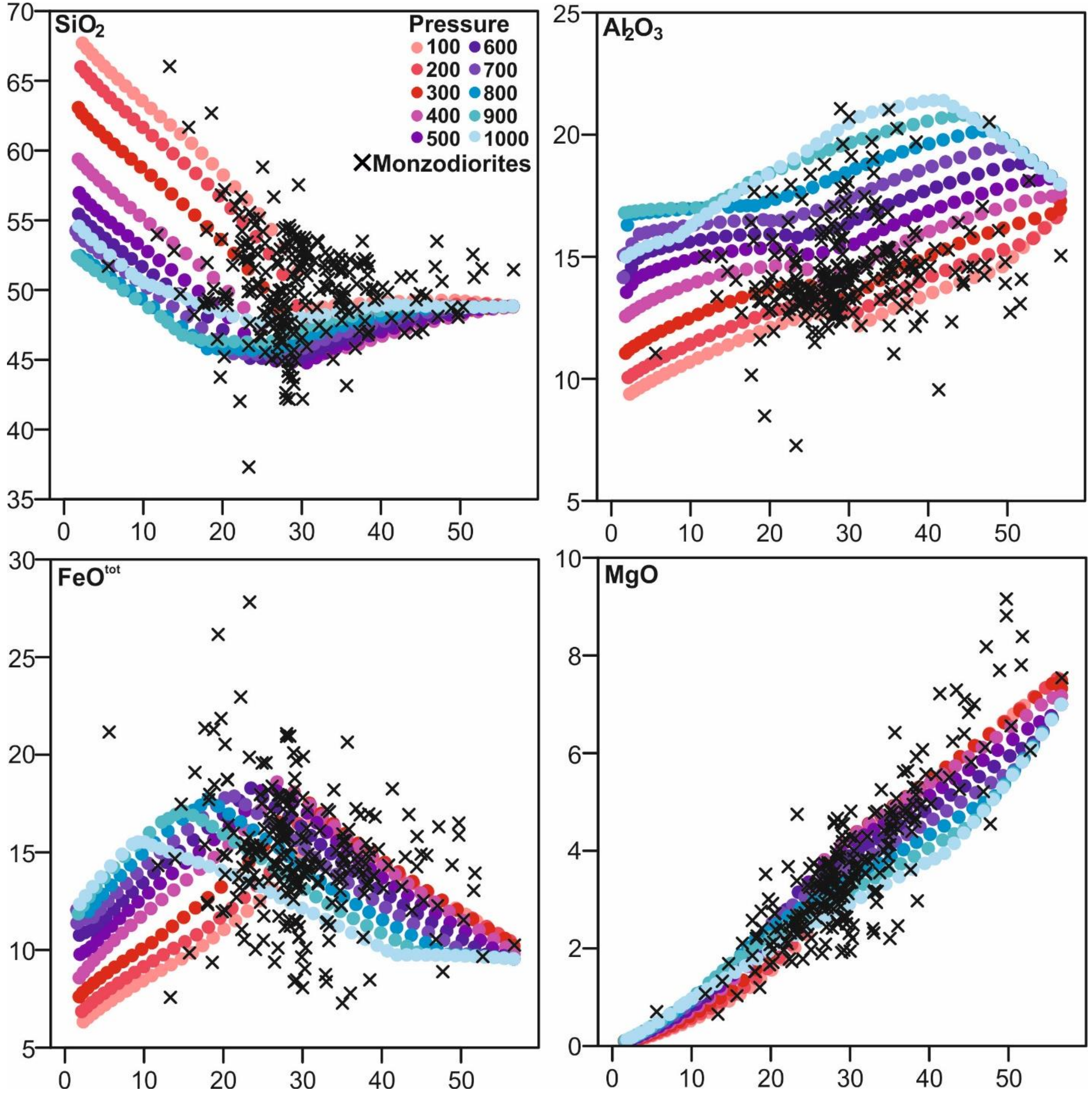
- 4 mantle-derived partial melts (Walter 1998; Takahashi 1986) were used as magma compositions and 11 lower crustal compositions (Rudnick and Gao 2003) as wallrock compositions
- Assimilation-fractional crystallization using MCS at 1000 MPa
- Similar melts with basaltic parental melts can be produced, but not with monzodioritic parental melts
- Best results were received using more mafic wallrock compositions



Walter 1998, J Pet 39; Takahashi 1986, Journal of Geophysical Research 91.

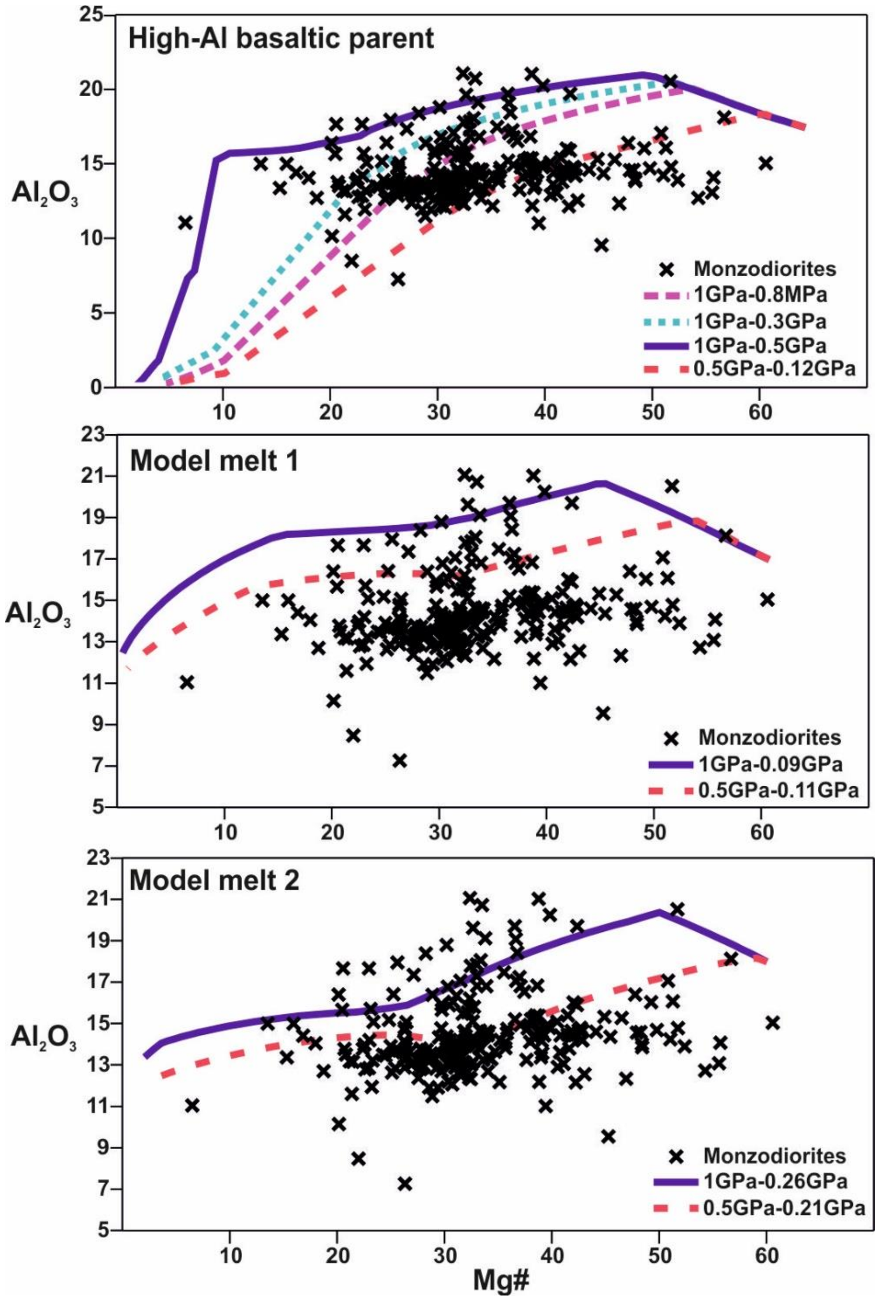
Isobaric fractional crystallization

- 5 starting compositions: two model melt compositions after AFC, one basaltic parent, and two monzodioritic parents
- Comparison data: global data set of monzodioritic rocks (Fred et al. 2020)
- Fractional crystallization using MCS at pressures of 100-1000 MPa
- Model melt and basaltic parent compositions produce similar melt evolution trends to those of the monzodioritic rocks

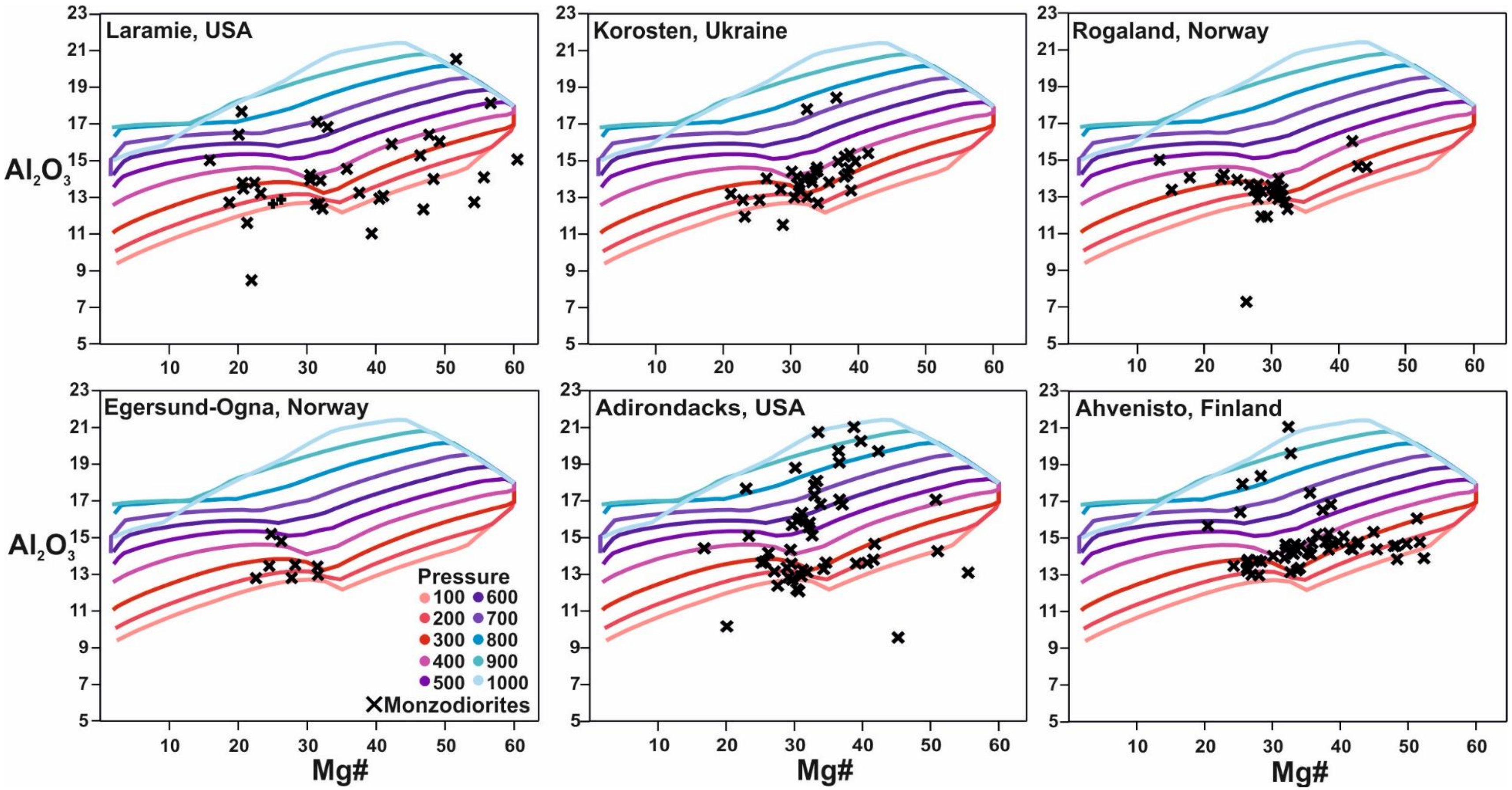


Polybaric fractional crystallization

- 3 starting compositions: one basaltic parent and two model melts after AFC
- Polybaric fractional crystallization using rhyolite-MELTS with different starting pressures and varying dP/dT
- Best fit with the general monzodioritic trend is produced in polybaric FC at lower pressures (500 MPa →)
- The monzodioritic data show wide variation in some elements
  - Is this a general phenomenon or more local?



Local comparison



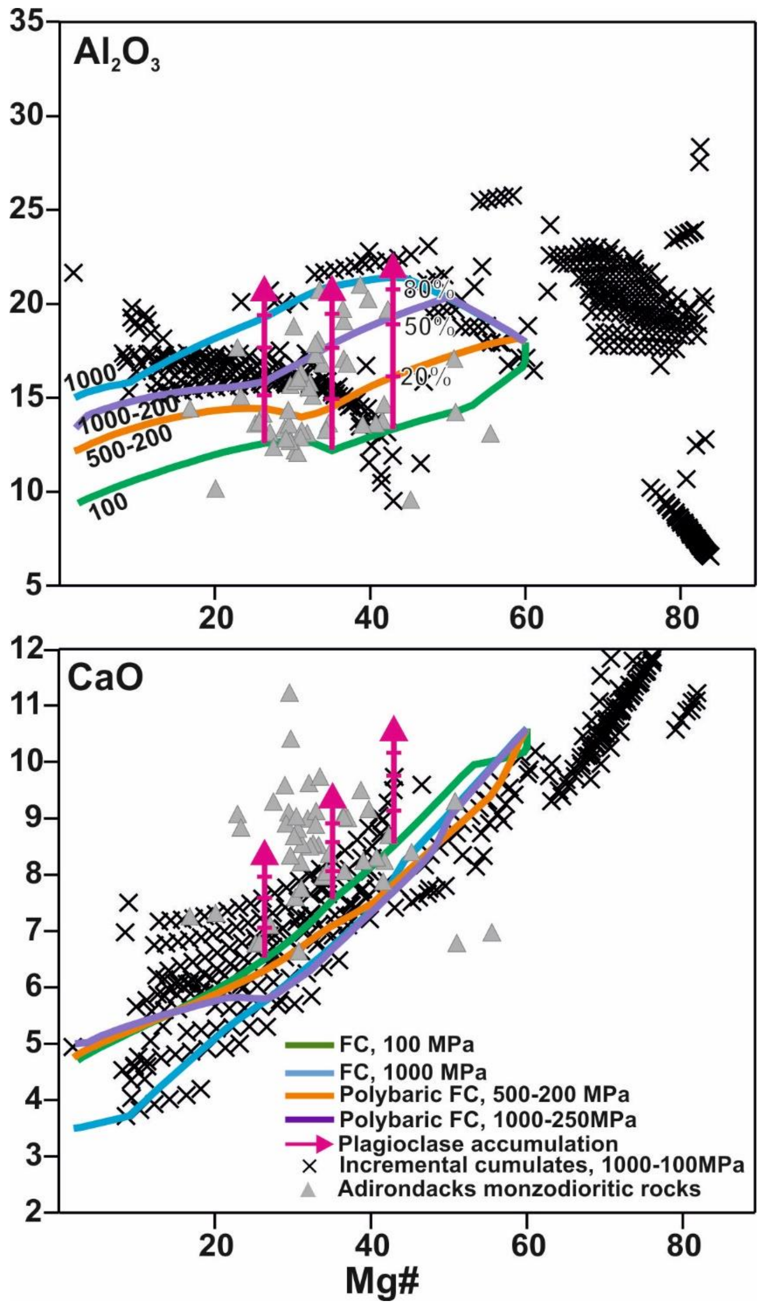
- Locally the usual monzodioritic trend is similar to the melt evolution trends at lower pressures
- In few intrusions some samples deviate from the main trend
- Is this due to different crystallization pressure or are there other possible explanations?

Implications of crystallization and accumulation processes

- Comparison of monzodioritic rocks from Adirondacks mountains to
  - Polybaric and isobaric FC melt evolution trends
  - Incremental cumulate compositions of FC simulation
  - Plagioclase accumulation trend

- Majority of the global monzodioritic data plot on similar trend

→ We suggest that some of the samples in the dataset contain cumulus plagioclase or actually represent anorthositic cumulates



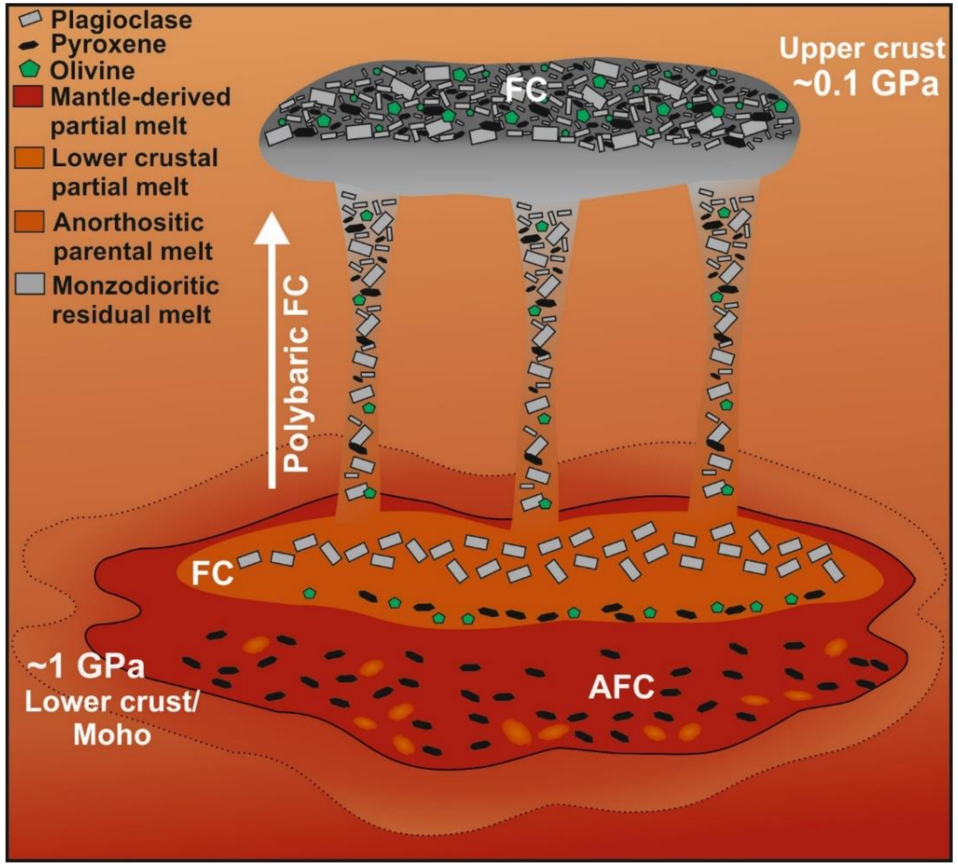
Conclusions

- We suggest that a mantle-derived magma assimilated mafic lower crustal material at deep crustal levels (~1000 Mpa) leading to production of high-Al basaltic parental melts

- The production of parental melts by melting the lower crust only would require the crust to melt completely, which we consider improbable

- Further fractional crystallization of the basaltic parental melts gives similar melt evolution trends to those shown by the monzodioritic rocks

- Despite the limitations of the modeling software and simplifications of our models, the results suggest that our models represents the general processes during massif-type anorthosite formation and provides foundation for more detailed modeling in the future



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