The Origin and Melt Evolution of Massif-type Anorthosite 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)

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

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

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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

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/
Lower crustal melts

• 11 lower crustal compositions compiled in Rudnick and Gao (2003)

• Equilibrium melting using rhyolite-MELTS at 1000 MPa


• Melts similar to basaltic parental melt compositions can be produced, but not with monzodioritic parental melts

• Requires the crust to melt completely
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.

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

Thank you!

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