Major Element Variations in the Evolving Skaergaard Magma Chamber

A Computer Simulation to test the sequential extraction model

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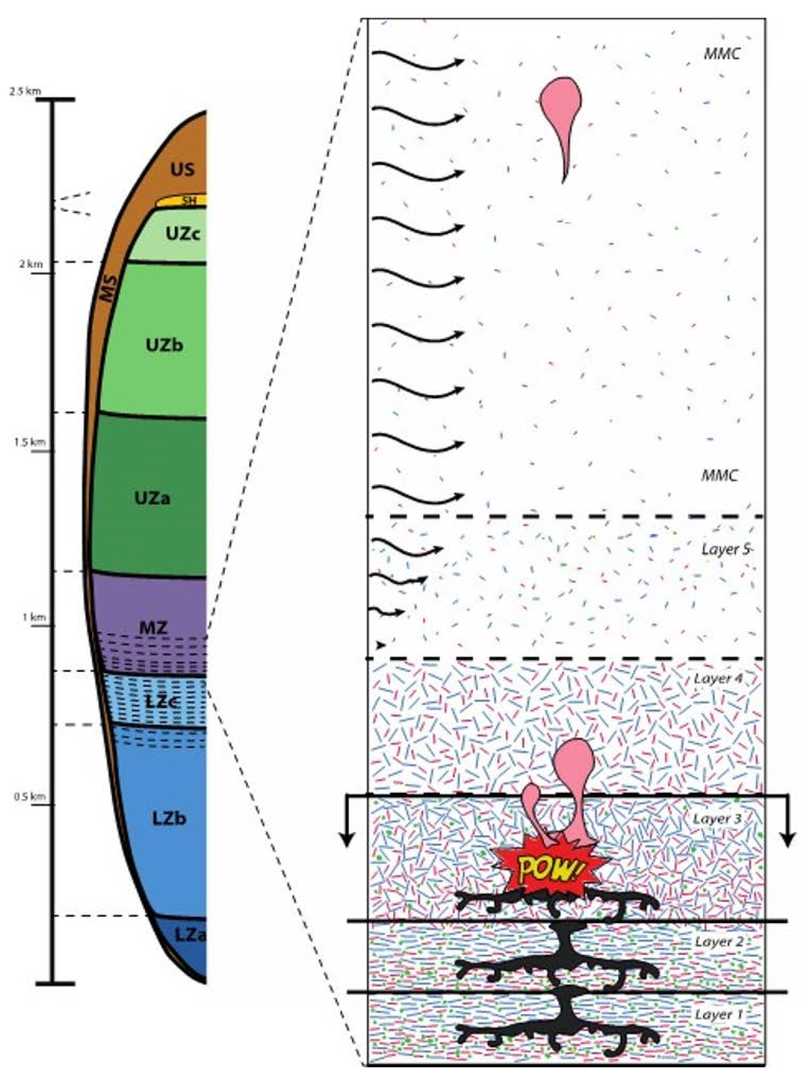
Abstract

Chemical evolution within basaltic magma chambers is still the subject of intense debate. The Skaergaard Intrusion in southeast Greenland has been the subject of considerable study for nearly a century, and yet today no consensus exists to explain several first-order observations of the crystallized magma body. Recently, a promising new model, the Sequential Extraction Model (SEM), was proposed to explain the many enigmatic features observed in the Skaergaard intrusion. The SEM invokes the process of liquid immiscibility inside segregated boundary layers that form at the bottom of the evolving magma chamber. Two resultant liquids with dramatically different densities physically separate from one another. Here, we test the SEM using a computer simulation that follows the crystallization sequence within the cooling magma body. To guide chemical evolution of the magma within the code, we use the observed modal abundances and chemical compositions of the main primocryst phases (olivine, pyroxene, and feldspar) measured within the intrusion. Our code allows us to set constraints on such parameters as the amount of buoyant liquid that accumulates above layered mafic intrusions and the relative amount of this material that is returned to the magma chamber upon ascent.

Introduction

Sequential Extraction model

Basaltic magma chambers are thought to undergo convection while they cool and crystallize. This process necessarily establishes a boundary layer between the convecting magma and the stagnant floor. As the boundary layer cools, new minerals continue to crystallize until the layer becomes too stiff to continue convective motion. At this point, a new boundary layer is established above this layer. The interstitial liquid in the underlying layer continues to crystallize until it reaches a composition whereby it splits into two conjugate liquids (one Si-rich and the other Fe-rich) with dramatically different densities. The bulk of Si-rich material ascends out of the layer into the overlying convecting chamber and beyond. Some of this material is entrained into the magma chamber, and some ascends to the roof (and beyond). The dense Fe-rich material cannot escape the boundary layer.

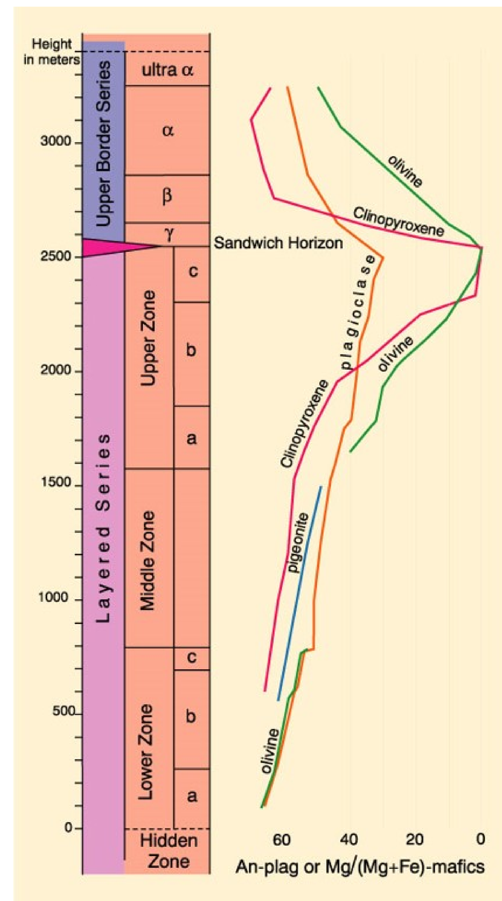


Sequential Extraction Model and Liquid Immiscibility

Method

Using previous data

Using data from previous studies (Brown & Vincent, 1961; Maaloe, 1976; Tegner et al., 2009), we fit expressions that describe the change in chemical composition and modal abundance of olivine, orthopyroxene, clinopyroxene, and feldspar with depth in the Skaergaard intrusion.



Winter, J. D. (2001). *An Introduction to Igneous and Metamorphic Petrology*. Upper Saddle River, NJ: Pentice-Hall. Page 231

Adjustable parameters

- Initial mass of magma chamber
- Number of boundary layers
- Percent of layer that crystallizes in equilibrium with magma chamber
- Percent of layer that crystallizes before interstitial liquid reaches immiscibility
- Percent of ascending Si-rich material that remixes back into overlying magma chamber

Other parameters

- Weight percent of each oxide:
  - SiO2
  - Al2O3
  - CaO
  - FeO
  - MgO
  - Na20
  - K20
  - TiO2

Flow of the program

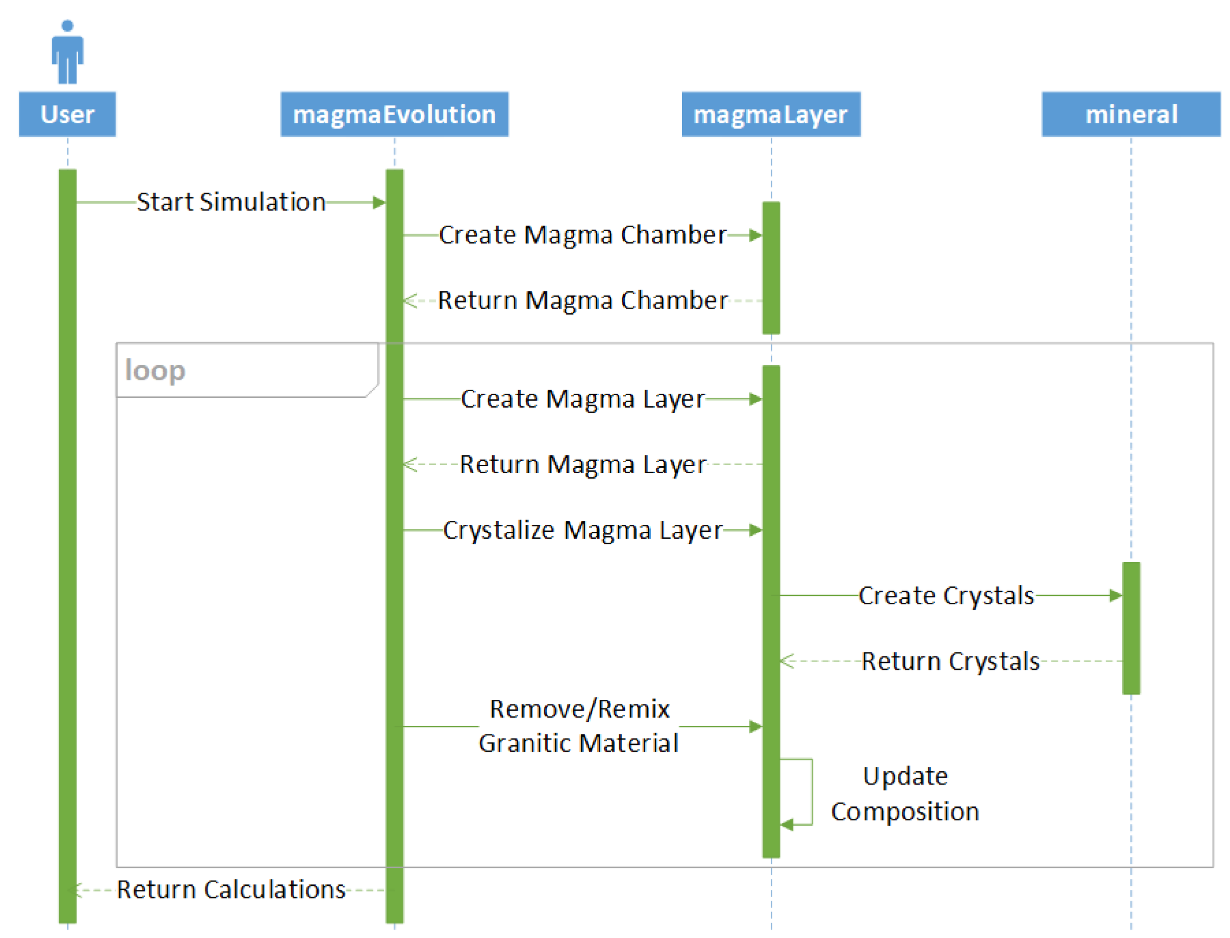
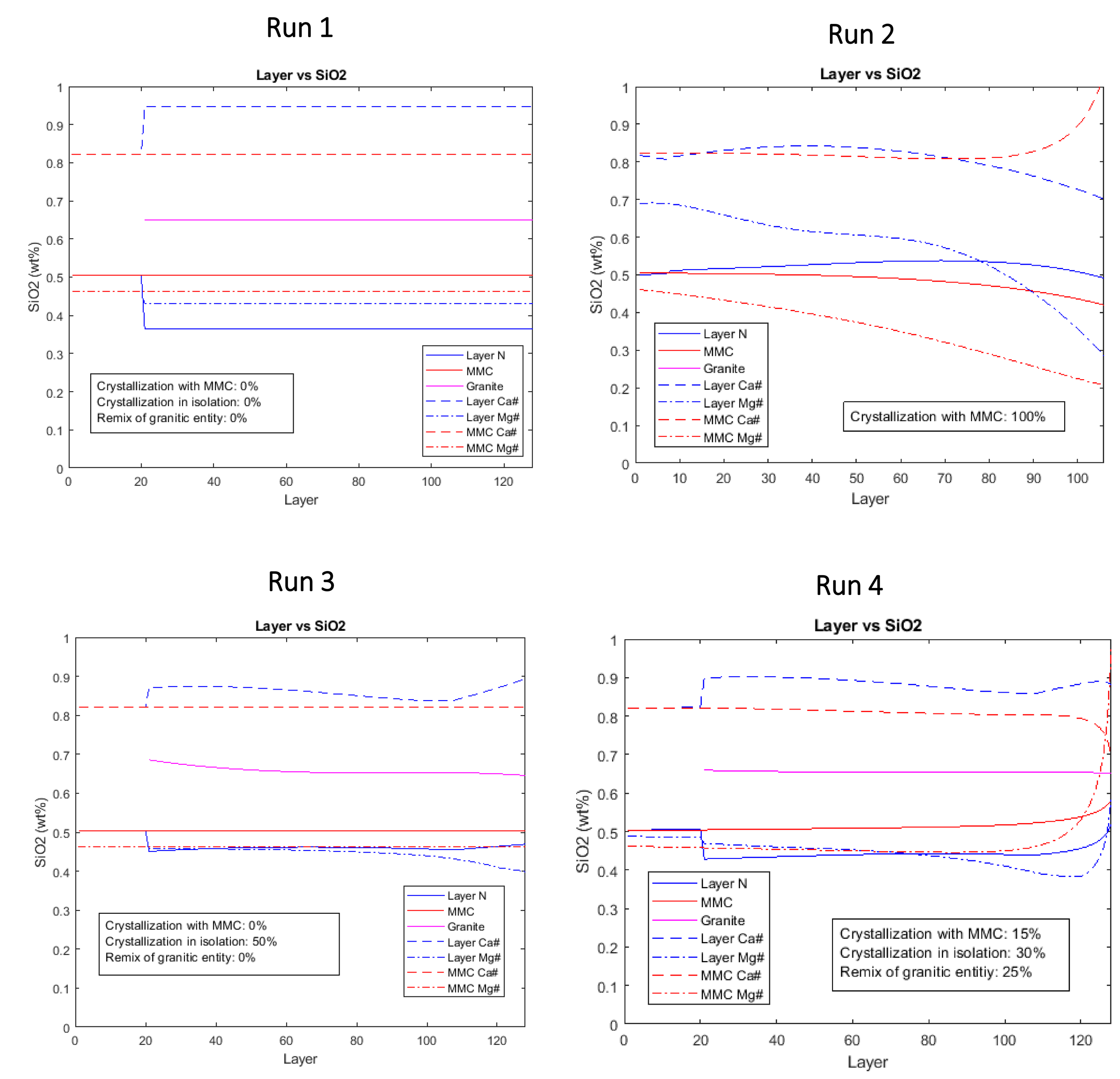


Diagram depicting flow of our program

Results



Interpreting the data

The above graphs were created to check that the program runs as expected and to explore our parameter space to test the viability of the standard, closed-system model, as well as the Sequential Extraction model.

Run 1 represents the case in which the magma chamber is separated into equally divided layers and none of the Si-rich material remixes back into the overlying magma chamber.

Run 2 is a test of the standard, closed-system model. It follows the evolution of the system if each layer crystallized entirely in equilibrium with the overlying magma chamber. The magma chamber ran out of Na2O during this run and highlights one of the major problems with the standard model.

Run 3 shows what would happen if 50% of the layer undergoes liquid immiscibility and no Si-rich material remixes into the magma chamber.; these conditions therefore are consistent with evolution of the Skaergaard.

Run 4 shows what would happen if 15% of each layer crystallizes in equilibrium with the magma chamber, with another 15% of each layer crystallizing in isolation before immiscibility is reached. This run allowed 25% of the Si-rich material to remix back into the magma chamber. As in Run 3, none of the oxides were entirely used up during crystallization.

Concluding Remark Our code shows that some combinations of adjustable parameters using the Sequential Extraction model are consistent with current observations of the Skaergaard intrusion. We intend to further explore our parameter space to map out the range of conditions that are compatible with these observations.

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