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Insights into melt and chemical transport rates in the mantle from the volcanic response to glacial unloading in Iceland

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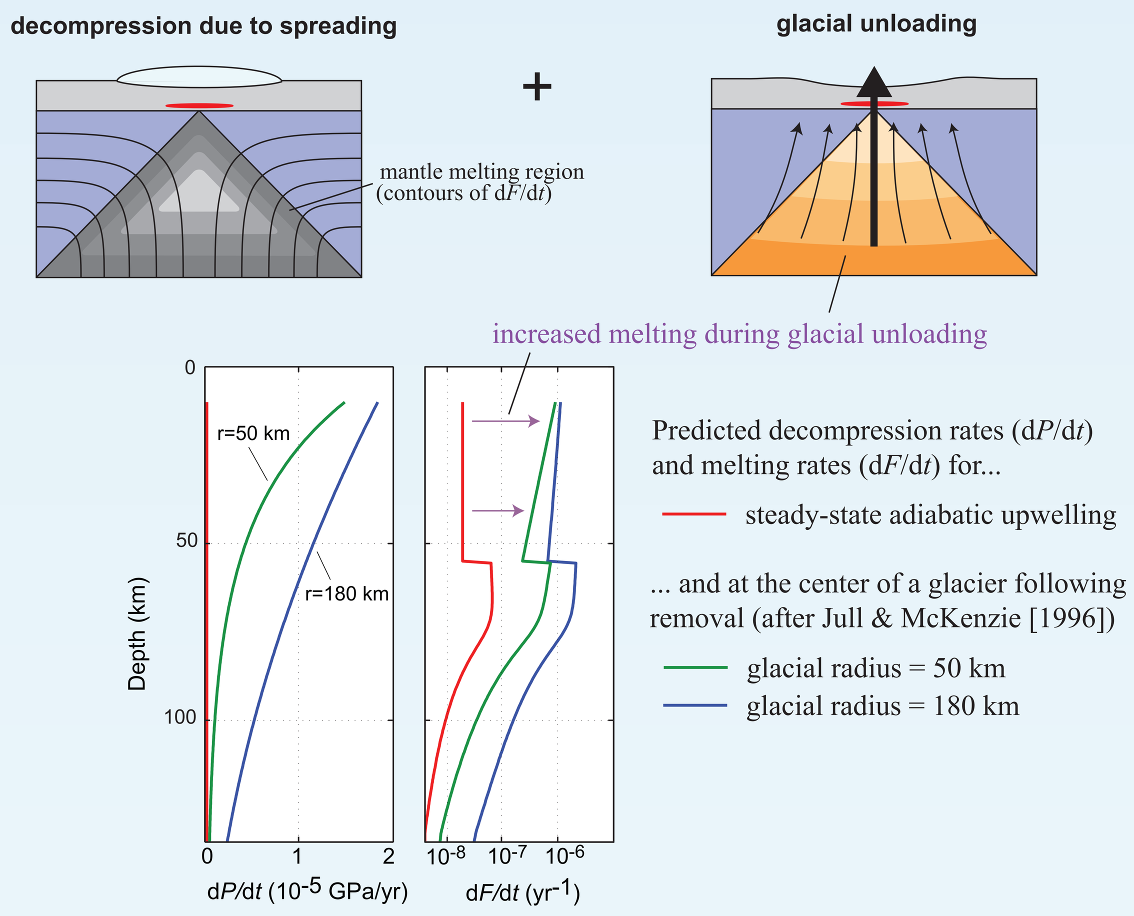
Introduction

Deglaciation leads to enhanced melt production under Iceland due to a temporary increase in mantle decompression rates during glacial unloading. As the ice retreats, the load on the lithosphere and asthenosphere is reduced and they rebound back to their equilibrium levels. The mantle's response to deglaciation is dependent on the volume and geometry of the ice removed as well as the rate of glacial melting. Models of mantle decompression following ice sheet removal predict the greatest melt perturbations at shallow depths in the mantle, with corresponding changes in the chemical composition of erupted material.



Previous modeling has shown that this process can explain a variety of temporal features observed in Iceland just after the last deglaciation, including increased volcanic production and changes in lava chemistry immediately following the ice sheet removal [e.g., Jull & McKenzie, 1996; Slater et al., 1998; Maclennan et al., 2002].

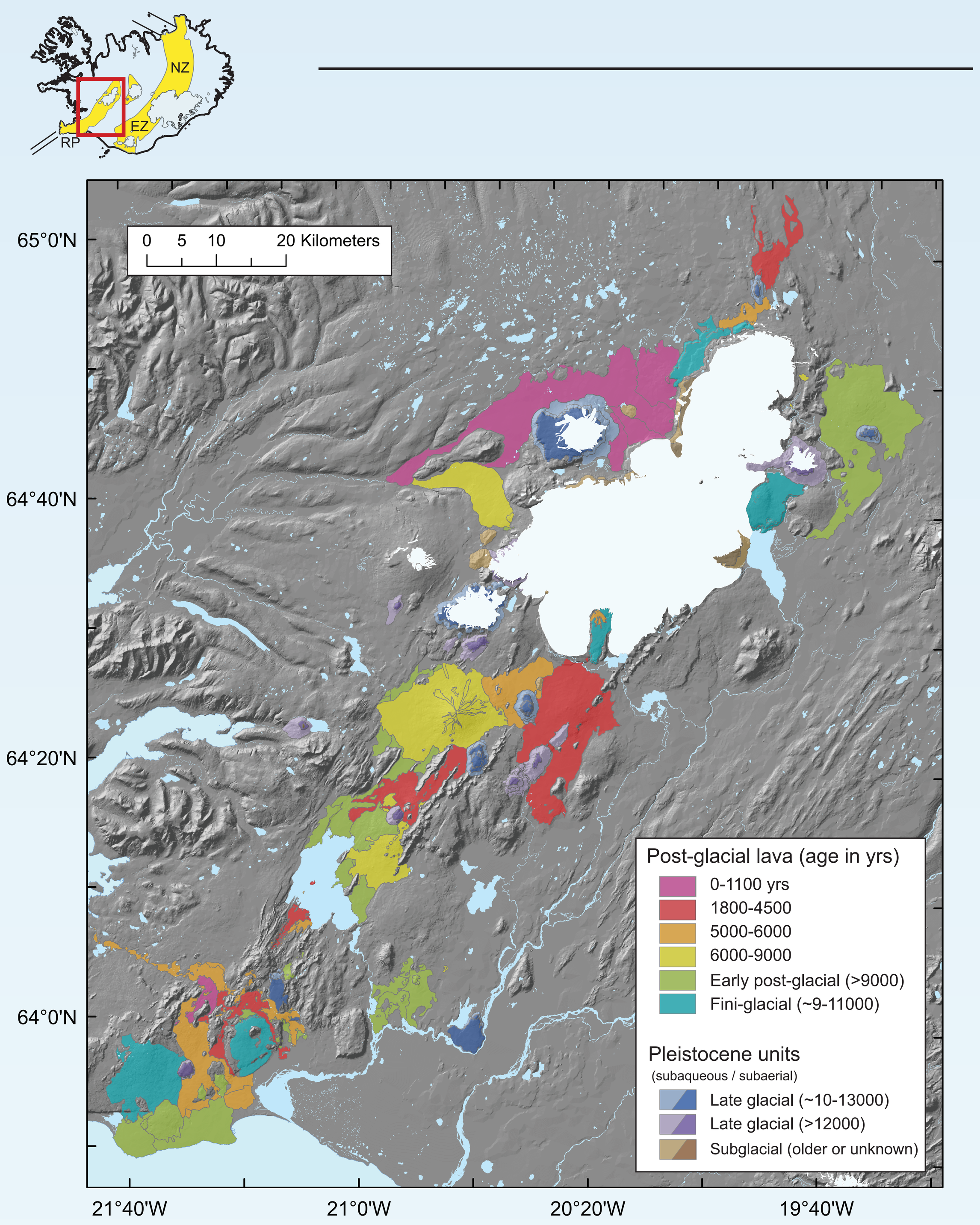
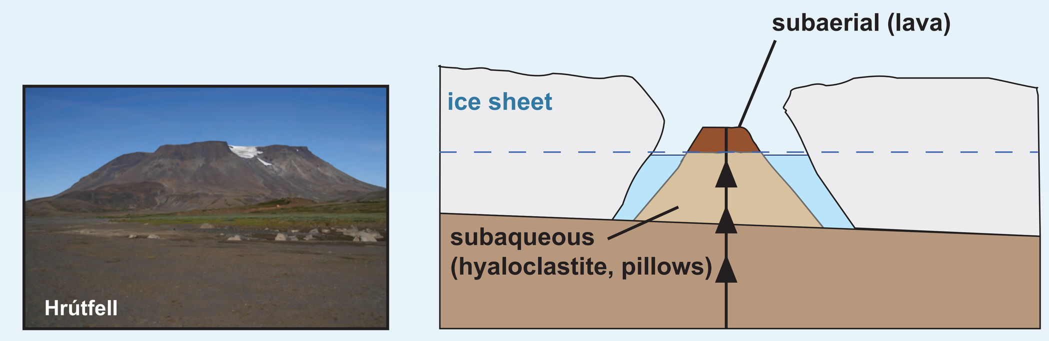


Table Mountains in the WVZ

Some table mountains in Iceland are thought to have erupted through a thinning ice sheet during ice retreat following the last glacial maximum (~15-10 ka). New observations and geochemical analyses of table mountains in the 170-km long Western Volcanic Zone (WVZ) extend the known eruptive timeline into the late-glacial period and help constrain spatial and temporal variations in volcanic production and composition associated with glacial unloading.



In this study we use a combination of lava surface morphology, heights of transition from subaqueous to subaerial eruption environments, and ^{3}He exposure age dating [Licciardi et al., 2007] to construct an eruption chronology for these subglacial units. These data supplement existing fini- and post-glacial data [Sinton et al., 2005] to form a detailed eruptive history for this hot-spot affected ridge segment since ~15 ka.

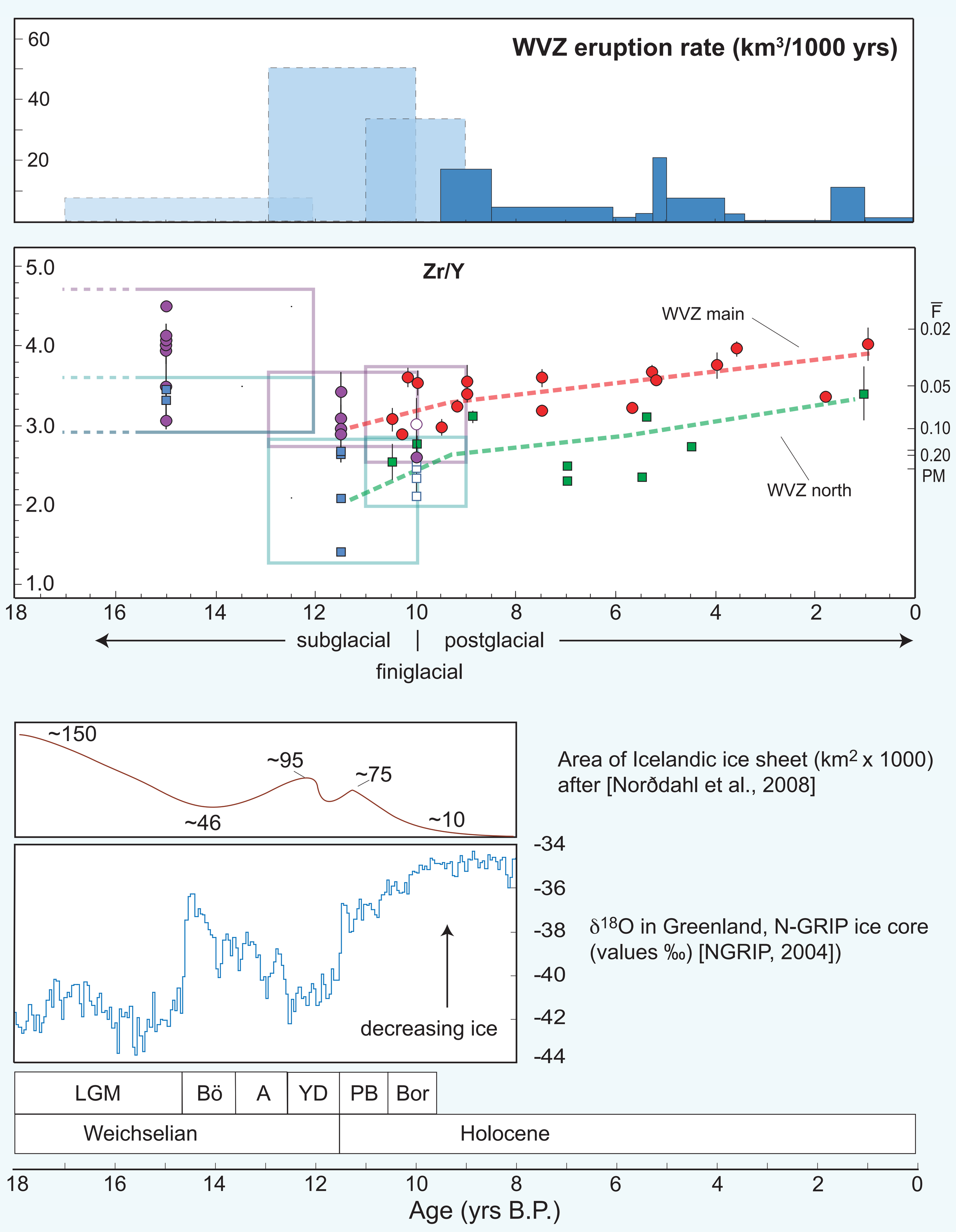
WVZ Chronology

Age Groups

Unit Type (Age Group)	Age Range	Units	Interpretation
Post-glacial	0-10+ ka	(e.g., Skjaldbreiður, Lambahraun, Nesjahraun, etc.)	(no ice interaction or coverage post-formation)
Fini-glacial (Group 1)	~9-11 ka	Heiðin Há, Hagafell shield, N. Langjökull, Jökulstallar, Leggjabrjótur, Trölladalur	Minor ice interaction during formation; ice up to 100 m thick present locally during eruption
Sub-glacial (Group 2)	~10-13 ka	Þórisjökull, Hlöðufell, Kjalfell, Bitra, Hestfjall, Skríða, Krákur, Eiríksjökull	Subglacial eruption through >200 m of ice; no signs of subsequent glaciation
Sub-glacial (Group 3)	~12- ? ka (max age unknown)	Hvalfell, Hrafnabjörg, Geitlandsjökull, Geitafell, Hrútfell, Rauðafell, Högnhöfðí, Stóra & Lítla Björnsfell, Fanntófell	Subglacial eruption followed by extensive surface modification; glacial straie or polish on some units; can't constrain maximum age

Volcanic production peaks during deglaciation with the eruption of a number of large-volume table mountains, then decreases during the early post-glacial period.

Coupled with this is a **maximum depletion in incompatible elements** near the end of deglaciation, as well as **elevated SiO_2 and CaO concentrations, consistent with enhanced melting at shallow levels in the upper mantle** as predicted by models of glacial unloading. Incompatible element ratios progressively increase throughout the post-glacial period, consistent with an overall decline in the extent of melting (F) [Sinton et al., 2005].

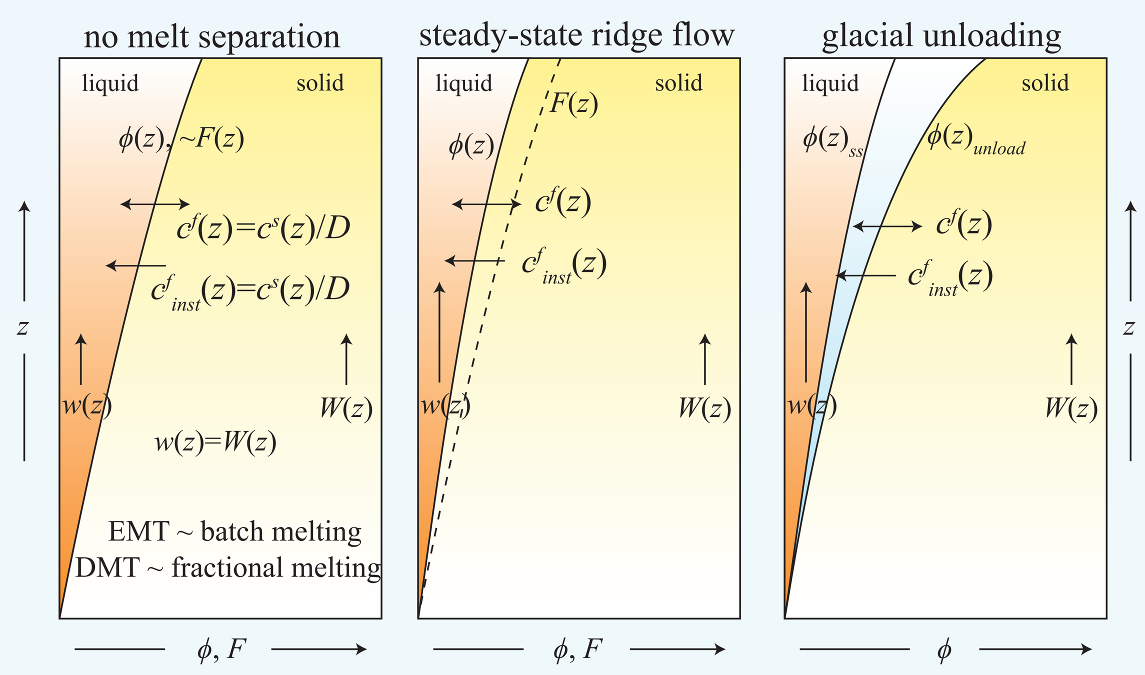


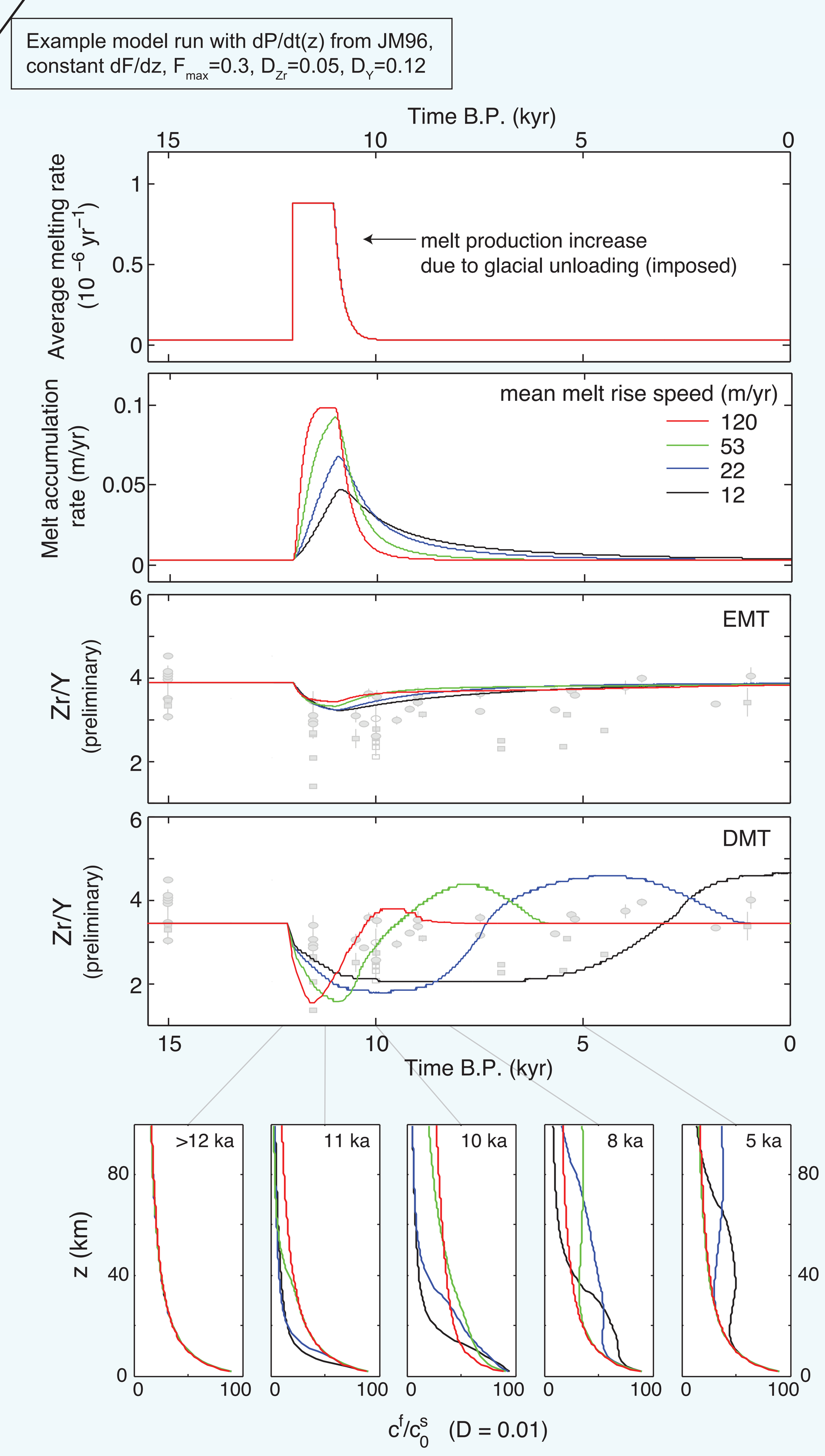
Melt & Chemical Transport

The consequences for eruptive flux and magma composition depend partly on the rates at which melt travels to the surface. Using conservation equations describing the generation and porous transport of melt in a viscous matrix [Spiegelman 1993, 1996], we model melt migration in the mantle during and after ice sheet removal (glacial unloading calculated after Jull & McKenzie [1996]), as well as trace element transport through the system for both equilibrium (EMT) and disequilibrium melt transport (DMT).

The transport rate of a given chemical element is inversely related to its partition coefficient (*D*). By examining the time-dependent behavior of different incompatible elements across a range of *D*s, we can find best-fit models for various parameters of the melt system, including the nature and rate of melt transport, and the melt profile with depth (*F* vs. *z*).

In this way, we hope to exploit this short-lived melting perturbation in Iceland to gain insight into time-dependent processes normally obscured to us by the time-averaged nature of eruptive products.





Left: the results of some preliminary calculations. Notably, the predicted geochemical time series at the surface is especially sensitive to the mode of chemical transport, with trace element compositions modeled using **disequilibrium transport exhibiting a greater dependency on melt ascent rate than for equilibrium melt transport**.

These early results emphasize the potential importance of the nature and rate of melt migration in controlling compositional variability at spreading centers and ocean islands.

EMT: ***melt & solid in equilibrium at all times***

... surface compositions respond quickly to changes in melt system

DMT: ***instantaneous melt produced is locally in equilibrium*** *with the solid source, but the solid does not interact with the melt that flows through it*

... compositional changes due to melting can take much longer to propogate through the melt region (see bottom panel set), but have a greater amplitude

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