TESTING HYPOTHESES FOR THE ORIGIN OF MARTIAN ALKALI BASALTS THROUGH FRACTIONAL CRYSSTALLIZATION OF PRIMARY MAGMAS. M. C. Rudin1,2 and J. B. Balta1, 3The Lunar and Planetary Institute, USRA, 3600 Bay Area Blvd., Houston, TX 77058; 2Department of Geosciences, University of Texas at Dallas, Richardson, TX 75080 (mia.rudin@utdallas.edu).

Introduction: Martian alkali basalts found at Gusev Crater have been proposed to source from a single magma series linked by fractional crystallization [1,2,3]. It was similarly proposed that basalts with still higher alkali enrichment at Gale Crater, such as Jake_M [4], could also be part of a similar magma series, except formed under different crystallization conditions [5,3]. If the alkali basalts at Gale and Gusev Crater both represent a single magma series, this could indicate simple and global magmatic processes and compositions exist on Mars. If this hypothesis is not supported, it would suggest that the formation of these alkali basalts requires distinct melting processes at each site. Context for the formation of the alkali basalts at Gale Crater will therefore benefit the overall understanding of Martian volcanism.

The MELTS family of algorithms [6,7,8,9,10] are the set of thermodynamic modeling tools most often used to simulate Martian igneous systems. MELTS algorithms use Gibbs free energy minimization to calculate stable phase equilibria and are capable of computing automated fractional and equilibrium crystallization paths [11]. The THERMOCALC suite of algorithms [12,13,14,15,16,17] is another set of common modeling tools that, in general, solve a series of non-linear equations to produce a phase diagram [11], a process that requires hours to produce results. However, a newly published software package, MAGEMin [18], or Mineral Assemblage Gibbs Energy Minimizer, produces point-wise results based on the THERMOCALC database in seconds.

Hernández-Urîbe et al. (2022) [11], Otto et al. (2023) [19], and Astudillo Manosalva et al. (Pers. Comm, 2024) [20] each conducted a series of calculations using MELTS and THERMOCALC, finding that the tools have distinct compositional ranges where their calculations are more accurate. These studies indicate that THERMOCALC algorithms, such as MAGEMin, may be calibrated to model the formation of alkali basalts, such as those on the Martian surface, more accurately. However, this has not been previously done.

We conducted a series of fractional crystallization calculations in MAGEMin to test the hypothesis that alkali basalts at Gale Crater are related to Gusev near-primary magmas by fractional crystallization, and then compared results to those previously calculated in MELTS to assess their differences. If MAGEMin results do not support the hypothesis, this would indicate that Gale alkali basalts were formed from distinct melting processes or a metasomatized source.

Methodology: We use the same measured Martian near-primary magma compositions Humphrey [21,1,3] and Fastball [22,3], temperatures, and pressures from MELTS calculations by Udry et al. (2014) and McSween et al. (2006) (Table 1) to compare their results to ours done using MAGEMin v. 1.3.2.

A MAGEMin interface in the Julia programming language allows us to calculate single point-wise compositions. To calculate a fractional crystallization path, we input a measured near-primary composition, temperature, and pressure from literature (Table 1) to produce an output. We record the result composition, then reenter it with a 10°C-temperature drop in sequence. This process is repeated to produce a series of points, making up an isobaric fractional crystallization path comparable to the results of Udry et al (2014) and McSween et al. (2006). MAGEMin calculations are unautomated and not user-friendly for fractional crystallization. Conducting a single calculation requires the user to manually input and record results at each step. We conducted over 500 calculations, producing 17 isobaric fractional crystallization paths (Table 1) that bracket results of previous studies using the MELTS algorithm to test the hypothesis.

<table>
<thead>
<tr>
<th>Primary Magma</th>
<th>Pressure</th>
<th>Water Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fastball</td>
<td>1, 6, 12 kbar</td>
<td>0 wt.%</td>
</tr>
<tr>
<td>Humphrey</td>
<td>1, 6, 12 kbar</td>
<td>0 wt.%</td>
</tr>
<tr>
<td>Fastball</td>
<td>1, 6, 12, 14 kbar</td>
<td>0.5 wt.%</td>
</tr>
<tr>
<td>Humphrey</td>
<td>1, 10 kbar</td>
<td>0.5 wt.%</td>
</tr>
<tr>
<td>Fastball</td>
<td>1, 6, 12 kbar</td>
<td>1.67 wt.%</td>
</tr>
<tr>
<td>Fastball (FMQ-3)</td>
<td>1, 12 kbar</td>
<td>0.5 wt.%</td>
</tr>
</tbody>
</table>

Table 1. Input parameters chosen from Udry et al. (2014) and McSween et al. (2006) for the 17 isobaric fractional crystallization path calculations done in MAGEMin.

Results: Using MAGEMin, the highest alkali contents produced from fractional crystallization of a Fastball-like primary magma occurred at the highest H2O content and pressure (1.67 wt.% H2O, 12 kbar), reaching over 6 wt.% total alkali content. The highest alkali content from a Humphrey-like primary magma, similarly, was produced under the highest pressure and H2O contents calculated (0.5 wt.% H2O, 10 kbar).
In all calculations, Na$_2$O/K$_2$O ratios drop with increased crystallization, but drop sooner at higher pressure conditions and lower H$_2$O contents. The fractional crystallization of a dry Fastball composition at 1 kbar yields the most potassic ratio of those tested.

We recalculated the Fastball composition at an FO$_2$ of FMQ-3 for an additional set of calculations [23] (Table 1), resulting in significantly increased total alkali content at both 1 and 12 kbar (Fig. 1). The Na$_2$O/K$_2$O ratios of a reduced composition decrease sooner than calculations with oxidized starting compositions.

![Figure 1](image)

**Figure 1.** 4 fractional crystallization paths of reduced and oxidized Fastball compositions with 0.5 wt.% water at 1 and 12 kbar.

**Discussion:** Using MELTS, McSween et al. (2006) suggested that the Gusev alkali basalts represent a magma series linked through fractional crystallization, and our MAGEMin results support those findings.

Jake_M, an alkali basalt found at Gale Crater, has particularly high alkali content (8.62 wt.%), and a Na$_2$O/K$_2$O ratio of 2.86. Udry et al. (2014) finds that a Fastball composition with 0.5 wt.% H$_2$O at 12 kbar fractionally crystallizes to a Jake_M-like total alkali composition using MELTS (Fig. 1). In MAGEMin, adding H$_2$O into the starting composition yields elevated total alkalis with increasing pressure, but our results have still significantly lower alkali contents compared to MELTS at the same conditions, and none reach an alkali content like Jake_M (Fig. 1).

Low Na$_2$O/K$_2$O ratios are supported by low water contents. The closest ratio to Jake_M of all tested, approximately 5.17, was produced from a Fastball composition with no H$_2$O at 1 kbar. This difference may be explained by the rate plagioclase crystallizes; if H$_2$O content is high, plagioclase crystallization is suppressed, and less Na is removed from the melt.

MAGEMin results suggest that liquid lines of descent are defined by whether olivine or pyroxene crystallizes first. At 1 kbar, MAGEMin tends to crystallize olivine before pyroxene, whereas in MELTS results, unless the composition includes high H$_2$O contents (1.67 wt.%), orthopyroxene crystallizes before olivine. If pyroxene crystallizes first, SiO$_2$ is depleted sooner, and alkali contents are elevated at a given SiO$_2$ content (Fig. 1). This effect is magnified in the reduced case, where there is additional divalent iron. However, this is contrary to findings in Udry et al. (2014), that FO$_2$ does not significantly impact liquid lines of descent.

Because alkali basalts may more closely match experiments used to calibrate THERMOCALC databases, results calculated in MAGEMin may be more accurate than results previously done in MELTS. Our results do not support hypotheses that alkali basalts at Gale Crater are related to Gusev primary magmas by fractional crystallization, and instead suggest a distinct melting process at each site or a metasomatized source for Gale alkali basalts.

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