THE ROLE OF ASSIMILATION AND FRACTIONAL CRYSTALLIZATION IN THE FORMATION OF THE MARS CRUST. A. M. Ostwald[1], A. Udry[1], V. Payré[2], E. Gazel[3], and P. Wu[2], [1]University of Nevada, Las Vegas, 4505 S Maryland Pkwy, Las Vegas NV 89154; ostwald@unlv.nevada.edu, [2]Northern Arizona University, 624 Knoles Dr., Flagstaff, AZ 86011, [3]Cornell University, 2122 Snee Hall, Ithaca, NY 14853.

Introduction: The Mars crust, primarily tholeiitic basalt, contains localized compositional diversity indicative of evolved (silicic, alkalic) magmatism [1,2]. The *Curiosity rover* at Gale crater found felsic (>55 wt.% SiO_2) targets [2]. Martian felsic rocks possibly formed via fractional crystallization (FC) after large amounts of solid fractionation (>60%), however, residual melt is difficult on Earth to extract from crystal accumulation above 55% without a secondary process such as compaction or filter pressing [2–6]. On Earth, some crustal diversification in primarily basaltic systems is attributed to assimilation and fractional crystallization (AFC) [e.g., 7]. In this study, we examine the possible role AFC played in the diversification of the Mars crust by thermodynamic modeling in Mars-relevant conditions.

Methods: We conducted AFC and FC modeling using the Magma Chamber Simulator (MCS), which commands multiple MELTS windows to model each subsystem (magma, wallrock or assimilant, and cumulates) [8]. We selected the Rhyolite_MELTS v.1.0.2 algorithm in order to mimic a hydrous, low-pressure, silica-saturated magma [9]. The MCS model approximates magma intruding a crustal wallrock. As FC (the exothermic process of solid minerals forming and separating from the liquid magma) begins, wallrock partially melts and mixes into the bulk magma body to drive magmatic evolution [8].

Initial compositions and model parameters. All models are isobaric, conducted at pressures equivalent to the shallow subsurface to the base of the average crustal thickness of Mars (1, 2, 4, and 6 kbar) [2,10]. We constrained the models at the fayalite-magnetite-quartz (FMQ) oxygen fugacity (fO_2) buffer.

We selected near-primary Fastball and Adirondack martian basalt compositions for the initial magma composition [11,12]. We varied the water contents of the initial magmas (to include 0.07, 0.50, and 1.0 wt.% H_2O) to test the effects of water saturation. We used the bulk rock composition of the martian regolith breccia Northwest Africa (NWA) 7034 and the average Mars crust for wallrock compositions [13,14]. The initial water content for NWA 7034 is reported in [13]. We use a value of ~0.14 wt.% H_2O for the average crust, as reported in [15]. Wallrock starting temperatures were calculated along multiple thermal gradients, but we will be presenting results for 15°C/km as they are representative of the potential thermal gradient at Gale crater in the Noachian, where observations of felsic materials were made [16].

Results: Fastball initial magma compositions undergoing FC-only reach 55 wt.% SiO_2 (felsic compositions) at ~60–80% crystallinity at varying pressure conditions with different initial water contents (Fig. 1a). At 6 kbar, the FC model for Fastball reaches trachy-basaltic compositions (~45–50 wt.% SiO_2) at 55% solid fractionation (Fig. 1b). The AFC models wherein Fastball assimilates NWA 7034 wallrock forms trachy-andesitic melt (~53–56 wt.% SiO_2) at 55% fractionation in the same conditions (Fig. 1c–d).

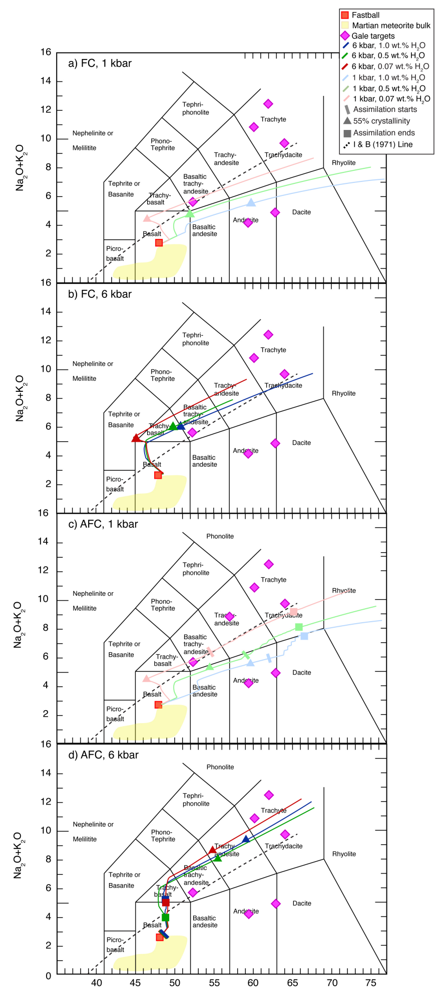

Fig. 1: Total alkali-versus-silica diagrams for a) FC of Fastball at 1 kbar, b) FC of Fastball at 6 kbar, c) AFC of Fastball with NWA 7034 wallrock at 1 kbar, and d) AFC of Fastball with NWA 7034 wallrock at 6 kbar. Alkaline compositions are above dashed line [17].

AFC and FC models follow similar liquid lines of descent. However, AFC achieves higher degrees of evolution at lower degrees of fractionation (Fig. 1). Modeled liquid lines of descent are more alkaline at higher pressures, which also correspond to more rapid assimilation of wallrock in AFC models (Fig. 1). Liquid lines of descent vary more between differing initial water compositions in low-pressure AFC magmas, and in FC magmas. Water undersaturated (0.07 wt.% H_2O) models are more alkaline than models containing 1.0 wt.% H_2O initially. Generally, AFC models provide good fits to observed Gale felsic targets (Fig. 1).

Mineralogy. AFC models at 4–6 kbar form less feldspar than models at 1–2 kbar (11–25 wt.% vs 23–35 wt.%, respectively) (Fig. 2). A variety of pyroxene forms in the models, with 4–34% orthopyroxene, ~11–40 wt.% pigeonite, and 3–23 wt.% augite (Fig. 2). Other phases include olivine, whitlockite, spinel, apatite, and rarely garnet and quartz (Fig. 2).

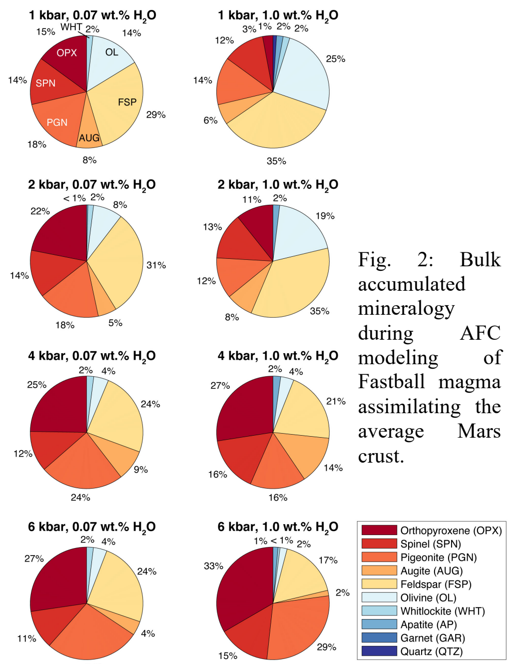

Fig. 2: Bulk accumulated mineralogy during AFC modeling of Fastball magma assimilating the average Mars crust.

Discussion: AFC models provide good fits to Gale crater felsic and evolved materials within lower degrees of crystallinity than do FC-only models (Fig. 1). AFC occurs earlier in models at higher pressures due to higher wallrock temperatures (Fig. 1). Similarly, increasing the crustal thermal gradient, and thus initial wallrock temperatures, also results in more rapid onset of wallrock partial melting and mixing.

Higher pressure models generate more alkaline liquids, forming less feldspar overall (Fig. 1, 2), than lower pressure models. Therefore, pressure and its correlative wallrock initial temperatures are important controls on the outcome of AFC models. Pressure also plays a role in the variability of magma compositions due to water saturation (Fig. 1). At higher pressures in assimilation models (2–6 kbar), incompatible water readily leaves its host rock and reduces the spread between alkaline water undersaturated (0.07 wt.% H_2O) and saturated (1.0 wt.% H_2O) models.

With its dependence on pressure and temperature conditions, AFC leads to magmatic diversification at lower degrees of crystallinity than FC alone as each addition partially melted wallrock contributes to the overall volume of liquid in the magma. Increasing pressures in the system leads to higher wallrock temperature and increased evolution of the magma with larger volumes of liquid magma throughout the model.

Early Mars likely had a hotter crustal thermal gradient on average [18]. With elevated crustal temperatures, Mars at the time observed felsic targets formed may have generated magmas of silicic compositions and at relatively low degrees of crystallinity by AFC processes and at pressures as low as 2–4 kbar (Fig. 3). Mars, overall, has colder crustal thermal estimates than the crust of Earth. Therefore, evolved volcanism on Mars is generally expected to be spatially restricted to smaller volumes than intraplate felsic materials on Earth (Fig. 3).

Future work should address other open-system processes such as recharge and assimilation fractional crystallization (RAFC). Additionally, orbital investigations of Jezero crater indicate that the crater floor unit may be igneous and formed in the Noachian [18]. If so, it may contain isotopic characteristics of assimilation that can be resolved with sample return.

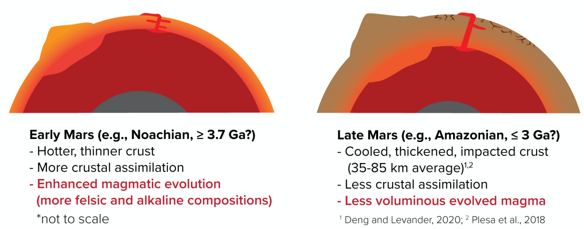

Fig. 3: Schematic detailing major take-aways.

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