# Polybaric crystallization of martian alkaline basalts

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## Introduction: Martian basalts

- Martian basalts: tholeiitic composition apart from some rare exceptions (alkaline basalts)
- No exhaustive polybaric fractional crystallization experiments or computer modeling conducted on martian basalts

**Goal of this study:**

- Evaluate polybaric fractional crystallization for alkaline magma on Mars from various martian primary melt compositions (Humphrey [1], Fastball [2], Y-98 [3], and Nakhlite parental melt [4,5]) using different crystallization conditions (PT paths, fO2, water content)
- Assess if these primary melt compositions can produce alkaline compositions observed in martian rocks

## Methods: pMELTS and MELTS

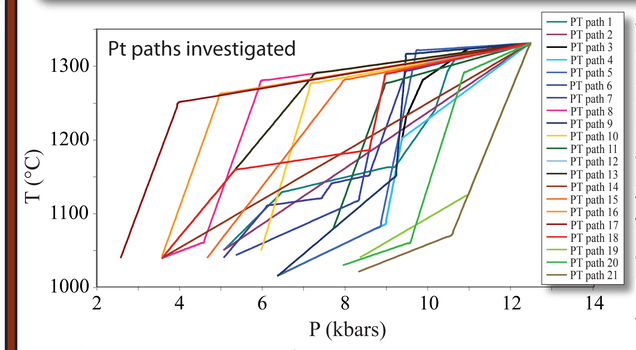



Fig. 1. Various PT paths (from Humphrey magma) used in this study (PT paths: rapid ascent/ melt held at High P)

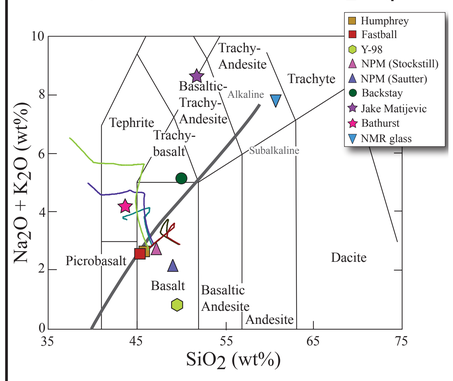
- Fractional crystallization calculations conducted using the adiabat_1pH front end of the MELTS algorithm [6] that runs the routine of MELTS and pMELTS [7]
- Calculate equilibrium assemblages along a crystallization path using the thermodynamic properties of the phases and components present
- Fractional crystallization calculations started above liquidus including various PT paths (Fig. 1), $fO_2$, and water content

## Martian primary magma evolution

### Humphrey

Gusev plain rock [1]

Fig. 2. FMQ-2 0.07wt% $H_2O$ (pMELTS)

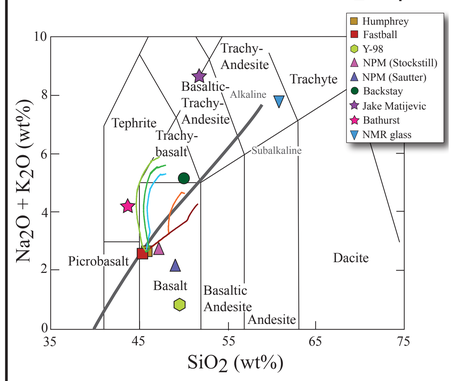



**Alkaline magma formation** from Humphrey composition with primary melt held at HP, tholeiitic magma results from LP crystallization

### Fastball

Home Plate rock [2]

Fig. 3. FMQ-1 0.5 wt% $H_2O$ (pMELTS)

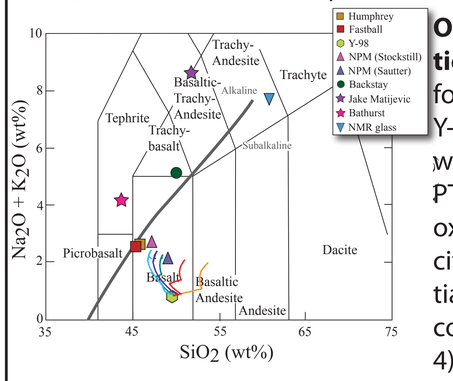



**Alkaline magma formation** from Humphrey composition with primary melt held at HP, tholeiitic magma results from LP crystallization

### Y-980459

Shergottite [3]

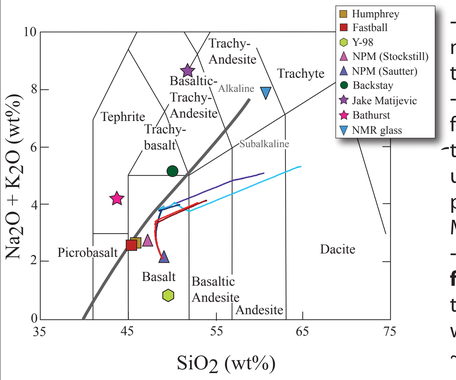
Fig. 4. IW+1 no $H_2O$ (pMELTS)




**Only tholeiitic magma** formed from Y-98 magma with various PT paths, oxygen fugacities, and initial water content (Fig. 4)

### Nakhlite parental magma (NPM)

Fig. 5. FMQ-1 no $H_2O$ (MELTS)




- Two parental magma composition used [4;5]
- NPM from [5]: form only tholeiitic magmas (Fig. 5) using both pMELTS and MELTS
- NPM from [4]: **form alkaline** and tholeiitic magmas with no water and ~FMQ-1 (Fig. 9)

## Martian alkaline rocks formation

### Backstay

Columbia Hill rock [9]

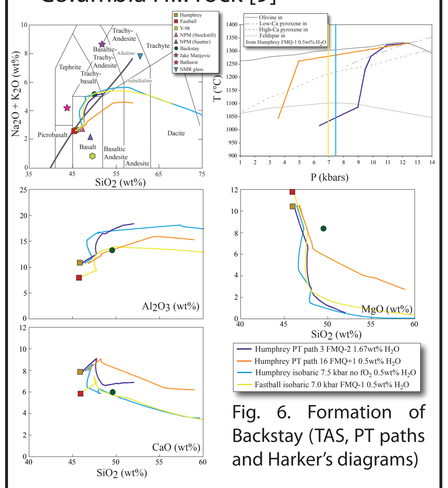



Fig. 6. Formation of Backstay (TAS, PT paths and Harker's diagrams)

- **Formed from Humphrey-like composition at isobaric and polybaric conditions or from Fastball at isobaric conditions** (Fig. 6)
- Needs initial water to form (0.5wt%)
- Requires relatively high $fO_2$ (~FMQ-1)

### Jake Matijevic

Gale Crater rock (sol 43-44) [10]

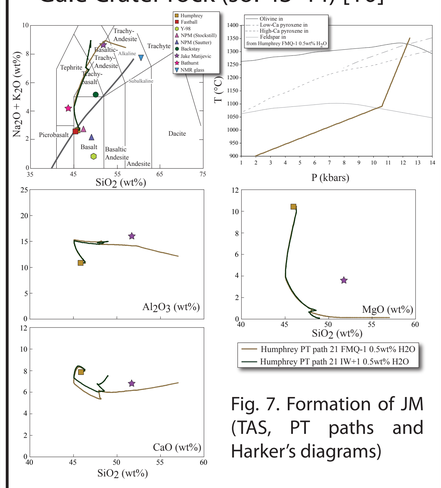



Fig. 7. Formation of JM (TAS, PT paths and Harker's diagrams)

- Closest compositions found at 0.5wt% $H_2O$ and FMQ-1 from Humphrey-like composition (Fig. 7)
- 90% fractionation: not realistic
- May have **formed from metasomatized alkaline rich parent magma**

### Bathurst

Gale Crater rock (sol 43-44) [10]

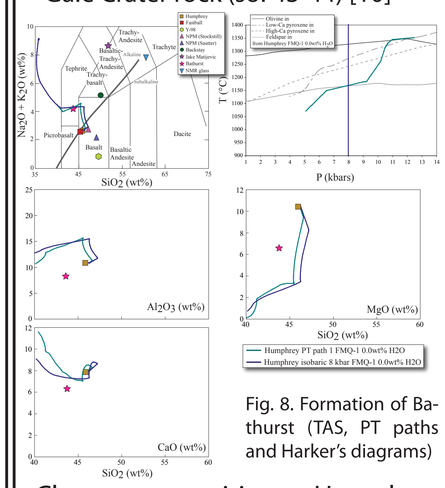



Fig. 8. Formation of Bathurst (TAS, PT paths and Harker's diagrams)

- Closest composition to Humphrey without initial water (Fig. 8).
- But requires less $Al_2O_3$ and more MgO to form Bathurst composition
- Likely **not formed from known primary magmas**

### NMR glass

Miller Range intercumulus glass [12;13]

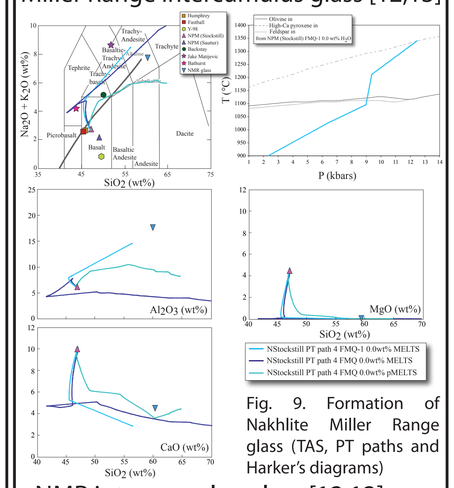



Fig. 9. Formation of Nakhlite Miller Range glass (TAS, PT paths and Harker's diagrams)

- NMR intercumulus glass [12;13]: same as other nakhlite glass compositions
- Single alkaline composition found in SNCs
- **Formed from NPM Stockstill** composition [6] without $H_2O$ and FMQ-1

## Conclusions

- Either polybaric or isobaric crystallization can produce alkaline magmas given an appropriate starting composition
- To form alkaline magma on Mars:
  - $H_2O$ content is not required
  - Primary melt being held at high pressure (depth) is necessary
  - Entails relatively high $fO_2$ (~FMQ-1)
- EASY to form alkaline magmas on Mars! These models suggest that alkaline rocks may be more common on Mars than previously thought

References: [1] Monders et al. (2007) MAPS 42, 131-148; [2] Filiberto et al. (2010) Geophys. Res. Let. 37, L13201; [3] Musselwhite et al. (2006) MAPS 41, 1271-1290; [4] Stockstill et al. (2006) 40, 377-396; [5] Sautter et al. (2012) MAPS 47, 330-344; [6] Smith and Asimow (2005) G3, Q02004; [7] Ghiorso and Sack (1995) Contrib. Min. Petr. 119, 197-212; [8] McCubbin et al. (2008) JGR 113, E11013; [9] McSween et al. (2006) JGR, E09S91; [10] Stopler et al. (2013) abstract #1685, 44th LPSC. [11] Sautter et al. (2013) abstract #1985, 44th LPSC; [12] Udry et al. (2012) MAPS 47, 1575-1589; [13] Day et al. (2006) MAPS 41, 581-606