Igneous Float Rocks at the Ireson Hill & Bressay Localities, Gale Crater, Mars

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During exploration of Gale crater, Mars, the *Curiosity* rover has discovered numerous igneous float samples. We examine a set of these samples from the Ireson Hill, Bressay and Kimberley localities, including a pair of feldspar cumulate samples. Examination of the cumulate samples' geochemistry using the ChemCam and Alpha Particle X-Ray spectrometer instruments allow us to identify individual crystal phase chemistries, which include possible amphibole minerals among the mafic phase. One sample has undergone alteration, enriching the feldspar phase with silica, in some cases to over 80% of total weight. We also employ the MELTS thermodynamic modelling package to simulate feldspar fractionation from a variety of Martian source magmas in order to constrain the magmatic origin of these cumulates.

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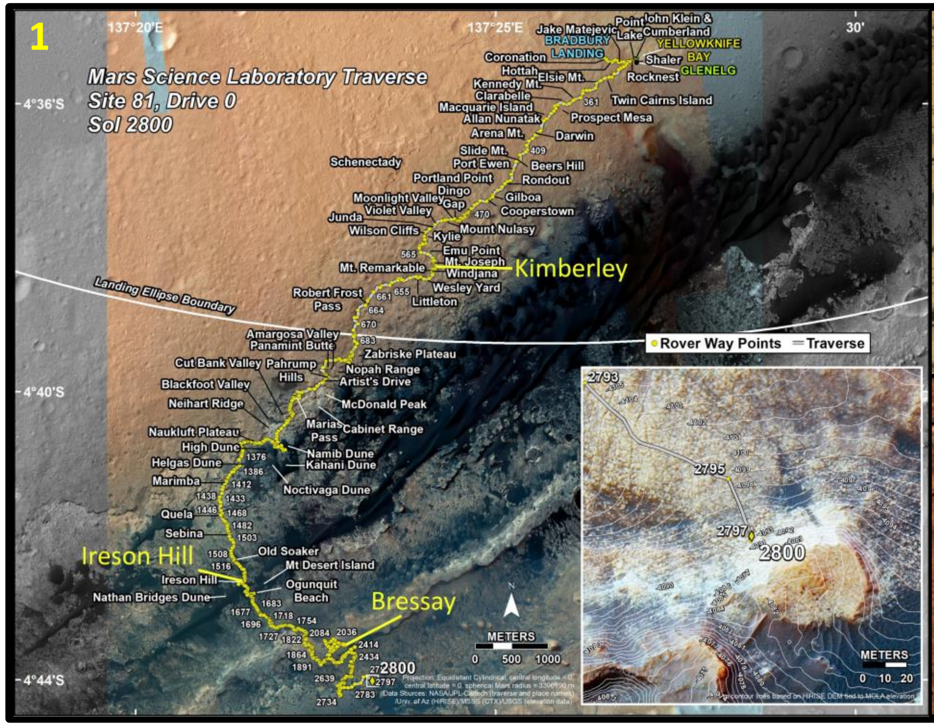
Introduction

- Igneous chemistry in Gale crater is more varied than any other currently explored site on Mars, with a range of basaltic-trachybasaltic compositions [1-3],
- These compositions can be generated by fractionation of magma with similar composition to the Adirondack basalts found in Gusev crater [3].
- At the Bressay and Kimberly localities, the rover examined two float samples, “Askival” and “Bindi”, which show characteristic texture and chemistry of feldspar cumulates.
- These cumulates offer an opportunity to examine magmatic processes in the Gale crater region. Their large feldspar grains are ideal for investigation using the ChemCam instrument, which functions as a geochemical microprobe.
- Ireson Hill also presents a number of possible igneous float samples with varying chemistries. Due to the relative quality of data from Askival & Bindi, the following discussion focusses on the cumulate targets.



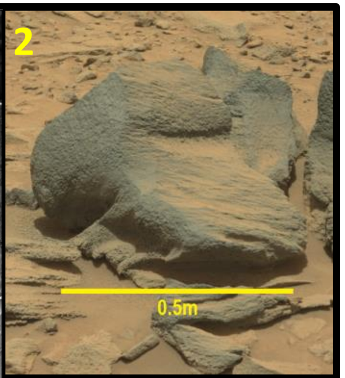


Fig. 1: Curiosity rover traverse map up to sol 2800, with Kimberley, Ireson Hill and Bressay sites highlighted.

Fig. 2: MastCam image of “Johnnie” igneous float rock, Gale crater

Fig. 3: PanCam image of “Adirondack” float rock, Gusev crater [4]

1. Schmidt, M.E., et al., *Geochemical diversity in first rocks examined by the Curiosity Rover in Gale Crater: Evidence for and significance of an alkali and volatile-rich igneous source.* Journal of Geophysical Research: Planets, 2013. **119**(1): p. 64-81. **2.** Cousin, A., et al., *Classification of igneous rocks analyzed by ChemCam at Gale crater, Mars.* Icarus, 2017. **288**: p. 265-283. **3.** Edwards, P.H., et al., *Basalt-trachybasalt samples in Gale Crater, Mars.* Meteoritics & Planetary Science, 2017. [4] Image courtesy of NASA/JPL & M. Lyle

Methodology

Instruments

Geochemistry

Geochemical data was taken from two instruments:

- The ChemCam instrument [5] [6] is a laser-induced breakdown spectroscopy (LIBS) instrument, which uses a 1067nm laser to induce atomic emission from a target, at typical ranges up to 3m.
- The Alpha Particle X-Ray Spectrometer (APXS), which uses an alpha particle source to induce x-ray emission in contacted targets.

Imagery

Images were taken using a combination of the MastCam stereo camera, the Mars Hand Lens Imager (MAHLI) and ChemCam Remote Micro-Imager (RMI), allowing for a range of spatial resolutions and fields of view covering the targets.

Software

MELTS

In order to simulate magmatic activity in Gale crater, we use the MELTS software package [7], using the Rhyolite-MELTS algorithm [8] and graphical interface as well as the alphaMELTS command frontend.

- MELTS provides a wide range of crustal temperatures and pressures, calibrated using experimental data.
- Numerous previous works have used MELTS to investigate compositions from Martian meteorites and in situ samples, and accuracy has shown to be equivalent when compared to terrestrial modelling.
- Low temperature modelling of phases such as amphibole is also not recommended with MELTS, and modelling of these phases using alternative software is ongoing.

5. Maurice, S., et al., *The ChemCam Instrument Suite on the Mars Science Laboratory (MSL) Rover: Science Objectives and Mast Unit Description.* Space Science Reviews, 2012. **170**(1-4): p. 95-166. **6.** Wiens, R.C., et al., *The ChemCam Instrument Suite on the Mars Science Laboratory (MSL) Rover: Body Unit and Combined System Tests.* Space Science Reviews, 2012. **170**(1): p. 167-227. **7.** Ghiorso, M.S., M.M. Hirschmann, and R.O. Sack, *New software models thermodynamics of magmatic systems.* Eos, Transactions American Geophysical Union, 1994. **75**(49): p. 571-576. **8.** Gualda, G.A.R., et al., *Rhyolite-MELTS: a Modified Calibration of MELTS Optimized for Silica-rich, Fluid-bearing Magmatic Systems.* Journal of Petrology, 2012. **53**(5): p. 875-890.

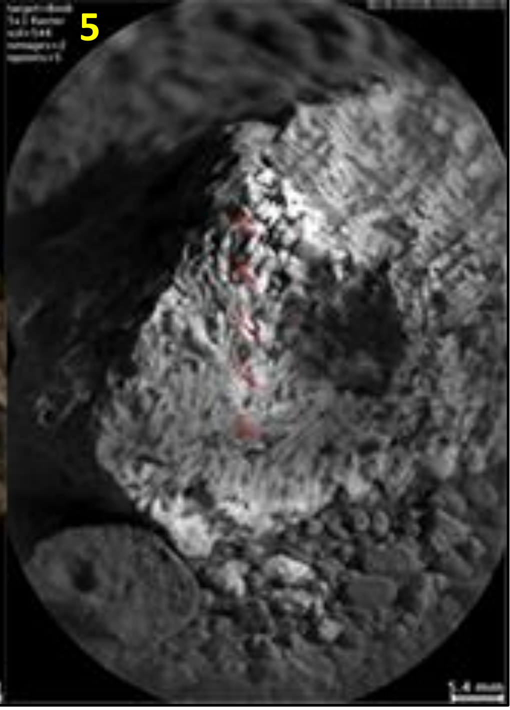
Results

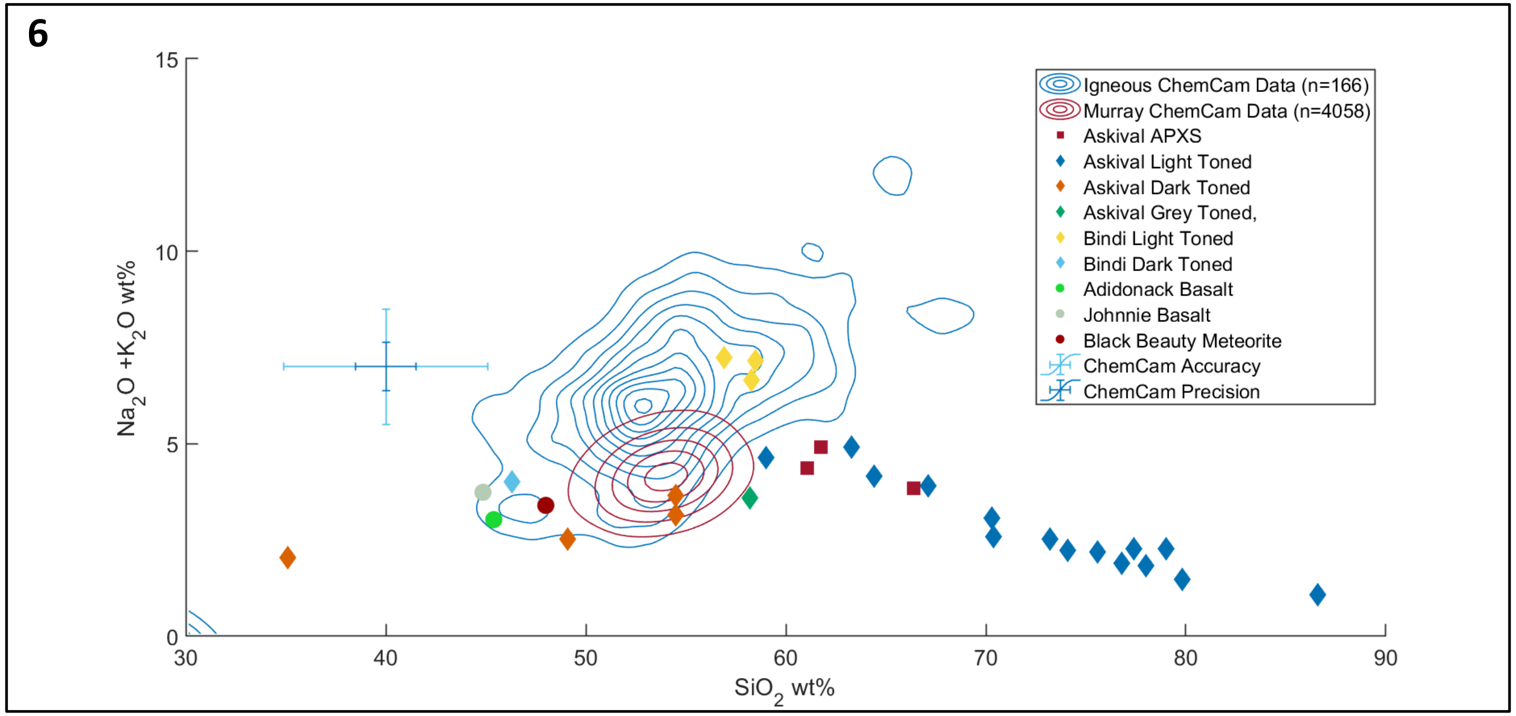
Figs 4 & 5: RMI Images of Askival (4) and Bindi (5). Red markers indicate the locations of LIBS target points. Both samples consist primarily of a light toned phase with large (>1cm) grained crystals, with an interstitial dark phase which occasionally also occupies larger spaces.

Fig 6: Total Alkali vs Silica diagram showing the geochemistry of Askival and Bindi. Points are divided into phase groupings based on RMI targeting images. Additionally, bulk ChemCam data from both igneous and sedimentary targets is displayed as contours.

The light phase in both targets is chemically identifiable as feldspar. However, as shown here, Askival's light phase has a wide range of silica content, which suppresses other chemical oxide abundances as it increases. We interpret this as the result of some fluid-driven alteration of the cumulate post-formation. Prior to this alteration, Askival and Bindi's feldspar chemistry was similar.

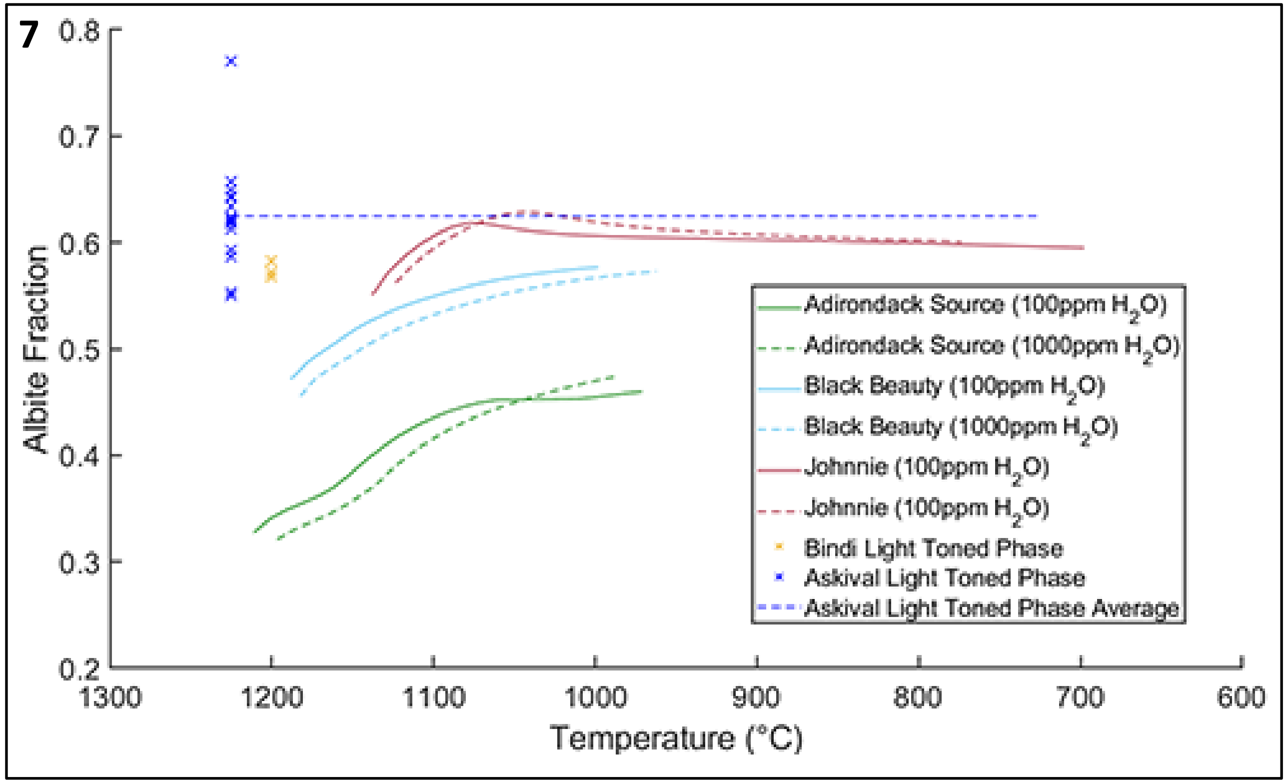
The dark phase in both rocks has a mafic composition, with Askival's dark phase again having a range of silica content; however, other elemental abundances also vary in these measurements, so this variation may be intrinsic to the minerals formed rather than the result of alteration. The target point with lowest SiO_2 has chemistry reminiscent of amphibole.





Discussion

- Using MELTS, we simulated the fractionation of solid phases from a set of basaltic Martian compositions: the Adirondack basalt from Gusev crater [9], the Johnnie basalt from Gale crater [2] and basaltic clasts of the Martian meteorite NWA7034 (“Black Beauty”) [10].
- Simulations were performed using a pressure of 5kbar and a variety of water contents – 100ppm and 1000ppm H_2O results are shown opposite.
- Fig. 7, opposite, shows the resulting compositions. We see that feldspar of the same phase proportion as the Askival and Bindi targets was most likely formed from a magma with similar composition to the Johnnie sample under these conditions.
- We are currently expanding this modelling to investigate a wide range of lower pressures using an automated alphaMELTS input.
- In addition, modelling of the low temperature crystallisation of mafic phases using Perple_X, which is more suited to examination of possible amphibole-bearing phases than MELTS.



2. Cousin, A., et al., *Classification of igneous rocks analyzed by ChemCam at Gale crater, Mars.* Icarus, 2017. **288**: p. 265-283. **9.** McSween, H.Y., et al., Characterization and petrologic interpretation of olivine-rich basalts at Gusev Crater, Mars. Journal of Geophysical Research: Planets, 2006. 111(E2). **10.** Santos, A.R., et al., Petrology of igneous clasts in Northwest Africa 7034: Implications for the petrologic diversity of the martian crust. Geochimica et Cosmochimica Acta, 2015. 157: p. 56-85.

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Conclusions

- The Askival and Bindi cumulates offer an excellent opportunity to examine individual phase chemistry using the ChemCam LIBS instrument, informing our knowledge of intrusive igneous activity in the Gale crater region.
- Simulation using MELTS shows that the feldspar cumulates could have formed from a magma with similar composition to basaltic rocks found elsewhere in Gale crater.
- These compositions have previously been shown to evolve through fractionation of magma with composition similar to the Adirondack basalts from Gusev crater, which does not fractionate matching feldspars in our simulation.
- This suggests a multi-stage process with an intermediate stage of fractionation to a Gale crater basaltic composition may be necessary to produce cumulates with this chemistry.
- The Askival sample has undergone a process of silica enrichment post-formation, which correlates with hydration of the feldspar phase, implying a process of fluid alteration.
- Modelling of low-temperature crystallisation in order to examine possible amphibole formation in the mafic phase is ongoing.

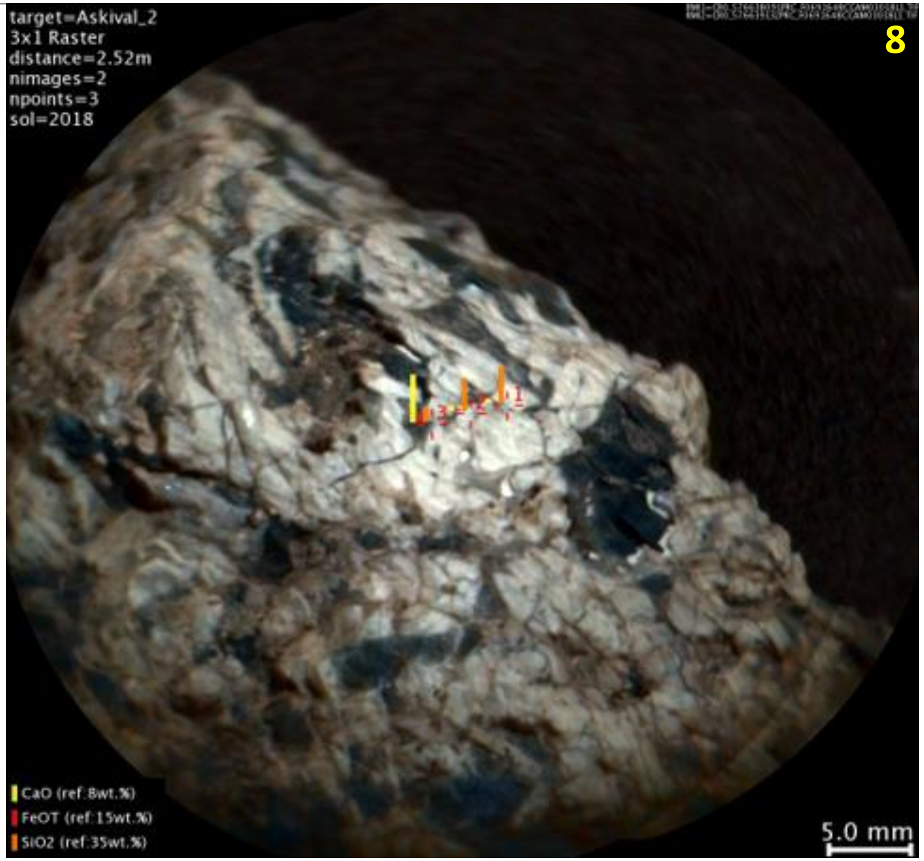

Fig. 8: RMI Image of Askival showing 3 LIBS target points and associated major oxide abundances