Askival: A Silicified Feldspathic Cumulate Sample in Gale Crater

J. C. Bridges[1], A. Cousin[2], V. Sautter[3], W. Rapin[4], S.P. Schwenzer[5], C. Bedford[5], V. Payre[6], O. Gasnault[2], O. Forni[2], P. Pinet[2], R. Wiens[6], A. Yingst[7] [1]University of Leicester, UK j.bridges@le.ac.uk [2]Institut de Recherches en Astrophysique et Planétologie, Toulouse, France, [3]Inst. de Minéralogie, de Physique des Matériaux et de Cosmochimie, Paris, France [4]JPL/Caltech, Pasadena, USA, [5]Open University, UK, [6]LANL, Los Alamos, USA. [6]EEPS, Rice University, Houston, USA,[7]Planetary Science Institute, USA.

Introduction

On sol 2016 of Curiosity's traverse in Gale Crater, at the Bressay locality, a group of float rocks were studied in detail (Figs 1,2). One of these – Askival – is a light toned rock with an igneous texture. Askival has a texture similar to Peacock Hills, observed on sol 19 and Bindi (sol 544), suggesting that they represent a distinct type of Gale igneous float rocks, unique in the inventory of landing site igneous samples and martian meteorites. ChemCam, APXS and MAHLI data gathered principally on Askival enable us to characterize these igneous rocks revealing a history of cumulate processes and subsequent alteration.

Methods

ChemCam contains a NIR laser and telescope within MSL's mast and 3 spectrometers inside the body unit [1,2]. It remotely analyses targets by Laser Induced Breakdown Spectroscopy LIBS, with optimal performance at ≤4 m, and also has a Remote MicroImager (RMI). Typically, there are around 30-50 laser shots on a single observation point in a raster (e.g. two 10 x 1 rasters and one 3 x 1 raster on Askival). ChemCam uses a combination of Independent Component Analysis (ICA) and Partial Least Square (PLS) techniques to derive most major oxide compositions [3]. However, H_2O is determined with a univariate method [4]. Sulfur peaks can be detected but not quantified by ChemCam. The Alpha Particle X-ray Spectrometer (APXS) provided 3 complementary analyses on Askival [5]. This float rock was first identified during MSL operations using MastCam and MAHLI images (Figs 1,2).

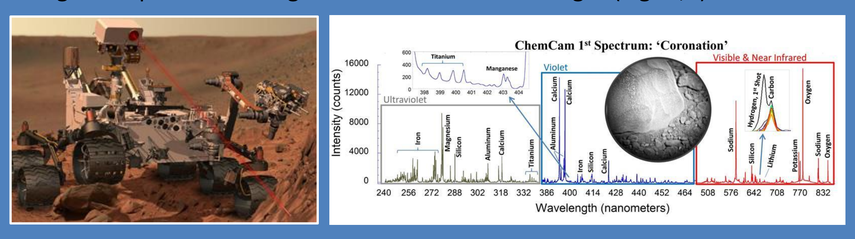


Figure 3. ChemCam UV-NIR spectra

Individual LIBS points and their constituent shots are used to characterise the mineralogy of individual phases, which at the scale of the laser spot (several hundred microns) on the sample are sometimes a mixture. In order to illustrate the distribution of compositions and highlight key compositions we use density contour plots.

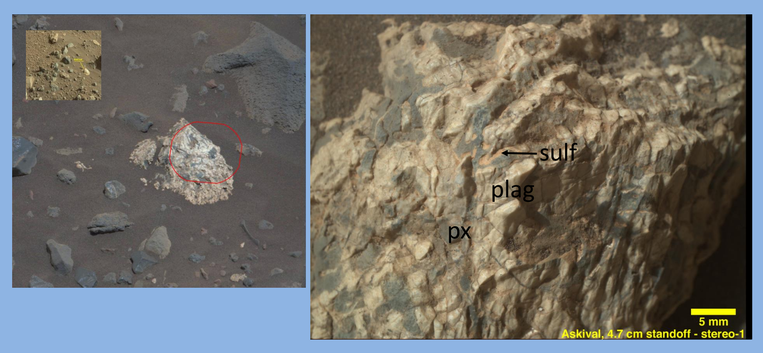


Figure 1. MastCam images of Askival sample at Bressay locality (sol 2016). 2. MAHLI image of Askival – px pyroxene, plag plagioclase, sulf sulfate. Askival is a 10 cm long, partially buried, float rock. It contains light-toned subhedral mineral grains (up to ±10 mm long) as well as dark and grey-toned minerals and veins. The light-toned grains comprise 65/70 % of the rock, and are in places poikilitically enclosed by the dark-toned assemblage which comprise 30/35 % of the rock.

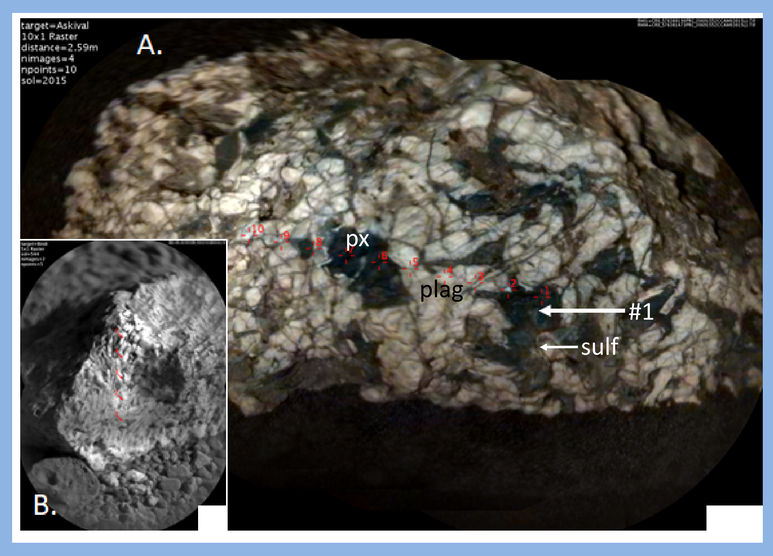


Figure 2A. Askival Colourised RMI. 10 x 1 LIBS raster. A cumulate texture is seen with relict feldspar grains poikilitically enclosed by dark mafic phases. Amphibole-FeO mixture arrowed at Askival point #1. A network of fine alteration veins is also seen. (B) Bindi feldspathic cumulate with 1x3 LIBS raster, RMI image. 5 mm scale bars.

Askival Composition

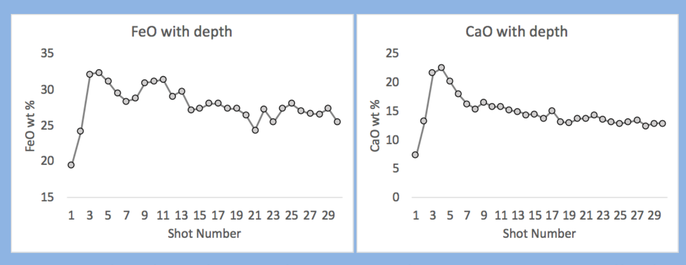


Figure 4. Askival #1 shot to shot FeO and CaO content. Usually the first 2-3 shots are related to the presence of dust

LIBS 'shot to shot' analyses of the Askival Point #1 (Fig. 2A, 4, 5) show that FeO and CaO contents are significantly higher in the early shots (after the first 2-3 shots due to the dust). This is the result of Fe oxide and Ca sulfate grains within part of the laser shot pit. The overall composition of the Askival #1 point best fits a mixture of Fe oxide, Ca sulfate and an amphibole. Traces of F have been identified by LIBS suggesting that the amphibole is not purely an OH in the hydroxyl site. The A site occupancy by Na, presence of Al and Fe-rich nature are consistent with ferrohastingsite.

However, spot #7 (Fig. 5) best fits an augite-like pyroxene dominated composition. Shot to shot correlations of FeO content with SiO_2 are consistent with silicates rather than any oxides in that shot pit. Nor do we see S peaks in the LIBS spectrum of point #7.

The Askival #1 formula is:

$$(Na,K)_{0.8}(Ca_{1.2}Fe^{2+}_{0.8})_{2.0}(Al_{1.4}Fe^{2+}_{2.8}Ti_{0.2}Mg_{0.6})_{5.0}(SiAl)_{8.0}(F,OH)_{2-x} + FeO_x + CaSO_4.xH_2O$$

Askival #7:

$$(Ca_{0.4}Fe^{2+}_{0.7}Mg_{0.3}Al_{0.2}Ti_{0.1}Na_{0.1})_{1.8}Si_{2.1}O_6$$

En = 20%, Fs = 50%, Wo = 30%

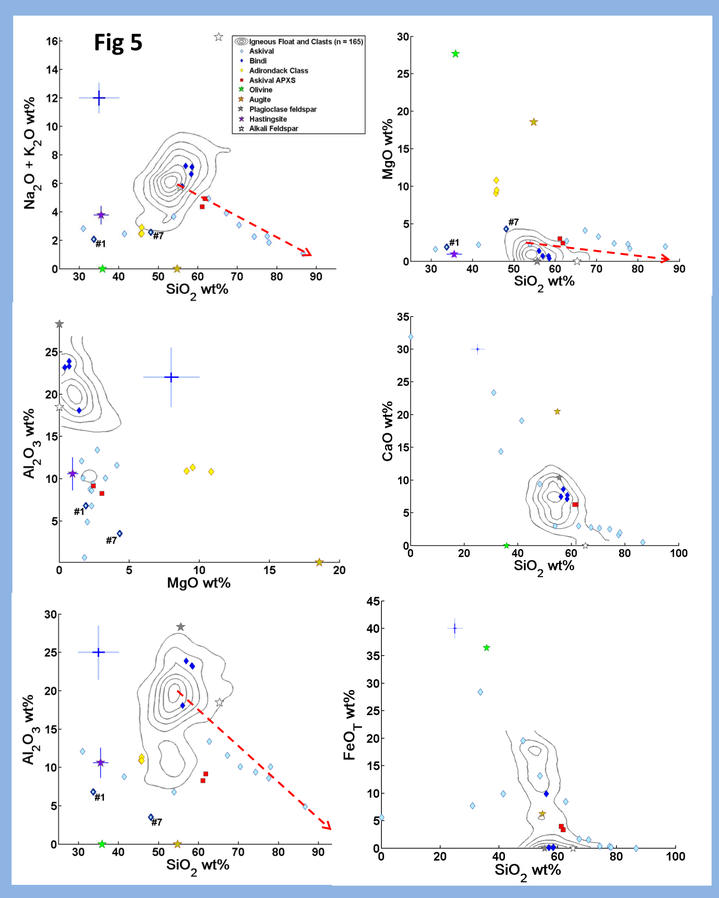


Figure 5. ChemCam, APXS analyses on Askival, and Bindi ChemCam. Density contour plots of Gale igneous basalt-trachybasalts plotted [6]. Red dashed lines show a mixing line between unaltered feldspathic cumulate represented by Bindi and hydrated silica, with intermediate, silicified feldspar mix. Askival #1 has a composition similar to nakhlite amphibole [8,9] ferrohastingsite mixed with a small proportion of Fe oxide and sulfate. Askival #7 point is dominated by an augite-like pyroxene component. ChemCam 1σ precision and accuracy are shown as dark and light blue crosses.

Hydrogen – H_2O LIBS analyses

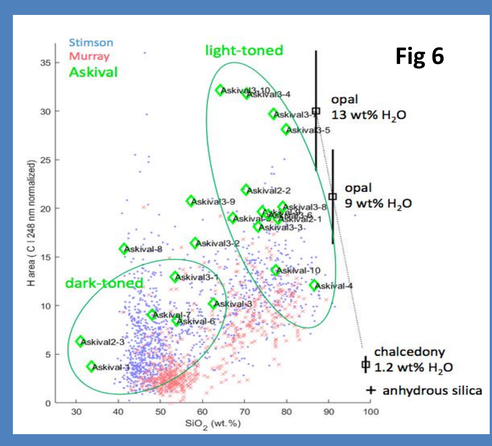


Figure 6. ChemCam hydration analyses of Askival. The least altered dark-toned phase (Askival #1) corresponds to an amphibole-like composition but with extra Fe oxide and sulfate (Figs 4, 5). The light toned, relict feldspar grains show hydration and silicification equivalent to ≤13 wt% H_20. The dark toned phases show a correlation of SiO2 with H, suggesting they have also been variably altered. Stimson and Murray analyses shown for comparison. Technique described in [4].

Discussion

Our compositional and textural data suggest that Askival was originally a plagioclase-mafic cumulate that has been silicified and hydrated. Bindi is also a feldspathic cumulate but escaped this alteration, suggesting silicification was localised. The cumulate melt for these feldspathic cumulates is likely to be related to the trachybasalt melt identified for many of the Gale igneous float rocks and clasts (Fig. 5) [6,7,10]. This in turn was formed through fractional crystallisation of an Adirondack-type melt [6].

Relatively intense alteration of the feldspar and mafic phases occurred as the Askival parent was silicified and hydrated, postdating the igneous processes. The fine network of veins in Askival may be another sign of the mafic alteration though the exact nature of the altered mafic mineralogy is unclear. Minor sulfate veining may have occurred at the same time. Rhyolite-MELTS analysis is consistent with low temperature, anhydrous fractional crystallisation from a trachybasalt melt but heavily overprinted by later alteration.

In situ silica remobilization has been identified in Gale sediments [11]. This is believed to have occurred under low temperature, diagenetic conditions. However, the absence of such alteration in other rocks of the Bressay locality indicates that the Askival silicification occurred prior to emplacement at its current position. Askival offers further evidence that extensive silica remobilization occurred in many parts of Gale crater and its immediate catchment. In addition to revealing plagioclase cumulate processes, possibly with a unique for Mars, ferrohastingsite, Fe oxide and augite mafic assemblage, Askival offers the only known example of silicification of igneous samples, adding to the diversity of known igneous samples on Mars [12-14].

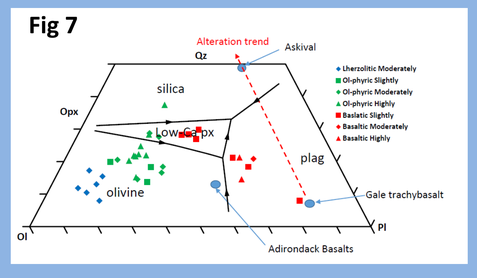


Figure 7. Ol-Pl-Qz phase diagram. Gale Trachybasalt focal compositions [4], Askival APXS, Adirondack basalts [13] and shergottite compositions. The diagram is consistent with Askival (and Bindi) forming through accumulation of feldspar from a trachybasalt type melt, followed by silicification and hydration. Oxygen molar (equivalent to volume) units, adapted from [15].

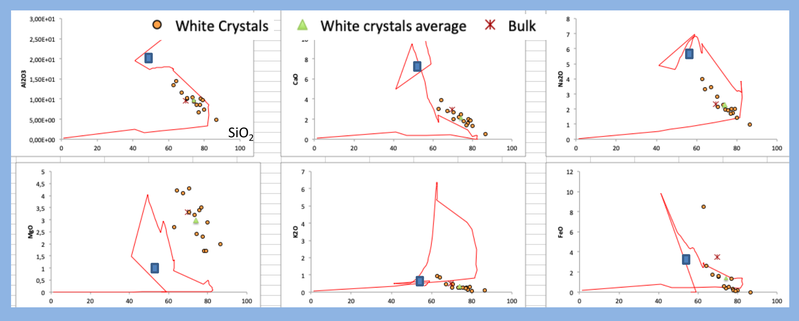
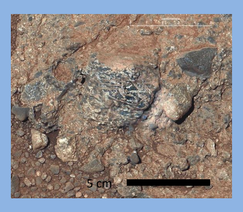


Figure 8. Rhyolite-MELTS modelling [16] example of compositions crystallised at 4 kbars, FMQ +1, 0.5% H_2O. Starting trachybasalt melt composition from Edwards et al. [6]. Askival analyses, apart from blue squares Bindi plagioclase-mafic modal average composition.

The model (and a similar one at 1 kbar) for Al_2O_3 v. SiO_2 is consistent with fractional crystallisation from an anhydrous trachybasalt melt at low pressure from Bindi to Askival, but heavily overprinted by subsequent alteration as shown by alkali depletion and silica enrichment.

Figure 9. Harrison clast sol 514. A trachybasalt which is close to the melt composition [6] from which the Bindi, Askival, Peacock Hills plagioclase-px-amphibole cumulates crystallised.



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