

**APATITES IN GALE CRATER.** O. Forni<sup>1</sup>, P.-Y. Meslin<sup>1</sup>, C. Drouet<sup>2</sup>, A. Cousin<sup>1</sup>, G. David<sup>1</sup>, N. Mangold<sup>3</sup>, E. Dehouck<sup>4</sup>, E.B. Rampe<sup>5</sup>, O. Gasnault<sup>1</sup>, M. Nachon<sup>6</sup>, H. Newsom<sup>7</sup>, D. L. Blaney<sup>8</sup>, S. M. Clegg<sup>9</sup>, A. M. Ollila<sup>7</sup>, J. Lasue<sup>1</sup>, S. Maurice<sup>1</sup>, R.C. Wiens<sup>7</sup>, <sup>1</sup>Institut de Recherche en Astrophysique et Planétologie, Toulouse, France, <sup>2</sup>CIRIMAT, Toulouse, France <sup>3</sup>LPGN, Nantes, France, <sup>4</sup>LPL-TPE, Lyon, France, <sup>5</sup>NASA JSC, Houston, USA, <sup>6</sup>Texas A&M University, USA, <sup>7</sup>UNM, Albuquerque, USA, <sup>8</sup>JPL, Pasadena, USA, <sup>9</sup>LANL, Los Alamos, USA; [olivier.forni@irap.omp.eu]

**Introduction:** ChemCam is an active remote sensing instrument suite that has operated successfully on MSL since landing Aug. 6<sup>th</sup>, 2012 [1, 2]. It uses laser pulses to remove dust and to analyze rocks up to 7 m away. Laser-induced breakdown spectroscopy (LIBS) obtains emission spectra of materials ablated from the samples in electronically excited states. The intensities of the emission lines scale with the abundances of the related element. ChemCam is sensitive to most major rock-forming elements [3] as well as to a set of minor and trace elements such as F, Cl, Li, P, Sr, Ba, and Rb [4]. The measured chemical composition can then be used to infer the mineralogical composition of the ablated material. Here, we report a summary of inferred apatite detections [5] along the MSL traverse at Gale Crater. We present the geologic settings of these findings and derive some interpretations about the formation conditions of apatite in time and space.

**Geological context:** From Sol 14 to Sol 750, the Curiosity rover explored the Bradbury Group, which consists of the Yellowknife Bay formation [6] (composed of basalt-derived fine, medium-, and coarse-grained sandstones), the Rocknest formation [7] and the Kimberley formation where Curiosity spent sols 572-632 analyzing its outcrops of sandstone, siltstone, and conglomerate [8]. The Murray formation follows up-section and its contacts with the Bradbury group are considered transitional with interfingering facies [6]. Rocks comprising the Murray formation (> 300 m thick) are presently divided into eight members representing three major facies associations. The eight members in ascending order are: Pahrump Hills, which consists of finely laminated mudstones, with interstratified cross-bedded basaltic sandstones [9]; Hartmann's Valley, Karasburg, Sutton Island, Blunts Point, Pettegrove Point and Jura that together make the Vera Rubin Ridge [10]. The Jura member comprises bedrock showing areas of red and gray coloration. VRR is comprised of planar-laminated mudstones similar to lithologies observed in the underlying members of the Murray formation [11].

**Apatite detection:** Apatites are identified with ChemCam mainly through the combined detection of calcium, fluorine, chlorine and, when large enough, with phosphorus [5]. The detection of fluorine and chlorine is made possible by the identification of molecular emissions of CaF and CaCl, respectively, created in the laser plasma. For chlorine, the atomic line is also used.

A combination of Ca, P and F or Cl was detected in ~50 individual points, which represent the most robust apatite detections. When P was not detected, shot to shot correlations between calcium lines and fluorine molecular emissions were performed in order to detect possible candidates by the association of both elements. With these criteria, more than 280 tentative detections of apatites were obtained (Fig 1.).

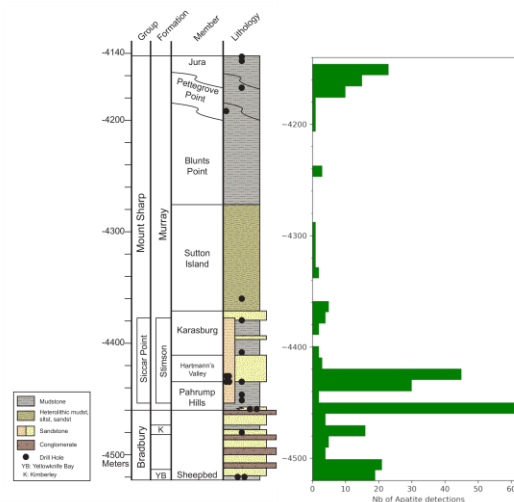


Figure 1: Number of apatite candidates as a function of elevation. The bin height is 10 m.

**Apatite settings:** First, apatites have been detected in igneous rocks found on Mars [12]. They are associated in intrusive fine-grained rocks like Beacon, in porphyric effusive rocks like Harrison but also in aphanitic effusive rocks and in the float rocks of the Bressay lag deposit. Their presence is ubiquitous to the igneous rocks, independently of their basaltic or trachy-andesitic composition. They are probably primary and of magmatic origin. They also can represent the source of detrital apatites found in the sediments.

Apatites have been found in many conglomerates encountered during the traverse – like the Goulburn and Deloro conglomerates belonging to the Bradbury group – but also at the base of the Pahrump Hills member in the Bald Mountain conglomerates [13]. They have also been identified in the Rocknest sandstone [7] which is characterized by low silicon content and high iron and titanium, reflecting the probable presence of ferrous and/or titaniferrous oxides like magnetite, hematite, and/or ilmenite. Apatites are observed in the lower part

of the Pahrump Hills member and found in association with detritic features and veins [14]. Fluorapatites were also detected at the 1-2wt% by CheMin at this location [9]. Apatites were also found at the contact between the Stimson and Murray formations which also exhibit calcium sulphate veins [15]. The majority of the detections was made very close to the unconformity between the Murray mudstone and the Stimson sandstone and is mainly located in the Stimson formation. Apatites observed after Marias Pass were observed in the Naukluft Plateau and in the area of Murray Buttes. These detections are mainly found in fracture fills, in dark-toned veins or maybe in the interstitial space between these veins and the sulphate veins [16]. Higher in the Murray formation, some candidate apatites are found in the VRR. More than half are located in the Pettegrove Point member and the remaining are equally distributed between red and grey Jura members and associated with the bedrock [17]. They are also found in the Stoer and Rock Hall drill holes, as confirmed by CheMin for the latter [18].

**Discussion:** Mainly three types of apatites have been identified: primary igneous apatites, detrital apatites mainly found in the conglomerates, in Rocknest and in the Bressay rock lag deposit, and secondary apatites found throughout the Murray formation. The common characteristic of these apatites is that they are mainly fluorapatites (i.e., with F as the dominant monovalent anion). Chlorine was also detected in a subset of apatites, but to a few exceptions, Cl appears to be less abundant than F in the structural formula and seem to be predominantly associated with the igneous rocks like the Harrision target (Fig. 2). This observation, which is supported by CheMin through modelling of the XRD pattern of the apatite peak (Rampe, pers. comm.), contrasts with what is currently observed in SNC meteorites. [19], [20] [21] and [22] have observed that there are two populations of terrestrial apatite: fluorine-rich, water-poor types found in the melt-inclusions, and chlorine-rich types found in the interstitial space. They concluded that the fluorapatites formed in a closed system process within the melt inclusions while the chlorapatites formed via open system fluid migration. Various explanations may elucidate the discrepancy between observations in Gale crater and those of Mars meteorites. With LIBS spectroscopy, the detection limit of chlorine in apatites is poorer/larger than that of fluorine. Moreover, the formation of the CaCl molecular line is less favoured when competing with the CaF molecular emission [23]. Nevertheless, the prevalence of F-rich apatites is also observed in a majority of samples where chlorine has also been detected. It is worth noting that many apatites are associated

with high-iron content, like in the Rocknest sandstone. This can indicate that those apatites are detrital, deriving from a source that underwent strong hydrothermal activity, similar to what is observed for the Durango apatites in the Tertiary iron-magnetite deposits of Cerro de Mercado, Mexico [22]. However, in the VRR mudstones with their strong diagenetic imprint [23], the context of these apatites suggests a formation through precipitation by fluids, perhaps from initially acidic fluids that dissolve P-bearing minerals and reprecipitate apatite after these fluids were neutralized.

**Conclusion:** Apatite is a ubiquitous minor phase whose stability field and conditions of formation can constrain the temperature and pH conditions that prevailed at the time of their occurrence. The apatites found at Gale so far are mainly fluorapatites, in contrast to what is found in SNC meteorites. No clear signature of REE has been identified so far in these apatites [24]

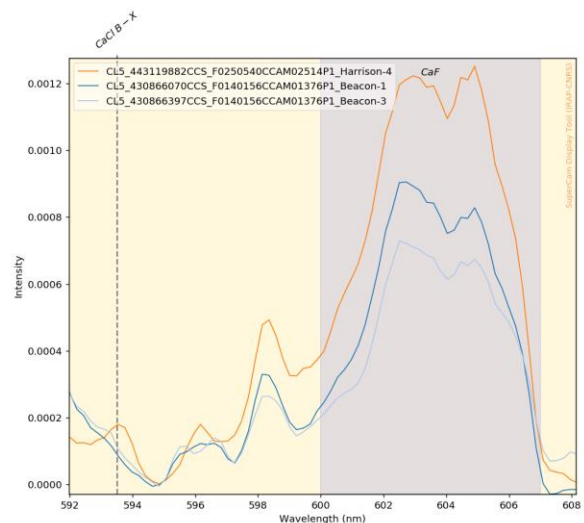


Figure 2: Spectral extract of two igneous rocks in the fluorine-chlorine molecular region showing the presence of CaCl for the target Harrison and not for the target Beacon (dashed line, left).

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