GRETNA GREEN, A POSSIBLE CHONDRITE DETECTED AT GLEN TORRIDON IN GALE CRATER.

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Introduction: This work reports a possible chondrite detection by MSL in addition to the ones previously reported [1] and informs an interpretation of the measurements for the rate of meteorite falls on Mars and their survival in the martian environment. Analyses of Gretna Green (Fig. 1) were performed by APXS and ChemCam on sol 2608.

ChemCam is a Laser-Induced Breakdown Spectroscopy (LIBS) instrument on-board the NASA Mars Science Laboratory (MSL) rover that has been exploring Gale Crater, Mars, for the past seven years [2, 3]. Typically, ChemCam samples several locations per target and probes each location with 30 laser shots. Each shot on a specific point removes a few nanograms of material. The first five shots are contaminated by martian aeolian dust and are systematically removed for data processing and the determination of rock composition [4].

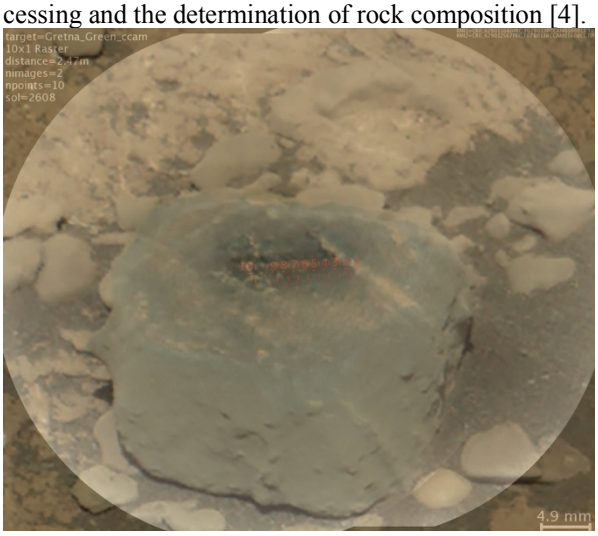

Figure 1: Sol 2608 RMI merged with Mastcam mosaic of target Gretna_Green_ccam, a possible chondrite analyzed by ChemCam and APXS.

Meteorite falls on Mars: On Earth, the large majority (>70%) of observed meteorite falls are due to ordinary chondrites, while iron meteorites represent a small fraction of falls (~4%) [5]. In contrast to these numbers, on Mars, the MER rovers did not definitively detect chondritic meteorites, instead finding iron and stony achondrite meteorites [6, 7, 8]. These meteorites were weakly altered mostly due to wind abrasion, coating-forming chemical alteration and possibly aqueous acidic exposure [9].

The MSL rover has observed a few dozen iron meteorites since the beginning of the mission [10, 11], and 20 of them were analyzed by ChemCam in the rover workspace [12, 13]. Assuming that the alteration rate is relatively similar between meteorites across the current Martian surface, this number of irons would correspond to at least 300 ordinary chondrites and a number of carbonaceous chondrites that should have been detected by MSL in its workspace.

Even when using higher alteration estimates for chondrites, the terrestrial fall numbers would imply anywhere between 5 and 5000 chondritic fragments >10 g in the surface area covered by the rover since the beginning of the mission [13, 14]. Chondritic meteorites on Mars have been indirectly identified as a component of the polymict breccia NWA 7533 [15]. Identifying such samples on the Martian surface would be beneficial to better understand weathering/alteration on Mars, and could prove to be important to constrain the exogenous carbon input [16].

Detection of chondrites with ChemCam: ChemCam can detect elemental compositions on a 0.5 mm spot up to 9 m from the rover. The target Gretna Green analyzed on sol 2608 presents a definitive signature of high nickel content (from ChemCam in Fig. 2, and APXS gives Ni=2600ppm [17]), elevated MgO content (>25 wt.% for a total of 94.3 wt.%) and moderate copper (>100 ppm) [18] with major elements ratios unlike any other bedrock compositions seen at Gale (Fig. 3 and 4). Two previous targets, Normandien (sol 1831) and Omusati (sol 1463), presented similar ratios and were argued to be of chondritic origin [1].

The Ni-Mg abundance obtained from those samples is inconsistent with the values obtained from typical Mars rocks and their alteration products as described in [19]. We interpret the association between high Mg and high Ni as a possible mixture between olivine and a metal phase. Most major and trace elements measured by ChemCam fall well outside their typical values measured at Gale crater, making these rocks unique.

Their composition is different from the stony meteorites analyzed by *Opportunity* at Meridiani Planum [7], the MSL meteorites have higher Mg and Ni contents. The Meridiani finds have a composition more similar to eucrites, but with additional metal.

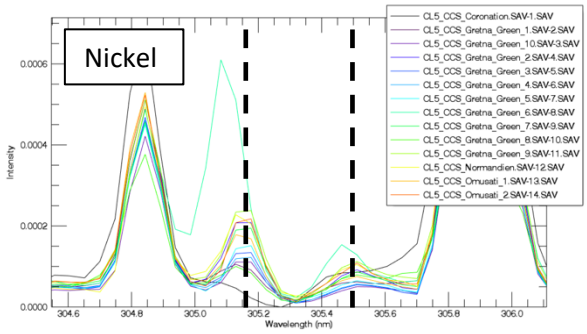

Figure 2: Ni lines (305.17 nm and 305.52 nm) of Normandien (sol 1831), Omusati (sol 1463) and Gretna Green (sol 2608) as compared to the basaltic target Coronation (sol 13).

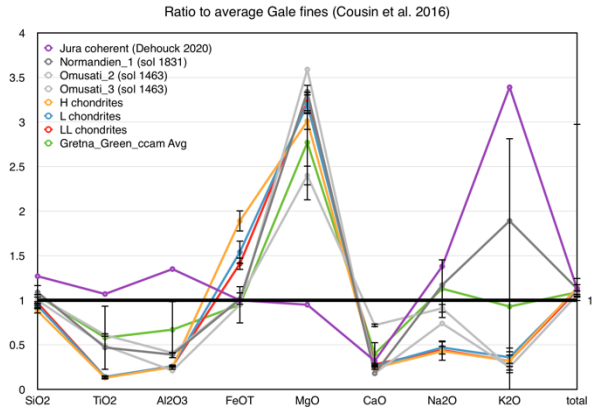

Figure 3: Major elements ratio to Gale fines[20]: Normandien, Omusati, Gretna Green, the main ordinary chondrite groups (H, L, and LL [22]) and Jura coherent bedrock [21].

As illustrated in Figs. 3 and 4, the major element composition of these samples compared to local soil fines and local bedrock Jura coherent analyzed by ChemCam [20, 21] follow trends that are similar to those of the major groups of ordinary chondrites : H, L and LL (average composition taken from [22]). Especially, Mg/Si at ratios of 0.9 are consistent with an origin as an ordinary or carbonaceous chondrite. The alkali contents are variable but tend towards lower values as well, which is expected for chondrites.

Geological context: Gretna Green was imaged by ChemCam and Mastcam as illustrated in Fig. 1. It is a 2-3 cm oblong pebble unlike other pebbles surrounding it. The bottom part of the rock, which appears to be eroded, presents nodular structures that could be reminiscent of chondrules. The image of the target could be consistent with the hypothesis that Gretna Green is a fragment of an ordinary chondrite. However, the target was found near a local butte and could originate from higher layers with a more mafic composition, though the composition of the capping unit of the buttes has been determined to be different with an enrichment in FeO and a lower MgO content [23].

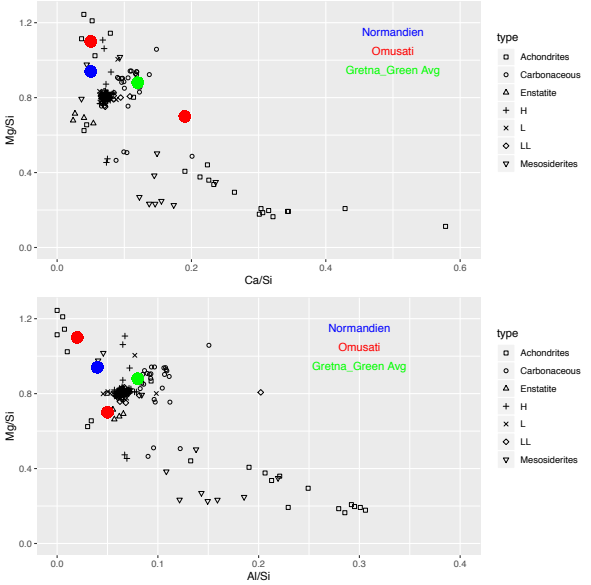

Figure 4: Major elements Mg, Ca, Al, ratioed to Si overplotted with diagnostic meteoritic ratios adapted from [22].

Conclusion: With the addition of Gretna Green, three cm-sized possible chondritic fragments have been identified by ChemCam along the MSL traverse, in the lower range of what is expected from models [13]. Their chemical compositions include elevated Ni content (>1 wt.%), MgO content (~20-30 wt.%), and enhanced Cu (>100 ppm) together with high Mg/Si ratios unlike other martian targets analyzed by ChemCam at Gale [24]. Their chemical composition and visual appearance are consistent with an origin as fragments of chondrites.

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References: [1] Lasue et al. 2019, LPSC #2274 [2] Maurice *et al.* (2012) SSR, DOI 10.1007/s11214-012-9902-4 [3] Wiens *et al.* (2012) SSR, DOI 10.1007/s11214-012-9912-2 [4] Maurice *et al.* (2016) JAAS, DOI 10.1039/C5JA00417A [5] The Meteoritical Society: Meteoritical Bulletin Database (Sep. 2017) [6] Van Cromphaut et al. (2007) MAPS, 42, 2119. [7] Schröder et al. (2008) JGR, DOI 2007JE002990 [8] Schröder et al. (2010) JGR, DOI 2010JE003616 [9] Ashley et al. (2011) JGR, DOI 2010JE003672 [10] Wellington et al., 2018, LPSC #1832 [11] Wellington et al. (2019) LPSC #3058. [12] Johnson et al. (2020) *this conf.* [13] Meslin et al. (2019) LPSC #3179 [14] Bland and Smith (2000) Icarus, DOI icar.1999.6253 [15] Humayun et al. (2013) Nat., DOI nature12764 [16] Yen et al. (2006) JGR, DOI 2006JE002797 [17] Gellert et al. (2020) *this conf.* [18] Goetz et al. (2020) *this conf.* [19] Ming et al. (2006) JGR, DOI 2005JE002560 [20] Cousin et al. (2015) Icarus, j.icarus.2014.04.052 [21] Dehouck et al. (2020) *this conf.* [22] Jarosewich (1990). *Meteoritics*, *25*(4), 323-337. [23] Wiens et al. (2020) *this conf.* [24] Cousin et al. (2017) Icarus, DOI icar.2017.01.014