SIGNIFICANT HALITE ENRICHMENT IN THE SULFATE-UNIT OF GALE CRATER, MARS. P.-Y. Meslin[1], W. Rapin[1], O. Forni[1], A. Cousin[1], O. Gasnault[1], M. Loche[1], E. Dehouck[2], N. Mangold[3], G. Caravaca[1], S. Schröder[4], P. Gasda[5], S. Le Mouélic[3], J. Lasue[1], J. Frydenvang[6], B. Clark[7], A.G. Fairen[8], S. Maurice[1], R.C. Wiens[5], N. Lanza[5], [1]IRAP, Université Paul Sabatier, CNRS, CNES, Toulouse (pmeslin at irap.omp.eu). [2]Univ. Lyon 1, ENSL, LGL-TPE, Lyon. [3]LPG, Nantes. [4]DLR, Berlin. [5]LANL, Los Alamos. [6]Globe Institute, Univ. Copenhagen. [7]Space Science Institute, Colorado. [8]CAB, CSIC-INTA, Madrid.

Context: Since its landing in 2012, the *Curiosity* rover has been exploring geological records of a paleo-lacustrine environment in Gale crater. It started with the fluvio-deltaic and lacustrine deposits in the lowermost Bradbury Group, followed by ~300 m of stratigraphy through the Murray formation (from the Pahrump Hills to the Jura member) dominated by mudstones and occasionally heterolithic mudstones, siltstones and sandstones. Along this traverse, it also crossed the unconformity with the overlying Stimson formation, dominated by aeolian sandstones, and the Vera Rubin Ridge, an erosion-resistant section of the Murray fm., which has undergone extensive diagenesis [1]. From Sol 2300 to 3072 (Jan. 2019 to Jan. 2021), *Curiosity* has explored the Glen Torridon region, previously named "Clay-bearing unit" because of the orbital signatures of clays detected in this area. Since Sol 3100 (Mont Mercou), the rover entered the basal Layered Sulfate unit (also named after orbital observations) with the objective of documenting a possible major change in Mars climate history. Evaporitic salts could represent a geochemical marker of this transition. Here, we provide an overview of previous halite detections by ChemCam [2, 3] and report on new detections made in the sulfate-bearing unit.

Data and Method: This study covers data acquired by the ChemCam instrument over the first 3300 sols of the mission and corresponding to ~27800 LIBS analysis points. The detection of halite is made possible by measuring the chlorine emission line at 837.8 nm. Comparing the chlorine peak area to the Na abundance reveals the presence of a group of points showing a strong linear correlation between the two elements (Fig. 1).

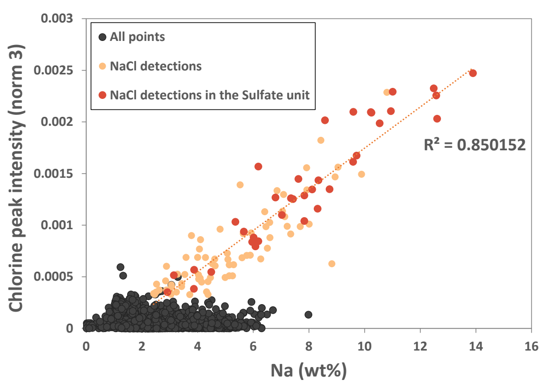

Fig. 1: Chlorine – Sodium correlation used to define halite detections (oxygen peak analysis not shown). Pure halite contains 39.3 wt% Na.

These points reach the highest Cl and Na concentrations observed in the ChemCam dataset. The oxygen line intensity is used to discriminate between halite and Na-perchlorate [4]. It is found to decrease with increasing Cl intensity in this group of points, which confirms the presence of halite. Although the LOD for chlorine is close to ~1wt%, a detection threshold of ~2.5 wt% Cl is applied for halite, which is the visual limit between the group of points described above and the remainder of the dataset shown in Fig.1. Halite could be present in lower abundance in the latter (halite<4wt%), but a shot-to-shot analysis would be necessary to better constrain the nature of the Cl-bearing phases. Other Cl-bearing phases identified in Gale crater so far are chlorates/perchlorates [5], akaganeite [6] and chlorapatites [7].

Results/Observations: A total of 107 halite detections was obtained, which represents only 0.4% of the whole dataset. The distribution of halite is not homogeneous along the traverse (Fig.2).

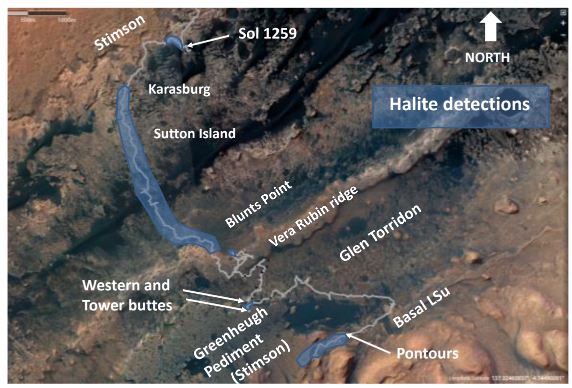

Fig. 2: Distribution of halite detections (starting on sol 1259)

Except in a few very rare targets in the Bradbury group [8], halite was not detected until sol 1259, when Curiosity was in the Murray formation, approaching the base of the Naukluft plateau (Stimson formation) [2], and then occasionally while crossing the Hartmann's Valley (dominated by sandstones), Karasburg (sandstones and mudstones), Sutton Island (heterolithic mudstones and sandstones) and Blunt Points (mudstones) members of the Murray formation [3]. Two broad categories of geological settings were found. The first is associated with diagenetic features, along edges of vertical and subhorizontal fractures, along erosion-resistant vein ridges, adjacent to calcium sulfate fills or phosphate-rich dark inclusions. The second category consists of isolated detections in the bedrock. No detection was made in the sandstones of the Stimson unit.

It is noteworthy that only two detections (near detection threshold) were made in the Vera Rubin Ridge and only one in the clay-rich Glen Torridon region, despite the almost ubiquitous presence of cross-cutting calcium-sulfate veins. It is only near the base of the Western butte, on the flank of Tower butte and in the trough between them, near the Siccar Point unconformity (at the base of the Greenheugh pediment capping unit), that halite was detected again. This area is characterized by the presence of numerous diagenetic concretions [9], an increase in Ca-sulfate features [9] and is marked by an increase of Ca and Na in the bedrock [10]. A high number of fluorine detections, both in the bedrock and in diagenetic features, was also reported there and probably associated with the presence of fluorapatite [10,11]. In this area, halite is detected as isolated grains in nodular or knobby bedrock facies.

Finally, a sharp transition was observed from Sol 3171 on, starting around the Pontours drill site, after Curiosity entered the basal Layered-Sulfate bearing unit (LSu) and after traversing lithologies marked by the presence of polygonal ridges enriched in Mg-sulfates [12]. This is the topmost section of the stratigraphic column explored so far. Numerous halite detections were made there (~1/3 of the total number of detections) (Fig.1). The halite concentration in individual points was also found to increase, reaching ~35 wt% halite. The associated facies have also changed. For the first time since the beginning of the mission, we observed contiguous detections of halite (as opposed to isolated grains) in planar and erosion-resistant grey laminae (Fig.3a). What makes them resistant to erosion remains to be determined. Halite was also detected in mm-sized spherules, which are possibly nodules eroded from the surrounding bedrock (Fig.3b).

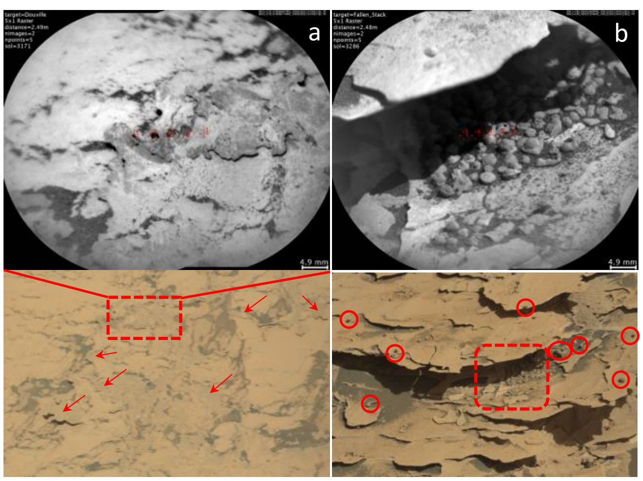

Fig. 3: Halite-rich features found in the Pontours member.

Discussion: Multiple diagenetic features have been observed throughout the Bradbury group and Murray formation [9,13,14], but geochemical evidence indicative of an evolution of depositional environment (e.g., shallow lacustrine or evaporitic environment) has been scarce or ambiguous. For example, desiccation cracks enriched in Cl and Br were found in the Sutton Island member [15], followed by a series of subhorizontal dark laminae enriched in Fe and P, progressively giving way to mm-size dark nodules enriched in Mn, Mg and P [16] and to Mn-rich sandstones [17,18]. These laminae/nodules were interpreted as syndepositional or early diagenetic features having formed in a shallow lake or lake margin environment [16-18]. In the same area near the Sutton Island – Blunts Point boundary, evidence for Mg-sulfate brines concentration by evaporation was also found [19]. The laminated mudstones where halite was detected in this section contain many $CaSO_4$-filled fractures/laminae (and halite is usually adjacent to these fractures). Because these subhorizontal fractures do not always follow the bedding planes, they were interpreted as diagenetic [20]. However, they could have been filled by a local remobilization of primary evaporites. In a closed evaporitic lake in steady-state, the absence of halite laminae could easily be explained by a sediment deposition rate exceeding the halite precipitation rate. Thin halite evaporitic beds could also be eroded if exposed, or be dissolved by subsequent aqueous events. Halite could then be further diluted in the sedimentary column, or transported to an evaporating front (e.g., at matrix/fracture interfaces).

Although the Pontours member and the base of the Siccar Point unconformity are characterized by a strong diagenetic overprint, some of the halite-rich facies found in the Sulfate-bearing unit are suggestive of primary evaporitic layers, because of their planar configuration. In contrast to previous occurrences, halite constitutes an important fraction of the laminae and is not accompanied by the presence of Ca-sulfates. In fact, some of these laminae are crosscut by $CaSO_4$ veins, which indicates that they pre-date this diagenetic event and that they have not been totally dissolved by subsequent aqueous events. However, other layers seem to form an angle with the bedding planes. Together with the nearby mm-sized spherules found in the bedrock, they may represent secondary evaporites formed by partial dissolution of adjacent evaporitic beds. A better understanding of their geometry, e.g. using 3D reconstruction [21], would help assess their origin.

Although a possible relationship to the Siccar Point unconformity should be further addressed (since halite was also detected during its first approach), the presence of these new halite-rich facies and the nearby presence of $MgSO_4$-rich polygonal ridges could reflect a change in depositional environment characterized by more arid conditions than previously encountered. The SAM instrument also recorded an increase in HCl released by samples during EGA analyses [22] and halite is a good candidate to explain this trend. The proportion of halite expected during evaporation of a Gale-like lake on Mars is being investigated by source-to-sink geochemical modeling [23].

The unequivocal identification of a halite enrichment in the Sulfate unit is also relevant to understand the potential habitability of the early Gale lake, as salts would have allowed water to remain longer in the liquid phase during subsequent cooling [24].

References: [1] Fraeman et al., 2020, JGR. [2] Forni et al., 2017, LPSC. [3] Thomas et al., 2019, GRL. [4] Schröder et al., 2017, LPSC. [5] Clark et al., 2021, Minerals. [6] Rampe et al., 2020, JGR. [7] Meslin et al., 2016, LPSC. [8] Nachon el al., 2014, JGR. [9] Gasda et al., 2022, accepted in JGR. [10] Dehouck et al., submitted to JGR. [11] Forni et al., 2021, LPSC. [12] Rapin et al., this meeting. [13] Nachon et al., 2017, Icarus. [14] Sun et al., 2015, Icarus. [15] Stein et al., 2018, Geology. [16] Meslin et al., 2018, LPSC. [17] Gasda et al., 2018, LPSC. [18] Lanza et al., 2018, LPSC. [19] Rapin et al., 2019, Nature. [20] Fedo et al., 2018, LPSC. [21] Caravaca et al., 2020, LPSC. [22] Archer et al., LPSC, this meeting. [23] Loche et al., LPSC, this meeting. [24] Fairen et al., 2009, Nature.