**CARBONATION OF MAFIC ROCKS IN THE MARGIN UNIT, JEZERO CRATER, MARS.** E. Clavé[1] (elise.clave@dlr.de), P. Beck[2], O. Beyssac[3], O. Forni[4], S. Schröder[1], N. Mangold[5], C. Royer[6], L. Mandon[2], E. Dehouck[7], S. Le Mouélic[5], C. Quantin-Nataf[7], A. Udry[8], J. Aramendia[9], C. Bedford[10], K. Benison[11], S. Bernard[3], A. Brown[12], E. Cardarelli[13], L. Coloma[9], S. Connell[10], T. Fouchet[14], J. Johnson[15], G. Lopez-Reyes[16], J.M. Madariaga[9], J.A. Manrique[16], S. Maurice[4], P.-Y. Meslin[4], A. Ollila[17], C. Pilorget[18,19], K. Rammelkamp[1], F. Seel[1], J. Simon[20], Wolf[16], A. Zastrow[17], S. Clegg[17], O. Gasnault[4], A. Cousin[4], R.C. Wiens[10] & the SuperCam Team; [1]DLR-OS, Berlin, [2]IPAG, Grenoble, [3]IMPMC, Paris, [4]IRAP, Toulouse, [5]LPG, Nantes, [6]LATMOS/IPSL/CNRS, Guyancourt, [7]LGL-TPE, Lyon, [8]UNLV, Las Vegas, [9]University of Basque Country, [10]Purdue University, [11]West Virginia University, [12]NASA Headquarters, [13]UCLA, [14]Observatoire de Paris, [15]JHU/APL, Laurel, [16]ERICA group, University of Valladolid, [17]LANL, NM, [18]IAS/Université Paris-Saclay/CNRS, [19]Institut Universitaire de France, [20]ARES, JSC.

**Introduction:** Jezero Crater lies in the most extensive carbonate-rich region on Mars [1, 2], and diverse carbonate-bearing units were detected from orbit within the crater [3-6]. In particular, a unit along the Western rim of the crater stands out with especially strong carbonate signatures in CRISM data. Several origins have been considered for these "Marginal Carbonates", including a lacustrine origin, with a possibly high astrobiological potential [4]. For more than 200 sols, the Perseverance rover has been exploring this unit, called Margin Unit in the context of the Mars 2020 mission (Fig. 1A) [7].

**Method**: We use data collected with the SuperCam instrument [8, 9] during the Margin Campaign (sols 910-1124), with three complementary spectroscopy techniques for chemical (laser-induced breakdown spectroscopy, LIBS) and mineralogical characterization (Raman and infrared reflectance spectroscopy, IRS) of rocks along the rover traverse. Additionally, the Remote Micro-imager (RMI) provides high resolution color images to contextualize the spectroscopic analyses. These techniques are used together to characterize geologic targets within several meters around the rover.

LIBS enables us to derive abundances for major oxides (MOC) [10], which can be used to identify specific minerals based on stoichiometric analyses, in particular olivine and pyroxene [11]. Carbonates (above ~50 vol%) can be identified based on a combination of MOC and C signal characterization [12, 13]. With Raman, the position of the carbonate $\nu_1$ mode can be used to derive the composition of Fe-Mg carbonates (Mg# defined as Mg/(Fe+Mg)) [14].

**Results**:

*LIBS* – The Margin Unit shows the highest concentration of both carbonate-bearing and high silica points along the entire traverse (49% of carbonate detections and 73% of points with $SiO_2$ > 65 wt.% for 22% of LIBS analyses). Besides these significant amounts of carbonates and high silica points, rocks in the Margin Unit are generally of mafic composition, including multiple detections of olivine and pyroxene (Fig. 1 C-F, [11]). Although all the carbonates are Ca-poor and Fe-Mg rich, we observed an interesting change in their composition in the middle of the campaign: before sol 1027, carbonates covered a large range of composition, with Mg# varying between ~0.3 and 0.8; since sol 1027, the Mg# of identified carbonate-bearing points are clustered in the 0.6-0.8 range (Fig. 1D, F). These compositional changes are correlated with changes in rock morphologies and textures [7, 15, 16], so we decided to consider two sub-units: the Eastern Margin before sol 1027 and the Western Margin afterwards (Fig. 1B).

*IRS* – With IRS, the Margin Unit is characterized by three main signatures: i) the 1.9 μm hydration band, comparable to what is observed in the vast majority of targets in Jezero Crater [17, 18]; ii) a 2.2 $\mu$m band, more frequent and deeper in some targets than in previous units and attributed to Si-OH based on the correlation with LIBS data; iii) absorption bands at 2.3 and 2.5 $\mu$m corresponding to carbonates, with a possible contribution of clays. Most spectra also show a positive slope between 1.3 and 1.8 $\mu$m, attributed to $Fe^{2+}$ in either olivine or carbonate. Additionally, a small band at 2.39 $\mu$m indicates the presence of Fe-phyllosilicates in some targets, but their precise characterization is complicated by the strong carbonate signatures.

*Raman* – For the first time in the mission, carbonates were detected not only in abraded patches (all three of them, Fig. 1B) but also on natural surfaces (on six different targets, all in the Western Margin). Some significant variability in Mg# is observed, with a median value of ~0.45 in the Eastern Margin and ~0.6 in the West. With Raman, olivine was also detected in the first abrasion patch in the Eastern Margin, as well as Ca-sulfate in white patches on the 2nd abraded patch in the Eastern Margin. No high-silica phase was detected with SuperCam Raman, although this is expected to be challenging due to an instrumental artifact.

**Summary & Discussion**: Several lines of evidence indicate that the Eastern and Western Margins may be distinct. In particular, observations of layering and clastic textures show that the Eastern Margin is likely of sedimentary origin. The Western Margin lacks clear structure to conclude confidently [7, 15, 16].

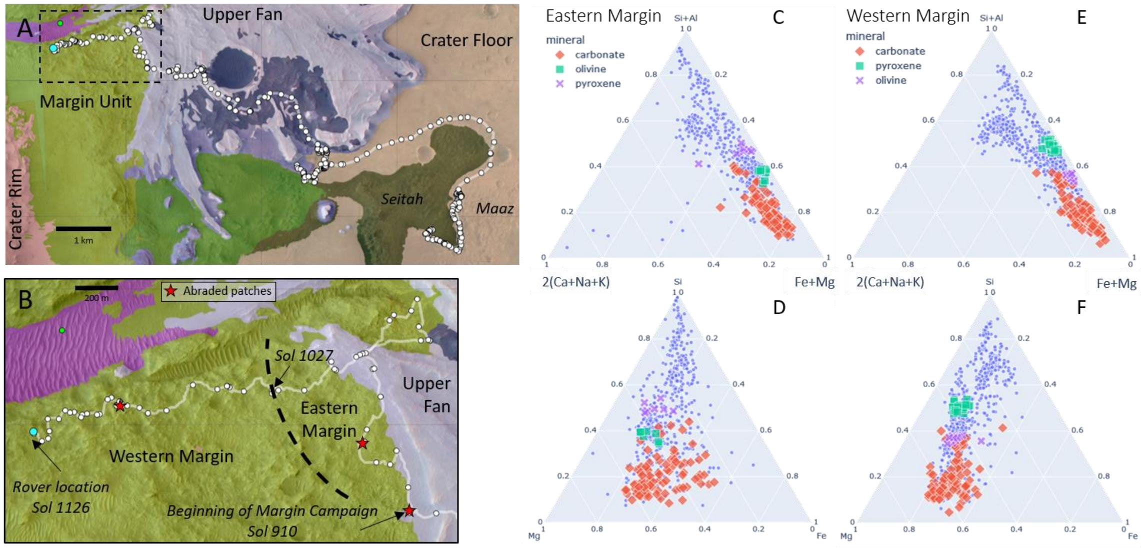

Figure 1 – Context of the Margin (A) and the separation between Eastern and Western Margins (B). Compared compositions (MOC) of Eastern (C-D) and Western (E-F) Margins, including minerals of interest (carbonates, olivine and pyroxene).

The SuperCam multi-technique data consistently indicates that the Margin Unit is uniquely enriched in both Fe-Mg carbonates and a silica-rich phase. The silica is at least hydroxylated based on the IRS, but its hydration state is not well constrained. Additionally, points with mafic compositions in LIBS, including olivine and pyroxene grains, are also omnipresent in this unit. Beyond these general observations, we note some variability within the Margin Unit, and in particular between the Eastern and Western parts. The Western Margin present a more restrained range of carbonate compositions, with only Mg-rich carbonates, covering the same range of composition as the primary minerals identified in this sub-unit (Fig. 1F). On the other hand, in the Eastern Margin, the range of carbonate composition is wider, and wider than the range of primary mineral compositions (Fig. 1D).

The compositional and mineral assemblages identified in the Margin Unit are consistent with aqueous alteration of mafic/ultramafic material by $CO_2$-rich fluids, which results in the dissolution of Si and Mg, and subsequent precipitation of silica and carbonates. This may occur with or without secondary silicates such as serpentine or talc depending on the conditions [19, 20], but these phases were not clearly identified with SuperCam. Note that the formation of silica coatings on olivine grains can result in passivation of olivine surfaces, which can explain their continued presence despite extensive alteration [20, 21]. The co-presence of remaining olivine and its alteration products indicates that – at least part of the – alteration likely happened in situ. In the Western Margin, the matching composition of the primary and secondary minerals is consistent with isochemical alteration, indicating possible low water-to-rock ratios and closed system. These observations could be consistent with rocks of various origins and do not provide strong constraints on the nature of the Western Margin.

In the Eastern Margin, the highest compositional variability could indicate more reworking of sediments or a different formation process for at least part of the carbonates (lower Mg# ones). For example, carbonate could have precipitated in situ, from fluids of variable compositions; there could also be some detrital carbonates, as indicated by observations of carbonate grains in the Eastern Margins [22, 23]).

For both Eastern and Western Margin, the fluids involved in the alteration must have been reducing, based on the $Fe^{2+}$ detection in IRS. Moreover, the protolith is consistent with the olivine-rich mineralogy observed in other places in Jezero: in particular, the Seitah formation [24] and the olivine-rich boulders observed on top of the delta [25], although both of these were significantly less altered, indicating a possible common origin, potentially linked to the regional olivine unit [2].

**References:** [1] Ehlmann, Mustard et al. (2008) *Nature geosc.*, [2] Mandon et al. (2020), [3] Goudge et al. (2017), [4] Horgan et al. (2020), [5] Tarnas et al. (2021), [6] Zastrow & Glotch (2021), [7] Horgan et al., this conf. [8] Maurice et al. (2021) *SSR*. [9] Wiens al. (2021) *SSR*. [10] Anderson et al. (2022) *SAB*. [11] Udry et al., this conf. [12] Clavé et al. (2023) *JGR*. [13] Beck et al. (2024) *Icarus* [14] Beck & Beyssac et al., *sub*. [15] Jones et al., this conf. [16] Ravanis et al., this conf. [17] Mandon et al. (2023) *JGR*, [18] Dehouck et al. (2023) *LPSC*, [19] Beinlich et al. (2010) [20] Johnson et al. (2019) [21] Daval et al. (2011) *Chem. Geol.* [22] Wiens et al. (2024) *LPSC* #1329. [23] Hurowiz et al. (2024) *LPSC* #2541 [24] Beyssac et al. (2023) *JGR*, [25] Beyssac et al. (2024) *LPSC* #1493