K-Rich Rubbly Bedrock at Glen Torridon, Gale Crater, Mars: Investigating the Possible Presence of Illite. A. Cousin[1], M. Desjardins[2], E. Dehouck[3], O. Forni[1], G. David[1], G. Berger[1], G. Caravaca[4], P. Meslin[1], J. Lasue[1], A. Ollila[5], W. Rapin[1], P. Gasda[5], S. Maurice[1], O. Gasnault[1], R. Wiens[5], [1]IRAP, Toulouse, France (agnes.cousin@irap.omp.eu), [2] Lasalle Beauvais, Beauvais ; [3]Université de Lyon, [4] Université de Nantes; [5]LANL, Los Alamos, NM, USA.

Introduction: The *Curiosity* rover reached the Glen Torridon (GT) area around sol 2300 (January 2019). GT is known to display relatively strong and extensive smectite signatures from orbit [1]. During the last two years of exploring this area, *Curiosity* has revealed variations in chemical compositions correlated with bedrock facies [2-4]. The spatially dominant type of rock in the lowermost part of GT (which is a lateral continuation of the Jura member) is described as the "rubbly" bedrock because it outcrops as small pieces of bedrock embedded in soil. The rubbly bedrock is composed of finely-laminated mudstones and is characterized by enrichments in K_2O and SiO_2 [3], whereas the slabs of coherent bedrock adjacent to it are lower in K_2O but enriched in MgO [3]. Another mudstone layer with a low MgO/high K2O type of composition is also observed in the overlying Knockfarril Hill member, between Glen Etive and Central Butte. X-ray diffraction (XRD) analyses performed by the CheMin instrument showed that the Jura coherent bedrock contains ~30 wt% of Fe-smectites [5]. However, no XRD analysis was performed on the rubbly bedrock, and the discussion below is thus based solely on elemental compositions measured by ChemCam [6,7].

The objective of this work is to discuss clues regarding the mineralogy of the GT rubbly bedrock: in particular whether the enrichment in K_2O is related to partial illitization of the clay minerals, or to a mixing with K-feldspars? Elevated K_2O abundances were previously observed in the Kimberley area [8-9], on the floor of Aeolis Palus [10], where CheMin results showed an associated enrichment in K-feldspar (sanidine) [9]. K-feldspars were also observed in igneous rocks such as trachytes [11,12]. In this study, data from the rubbly bedrock of GT are therefore compared to data from Kimberley and from the trachytic igneous rocks observed at Bradbury. Some plagioclase-rich igneous rocks are also used for comparison [12].

Methodology: ChemCam uses the LIBS technique to perform remote chemical analyzes [6,7,12]. The laser beam (300-500 µm, [13]) is large enough that it mostly samples mixtures of mineral phases (as opposed to pure phases), especially in mudstones. Therefore, we used trends in elemental ratios to interpret the mineralogy of the rocks. Compositions with a sum of oxides <90 % were discarded in order to minimize the contribution of the ubiquitous Ca-sulfate veins. Concerning minor elements, peak areas have been used, as described in [11].

Data used to be compared with the GT rubbly bedrock have been filtered in order to have relatively pure phases. For that, data points were plotted in mineralogical plot to select only relatively pure K-feldspars and plagioclase from trachytes, trachyandesites [12] and Kimberley rocks [8].

Results and Discussion: Illite data points can have a trend that is different from the K-feldspars on a K/Al molar ratio plot. However, as shown by the chemical formula ($K(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$), the K/Al ratio can vary easily in natural illites. Figure 1 shows the K/Al molar ratio for the Kimberley dataset, for nearly-pure K-feldspars and plagioclase analyzed by ChemCam, and forthe GT rubbly bedrock observed in Jura and Knockfarril Hill members. Theoretical trend lines are also plotted for comparison.

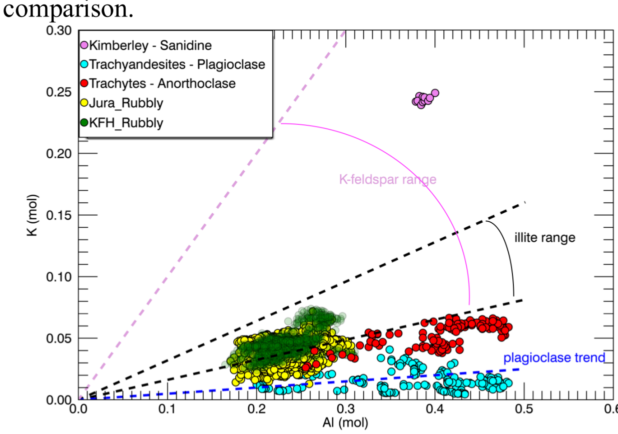

Fig.1: K vs Al (mol) for the GT Rubbly bedrock along with feldspars seen along the traverse. Each data point corresponds to a single laser shot. The dashed lines correspond to the theoretical trend for plagioclase (blue), sanidine (pink), with K-feldspar (pink) and illite (black) ranges.

The sanidine-rich points from Kimberley, the andesine-rich points and the orthoclase-rich points all follow reasonably well the corresponding trend lines (in pink, in blue and in red, resp. In comparison, most of the rubbly bedrock points are located in-between the two illite endmembers lines (in black), even though some are below that range. Figure 1 shows that even though this type of plot can efficiently separate plagioclase and K-feldspars, the range for illite is wide and it overlaps with the K-feldspars range. Therefore, this type of elemental ratio can not be solely used to differentiate between K-feldspars and illite. In addition, this approach does not rule out the possibility that K/Al ratio observed the Jura rubbly bedrock is due to a mixture of K-feldspars and plagioclase.

However, if plagioclase was responsible for the intermediate K/Al ratio of the rubbly bedrock, we should observe a positive correlation between Sr and Ca [16], which is not the case. Furthermore, the K/Rb ratio is lower in the rubbly bedrock compared to K-feldspars from trachytic-rocks and Kimberley, as well as compared to plagioclase for trachy-andesitic rocks (Fig. 2). This observation suggests that the K in the rubbly bedrock is mainly contained in a clay mineral, because the K/Rb is generally lower in K-rich clay minerals than in igneous materials [17,18].

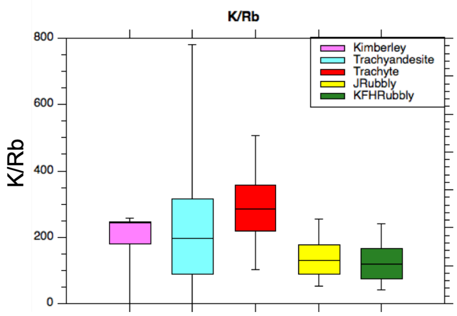

Fig. 2: K/Rb ratio for the Kimberley sediments enriched in sanidine, trachyandesite/plagioclase and trachyte/orthoclase, and for the Rubbly bedrock of Jura member.

Minor elements might be the best way to obtain some hints about the presence of illite in the rubbly bedrock. For example, Cr is known to be adsorbed in clays, whereas it is very low in feldspars [19]. Li tends to be adsorbed in clays as well [20, 21]. Figure 3 shows the Cr and Li distribution (in peak areas) of these two elements, in feldspars (plagioclase from trachy-andesites, orthoclase from trachytes and sanidine from Kimberley), in the rubbly bedrock, as well as in the coherent bedrock of the Jura member. The rubbly bedrock points are clearly enriched in Li and Cr compared to the feldspars, which suggests again that these rocks contain K-rich clay minerals instead of significant amount of K-feldspars. Another hint is that Li and Cr are also enriched in the coherent bedrock (in grey), which contain around 30 % of clay minerals, identified as Fe-rich smectite such as nontronite [5], and only ~1% sanidine. Not only are the rubbly bedrock points enriched in Li and Cr, but their Al/Cr ratio is clearly lower than that of the feldspars (Fig. 4), also pointing out that the mineralogy might be different in the rubbly bedrock. In fact, the Al/Cr ratio of the rubbly bedrock is similar to that of the coherent bedrock , suggesting that the rubbly bedrock contains K-rich clay minerals.

The possible presence of illite in the GT rubbly bedrock raises the question of the source of potassium and the diagenetic reactions having affected these sediments. Taking Earth as a proxy, K-feldspar is the usual source of potassium, but this mineral is not as ubiquitous on Mars, although it was identified in several rocks along *Curiosity*'s traverse [8-9, 11-12].

However, other K-rich mineral phases have been observed at Gale, such as possible micas [22]. The illitization process is highly dependent on the temperature and pH [23,24, 25] and therefore increases with depth during burial of sediments. However, illite can also form during hydrothermal events [26]. The close proximity of the rubbly bedrock with the coherent bedrock suggests that these two types of sediments come from different sources.

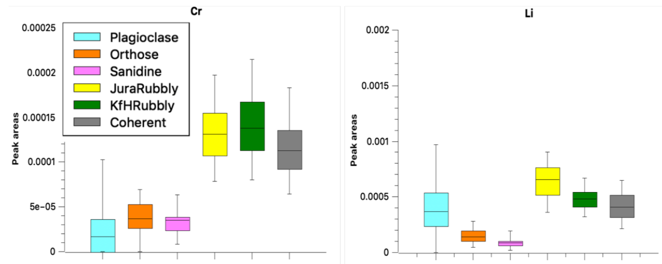

Fig. 3: Cr (left) and Li (right) peak areas distribution in the feldspars (Plagioclase, Orthose and Sanidine) and in the Rubbly (Jura and KHm) and Coherent bedrock.

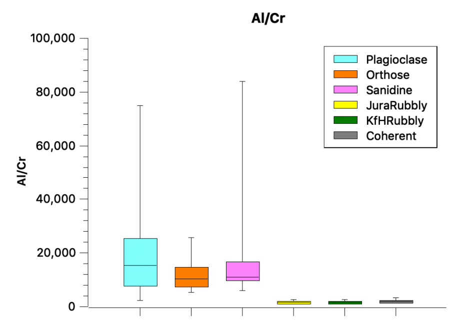

Fig. 4: Al/Cr ratio distribution in the feldspars (Plagioclase, Orthose and Sanidine) and in the Rubbly (Jura and KHm) and Coherent bedrock.

Conclusions: In this study, we investigated the mineral phase(s) that may be responsible for the K_2O enrichment observed in the rubbly bedrock of the GT Jura member. After an inventory of the possible candidates (excluding the amorphous component), we found that the most likely one is illite. Its formation process is unknown, but the observation of K-rich bedrock in close spatial association with smectite-rich ones [1-5] is intriguing and suggests that these sediments come from a different source.

References: [1]Grotzinger et al., 2012; [2]Fox et al., 2020; [3]Dehouck et al., 2020; [4]O'Connel-Cooper et al., 2020; [5]Thorpe et al., 2020; [6]Maurice et al., 2012; [7]Wiens et al., 2012; [8]Le Deit et al.,2016; [9]Treiman et al.2016; [10]Palucis et al., 2014; [11]Sautter et al., 2015; [12]Cousin et al., 2017 ; [13]Clegg et al.,2017; [14]Maurice et al., LPSC 2012;[15]Payré et al., 2017; [16]Simmons, 1999b; [17]Heier and Billings, 1970; [18] Reynolds et al., 1963; [19] Ajouyed et al., 2011 ; [20]Turekian and Wedepohl., 1961 ; [21] Williams and Hervig., 2005 ; [22]Forni et al., this meeting ; [23]Eslinger and Glasmann, 1993 ;[24] Huang et al., 1993 ; [25] Huggett, 2005 ; [26] Srodon et al., 2010.