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Evaluating the homogeneity of the X-ray amorphous component along the *Curiosity* rover traverse

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Abstract

Mass balance calculations are used to evaluate the chemical homogeneity of the X-ray amorphous component among the soil and rocks samples collected by the *Curiosity* rover at Gale crater, Mars.

1. Introduction

Since its landing in Gale crater in August 2012, the Mars Science Laboratory (MSL) rover *Curiosity* has collected several soil and rock samples along its traverse. X-ray diffraction (XRD) patterns of the <150-µm fraction of these samples have been acquired by the Chemistry and Mineralogy (CheMin) instrument [1] and have revealed a significant amorphous component of unclear origin [2-5]. Efforts to characterize the amorphous component so far have included estimates of its composition and abundance through mass balance calculations [6,7], and comparisons with XRD patterns of laboratory analogs [8,9]. Here, we report the results of preliminary mass balance calculations for the Windjana sandstone and compare the estimated composition of the amorphous component of this sample with the ones of the Rocknest soil and Sheepbed mudstone.

2. Methods

Following an approach similar to [3,4,6], we have based our calculations on bulk chemical compositions measured by the APXS instrument, and on phase abundances and structural formulas derived from the CheMin XRD patterns by [2-4]. We have developed a Scilab program that calculates all the possible chemical compositions of the crystalline component – and thus of the complementary amorphous component – of each sample, taking into account the uncertainties on the phase abundances derived from CheMin data [2,4]. Taking into account these uncertainties allow us to more rigorously compare the similarities and differences between two individual samples analyzed by *Curiosity*'s payload.

We have explored a range of values between 10 and 50 wt% of amorphous component but, for more detailed analyses, we have focused on 30 wt%, a value close to the XRD-based estimates for Rocknest and Sheepbed [2,4]. In some cases, the calculated amorphous component may have one or more oxides with concentrations below 0 wt%; the combination is then "chemically unrealistic" and thus rejected by the program. Therefore, this constraint can be used to determine a lower limit to the overall abundance of the amorphous component, i.e., the minimum amount required to have all oxides ≥0 wt%.

3. Results

3.1 Rocknest sand and Sheepbed mudstone

Detailed results of mass balance calculations performed with data from the Rocknest sand and the Sheepbed mudstone are reported in [7]. Despite obvious differences (in nature and age) between the two samples, their amorphous components were found to be chemically very similar to each other, having comparable estimated concentrations of SiO_2, TiO_2, Al_2O_3, Cr_2O_3, FeO_T, CaO, Na_2O, K_2O, and P_2O_5 (Table 1). MgO tends to be lower in Rocknest, although it may also be comparable between the two samples depending on the exact composition of the smectite clay in Sheepbed. The only unambiguous difference is the SO_3 content, which is always higher in Rocknest, suggesting the presence of amorphous sulfates or adsorbed SO_4^{2-} in the soil. Estimated minimum abundances are 21–22 wt% for Rocknest and 15–20 wt% for Sheepbed, in good agreement with estimates derived from the XRD patterns [2,4].

3.2 Windjana sandstone

Preliminary mass balance calculations have been performed using the mineralogy of the Windjana sandstone reported by [5]. Future adjustments are expected as the structural formulas of primary silicate minerals are further refined. In addition, the nature of the phyllosilicate component is not yet definitely established: a ferromagnesian smectite analogous to the one of the Sheepbed mudstone is favored [5], but other species such as illite cannot be ruled out. Thus, we have considered the two possibilities here.

Compared to Rocknest and Sheepbed, the amorphous component of Windjana has comparable ranges for SiO_2, Al_2O_3, FeO_T and CaO (Table 1). Na_2O is lower, which directly reflects the much lower Na content of the bulk sample as measured by APXS [5]. The fate of K_2O is highly dependent on the nature of the phyllosilicate. SO_3 is lower than in Rocknest and comparable to Sheepbed. Finally, the range of MgO concentrations is clearly shifted to higher values, especially when compared to Rocknest. Estimated minimum abundances are <10 wt% with illite and ~10-15 wt% with saponite.

4. Discussion and future work

Despite the caveats mentioned above, early results indicate that the amorphous component of Windjana share some similarities with the ones found at Rocknest and Sheepbed (high Si and Fe, low Al and Ca). S-rich amorphous component seems to be characteristic of the soil, which could be consistent with adsorbed SO_4^{2-}. Finally, Mg appears to be the most variable element between the amorphous components investigated so far.

Future work will include refinements of the calculations as more information on the samples are derived from the CheMin XRD patterns. Additional calculations will also be performed for the samples collected by *Curiosity* at Pahrump Hills.

Table 1: Comparison of the estimated composition of the amorphous component of the Rocknest soil (RN), Sheepbed mudstone (Cumberland drill, CB) [7], and Windjana sandstone (WJ), assuming an abundance of 30 wt%. G = Griffith saponite. I = illite.

(wt%)	RN	CB-G	WJ-I	WJ-G
SiO_2	25.6-38.7	28.8-44.4	19.7-40.5	24.6-42.4
Al_2O_3	0.0-6.7	0.0-5.4	0.0-8.3	3.6-9.6
FeO_T	21.2-34.6	13.7-33.6	8.2-33.5	6.3-28.3
MgO	0.0-4.9	3.4-15.0	19.8-27.4	15.3-24.6
CaO	0.6-6.5	2.6-10.0	0.1-6.2	0.0-5.4
Na_2O	3.8-5.1	3.7-6.1	0.7-1.1	0.7-1.0
K_2O	0.5-1.6	0.2-1.1	0.0-4.8	1.7-6.4
SO_3	14.7-17.2	0.0-5.9	2.1-7.0	2.1-7.0

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