

**AMORPHOUS COMPONENT COMPOSITIONAL RANGES IN GALE CRATER, MARS.** R. J. Smith<sup>1</sup>, E. Dehouck<sup>2</sup>, and S. McLennan<sup>1</sup>, <sup>1</sup>Stony Brook University (rebecca.j.smith@stonybrook.edu), <sup>2</sup>LGL-TPE, Université de Lyon, France.

**Introduction:** All of the fluviolacustrine sedimentary rocks in Gale crater analyzed by the CheMin X-ray diffraction (XRD) instrument have high abundances of an X-ray amorphous component (AmC) of unknown origin [1-10]. Hypotheses for the origin of these materials include: (1) weathered basaltic glass [1, 7], (2) detrital and subsequently altered soil or aeolian material [3-4], or (3) diagenetic cement [6]. The AmC compositions can be estimated using a mass balance calculation (MBC) approach where the AmC is assumed to make up the difference between the bulk and the crystalline compositions. This method has been applied to most of the drill hole (rock) samples measured by the CheMin instrument to date [1-11].

Most studies using the MBC approach only report the “best case” estimate, where the crystalline and AmC compositions are calculated ignoring AmC and mineral abundance uncertainties, yet these uncertainties have been shown to produce a range of possible AmC compositions [4]. Furthermore, poorly crystalline materials (clay minerals) have been considered part of the crystalline component in some studies [4], but not others [7-8, 11]. This makes it difficult to compare the estimated AmC compositions across all samples (including the non-clay-bearing ones).

It is therefore necessary to calculate the possible range of compositions for these materials before we can begin to understand possible formation mechanisms. Here we explore the range of possible AmC compositions for sedimentary rocks in Gale crater.

**Methods:** The MBC approach combines bulk XRD mineralogy from CheMin with bulk elemental analyses from the APXS instrument to calculate the bulk AmC composition [see 4 for details]. We utilize the Scilab program designed by [4] to calculate the range of possible AmC compositions for the rock drill samples encountered since [4]. APXS frequently acquires multiple compositions of the drill sample (e.g., undisturbed rock, drill tailings, discard pile). Where applicable, we used the same APXS measurements used in previous MBCs in order to be consistent with published results.

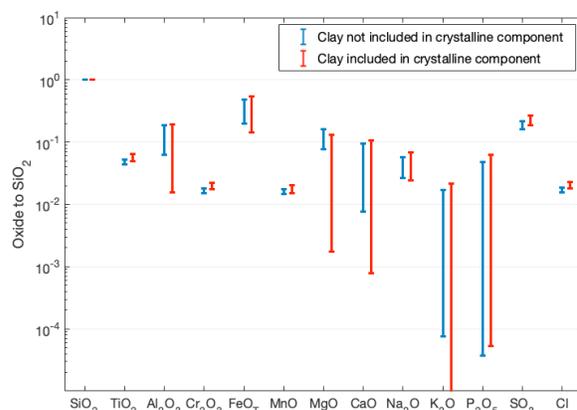
We calculate the AmC compositions using mineral and AmC abundance uncertainties as outlined in [4]. Additionally, for clay-bearing samples, we calculate the range of AmC compositions with and without clay minerals included in the crystalline component. We used Griffith Saponite 1 and 2 compositions [12] as proxies for the clay minerals in the lower Murray samples, and mixtures of Griffith Saponite and Fe-

montmorillonite (#12; [13]) for the upper Murray samples. These compositions have been compared to clay minerals in Gale crater in previous studies.

Caveats to keep in mind when interpreting results from the MBC method include: (1) the composition of crystalline phases that are below the detection limit of XRD will be allocated to the AmC composition; (2) minor elemental substitutions not reported in the ideal structure formula for crystalline minerals are also allocated to the AmC composition; (3) clay minerals can have complex compositions, and when poorly constrained, their presence makes it difficult to precisely determine the AmC compositions [4].

**Preliminary results:** Here we show results for a single clay-bearing sample, Confidence Hills (CH). CH is a mudstone in the lower Murray formation. The mineralogy of this sample was sourced from [7, 14], and includes 39±15 wt.% AmC and 8.0±2 wt.% phyllosilicates. The composition of the clay minerals is most likely ferrian saponite [15], and we use the Griffith Saponite 2 composition as a proxy.

Fig. 1 shows the range of oxides (ratio to SiO<sub>2</sub>) for the AmC of CH calculated using mineral abundance uncertainties and 39 wt.% AmC, with and without clay minerals included in the crystalline component. As expected, the oxide-to-SiO<sub>2</sub> ratios with the largest ranges are those found in minerals with the highest percent uncertainties: fluorapatite (CaO, P<sub>2</sub>O<sub>5</sub>) and jarosite (K<sub>2</sub>O). Most of the oxide ratio ranges overlap whether or not the clay minerals are included in the crystalline component. Oxide-to-SiO<sub>2</sub> ratio ranges with little to no overlap are minor components and/or are in



**Figure 1.** Ranges of calculated oxide-to-SiO<sub>2</sub> ratios for the CH AmC with and without clay minerals included in the crystalline component (note the logarithmic scale). Only one clay mineral composition (Griffith Saponite 2) is considered here.

the clay composition ( $\text{TiO}_2$ ,  $\text{Cr}_2\text{O}_3$ ,  $\text{SO}_3$ , Cl). In general, the ranges for most oxides differ from those reported for the Rocknest (RN) and Cumberland (CB) samples of the Bradbury Group [4].

The crystalline and AmC compositional ranges are distinct when plotted on a major elements (Si-Al-Fe) diagram (Fig. 2a). Additionally, the compositional ranges for each component (amorphous or crystalline) are very similar whether or not phyllosilicates are included in the crystalline component (Fig. 2a). Overall, the AmC is relatively enriched in Si compared to the crystalline component. Regardless of where the clay mineral compositions are considered, essentially no distinction can be made between the AmC and crystalline compositions when plotted on an A-CN-K-FM diagram (Fig. 2b).

The “best case” estimates accurately represent the Si-Al-Fe compositional trend between the crystalline and amorphous components (Fig. 2a), but do not accurately represent the lack of a compositional trend with the A-CN-K-FM oxides (Fig. 2b).

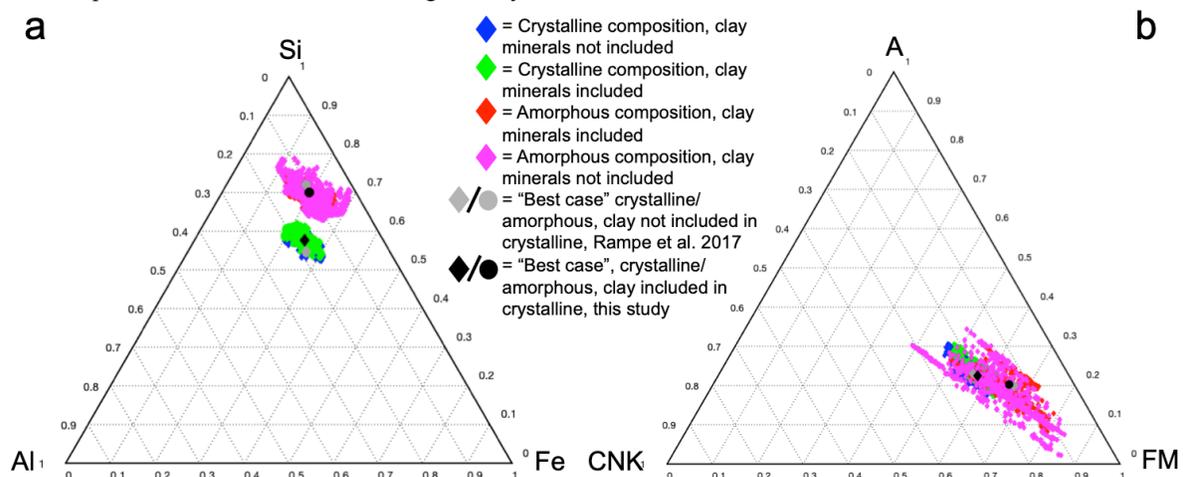
**Discussion:** The range of compositions for the crystalline and amorphous components are not significantly influenced by whether or not phyllosilicates are included in the crystalline component. However, CH has a relatively low abundance of phyllosilicates, and it is reasonable that the effect would be more noticeable for samples with higher abundances, such as the more recent clay-bearing Murray samples (e.g., Marimba ~30 wt.%; [14]).

[4] found considerable overlap between the range of AmC compositions for the RN and CB samples, but the range of AmC compositions for CH is noticeably different. CH has AmCs enriched in Si compared to their crystalline counterparts (Fig. 2a). Whereas the AmC compositions for RN and CB are generally en-

riched in Fe compared to their crystalline counterparts. Additionally, [4] found that some of the AmC compositions for CB and RN intersected the Si-Fe join on a Si-Fe-Al diagram, and some were even consistent with hissingite [4]. However, that is not the case for the range of CH AmC compositions calculated using Griffith Saponite 2. These differences suggest that the AmC composition is likely different between the Bradbury Group and lower Murray rocks.

**Summary:** Our preliminary results, along with the results of [4], show that the “best case” composition estimate can be useful for determining major element (Si-Al-Fe) relationships between the crystalline and AmC compositions, but might not be useful for minor elements and those in minerals with high uncertainties. Additionally, our results show that the AmC compositions do vary between samples, suggesting different origins, timing, and/or formation conditions. Further MBC analyses can help distinguish any compositional trends associated with stratigraphic groups, and the accuracy with which a “best case” estimate can represent those chemical trends.

**References:** [1] Bish et al. (2013) *Science*, 341. [2] Blake et al. (2013) *Science*, 341. [3] Vaniman et al. (2014) *Science*, 343. [4] Dehouck et al. (2014) *JGR*, 119, 2640-2657. [5] Morris et al. (2016) *PNAS*, 113, 7071-7076. [6] Treiman et al. (2016) *JGR-P*, 121, 75–106. [7] Rampe et al. (2017) *EPSL*, 471, 172-185. [8] Achilles et al. (2017) *JGR-P*, 122, 2344–2361. [9] Yen et al. (2017) *EPSL*, 471, 186-198. [10] Achilles et al. (in prep.). [11] Morrison et al. (2018) *Am. Min.*, 103(6), 857-871. [12] Treiman et al. (2014) *Am. Min.*, 99, 2234-2250. [13] Brigatti (1983) *Clay Min.*, 18(2), 177-186. [14] Bristow et al. (2018) *Sci. Adv.*, 4(6). [15] Bristow et al. (2015) *Am. Min.*, 100(4), 824-836.



**Figure 2.** Comparison of crystalline and amorphous component compositions for CH on (a) a Si-Al-Fe molar (elemental) diagram and (b) a A-CN-K-FM molar (oxide) diagram. Ranges are found by calculating the crystalline component using mineral abundance uncertainties. Different colors represent crystalline and amorphous component compositions calculated with and without clay minerals included in the crystalline component. We also show “best case” estimates that do (this study) and do not [7] include clay minerals in the crystalline component.