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MINERALOGICAL AND GEOCHEMICAL TRENDS OF THE MURRAY MUDSTONES, GALE CRATER: A COMBINED SAMPLE ANALYSIS AT MARS-EVOLVED GAS ANALYZER AND CHEMISTRY AND MINERALOGY INSTRUMENT ASSESSMENT. B. Sutter[1,2], A.C. McAdam[3], E.B. Rampe[2], P.D. Archer[1,2], , D.W. Ming[2], P.R. Mahaffy[3], R. Navarro-Gonzalez[5], J.C. Stern[3], J.L. Eigenbrode[3], H.F. Franz[3] [1]Jacobs, Houston, TX 77058, brad.sutter-2@nasa.gov, [2]NASA/JSC Houston, TX 77058, [3]NASA/GFSC, Greenbelt, MD 20771. [4]Universidad Nacional Autónoma de México, México, D.F. 04510, Mexico

Introduction: The Murray formation is predominantly composed of lacustrine mudstone that forms the basal layer of Aeolis Mons (informally Mt. Sharp) in Gale Crater, Mars. The Murray formation has distinct iron and sulfur mineralogical variation within its stratigraphy detectable by the Chemistry Mineralogy (CheMin) instrument consisting of magnetite/hematite in the lower Murray and higher hematite, $CaSO_4$, and smectite content in the upper Murray (Fig. 1) [1,2,3]. The objectives of this work were evaluate the Sample Analysis at Mars Evolved Gas Analyzer (SAM-EGA) data to 1) Determine what SAM-EGA detectable phases correlate or do not correlate with the Murray mineralogical composition detected by CheMin and 2) Utilize CheMin/SAM results to propose possible formation scenarios for the observed Murray mudstone mineralogy.

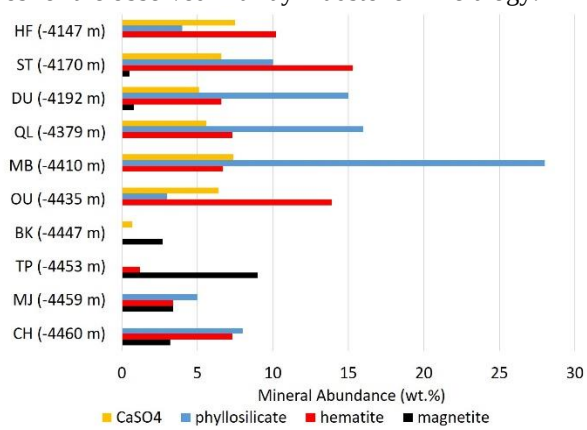

Fig. 1 CheMin-derived Ca-sulfate, Fe-oxide, and phyllosilicate abundances for samples from Murray fm. Sample elevations indicated in parentheses.

Materials & Methods: Drilled mudstone samples analyzed by SAM and CheMin were acquired along an elevation transect (Fig. 1). Analyzed samples were Confidence Hills (CH), Mojave2 (MJ), Telegraph Peak (TP), high-silica containing Buckskin (BK), the cross-stratified, fluvial interval Oudam sample (OU), Marimba (MB), Quela (QL), Duluth (DU), Stoer (ST) and Highfield (HF). All were heated (~35 ˚C min^{-1}) to ~870˚C where He carrier gas (~0.8 sccm; 25 mbar) swept evolved gases from the SAM oven to a quadrupole mass spectrometer (QMS) for identification. Evolved gases (e.g., SO_2, CO_2, etc.) released at characteristic temperatures from volatile bearing phases were used to identify mineral and/or organic phases [4].

Results/Discussions: ***SO_2*** **-** The broad temperature (500-825°C) SO_2 release in most Murray samples was consistent with Fe-sulfate/sulfide and/or Mg-sulfates (Fe/Mg-S) (Fig. 2). Some evolved SO_2 from CH, MJ, TP, MB, QL, and ST was attributed to jarosite that was also detected by CheMin [1,2]. Jarosite did not account for all of the evolved SO_2. The remaining SO_2 was consistent with amorphous Fe/Mg-S phases or a mixture of crystalline Fe/Mg-S phases below the CheMin detection limits. The SO_2 release temperatures suggest that OU and ST sulfur was dominated by Fe-sulfate/sulfide while MB was dominated by Mg-sulfate (Fig. 2).

The nearly similar SAM- and APXS-SO_3 contents in CH, MJ, TP, and BK (Fig. 2) indicate that Fe/Mg-S dominate the lower Murray S phases. Total S (APXS-SO_3) content in the OU sample and above, however, is greater than SAM-SO_3 content (Fig. 1) indicating that Ca-sulfate dominates S in these samples because $CaSO_4$ detected by CheMin cannot be detected by SAM [4].

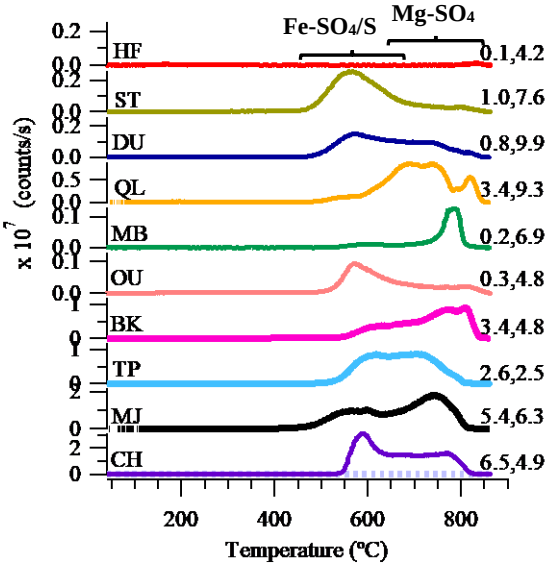

Fig. 2. Evolved SO_2 detected by SAM-EGA. wt. % SO_3 are indicated as measured by SAM (left) and APXS (right).

NO, O_2 **–** Evolved NO and O_2 indicated nitrate and (per)chlorate, respectively, in the Gale sediments (Figs.

3,4). Nitrate and (per)chlorate contents were variable between CH and BK and were mostly lost above OU (Figs. 3,4). The drop in nitrate and (per)chlorate contents coincide with the hematite and $CaSO_4$ increases and significant magnetite decrease (Fig. 1). Either the source sediments were low in nitrate and (per)chlorate or post-depositional processes leached the soluble nitrate and (per)chlorate from the sediments. $CaSO_4$-filled fractures in the OU to HF sediments suggest post-depositional $CaSO_4$ fluids could have leached nitrate and (per)chlorate away. However, leaching is difficult to reconcile when total Cl (0.5 - 1 wt.%) possibly consisting of soluble chlorides occurs in these samples.

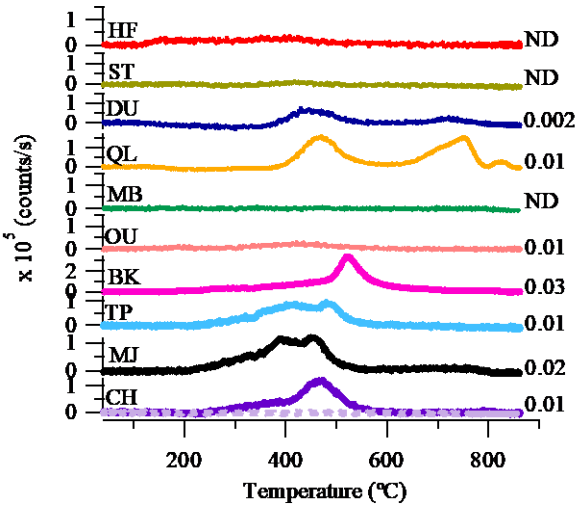

Fig. 3. Evolved NO detected by SAM-EGA. wt. % NO_3^- indicated at right

CO_2 – CO_2 releases were consistent with organic-C over the entire SAM temperature range (Fig. 5). Carboxylic acids from meteoritic or magmatic materials are candidate sources of the CO_2-carbon. [4,5,6]. Evolved CO_2 above 450°C could also be attributed to carbonate especially in TP and QL. Coexisting jarosite and carbonate (if present) suggest TP and QL were exposed to variable acidic and alkaline solutions. Total carbon abundance (Fig. 5) did not trend with phyllosilicate or any other mineralogical content (Fig. 1).

Conclusions: The Murray formation mudstones have been exposed to complex geochemical conditions of varying redox and pH. One possible scenario was that: 1) All Murray mudstones were deposited under varying reducing/oxidizing conditions that caused the precipitation of magnetite/hematite and Fe/Mg-S phases. 2) Upper Murray mudstones (OU to HF) were exposed to post-depositional oxidizing fluids that promoted hematite and increased phyllosilicate formation, transformation of most magnetite to hematite, and leaching of soluble (per)chlorate and most nitrate. Geochemical

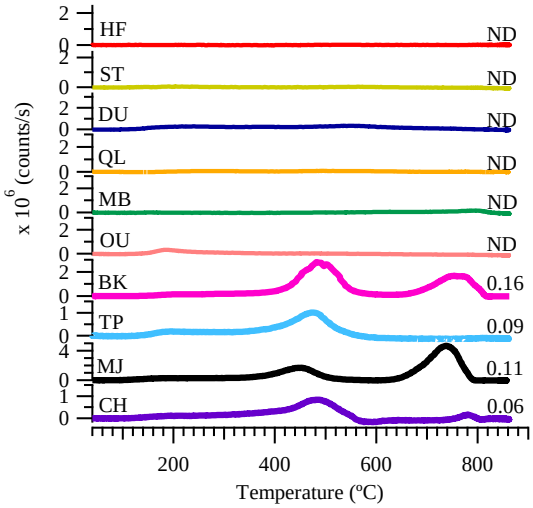

Fig. 4. Evolved O_2 detected by SAM-EGA. wt. % ClO_4^- indicated at right.

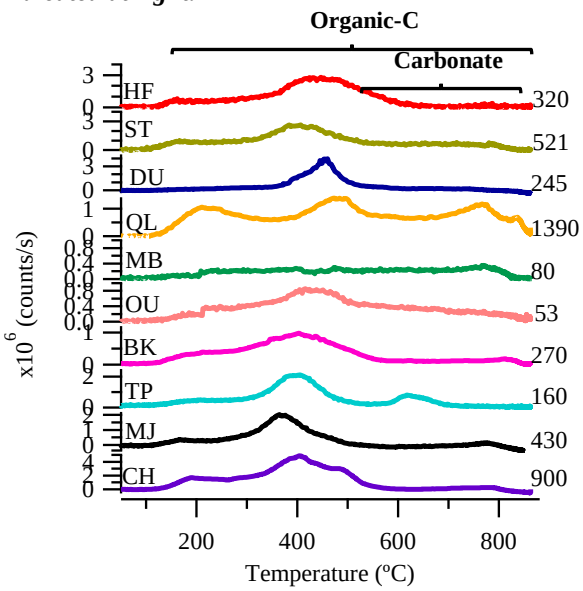

Fig. 5. Evolved CO_2 detected by SAM-EGA. μgC/g indicated on right.

fluids with varying pH could be indicated by the co-occurrence of jarosite and possibly carbonate in some Murray materials. The total C content did not trend with the observed Murray mineralogical variation, suggesting that geochemical conditions (pH, redox) reflected in the mineralogy may not affect total C deposited in Gale sediments. Source sediments may control total C content in Gale Crater.

References: [1]Rampe et al. 2017) *EPSL,471*,172 [2] Bristow et al. (2018) *Sci.Adv,4*, [3]Bristow et al. (2019) *LPS L*, [4] Sutter et al. (2017) *JGR,122*, [5] Benner et al., (2000) *PNAS,97*,2425 [6]Eigenbrode et al. (2018) *Science,360*,1096