

FIELD AND LABORATORY STUDIES OF SAMPLES FROM THE BOCKFJORD VOLCANIC COMPLEX IN THE 2009 ARCTIC MARS ANALOG SVALBARD EXPEDITION. P. R. Mahaffy¹, J. C. Stern¹, H. B. Franz¹, F. Stalport¹, J. Eigenbrode¹, D. F. Blake², Pamela Conrad³, Andrew Steele⁴, and A. C. McAdam¹, ¹NASA Goddard Space Flight Center, Code 699, Greenbelt, MD 20771 ²NASA Ames Research Center, ³Jet Propulsion Laboratory, ⁴Geophysical Laboratory, Carnegie Institute of Washington.

Introduction. The Arctic Mars Analogue Svalbard Expeditions (AMASE) enable *in situ* measurements of environmental chemistry relevant to habitability and biosignature detection using instruments that are under development or study for future Mars surface missions. More detailed subsequent characterization of samples by laboratory instruments allows the strengths and limitations of the suite of field instruments to be evaluated. AMASE field studies are also able to address sample collection, caching, and contamination issues that are relevant to future sample return missions.

Two experiments employed during the AMASE-2009 campaign, X-ray diffraction (XRD) and evolved gas analysis (EGA) closely mimicked similar experiments that are planned for the 2011 Mars Science Laboratory (MSL). These 2 MSL investigations are SAM (Sample Analysis at Mars) and CheMin (the Chemistry and Mineralogy experiment). Additional 2009-AMASE field instruments employed are similar to those under development for the ESA ExoMars or other rover missions. These provided imaging, spectroscopic, and subsurface sounding data. A variety of microbiology and field life detection techniques rounded out the AMASE-2009 analytical tools. Here we focus on data obtained from the EGA analyses of carbonate rocks from a site in the Bockfjord Volcanic Complex (BVC).



Figure 1. The Sverrefjell volcano of the BVC is ~500 m high and 3 km wide. Small carbonate-rich caves found at higher elevations appear to be relic springs.

The 2009-AMASE Sverrefjell Site as a Mars Analog. This Quaternary basaltic volcano like others in the BVC site (Sigurd fjell and Halvdanpiggen) may have been covered by a glacier while active [1] and it is likely that this situation existed on Mars during past times of active volcanism. The Sverrefjell site contains

an unusually high fraction of xenoliths and the abundant carbonate globules found in the BVC rocks have been compared with very similar structures in the widely studied ALH84001 Martian meteorite. The origin of the ~4.0 Ga carbonate globules in ALH84001 has been the subject of intensive study and the similar Sverrefjell association of carbonate globules with olivine in basaltic rocks has been examined in this context [2,3]. More massive forms of carbonate of the type that might be detected by remote spectroscopy are also found in association with the BVC basalts and in this context it is noted that magnesium carbonates have recently been discovered by the Mars Reconnaissance Orbiter infrared experiment in the Nili Fossae region in bedrock units associated with other minerals that show evidence of aqueous alteration [4]. There is also some evidence of calcium carbonate in soils at the Phoenix landing site [5]. Figure 1 shows the Sverrefjell volcano and Figure 2 a BVC carbonate rich region in the BVC basalt and one of the analyzed rocks.



Figure 2. A BVC carbonate rock region surrounded by basalt. The marks on the rock in the lower pane shows the location of layers (left to right 1 to 9) selected for subsampling and analysis by EGA and XRD.

A Model for Aspects of the MSL/SAM EGA Experiment. The 2009-AMASE activity allowed a more detailed comparison to be made on a variety of carbonates between the data obtained by the field model of CheMin and direct EGA analysis similar to experiments that MSL will be able to implement with SAM. The higher precision SAM isotopic analysis secured by the tunable laser spectrometer [6] and the more sensitive organics analysis [7] by gas chromatograph mass spectrometry that will also be implemented by SAM were not addressed during the 2009-AMASE field expedition but additional such analyses on samples returned from the field site are presently in progress in the laboratory.

Field Experiment Procedure and Equipment: The 2009-AMASE EGA experiment consisted of a custom fabricated oven interfaced with a commercial (Hiden HAL/3F 301) mass spectrometer. Powdered rock samples were dremeled from layers in the rock and sieved to the <150 microns necessary for XRF

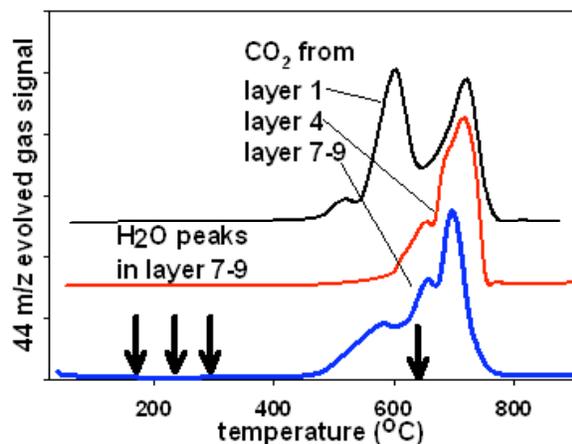


Figure 3. In order to directly compare XRF and EGA data, distinct layers of carbonate rocks were micro-sampled, sieved, and then analyzed in the field by both techniques. Evolved gas signals for the 44 m/z mass spectrometer channel are here shown and the arrows indicate the location of peaks in the water signal for layers 7-9 where the XRD had identified clays.

analysis were placed in a quartz boat in the oven. As the oven was heated with a linear temperature ramp evolved gases swept away from the sample by a He carrier gas and continuously monitored by the mass spectrometer. The sample heating rate of 40 °C/minute, the carrier gas flow, and the He pressure over the sample were adjusted to model the typical experimental conditions we have selected for the MSL/SAM experiment. For carbonates CO₂ is evolved as the mineral decarboxylates at elevated temperatures.

Example EGA Data from Carbonate Samples and Comparison with XRD data. Figure 3 shows example data from several microsampled layers of the sample shown in the bottom frame of Figure 2 with the layers identified by the marks on the rock. In layers 7-9 both low and higher temperature water was also evolved with the largest release rate at ~220 C. The temperature locations of four distinct water peaks are shown by the arrows in Figure 3. XRD field analysis identified layer 1 to be ~75% dolomite (CaMg(CO₃)₂) and 25% ankerite (Ca(Fe, Mg, Mn)(CO₃)₂) while layer 4 was 100 % ankerite, and a mixture of powders from layers 7-9 ~49% dolomite, 29% magnesite (MgCO₃), 3% calcite (CaCO₃), 17% montmorillonite ((Na,Ca)_{0.33}(Al,Mg)₂(Si₄O₁₀)(OH)₂·nH₂O), and 2% siderite (FeCO₃). Samples of the carbonate rocks of this type were returned for later laboratory analysis.

Discussion: Although previously obtained isotope data indicates a low temperature formation of the BVC carbonates, extensive microbial activity associated with the formation of these rocks is not obvious from the field work to date. Detailed mineralogical micro-Raman and imaging studies of carbonate globules embedded in Sverrefjell xenoliths have suggested dominant abiotic formation processes [2]. In contrast, in the currently active Troll and Jotun hot springs not far from Sverrefjell there is an abundance of volatile organic biosignatures in the springs and the associated travertine deposits [8]. In small Sverrefjell caves that contain both relic ice and carbonates there is some current active microbial activity. In the interior of the carbonate rocks studied in the field we find some volatile organic compounds and continued examination in our laboratory is in progress with more sensitive instrumentation. The evolved water from layers 7-9 of the sample illustrated show both low temperature release associated with interlayer water from the clays and dehydroxylation of the montmorillonite. The XRD and EGA data are generally consistent although additional analyses are underway to clarify the precise relationship between the EGA peaks and the range of carbonate minerals identified by the XRD.

[1] Skjelkvåle B.-L. et al. (1989) *J. Volcanol. Geotherm. Res.* 37, 1-19. [2] Steele, A. et al. (2007) *Met. & Plan. Sci.* 42, 1549. [3] Treiman, A. H. (2008) *Lunar & Planet. Sci.* XXXVI, 1107. [4] Ehlmann, B. L. et al. (2009), *JGR*, 114, E00D08. [5] Boynton, W. V. et al. (2009) *Science* 325, 61-64. [6] Mahaffy, P.R. (2009) *Geochem. News*, 121. [7] Mahaffy, P.R. (2008) *Space Sci. Rev.* 135, 255. [8] Jamtviet, B. et al., *Norwegian Journal of Geology* (2006) 86, 387-395. **Acknowledgement:** This research was funded by the NASA ASTEP program (PI: A. Steele).