

LOW-TEMPERATURE HYDRATED SALTS ON AXEL HEIBERG ISLAND, ARCTIC CANADA, AS AN ANALOGUE FOR EUROPA. M. G. Fox-Powell¹, G. R. Osinski², M. Gunn³, D. Applin⁴, E. Cloutis⁴ and C. R. Cousins¹. ¹School of Earth and Environmental Sciences, University of St Andrews, Irvine Building, North Street, St Andrews, UK (mgfp@st-andrews.ac.uk), ²Centre for Planetary Science and Exploration, Dept. Earth Sciences, Dept. Physics & Astronomy, University of Western Ontario, London, Ontario, Canada, ³Department of Physics, Penglais Campus, Aberystwyth University, Aberystwyth, UK, ⁴Department of Geography, University of Winnipeg, Winnipeg, Manitoba, Canada

Introduction: Jupiter's moon Europa hosts a liquid water ocean underneath a crust of water ice [1]. Non-icy material on the surface, spatially associated with geologically young features [2], has been hypothesised to originate from the ocean, and thus record compositional information crucial to constraining European ocean chemistry and habitability. Whilst the exact nature of this non-icy material is not fully understood, there is strong evidence that it comprises a mixture of hydrated sulfate and chloride salts [2]. To date, spectroscopic studies of relevant materials have focused on pure salts produced under controlled laboratory conditions. Here, we present ongoing work characterising natural sulfate and chloride salts from cold saline springs in the Canadian High Arctic, and discuss their relevance to Europa exploration.

Description of field locations: Axel Heiberg Island, Nunavut, Canada, is situated in the Sverdrup sedimentary basin (Fig. 1). The island is underlain by carboniferous evaporites (anhydrite, gypsum, calcite and halite) hundreds of metres thick that are expressed on the surface through widespread diapirism. Associated with the evaporite diapirs is a series of anoxic, perennially sub-zero hypersaline springs, which remain fluid in winter, and precipitate large-scale salt 'aprons' of varying composition [3].

Three springs were sampled in July 2017 (Fig. 1). Detailed mineralogical and geochemical datasets are

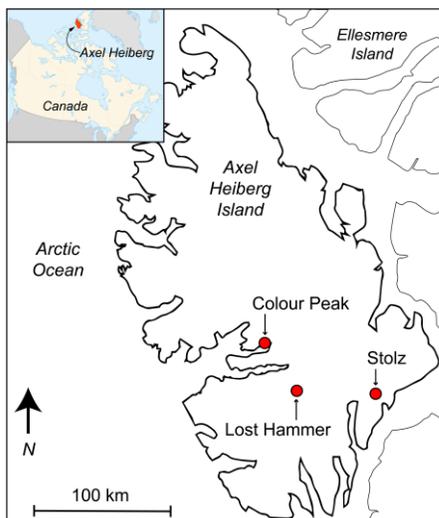


Fig. 1: Spring locations on Axel Heiberg Island

available for two of these springs (Lost Hammer and Colour Peak) [3, 4], whilst the third (Stolz) has not been described. Salt samples were acquired to cover a representative range of mineralogy. Due to the assumed presence of metastable hydrated phases, salt samples were stored at 4° C until analysis. Since an aim of this work was to explore spectral signatures of salts in the context of the parent fluid chemistry, brine samples were taken at each location for ionic composition analyses. Temperature, pH and dissolved oxygen content were measured *in situ*; anion concentrations were quantified by ion chromatography at the University of St Andrews.

Lost Hammer. Lost Hammer Spring (79.076856, -90.210472) emerges as a single outlet from the valley floor, approximately 500 m from the base of Wolf Diapir (Fig. 2). Brine chemistry was found to be in good agreement with the most recent published data [5]. The fluids were dominated by sodium and chloride (3.9 M), and contained the highest sulfate concentration of the three spring systems (approx. 6 gL⁻¹). Spring waters were characterized by low oxygen content (0.14 mgL⁻¹), sub-zero temperatures (-3.6° C) and moderately acidic pH (5.96). A large dome of salt has built up around the vent, flanked by an apron of salts which display terracing and layering, indicative of cyclic or seasonal deposition (Fig. 2).

Stolz. Stolz Springs (79.090117, -87.048248) emerge from two outlets high on the side of Stolz Diapir in the southwest part of Axel Heiberg. The springs mix approximately 20 m downstream from the outlets and have precipitated a salt apron that fills a kilometer-scale ravine on the diapir. These springs lack formal description in the published literature. The brines are the most saline with respect to chloride (5.2 M) out of those sampled, and similar to Lost Hammer possess an acidic pH (~6) and sub-zero temperature (-2.9° C). Salts are segregated into dark/gray terraces and white precipitates (Fig. 2).

Colour Peak. Colour Peak Springs (79.38, -91.27) emerge as a number of separate outlets from the side of Colour Peak Diapir. These outlets are relatively warm (3.8-8.4° C) and possess an alkaline pH (6.98-7.75), and an intermediate dissolved oxygen content (0.4-3.53 mgL⁻¹). Overall, salt concentrations were the lowest of

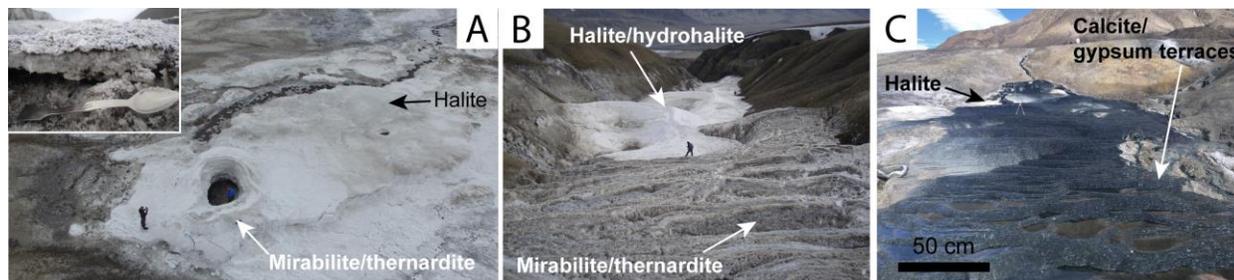


Fig. 2: Salt mineral precipitates associated with the three sample locations on Axel Heiberg. (A) Lost Hammer Spring, showing single vent and salt apron. Inset image shows depositional layering in salt crusts. Geologist for scale. (B) Salt apron associated with Stolz Spring. Geologist for scale. (C) Typical dark green terraces associated with Colour Peak Springs.

the three springs, containing approximately 2.7 M Cl⁻. In contrast to Lost Hammer and Stolz springs, precipitates take the form of sintered terraces and hard mineral deposits that line spring channels, and exhibit green and black colouration not observed at either of the other springs (Fig. 2).

Mineralogical analyses: XRD was performed at ambient temperature and pressure at the University of St Andrews. Visible-short wave infrared reflectance (vis-SWIR) and Raman spectroscopy of salt samples were carried out at the Department of Physics, Aberystwyth University at ambient temperature and pressure.

Results and discussion: Mineralogy of Lost Hammer and Colour Peak springs were consistent with previous work [3], exhibiting abundant hydrated Na-sulfates and calcite/gypsum (respectively). Stolz was found to be dominated by chlorides with a lesser contribution from sodium sulfates. These differences highlight how brines with similar major ion chemistries can form qualitatively different mineral assemblages; an important consideration for missions that aim to reconstruct moon ocean composition from surficial salt deposits.

Vis-SWIR spectra of all samples reveal characteristic water hydration bands at ~1.0, ~1.25 ~1.4 and ~1.9 microns, which are also observed in spectra from Europa's non-icy surface material (Fig. 3) [2]. Colour Peak and Stolz dark precipitates exhibit further absorptions at ~2.2 microns which are not observed at Europa. Other minor absorptions in some of the natural salts, such as a Fe³⁺ band at ~630 nm, are attributable to geochemical or microbial activity preserved in the salts. Such signatures are not present in pure laboratory salts, and yet may help to explain some of the unknown features in spectra from other planetary bodies. This demonstrates the merit of combining analyses of pure minerals with that of natural samples.

Ongoing work: All spectral analyses will be repeated, both at Arctic temperatures (-20° C) and at icy

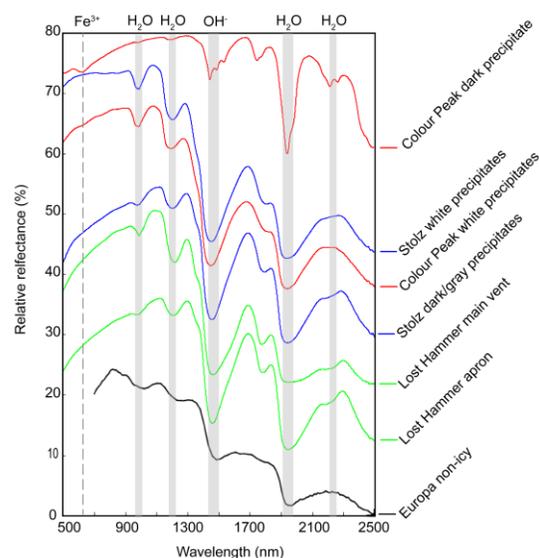


Fig. 3: Representative spectra from salts from each spring on Axel Heiberg Island, offset for clarity. European spectra reproduced from Dalton *et al.* [6].

moon surface temperatures, to quantify the important spectral shifts and hydration state changes that occur under these conditions. Linear spectral mixing will be employed to generate the nearest vis-SWIR match to data from the European surface. Following this, select samples will be irradiated with high energy electrons at European surface temperature and pressure to simulate exposure on the European surface, building on work with pure salts by Poston *et al.* [7].

References: [1] Carr, M. H. *et al.* (1998) *Nature* 391, 363-365; [2] Brown, M. E. & Hand, K. P. (2013) *Astronom. J.* 145, [3] Battler, M. M. *et al.* (2013) *Icarus* 224, 364-381, [4] Omelon, C. R. *et al.* (2006) *Appl. Geochem.* 21, 1-15, [5] Lay, C. Y. *et al.* (2012) *Extremophiles* 16, 177-191, [6] Dalton, J. B. *et al.* (2005) *Icarus* 177, 472-490, [7] Poston, M. J. *et al.* (2017), *JGR Planets* doi: 10.1002/2017JE005429