MORPHOLOGY AND SUBSURFACE STRUCTURE OF SORTED STONE CIRCLES IN SVALBARD, NORWAY – AN ANALOG STUDY FOR MARS. A. D. Johantges[1], H. Hiesinger[1], N. Schmedemann[1], D. M. H. Baker[2], E. S. Shoemaker[2], E. Hauber[3], A. Johnsson[4], [1]Institut für Planetologie, Westfälische Wilhelms Universität, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany (ajohantg@uni-muenster.de), [2]Solar System Exploration Division, NASA Goddard Space Flight Center, Greenbelt, MD 20771, [3]DLR-Institut für Planetenforschung, Rutherfordstr. 2, 12489 Berlin, Germany, [4]Dept. of Earth Sciences, Medicinaregatan 7, Univ. of Gothenburg, Box 460 SE-405 30 Gothenburg, Sweden.

Introduction: In this study, we investigate networks of sorted stone circles (SSCs) on the Western Spitsbergen Peninsula in Svalbard, similar in shape to those observed on the margin of an erosional channel known as "Lethe Vallis" in Elysium Planitia on Mars [1,2]. We use airborne imagery and ground observations to assess surface morphology and ground-penetrating radar (GPR) to characterize subsurface structure. GPR systems have been widely used to investigate Mars-analog permafrost environments [e.g., 3], and have been in use on Mars with NASA's Perseverance rover (RIMFAX) and recently China's Zhurong rover.

Identifying and characterizing the locations of shallow (0–10 m) subsurface ice on Mars is important for addressing high-priority science and human exploration objectives [4]. Our main objective is using SSCs as an analog to understand similar periglacial landforms and structure on Mars. Through investigating the relationship between SSC morphometric measurements and radar by correlating the surface with the subsurface, we develop a potential method for investigating Martian subsurface ice.

Field Location Background: Western Spitsbergen is located in the high-arctic archipelago of Svalbard with well-developed SSCs that formed in a cold-climate environment analogous to Martian periglacial landforms [4]. SSCs (see Fig. 1) are a form of sorted patterned ground in the Arctic regions having a characteristic circular shape [5] and fine-grained interior bordered by coarser-grained material [2]. Here, we investigate the subsurface of sorted stone circles located on Kvadehuksletta, at the northwestern tip of the Broegger Peninsula, located at the west coast of Spitsbergen [2].

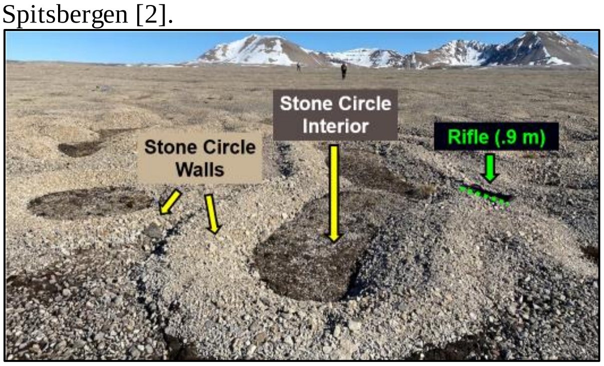

Fig. 1: Sorted Stone Circles (SSCs) on Kvadehuksletta

Regarding the climate, temperatures rise above 0°C between late June and the end of September thawing the permafrost [2]. During this thaw and freeze cycle, SSCs emerge as self-organized patterns from a laterally uniform active layer that becomes laterally sorted as frost heave deforms the interface between a stone layer and an underlying soil layer [6]. Previous studies dug trenches to investigate the SSC subsurface but standing water above the permafrost prevented digging deep enough to the bottom of the active layer [7]. A drilling investigation on the North end of the peninsula demonstrated that at a depth of 2 meters the ground transitions from sediment to boulder rich sediment/ weathered bed rock, and at 3.2 meters bed rock is reached [8]. Other studies have shown that the active layer thickness is currently around 1.8 m, trending deeper into the subsurface due to the warming climate (less than 1 m in 1999) [9].

Data and Methods: We analyze six GPR traverses collected at Kvadehuksletta (Fig. 2) in the summer of 2022, totaling 3 km in length and obtained using a GSSI SIR3000 GPR system and 400 MHz antenna. We processed GPR radargrams and compared them to field surface observations and airborne imagery.

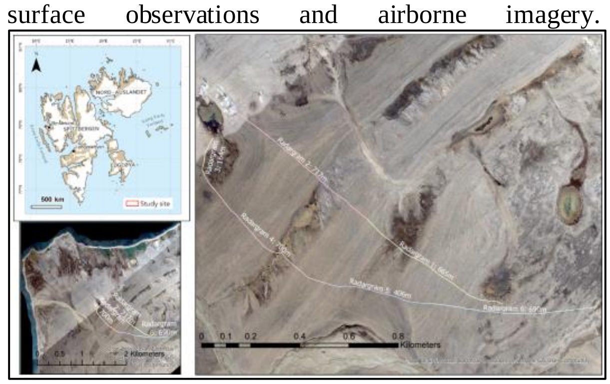

Fig. 2: Study Site on Kvadehuksletta Map[10] showing 6 GPR Traverses from the 2022 Field Campaign.

Methodology: First, raw GPR data were processed in order to visualize the subsurface as a cross-section and standardize the radar responses across each radargram. This includes filters, gain functions, and topographic correction. An example of a processed example is provided below in Figure 3.

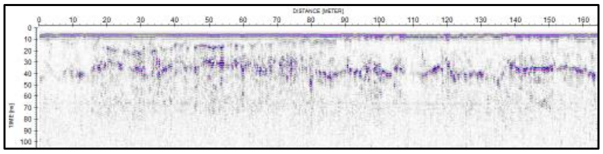

Fig. 3: Radargram 3 processed with 100 and 800 MHz filters and Topographic Correction.

Subsurface radar reflections were identified from processed radargrams and then correlated with surface morphology and topography to assist in radar interpretation and to assess the connection between surface and subsurface structure.

Results: We identify the following layers from reflectors in the radargrams, some which have been identified from previous dug trenches [7].

Active Layer: Strong, continuous reflections at 20-60 ns two-way time delay are likely the bottom of the active layer (i.e., top of ice table). First, assuming a constant radar wave velocity of .1 m/ns, the active layer depth fluctuates between 1-2 meters in Fig. 4.

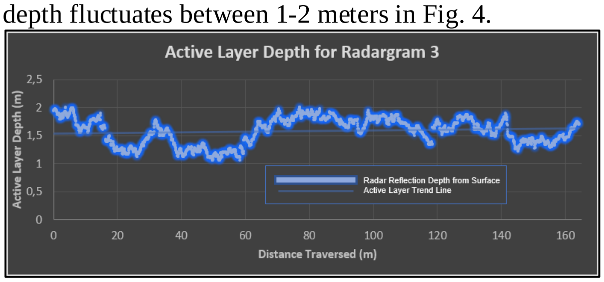

Fig. 4: Depth to Active Layer Reflector of Radargram 3 determined assuming a constant velocity of .1 m/ns.

However, the depth to this reflector is dependent on assumptions in the permittivity, which may vary significantly across the stone circles. The walls of the stone circles were observed to be coarse-grained (coarse gravels to cobbles) and well-drained where the interior of the stone circles were observed to be finer grained and moist to wet with some vegetation. Thus, now assuming instead a constant active layer thickness of 1.8 m, this would imply a velocity range due to changes in permittivity of .15 to .1 m/ns from the exterior to interior of the stone circles, which is consistent with higher soil moisture content within SSC interiors.

Shallow Reflectors: Additional reflectors occur at shallower depths and occur in regions where profound sorting (higher quantity of SSCs) is evident on the surface. For instance, a shallower reflector from 157 to 167 m above the inferred active layer in Fig. 5 may be one such example. These reflectors likely represent changes in soil properties and moisture content, such as transitions in grain size and presence of near-surface aquitards.

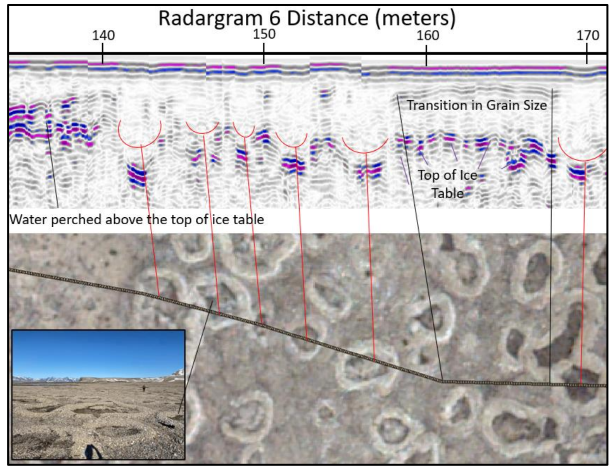

Fig. 5: Five SSC's in a swale from a selection of Radargram 6.

Discussion: Our analysis confirms an annual deepening of the bottom of the active layer [9]. Both the permittivity and active layer thickness are significantly variable across the SSCs due to different grain sizes and thermophysical properties of the soils [e.g., 11]. Thus, for more accurate active layer measurements, soil moisture data must be collected along traverses.

We find a relationship between the surface expression of the SSCs and their subsurface in collected radargrams through the evidence of shallow reflectors within SSC-dominated areas. These shallow reflectors may be aquitards or where water pools atop coarser grains or sorted rock. If water above laterally uniform coarser grained soil is present at shallower depths than the bottom of the active layer, then sorting is occurring at multiple depths. This inference alongside other studies suggesting active sorting [5,7] indicate that SSCs are still self-organizing [6].

Determining the current forming activity of SSCs is important for identifying the spatio-temporal analog suitability of Spitsbergen for Mars. In this sense, this study is informative about how SSCs form and subsurface ice presence in an earlier wetter climate on Mars [e.g., 4].

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