SORTED STONE CIRCLES ON SVALBARD –AN ANALOG STUDY FOR MARS S. F. Buer[1], H. Hiesinger[1], D. Reiss[1], E. Hauber[2], A. Johnsson[3], H. Bernhardt[4], [1]Institut für Planetologie, Westfälische Wilhelms-Universität, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany (s.buer@uni-muenster.de), [2]DLR-Institut für Planetenforschung, Rutherfordstr. 2, 12489 Berlin, Germany, [3]Univ. of Gothenburg, Box 100 SE-405 30 Gothenburg, Sweden, [4]Arizona State University, School of Earth and Space Exploration, 550 East Tyler Mall Bateman Physical Sciences Center F-Wing Room F506 Tempe, AZ 85287-1404, USA.

Introduction: On Mars, patterned ground was observed in several locations across a wide range of latitudes, in particular above latitudes of 55° on the northern and southern hemispheres [1-8]. Patterned ground was also observed in patches near the equator, e.g., at Elysium Planitia [7-9]. It has been proposed that the formation of patterned ground reflects the presence of near-surface ice and cold climate conditions [5-11].

Here we concentrate on sorted stone circles (SSC), which represent one type of patterned ground [8, 9]. Balme et al. [9] studied over 200 circular polygonal stone circles in the Lethe Vallis on Mars. The SSCs have clastic margins, which separate them from each other and form a network pattern (Fig. 1) [8, 9]. Their finer-grained interior is flat and the walls have a width up to 5 m [8, 9]. The Martian SSCs have a minimum diameter of 6 m, a maximum diameter of 23 m, and an average diameter of 13.7 m (Fig. 1) [8, 9].

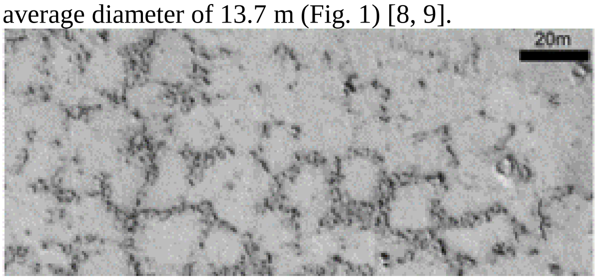

Fig. 1: Stone circles on Mars in Elysium Planitna [8].

Balme et al. [9] proposed that these Martian SSCs might share the same origin as SSCs on Earth, i.e. sorting by repeated freeze-thaw cycles due to an active layer. However, it remains debatable whether the active layer on Mars is/was thick enough to form the Martian SSCs [8]. To decipher the formation mechanisms of SSCs on Mars, we studied analog SSCs on Earth.

Western Spitsbergen in the high-artic archipelago of Svalbard was chosen as study area, because there are well-developed SSCs that formed in a cold-climate environment displaying Mars-analogue periglacial landforms [12]. The study area is located west of the research station Ny Ålesund at the tip of the Brøggerhalvøya peninsula called Kvadehuksletta [8]. Kvadehuksletta is a costal strand flat area with several ridges and intermittent swales. Isostatic rebound after the last glacial maximum (26,500-20,00 year ago) [13] left behind these beach ridge systems, representing ancient shorelines [8]. We performed multi-year (2009-2018) studies on SSCs at Kvadehuksletta and here report on SSCs that were explored in 2016 and 2017.

Methods: To investigate the SSCs in Svalbard, we measured the topography (only 2016) of the SSCs and dug trenches to analyze vertical profiles through the SSCs. We measured soil temperatures, sampled the trench wall at numerous depths and locations and also took areal pictures of the SSCs using a kite and a ~3 m high pole. Since 2013, we also observed the movement of rocks in the SSC walls of several circles marked with spray paint in 2012. The grain size distribution of the returned samples was analyzed in our laboratory with a combined sieving and hydrometer test. We also measured soil moisture (according to DIN 18121-1) [14] and soil organic carbon (SOC) in the laboratory to compare with those of [15]. The total carbon and the inorganic carbon were measured with an ELTRA CS-mat 580 carbon sulfur analyzer.

Results: Three SSCs were examined during the field work in 2016 and 2017. Stone circle 16SC2 is a well-developed circle in a swale and has a nearly circular shape. 16SC2 has an average diameter of 2.8 m, a width of the wall of ~0.7 m and a wall height of ~0.15 m. Some lichens and grass were found in the center of the stone circle, i.e., the inner domain.

The second stone circle 16SC4 is located on a beach ridge, is small, circular, and coarse-grained with almost no inner domain. Its diameter is ~1.7 m, the width of the wall ~0.8 m, and the height of wall is ~0.17 m. No plants or lichens were visible.

The stone circle observed in 2017 (17SC1) is also located in a swale and has a very irregular shape (Fig. 2). It is asymmetrical and elongated, but well sorted. Its inner domain is very fine-grained and the wall coarser grained. Some very small plants (salix) and lichens occurred in the inner domain. The inner domain of 17SC1 to a depth of ~0.15 m is interspersed with a very fine and intact root network. Due to its irregular shape, 17SC1 has diameters of ~1.7 m to ~2.8 m. It has a width of the wall of ~0.4 m and a wall height of up to ~0.2 m.

Circles 16SC2 and 17SC1 have a sharp boundary between the inner domain and the wall (Fig. 2) but 16SC4 shows no such a clear boundary.

Stone circles 16SC2 and 17SC1 show semi-rounded to well-rounded fine-grained rocks and more angular larger fragments. In 16SC4, all material is semi-rounded to well-rounded. The temperatures measured across the circle cross-sections indicate that the coarser parts are cooler than the finer parts.

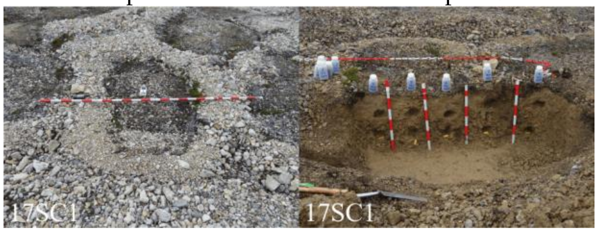

Fig. 2: Sorted stone circle 17SC1 on Svalbard. View before trenching (left) and the sampled cross section of the circle (right).

72 samples of 16SC1 (35), 16SC4 (7), and 17SC1 (30) were analyzed. The soil moisture of all samples varies between 0.16 % and 36.55 % with an average at 7.77 %. The soil moisture of stone circles is generally higher in the swales than on the beach ridges, consistent with a previous analysis [8].

The grain size analyses show that the walls have coarser material than the inner domain. Often, gravel (61 out of 72) and silt (10 out of 72) are dominant. Clay is sometimes present in the inner domain samples, but is only a minor constitute. Sand is also present, but only dominant in one out of 72 samples. Four types of grain size distribution are identified (Fig. 3).

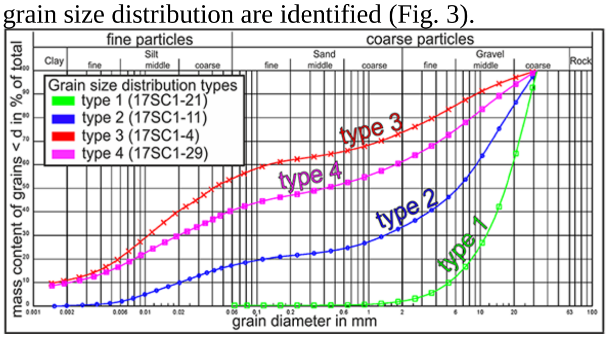

Fig. 3: Grain size types of sorted stone circle 16SC2 on Svalbard.

The grain size analyses yielded results that are consistent with previous analyses of SSCs on Svalbard [e.g., 8]. Type 1 has the coarsest constituents and represents the walls (Fig. 3). Type 2 has an intermediate grain size distribution and type 3 is characterized by the finest grain size distribution. They both represent the inner domain. Type 4 was found in the SCC on the beach ridge and contains almost the same proportion of fine- and coarse-grained material (Fig. 3).

The SOC of 16SC2 and 16SC4 was analyzed and was found to vary between 0 wt% and 0.75 wt% of the sample. The highest SOC content of 0.75 wt% was measured at the surface of the 16SC2. The measured SOC contents are less than previously measured (0 wt% to 1.97 wt% [8]) and much less than 0.1 wt% to 3.9 wt% [15]. The SOC-distributions are similar at the boundary between the wall and the inner domain, but the hole cross-section do not show the same distribution as reported by [15]. In particular, in the circles sampled in 2014 [8] and 2016, we do not observe a pattern of SOC values that is reminiscent of a convection-like movement of particles in the inner domain as found by [15].

Discussion/Conclusions: At the surface, soil moisture is higher in the fine material (type 2,3) than in the coarser walls (type 1) (Fig. 4). At a depth of ~0.9 m in the trench of 17SC1, we reached the water table. At this depth, the trench was filled with laterally moving water, presumably accumulating above the ice table or an aquitard (Fig. 4).

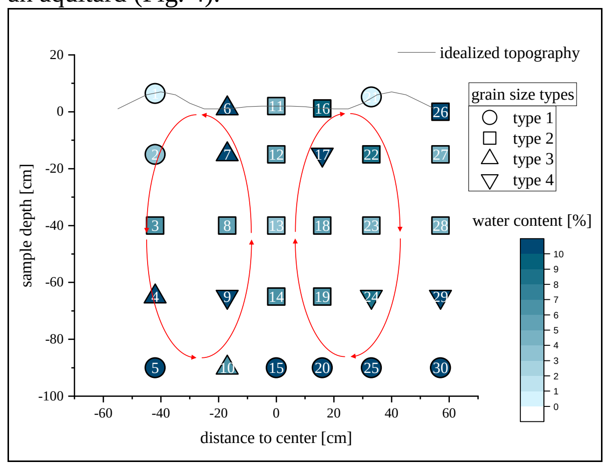

Fig. 4: Cross-section of sorted stone circle 17SC1 on Svalbard. Soil moisture (color) and grain size type (shape) of the samples taken from the cross-section are shown to a depth of 0.9 m below the surface, which is shown as thin black line to indicate the position of each sample with respect to the SSC walls and inner domain. in the profile of SSC 17SC1. The red arrows indicate the convection-like movement proposed by [15].

We hypothesize that in fall, thawed stone circles likely freeze top-down. In such a scenario, the cooler, drier and permeable coarser-grained walls might conduct cold air downwards, so that the walls and the parts adjacent and beneath the walls freeze before the central interior of the SSC. If this working hypothesis is correct, a convection-like movement of soil as proposed by [15] might be an oversimplification. In particular, neither the distribution of grain size types and soil moisture nor the SOC strongly support a convection-like movement.

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