**Movement of Sorted Stone Cirlces on Svalbard, Norway.** Henning Sander[1], Harald Hiesinger[1], Ernst Hauber[2], Andreas Johnsson[3] and Nico Schmedemann[1], [1]Institut für Planetologie, Westfälische-Wilhelms-Universität, 48149 Münster, Germany, (henning.sander@uni-muenster.de), (hiesinger@uni-muenster.de), (nschmede@uni-muenster.de), [2]Institut für Planetenforschung, Deutsches Zentrum für Luft- und Raumfahrt (DLR), 12489 Berlin, Germany, (Ernst.Hauber@dlr.de), [3]Department of Earth Sciences, University of Gothenburg, Box 460, Gothenburg SE-405 30, Sweden, (andreasj@gvc.gu.se).

**Introduction:** Stone circles are a form of sorted patterned ground in arctic regions, and are characterized by their circular shape [1] and a fine-grained center bordered by coarser-grained material [2]. The occurrence of those circles is a phenomenon that is not only limited to Earth. Networks of sorted stone circles have been observed on the margin of an erosional channel known as “Lethe Vallis” in Elysium Planitia on Mars [3]. One area to study terrestrial stone circles as analogs for Mars are the islands of Svalbard, an archipelago in the arctic ocean, which administratively belongs to Norway. The biggest island is known as Spitsbergen. Here, we investigate the evolution of a stone circle, which is located on Kvadehuksletta, at the northwestern tip of the Brogger peninsula, located at the west side of Spitsbergen [4]. The exact coordinates are 78° 57’ 1.069’’ N; 11° 27’ 6.925’’ E [5].

The present climate on Svalbard is arctic with precipitations of 180 mm in the mountains and 400 mm in the coastal area [6]. 60% of the landscape is covered by glaciers, the rest is characterized by permafrost [7]. The study area belongs to the permafrost-region, which is continuously frozen except for a short period during the summer. Between late June and the end of September, the temperatures rise above 0°C and the permafrost has the possibility to thaw [8]. During this thaw and freeze cycle, the active layer of the permafrost is affected by multiple processes, which result in the formation of the sorted stone circles.

This study focuses on the movement of stones within the circle to obtain more information about the behavior and formation of the circles. The results are based on photographics of the expeditions by Hiesinger, Hauber, and Johnsson in the years 2012, 2013, 2014, 2016, 2017, 2018, and 2019. The images were used to build 3D models and orthoimages, which will be analyzed and discussed.

**Method:** The 3D models of the investigated stone circles were built with the computer program Agisoft and visualized with ArcGIS Pro.

The first step was to sort the photos by circle and year and to import them to Agisoft Photoscan. Agisoft is a software for photogrammetric processing of digital images, which generates 3D spatial data, which can be used in GIS applications.

First, all images of the circle were added to a new Agisoft project. The next step was using the alignment tool to identify common reference points of the images. With these points, the program calculates a point cloud, which builds a first model by displaying all overlapping points. Photos that could not be aligned had to be detected manually with a marking tool. Then the photos were separated by years 2012 to 2019.

The following steps included building the dense cloud and the calculation of the mesh, which creates a 3D surface. The last step included the building of the orthomosaics and to import them into ArcGIS for continuing the analysis (Fig. 1).

*Figure 1: Calculated orthoimage of stone circle number 4 in 2019 in Agisoft. The blue lines are markings that were used to identify the movement of individual rocks of the stone circle.*

The imported models were added as layers into the ArcGIS project. To compare movements in between the years, the orthoimages with the best quality were chosen, which include the ones from 2013 and 2019. Seventy-three stones from these years were marked by drawing their outline for a better identification, which made it possible to follow their movement and direction about the years. For the calculation of the changing positions, the centroids of the stones were calculated. With these fixture points, it was possible to measure the distance with the “distance and directions” tool in ArcGIS. The tool allows to calculate vectors between the position of the centroid in 2013 and in 2019, which are represented as red arrows in Fig. 2 and

Fig. 3. The calculated distance between the stones has been saved in an attribute table.

**Results:** The results indicate that individual rocks moved in a consistent pattern from year to year. The longest distance a stone moved during these six years was about 8.12 cm, with an average value of about 3.19 cm. We could observe clear evidence of movements in different directions with one direction moving from the middle of the wall to the inner area of the circle and the other movement from the middle to the outer part of the circle. Those two directions are separated by a thin area, which is characterized by a trench located at the middle of the circle wall. It seems that the stones are beginning their movement from this trench and are moving away from it to both sides.

Another result is that the movement to the inner part of the circle is much faster than the movement to the outer part of the circle. As displayed by the length of arrows in Fig. 2, the movement of the stones is larger towards the inner area of the circle. Further investigations will study if the amounts of movement are directly linked to the dynamics within the wall or whether this is an effect of regional slopes.

*Figure 2: Stone Circle 4 in 2013. The inner part of the cirle is located in the lower part of the image. The outer part in the upper area. The black points represent the positions of stones in 2013, the red points are the positions in 2019. The red arrows show the movement from 2013 to 2019.*

Furthermore, we observed several vertical movements in the trench area. In 2013, some stones were covered and not completely visible whereas in images from 2019, they are exposed. These observations occurred only in the area of the trench and show that there must be a vertical component to the movement of these stones. Stone number 3 is an example of this vertical movement near the trench area (Fig. 3). The stone shows lateral and vertical movements. In contrast to 2019, the stone was still covered with dirt and other small stones in 2013 and it was not possible to observe the stones' full shape. In 2019 the stone was completely free and visible. In addition to this vertical movement, the stone moved 2.25 centimeters to the inner part of the circle. It is necessary to note that the stone measures about 10 centimeters and is one of the larger stones within the wall area.

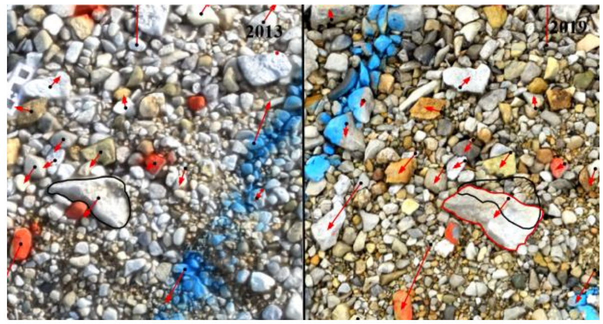


*Figure 3: Stone number 3 in 2013 (left) and 2019 (right). The stone was transported upward and moved to the inner part of the circle.*

**Conclusion:** The analysis of stone circle number 4 provides evidence that the stones of the circle were in motion during at least 6 years. This work shows consistent movement patterns of stones in the circle wall related to geological processes, since individual environmental influences, e.g., snow load or crossing animals are not generating such patterns. Further work has to show, which processes are responsible for the movements. In addition, the movement needs to be discussed in the context of existing models for the formation of stone circles. To understand the characteristics and behavior of the stone circles on Svalbard could help to explain the formation process of extraterrestrial features on Mars.

**References:**

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