**Mapping Rock Heights for the Mars Sample Return Landing Site and Depot Sites in Three Forks, Jezero Crater.** F.P. Russo[1,2], A. Trussell[1,3], C.L. Brooks[1,4], N.R. Williams[1], M.P. Golombek[1], F.J. Calef III[1], S. Do[1], H. Lethcoe[1], M. Cameron[1], S. Hibbard[1]. [1]Jet Propulsion Laboratory, California Institute of Technology, [2]Department of Geology and Environmental Science, University of Pittsburgh, [3]School of Earth and Space Exploration, Arizona State University, [4]Department of Geology, Kansas State University.

**Introduction:** As part of the Mars Sample Return (MSR) campaign, the Mars 2020 Perseverance rover has collected samples of rocks and soil for return to Earth [1]. The Mars Sample Return Lander and Sample Recovery Helicopters (MSR SRL/SRH) would be sent to retrieve these samples from the martian surface. Members of the MSR campaign have mapped and analyzed candidate landing and depot sites for samples collected by the Perseverance rover [2,3]. Three Forks, a region located adjacent to the delta in Jezero crater, has been selected for the initial depot and corresponding landing site [3]

Prior mapping of these sites used orbital High Resolution Imaging Science Experiment (HiRISE) [4] images to detect potential hazards and rocks [5-6]. Newer surface images from Perseverance's Navigation Camera (Navcam) [7] provide better resolutions to map rock diameters and heights. Rocks that could potentially complicate the MSR campaign were mapped at each landing and depot sites. Rock maps can also be used for statistical analyses on the likelihood that the lander, helicopter, and/or sample tubes may be affected by a rock within the area of interest.

**Rock Requirements:** One aspect of the certification for the Jezero crater site is the creation of rock height maps [3]. The landing site for the MSR SRL is a 120 m diameter circle. The SRL landing gear is designed to accommodate rocks up to 19 cm high. There must also be at least 11 distinct drop zones, where Perseverance could drop the sample collection tubes and SRH can retrieve them. These depot sites must be ≥200 m away from the landing site and have a ~11 m diameter. There cannot be any rocks taller than 5 cm in the depot sites, as the SRH can only tolerate rocks less than 5 cm high. Depot sites contain a small inner circle with a diameter of 0.7-0.95 m, where the sample tubes will be dropped. Rocks taller than 2 cm within this inner circle cannot be present in order for the helicopters to easily pick up the sample tubes. Additionally, the Cumulative Fractional Area (CFA) of rocks covering the landing site cannot be greater than 4% [e.g., 5].

**Data and Methods:** A basemap was previously created using orbital data from HiRISE at ~25 cm/pixel [4,8]. Navcam images, mosaics, orthomosaics, and Digital Elevation Models (DEMs) from Perseverance at a resolution of ~1 cm per pixel were georeferenced to the orbital basemap.

In order to create rock height maps for these sites, the orthomosaics from Navcam had to be georeferenced to the basemap layer of Jezero crater. Areas with potential hazards based on an automated analysis of relief were excluded from the depot sites during initial mapping [5]. We then loaded the basemap layer into ArcGIS Pro, followed by the Navcam orthomosaic images.

Rocks in Navcam images typically have bright sides illuminated by the sun and adjacent dark shadows. These rocks typically occlude areas behind them in the down look direction due to their height. For rock counting, polygons were drawn to outline the pixels that compose the rocks in a new feature layer (Fig. 1). In the depot sites, the rocks outlined included rocks within a 1 m buffer of the depot site as originally drawn. When all rocks ≥ 2 cm in diameter (~3-pixel width) were counted, a convex hull was fit on the feature layer. The convex hull calculates the minimum and maximum axes of each rock. The rocks closest to Perseverance are not distorted in the downlook direction, and the diameter is represented by the average of the minimum and maximum axes. At distances greater than 10 m from Perseverance, Navcam images are stretched in the down look direction. To avoid including a falsely elongated axis, the minimum axis provided a good approximation for the diameter of the elongated rocks. For rock height calculations, a 3 cm buffer was added to the perimeter of each rock. This buffer ensures that both the highest point on the rock and the lowest point where the rock meets the ground will be included in the height calculation. DEMs were used to obtain the minimum and maximum elevation value for each rock, and then to calculate the difference between these values, which provided individual rock heights.

To highlight rocks of different heights, a graduated color scheme was placed on the layer, utilizing manual breaks in the heights for rocks at the landing (Fig. 2; max height = 19 cm) and depot (max height = 7cm) sites. This process creates a visual map for displaying the highest rocks mapped within the landing and depot sites. This dataset was exported to Excel, where the CFA percentages are calculated [e.g., 5]. These calculations were then imported into MATLAB to generate plots for the CFA versus diameter (Table 1).

**Table 1:** CFA data for the landing site orthomosaics.

| Map | CFA % |
|---|---|
| Western Orthomosaic | 0.6-0.9 |
| Eastern Orthomosaic | 0.5-1 |

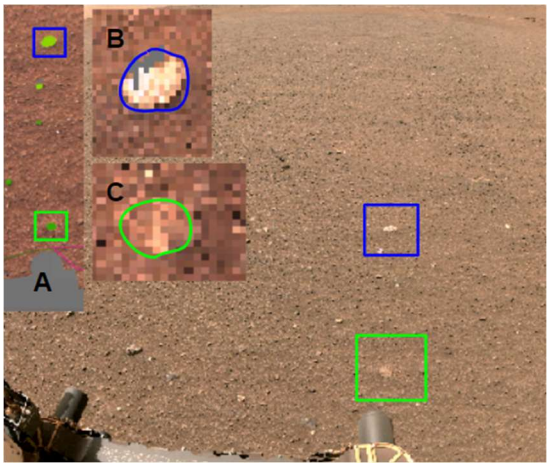


**Figure 1:** Rock appearance in the Navcam images and orthomosaics. The blue square in inset A corresponds to the blue squares in the main image and inset B. It highlights a larger rock that occludes a small area behind it, the grey pixels to the southeast of the rock. The green square in inset A corresponds to the green squares in the main figure and inset C. This highlights a smaller rock; the bright pixels distinguish the rock from the surrounding sediment.

**Discussion:** The orthomosaics from the Perseverance Navcam covered 4472 $m^2$ of the 120 m diameter landing site, or 40% of the total area for the landing site. Utilizing the above method for this percent of the site, the rock height map displays no rocks taller than 19 cm, with the tallest rock having a height of 12 cm ± 1 cm. CFA plots are between 0.5% and 1% for the landing site, which is also below the 4% maximum for the site. This indicates that there are no hazardous rocks in the area mapped using this method and the CFA is within the requirements for MSR SRL. Rocks outside of the orthomosaics were mapped using a different method.

Subsequent to rock height mapping, 7 of the preliminary 14 depot sites assessed covered 360° azimuth accessibility, or the directionality at which the sample tube can be approached by the helicopters. The remaining 7 sites contained rocks taller than 5 cm in height and were redrawn to exclude the areas containing these rocks as a direction of approach.

Rock height analysis has provided context for features seen in the Navcam images from the Perseverance mission. Mapping improved our understanding of potential hazards for the MSR campaign in the Three Forks landing site. The proposed landing site at Three Forks contains no rocks taller than 19 cm. In addition, Three Forks has a few 5 cm high rocks within the depot sites that can be avoided by the SRH. Thus, Three Forks is an excellent candidate for the MSR campaign from a rock height perspective.

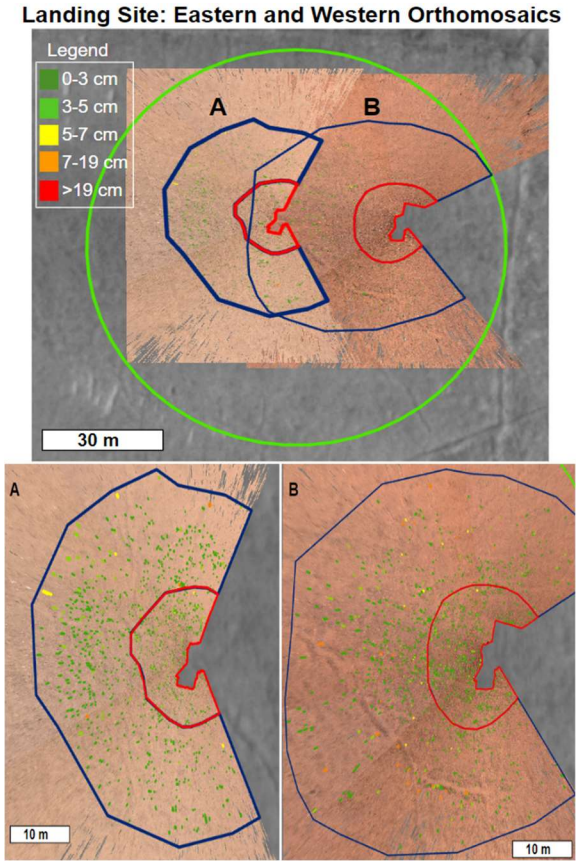


**Figure 2:** Height Map for the orthomosaics in the Landing Site. Both the eastern (B) and western (A) orthomosaics are displayed. Rock heights are separated into classes to highlight rocks with different heights. Neither the eastern nor western orthomosaic have rocks that are taller than 19 cm.

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