# Future Exploration Sites for Perseverance Rover in Jezero Crater, Mars

## Introduction

Mars has fascinated us for centuries. Although we have learned a great deal about the Red Planet, its mysteries still occupy our imagination and inspire us to explore the planet. The Perseverance rover, part of NASA's Mars 2020 mission, made its historic landing in the Jezero Crater on Mars on February 18, 2021. NASA has set four main goals for the mission: First, to study and understand the geology of the landing site. Second, look for ancient environments on Mars where life could have existed, identify rocks that might contain signs of past life, and use its instruments to search for these signs. Third, collect and record a set of important samples that might be brought back to Earth by a future mission. And fourth, to set the stage for human exploration of Mars (Farley et al., 2020).

The landing spot was chosen because of its historical importance and potential for scientific research. Jezero Crater, which is 45 kilometers wide, is located on the west side of Isidis Planitia, near Mars' equator. It's thought to have had water and an ancient river delta. Scientists think that more than 3.5 billion years ago, rivers flowed into the crater, creating a lake and bringing in clay from nearby. This place might have been good for tiny life forms to live in, so Jezero Crater is a perfect place to look for old life signs and learn about how rocky planets like Mars developed (Beaty et al. 2019).

According to NASA, Perseverance’s top speed on flat, hard ground of a little less than 0.1 mph or 152 meters per hour. This slow pace allows for careful navigation and scientific observation. The rover's average daily travel distance is less than the length of a football field. The rover can handle slopes up to 45 degrees in tilt under ideal conditions, but the mission operators typically limit it to slopes of 30 degrees or less to ensure safety and stability. The rover has a robotic arm that extends about 2 meters (7 feet) and carries a drill for coring samples from Martian rocks and soil. This arm is also equipped with cameras and scientific instruments for close-up examinations. The rover is designed to collect samples of Martian rock and soil using its drill and store them in sealed tubes for potential future return to Earth. Perseverance also carried the Ingenuity helicopter, a technology demonstration to test powered flight on another planet. While Ingenuity operates independently, Perseverance played a supporting role in its initial deployment and communication relay.

Perseverance's drill sites have been a focal point of its mission. The rover has performed drilling operations on several distinct sites, each offering unique insights into Martian geology. These efforts at the Perseverance rover's landing and drill sites represent significant strides in Martian exploration, with the potential to unravel mysteries about Mars' past habitability and the formation of rocky planets in the solar system.

In this project report, we will discuss the methods and results of our attempt to find new drill sites, identify surface features in the study area that the rover should avoid, compute cost surface and the least cost paths to the drill sites.

## Study Site

For this project, we selected a 13.91 km long and 5.13 km wide area in Jezero Crater (Fig. 1) with Perseverance's landing site roughly at the center. The coordinates of the landing site are 18.38°N, 77.58°E. According to NASA, over 3.5 billion years ago, rivers overflowed into the crater, forming a lake. This lake likely contained clay minerals washed in from nearby areas. It's possible that during these wet periods, microbial life existed in Jezero. If this was the case, evidence of their existence could be present in the sediments of the lakebed or along the shorelines of the study site.

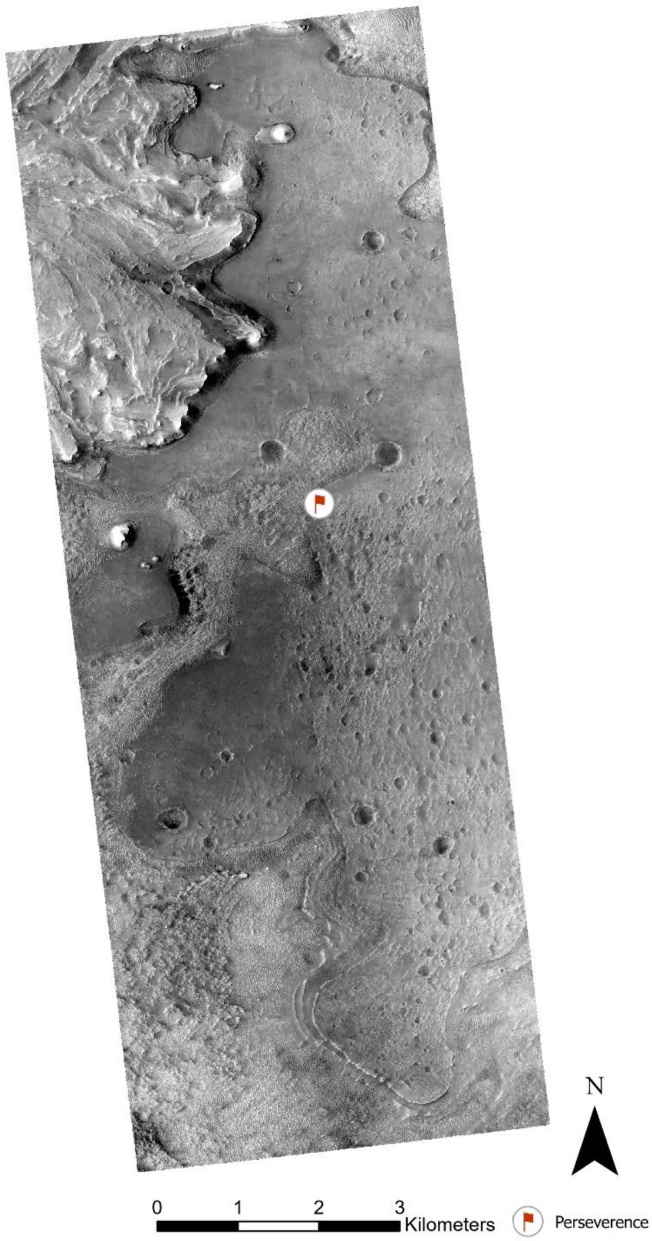


***Figure 1*** *Study site for this project*

# Data

The data primarily consists of a digital terrain model and an orthoimage of the study site. The coordinate of the landing site was added manually as a point type vector layer. Following are more detailed information about the DTM and orthoimage.

**DTM**

Filename: DTEEC_045994_1985_046060_1985_U01 (link)
Organization website: https://www.uahirise.org/
Produced by: USGS
Resolution: 1m
Projected Coordinate system: Equirectangular Mars
Latitude (center): 18.4°
Longitude (center): 77.44°
Unit: Meter
File size: 381 MB

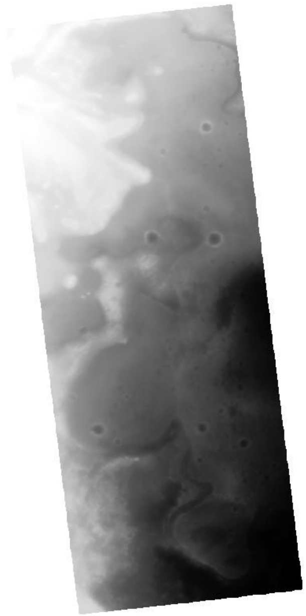

***Figure 2*** *DTM*

**Orthoimage**

Filename: ESP_046060_1985_RED_A_01_ORTHO (link)
Organization website: https://www.uahirise.org/
Produced by: USGS
Resolution: 0.25m
Projected Coordinate system: Equirectangular Mars
Latitude (center): 18.4°
Longitude (center): 77.44°
Unit: Meter
File size: 408 MB

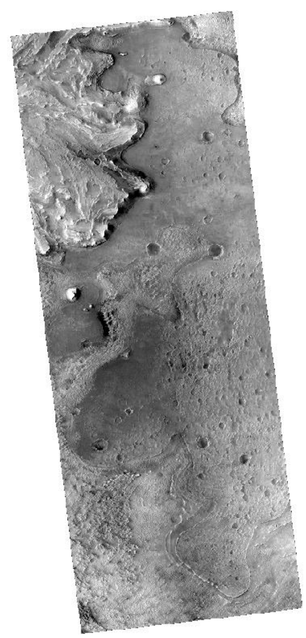

***Figure 3*** *Orthoimage*

# Methods

**Flowline delineation**

To delineate the flowlines, we first filled the sinks in the elevation model. Then computed flow direction raster from the filled elevation model. Next, we calculated the flow accumulation raster using the flow direction raster from the previous step. Then we isolated the flowlines that have flow accumulation > 10000 units. Finally, we thinned the flowlines and converted them to vector lines.

**Identifying depressions**

To identify depressions in the study site, we filled the sinks in the elevation model and then subtracted the original elevation raster from the filled elevation raster. Next, we separated the depressions into three layers, 0.5m, 5m and 10m depressions.

**Identifying peaks**

Identification of the peaks involved three steps. First, we subtracted the elevation raster from 0 which produced an inverse raster where the peaks have become depressions. Next, we filled the sinks in the inverted elevation model and then subtracted unfilled inverted elevation from the filled elevation to isolate the peaks. Finally, we separated the peaks into three layers, 0.5m, 5m and 10m peaks.

**Isolating sandy regions**

We were unable to find a technique to isolate the area covered in sand using map algebra or any other tool. So, the polygons representing sandy regions in the study site were hand drawn over the orthoimage.

**Selecting drill sites**

After creating a map of flowlines, depression, peaks, and sand, we selected a total of five drill sites, three of which were selected based on their proximity to flowlines and surrounding landscape. The other two sites were selected in an area that appears to be a dried lakebed.

**Cost surface analysis**

To perform cost surface analysis, we first needed to create a speed raster for the study area. By taking into account the fact that Perseverance's max speed is 152 meters per hour and the steepest slope it can climb is 45 degrees, we created a speed raster (meters/hour) based on the following rules.

(a) Speed on slopes: 152 – (3.4 * slope)
(b) Speed on sand: 76
(c) Speed on 0.5m peaks = 100
(d) Speed on 1m or higher peaks = 1
(e) Speed on 0.5m depressions = 100
(f) Speed on 1m or lower depressions = 1

The formula in rule (a) allows for high speed in flatter areas and low speed in steep areas. If the steepness is over 45 degrees the formula will return a negative value, which we replaced with 1 to signify places the rover should avoid. The constant 3.4 came from dividing the max speed of the rover with 45 (the steepest slope the rover can climb). We combined all the rules and whichever gave the lowest speed for a particular cell was recorded as the final speed.

After we created the speed raster, we calculated the cost surface with the landing side as the starting point.

**Computing least cost path**

We calculated a travel cost raster in hours from the speed raster we created before. Then we computed the least cost paths to the drill sites from the landing site.

# Results and Discussion

The flowlines derived from the elevation model can be seen in Figure 4. Since the large part of the site is relatively flat, the flowlines were shorter and numerous. The longer flowlines can be found on the northwestern part of the study area.

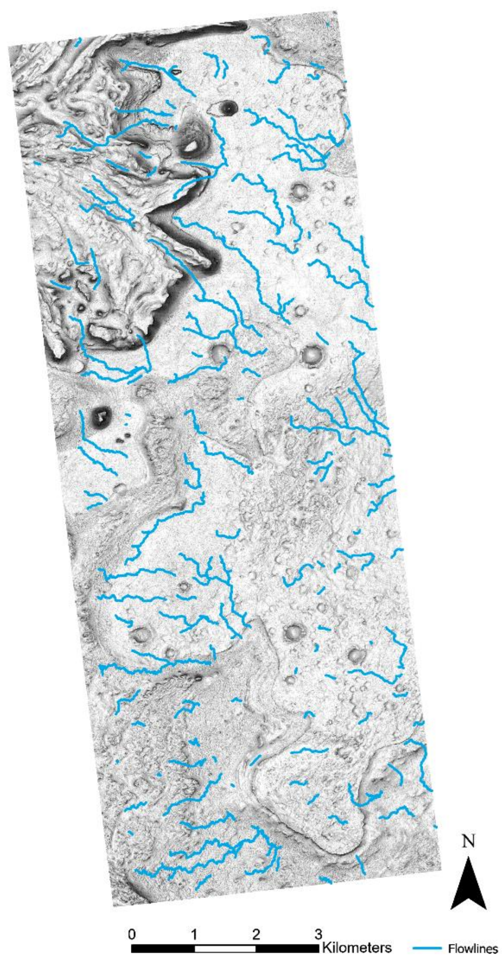


***Figure 4*** *Flowlines*

Figure 5 shows the map of depressions in the study area. There are many craters of various sizes. Some are relatively shallow, and some are quite deep. To drive safely, the rover must avoid 5m and 10m depressions.

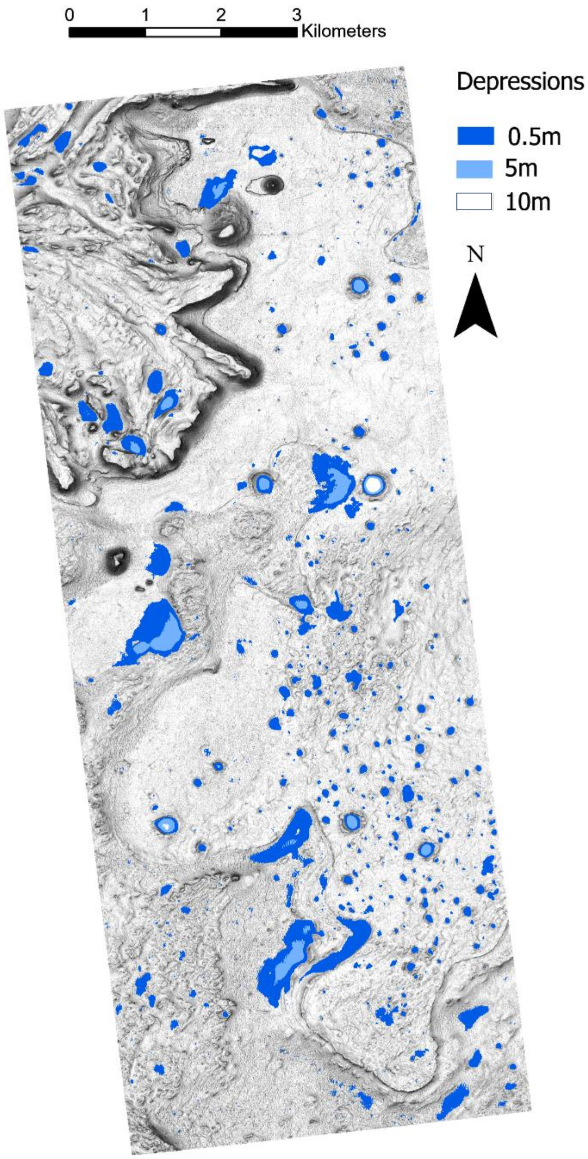


***Figure 5*** *Map of depressions*

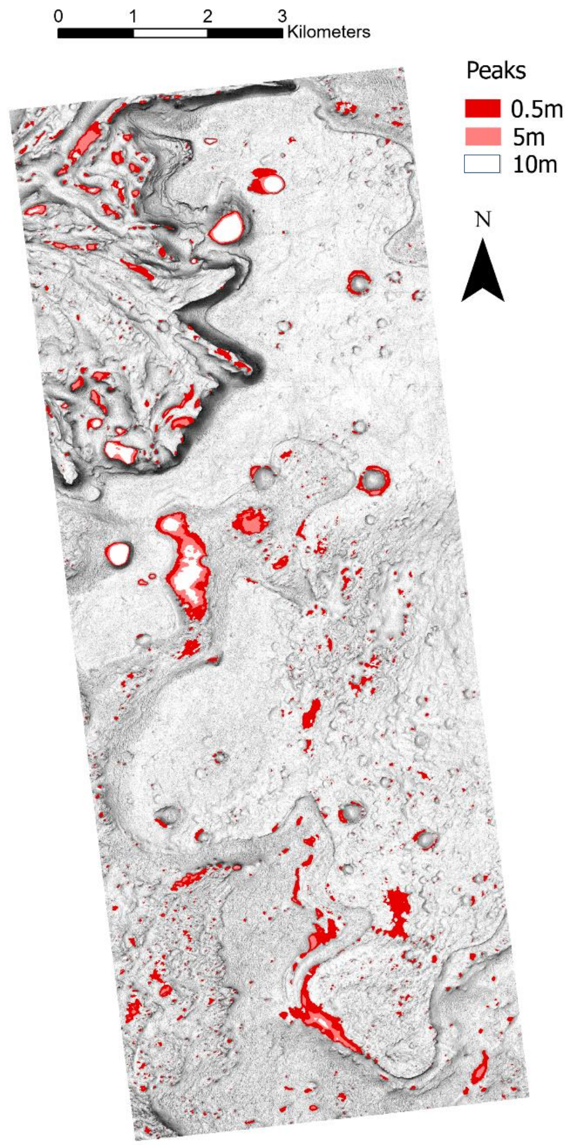


***Figure 6*** *Map of peaks*

The map of peaks can be found in Figure 6. While 0.5-meter-high peaks are not major obstacles for Perseverance, the 5-meter and 10-meter peaks must be avoided.

The hand drawn map of the sand cover can be found in Figure 7. In addition to slowing the rover down, sand increases the probability of getting stuck and damaging equipment that Perseverance is carrying. The combined map of sand, depressions, peaks, flowlines, and drill sites are shown in Figure 8. The first three drill sites are in the northwestern region near flowlines and the other two drill sites are in the southern part of the study area.

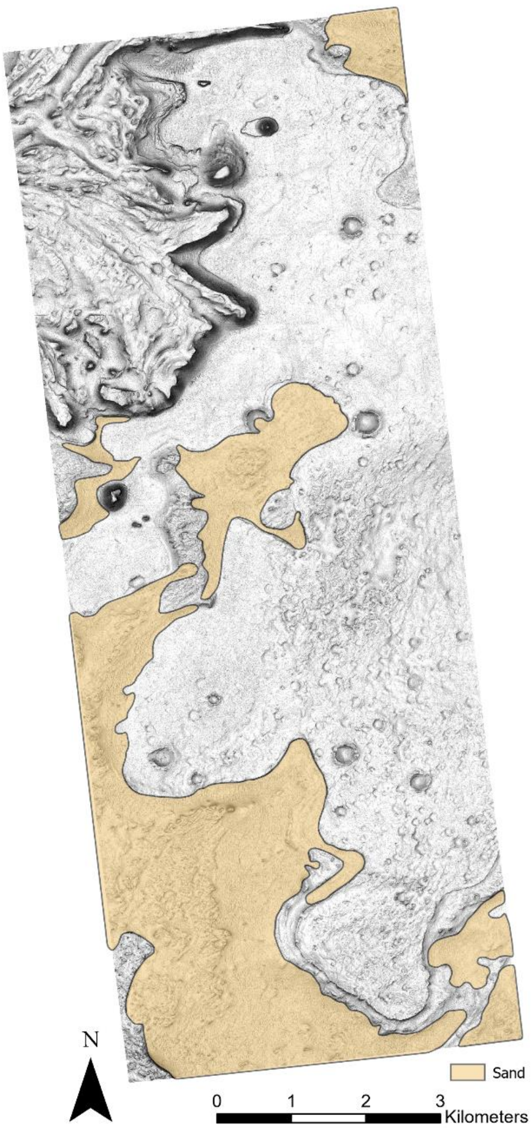


***Figure 7*** *Map of areas covered in sand*

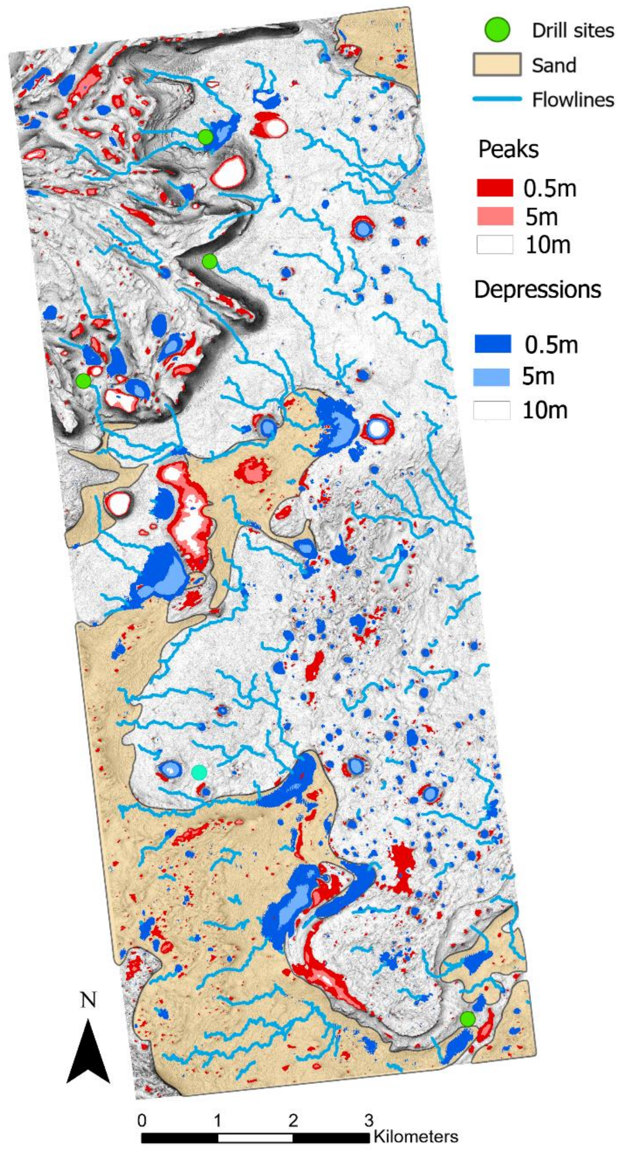


***Figure 8*** *Map of surface features and drill sites*

The speed raster showing the maximum speed at which Perseverance can travel each cell is shown in Figure 9. The areas that the Rover must avoid were assigned a speed of 1 meter/hour (shown in dark red in the map in Fig. 9).

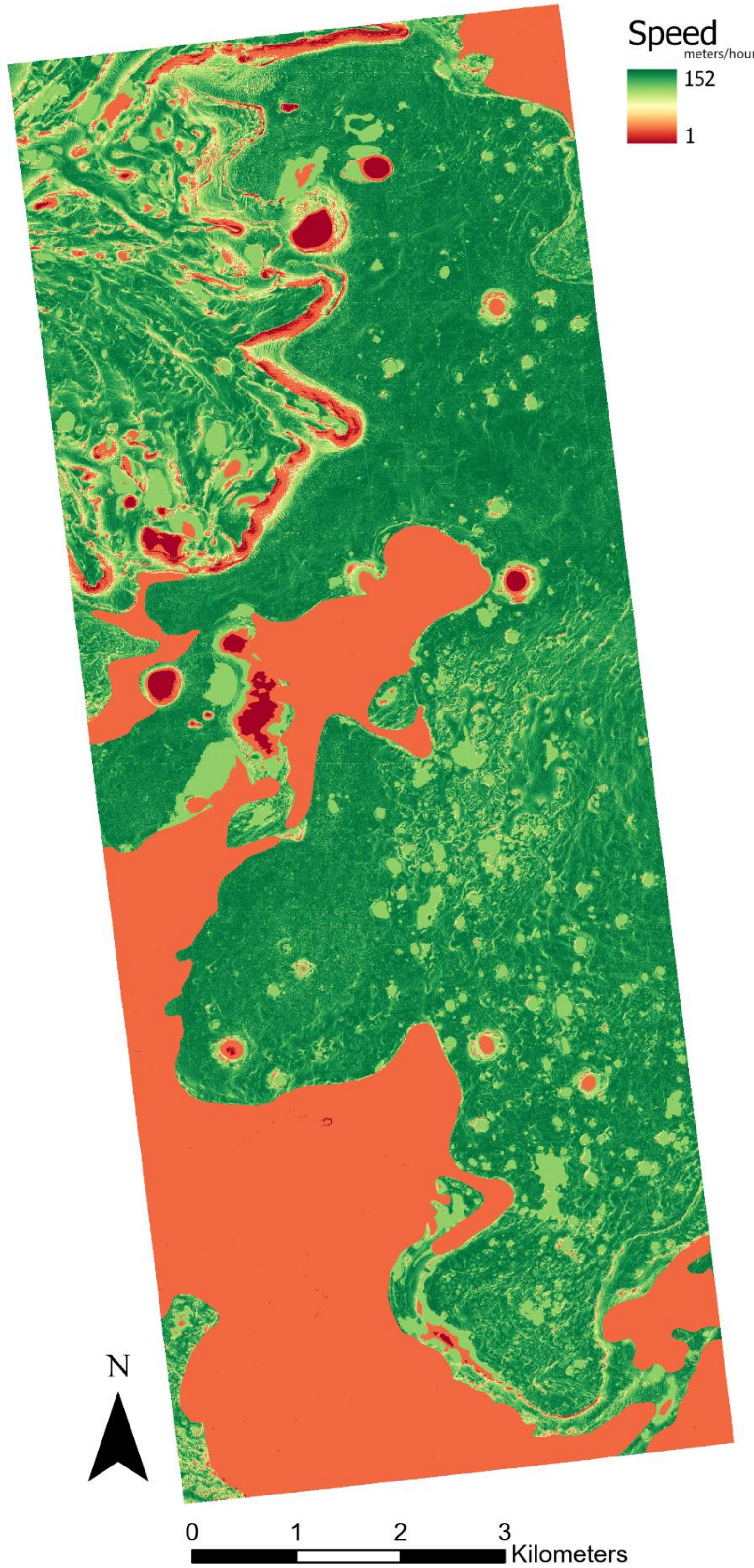


***Figure 9*** *Speed raster showing the maximum speed at each cell*

The cost surface map with 5-hour contours and the drill sites can be seen in Figure 10. The dark areas with very high travel costs are the places the rover must avoid.

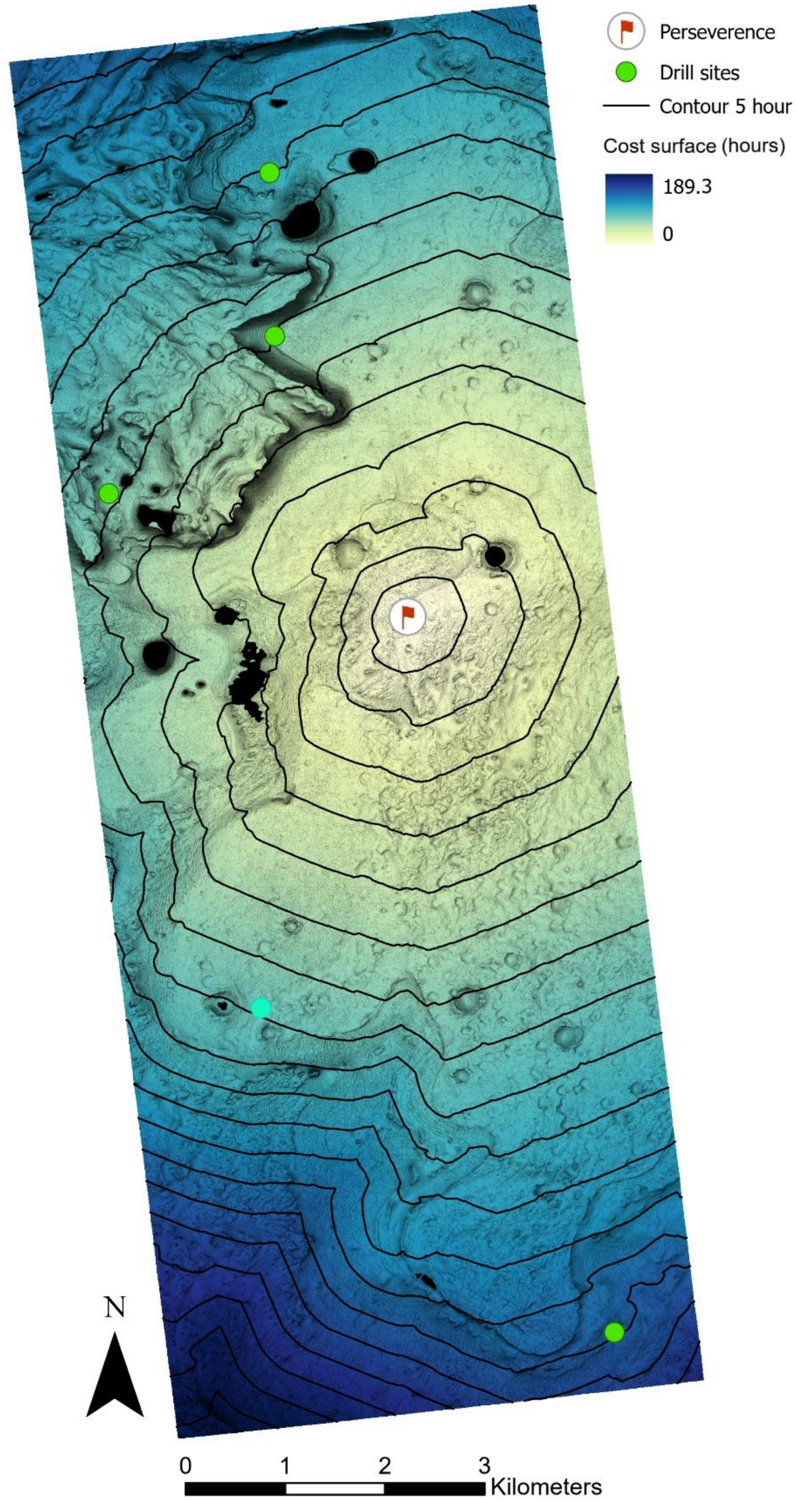


***Figure 10*** *Cost surface map with 5-hour contours and drill sites*

Figure 10 shows the map of least cost paths to the drill sites from Perseverance's landing site. If we look closely at the map, we can notice that the least cost paths avoid the high slope areas, peaks and depressions. It does not avoid traveling through sand altogether because the speed on sand was set to 76 meter/hour. If we do not want the rover to travel through sand at all, then we can change the speed on sand to 1 meter/hour.

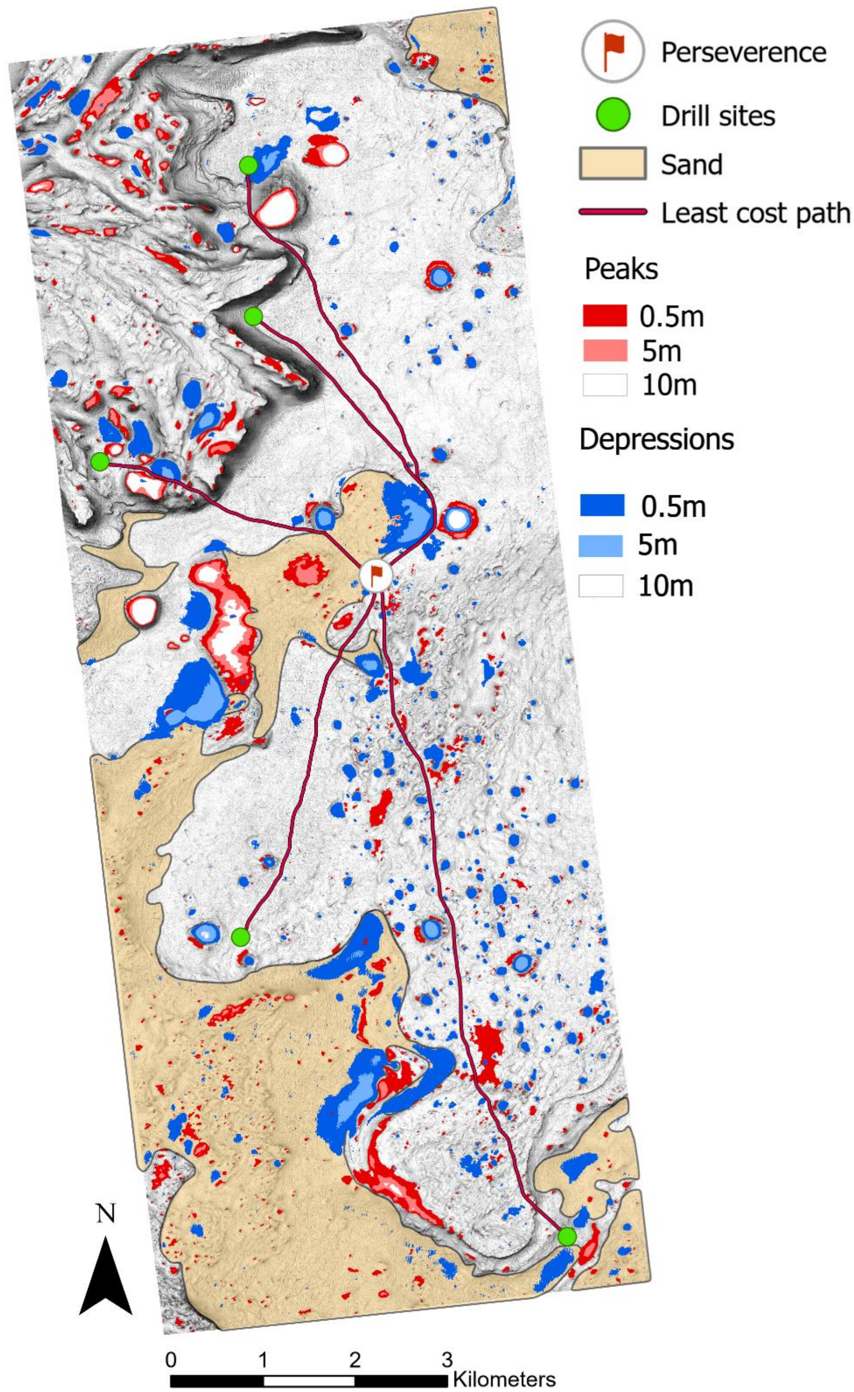


***Figure 11*** *Least cost paths to the drill sites*

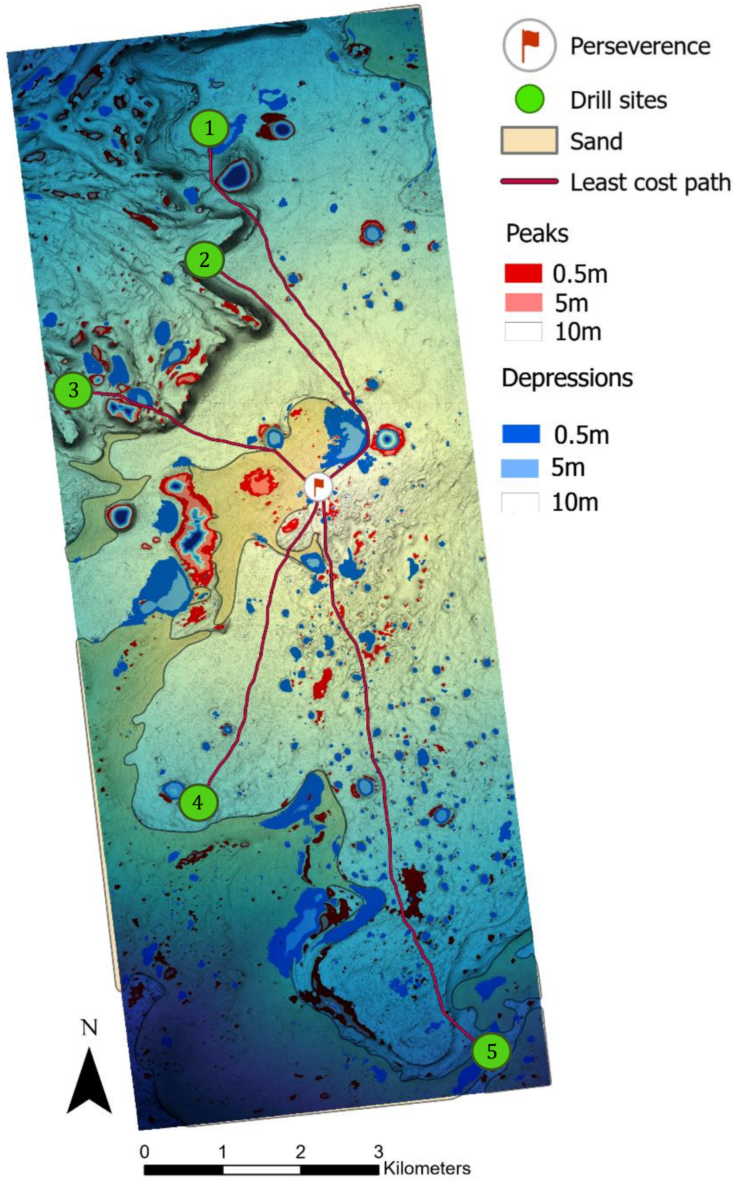


***Figure 12*** *Least cost paths to the drill sites*

| Site No. | Travel Time (hours) |
|---|---|
| 1 | 49.83 |
| 2 | 34.86 |
| 3 | 36.09 |
| 4 | 39.27 |
| 5 | 69.56 |

***Table 1*** *Travel time to the drill sites*

The minimum travel time to reach the drill sites can be found in Table 1. The numbered drill sites are shown in Figure 12.

## Conclusions

In this project, we have successfully identified areas that are safe for Perseverance to travel, created a travel cost map, selected five drill sites, and found the least cost paths to the choses drill sites. The results can be further improved if we could collect data from NASA about Perseverance's speed on slopes and sand. The technique we used in this project can easily be applied to other regions of the Jezero Crater. Our future work includes solar radiation analysis and sand dune migration in the region.

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# Appendix

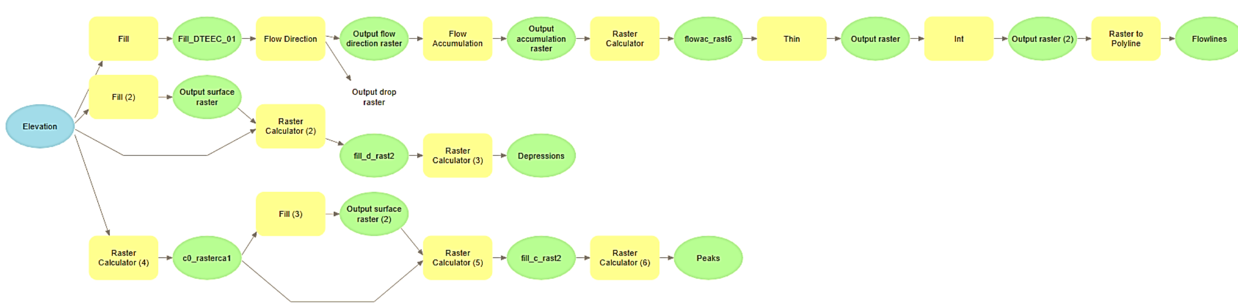


***Figure 13*** *ArcGIS Pro Model*