Life on Mars: Suitability analysis for the location of the first Martian colony

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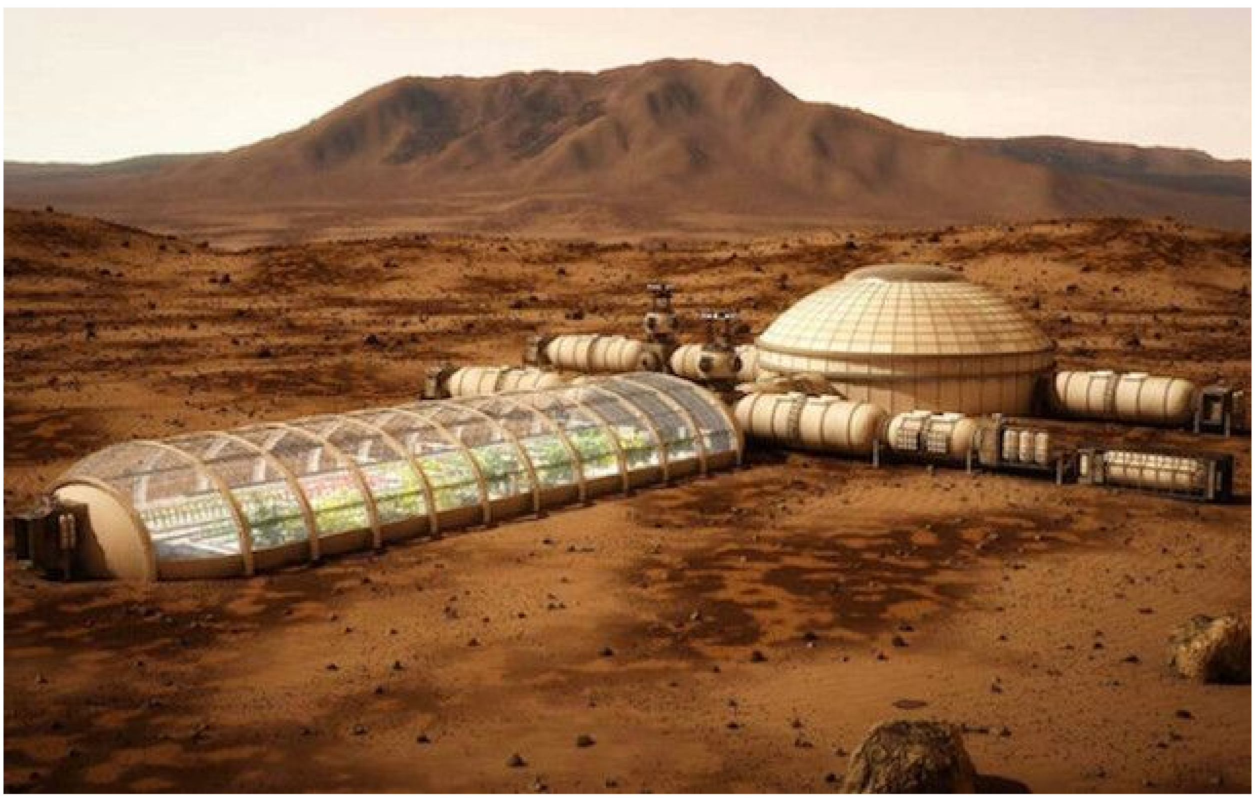

Introduction:

The idea of a long term human mission to Mars has been considered by scientists, engineers, and investors for many years (Mars One, National Geographic, National Space Society). Once we overcome the engineering barriers to make the trip possible, we are presented with another problem: is there a region on the surface of Mars that is most suitable for human habitation? This project seeks to use a variety of parameters to select a location to start the first human settlement on Mars.

Parameters Used:

Many of these parameters were chosen based on the Hot Science Cool Talk "Will We Live on Mars?" by Joe Levy and presentations from NASA's first Landing Site/Exploration Zone Workshop for Human Missions to the Surface of Mars.

1. *≤ 5km from a water source*

The first parameter used is that the long term settlement must be within 5 km of a water source (Levy, 2020; Hoffman, 2015). This is because water is a key resource for humans to survive. Although liquid water is not known to exist on the surface of Mars, there are many debris covered glaciers with > 90% water content. It would be possible to drill through the 10m of debris to reach the water ice below and harvest water for human consumption and use.

2. *Limited dust*

The next parameter is that the region can not be too dusty or susceptible to dust storms (Levy, 2020). This is because many instruments and spacecraft utilize solar panels that, if covered by dust, could become useless. Additionally, dust storms would be dangerous for humans that could get lost or trapped in conditions in which they can not see or move around. Therefore, a less dusty area would be ideal.

3. *Between -30 and +30 latitude*

Another parameter is that the base must be set up somewhere relatively close to the equator, between 30 degrees latitude South and 30 degrees latitude North. This is not only because it is generally warmer closer to the equator, where temperatures can reach 20 degrees C at the equator during the summer (space.com), but also because of the amount of daylight that different latitudes of the planet receive. Moving just 10 degrees further from the equator to -40 or +40 degrees means that there will be some days that will receive no daylight during the winter when the hemisphere is tilted away from the sun (Gangale, 1989). As stated earlier, sunlight is crucial for obtaining power and electricity from solar panels.

4. *<3,500m elevation*

There is also an elevation dependence that the site must be below the large volcanoes <3500 m (Levy, 2020). This is because the already extremely thin atmosphere on Mars becomes even more thin at these elevations This makes it more challenging to land on the surface, as well as perform daily tasks that require slightly more air pressure to work. Additionally these elevations will be incredibly cold making life even more difficult for the martian residents.

5. *Slope < 10°*

Finally, there is a slope dependence. Landing and building on the surface of Mars must be done in a relatively flat area (Levy, 2020; Hoffman, 2015). The slope must be below 10 degrees to build or land.

Data Collection and Preprocessing:

First, a global map of Mars was required to extract location/latitude, elevation, and slope. The Mars Orbiter Laser Altimeter (MOLA; Smith et al., 2001) dataset was used for these purposes which can be accessed at astrogeology.usgs.gov. This dataset is an integer elevation raster of the surface of Mars, a digital elevation model (DEM) with a size of 46080 x 22528 px and a resolution of ~463 m/px. It has an equidistant cylindrical coordinate system. A hillshade raster was made from this DEM to visualize the surface of Mars. For the final maps, the data was projected into a Mollweide Auxiliary Sphere projection with a GCS Mars 2000 coordinate system (Figure 1). These will be the base maps for the rest of the analysis.

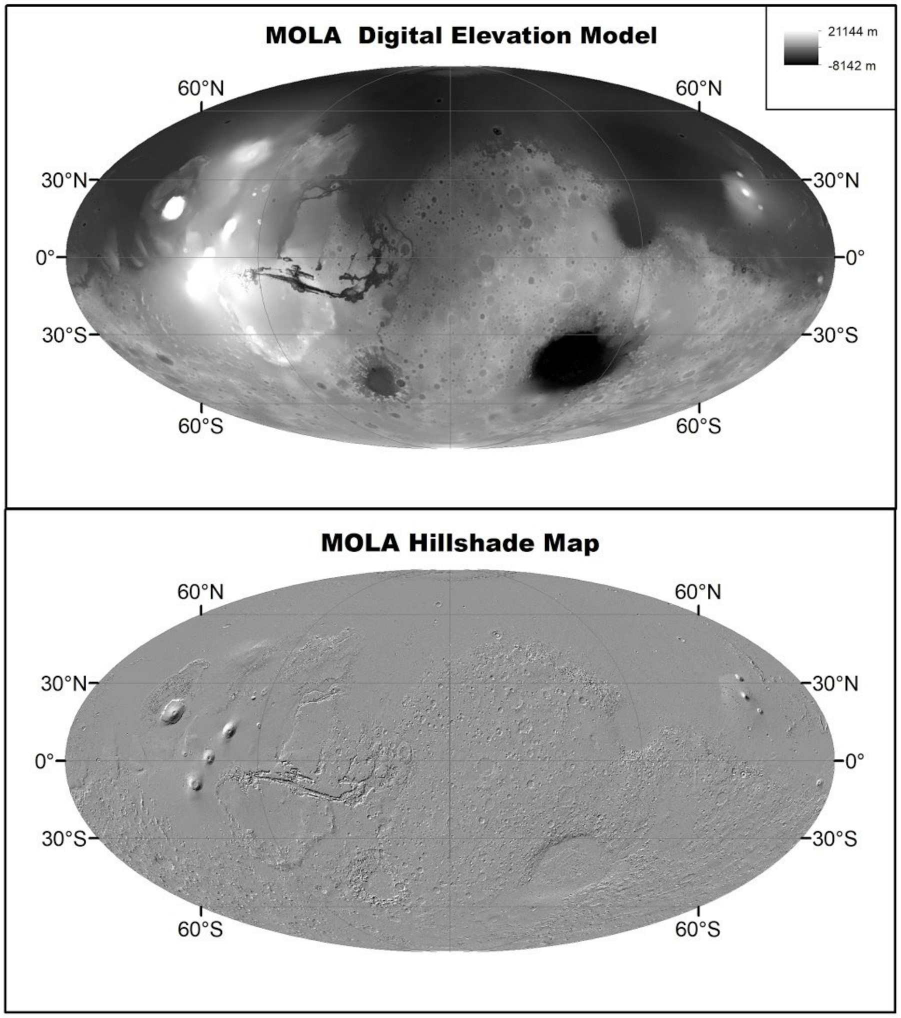

Figure 1. (Top) DEM from MOLA shotpoints. (Bottom) Hillshade map created from MOLA DEM. Both maps have a Mollweide Auxiliary Sphere projection with a GCS Mars 2000 coordinate system.

The location of debris covered glaciers across the surface of Mars has already been mapped by Levy et al., 2014. Shape files of the three types of debris covered glaciers (lobate debris aprons, lineated valley fill, and concentric crater fill) were downloaded from the supplemental files of the paper. Each of these three shape files were projected into the same coordinate system as the MOLA DEM using the “project” tool.

The other key piece of data that required preprocessing is the dust cover across Mars. No shape file of the dust coverage was readily available, so it was necessary to make original shape files based on published figures of dust coverage across Mars. This data was obtained from Ruff and Christensen, 2002 in JPG format. The JPG was then manually georeferenced to the MOLA DEM and hillshade so that the dusty areas could be traced as shape files during ArcMap processing (Figure 2).

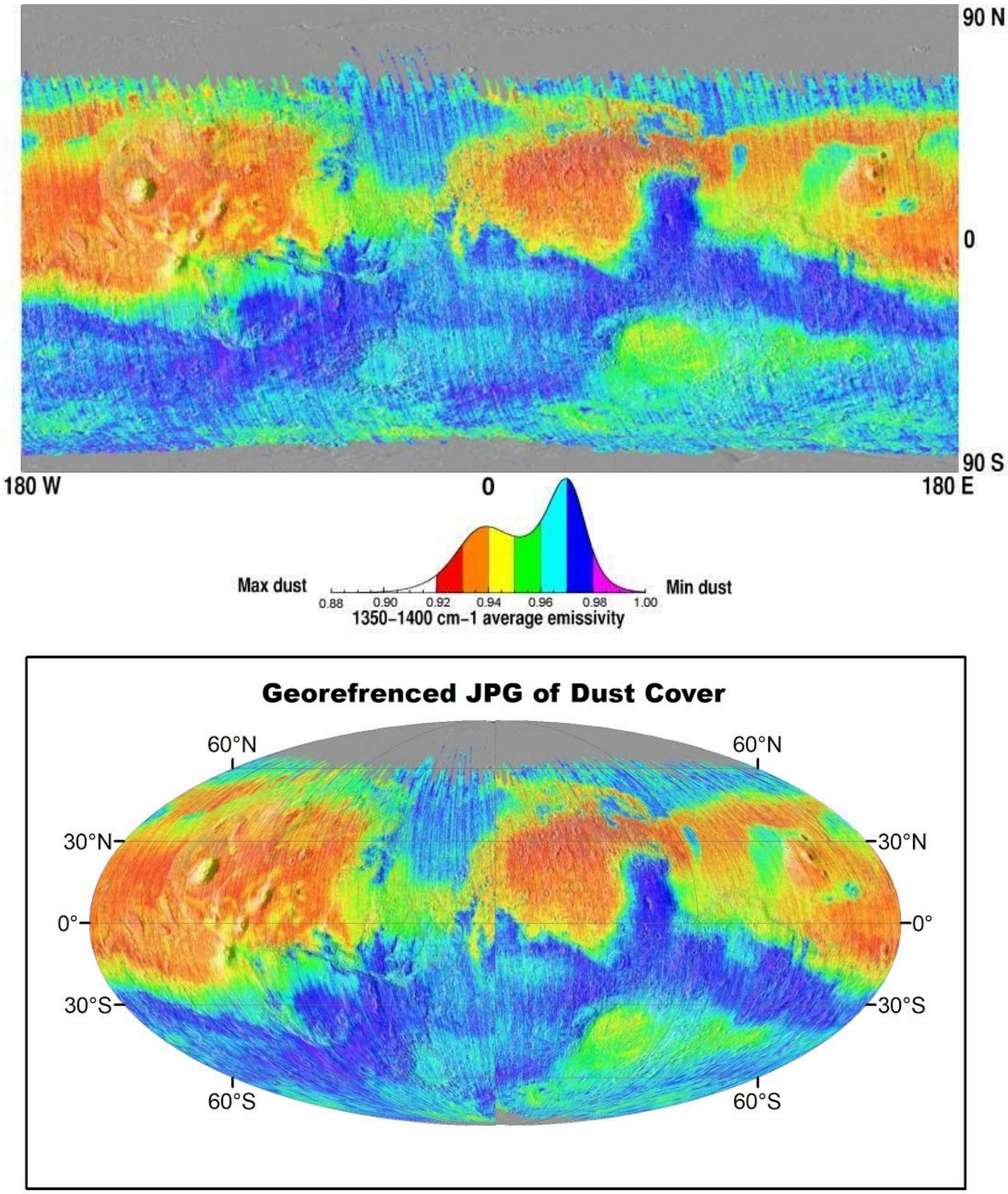

Figure 2. Top: JPG image taken from [Ruff and Christensen, 2002](#) showing the amount of dust coverage across the surface of Mars. Bottom: The JPG image manually georeferenced to the MOLA DEM and hillshade

ArcMap Processing

Creating the Shapefiles

The starting parameter is that the ideal site must be within 5 km of a water source. To perform this analysis, 5km buffers were created around each glacier from the three glacier shapefiles, and then merged into a single “glacier buff” shapefile (Figure 3). The other parameters used throughout the rest of the study will map out “forbidden regions” or areas where a settlement cannot be built. The goal is to create shapefiles outlining all the forbidden regions as defined by the other parameters. These regions will constrain the original area outlined by the glacier buffers. The exception to this is the latitude constraint, because the glacier shapefiles already have the latitude of each feature stored in the attribute table from the Levy et al., 2014 paper.

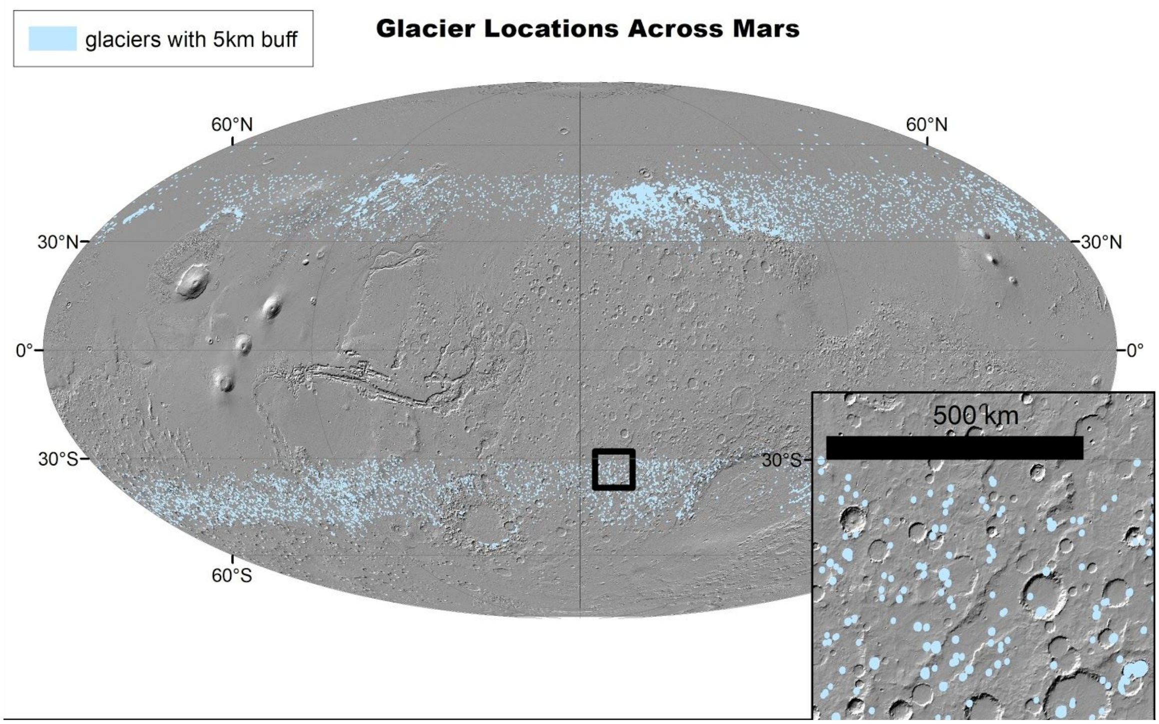

Figure 3. Global distribution of debris covered glaciers across the surface of Mars with 5km buffers around each feature. There is a punch-in to show the relative sizes of the different glaciers. These are the starting points for where the settlement could be. They will be further constrained through further analysis.

The next parameter used to constrain the location is the dust cover. The forbidden regions created by this parameter were manually mapped by a polygon shapefile over the red and orange areas marking high dust coverage on the georeferenced JPG image (Figure 4).

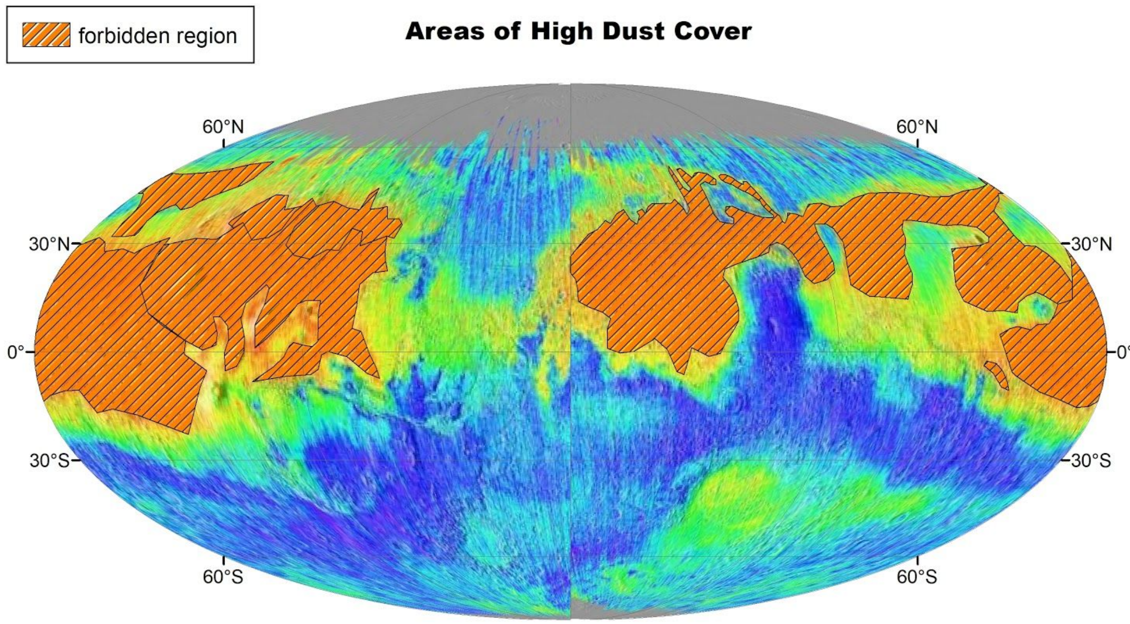

Figure 4. Manually traced regions of high dust cover (forbidden regions) as polygon shapefiles over the JPG image of concentrations of dust cover across the surface of Mars.

Next, a raster was created of the slopes across Mars derived from the MOLA DEM using the slope tool. This raster was then turned into a binary raster using the raster calculator tool where all slopes 10^o and greater were given a value of one and all slopes below 10^o are zero. This raster was then converted to a polygon shapefile using the raster to vector tool. The attribute table of the shape file was pulled up and all features with a value of zero (areas with regions less than 10 degrees) were deleted. This left a polygon shape file of all the forbidden regions across Mars that are too steep to build and land on (Figure 5).

A similar technique was used to find the forbidden regions associated with high elevations (landing and building cannot occur at elevations 3,500m and greater). A binary raster was created using the raster calculator with the MOLA DEM as the input. All elevations less than 3,500m were set equal to zero while all elevations 3,500m and greater were set equal to one. This binary raster was then put through the raster to vector tool resulting in a polygon shapefile. All features with a value of zero were then deleted. This left a shapefile with only the forbidden regions of high elevation mapped out by polygons (Figure 5).

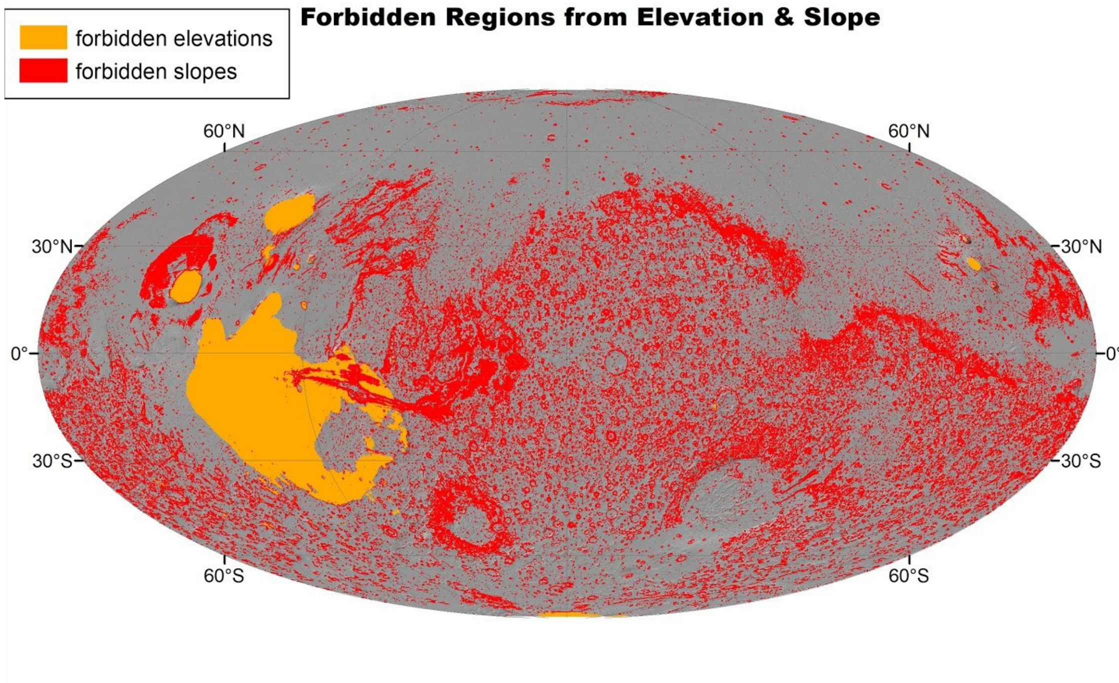

Figure 5. The combined forbidden regions associated with elevations that are too high (≥ 3,500m) in orange, and slopes that are too steep (≥10º) in red across the surface of Mars.

Filtering the Shapefiles

The study began with 11,242 glaciers that could be used as a possible settlement location. These were first filtered out by latitude. All glaciers that were at latitudes greater than +30º or less than -30º were filtered out for not being close enough to the equator. This was done by going to 'select by attribute' in the selection tab of ArcMap and selecting the glacier buffers with latitudes >-30º and <+30º as shown by the first panel in Figure 6. This resulted in only 79 of the original 11,242 glaciers being selected, meaning the possible site of settlement has already been narrowed down to 79 possible sites.

The glacier sites were then filtered further using the forbidden elevation and dust cover regions by using 'select by location' and clicking 'remove from the currently selected features' in the top dropdown menu (illustrated in the second panel of Figure 6). The target layer is the glacier 5km buffers we have 79 features selected in, the source layer is forbidden elevations (and later forbidden dust cover region) and we deselected any glacier 5km buffers that were within this source layer feature. Presumably, even if a small area of the 5km buffer intersects with one of these regions, the dust cover and elevation will be too much to sustain a human settlement even 5km away. This step was done twice, once using forbidden elevation as the source layer and another time using the forbidden dust cover regions.

Finally, the same thing was done with the forbidden slope regions where we used 'select by location' and clicking 'remove from the currently selected features' with the selected glacier 5km buffers as the target layer, but the target method was changed to "completely within the source layer feature." This is because if one of the buffers only has a small area with slope ≥ 10°, it is possible it can still be landed and settled on using the rest of the space within the buffer. This was done with the intention to visually check all the final candidate sites to make sure there is still enough space with slopes <10° in the 5km glacier buffer to land and settle within.

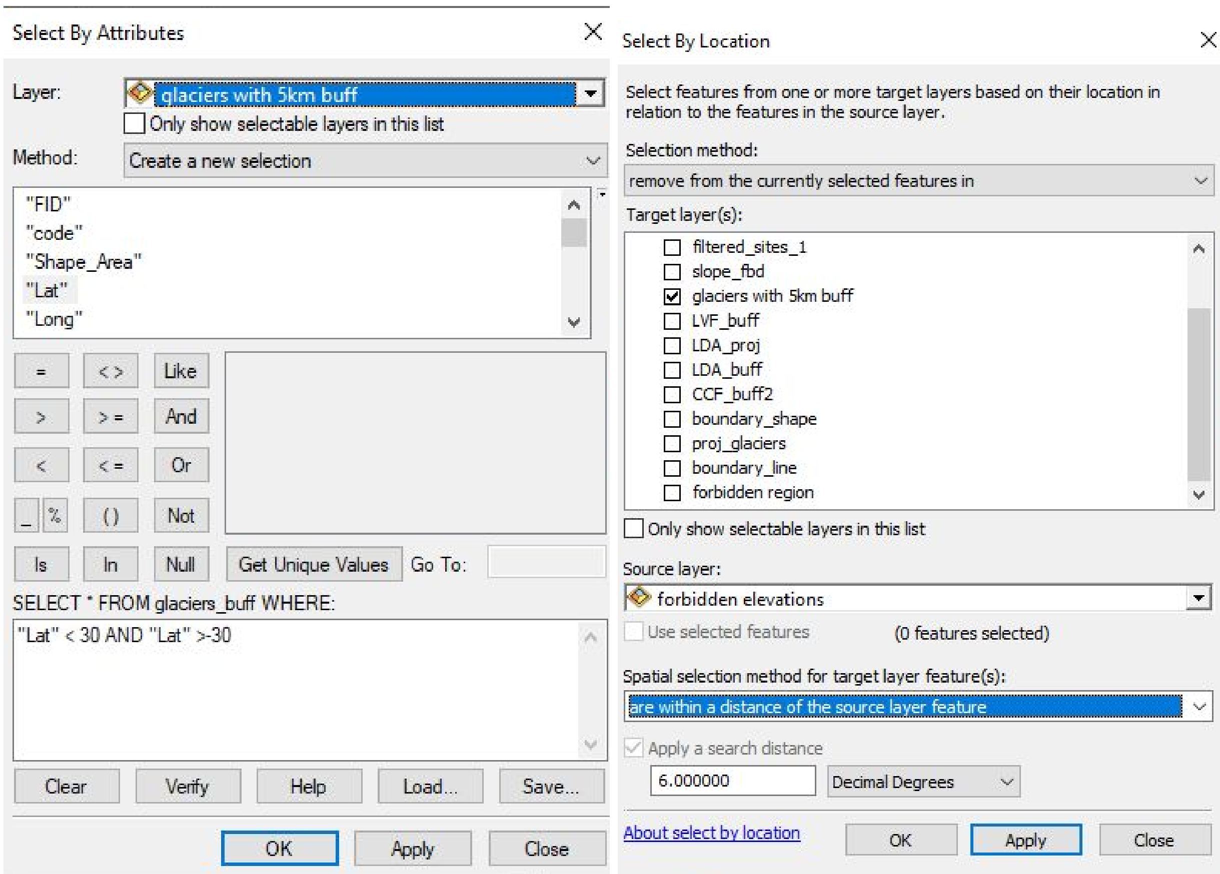

Figure 6. Left: The settings used to select the glacier buffer features by attributes. Right: The settings used to deselect the glacier buffer features based on multiple forbidden regions mapped out previously.

After filtering the 11,242 glacier buffers with these constraints, 45 possible sites remained. The details of these results are shown in Table 1 at the end of this paper. 43 of these sites occur around debris covered glaciers classified as concentric crater fill (CCF), meaning the site is contained inside a crater. The other 2 sites occur around lobate debris aprons (LDA) these are identified by FID #0 and FID #1 in Table 1. The purpose of this study was to identify the sites that fit the original parameters, which all 45 sites do, but as there is a wide selection to choose from, it is possible to narrow down this selection even further. Presumably, a settlement of Mars would include scientists who want to explore the planet. Building a settlement inside a crater has the drawback that everytime someone were to venture outside the settlement and possibly visit a different region of Mars, they would have to traverse the steep sides of a crater. Additionally, deeper craters might result in large shadows so that the sun would not be able to power the solar panels. Therefore, it is the author’s recommendation that the two LDA sites be prioritized as possible sites of human settlement.

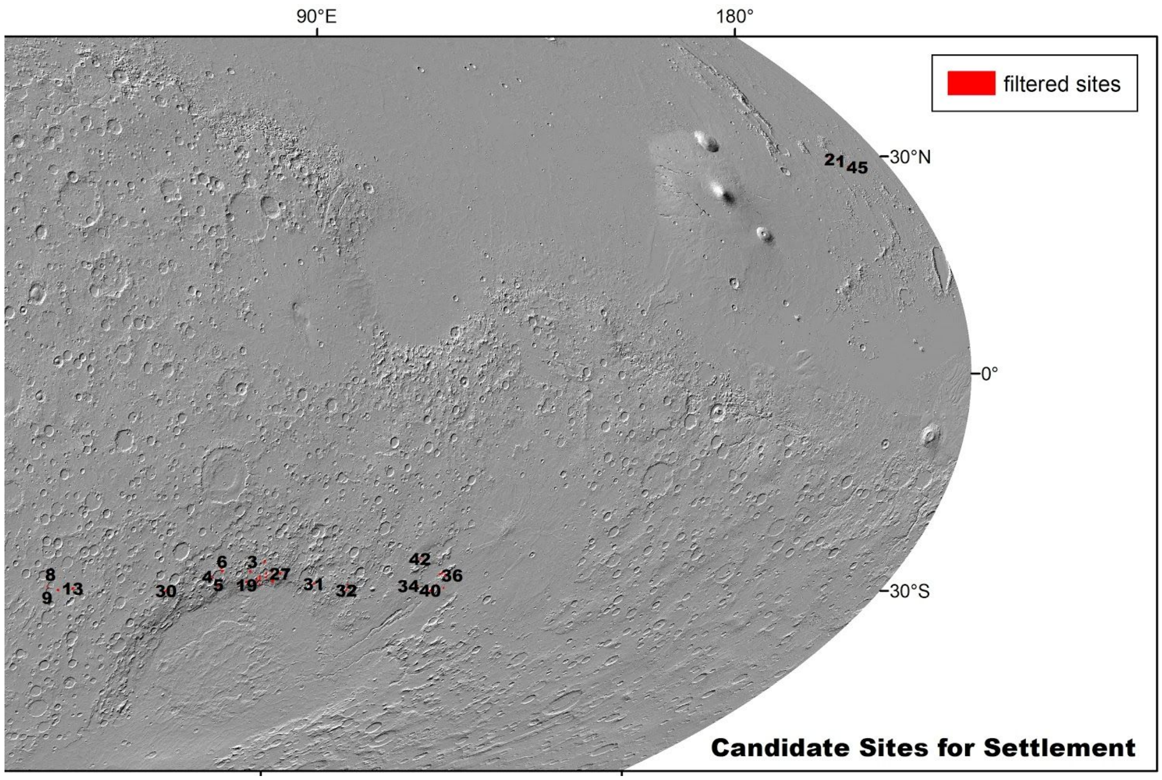

Figure 7. Slight zoom in on the surface of Mars to show the 45 possible sites for settlement after filtering the glacier buffers out using the mapped forbidden regions.

Priority Sites

To examine these sites in closer detail, images were downloaded as pyramtized TIFFs from the [Context Camera (CTX) database](#) that covered the regions of interest. Specifically, CTX images with IDs P17_007671_2122_XN_32N190W and P12_005535_2109_XI_30N188W. These CTX images have a resolution of ~1m/px.

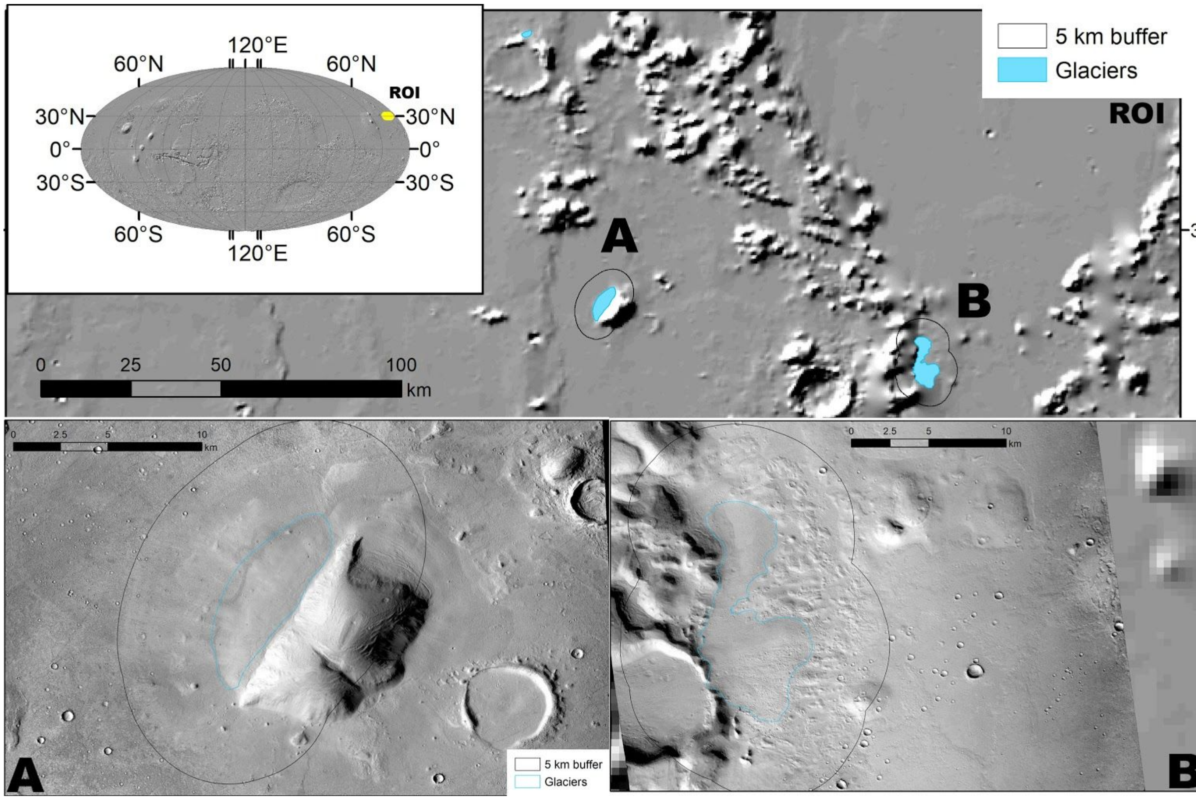

Figure 8. Top: Region of interest that includes two candidate sites for settlement less than 100km away from one another. The location of this region is shown on the overall map of Mars with the yellow square. Bottom: Higher resolution images of both sites A (CTX image P17_007671_2122_XN_32N190W) and B (CTX image P12_005535_2109_XI_30N188W). North is towards the top in all of the images.

Figure 8 shows the two priority locations (A and B) in finer detail. These two sites are both LDAs in the same region (Table 1). They are both in relatively flat areas with over 80% of both sites shallower 10°. The main difference between the two is that the glacier for site A (FID #0 in Table 1) has a smaller area, and is facing NW. The glacier at site B (FID #1 in Table 1) has almost double the area and is facing directly East. The consequence of the positioning of these sites with the shadows of nearby topographic highs would be that settling at site B would give the most sunlight in the morning and early afternoon of the martian sol, while site A would give more sunlight in the evening.

In summary, 45 possible locations were found to be possible sites for the first human settlement on Mars. Of these 45 sites, two in particular stood out as priority locations based on accessibility over large distances (i.e not inside a crater). These sites are both <5km from a water source in the form of a LDA, have limited dust cover, are in the equatorial region between -30 and +30 degrees latitude, have an elevation <3,500m and a majority of the site has a slope <10°. When planning the first Martian settlement, both of these two locations should be considered as possible sites for long term stays.

Tables

FID	Glacier Type	Lat (°N)	Long (°E)	Glacier Area (m^2)
0	lda	29.3721	172.1026	56855428.3
1	lda	29.66149	170.5984	28842000.85
2	ccf	-25.8123	63.2702	4840219.972
3	ccf	-27.9405	56.6803	1912377.99
4	ccf	-29.0981	58.21155	216715830.8
5	ccf	-27.1366	58.24895	54055386.41
6	ccf	-26.6842	57.96945	36456393.68
7	ccf	-27.6107	27.37126	19518638.12
8	ccf	-29.3394	26.99141	3560544.293
9	ccf	-29.8246	29.013	13075641.97
10	ccf	-29.9156	29.12346	1807079.742
11	ccf	-29.1489	30.56614	31925665.67
12	ccf	-29.6436	31.68437	65366757.4
13	ccf	-25.7957	65.41527	24754848.62
14	ccf	-29.0146	65.68351	4683841.92
15	ccf	-27.9427	65.29541	20199512.15
16	ccf	-28.2644	65.43711	12526408.77
17	ccf	-28.4111	64.90386	10244939.56
18	ccf	-28.6999	63.14851	35498309.93
19	ccf	-27.1862	63.29366	41483402.66

20	ccf	-28.6353	67.87719	34889413.2
21	ccf	-28.5313	67.81504	13194683
22	ccf	-28.448	67.82366	7910661.371
23	ccf	-28.4624	67.94679	6125265.082
24	ccf	-27.4649	66.31579	15504103.68
25	ccf	-28.0208	66.46145	15981472
26	ccf	-27.4769	68.82175	27321244.3
27	ccf	-28.2638	68.45087	13512827.57
28	ccf	-27.2992	67.31656	5661301.921
29	ccf	-29.9678	48.89135	22120715.32
30	ccf	-28.9461	75.54711	22741824.05
31	ccf	-29.8812	81.90564	16132391.15
32	ccf	-29.1473	81.86642	6407275.684
33	ccf	-29.2672	94.6085	3936617.152
34	ccf	-27.38	98.08091	6665216.275
35	ccf	-27.7426	98.78608	19975960.32
36	ccf	-27.5467	97.7327	4014999.551
37	ccf	-29.137	97.96529	7670486.028
38	ccf	-29.953	97.96649	16620922.8
39	ccf	-29.9148	97.36893	21103087.59
40	ccf	-29.7834	96.80641	7607058.802
41	ccf	-25.4444	93.10958	1228772.696
42	ccf	-29.5493	99.58263	2915473.532
43	ccf	29.28499	171.9969	28775023.21
44	ccf	28.52707	172.6117	7592774.631

Table 1. List of all 45 candidate sites that pass the five tests described in the introduction. They are identified by their FID number, also the latitude, longitude, area of the glacier in m^2, and classification (lobate debris apron as lda, or concentric crater fill as ccf) are listed based on the information provided in Levy et al., 2014.

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