GOSTEAM Hands-on Activity Template *(Inquiry-based)*

Title:

Potential landing sites on the Moon and Mars for my rover

Short Description (Max 500 words):

Rigorous selection of a landing site for a Martian rover plays a crucial role in the success of the mission because it guides the rover to a location on Mars where the science objectives can be best achieved. Selecting an optimal site is a complex multi-objective optimization problem enumerating a vast number of criteria.

During this activity, we focus on certain surface-related parameters, including elevation, latitude and slopes in order to extract an optimal landing sites for a Martian rover! Do you think that's an easy task? Let's find out!

Keywords (Up to 5):

Spatial Modelling, Surface Analysis, 3D terrain

Information about the Implementation

Age and language of the students:

Language: Greek	Age:	9-12	12-15	15-18	18+
		☐	☐	☑	☐

Number of Lessons – Duration (per lesson):

Number of Lessons: 2 Duration per Lesson: 45'

Subjects:

For which subject(s) the activity is usable, is it an interdisciplinary activity?

Science ☑

Physics ☑ Chemistry ☐ Biology ☐ Geosciences ☑ Environmental ☐ Other ☐

Technology ☑

Engineering ☑

Arts ☐

Mathematics ☑

Information about the Scenario

Curriculum and country:

Link of the current activity to the curriculum:

Country:	Greece	Class:	Secondary	Grade:	9 - 12

Topic:

2D – 3D Surfaces, Spatial Analysis,

Surface characteristics

Objectives (Max 100 words):

Description of the learning objectives

Some of the key objectives to be addressed through this activity include:

1. The use of Geographic Information Systems to perform important surface analysis procedures (i.e., estimate slopes) or to recreate 3D surfaces,
2. To understand some crucial aspects and spatial characteristics for identifying potential landing sites on Mars and the Lunar surfaces.

Materials (Max 100 words):

Which resources and materials (software, hardware) are needed?

Material: Search Engines, Satellite Images

Software: QGIS (qgis2threejs)

Spatial concepts, skills, and abilities:

Which spatial concepts and skills are covered by the activity?

Spatial concepts:

Primitives:	Identity/Name ☐	Location ☑	Space/Time ☐	
Simple:	Distance ☐	Direction ☐	Connectivity ☐	Movement ☐
	Boundary ☐	Shape/Area ☑	Adjacency ☐	
Difficult:	Overlay ☑	Buffer ☐	Topology ☐	Coordinate ☐
	Map ☐	Scale ☐	Shortest Path ☐	Navigation ☐
	Surface ☑	Slope/Gradient ☑	Aspect ☐	Contour ☐
Complex:	Interpolation ☐	Map Projection ☐	Spatial Dependency ☐	
Other:				

Spatial skills:

- ☐ Map literacy
- ☐ Navigation/orientation
- ☐ Estimating distances and directions
- ☑ Recognizing and understanding patterns/Understand and identify models of spatial organization
- ☑ Select an ideal location based on the given spatial features
- ☑ Visualization
- ☐ Understand and identify spatial correlations/ dependencies
- ☐ Categorize spatial entities/ geographic features and identify hierarchies
- ☐ Compare spatial entities and draw analogies among them
- ☐ Identify/determine connections/relations
- ☐ Understanding scale in space and time
- ☑ Delineation of spatial regions/ zones based on given features/ properties

Short Description

Navigation/orientation: Finding one's way in unfamiliar environments, interpreting and giving walking and driving directions.
Estimating distances and directions: Measure paths, weighted distances, angles.
Map literacy: Using, interpreting/understanding, learning from, and communicating acquired spatial knowledge from maps, comprehension of geographic features represented as points, lines, or polygons.
Recognizing and understanding patterns/Understand and identify models of spatial organization. Delineation of spatial regions/zones based on given features/properties: Regionalization processes, pattern recognition and clustering identification in the 2d and/or the 3d world.
Select an ideal location based on the given spatial features: Single or multi-criteria siting and optimal areas identification.
Visualization: Visualizing spatial entities from written/oral verbal descriptions, from their 2d or graphical representations or through mental transformations; such as axis rotation or perspective taking.
Understand and identify spatial correlations/ dependencies: The ability to realize, identify and explain patterns, clusters and relevant spatial dependencies.
Categorize spatial entities/geographic features and identify hierarchies: Identify the hierarchical form of data and gradients between spatial entities.
Compare spatial entities and draw analogies among them: Calculate and compare different geometric objects' shapes, area and boundaries.
Identify/determine connections/relations: The ability to identify links and common characteristics among spatial entities and between humans and spatial entities.
Understanding scale in space and time: The understanding of changes/transitions through space and time for different spatio-temporal scales.

Geospatial concepts and spatial abilities documentation (see Section 3.2):
http://www.gosteam.eu/wp-content/uploads/2021/05/GOSTEAM_IO1_A1_final.pdf

Description of the activity in detail

Question Eliciting Activities

Provoke curiosity

Describe ways and materials that teachers will present to their students to attract their attention to the topic investigated.

Usually, the most effective way to provoke students' curiosity is by presenting an exciting video or a series of photos

https://www.youtube.com/watch?v=4czjS9h4Fpg

(Perseverance Rover's Descent and Touchdown on Mars)

But how did we manage to get to the final landing stage?

Propose preliminary explanations or hypotheses

Formulate the scientifically oriented questions that teachers will present to the students to trigger their engagement in thinking about the topic investigated based on their existing knowledge. Make these questions digitally available and easily usable, e.g., by integrating them in the materials described in the previous step.

It is best to ask these questions in the context of a relative discussion.

Is it an easy task to identify potential optimal sites?

What criteria are needed?

What is the scope of the mission?

Active Investigation

Plan and conduct simple investigation

This is the phase in which students are being prepared for the subsequent phase of evidence gathering during observation.

Provide the teachers with a specific plan of the investigation that will take place. Offer instructions about the activities they students will need to perform and what kind of materials they may need. Describe ways to facilitate the students to focus on evidence.

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- During this step, students may collect evidence regarding the criteria needed to identify optimal landing sites. Delineate which of these criteria are based on the surface characteristics and which are not.
- It is already difficult to gather enough spatial data even for the Earth's surface, thus, consider for Mars.
- After the criteria identification, students will get introduced to the spatial concepts needed to understand (i.e. slope and aspect calculation, geographic coordinates etc.).

Support material for both the Martian and the Lunar missions:

Mars landing: How to Select a Landing Site on Mars

Mars 2020 Mission: The Perseverance Rover Landing

China Mars Rover: Why the China Mars rover's landing site has geologists excited

Mars: Landing Sites

Mars Landing: Picking a Landing Site for NASA's Mars 2020 Rover

Moon landing: Appolo Missions Landing sites

Moon landing sites: Landing sites Map

Lunar Surface: Different spatial data representation

50 Years Ago: Lunar Landing Sites Selected

Criteria for landing sites identification (Search for the criteria):

Key criteria for potential landing sites, considering ExoMars and Mars 2020 missions.

Use the following resources to examine for further insights about the problem:

Selecting Landing site for the Mars 2020 rover

Mars Landing Site Selection

Table 1 Summary of the ExoMars 2020 and the Mars 2020 surface/terrain engineering constraints as from the ExoMars landing site call (http://exploration.esa.int/mars/53462-call-for-exomars-2018-landing-site-selection/) and from Golombek et al. (2012)

	ExoMars 2020	Mars 2020
Landing latitude	5°S–25°N	30°S–30°N
Landing elevation	$\leqslant -2$ km MOLA	$\leqslant +0.5$ km MOLA
Landing ellipse dimensions	104 × 19 km	25 × 20 km (nominal)
(major × minor axis)		18 × 14 km (range trigger)
		13 × 7 km (range trigger)
Landing ellipse orientation	83–127°	Roughly east–west
Slopes at 2 to 10 km length scale	$\leqslant 3.0°$	$\leqslant 5.71°$
Slopes at 333 m length scale	$\leqslant 8.6°$	$\leqslant 5.71°$
Slopes at 7 m length scale	$\leqslant 12.5°$	$\leqslant 25.0–30.0°$
Slopes at 2 m length scale	$\leqslant 15.0°$	$\leqslant 25.0–30.0°$
Rock abundance	$K \leqslant 7\%$	$K \leqslant 12\%$, locally $K \leqslant 20\%$
Thermal inertia	$\geqslant 150$ J m^{-2} s$^{-0.5}$ K^{-1}	$\geqslant 100$ J m^{-2} s$^{-0.5}$ K^{-1}
Albedo	$0.1 \leqslant$ Albedo $\leqslant 0.26$	Albedo $\leqslant 0.25$
Radar reflectivity	-15 dB $\leqslant$ RR $\leqslant 27.5$ dB	-20 dB $\leqslant$ RR $\leqslant 15.0$ dB

Figure 1: Landing criteria for the ExoMars and Mars2020

(**Source:** Pajola et al. 2019)

Criteria for landing sites identification (Explore the following maps):

Scale up the difficulty!

1. Key criteria for potential landing sites, considering ExoMars and Mars 2020 missions.
2. Landing elevation, dimensions, slopes and aspect.
3. You can use additional criteria from:

https://www.mars.asu.edu/data/ (All available data for Mars)

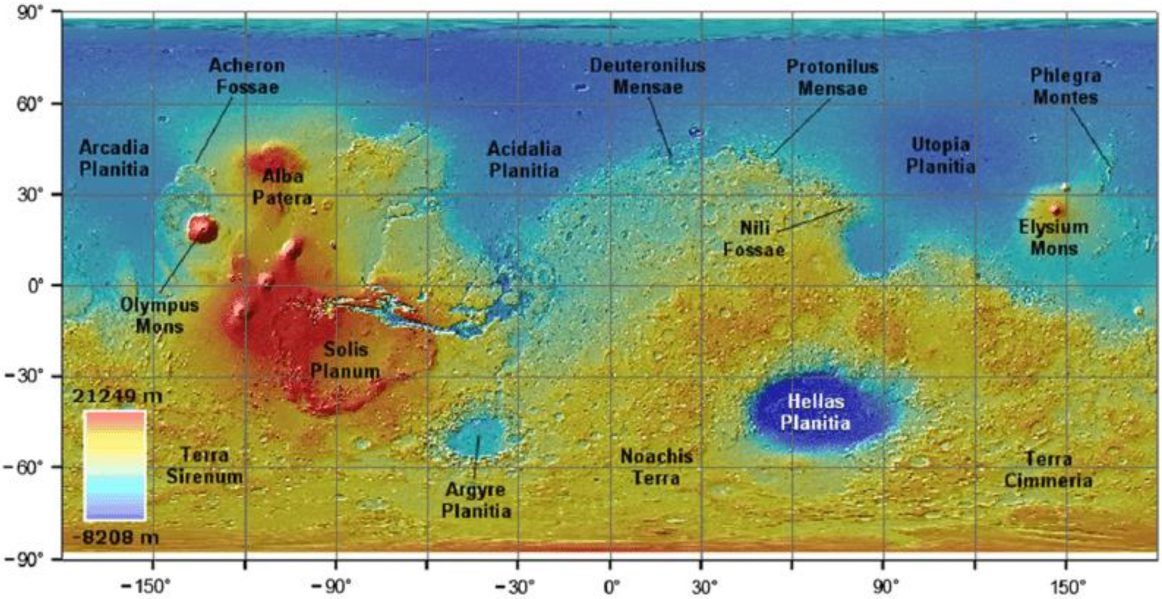


Figure 2: Digital Elevation Model (DEM) of Mars, Source

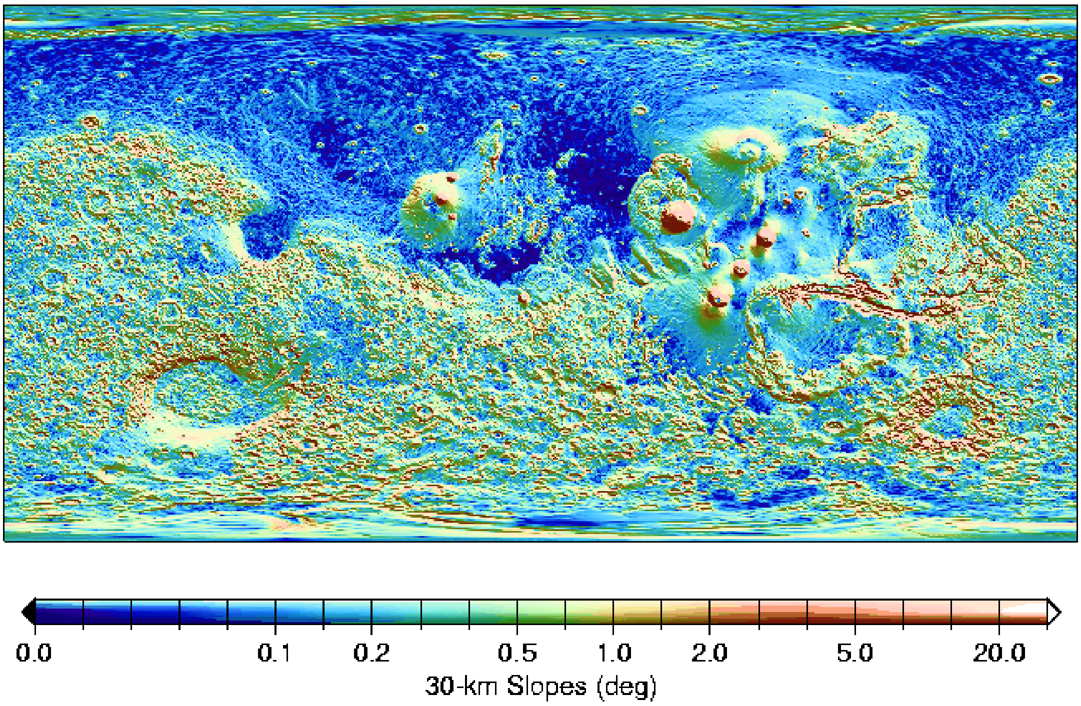


Figure 3: Terrain slopes on Mars (Inversed image), Source

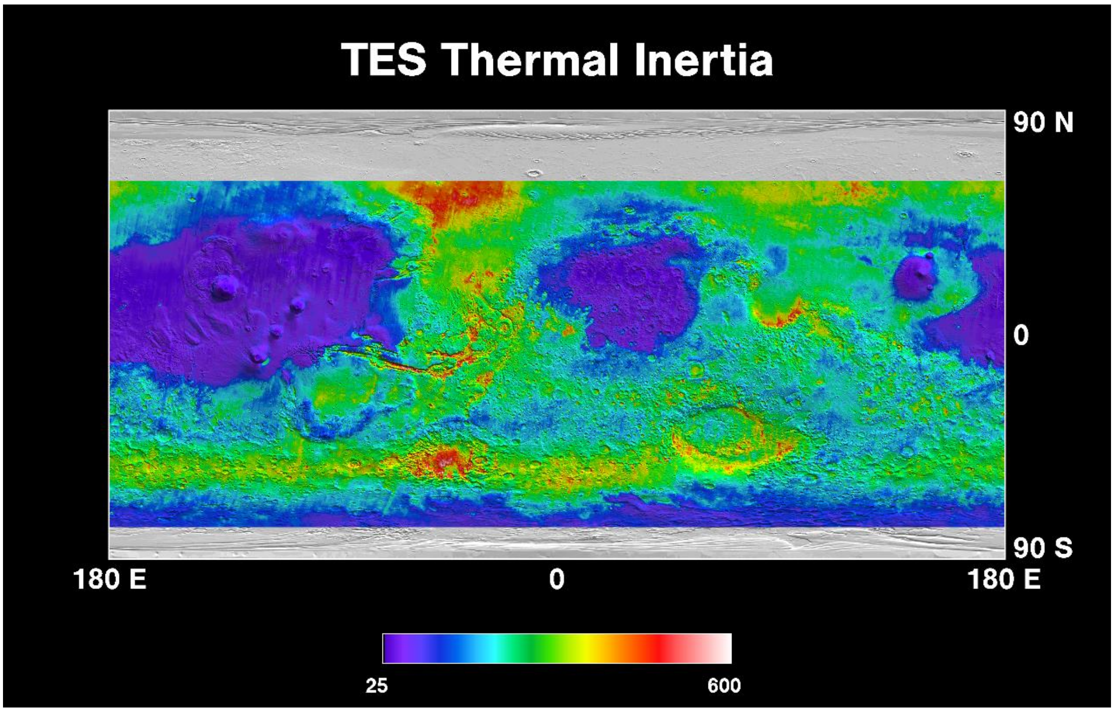


Figure 4: Thermal Emission Spectrometer(TES) Thermal Inertia on Mars

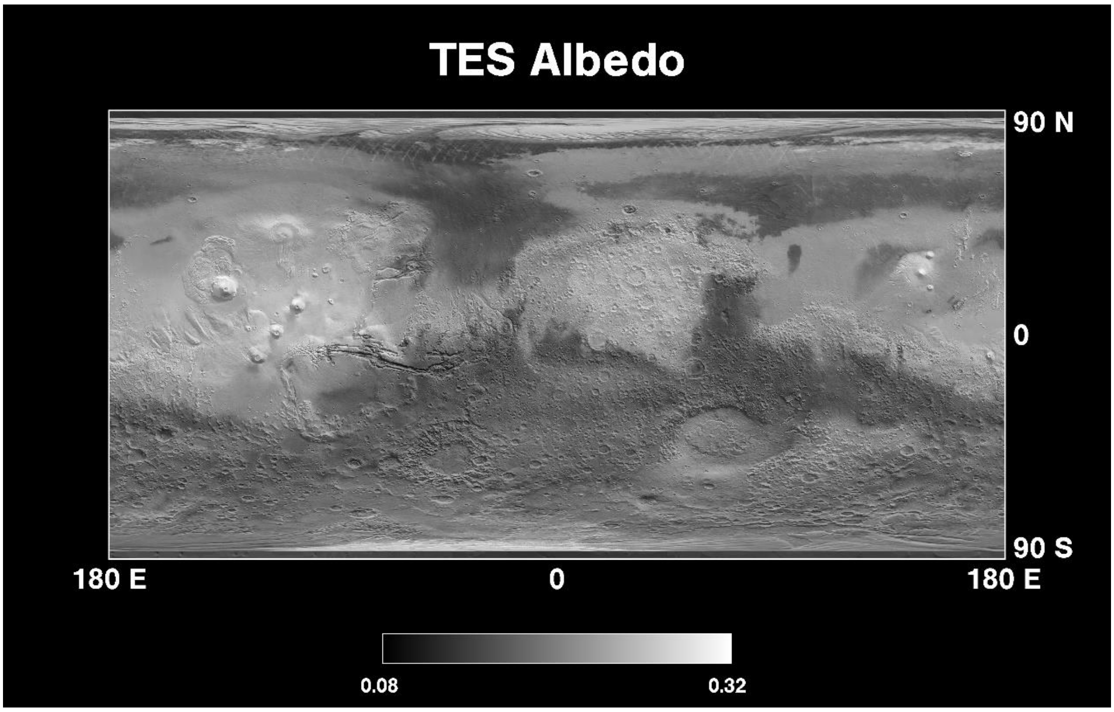


Figure 5: Thermal Emission Spectrometer(TES) Albedo on Mars

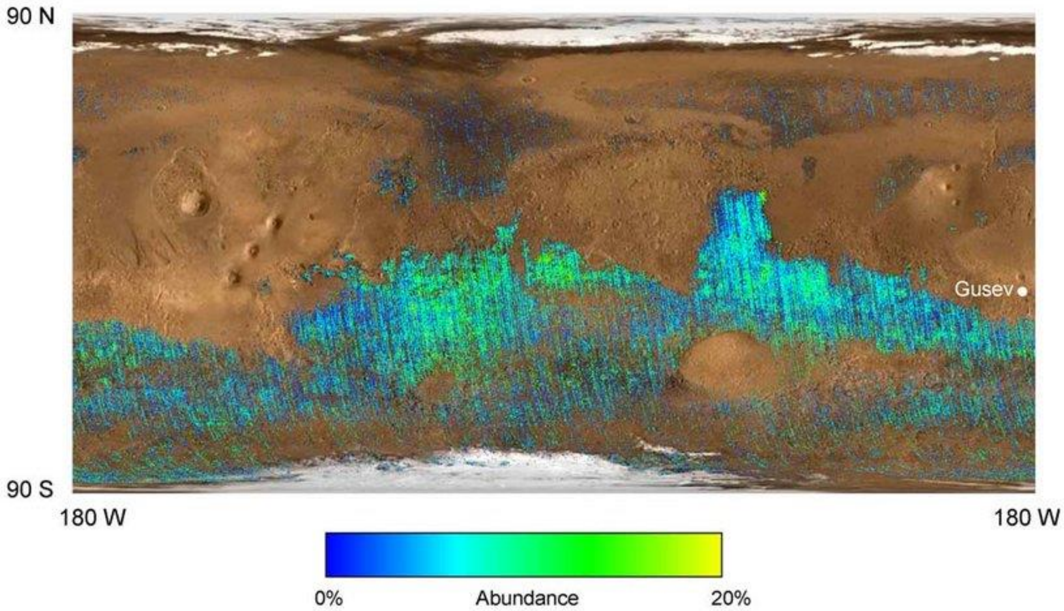


Figure 4: Rock Abundance on Mars

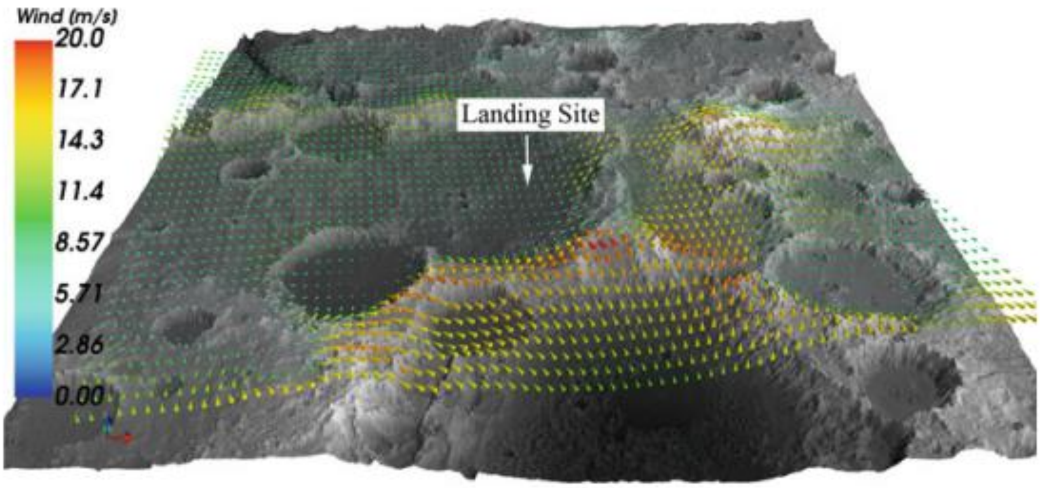


Figure 5: Surface elevation and wind speeds on Mars

At this point, based on **Figure 1**, you can ask students why do they think we need areas below or near 0 level, almost flat areas, low albedo, high thermal inertia and minimum rock abundance levels for our landing sites?

Elevation	Sufficient atmosphere braking during landing, Potential areas covered with water, lower wind speeds
Slopes	Flat areas for safe landing and navigation
Albedo	Rover's thermal design constraints
Thermal inertia	Avoid landing on a dusty surface
Rock abundance	Absence of rocks during landing to avoid damage

Explaining Slopes estimation:

For each cell, the Slope tool calculates the maximum rate of change in value from that cell to its neighbors. Basically, the maximum change in elevation over the distance between the cell and its eight neighbors identifies the steepest downhill descent from the cell (see Figure 7 to understand the neighborhood method).

The output slope raster can be calculated in two types of units, degrees or percent (percent rise). The percent rise can be better understood if you consider it as the rise (height) divided by the run (horizontal distance), multiplied by 100. Consider triangle *B* below. When the angle is 45 degrees, the rise is equal to the run, and the percent rise is 100 percent. As the slope angle approaches vertical (90 degrees), as in triangle *C*, the percent rise begins to approach infinity.

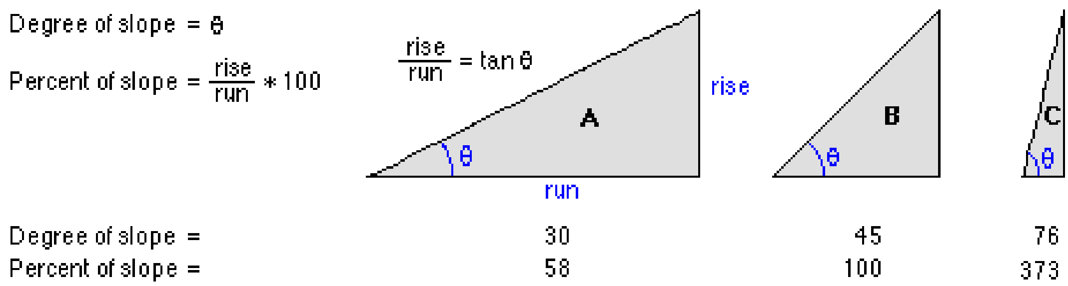


Figure 6: Slope estimation in degrees and percent of slope

Where:

ϑ (radians) = $\text{atan}\left(\sqrt{([dz/dx]2 + [dz/dy]2)}\right)$

ϑ (degrees) = $\text{atan}\left(\sqrt{([dz/dx]2 + [dz/dy]2)}\right) 57.29578$

Note: *The value 57.29578 shown here is a truncated version of the result from 180/pi.*

The neighborhood algorithm estimates percent slope at grid cell ***e*** (Figure 6) as the sum of the absolute values of east-west slope and north-south slope.

The values of the center cell and its eight neighbors determine the horizontal and vertical deltas. The neighbors are identified as letters from *a* to *i*, with *e* representing the cell for which the aspect is being calculated.

The rate of change in the x direction for cell *e* is calculated with the following algorithm:

$[dz/dx] = ((c + 2f + i) - (a + 2d + g)) / (8\ x\_cellsize)$

The rate of change in the y direction for cell *e* is calculated with the following algorithm:

$[dz/dy] = ((g + 2h + i) - (a + 2b + c)) / (8\ y\_cellsize)$

See Figure 6 to understand what the parameters *a-i* are express as also, the cell size that is "translated" as the pixel's size

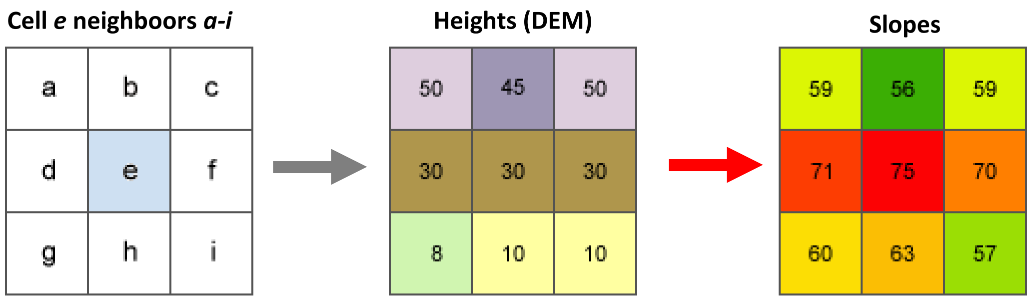


Figure 7: Slope estimation based on the neighborhood method

The cell size is 1 unit. The default slope measure of degrees will be used.

[dz/dx] = ((50 + 60 + 10) - (50 + 60 + 8)) / (8 * 1) = 0.05

[dz/dy] = ((8 + 20 + 10) - (50 + 90 + 50)) / (8 * 1) = -3.8

rise_run = $\sqrt{(0.05^2 + (-3.8^2))}$ = 3.80032

slope_degrees = atan(3.80032) * 57.29578 = 75.25

Important note: If there is a cell location in the neighborhood with a NoData z-value (height value), the z-value of the center cell will be assigned to the location. For example, at the upper left edge of the raster (value 50 in Figure 6 - Heights), consider that 5 neighbours are missing (NoData). Hence, we create 5 pseudo-cells and we assign the value of the cell we want to estimate slope (i.e. 50).

An indicative example of a slope surface is demonstrated in **Figure 8.** You can see that areas of increased altimeter (white color) are expected to result increased slopes (red colors on the right image) because of the steep surfaces occurred near the peak of the mountains.

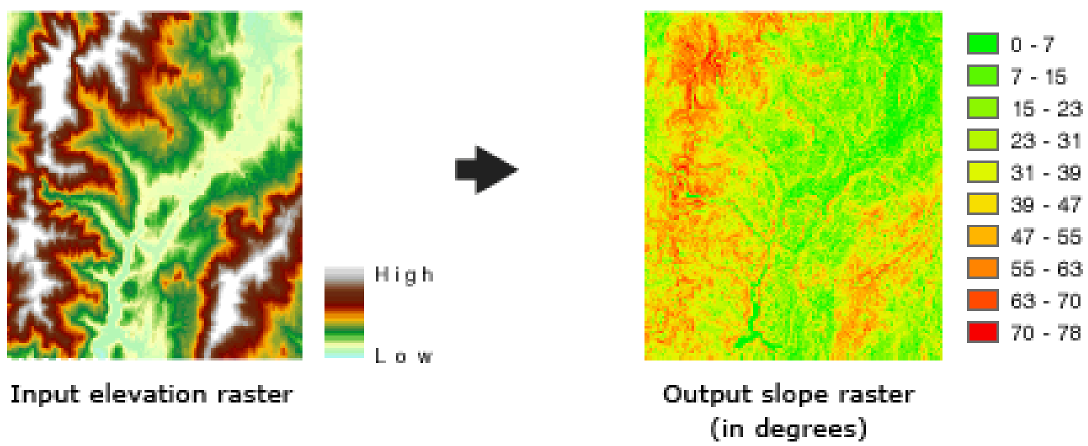


Figure 8: Elevation raster and extracted slope raster example

Creation

Gather evidence from observation

The selected resource (e.g., a simulation, an experiment, an animation, a graph, or other exhibit of similar nature) must provide students with an opportunity to collect evidence addressing the scientific questions presented in previous stages through direct or indirect observation. Provide guidance to the teacher organize and manage the activity most effectively and efficiently.

It is recommended to introduce group work at this stage. Guide the teachers to divide students in groups, each of which will be facilitated by the teacher to formulate and to evaluate explanations to the scientific questions based on the collected evidence.

Students can work in groups of three where each member of the group is responsible for:

1) data collection (maps, spatial data etc.)
2) previous missions' landing criteria, scope and objectives and finally,
3) future missions' objectives and goals.

Preparative steps

1. Download QGIS 3.18.1 version

2. [Download Mars DEM data](#)

   [Download Lunar DEM data](#)

QGIS

The above-mentioned DEM datasets have increased accuracy and size. It is much easier to test the activity with the resampled datasets you can find on the link below:

https://drive.google.com/drive/folders/1S-RGqCzWnnOEOIYJTG8RfSwSy9CMqPYx?usp=sharing

You can select to download Mars DEM folder. The file you will work with is *'Mars_DEM_5000.tif'*

Part 1 (Open QGIS)

Some technical guidelines considering the tools (QGIS Platform) we will use during this Activity!

Load data: In general, data can be loaded in four ways. The first way (Figure 8-selection 2) is to use the Layer > Add Layer menu and select the appropriate type of data you wish to load. The second way (Figure 8-selection 1) is to open the Browser panel, navigate to the data you wish to load, and then drag the data on to the map display, or on to the Layers panel. The third way (Figure 8-selection 6) to load data is to enable the Manage Layers toolbar and click on the button representing the data type you wish to load. The fourth way is to locate the data in QGIS Browser, drag to the data, and drop it onto the QGIS Desktop Map Display or Layers panel (Source: https://www.gislounge.com/loading-data-mastering-qgis/).

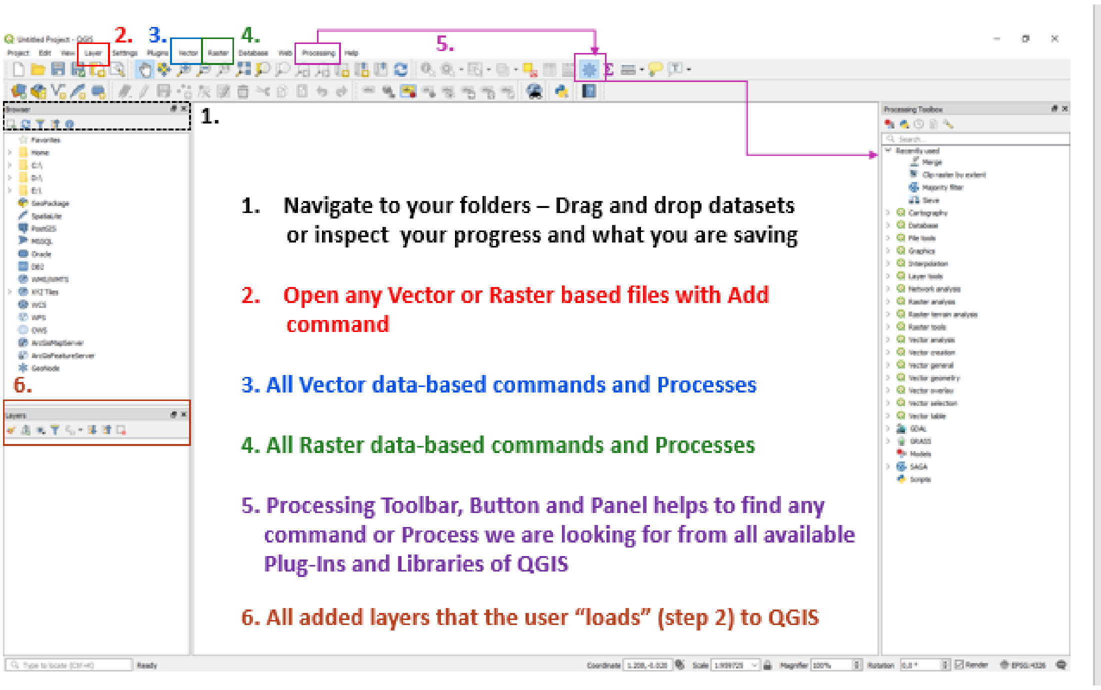


Figure 9: QGIS interface and some key functionalities

Part 2 – Load Mars surface data (Digital Elevation Model)

Mars surface data – DEM – Simplified scenario:

1. During the first step of the Activity, load Mars surface data in the QGIS platform.
2. Use the Main toolbar (top of the screen) -> Layers -> Raster Layer -> Navigate to your folder and select Mars_DEM_5000.tif
3. Change layout colors using Layer Properties (double-click on the .tif image you've loaded) -> Symbology -> Single-band Pseudocolor -> Classify.
4. Identify mountains and pits, find altimeter values (identify button).

Source: https://www.istockphoto.com/photos/mars-white-background

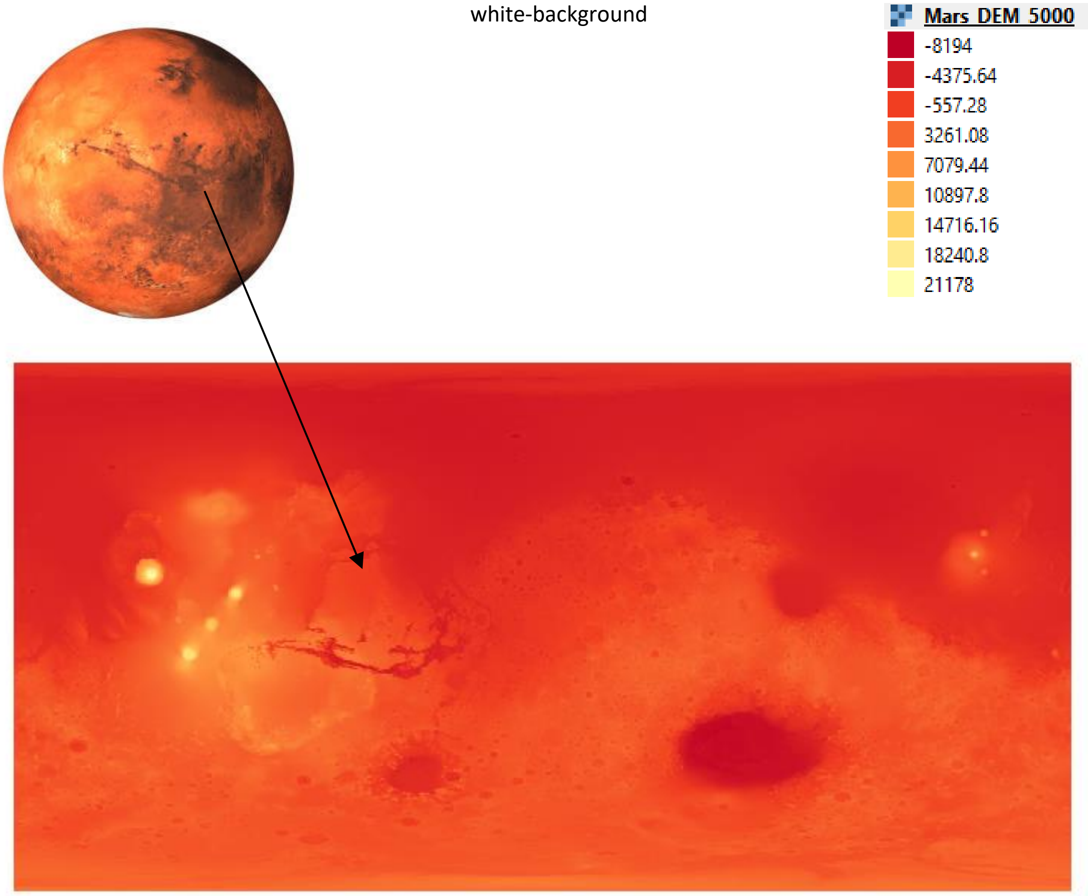


Figure 9: Map surface in reality and as a projected map

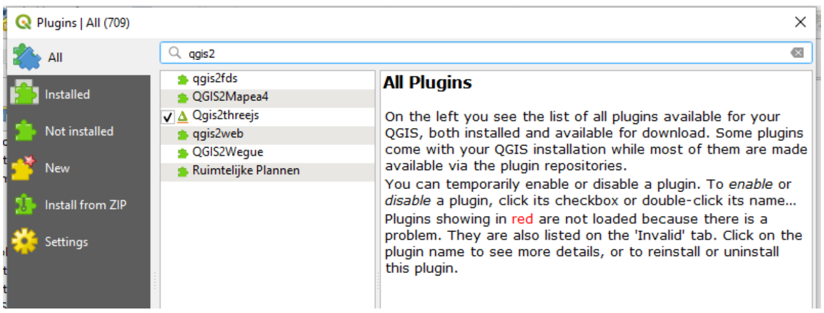
Part 3 – Install new Plugins:

To begin using plugins, you need to know how to download, install and activate them (Figure 6). To do this, you will learn how to use the **Plugin Installer** and **Plugin Manager.** But what a Plugin is?

Plugins in QGIS add useful features to the software. Plugins are written by QGIS developers and other independent users who want to extend the core functionality of the software. These plugins are made available in QGIS for all the users (Source: QGIS Tutorials).

Install **qgis2threejs** plugin:

Plug-ins > Manage and Install Plugins > See the image below and Figure 10.



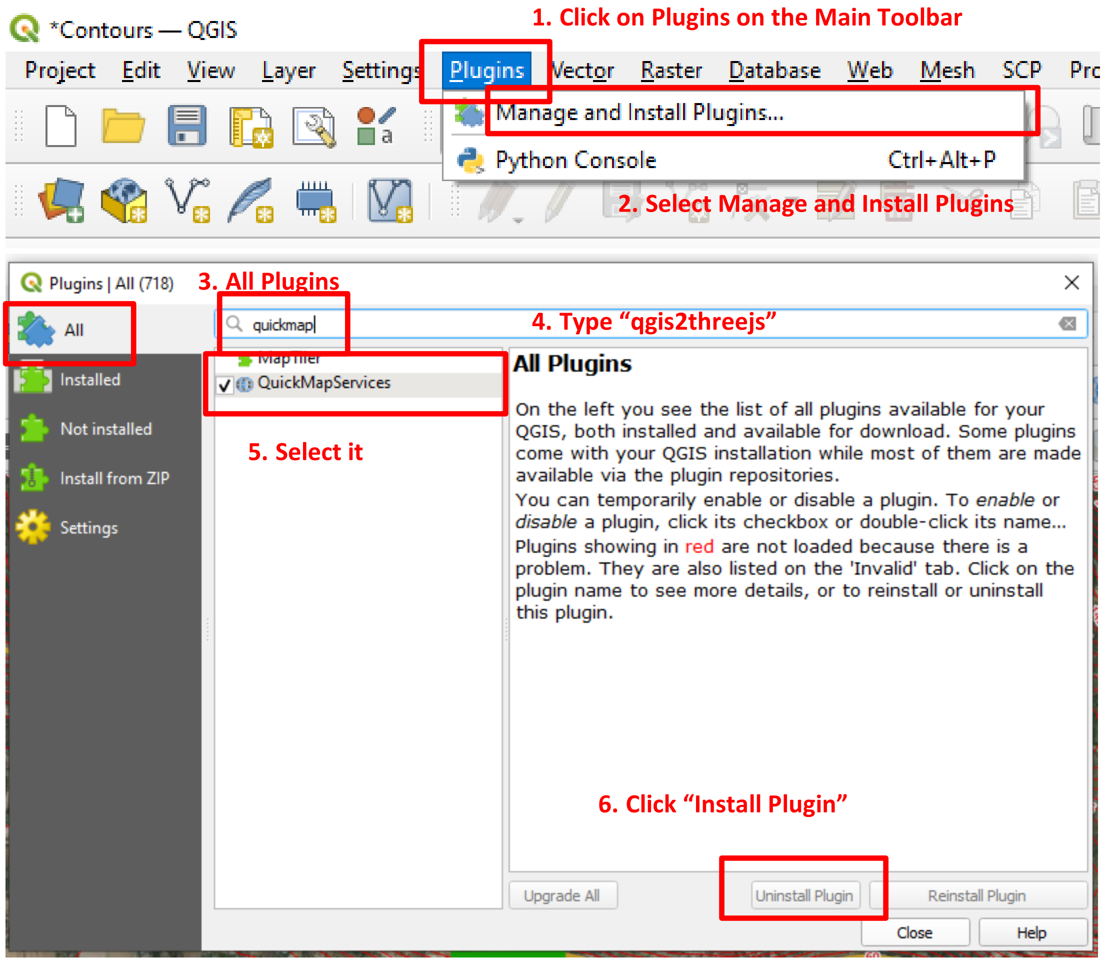
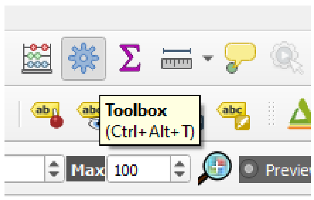


Figure 10: Plugin Management window

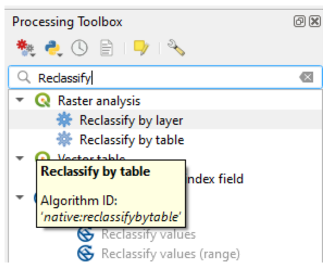
Part 4 - Mars DEM Reclassify heights:

Reclassify DEM heights using "Reclassify by Table" tool:

Click on the Processing Toolbox icon



On the Processing Toolbox window on the right, type "Reclassify" and select the Reclassify by Table tool.



On the ***Reclassify by Table*** window select as raster layer > Mars_DEM_5000

Click on the Reclassification Table and insert the criteria of **Figure 11**

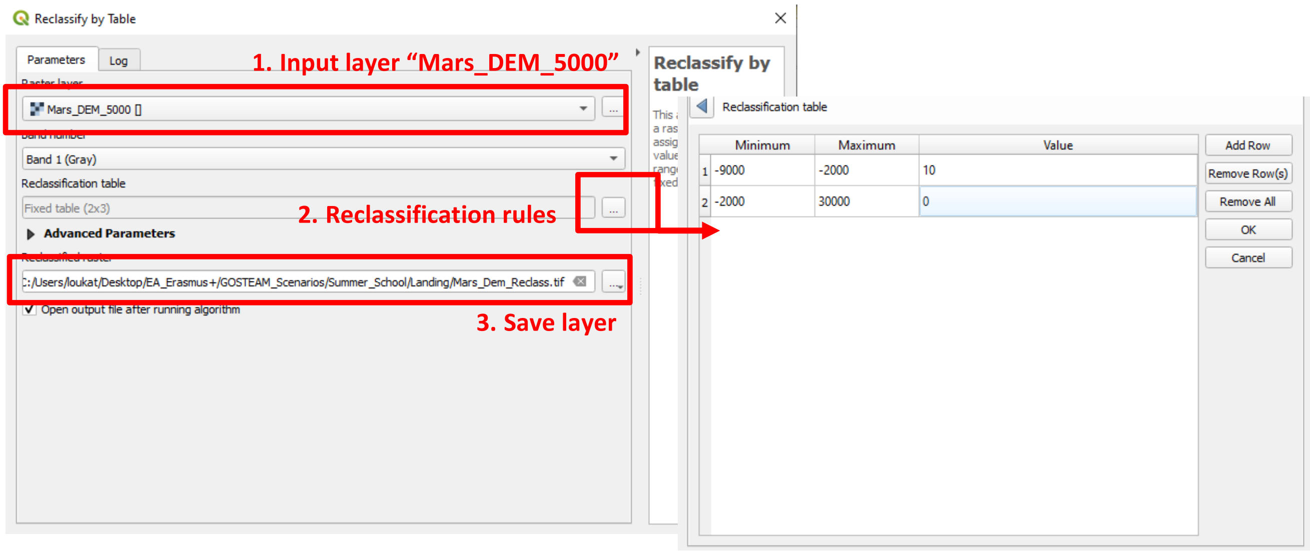


Figure 11: Reclassify by Table window

Mars DEM Reclassify Results:

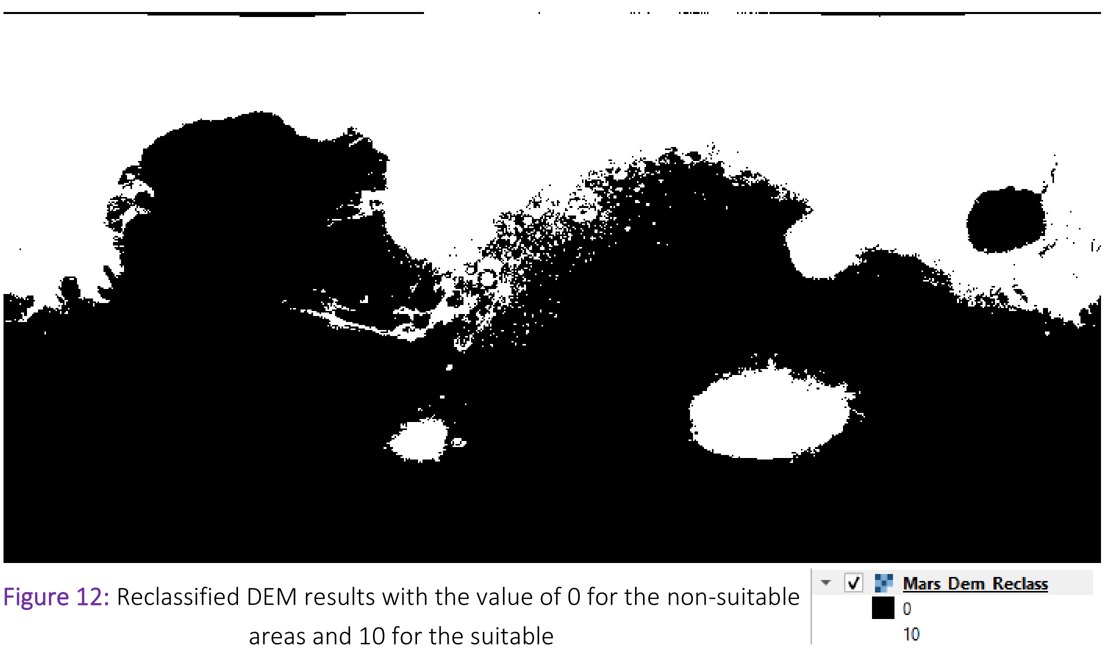


Figure 12: Reclassified DEM results with the value of 0 for the non-suitable areas and 10 for the suitable

Figure 12 presents the results of the reclassified DEM values. At this point you can ask from students to connect the values of the reclassified raster (0,10) with the Table they used in the Reclassify by Table tool (**Figure 11**).

Part 5 – Estimate Mars Slopes:

Estimate slopes on Mars using Raster Analysis Tools!

Navigate to *Raster > Analysis > Slope (see Figure 14)*

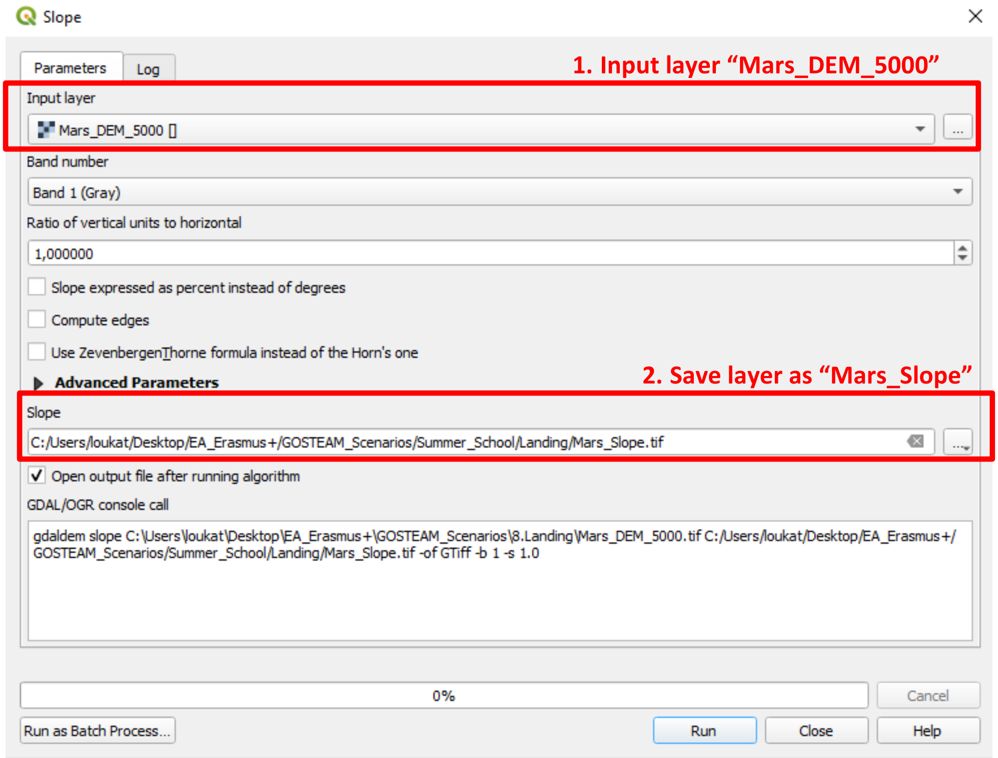
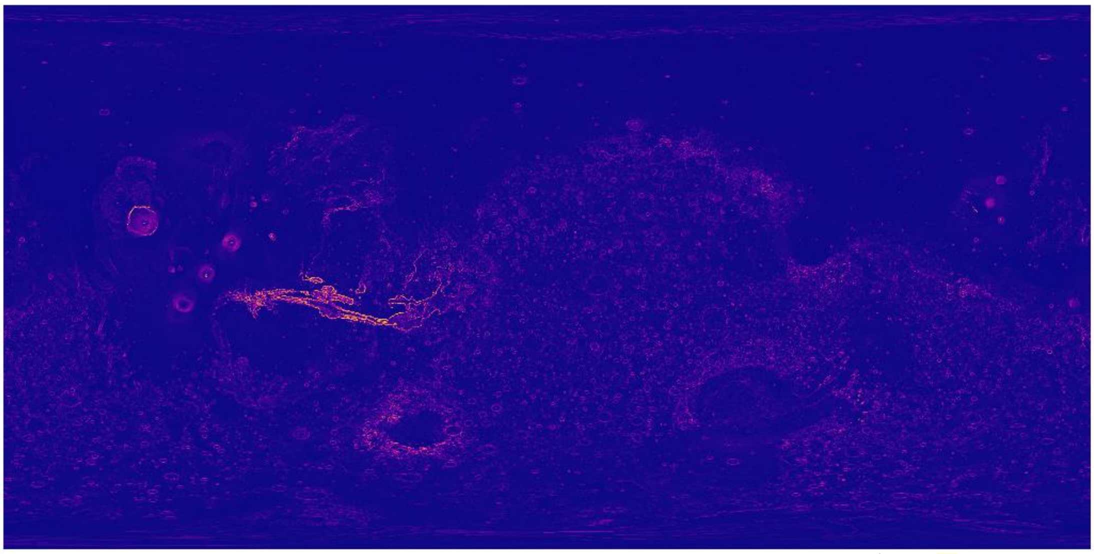


Figure 13: Slope tool parametrization



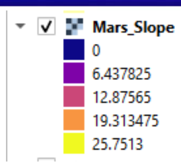


Figure 14: Slope results in the range between 0 – 25.75 degrees

When we estimate the slopes, we look back to the criteria table **(Figure 1)** and we focus on the slopes' threshold values! For instance, we want to identify areas where the slopes are below 2 degrees or 5 degrees etc. To succeed that, we will also reclassify the slopes raster surface (as DEM) using the instructions of **Figure 15**.

Part 6 – Slopes Reclassification:

On the ***Reclassify by Table*** window select as raster layer > Mars_DEM_5000

Click on the Reclassification Table and insert the criteria of **Figure 15/**

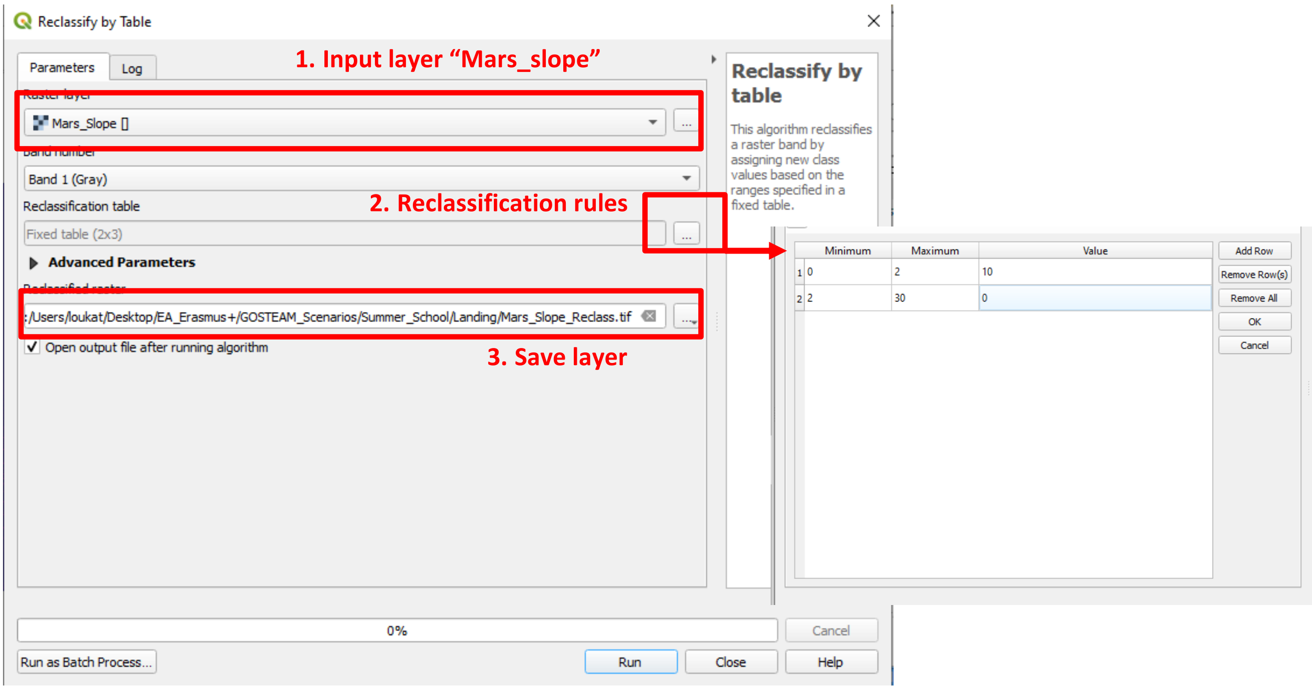


Figure 15: Slopes reclassification tool parametrization

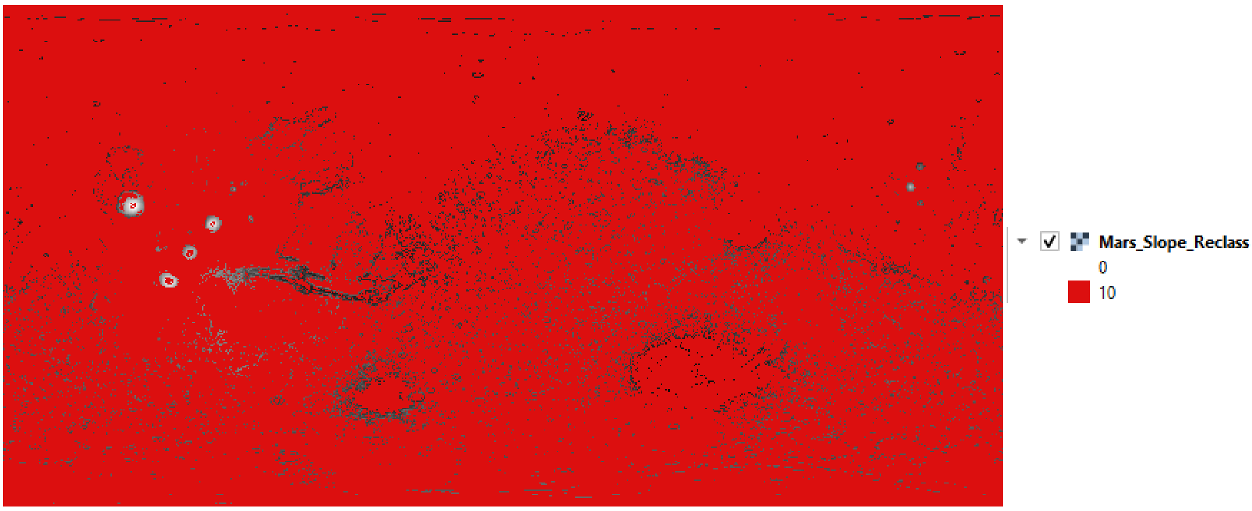


Figure 16: Slopes reclassification resulted map, red areas (suitable 10), blank areas (unsuitable 0)

Now that we have the reclassified areas of the Martian surface, based on the DEM and slopes data, we can overlay the results and identify an optimal area that meets all of the criteria of Figure 1 (considering also the albedo, thermal inertia and rock abundance maps)!

Step 7 - Dem and Slope overlay:

Actually, we are searching for areas that lay within both the red and the blue colors (areas that meet the reclassification rules with a value of 10 as suitable).

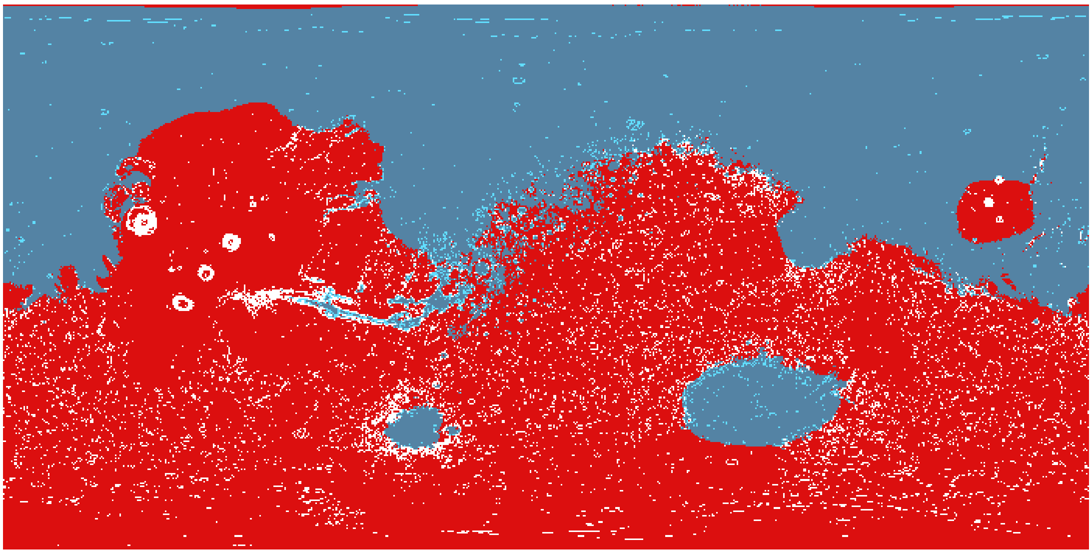


Figure 17: DEM and Slopes overlay

Final steps consist of selecting and "cutting" one specific area that we consider as the optimal one!

Part 8 (Create Mask Layer) Next step consists of cutting/clipping a specific area of interest; thus, we must create a new empty shapefile layer and create a polygon mask!

Why? To differentiate students' results and trigger their interest upon different areas!

Create an empty polygon shapefile and edit an area you consider as the most suitable as illustrated in Figure 18.

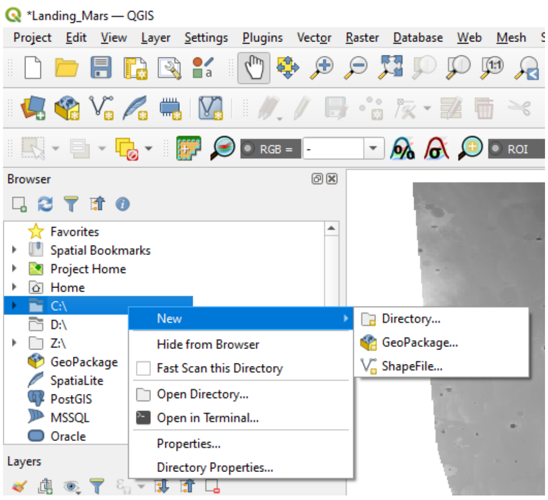


Figure 18: Create a new empty shapefile

After selecting to create a new Shapefile the following window will appear (Figure 19).

All you have to do is to select a path to save your new file (save as *Mask.shp*), to set the shapefile geometry type (polygon) and finally, to select the appropriate coordinate system.

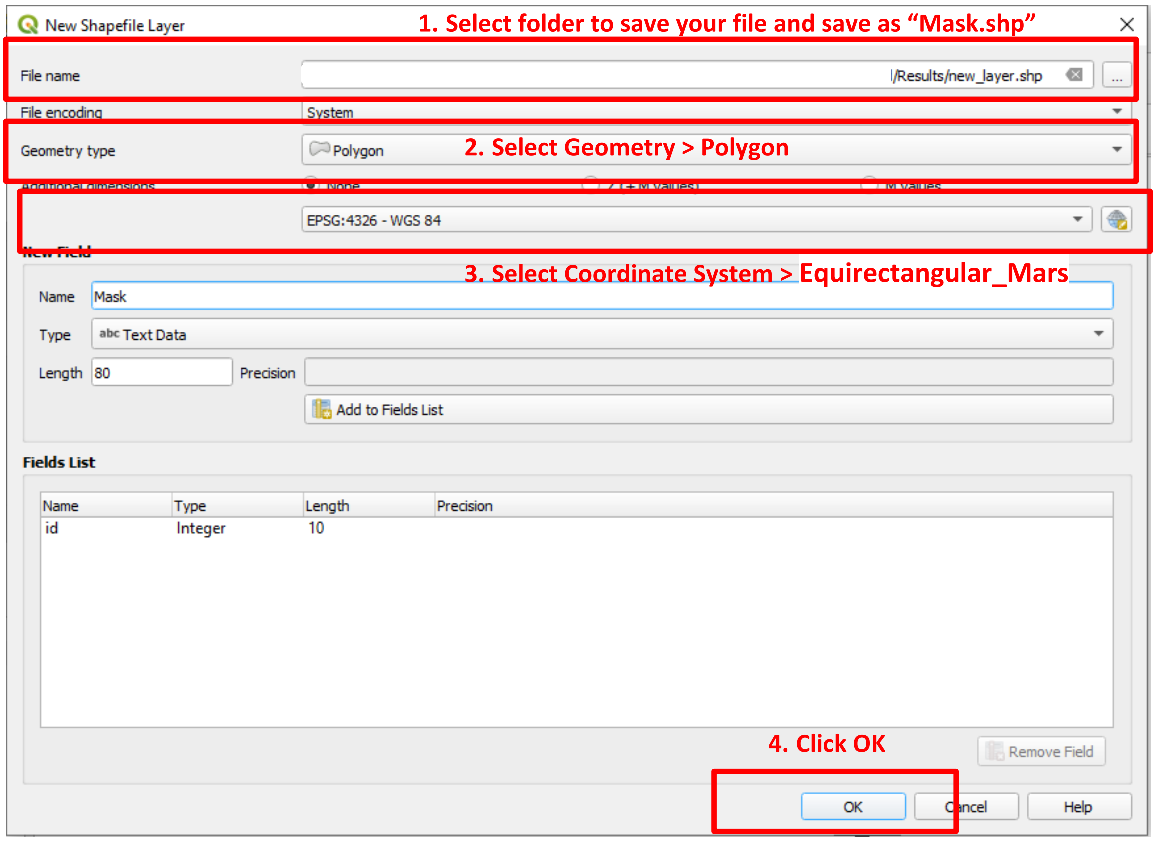
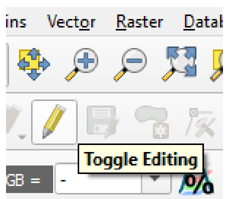


Figure 19: Create a new empty shapefile window

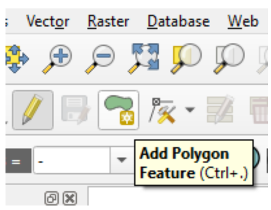
Part 9 – Edit/Digitize your optimal area as Polygon

Load your new empty shapefile (Mask.shp)

Select the new layer on the Layers menu and click on "Toggle Editing".



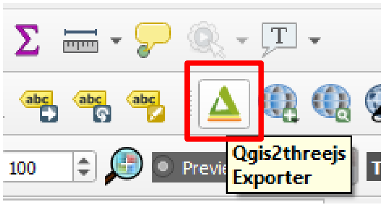
Click on "Add Polygon" and draw a Polygon that will be used as a Mask.



On your Map screen a cross inside a circle will appear and you can star digitizing your Polygon area. To the final point you edited, press right-click by adding number 1 as the Polygon "id".

Part 10 – Use the qgis2threejs Plugin to extract and visualize in 3D the results

Select the qgis2threejs icon in order to load the plugin window.



Then, the window, as illustrated in Figure 20 will appear!

As you can see on Figure 20, the main drawing window is empty. In order to load and visualize a file, you have to select the file (Mars_DEM_5000) on the left panel!

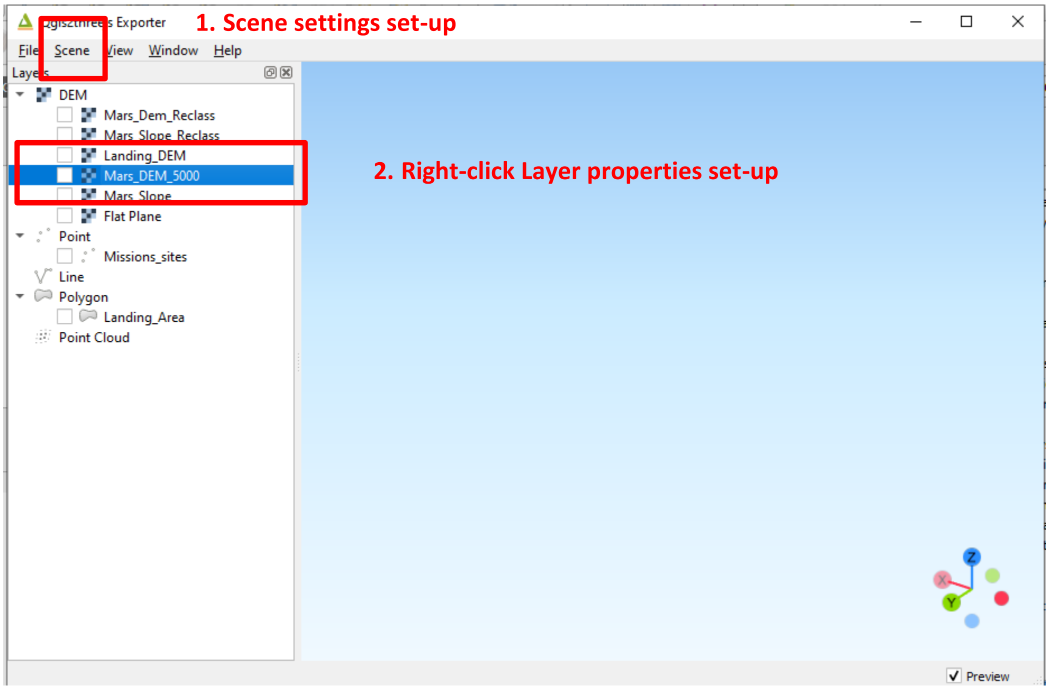


Figure 20: Qgis2threejs interface window

First you can modify the Scene settings!

You can select for the base case scenario the values illustrated on the below Figure, by setting the ***Base width*** and ***Vertical exaggeration*** as 100.

You can always press Apply to all changes you make to see the updated result. Also, you can change the Vertical exaggeration value to 1, 10 and 1000? You can also disable the Outline effect box!

Can you spot the differences and why the Vertical exaggeration value is used for?

See the results in Figure 21!

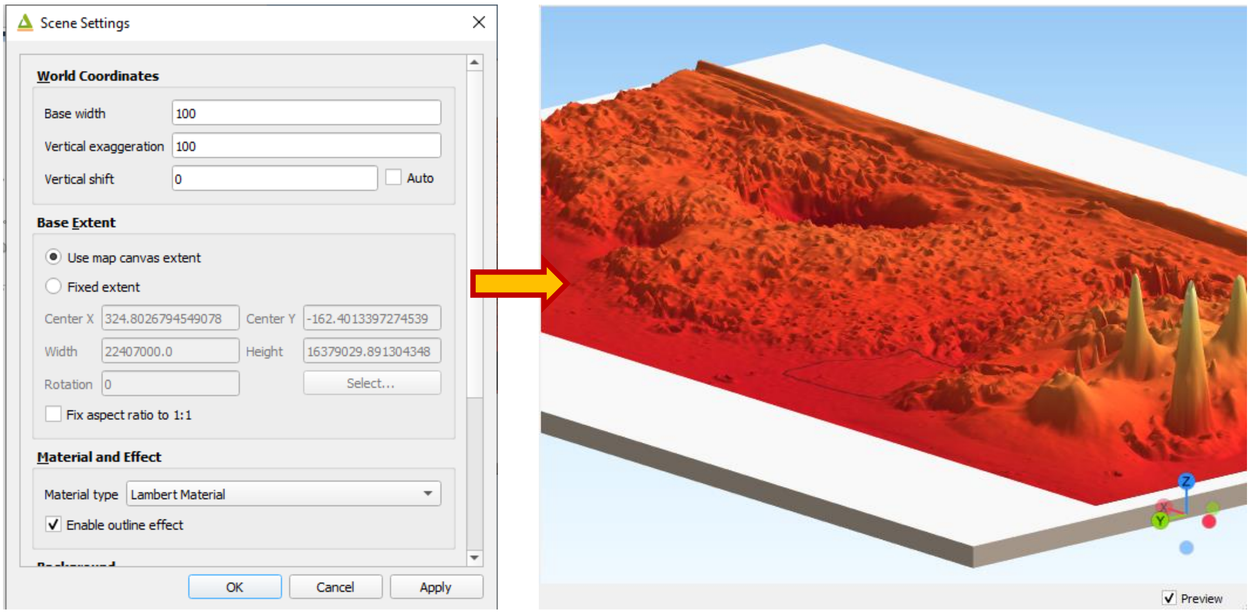


Figure 21: Mars surface visualized using qgis2threejs

Now right-click on the Mars_DEM_5000 layer and a new window will appear as illustrated in Figure 22!

Now you can clip the Martian surface on the polygon extent that you have already created during the previous step!

Use Clip DEM with polygon layer and select "***Apply***". You can also change the ***Resampling level,*** you can click on "***Enable shading***" or modify the ***Other Options*** preferences.

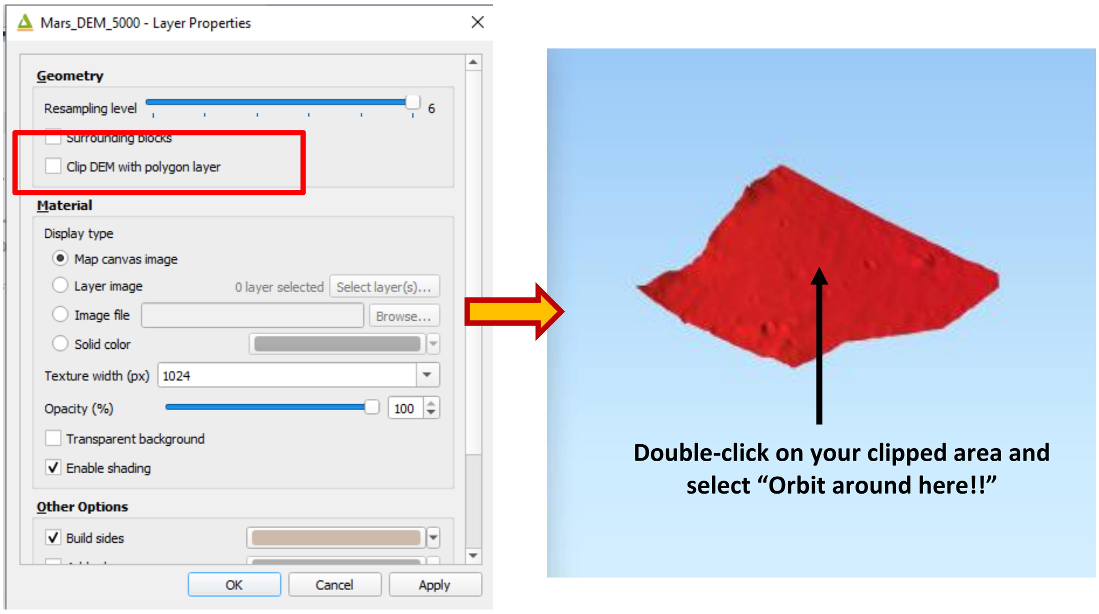


Figure 22: Clipped landing area using qgis2threejs

Inspect the final landing area to see if there are mountains or hills, craters and overall, if it is a flat and safe area for landing!

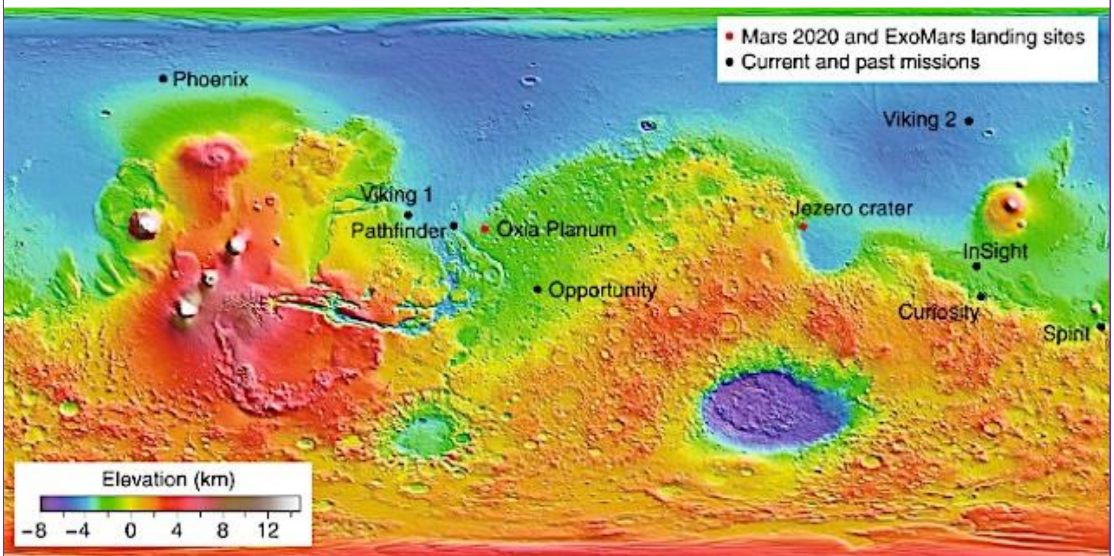
Discussion

Explanation based on evidence

Encourage your students to provide correct explanations for the topic(s) investigated.

Describe ways and they can use to this end and give them directions how to discover them.

Find previous landing sites on Mars (or the Moon) and compare your results.



Source: http://redplanet.asu.edu/?p=33040

- How do you explain the spatial distribution of the landing sites on Mars?
- Can we apply the same procedure for the Lunar surface?
- Which objectives change and what is the purpose of a Lunar Mission?

Consider other explanations

Facilitate the student groups to evaluate their own explanations in the light of alternative explanations, particularly those reflecting scientific understanding. Illustrate examples they can use and give them instructions how to locate them.

Reflection

Communicate explanation

Guide teachers to facilitate each student group to reflect on the previous experiences and to produce a report with its findings, presenting and justifying the proposed explanations to the other groups and the teacher.

Provide content which the teacher can use to help the students to get familiarized and to become efficient in scientific writing.

Students can deliver a short report of previous missions landing sites, the selected criteria for these missions and the objectives.

They can link the criteria with different spatial aspects by reviewing and discussing in parallel the criteria they used, the geophysical characteristics in the landing site they propose etc.

Computer Vision on Mars

Mars Rover movement algorithms

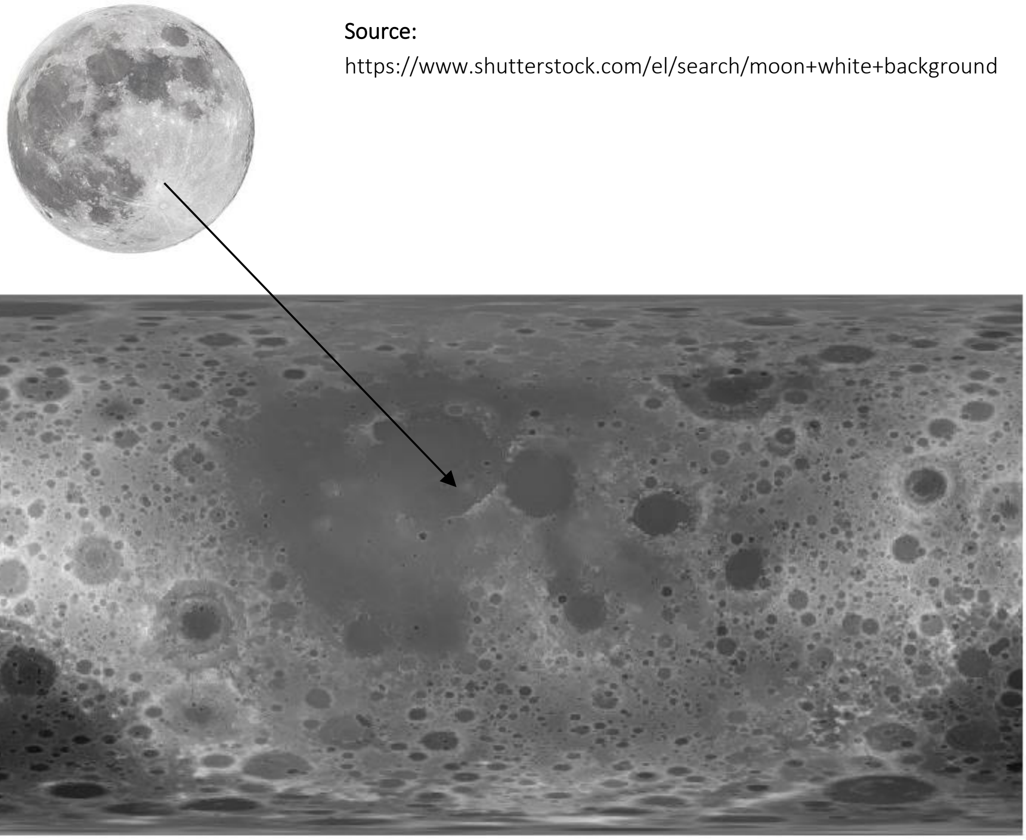
Follow-up activities and materials

Describe and direct the user to any follow-up activities or materials that can be used to wrap-up the hands-on activity.

These could include appropriate learning assessment and/or reminder materials (e.g., quizzes, games, other user-friendly tests), hints for further activities etc.

Moon surface data – DEM:

Source:
https://www.shutterstock.com/el/search/moon+white+background



Sustainable contact

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References (if any):

Assessment (if any):