Generating Least-cost Paths for the Mars Science Laboratory

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MS-GIST Program

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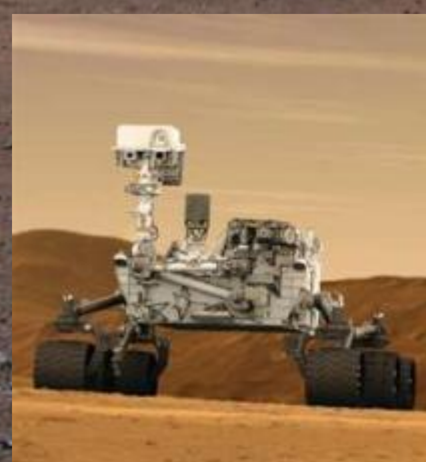


THE UNIVERSITY OF ARIZONA

MS-GIST Geographic Information Systems Technology Degree Program

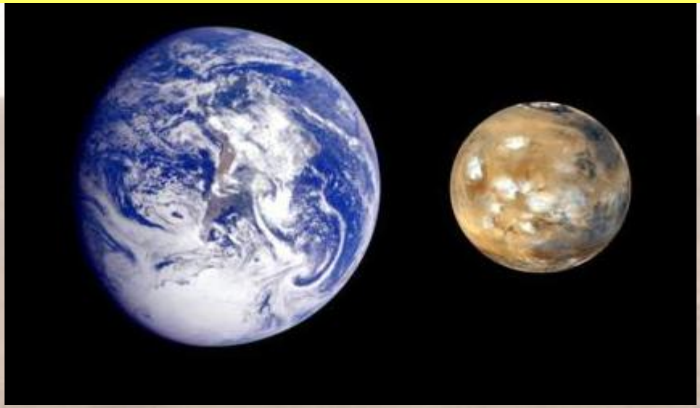
Primary goal of project: Create efficient routes that the Mars Science Laboratory could follow across the Martian terrain

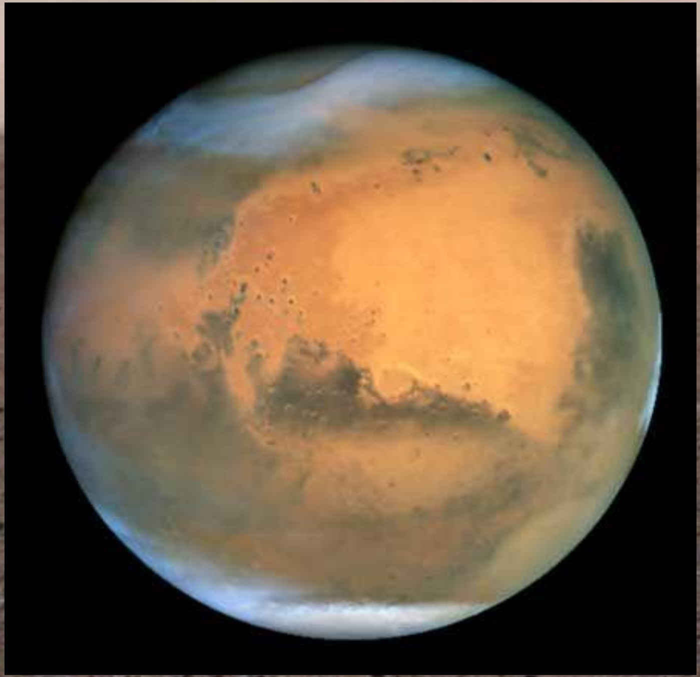
Purpose: Study the geologic features the rover will encounter

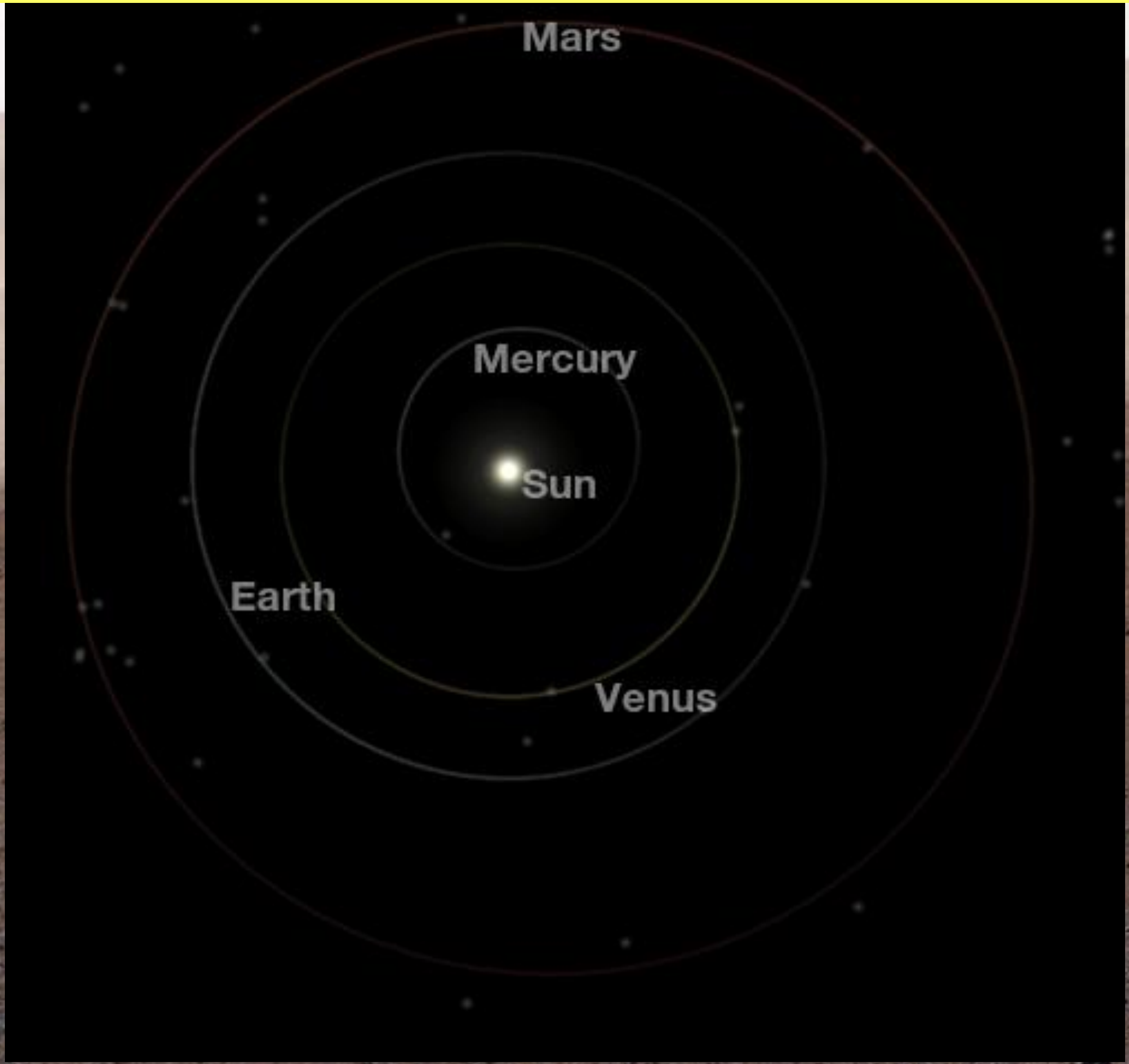
Secondary goal: Get some insight into the challenges faced by planetary scientists

Mars in Context

Mars is about half the diameter of Earth. It's the fourth planet from the sun, it's windy, it's dusty, and it gets colder than Antarctica.







U.S. Mars Exploration History

Flybys

SPACECRAFT	LAUNCH	RESULT
Mariner 3	1964	Failed
Mariner 4	1964	Successful

Orbiters

SPACECRAFT	LAUNCH	RESULT
Mariner 8	1971	Failed
Mariner 9	1971	Successful
Viking 1	1975	Successful
Viking 2	1975	Successful
Mars Observer	1992	Failed
Mars Global Surveyor	1996	Successful
Mars Climate Orbiter	1998	Failed
2001 Mars Odyssey	2001	Successful
Mars Express (U.S./Europe)	2003	Successful
Mars Reconnaissance Orbiter	2005	Successful

U.S. Mars Exploration History

Landers

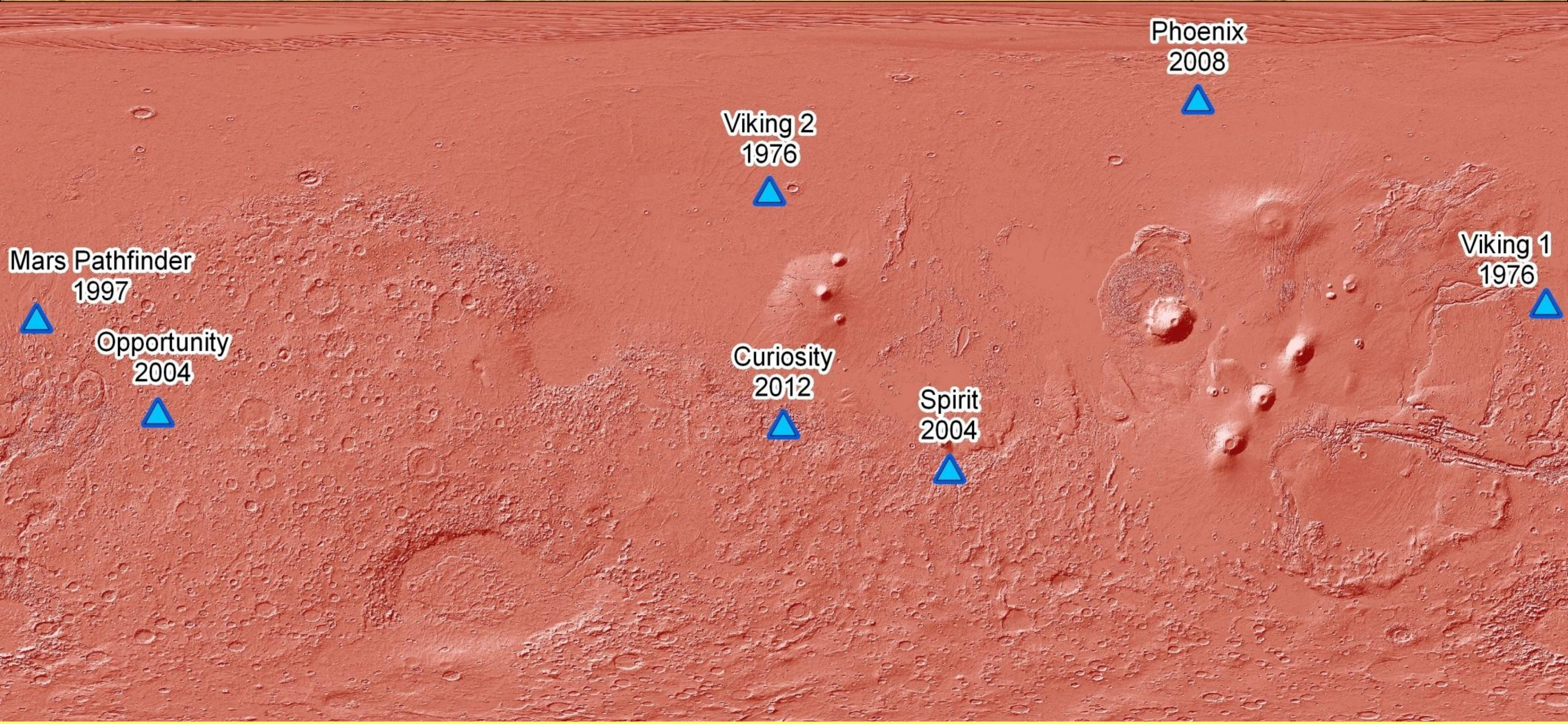
SPACECRAFT	LAUNCH	RESULT
Viking 1	1975	Successful
Viking 2	1975	Successful
Mars Polar Lander	1999	Failed
Phoenix	2007	Successful

Rovers

SPACECRAFT	LAUNCH	RESULT
Mars Pathfinder	1996	Successful
MER "Spirit"	2003	Successful
MER "Opportunity"	2003	Successful
MSL "Curiosity"	2011	Successful

For all the nations of Earth, there have now been 16 successful Mars missions and 24 failures.

Landing Sites

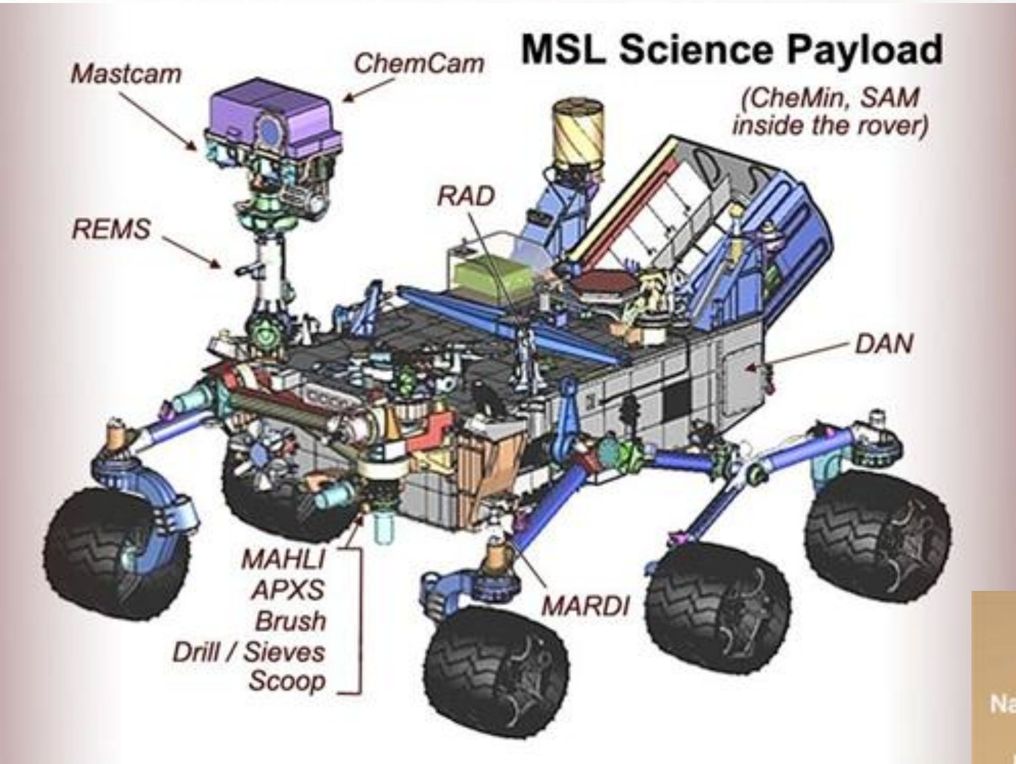


These are the landing locations and images of all of the successful landers and rovers.





Mars Science Laboratory

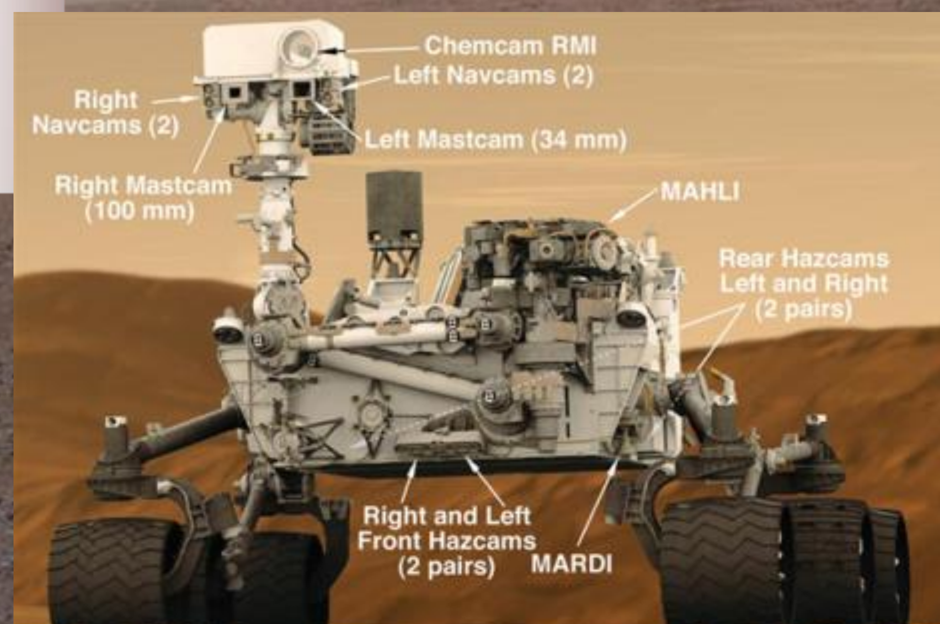


10 Instruments

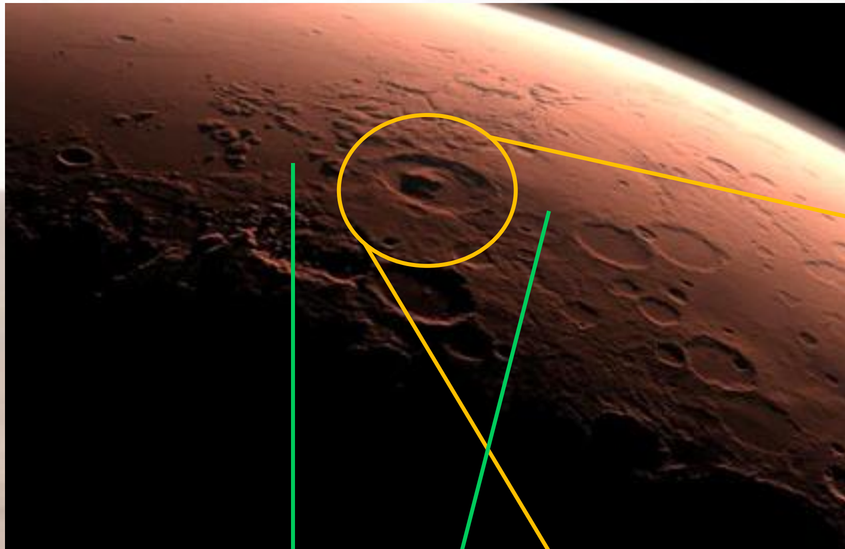
Geology
Geochemistry
Meteorology

17 Cameras

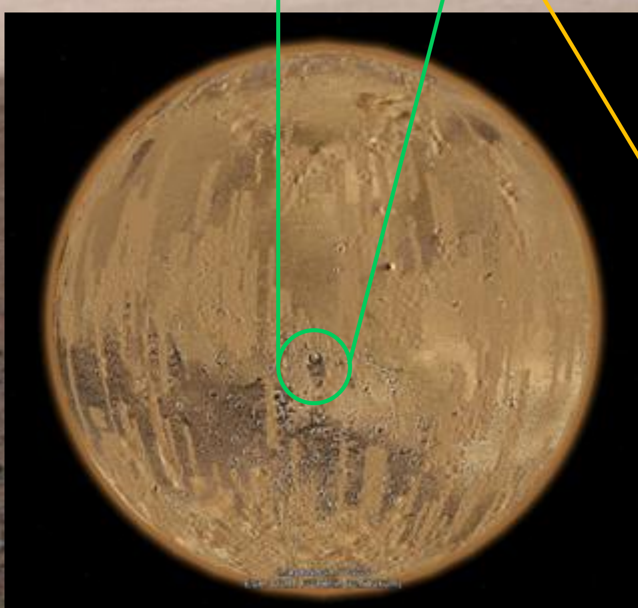
Navigation
Science Investigations

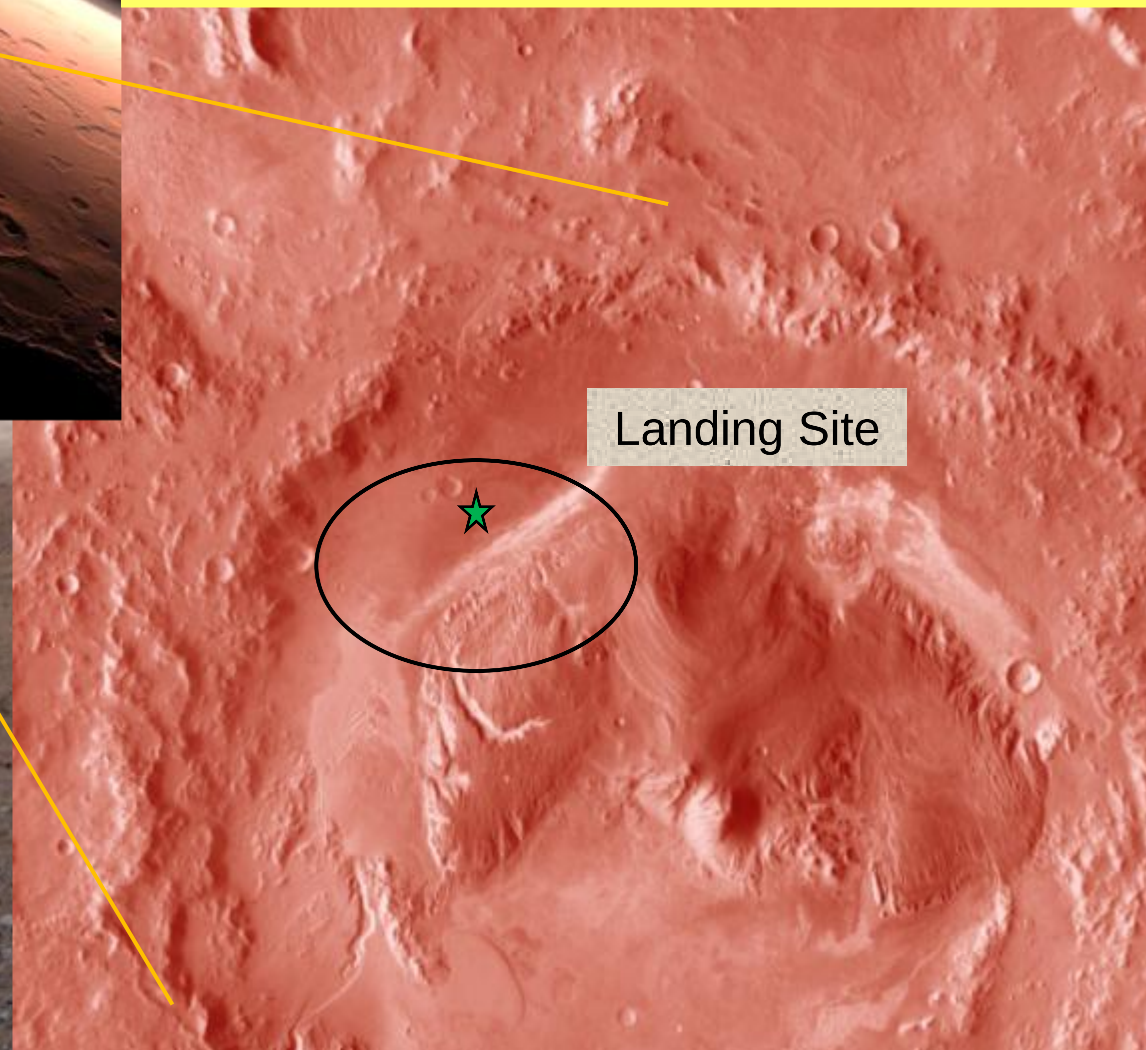


Study Area



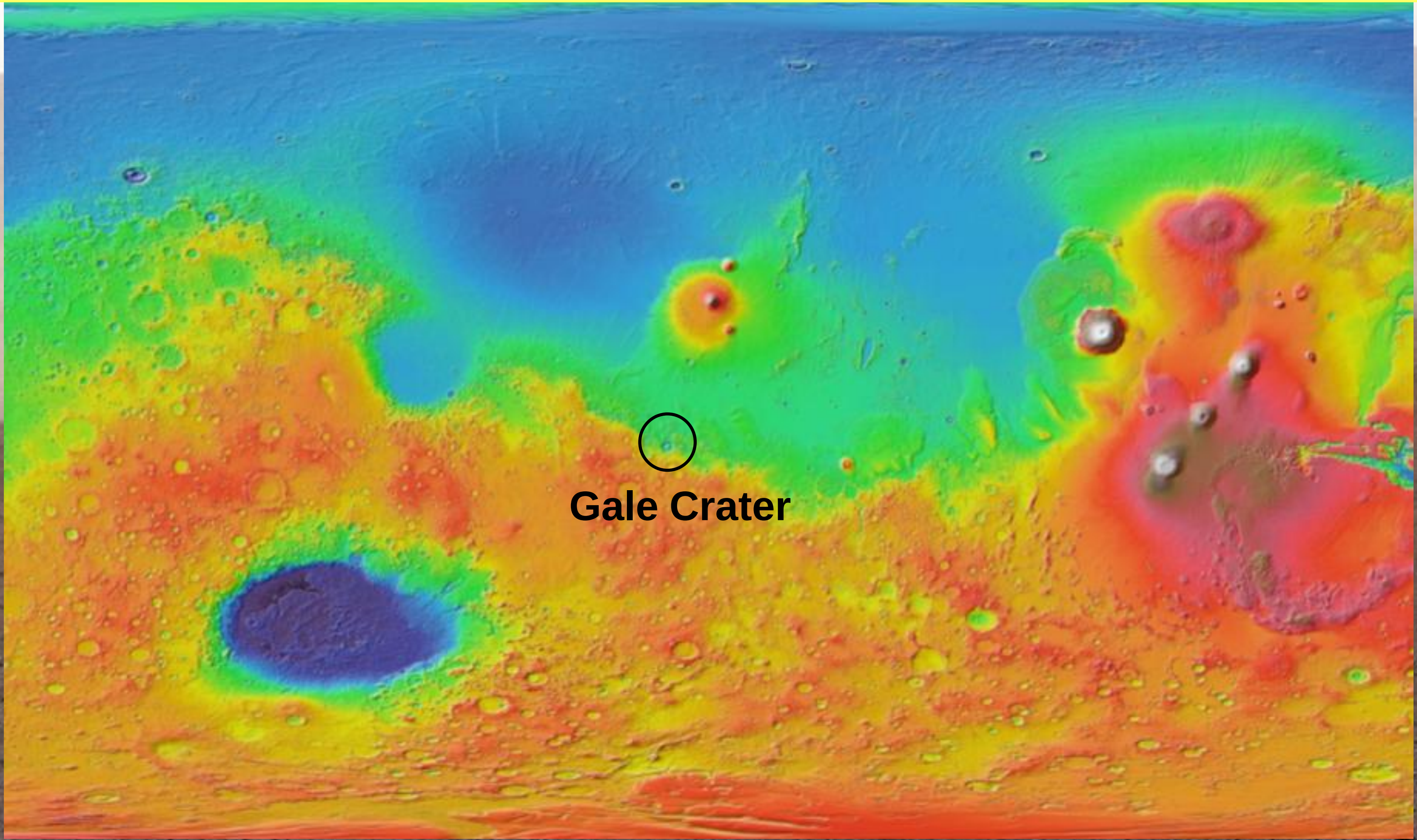
The study area is Gale Crater, which is 96 miles across and which contains a 3-mile-high mound of sediment called Mount Sharp.





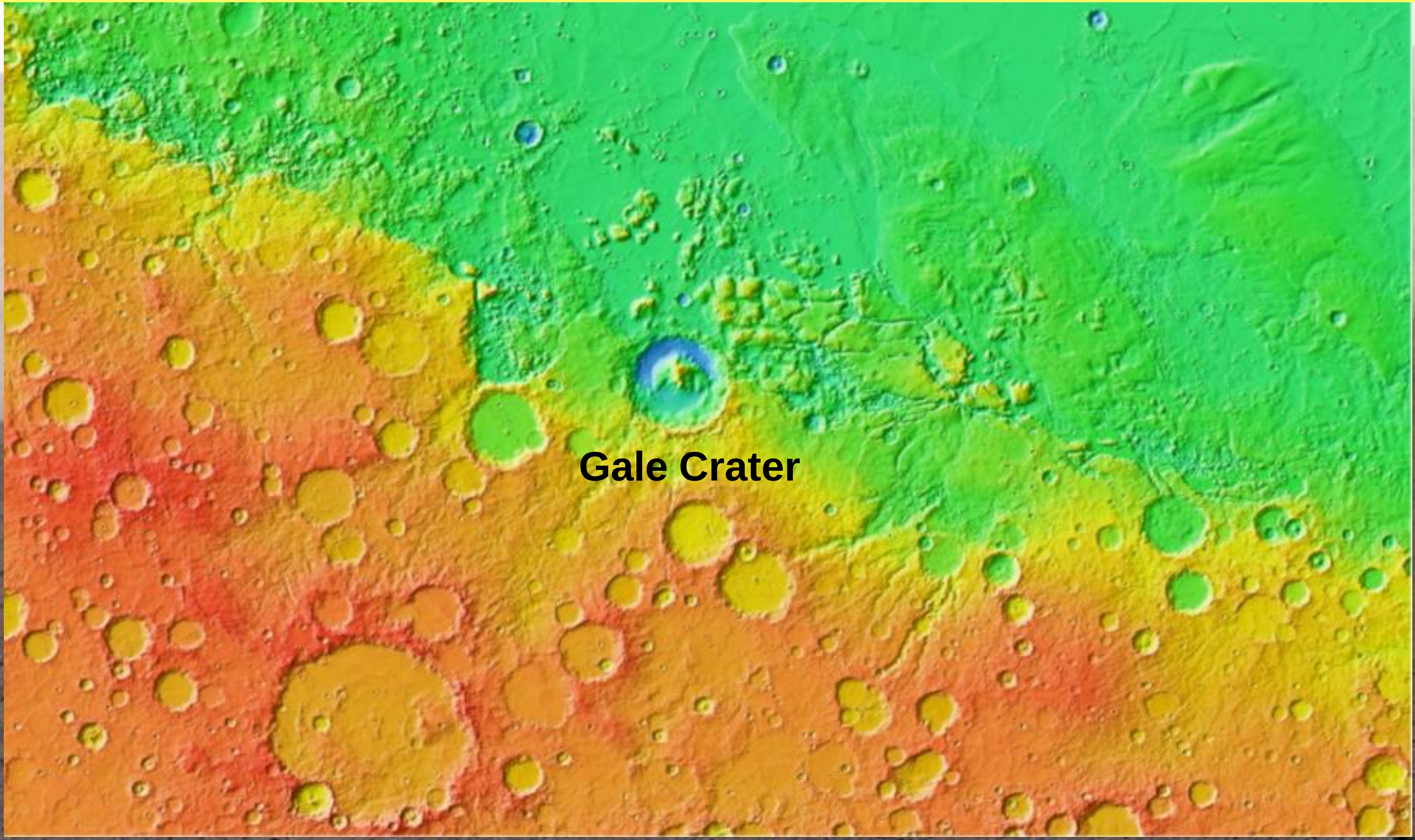
Martian Topography

The southern region of Mars is high in elevation with craters, mountains and volcanoes. The northern region is lower in elevation and very smooth. Gale Crater is in the transition zone between the high and low elevations.



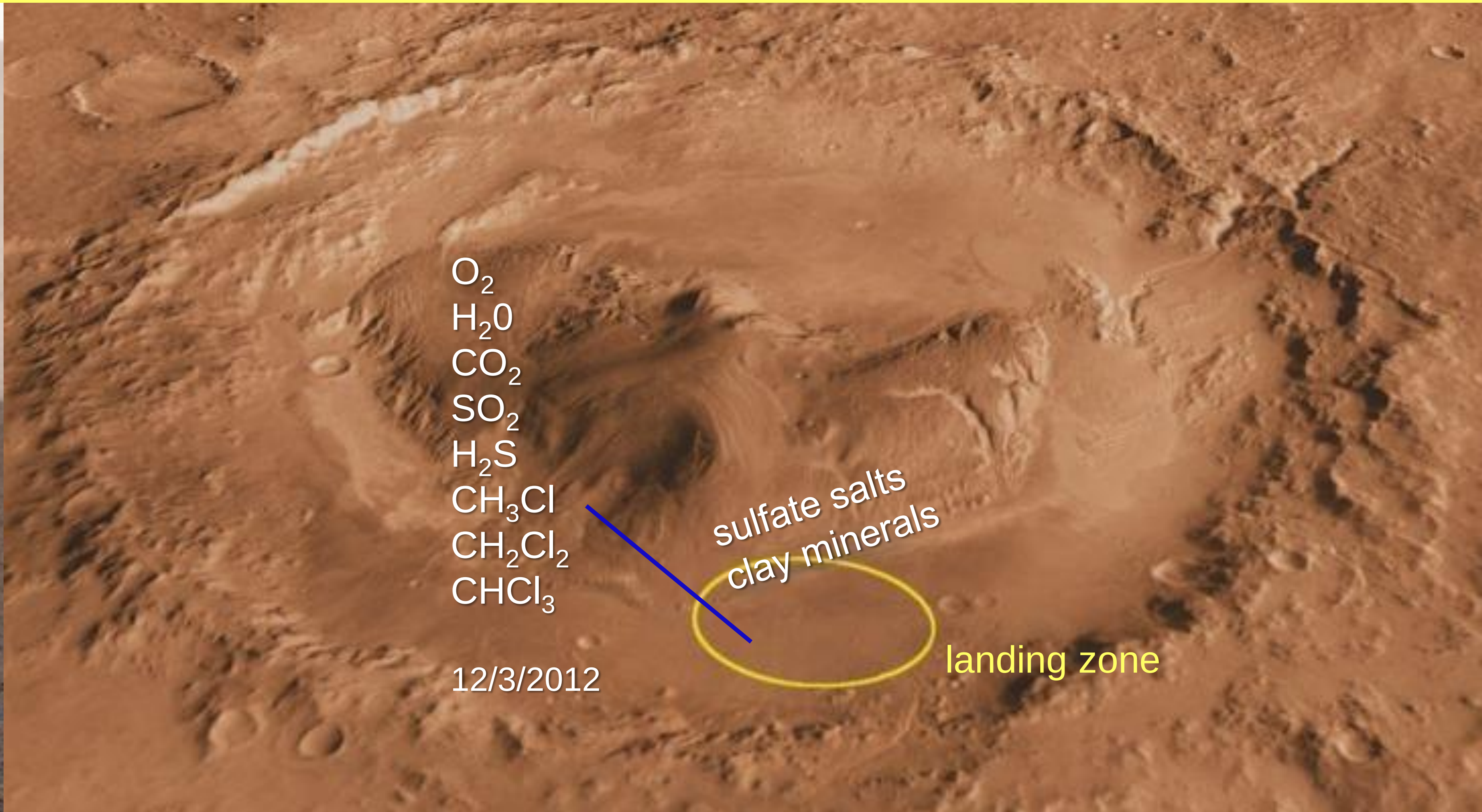
Martian Topography

The crater is on the downhill side of the transition zone. The bottom of the crater is lower in elevation than the surrounding terrain, which makes it an ideal repository for sediment.



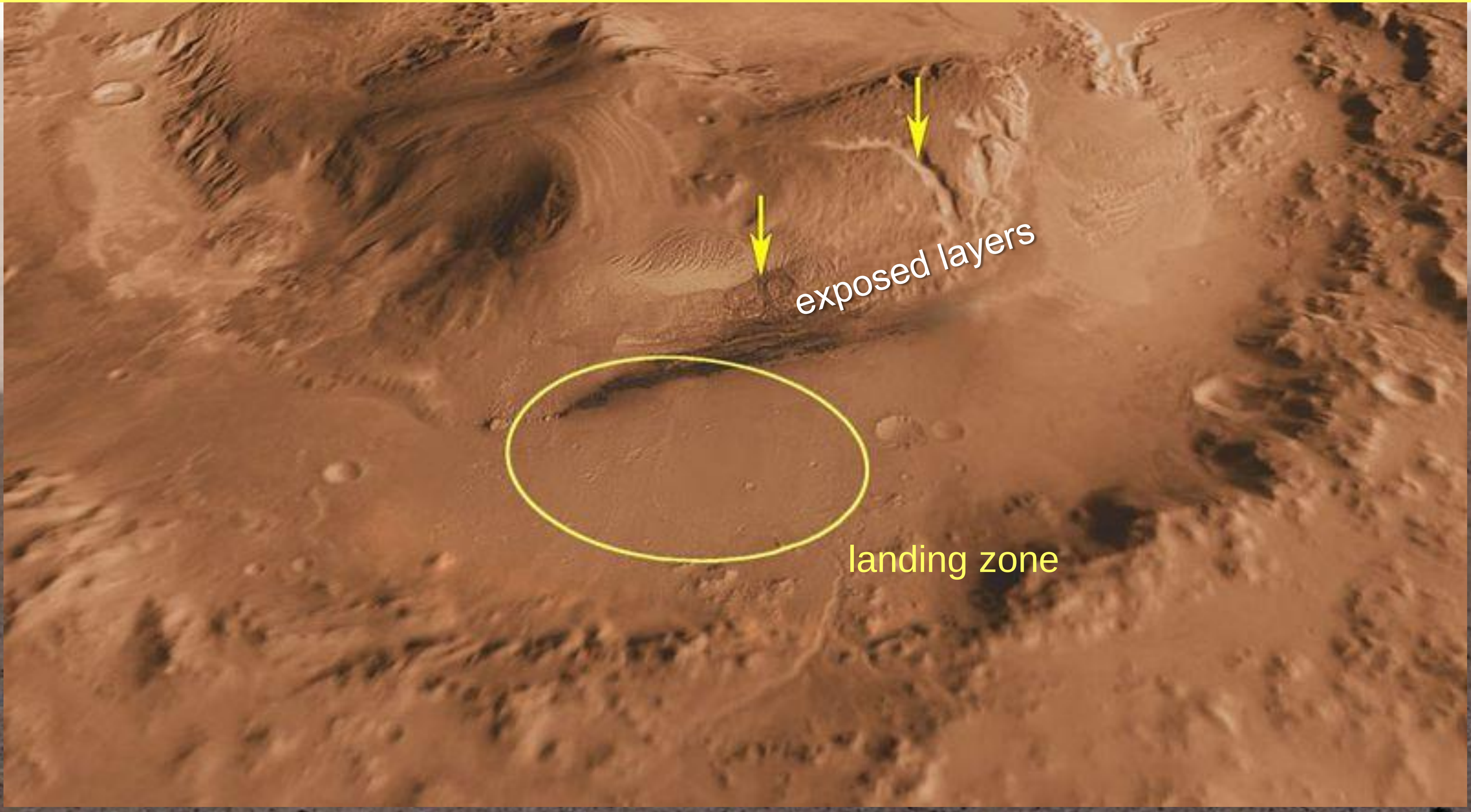
Mount Sharp Mineralogy

At the base of Mount Sharp are layers of clay minerals. Above those are layers of sulfates. Clays and sulfates are formed in the presence of water, which is a major reason why NASA wanted to explore this area.
On December 3rd, 2012, NASA announced the chemical findings of the rover's first soil analysis (listed below).



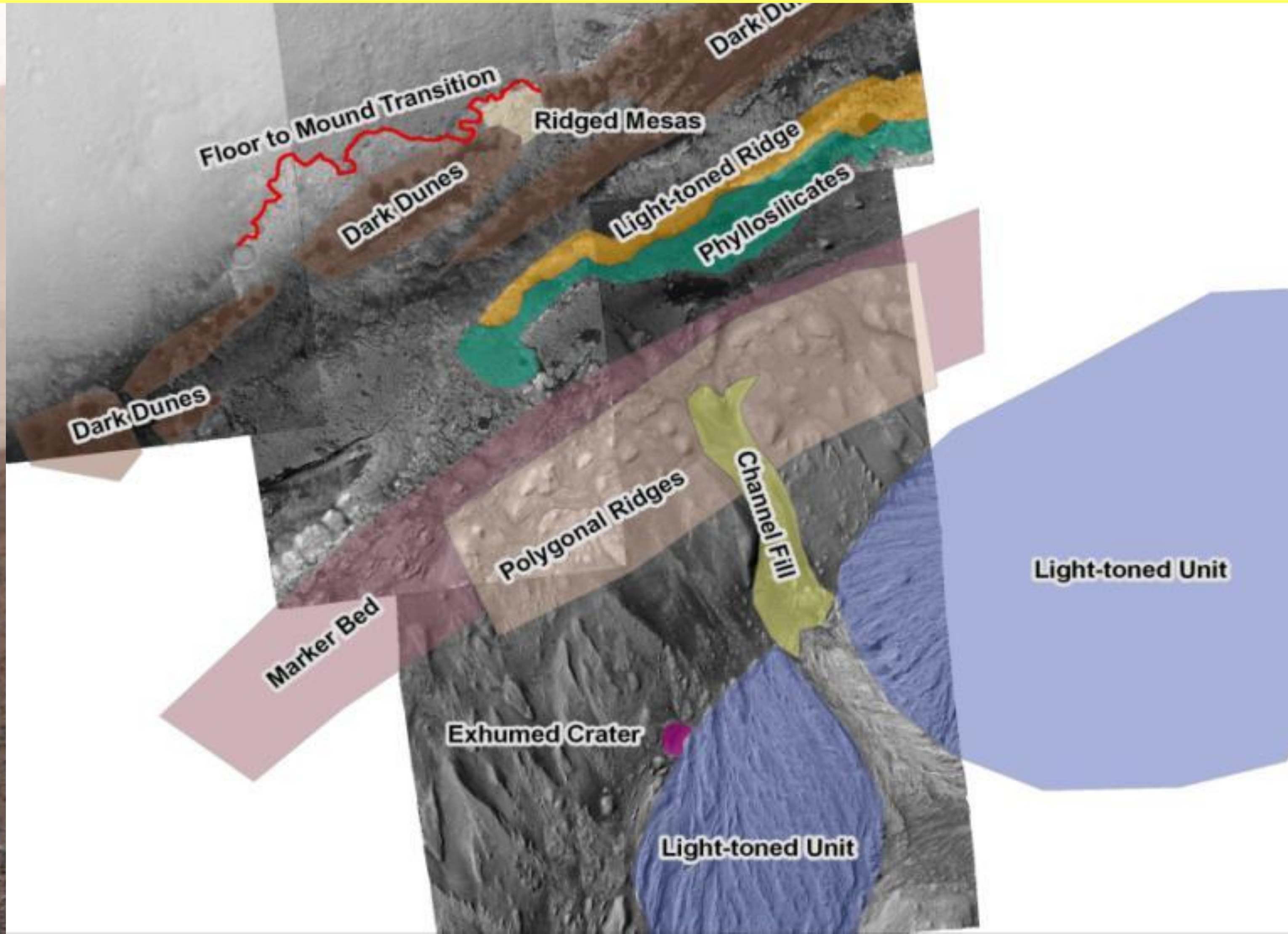
Mount Sharp Canyons

Mount Sharp has two small canyons. These canyons expose depositional layers, just like the Grand Canyon on Earth. In coming years (2016?) the rover will likely be climbing up the smaller canyon on the left. The black material at the foot of the mound is a field of sand dunes.



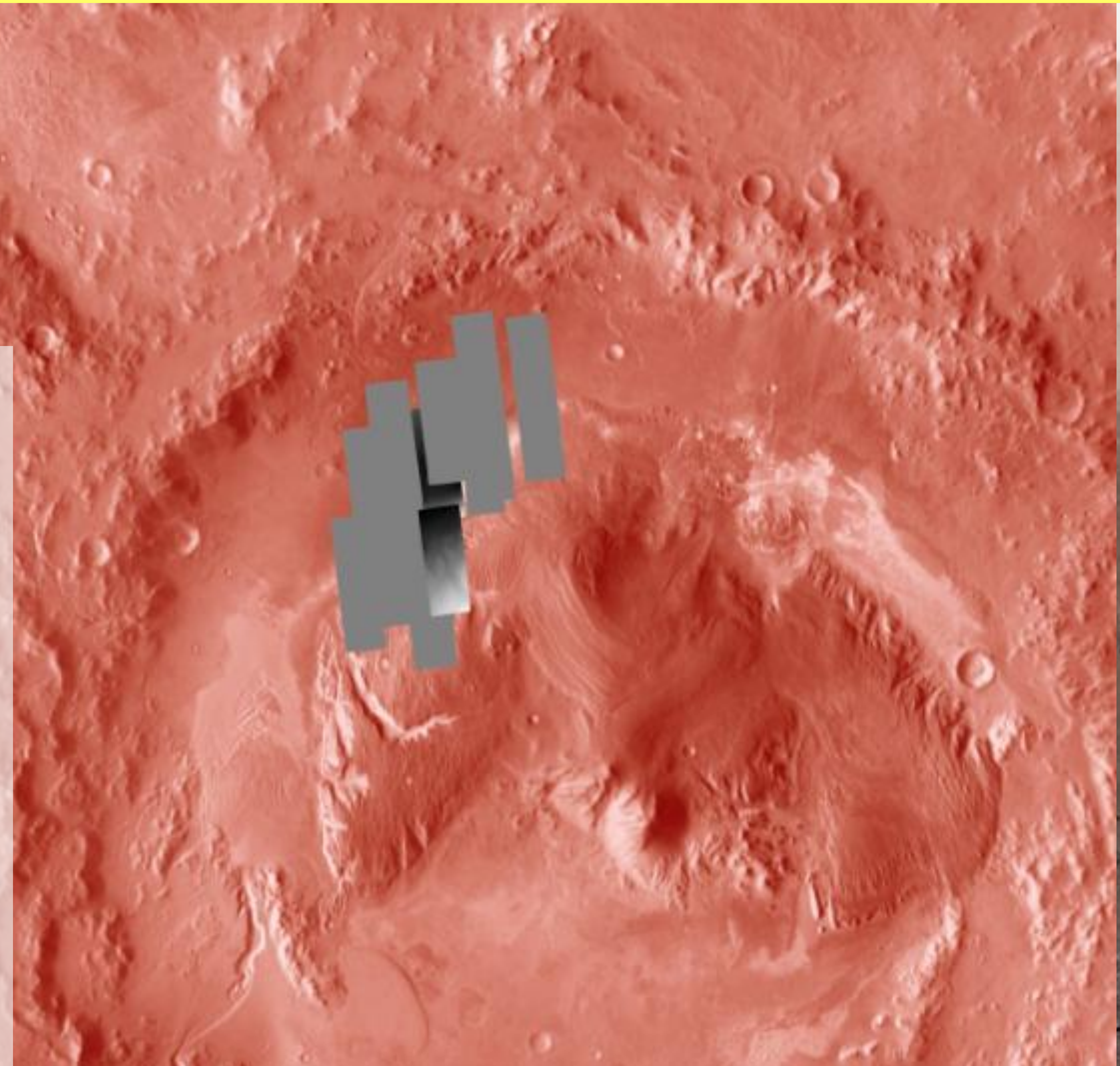
Geological Features

This is what the rover will find when it arrives at the mound: many different types of geological features.
The mission scientists will have many options as to where to send the rover to investigate Mars' history.



DEMs & Orthophotos

The data for this project consisted of high-resolution DEMs and orthophotos. These high-resolution data are only available within the gray rectangular areas.



Orthophotos: 0.5 m resolution
DEMs: 1 m resolution

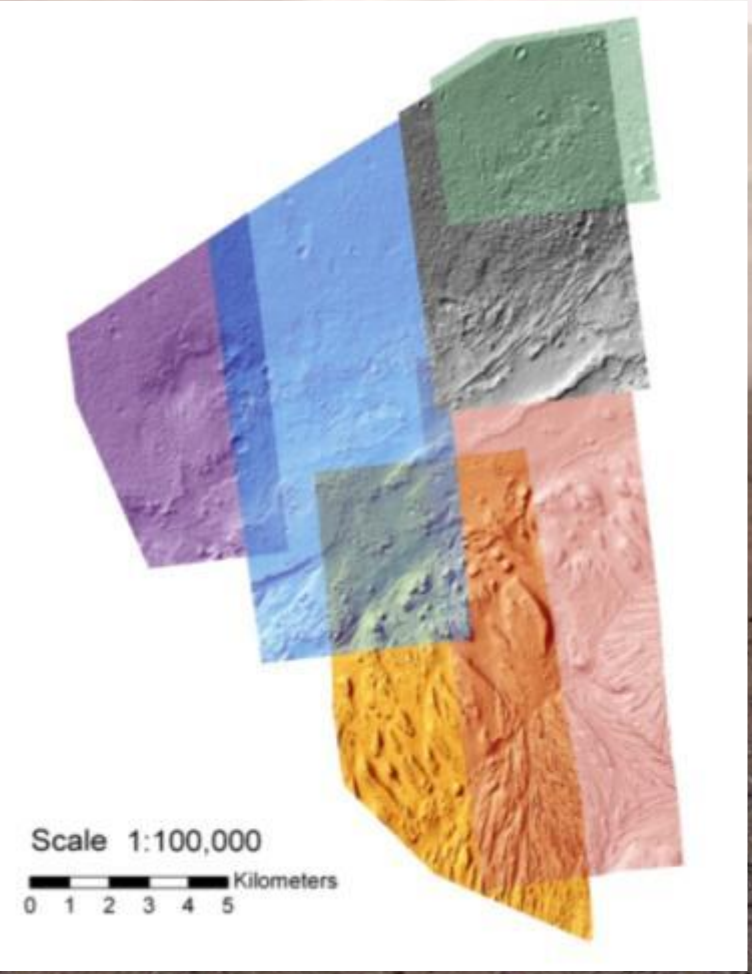
Spacecraft:
Mars Reconnaissance Orbiter

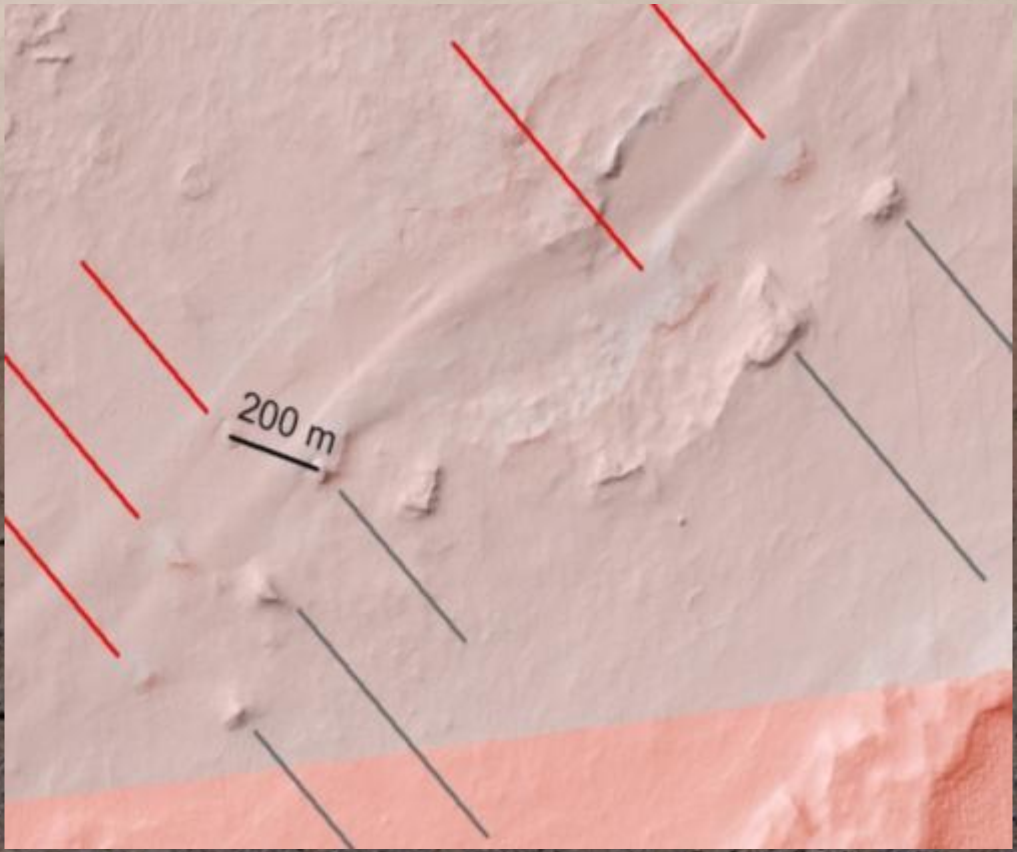
Instrument:
HiRISE (High Resolution Imaging Science Experiment)

Agencies: NASA, JPL, USGS

DEM Overlaps

The DEMs overlapped but they were not spatially aligned. They were off by a few hundred meters.





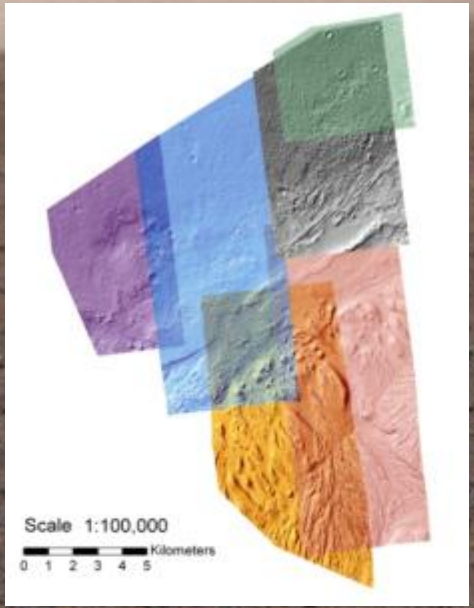
Quandary

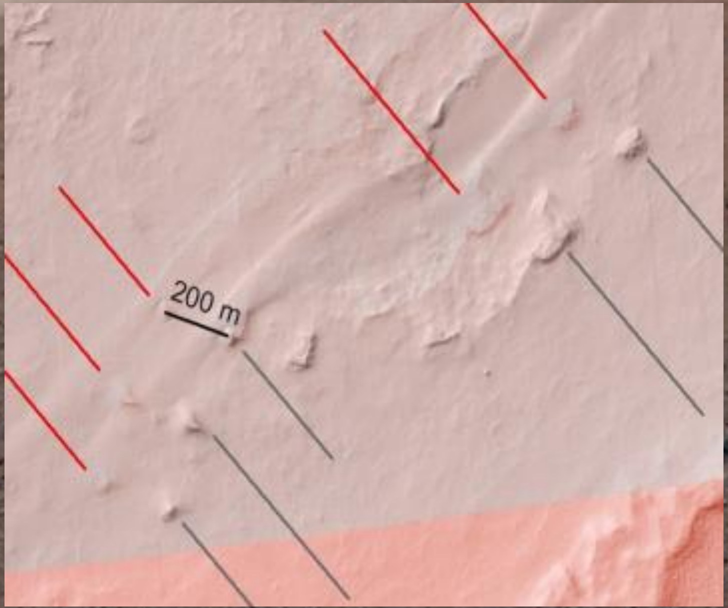
The DEMs had to be adjusted to fit each other, but each alternative presented problems.

Unknown: Offset distances and rotations between DEMs

Shift tool: Needs X & Y offsets, doesn't account for rotation

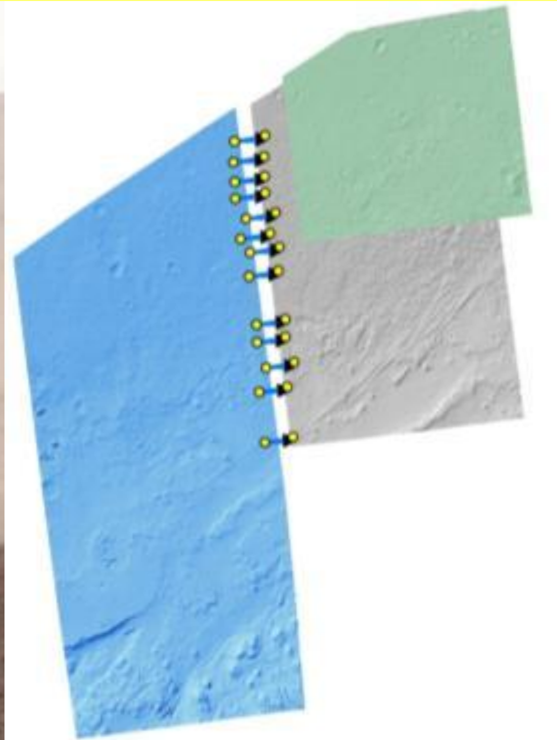
Rubber sheeting: Risk of stretching data & warping terrain



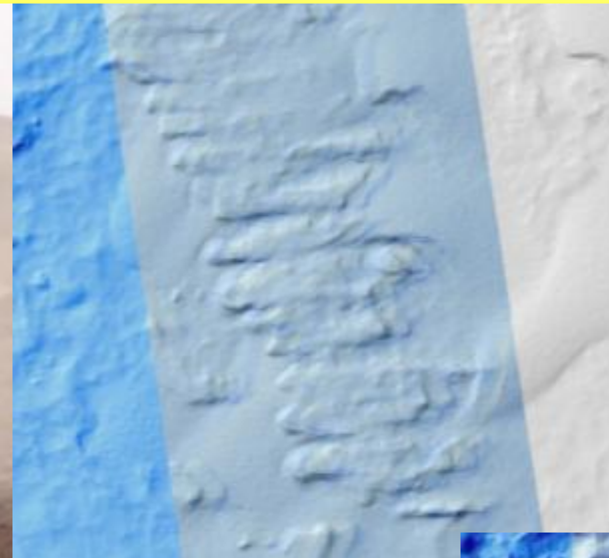


Data Adjustment

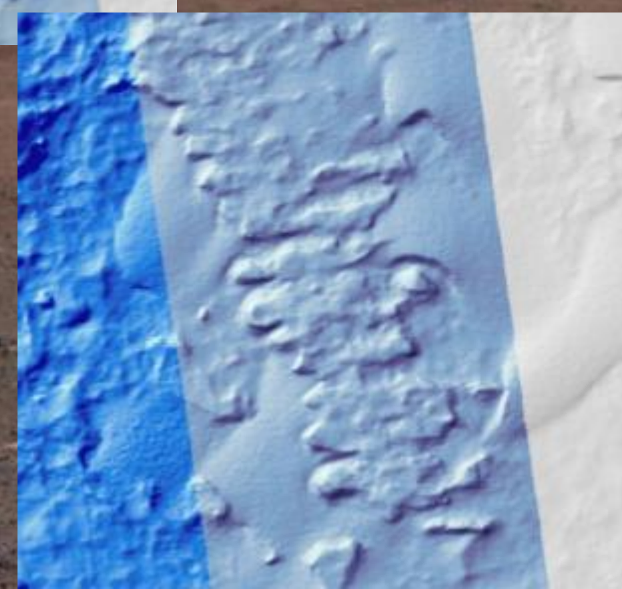
The X-Y shift method didn't result in a good match, but rubber sheeting did. Rubber sheeting was used to adjust the surfaces.



Gap created by shifting gray surface to match green surface



X – Y Shift

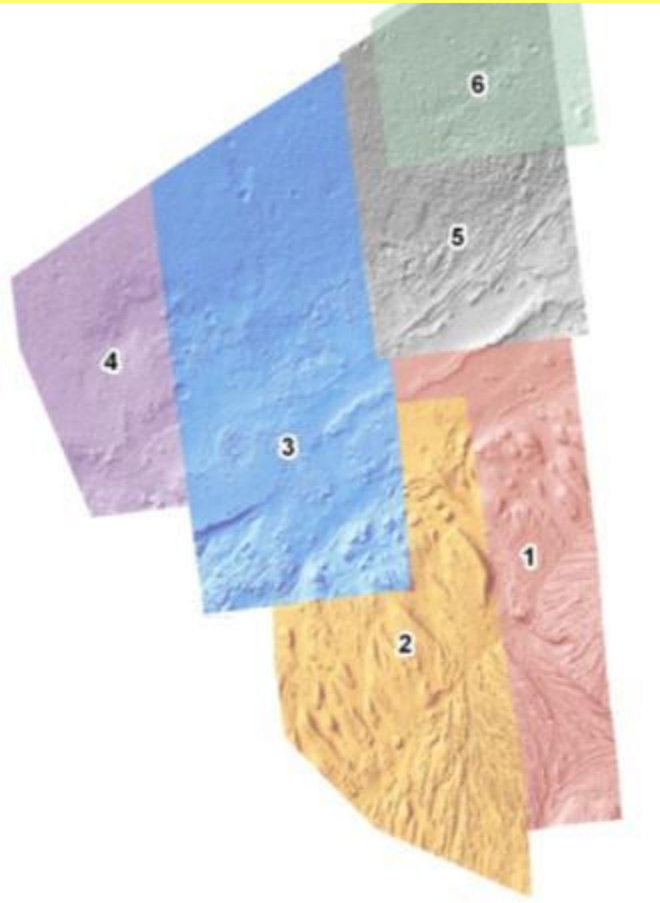


Rubber Sheeting

Appended Surfaces

After adjusting the DEMs, they were appended into a single surface. This was done twice. In the first trial, they were clipped to have an overlap of only 15 meters. In the second trial, no clipping was done. The append order of the second trial is indicated by the numbers in the right-hand image.

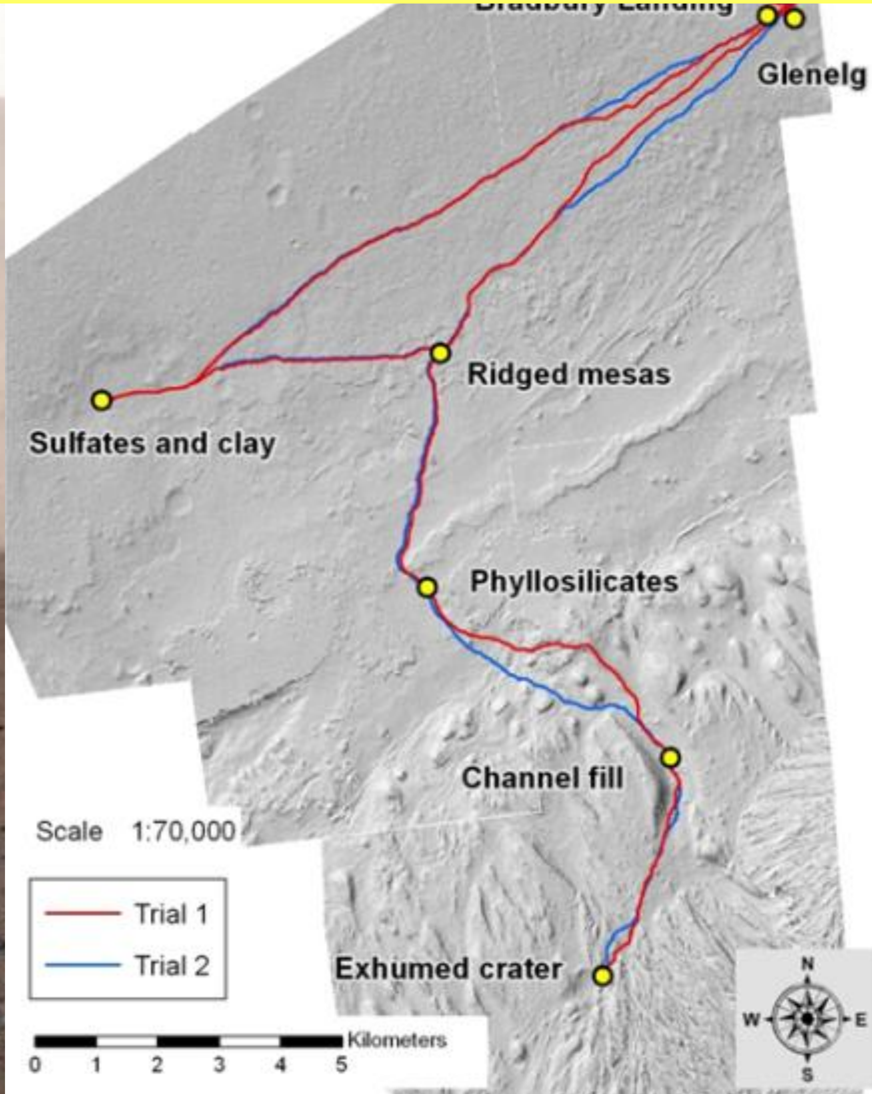
Trial 1: Clipped with 15 m overlaps

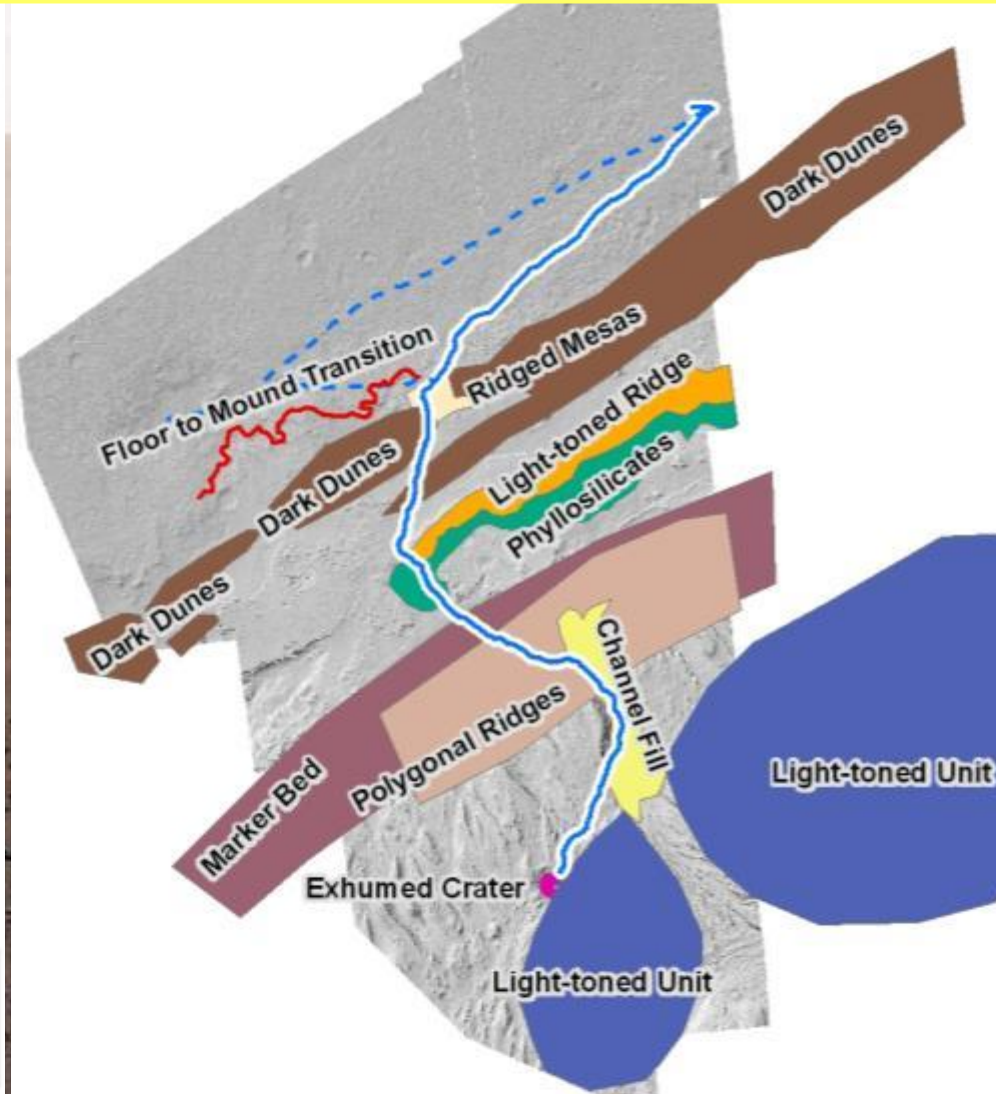


Trial 2: No clipping, unaltered overlaps

Path Results

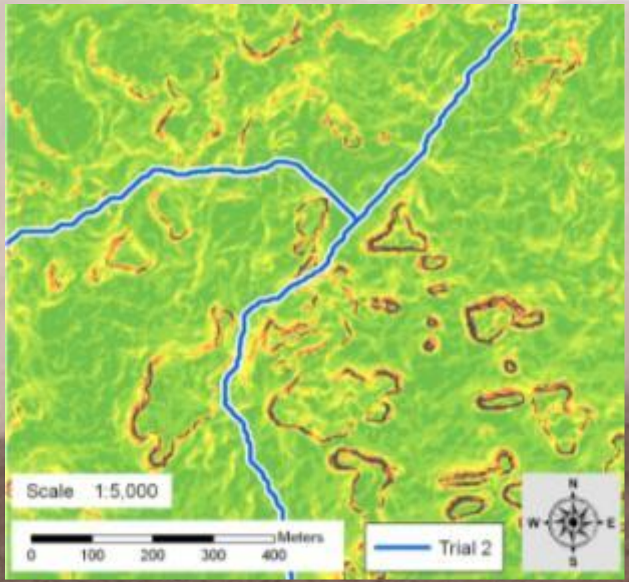
Left: The two surfaces with different overlaps resulted in two different paths (blue and red).
Right: The destination points were chosen so that the paths would intersect the geological features.



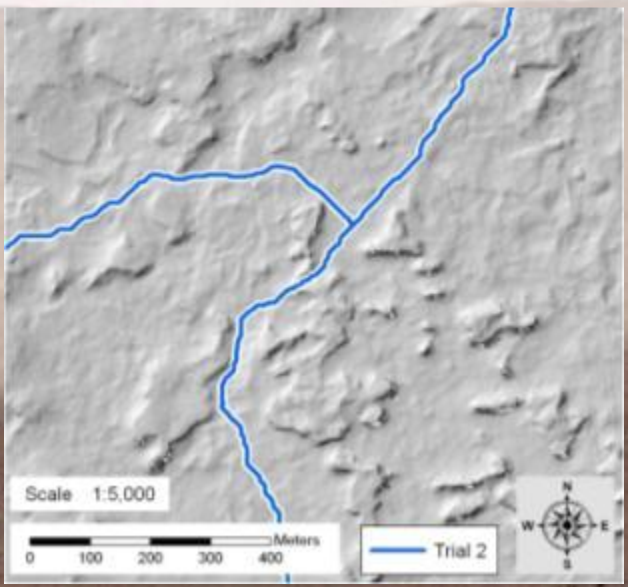


Path-Surface Comparisons

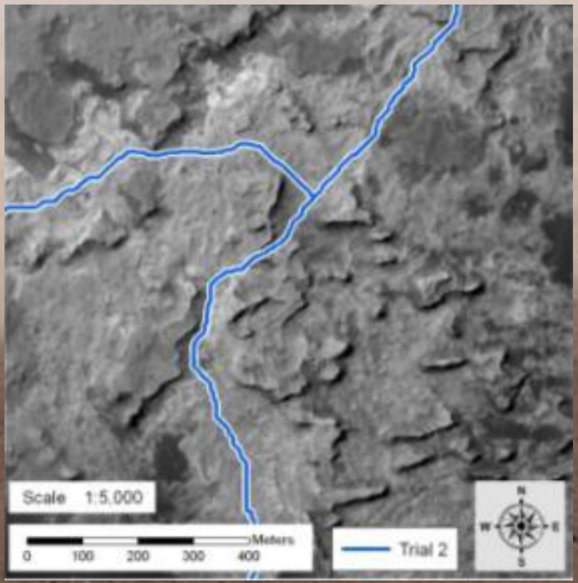
The paths were compared to different surfaces to determine if they followed low slopes and conformed to the terrain.



Slope



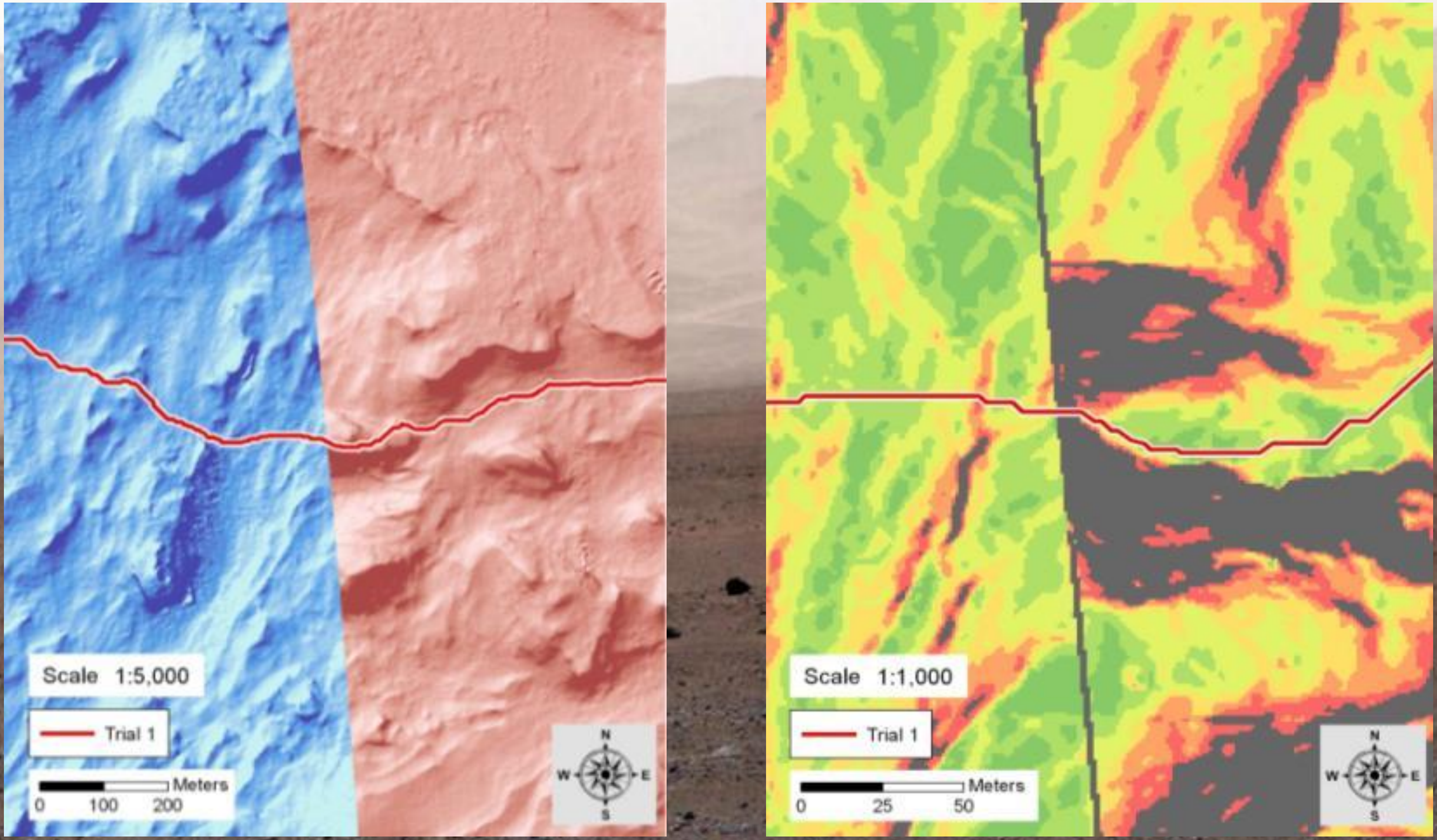
Hillshade



Orthophoto

Path Errors

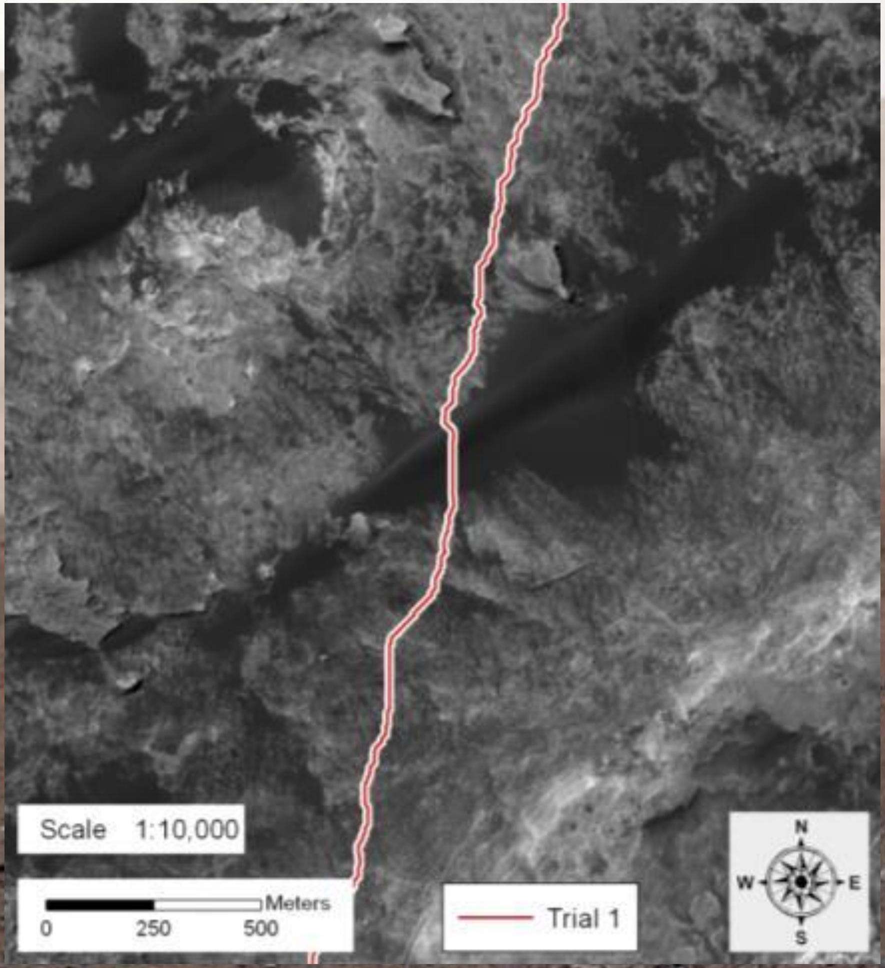
The rover is programmed not to drive on slopes above 30°. In a few cases the path crossed these forbidden slopes. The problem relates to the append process and the difficulty of properly aligning the DEMs.



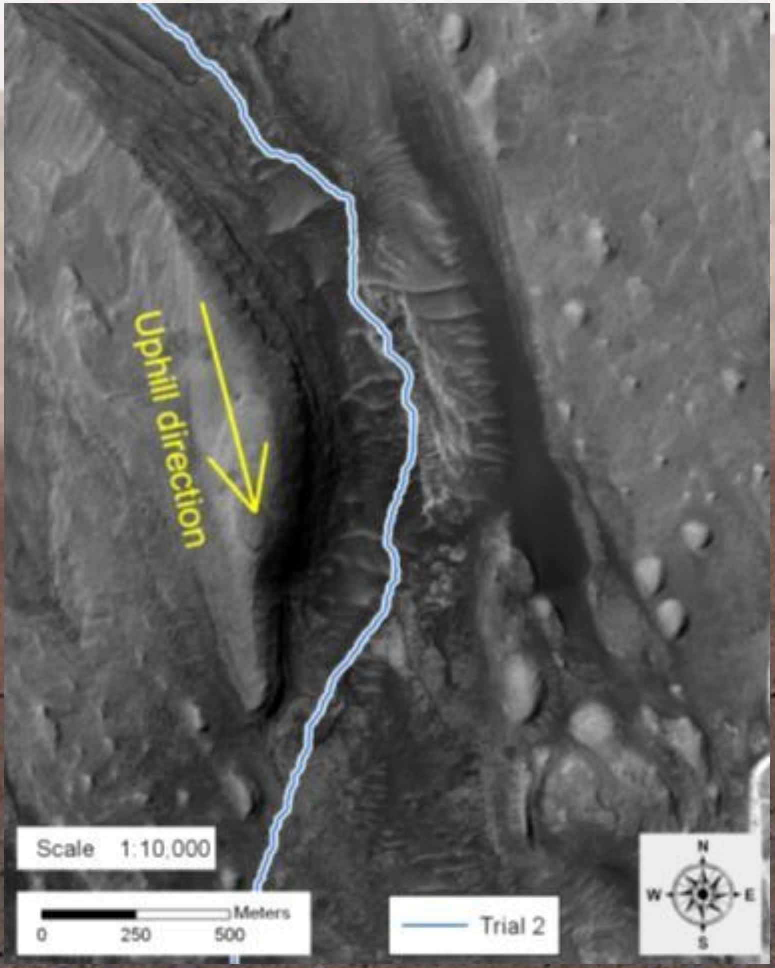
Black = slopes above 30°

Path Dangers

Left: The path crosses a dune. Mission scientists will have to avoid dunes to keep the rover from getting stuck.
Right: Horizontal structures in the canyon may or may not present difficulties for the rover.



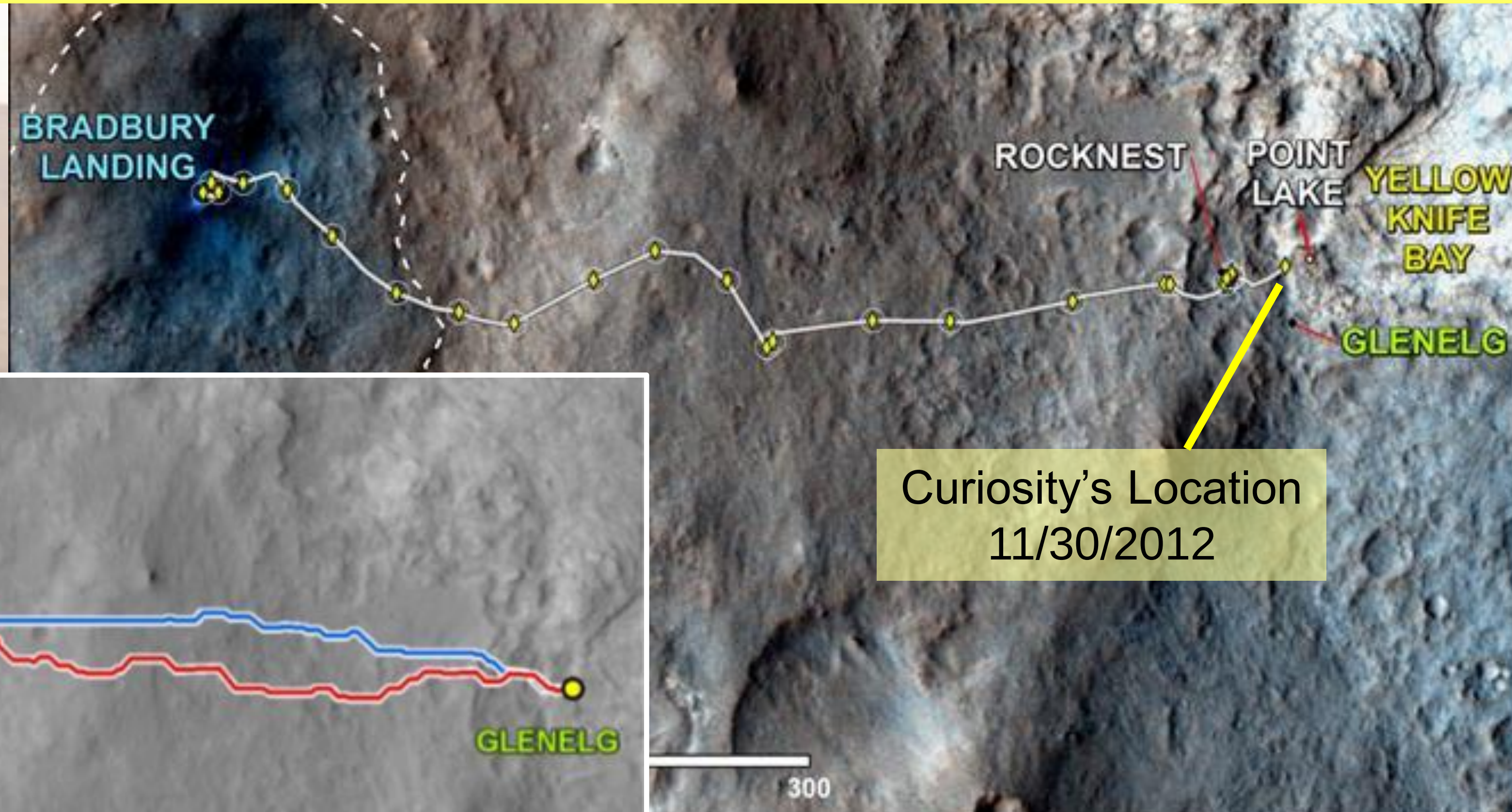
Crossing sand dune

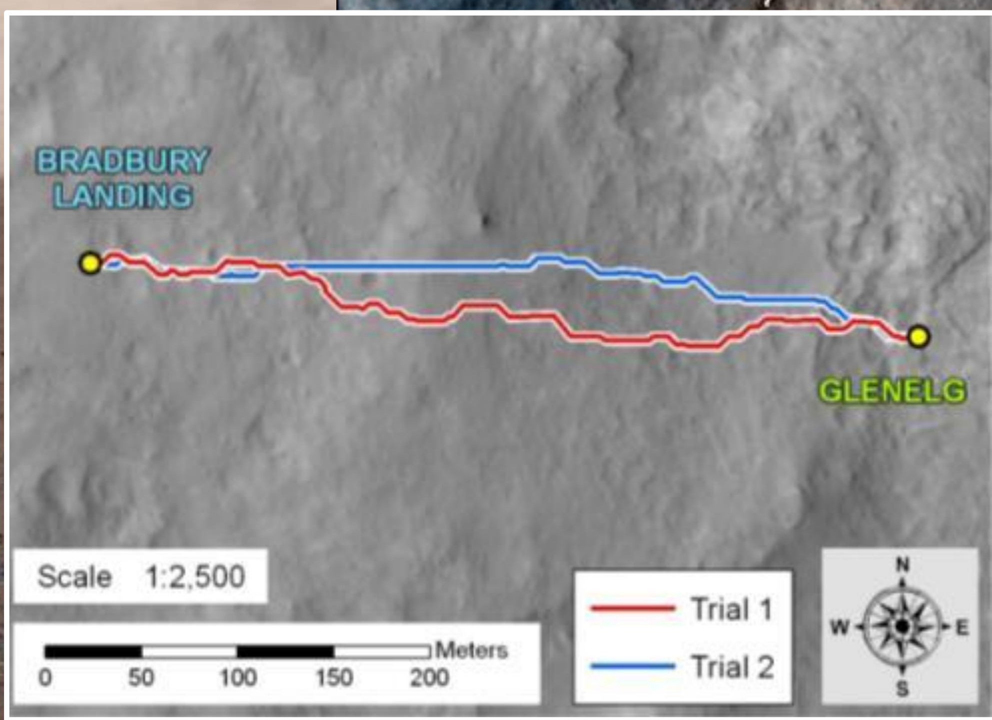


Horizontal structures

Theory vs Practice

Generated paths (bottom left) compared to the actual path of the rover. Mission scientists consider many factors in deciding where to send the rover. Least-cost paths can be used as guidelines.





Seeking the Path

Looking east into Glenelg, sol 102
11/18/2012

"During a Thanksgiving break, the team will use Curiosity's Mast Camera (Mastcam) from Point Lake to examine possible routes and targets to the east. A priority is to choose a rock for the first use of the rover's hammering drill, which will collect samples of powder from rock interiors."

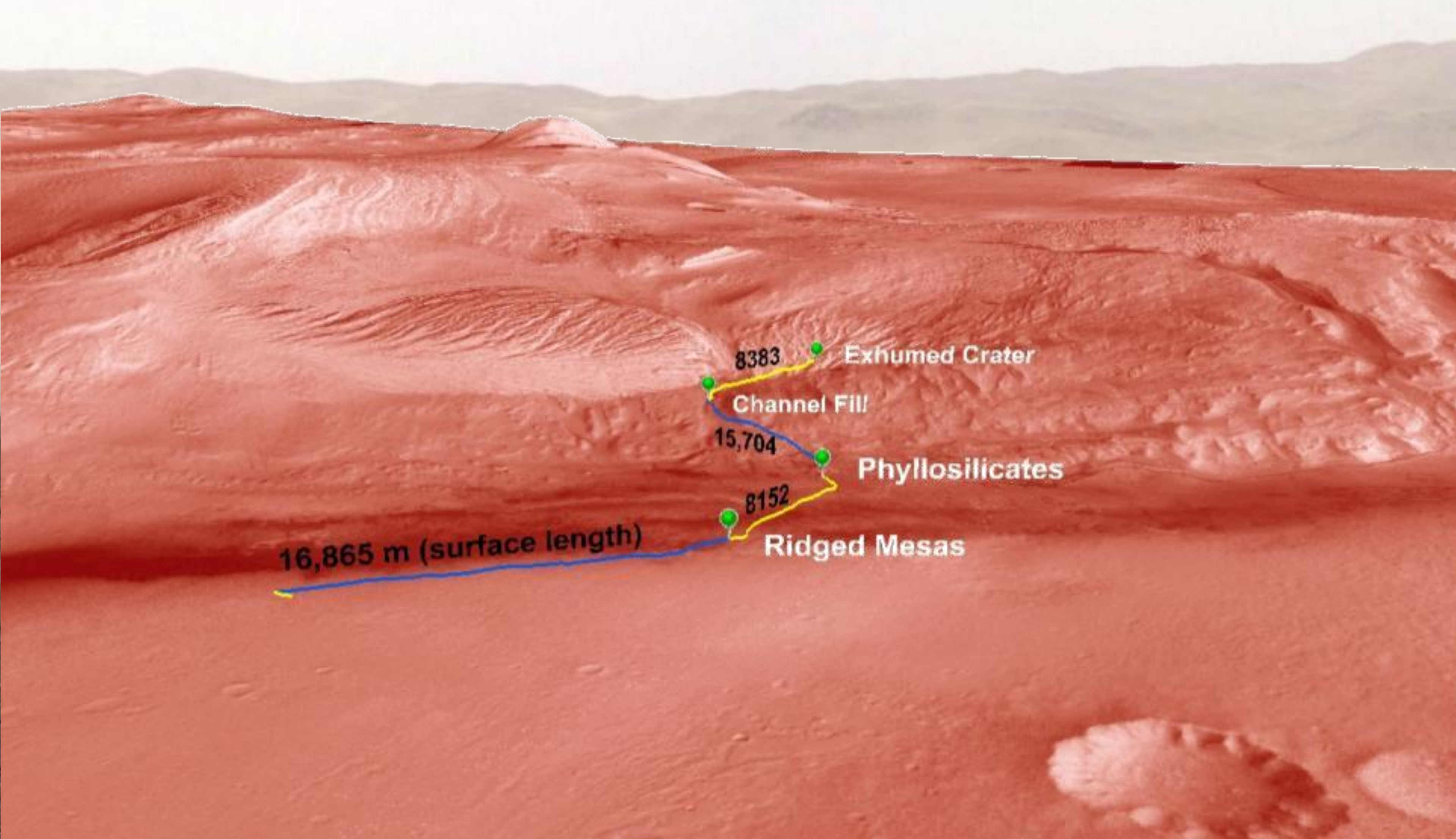
11/20/2012

Mission scientists use ground photos, orthophotos, and DEMs to help decide where to send the rover.

Panorama looking east from Rocknest, October/November 2012

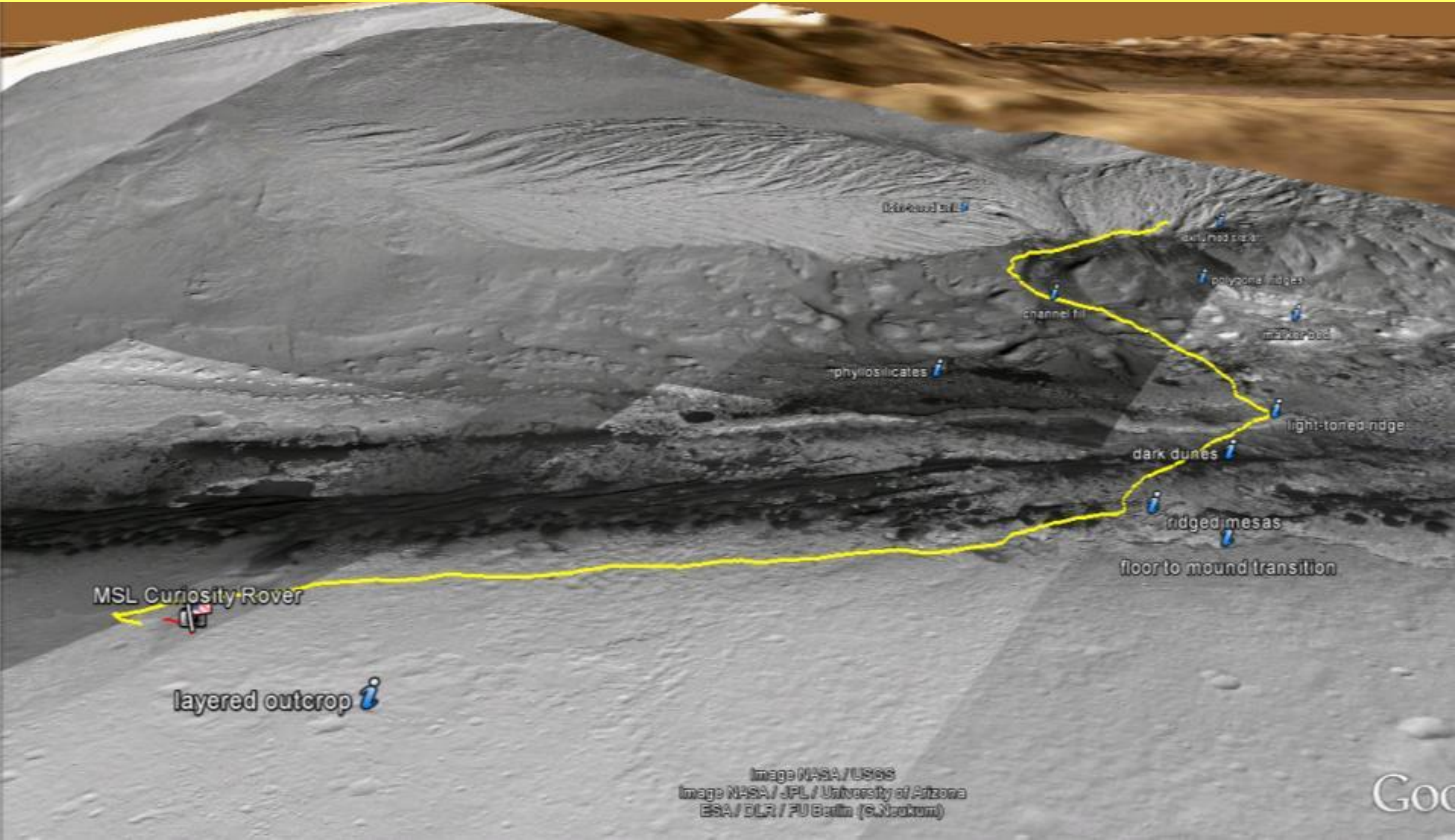
3-D Views

Elevation data allow us to calculate vital information. The numbers show the true three-dimensional lengths of the path segments. They account for elevation changes along the path.



Google Mars

Exporting the path to Google Mars allows one to easily pan, zoom, and rotate the scene. The high resolution images reveal the details of the terrain that the path passes through.



Lessons Learned

A) Generating least-cost paths on a 3-D surface is comparatively easy.

B) Constructing an accurate 3-D surface is not.

Recommendation: If you intend to conduct a similar analysis, plan to spend most of your time preparing the surface. Take a rigorous approach to adjusting and merging the DEMs.

C) Least-cost paths can provide vital information when planning long traverses over a 3-D surface (no matter what planet you're on).