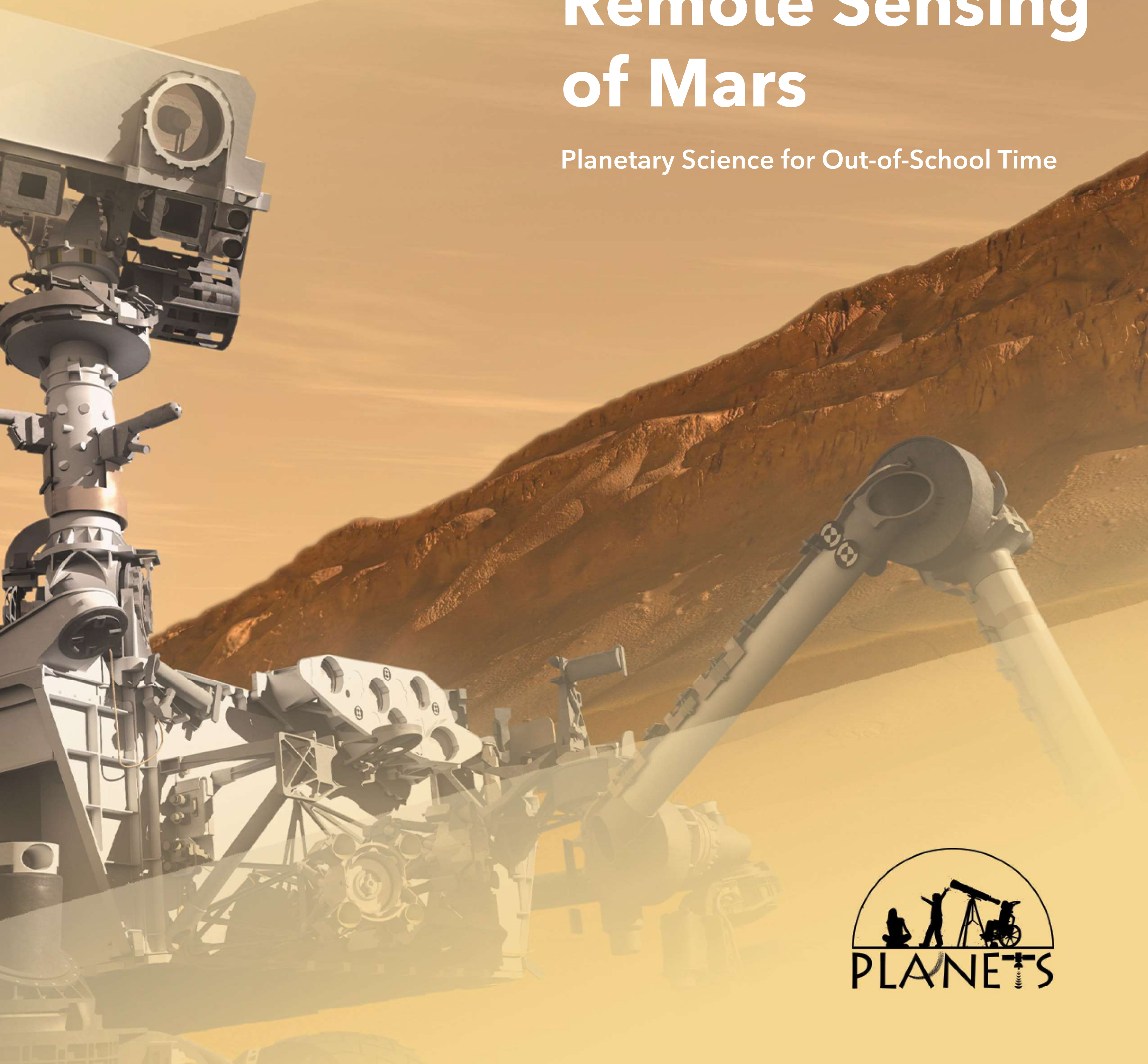
PLANETS **Science Series**

Remote Sensing of Mars

Planetary Science for Out-of-School Time



Remote Sensing of Mars

Planetary Science for Out-of-School Time

EDUCATOR *GUIDE*

PLANETS

PLANETS (Planetary Learning that Advances the Nexus of Engineering, Technology, and Science) is a partnership for the development and dissemination of NASA out-of-school time curricular and educator resource modules that integrate planetary science, technology, and engineering, particularly with underrepresented audiences.

Partner

This material is based upon work supported by NASA under cooperative agreement award number NNX16AC53A. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Aeronautics and Space Administration (NASA).

NORTHERN ARIZONA UNIVERSITY
Center for Science Teaching and Learning

USGS science for a changing world

Museum of Science
STEM Curricula PreK–8

NAU Collaborators:
Haylee Archer Graduate student
Nadine Barlow Professor, Department of Physics and Astronomy
Christopher Benson Graduate student
Nena Bloom Evaluation Coordinator and Researcher
Joëlle Clark Principal Investigator
Vanessa Fitz-Kesler Professional Development Associate
Maegan Foltz Undergraduate student
Dane Henderson Graduate student
Anne Hamlin Professional Development Coordinator
Kenric Kesler Professional Development Coordinator
Lori Pigue Graduate Research Assistant, Department of Physics and Astronomy
Elisabeth Roberts Evaluation Coordinator and Researcher
Lori Rubino-Hare Professional Development Coordinator
Sean Ryan Professional Development Coordinator
Brandon VanBibber Undergraduate student

PLANETS

USGS Collaborators:
Ryan Anderson Research Scientist
Lauren Edgar Research Scientist
Tenielle Gaither Research Scientist
Moses Milazzo Research Scientist now with Other Orb LLC
M. Elise Rumph Research Scientist
Greg Vaughan Research Scientist

Museum of Science – Boston Collaborators:
Christine Cunningham now with Penn State University
Martha Davis Director of Curriculum Development
Christine Gentry Research & Evaluation Analyst
Mary Eileen McDonnell Curriculum Developer
Natacha Meyer Curriculum Development, Manager
Bekka Nolan Curriculum Developer
Christopher San Antonio-Tunis Research & Evaluation Manager
Kate Sokol Senior Curriculum Developer

***PLANETS* Evaluation:**
Carol Haden Magnolia Consulting

Other Collaborators:
Mindy Bell Flagstaff STEM City
Mansel Nelson Institute for Tribal Environmental Professionals
Courtney Sullivan Arizona Center for Afterschool Excellence

EDUCATOR *GUIDE*

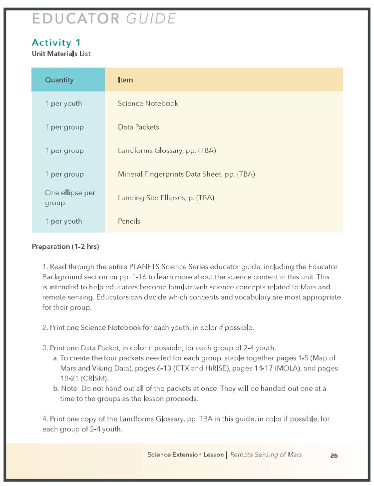
Table of Contents

About the ***PLANETS*** Science Series

The PLANETS Science Series supports youth exploration in the field of planetary science, by using real NASA data as they engage in and interpret the remote sensing of Mars. This unit can be done independently, but is designed to complement the PLANETS Engineering Everywhere “Worlds Apart: Engineering Remote Sensing Devices” activities available at the link below:

planets-stem.org/remote-sensing

This PLANETS Science Series unit has several parts. Educator support and all of the available materials can be downloaded from the PLANETS website.



EDUCATOR *GUIDE*

Activity 1
Unit Materials List

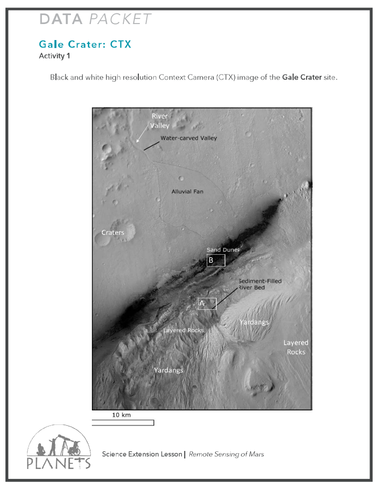
Quantity	Item
1 per youth	Science Notebook
1 per group	Data Packets
1 per group	Landforms Glossary, pp. (TBA)
1 per group	Mineral Fingerprints Data Sheet, pp. (TBA)
One ellipse per group	Landing Site Ellipses, p. (TBA)
1 per youth	Pencils

Preparation (1-2 hrs)

1. Read through the entire PLANETS Science Series educator guide, including the Educator Background section on pp. 1-16 to learn more about the science content in this unit. This is intended to help educators become familiar with science concepts related to Mars and remote sensing. Educators can decide which concepts and vocabulary are most appropriate for their group.
2. Print one Science Notebook for each youth, in color if possible.
3. Print one Data Packet, in color if possible, for each group of 2-4 youth.
   a. To create the four packets needed for each group, staple together pages 1-5 (Map of Mars and Viking Data), pages 6-13 (CTX and HiRISE), pages 14-17 (MOLA), and pages 18-21 (CRISM).
   b. Note: Do not hand out all of the packets at once. They will be handed out one at a time to the groups as the lesson proceeds.
4. Print one copy of the Landforms Glossary, pp. TBA in this guide, in color if possible, for each group of 2-4 youth.

Science Extension Lesson | *Remote Sensing of Mars* 26

Educator Guide



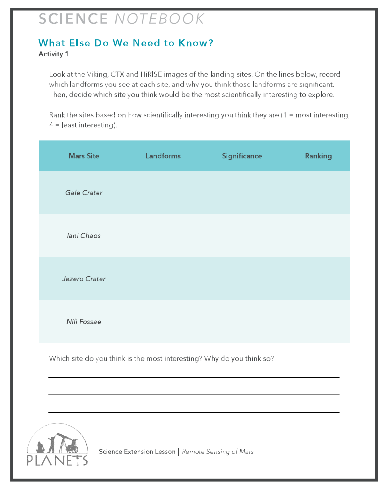
DATA *PACKET*

Gale Crater: CTX
Activity 1

Black and white high resolution Context Camera (CTX) image of the **Gale Crater** site.

Science Extension Lesson | *Remote Sensing of Mars*

Data Packet



SCIENCE *NOTEBOOK*

What Else Do We Need to Know?
Activity 1

Look at the Viking, CTX and HiRISE images of the landing sites. On the lines below, record which landforms you see at each site, and why you think those landforms are significant. Then, decide which site you think would be the most scientifically interesting to explore.

Rank the sites based on how scientifically interesting you think they are (1 = most interesting, 4 = least interesting).

Mars Site	Landforms	Significance	Ranking
Gale Crater			
Iani Chaos			
Jezero Crater			
Nili Fossae			

Which site do you think is the most interesting? Why do you think so?

Science Extension Lesson | *Remote Sensing of Mars*

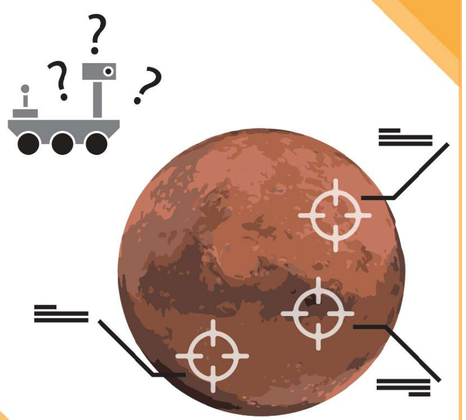
Science Notebook

Learning Progression - Science

www.planets-stem.org

These activities provide youth opportunities to explore visual, topographic, and spectroscopic data from Mars that were collected with NASA's remote sensing technologies in order to choose the best landing site for a rover.

S1



Remote Sensing & Mars
Exploring Visual Images

Purpose

Youth use images of Mars to find a landing site for a rover of scientific interest to NASA that may indicate past water.

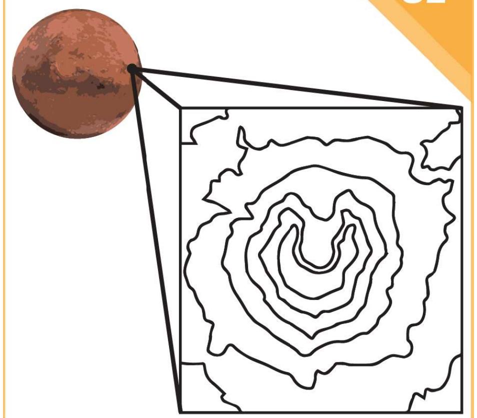
Key Take Away

Today we investigated remotely sensed images to find landforms on Mars that indicate water. These reveal evidence that Mars once had water on its surface.

Science Reflection

We can identify landforms in remotely sensed images of Mars that might indicate evidence of past water.

S2



Landing Site Topography
Exploring Topographic Maps

Purpose

Provides opportunities for youth to compare topographic features of four potential landing sites.

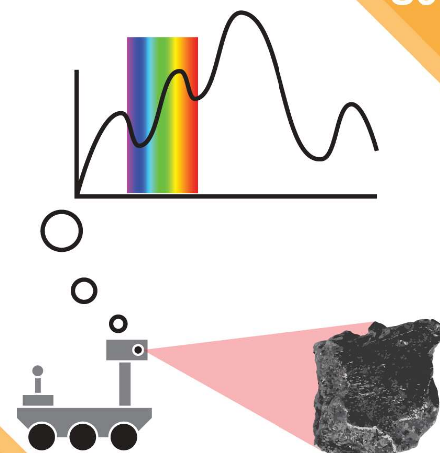
Key Take Away

We can use topographic maps created with remote sensing technology (LiDAR) to determine the shape and height of the terrain on Mars.

Science Reflection

Today we investigated topographic maps created with LiDAR. These reveal the shape and height of landforms.

S3



Mineral Fingerprinting
Exploring Spectroscopic Graphs

Purpose

Youth identify minerals that indicate past water or volcanism.

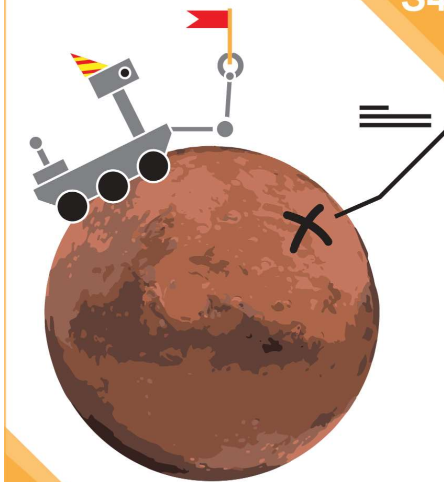
Key Take Away

We can identify minerals on Mars by looking at graphs of the light they reflect created by remote sensing technology (spectrometers).

Science Reflection

Today we investigated spectral graphs for minerals that indicate past water. Spectral graphs reveal different minerals because of how they absorb and reflect light.

S4



Choose a Landing Site
Evaluating Data

Purpose

Youth combine all data to recommend the safest, most interesting landing site.

Key Take Away

We can use data gathered from remote sensing technology to recommend the safest, most interesting landing site.

Science Reflection

Scientists often use multiple sources of data to make claims or decisions. Engineers and scientists work together to solve problems.

Learning Objectives

In the Remote Sensing of Mars: Science Extension Unit, youth will be challenged to answer the following guiding question: How do planetary scientists use remote sensing data to find scientifically interesting landing sites on Mars?

- » Youth will learn that remote sensing can teach us more about other planets than we could learn with the naked eye.
- » Youth will learn about how visible-light images can be used to find safe landing and geologically interesting locations.
- » Youth will learn how topographic data can be used to identify safe locations to land on Mars.
- » Youth will learn about how spectroscopy is related to what color things are, and how it can be used to identify scientifically interesting minerals.

Connections to Standards

The activities included in this unit support the teaching of multiple standards, including:

Next Generation Science Standards

MS-ESS1-3 Analyze and interpret data to determine scale properties of objects in the solar system.

MS-ESS2-3 Analyze and interpret data on the distribution of fossils and rocks, continental shapes, and sea floor structures to provide evidence of past plate motions.

MS-ETS1-3 Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

Unit Map

This Unit Map shows the activities that are part of this unit and how they all fit together.

Activity 1

Introducing Mars and Remote Sensing

What do scientists want to learn about Mars? Youth brainstorm questions about Mars and the evidence needed to answer them. They learn NASA's questions about Mars, and how NASA remote sensing data are used to choose landing sites.

Activity 2

Landing Site Topography

How can we use maps of landforms (the shape of the land) to choose a landing site on Mars? Youth learn that topographic data can help us to choose places where it is safe to land on Mars.

Activity 3

Mineral Fingerprinting

How can we identify different minerals to search for evidence for past water on Mars? Youth learn that spectroscopy lets us see the "fingerprints" of different minerals, and that certain minerals only form in water. Youth apply that knowledge to the selection of a landing site.

Activity 4

Choosing a Landing Site and Share Out

Which location will youth choose for their landing site? Youth put together all the information they have gathered in the previous three activities to choose the best site for their mission. Groups present the site they chose and share why they chose that particular site.

Unit Overview

In this activity, youth will learn about the real-life equipment that the model remote sensing devices in the Engineering Everywhere unit, Worlds Apart: Engineering Remote Sensing Devices, are based on. Youth will explore how remote sensing data can be used to find out more about the conditions and features of Mars from a distance. In the final activity, youth will identify potential landing sites for further scientific exploration and share their findings with the group.

Although this activity is builds upon Engineering Everywhere's Worlds Apart: Engineering Remote Sensing Devices unit, it is not necessary for youth to complete it in order to participate in PLANETS Science Series activities. The activities in this unit can be completed in parts, or in one longer session.

In Activity 1, "Introducing Mars and Remote Sensing," youth share what they know about Mars and what questions they have. They then learn about the main research questions that NASA wants to answer, and what data are available to help choose a landing site that is safe and scientifically interesting.

Activity 1 Guiding Questions

- » What do scientists want to learn about Mars, and why is it necessary to land on the surface?
- » What makes a good landing site?
- » What NASA remote sensing data are available to help choose a landing site?

Scientists are looking for evidence of habitable environments that existed in the past – places where liquid water existed on the surface for a long time. They are also interested in the age of rocks on Mars so that we can understand when the climate changed. For example, scientists know that today, Mars has low air pressure, only 1% as dense as Earth's air pressure at sea level. Scientists also know that Mars is very cold, with temperatures typically around -67 °F (-55 °C). These conditions mean that Mars does not have liquid water on its surface today, though dry river valleys and dry lake beds indicate that liquid water once flowed across Mars' surface billions of years ago.

Activity 2 Guiding Questions

In Activity 2, "Mapping Landforms," youth look at topographic maps of Mars and choose the best place to land a spacecraft.

- » How do we identify different landforms and how rough the surface is?
- » How can we use maps of landforms (the shape of the land) to choose a landing site on Mars?

Volcanoes and impact craters dominate the topography of Mars. There are several very big volcanoes on Mars which are no longer active but have left behind large mountains and long lava flows. There are also places where rocks have been eroded in the distant past by flowing water, and places where the eroded sediments have accumulated and been compressed into sedimentary rocks. The topography of Mars is always changing. For example, there are landslides, dust storms, and sand dunes that move around with the winds. Near the poles, water ice and carbon dioxide ice are deposited and removed with the seasons.

We can use topographic data to study the shapes of the land on the surface, called landforms, and get a good idea of the elevation at which different rock types are located, as well as where areas are flat and not too rough to land.

High-resolution images of the surface provide even more information, allowing scientists to identify landforms that are formed by water such as valleys, canyons, deltas, and alluvial fans. Images can also reveal whether the landscape is made of layered sedimentary rocks that might be formed by wind or water, or if volcanic rocks are more common.

In Activity 3, "Mineral Fingerprinting," youth use spectra to identify minerals present on the surface of Mars and decide which location would make the best landing site, based on the minerals that are found there.

Activity 3 Guiding Questions

- » How can scientists find out whether life could have existed on Mars? How do we know how old Mars rocks are?
- » How can we use infrared spectroscopy to identify a scientifically interesting landing site?

If youth have completed Engineering Everywhere's Worlds Apart: Engineering Remote Sensing Devices activities, they have already explored reflection of light with mirrors, and filtering of light with cellophane. Here, youth will learn about types of light that we cannot see with our eyes because they are outside of the visible spectrum, such as infrared light.

In Activity 3, youth will explore the reflection of specific colors of light using real NASA remote sensing data to identify specific minerals.

Remote sensing instruments called spectrometers allow us to "see" colors beyond the capabilities of our eyes. All materials, including rocks, minerals, soils, plants, water, ice, and clouds, reflect and absorb different colors of light in different amounts. Just like color filters absorb some colors and let others pass through, different materials absorb or reflect different colors of light. Spectrometers measure the amount of reflected light at each wavelength.

Activity 4 Guiding Questions

- How can we choose a landing site that will meet our criteria?
- How can we share what we found out?

In this activity, youth consider all the data they have collected during the previous activities to decide which location will be the most scientifically interesting, choose their landing site, and then present their findings to the class. Groups share the site they selected with the full group and explain their reasoning and the evidence they found to support their choice.

Educator Background

Planetary Science and the Study of Mars

This guide section describes background information for concepts used in the series. Concept videos, FAQs, tips, and more are found on our website: planets-stem.org/remote-sensing.

If youth completed the Engineering Everywhere unit, Worlds Apart: Engineering Remote Sensing Devices, they learned about three types of remote sensing technologies: telescopes, filters, and **Li**ght **D**etection **a**nd **R**anging (LiDAR). This PLANETS Science Series Lesson will explore similar instruments that help scientists learn more about the minerals and topography of Mars so they can choose a landing site. In these activities, youth learn more about remote sensing tools and techniques that planetary scientists use to understand habitable environments on Mars, and how the planet has changed over geologic time.

Planetary scientists try to answer big questions such as:

- How have the planets in our Solar System changed over time?
- Did life evolve only on Earth, or is there evidence that life evolved on other planets, too?

This unit focuses on the exploration of Mars. Scientific evidence indicates that Mars may have once had a more Earth-like climate, but now it is a dry and cold desert. Scientists want to know how the climate on Mars changed and whether life could have evolved there. Mars is also closer to the Earth than many other planets, making it easier to send future missions there.

One reason to land on Mars is to collect samples that can be returned to Earth for detailed analysis in a laboratory. For example, volcanic rocks contain minerals that can be analyzed to find out how old the rock is, allowing scientists to get a much better understanding of how Mars changed over time. Some types of sedimentary rocks may contain organic (carbon-based) materials that give clues to whether life could ever have evolved on Mars.

Even without returning samples to Earth, landing robotic rovers on Mars allows scientists to explore new areas and understand the processes that shaped the surface of the planet. Some of the most scientifically interesting locations to visit are places like impact crater walls or canyons where different rock layers are exposed in the walls. Layers of rocks are like the pages in a book that tell the story of the geologic history of an area.

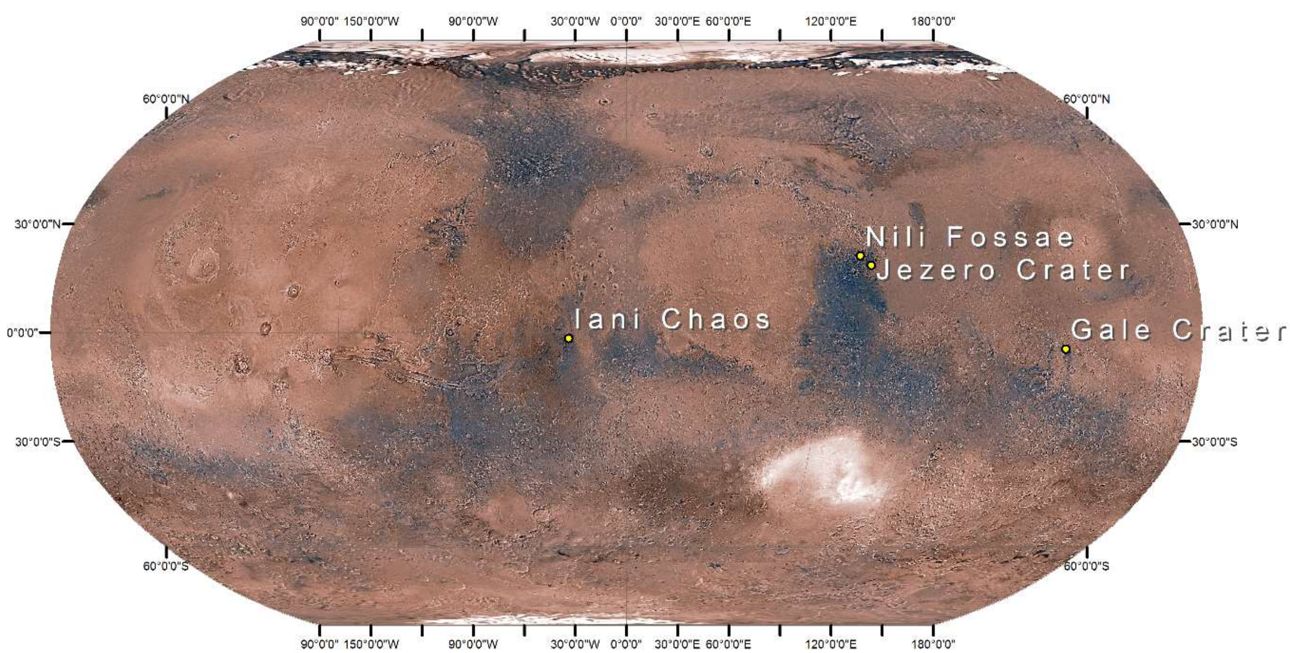
But steep canyons and crater walls are dangerous places to try to land a spacecraft. There is a trade off between sites of interest to scientists, and sites that are safe to land on.

The ideal site has a broad, flat area to land on, as well as interesting minerals and landforms nearby, so scientists can learn more about the planet's past. In the following activities, youth will learn how they can use remote sensing to identify such a site.

Landing Sites on Mars

To help youth work through the activities, it is helpful for educators to have some background knowledge about each of the locations that youth will be studying. All of the following locations are actual Mars rover landing sites or have been considered as landing site candidates.

Note: These descriptions are intended for educators, and include "answers" for each of the sites. Youth-oriented descriptions of the sites are included in the activity.



Global map of Mars using Viking color data.
The four sites used in these activities are indicated.

Site 1: Gale Crater

The Mars Science Laboratory rover Curiosity landed in Gale crater in 2012 and continues to explore. Gale is a large impact crater. This site is interesting because the middle of the crater contains a mountain that is 3.4 miles (5.5 km) tall and is made of layered sedimentary rocks. The layered rocks have spectral signatures of clay minerals and sulfates, indicating multiple different environments involving water. The crater floor is also made of layers of sediment washed down from the crater rim. The floor is flat and safe for landing. Near the base of the mountain there are black sand dunes containing olivine and pyroxene.

In the HiRISE insets provided to the youth, location A shows layered rocks and a channel carved into the rocks by water and filled with sediment. Location B shows the black sand dunes.

Site 2: Jezero Crater (Yez-er-oh or Jez-er-oh)

Jezero crater is the landing site for the Perseverance rover. It is a large impact crater. It is interesting because the northwestern rim of the crater is breached by an ancient river channel which ends in a fan-shaped deposit of layered sedimentary rocks (likely an ancient river delta). River deltas form when flowing water carrying sediment empties into a standing body of water like a lake. The Jezero delta contains clay minerals, and some of the crater floor deposits contain carbonate minerals. Much of the crater floor is covered by what may be an old lava flow, which forms a flat surface with many small impact craters.

In the HiRISE insets provided to the youth, location A shows complex layers deposited in the delta. Location B shows the edge of the heavily cratered lava flow unit, with many small dunes at its base.

Site 3: Nili Fossae Trough (Nee-lee Foss-eye)

Nili Fossae was considered as a landing site for both the Curiosity and Perseverance rovers, but in the end it was not selected. It is located in a large, long valley, called a graben, or trough. The floor of the valley contains a lava flow and some clay minerals. The eroding walls also expose clay minerals, possibly formed by circulating hot water. Olivine (a mineral that comes from volcanoes) is also exposed in the walls. The higher ground outside the valley is very rugged and resistant to erosion because of a lava flow. In the HiRISE insets provided to the youth, location A shows some large sand dunes. Location B shows the edge of the cratered lava flow unit.

Site 4: Iani Chaos (ee-Ah-nee Kay-oss)

This area is one of several "chaos" terrains on Mars, which are areas where a huge amount of underground water was released, resulting in giant floods and the collapse of the area where the water was stored. Within Iani Chaos, there are layered deposits of sulfate minerals. The location in the Data Packet was chosen as an example of a scientifically interesting location that would not make a good landing site because it is too rough and not safe to land there.

In the HiRISE insets provided to the youth, location A shows an outcrop of sulfate-bearing fractured rock. In the CTX data, layers can be seen in the rocks at this site, but at this higher resolution we can see that there aren't obvious finer-scale layers. Location B shows the edge of a cratered lava flow unit, partially covered by small dunes.

Types of Remote Sensing Data

The chart below is intended for the educator's background knowledge, but youth may also benefit from summarizing the data types in this way.

Data type	What the data tell us	NASA remote sensing tools
Visible images	What the planet's surface would look like to our eyes	Context Camera (CTX) - High spatial resolution black and white HiRISE - Extremely high spatial resolution black and white
Topographic images	How high or low the surface of the planet is	Mars Orbital Laser Altimeter (MOLA)
Spectroscopic data	What minerals are present, which can tell us about the planet was like in the past	Compact Reconnaissance Imaging Spectrometer for Mars (CRISM)

The Data Packets contain NASA remote sensing data for the different Martian sites described above. Each data type provides a different "piece of the puzzle" when using them to answer questions about Mars' geologic history. Youth will study the data types to become familiar with the concepts, and then use them all together to choose a landing site for a sample return mission.

Visible Light

Images collected using visible light can be displayed as either black and white images, or as color images that show what the surface would look like to a human observer. For example, the reddish colors are the actual colors of Martian rocks. Visible light images were acquired covering the entire planet with the ***Viking*** orbiter in the 1970s. These images are useful to get an overview of large areas, and for comparison to more recent remote sensing data. Because Viking was a 1970's era spacecraft, the images are not as high in quality as images from modern spacecraft. Visible light images covering the entire planet have also been acquired with the ***Context Camera (CTX)*** on-board a satellite called the Mars Reconnaissance Orbiter, which started orbiting Mars in 2006. This camera only acquires black and white images, but they are better quality images, with more details about surface features, than older Viking images.

The Data Packet includes annotated versions of the CTX images, with key geologic features labeled. A small portion of the surface of Mars has been observed at extremely high resolution using the High Resolution Imaging Science Experiment (HiRISE). This camera also acquires mostly black and white images, but they have a resolution of 25 cm per pixel, as compared to 6 meters per pixel with CTX.

Laser Light (LiDAR)

Laser light can be bounced off an object and used to determine how far away it is (because we know how fast light travels). This is called **Light Detection and Ranging (LiDAR)** technology. If you are flying over a planet's surface with a LiDAR instrument, you can bounce laser light off its surface and determine the elevation and the shapes of objects on the surface, which are called landforms. A map that shows the elevations in an area is called a topographic map. The **Mars Orbiter Laser Altimeter (MOLA)** is a LiDAR instrument that was on the Mars Global Surveyor (MGS) satellite, which operated in orbit around Mars from 1997 to 2007. MOLA mapped the topography of the entire planet. In the Data Packet, MOLA topographic maps are shown for each of the potential landing sites. The colors on the MOLA maps correspond to different elevations, and contours trace lines of equal elevation. Areas in the images that have the same color and widely spaced contour lines are at the same elevation. Areas where the color changes and the contour lines are close together are steep slopes.

Infrared Light

The **Compact Reconnaissance Imaging Spectrometer for Mars (CRISM)** is an instrument that can acquire images in the visible and infrared parts of the electromagnetic spectrum. By taking hundreds of images of the same location at different wavelengths of light and stacking them, each pixel contains a spectrum that provides clues about what minerals are located there. These data can be used to make maps that show the location of volcanic minerals and water-related minerals that indicate the past presence of liquid water, or hot springs, or lakes on the surface of Mars.

In the Data Packet, the patterned areas on the mineral maps correspond to locations where specific minerals are detected with the CRISM instrument. For each pattern, there is a graph of the reference spectrum of the important mineral. Youth can compare these spectra to those on the Mineral Fingerprint Data Sheets to identify the minerals.

Vocabulary

Alluvial Fan: A fan- or cone-shaped deposit of sediment crossed and built up by intermittent streams, usually found where a canyon emerges out onto a flatter plain.

Carbonate Minerals: A class of minerals that includes the carbonate ion (CO_3^{2-}) within their crystal structure. They commonly form in areas where sedimentary rock formation processes have occurred. They are an important indicator for areas that have once had liquid water, since carbonates only form in neutral or basic (high pH) water.

Clay Minerals: A group of minerals that contain water and have layered crystal structures. Clay minerals only form in the presence of liquid water with a relatively neutral pH, so they are an important indicator mineral for areas that once had water that was safe for life. Clay minerals also trap organic molecules, which is helpful in the search for past life.

Delta: A river delta is a landform made when a river enters a standing body of water such as an ocean, sea, or lake and deposits the sediment it was carrying. The Mississippi River delta and the Nile River delta are famous examples on Earth.

Electromagnetic spectrum: The range of wavelengths, or frequencies, over which electromagnetic radiation (light) extends. It ranges from short-wavelength, high-frequency gamma rays, to long-wavelength, low-frequency radio waves. The human eye is only sensitive to a narrow part of the spectrum, called the visible region. See videos at planets-stem.org/remote-sensing

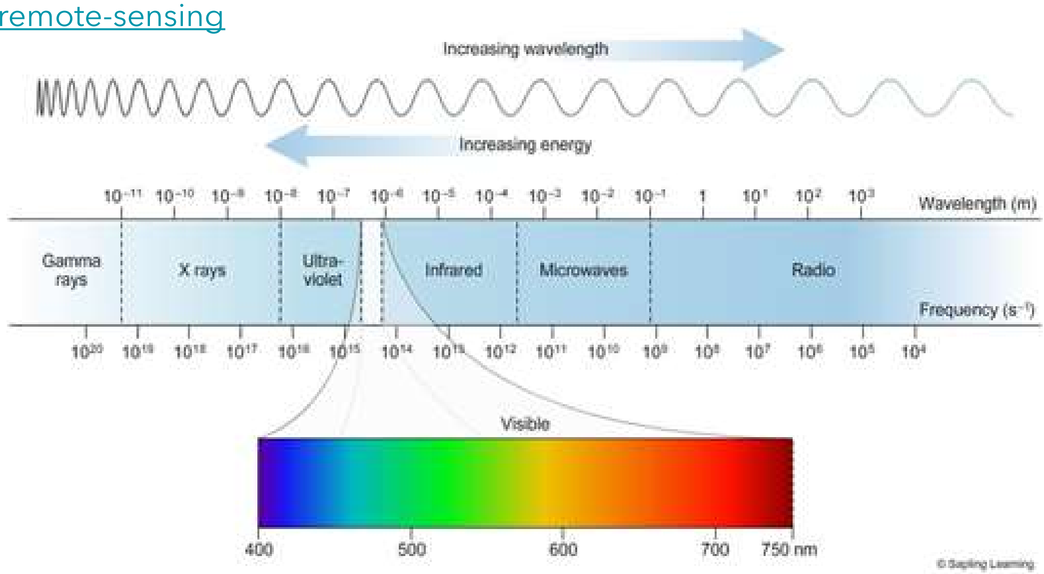


Image source: https://sites.google.com/site/chempendix/em-spectrum

Ejecta: Ejecta is the material evacuated from an impact crater and spread across the surrounding area. For fresh impact craters, the ejecta is often visible as irregular "rays" extending for several times the radius of the crater in all directions. Ejecta around older craters is often worn away by erosion.

Filter: A device or process that removes some components from a signal, and allows others to pass thorough. In this context, a filter can be used to allow certain colors of light to pass through, while absorbing other colors.

Geologic History: Refers to the history of geologic processes that have shaped a planetary body over the course of geologic time, which extends back to the formation of the Solar System, about 4.5 billion years ago.

Graben: Also called a trough, an elongated block of a planet's crust that has been pushed downward relative to the blocks on either side, forming a long valley.

Habitable environment: An environment that supports life. Life as we know it requires liquid water, a source of carbon, and a source of energy (such as the sun, a hydrothermal vent, or certain minerals). Most life also requires a relatively neutral pH and moderate temperatures.

Impact crater: A landform created by the explosion from a piece of rock or ice falling from space at a very high velocity. Impact craters are round holes in the ground, with raised rims. Large craters can have mountains in the middle and multiple terraces around the rims. Fresh craters are surrounded by ejecta.

Infrared (IR): Refers to electromagnetic radiation (or light) that has wavelengths that are longer than the wavelengths of light in the visible red part of the electromagnetic spectrum. This part of the electromagnetic spectrum is not visible to human eyes.

LiDAR (Light Detection And Ranging): A remote sensing technology that measures the distance to a target by illuminating that target with a laser and measuring how quickly the reflected laser light comes back to the instrument. Since light always travels at the same speed, the time it takes to bounce back can be converted to a distance. If flown on an aircraft or spacecraft and aimed at the surface of a planet, it can be used to map the shapes and topography of a landscape.

Minerals: Naturally occurring, solid, crystalline chemical compounds that are the "building blocks" of rocks. Minerals have specific environments where they form, that depend on temperature, pressure, chemistry, and the amount of water present.

Remote sensing: The process of using technology to obtain information about an object without touching the object. In this context, it refers to the use of imaging technology that can detect various parts of the electromagnetic spectrum, including parts that cannot be seen by the human eye.

Sediment: Matter, usually broken bits of rock, that is transported by wind or water and is deposited in layers in low areas such as a streambed or lake.

Sedimentary Rocks: Rocks that are formed from the accumulation and compaction of sediments. Some sedimentary rocks form from wind-blown sediment while others form from sediment transported by liquid water.

Spatial Resolution: The number of pixels per unit area used to create a digital image. Images with higher spatial resolution have a greater number of pixels than those of lower spatial resolution. The higher the resolution of an image, the more details it can show.

Spectral data: (singular: spectrum; plural: spectra): A plot of the intensity of light versus the wavelength of light. All materials have unique spectra, which can be used as "fingerprints" to identify the material remotely.

Spectrometer: An instrument used for recording and measuring spectral data from different parts of the electromagnetic spectrum. Some spectrometers just measure spectral data from a point on a surface. Imaging spectrometers can measure spectral data from many different points at the same time, and generate an image where each pixel contains spectral data from that location.

Spectroscopy: The study of how light of different wavelengths, or color, is absorbed, transmitted, emitted, or reflected by different materials.

Sulfate Minerals: A class of minerals that include the sulfate ion (SO_4^{2-}) within their crystal structure. They tend to form from evaporating water, or volcanically heated water. They are an important indicator for areas that once had liquid water. Some sulfates form only in acidic (low pH) water.

Topography: The shape, arrangement, and elevation (or height) of landforms or other physical features on the surface area of a planet.

Volcanic Rocks: Rocks formed from the material erupted from a volcano. They are important in planetary exploration because they contain minerals that can be analyzed in a laboratory to determine how old the rock is and when it was formed.

Volcano: A vent or crack through which lava, rock fragments, and gases erupt from beneath a planet's surface, sometimes creating new landforms.

Wavelength: The distance between one peak of a wave and the next peak. For visible light, the wavelength determines its color (red light has a longer wavelength than blue light). Other types of light like ultraviolet and infrared also have a wavelength but no color since the human eye can't see them. Longer wavelengths correspond to lower energies of light, shorter wavelengths have higher energy.

Materials List & Preparation

Unit Materials List

Quantity	Item
1 per youth	Science Notebook
1 per group	Data Packets
1 per group	Landforms Handout
1 per group	Mineral Fingerprints Data Sheet
One ellipse per group	Landing Site Ellipses
1 per youth	Pencils

Preparation (1-2 hrs)

1. Read through the entire PLANETS Science Series educator guide, including the Educator Background section on pp. 8-13 to learn more about the science content in this unit. This is intended to help educators become familiar with science concepts related to Mars and remote sensing. Educators can decide which concepts and vocabulary are most appropriate for their group.

2. Print one Science Notebook for each youth, in color if possible.

3. Print one Data Packet, single-sided and in color if possible, for each group of 2-4 youth.
   - » To create the four packets needed for each group, paper clip together pp. 1-9 (CTX and HiRISE), pp. 10-14 (MOLA), and pp. 15-19 (CRISM).
     - » Note: Do not hand out all of the packets at once. They will be handed out one at a time to the groups as the lesson proceeds.

4. Print one copy of the Landforms Handout single-sided and in color, if possible, and paper clipped together for each group of 2-4 youth.

5. Print one copy of Mineral Fingerprints Data Sheet single-sided and in color, if possible, and paper-clipped together for each group of 2-4 youth.

6. Print out one copy of Landing Site Ellipses on transparency or regular paper.
   - Cut along the dotted lines to separate the ellipses so there is one for each group of 2-4 youth.
   - Cut around the red oval to make individual ellipses.

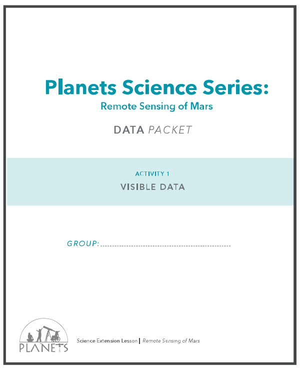
Tip: Use page protectors and dry-erase markers to make the Data Packets reusable. Clasp packets together with metal rings or twist ties.

Activity 1: Introducing Mars and Remote Sensing (60 min)

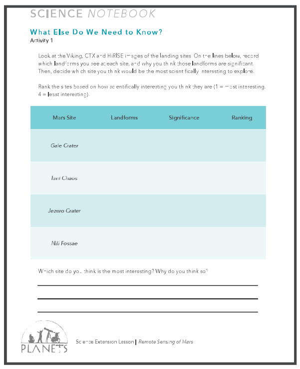
Overview

What do scientists want to learn about Mars? Youth brainstorm questions about Mars and the evidence needed to answer them. They learn NASA's questions about Mars, and how NASA remote sensing data are used to choose landing sites.

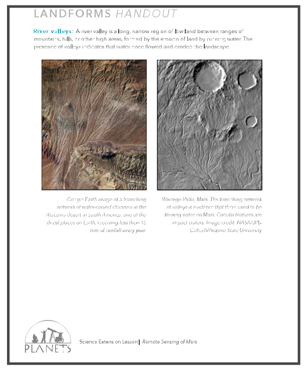
In this activity:



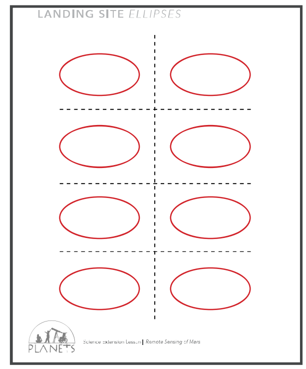
Visible Data Packet (CTX & HiRISE images) 1 per group



Science Notebook 1 per youth

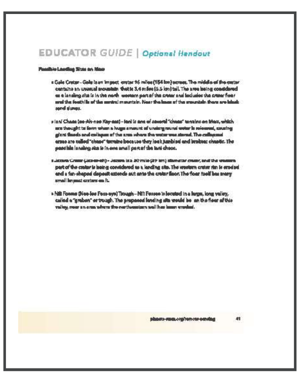


Landforms Handout 1 per group



Ellipses Sheet Cut out 1 ellipse per group

Optional:



Optional Handout 1 per group

Introduction (5 min)

1. Let youth know that today, they will use real remote sensing data collected by NASA scientists to help decide where to land a spacecraft on Mars.

2. Review what youth already know about remote sensing and post the following definition so they can reference it throughout the activity: "Remote sensing is the science of obtaining information about objects or areas from a distance." Examples of devices that collect these data include cameras, video cameras, telescopes, microscopes, and the human eye. These devices are often mounted on aircraft, satellites, and spacecraft to collect remote sensing data.

3. Ask youth to share what they know about Mars. Be sure to correct any misconceptions that appear.

Common Misconceptions About Mars

Misconception	Truth
Astronauts have been to Mars	Earth's moon is the only planetary body that astronauts have visited so far.
We have already collected samples from Mars	Nothing we have sent to Mars has ever been intended to return to Earth. We don't have any samples from Mars yet (except meteorites).
There is a lot of liquid water flowing on Mars	It is too cold and the atmosphere is too thin for there to be significant amounts of liquid water on present-day Mars.
There is no water at all on Mars	Mars does have water, it is just mostly in the form of ice at the poles or trapped in minerals and the ground.

Formulating Science Questions (5 min)

1. Once youth have had a chance to share their prior knowledge about Mars, ask them: "What questions do you still have about Mars?" Have students take a minute to write down questions in their Science Notebooks.

2. Have youth volunteer to share a few of their questions.

3. Have youth discuss with their group and brainstorm ways they think scientists might try to answer those questions in the table on p. 2 in their Science Notebooks. What evidence or observations of Mars would they need to answer their questions? Encourage them to think about how landing a rover on the surface might help find answers.

4. Explain to youth that they will play the role of scientists answering these questions for the first time. It's their job to use remote sensing technologies to find out more about what the surface of Mars is like.

5. Acknowledge all questions youth have as important science questions, and then tell youth about NASA's main question about Mars:

   » NASA is most interested in learning about habitability: What evidence can we find to indicate that Mars could have supported Earth-like life in the distant past?

   » One of the key requirements for life as we know it is liquid water, so evidence for liquid water on Mars is what planetary scientists are interested in.

Tip: If youth are not familiar with rovers, take some time to learn more about what rovers do:

Resources for educators:
planets-stem.org/remote-sensing

NASA's main Mars page:
mars.nasa.gov

Perseverance Rover:
mars.nasa.gov/mars2020/

> **Did you know?** There are other requirements for habitability, such as an energy source, water chemistry that is safe for life, the presence of key nutrients, safe temperature range, not too much radiation, etc. but these are all very hard to detect using remote sensing – that's why NASA wants to send a rover!

Introduce the Challenge (5 min)

1. Let youth know:
   - » NASA needs help to decide where to land its next rover on Mars!
   - » The ideal landing site should be safe to land on, with minerals and landforms that indicate evidence for past water.
   - » You will have the chance to examine different types of real NASA data from four possible landing sites and decide which site to recommend to NASA.

Explore the Visual Data (15 min)

1. Divide youth into groups of four. Hand out the Data Packets containing CTX (Context Camera) and HiRISE (High Resolution Imaging Science Experiment) images, from instruments on the Mars Reconnaissance Orbiter, a satellite that has been orbiting Mars since 2006.

2. Let youth know:
   - » On the CTX images of the sites, there are small white boxes, labeled "A" and "B"
   - » These are locations where extremely high-resolution images (from the HiRISE camera show landforms in even better detail than CTX. For example box "A"on p. 2 corresponds with image 'A" on p. 3.
   - » Now we will examine these landform types and see what they can tell us about the geologic history of Mars.

Look for Evidence of Landforms on Mars (20 min)

1. Pass out one copy of the Landforms Handout to each group. Discuss with youth the landforms shown on the handout: river valleys, layered rocks, alluvial fans, river deltas, lava flows, sand dunes and yardangs.

- » River valleys – Indicate that water once flowed and eroded the landscape
- » Layered rocks – Some layered rocks are deposited in water but others are deposited by the wind. It can be hard to tell the difference without studying them up-close!
- » Alluvial fans – An alluvial fan is a fan-shaped pile of sand and gravel that is deposited by water flowing into an open area like a crater.
- » River delta – A delta is a fan-shaped feature made of layered rocks deposited when flowing water encountered standing water in a lake or sea. They require a lot of water to form.
- » Lava flows – Areas that form a hard "cap" rock, often with lots of craters, might be lava flows which can be used to learn the ages of rocks on Mars.
- » Sand dunes – These moving piles of sand can carry minerals.
- » Yardangs - Wind erosion can sculpt soft rock into elongated, streamlined groups of ridges and hills called yardangs. These are most often found on the Earth in deserts.

2. Let youth know:
   - » They can rearrange the pages in the handout into different categories, and group them by site or by data type.
   - » Next, describe the four potential landing sites to youth (see optional handout at the end of this guide, p. 41).
     - Gale Crater - Gale is an impact crater 96 miles (154 km) across. The middle of the crater contains an unusual mountain that is 3.4 miles (5.5 km) tall. The area being considered as a landing site is in the north western part of the crater and includes the crater floor and the foothills of the central mountain. Near the base of the mountain there are black sand dunes.
     - Iani Chaos (ee-Ah-nee Kay-oss) – Iani is one of several "chaos" terrains on Mars, which are thought to form when a huge amount of underground water is released, causing giant floods and collapse of the area where the water was stored. The collapsed areas are called "chaos" terrains because they look jumbled and broken: chaotic. The possible landing site is in one small part of the Iani chaos.

- Jezero Crater (Jez-er-oh) – Jezero is a 30 mile (39 km) diameter crater, and the western part of the crater is being considered as a landing site. The western crater rim is eroded and a fan-shaped deposit extends out onto the crater floor. The floor itself has many small impact craters on it.

- Nili Fossae (Nee-lee Foss-eye) Trough – Nili Fossae is located in a large, long valley, called a "graben" or trough. The proposed landing site would be on the floor of this valley, near an area where the northwestern wall has been eroded.

3. Explain to youth that they will need to:

   » Study their data (CTX and HiRISE) of the four potential landing sites (Gale, Iani, Jezero, and Nili).

   » Look for an interesting place to land in the CTX image of each landing site and explain why they think that site is the best.

4. Pass out a landing site ellipse to each group. Tell youth:

   » Landing on Mars is difficult! We can be sure the rover will land in an area the size of this ellipse (16 km by 8 km; 10 miles by 5 miles), but we can't pinpoint the landing location any better than that.

   » Rovers can't drive very quickly or very far, so a scientifically interesting landing site should contain evidence for water within the ellipse or very nearby.

   » As a bonus challenge, groups can look for evidence of volcanic activity which is also scientifically interesting because it can tell scientists how old the rocks are and how geologically active the planet is.

5. Ask youth:

   » Within each CTX image, where would you put this landing site ellipse and why?

   » Decide with your group, and trace your chosen areas in the Gale, Iani, Jezero, and Nili CTX images. Reminder: Don't trace ellipses on the HiRISE images—the scale isn't the same.

6. Have youth record the landforms present at each site, the scientific significance of each landform, and rank the sites based on how scientifically interesting they are.

   » Guide youth to emphasize scientific significance in their ellipse placement, providing some time to update their initial landing locations if necessary.

Wrap Up (10 min)

1. Summarize by going through each site and leading a discussion about which images show geological features that indicate that water might have been there and why.

   » Describe why the areas you chose would be good landing sites –what's good or bad about each one?

   » What is the evidence for describing each area as "good" or "bad"?

2. Wrap up for the day by congratulating youth on their excellent scientific work. Let youth know that next time, they will use new data to learn more about the surface of Mars.

Site	**Landforms (water-related landforms are underlined)**
Gale	River valley, alluvial fan, layered rocks*, sand dunes, yardangs, craters
Iani Chaos	Layered rocks,* chaos terrain**, canyons, lava flow, sand dunes
Jezero	Delta, river valley, lava flow, crater rim, craters
Nili Fossae	Sand dunes, craters, lava flow, cliff

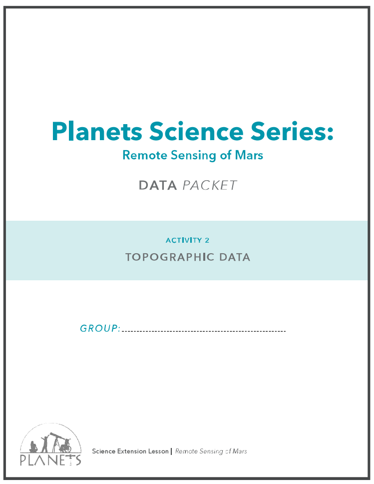
* Layered rocks are ambiguous. Sometimes they form in water, other times not.
** Chaos terrain itself (best seen in the Viking data online at planets-stem.org/remote-sensing) is thought to be water-related!

Activity 2: Landing Site Topography (40 min)

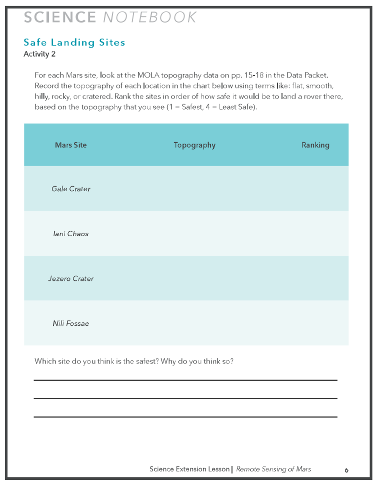
Overview

How can we use maps of landforms to learn more about the surface of Mars? In this activity, youth learn that topographic data can help us to choose a safe and interesting landing site.

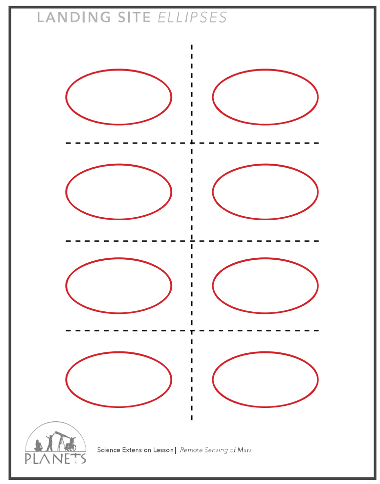
In this activity:



Topographic Data Packet
1 per group



Science Notebook
1 per youth



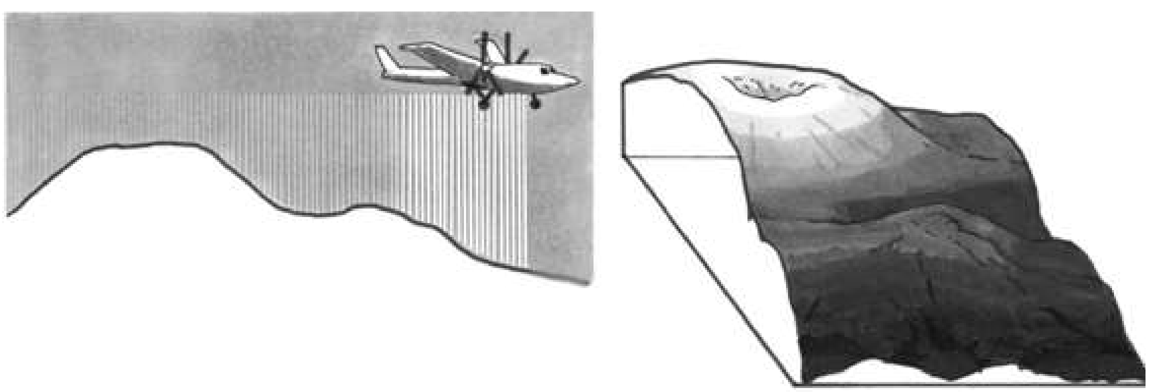
Ellipses Sheet
Cut out 1 ellipse per group

Introduction to LiDAR (5 min)

1. Hand out the MOLA Topography for each group to add to their data packets. These images also show the same area of interest as the CTX images.
   » If youth have previously completed the Worlds Apart engineering activities, ask them to think back to what LiDAR stands for, how LiDAR works and what it is used for.
   » LiDAR, or Light Detection and Ranging, is a tool that sends out laser pulses from an airplane or spacecraft to a landscape and measures how long those pulses take to return. The data gathered from LiDAR can be used to create precise, three-dimensional maps of the terrain.

2. Let youth know:
   » LiDAR is a technique used by scientists to study surfaces of the Earth and other planets.
   » LiDAR uses laser light bounced off the surface of a planet to measure the height of the surface.
   » The Mars Orbital Laser Altimeter (MOLA) is a LiDAR instrument that measured the elevation of the entire surface of Mars.

Interpreting LiDAR Data (10 min)



1. Use Jezero Crater: MOLA Topography (Data Packet, p. 13) to guide youth through the following prompts:
   » Ask youth to explain what they think the color scale means. (The colors represent elevation: Yellow = high elevation, blue = low)
      - If printed in black and white: brighter = high elevation, darker = low.

- » Ask youth to explain what they think the contour lines mean.
    - Each line traces constant elevation. Think of a ring left around the bathtub.

- » Point to different parts of the crater and ask youth to interpret the steepness of the terrain based on the contours.
    - Where there are a lot of contour lines close together, the slope is very steep - like hills or mountains. Where they are widely spaced, the slope is shallower – like a flat plain or field. The color scale tells the direction of the slope.

- » Ask youth what the criteria might be for a good landing site. A landing site should be on a flat surface, not on a steep surface.

- » Point to different parts of the crater and ask youth to interpret the elevation based on the color.
    - The crater rim is high. The crater floor is low.

Analyzing the Site (15 min)

1. Give youth time to look at and describe the topography of each site with their group. Remind them to also look at their CTX and HiRISE data.
    - » Have each group share their ideas with everyone.
    - » Have youth record their observations of the topography of each site in the table on p. 5 of their Science Notebooks.

2. Ask youth:
    - » Why do you think scientists are interested in topographic data? *Topography can help identify and interpret landforms.*
    - » Why do you think engineers responsible for landing a rover on Mars are interested in topographic data? *Topography can reveal areas that are safe for landing.*

- What things can they learn from topography that is uncertain in the CTX photos? *It can be hard to tell what areas are high or low from visible images alone*.
- How did topographic data help you understand the landforms in the different landing sites?

3. Now ask youth to trace a new landing ellipse within each of the four potential landing sites, using the Ellipses from the last activity.
   - Tell youth: "Using the ellipse, trace one or more ovals (16x8 km) indicating where you think it might be safe and scientifically interesting to land at each of the four potential landing sites."
     - Remind youth that a safe landing site should be flat (or as close to flat as possible)
     - Remind youth that a scientifically interesting site should be on or near landforms that indicate past water or volcanic activity (both is even better).

4. Ask youth to rank the sites in order of best to worst in terms of safety in the table on p. 5 of their Science Notebooks.

Wrap Up (10 min)

1. Summarize by going through each site and leading a discussion about the topography and landforms at the four sites. Ask:
   - After looking at the CTX and MOLA Topography images, do you have any better sense of where the best landing site might be?
   - Did your rankings change with the addition of new topography data?
   - How/why did the topography data change your decision about the best places to land?

2. Reinforce the connection between evidence for past water on Mars and habitability for life so that youth can use this information later on in the activities.

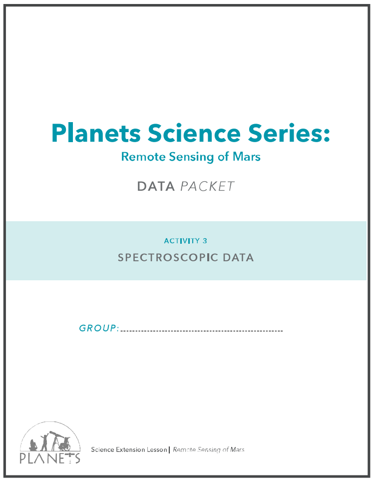
3. Wrap up for the day by congratulating youth on their scientific work. Let youth know that next time, they will look at one more way they can collect remote sensing information about sites on Mars.

Activity 3: Mineral Fingerprinting (40 min)

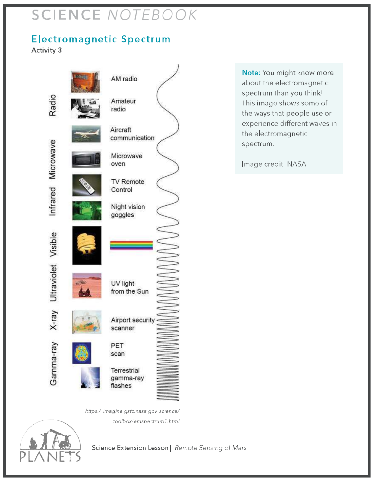
Overview

How can we use minerals to help us identify where water may have been on Mars? In this activity, youth learn that spectroscopy lets us see the “fingerprints” of different minerals. They examine images of regions on Mars and use spectral data to decide which location has the most evidence for past water on Mars, based on the minerals they discover.

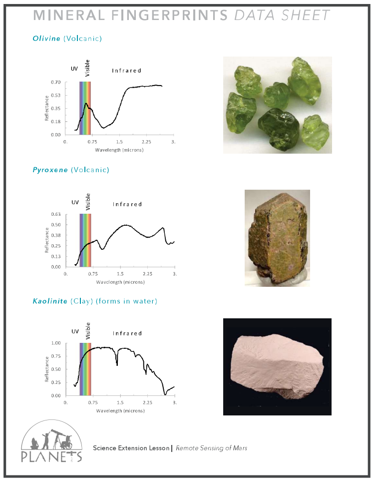
In this activity:



Spectroscopic Data Packet
1 per group



Science Notebook
1 per youth



Mineral Fingerprints Data Sheets
1 per group

Introduction to Spectrometry (10 min)

1. Ask youth to look at the electromagnetic spectrum figure on pg. 6 in their Science Notebooks and let them know that this diagram shows all the wavelengths of light, even the ones that our eyes can't see. Tell youth that remote sensing instruments called spectrometers can help us see many other types of light that our eyes cannot detect.

> **Note:** For more on what the rainbow would look like to other animals, listen to this episode of Radiolab: https://www.wnycstudios.org/podcasts/radiolab/segments/211178-rip-rainbow

» Some other animals can see types of light that humans can't. For example, butterflies can see ultraviolet light, certain snakes can detect infrared light, and an animal called the mantis shrimp may be able to see an enormous range of colors beyond what we can.

2. Let youth know that spectrometers measure light in different wavelengths/colors, including those that the human eye can't see. The measured spectral data are graphed to show how much light of each wavelength was measured. This graph is called a spectrum. The shape of the spectrum can tell us what rocks and minerals are on the surface of Mars.

> **Tip:** "Spectrum" is singular and "spectra" is the plural form of the same word.

3. Explain that all materials (including minerals) either absorb or reflect different colors of light, so each unique spectrum is like a "fingerprint" that can be used to identify the material.

» The concept of spectra builds upon the color filters used in the Engineering Everywhere Worlds Apart: Engineering Remote Sensing Devices activities, available at planets-stem.org/remote-sensing. If you measured the brightness of something using a lot of different filters, each tuned to a specific wavelength of light, you would end up with a spectrum. In other words, using a filter lets us see the light from one specific piece of the full spectrum.

Observing Different Spectra (15 min)

1. Have youth refer to the figure on p. 7 in their Science Notebooks showing the spectra of summer and fall leaves. Guide them to understand what the red and green lines mean: they show how much light is reflected from the leaf at each wavelength. Point out the rainbow representing the part of the electromagnetic spectrum that is visible to humans.

   » Ask youth to make observations of the two spectra. The spectrum of the green leaf shows the highest reflectance at the wavelengths of green light, so the leaf is reflecting mostly green light and appears green to our eyes. The spectrum for the red leaf is highest at the wavelengths of red light, so it reflects mostly red light and appears red to our eyes.

2. Now ask youth to refer to the figure on p. 8 in their Science Notebooks showing the spectrum of Olivine, a mineral found in volcanic rocks on Earth and Mars.

   » Ask youth to make observations about the spectrum and predict what color they think olivine would look like to the eye. Compare Olivine's spectrum on p. 8 of the Data Packet to that of the green leaf on p. 7 of the Science Notebook. Although the scales and graphs are different, both have the highest peak in the visible spectrum (the only part our eyes can see as indicated with the rainbow) in the green part, so they both probably look green.

3. Hand out to each group one copy of the Mineral Fingerprints Data Sheet.

   » Point out the olivine minerals on the fingerprint sheet: they are green!

   » Reiterate that a spectrum shows how much light is reflected at each color (or wavelength). Point out that the rainbow on each plot on the Mineral Fingerprints sheet shows the range of light that the human eye can see, but the spectrometer sees many other types of light that our eyes cannot detect, like ultraviolet and infrared.

   » Optional: Give youth time to look at the other minerals on the fingerprint sheet and compare their spectra to their colors in the pictures.

      » Point out the type of material - clay, volcanic, sulfate

Explore Spectrometry Data (10 min)

1. Pass out the Spectroscopic Data Packets to each group. Tell youth that CRISM is a spectrometer on-board the Mars Reconnaissance Orbiter.

2. Tell youth that they will now use spectroscopy to help them find the best landing site on Mars. They should look for water-related minerals like clays and sulfates, that might indicate evidence of past water (and therefore habitability).

3. Explain that each patterned area on the CRISM Data images in their data packets has a corresponding spectrum.

4. Ask youth to turn to p. 9 in their Science Notebooks and read the directions. They will compare the spectra for each site to the Mineral Fingerprints Data Sheet.

5. Invite groups to write the minerals found at each site in the table on p. 9 in their Science Notebooks and rank the sites based on which sites show the most water-related minerals.

   » Optional: To make this activity more challenging, rather than simply tallying the number of water-related minerals, have youth consider which minerals the rover could actually access from a safe landing ellipse and which might be too far away or in places with dangerous topography.

   » Volcanic minerals are also interesting in this scenario, because they can be analyzed to tell how old the rocks are.

Notes: These patterned areas are idealized and simplified, but in most cases, they are based on actual CRISM observations of these locations on Mars. The minerals listed really are at these locations! They are based on actual CRISM observations of these locations on Mars.

"Spectra" is the plural form of "spectrum"

Reflect (5 min)

1. Summarize by going through each site and leading a discussion about which minerals are present. Which sites do youth think might have once had water based on the minerals detected? *See table below for educator reference but do not show it to youth until after Activity 4.*

2. Let youth know that next time, they will put together everything they have learned from their explorations of Mars and choose a site for the rover to land.

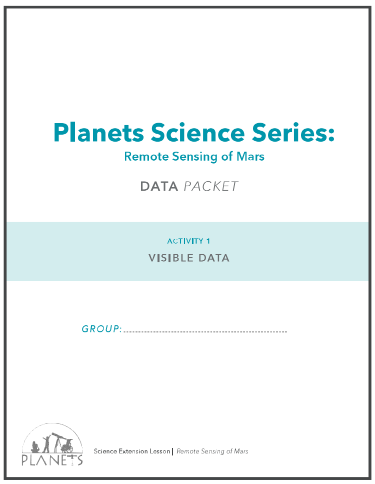
Site	Minerals (water-related minerals are underlined)
Gale	Olivine, <u>Nontronite, Kieserite</u>
Jezero	Olivine, Pyroxene, <u>Kaolinite, Magnesite</u>
Nili Fossae	Olivine, Pyroxene, <u>Nontronite</u>
Iani Chaos	Pyroxene, <u>Kieserite</u>

Activity 4: Choosing a Landing Site and Share Out (55 min)

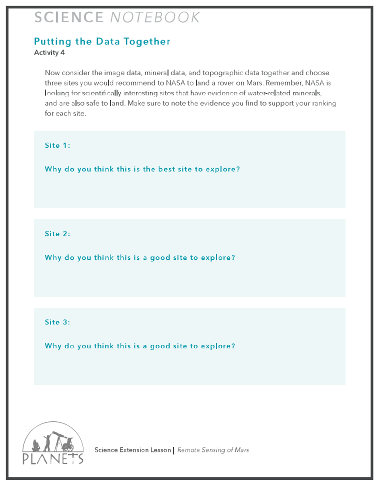
Overview

How can we choose a landing site that will meet our criteria? How can we share what we found out? In this activity, youth consider all the data they have collected during the previous activities to decide which location will be the most scientifically interesting, choose their landing site, and then present their findings to the class.

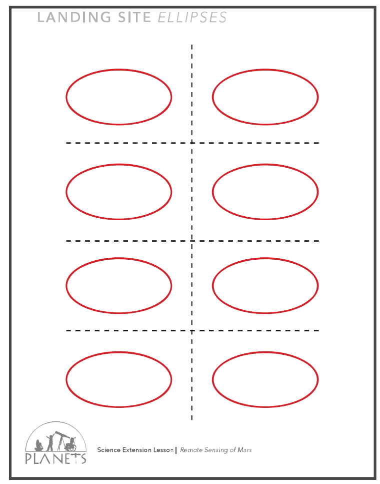
In this activity:


Planets Science Series:
Remote Sensing of Mars
DATA *PACKET*
ACTIVITY 1
VISIBLE DATA
GROUP:
PLANETS
Science Extension Lesson | *Remote Sensing of Mars*

All Data Packets
1 per group


SCIENCE *NOTEBOOK*
Putting the Data Together
Activity 4
Now consider the image data, mineral data, and topographic data together and choose three sites you would recommend to NASA to land a rover on Mars. Remember, NASA is looking for scientifically interesting sites that have evidence of water-related minerals, and are also safe to land. Make sure to note the evidence you find to support your ranking for each site.
Site 1:
Why do you think this is the best site to explore?
Site 2:
Why do you think this is a good site to explore?
Site 3:
Why do you think this is a good site to explore?
PLANETS
Science Extension Lesson | *Remote Sensing of Mars*

Science Notebook
1 per youth



1-2 ellipses per group

Introduction (5 min)

1. Let youth know that today they will need to consider all the data they have collected over the previous activities and choose the most scientifically interesting location for their landing site.

2. Let youth know that as they review their data, they should keep in mind that they will need to share their results with the class, so they should think about the evidence they use to make their decision and how they will explain their reasoning.

Prepare for the Presentation (15 min)

1. Ask groups to review their data by looking in their Science Notebooks at the three tables with sites ranked based on (1) Landforms visible in images, (2) Safety based on topography and images, and (3) minerals detected.

2. Have youth use pp. 10-11 in their Science Notebooks and the Landing Site Ellipses Sheet to help them prepare a presentation about the landing site they select. Let them know they will share their presentation with the class and invited guests, if it is possible to do so at your site.

3. As groups are working, help guide their thinking by asking:
   - » What evidence did you look at to help you choose your landing site?
   - » Which site do you think will be the most scientifically interesting? Why?
   - » What surprised you about working with the data?
   - » What is one thing you will remember about the exploration of Mars?

Tip: The presentation is a chance for youth to explain their thinking and reflect on what they learned about remote sensing throughout the unit. Youth can present and share in a variety of ways, including:

» Invite youth to rank the landing sites based on all the available information.

» Ask youth to write a compelling argument to NASA about which scientifically interesting site should be selected.

Share Out and Discussion (30 min)

1. Ask groups to share which site they determined to be the most scientifically interesting. As each group shares, ask them to refer to their Data Packets and provide examples of evidence that led to their recommendation and to explain their thinking. After each group presents, ask questions like:

   » What surprised you about working with the data?

   » What is one thing you will remember about Mars?

2. After all groups have shared, ask: Is there consensus on where to send a spacecraft that would be scientifically interesting and safe to land?

3. Discuss how landing at sites selected using remote sensing data allows scientists to learn as much as possible about Mars to help answer their questions. Sometimes, there are multiple sites that could be considered scientifically interesting, so the evidence scientists use to explain their reasoning is really important.

4. Congratulate youth on their excellent scientific work. Let them know that they have just followed a process very similar to what NASA scientists and engineers do when choosing landing sites!

Wrap Up (5 min)

1. Conclude the session by letting youth know what really happened when scientists and engineers had to choose a landing site for the Perseverance rover:

   » Gale Crater was the site chosen as the landing site for the NASA Curiosity rover, which landed there in 2012 and has been exploring ever since.

   - Exciting NASA video about the challenges of landing Curiosity at Gale crater: “Seven Minutes of Terror” - https://www.jpl.nasa.gov/video/details.php?id=1090
   - To learn more about the Curiosity rover and see pictures from inside Gale crater, visit: https://mars.nasa.gov/msl/

- Jezero crater was chosen in 2018 for the Perseverance rover.
    - Jezero was chosen because deltas form in lakes and they are very good at concentrating and preserving evidence for past life.
    - Perseverance will collect rock and soil samples from Jezero that may be retrieved by a later mission and returned to Earth for scientists to study in the laboratory.
    - To learn more about the Perseverance rover, and see pictures from Jezero crater after the rover lands in February of 2021, visit: mars.nasa.gov/mars2020/

- Iani Chaos and Nili Fossae were both considered as landing sites but were ruled out. Iani Chaos was too rough, and although both sites have water-related minerals, they lacked water-related landforms.

Possible Landing Sites on Mars

- Gale Crater - Gale is an impact crater 96 miles (154 km) across. The middle of the crater contains an unusual mountain that is 3.4 miles (5.5 km) tall. The area being considered as a landing site is in the north western part of the crater and includes the crater floor and the foothills of the central mountain. Near the base of the mountain there are black sand dunes.

- Iani Chaos (ee-Ah-nee Kay-oss) – Iani is one of several “chaos” terrains on Mars, which are thought to form when a huge amount of underground water is released, causing giant floods and collapse of the area where the water was stored. The collapsed areas are called “chaos” terrains because they look jumbled and broken: chaotic. The possible landing site is in one small part of the Iani chaos.

- Jezero Crater (Jez-er-oh) – Jezero is a 30 mile (39 km) diameter crater, and the western part of the crater is being considered as a landing site. The western crater rim is eroded and a fan-shaped deposit extends out onto the crater floor. The floor itself has many small impact craters on it.

- Nili Fossae (Nee-lee Foss-eye) Trough – Nili Fossae is located in a large, long valley, called a “graben” or trough. The proposed landing site would be on the floor of this valley, near an area where the northwestern wall has been eroded.

Planets Science Series:

Remote Sensing of Mars

DATA *PACKET*

ACTIVITY 1

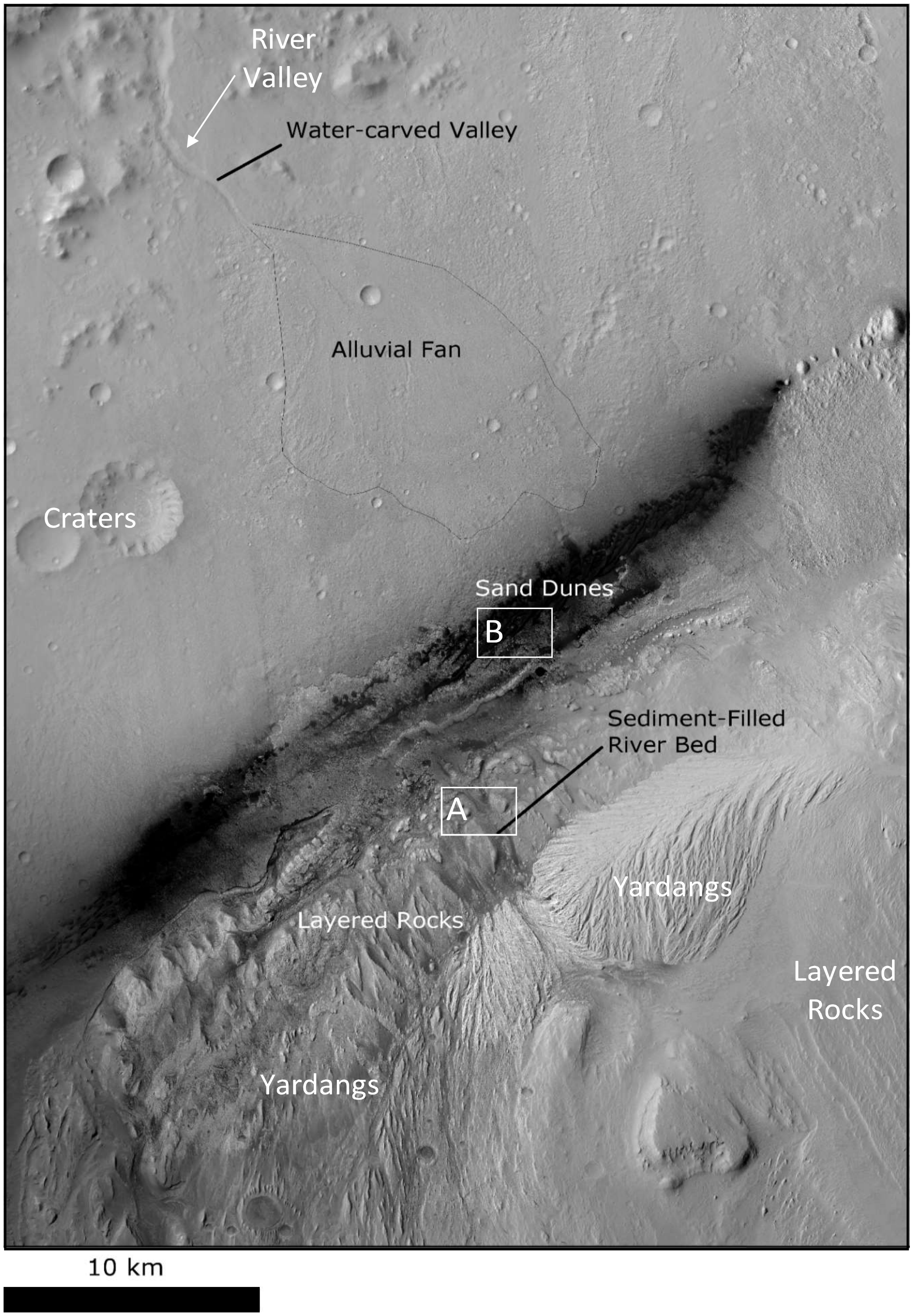
VISIBLE DATA

GROUP: --

DATA *PACKET*

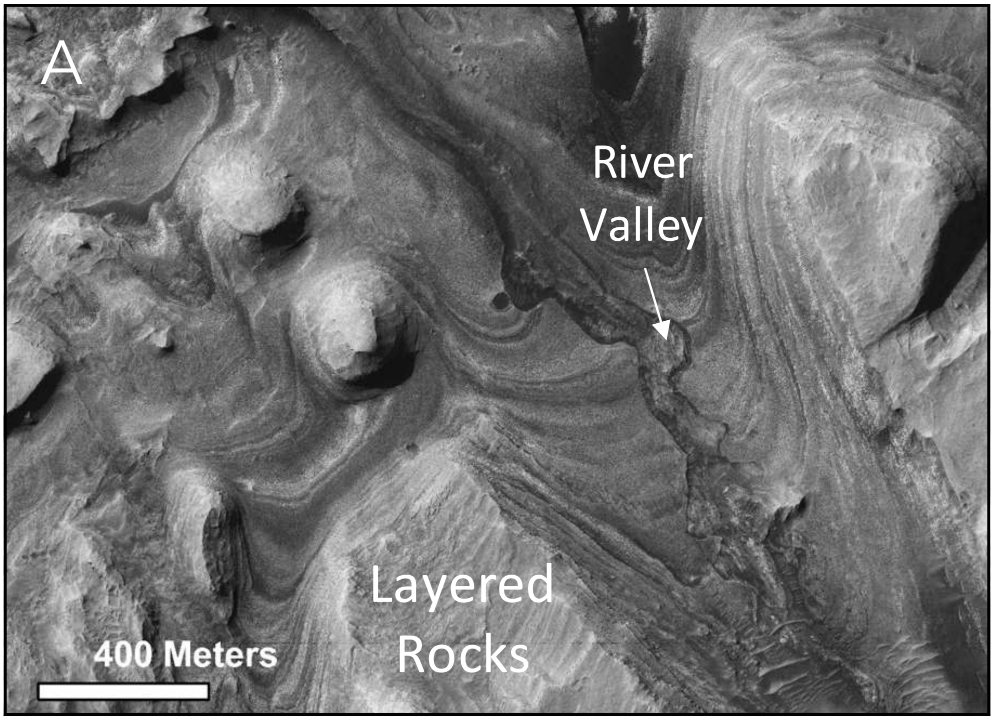
Activity 1 Gale Crater: CTX

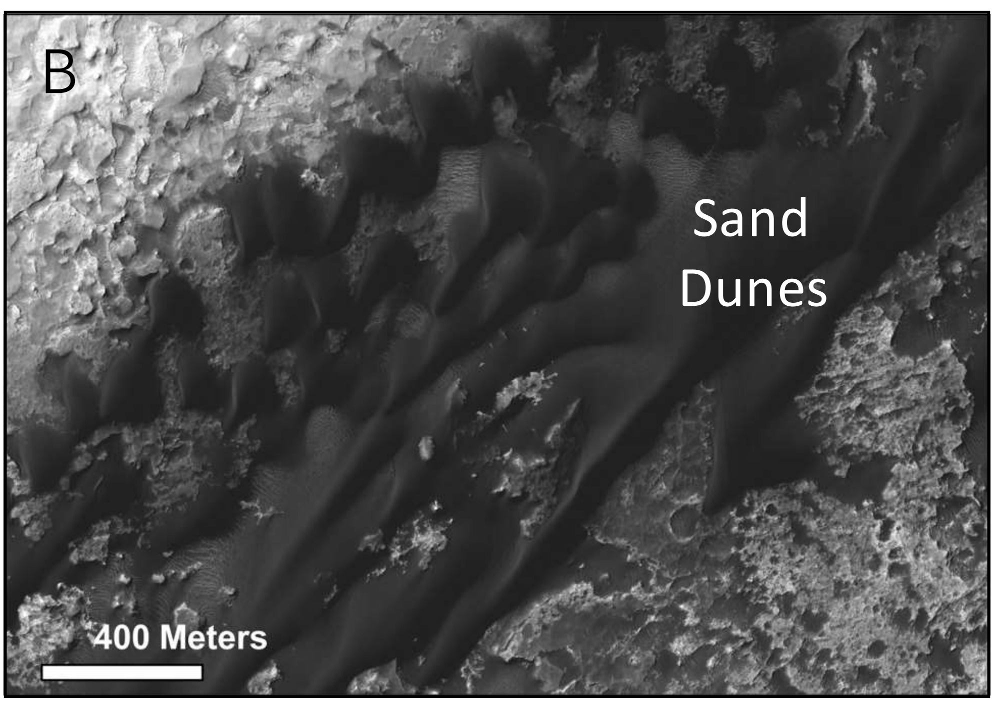
Black and white high resolution Context Camera (CTX) image of the **Gale Crater** site.



Activity 1 Gale Crater: HiRISE

Black and white very high resolution HiRISE images of the **Gale Crater** site.

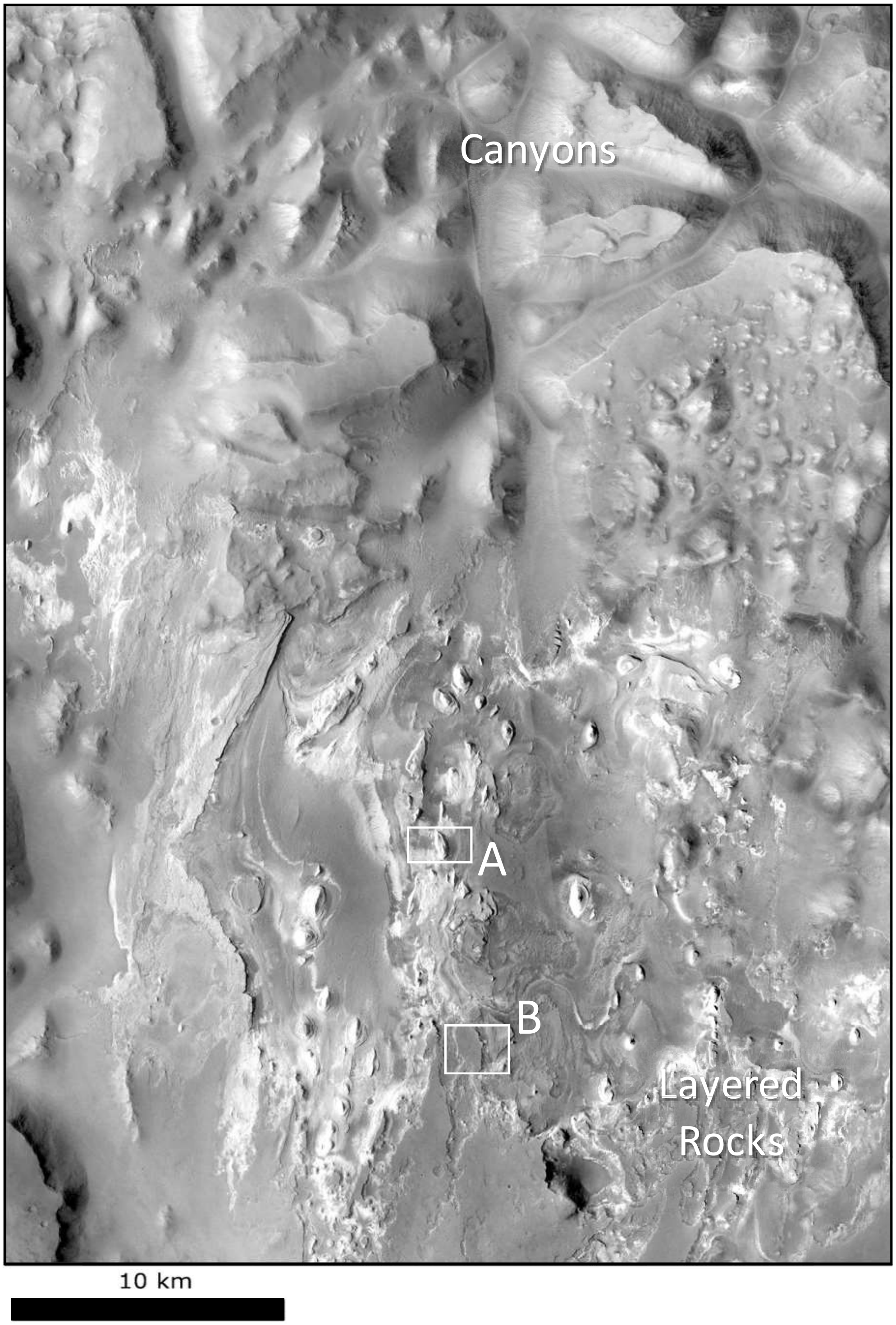




DATA *PACKET*

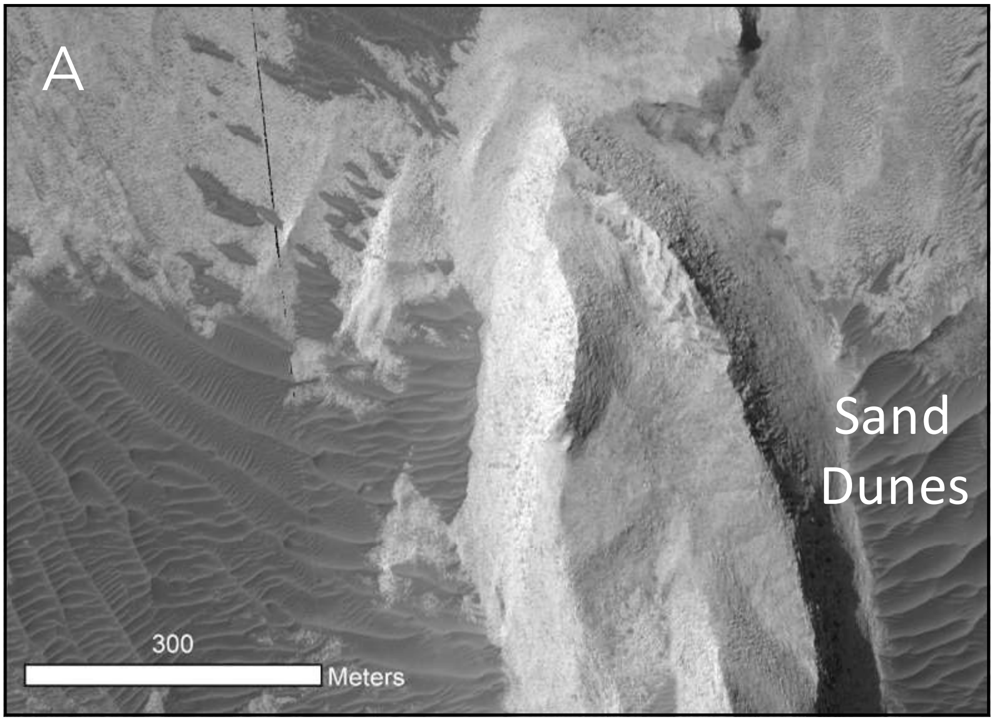
Activity 1 Iani Chaos: CTX

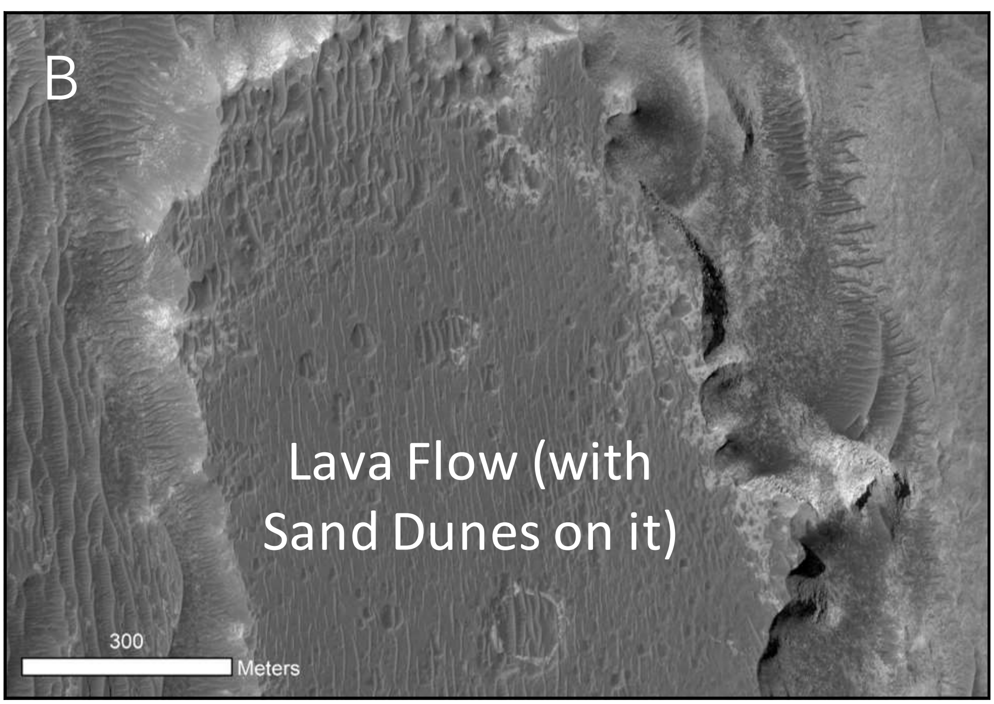
Black and white high resolution Context Camera (CTX) image of the **Iani Chaos** site.



Activity 1 Iani Chaos: HiRISE

Black and white very high resolution HiRISE images of the **Iani Chaos** site.

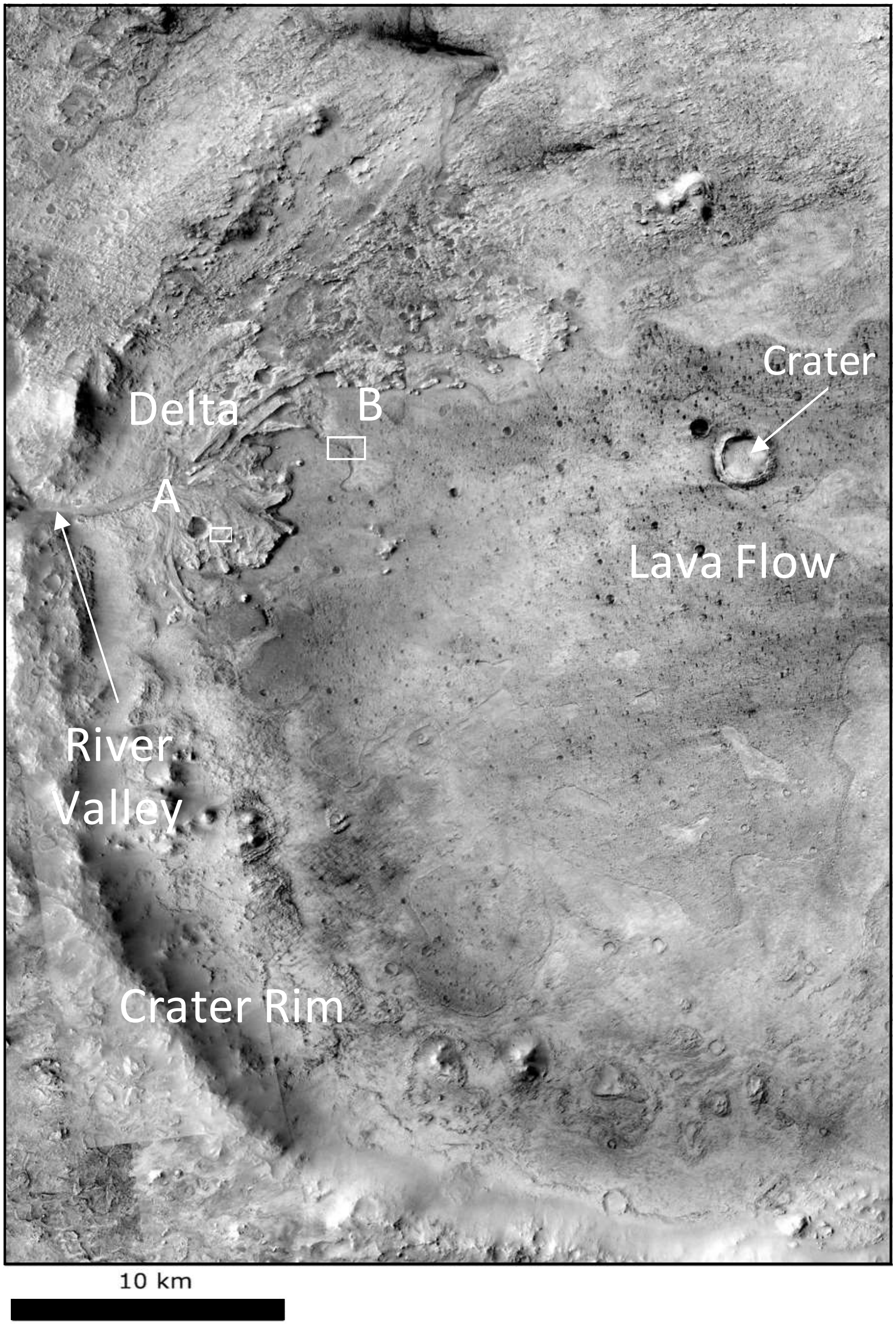




DATA *PACKET*

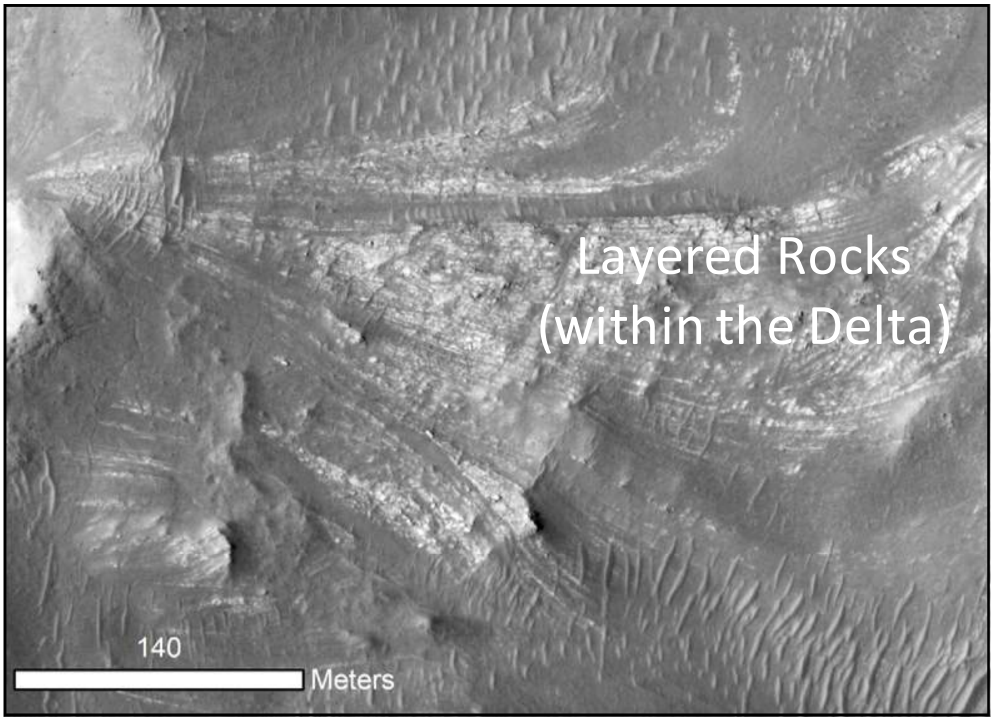
Activity 1 Jezero Crater: CTX

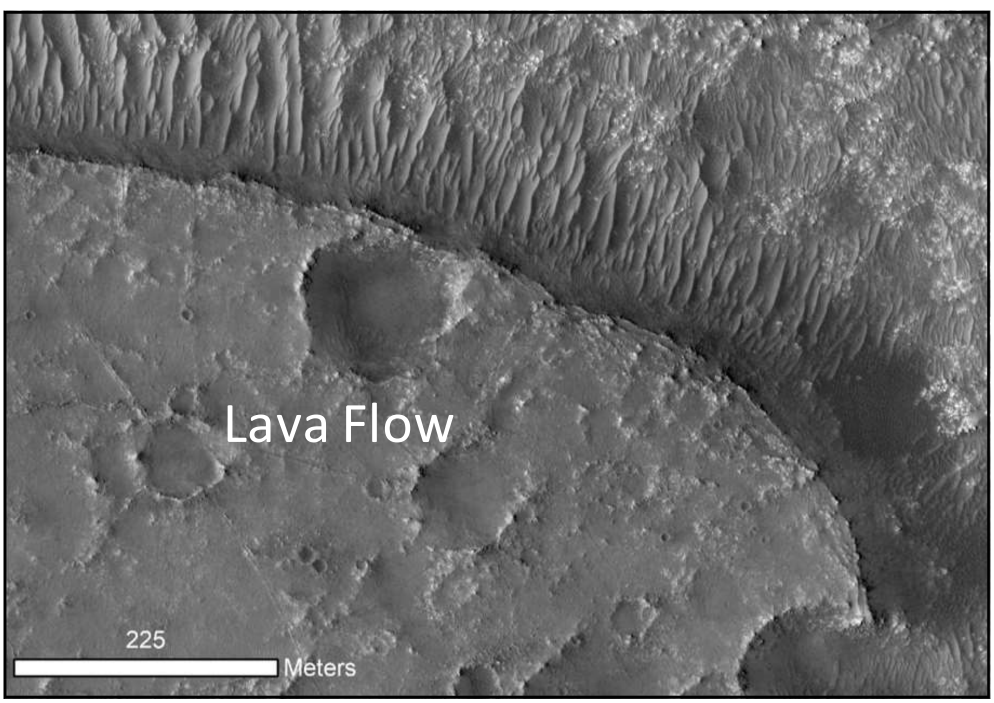
Black and white high resolution Context Camera (CTX) image of the **Jezero Crater** site.



Activity 1 Jezero Crater: HiRISE

Black and white very high resolution HiRISE images of the **Jezero Crater** site.

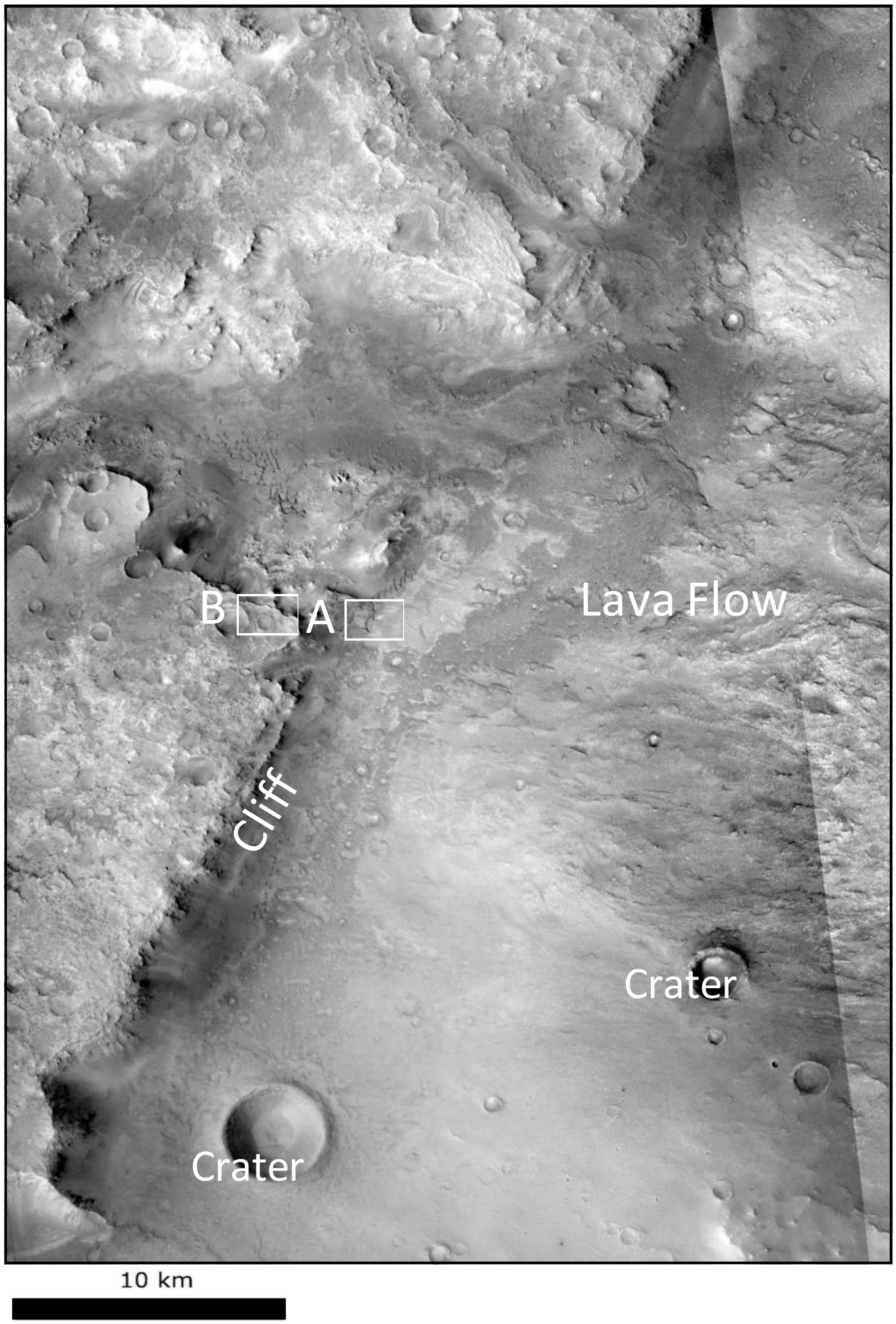




DATA *PACKET*

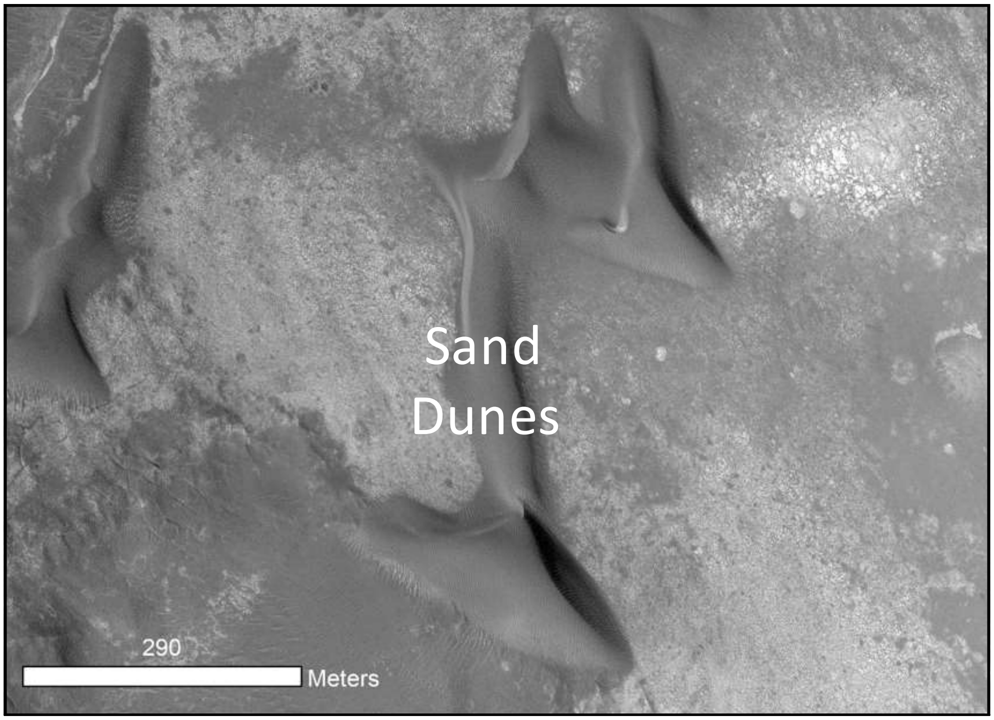
Activity 1 Nili Fossae: CTX

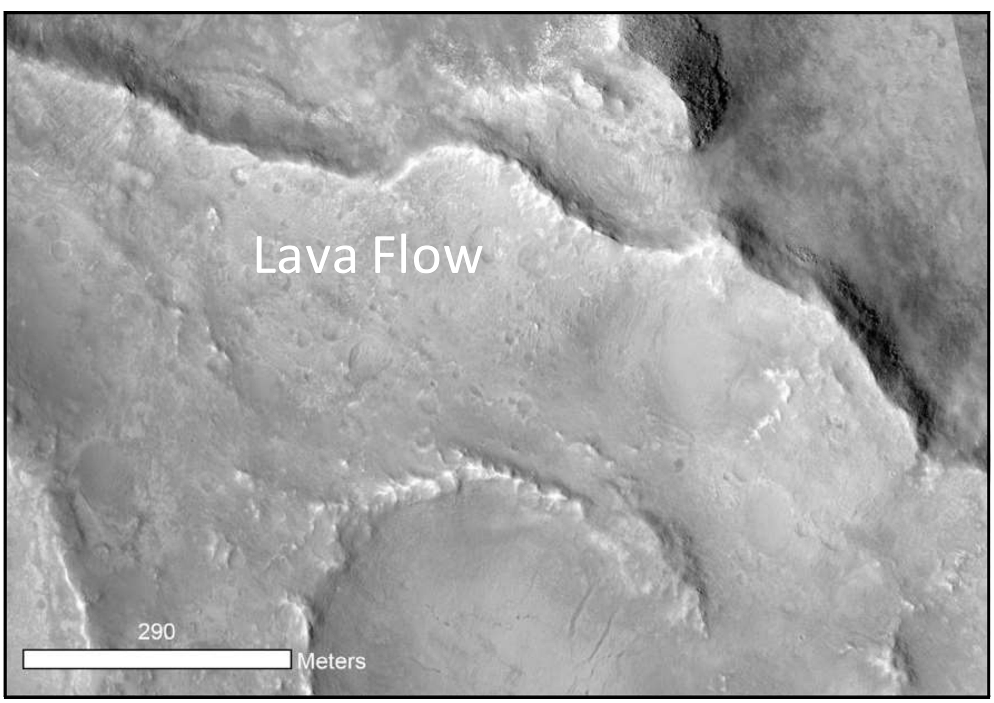
Black and white high resolution Context Camera (CTX) image.



Activity 1 Nili Fossae: HiRISE

Black and white very high resolution HiRISE images of the **Nili Fossae** site.





Planets Science Series:

Remote Sensing of Mars

DATA *PACKET*

ACTIVITY 2

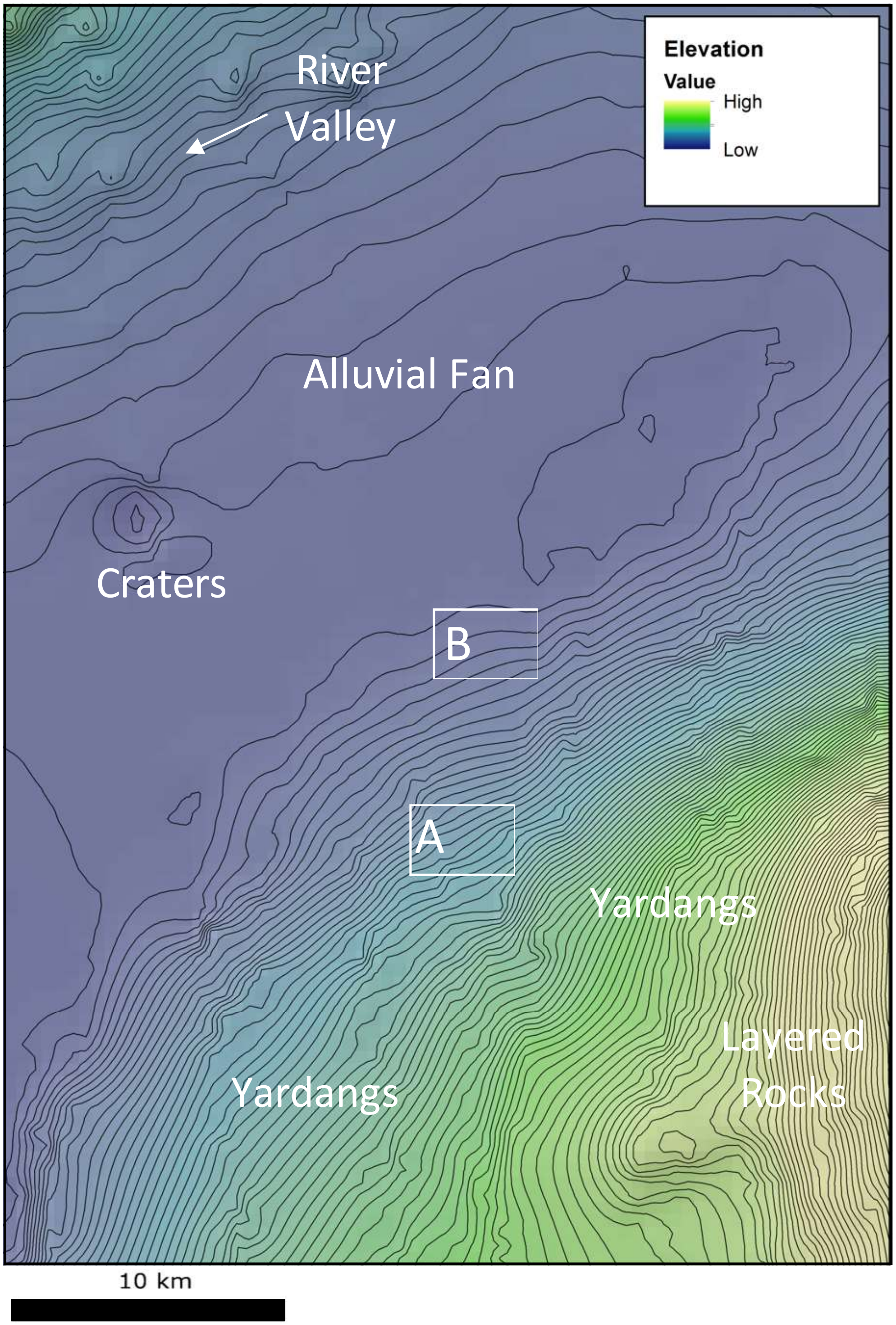
TOPOGRAPHIC DATA

GROUP: --

DATA *PACKET*

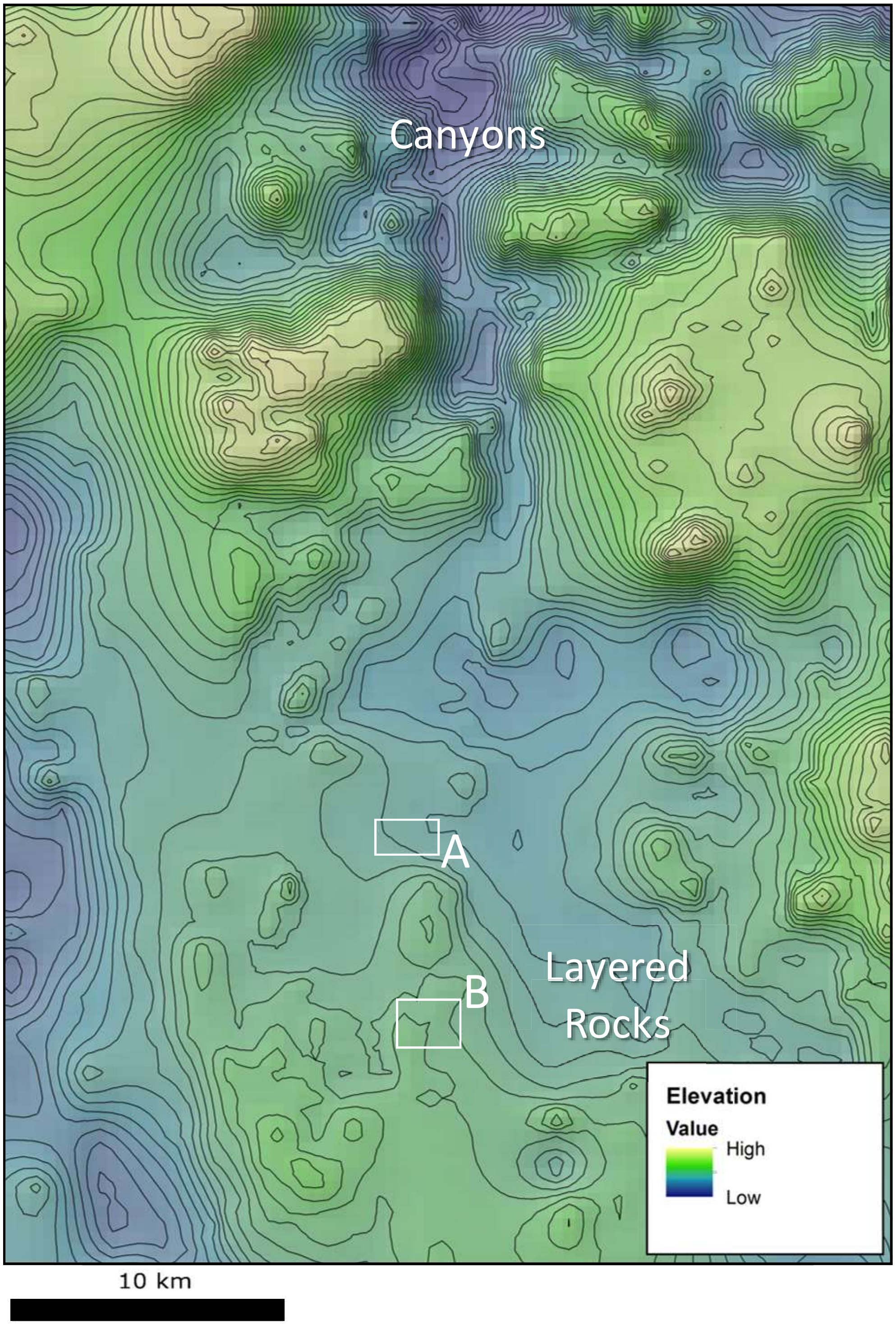
Activity 2 Gale Crater: MOLA Topography

Color indicates elevation, and contours are spaced every 50 meters. Areas where contours are closer together have steeper slopes.



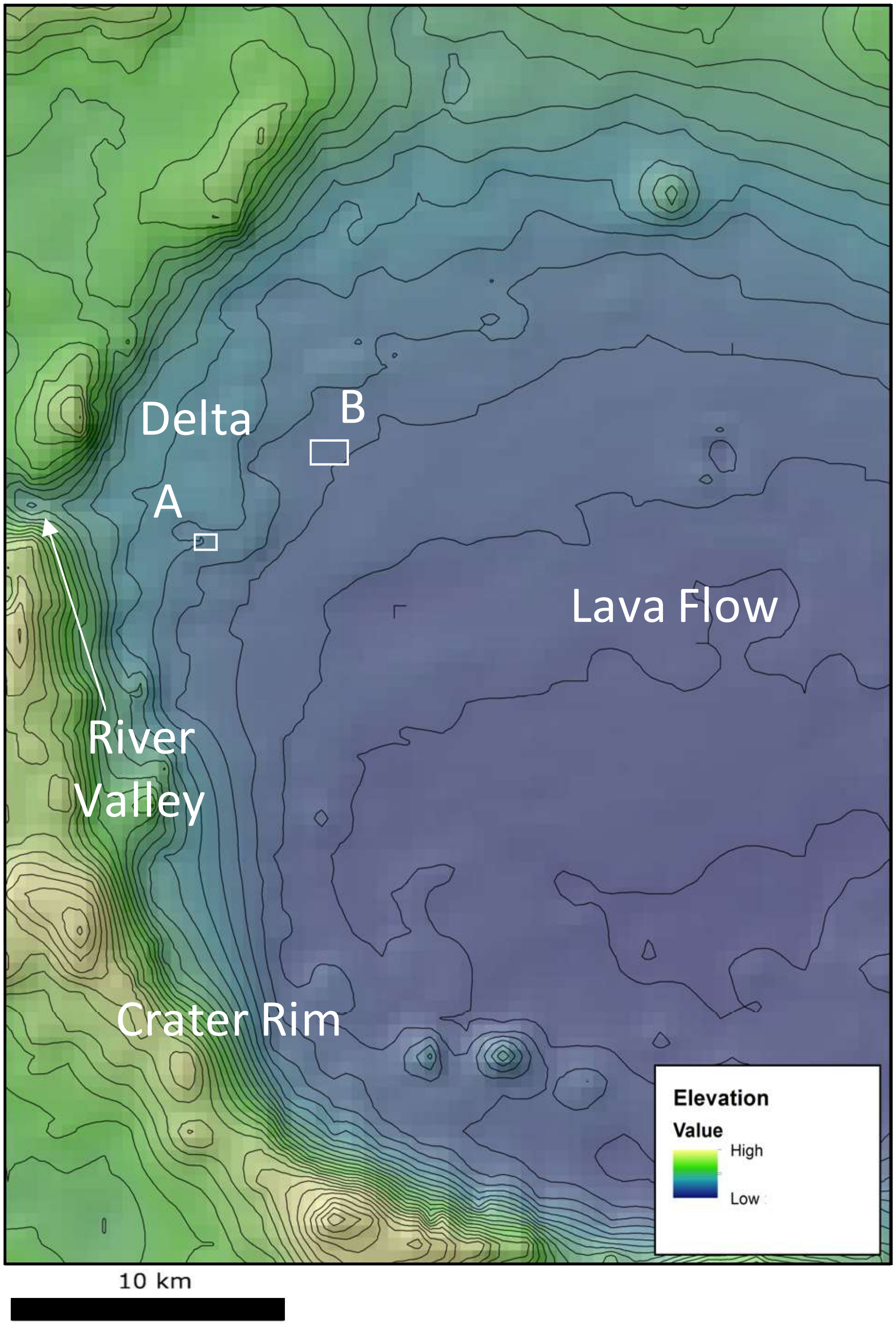
Activity 2 Iani Chaos: MOLA Topography

Color indicates elevation, and contours are spaced every 50 meters. Areas where contours are closer together have steeper slopes.



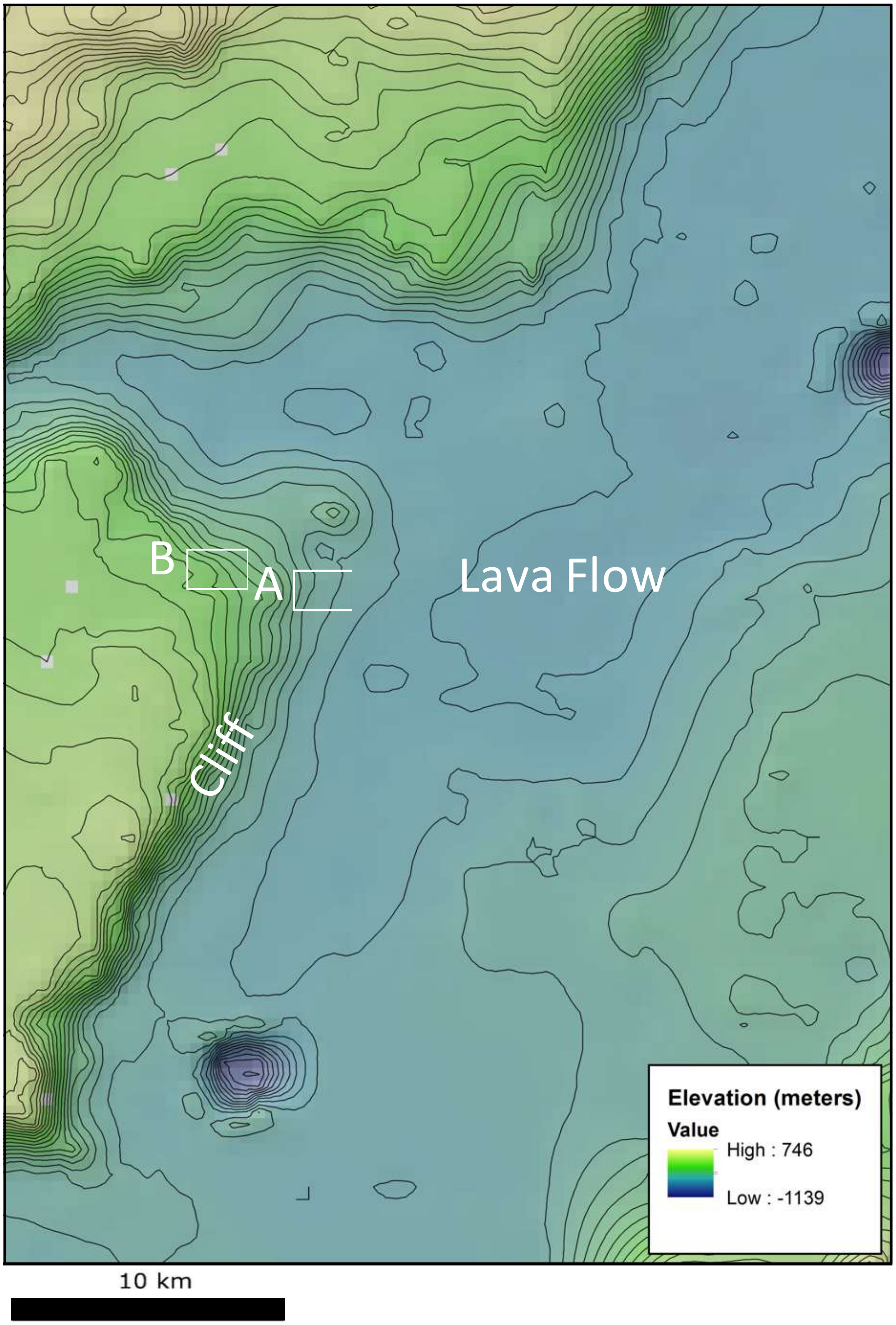
Activity 2 Jezero Crater: MOLA Topography

Color indicates elevation, and contours are spaced every 50 meters. Areas where contours are closer together have steeper slopes.



Activity 2 Nili Fossae: MOLA Topography

Color indicates elevation, and contours are spaced every 50 meters. Areas where contours are closer together have steeper slopes.



Planets Science Series:

Remote Sensing of Mars

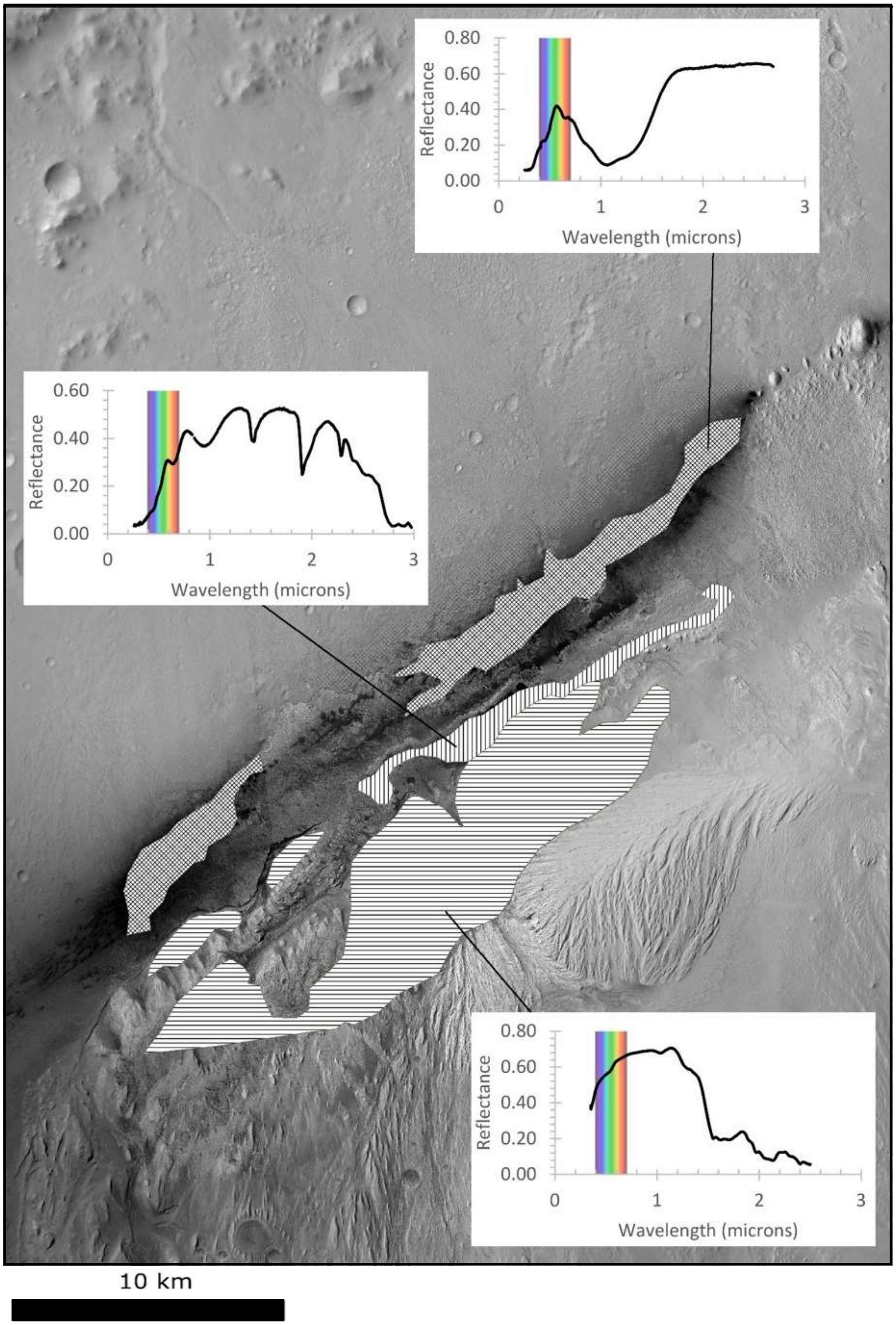
DATA *PACKET*

ACTIVITY 3

SPECTROSCOPIC DATA

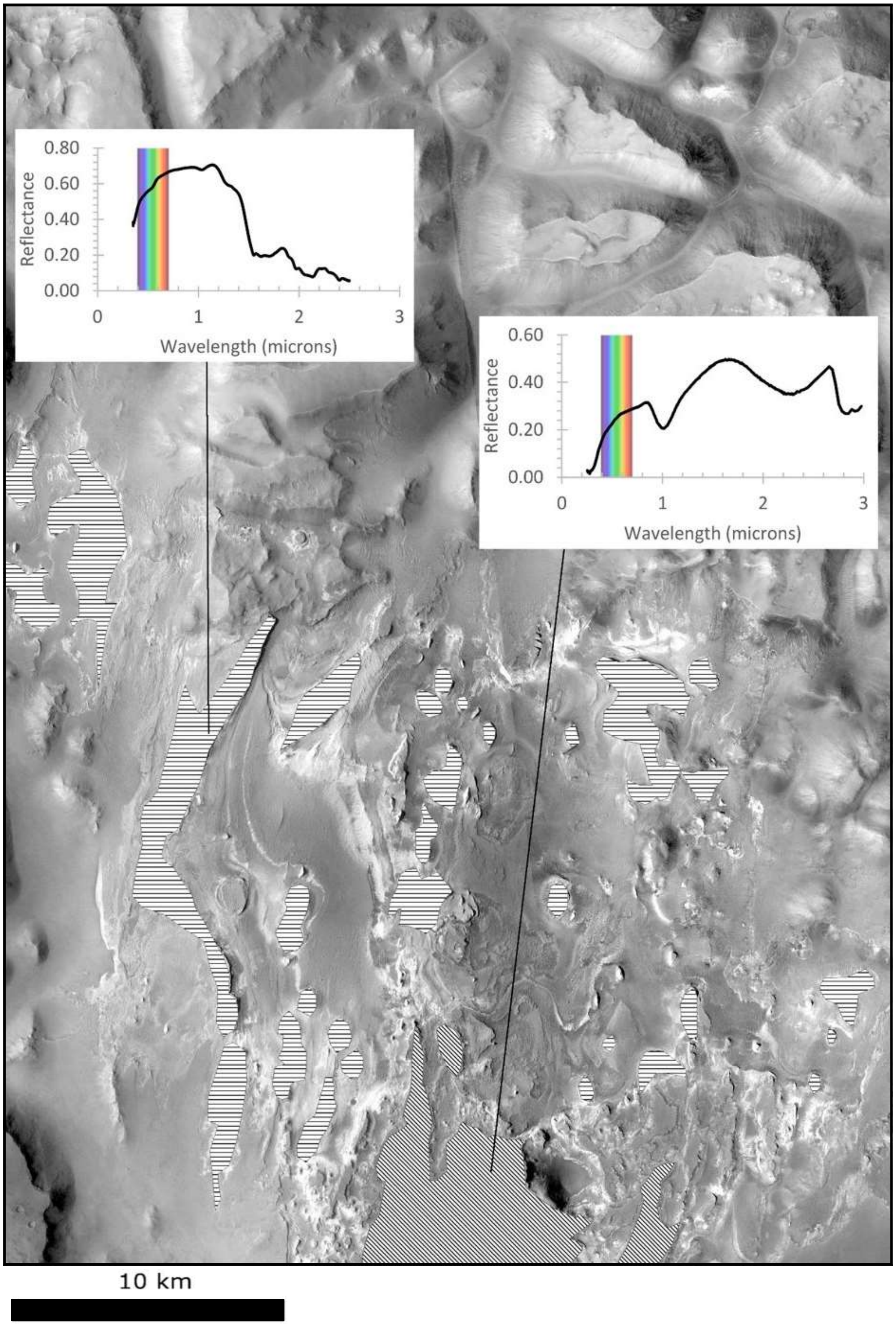
GROUP: --

Activity 3 Gale Crater: CRISM Data



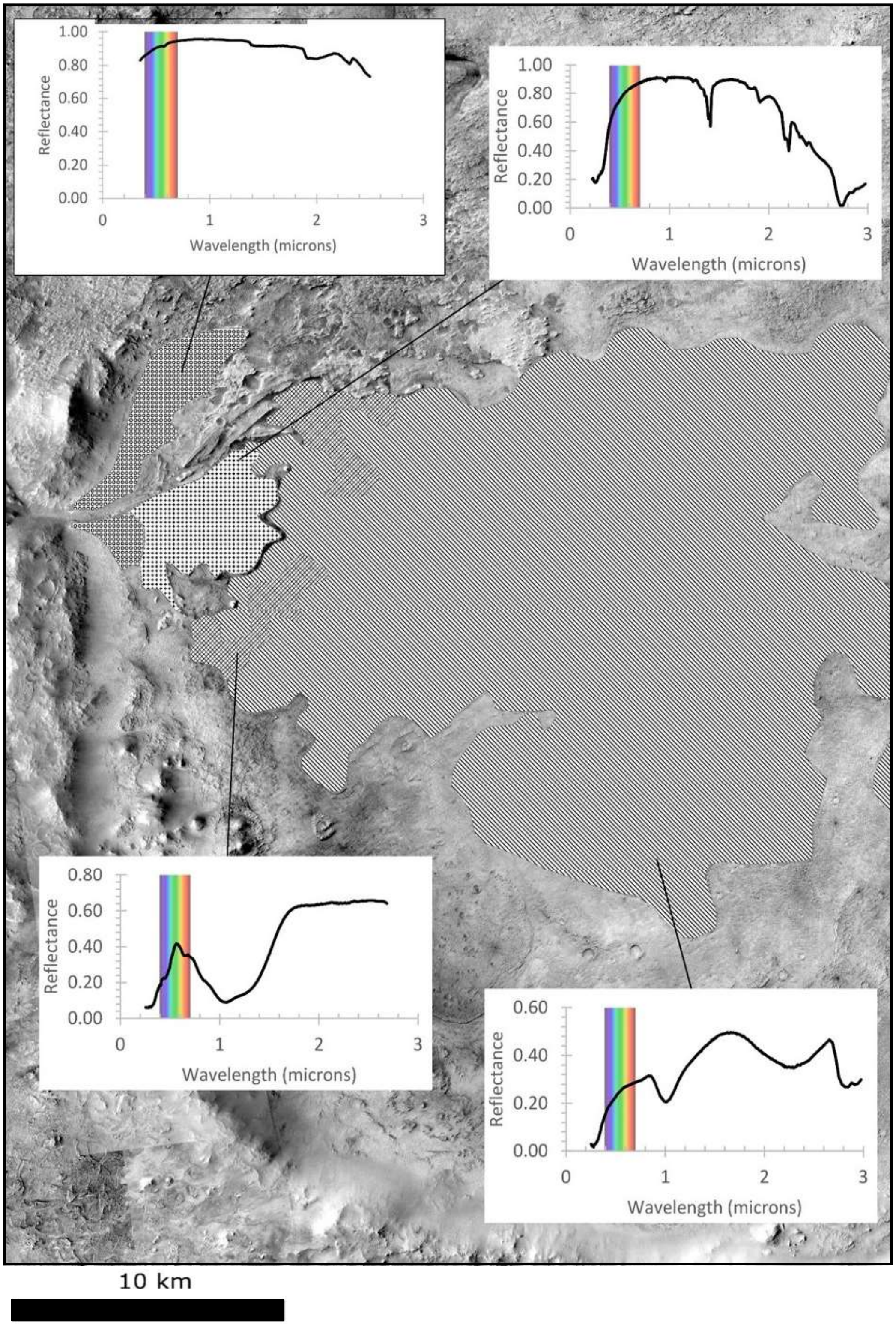
DATA *PACKET*

Activity 3 Iani Chaos: CRISM Data



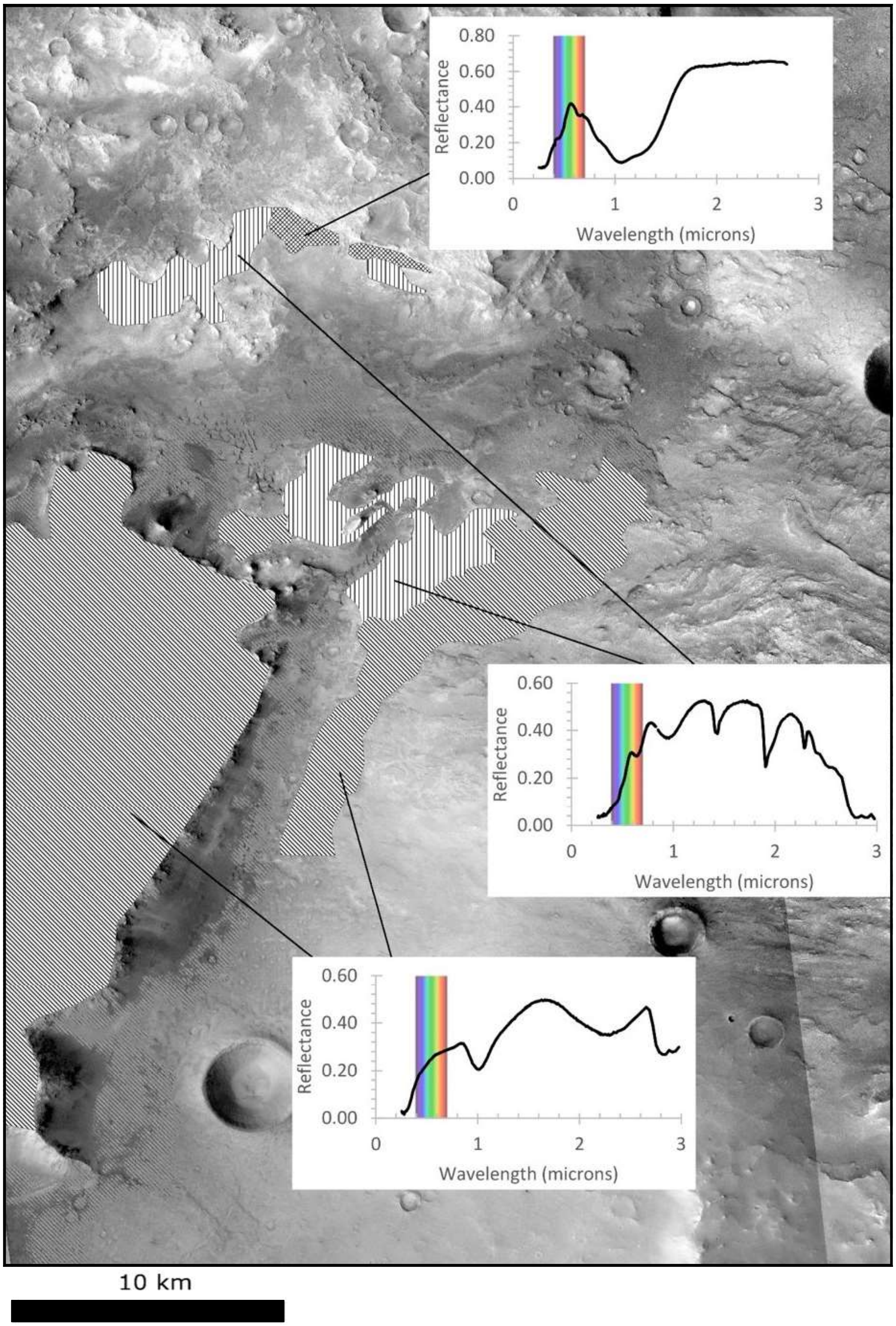
DATA *PACKET*

Activity 3 Jezero Crater: CRISM Data



DATA *PACKET*

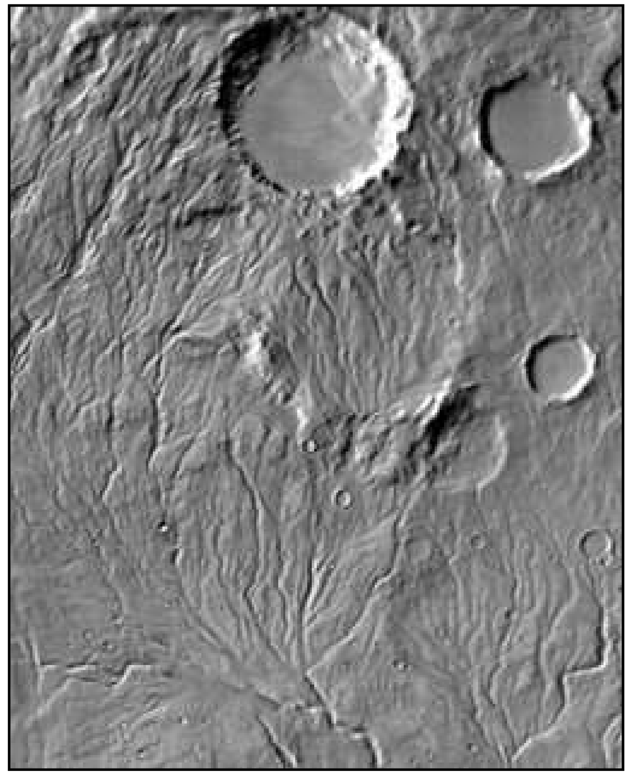
Activity 3 Nili Fossae: CRISM Data



LANDFORMS *HANDOUT*

River valleys: A river valley is a long, narrow region of low land between ranges of mountains, hills, or other high areas, formed by the erosion of land by running water. The presence of valleys indicates that water once flowed and eroded the landscape.

Google Earth image of a branching network of water-carved channels in the Atacama desert in South America, one of the driest places on Earth, receiving less then 15 mm of rainfall every year.



Warrego Vallis, Mars. The branching network of valleys is evidence that there used to be flowing water on Mars. Circular features are impact craters. Image credit: NASA/JPL-Caltech/Arizona State University

LANDFORMS *HANDOUT*

Layered rocks: Layered, or sedimentary, rocks are formed by the deposition and cementation (hardening) of small particles (like sand) at the surface of a planet. Some layered rocks are deposited in water, while other types are deposited by the wind.

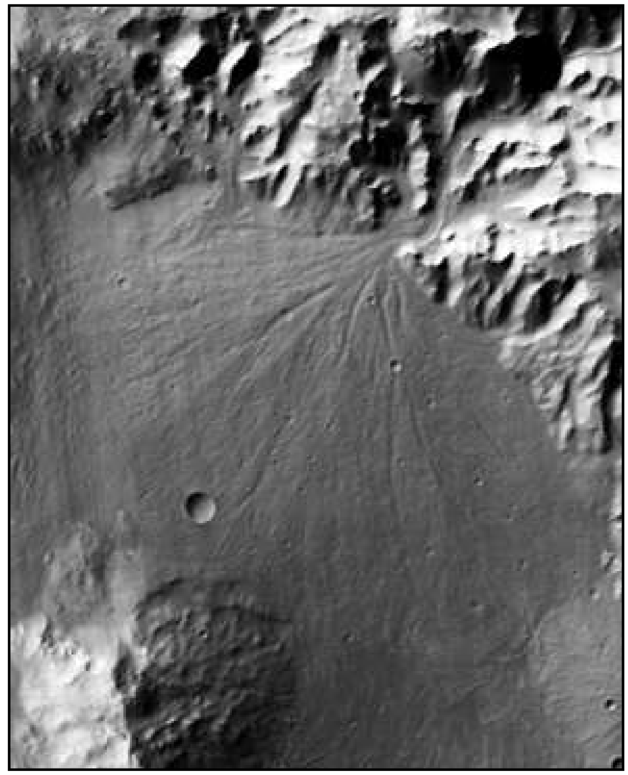
Google Earth image of layered sedimentary rocks in a tributary of the Grand Canyon. The rock layers were deposited by water (limestone and shale) and wind (sandstones).

This grayscale image shows layered rocks formed through the accumulation of sediment (sand and dust) in an impact crater in the Meridiani Planum region of Mars. These sediments once covered the floor of the crater, but have been eroded by the wind to their present shape. Image credit: NASA/JPL/ University of Arizona

LANDFORMS *HANDOUT*

Alluvial Fan: A fan- or cone-shaped deposit of sediment crossed and built up by streams, usually found where a canyon draining from mountainous terrain emerges out onto a flatter plain.

False color example of a large alluvial fan in China. Image source: NASA/METI/AIST/ Japan Space Systems, and U.S./Japan ASTER Science Team.



Grayscale image of an alluvial fan in a crater on Mars. Image credit: NASA/JPL/ MSSS

LANDFORMS *HANDOUT*

Delta: A river delta is a landform formed when a river enters a standing body of water such as an ocean, sea, or lake and deposits the sediment it was carrying. The Mississippi river delta and the Nile river delta are famous examples on Earth.

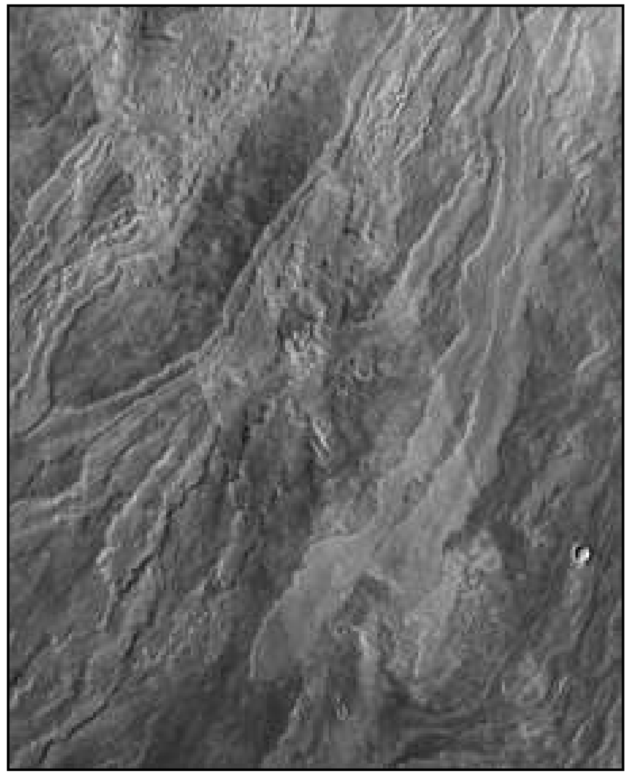
False color image of the Selenga river delta in Russia. Image credit: Landsat/ USGS.

Eberswalde delta on Mars. Image credit: NASA/JPL/MSSS.

LANDFORMS *HANDOUT*

Lava flows: Flowing lava hardens into "lobes" of very hard volcanic rock. Lava flows often are stronger than other rocks in the area, so they form a hard "cap" that resists erosion, and on Mars they often have lots of impact craters. Volcanic rocks can be analyzed to determine how old they are.

Google Earth image of SP Crater in northern Arizona. Black and gray volcanic rocks overlying tan and red sedimentary rocks.

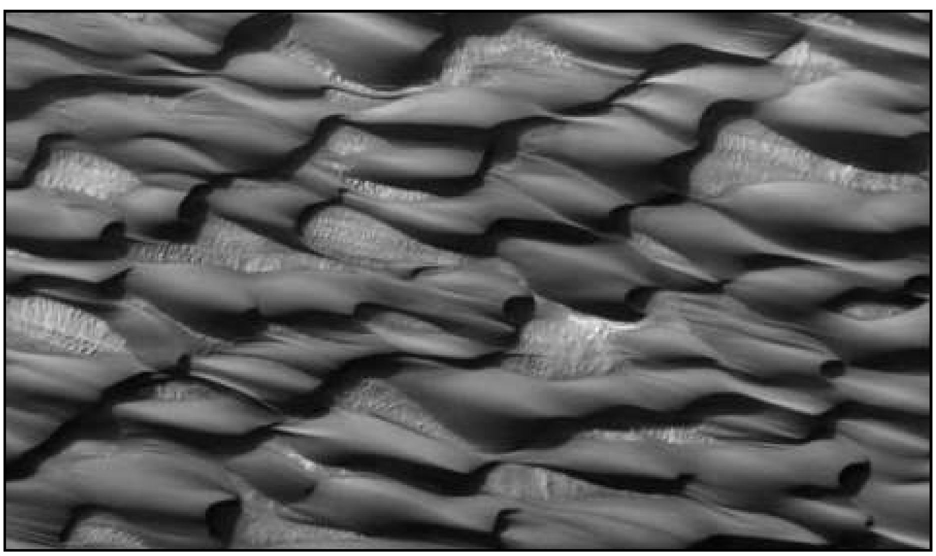


Grayscale image mosaic of young lava flows on the flank of the giant volcano Arsia Mons on Mars. Diagonal lines are seams between individual images. Image credit: NASA/JPL/MSSS

LANDFORMS *HANDOUT*

Sand dunes: These moving piles of sand can carry minerals from elsewhere and are interesting targets to learn about the environment on modern Mars, but don't tell us as much about ancient Mars. Many sand dunes on Mars are dark because the sand comes from the erosion of black volcanic rocks.

Google Earth false color image of the Rub' al Khali dune field in Saudi Arabia.

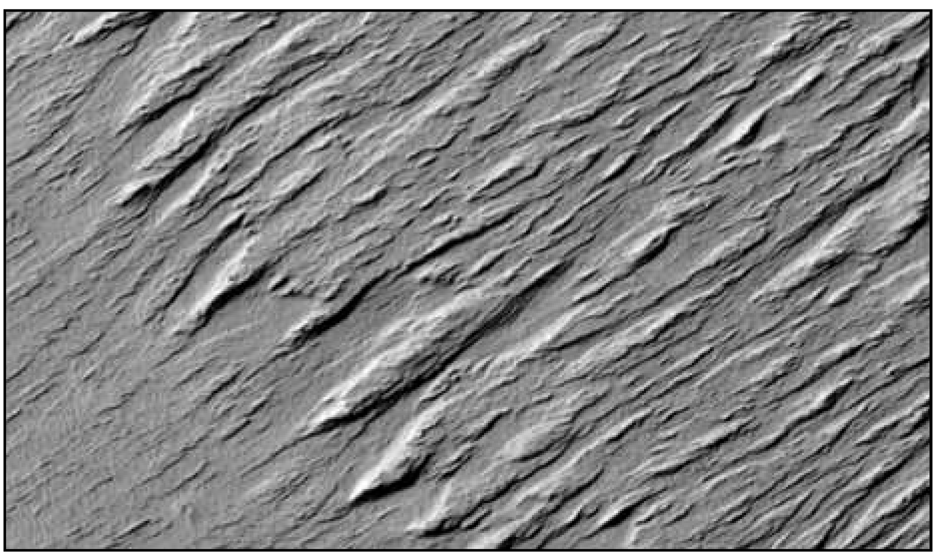


Grayscale image of sand dunes on Mars in an area called Abalos Undae near the north polar ice cap.
Image credit: NASA/JPL/University of Arizona

LANDFORMS *HANDOUT*

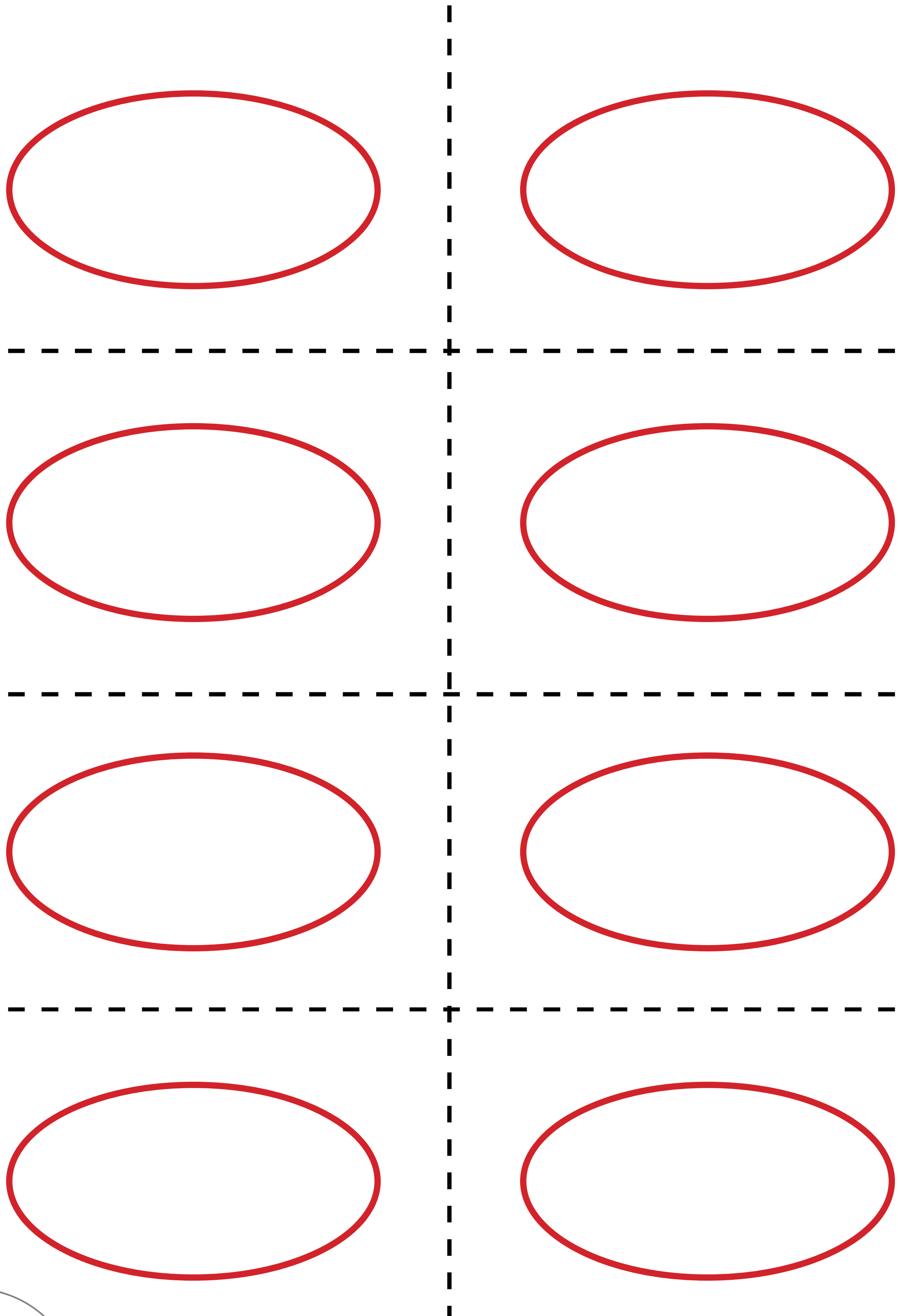
Yardangs: Wind erosion can sculpt soft rock into elongated, streamlined groups of ridges and hills called yardangs. These are most often found on the Earth in deserts.

Google Earth image of yardangs in the Dasht-e Lut desert, Iran.



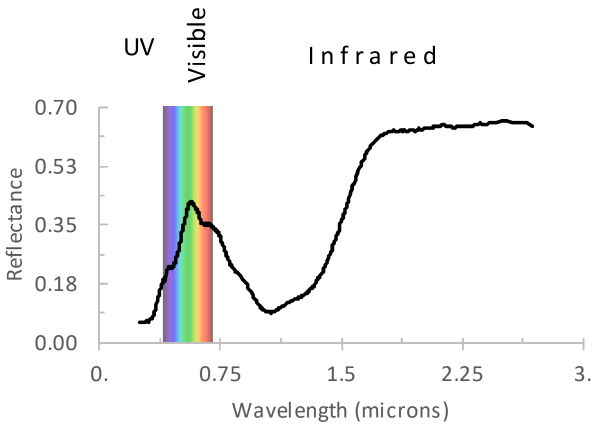
Grayscale image of yardangs on Mars in an area called the Medusae Fossae Formation. Image credit: NASA/MSSS

LANDING SITE *ELLIPSES*

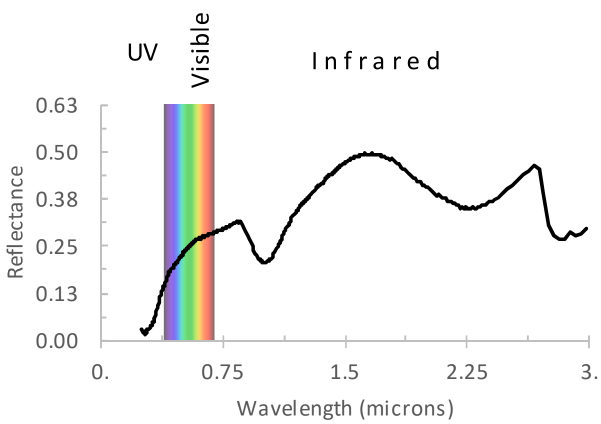


MINERAL FINGERPRINTS *DATA SHEET*

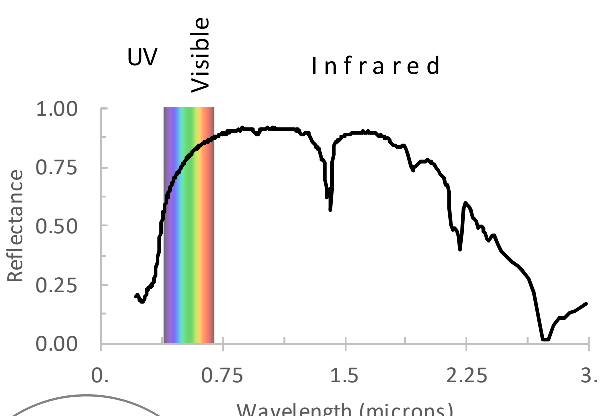
Olivine (Volcanic)

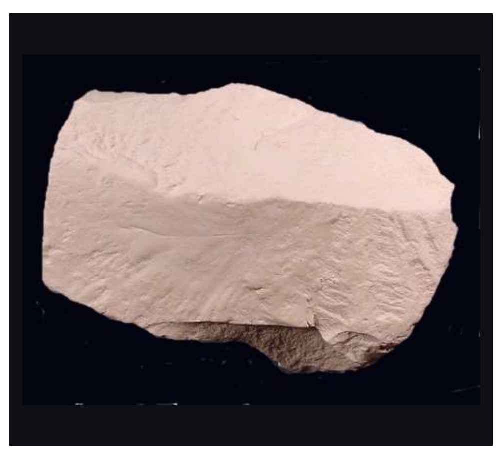


Pyroxene (Volcanic)



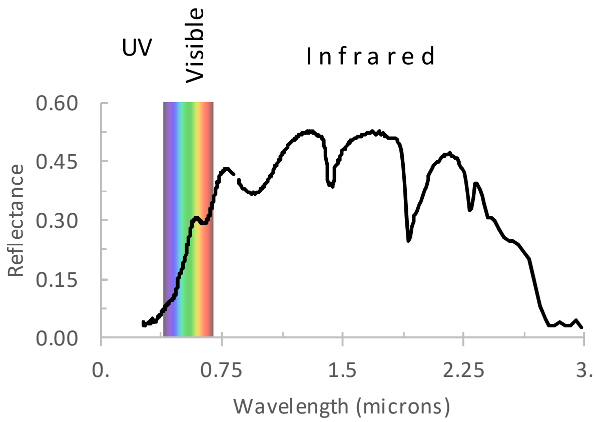
Kaolinite (Clay) (forms in water)



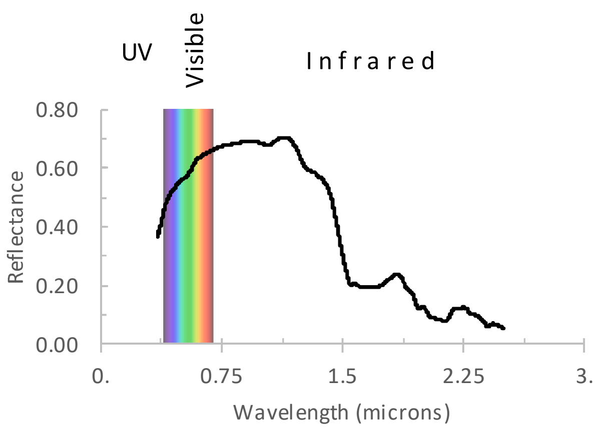


MINERAL FINGERPRINTS *DATA SHEET*

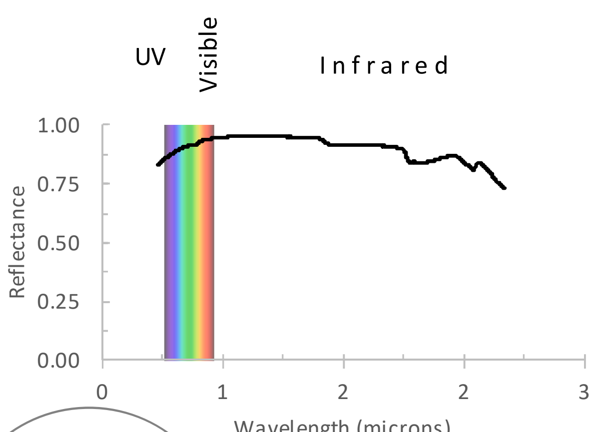
Nontronite (Clay) (forms in water)



Kieserite (Sulfate) (forms in water)



Magnesite (Carbonate) (forms in water)



PLANETS

planets-stem.org/remote-sensing