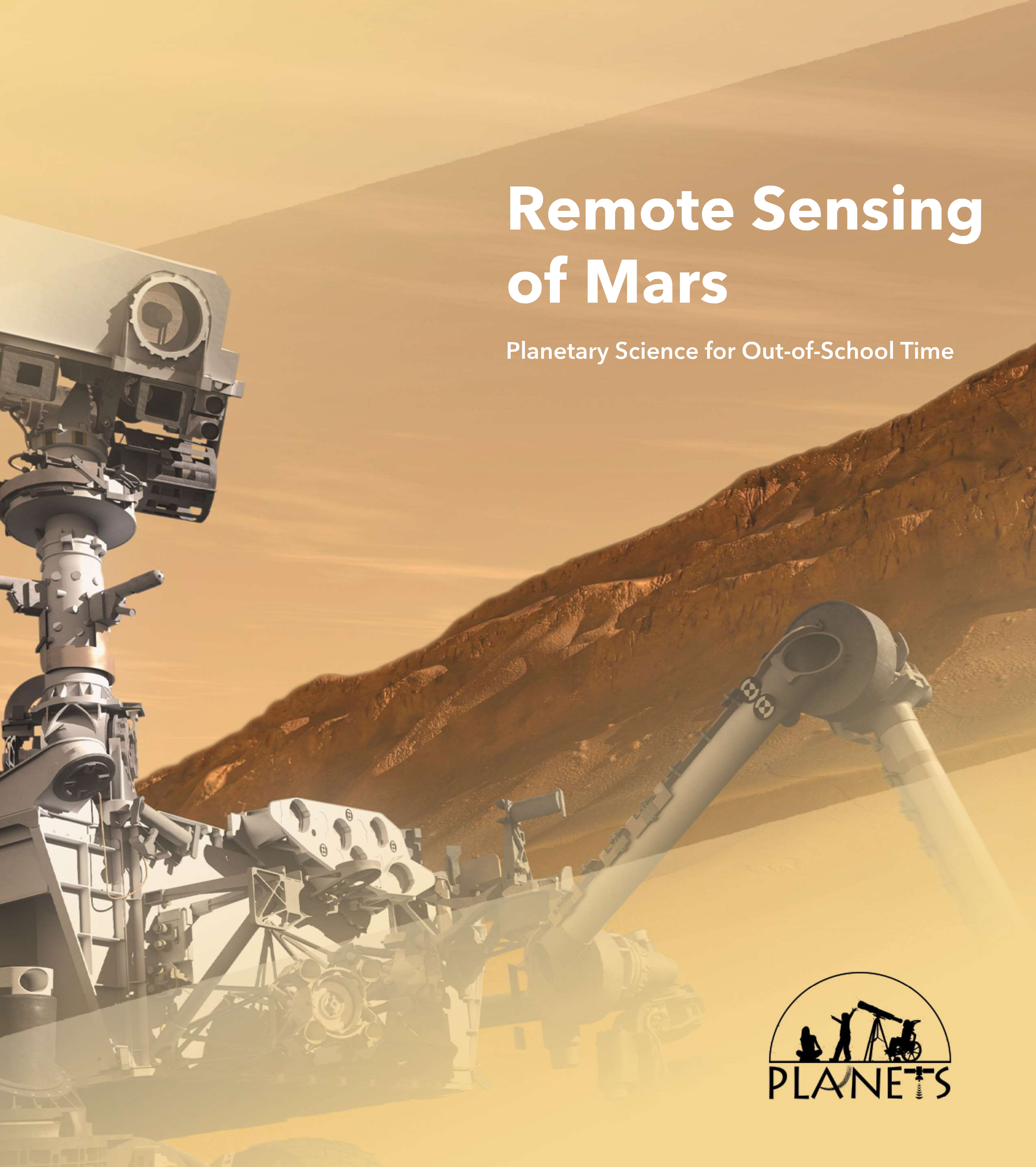
PLANETS Science Series

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

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USGS science for a changing world

EiE
Museum of Science
STEM Curricula PreK–8

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EDUCATOR *GUIDE*

Table of Contents

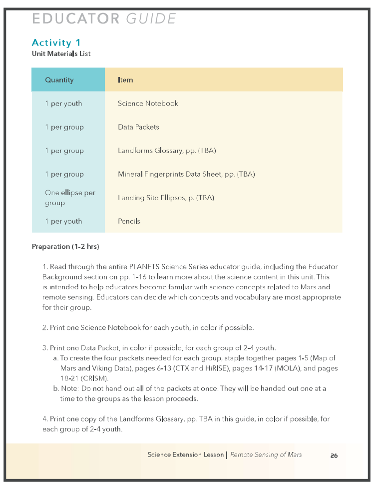
EDUCATOR *GUIDE*

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.



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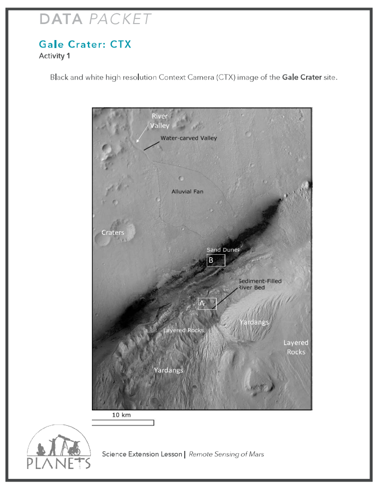
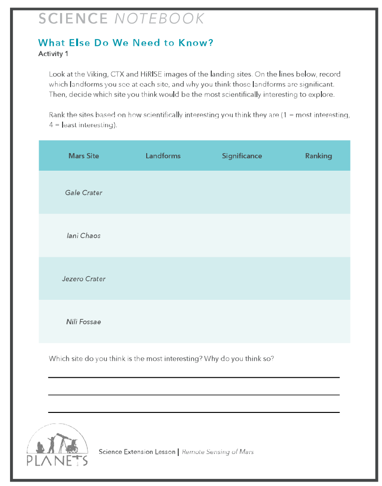


Data Packet



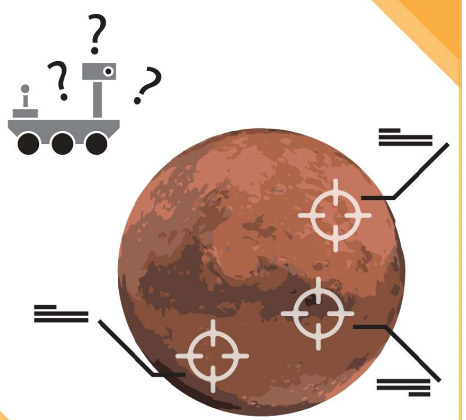
Science Notebook

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.

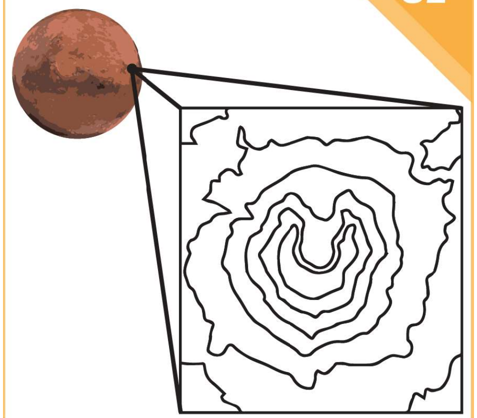
Key Take Away

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.

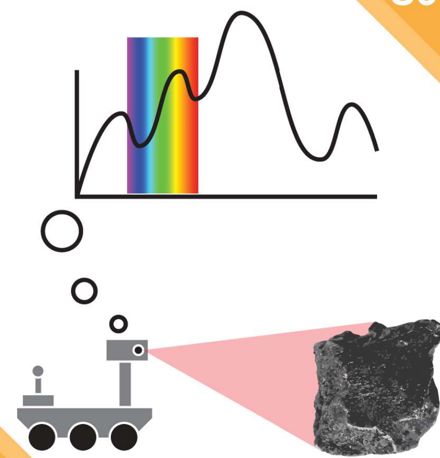
Key Take Away

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.

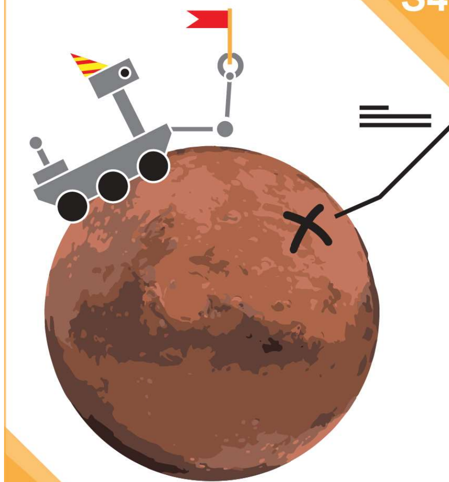
Key Take Away

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.

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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.

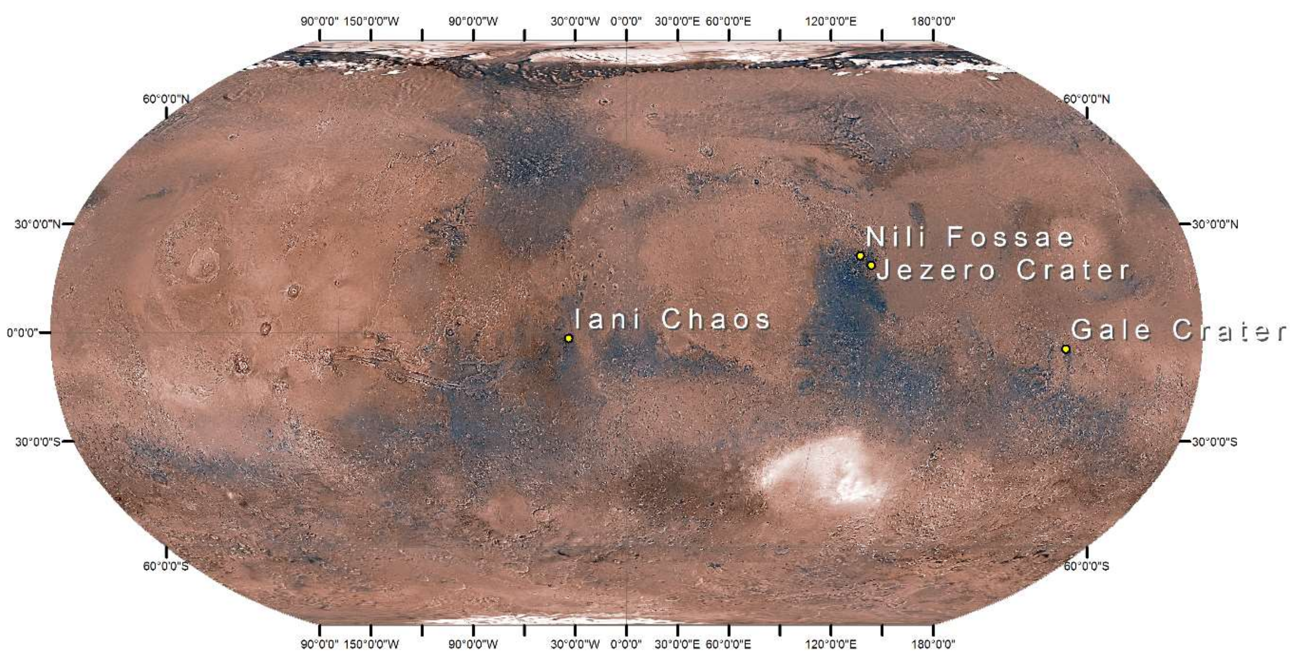
But steep canyons and crater walls are dangerous places to try to land a spacecraft. There is a trade off between sites of interest to scientists, and sites that are safe to land on.

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

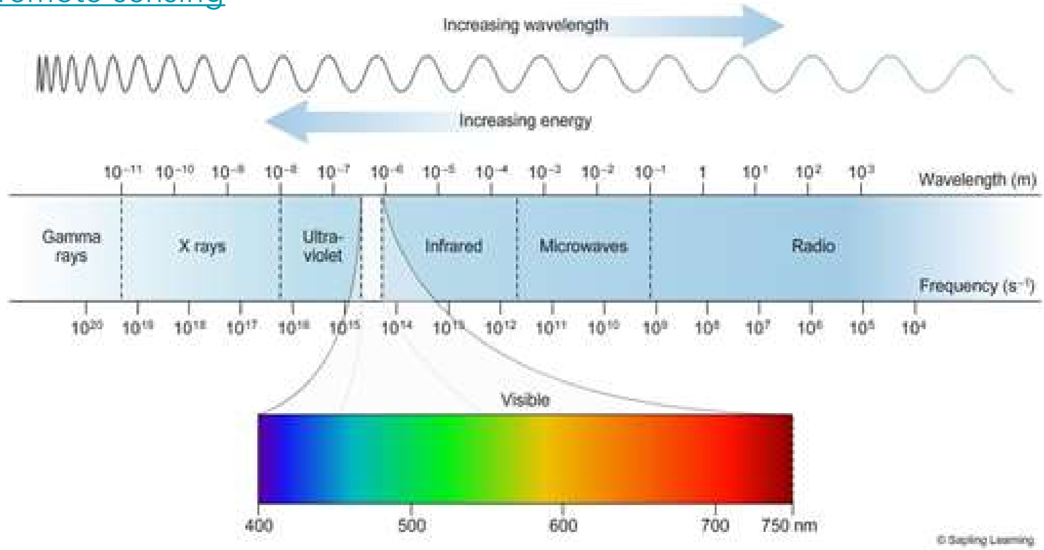


Image source: https://sites.google.com/site/chempendix/em-spectrum

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.