ASTROEDU

Peer-reviewed Astronomy Education Activities

# Become a Geo-detective!

## Become a Geo-detective with a hands-on Introduction to planetary geologic mapping!

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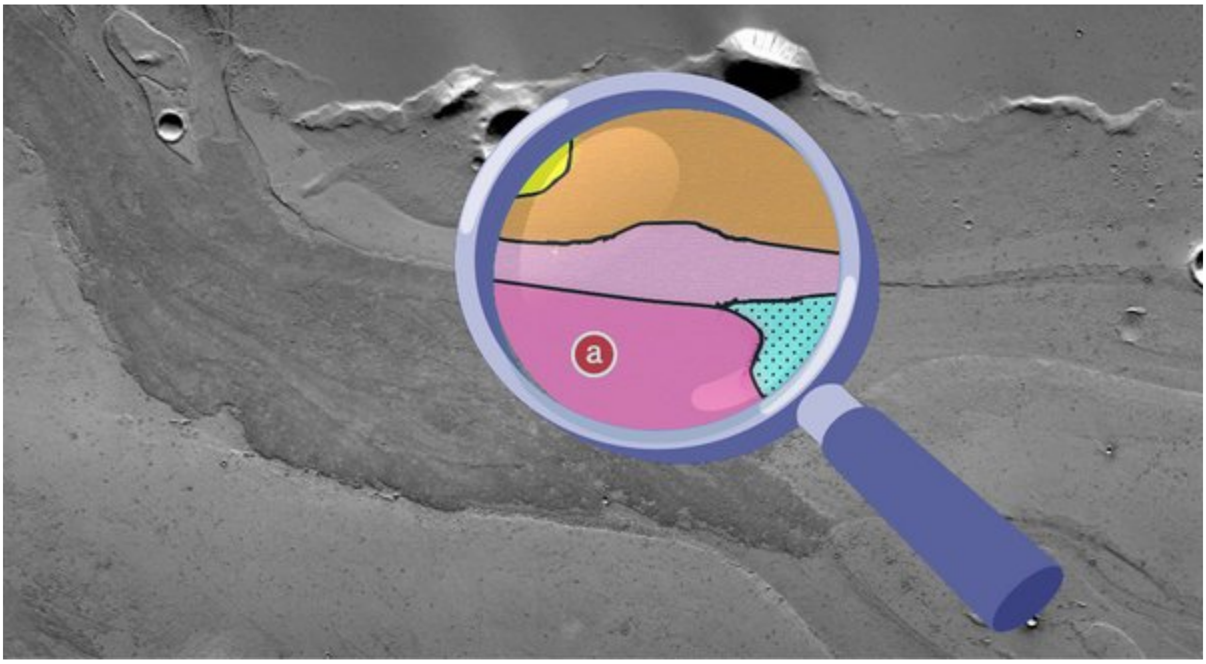

KEYWORDS

volcano, crater, mars, planetary science, planetary map, geology, geography, earth

CATEGORY

Earth, Other, The Solar System

AGE

12 - 16

LEVEL

Middle School, Secondary

TIME

2h

GROUP

Group

## COST

Free

## SKILLS

Analysing and interpreting data, Constructing explanations

## TYPE OF LEARNING

Discussion Groups, Guided-discovery learning, Observation based, Problem-solving

## MATERIALS

- an introduction video that can be used in classroom in Activity 0 or the following;
- a presentation to be projected or printed and distributed in Activity 0 (Attachement: **Introduction.ppt** )
- a handout without solutions for the 4 activities (to be printed, one for each student) (see attached material: **Handout-without-solutions.pdf**)
- an handout with solutions for the 4 activities to be used by the teacher or distributed at the end of each activity (see attached material **Handout-with-solutions.pdf**)
- color markers

## GOALS

- Develop skills on distinguishing and organizing visual information (patterns and shapes)
- Identify the elements of the planetary surface using spacecraft images and understand how planetary surfaces are mapped

## LEARNING OBJECTIVES

- Learn about basic methods of geologic mapping of planetary surfaces
- Learn to distinguish surface geologic units
- Learn to distinguish between visual patterns and shapes
- Learn to reconstruct surface relief from shadows and shading
- Learn to distinguish observation (description) from interpretation
- Use a descriptive vocabulary

- Understand a sequence of geologic events and be able to form a “story” timeline
- Use stratigraphic principles

**BACKGROUND**

## How do scientists study the history of other planets?

Scientistis study other planets and moons using images caught by cameras onboard space missions. But, not being able to land and observe these surfaces directly, they do not have direct information on the material of surface rocks and historic data on surface events. So they need landers to examine rocks dirctly and they need to reconstruct surface geology from morphology, the shapes (relief) and patterns of the terrain.

Scientists so learn how to distinguish between observations and interpretations. For observations, we use a descriptive vocabulary. For interpretations, they reconstruct the evolution history of that surface, deducing the geologic processes that must have happended on the surface.

## Some definitions

To do this, it is important to recognize the morphology, the shapes ofwhat we see on these surfaces. Some of these shapes are due to geological phenomena that we know very well on Earth.

There are geological features that we can identify and study on Earth that can also be found on other terrestrial (or rocky) planets and moons.

Let’s start with some definitions:

- **A young crater** is a circular depression with high-standing rim and a debris apron around it.
  It is formed by an impact that ejected material from the crater interior to the terrain around the crater
- **An old crater** has become subdued in topography: its formerly sharp rim eroded and got lower and more round, and its interior got infilled with materials that have fallen or slided into it.  The old crater lost its ejecta blanket on the outer side of the crater rim. They are thus shallower than young craters. They also may have other craters on them. The more small craters are in a crater the older it is.

*Image: Young impact craters. Left: Meteor (Barringer) Crater in Arizona, USA. The crater is about 1 km across and is 50,000 years old. Perspective view. Credit: Shane.torgerson, Wikimedia Creative Commons Attribution 3.0 Unported [https://creativecommons.org/licenses/by/3.0/deed.en](https://creativecommons.org/licenses/by/3.0/deed.en)*
*Right: A young impact crater on Mars. The crater is about 1 km across. The upper part of the image is in color. HiRISE ESP_012857_1910 NASA/JPL-Caltech/UArizona*

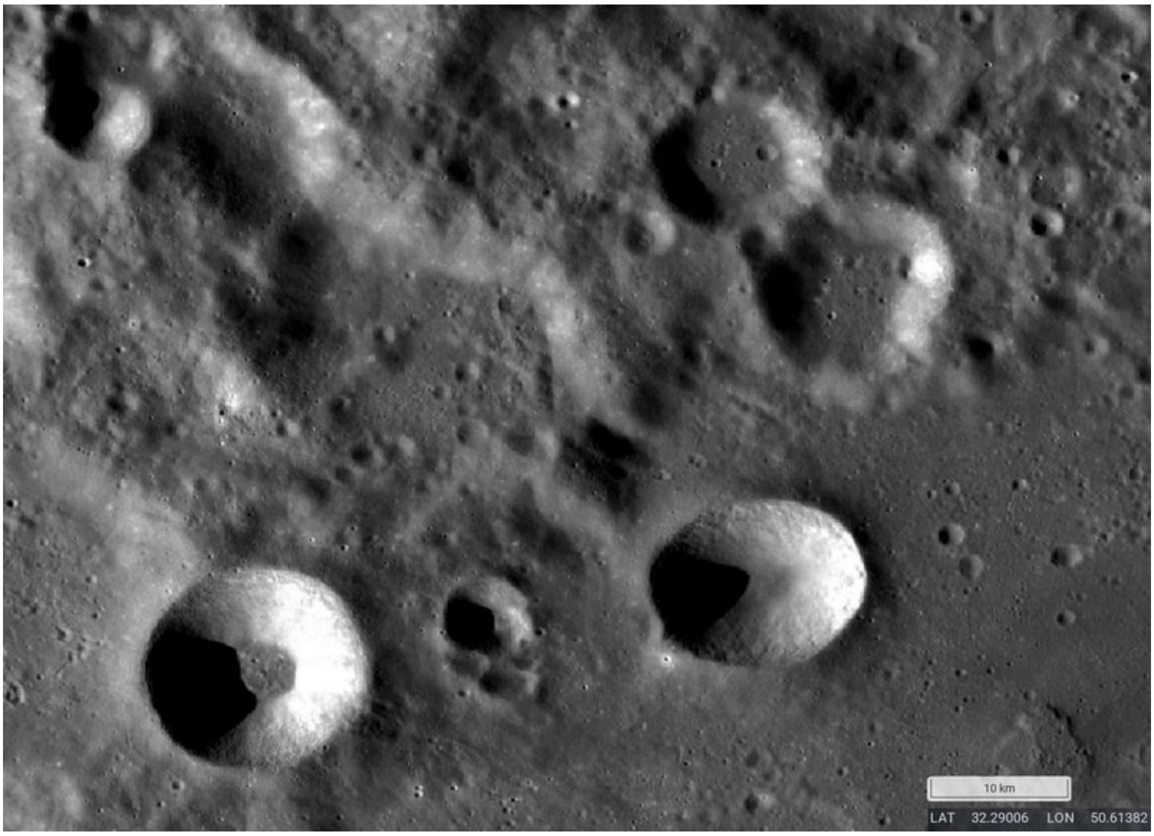


*Image: young and old simple craters on the Moon.*

- **A volcanic caldera** is a large cauldron-like hollow that forms shortly after the emptying of a magma chamber in a volcano eruption.

*Image: caldera. Left: Aerial photo of Halemaumau pit crater in 2009, showing a white plume being emitted by a small, active lava lake. The crater is located within the much larger Kīlauea caldera of Hawaii. Credit: Hawaii Volcano Observatory, USGS Right: The nested, complex caldera at the top of the highest volcano on Mars, Olympus Mons. The caldera is 10 km across. Credit: ESA/DLR/FU Berlin (G. Neukum)*

- **A lava flow** is a lobate-margin, rough surfaced, elongated accumulation of material.
  It was made of volcanic lava flowing when hot and fluid and then becoming solid when cooling down, flowing down the slope.

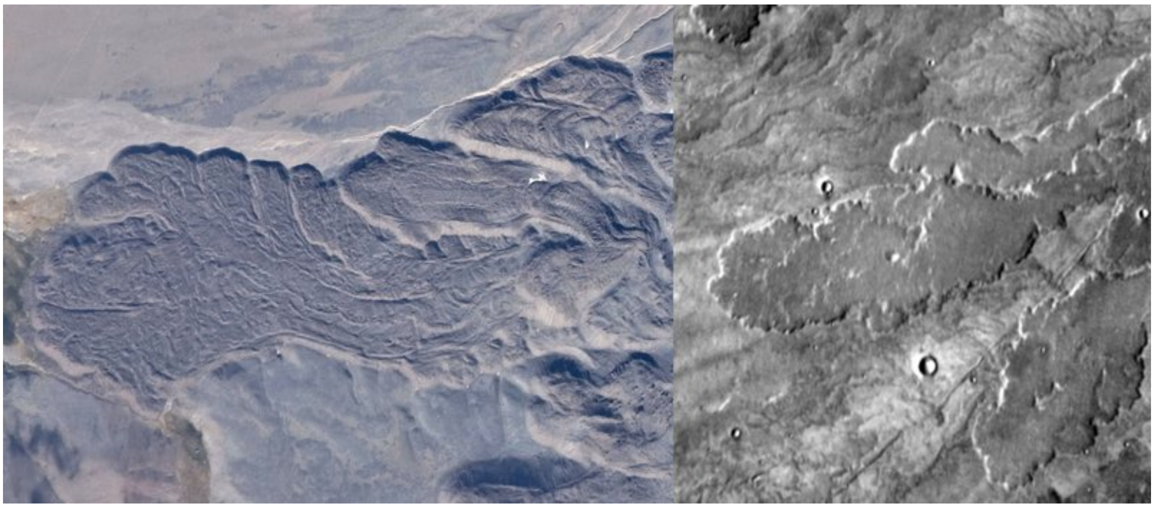

*Image: Lava flow. Left: Lava flow from Sabancaya Volcano, Peru. Credit: NASA, International Space Station Science, 07/15/10, Attribution-NonCommercial (CC BY-NC 2.0) Right: Lava flow on Mars, from the south slope of Arsia Mons at 20.824°, 233.290°E. THEMIS image, Credit: NASA/JPL-Caltech/Arizona State University.*

- **A channel** is a very long, curbing depression with a smooth, flat bottom and steep edge.
  It was cut into the ground by flowing water or, in some places, by flowing lava.
- **A streamlined island** is a teardrop-shaped land raised over a lower.standing region.
  It was formed by a current of fluid material cutting around it.

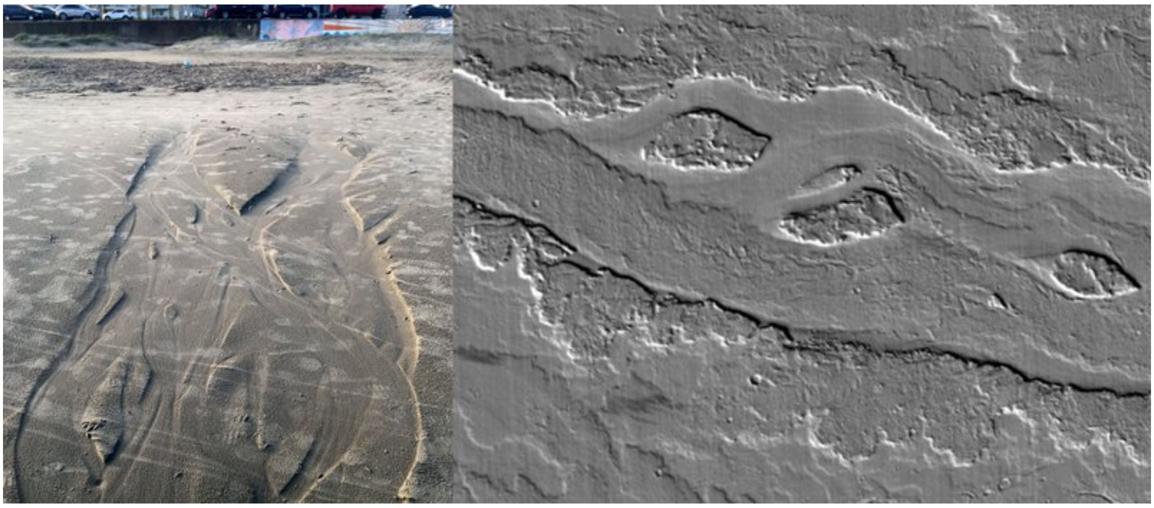

*Image: Channel and streamlined island: Left: Small channels with streamlined islands, on the sandy beach of Galveston, Texas. Credit: HH (author). Right: Channels on Mars, east of Olympus Mons, flanked by lava flows. The channels contain additional lava flows but water may have also flowed in it in the past. It is probably a lava channel. It has streamlined and more irregular islands, created by water or very fuid (low-viscosity) lava. Credit: NASA/JPL-Caltech/Arizona State University.*

## An introduction video

To learn how to get information by observing images from satellites, watch the following introduction video on how to become a Geo-detective! This video can also be used in calssroom to be shown to the students (see Activity 0).

Link to the video

## The basic rules for a Geo-detective

**Distinguish between negative and positive reliefs**

The first thing to know when approaching an image of a planetary surface is how to **distinguish between negative and positive relief** using light and shadows to distinguish high and low relief forms from flat surfaces (see the video to better understand how).

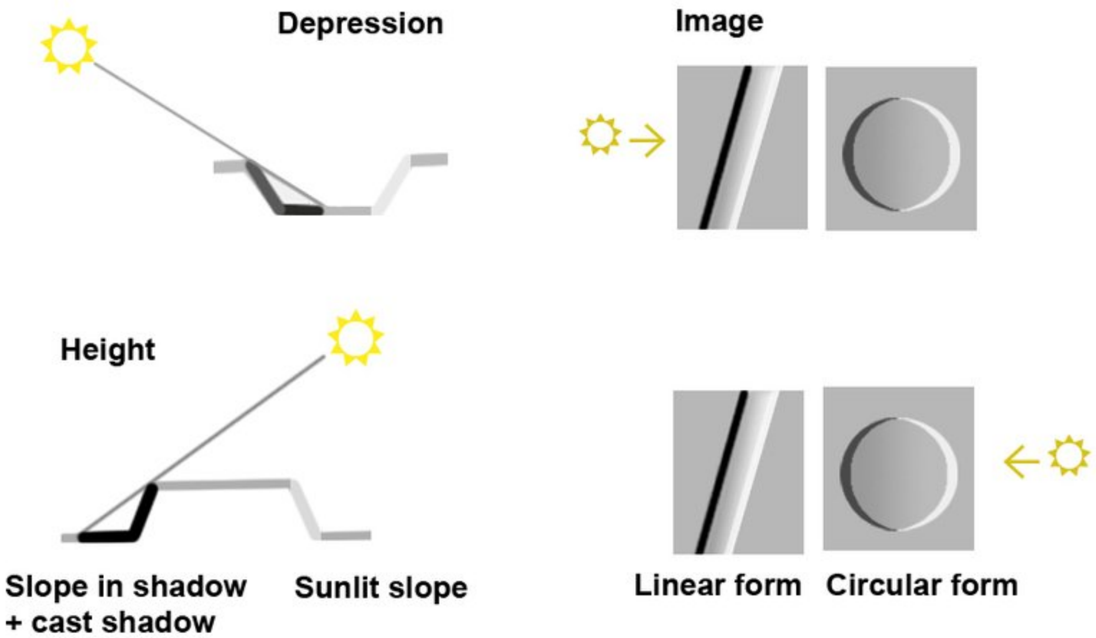


*Image: This figure explains the relationship between the direction of illumination, shadows /shading and relief. The same image can result from two different relief situation depending on where the illumination comes from. Without familiar objects, or knowing the direction of the Sun, we are unable to determine the correct relief. The left hand part of the figure shows relief from the ground as a cross section while the right hand side shows the same objects from above as seen on a spacecraft image. The upper part shows how depressions would look like, and the lower part shows elevations.*

**Distinguish old from new surfaces**

Geologists reconstruct the story of how a landscape formed by determining which rocks and forms formed when in that region.

In stratigraphy, you will have four tools to determine which unit is older. Results from the four tools should be consistent with each other.

- The law **of superposition** states that the unit that covers (overlies) another one is the youngest of the two.
- The principle of **cross-cutting** relationships says that the feature that cuts through/into another one is the youngest of the two.
- **Crater density:** a unit with denser impact cratering is older than one with less craters per unit size, because it was exposed to impact cratering for longer times.
- **Degradation:** a feature with subdued topography is usually older than a feature with sharp outlines. Erosion and deposition removes high standing forms and transport their materials into low standing lands, infilling basins and eroding mountains. Even on the Moon, where there is no atmosphere and therefore no rain or wind, erosion is done by cosmic erosion: the impacts of small and large meteorites.

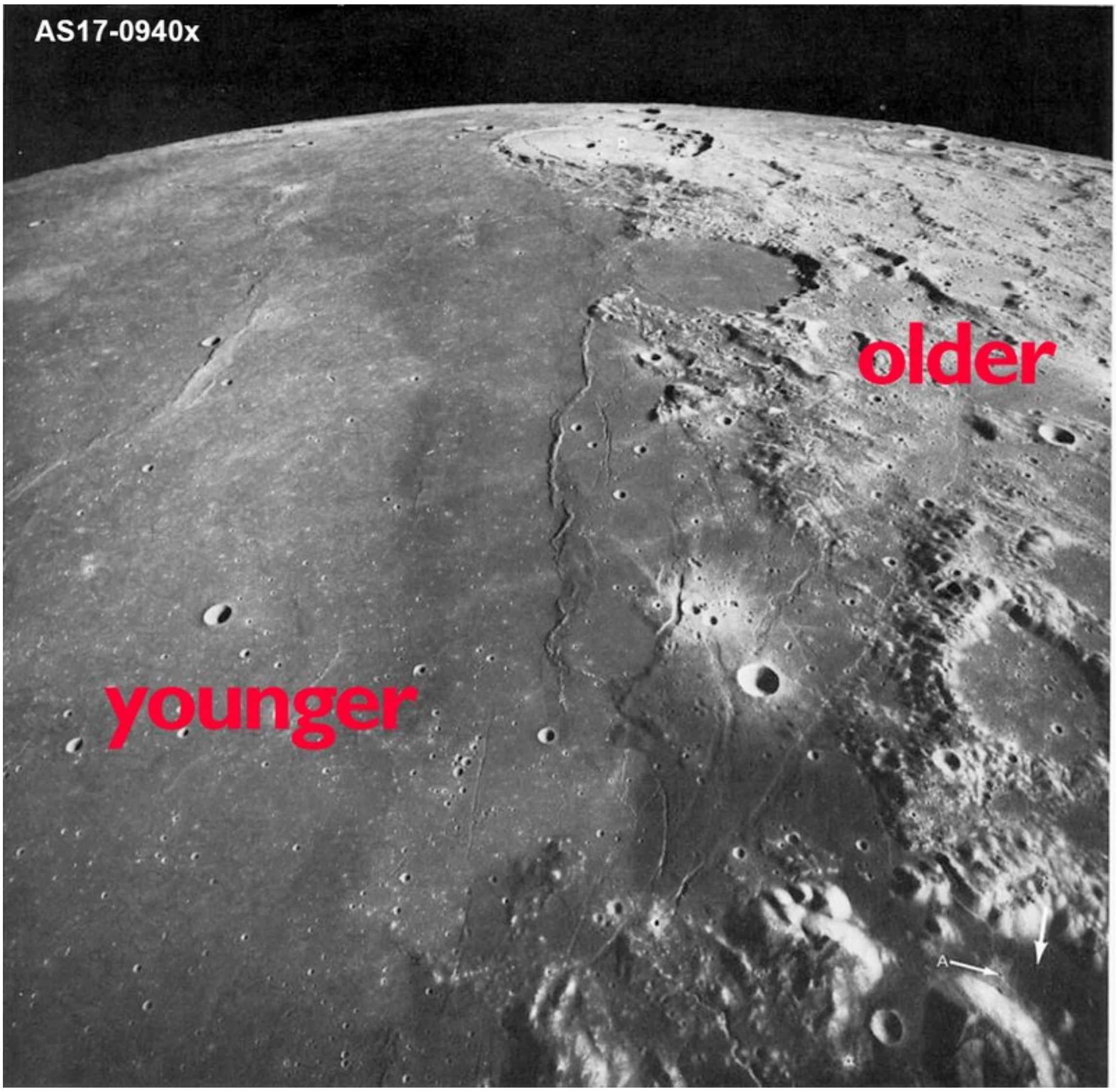


*Image: an image of the Moon where you can see the importance in crater density to evaluate the age of a surface. The smooth, dark mare (lava plain) is younger (left side – it has only few, small craters). The rough, densely cratered highland terrains are older (right side). The rough surface is the result of crater depressions and crater ejecta on the top of each other. Credits: NASA.*

**FULL DESCRIPTION**

## Before the activity

- Activity 0 is an introduction that uses the **Introduction.ppt** you find in the attachments (to be projected or printed and distributed)
- For Activities 1 to 4, print the **Handout-without-solutions.pdf** to be distributed to students (print one for each)
- Read carefully the info in the background field and the **Handout-with-solutions.pdf**
- Activity 1 is described step by step, then we provide 3 additional images for Activities 2, 3 and 4 to replicate the process on other zones.

# Activity 0 - introduction

For this Introduction activity you will need to project the slides or distribute printed copies of **Introduction.ppt** and stimulate a class discussion with students, asking questions and discussing answers.

## Step 1 - Learn how to distinguish negative from positive relief.

- Tell the students that they will learn how to use shadows to distinguish high and low relief forms from flat surface on satellite images. However, we will see that this is not enough to determine which form is high and which is low.
- Show to your students the first image in the presentation (Image A), an image of the icy moon Europa.
  and then ask the following question about Image A:
  **QUESTION:** Are linear features deep cracks or high ridges? Are circular features depressions/craters or mounds?
- Discuss the possible answers and then explain to students **THE PROBLEM OF OPTICAL ILLUSION**: In spacecraft images it is difficult to distinguish high-standing circular mounds/cones from circular depressions because there are no familiar landmarks in the scene. In these images the relief is often inverted when we turn the image upside down. It is, therefore, essential to find a familiar landform that can be used for determining the relief correctly. On Earth familiar landforms are buildings, trees, high mountains with snow-caps - there are no such things on Mars. On the ice-covered Europa the ice landforms look so unusual that we cannot compare them to any terrestrial experience.
- Show to students Image B of the presentation: the second image on the right shows the same scene but upside-down and makes it clear that:
  **PARTIAL ANSWER:** You may only be able to answer this if you know the direction of illumination because there are no familiar objects on the image.
- Tell students that the direction of the illumination can be read from the original spacecraft image data label (by scientists) calculated from the spacecraft location relative to the sun and the target planet at the time of taking the image, or have prior geologic knowledge of the geology of Europa where most linear features are ice ridges built by water pressed out of cracks from the subsurface ocean and frozen on the surface. In most cases, however, circular forms are almost all craters, that is, depressions.
- Tell students the correct interpretation for IMAGE A: **LIGHT IS COMING FROM THE RIGHT!**
  **CORRECT ANSWER:** The correct answer is: 1 is a dome, 2 is a ridge, 3 is a depression
- Tell now to look at Image C and practice with students to understand the relationship between the direction of illumination, shadows /shading and relief.
  Point out that the same image can result from two different relief situations depending on where the illumination comes from. Without familiar objects, or knowing the direction of the Sun, we are unable to determine the correct relief. The left-hand part of the figure shows relief from the ground as a cross-section while the right-hand side shows the same objects from above as seen on a spacecraft image. The upper part shows how depressions would look like, and the lower part shows elevations.

## Step 2 - Distinguish old from new surface

- Explain to students the 4 tools to determine which unit is older: the law **of superposition, cross-cutting** relationships, **crater density** and **degradation** (for more information, see in Background section and Video).
- Tell students to look at image D of the presentation and ask them the following:
  **QUESTION:** Which part of the image is older, the right or the left hand side?
  **ANSWER:** The smooth, dark mare (lava plain) is younger (left side – it has only a few, small craters). The rough, densely cratered highland terrains are

older (right side). The rough surface is the result of crater depressions and crater ejecta on top of each other.

- Tell students to look at image E and ask them the following question:
  **QUESTION:** put the craters a–d into chronological order.
  **ANSWER:** Solution: from oldest to youngest: c, a, b.

# Activity 1

## Step 1

- Organize the students in the classroom for a discussion and introduce the lesson saying that they will learn how to recognize what happened on the surface of a planet looking at images taken by satellites and space missions. To do this, they will become true geo-detectives and learn what to look for!
- Distribute **Handout-Without-solutions.pdf** to students.

## Step 2

- Point out to students the Image below and start a discussion asking students what it is.

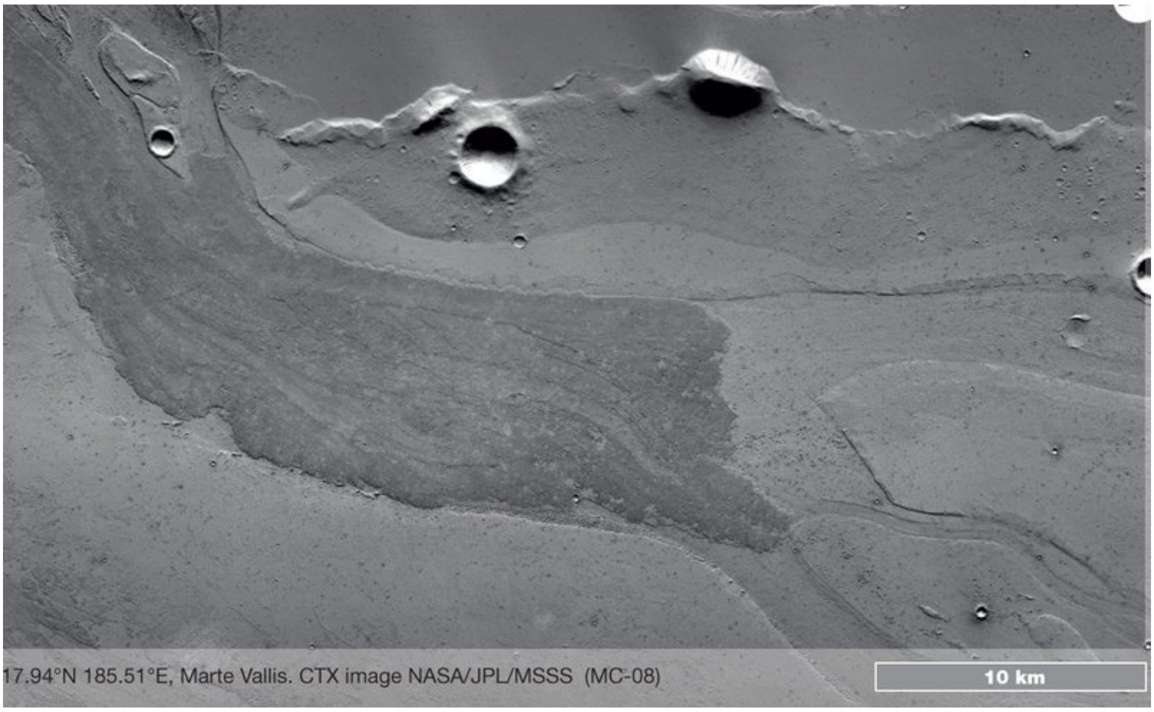


*Image 1: Mars. Part of Marte Vallis, Mars. It is a south from the large volcanic Elysium Rise. Credits NASA/JPL/MSSS*

- After discussion, you can tell them that it is Mars. It is one of the youngest regions of the planet, where geological activity not very long ago re-shaped the surface. YOUNG means 10s-100s millions of years ago by Martian standards.

## Step 3

- Start guiding students through the analysis of the Image, asking them questions and moderating the discussion.

- Let's list the features you can recognize on the image and what kinds of terrestrial landforms do you know (small or large) that have the same characteristic? (shape, elevation, smoothness, brightness).
    - By shape
        - show the CIRCULAR FORMS
        - show the ELONGATED FORMS
        - show the STREAMLINED FORMS
        - show the LOBATE-MARGIN FORMS
    - By elevation
        - where are HIGH STANDING FORMS?
        - where are LOW STANDING FORMS?
        - where are FLAT FORMS?
        - where are the STEEPEST SLOPES?
        - is the circular feature A HOLE OR MOUND? How can you tell?
    - By size
        - how long would it take to cross the channel by foot (see the scale bar)?
    - By roughness
        - show the SMOOTHEST REGIONS
        - show the ROUGHEST REGIONS
    - By brightness/darkness (relative to the surroundings)
        - show the DARKEST PARTS of the image
        - show the BRIGHTEST PARTS of the image

## Step 4

- Guide the students through a discussion about the geological history of this landform, asking the following questions:
    - Can you determine when these forms were formed?
        - is the CIRCULAR DEPRESSION younger or older than the land below it?
        - is the LAVA FLOW younger or older than the channel?
        - is the LARGE CRATER younger or older than the channel?
    - Can you determine which geological process generated these forms?
        - how was the CIRCULAR DEPRESSION (OR CRATER) formed?
        - how was the CHANNEL FORM formed?
        - how was the LAVA FLOW formed?
        - how were the STREAMLINED FORMS formed?

## Step 5

- When you feel they are ready, show the students the Geo-detective video and discuss the topics presented in the video (you can also use the Introduction presentation if needed):

see Video at Link https://drive.google.com/file/d/1FMbxK-p1sTakHe0gd1PXT4n2EDgqmZ8s/view?usp=sharing

## Step 6

- Now the students will draw on the handout to reconstruct the geological story of this land. The first step is to draw a sketch map over the image, tracing the outlines: observe in the photo where there are distinct shapes and patterns. These are the geologic units. Students should delineate the units by drawing lines around them (see Image below 2).

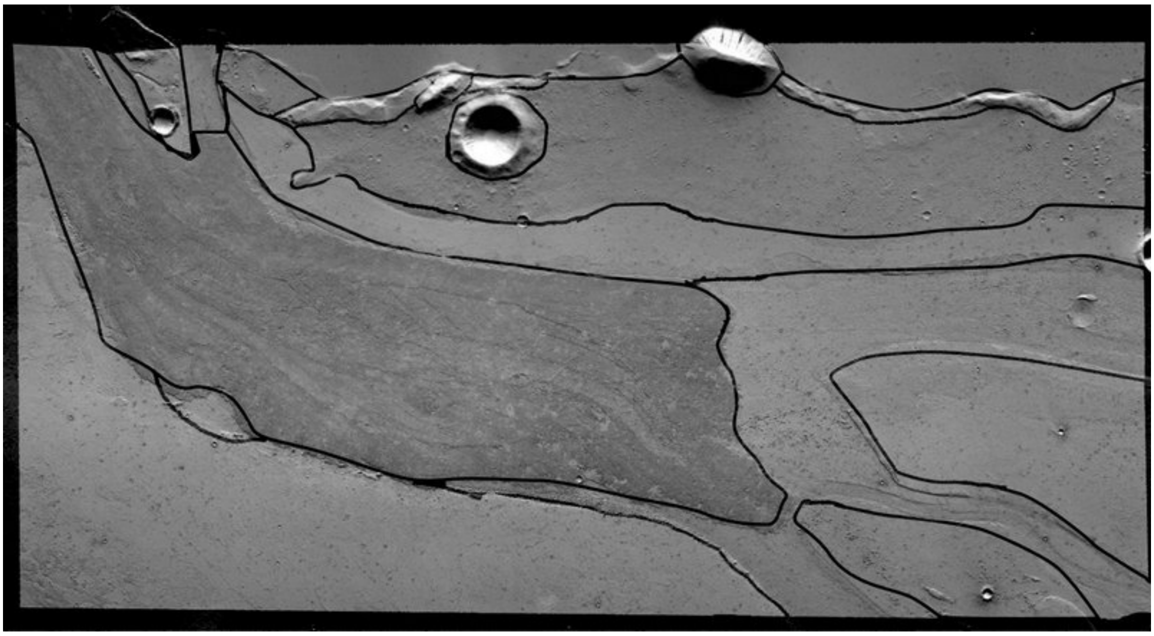

*Image 2: Mars map with outlines. Credits: Henrik Hargitai*

*NOTE: Why is the outline of the crater in the image above larger than you would imagine? Be careful, because the bowl-shaped depression is only part of a crater! The outline should be at the base of the rim, including the rim and the depression. This is the outline of the crater's geomorphologic unit. In the outline the rocky materials thrown out from the crater can be included too. This is the crater's geologic unit, because it includes every material on the ground that is connected to the formation of this crater. The material of the ejecta in older craters is already eroded away. So be careful! In our exercises when we do geologic mapping, we should map the material (rock) units that formed in one event, and not the geomorphic shapes of the landscape.*

- Then students should color the inside of the outlines with different colors, imagining their history and choosing stronger colors for younger forms and pale ones for older ones. In Image 3 below : 1) crater – yellow; 2) crater filling – green; 3) plain - pink; 4) wrinkle ridge, island - red, 5) rough, rolling surface - yellowish brown, 6) sinuous channel - blue, with dots, 7) straight trench - dark brown.

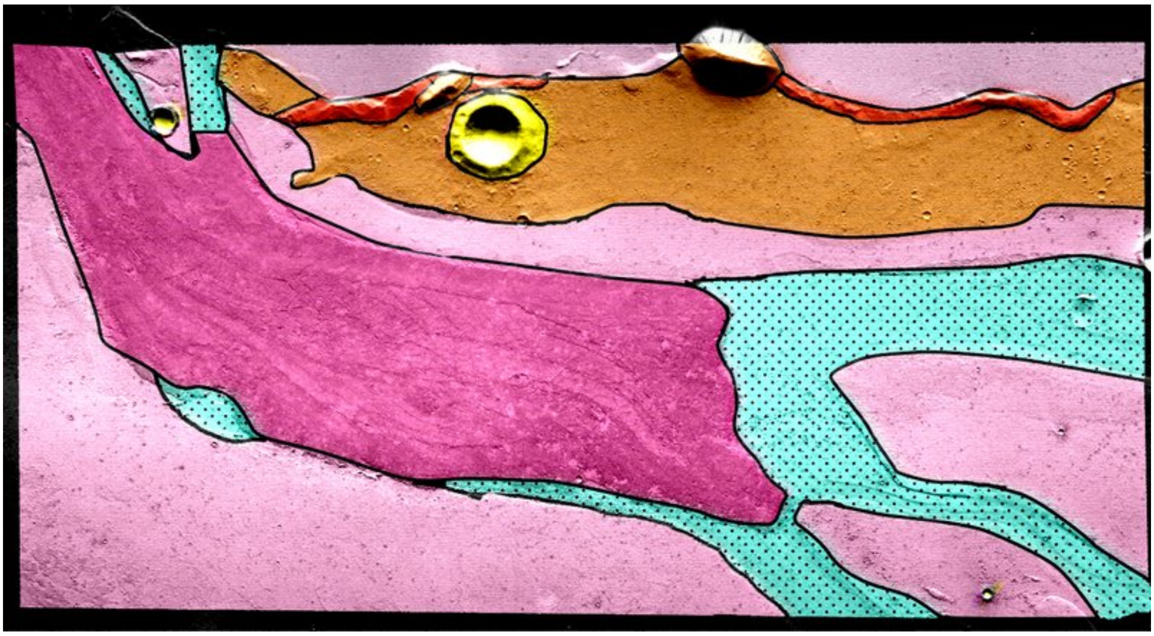

*Image 3: Mars map with outlines and colored zones. Credits: Henrik Hargitai*

- At this stage, students can imagine which events must have happened before and which after based on the relationship of the landforms (crossing, overlapping). They should then mark the units of the same color with letters: the youngest (uppermost) layer will be unit "A", the older one will be "B", etc.

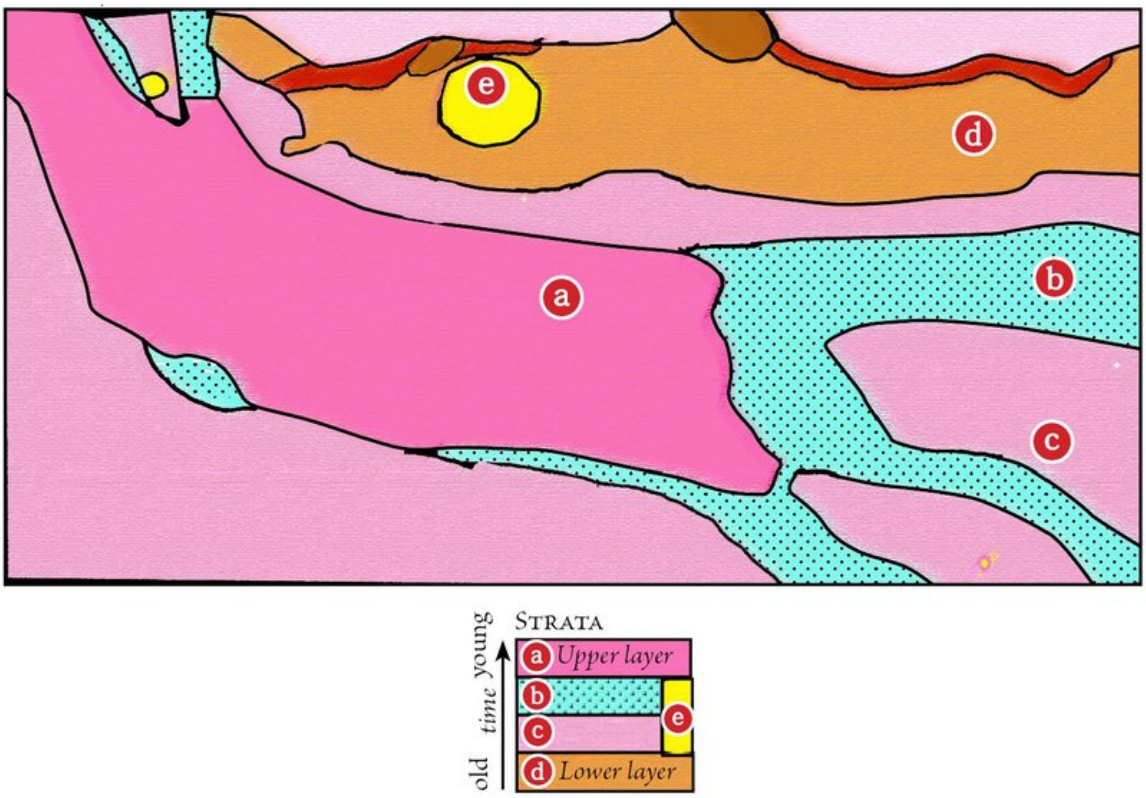


*Image 4: Mars map with history. Credits: Henrik Hargitai*

### Step 7

- Show the first page of the Handout with solutions to the students, checking with them if the story they imagined is right.

# Activity 2, 3, 4

In Handout and Handout with solutions, we provide Images to be used to replicate the activity on other geological areas.

## EVALUATION

Four different images from Mars are provided to be used in this activity. One of them can be used as a final evaluation to understand how much students have learned from this activity.

On this map the teachers can ask students to:

- Label similar geologic units using descriptive terms
- Distinguish positive from negative relief correctly
- Name surface units descriptively and also assign and interpretation to each unit
- Assign geologic processes as categories to surface patterns and shapes
- Put the units in chronological order

## CITATION

Henrik Hargitai; Livia Giacomini; Federica Duras, 2023, *Become a Geo-detective!*, astroEDU, 2301