MER Image Analysis

Suggested Grade Level: 6–10

Summary

- Students will study and analyze some of the images returned from the MER rovers Spirit and Opportunity.
- Students will learn about some of the significant science discoveries in the images returned from Mars.
- Students will experience real planetary science analysis.

Standards

- NM Science Content Standards: Strand I, Scientific Thinking and Practice; Strand II, Standard III, Earth and Space Science
- National Science Standards: Content Standard A, Scientific Inquiry; Content Standard D, Earth and Space Science; Content Standard G, History and Nature of Science

Background Information

Images returned from spacecraft missions are an important scientific data set used in making new discoveries about a planet. (Note: the word image is generally used rather than photograph because the pictures returned to Earth by spacecraft and rovers are digital images that require computer processing and it is important to remember that they are not traditional photographs.) The Mars Exploration Rover (MER) mission was designed to acquire images of the surface of Mars, and especially images of the rocks of Mars, at many different scales or resolutions. Regional views of Mars were taken by orbiting spacecraft such as Mars Global Surveyor, high-resolution panoramic images of the surface of Mars and detailed rock outcrop images were taken by the pancam on the rovers, and close-up images of rock surfaces were taken by the instrument called the Microscopic Imager on the rovers. All of these images were carefully analyzed by the scientists on the MER science team. Part of the scientific process is the presentation of scientific discoveries to colleagues in a clear and concise manner. After analyzing an image returned from the MER mission, the MER scientists would immediately present their discoveries to their colleagues who would review and make use of the new discoveries in the analysis of other images. The five images included in this activity include a range of image types:

- Image 1 shows Meridiani Planum (Opportunity landing site) from Mars orbit, taken by Global Surveyor.
- Image 2 is a navcam (navigation camera) image mosaic showing a large field of view of the surface terrain from Spirit.
- Image 3 is a navcam image of a significant outcrop, taken by Opportunity.

- Image 4 is a close-up of the RATed area of a rock called Humphrey, taken by the microscopic imager camera on Spirit.
- Image 5 is a pancam (panoramic camera) high-resolution image showing a significant rock from Spirit.

Materials

- Five annotated images and captions included in this activity
- MER Image Analysis Investigation Log booklet included in the activity
- MER Image Analysis teacher's key and science conclusions/observations teacher's key, both included in this activity

Preparation

1. Print, photocopy, and assemble the MER Image Analysis Investigation Log booklets. Booklets can be assembled by the following steps: print pages 8 and 9 of this activity as a double-sided page and print pages 10 and 11 as a double-sided page (or print all pages separately and staple or glue 8 and 9 and 10 and 11 together back to back), then put the sheets together and fold in half.

2. Print each of the large images (#1 through #5) on a single standard sheet of paper. If you can print on photographic paper, more details will be visible in the images. The captions/notes can be printed separately and attached to each image or printed on the back of each image.

Introduction for Students

You are going to be a Mars rover scientist. You must study and analyze the images returned from the rovers Spirit and Opportunity.

Procedure

1. Students should work in teams and work with one image. If desired, the teams can also rotate through several images.

2. Each team should first observe and describe the image that they are analyzing.

3. Each team should identify and match each feature in the image with the numbered items listed on the MER Image Analysis Investigation Log.

4. Each team should locate and circle the features on the image in the MER Image Analysis Investigation Log.

5. Each team should list on the back page of the log observations they have made in support of the science conclusion(s).

6. Each team should select a spokesperson who presents their image, and the features that they have identified within it, to the class.

Process/Closure

This is exactly how mission scientists analyze and interpret images. Were these images easy to interpret? What features were difficult to identify? These images are from orbiting spacecraft, a rover on the surface, and a close-up camera: which of the images would tell scientists more about the surface of Mars? About the rocks of Mars? About the geologic history of Mars? Are all of the different types of images needed? What other types of images or data might be needed? Did you agree with all of the science conclusions made by the Mars Exploration Rover science team? What observations were difficult to make and why?

Extension/Enrichment

Each team should define a question that they have about one of the features depicted in their image and plan a course of action for the rover that would help to answer that question. For example, they might decide to drive toward a specific feature in the image, go to a specific rock in the field of view and get a closer look with one of the cameras, use one of the other instruments on the rover (the RAT or spectrometer) to acquire more data about a specific rock.

Give students the glossary terms without definitions and have them research the terms and write their own definitions. For younger students, the teacher may wish to lead the discussion of an image with the full class.

For older students, each team should make new science conclusion(s) based on their scientific analysis and observation of their image. For example, they could say: The interior of the rocks named El Capitan and Humphrey (in Image #3 and #4) suggests that Mars rocks had interactions with water over long periods of time.

Credits

This activity was created by Amy Grochowski and Jayne Aubele, New Mexico Museum of Natural History & Science.

Glossary of Terms in this Activity

Backshell: the back half of the protective aeroshell that covered the lander as it entered the atmosphere of Mars, jettisoned before landing.

Deflation: the removal of material, usually fine sand or silt from a desert or other land surface, by wind action.

Flow-banding: the structure of an igneous rock, characterized by layers and/or texture, formed as a result of the flow of magma or lava.

Heat shield: one-half of the protective aeroshell covering the lander, protects the lander from heat, acts as a shield in front of the landers to protect them during entry into Mars atmosphere, jettisoned before landing.

Impact crater: a depression formed by the impact of a body such as a meteorite, comet, or asteroid on the surface of a planet.

Olivine: a common mineral in volcanic rock, consisting of magnesium, iron, and silica, generally green to brown in color, gem variety called peridot.

Parachute: a lightweight canopy attached by cords and opened during descent in order to slow the MER landers during atmospheric entry (retro rockets were also fired after the parachute was jettisoned when the landers were near the ground and then air bags were inflated for the final landing).

Vesicle: a small cavity in volcanic rock, formed by the expansion of a bubble of gas or steam during the eruption of the rock.

MER Image Analysis: Teacher's Answer Key

Image 1: Meridiani Planum: Landing Site of Opportunity

Question 1. The first bounce mark of the rover's lander appears as a large faint mark on the surface. Answer is C.

Question 2. The heat shield impact site of the rover's lander appears as a small dark circular depression. Answer is D.

Question 3. The lander is seen on the surface as a white speck within a small crater. Answer is A.

Question 4. The backshell and parachute of the rover's lander appear as a large white dot with a faint white object connected to it. Answer is B.

Image 2: Bonneville Crater from Spirit

Question 1. Scientists think these sand dunes might consist of wind-deposited par¬ticles that are the same as the dark material found against the back wall of the crater. Answer is C.

Question 2. Bonneville Crater viewed from the southwest rim. Answer is A.

Question 3. The dark material just below the far rim of this crater is similar in com¬position to rocks that scientists have analyzed along their journey. Answer is B.

Image 3: El Capitan from Opportunity

Question 1. Rover tracks look just like tire tracks. Answer is B.

Question 2. The RAT makes circular patterns on a rock's surface. Answer is A.

Image 4: Humphrey from Spirit

Question 1. These dark spots in the center of the hole may be crystals of the mineral olivine. Answer is C.

Question 2. A vesicle looks like an irregularly shaped hole in the rock. Answer is B.

Question 3. A natural light-colored vein in the rock looks like an irregularly shaped scratch on the rock's surface. Answer is A.

Image 5: Sandia from Spirit

Question 1. Vesicles look like small holes in a rock, and they were probably once gas bubbles within the lava. Answer is B.

Question 2. Flow banding looks like horizontal lines on the side of a rock and occurs when lava flows. Answer is A.

Question 3. Deposition (or accretion) occurs when wind deposits material that slowly buries rocks. Deflation occurs when surface material is removed by wind, exposing more and more of the rock. Answer is C.

MER Image Analysis Conclusions- Teachers' Key to Observations

Image 1 (Opportunity Landing Site) Science Conclusions and Possible Observations

Conclusion: The landing site is a relatively young (geologically) area that has not changed much since its formation.

Observation: it is a very flat plain with only a few impact craters on it.

Conclusion: The surface must be covered by loose surface material like sand or dust that can be moved or scuffed.

Observation: light and dark patches where the lander bounced.

Image 2 (Bonneville Crater): Science Conclusions and Possible Observations

Conclusion: There is evidence of wind at this site.

Observation: Dunes probably formed by sand-sized material moved by the wind.

Observation: Bonneville crater is very shallow and is probably filled with wind deposited material.

Conclusion: The rocks around the crater are probably volcanic rocks.

Observation: Angular rocks, some are dark in color.

Image 3 (El Capitan): Science Conclusions and Possible Observations

Conclusion: This outcrop of rock represents water-deposited material. Observation: the outcrop appears to be layered which is common in water-deposited rock.

Observation: the chemistry of the rocks indicates that they were deposited in association with water.

Observation: the area around the outcrop and the outcrop rock itself is fairly soft because the rover wheel tracks are obvious and the hole ground by the rock abrasion tool (RAT) is quite deep.

Image 4 (Humphrey): Science Conclusions and Possible Observations

Conclusion: Humphrey is a volcanic rock and probably part of an old lava flow.

Observation: Humphrey contains crystals identified as the mineral olivine (common in volcanic rock) and vesicles.

Conclusion: Humphrey shows evidence of being affected by water some time in the past.

Observation: The light-colored vein is a mineral filling a crack in Humphrey. This mineral was probably deposited by water circulating through the ground when Humphrey was buried.

Image 5 (Sandia): Science Conclusions and Possible Observations

Conclusion: Sandia is a volcanic rock.

Observations: Vesicles and flow-banding are both common in volcanic rock.

Conclusion: This kind of rock (volcanic) is beneath the surface of Mars in this area.

Observation: Sandia is on the rim of Bonneville Crater. It is probably ejecta that was thrown out of the crater which means that it was excavated from beneath the surface.

Conclusion: The wind on Mars sometimes deposits material and sometimes erodes material at the surface.

Observations: Some of the smaller rocks appear to be buried by dunes while others are totally exposed at the surface.

Large Image 1. Meridiani Planum: Landing Site of Opportunity

From Mars Global Surveyor Orbiter; image is about 1300 m long. The landing site of the Mars Exploration Rover Opportunity in Meridiani Planum, Mars. Signs of the rover landing are visible, including the lander, backshell, and parachute, and the first bounce mark made by the airbags and the site where its heat shield impacted the surface. This image was taken by a camera on board the Mars Global Surveyor Orbiter, which was able to monitor, image, and relay messages from the rovers to Earth during the MER mission. Image credit: NASA/JPL/ MSSS.

Large Image 2. Bonneville Crater

From the MER rover Spirit. The interior and far walls of the impact crater named Bonneville can be seen in the background. In the foreground are wind-deposited drifts or dunes of dust or sand. It looks like a scene from a desert area on Earth. The rover Spirit completed this mosaic (multiple images put together to form a larger image) on Sol (Mars Day) 71, Earth Date March 15, 2004. This mosaic was taken by the Navcam (navigational cameras) on the rover and covers 180 degrees in the field of view. Scientists are interested in craters and dunes because they give insight into the processes that formed and affect the surface of Mars. Analysis by the rover science team indicates that the dark material just below the far rim of this crater is similar to the composition of rocks that Spirit has analyzed along its journey to this location. Note that the rocks in the foreground are angular-looking and some appear to be dark in color. Image credit: NASA/JPL.

Large Image 3. The outcrop named El Capitan

From the MER rover Opportunity. This is a Navcam (navigation camera) image taken by the rover named Opportu¬nity on Sol 36 (the 36th Mars Day of its exploration) or Earth date March 1, 2004.The image shows the layered rocks of the area named El Capitan, located near the landing site of Opportunity in Meridiani Planum. Visible on two of the rocks are the holes drilled by the RAT (Rock Abrasion Tool). By using the RAT to grind through the dust and weathered coatings or rind on the surface of the rock, mission scientists were able to determine the chemical composition of the rock.The chemical data indicated that the rocks contained sulfur that could only have been formed by interactions between water and rock. The layering of the rocks seems to indicate that they were deposited slowly one layer at a time, perhaps in water, in a similar process to the formation of layers of sedimentary rock such as shale or sandstone on Earth. Wheel tracks from the rover Opportunity can be seen at the bottom left and right sides of this image. The tracks extend to the center of the image, indicating the position where Opportunity sat when it analyzed the rocks with the scientific instruments on its robotic arm. Image Credit: NASA/JPL.

Large Image 4. The rock named Humphrey

From the MER rover Spirit. This image is a mosaic (multiple images put together to form a larger image) taken by the instrument called the microscopic imager (MI) on Spirit. Four individual close-up images have been very carefully fitted together to reveal the entire 5-centimeter-diameter (almost 2-inch) hole made by the instrument called the RAT (Rock Abrasion Tool) on this rock. The mosaic, created on March 7, 2004, is the first of its kind showing the fresh interior of a rock on Mars, and it gave scientists their first-ever microscopic view of a Mars rock. The MER mission geologists were interested in many of the small features of Humphrey. The light-colored veins within the rock are important. They may be filled with a mineral that was deposited by water and therefore may be evidence that water was moving through the rock while it was deep underground. The dark spots in the center have been identified as crystals of the mineral olivine. Olivine (also known as peridot, the August birthstone) is a common mineral in volcanic rock called basalt on Earth. Image credit: NASA/JPL/Cornell/USGS/Honeybee Robotics.

Large Image 5. The rock named Sandia

From the MER Rover Spirit. This image, taken by the high-resolution Pancam (panoramic camera) of the MER rover Spirit on Sol 53 (the 53rd Mars Day of its mission), struck mission science and engineering team members as not only scientifically interesting but also remarkably beautiful. The large shadowed rock in the foreground is named Sandia for a mountain range in New Mexico. An imposing rock, Sandia is about 33 centimeters (1 foot) high and about 1.7 meters (5.5 feet) long. Geologists believe that Sandia is a volcanic rock called basalt that landed on its side after being ejected from the nearby impact crater, Bonneville Crater. The vertical lines on the side of the rock facing the camera are called flow-banding and are typical of volcanic lava flows. They usually run horizontally, indicating that Sandia is on its side. What look like small holes on the two visible sides of the rock are called vesicles. Vesicles are holes left behind by gas bubbles within the lava flow. The lighting not only makes this a very artistic view, it helps the mission scientists get a virtual three-dimensional view of the rocks. Observations taken at different times of day, as shadows move and the surface texture details on rocks are revealed, are entered into computer software that turns a two-dimensional image into a three-dimensional tool. Many smaller rocks can be seen in the background; they appear to be partly buried. Geologists believe that two processes might be at work on Mars, perhaps at different seasons of the year. There is evidence in this image for both deposition of fine-grained surface material by the wind and for removal of fine-grained surface material (called deflation) by the wind. Image credit: NASA/JPL/Cornell.

Write some observations supporting your conclusions here.

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Mars Exploration Rover Mission Investigation Log

MER Image Analysis

Name(s) _____

_____

Date _____

MER Images Investigation Log

Study the images returned from the Mars exploration rovers Spirit and Opportunity. In this log, fill in the appropriate letters from the corresponding large image. Find and label these features on the small images. Analyze the images. The mission science team has made some scientific conclusions about these images. What observations can you make about the images that would support these conclusions? List your observations on the back page of this log.

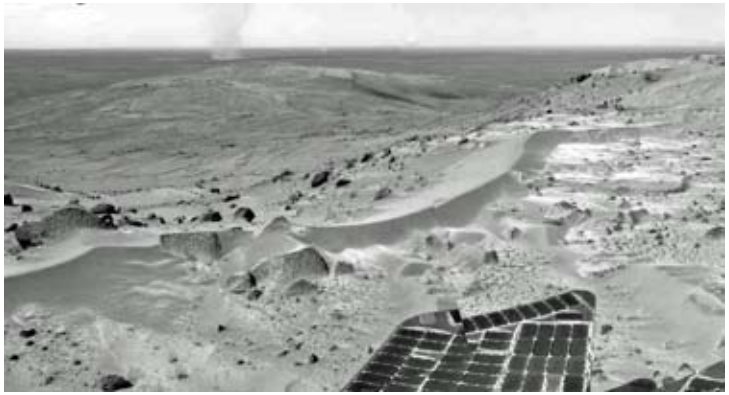
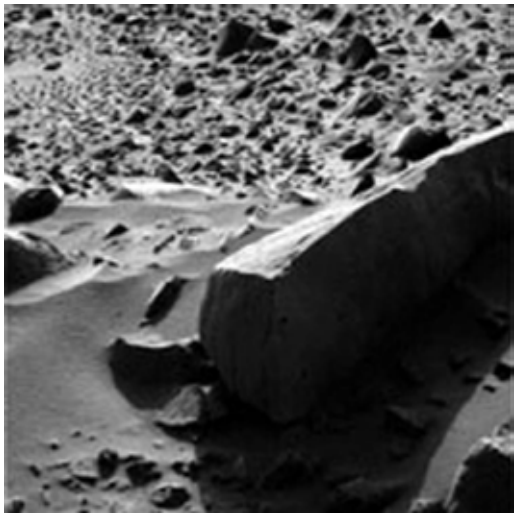


Image 5: Sandia from Spirit



Look for and identify the following features:

_____ 1. Vesicles look like small holes in a rock, and they were probably once gas bubbles within the lava.

_____ 2. Flow banding looks like horizontal lines on the side of a rock and occurs when lava flows.

_____ 3. Deposition (or accretion) occurs when wind deposits material that slowly buries rocks. Deflation occurs when surface material is removed by wind, exposing more and more of the rock.

Science conclusions:

- Sandia is a volcanic rock.
- This kind of rock (volcanic) is beneath the surface of Mars in this area.
- The wind on Mars sometimes deposits material and sometimes erodes material at the surface.

Image 4: Humphrey from Spirit

Look for and identify the following features:

_____1. These dark spots in the center of the hole may be crystals of the mineral olivine.

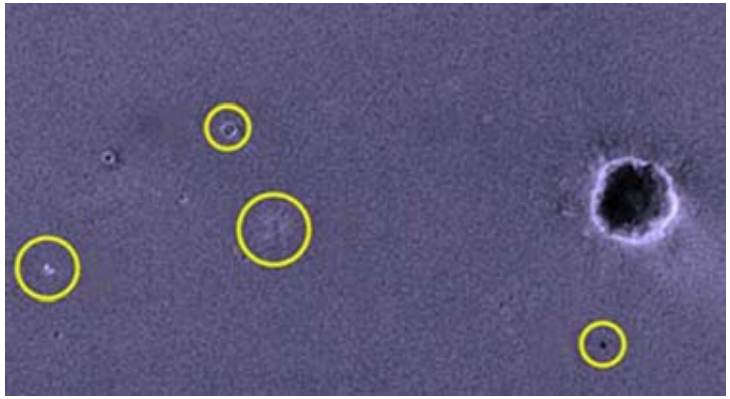
_____2. A vesicle look like an irregularly shaped hole in the rock.

_____3. A natural light-colored vein in the rock looks like an irregularly shaped scratch on the rock's surface.

Science conclusions:

- Humphrey is a volcanic rock and probably part of an old lava flow.
- Humphrey shows evidence of being affected by water some time in the past.

Image 1: Meridiani Planum: Landing Site of Opportunity



Look for and identify the following features:

_____1. The first bounce mark of the rover's lander appears as a large faint mark on the surface.

_____2. The heat shield impact site of the rover's lander appears as a small dark circular depression.

_____3. The rover's lander is seen on the surface as a white speck within a small crater.

_____4. The backshell and parachute of the rover's lander appear as a large white dot with a faint white object connected to it.

Science conclusions:

- The landing site is a relatively young (geologically) area that has not changed much since its formation.
- The surface must be covered by loose material like sand or dust that can be moved or scuffed.

Image 2: Bonneville Crater from Spirit

_____1. Scientists think these sand dunes might consist of wind-deposited particles that are the same as the dark material found against the back wall of the crater.

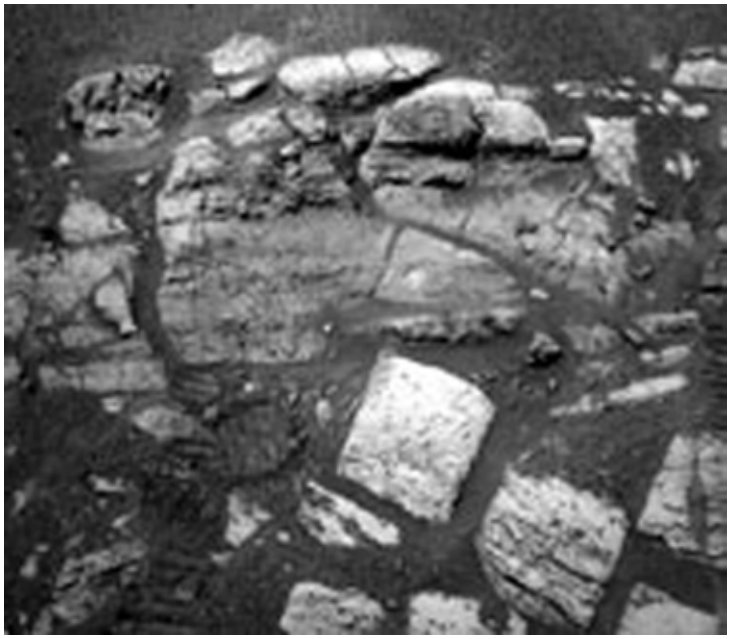
_____2. Bonneville Crater (220 m from rim to rim) viewed from the southwest rim.

_____3. The dark material just below the far rim of this crater is similar in composition to rocks that scientists have analyzed along their journey to this location.

Science conclusions:

- There is evidence of wind at this site.
- The rocks around the crater are probably volcanic rocks.

Image 3: El Capitan from Opportunity



Look for and identify the following features:

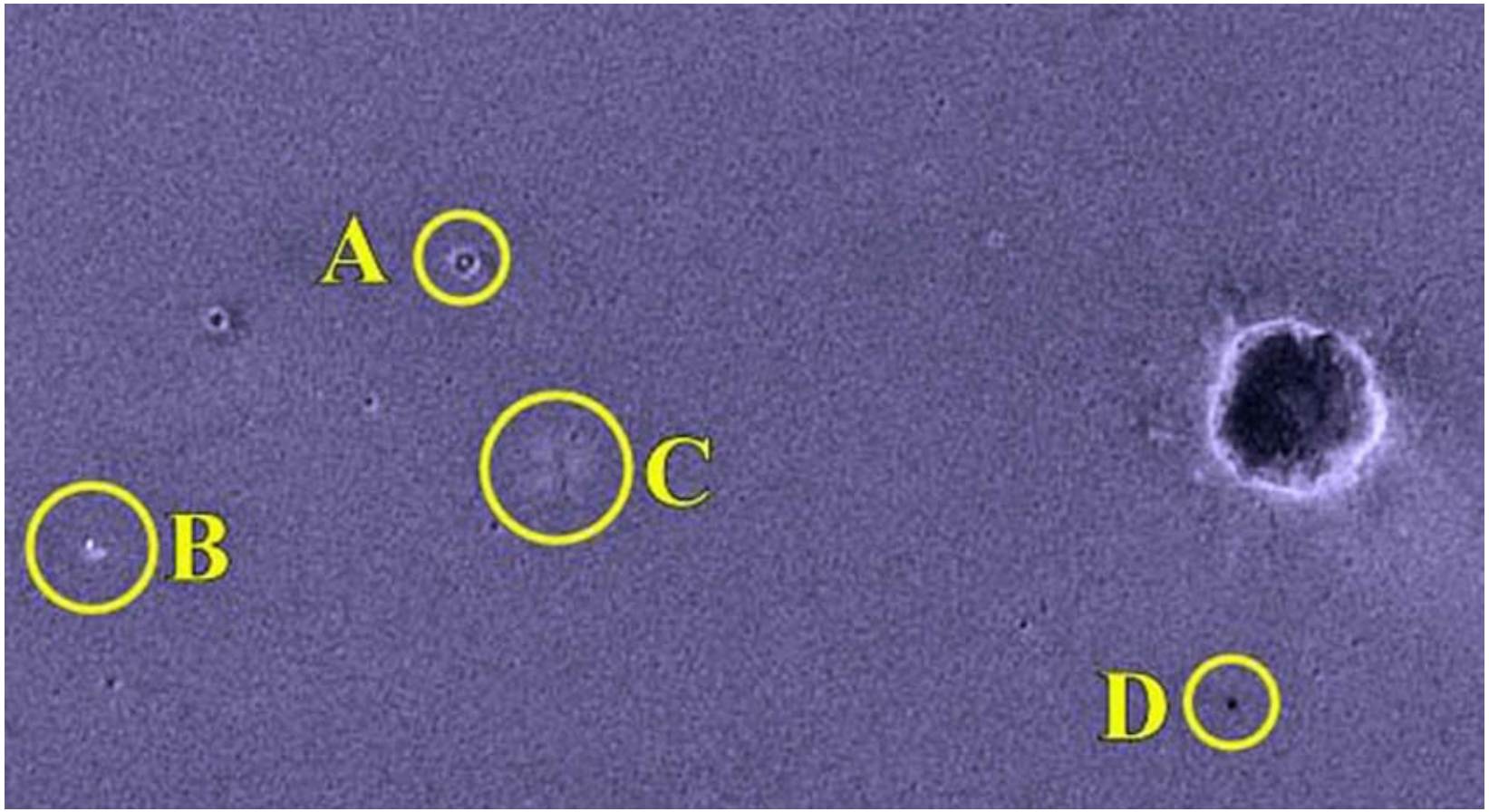
_____1. Rover tracks look just like tire tracks.

_____2. The rock abrasion tool (or RAT) makes circular patterns on a rock's surface.

Science conclusions:

- This outcrop of rock represents water-deposited material.

Large Image 1: Meridiani Planum: Landing Site of Opportunity



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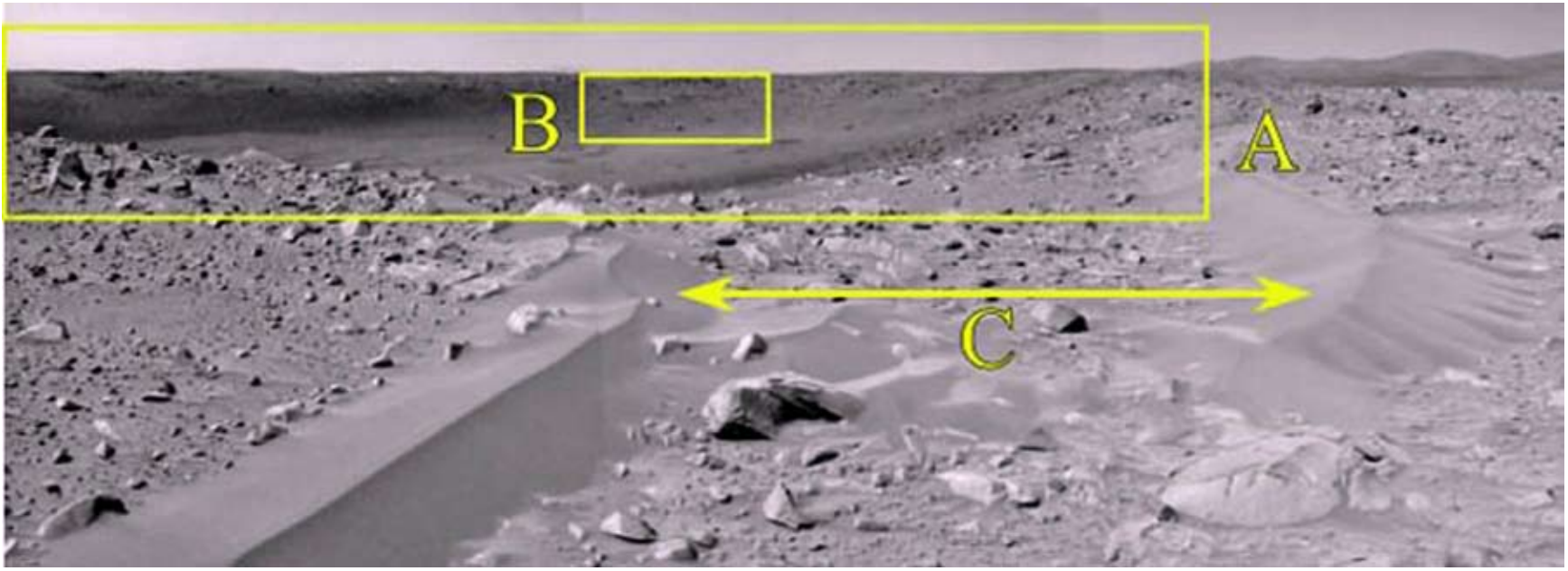
From Mars Global Surveyor Orbiter; image is about 1300 m long.

The landing site of the Mars Exploration Rover Opportunity in Meridiani Planum, Mars. Signs of the rover landing are visible, including the lander, backshell, and parachute, and the first bounce mark made by the airbags and the site where its heat shield impacted the surface. This image was taken by a camera on board the Mars Global Surveyor Orbiter, which was able to monitor, image, and relay messages from the rovers to Earth during the MER mission.

Image credit: NASA/JPL/MSSS

Large Image 2: Bonneville Crater from Spirit



Large Image 2. Bonneville Crater

From the MER rover Spirit

The interior and far walls of the impact crater named Bonneville can be seen in the background. In the foreground are wind-deposited drifts or dunes of dust or sand. It looks like a scene from a desert area on Earth. The rover Spirit completed this mosaic (multiple images put together to form a larger image) on Sol (Mars Day) 71, Earth Date March 15, 2004. This mosaic was taken by the Navcam (navigational cameras) on the rover and covers 180 degrees in the field of view.

Scientists are interested in craters and dunes because they give insight into the processes that formed and affect the surface of Mars. Analysis by the rover science team indicates that the dark material just below the far rim of this crater is similar to the composition of rocks that Spirit has analyzed along its journey to this location. Note that the rocks in the foreground are angular-looking and some appear to be dark in color.

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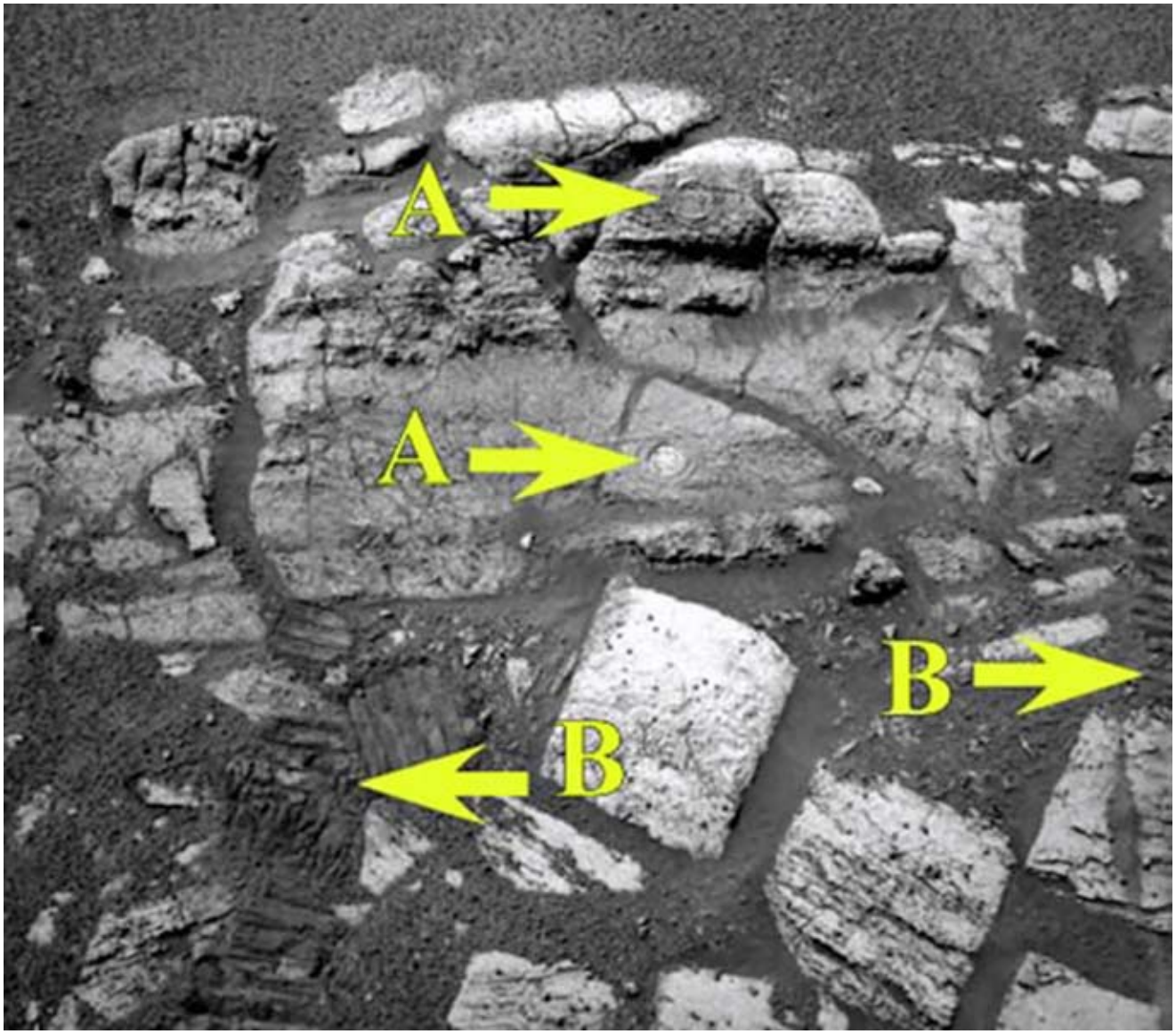
Large Image 3: El Capitan from Opportunity



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Wheel tracks from the rover Opportunity can be seen at the bottom left and right sides of this image. The tracks extend to the center of the image, indicating the position where Opportunity sat when it analyzed the rocks with the scientific instruments on its robotic arm.

Image Credit: NASA/JPL

Large Image 4: Humphrey from Spirit

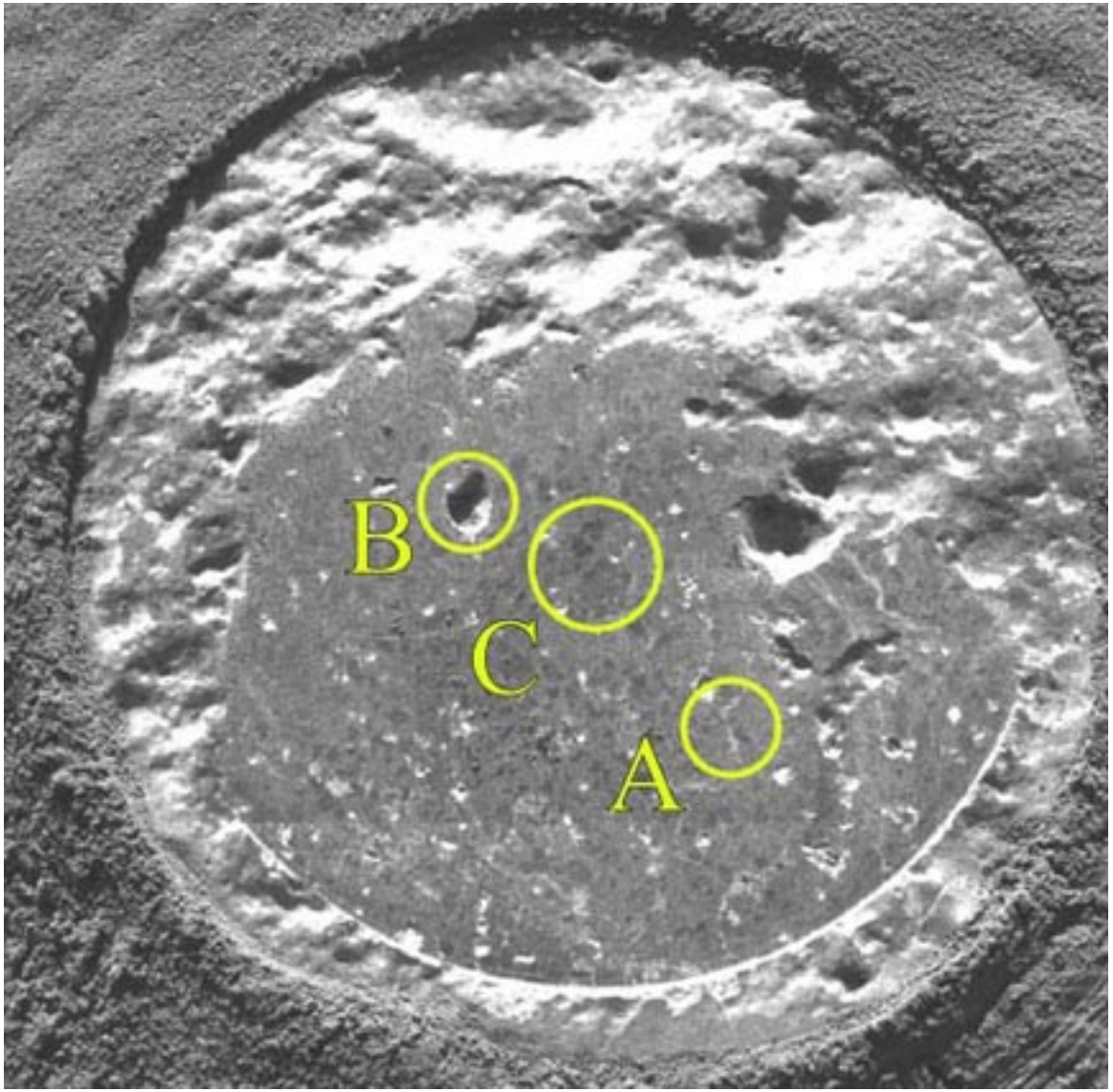

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Image credit: NASA/JPL/Cornell/USGS/Honeybee Robotics

Large Image 5: Sandia from Spirit

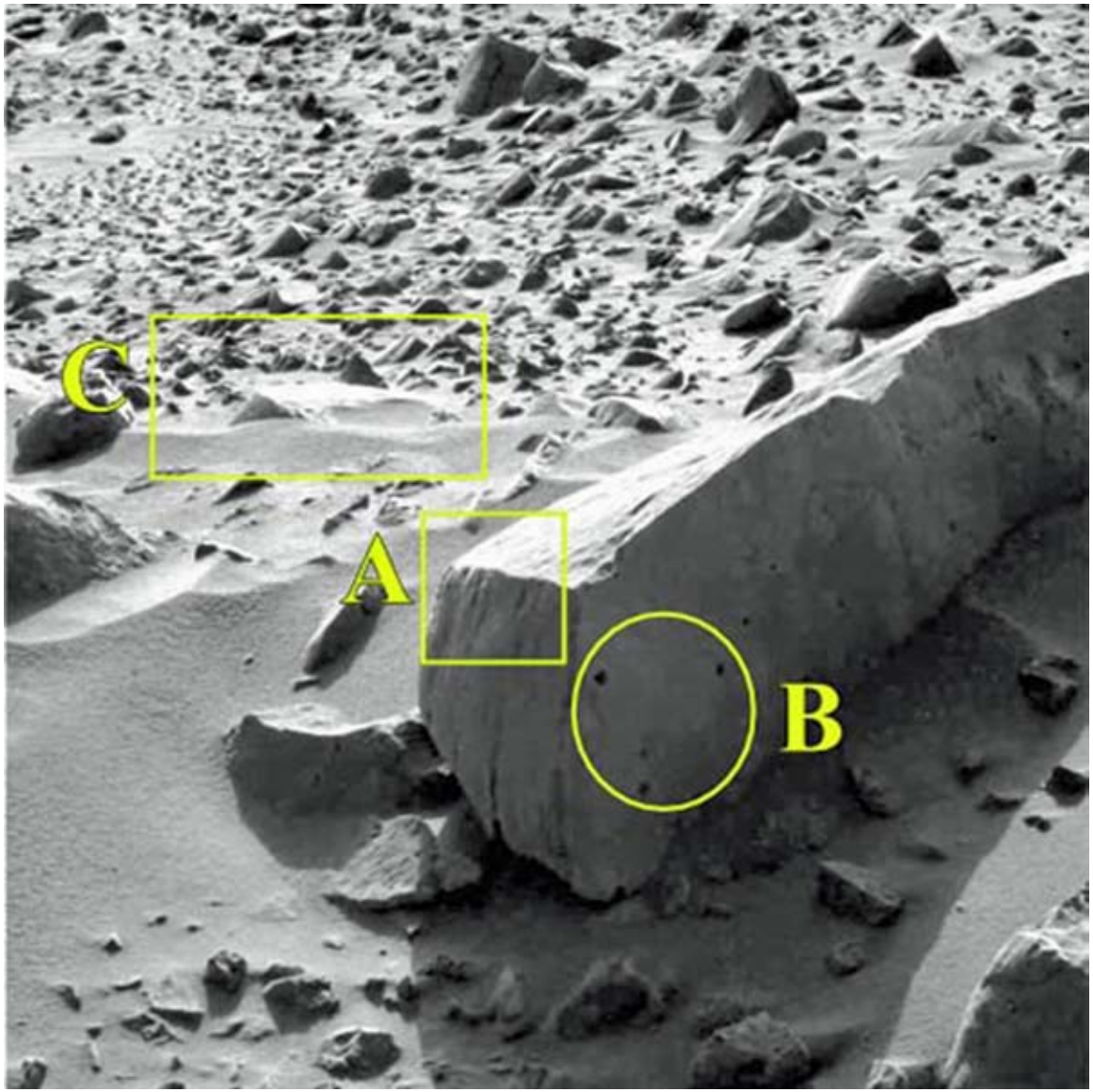

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Image credit: NASA/JPL/Cornell