EXERCISE 20

Examining the Terrestrial Planets

Of the terrestrial planets, Earth exhibits the most complex and diverse topography (Figure 20.1). Fortunately, living on the planet allows us the opportunity to investigate in detail those geologic processes that continuously modify its surface. However, scientists are also painfully aware that the processes active on today's Earth have also removed much of the record of our planet's geologic history.

With the use of increasingly more sophisticated earthbound instruments, and during recent decades, complex spacecraft, early speculation about the nature of the objects that comprise the solar system has given way to detailed scientific investigation. In this investigation you will explore those natural processes that shape not only our planet, Earth, but, to some degree, all the terrestrial planets.

Objectives

After you have completed this exercise, you should be able to:

1. List and describe the geologic processes that have shaped the landforms of the terrestrial planets.
2. Give an example of a feature on Earth or the Moon produced by each of the geologic processes that have shaped the landforms of the terrestrial planets.
3. List the primary geologic processes that have shaped the landforms on each of the terrestrial planets.
4. Describe the procedure for determining the relative ages of a planet's surface features.

Materials

ruler
colored pencils
calculator

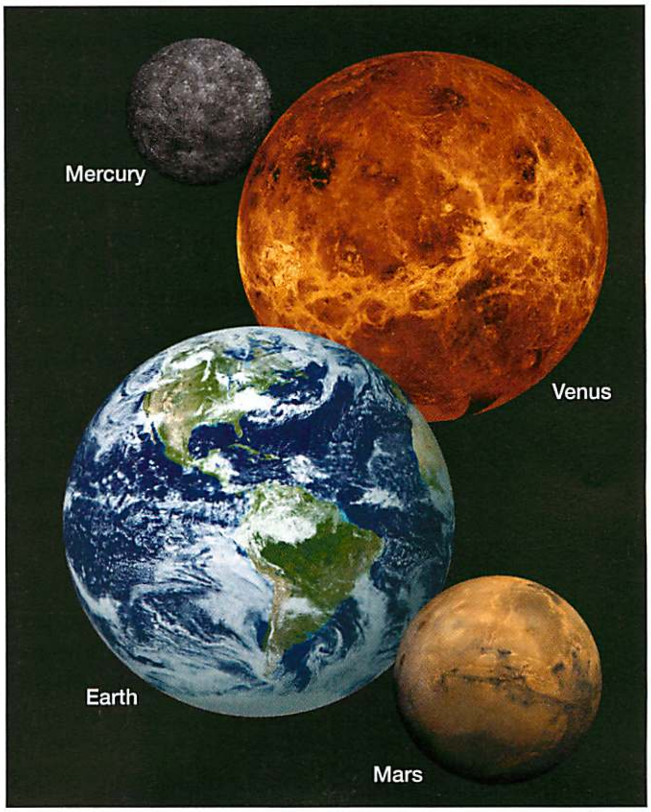

Figure 20.1 The terrestrial planets. (Image courtesy of NASA)

Terms

volcanism
tectonism
gradation
impact cratering

Geologic Processes of the Terrestrial Planets

The forces that drive Earth's evolution and contour its surface also operate elsewhere in the solar system. Thanks to detailed investigations of our Moon and neighbor planets, scientists are now examining how the four main geologic processes that act on Earth's surface (volcanism, tectonism, gradation, and impact cratering) have shaped the exteriors of other members of the solar system. Since each of these processes often produces distinctive landforms or surface features, by identifying and analyzing these objects it is possible to begin to unravel the geologic history of a planetary surface.

Volcanism and tectonism are driven by a planet's internal forces, with both tending to increase the relief and enhance the topography of a planet. The process of **volcanism** is the eruption of molten rock material (*magma*) and its associated gases onto a planet's surface. Steep, conical hills with summit *craters*, or large *calderas*, and regions covered by rock that appears to have at one time flowed are distinctive as volcanic in origin. **Tectonism** involves the movement of crustal rock by fracturing, faulting, or folding. The process is responsible for the major structural or deformational features of a planet. Landforms produced by tectonism are typically straight or gently curving and include mountain ranges, ridges, and fault scarps.

Gradation, the process that levels a surface to a common elevation by erosion and deposition, is controlled by the surface environment of a planet. Gravity, temperature, and the presence of an atmosphere all play key roles. The major agents of gradation include running water, gravity, wind, and ice.

The fourth geologic process acting on a planet's surface, **impact cratering**, is the consequence of rapidly moving *meteoroids* from space striking the surface. Large craters resulting from such impacts often have central pinnacles (peaks) and are surrounded by a blanket of material, called *ejecta*, which has been thrown from the crater.

Our understanding of the geologic histories of the planets and their satellites is based on observations of their surfaces. This exercise investigates and compares the surfaces of Mercury, Venus, Earth (and the Moon), and Mars at both global and detailed scales. At a global scale, only the largest and most prominent landforms and terrains—such as large volcanoes, canyons, mountains, etc.—are visible. However, detailed examination of a landform and its relation to the surrounding landscape can be used to understand a single feature's specific evolution.

Geologic Landforms on Earth

Geologic processes frequently result in distinctive landforms, which can be identified based on their shapes and forms. For example, the characteristic shapes of volcanoes or impact craters, and the branching pattern of a river system.

Begin your investigation of geologic processes by examining those at work on Earth and its Moon. Use the photographs in Figure 20.2 to answer questions 1–10.

1. Selecting from the lettered photographs (Figure 20.2a–j), list the letter of one or more examples of features produced by each of the four geologic processes that modify the surfaces of Earth and/or its Moon.

   Volcanism: ____________________

   Tectonism: ____________________

   Gradation: ____________________

   Impact cratering: ____________________

Photographs 20.2a, b, and h are representative of gradational processes on Earth. The major agents of gradation are running water, wind, gravity, and ice.

2. Indicate the agent responsible for the feature in each photo (Figure 20.2a, b, and h) by writing the name of the agent by the image.

Figure 20.2i is Meteor Crater, an impact crater in Arizona. Figure 20.2c is of Mount Capulin, a volcanic cone in New Mexico.

3. Describe the general shape of the impact crater compared to that of the volcanic cone.

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Meteor Crater has a diameter of approximately 1,200 meters. It is estimated that the object that produced it was about 25 meters across.

4. How many times greater is the size of the crater than the object that produced it? Suggest a reason(s) why such a comparatively small object can form such a large hole.

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5. Meteor Crater, one of the best preserved impact craters on Earth, has been somewhat eroded. Describe the evidence for this erosion.

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6. It is very likely that at one time Meteor Crater had a central peak. What might have happened to this feature?

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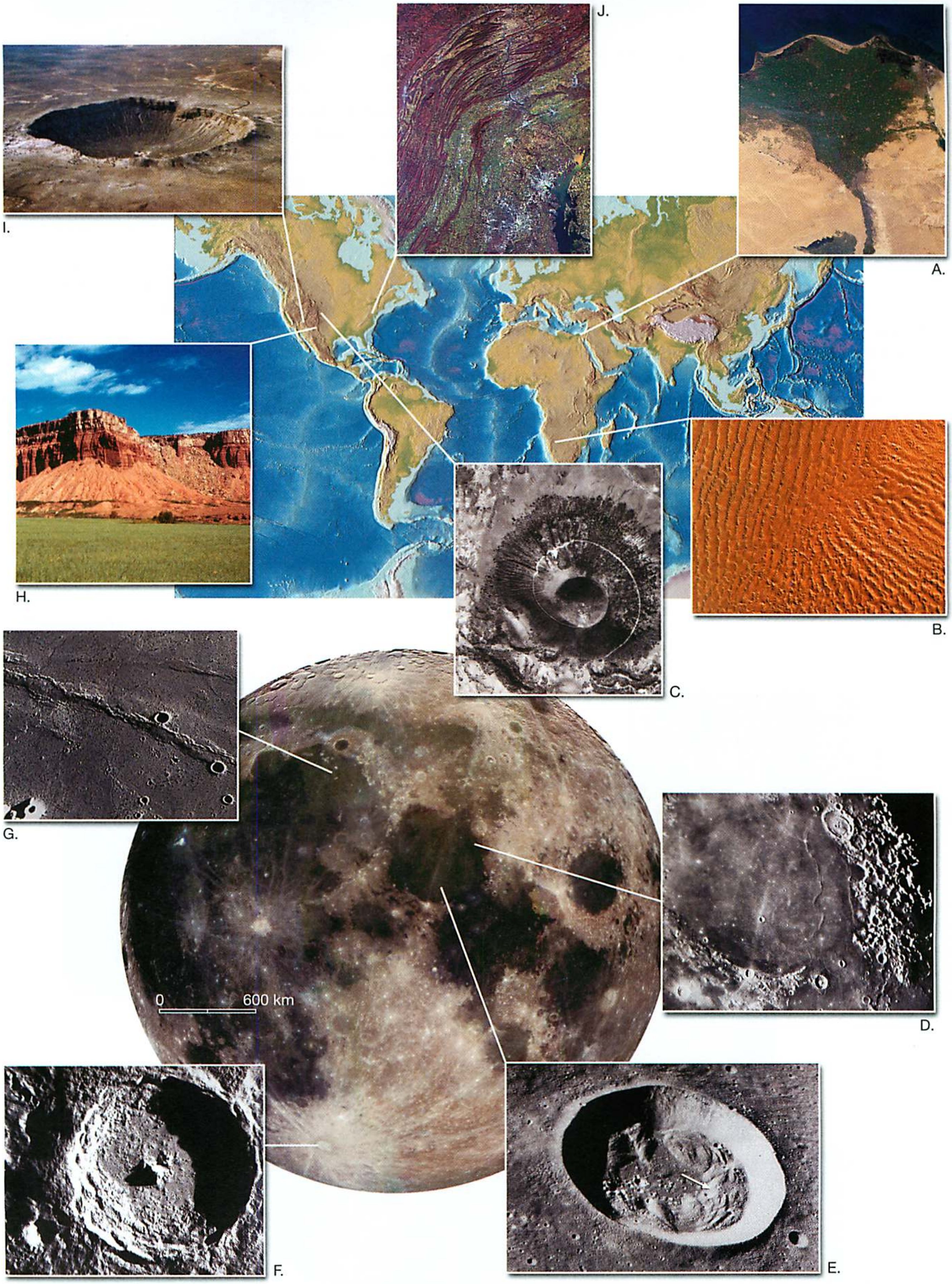

Figure 20.2 Geologic processes on the Earth and Moon. (A. and J. NASA/GSFC/JPL, MISR Team; B. Image provided by the USGS EROS Data Center Satellite Branch; C. Courtesy of U.S. Geological Survey; D. Lunar and Planetary Institute/Universities Research Association; E.-G. Courtesy of NASA; Moon, Courtesy of NASA/JPL-Caltech; H. Courtesy of USGS; I. Photograph by David Roddy, USGS)

7. Which lunar feature (Figure 20.2d, e, f, or g) most resembles Meteor Crater? Describe its appearance and probable origin.

8. Locate and label the lava flow at the base of Mt. Capulin (Figure 20.2c). Is it smooth or rough?

9. The large, smooth, dark lunar feature represented in Figure 20.2d was most likely formed by (volcanism, gradation), whereas the feature inside the crater in 20.2e is most likely the result of gradation by (wind, water, gravity). Circle your answers.

10. Figure 20.2j, a portion of the folded Appalachian Mountains, is representative of tectonism on Earth. Which lunar photo best represents the same geologic process on the Moon? What may have produced the lunar feature?

Mercury

Mercury, the closest planet to the Sun, is only slightly larger than Earth's Moon. This smallest planet has no atmosphere and experiences a surface temperature range of 600° (−173°C–427°C). With noontime temperatures approaching 800°F (427°C), its exterior is one of the most extreme environments in the solar system. Use the images in Figure 20.3 to answer questions 11–13.

11. How does the surface of Mercury, Figure 20.3, compare to that of the Moon? What are the similarities? What are some differences?

12. Of the four processes that alter a planet's surface, which is *least* effective on Mercury? Explain the reason for your choice.

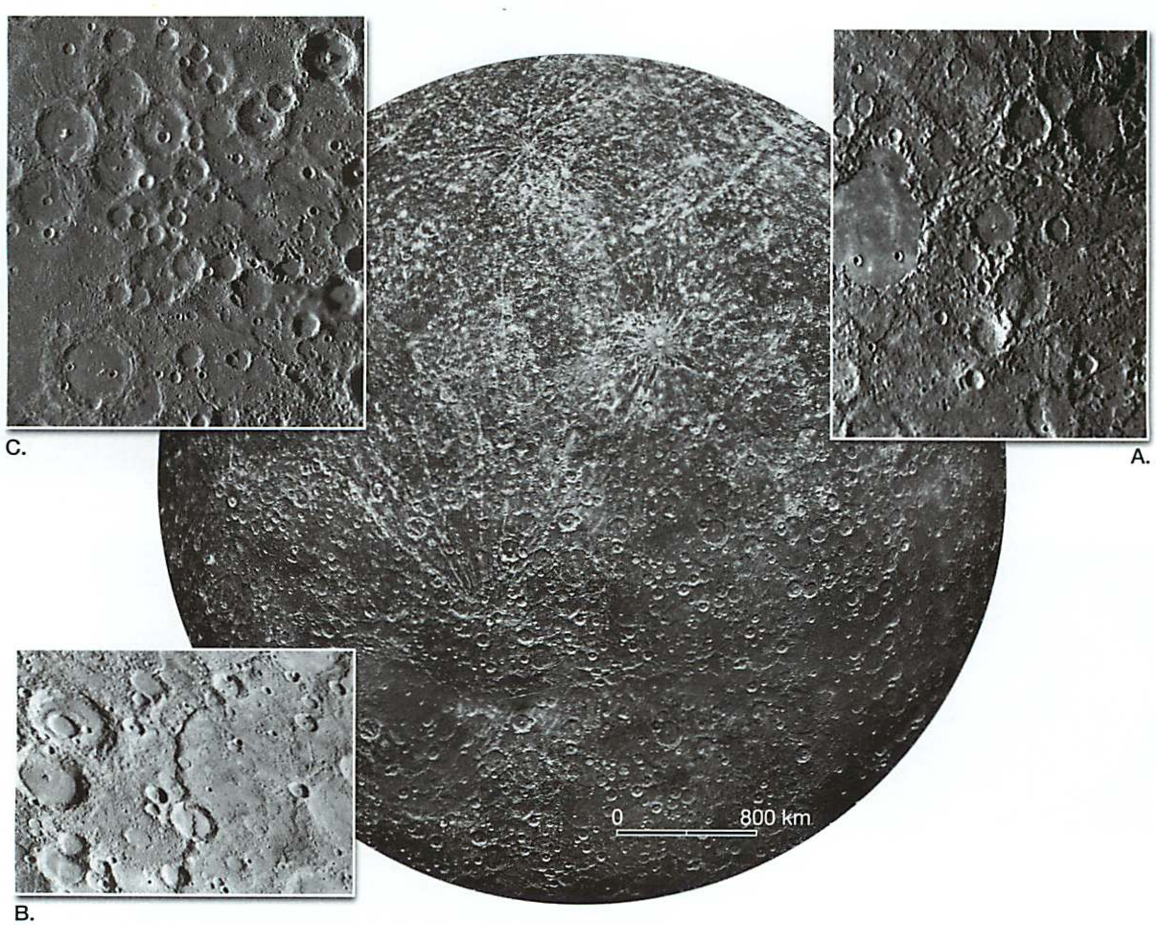

Figure 20.3 Geologic processes on Mercury. (Images courtesy of NASA Jet Propulsion Laboratory, NASA-JPL)

13. Choosing from the geologic processes that act on a planet's surface, write the name of the process most likely responsible for the features in Figures 20.3a, b, and c next to the image.

14. The primary source of a planet's primitive atmosphere is the release of volcanic gases that are dissolved in molten rock. Suggest a reason(s) why Mercury, although it has numerous volcanic features, is devoid of an atmosphere.

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Venus

Venus, second only to the Moon in brilliance in the night sky, is similar to Earth in size, density, mass, and location in the solar system. The "enhanced greenhouse effect" of the Venusian atmosphere, consisting of 97% carbon dioxide with only a scant trace of water vapor, is responsible for surface temperatures near 475°C (900°F). Although strong above-surface winds exist on the planet, surface winds average only a few meters per second. The planet is shrouded in thick, opaque clouds that completely hide the surface from viewing by traditional visible light cameras. Nevertheless, using radar, which can penetrate through clouds, the unmanned *Magellan* spacecraft has provided hundreds of images of the surface that reveal a varied volcanic topography (Figure 20.4). In general, these radar images show rough topography (mountains, crater rims, ejecta, etc.) as bright regions, and smoother material as dark. With its high surface temperature, lack of water, and an atmospheric pressure that is 90 times that at Earth's surface, Venus is certainly one of the most uninviting places in the solar system. Use the Venusian images in Figure 20.4 to answer questions 15–25.

15. Using the full-disk image of Venus in Figure 20.4, write a brief, general description of the planet's surface.

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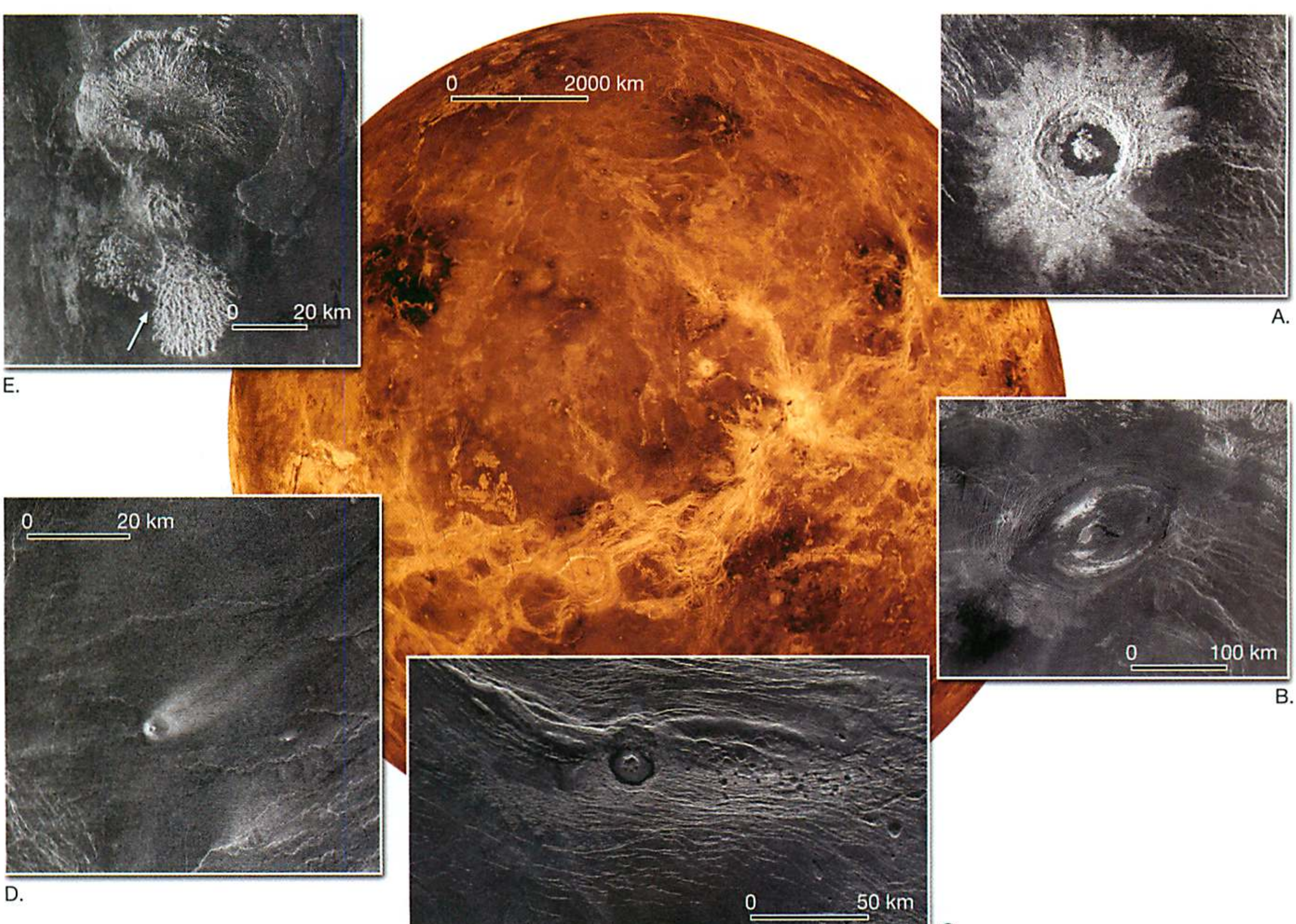

Figure 20.4 Geologic processes on Venus. (A.-E. Courtesy NASA/JPL-Caltech; Venus, Courtesy of NASA/JPL)

16. Choosing from the geologic processes that act on a planet's surface, write the name of the process most likely responsible for each feature in Figures 20.4a–e next to the image.

Figure 20.4a is a radar image of Golubkina crater, a 34-kilometer (21-mile) wide impact crater.

17. Why are parts of the image in Figure 20.4a bright white?

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18. Label the crater's central peak, crater floor, and ejecta on Figure 20.4a.
19. Is Golubkina crater younger or older than the surrounding landscape? How did you arrive at your conclusion?

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Figure 20.4b, Sacajawea, is a volcanic cone with a large summit caldera.

20. What is the approximate diameter in kilometers and miles of the summit caldera on Sacajawea?

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21. Suggest a cause for the system of concentric lines that surround the caldera on Sacajawea.

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22. The geologic process most likely responsible for producing the long, linear features in Figure 20.4c is (tectonism, gradation, impact cratering). Circle your answer.
23. The large crater in the upper left of center in Figure 20.4c is (older, younger, the same age) as the linear features. Circle your answer. How did you arrive at your conclusion?

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Figures 20.4d and e are of features produced by gradation.

24. The gradational agent responsible for the feature in Figure 20.4d is (running water, gravity, wind, ice), whereas those landforms composed of unconsolidated volcanic debris on the side of the volcanic cone in Figure 20.4e are probably the result of (running water, gravity, wind, ice). Circle your answers.
25. Approximately how far do the landforms at the base of the volcano in Figure 20.4e extend beyond the summit of the cone? The features are most likely (glaciers, rivers, landslides). Circle your answer.

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Mars

With its thin atmosphere, polar caps, and seasons, in many ways Mars is similar to Earth in that the same four geologic processes that shape our planet's surface have left their mark on Mars. The Martian surface is essentially volcanic. Although some of the largest volcanoes in the solar system are found on Mars, all are apparently extinct. However, numerous broad shield cones, vast lava flows, and plains of volcanic material all suggest an extensive volcanic history. Unlike Earth, Mars does not experience plate tectonics but does exhibit many tectonic features caused by compressional and extensional stresses. Furthermore, as on the Moon, Mercury, and Venus, impact craters are very evident on the Martian surface.

Gradation is the dominant geologic process altering the present-day surface of Mars. Gravity and wind are continuing agents responsible for frequent landslides and numerous dunes. Moreover, although extremely cold temperatures and low atmospheric pressures suppress the formation of liquid water on the surface of Mars today, many landforms suggest that, in the past, running water was an effective gradational agent.

After you examine the images of Mars in Figure 20.5, continue your investigation of the surfaces of the terrestrial planets by answering questions 26–33.

26. Selecting from the lettered photographs (Figure 20.5a–f), list the letter of one or more examples of features produced by each of the four geologic processes that modified the surface of Mars.

Volcanism: ______________________________

Tectonism: ______________________________

Gradation: ______________________________

Impact cratering: ______________________________

27. Using the full-disk image of Mars in Figure 20.5, write a brief, general description of the surface.

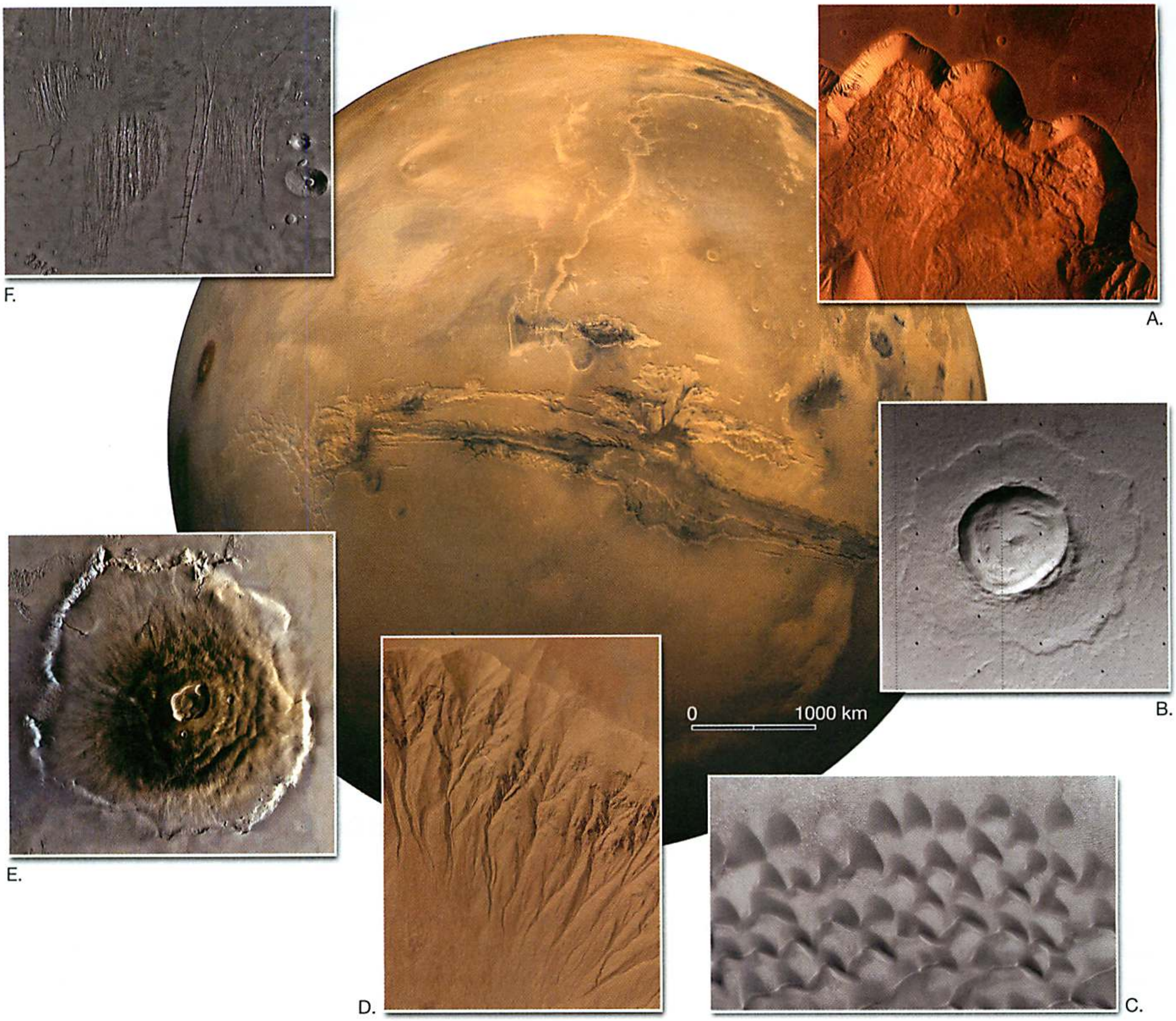

Figure 20.5 Geologic processes on Mars. (A. Courtesy NASA/JPL-Caltech; B: Courtesy of NASA/NSSDC; C. and F. Courtesy of NASA/Mars Orbiter Laser Altimeter (MOLA) Team; D. Courtesy of NASA/JPL/Malin Space Science Systems; E. Courtesy of the United States Geological Survey)

How does the Martian surface compare to the surfaces of Mercury and Venus?

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The long linear feature near the center of the full-disk image of Mars is Valles Marineris, the longest canyon system in the solar system.

28. How does the length of Valles Marineris compare to the width of the United States?

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29. Suggest a possible origin for Valles Marineras.

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30. Write the name of the gradational agent most likely responsible for producing the features illustrated in Figures 20.5a, c, and d by each image.

Figure 20.5e, Olympus Mons, one of four huge volcanoes in a region called Tharsis, is streaked down its sides by lava flows and has a caldera that measures approximately 50 × 80 kilometers.

31. What is the approximate width of Olympus Mons? How does the size of Olympus Mons compare to the distance across your home state?

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32. When compared to the surface of Mercury and the lighter regions on the Moon, Olympus Mons is geologically (young, old, about the same age). Circle your answer and explain how you arrived at your conclusion.

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The features in Figure 20.5d were most likely formed by water erosion. The barchan dunes illustrated in Figure 20.5c have been sculpted by wind.

33. Draw arrows on Figure 20.5d indicating the direction that the water that formed the channels flowed and on Figure 20.5c showing the prevailing wind direction in the region.

Figure 20.6 shows the Martian volcanic crater, Apollinaris Patera (letter A) and the surrounding region. Use Figure 20.6 to answer questions 34–38.

34. Compare Apollinaris Patera (letter A) to Olympus Mons (Figure 20.5e). How are the craters similar and how are they different?

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35. The landform marked B on Figure 20.6 consists of volcanic rock. What is the probable origin of the feature?

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The landform marked C on Figure 20.6 is a large impact crater.

36. Assuming the same ratio between the width of a crater and the diameter of the object that produced it you determined for Meteor Crater in question 4, approximately how large was the object that formed the Martian crater?

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Ma'adim Vallis is the sinuous channel marked D in Figure 20.6.

37. The geologic process most likely responsible for Ma'adim Vallis is (tectonics, impact cratering, gradation). The agent that produced the feature was (ice, wind, running water). Circle your answers.

38. Considering your answers to question 37 and the fact that the floor of Gusev, the 160-km diameter crater lettered E, slopes toward the top of the photo, what type of material might comprise the floor of Gusev? What evidence supports your conclusion?

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Surface Ages and General Topography

Although the Moon and planets formed at the same time approximately 4.5 billion years ago, due to variations in the levels of geologic activity their current surfaces differ in age. Throughout time one or more of the four primary landform shaping processes has worked to alter each of the original surfaces.

In comparing planetary surfaces, impact craters provide a means for determining relative ages. In general, older surfaces show more craters per unit area, larger craters, and more degraded craters than younger surfaces.

Begin your investigation of the relative ages of surfaces by reexamining the photograph of the Moon in Figure 20.2. Then answer questions 39–42.

39. Notice that the surface of the Moon consists of two general types of regions. Describe the characteristics of each.

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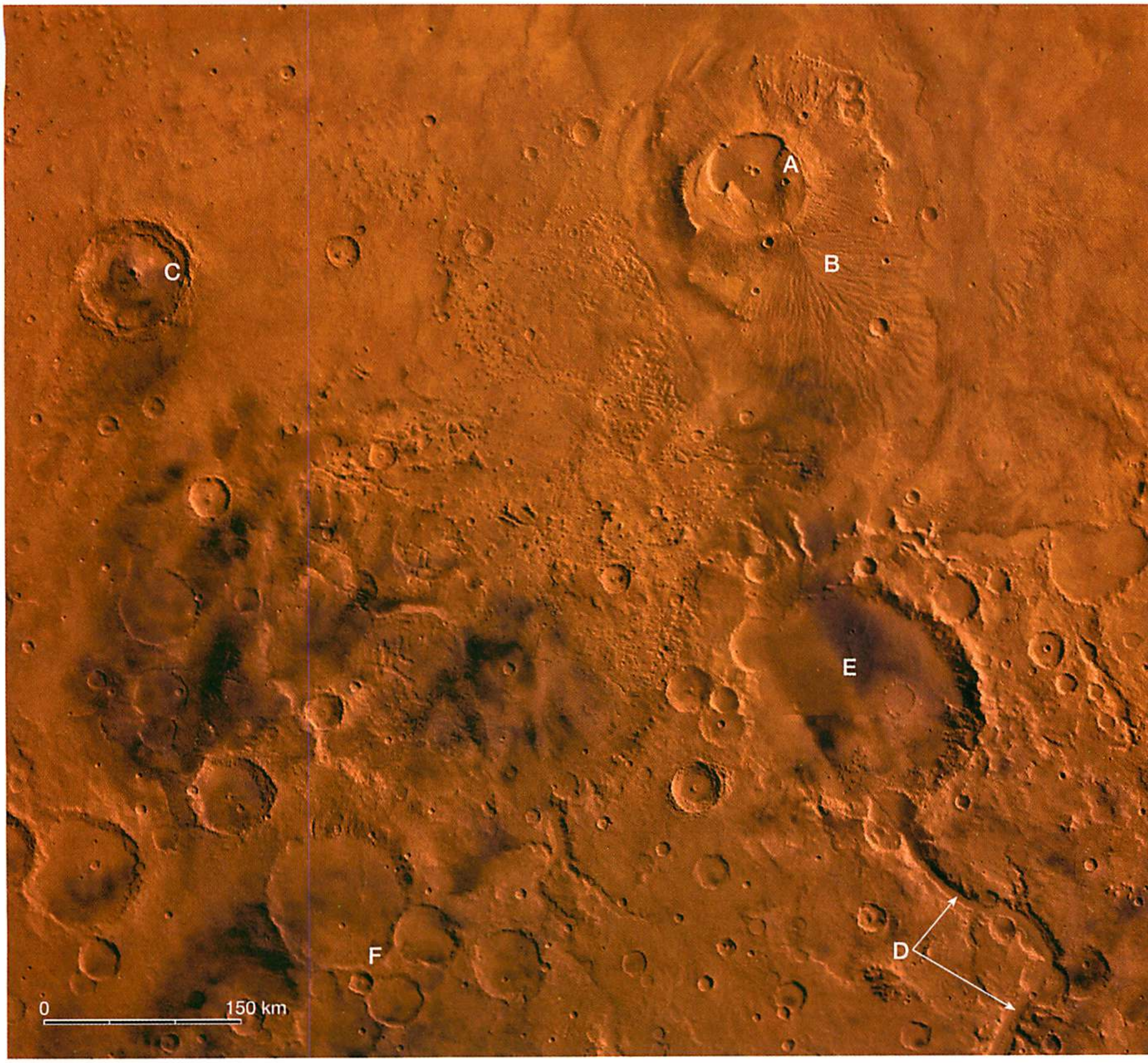

Figure 20.6 Apollinaris Patera (letter A) and surrounding region. (Courtesy NASA/JPL-Caltech. Produced by the U.S. Geological Survey)

40. The lighter areas on the Moon are referred to as *highlands,* and the darker areas are called *maria* (or plains). Which of the two is most densely cratered?

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41. Of the two regions, which is older—the highlands or maria? What fact(s) support your conclusion?

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42. Notice the craters that have bright ejecta deposits that form a star-like pattern of rays around them. Are these craters older or younger than the regions that surround them? How did you arrive at your conclusion?

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Use Figures 20.2–20.5 to answer questions 43–47.

43. Reexamine the full-disk image of Mercury in Figure 20.3. Describe the landforms and regions you observe.

44. Based on the density of craters, the surface of Mercury is (older, younger, about the same age) as the maria on the Moon. Circle your answer.

45. Based on the density of craters, the surface of Venus (Figure 20.4) appears to be (older, younger, about the same age) as the Moon's highlands and (older, younger, about the same age) as the surface of Mercury. Circle your answers.

46. What are the similarities and differences in the surface of Mars (Figure 20.5) compared to the surfaces of the Moon (Figure 20.2) and Mercury (Figure 20.3)?

47. On a global scale, which planet looks more like Venus (Figure 20.4): Mercury or Mars? Explain the reason for your selection.

Use Figure 20.6, Apollinaris Patera (letter A) and the surrounding region, to answer questions 48–51.

48. Compare the southern half of the photograph to the northern half. Which surface is older? How did you arrive at your conclusion?

49. What fact(s) supports the conclusion that the craters in the southern two-thirds of Figure 20.6 are of various ages?

50. In the following space, draw a sketch of the four craters in the vicinity of letter F. Label the craters in order of formation, with the number "1" being the oldest. Did you have any difficulty in assigning relative ages to the craters? If so, explain why.

51. Based on your observations of the features in Figure 20.6, what is the probable order of occurrence of features A, E, C, and D (first to last)? What evidence supports your answer?

Although the surfaces of the terrestrial planets have various origins and evolutions, they do have similar large-scale features.

52. After you compare the elevation maps of Venus and Mars shown in Figure 20.7 with the global topography map of Earth in Figure 20.2, briefly list some of the similarities and differences among the general features depicted on the images of the three planets.

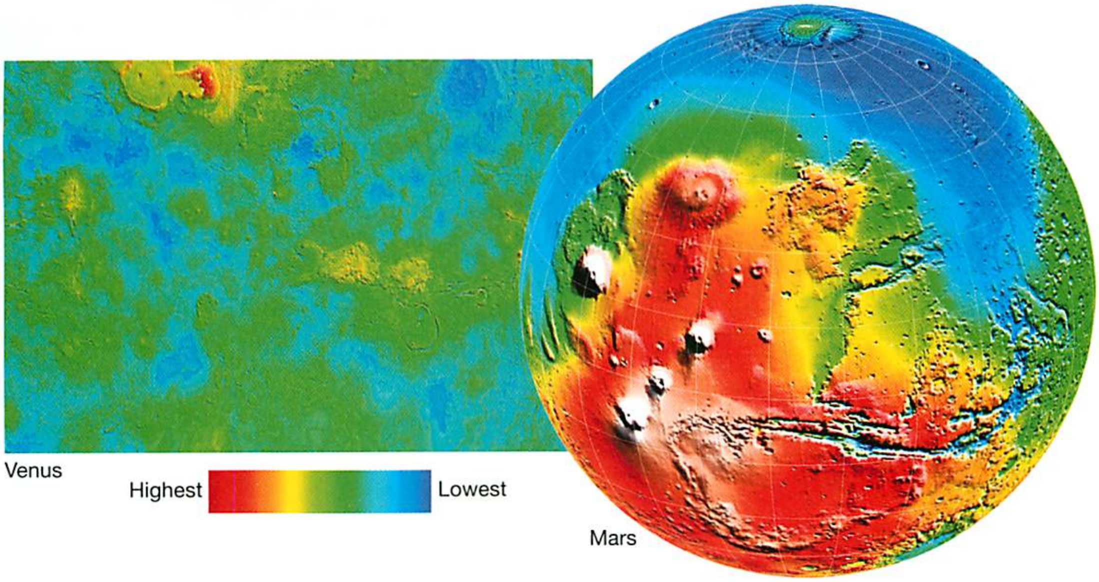

Figure 20.7 Surface elevation maps of Venus and Mars. (Venus map courtesy of NASA/NSSDC; Mars map courtesy of NASA/Mars Orbiter Laser Altimeter (MOLA) Team)

Closing Observations

Use the information you have learned about the geologic processes that shape the Moon and terrestrial planets to answer questions 53–56.

53. Describe the similarities and differences between the landforms of Earth and

Moon: ______________________________

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Mercury: ______________________________

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Venus: ______________________________

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Mars: ______________________________

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54. Based on the density of craters, types of landforms, and the number of geologic processes evident, list the five surfaces you have investigated in order from youngest to oldest.

Youngest ______________________________

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Oldest ______________________________

55. Which of the five surfaces you have investigated has the most active geologic history? Which has the least active geologic history? Explain your choices.

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56. List your thoughts concerning the future geologic evolution of

Mercury: ______________________________

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Earth: ____________________________________

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Mars: ____________________________________

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Examining the Terrestrial Planets on the Internet

Continue your analysis of the topics presented in this exercise by completing the corresponding online activity on the *Applications & Investigations in Earth Science* website at http://prenhall.com/earthsciencelab

Examining the Terrestrial Planets

Date Due: ____________________

Name: ____________________

Date: ____________________

Class: ____________________

After you have finished Exercise 20, complete the following questions. You may have to refer to the exercise for assistance or to locate specific answers. Be prepared to submit this summary/report to your instructor at the designated time.

1. What are the four geologic processes that have shaped the surfaces of the terrestrial planets and the Moon? Give an example of a type of landform produced by each of the four processes.

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2. The surface of the Moon most resembles the surface of (Mercury, Venus, Earth), whereas the surface of Venus is similar to that of (Earth, Mars). Circle your answers.
3. Which planet's surface has only been mapped using radar? Why has only radar been used?

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4. List the most significant geologic process(es) that shape the surface of each terrestrial planet and the Moon.

Mercury: ____________________

Venus: ____________________

Earth: ____________________

Moon: ____________________

Mars: ____________________

5. Of the major gradational agents, (running water, gravity, wind, ice) is the only one that alters the surface of all the terrestrial planets. Circle your answer.
6. Briefly describe how you can determine whether or not the age of one terrestrial planet's surface is older or younger than that of another terrestrial planet.

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7. List the five surfaces you have investigated in this exercise in order from youngest to oldest.

Youngest ____________________

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Oldest ____________________

8. Suggest a reason(s) as to why the surface of Mercury appears so much older than the surface of Venus.

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9. On which planet, other than Earth, is it most likely that water-deposited sedimentary rocks, perhaps containing fossils, occur? Explain your choice.

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10. List and briefly describe the geologic processes that have acted on the Martian surface shown in Figure 20.8. Give specific examples of features in support of your conclusions.

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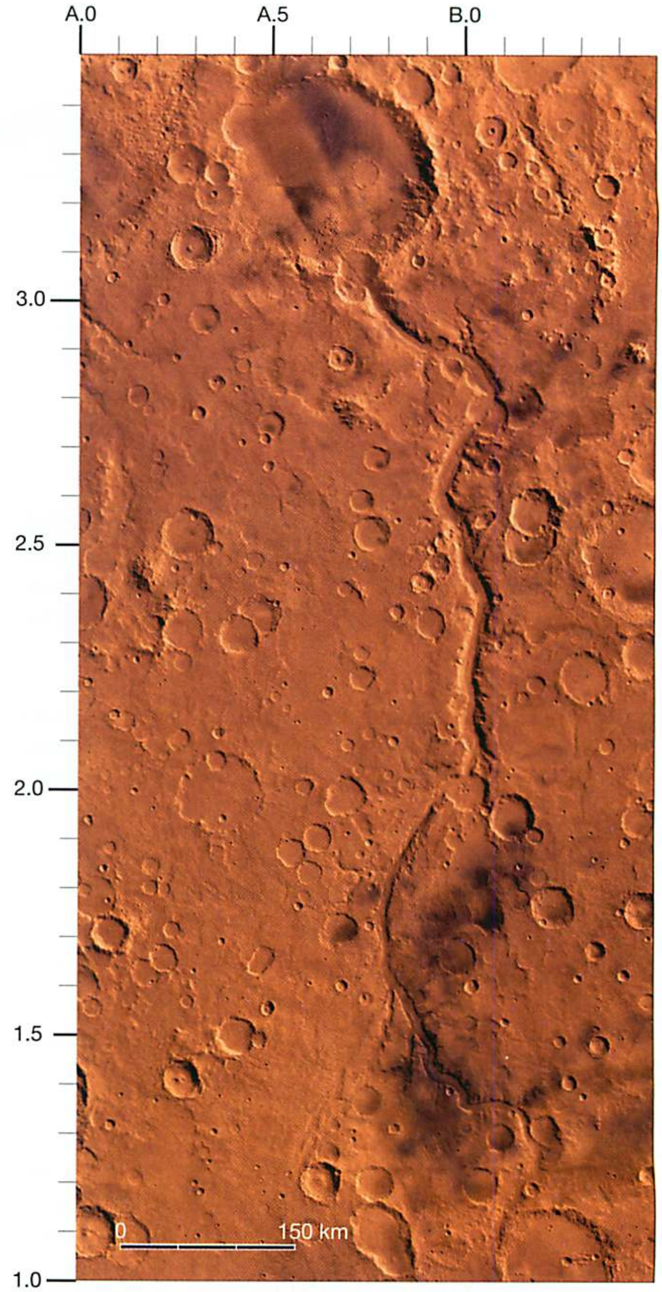

Figure 20.8 Photograph of the Martian surface to be used with question 10. (Courtesy NASA/JPL-Caltech. Produced by the U.S. Geological Survey)