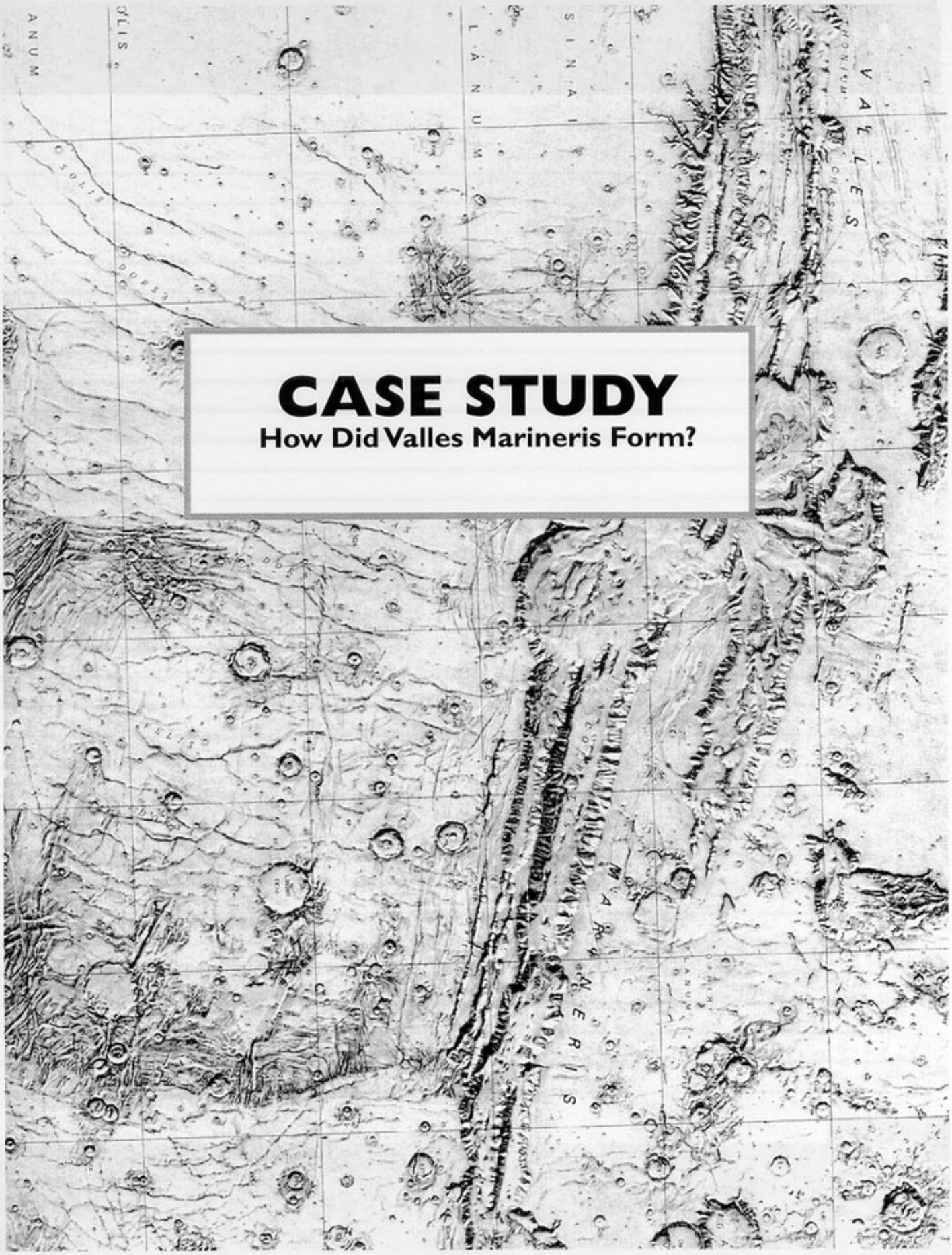


CASE STUDY

How Did Valles Marineris Form?

NOTES

AT A GLANCE

Overview

By looking at Valles Marineris as a whole system, students notice its size, shape, diverse features and its relationship to the rest of Mars. Students see examples of the processes they modeled earlier in the module and see them in the context of Valles Marineris. They think about how each process (or processes working in conjunction) might have contributed to the formation of Valles Marineris and develop these thoughts into hypotheses. They weave these hypotheses into a story which integrates their understanding and insight.

Content Goals

- Valles Marineris is a network of valleys, each showing evidence of a variety of geological processes.
- There are many competing hypotheses about the formation of Valles Marineris.
- Valles Marineris is immense.
- Each geologic process has its own signature, and these signatures can be observed in images and be used to piece together a story about the formation of Valles Marineris.

Skill Goals

- *Measuring* the size of features using a scale.
- *Comparing* the size of Earth and Martian features.
- *Building* a three-dimensional model of Valles Marineris.
- *Identifying* the signatures of geological processes.
- *Analyzing* and *interpreting* images and *locating* close-up images on a large-scale map.
- *Hypothesizing* about how each process contributed to the formation of Valles Marineris.
- *Synthesizing* understanding by writing stories about the formation of Valles Marineris.

Misconceptions

Valles Marineris is about the same size as the Grand Canyon.

Ask: What landform on Earth is of similar size to Valles Marineris?

Materials

"Two Faces of Mars" and "Explorer's Guide to Mars" posters, 3-D model of Valles Marineris, image sets (preferably one for every 2 students), Earth globe, string, and clear acetate sheets.

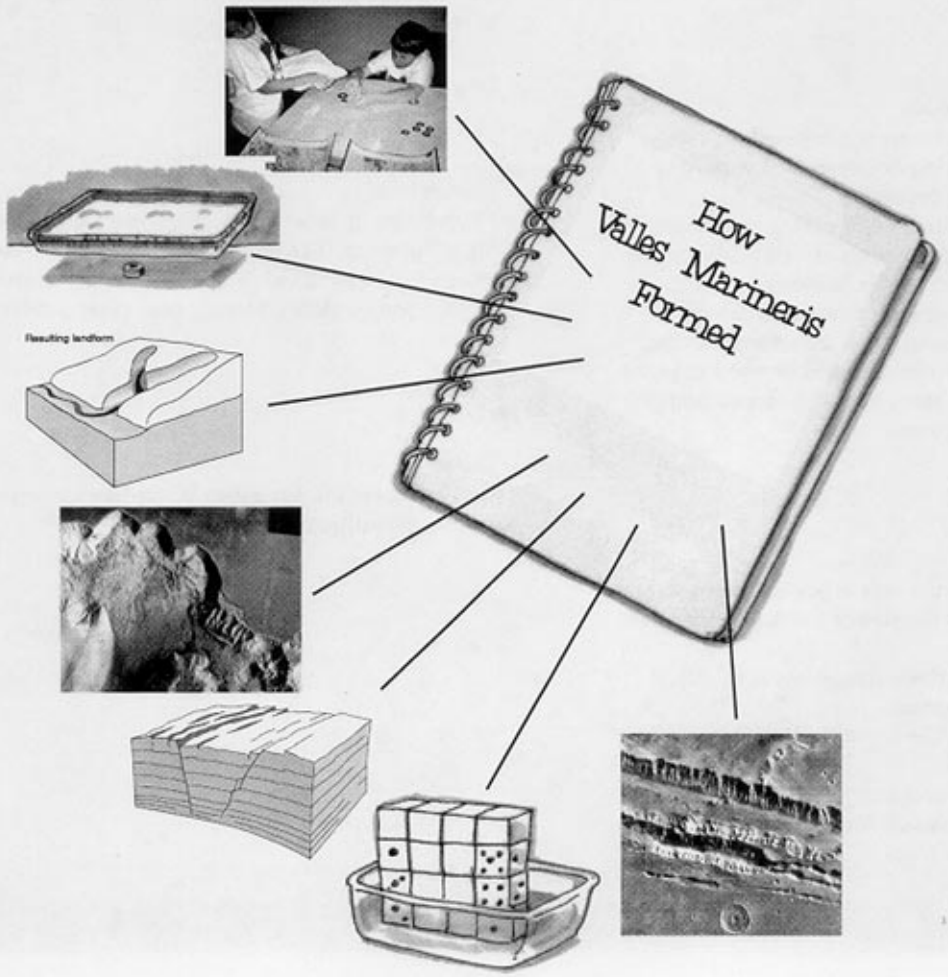
Time

3-5 class periods (or more if students pursue further investigations)

HOW IS A CASE STUDY DIFFERENT FROM AN ACTIVITY?

So far, each activity in the module has highlighted one process and examined it in isolation of other processes. Such a simplified treatment does not reflect the interaction between processes or the actual geological complexity of Valles Marineris. The goal of this case study is to have students create a plausible, coherent story about the formation of Valles Marineris. Furthermore, it is an opportunity to look at Valles Marineris as a whole entity rather than focusing on it piecemeal. Finally, the case study is an opportunity to synthesize the concepts introduced in the previous activities, and it provides a context for those concepts.

Creating a plausible story forces students to grapple with time sequences, the interaction between processes, and the degree to which each process contributed to the present conditions of the canyons. By forming their own hypotheses and finding evidence from maps, images and their modeling to support them, students relate their previous work to the processes on Mars. Weaving their analysis into a story develops students' abilities to synthesize concepts and summarize their thinking. Questions students might investigate include: Is there evidence for rifting? Where might slumping have widened the chasms? What is the role of water in the formation of the canyons? Is there any evidence of uplift? What came first, faulting, pit chains or landslides?



BACKGROUND

Part 1:
The Different Sections of Valles Marineris

Valles Marineris extends approximately 4,000 km (2,500 mi) across the surface of Mars and can be as much as 10 km (6.25 mi) deep. It is actually a network of valleys, each showing evidence of different geological processes. Noctis Labyrinthus, at the western end of Valles Marineris, has a rectangular canyon pattern. The central portion of Valles Marineris includes both linear canyons and wide depressions. The eastern end has broad, shallow canyons. The eastern canyons contain *chaotic terrain* (a landscape created when soil collapses as tremendous volumes of groundwater drain away) and channels that drain toward the northeast.

In the west is Noctis Labyrinthus (Fig. 4.1). It is characterized by 8-10 km (5-6.25 mi) deep canyons in a rectangular pattern. It is on top of the highest part of the Tharsis Rise, and it probably formed when the dome expanded and fractured the surface.

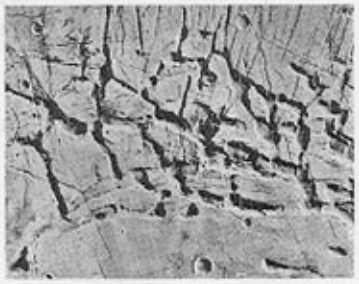


Fig. 4.1
Noctis Labyrinthus in the western portion of Valles Marineris. Image Set image #4.

The central portion is comprised of several chasms, 5-8 km (3-5 mi) deep (Fig. 4.2). They run east-west, and the prevailing theory is that the chasms started as parallel faults which occurred as a result of the Tharsis Rise. Then, through rifting, the sinking of grabens, slumping and subsidence, the chasms widened.

Fig. 4.2
Tithonium, Ius, Melas, Candor, Ophir, and Coprates in the central portion of Valles Marineris. Image Set image #2.

In the east, the linear central canyons change dramatically and become broad canyons, 3-5 km (2-3 mi) deep (Fig. 4.3). Even though parallel faults no longer define these eastern-most canyons, they still seem to be defined structurally, which is to say as a function of crustal dynamics rather than erosion. The floors of these eastern canyons contain large areas of chaotic terrain. A large volume of sub-surface water may have breached the surface and caused this chaotic terrain. Channels and streamlined features appear on the canyon floors. These channels merge and flow north out of the eastern canyons into the Chryse basin region.

Fig. 4.3
The Ganges, Capri and Eos Chasmas in the eastern portion of Valles Marineris. Image Set image #11.

Part 2:
Theories About the Formation of Valles Marineris

The three major hypotheses of the origin of Valles Marineris are origin by erosion, collapse and tectonism. No single hypothesis provides a full answer to the canyon's formation, and it is possible that some or all of the proposed hypotheses contributed in some way to the formation of the canyons we see today.

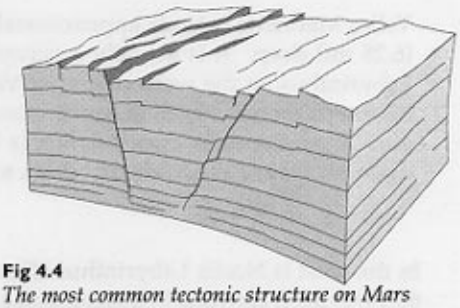


Fig 4.4
The most common tectonic structure on Mars related to uplift is the graben. Typically, Martian grabens are long (hundreds of km), narrow (a few km) flat-floored trenches bounded by two parallel faults with a typical spacing of tens of km between neighboring grabens.

A. Hypotheses Based on Erosion

- Rising magma melted ground ice and filled shallow, parallel grabens (Fig. 4.4) with water to form lakes. The lakes facilitated landslides and sapping, and enlarged the canyons. Eventually, neighboring lakes merged and ultimately broke out the ends of the canyons. These enormous amounts of water further eroded the canyons. By itself, this theory is considered insufficient to explain the canyons.

- Since there was a considerable amount of carbon dioxide during Mars's early history, it could have become fixed as carbonate rocks in the crust. Carbonates can be dissolved by acidic groundwater. The hypothesis proposes that carbonates underlay the canyons and were dissolved and removed, resulting in deep canyons (Fig. 4.5). However, it is uncertain whether there are substantial carbonate deposits, and it is difficult to remove all the trough materials by solution alone. Therefore, this mechanism may have worked in conjunction with other mechanisms.

- For wind to play a significant role in canyon formation, the materials would have to be fine enough for wind to carry away easily. However, it is unlikely that wind removed the volcanic cap rock of the upper plateau, and the walls show no evidence of wind erosion.

B. Hypotheses Based on the Collapse of the Crust

- Tension fractures deep below the surface may have opened, enabling materials to collapse into them. However, more rifting than has been detected would be needed to create a sufficient void.
- Magma may have been withdrawn from below the surface and transferred into the region under the Tharsis Rise, causing collapse.
- Individual subsidence pits may have coalesced to form chains, and then canyons. However, the straight canyon walls and current understanding of pit chain formation argue against this hypothesis.

C. Hypotheses Based on Tectonic Origins

- Valles Marineris are tectonic grabens (Fig. 4.4) related to tension developed by the Tharsis Rise. Subsurface aquifers may have localized the strain and reduced the strength of the crust in places, thus facilitating graben development. The opening of these grabens relieved enough stress so that no other set of fractures became similarly enlarged.

- The great depth of the canyons suggests faulting as deep as the lithosphere. Such faulting could produce block-faulted structures similar to large rifts found on Earth such as the Great Rift Valley in Kenya. The tall *scarps* (cliff faces) and down-dropped surfaces (e.g., the canyon floors) are characteristic of the shifting of large structural blocks.

- The Tharsis Rise is an elongated bulge, and the canyons lie along its crest. Their great size might be a function of the enhanced ability of a dome to rift apart along its crest.

- There may have been aborted planetary rifting which produced only the rifts associated with Valles Marineris.

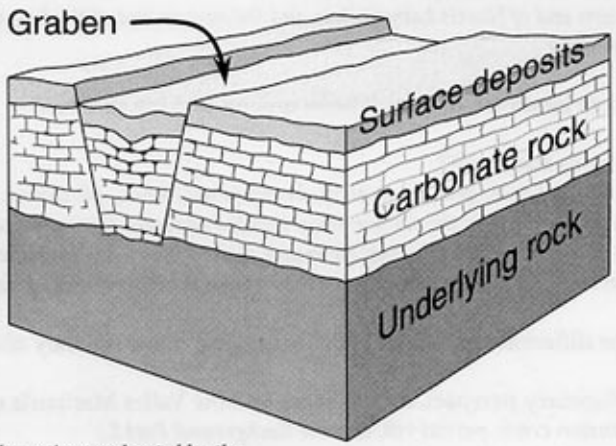


Fig. 4.5
Graben formation accelerated by the dissolving of carbonate rock by acidic groundwater.

#1: Understanding Valles Marineris As A Whole

1. Have students look closely at the "Two Faces of Mars" poster which shows Valles Marineris very prominently. Have them describe what they see in the poster. Since observation is the goal, the correctness of their comments is unimportant in this exercise. Simply write their responses on the board and/or have them write (or sketch) their thoughts in their Mars Exploration Journal. Some discussion questions include:

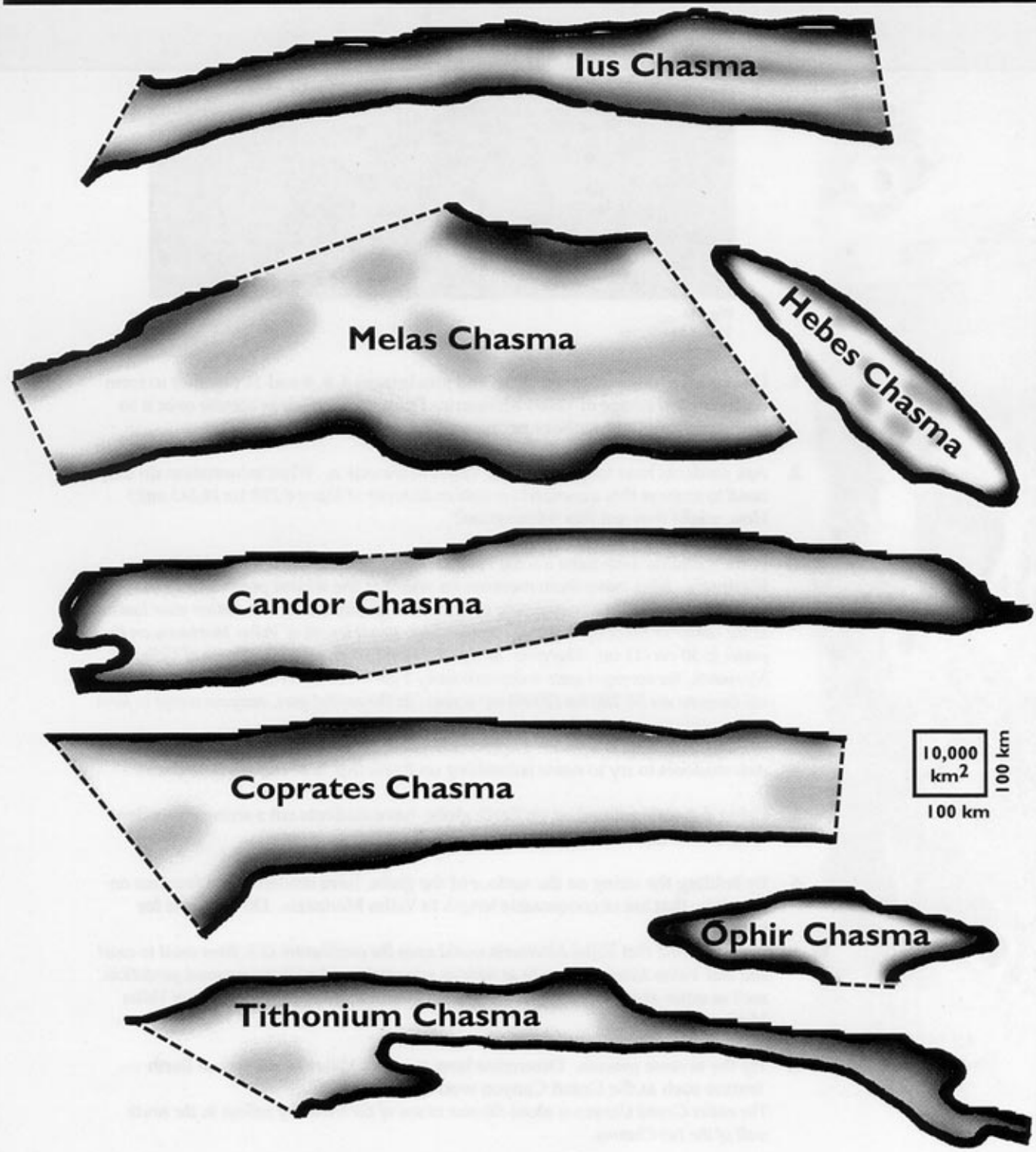
   - What stands out about this planet?
     Spherical shape, ice cap, red color, canyon, black areas, lots of craters in the south and fewer in the north, round blotches (volcanoes), large smooth areas, streaks in some of the black areas, no surface water, etc.
   - What might the climate on Mars be like?
     Possible answers: cold at the poles (true), dry (true), maybe hot since there is no surface water (false).

2. Focus the discussion on Valles Marineris, the canyon in the center of the upper picture.

   - What is it's size? *(Big, roughly 20% of the planet's circumference.)*
   - How would you describe its position and orientation on Mars?
     (Equatorial, running east-west.)
   - What is its general shape?
     (Long, narrow straight canyon at the bottom, widens in the middle with broad canyons, fractured at western end.)
   - Where does it start and stop?
     (At the western end of Noctis Labyrinthus and the eastern end of the Eos, Capri and Ganges Chasmas.)
   - Is it a uniform landform or does it have unique-looking sections?
   - What structures stand out?
     (Possible answers: faults, grabens, scalloped canyon wall edges, pit chains, landslides, tributary valleys, ridges on the canyon floor, isolated canyons, nearby volcanoes, relatively smooth plains surrounding the center of the Tharsis Rise and the western end of Valles Marineris, channels running northeast from the eastern end of Valles Marineris)
   - Contrast the different sections of Valles Marineris. How are they alike and different?
   - From the planetary perspective, speculate on how Valles Marineris might have formed. *(Tension crack, partial rift, etc. See Background Part I.)*

3. Have students assemble the Valles Marineris jigsaw puzzle.

JIGSAW PUZZLE



INVESTIGATION

#2: How Big is Valles Marineris?

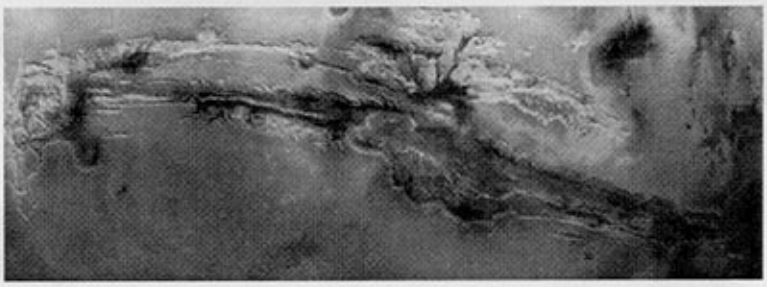


Fig 4.6
Valles Marineris.

1. Disassemble one image set. Trim and join Images 4, 6, 8 and 11 together to form one complete image of Valles Marineris. Place sheets of clear acetate over it so labels can be added without permanently marking the images.

2. Ask students how long they think Valles Marineris is. What information do they need to answer this question? *(A scale or diameter of Mars: 6,788 km [4,243 mi].)* How might they get this information?

3. Have students determine a scale and use it to calculate the length of Valles Marineris. Also, have them measure its width at the widest point.
On the "Two Faces of Mars" poster, the scale changes depending on whether your looking at the center or the periphery of the image. The overall length of Valles Marineris on the poster is 30 cm (12 in). Therefore, using 4,000 km (2,500 mi) as the length of Valles Marineris, the averaged scale is approximately 1 cm = 130 km (1 in = 210 mi). Individual canyons are 50-100 km (30-60 mi) across. In the central part, canyons merge to form a depression approximately 600 km (375 mi) wide.

4. Ask students to try to name something on Earth that is of comparable size.

5. Using the scale printed on an Earth globe, have students cut a string equivalent to 4,000 km (2,500 mi).

6. By holding the string on the surface of the globe, have students find features on the globe that are of comparable length to Valles Marineris. Do the same for its width.
They will find that Valles Marineris would span the continental U.S. from coast to coast and that Valles Marineris can be as wide as some states. Identifying personal yardsticks such as states and countries will help students comprehend the immense size of Valles Marineris.

7. Try the reverse process. Determine how much of Valles Marineris an Earth feature such as the Grand Canyon would cover.
The entire Grand Canyon is about the size as one of the tributary valleys in the south wall of the Ius Chasma.

INVESTIGATION

#3: Building the Grand Canyon of Mars Three-Dimensional Model

Fig. 4.7
The three-dimensional model of Valles Marineris.

A three-dimensional model of the central portion of Valles Marineris (Fig. 4.7) is available (see materials section). Earlier in the module, students modeled some processes involved in the formation of Valles Marineris and looked at images featuring these processes. This model compliments that work and provides students a visual, kinesthetic and concrete way to synthesize their learning and make certain geologic processes and relationships more obvious. Especially at first, many students relate more easily to the three-dimensional model than to the two-dimensional maps and images. In addition, the model gives students a context for the images in the Image Set and helps them get the most from their image analysis.

The model brings to life the great scale of Valles Marineris, the steepness of its canyon walls, the way its sections merge, and how gradually the land drops in elevation as one travels eastward from the heights of the Tharsis Rise. The model also brings to life relationships and prompts questions unlikely to be raised by looking at two-dimensional images and maps. For example, looking at the breached appearance of the walls separating the Ophir, Candor and Melas canyons raises the question: Did the floors subside leaving a thin separating wall which later collapsed? Also, seeing mountain ridges on the canyon floor challenges expectations students may have about water erosion creating the canyons.

Suggestions for Assembling the *Grand Canyon of Mars* Model

Two aspects of assembling the model can be tricky: cutting out the unwanted black areas accurately and not running out of adhesive pad. Cutting out the maps can be either an in-class or homework project. In both cases, sharp scissors, razor knives or single-edged razor blades are useful. Give the cutting assignment to people who are careful. If the cut-outs are to be done at home, make sure the layers are protected when carried in students' bags. Maps 5-8 can be quickly cut into two or more pieces enabling you to involve more people and get the job done faster. Often, art teachers can be enlisted to help with this stage as part of their classes.

The instructions say to cut EACH of the 18 double-stick foam rectangles into 20 pieces, yielding 360 pieces. The resulting size is unworkably small! True, one needs a lot of adhesive, but cutting each rectangle into ten pieces is sufficient. Before cutting the pad into small pieces, peel the backing off both sides and immediately reapply it. This way the backing has been loosened and later will detach easily. To rely even less on the double-stick foam, use other materials to separate the layers. For example, if you can find the small, green felt cushion dots sold in hardware stores, you can use them to do much of the separation between layers. Such a spacer is only sticky on one side, so use enough double-stick foam pieces to actually hold the layers together.

It takes one person about five hours to complete the model. With advanced preparation and clear task assignments, a class could complete the model in a class period. Once it is made, it will last a long time.

#4: Taking A Careful Look at the Images in the Image Set

1. To hone students' analysis skills, focus their attention on a single geological process such as slumping. For example, look at Image 12 and ask questions such as: What do you see? What are those things? What's happening here? How high are the walls and how far does the landslide debris extend? What's the sequence of events? Is anything similar to what we saw in our class models? What's unusual?

2. Turn their attention to the large map of Valles Marineris. Ask them to locate the close-up image on the larger map. Using a marker on the acetate, draw the outline of the close-up image on the map to show its location and how much of the canyon it depicts. Is it visible on the 3-D model?

3. Re-examine the close-up in the context of its location in Valles Marineris. Can students add anything to their interpretation of the close-up or their understanding of canyon formation?

4. Put the processes illustrated in the close-up in context by asking: Do you see this sort of thing happening anywhere else in Valles Marineris? Is this feature regularly found with other features? Is there a pattern to what we see? What might this contribute to our understanding of how Valles Marineris formed?

5. Continue this way with Images 9 and 10. Contrast the different slump images. How are they alike and different?

6. After looking at slumps and landslides, repeat Steps 1-5 with images showing other geological processes. Refer to the notes below for background on processes related to the formation of Valles Marineris and information about specific images. The goal is to have each image inform and extend students' understandings about how Valles Marineris formed. These images contain the evidence students will use in creating their stories. It is well worth taking the time to find out as much as possible from each image.

Notes on Landslides and Slumping

The signature of slumps is a scalloped plateau edge and landslide debris at the foot of the cliff, often including intact pieces of head blocks. Slumps suggest the presence of water, either lubricating the flow or saturating the material and causing it to lose its internal integrity. It has been estimated that the canyons were widened by as much as three times their original size by slumps and landslides. The debris below certain landslides seems to have been removed. Where might it have gone and how was it removed? Does debris removal happen only in certain sections of Valles Marineris?

- Image 12 shows a slump in the Ganges Chasma. The band of rock at the top of the cliff reveals the volcanic layer comprising the plateau. The layer is about 1 km thick. Since the volcanic rock is relatively strong, the head block is still relatively in tact. The apron is striated which indicates relatively resistance-free flow of the slump materials. Several aprons are superimposed on one another and are thin enough to reveal some underlying surface features. The crater predates the slump.

- Image 9 shows slumps in the Ophir Chasma. Contrast the spur and gully morphology on the right of the image with the three smooth-walled slump scars. Is the spur and gully rock more resistant? *(Yes)* Is the line behind the spur and gully section and indica tion of an aborted or future slump? The absence of impact craters on the slump deposits suggests that the slumps are more recent than the period of heavy bombardment by meteors that ended three billion years ago.

Notes on Structural Control

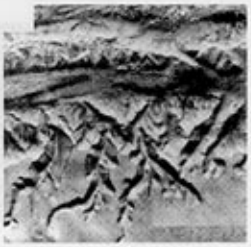
A surface landform is said to be controlled structurally when its morphology is determined by structures or processes deep below the surface (e.g., rifting) rather than processes at or above the surface (e.g., weathering). Thus, faults created by uplift and canyons shaped by faults are said to be controlled structurally. Evidence for structural control in Valles Marineris includes grabens, rifting, the collapse of the ground in the chaotic terrain, and fault lines which define the canyons and the orientation of pit chains. Also, south of the Ius Chasma, note how the surface is wrinkled by arc-shaped wrinkles, presumably created as the Tharsis Rise settled and compressed the surface.

Notes on Uplift

Evidence for uplift can be inferred by looking at the fracture patterns of Noctis Labyrinthus and the fractures and grabens radiating from the crest of the Tharsis Rise located beneath Noctis Labyrinthus. Fractures in the plateau can be seen to continue north of the Tithonium Chasma. The parallel faults bounding the east-west running canyons seem to be fractures associated with the uplift, and lesser developed fractures can be seen paralleling the Ius, Tithonium and Coprates Chasmas. Can students use fractures, wrinkle edges (mentioned under Structural Control) and grabens in the images to locate the center of the Tharsis Rise?

#4: cont.
Taking Careful Look at the Images in the Image Set

Notes on Subsidence
Pit chains can be seen south of the Ius Chasma, between the Ius and Tithonium Chasmas and south of the Coprates Chasma. Coalesced pits can be seen at the eastern end of the Tithonium Chasma, south of the Coprates Chasma, and in the Ganges Cantena. Contrast the pits with craters. Speculate whether some of the large chasms might have begun as pits or pit chains and grown wider and longer through slumping. What is the relationship between pits and faults? The eastern valleys have extensive areas of chaotic terrain. Chaotic terrain can also be seen in and around the Juventae Chasma northeast of the Candor Chasma.



Notes on Tributary Valleys
Image 13 shows tributary valleys which are thought to have been created by sapping. It has been suggested that aquifers south of Valles Marineris dip to the north, and this would deliver groundwater to the southern edges of Valles Marineris. This groundwater would flow along underground faults and joints and percolate out, eroding the overlying ground and ultimately flowing into the main canyon. Over time, continued sapping would cause the headward retreat of the valleys observed in these images giving them their compact, uniform, non-dendritic appearance. Did Valles Marineris start as sapping? Why or why not?

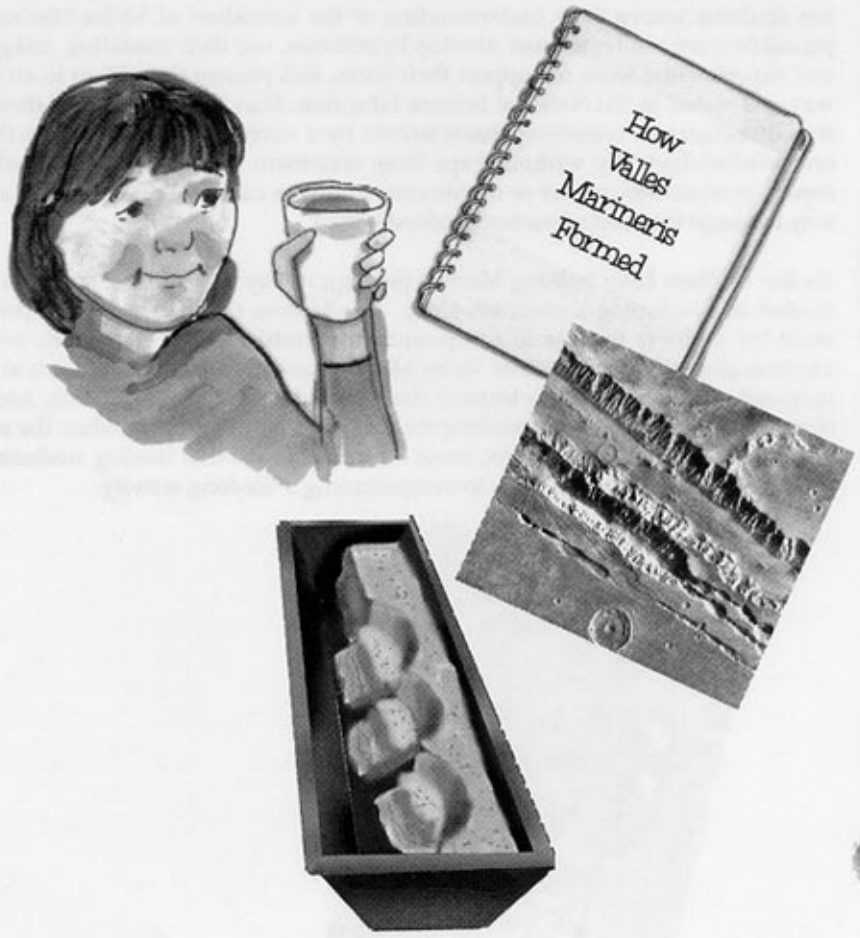
General Themes

- Use the number of craters (i.e., the density) to help determine ages. *(Older areas have higher crater densities than younger ones.)*
- What processes might still be happening? *(Wind and landslides.)*
- Which of these processes do we see on Earth?
  (All of them, but usually at a smaller scale: rift valleys, springs and sapping, land slides, uplift, subsidence, slumping, and structural control.)

INVESTIGATION

#5: Creating a Story About How Valles Marineris Might Have Formed

Based on their experiences in the module, students should now be able to create a plausible story for how Valles Marineris might have formed. Since it is unknown how the canyon actually formed, the focus is on creating hypotheses, identifying evidence to support those hypotheses and synthesizing the concepts to which they have been introduced. A thorough discussion would mention each of the processes and their effect on forming or modifying the canyons. In addition, it would relate the processes to one another and discuss possible combined effects. Review page 40 for additional criteria for creating an effective story and for some additional questions students might discuss.



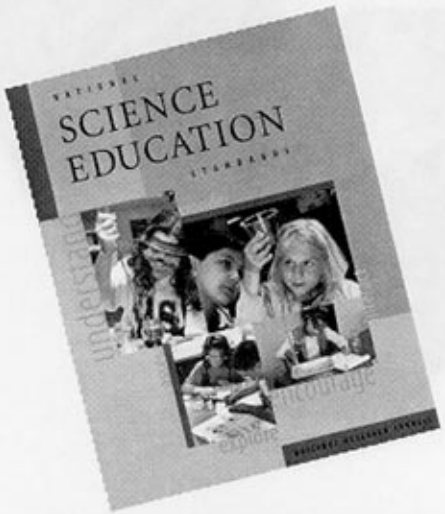
TEACHING POINTERS

In the case study teachers play the possibly unfamiliar role of facilitator, posing questions, asking for clarification and pushing students to find evidence to support their hypotheses. The case study goals are only partly content knowledge about Valles Marineris. Equally important goals are:

- to engage students in relevant investigations;
- to have students develop confidence in their abilities to develop hypotheses supported by evidence;
- to engage students in some of the unsolved Martian mysteries.

Since one of the best techniques for assessing inquiry learning in science involves having students actually perform tasks that demonstrate their mastery, the case study is the intended assessment of student understanding developed in this module. By having students weave their understanding of the formation of Valles Marineris into a plausible story, students must develop hypotheses, use their modeling, image analysis and experimental work to support their ideas, and present their ideas in an organized way. As stated in the National Science Education Standards, "A well-crafted justification demonstrates reasoning characterized by a succession of statements that follow one another logically without gaps from statement to statement." Whether it is a report, presentation, poster or multimedia project, a culminating product is a powerful way to gauge the level of student understanding.

As few teachers have training Martian geology, it may be unclear if students have succeeded in developing a plausible story. In addition, the lack of a widespread agreement for teachers to refer to compounds the problem. But remember, no absolute answers about the formation of Valles Marineris exist; Mars exploration is at its beginning and much more is to be learned about Mars history than is presently known. Furthermore, some of the most exciting teaching and learning occur when the answers to questions are unknown. In fact, some educators argue that leaving students wondering may be one of the best ways to make learning a life-long activity.



Possible Assessment or Summary Sheet For Valles Marineris

Focus Questions	General Characteristics of Valles Marineris
How would you describe the general end-to-end shape of Valles Marineris?	
Does the main canyon and its side canyons retain the same basic appearance as one goes from one end to the other?	
Do the canyon walls have any particular shape or pattern? If so, what is it?	
How would you describe the steepness of the canyon walls?	
How level is the canyon floor?	
What seems to cover the floor of each canyon?	
Generally, what is the cross-sectional shape of each canyon?	
Are there any canyon sections physically isolated from the main canyon?	
When one section of a canyon meets the next, is there a smooth, continuous merge or are there abrupt changes?	
Is any water visible?	
Is there evidence of water erosion?	

Possible Assessment or Summary Sheet For Valles Marineris Answer Sheet

Focus Questions	General Characteristics of Valles Marineris
How would you describe the general end-to-end shape of Valles Marineris?	The walls of the east-west parts are generally parallel to one another. Several roundish canyons join from the north near the middle. The western end is comprised of rectangular canyons.
Does the main canyon and its side canyons retain the same basic appearance as one goes from one end to the other?	No. Valles Marineris seems to be made up of a central section and two end sections, each of which look completely different. Noctis Labyrinthus at the Western end is very fractured. The main canyon is long and straight. Several canyons are roundish.
Do the canyon walls have any particular shape or pattern? If so, what is it?	Scalloped, U-shaped. Fluted with vertical striations. Landslide debris at the base.
How would you describe the steepness of the canyon walls?	Very steep.
How level is the canyon floor?	Wide, flat, level. However, several canyon floors, such as the Ophir's and Candor's, have significant topography.
What seems to cover the floor of each canyon?	Dust, dirt and landslide debris. Note the layering visible near the canyon walls in the close ups.
Generally, what is the cross-sectional shape of each canyon?	Rectangular.
Are there any canyon sections physically isolated from the main canyon?	Yes, the Hebes and Juventae Chasmas and several small pockets such as the eastern end of the Tithonium Chasma are physically isolated.
When one section of a canyon meets the next, is there a smooth, continuous merge or are there abrupt changes?	Often, there are abrupt changes suggesting several processes at work at different times.
Is any water visible?	No
Is there evidence of water erosion?	The side canyons entering from the south suggest water erosion. However, these networks exhibit a distinctive morphology and are not extensive enough to support the idea that the large canyons began as tributary valleys. See Activity 2.

Possible Assessment or Summary Sheet For Specific Processes

Uplift	
Can you find any evidence for magma rising to the surface in any of the images?	
Can you tell if one end of Valles Marineris is higher than the other?	
Fracturing	
What shapes or patterns similar to the ones you saw in the corn starch can you find?	
How do Valles Marineris's canyon walls compare to what you saw when you looked at the fractures in the corn starch with the magnifying glass?	
Collapse of Canyon Walls	
What evidence is there, if any, that the canyon walls may have collapsed?	
What is the significance of the way the material on the canyon floor is distributed?	
Are there any canyon sections that seem to have gotten connected through the collapse of the partitioning wall?	
Subsidence	
Are there any parts of Valles Marineris that resemble a sequence of circular depressions or pits?	
Can you find evidence for large-scale subsidence?	
General	
Would you say that one process was largely responsible for the formation of the canyon or more than one process? Explain.	

Possible Assessment or Summary Sheet For Specific Processes

Uplift	
Can you find any evidence for magma rising to the surface in any of the images?	Volcanoes. In addition some students may know that the large, black areas in certain areas of Mars are flows of basalt.
Can you tell if one end of Valles Marineris is higher than the other?	Careful reading of the topographic maps can reveal uplift in the western region near the volcanoes. The canyon walls are also higher in the western end.
Fracturing	
What shapes or patterns similar to the ones you saw in the corn starch can you find?	The edges of the east-west portions of Valles Marineris are defined by a series of parallel faults. Noctis Labyrinthus, the Alba Patera, and the Tempe Terra, are other examples.
How do Valles Marineris's canyon walls compare to what you saw when you looked at the fractures in the corn starch with the magnifying glass?	They should look similar.
Collapse of Canyon Walls	
What evidence is there, if any, that the canyon walls may have collapsed?	Layered landslide debris on the canyon floor, scalloped canyon walls, crisp edges at the tops of the canyon walls.
What is the significance of the way the material on the canyon floor is distributed?	The layered flows strongly suggest repeated collapses.
Are there any canyon sections that seem to have gotten connected through the collapse of the partitioning wall?	Yes. The way the Ophir, Candor and Melas Chasmas are connected suggest such a collapse.
Subsidence	
Are there any parts of Valles Marineris that resemble a sequence of circular depressions or pits?	Yes. See Background, Activity 3.
Can you find evidence for large-scale subsidence?	The extensive chaotic terrain in the eastern canyons suggests subsidence on a large-scale.
General	
Would you say that one process was largely responsible for the formation of the canyon or more than one process?	More: rifting, water erosion, subsidence, faulting, canyon wall collapse, and grabens.