# LESSON 2 The Moon: Earth's Fellow Traveler

## Quick Write

If you had been one of the Apollo 11 astronauts, what about the Moon would you have been most curious to see or experience for yourself?

## Learn About

- the Moon's size and distance from the Earth
- the relationships between the Moon and the Earth
- the Moon's origin and surface

"Houston, Tranquility Base here. The *Eagle* has landed." Those were American astronaut Neil Armstrong's words at 4:18 EDT on 20 July 1969. The first crewed flight to the Moon had just touched down. Within a few hours Armstrong would become the first human to set foot on the Moon.

Only a little more than eight years before, President John F. Kennedy had told a joint session of Congress, "I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth. No single space project in this period will be more impressive to mankind, or more important for the long-range exploration of space…."

Now Armstrong and his colleague, Edwin E. (Buzz) Aldrin Jr., were there in their lunar module, the *Eagle*, on their way to fulfilling the goal that Kennedy had set, and the nation had adopted. They were about to step down onto the Moon's barren, dusty landscape. Space scientists dreamed of exploring even more distant worlds. But the Moon was the first stop.

## The Moon's Size and Distance From the Earth

Since the 1960s the space program has taught scientists a great deal about the Earth and Moon. But early astronomers were able to make some important calculations about these two bodies simply on the basis of naked-eye observations.

### The Distance From the Earth to the Moon

Remember what you read in Chapter 1, Lesson 1, about parallax—the apparent shift of an object when seen from different positions (Figure 2.1). An astronomer looking up at the Moon over Alexandria, Egypt, for instance, would see it in a different position—against a slightly different background of stars—from what an astronomer in Beijing would see.

The astronomer Ptolemy used his understanding of the parallax effect to determine the distance from the Earth to the Moon. He calculated the distance at 27.3 Earth diameters. Today astronomers figure the average distance to the Moon is about 30.13 Earth diameters. What's significant about Ptolemy's measurement is not only that it came so close to the actual value, but that it shows how close the ancient Greeks came to having a realistic map of the Solar System about 2,000 years ago.

As you read in Chapter 1, Lesson 2, the Greek astronomer Aristarchus came up with a heliocentric model of the universe centuries before Ptolemy proposed his geocentric theory.

**Vocabulary**

- perigee
- apogee
- tidal force
- spring tides
- neap tides
- tidal friction
- precession
- maria
- meteorite
- meteoroid
- double planet theory
- fission theory
- capture theory
- large impact theory

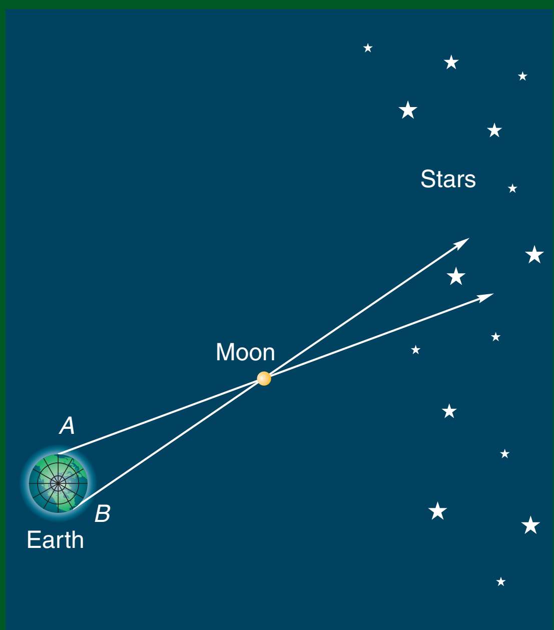



**Figure 2.1** When viewed from two different spots on Earth (A and B) the Moon seems to be at two different places among the stars—the parallax effect. The drawing exaggerates the effect to help you visualize it.

Aristarchus also had correctly calculated the relative sizes and distances of the Earth, the Moon, and the Sun. He had a map, but without a scale. If his understanding of the relative positions and sizes of these bodies had been combined with Ptolemy's calculation of the distance from the Earth to the Moon, the progress of astronomy would have been advanced by about 1,300 years.

Today we know that Earth's diameter is about 8,000 miles, or 12,800 km. The Moon is about 240,000 miles (380,000 km) from Earth.

## How the Moon's Size Is Estimated

Once you know how far away the Moon is from Earth, you can determine its size. Data from spacecraft can help with calculations of the Moon's diameter. But there is a more earthbound way to do the math, too.

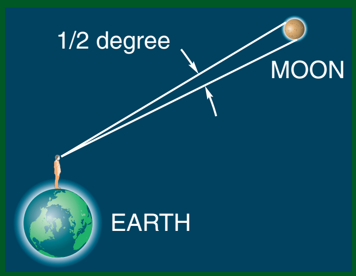
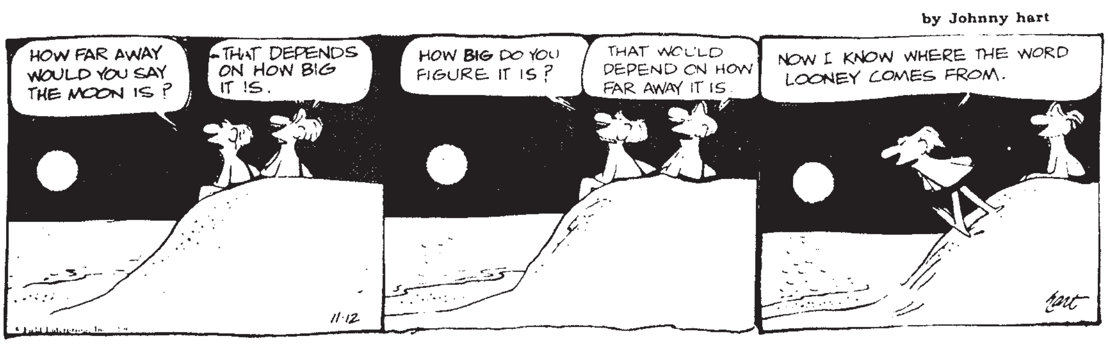



**Figure 2.2** The Moon's angular size, or angular diameter, is about one-half a degree.

One method involves calculating from the basis of the angular size of the Moon. An object's angular size is the angle between two lines that start at the observer and go to opposite sides of the object. The angular size of the Moon seen from Earth is about one-half degree. Figure 2.2 will make this clearer.

Scientists can use their knowledge of the Moon's angular size, as seen from Earth, plus the distance from the Earth to the Moon, to calculate the diameter of the Moon. They call the simple equation that they use to make this calculation the *small-angle formula*.

Using the most accurate data, scientists can calculate that the Moon's diameter is 2,160 miles (3,476 km). That's almost one-fourth the diameter of Earth.




By permission of Johnny Hart and Creators Syndicate, Inc.

**Figure 2.3** Both characters are right. To determine size, you must know the distance. And the word "looney" does indeed come from "lunar."

*Reprinted by permission of Creators Syndicate and John L. Hart FLP*

One of these two photos of the Moon was taken when the Moon was closest to Earth; the other when it was farthest.

Courtesy of Galileo Project, NASA

## Why the Moon Appears to Be Larger at Certain Times

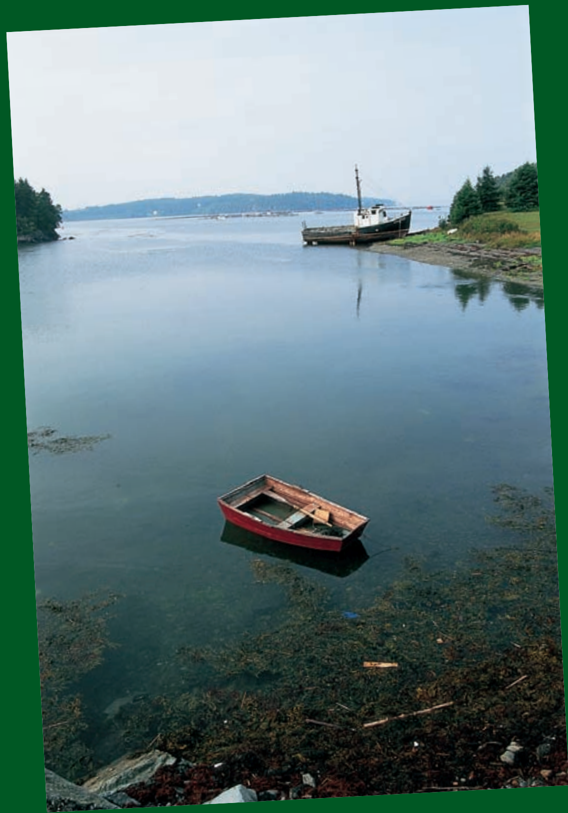
Your perception of the size of a heavenly object is the result of a combination of its distance and its real size. This is the point of the cartoon in Figure 2.3.

The Moon appears to be larger at some times than others because its distance from Earth varies. Its orbit is elliptical, like those of other bodies in the Solar System. And it's a fairly eccentric ellipse—in other words, its two foci are relatively far apart. Or, to put it in more basic terms, it's not the kind of ellipse that's almost a perfect circle.

The Moon appears to be larger when it is at its **perigee**, or *closest distance from the Earth*, about 227,000 miles (363,000 km). It appears smaller when at its **apogee**, or *farthest distance from the Earth*, about 253,000 miles (405,500 km). The Moon also looks larger as it is rising and setting in the sky than it does when it is high in the sky. (So do the Sun and other objects.) This is an optical illusion. You can prove this by holding up a piece of ring-binder paper at an arm's length. The Moon will just fill the hole both when rising and when it's high in the sky.

This photo shows low tide in a bay at Campobello Island, New Brunswick, Canada. Note how much of the water simply disappears.





The same spot a few hours later: The water has flowed back in.



## The Relationships Between the Moon and the Earth

As you read in Lesson 1, the Moon is a big reason the Earth is so hospitable to so many life forms. The Moon helps stabilize Earth in its orbit. And the gravity of both the Moon and Sun creates tides.

### How the Gravitational Force of the Moon and Sun Influences the Ocean Tides

The tides are familiar to those who live near the ocean or visit there often; to those away from the coasts, less so. But, as you will read, even places far from the sea are subject to tidal forces. A tidal force is *a gravitational force that varies in strength and/ or direction over an object and causes it to deform*.

The Moon exerts a gravitational force not on the Earth as a whole, but on each individual part of the Earth. Gravity, you will recall, is the result of both mass and distance. The Moon's gravity pulls harder on those parts of Earth closer to it than on parts farther away. This pull produces a high tide on the point on Earth closest to the Moon at any given time (point A in the diagram). The Moon pulls the ocean away from Earth, in effect. It also produces a high tide on the other side of Earth (point C) by pulling the main body of Earth away from the ocean (Figure 2.4).

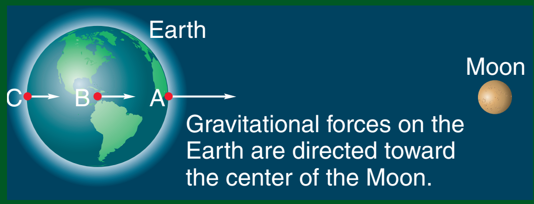



**Figure 2.4** The mass at point A is subject to the greatest lunar gravitational force of the three points marked, and the mass at point C feels the least force.

The Sun is a factor in the Earth's tides, too. The Sun is vastly larger than the Moon, but the Moon is much closer to Earth. So the tidal force exerted by the Moon is 2.2 times that of the Sun. When the Sun and the Moon line up with the Earth, near the times of a full moon or new moon, the Sun's tidal forces intensify the Moon's tidal pull. **Spring tides** are these *exceptionally high and low tides that occur at the time of the new moon or the full moon, when the Sun, Moon, and Earth are approximately aligned*. When the Moon is in its first or third quarter, the lunar and solar tidal forces tend to partly cancel each other out. **Neap tides** are *the tides that occur when the difference between high and low tides is least* (Figure 2.5).

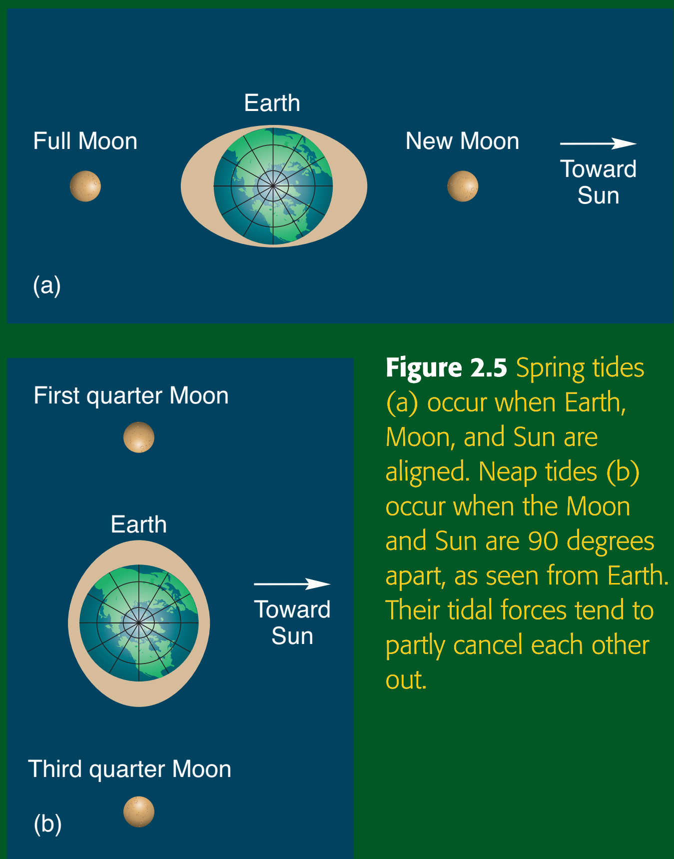



**Figure 2.5** Spring tides (a) occur when Earth, Moon, and Sun are aligned. Neap tides (b) occur when the Moon and Sun are 90 degrees apart, as seen from Earth. Their tidal forces tend to partly cancel each other out.

## The Moon's Rotation and Revolution

The period of the Moon's rotation exactly matches that of its revolution. The Moon thus keeps the same face to Earth at all times. Scientists reckon it hasn't always been this way, though. They calculate that in times past, the Moon must have gone through a rotation period different from its revolution. **Tidal friction**—*the friction that results from tides on a rotating object*—has slowed the Moon down.

**Star POINTS**

The tides you actually see in a given location, of course, depend on many complicated factors. The shape of the shoreline, the depth of the water, and the Moon's location all play a role in determining just when high and low tides occur at that location—and how high and low those tides are.

Just as the Moon and Sun cause tides on Earth, the Earth and the Sun cause tides on the Moon. It has no vast oceans. But the Moon's surface may move as much as four inches (10 centimeters) over a month.

Tidal friction is at work on the Earth as well, slowing the planet down by about 25 billionths of a second every day. Billions of years from now, the Earth's rotation time will increase to the point that the Earth always keeps the same face toward the Moon.

By the way, tides also occur on dry land on Earth. Rocks and dirt actually stretch under the force of gravity. Parts of a continent may move as much as 20 inches (half a meter) in a day. So even if you live in Iowa, you're subject to tidal forces!

## How the Moon's Location Influences the Earth's "Wobble"

If you've ever spun a child's top on a smooth table, you know that the axis of the top doesn't usually stay completely upright. It wobbles as it spins. The math behind this phenomenon is complicated. But the gist of it is that the top has a tendency to fall over, and its rotation keeps this from happening. The top wobbles around, keeping the same angle with the table's surface until friction slows it down. Whenever a force acts on a spinning object to change the orientation of its axis, the object will wobble. Scientists call this wobble precession and define it as *the conical shifting of the axis of a rotating object*.

The force acting on Earth to change its spin is gravity—the gravity of the Moon and the Sun. It's a slow process. Earth takes about 26,000 years to complete a precession cycle.

**Star POINTS**

Right now, there is no "South Star." But as the Earth wobbles, or precedes, there will be one at different times.

The precession of the Earth means that eventually there will be a new "North Star." Polaris, currently the brightest star close to the north celestial pole, now fills this role—in fact, its name means "pole star." But scientists estimate that in about 12,000 years, Vega, the brightest star in the constellation Lyra, will be at the celestial North Pole.

## The Moon's Origin and Surface

The Moon is a very near neighbor. But in contrast with Earth's rich diversity of environments and life forms, the Moon is a very different place. Cold and lifeless, it has little interior heat and no plate tectonics. Still, there is much to learn from studying the Moon.

**Star POINTS**

The far side of the Moon was first seen in 1959, when a Soviet spacecraft photographed it.



### The Moon's Lowlands (Maria) and Craters

The moonscape has two principal features: the **maria** or "seas"—*lunar lowlands that resemble seas when viewed from Earth*—and the cratered mountainous regions. (The singular form of "maria" is "mare." It is the Latin word for "sea.") Craters almost completely cover the Moon's far side. Until the mid-twentieth century, scientists assumed volcanoes formed the Moon's craters. After all, most craters on Earth arise from volcanic activity. Today, however, scientists have determined that the craters are the result of the impact of **meteorites**—*interplanetary chunks of stone or matter that have crashed into a planet or moon from space*.

Volcanic eruptions, however, did produce the maria in the Moon's past. Impacts from large asteroids formed the craters to begin with. Later, dark lava flooded the basins of the craters to form the maria.

**Star POINTS**

Lunar craters aren't formed just from material being "splashed away" from the point of impact. Rather, a **meteoroid**—*an interplanetary chunk of matter that becomes a meteorite once it strikes the surface of a planet or moon*—that collides with the Moon does so at such high speed that it burrows below the surface. It compresses and heats lunar material to the point where it creates an explosion. It's like a nuclear bomb being detonated underground. The result is a circular crater, no matter what the angle of the original incoming meteoroid's fall.

### The Features of the Moon's Crust

The Moon's crust ranges from about 35 miles to 60 miles (about 60 km to 100 km) deep (Figure 2.6). It's thinner on the side facing the Earth. The molten lava released when the maria formed flowed toward the side with the thinner crust. This is natural, since lava has a greater density than the rocks of the highland areas. As you read earlier in this lesson, tidal forces slowed the Moon's rotation. They also acted on the Moon's uneven distribution of mass to make the denser side face the Earth.

The Moon's mountains formed differently from Earth's. Earth's came about by the shifts of tectonic plates and the explosion of volcanoes. Lunar mountains, by contrast, are the result of millions of ancient craters piled up on top of one another.

## Star POINTS

The Apollo astronauts left sensors on the Moon to measure moonquakes. Some of these were artificially produced by striking the Moon at various places. But about 3,000 natural moonquakes occur each year. Tidal interaction between the Moon and the Earth causes these quakes.

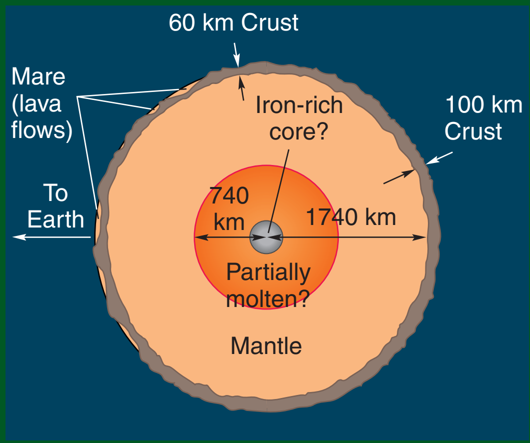



**Figure 2.6** A cross-section of the Moon. Note how the Moon's crust is thinner on the side facing the Earth. Because the density of the Moon is close to the average density of rocky material, scientists assume that if it has an iron core, that core must be small.

## Four Theories of the Moon's Origin

Since the early nineteenth century, scientists have advanced three main theories of the Moon's origin.

The double planet theory holds that *the Moon was formed at the same time as the Earth*. This theory goes back to the early nineteenth century. The idea is that as the Earth formed from a spinning disk of material, some leftover material that wasn't absorbed into the planet formed an orbiting Moon instead. The problem with this theory is that it doesn't account for the fact that the Moon is much less dense than Earth: 3.35 grams per cubic centimeter (3.35g/cm$^3$) for the Moon, compared with Earth's 5.52 g/cm$^3$.

In 1878 Sir George Howard Darwin (Charles Darwin's son) proposed the fission theory. It held that *the Moon formed from material spun off from the Earth*. Darwin proposed that the combination of a fast rotation of Earth and the force of solar tides caused a large glob of stuff to spin off from the area where the Pacific Ocean is now. This theory has two main drawbacks. No one has offered a satisfactory explanation of just how this spinoff might have occurred. And if the Moon had been ejected from Earth, it would presumably orbit in the plane of Earth's equator. It does not.

In the early twentieth century the capture theory held that *the Moon is made up of Solar System debris captured by Earth*. The problem with this theory is that colliding celestial objects don't easily "capture" one another. If one actually collides with another, capture is possible. Alternatively, if one object actually came very near another, it might slow the second one down so that a third object could capture it. But such a three-way near miss seems highly unlikely.

In the 1970s A. G. W. Cameron and William Ward of Harvard University proposed the large impact theory of the Moon's origin. It holds that *the Moon formed as the result of an impact between a large (Mars-sized) object and the Earth* (Figure 2.7). The metal cores of the two bodies combined to form the massive core of Earth. The lighter material became the Moon. Since the mid-1980s a scientific consensus has been building for this theory as the one that best fits the data. It explains both the geologic similarities and differences between the Earth and the Moon. It also fits data from calculations about other possible rates of rotation for Earth.

Understanding the Moon and the Earth allows scientists to better understand the Solar System and humanity's place in it. Helped by what they learned from the *Apollo* missions, scientists are able to explain the features on the Moon's surface and the mystery of the Moon's origin.

The next chapter will take a look at the various members of the Solar System, starting with its central player—the Sun.

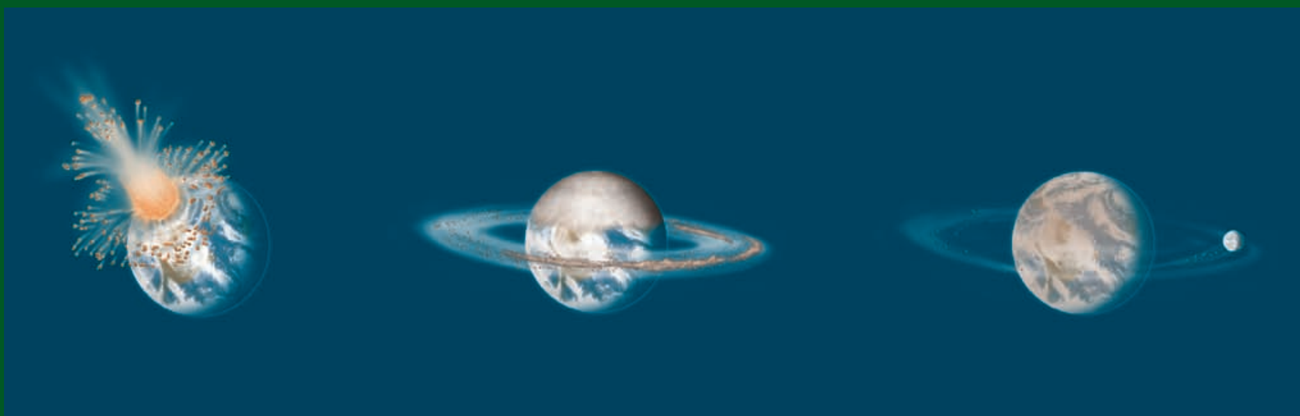


**Figure 2.7** The large impact theory holds that a large object hit the young Earth. Material thrown off after this "merger" became first a Saturn-like set of rings, and then the Moon.

## Reading the History of the Moon

Scientists can "read" the Moon's craters and determine which ones are relatively newer than others. If one crater overlaps another, the overlapping crater is surely newer than the one overlapped. Scientists thus know that the crater Tycho, named for the Danish astronomer you read about in Chapter 1, Lesson 2, is relatively young. Lunar rays provide another way to "date" features of the lunar landscape. These rays streak out from craters like the "rays" in a child's drawing of the Sun. Lunar rays darken over time, and so brighter ones are likely to be newer.

Knowing the order in which things happened isn't the same as knowing when they happened, though. Not until the *Apollo* astronauts returned with 840 pounds of Moon rocks could scientists work out a reliable timescale for the Moon's history. Now they know the Moon formed about 4.6 billion years ago. The oldest Moon rocks the astronauts brought back were about 4.42 billion years old. The Moon's surface was molten for millions of years. As the Moon solidified and cooled, impacts with meteoroids marked its surface with craters. Most craters formed between 4.2 billion and 3.9 billion years ago. Giant impacts toward the end of this period, followed by lava flows into crater basins, led to the creation of the maria we see today. After the cratering period came a period of considerable volcanic activity. This ended about 3.1 billion years ago.

Cratering continues today, but at a slower pace. Our part of the Solar System has been largely swept clear of most large chunks of matter, and so the Moon isn't taking as many hits nowadays.

## CHECK POINTS

### Lesson 2 Review

Using complete sentences, answer the following questions on a sheet of paper.

1. What was significant about Ptolemy's measurement of the distance from the Earth to the Moon?
2. Scientists can calculate the Moon's diameter by knowing the angular size of the Moon, plus what other measurement? What is the simple equation they use to make this calculation called?
3. Why does the Moon appear to be larger at some times than others?
4. What are neap tides and why do they occur?
5. What effect do tides have on the Moon?
6. What big change in the northern skies do scientists expect to see in about 12,000 years?
7. What assumption about the Moon's craters did scientists make until the middle of the twentieth century? What assumption do they make today?
8. How were the lunar mountains formed?
9. What are the two main drawbacks of the fission theory of the Moon's formation?

## APPLYING YOUR LEARNING

10. Suppose you lived 2,000 years ago. What observations could you make that would lead you to conclude that the Moon plays a role in the Earth's tides?