Pulling together an understanding of the Earth–Moon system

by Bob Riddle

In this column I'd like to explore the pull that exists between the Earth and our Moon: gravity. *Pull* refers to a force exerted by one object on another, and because forces are equal and opposite according to Newton's first law, students can use gravity to think about celestial bodies' effect on each other. Gravitational forces are at work on everything we see, causing tides on Earth, volcanic activity on some of the moons in our solar system, and even adjustments in a spacecraft's trajectory as it passes by a planet. Some also believe that gravitational pull affects crime, births, and the ability to balance eggs on their ends. But does it?

When we think of *tides*, we usually think of the daily rising and falling in the levels of bodies of water. However, the same gravitational forces that cause the oceans to rise and fall also cause land masses to rise and fall. The Earth and Moon are attracted to one another by gravity, but the attraction is not evenly distributed: The side of the Earth closer to the Moon is pulled toward the Moon more strongly than the opposite side of the Earth. This difference in tidal pull is directly related to the distances these two opposite sides of the Earth are from the Moon. It is the difference in gravitational attraction between the two that creates tides on both objects. On the Earth, the Moon's tidal pull creates two *tidal bulges*, amounting to ocean level rises of about 2 m and land rises of less than 1 cm. As the Earth rotates, the part of the Earth that passes "under" the Moon experiences tidal bulge, and as the Earth continues rotating, the tidal bulge "moves" toward the west. The opposite side of the Earth is pulled less, but with enough force to create a smaller tidal bulge on that side.

As the Earth rotates, tidal bulge causes two high tides, with two low tides occurring midway between the high tides. This cycle occurs over approximately 24 hours and 50 minutes because each day, the Moon rises about 50 minutes later than the day before. The times for high tides represent the amount of time it takes for the Moon to return to its highest point over any spot on the Earth, causing a high tide at that location. For an in-depth explanation of tides and misconceptions about them, see "Tidal misconceptions" in Resources.

For students

Recently, the term "Super Moon" has gained some notoriety, and to a lesser extent, the term for its opposite, "Super Mini-Moon." A *Super Moon* occurs when the full Moon is closest to the Earth (at *perigee*). A *Super Mini-Moon*, on the other hand, occurs when the full Moon is at *apogee*, its greatest distance from the Earth. Both terms are somewhat tongue-in-cheek; however, there is some significance to knowing when the super Moon occurs, as whenever there is a super Moon, there also will be a highest tide.

An interesting school year–long investigation could examine the physical relationship between the Earth and Moon. The activity could also illustrate the significance of NASA's Earth-orbiting observational programs (see the January 2015 Scope on the Skies column for more information about satellites).

Using the Moon phases and the lunar perigee and apogee calculator (see Resources), students can select different years and graph the dates for various Earth and Moon events. Then, students can add to the graph dates of volcano eruptions or earthquakes, students' classroom behavior, crime rates, and births, for example.

Students can then look for patterns, and if any are observed, such as overlapping dates, ask them if there is a connection, or if these events are coincidental. Are enough data collected for a long-enough time period to verify a pattern?

Tides, bulges, and volcanoes

The Moon travels in an elliptical orbit and, as a result, the Earth and the Moon are farthest from each other at the Moon's *apogee* position and closest at the Moon's *perigee* position. The Moon's elliptical orbit also ensures that it will not always be at the same Earth-to-Moon distance each time it reaches a particular phase. The Moon's distance also affects its gravitational pull on the Earth. Using internet research on tides, Moon phases, and Moon distances, students can explore the ever-changing distance between the Earth and the Moon and how this relationship may or may not affect the Earth (see Resources). For example, students can answer questions such as, "Can the Moon's tidal influence trigger huge volcano eruptions, such as the Mt. St. Helens eruption in 1980, or the more recent volcanic eruptions in Chile?" and "What are the dates for the 'Super-Moon' and 'Super Mini-Moon' in previous years and did any of these dates match records for volcanic eruptions or earthquakes?" Students can also investigate the contention that there is a correlation between a full Moon and behavior, crime rates, and births.

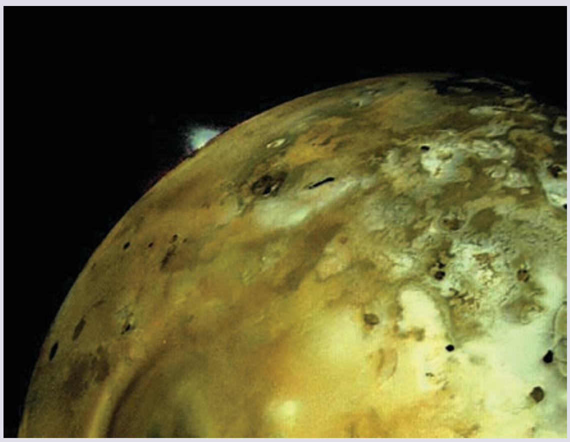
To explore the question about Mt. St. Helens, students should gather tidal information from May 1980, when the volcano erupted, as well as lunar phase and distance information. Using the data tables generated by the Lunar Perigee and Apogee Calculator (see Resources) students can see the dates and times for the entire year of 1980. At the National Oceanic and Atmospheric Administration (NOAA) website, students can see historic tidal tables for May 1980 from various stations along the Oregon coast. At the U.S. Geological Survey (USGS) website, students can read about the volcano and see a summary of the sequence of events leading up to the eruption. Wikipedia has a detailed time line of the eruption and the time for specific events that was summarized from information provided in USGS publications (see Resources). Using the information on Wikipedia or from students' perusal of the USGS publications, they can create their own time lines or data tables to compare dates and times of the volcano's activity during the months leading up to the eruption, the eruption itself, tides, and Moon phases to see if there is any correlation.

While the connection between volcanic eruptions and the Moon's gravitational pull is still not certain, there does appear to be a link between gravitational pull and volcanic eruptions on Jupiter's moon, Io, as well as possibly on some of the icy moons orbiting Saturn, Uranus, and Neptune. Actively erupting volcanoes were observed on Io during the *Voyager 1* and *2* flybys in 1979, and Io is the most volcanically active body in the solar system. What makes Io's volcanoes so different from those on the Earth is that the energy that drives Io's volcanoes does not come from interior heat; rather, the surface is under tremendous tidal influence, or *stress*, from Jupiter on one side and the combined stress from Jupiter's other large moons, Europa, Ganymede, and Callisto, on the opposite side. This tug-of-war causes a tidal bulge in the solid surface of Io such that the heat created by this flexing is enough to create and perpetuate volcanic activity (see Figure 1).

Gravitational forces also have an effect on some icy moons. For example, Jupiter's moons Europa and Ganymede have icy surfaces that show features caused by the tidal stress from Jupiter. Ganymede's surface is covered by cracks and grooves thousands of miles in length. Scientists believe these formed as a result of tectonic activity and water welling up from the subsurface ocean as a result of tidal pull. Europa is closer to Jupiter than Ganymede, so the tidal stresses from Jupiter are much greater, also resulting in a cracked surface.

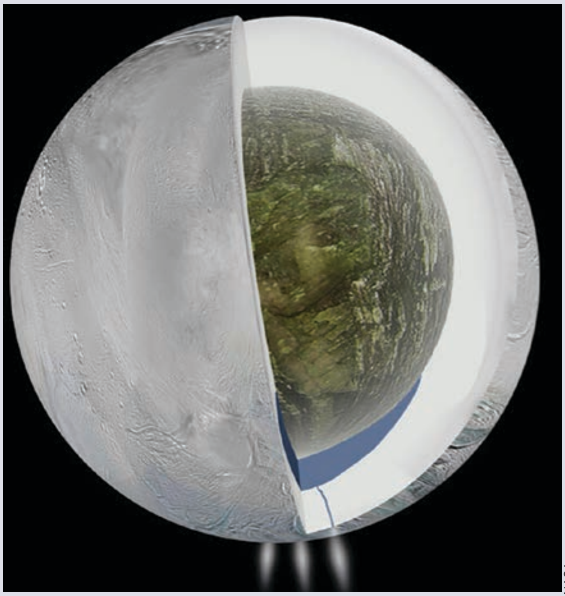
Other ice-covered moons in the solar system show the effects of tidal stress differently. While there are surface cracks and grooves on these moons, many of them also show signs of volcanic activity. However, volcanism on an icy moon does not involve the flow of molten rock, but rather ices and liquids in what is called cryovolcanism.

FIGURE 1 Volcano eruption on Io



NASA

FIGURE 2 Enceladus layers and plumes



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Cryovolcanism is a process in which liquids including water, ammonia, and methane are trapped under pressure below an icy surface in a slushy mixture that is not quite frozen. As icy moons orbit their respective planets in their elliptical orbits, they experience different amounts of tidal stress as their distance from the planet changes. This could result in surface tension, much like the flexing surface of Io. The slushy subsurface mixture is able to break through to the surface when it erupts as plumes that expand and rise above the moon's surface. At some point, the plume slows its expansion; as the material cools, it rains back down on the surface. Some of the plume material may actually escape the moon's gravitational field and merge with the ring material around its parent planet (see Figure 2). ■

Visible planets

Mercury, for the first half of the month, will be visible, but low over the western horizon before sunset local time.

Venus will be visible over the eastern horizon before sunrise local time.

Mars will be visible over the eastern horizon before sunrise local time, but lower than Venus.

Jupiter will move out from behind the Sun and gradually become visible over the eastern horizon at sunrise local time.

Saturn will be visible over the southwestern horizon before sunset local time and will set several hours later.

September

1	Neptune at opposition
	Waning gibbous Moon near Uranus
2	Venus near Mars
4	Mercury at east elongation
5	Waning gibbous Moon near Aldebaran
	Last quarter Moon
10	Waning crescent Moon near Mars and Venus
11	Waning crescent Moon near Jupiter and Regulus
13	New Moon
	Partial solar eclipse
	Moon ascending node
14	Moon at apogee: 406,500 km (252,587 mi.)
15	Waxing crescent Moon near Spica
18	Waxing crescent Moon near Saturn
20	Venus at maximum brilliance (-4.5)
21	First quarter Moon
23	September equinox (2:21 am EDT)
24	Mars near Regulus
27	Moon at descending node
	Moon at perigee: 356,900 km (221,767 mi.)
	Full Moon
	Total lunar eclipse
29	Waning gibbous Moon near Saturn
30	Mercury inferior conjunction

Resources

1980 eruption of Mount St. Helens—*http://en.wikipedia.*

org/wiki/1980_eruption_of_Mount_St._Helens
Evidence of cryovolcanism on Titan—*http://astrogeology.usgs.gov/geology/titan-cryovolcanism*
Cassini Solstice mission—*http://saturn.jpl.nasa.gov*
IRIS—*www.iris.edu/hq*
Lunar perigee and apogee calculator—*www.fourmilab.ch/earthview/pacalc.html*
Moon phases—*www.timeanddate.com*
Mount St. Helens—*http://mountsthelens.com/index.html*
Riddle, B. 2015. Scope on the Skies: A new year, a new world view. *Science Scope* 38 (5): 68–71.
Saturn stressing Enceladus—*www.nasa.gov/mission_pages/cassini/whycassini/cassini20120319.html*
Smithsonian Institution Global Volcanism Program—*www.volcano.si.edu*
Tidal misconceptions—*www.lhup.edu/~dsimanek/scenario/tides.htm*
Tides and currents (NOAA)—*http://tidesandcurrents.noaa.gov; http://tidesandcurrents.noaa.gov/stations.html?type=Historic+Water+Levels#Oregon*
USGS Earthquake Hazards Program—*http://earthquake.usgs.gov/earthquakes*
USGS Mount St. Helens eruption information—*http://pubs.usgs.gov/gip/msh*
USGS Mount St. Helens factsheet—*http://pubs.usgs.gov/fs/2000/fs036-00/fs036-00.pdf*
Voyager mission—*http://voyager.jpl.nasa.gov*

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