PLANETARY GEOLOGY

"All these worlds are yours, except Europa." - A.C. Clarke

SYNOPSIS: This exercise will introduce several methods by which the surfaces of planets are analyzed. Specifically, the geologic features of the Galilean moons of Jupiter will be explored and the surface of Venus in radar. The objective of this lab is for you to have a look at some of the pictures of these distant worlds and to learn what such pictures tell us about their surfaces, interiors and past histories.

EQUIPMENT: Galileo photographs of the Galilean moons, Magellan photographs of Venus, clear acetate, projector markers, tape, a ruler and a calculator. The images come from the Galileo website http://www.jpl.nasa.gov/galileo/sepo/

LENGTH: Two lab periods.

Please do NOT mark on the photographs!

Encounter with the Galilean moons

Part I. Properties of the Galilean Satellites

Jupiter's four large moons were first discovered by Galileo in 1610 and looked at in close detail by the Voyager I and II spacecraft in 1979. Launched in October 1989, NASA's Galileo spacecraft entered orbit around Jupiter on December 7, 1995. Its mission was to conduct detailed studies of the giant planet, focusing on its largest moons and the Jovian magnetic environment.

The table below shows properties of the Galilean satellites as well as the Moon and Venus for comparison. ***Figure 1*** in the folder shows family portrait of the four Galilean moons. Note that Io and Europa are similar in size to the Moon while Ganymede and Callisto are comparable to Mercury in size. But when we look at other properties, such as density and albedo, the similarities do not hold up.

	Radius (km)	Average Density (kg/m^3)	Albedo (reflectivity)	Orbital Distance, a ($R_{jupiter}$)	Orbital period, P (days)	Orbital period (P/P_{Io})
Moon	1738	3340	0.11	---	---	---
Io	**1821**	**3530**	**0.61**	**5.9**	**1.77**	**1.00**
Europa	**1565**	**3030**	**0.64**	**9.4**	**3.55**	**2.01**
Ganymede	**2634**	**1930**	**0.42**	**15.0**	**7.15**	**4.04**
Callisto	**2403**	**1790**	**0.20**	**26.4**	**16.69**	**9.43**
Venus	6051	5250	0.80	---	---	---

Each of the four Galilean moons is believed to have some iron at their center, surrounded by rock with perhaps a layer of water/ice on top. The density of iron is about 8000 kg/m^3, the density of rock is 2000 to 3000 kg/m^3, and the density of water/ice is about 1000 kg/m^3.

I.1 Considering just the average densities in the table above, (a) which Galilean moon would you expect to have the most ice (least rock/iron); and (b) which moon could be all rock and iron, with no ice on the surface?

Our Moon's interior cooled and most volcanic activity stopped over 3 billion years ago. This was a result of the processes by which a planet/moon cools (conduction, convection, and eruption) and, most importantly, its size (Chapter 9, *The Cosmic Perspective*). The table above shows that the Galilean moons are all close to the same size as the Moon and therefore should have also cooled at the same time. In this lab you will discover that at least three of the Galilean moons show evidence for geologically recent activity, contrary to our assumption about how planetary bodies cool. What are we missing? Well it turns out that there are two additional processes acting on the Galilean moons (and some moons around other planets) that were not listed previously– **tidal heating** and **orbital resonance**.

Tidal heating is mainly generated by the force of gravity exerted on a moon by the planet it orbits. This force "stretches and squeezes" the moon eventually causing it to rotate synchronously with the planet it orbits (like our moon).

I.2 Calculate the force of gravity between Jupiter and each of the Galilean moons.

$$F_g = \frac{Mm}{d^2}\,\mathrm{G} \qquad \text{(Equation 1)}$$

where: M = the mass of Jupiter

m = the mass of the Galilean moon

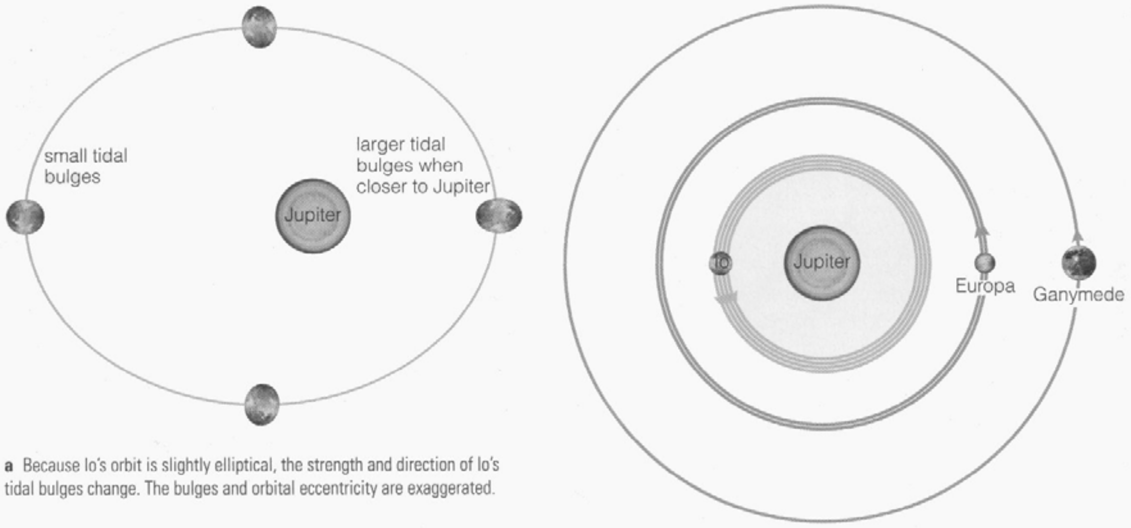
d = the distance between Jupiter and the moon

(all numbers can be found in Appendix E of your textbook)

Your answers will be in Newtons and watch out for your units (mks)

While these numbers are high and would be more than sufficient to create the features you will observe in this lab, there is still a problem. Once a moon achieves synchronous rotation with the planet it orbits the "stretching and squeezing" essentially ceases. Our moon is a good example of this. It synchronously rotates about the Earth and has been geologically dead for over 3 billion years. The much larger forces exerted by the more massive Jupiter would have brought its moons into synchronous rotation even faster and therefore the surfaces of the Galilean moons should be as old or older than our own moon. Again, evidence obtained from images of the surface tells us that at least three of the Galilean moons are much younger than the Moon.

The answer to this problem is found in orbital resonances. An orbital resonance is simply any situation in which one object's orbital period is a simple ratio of another object's orbital period (i.e. 1:2, 1:3, 2:3, 3:4, …. , etc.). In such cases, the two objects periodically line up with each other, and the extra gravitational attractions at these times can accumulate and affect the objects' orbits.



a Because Io's orbit is slightly elliptical, the strength and direction of Io's tidal bulges change. The bulges and orbital eccentricity are exaggerated.

b About every seven Earth days (one Ganymede orbit, two Europa orbits, and four Io orbits), the three moons line up as shown. The small gravitational tugs repeat and make all three orbits slightly elliptical.

FIGURE 11.18 Orbital resonances cause tidal heating on Io, Europa, and Ganymede.

I.3 Which three moons are in orbital resonances and what are the ratios of those resonances (use the table above)?

I.4 Using the numbers and equation (1), calculate the force of gravity exerted by Europa on Io when they are closest together in their orbits. Ganymede on Io. Compare these values (percent difference) with the force of gravity exerted by Jupiter on Io (I.2).

You should find that the gravitational force between each moon is a mere drop in the bucket compared to the force exerted by Jupiter. If you think about it, this should make sense. In systems that are not in orbital resonance the moons pass each other but always at different locations in their respective orbits. The effect is that the force exerted by the planet always dominates.

What makes orbital resonances special is that the bodies in resonance always come closest to each other in the same position in their respective orbits. This allows the gravitational forces between the moons to accumulate and perturb their orbits. As an analogy, imagine pushing a friend on a swing. If you were to try to push them at random times and places they probably wouldn't have much fun (of course you might have a great time). By always pushing your friend at the same place and time though, you increase the height to which they swing and they do have fun (and you stand there all bored and stuff).

I.5 Now calculate the force of gravity exerted by Europa on Io when they are farthest apart in their orbits. Ganymede on Io. How many times stronger is the gravitational force between the two bodies when they are closest together as opposed to furthest apart? As this effect accumulates, how do you think the orbits of the bodies would change (assume they are circular to start with)? With Jupiter always pulling on the moons, would this process tend to keep the moons "hot", cool them down, or have no effect? Explain.

Part II. Io: The Jovian Cauldron

Let us now consider the moon most affected by tidal heating and orbital resonance – Io.

Figure 2 shows Io photographed by the Galileo spacecraft in front of Jupiter's cloudy atmosphere. The image is centered on the side of Io that always faces away from Jupiter. The color in the image was derived using the near-infrared, green and violet filters of the Galileo camera, and has been enhanced to emphasize variations in color and brightness that characterize Io's volcano-pocked face. The near-infrared filter makes Jupiter's atmosphere look blue. The white patches are sulfur dioxide frost. The black and bright red materials correspond to the most recent volcanic deposits, some less than a few years old.

II.1 The dark spots are volcanoes. Make a rough count of the number of volcanoes in the image.

The active volcano Prometheus is seen near the center of the disk (arrow). To appreciate the size of the volcanoes on Io, we have to determine the **scale** of the photograph:

II.2 Measure the diameter of Io on photo #2 (measure in millimeters). Io is actually 3,630 km in diameter. Determine the scale factor S, of the image: How many (real) kilometers correspond to 1 millimeter on the photo?

S (km / mm) = Diameter of Io in km / Diameter of image in mm

II.3 Measure the diameter of the volcano Prometheus as seen on photo #2, including the bright ring around it. Use the scale factor above to determine its actual size. What is its actual size in kilometers? Compare this to the sizes of the volcano Mauna Kea in Hawaii (~80 km across, about the size of a metropolitan area) and Olympus Mons on Mars (the largest volcano in the solar system at 700 km across, about the size of Colorado).

Figure 3 is another image of Io, also taken by Galileo, that shows a new blue-colored volcanic plume, named Pillan, extending into space (enlarged in the inset with the plume - the other inset is an enlargement of Prometheus near the center of the moon). The blue color of the plume is consistent with the presence of sulfur dioxide gas erupting from the volcano, scattering sunlight (similar to water molecules making the Earth's sky blue). The sulfur dioxide freezes into "snow" in Io's extremely tenuous atmosphere and makes the white patches on the surface. These eruptions are common on Io and were first discovered when Voyager passed Io in 1979. Interestingly, they were *not* discovered by Voyager scientists, but rather by Linda Morabito, a young member of the Navigation Team. Morabito discovered them when she had difficulties matching the edge of Io's image with a circle, and then enhanced the images to investigate the problem.

These volcanic eruptions on Io are far larger than any found on Earth. Because Io's atmosphere is exceedingly thin, there is no air resistance and the gas molecules that erupt from a volcano follow paths like shells fired from a cannon. These paths are called **ballistic** trajectories (after *ballista*, an engine used in ancient warfare for hurling stones).

The maximum height *H* an object on a ballistic trajectory can reach is given by:

$$H = \frac{v^2}{2\,g} \qquad \text{(Equation 2)}$$

where v is the initial velocity of material exiting the volcano and *g* is the acceleration of gravity which is 9.80 m/sec^2 on Earth, but only 1.81 m/sec^2 , about a factor of 5 less, on Io.

II.4 The scale factor S for the inset with the plume of photo #3 is about 10 km per millimeter**.** Measure the height of the blue plume and determine its actual physical height. Convert this height to meters.

II.5 Using your value for the height (in meters) of the blue plume, determine the initial vent eruption velocity of the plume (in meters / second). For comparison, 1000 m/s equals about 2000 mph.

II.6 Volcanic eruptions on Earth cannot throw materials to such high altitudes because of atmospheric resistance and stronger gravity. Ignoring atmospheric friction and considering the factor of 5 greater gravity on Earth, what would be the height of the Pillan plume be if it had erupted from a similar volcano on Earth? For comparison, Mount Everest is just over 8 km high, commercial jets fly at about 15 km, and the Space Shuttle orbits the Earth at 150 - 500 km. Would such plumes be a hazard to commercial jets or the Shuttle?

II.7 Tall plumes (and high velocities of ejected material) are due to the pressures that build up because of internal sources of heat. Compare the height of the Pillan plume, *scaled down to the Earth's gravity*, with the height of the geyser “Old Faithful” (around 70 meters - about the height of the Gamow Tower) and the plume from the eruption of Mount St. Helens (1000 meters). What does this tell us about the pressures that build up inside Io compared with inside volcanoes on Earth?

Scientists are noting many changes that have occurred on Io's surface since the Voyager flybys 17 years ago, and even a few changes from month to month between Galileo images. ***Figure 4*** shows two images taken in 1997 on April 4 (upper) and September 19 (lower). The large black area in the September 19th image is material that has been ejected by the Pillan plume.

II.8 The diameter of the new black patch of volcanic material is 400 kilometers (half the state of Colorado). This corresponds to about 1% of the surface area of Io. If such eruptions occur at random over the surface every 6 months, estimate how many years it would take to resurface the moon.

II.9 Do you see any impact craters on any of the Io pictures? Explain your observation.

Part III. Europa: Water World?

Jupiter's moon Europa has a density closer to that of rock than water, yet spectroscopic analysis had shown that the surface of Europa is composed almost entirely of water ice.

The ice seen on the surface can be the top of only a thin layer of water/ice over a rocky interior. Recent measurements of the effects of Europa's gravitational pull on the Galileo spacecraft allow us to put an upper limit of about 170 km for the thickness of the water/ice shell.

III.1 What percentage of Europa's radius is this outer water /ice shell?

In ***Figure 5***, Galileo pictures of Europa show an icy crust that has been severely fractured. The upper gray image covers part of the equatorial zone of Europa, an area of about 360 by 770 kilometers (220 by 475 miles, or about the size of Nebraska), and the smallest visible feature is about 1.6 kilometers (1 mile) across.

In the lower (square) image the color has been greatly exaggerated to enhance the visibility of certain features. The fractures, called linea, and the mottled terrain appear brown/red, indicating the presence of contaminants in the ice. The blue icy plains are subdivided into units with different albedos at infrared wavelengths, probably because of differences in the grain size of the ice. The area shown is about 1,260 km across (about 780 miles - the size of Texas).

III.2 From these two images, does it look like the contaminants come from below (e.g. seeping through the cracks) or from above (e.g. meteorite dust deposited on the surface)? Explain.

III.3 ***Figure 6*** shows global views of Europa and of the Moon - Europa is only 10% smaller than the Moon. Which moon has the older surface? Explain your reasoning.

When asteroids and comets collide with planets and moons, the explosions resulting from the collisions are extremely violent. Matter is excavated from great depths and can be flung wide distances from the resulting crater. Larger impacts create larger craters and expose materials from greater depths. The appearance of the crater resulting from such an impact depends, among many things, upon the material properties of the material in which crater is formed. In ***Figure 7*** there are four examples of impact features, two on the Moon and two on Europa.

III.4 At 5.2 AU from the Sun, and having an albedo of 0.64, the temperature on the surface of Europa is nearly two hundred degrees Celsius below the freezing point of water. The lunar surface is composed primarily of a volcanically-derived type of rock known as basalt. Given the similar appearance of the two small craters, what can you conclude about the material properties of water ice at Europan temperatures and those of basalt?

Also shown in Figure 7 is the aftermath of two much larger impacts. The Europa impact feature, known as Tyre Macula, looks very different from the lunar crater, but it can still be identified as an impact feature from the clusters of surrounding small secondary craters that were created during the big (primary) impact.

From seismology experiments carried out during the Apollo missions, we know that the Moon's crust is very thick and is composed of the same material throughout. This is why, up to a certain size, most lunar craters look very similar.

III.5 Since larger impacts excavate material from greater depths and "see" more of the interior, what does the peculiar appearance of this large impact structure on Europa suggest about its crust of ice? Do you think it is frozen solid all the way through? What do you think happened to the impactor that made Tyre Macula?

Figure 8 shows an image of "chaos terrain" which looks as if it were created when the surface surrounding the ice blocks was slushy and the ice blocks, or "ice rafts" were free to float about.

III.6 Is this terrain the youngest seen on the surface, the oldest, or somewhere in between? What evidence in photo #8 tells you this?

If an ocean does exist, it might be a possible place for life to exist. Life, as we know from studies of life here on the Earth, can be very hardy and can adapt to survive in many regions. Life has been found near volcanic vents at the bottom of the ocean where no sunlight can reach, the frozen lakes of Antarctica and even inside rocks!

III.7 What difficulties do you think life in a hypothetical Europan ocean would have to overcome in order to survive?

Part IV. Ganymede: The Giant Moon

Ganymede is the largest moon in the Jovian system and also the entire Solar System. In fact, it is even larger than Pluto and Mercury! Furthermore, the Galileo spacecraft detected a magnetic field near Ganymede that indicates that the moon has a liquid iron core (similar to the Earth and to Mercury). However, the average density of Ganymede is close to that of water so that the outer layers of Ganymede must be water/ice rather than rock.

IV.1 ***Figure 9*** shows global pictures of Ganymede and of Moon. Superficially, they look rather similar. For the Moon, which is older: the lighter or darker regions? Explain.

Figure 10 and ***Figure 11*** are close ups of a darker and lighter region on Ganymede, respectively. When we look closer, any resemblance to the Moon disappears.

IV.2 The dark regions on Ganymede are older than the newer, lighter regions. The dark material is probably meteorite dust that has accumulated on the surface. Looking at the close up of the dark region in Figure 10, how do the craters on the icy surface of Ganymede change as they get older? (Compare them to the "fresh" lunar craters shown in Figure 7.)

IV.3 What has happened to the crust in the blown-up image of the light region in Figure 11?

The high-resolution image from the light region on Ganymede covers a region about the same size as San Francisco Bay - compared in ***Figure 12***. On the left the resolution is that of the best images taken by Voyager in 1979 and on the right the images are at the Galileo resolution.

IV.4 For the cases of (a) San Francisco Bay and (b) Ganymede, describe how the higher resolution images change our interpretation of the surfaces of these two regions.

You may remember Comet Shoemaker-Levy-9 making a spectacular display when it bombarded Jupiter in 1994. A couple of years before, the comet had been broken up into about 21 fragments when it had passed close by Jupiter. When it came back to Jupiter in 1994, the comet fragments plunged (and exploded) in Jupiter's atmosphere. It was realized at this time that comets are probably frequently broken up by Jupiter's gravity. Sometimes these broken up comets hit the moons rather than the planet.

IV.5 ***Figure 13*** shows a chain of craters on Ganymede that may have been produced by a broken up comet. How many pieces of comet impacted Ganymede?

Part V. Callisto: A Battered World

Callisto, the fourth Galilean moon, has the dubious distinction of being the most cratered moon in the solar system. Callisto is a little smaller than Ganymede (about the size of the planet Mercury) and is apparently composed of a mixture of ice and rock similar to Ganymede.

Unlike the other Galilean moons, Callisto has endured virtually no tidal heating. Callisto's albedo is about half that of Ganymede but Callisto is still more reflective than the Moon. The darker color of Callisto suggests that its upper surface is “dirty ice” or water rich rock frozen at Callisto's cold surface. The abundance of craters on its surface suggests that its surface is the oldest in the Galilean system, possibly dating back to final accretion stages of planet formation 4 to 4.5 billion years ago. And, unlike the other Galilean moons, Callisto's surface shows no signs of volcanism, tectonics or other geologic activity, further supporting the hypothesis that Callisto's surface took its present form long ago, and is hence very old.

Valhalla, the prominent “bulls eye” type feature in the 1000-km image in ***Figure 14***, is believed to be a large impact basin, similar to Mare Oriental on the Moon and the Caloris Basin on Mercury. The ridges resemble the ripples made when a stone hits water, but here they probably are the result of a large meteorite. The fractured ice surface was partially melted by the impact, but it re-solidified before the “ripple” could subside.

The four images in Figure 14 show increasing detail as Galileo zoomed in to smaller and smaller scales. Notice how the top (large-scale) two pictures show the surface of Callisto is saturated with craters so that if another impactor hit, it would probably cover up on old crater.

V.1 But when we go to smaller scales, does the surface remain saturated with craters?

V.2 What is the approximate size of the smallest crater that you can distinguish as a crater in the 1 kilometer image?

The dark material is probably dust produced by the break up of micro-meteorites (tiny, dust-sized meteorites). It is probably very similar to the dust on the surface of the Moon.

V.3 If all smaller craters are covered up with meteorite dust, roughly how thick must the dust layer be? (*Hint:* As a general rule of thumb, most craters are about 1/10th as deep as they are wide. That is, craters tend to have a width-to-depth ratio of 10:1.)

V.4 Is Callisto in an orbital resonance with any of the other Galilean moons? Explain. How does its surface age compare with the other Galilean moons? Is this consistent with our understanding of the processes by which planets/moons heat up and cool down? Explain.

Radar Mapping of Venus's Surface

Now we will switch gears and look at a planet closer in composition to our own: Venus. It is often referred to as Earth's sister planet and with good reason. It is the closest planet in both size and distance to our own and is made of similar materials. There is a problem with Venus though. Recall from the *Planetary Temperatures, Albedos, and Greenhouse Effect* lab that the clouds in Venus's atmosphere reflect 80% of the incident light. This would pose a problem for planetary scientists using typical instruments to examine the surface (by "typical" we mean a camera using visual wavelengths). A camera, like our own eyes, is a passive system. It only **receives** reflected energy (as from the sun or any other light source) and since Venus is covered in clouds a camera would only see the light that is reflected from those clouds. To penetrate the clouds and see what Venus's surface looks like, we use **radar**.

Radar is an imaging and detection system that uses the **microwave** portion (~1mm to ~1m wavelengths) of the **electromagnetic spectrum**. It is an active system in that a signal is **transmitted and received** by an instrument on the spacecraft. Because radar produces and receives its own energy, it is not generally dependent on environmental conditions for its use. In other words, it can be used day or night, and because radar wavelengths can penetrate clouds, it can be used during most kinds of weather.

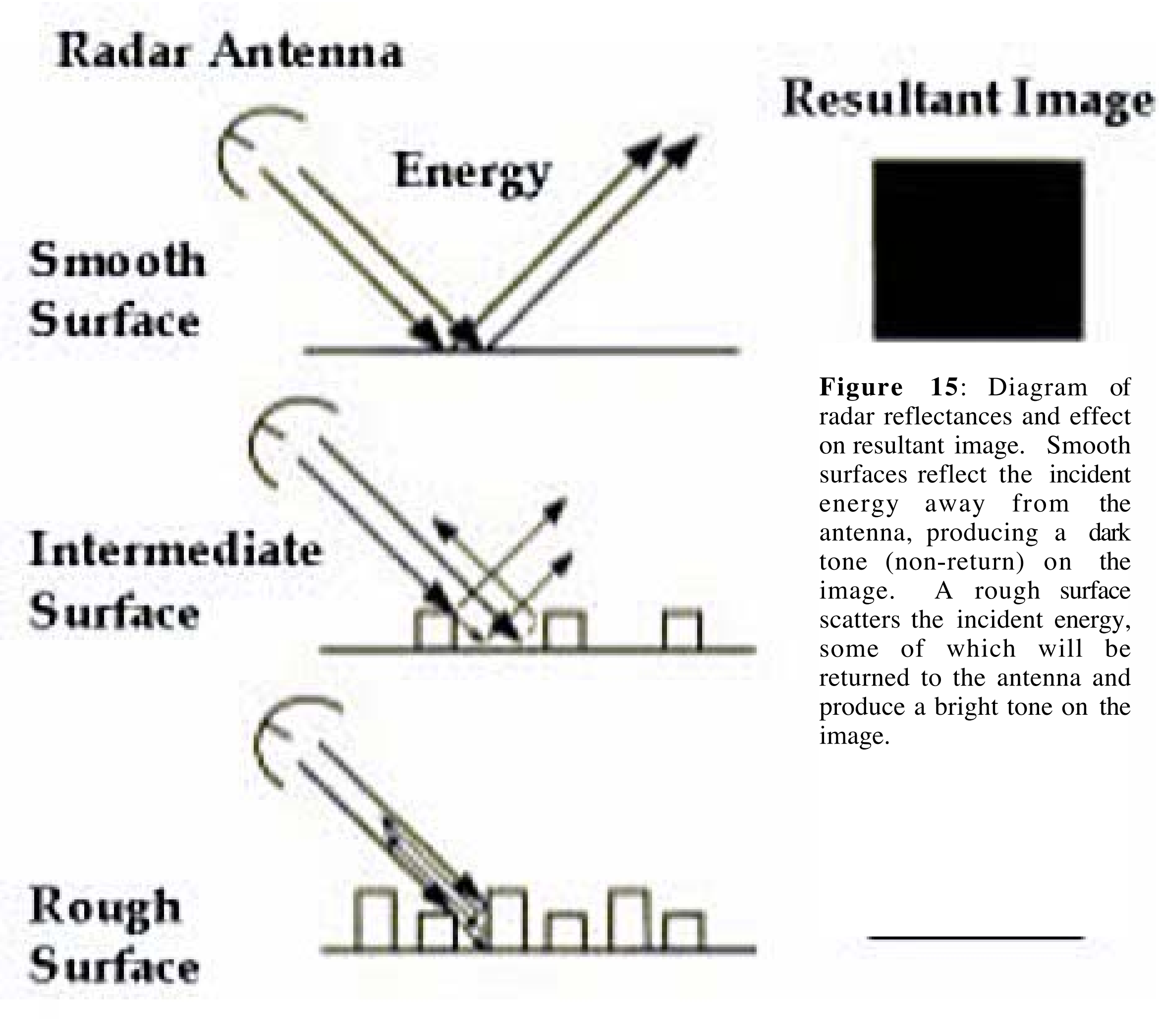


Figure 15: Diagram of radar reflectances and effect on resultant image. Smooth surfaces reflect the incident energy away from the antenna, producing a dark tone (non-return) on the image. A rough surface scatters the incident energy, some of which will be returned to the antenna and produce a bright tone on the image.

All electromagnetic energy interacts with the objects and surfaces it encounters by being absorbed, transmitted, or reflected. We see only the light that is reflected (bounced) toward our eyes. Likewise a radar instrument will only "see" the radar waves reflected back to the antenna (***Fig. 15***). The more energy that is reflected back to the antenna, the brighter the tone created in the resultant image. In general, smooth surfaces are dark in a radar image and rough surfaces are bright. One way to think about radar is that it shows how a surface "feels" (rough or smooth), whereas a conventional camera image shows how a surface "looks" (color and brightness). Because we are not accustomed to thinking about a surface in terms of texture, working with radar images can be difficult at first.

Figures 16 a and ***b*** show the same area of the Mojave Desert of California. *Figure 16a* is a visible wavelength Landsat photo and *16b* is a Seasat radar image. The feature marked A is a lava flow. In the Landsat photo it is dark, because the rocks are dark in visual appearance; but on the radar image the lava flow is very bright, because the surface is very rough and scatters the radar energy back to the antenna. The feature marked B is a dry lakebed. In the Landsat photo it is light, because the materials are light colored sands and clays. In the radar image, the lakebed is very dark and difficult to distinguish from the surrounding dark areas. This is because both the lakebed and the surrounding sands are both very smooth. Mountains appear bright in the radar image and they are easier to distinguish than in the Landsat photo. Because of the radar's sensitivity to surface texture, it is able to image structural features (such as faults and fractures) that may go undetected in a visible wavelength photo. Note that a cinder cone within the lava flow (marked C) is easier to see in the radar image than in the Landsat photo.

Cinder cone: A conical hill formed by the accumulation of cinders and other pyroclasts around a volcanic vent. They often look like a smaller version of a volcano (tens of square meters to a square kilometer) and are typically found in the midst of a lava flow.

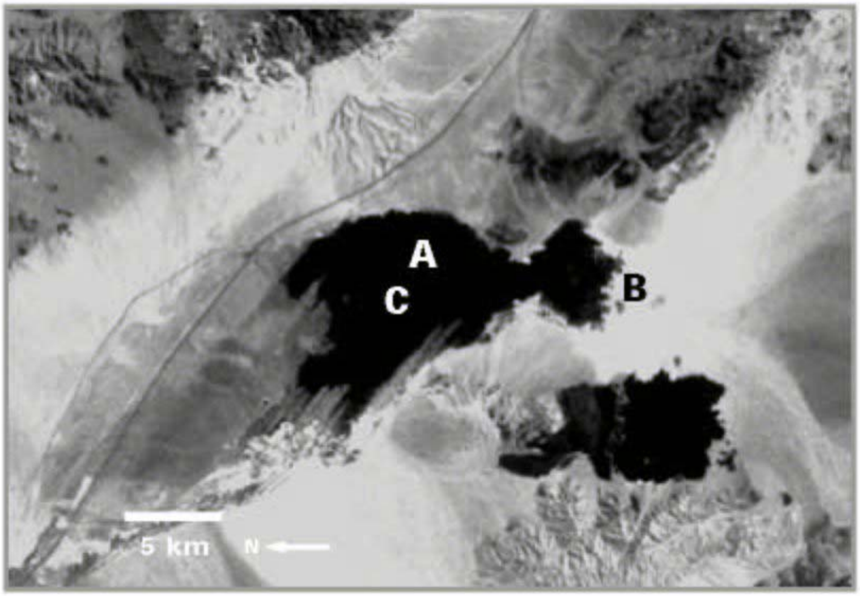


Figure 16a. Landsat photo of part of the Mojave Desert, CA.

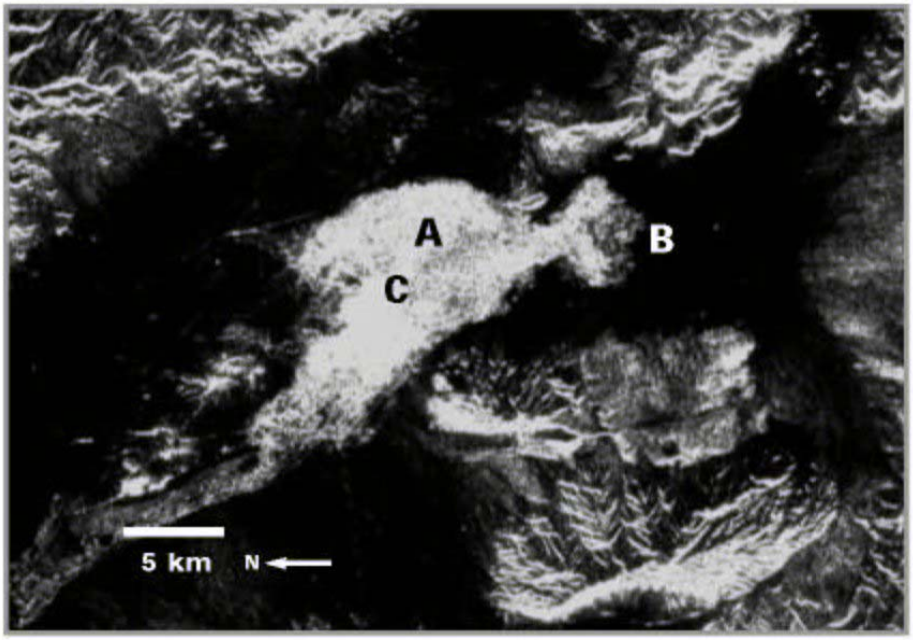


Figure 16b. Seasat radar image of the same region of the Mojave Desert, CA as shown in Figure 16a. The feature labeled A is Pisgah lava flow. The feature labeled B is a dry lakebed. The feature labeled C is a cinder cone.

Part VI. Geologic Features of Venus

The Magellan orbiter spent four years taking radar images of the surface of Venus. It was able to radar-map 98% of the planet's surface before its mission ended in October of 1994. You will now study some of Magellan's radar images to gain an understanding of Venus's surface.

Figure 17 shows two impact craters on Venus. They are surrounded by smooth volcanic plains, which are dark in the radar image. The crater rims are easily identified, as are the **ejecta** deposits.

VI.1 a) Describe the ejecta, rim, floor, and central peak of the smaller crater in terms of texture.

b) The ejecta of the larger crater is different from that of the smaller crater. Part of the ejecta of the larger crater was molten rock and formed flows. What is the texture of the ejecta flow labeled A?

The right side of ***Figure 18*** shows a rift zone on Venus. Although the rift zone appears almost flat in the image, the topography of the area is more like the Grand Canyon of Arizona, with steep cliffs and deep valleys. The other bright lineaments in this figure are fractures and faults.

VI.2 Note the crater at A. Is it younger or older than the rift? How do you know?

Figure 19 shows an area of "complex ridged terrain," the term used for some mountains and highlands on Venus. This area has been fractured, faulted, uplifted, and surrounded by younger smooth (dark) plains. The deformed area is very bright in the radar image because the complex structures have produced very rough terrain.

VI.3 Does the tectonic activity that formed the complex ridged terrain appear to have affected the volcanic plains? What does this indicate about tectonic activity in this area and the age of the volcanic plains?

Figure 20 shows many small (1 –10 km in diameter) volcanoes, constituting a "volcanic shield field." Volcanism has played a major role in the formation of the surface of Venus, and shield fields are common.

Shield vocano: A broad, gently sloping volcanic cone of flat domical shape, usually several tens or hundreds of square kilometers in extent (Mauna Loa on the island of Hawaii is a good example).

VI.4 List any similarities and differences among the individual volcanoes.

Most dark (smooth) plains on Venus are volcanic. However, not all volcanic flows on Venus are dark. ***Figure 21*** shows an area of volcanic flows that are bright.

VI.5 Describe the field of flows shown in the image. Include information as to the texture, outline, and any other interesting features.

So far all the figures have shown features that can be found on Earth as well as on Venus. ***Figure 22*** shows features that may be unique to Venus. Termed "coronae" (the singular is "corona"), these features are identified by circular sets of fractures. Some form low, circular domes that can have associated volcanic flows (for example, the flows to the north and northwest of the corona marked A); or the centers may have subsided, leaving bowl-shaped depressions, which can be filled by lava flows. Radial fractures commonly surround coronae, giving a "bug-like" appearance.

VI.6 What is the diameter of the largest corona in the image?

VI.7 a) Are the flows to the north and northwest of the corona labeled A rough or smooth in texture?

b) How far from the letter A did the volcanic material flow to the northwest?

Part VII. Planning a Venus Rover Mission

Figure 23 shows part of the Carson Quadrangle of Venus, centered at 11 S, 345 E. The area shown is equal to about two-thirds of the continental United States. All the types of features shown in the previous figures can be found on this image; however, due to their small size, shield fields are very difficult to see. The black areas are regions that were not imaged by the Magellan spacecraft. The bright circular spots are where meteoric material struck the surface without forming an impact crater. These are called ”splotches.” Be sure to note the difference in scale between this figure and the previous ones.

VII.1 Tape a piece of clear acetate to the figure. Draw a box outlining the image. Trace the scale bar and north arrow. On the acetate, identify all the features listed below.

A. Identify as many coronae as you can. Trace their outline and place a “C” within the outline.

B. Identify and mark with an “x” all the craters in the image area.

C. Outline and label with the letters “CRT” all the areas of complex ridged terrain.

D. Outline and label with an “R” all the rift zones

E. Outline and label with a “V” areas of volcanic flows. Do not include the extensive smooth plains flows. Look for the variation in texture as seen in *Figure 21*.

F.

One day, planetary scientists hope to send a robotic rover to the surface of Venus. Because the surface temperature is about 470 C, people will probably never set foot on this planet. In this part of the exercise you will plan a rover journey.

In planning the rover path remember these rules: 1) the robotic rover can only travel on smooth terrain (dark plains); 2) it cannot cross rift zones or complex ridged terrain; 3) it must travel in straight lines (turns are allowed, but the path must be lines and angled turns rather than curves); 4) the rover can cross the black non-imaged parts of the image, but you cannot drive for any great distance inside the black areas, because there may be unknown obstacles.

VII.2 Develop a rover path to include a visit to at least 1 crater, 2 coronae, the edge of a region of complex ridged terrain, and an area of volcanic flows (not including the smooth plains). Because of the high temperatures and pressures at the surface, spacecraft and rover engineers could only design the rover to travel a maximum distance of 3430 km (a distance of 25 cm on the image) starting from either landing point A or B. Use a ruler, the image, and your acetate map with the features identified to plan a rover path to visit the five features listed above. Trace the path on the acetate. There is no need to return to the starting point.

Part VIII. Follow-Up Questions

VIII.1 Is it valid to make inferences about the interiors of planets based on images of their surfaces? Given a large number of images of a planet's surface, how would you start to unravel its geologic history?

VIII.2 What remote sensing techniques might be used to clear up ambiguities in the interpretation of planetary images?

VIII.3 Formulate an unresolved question about the surface of any one planet/moon we have looked at in this lab. Design an instrument package for a potential mission to this body that would address this question. Be sure to specifically state how you would interpret the data from this instrument. Your grade will be based on the creativity of your answer and the clarity of your explanation. *As an example from the Moon: Test the hypothesis that the maria are younger than the lunar highlands, based on relative crater abundances measured from high-resolution optical imaging.*