Astrobiology Lab Manual

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Introduction

Natural Selection

Natural selection, first described by Charles Darwin, is the process by which life evolves. Those organisms with the greatest *fitness*, that is, with the greatest capability to survive and reproduce, are the ones who have the most offspring. Their offspring have the same favorable traits that their parents had. As a result, favorable genes become more common in a population.

New species will arise when selection operates differently on different parts of a population. For example, if a population is divided by a geographical barrier, with two parts of the population in two different habitats (such as Darwins Galapagos finches), selection may operate on these two segments in the population differently, causing them to diverge. This process is called *speciation.*

Extinction Events

If a significant portion of a population is killed, the small surviving population may not be fully representative of the original population's gene pool. By chance, certain types of genes may be more represented than others, and others may be underrepresented. Some may be eliminated completely. In fact, this can sometimes reduce genetic variability. This is called the *bottleneck effect.*

In the short run, a *mass extinction* lowers biodiversity. But in the long run, the effects of a mass extinction are astounding. A mass extinction event may wipe out whole species and large segments of populations, but this allows the remaining species to radiate and spread into the ecological niches that are now open. This is a perfect opportunity for evolution to do its work, leading to many new "origins of species".

Materials

Your group will need:
- a colored fabric habitat
- a collection of M&M organisms, sorted by color (red, blue, green and yellow)

Simulating Natural Selection

In this portion of the lab you will simulate the process of natural selection using a set of M&M "organisms" placed onto a fabric "habitat". One group member will be disgnated the "distributor" and the rest of the group members will be "predators".

Procedure

Perform the following instructions:

1. Spread your fabric habitat onto the table.

2. Have the distributor place 20 of each color of M&M onto the habitat (80 organisms in total). The M&Ms should be randomly placed and should be spaced (roughly) uniformly.

3. The predators will now take turns picking up M&M organisms one by one. Take turns picking up the organisms until only 20 are left on the fabric. Pick quickly but count carefully. Treat this as if you were a bird of prey: you would survey the habitat and choose the first organism you see.

4. Record the number of survivors of each color on the provided data table.

5. Each survivor now produces a set of three offspring. For each of the 20 survivors, the distributor will place three M&Ms onto the habitat of the same color as the surviving parent. You should now have 80 organisms on your habitat.

6. Record the number of organisms of each color on the provided data table.

7. Repeat steps 3-6 for an additional two times, simulating three total generations.

The color of my group's habitat is:

Natural Selection Data Table

	Red	Blue	Yellow	Green	Total
Start	20	20	20	20	80
After 1st Predation					
After 1st Reproduction					
After 2nd Predation					
After 2nd Reproduction					
After 3rd Predation					
After 3rd Reproduction					

Simulating a Mass Extinction

In this portion of the lab you will simulate a mass extinction. You will assume that all of your M&M organisms are equally as likely to die off during the extinction. While performing this section, consider the conditions under which this assumption is valid.

Procedure

Perform the following instructions:

1. Spread your fabric habitat onto the table.

2. Have the distributor place 80 M&Ms onto the habitat according to the distribution you recorded at the end of the natural selection simulation.

3. Simulate a mass extinction event by randomly removing 72 of the M&Ms from the 80 that are on the table. Record the distribution of colors on your data table.

4. Each survivor now produces a set of three offspring. For each of the eight survivors, the distributor will place three M&Ms onto the habitat of the same color as the surviving parent. You should now have 32 organisms on your habitat.

5. Record the distribution of colors on your data sheet.

Mass Extinction Data Table

	Red	Blue	Yellow	Green	Total
Start	20	20	20	20	80
After Mass Extinction					
After Reproduction					

Questions

Natural Selection Simulation

Using your results from the natural selection simulation, answer the following questions.

1. Did the distribution of colors change after the first predation and reproduction cycle? Which colors appeared with the highest frequency in the survivors?

2. What change, if any, occurred in the distribution of colors after the 2nd and 3rd predations?

3. How do you think the distributions of colors were related to the "habitat"? Do you think the color distributions would have been different if you were doing this activity on a different piece of cloth?

4. Which color M&Ms could be considered to have the greatest fitness, according to this simulation? Why?

Mass Extinction Simulation

Using your results from the mass extinction simulation, answer the following questions.

1. What change, if any, did you see in the distribution of colors after the mass extinction event?

2. At the end of your natural selection simulation some colors of M&M were more prevalent than others. Which color is more likely to survive the mass extinction, a less prevalent color or a more prevalent color? What does this say about *real* mass extinction events?

3. In this simulation, the removal of the organisms was entirely random, without regard to color. That is, no one "type" of organism was favored to survive the mass extinction event. How might this be different in a real mass extinction situation (such as in the case of a massive meteor collision)?

Tree of Life

Go to the Tree of Life website (*tolweb.org*). Choose your favorite organism (*e.g.* a grizzly bear, but feel free to choose any animal, plant, fungus, protist, bacterium, or archaeon) and, starting with the main page (at the transparent blue circle), try to navigate through all the groupings (taxa) to find your organism.

1. List the taxa that your organism belongs to. Start with the most general (*e.g.,* "eukaryotes") and end with the most specific (*e.g.,* "Homo sapiens"). (Note that some organisms have many more "groupings" (or taxa) that they belong to than others; and the website has more specific information on some taxa than others).

2. In which domain of life does your organism belong?

3. What is the citation of the page of your organism (written under "Citing this page:" at the bottom of the webpage)?

References

The following were used in the preparation of this activity:

Lopipero-Langmo, P. 2009, Evolution Lab.
http://fog.ccsf.cc.ca.us/plopiper/documents/Bio9EvolutionLab.pdf

Introduction

Every rock tells a story. By analyzing a rock we can learn where, when and under what conditions it formed. We can also learn about how the rock has been altered since its formation. The rock need not have originated on Earth; even meteorites tells a story. Meteoriticists and Geologists work at extracting these stories from rocks and combining the stories from a variety of rocks to create a grand narrative that helps explain the evolution of Earth and the Solar System.

Earth Rocks

Igneous Rocks

Igneous rocks are formed by solidification of cooling magma or lava from 650-1400°C to ambient temperatures. They may form in Earth's mantle, crust or surface. Igneous rocks make up the majority of Earth's crust. At Earth's surface, igneous rocks are characteristic of lava flows and volcanic eruptions. Common types of igneous rocks include basalt and granite. Igneous rocks can generally be identified by their mineralogical and chemical composition, where the sizes of the crystals that make up the rock indicate the rate at which the rock cooled and solidified (large crystals imply a long cooling time).

Sedimentary Rocks

Sedimentary rocks are formed by the deposition and consolidation of eroded or weathered rock materials and/or by the precipitation of minerals out of a solution. Sedimentary rocks cover the majority of Earth's surface and include common types of rocks such as limestone and sandstone. Sedimentary rocks may have fossils, organic matter or imprints of organisms (*e.g.,* dinosaur footprints) incorporated into them or may be formed by biological activity (*e.g.,* coral reefs), which are all indicators of the presence of life in the fossil record. Periodic layering or structures reflecting sediment transport are a defining feature of sedimentary rocks.

Metamorphic Rocks

Metamorphic rocks are formed by altering an existing rock type at relatively high temperatures and pressures. This happens, for example, under mountain ranges, in tectonic subduction zones or near intrusions of hot magma derived from melting of the Earths mantle. While the conditions under which a metamorphic rock forms are not extreme enough to cause complete melting, physical and/or chemical changes do occur within the rock. Common types of metamorphic rocks include slate and marble. Metamorphic rocks may have a layered appearance and may show signs of the physical stresses which these rocks encounter.

Weird Cases

Earth rocks can be altered by interesting processes which lead to the creation of strange rocks. Breccias are rocks that form by cementing several centimeter-sized rocks together (the centimeter-sized rocks may be igneous or sedimentary depending on the formation conditions). Other rocks like tektites and shatter cones form during the extreme conditions encountered when a metereorite strikes Earth's surface.

Space Rocks

Iron Meteorites

Iron meteorites are the most easily recognizable meteorites. Since even a casual examination shows that they are not ordinary rocks, they tend to be very common in collections although they are rare in space. They are very dense and, except for a thin crust (made by the melting of the skin during the passage through the atmosphere), they look and feel like metal. Chemically, they are composed mostly of iron with a few percent nickel and a little cobalt. Iron meteorites come from the cores of relatively massive asteroids which have been broken apart.

Stony Meteorites

Stony meteorites are the most common meteorites that fall to Earth. Since they tend to have a similar appearance and density as Earth rocks, stony meteorites are difficult to recognize in the field. Unless someone sees them fall, they usually go uncollected. Therefore, although stony meteorites are the most common type out in space, they are more rare than iron meteorites in collections on Earth. Stony meteorites show a wide variety of appearances: some light, some dark, some coarse grained, some fine–grained, but almost all stony meteorites contain some metallic iron. Chemically they are also diverse, thought they all have a telltale composition that tells us they are not from the Earth. Most stony meteorites are from the outer parts of an asteroid that suffered destruction by collision. Some are pieces of lava flows from the surface, some are pieces of impact breccia, and some are pieces of material that apparently never existed in a much larger body. Meteorites that come from such a small, undifferentiated body are called primitive meteorites.

Stony-Iron Meteorites

Stony-Iron meteorites are the rarest class of meteorites, comprising only about 1% of meteorites that fall to Earth. There are two broad classes of stony-iron meteorites: *Pallasites* (composed primarily of iron with crystals of a rock mineral called olivine embedded in it) and *mesosiderites* (that look like stony meteorites with lots of metallic iron veins running through them). *Pallasites* are thought to be material from the boundary zone between the iron cores and the stony outer mantles of the now-destroyed asteroids, while *mesosiderites* are theorized to be formed when an impact on an asteroid mixes material from the rocky mantle with iron from the core.

Carbonaceous Chondrite Meteorites

An especially important type of meteorite is the carbonaceous chondrite, a specific type of stony meteorite that originates from primitive asteroids. They are black to dark gray in color, rich in the element carbon (thus their black color), and contain small spherical droplet-like inclusions called chondrules. They are among the most primitive objects in the solar system, having survived almost unchanged for 4.6 billion years. Carbonaceous chondrites were the first place amino acids were found outside of the Earth, and it has been recently learned that some of the materials in these meteorites were formed outside of our solar system before our solar system was even formed, so they are not only an important probe into our early solar system history, but they may supply us with samples of materials from beyond our solar system. Although carbonaceous chondrites are fairly abundant among meteorites that fall to the Earth, they look enough like Earth rocks that they are rare in collections. They also weather very easily and do not survive long on the surface of the Earth.

Telling Your Rock's Story

In the space provided:

• Sketch your rock from two different viewing angles.

• Using the magnifying glass, sketch a magnified portion of your rock (try to find an interesting feature to sketch).

• On your sketches, highlight three interesting features of your rock. Features may include the overall shape of the rock or inclusions in the rock (to name a few).

Write a paragraph describing 1) how you think your rock formed and 2) what events/processes may have affected your rock. Mention the interesting features you highlighted above. The introduction to this lab (and your TA) may prove to be valuable resources.

The Fossil Record

The upper portion of the figure below depicts groups of organisms that can be found in the fossil record. The geologic periods through which these groups were present as well as the diversity of the groups through these periods are shown in the lower portion of the figure. The time spans of the geologic periods are shown in the figure on the following page.
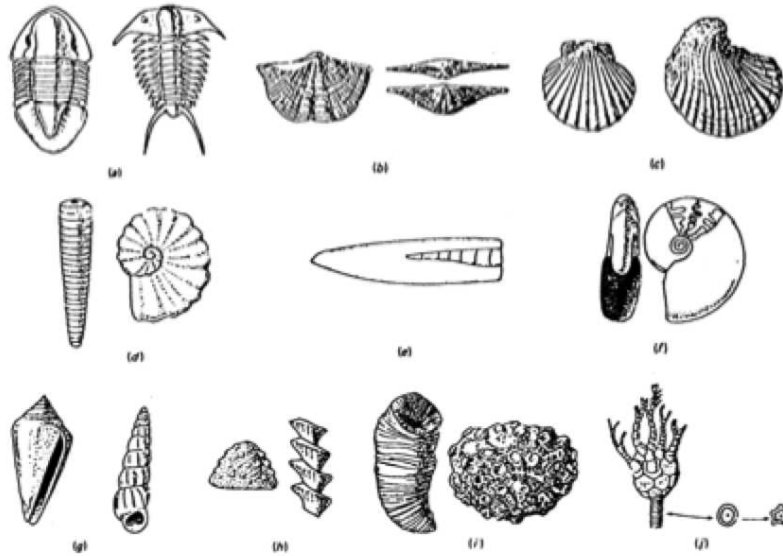
Representative sketches of common groups of invertebrates: (a) trilobite, (b) brachiopod, (c) pelecypod (clam), (d) nautiloid, (e) belemnoid, (f) ammonoid, (g) gastropod (snail), (h) bryozoan, (i) coelenterata (coral), and (j) crinoid.
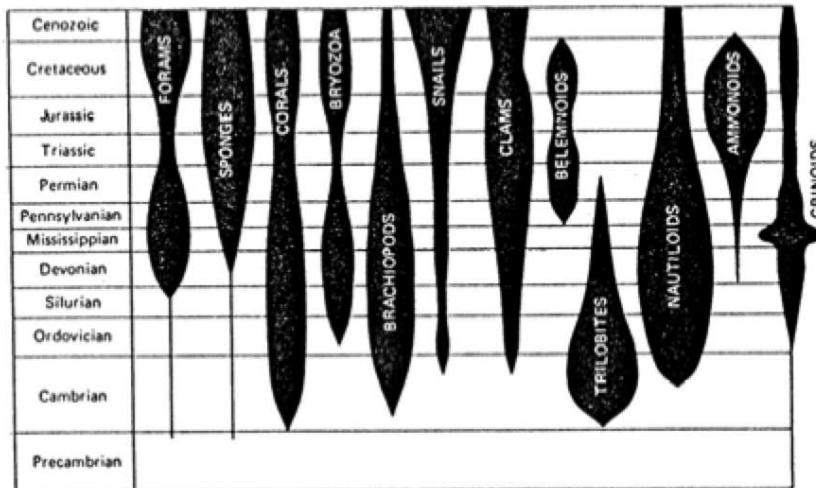
Generalized geologic ranges of the common invertebrate groups. Widths are proportional to fossil abundance (number of species in that group at that time).

The Geologic Time Scale

Era	Period		Epoch	Duration in Millions of years	Millions of years ago
Cenozoic	Quaternary	Neo-gene	Holocene	recent	
			Pleistocene	1.8	1.8
			Pliocene	3.5	5.3
	Tertiary		Miocene	18.5	
		Paleo-gene	Oligocene	9.9	23.8 / 33.7
			Eocene	21.1	
			Paleocene	10.2	54.8 / 65.0
Mesozoic	Cretaceous			79	
	Jurassic			62	144
	Triassic			42	206
Paleozoic	Permian			42	248
	Carboniferous	Pennsylvanian		33	290
		Mississippian		31	323
	Devonian			63	354
	Silurian			26	417
	Ordovician			47	443
	Cambrian			53	490
	Precambrian				543

Questions

Use the diagrams on the previous two pages to answer the following questions.

1. Which Period occured more recently, the Cambrian or the Tertiary?

2. How many millions of years ago did the Triassic Period begin? End? How long did the Triassic Period last?

3. Dinosaurs were present on Earth during the Mesozoic Era. For how many millions of years did dinosaurs walk the Earth?

4. Humans have been walking the Earth for about 200,000 (= 0.2 million years). How many *times* smaller is this number than the reign of the dinosaurs? Comment on your result.

5. Regarding the sketches of groups of invertebrates, what trait do these groups share that make them ideal for fossilization? Explain.

6. For how long were trilobites wandering the Earth?

7. How many millions of years ago were trilobites at their highest diversity?

8. The shaded region for clams begins in toward the end of the Cambrian Period. Does this mean that clams were not present earlier in the Cambrian period? Explain.

9. Many groups of invertebrates have their origin in the Cambrian Period (especially towards the earlier portion of the Cambrian Period). What might this imply about conditions on Earth during the Cambrian? (Note: This trend in the fossil record has been deemed the "Cambrian Explosion".)

Introduction

Since our direct samples of materials from other worlds is very limited, most of our knowledge about planetary surfaces comes from analyzing the light that they reflect. This is the idea behind the science of **remote sensing**. One way to do this is to simply examine images taken in visible light, images much like you would produce with an ordinary camera. Most of the objects you see in such an image (trees, soil, sand, snow, water, concrete . . .) do not emit their own light. Instead, we see them because they reflect sunlight (or moonlight, or light from light bulbs). However, when the light bounces off of them, some colors (*i.e.* wavelength ranges) are reflected and others are absorbed. Things with different compositions will absorb different parts of the spectrum (*i.e.* different colors). Much more information can be obtained by carefully analyzing how much of each different color of light is reflected by a surface. It is particularly informative if you look at light outside of the visible spectrum. **Reflectance Spectroscopy** — the analysis of the *spectrum* of reflected light — is a fundamental tool of planetary science. It allows us to determine the properties of planetary surface from which we have no direct samples, or even from places on Earth where sampling would be difficult or time consuming.

Rocks are made up of a collection of minerals, and these minerals are made up of a specific collection and structure of elements (usually in a crystal structure). For example, the "Genesis Rock" brought back from Apollo 15 is a type of rock called an *Anorthosite*. This rock is composed primarily of mineral called *plagioclase feldspar*. This mineral has the chemical formula $[CaAl_2Si_2O_8]$ meaning that it is made up of the elements Calcium (Ca), Aluminum (Al), Silicon (Si), and Oxygen (O) all arranged in a specific crystal structure.

When light is reflected off a rock, the various crystals in the rocks absorb different wavelengths of light. The specific wavelengths of light they absorb depends on the composition and structure of the crystal. By looking at the reflectance spectrum of a rock we can get an idea of the minerals that make up the rock. This turns out to be a very powerful tool in planetary astronomy. It allows us to determine the composition of a rock by looking at the reflected light. We do not need the have a sample in hand.

The Ground Truth

In this lab we will learn how reflectance spectroscopy can be used to determine the properties of a planetary surface. The world we will explore will be our own: the Earth. We choose the Earth because it is the world we are most familiar with, and it is a place where samples can easily be collected. Collecting samples is a very important part of remote sensing, because it allows us to establish what is called the "ground truth." Before we can recognize a lava flow on the Moon, we have to know the characteristics of light reflected from lava. In order to do that, we need a chunk of lava to bounce light off of and measure.

In order to establish the "ground truth," we are going to be using *reflectance spectrometers* to measure how much light of various colors in the spectrum is absorbed and reflected by objects we might see in images of the Earth taken from space. Instead of shining the whole continuous spectrum at the same time, these spectrometers shine one color of light at a time. Take a minute to look at your spectrometer — **DO NOT** put anything into the hole in the back! Each of the 11 buttons on the front makes a different colored L.E.D. shine. You will not be able to see the last four lamps since they are emitting light at wavelengths beyond the visible spectrum. In the middle of the circle of lights is a small photodetector. The display on the front of the spectrometer gives a measure of how much light it detects.

Calibration - Making the Numbers Make Sense

1. Set the spectrometer on a flat surface so that no light is allowed in. Notice that the detector does not read zero; rather, it reads a small number. This is called the **dark current**. The detector has been set so that even with NO light, a small number will be displayed on the readout. This number is important, because all your measurements will need to have this offset subtracted out in order to find out how much light the instrument actually measured.

2. Next we need to calibrate our instrument so that the numbers have some meaning. We are going to be measuring things in terms of how much light they reflect at each wavelength. Luckily, photographers also need to do the same type of calibration, so they have made a standard gray card that reflects 18% of the light at each wavelength. We will be comparing our measurements of other objects to our measurements of this gray card.

3. Position your reflectance spectrometer flat on the gray card. Turn on the lights one at a time and hold down the button until the numbers in the display stabilize. Record the number on the display in the first column of the calibration chart below . Make sure no stray light is entering the hole on the back of the spectrometer.

4. This is not the actual amount of light being reflected by the gray card — remember the dark offset! To determine the actual amount of light being reflected by the gray card, subtract the dark offset from each measurement and record the result in the second column.

5. Next we want to find out how much light each of the bulbs is actually emitting (and thus to figure out how much light our samples are reflecting). But we know that the gray card reflects 18% (or 0.18) of the light hitting it, so we can use our previous measurements to calculate this:

   Light reflected by gray card = 0.18 × Light emitted from bulb

6. Therefore, the light emitted is the measurement in the second column divided by 0.18. Record your calculations in the third column.
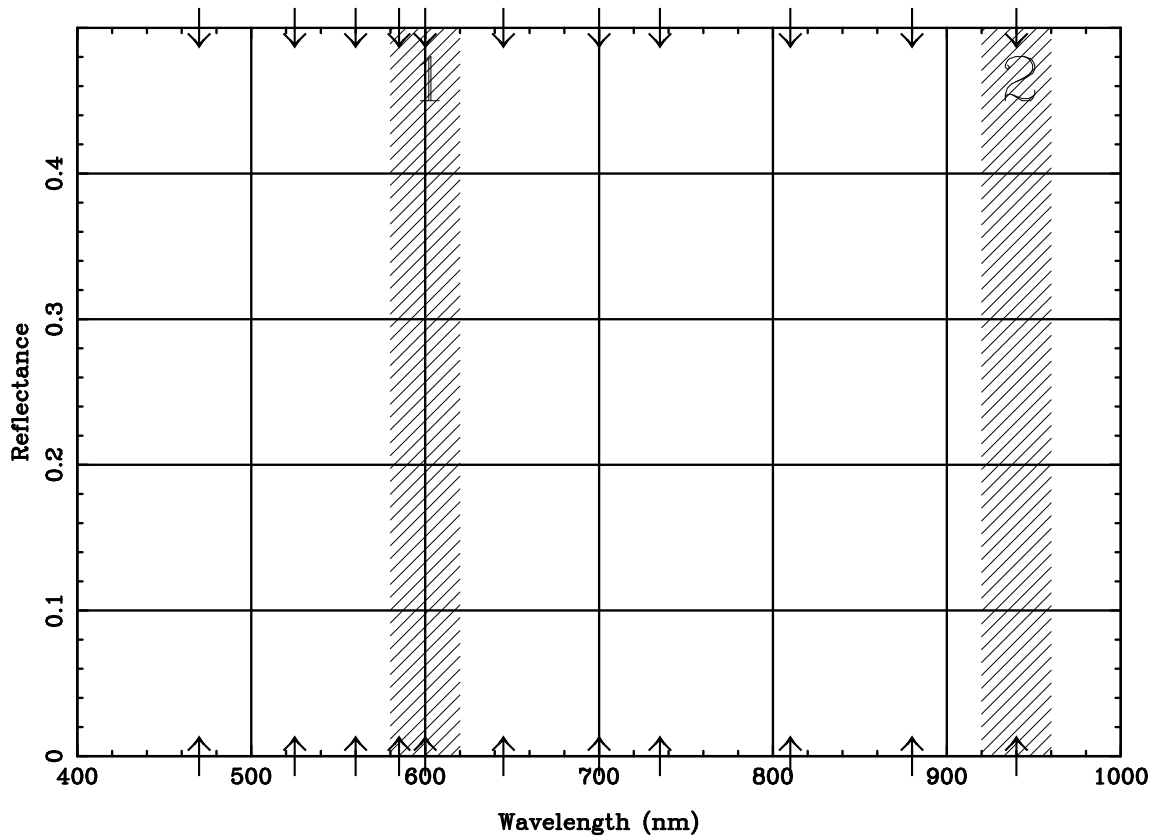
   Those are all the necessary calibrations we need in order to measure the reflectance of any object. In the next part of the lab, we are going to establish the "ground truth" by measuring the reflectance spectrum of various stuff found all over the Earth. Because you will be comparing your plots with photographs in the lab room, you should make your calculations and plot your results as you go along.

	Observed Amount of Reflected Light, Gray Card	Actual Amount of Reflected Light (Observed - Dark)	Amount of Light Emitted by Bulb (Obs - Dark)/0.18
470 nm			
525 nm			
560 nm			
585 nm			
600 nm			
645 nm			
700 nm			
735 nm			
810 nm			
880 nm			
940 nm			

- Now measure the green leaf at each of the wavelengths on the reflectance spectrometer. In the first column of the data table, record the numbers you observe (obs). In the second column of the data table (refl), take the number from the first column, subtract the dark offset, then divide this value by the amount of light the bulb is actually emitting (you calculated this in the last column of previous table). The numbers in the "refl" column should be between 0.0 (*i.e.* reflecting no light) to 1.0 (reflecting all the light). Plot your results and connect the points.

- Observe the rock samples. Calculate their reflectance, record them in the table. Plot your results on the same graph. Please use a different symbol, color, or line style to distinguish each of the lines on your plot.

	Green Leaf (obs)	Green Leaf (refl)	Basalt (obs)	Basalt (refl)	Olivine (obs)	Olivine (refl)	Anorth (obs)	Anorth (refl)
470 nm								
525 nm								
560 nm								
585 nm								
600 nm								
645 nm								
700 nm								
735 nm								
810 nm								
880 nm								
940 nm								

When you take an image with a camera, the film records an image of the entire visible spectrum. Most cameras on spacecraft take images of only a small chunk of the spectra and range far beyond the visible part. To take images of just a piece of the spectrum, filters are placed in front of the camera. Two such filters are indicated by the cross-hatched regions labeled "1" and "2" on your graph.

List the four samples from brightest to darkest as seen through filter #1:

List the four samples from brightest to darkest as seen through filter #2:

Assume that you *only* have data from filters #1 and #2.

Which unique characteristics of Anorthosite allow you to distinguish it from the other samples?

Which unique characteristics of Olivine allow you to distinguish it from the other samples?

Which unique characteristics of Basalt allow you to distinguish it from the other samples?

Which unique characteristics of leaves allow you to distinguish them from the other samples?

Landsat Images

Landsat are a series of Earth-observation satellites that have fundamentally changed how we look at our world. The first Landsat was launched in July of 1972 and the seventh in the series was launched April 15, 1999. The Landsat satellites image Earth at many different wavelengths, including wavelengths in the infrared.

Below are two images of Mount St. Helens that were taken by the Landsat satellite through a filter that closely corresponds to our Filter #2. the peak of Mount St. Helens is the dark object near the center of the left edge of each image. The image on the left was taken in 1973 and the image on the right was taken in 1983. Mount St. Helens erupted on May 18, 1980. It is easy to see the the dramatic change between the pre- and post-eruption images.
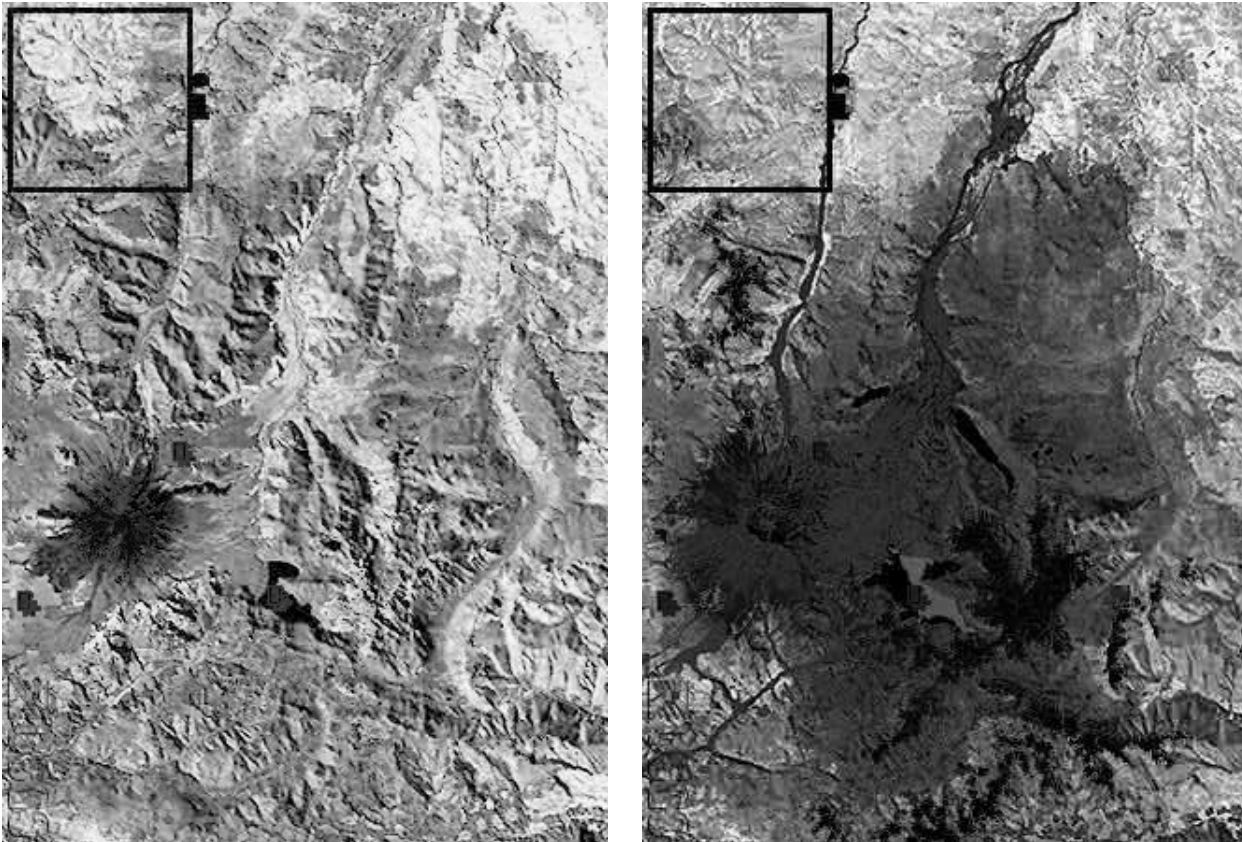
In the 1973 image, Mount St. Helens is surrounded by material that is bright in Filter #2. Based on the data we collected, what is this material?

In the 1983 image, Mount St. Helens is surrounded by material that is darker in Filter #2. Based on the data we collected, what is this material?

Explain the reason for the change.

Assume it was possible to take a similar Landsat image of the city of Seattle 200 years ago. Describe how that image would look different from one taken today, and explain the reason for this difference.

Other Worlds

In this section you will investigate a reflectance spectrum which is a composite of two different samples. The figure below is a reflectance spectrum of a combined Basalt and Olivine sample.
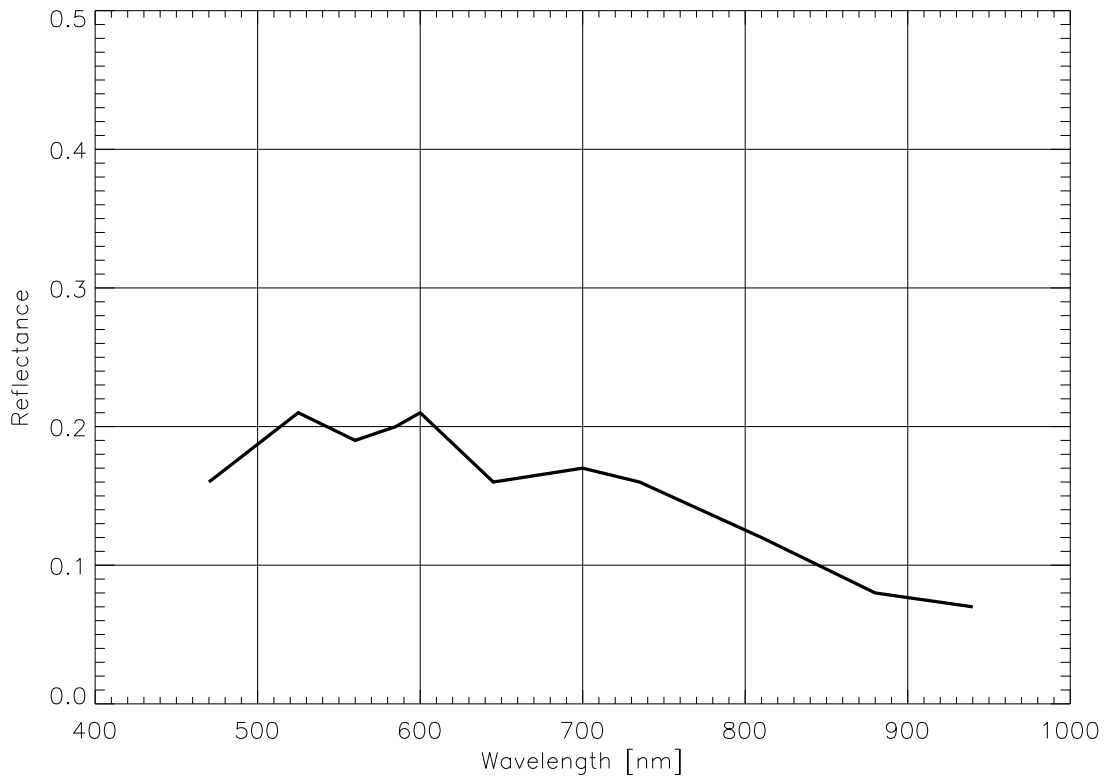
On the figure above, plot the reflectance spectra you obtained for Basalt and for Olivine. How does the composite spectrum compare to the spectra for the individual samples?

The figure below contains two reflectance spectra from a pair of imaginary worlds. You will now use the skills you developed in this lab to identify the compositions of these two worlds. This is a problem which planetary astronomers face frequently. The primary difference between their work and what you are doing is that the worlds which these researchers investigate can be composed of many more materials than simply Basalt, Anorthosite, Olivine and Green Leaves.
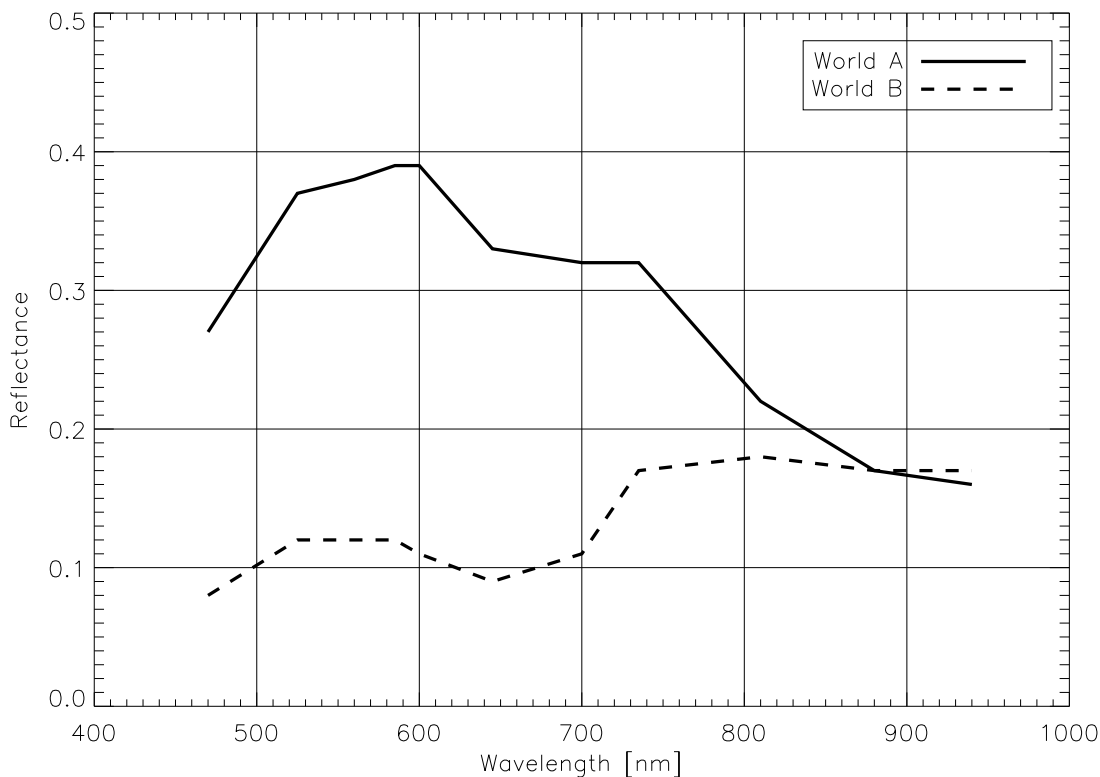
If these worlds are *only composed of materials analyzed in this lab* and *each* world is *only composed of two different samples*, what is the composition of World A?

World B?

Introduction

Astrobiologists are actively searching the Solar System and the Galaxy for signs of life. Intrinsic to this search is our definition of what "life" is. The purpose of this lab is to challenge your notions of what makes things living. The end result of this lab will be your own list of characteristics that can be used to identify whether or not a specimen is alive or dead. This activity has been adapted from a similar activity in Prather, Offerdahl & Slater (2007).

Interacting with its Environment

Martian rovers and landers (*e.g.,* Spirit, Opportunity and the Phoenix Lander) are always equipped with cameras that allow scientists to visually inspect the soil around the rover/lander. Your TA will provide to you a set of three Ziploc bags (labeled 1, 2 and 3) filled with unknown materials. Without opening the bags, which might contaminate your samples, visually investigate your samples and answer the following questions.

1. Do any of your samples appear to contain a living specimen? How have you deduced this?

2. Can you state confidently that any of your samples do not contain a living specimen? Why or why not?

The Viking Lander performed an experiment on Martian soil in which water was added to the soil in an enclosed compartment. Instruments aboard the spacecraft then monitored the composition of the gases that came out of the soil. In the spirit of this experiment, you will now add warm water to each of your samples. Be sure to quickly seal up the Ziploc bags when you are finished adding the water! After monitoring the samples for roughly 10 minutes, answer the following questions.

1. Which of your samples do you think contain a living specimen? How have you deduced this?

2. Do you think any of your samples do not contain a living specimen? How have you deduced this?

Dead or Alive?

Imagine that you have just landed on Earth for the first time. You collect two samples of (what Earthlings know as) leaves (provided by your TA). Answer the following questions.

1. Are either of the samples alive? If you think one/both are alive, explain how you deduced this.

2. Are either of the samples not alive? If you think one/both are not alive, explain how you deduced this.

3. If you had access to scientific instruments, how might you investigate whether or not the samples are living?

Class Discussion Questions

After performing the previous experiments, discuss the following questions.

1. A mule is the offspring of a donkey and a horse. Mules are incapable of reproducing. Is the mule living? Why or why not?

2. Rock crystals grow by incorporating material from their surroundings and repeating their crystalline structure. Are crystals living? Why or why not?

3. Fire consumes materials from its surroundings to produce energy. It also reacts to its surroundings (*e.g.*, by becoming at least partially extinguished when water is thrown on it). Is fire living? Why or why not?

4. Humans will one day be able to fabricate a robot which is capable of manufacturing reproductions of itself. Each reproduction has a chance that its components and/or programming could be slightly different from its "parent". Thus, these robots could undergo evolution. Are these robots living? Why or why not?

5. Viruses are capable of interacting with their surroundings (leading to infections) and undergo evolution. However, they can only reproduce by hijacking the reproductive systems of a living cell. Are viruses living? Why or why not?

Questions

After the class discussion, answer the following questions.

6. List a set of characteristics that you think can be used to determine whether or not a specimen is living.

7. Do you think your listed characteristics are general enough to be applied to life beyond Earth?

References

The following were used in the preparation of this activity:

Prather, E., Offerdahl, E. & Slater, T. F. 2007, Life in the Universe: Activities Manual. San Francisco, CA : Pearson Addison-Wesley.

Introduction

The theory of Darwinian Evolution has been tested and refined over the course of almost 150 years. Contentions to this theory have been raised by some groups, most notably supporters of the Intelligent Design (ID) movement. The result of these debates has been a great deal of media coverage and, in some cases, the perpetuation of misunderstandings. This assignment, which is designed to be performed as a class discussion following some individual research, will investigate the claims made by ID.

Discussion Questions

The class will engage in a discussion of ID. On the date that the discussion is to occur, you are to *bring a 0.5-1 page document which summarizes your thoughts on ID*. You should also *bring one question that you have about ID or Darwinian Evolution*. The questions that follow are meant to assist you in creating your document. You do not need to answer every question and you are encouraged to write on topics that you find especially intriguing.

ID Basics

These questions will help you to understand the basic components of ID.

   1.1: What is the central claim that ID makes?

   1.2: Given the definition of the scientific process that we discussed at the beginning of this course, is ID technically science?

   1.3: What is *irreducible complexity*?

   1.4: What is *specified complexity*?

   1.5: What is meant when one claims that the Universe is "fine tuned" for the existence of life?

ID and Public Education

The issue of teaching ID in public science courses came to a head in May of 2005 when the Kansas State Board of Education decided that ID would be taught in high school science classes.

   2.1: Should ID be taught in public science courses?

   2.2: Are there suitable courses in which ID can be taught?

ID in Academia

In his movie *EXPELLED: No Intelligence Allowed*, Ben Stein claims that those who investigate ID concepts are disciminated against in the scientific community.

   3.1: Should ID concepts be published in scientific journals?

   3.2: Should government funding for science be used for studying ID?

   3.3: Should colleges be permitted to reprimand employees who use research funding to study ID or who teach ID in college-level science courses?

Resources

The following webpages, articles and movies may prove useful to you when writing your document.

   Intelligent Design? : A series of essays published in Natural History Magazine. Arguments for ID are presented by famous ID proponents and counterarguments are presented by leaders in the field of evolutionary theory.

   www.discovery.org : A non-profit organization created for the advancement of ID.

   www.talkorigins.org : A newsgroup committed to discussing and debating ideas on the origin and evolution of life on Earth.

   EXPELLED: No Intelligence Allowed : A movie that seeks to prove that ID is discriminated against in the academic community.

   www.expelledexposed.com : A counterargument to the movie *EXPELLED: No Intelligence Allowed.*

   15 Answers to Creationist Nonsense : An article by John Rennie that responds to the objections to Darwinian Evolution that are made by adherents to ID (and Creationism).

   www.wikipedia.org : Many articles relating to ID can be found on Wikipedia. You are encouraged to investigate the resources listed below each article. **Do not simply copy statements from Wikipedia articles.**

Introduction

Mars, the fourth planet in our Solar System, is similar to Earth in a number of ways. The coldest temperatures on the surface (-140 Celsius) are not far below polar temperatures here on Earth, and the high temperatures get up to a balmy 20 Celsius for short periods of time. Mars also has a thin but active atmosphere with clouds, weather systems, and winds that erode the surface. Both water and CO_2 ice collect at the poles, forming Martian polar caps much like Earth's polar regions.

However, there are some striking differences between Mars and Earth. First, the thin atmosphere prevents water from existing on the surface as a liquid, so there are no large oceans (only ice at the poles). Second, since the surface has not been recycled by plate tectonics, it provides a record stretching back more than 3.5 billion years. Finally, dust and wind dominate the erosion on Mars, with some dust storms reaching global scales.

Mars Versus Earth

Answer the following questions. For some of these questions, you will need to visit *www.google.com/mars/*. You may find the 'Search' function on this webpage to be quite useful. The elevation map is defined as height above/below a planetary mean elevation.

1. The radius of Mars is about 3,400 kilometers while the radius of Earth is about 6,400 kilometers. A jet airliner travels at roughly 900 kilometers per hour. How many hours does it take a jet airliner to circle Earth's equator? Mars' equator? Recall that the circumference of a circle of radius r is given by $C = 2\pi r$ and that time of travel will be given by $t = C/v$, where v is the speed of the airliner. Show your work.

2. Using the Google Mars map: What is the latitude and longitude of Olympus Mons, the largest volcano in the Solar System?

3. Using the Google Mars elevation map: What is the height of Olympus Mons? Be careful; height should be measured as distance above the surrounding region, *not* as height above a planetary mean elevation.

4. Mount Rainier is 4.4 kilometers in height. How many *times* higher is Olympus Mons than Mount Rainier? Show your work.

5. Using the Google Mars map: How wide is Olympus Mons?

6. Washington State is about 580 kilometers wide. How does the size of Washington State compare to the width of Olympus Mons?

7. Using the Google Mars map: What is the approximate latitude and longitude center of Valles Marineris, a giant canyon on the surface of Mars?

8. Valles Marineris is roughly 5,000 kilometers long while Washington D.C. and Los Angeles are separated by about 3,700 kilometers. How many *times* longer is Valles Marineris than the United States? Show your work.

9. Using the Google Mars elevation map: How deep is Valles Marineris? As when measuring the height of Olympus Mons, you need to be careful with how you measure the depth of this canyon.

10. The Grand Canyon is 1.8 kilometers deep. How many *times* deeper is Valles Marineris than The Grand Canyon? Show your work.

North Versus South

Using either the elevation or visible map of Mars at *www.google.com/mars/*, zoom out so that you can clearly see the Northern and Southern hemispheres of Mars. Drag the map so that you are centered over some region of the Northern hemisphere and increase the zoom so that the magnification indicator (upper left of Google Mars map) is sitting at the fourth tick mark from the top. Count the number of craters that you see in your image and place this number in the following table. Now change your view to another portion of the Northern hemisphere, repeat your crater count and enter your new count into the table. Repeat this process for a total of three counts in the Northern hemisphere and three counts in the Southern hemisphere. **It is very important that every count which you perform is done at the same level of zoom/magnification**.

Mars Crater Counts

Hemisphere	Count 1	Count 2	Count 3	Average
Northern				
Southern				

The averaqe crater count for Mars' Northern hemisphere should be quite different from the average count for the Southern hemisphere. If each hemisphere is equally as likely to be struck by an impactor, how can you explain the differences in these two numbers?

Past Versus Present

The image below shows layering near the north polar region of Mars. The spacing of the layering may be due to variations in Mars' climate. (Image Credit: Malin Space Science Systems/NASA)
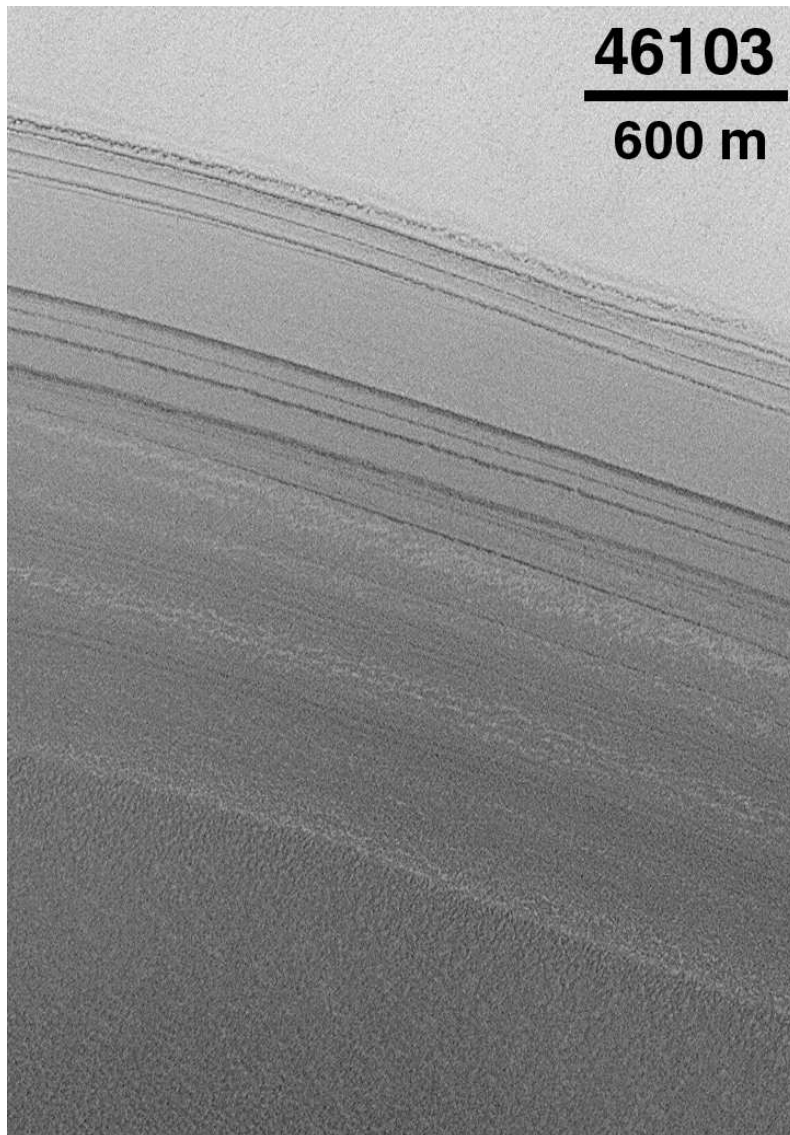
1. If each layer in this image corresponds to roughly 100,000 years of accumulated ice and dust, how many years of Martian climate are recorded in these deposits? If we could sample these different layers, what might we learn about Mars' climate history?

2. Using the Google Mars map: Perform a search for "Filled Crater" and then select the green indicator that appears on the map. What material filled in this crater? The preservation state of the walls of the crater could indicate that the crater is relatively young. What does this imply about the recent geological history of Mars? Hint: Be sure to click on the links provided by the green indicator!

3. Using the Google Mars map: Perform a search for "Deuteronilus Mensae" and then select the green indicator that appears on the map. What do these images remind you of? What does this imply about the habitability of ancient Mars? Hint: Be sure to click on the links provided by the green indicator!

Introduction

NASA and Google have worked to produce high-resolution, three-dimensional map of Mars within Google Earth. Data from a variety of missions have been included within this map, which will help users to better visualize and understand the wealth of knowledge that scientists have gathered from the Red Planet. Users can fly virtually through canyons, scale virtual mountains and view the latest images from NASA's Mars Reconnaissance Orbiter.

Installation and Operation

The following steps will help you to get started running and exploring Google Earth in Mars Mode. The version of Google Earth required to perform this lab will only run on Windows or Mac computers.

1. Visit *http://earth.google.com/* and download Google Earth 5.0 (or greater).

2. Install Google Earth on your laptop or desktop.

3. Open Google Earth.

4. To enable Mars Mode, click on the icon resembling Saturn along the top of the Google Earth window. Simply select the word 'Mars' after clicking on this icon.

Exploration

Let's begin by investigating some interesting features within Mars Mode. You will learn how to view high-resolution images, enter into panoramic surface views and how to connect to webpages associated with certain sites of interest. The questions that accompany this section can be answered by simply reading the material associated with the images within Mars Mode.

In the 'Fly To' function, enter 'Olympus Mons' and press Enter/Return. The colored squares are locations where high-resolution images have been taken. Explore these images and answer the following question.

1. Olympus Mons is surrounded by a *scarp* that marks its base. How was this scarp formed?

In the 'Fly To' function, enter 'Phoenix' and press Enter/Return. Click on the camera icon near the center of the screen and then click on the link labeled 'Fly into this high-resolution photo'. Investigate this image and, when you are finished, click 'Exit Photo'.

2. Roughly how many photos were combined in order to create this view?

In the 'Fly To' function, enter 'Pathfinder' and press Enter/Return. Click on the American flag icon near the center of the screen and then click on the link labeled 'Learn more...'. You will be directed to the Mars Pathfinder homepage.

3. What is the name of the rover that was used during the Pathfinder mission?

Mars Science Laboratory Landing Sites

NASA's Mars Science Laboratory (MSL) is a rover that will launch in 2011. It is larger and more versatile than the rovers Spirit and Opportunity. The scientific goals of the mission are to investigate Mars' past and present habitability. Scientists are still debating where MSL should land in order to best accomplish these goals. In this section you will visit the proposed landing sites for MSL, learn why these sites are of astrobiological importance and then rank the proposed landing sites based on what you have learned.

The prospective MSL landing sites are:

- Nili Fossae

- Holden Crater

- Mawrth Vallis

- Eberswalde Crater

- Miyamoto

- Gale Crater

- Meridiani Planum

In Mars Mode, visit each of these sites and fill in the following table. Note that some landing sites demonstrate certain obstacles to landing (these are mentioned within certain captions). Be sure to note these in your table.

Site	Astrobiological Relevance	Landing Difficulties (?)
Nili Fossae		
Holden Crater		
Mawrth Vallis		
Eberswalde Crater		
Miyamoto		
Gale Crater		
Meridiani Planum		

Using the information that you have gathered, rank the sites from 1 being your preferred landing site to 7 being your least preferred site. Provide a brief justification for your ranking.

Site	Ranking	Justification
Nili Fossae		
Holden Crater		
Mawrth Vallis		
Eberswalde Crater		
Miyamoto		
Gale Crater		
Meridiani Planum		

Introduction

Bacteria and archaea on Earth survive in a tremendous variety of habitats and are able to do so through their diversity of metabolisms. Some bacteria can photosynthesize by turning light into energy they can use, while others can gain energy by from compounds like sulfur or iron. Still others obtain their energy by consuming organic matter, as we do. Throughout the planet, these microorganisms thrive in communities in which these diverse metabolisms work in concert; the waste product of one metabolism may be an important resource for another. We see this every day, as the oxygen that we breathe is a waste product of oxygen photosynthesis.

A Winogradsky column, first developed by Russian scientist Sergie Winogradsky in the 1880s, demonstrates the interdependence of microbial communities. The column creates a gradient of light, oxygen and sulfur to create different environments in which these communities can thrive.

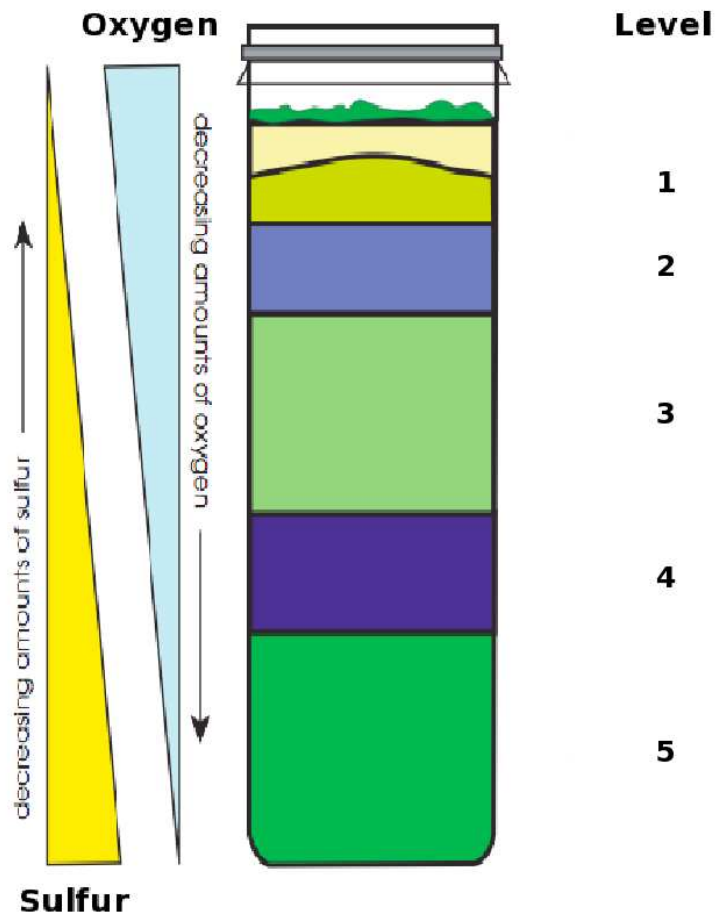## Materials

Your group will need:
- newspaper
- small bucket or bowl
- mud from a local pond
- stirring implement
- water from a local pond
- chalk
- Epsom salt
- plastic bottle, top cut off to act as funnel
- scooping device
- clear plastic wrap
- rubber bands
- marker

Procedure

Follow these steps to construct your Winogradsky column.

1. Cover your lab area with clean newspaper.

2. In a small bucket, add 5 cups of mud or sand. Remove any sticks, leaves, or rocks.

3. Stirring the mud or sand with a stirring implement, slowly add water until the mixture is like thick cream. Be careful not to add too much water.

4. Shred a full sheet of newspaper into very small pieces. Add the newspaper shreds (carbon source) to the mixture.

5. Add 1 tablespoon of powdered chalk (carbon source) to the mixture.

6. Add 1 teaspoon of Epsom salts (sulfur source) to the mixture.

7. Stir the mixture gently. Make sure the mixture is fluid so it will flow through the funnel.

8. Set the funnel into the mouth of the bottle. Secure the funnel by having a group member hold the funnel in place.

9. Pour or scoop a small amount of the mixture into the base of the bottle.

10. Place your hand over the top of the bottle and tap the bottom of the bottle firmly on the table. This helps the mixture settle and removes oxygen that is trapped in the mixture.

11. Repeat the two previous steps of adding a small amount of mixture and settling the mixture until the bottle is about 90 percent full.

12. Stir the mixture in the bottle to remove any air bubbles.

13. Cover the bottle with foil or plastic wrap and a rubber band.

14. Label the bottle with your names.

Questions

Answer the following questions.

1. A Winogradsky column is meant to be an environment for microbial growth. Where would the microbes have come from?

2. Would you expect the microbes to all have the same metabolism? Why?

3. Construct a hypothesis for what you expect to see in the column over time. Be sure to address the following: how the column will change in time, how sunlight availability will affect the column, variations in the types of microbes at different levels in the column. Feel free to draw pictures and diagrams.

The figure above is an idealized Winogradsky column. The qualitative variations of oxygen and sulfur with height are depicted. Read the following descriptions of different types of organisms, decide which level in the column a given organism inhabits and fill in the table below.

Red non-S bacteria: These organisms need light for energy, but are intolerant of high levels of oxygen. For their carbon source (building blocks for cells), they use organic acids that can be the waste products of someone elses fermentation. They are intolerant of high hydrogen sulfide (H_2S).

Desulfovibrio: These organisms reduce sulfur for their energy, meaning they use sulfur compounds to make H_2S. This can diffuse upwards into the water column. These are anaerobes, meaning they are very intolerant of oxygen.

Cyanobacteria: These are photosynthetic organisms. They use light to fix carbon dioxide into fuel, and release oxygen as a waste product.

Green S bacteria: These are photosynthetic bacteria that gain energy from light, but unlike *cynobacteria*, they use H_2S instead of water, so they release H_2S instead of oxygen. They are also anaerobic, so they do not tolerate high levels of oxygen.

Purple S bacteria: These are similar in nature to the *green S bacteria*, but are slightly less tolerant of high levels of hydrogen sulfide (H_2S).

Where Do They Live?

Organism	Level Inhabited
Red non-S bacteria	
Desulfovibrio	
Cyanobacteria	
Green S bacteria	
Purple S bacteria	

Discussion Questions

It is thought that the early earth was populated entirely by prokaryotes of various metabolisms occupying various niches on Earth. Discuss how we might apply concepts from the Winogradsky column to understanding what life on early Earth may have looked like and how it functioned.

References

The following were used in the preparation of this activity:

NASA Ames Research Center. Building a Winogradsky Column, EG-2001-08-###-ARC.

"Investigating Bacteria with the Winogradsky Column." Brian Rogen. The Woodrow Wilson Foundation Leadership Program for Teachers.

"The Microbial World: Winogradsky column: perpetual life in a tube." Jim Deacon, Institute of Cell and Molecular Biology, The University of Edinburgh.

Introduction

At this point in the quarter, you have learned all of the basics that you need to know to begin to understand worlds in an astrobiological context. You have also seen how astrobiologists have targetted certain worlds in the Solar System as being particularly habitable. In this assignment you will use the tools that you have acquired in this course to analyze a world as an astrobiologist would.

Group Presentation

As a group you will be assigned a specific world in the Solar System (either Mars, Europa, Titan or Enceladus). Your group will be responsible for preparing a *10-minute* presentation on that world. Your presentation should present the physical characteristics of your world (*e.g.,* surface temperature, size), the history of and data gathered by missions that have visited your world (*e.g.,* NASA missions to Mars, ESA missions to Titan), and the reasons why your world is of Astrobiological significance. The questions that follow are meant to serve as a *guide* for presentation. You do not need to answer all of these questions in your presentation but you should try to address as many as are relevant to your world. *The Powerpoint presentation that your group creates must be emailed to your TA on/before the evening prior to the day that you present.*

Physical Characteristics

These questions relate to the physical characteristics of your world.

1. Is your world a planet or a moon?

2. Where in the Solar System is your world located?

3. How large is your world?

4. What is your world composed of?

5. What is the rotational period of your world? Orbital period?

6. What is the albedo of your world?

7. What is the surface temperature on your world?

Missions

Using your textbook and the internet, learn about the past, ongoing and future missions that have visited or will visit your world.

1. How many missions have visited your world?

2. What agency/agencies funded these missions?

3. What were the goals of these missions?

4. What did we learn from these missions?

5. Are there missions to your world that are planned for the future?

6. What are the goals of these future missions?

Astrobiological Relevance

Use the knowledge that you have acquired in this class to provide an analysis of your world from an astrobiological perspective.

1. Is the surface of your world habitable? The subsurface?

2. Where do we expect to find a liquid medium for life on your world?

3. What would be an energy source for life on your world?

4. Where would life on your obtain the materials needed to grow and reproduce?

5. Could there be intelligent life on your world?

Resources

The following webpages are great resources for learning about worlds in the Solar System.

- *www.esa.int* : European Space Agency
- *www.nasa.gov* : NASA hompepage
- *nssdc.gsfc.nasa.gov/planetary* : NASA lunar and planetary science homepage

Grading

Your group will be graded on the quality and completeness of your presentation. To encourage participation within your group, you will also be responsible for grading your group members based on how much they participated in this assignment. This will factor in to the lab score for each group member individually and will factor into each group member's participation grade for the class. For example, if your TA grades your presentation at 100% but your group members (on average) give you a 75% participation grade, then your score for the lab will be 75% of 100%, or 75/100. The table below is your opportunity to grade your group members. Your group members will not see your grading, so please be honest and thorough when writing these evaluations. The grade that you receive for this lab will not be affected by the scores that you asssign to other group members.

Name	Participation Grade	Comments
John Doe	100%	Very helpful, was a great asset to the group
Dohn Joe	65%	Little participation, provided little help to the group
1.		
2.		
3.		
4.		
5.		
6.		
7.		

Introduction

Estimation is a powerful skill that can be used to simplify a very complicated problem. The Drake equation is a tool that allows scientists to calculate a simple estimate of the number of communicating civilizations that currently inhabit the Milky Way galaxy. It is important that, in this case, *communicating* simply means capable of sending and receiving radio signals. While chimpanzees, dolphins and parrots are intelligent and able to use tools and language, they cannot build radio telescopes to communicate with civilizations on other worlds.

At first glance, it may seem like estimating the number communicating civilizations in our galaxy is a wasted effort. We have not yet managed to contact another advanced civilization, so who knows if they even exist?! However, as you will learn in this lab, the steps that go into calculating this estimate are more useful than the estimate itself; each component of the Drake equation causes us to question and improve our knowledge of life in the Universe.

An Exercise in Estimation

As a classroom discussion, let's consider a fairly complicated question: How many female undergraduate students with short hair will be eating dinner with their left hand at Thai Tom at 7:00 tonight?

Before we go any further, write down your predicted answer to the question.

Prediction:

Now let's fill in a table with all of the variables that will affect our problem. This is our first step towards estimating the answer to our question.

Variable	Description	Estimated Value

We can now compute our estimate. Let **N** be the number of female undergraduate students with short hair that will be eating dinner with their left hand at Thai Tom between at 7:00 tonight. First, write down the equation that will allow us to calculate our estimate.

N =

Now plug in your estimated values from the table above to get your numerical estimate:

N =

How does this compare to your prediction?

Using the Drake Equation

One form of the Drake equation is:

$$N_c = N_s \times f_p \times N_e \times f_l \times f_i \times f_c \times L$$

where these variables are:

Variable	Description
N_c	number of communicating civilizations in our galaxy
N_s	number of stars in the galaxy which live long enough for life to develop
f_p	fraction of stars with planets
N_e	number of habitable planets in a typical planetary system
f_l	fraction of these habitable planets where life develops
f_i	fraction of worlds that eventually develop intelligent life
f_c	fraction of intelligent civilizations that develop radio-communication technology
L	lifetime of communicating civilization divided by the age of the galaxy (10 Gyrs)

Before we go any further, write down your predicted value for N_c

Prediction: $N_c =$

We will now work towards determining values for the variables described in the table above. Some things you should consider:

• There are about 200 billion (2×10^{11}) stars in our galaxy. Only 75% of these have lifetimes that are longer than 4 billion years.

• Surveys aimed at detecting extrasolar planets have found that at least 10% of stars have planets orbiting them. Simulations show that this number may be as high as 100%.

• Some of the variables in the Drake equation have yet to be measured for extrasolar planetary systems. However, our Solar System can give us some insight. For example, what is the value of N_e for our Solar System? Do you count Mars and/or Venus?

• Is it inevitable that life evolves on a habitable planet? What is the value of f_l for the Solar System?

• Does life always evolve intelligence? What is the value of f_i and f_c for the Solar System?

• If you think that communicating civilizations last for 1000 years, then the value of L is 1×10^{-7} (which is 1000 years divided by 10 Gyrs). When estimating the value of L you may want to keep in mind that humans have only been using radio telescopes for about 50 years.

Using the information above, determine **reasonable** lower and upper limits for the variables in the Drake equation. Consider which variables can be 'measured' using the Solar System as a proxy for a standard planetary system. Finally, decide on your preferred value for each variable.

Variable	Lower	Upper	Solar System	Preferred
N_s	1.5×10^{11}	1.5×10^{11}	1.5×10^{11}	1.5×10^{11}
f_p				
N_e				
f_l				
f_i				
f_c				
L				

We can now calculate several estimates for N_c using the values in the table above.

Lower: $N_c =$

Upper: $N_c =$

Solar System: $N_c =$

Preferred: $N_c =$

The Fermi Paradox

When presented with the idea that intelligent life may be common in our galaxy (as we saw in the previous section), the famous physicist Enrico Fermi is said to have exclaimed, "Where are they?". The apparent contradiction of the idea that intelligent life is common and the fact that we have not established contact with a communicating civilization is known as the *Fermi Paradox*.

For starters, we can compute how near to us the next communicating civilization should be (on average). This distance d will be measured in light years and is given by:

$$d = \left(\frac{5 \times 10^{13}}{N_c}\right)^{1/3} \text{ light years}$$

where you computed N_c in the previous section.

Find d for the four values of N_c that you computed above.

Lower: $d =$

Upper: $d =$

Solar System: $d =$

Preferred: $d =$

Comment on these values. Keep in mind that the nearest star to the Sun is about 4 light years away and that there are about 50 stars within a 20 lightyear radius around the Sun.

Research and Discussion Question

Many solutions to the Fermi Paradox have been presented. Using the internet, find and describe (on a separate piece of paper) one possible solution.