Purpose
The objective of this exercise is to use stereoscopic ("three-dimensional") photographs in understanding the four major geologic processes (gradation, impact cratering, tectonism, and volcanism).

Materials
Pocket stereoscope, protractor, ruler, calculator

Background
Before working this exercise, students should be introduced to the concept of stereoscopic viewing. Objects appear "three-dimensional," that is, they show depth, because we view them with each eye from slightly different perspectives. Stereoscopic photographs appear three-dimensional because they consist of two images of the same feature taken from two different perspectives. When viewed in a stereoscope, the features appear to have depth. The stereo images have different degrees of "vertical exaggeration," the apparent increase in vertical relief that results when viewing images obtained from viewing perspectives separated by a large distance. These ideas are further explained in the student part of this activity.

This exercise uses pairs of stereoscopic photographs that illustrate landforms shaped by the four principal geologic processes: volcanism, tectonism, gradation, and impact cratering. Students should be introduced to these processes through lecture before working the exercise (see introduction to Unit One).

Parts A through D concentrate on specific examples of the four geologic processes and generally increase in difficulty; part E involves synthesis of the preceding parts. Starred (*) questions might be omitted at the high school level. In some instances, in-depth material that pertains to specific questions is found in the instructor answer key.

It is best for students to work this exercise in pairs or small groups. If the availability of images or stereoscopes is limited, then students might move among work stations prearranged by the instructor.

When first trying to view stereo photographs, some students may become frustrated. Encouragement and patience are important in getting this exercise started. It is helpful to have the students place their index fingers on the same object within each photo of the stereo pair and then adjust the position of the stereoscope until their fingers appear to overlap. When they remove their fingers, the stereo effect should become apparent. However, vision problems may prevent some students from seeing in stereo at all. These students should not be penalized, but should analyze the photographs "monoscopically," while working with other students who can achieve the stereo effect.

The instructor may wish to explore some additional demonstrations to illustrate aspects of stereo photography. If a stereo pair is cut along the dividing line and the left and right images are switched, inversion occurs; that is, mountains become depressions, and valleys become ridges. If you have a camera (an instant camera is best), you can make your own stereo pairs. Take two photos of your classroom (or any other object) from positions a few feet apart. Place the photos side by side under a stereoscope and adjust them until they align and the stereo effect is seen. The further apart the photos are taken, the greater the vertical exaggeration.
1. a. Sketch should show steep sides and a relatively flat top.
   
   b. The crater is roughly circular, but is irregular in detail, with multiple scallops.
   
   c. The scalloped outline reflects craters from multiple eruptions.
   
   d. Gullies have been carved down its flanks by runoff of rainfall, waves have eroded the visible base of the volcano, and the inlet has cut into volcanic material.
   
   e. The flanks have been eroded to form deep parallel gullies. The easily eroded material is unlikely to be rock but is probably ash.
   
   f. Rainfall is typically greatest on the windward side of a high-standing volcano. This is because air cools as it rises up the mountain's flanks, promoting condensation and precipitation of water. The air is relatively dry as it passes over the other side of the volcano.

2. a. Wind blows from the southwest (lower right). The dunes show slip faces on their northeast sides.
   
   b. A dune in the center of the photo will migrate towards the northeast (the upper left of the photo).
   
   c. In the lower right, dunes coalesce into linear ridges (called “transverse dunes”). Crescent shaped (“barchan”) dunes form toward the center, near a dark area blown free of dunes. Toward the upper left of the photo, dunes are U-shaped and convex the opposite way from the dunes in the lower right.
   
   d. Sand supply, consistency of wind direction, wind velocity, and the presence of vegetation all affect dune morphology.

3. a. The sketch should show a tree-like “dendritic” pattern of smaller branches that join into the main trunk stream.
   
   b. South. The downhill direction is indicated by the direction small streams flow near their intersection with the larger one. A “Y” pattern typically results, with the Y pointing downstream.
   
   c. Material is eroded from the rock cliffs of the waterfall and washed downstream. Gradually the cliffs will retreat in the upstream direction, lowering the overall topography of the region. This process is termed “headward erosion.”
   
   d. The ridge is becoming more narrow as debris is washed down the steep slopes to either side during rains. Some of this material is visible in fans near the bases of the steep slopes. Eventually the more resistant material atop the ridge will be eroded through, and the less resistant material beneath will erode away relatively rapidly.
   
   e. Sketch should include bowl shape, rim-to-rim width of about 1200m [6cm] depth of about 200m [1cm], and raised rim.
   
   f. Similarities: Roughly round shape overall, steep and gullied interior walls, highest

4. a. Gray. The white layers form ridges but the gray material is eroded out into valleys. In some locations, white layers have sheltered and protected the gray material from erosion. No river channels are apparent in the white material; gullies indicate that the gray material erodes easily.
   
   b. SSW
c. N65W
   
   d. 35m
e. 220m
   
   f. The stereo view reveals that the strata are probably not curved, but have a constant strike, and a constant dip to the southwest. As the river cut downward, it exposed portions of the white layers to the south that are still buried elsewhere. Therefore, the apparent curvature in the monoscopic photo is a geometric consequence of the river having cut into the dipping strata, exposing the white layer at different elevations.

5. a. About 1200m.
   
   b. About 240m.
   
   c. Large vertical exaggeration (appears as deep or deeper than wide).
   
   d. The crater shows a raised rim that stands above the surrounding plain. The rim rises 30 to 60m above the surrounding plain.
   
   e. Sketch should include bowl shape, rim-to-rim width of about 1200m [6cm] depth of about 200m [1cm], and raised rim.
Answer Key

along rim, relatively flat along crater bottom. Differences: volcanic crater is irregular in outline and shows multiple scallops, sits atop an edifice; impact crater lies principally below surrounding plains, has a raised rim, is round to squared off in shape.

6. a. Steeply tilted.
   b. Roughly north-south strike; eastward dip.
   c. Erosion has destroyed most of a volcanic plain that once was continuous across the region.
   d. As is true of most places on Earth, impact craters have been long since destroyed by deposition of sediments, by tectonism, by volcanic flooding, and by gradation.
   e. Top to bottom: 2, 1, x, 4, 3
Purpose

By using stereoscopic pairs of aerial photographs, you will learn to recognize some of the landforms that result from the four major geologic processes: volcanism, gradation, tectonism, and impact cratering.

Materials

Stereoscope, protractor, ruler, calculator.

Introduction

Because our eyes are separated by a short distance, we view the world from two slightly different perspectives simultaneously. This enables us to perceive a scene in three dimensions. In other words, we are able to perceive the distances to objects and depth within them. When you look at a photograph, your eyes see the distance to the flat photo, rather than the relative distances of objects within the image. The photo appears flat, even though it is an image of the three-dimensional world. To perceive apparent depth in photographs, geologists obtain two pictures of the same object or region from slightly different perspectives, as illustrated in Figure 3.1. When the images are viewed simultaneously, one with each eye, a “three-dimensional,” or stereoscopic, effect results.

This perception of vertical relief in aerial photos can greatly aid the geologic interpretation of landforms in the image. Most stereoscopic photographs are obtained from aircraft. Because the distance the plane moves between subsequent photos is much greater than the distance between a person’s eyes, the apparent vertical relief of the stereo photos is exaggerated, appearing much greater than the actual relief. This vertical exaggeration increases the farther apart the photographs are taken.

Figure 3.2 shows how to set up a pocket stereoscope. Place the stereoscope over a stereo pair with the seam of the photos in the middle of the stereoscope. Look through the lenses at the two photos, so that each eye sees just one photo. Pick out a feature that is visible in both photos, relax your eyes, and allow your focus to change until the two images appear to merge. You may need to adjust the position of your stereoscope slightly as you look through it to help the photos merge. When they do merge, you should see a stereoscopic effect. This may take time and patience. Some of the photographs are stereo.

Figure 3.1. Stereoscopic photographs are typically obtained from airplanes. The farther apart two photographs are obtained, the greater the vertical exaggeration of the resulting stereoscopic images.
“triplets” with one photograph in the middle and additional photographs on both the right and left sides. The stereoscope should be positioned to view the middle and right photos as one image pair, and the middle and left photos as another image pair.

Questions

Volcanism

1. Figure 3.3 shows a volcano on the island of New Britain, north of Australia. First study the photos “monoscopically,” without the stereoscope. In the photos, water appears black. The top of the high-standing volcano shows a circular depression termed a summit crater.

a. Sketch how the volcano might look from the ground.

Sketch area

Now position the stereoscope over the left dividing line and view the volcano in stereo. Reposition the stereoscope over the right seam and view this portion of the volcano in stereo.

b. Observe and describe the shape of the summit crater.

c. Do you think the summit crater formed by a single eruption or from multiple eruptions? Explain.

d. List at least two pieces of evidence that the volcano has been eroded.

e. Do you think the volcano is made of hard rock that is difficult to erode or soft ash that is easy to erode? Explain.

*f. Why is the volcano more heavily forested on one side than the other?
**Gradation**

2. Figure 3.4 shows a portion of White Sands, New Mexico, an area affected by aeolian (wind) processes. The crescent-shaped features are dunes composed of sand. Most sand dunes have a gentle slope on their windward side and a steeper slope to the leeward side. High velocity winds blow sand up the windward side to the brink of the dune; sand then slides down the leeward slip face of the dune.

   a. Examine the photographs stereoscopically and identify the slip faces on the dunes. From which direction is the wind blowing?

   b. Consider one of the dunes near the center of the photo. Where will its sand go in time?

   c. How does the morphology of the sand dunes change across the photo? Use sketches of at least two dunes to illustrate your answer.
*d. What factors might affect the dune morphology across the region?

3. Examine Figure 3.5, which shows a system of canyons cut by rivers and streams in northwestern New Mexico. The gradation is affecting relatively flat-lying sedimentary rocks.
   a. Look at the places where smaller tributary streams join larger rivers. In the space below, make a sketch of the pattern you see.

   Sketch area

   b. Which direction does the water flow in the prominent river that crosses the central portion of the photo?

   c. Identify a place in the photograph where you might expect a tall, steep waterfall. How would such a waterfall aid the process of erosion in this area?

   d. Over time, what will happen to the high standing, narrow ridge that separates two east-west trending valleys in the central portion of the photo?

Tectonism

Most rocks on Earth are laid down in relatively flat layers. Sedimentary rocks (such as those in Figure 3.5) are laid down over broad areas by wind or water, in layers called strata. Tectonism deforms such rocks in various ways. Tectonic stresses in the Earth can pull or push on rocks until they break, moving along faults. Broad-scale tectonic deformation can also cause originally horizontal rock layers to be tilted.

4. Figure 3.6 shows Lookout Ridge, Alaska, an area affected by tectonic deformation. Notice that the white and gray sedimentary rocks have been steeply tilted, now standing nearly on their ends.
   a. Which rock layers are more easily eroded, the white or the gray? Support your answer.
b. Examine the broad, steep face that is shown by one of the white layers near the center of the stereo photo. When rainfall lands on this surface, in which direction would it run down? This is the **dip** direction of these tilted rocks.

c. Examine the overall trend of the visible edges of the tilted strata. Use a protractor to measure the direction of this trend, and report your answer in terms of the number of degrees west of north. (For example, N20W would mean the trend is 20° west of north.) This is the **strike** direction of the tilted rocks.

d. Notice the small-scale faults that cut and displace the white and gray strata near the center of the stereo image. Use the scale bar on the photograph to estimate the amount of displacement along these faults.

e. A greater displacement of strata can also be observed in the southeast corner of the left hand monoscopic image. Use the scale bar to estimate the amount of displacement there.

*f. In the right hand image, the strata appear to curve as they cross the prominent river that cuts north-south across the photo. Using information available to you from the stereo scene, explain this apparent curvature.

**Impact Cratering**

5. Figure 3.7 shows Meteor Crater, Arizona. The impact crater is about 20,000 years old and is one of the best-preserved impact structures on Earth. In this stereo pair you can see the crater floor, walls, rim, and remnants of **ejecta**, material thrown from the crater by the impact. Some ejecta appears as irregular bright patches around the crater.

a. Using the scale bar on the photograph, determine the diameter of the crater in meters.

b. Before erosional infilling, an impact crater in Meteor Crater’s size class has a diameter about five times greater than its depth. Based on this, how deep was Meteor Crater when it formed?

c. Based on the appearance of Meteor Crater in these stereo images, and considering your previous answers, is the vertical exaggeration of this stereo pair large or small?

d. What do you notice about the elevation of the rim of the crater compared to the elevation of the surrounding plain?
e. Sketch a non-exaggerated profile across Meteor Crater in the space below. Use a scale of 1cm = 200m. The present depth of the crater is about 85% of its original depth, due to erosional infilling. Use your answer from 5.b. to determine the present depth to use for your profile.

Sketch area

f. List some similarities and differences in the morphology of Meteor Crater compared to the volcanic summit crater seen in Figure 3.3.

Synthesis

Planetary surfaces represent combinations of some or all of the four geologic processes. In the following questions, you will synthesize information from the previous questions and photographs.

6. Examine Figure 3.8, which shows the Caballos mountains of southwestern New Mexico. The two nearly featureless “islands” of high standing rock are volcanic in origin. Beneath them are rocks that were laid down as sedimentary strata.

a. Examine the strata of Figure 3.8, comparing this scene to Figures 3.5 and 3.6. Are the strata of the Caballos mountains tilted or flat-lying?

b. Estimate the strike and dip directions of the strata in the region beneath the western “island” of volcanic rock.

c. What is the most likely explanation to account for the isolated islands of volcanic plains?

d. Why are no impact craters visible in this area?
e. Determine the sequence of events that affected this region by numbering the events below from 1 (first event) to 4 (most recent event). Mark with an “x” the one event that did not occur in this region.

___ Tectonic forces caused folding and tilting of the rocks.
___ Sedimentary strata were laid down horizontally.
___ Volcanic plains were faulted and tilted.
___ Erosion by rivers and streams dissected the region.
___ Volcanic plains were laid down horizontally.
Exercise Three: Geologic Landforms
Seen on Stereoscopic Photos

Figure 3.3. Gazelle Peninsula, island of New Britain, New Guinea. (University of Illinois Catalog of Stereogram Aerial Photographs #107).

200 m
Exercise Three: Geologic Landforms
Seen on Stereoscopic Photos

Figure 3.4. White Sands, Tularosa Basin, New Mexico. North is to the left (University of Illinois Catalog of Stereogram Aerial Photographs #8509).
Figure 3.5. Monument Rocks, San Juan County, New Mexico. North is to the left. (University of Illinois Catalog of Stereogram Aerial Photographs #521).
Exercise Three: Geologic Landforms
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Figure 3.6. Lookout Ridge, Alaska. North is to the bottom. (University of Illinois Catalog of Stereogram Aerial Photographs #156).
Figure 3.7. Meteor Crater, Arizona. North is to the bottom. (University of Illinois Catalog of Stereogram Aerial Photographs #5).
Figure 3.8. Sierra Caballos Mountains, New Mexico. North is to the left. (University of Illinois Catalog of Stereogram Aerial Photographs #138).