EXERCISE 8

Landslides and Avalanches

INTRODUCTION

Downslope movement, or mass movement, of earth materials is taking place continuously at rates that vary from the very slow creep of soil and rock to extremely rapid rockfalls and avalanches. The movement may involve only a few cubic yards or as much as 5 cubic miles of widely differing consolidated and unconsolidated materials. The primary purpose of this exercise is to understand the nature of mass wasting and some of the ways in which it impacts the human colony. We will investigate the types and causes (including human activity) of mass wasting and options for damage reduction with examples of landslides from California, Montana, Ohio, and Washington and snow avalanches from Colorado and Utah. Snow avalanches are a major winter hazard in mountainous terrain throughout the world. More people than just skiers, snowmobilers, and owners of mountain cabins or homes are at risk. Because many avalanche paths cross highways or railroads, snowslides may impact travelers as well. Avalanche risks can be high throughout the year in mountains with glaciers or permanent snowfields.

Geologists and engineers have classified slope movements (e.g., Sharpe, 1938; Varnes, 1978). Although numerous classification schemes have been devised, the one that is probably used most today is the scheme developed by the National Research Council (Table 8.1).

The most common types of slope movement are falls; slides, which are classified as rotational (slumps) and translational; and flows (Table 8.1 and Figures 8.1 and 8.2). The term landslide, which will be used in this exercise, remains a widely used non-technical term for most perceptible forms of downslope movement even though some by definition involve little or no sliding. Landslides are a geologic hazard that annually causes millions of dollars of damage to structures and substantial loss of life. The most destructive landslides in recorded history occurred in Kansu Province, China. There more than

TABLE 8.1 Classification of Slope Movements

Type of Movement			Type of Material		
			Bedrock	Engineering Soils	
				Predominantly Coarse	Predominantly Fine
Falls			Rock fall	Debris fall	Earth fall
Topples			Rock topple	Debris topple	Earth topple
Slides	Rotational	Few units	Rock slump	Debris slump	Earth slump
	Translational	Many units	Rock slide	Debris slide	Earth slide
Lateral Spreads			Rock spread	Debris spread	Earth spread
Flows			Rock flow	Debris flow	Earth flow
Complex	Combination of two or more principal types of movement				

(modified from Varnes, 1978)

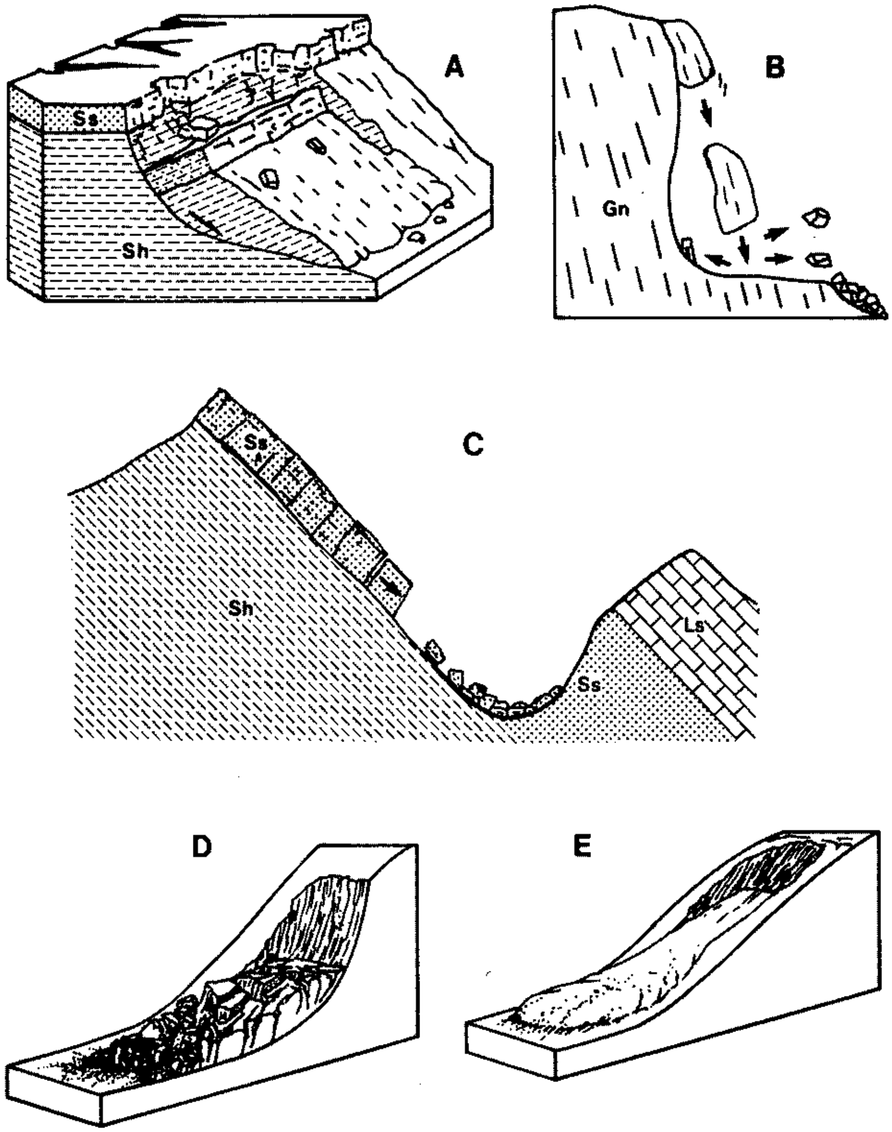

FIGURE 8.1 Common types of landslides. A, rock slump: rotational slide of coherent or intact masses that move downslope along a curved surface; B, rock fall: rock masses that move by falling through air; C, rock slide: translational movement downhill along a more or less planar surface; D, debris slide: broken masses of rock and other debris that move downslope by sliding on a surface under the deposit; E, earth flow: soil and other colluvial materials that move downslope in a manner similar to a viscous fluid. Ss = sandstone; Sh = shale, Gn = granite, Ls = limestone.

(Modified from Nilsen and Brabb, 1972; Varnes, 1978)

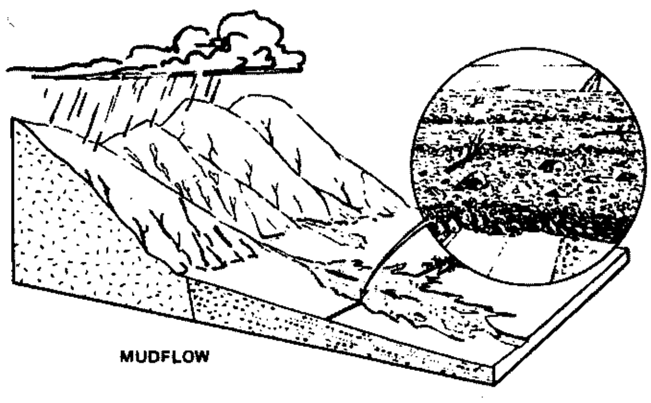

FIGURE 8.2 Mudflow deposits.

(From Van Horn, 1972)

100,000 people were killed in their homes dug into loess (weak wind-blown deposits) during an earthquake in 1920. The identification of former landslides and the assessment of the potential for future landslides, particularly under new land uses, are very important in land-use planning.

Landslides occur when the pull of gravity on earth materials overcomes their frictional resistance to downslope movement. Slope stability is affected by

1. *Type of earth materials present.* Unconsolidated deposits will move downslope more easily than bedrock.

2. *Structural properties of earth materials.* The orientation of layering of some rocks and sediments relative to slope directions, as well as the extent of fracturing of the materials, will affect landslide potential.

3. *Steepness of slopes.* Landslides are more common on steeper slopes.

4. *Water.* Landslides are generally more frequent in areas of seasonally high rainfall because the addition of water to earth materials commonly decreases their resistance to sliding by decreasing internal friction between particles (such as soil or sand grains) and by decreasing the cohesive forces that bind clay minerals together. Water also lubricates surfaces along which failure may occur; adds weight to the material; reacts with some clay minerals, causing volume changes in the material; and mixes with fine-grained unconsolidated materials to produce wet, unstable slurries.

5. *Ground shaking.* Strong shaking, for example during earthquakes, can jar and loosen earth materials making them less stable.

6. *Type of vegetation present.* Trees with deep, penetrating roots tend to hold bedrock and surficial deposits together, thereby increasing ground stability. Removing such trees can increase the likelihood of landslides. Trees add weight, however, and roots can break up rock.

7. *Proximity to areas undergoing active erosion.* Rapid undercutting and downcutting along stream courses and shorelines makes the resulting slopes particularly susceptible to landsliding. (Nilsen & Brabb, 1972)

The parts of a landslide are shown in Figure 8.3. The key nomenclature follows (from Nilsen and Brabb, 1972):

PART A. RECOGNIZING LANDSLIDES ON TOPOGRAPHIC MAPS, AERIAL PHOTOGRAPHS, AND LIDAR IMAGES

According to Nilson and Brabb (1972), landslide deposits are commonly characterized by one or more of the following features:

1. Small, isolated ponds, lakes, or other closed depressions
2. Abundant natural springs

Main scarp	The steep surface between the slide and the undisturbed ground. The projection of the scarp surface under the slide material is the rupture surface.
Minor scarp	A steep surface on the displaced material produced by differential movements within the slide mass.
Head	The upper part of the slide material along the contact between the displaced material and the main scarp.
Crown	The material that is still in place, undisturbed, adjacent to the highest parts of the main scarp.
Toe	The margin of displaced material most distant from the main scarp.

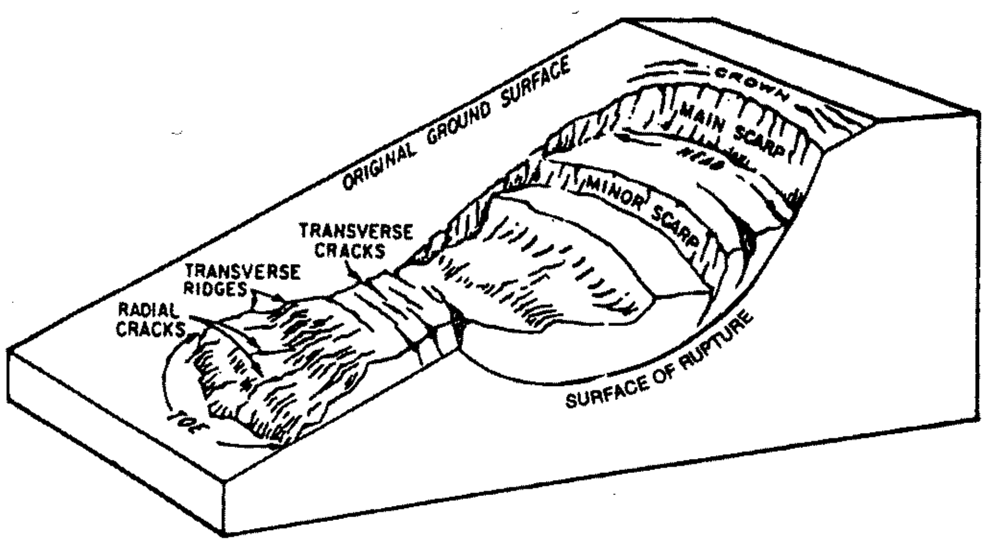

FIGURE 8.3 Parts of a complex (slump-earth flow) landslide (Nilsen and Brabb, 1972).

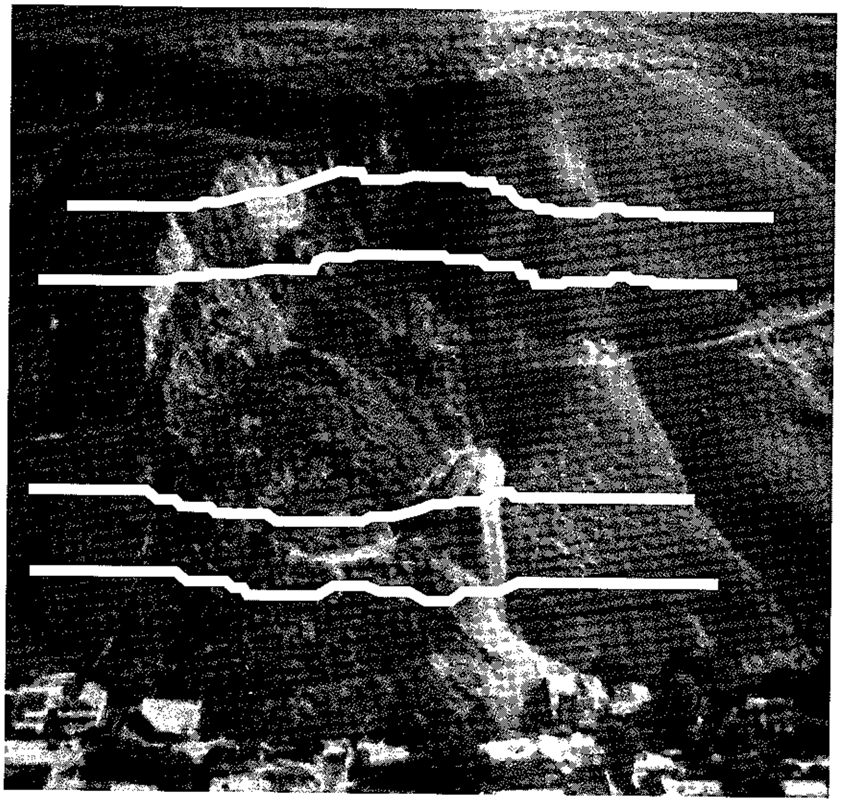

FIGURE 8.4 On an oblique photograph, contours on the upper, scarp, area of a landslide bend into the hill, and contours on the lower, hummocky, area of the landslide bend out from the hill. See Figure 8.3 for the parts of this landslide. Photograph courtesy of http://www.geog.ucsb.edu/~ jeff/projects/la_conchita/1995/95_slideshots.html

3. Abrupt and irregular changes in slope and drainage pattern
4. Hummocky irregular surfaces
5. Smaller landslide deposits that are commonly younger and form within older and larger landslide deposits (in other words, if an area has slid in the past, it is subject to both small and large renewed slides)
6. Steep, arcuate scarps at the upper edge
7. Irregular soil and vegetation patterns
8. Disturbed vegetation
9. Abundant flat areas

QUESTIONS (8, PART A)

La Conchita, California

Figure 8.4 shows a landslide that occurred in 1995 above the small town of La Conchita, California. This landslide reactivated in the wet winter of 2005, with disastrous consequences. Note the shape of contours as they cross the landslide. Figure 8.5 shows a vertical aerial photograph of the same site, and note how contours appear on this photograph.

1. a. Can you recognize the shape of contours that may indicate a landslide? Check with your Teaching instructor before going on to the next question.

b. In Figure 8.4 and 8.5, were any homes damaged? Explain.

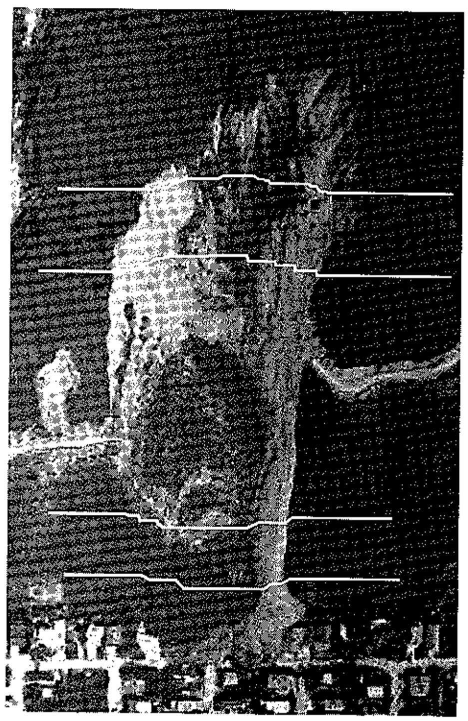

FIGURE 8.5 Contours that cross landslides, as shown on vertical photos, bend to follow concave part of slope in the upper scarp area of the slide. Contours in the lower part of a landslide will be convex and irregular over hummocky terrain. La Conchita, California, 1995; Same site as in Figure 8.4. Photograph courtesy of Pacific Aerial Surveys, http://www.geog.ucsb.edu/~ jeff/projects/la_conchita/1995/95_slideshots.html

Gardiner, Montana

Figure 8.6 is a photograph of the lower part of a landslide complex south of Gardiner, Montana. Direction of view in the photograph is to the south from the townsite. This is an old landslide, but it well illustrates hummocky terrain related to landslide deposition. Refer to Figure 8.7, the aerial photograph, and Figure 8.8, the topographic map.

2. Mark on the aerial photograph (Figure 8.7) the area of the landslide(s). Look for irregular terrain, typified by hummocky topography.

3. On the topographic map (Figure 8.8), mark areas of the landslide(s). Particularly look for areas of highly crenulated (folded, angular) contours rather than smooth contours. The 5,400-foot contour south of the town of Gardiner is an example of a crenulated contour. An example of an area with smoother contours is the area northwest of the town of Gardiner.

4. What other landslide features identified by Nielson and Brabb (listed above) are present in this landslide complex?

Green River Gorge, Washington

This gorge, southeast of Seattle, has many landslides along its slopes. They can be hard to identify on aerial photographs and topographic maps due to forest cover. A relatively new technology, LIDAR, is expected to improve identification.

5. Figure 8.9 is a vertical aerial photograph of the Green River Gorge. Mark on this photograph areas that you think, based on topography, may have landslides. What landslide characteristics helped you make your identification?

6. Figure 8.10 is a topographic map of the Green River area. Use this map and see if you can find any landslide areas. Are there any areas that have similar topographic contours to those shown in Figures 8.4, 8.5, and 8.8? If so, mark them.

7. LIDAR images can show landslides more clearly than either aerial photographs or topographic maps. LIDAR allows "virtual deforestation," that is computer processing that removes trees and lets the ground surface be mapped. Figure 8.11 is a LIDAR image of the Green River Gorge. Note that Figure 8.11 covers a larger area than Figure 8.9. Mark on this image all the landslides you can find. Do you agree or not that LIDAR allows identification of more landslides than maps or photographs?

8. Use a colored pencil, and transfer these landslides back to the topographic map (Figure 8.10) and the aerial photograph (Figure 8.9). How many more landslides could you identify on LIDAR than on the map? The photograph?

FIGURE 8.6 Gardiner, MT, landslide(s). View to SSW. (Photograph by © Duncan Foley)

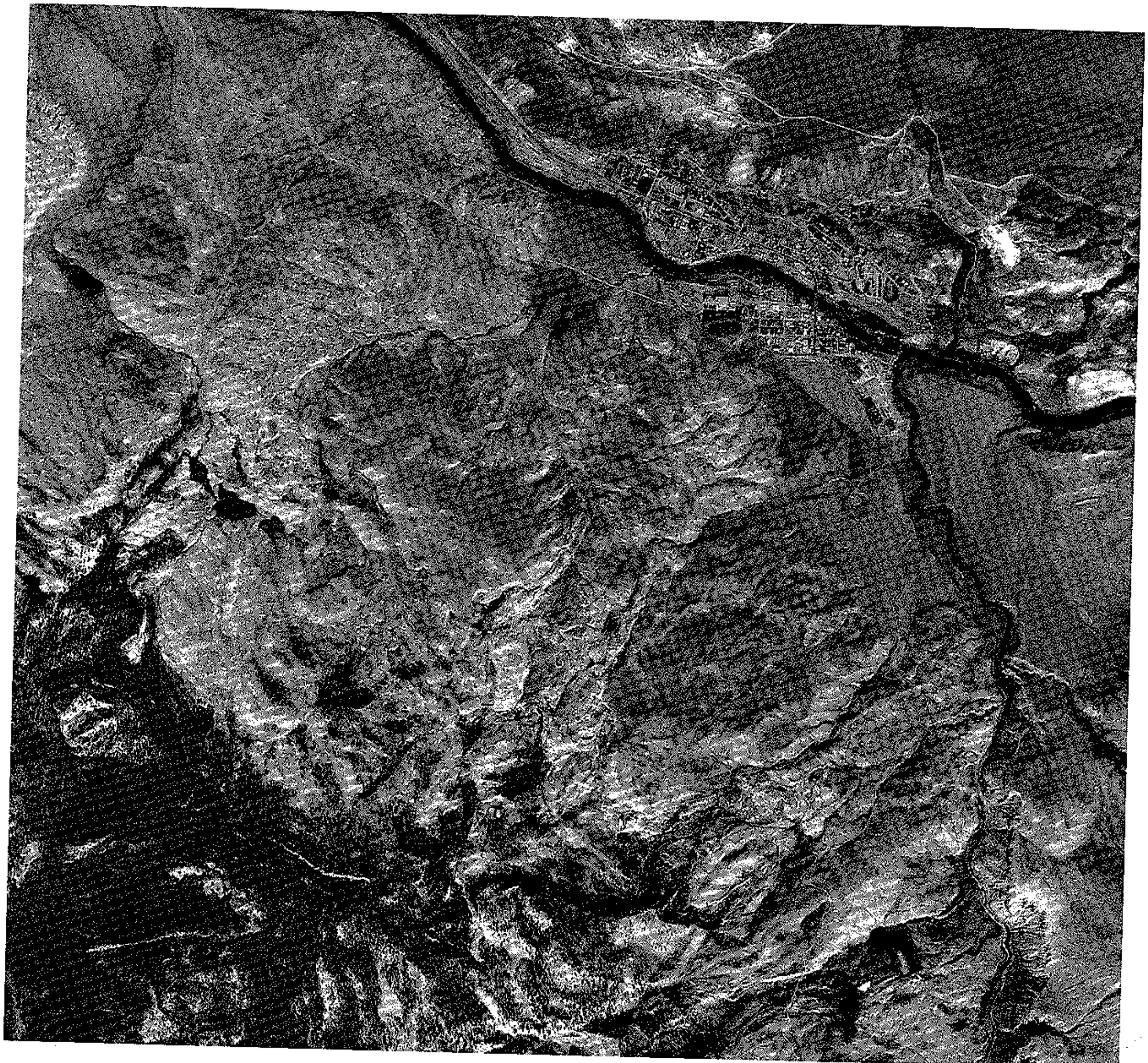

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FIGURE 8.7 Landslides southwest of Gardiner, MT. See Figure 8.8. (USGS Digital Ortho Quarter Quad downloaded August 11, 2008, from http://nris.state.mt.us/nsdi/doq.asp?Srch24=4511016)

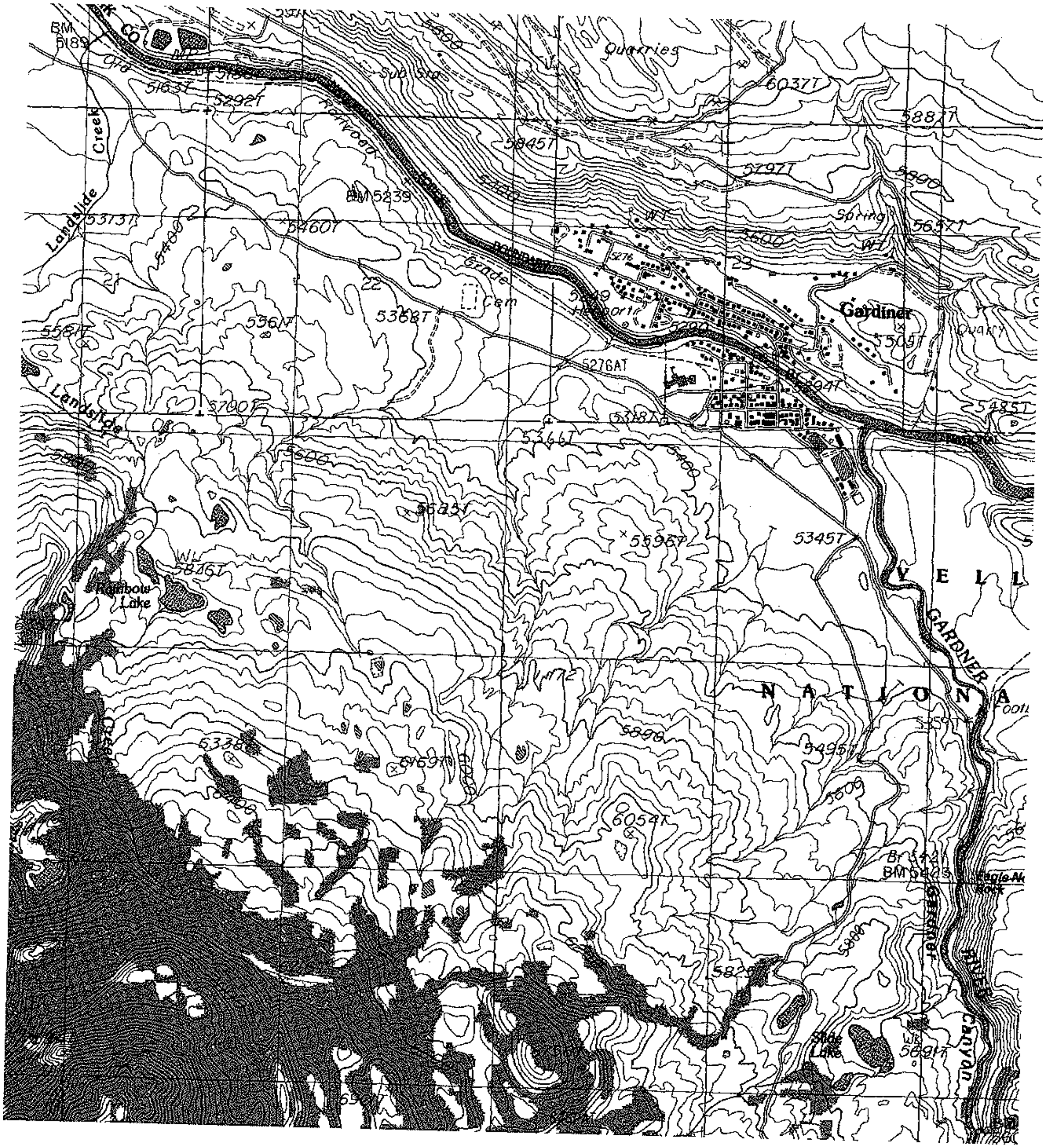


FIGURE 8.8 Gardiner, MT. Topographic map. Contour Interval = 40 ft. See Figure 8.7.

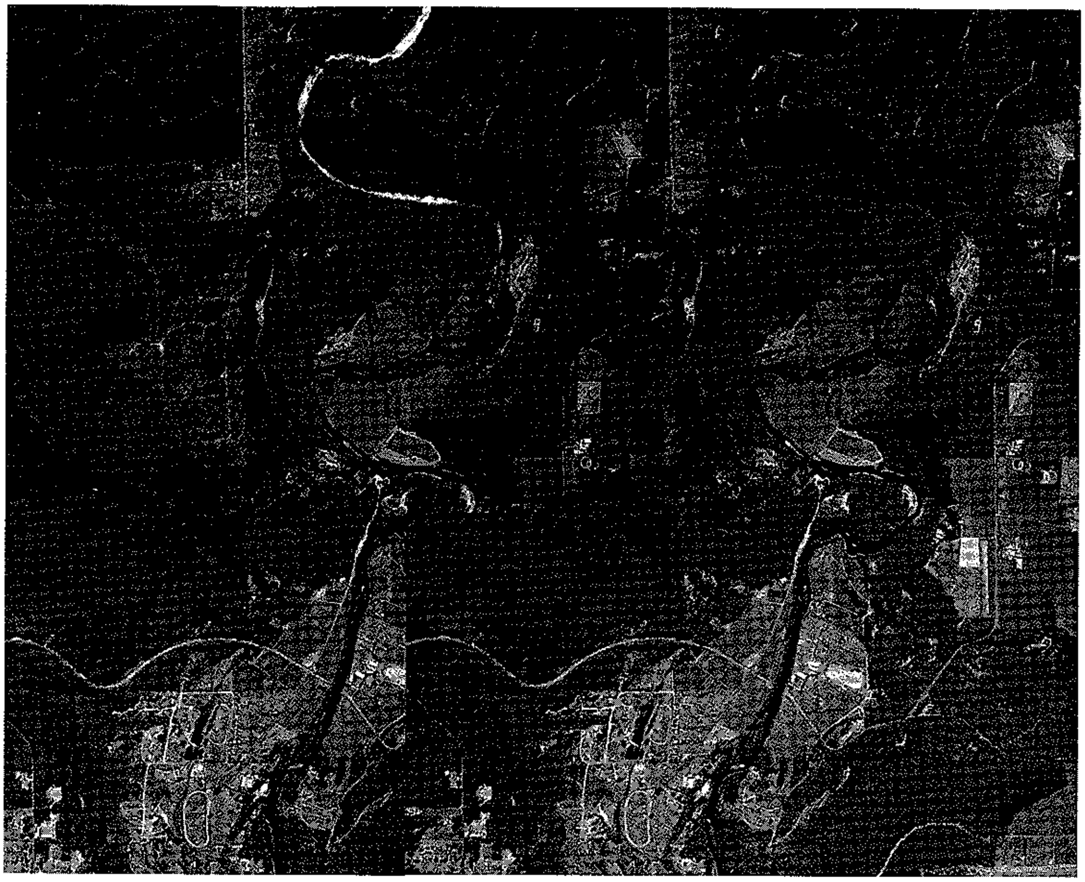


FIGURE 8.9 Stereo aerial photos of Green River Gorge, Washington. Photos courtesy of Washington Department of Transportation.

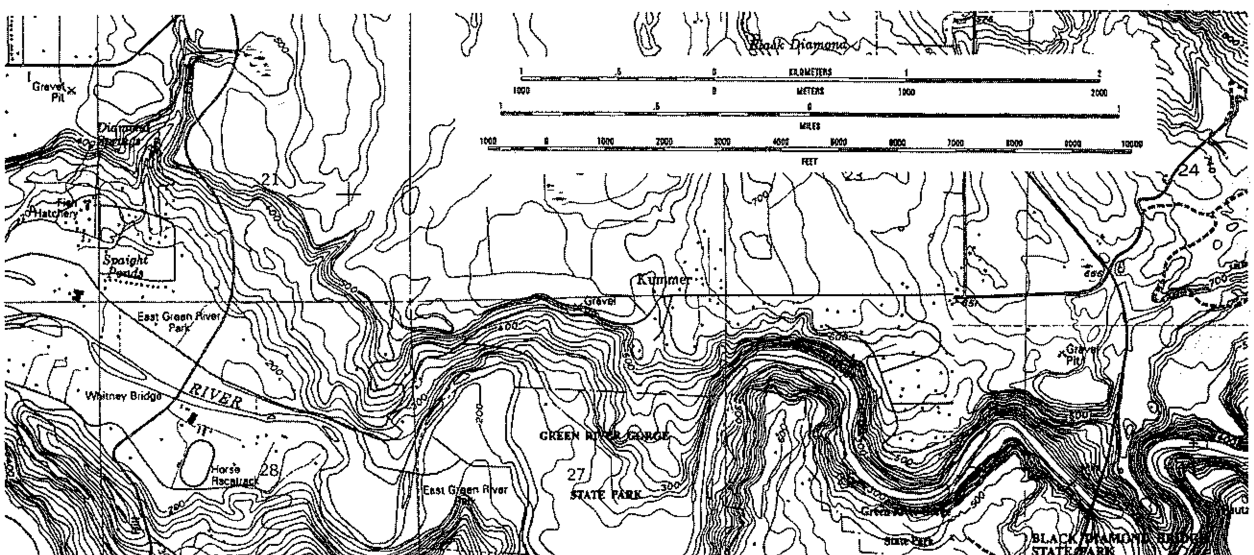


FIGURE 8.10 Topographic map, Green River Gorge. Contour Interval = 25 ft.

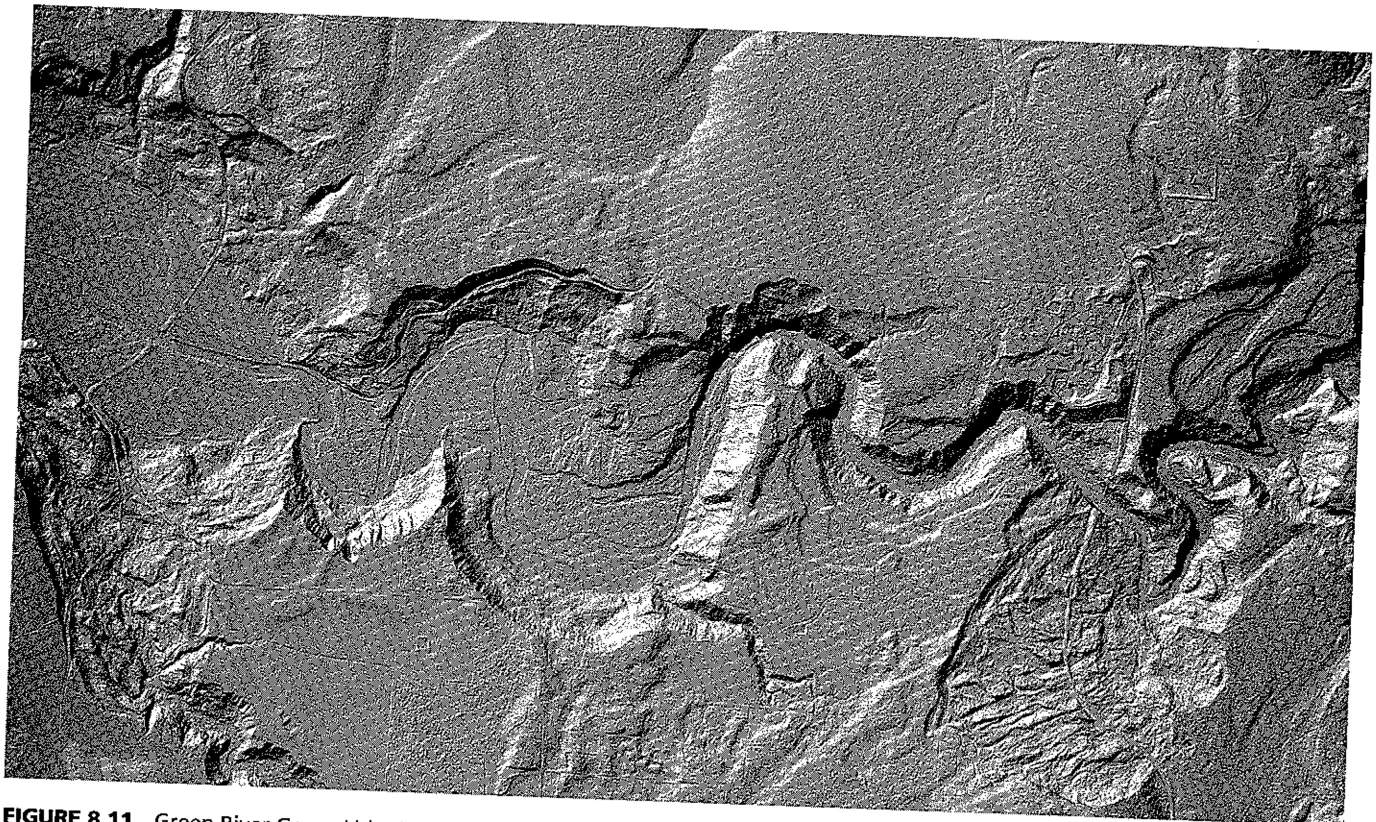


FIGURE 8.11 Green River Gorge Lidar Image. (Courtesy of King County, Washington, GIS Center)

PART B. LANDSLIDES IN SAN JOSE, CALIFORNIA

Landslide deposits in the northeastern part of the city of San Jose were first shown on a geologic map done by Crittenden (1951). A subsequent map, based on interpretation of aerial photographs and field investigations, included many additional landslide deposits that are shown as lighter areas with arrows (Figure 8.12, Nilsen and Brabb, 1972). Damage to urban structures within part of the landslide-prone area is shown in Figure 8.14. The landslides, which may be continuously or intermittently moving, or not moving at all, are primarily the result of natural processes. Human activities may alter these processes and even render some areas unstable. In order to determine the stability of a particular site, a landslide deposit map, such as Figure 8.12, would be used in conjunction with other information concerning soils, vegetation, hydrology, and other geologic factors.

In general, fewer of these characteristics will be noted in smaller deposits. Detailed site studies, of course, are required for predicting the behavior of landslide deposits under changing conditions.

QUESTIONS (8, PART B)

1. Review Part A, carefully examine Figure 8.12, the explanation for this figure, and the topographic map for this area (Figure 8.13 in the map section at the back of the book). Note that two different contour intervals are used on each map.

   a. What are these contour intervals?

   b. Explain why two different contour intervals were necessary for each map.

2. Place an X in the area of the largest landslide deposit within the enclosed area in the center of Figure 8.12. What is the approximate area of this slide, in square miles?

3. What materials make up the landslide deposit?

4. The density of contour lines changes from the northeast part of the map to the southwest part, indicating a change from steep to gentle slopes and suggesting an increase in potential for landslides. What is the difference in elevation between A and B?

5. What is the distance from A to B in miles?

6. What is the average gradient (slope), in feet per mile, from A to B?

7. The gradient from X to Y is _____, and from K to L it is _____.

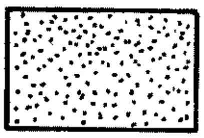
FIGURE 8.12 Landslide and other surficial deposits in northeastern San Jose, California. (Nilsen and Brabb, 1972).

Explanation for Figure 8.12

Qal

Alluvial deposits

Irregularly stratified, poorly consolidated deposits of mud, silt, sand, and gravel deposited in stream and river beds and on adjoining flood plains. Includes older and younger alluvial fan deposits that form broad, extensive, gently sloping surfaces. Deposition is continuing on the younger parts of these fans and in the major alluvial channels that cut across the fan surfaces.



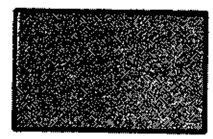
Colluvial deposits

Colluvial deposits: unstratified or poorly stratified, unconsolidated to poorly consolidated deposits composed of fresh and weathered rock fragments, organic material, sediments, or irregular mixtures of these materials that accumulate by the slow downslope movement of surficial material predominantly by the action of gravity, but assisted by running water that is not concentrated into channels. Colluvial deposits have been mapped only where they form a distinct apron near the base of slopes or where they fill and flatten canyon, ravine, and valley bottoms. Colluvial deposits are probably forming on almost every slope in the bay region, but only the thicker and extensive accumulations that are recognizable on aerial photographs have been mapped.

Landslide deposits

Arrows indicate general direction of downslope movements; queried where identification is uncertain

Debris composed of fresh and weathered rock fragments, sediment, colluvial material, and artificial fill, or any combinations thereof, that has been transported downslope by falling, sliding, rotational slumping, or flowing. Landslide deposits smaller than approximately 200 feet in longest dimension are not shown on the map. Complex landslide deposits, which result from combinations of different types of downslope movement, are perhaps the most common type of landslide deposit in the bay region. In particular, materials near the head of landslide deposits typically move in a different manner than materials at the toe. The landslide deposits shown on this map have not been classified according to either type of movement or type of material of which the deposit is composed. The deposits vary in appearance from clearly discernible, largely unweathered and uneroded topographic features to indistinct, highly weathered and eroded features recognizable only by their characteristic topographic configurations. The time of formation of the mapped landslide deposits ranges from possibly a few hundred thousand years ago to 1970. No landslide deposits that formed since 1970 are shown. The thickness of the landslide deposits may vary from about 10 feet to several hundred feet. The larger deposits are generally thickest; many small deposits may be very thin and may involve only surficial materials.



Bedrock
(queried where identification uncertain)

Igneous, metamorphic, and sedimentary rocks of various ages, physical properties, and engineering characteristics. Areas not shown on the map as covered with surficial deposits probably contain bedrock either exposed at the surface or mantled by a thin veneer of surficial deposits, most commonly colluvial material. The bedrock is commonly weathered to a considerable depth, so that there is a gradual change downward from highly weathered organic-rich soil to fresh bedrock. Thus, many of the small landslide deposits and some of the large landslide deposits that are shown on the map to lie within bedrock areas probably involve only material derived from weathered bedrock and other colluvial material.

Qaf

Artificial fill

Highway, railroad, and canal fills composed of rock and soil derived from nearby cuts or quarries; only large fill areas are shown on the map.

8. According to gradient, is the potential for landslide greater at X or K? Explain.

9. What is the material labeled "Qal" on the map? (Q is an abbreviation for Quaternary, a geologic period.)

10. What are the two ways in which Qal is formed (see description)?

11. Locate the deposit Qaf. What is it?

These deposits are becoming more common as humans continue to alter the landscape. Some geologists use the term anthropogenous deposits for these materials.

12. Review the drawing of the mudflow in Figure 8.2. Observe the topography shown on Figure 8.12, and mark with "X" as two areas that might be subject to mudflows. Explain your decisions. (Hint: See Colluvial deposits on the explanation for Figure 8.12.)

a.

b.

13. a. How far (in feet) is Noble School from a landslide deposit or an area of damage from landslides (refer to Figures 8.12 and 8.14).

b. Are any schools on or closer to mapped landslides?

14. Would you expect a landslide to develop under Noble School? Explain.

15. Note that a road in the subdivision had to be abandoned. What road was extended to accommodate the traffic?

16. In what subdivision are the badly damaged and abandoned houses?

17. Would you purchase a house on the north side of Boulder Drive, east of Sophist Drive (see Figures 8.12 and 8.14)? Explain.

18. Why have the utility lines been placed above ground on the west side of Boulder Drive?

19. Money and resources are still being used to make this landslide region habitable. What short-term and long-term solutions to the community's problems might be appropriate?

20. On Figure 8.15 (1963), outline three major landslides.

Hint: Use the maps (Figures 8.12 and 8.14) showing areas of movement or damage for clues.

21. Are there landslides on Figure 8.16 (1993) that did not appear on the 1963 stereopair? If so outline them.

22. Mark two areas of additional houses and one other cultural feature that appear in the 1993 photo that are not on the 1963 photo.

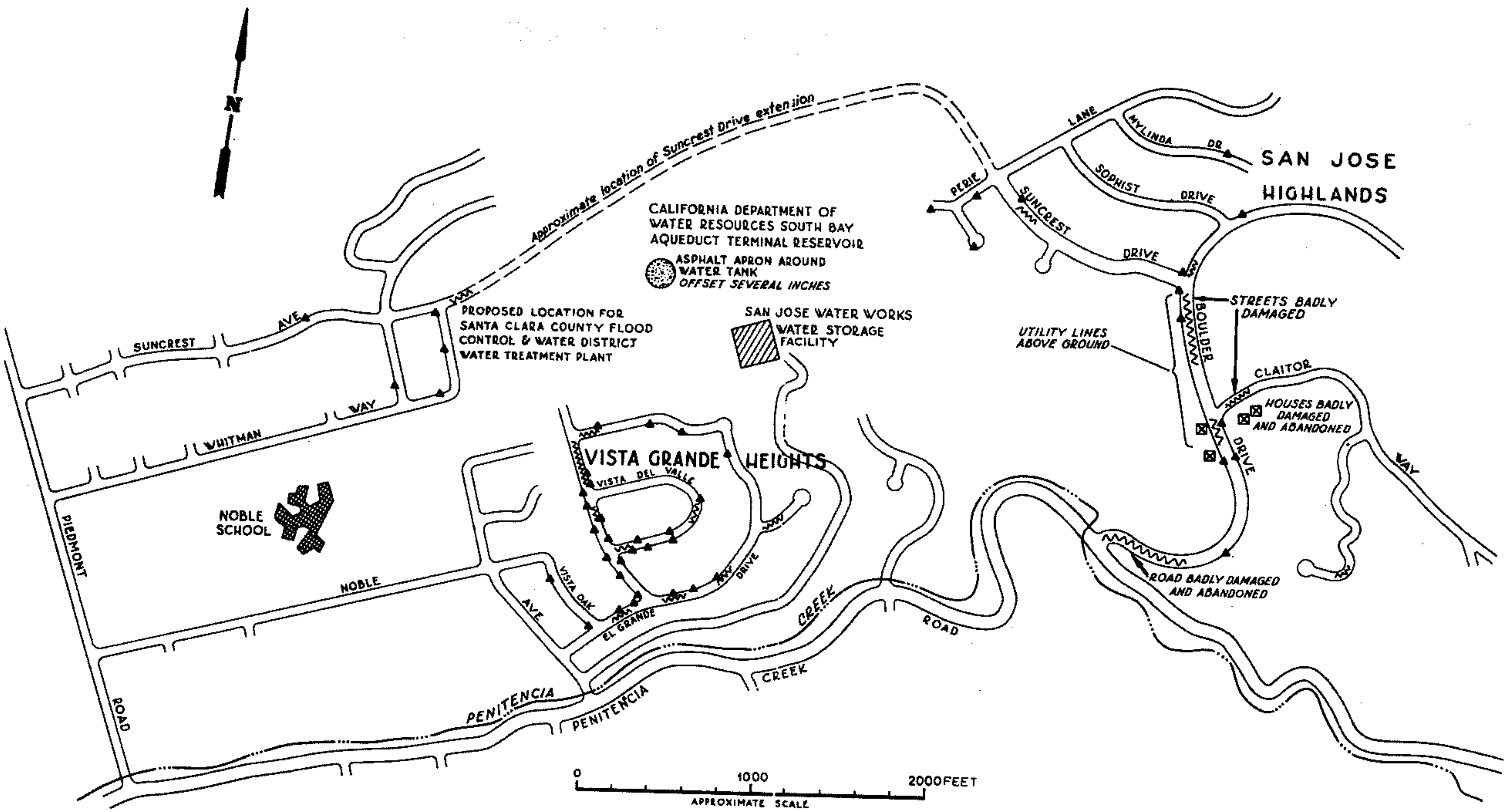
23. Using a colored pencil draw the contact between the base of the mountain and the alluvial fan on which San Jose is built. What is the approximate elevation of this line (compare with the map, Figure 8.13 in the back of the manual or Figure 8.12)?

24. a. What advice would you give to those seeking a building site in the mountain area?

b. As a consulting geologist, what advice would you give to the local zoning commission in this area?

PART C. LANDSLIDES IN ATHENS, OHIO

Landslides in Athens, Ohio, are representative of those throughout much of the Appalachian Plateau Physiographic Province. They include many of the types of mass wasting listed in the Introduction to Exercise 8. The most common types in Athens and southeastern Ohio are slump-earthflow, rock falls, and rockslides. Recognition of geomorphic features of landslide deposits (see Part A) is important if we are to avoid potentially hazardous sites and understand the processes of change in the landscape. In this exercise we investigate, using a series of photographs, the changes in an apartment complex constructed in the 1960s adjacent to the Hocking River near Ohio University. Study the indicated aerial photographs and maps and Table 8.2 to answer the questions.



△ Curb broken or offset at joints

〰 Road damaged

☒ House damaged

The damage observed appeared to be, or in some cases definitely is, related to landslide movement. No comparable damage was observed outside of the area mapped as landslides. Several of the roads, curbs, and houses within the landslide areas were checked and had no apparent damage, but a more thorough survey must be made before the extent of the damage can be fully assessed.

Observations of damage were made during 2 days of field checks in July and September 1971. Damage repaired before those dates is not shown on the map.

FIGURE 8.14 Map showing damage observed in July and September 1971 (Nilsen and Brabb, 1972).

FIGURE 8.15 Stereopairs for northeastern San Jose, California, in 1963.

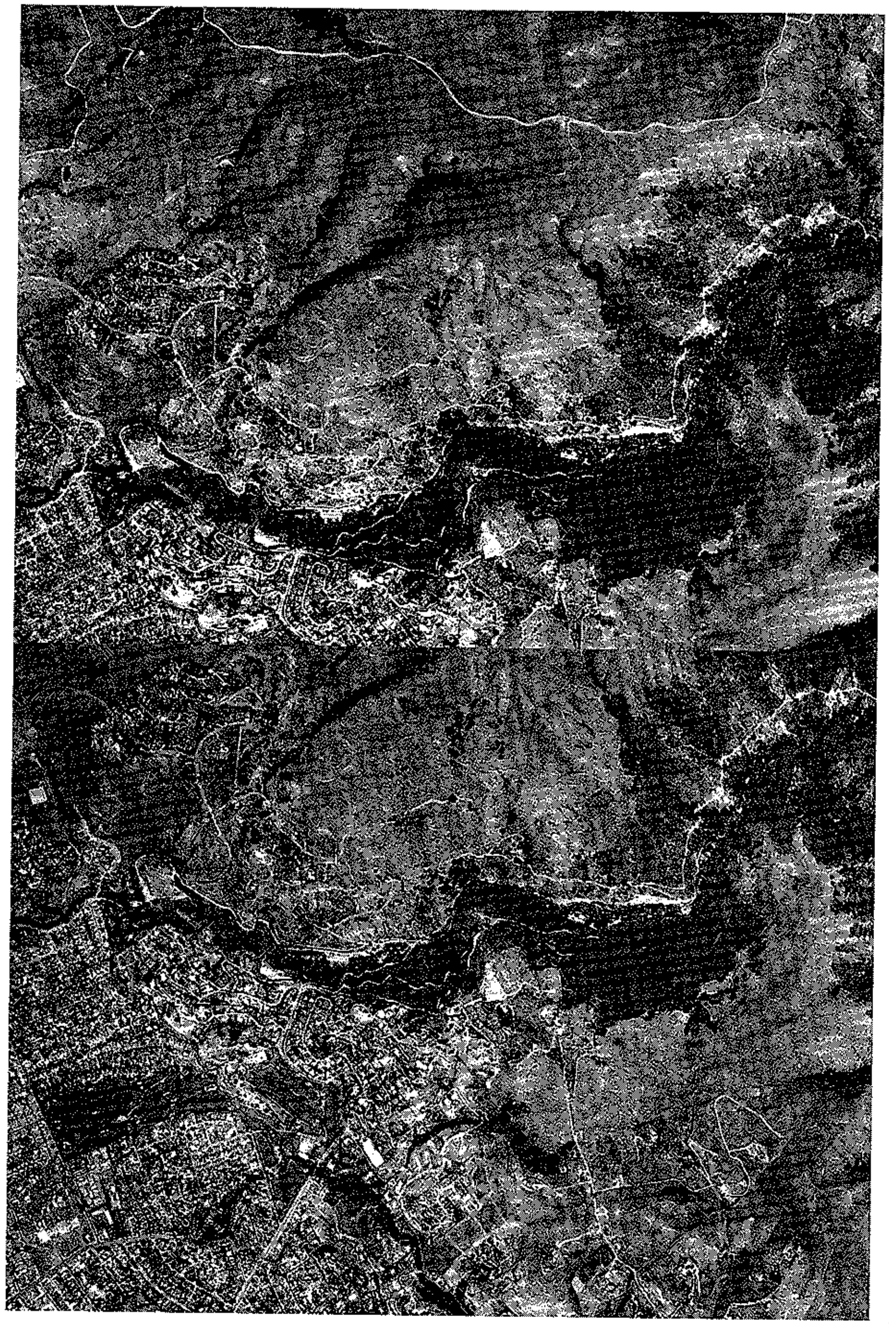


FIGURE 8.16 Stereopairs for northeastern San Jose, CA in 1993.

TABLE 8.2 Some Representative Descriptions of Members and Formations of Systems in Ohio

Description	Formation or Member	System
Green plastic shale; sandstone	Fulton	Pennsylvanian
Coal	Meigs Creek No. 9	Pennsylvanian
Sandstone	Pomeroy	Pennsylvanian
Red plastic clay, clay shale	Pittsburgh	Pennsylvanian
Limestone	Cambridge	Pennsylvanian
Plastic clay and shaly sandstone	Sciotoville	Pennsylvanian
Conglomerate and shaly sandstone	Black Hand	Mississippian
Shale	Sunbury	Mississippian
Limestone	Berea	Mississippian
Shale	Ohio	Devonian
Limestone	Columbus	Devonian
Dolomite	Greenfield	Silurian
Dolomite	Guelph	Silurian
Limestone	Brassfield	Silurian
Limestone and calcareous shale	Richmond	Ordovician
Limestone and calcareous shale	Maysville	Ordovician

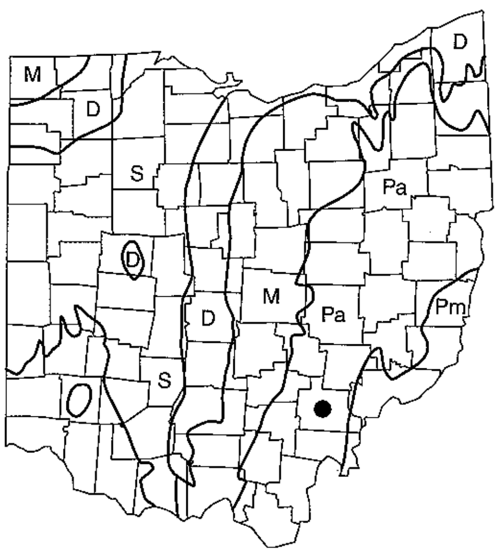


FIGURE 8.17 Geologic map, of Ohio. Athens marked by dot. Geologic systems marked by letters, Pa-Pennsylvanian, Pm=Permian.

QUESTIONS (8, PART C)

1. Locate Athens, Ohio, on Figure 8.17 the geologic map of Ohio.

   a. What is the geologic system (age) of rocks in Athens?

   b. From your knowledge of geologic materials (clays, shales, limestones, sandstones, etc., which are reviewed in Exercise 1) and the detailed descriptions in Table 8.2, which of the four youngest geologic systems would be the most susceptible to landsliding? Explain.

   c. Which formations or members would most likely deform by flow? (Hint: Engineers in Ohio refer to them as "those d——d redbeds"; Delong 1996.)

   d. Much of the Appalachian Plateau (Physiographic Province) is underlain by Pennsylvanian age and similar rocks. Would you expect similar landslide conditions in other area of the plateau such as Pittsburgh, Pennsylvania, to the east of Athens County? Explain.

2. Knowing that the bedrock in Ohio is nearly flat, list those slope stability factors (select from those in the Introduction to Exercise 8) that are important in causing landslides in Ohio.

3. List two human activities that could increase the potential for landslides.

4. Figure 8.18 shows an apartment complex under construction near the top of a hill that has been graded to produce a flat area for the buildings. On this aerial photo taken in 1968 near Athens, Ohio, identify

   a. a pond on the floodplain (P)

   b. the apartment buildings with dark roofs at the construction site (A) (one is given)

   c. two landslides (L)

5. How many buildings are roofed or partially roofed?

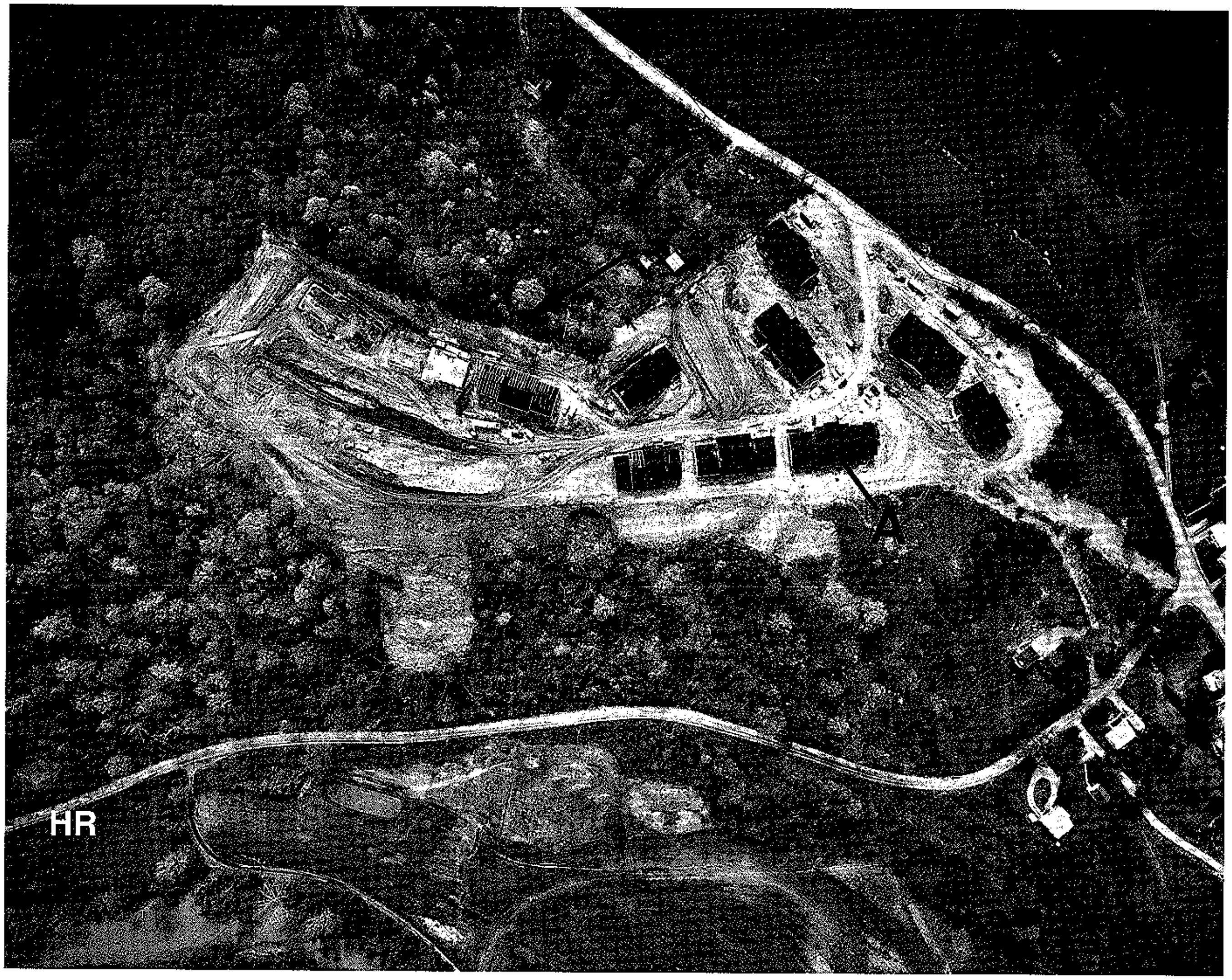


FIGURE 8.18 Aerial photo (1968) of apartment site overlooking the Hocking River, south of Ohio University. North arrow in the upper middle of the photo points to lower left of photo. Building "A" is marked on this photo and on Figure 8.23 (in color plate section at the back of the book). Hocking River "HR" in lower left side of bottom edge of photo.

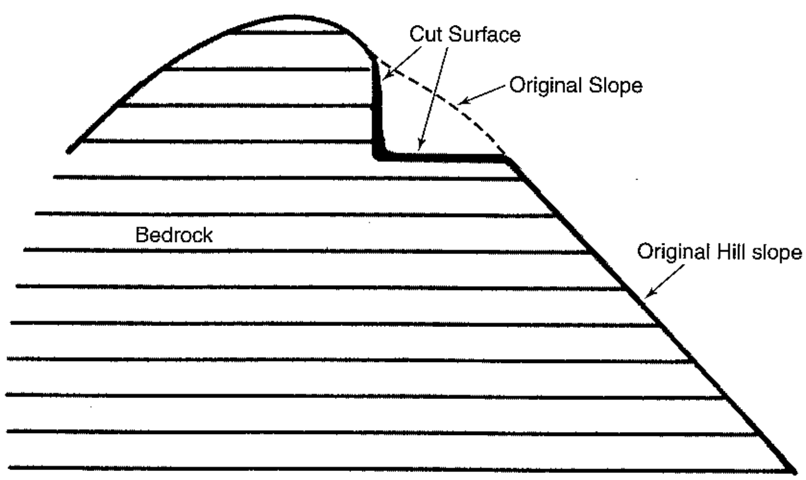


FIGURE 8.19 Sketch of cross section of apartment site adjacent to the Hocking River. Complete the profile to show placement of the material removed from the cut in the slope.

6. The rock and regolith graded from the high areas of the hillside were used as fill to provide additional building sites on the slope of the hill adjacent to the cut surface. Complete the sketch (Figure 8.19) to illustrate the site.

7. a. Where would the landslides observed in the 1968 photo (Figure 8.18) be in your sketch (Figure 8.19)?

b. What is the material of this landslide: bedrock, fill or regolith?

8. On the 1971 stereo triplet (Figure 8.20),

a. Mark the area of rockfall hazard for the apartments with (R).

b. Compared to the 1968 (Figure 8.18) photo, where is the increased area of mass movement?

c. How many apartment buildings are there in the completed complex in 1971 (Figure 8.20)?

9. On the 1975 stereopair (Figure 8.21)

a. Outline the areas of landslides (L)

b. How many different landslides can you identify?

c. Identify any site(s) where a building has been removed.

d. Mark buildings with an "X" that you think will be lost or removed because of mass wasting.

e. What is the purpose of the chain-link fence (F) behind the apartment?

f. What type of mass wasting deposit would you find adjacent to the fence? Explain.

10. From the 1976 image (Figure 8.22),

a. Is the road at the base of the hill suitable for automobiles?

b. How many apartments are left?

c. Why did they not build these structures where it is flat, such as at B?

d. What is the type of mass wasting that destroyed the road?

Consult the maps (Figure 8.23 in back of book) to answer questions 11–13.

11. a. Circle the location of the apartment complex on each map.

b. From the maps, how many buildings were on the site in 1961? ___ In 1995? ___

c. On the 1995 map, add the apartment buildings that once existed (see 1975 photo). The maximum number was ___?

d. The thin dashed line represents the city boundary. How does the river influence this boundary or does it?

e. The Hocking River underwent a major change in form and position between 1961 and 1995. Describe these changes near Ohio University.

f. On the 1995 map, mark one location where natural change in the river has occurred following channelization by humans in the early 1970s. What is the change and what is your evidence that it has occurred?

12. From what you know of the landscape in the vicinity of the apartment site between 1968 (photo) and 1995(map), mark the location where highway 33/50 passes over the toe of a landslide.

13. Briefly describe what happened to the river near the row of trees on the river bank between 1968 (Figure 8.18) and 1975 (Figure 8.21).

14. Now that you have nearly completed the exercise you should be able to see the development of the major landslide, active before all the apartments were built. Describe changes in the road and flood plain from the photos:

a. 1968–1971

b. 1971–1975

c. 1975–1976

15. What recommendation would you give to anyone preparing a building site in the vicinity of and at the same level (and presumably with the same strata) as the apartment site?

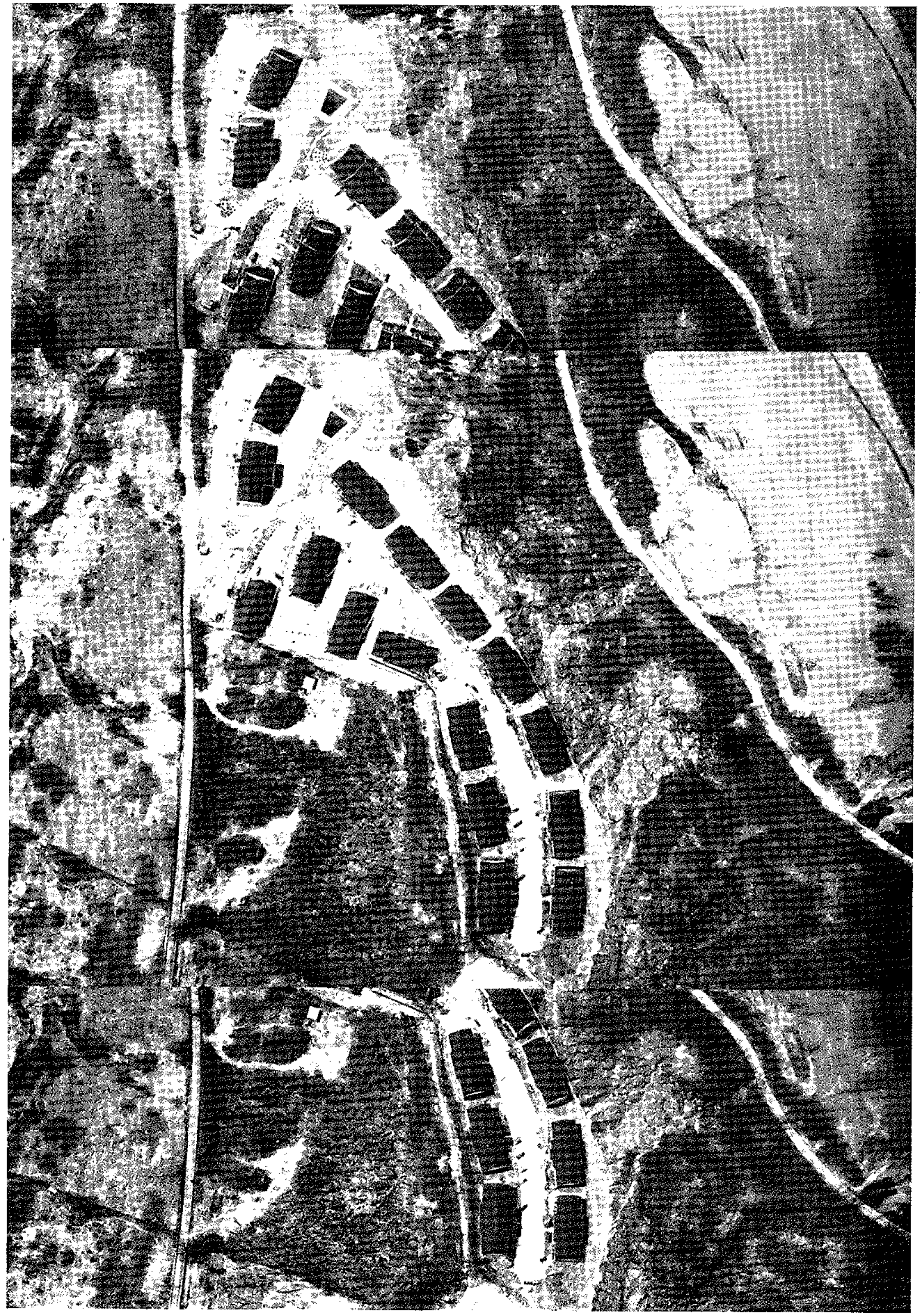


FIGURE 8.20 Stereo triplet (1971) of the apartment site.

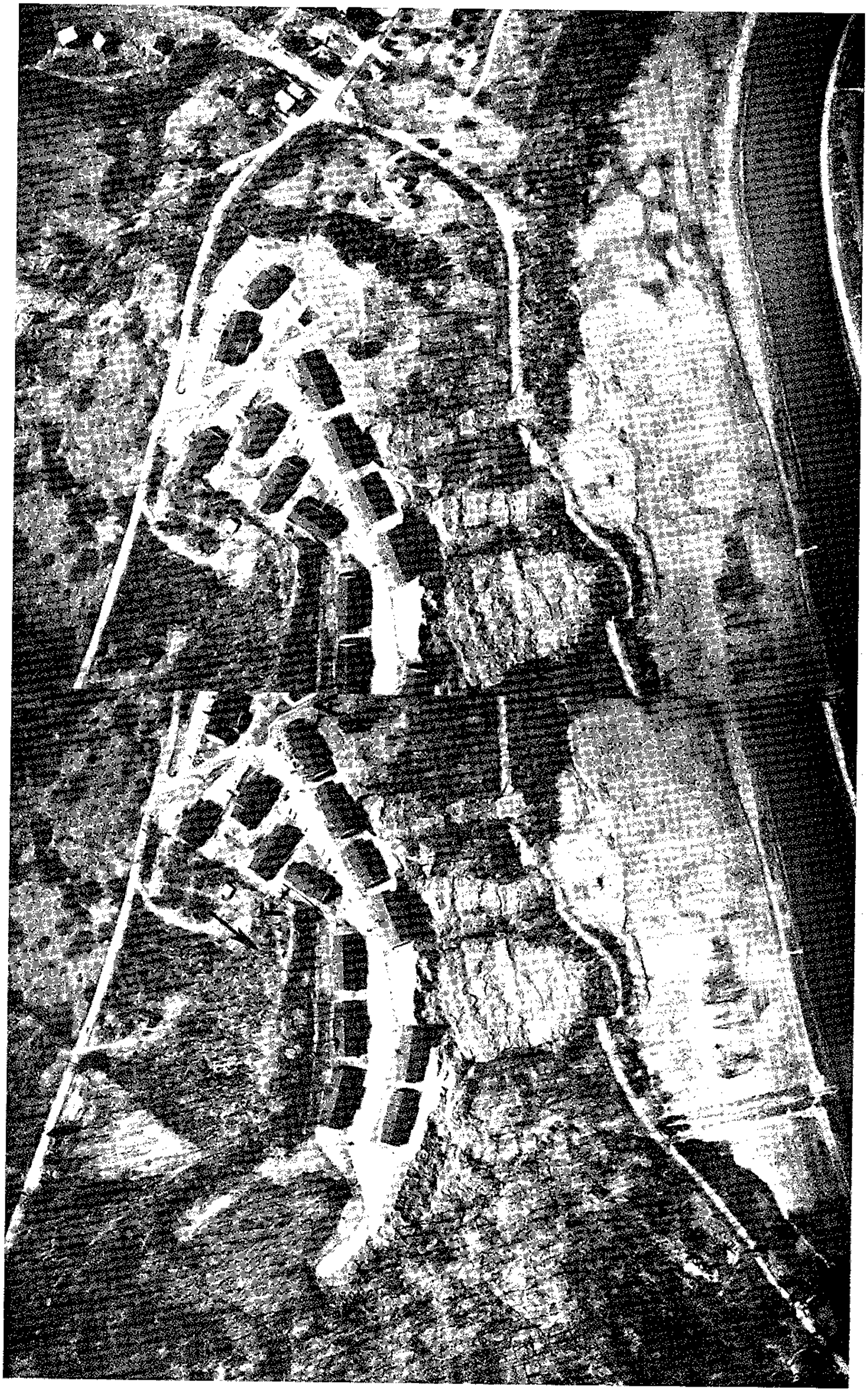


FIGURE 8.21 Stereo pair (1975) of apartment site. The channelized Hocking River is adjacent to the flood plain at bottom of the hill.

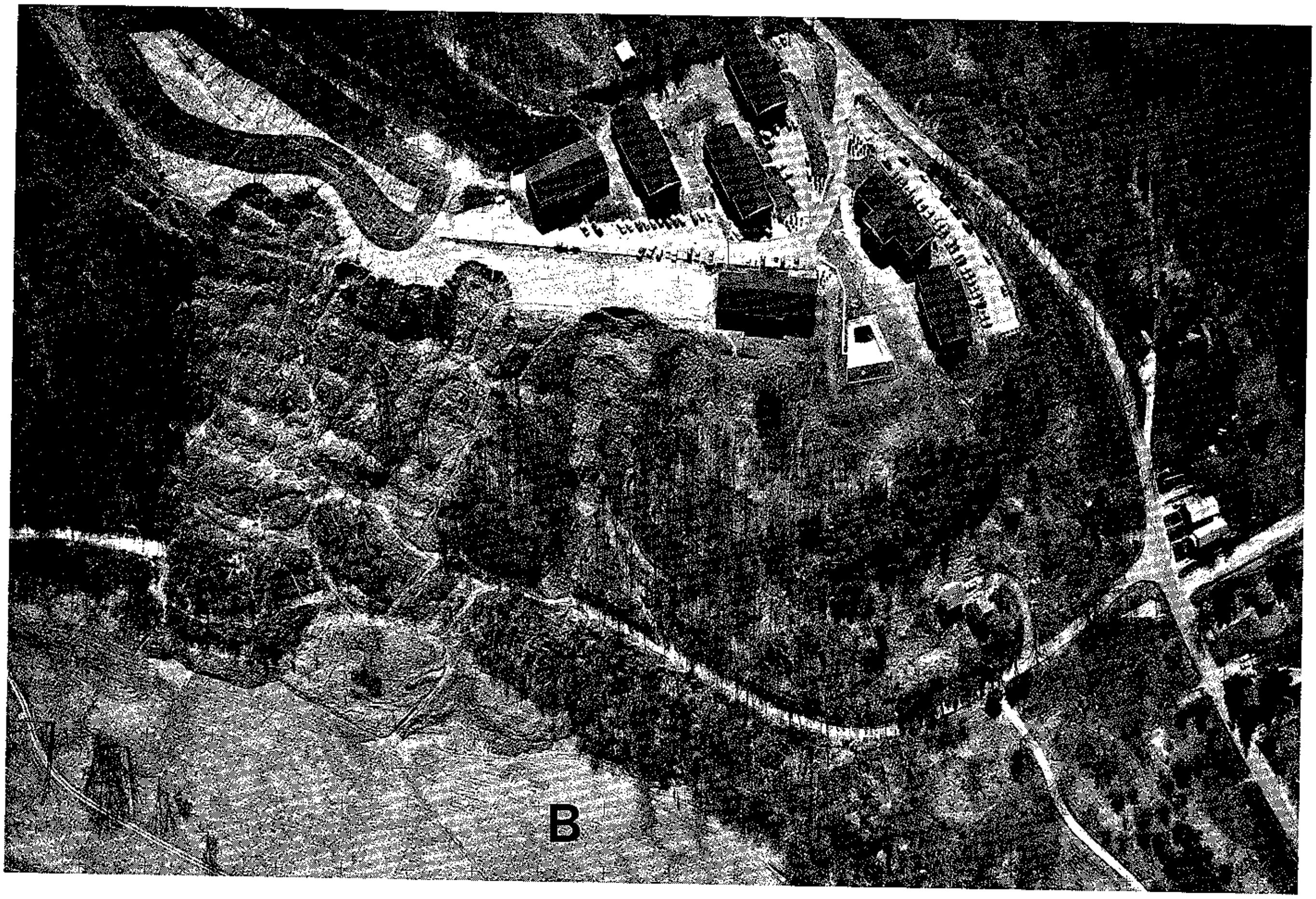


FIGURE 8.22 Aerial photo (1976) of apartment site.

PART D. THE NATURE AND OCCURRENCE OF SNOW AVALANCHES

The goals of part of the exercise are to familiarize you with some of the basic causes of avalanches and introduce you to various types of avalanche terrain.

The following text is slightly edited from the U.S. Forest Service brochure "Snow avalanche: General rules for avoiding and surviving snow avalanches."

There are two principal types of snow avalanches: loose snow avalanches and slab avalanches. These types are illustrated in Figure 8.24. Loose snow avalanches start at a point or over a small area. They grow in size and the quantity of snow involved increases as they descend. Loose snow moves as a formless mass with little internal cohesion. Slab avalanches, on the other hand, start when a large area of snow begins to slide as a mass.

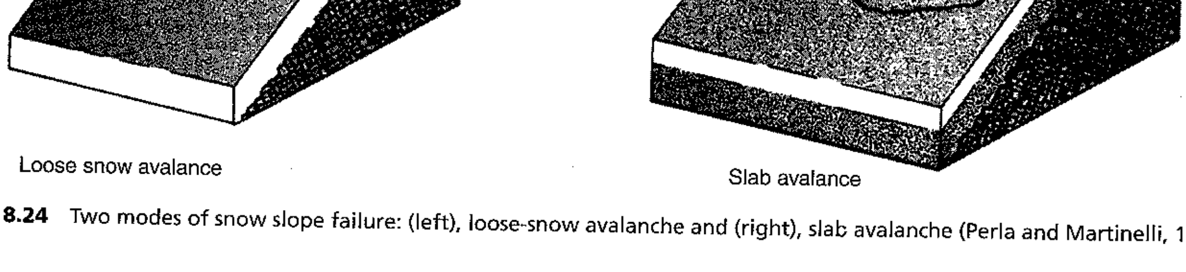


FIGURE 8.24 Two modes of snow slope failure: (left), loose-snow avalanche and (right), slab avalanche (Perla and Martinelli, 1978).

A well-defined fracture line occurs where the moving snow breaks away from the stable snow. In slab avalanches snow crystals tend to stick together. Angular blocks or chunks of snow may be part of the slide. According to Perla and Martinelli (1978), the slab may range from 100 to 10,000 square meters in area and from 0.1 to about 10 m thick. Slab avalanches are the more dangerous of the two types.

Avalanches are the result of both the underlying terrain and the conditions of the snowpack. This exercise concentrates on terrain factors, including slope steepness, slope profile, slope aspect, and ground cover.

The relevant terrain factors, as described by the U.S. Forest Service, are:

Slope steepness. Avalanches most commonly release from slopes of 30 to 45 degrees (60 to 100 percent), but may begin on slopes ranging from 25 to 65 degrees (45 to 215 percent). LaChapelle (1985) notes that many avalanches begin on slopes of 35 to 40 degrees (70 to 85 percent).

Slope profile. Dangerous slab avalanches are more likely to begin on convex slopes but may also begin on concave slopes. Short slopes may be as dangerous as long slopes; 42 percent of all avalanche fatalities result from slides with a slope distance of less than 300 ft (100 m).

Slope aspect. Snow on north-facing slopes may be slower to stabilize than snow on slopes that face other directions. South-facing slopes are especially dangerous in the spring due to solar heating. Leeward (downwind, or the direction the wind is blowing toward) slopes are dangerous because they accumulate wind-deposited snows that add depth and may create unstable slabs of snow. Windward (upwind, or the direction the wind is coming from) slopes generally have less snow; the snow is more compacted and usually more stable than snow deposits on leeward slopes.

Ground cover. Large rocks, trees, and heavy brush help anchor the snow. Smooth, open slopes are more dangerous, but avalanches can start even among trees.

Old slide paths and recent avalanche activity. Generally, avalanches may repeatedly occur in the same areas. Watch for avalanche paths. Look for pushed-over small trees, trees with limbs broken off. Avoid steep, open gullies and slopes. If you see new avalanches, suspect dangerous conditions. Beware when snowballs or "cartwheels" roll down the slope.

If you are planning to travel in avalanche country, you should also be aware of the impact of different weather conditions on the occurrence of avalanches. Some of these factors, as described by the U.S. Forest Service, are:

Old snow. When the old snow depth is sufficient to cover natural anchors, such as rocks and brush, additional snow layers will slide more readily. The nature of the old snow surface is important. For example, cold snow falling on hard, refrozen snow surfaces, such as sun or rain crusts, may form a weak bond. Also a loose under-lying snow layer is more dangerous than a compacted one. Check the underlying snow layer with a ski pole, ski, or rod.

Wind. Sustained winds of 15 mi/hr and over may cause avalanche danger to increase rapidly even during clear weather, if loose surface snow is available for the wind to transport. Snow plumes from ridges and peaks indicate that snow is being moved onto leeward slopes. This can create dangerous conditions.

Storms. A high percentage of all avalanches occur shortly before, during, and shortly after storms. Be extra cautious during these periods.

Rate of snowfall. Snow falling at the rate of 1 in/hr or more increases avalanche danger rapidly.

Crystal types. Observe general snow-crystal types by letting them fall on a dark ski mitt or parka sleeve. Small crystals—needles and pellets—often result in more dangerous conditions than the classic, star-shaped crystals.

New snow. Be alert to dangerous conditions with a foot or more of new snow. Remember that new snow depth may vary considerably with slope elevation, steepness, and direction.

Temperature. Cold temperatures will maintain an unstable snowpack while warm temperatures (near freezing) allow for snow settlement and increasing stability. Storms starting with low temperatures and dry snow, followed by rising temperatures and wetter snow, are more likely to cause avalanches. The dry snow at the start forms a poor bond to the old snow surface and has insufficient strength to support the heavier snow deposited late in the storm. Rapid changes in weather conditions (wind, temperature, snowfall) cause snowpack changes. Therefore, be alert to weather changes. Snowpack changes may affect snow stability and cause an avalanche.

Temperature inversion. Higher temperatures with higher elevations can occur when warm air moves over cold air, which is trapped near the ground and in valleys. This weather situation may produce dramatic variations in local snow stability.

Wet snow. Rainstorms or spring weather with sunny days, warm winds, and cloudy nights can warm the snow cover. The resulting free and percolating water may cause wet snow avalanches. Wet snow avalanches are more likely on south slopes and slopes under exposed rock.

The U.S. Forest Service suggests that "the safest routes for travel in avalanche terrain are on ridgetops and slightly on the windward side of ridgetops, away from cornices (accumulations of drift snow on the leeward side of the crest of a ridge). Windward slopes are usually safer than leeward slopes. If you cannot travel on ridges, the next safest route is out in the valley, far from the bottom of slopes. Avoid disturbing cornices from below or above. Gain access to ridgetops by detouring around cornice areas . . . .

If you must cross dangerous slopes, stay high and near the top. If you see avalanche fracture lines in the snow, avoid them and similar snow areas. If the snow sounds hollow, particularly on a leeward slope, conditions are probably dangerous. If the snow cracks and the snow cracks run, this indicates slab avalanche danger is high. If you must ascend or descend a dangerous slope, go straight up or down along the side; do not make traverses back and forth across the slope. Take advantage of areas of dense timber, ridges, or rocky outcrops as islands of safety. Use them for lunch and rest stops. Spend as little time as possible on open slopes."

QUESTIONS (8, PART D)

1. What are the most common slopes for avalanches in degrees and in percent?
   degrees
   percent

2. Why are avalanches not as common on slopes that are less steep or that are more steep?

3. Where on a slope profile is an avalanche most likely to begin?

4. If the winds from a storm are blowing out of the west, on which side of a mountain will most of the snow accumulate? Why?

5. Describe three possibilities for a safe route through avalanche terrain.
   a.

   b.

   c.

PART E. AVALANCHE PATH IDENTIFICATION

Avalanche hazards in the Aspen, Colorado, area have been simplified for this exercise; actual hazards from avalanches depend on the local snow and terrain conditions, and may be more or less than those used for illustration in this exercise. There is still much to learn about avalanches, and caution in areas or times of increased hazard is imperative.

Avalanche paths are separated into three zones: the starting zone, the track, and the runout zone. Figures 8.25, 8.26, and 8.27 illustrate these and their captions discuss important aspects of avalanche travel and hazards. Use these figures as you investigate the maps discussed below.

QUESTIONS (8, PART E)

Aspen, Colorado

There are two zones of avalanche hazard presented on the Aspen map (Figure 8.29 in the colored maps section). Darker zones are known avalanche areas, and lighter zones are areas that may sometimes have small avalanches. Lighter areas also represent extensions of the known areas. Bryant (1972) notes, "The most obvious avalanche paths are in gullies or on steep treeless [or sparsely vegetated] slopes below treeline."

1. Calculate slopes in degrees or percent for the following paths or potential slide areas:
   a. the path marked A, just south of Tourtellotte Peak

   b. the path marked B, for its full length from the highest elevation in the shaded zone above the B to its lowest point near the word "Fork."

   c. the lighter-colored zone immediately south of Aspen, beneath the ski lift east of Pioneer Gulch.

   d. Describe the relationship between the results you calculated above and your answer to question 1, part A. Based on your calculations, are the avalanche areas depicted on the map justifiable on the basis of their slope (as the only data)?

2. Now inspect other slopes that have mapped avalanche paths depicted on Figure 8.29. Are these slopes likely to have avalanches based on the answer to question 1, part D?

3. In addition to slope, what other kinds of data might the author have used in depicting avalanche areas on this map?

4. Mears (1976) gives the following formula for calculating the runout distance (defined as the lower boundary of the track to the outer limit of impact) of an avalanche with a confined path:

$$S = 214 + 11.4A$$

where S = runout distance in meters, and A = area of the starting zone in hectares.

This formula is based on snow and terrain conditions found in Colorado, and may not be as applicable in other locations. A hectare is an area of 10,000 square meters, or 100 m on a side. It compares with an acre, which has 43,560 square feet, and has about 209 ft on a side. One hectare equals 2.47 acres and 1 meter is 39.4 in. See Appendix I for additional conversions. Use the formula given by Mears to calculate the runout distance of the avalanches from McFarlane Creek. Use Figures 8.26b and 8.27 to help identify the points of the McFarlane Creek path. Figure 8.28 is a topographic

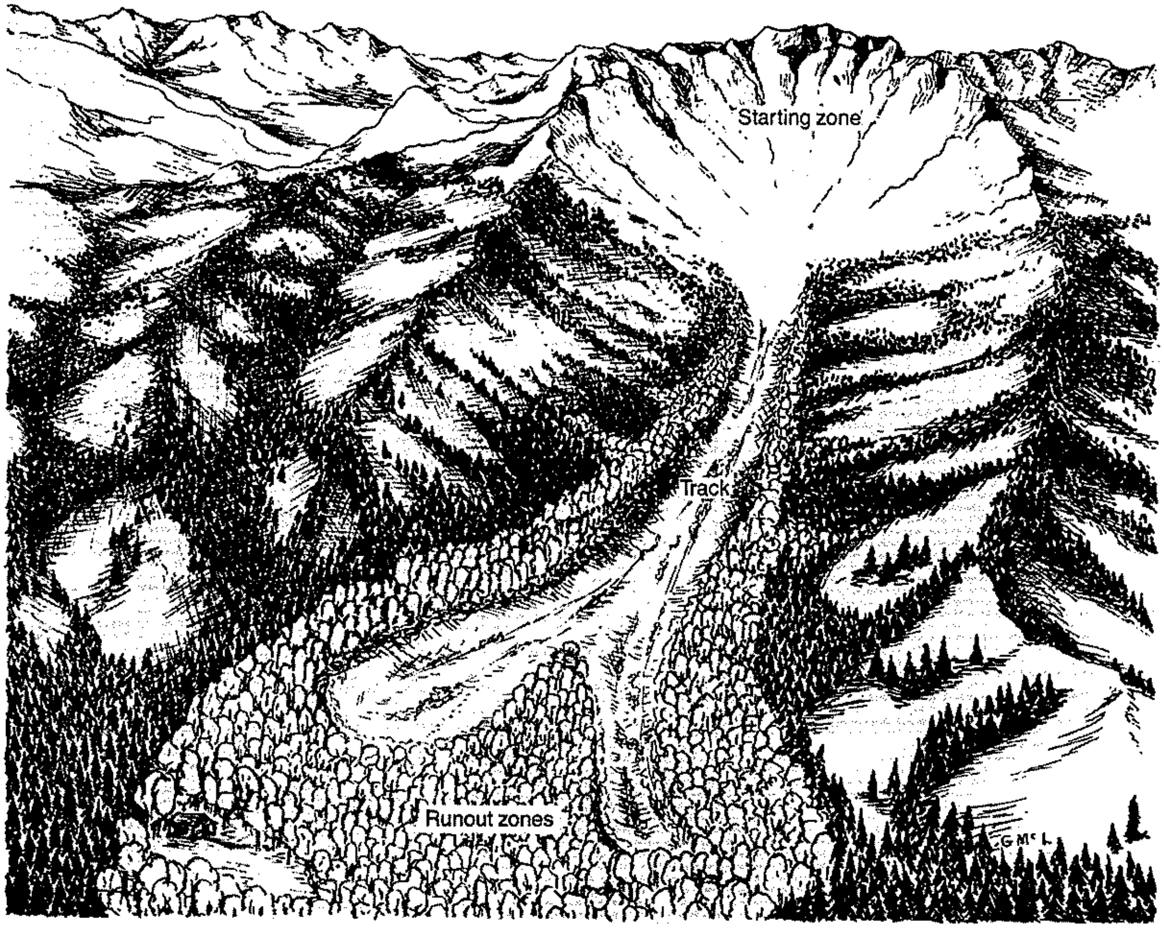


FIGURE 8.25 Large avalanche path showing various features. The smaller runout zone, reached more frequently, is cut through the aspen forest. The larger zone is reached much less frequently, is revegetated by aspen, and must be considered in planning any development (Mears, 1976; after Salm, 1975).

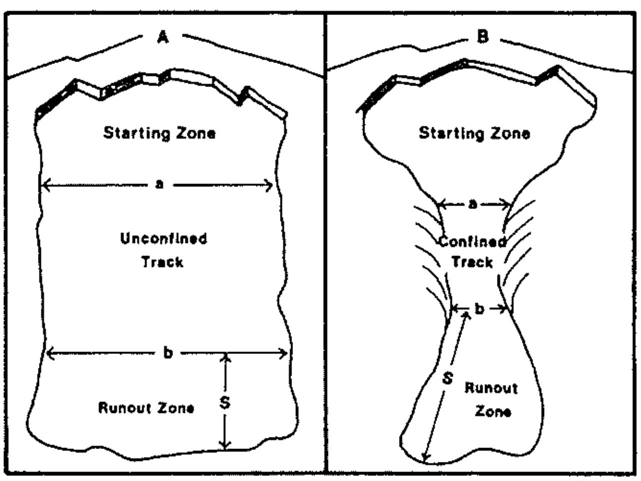


FIGURE 8.26 Comparison of an unconfined avalanche path (A) and a confined avalanche path (B). In path A, the runout distance, S, is not affected by the width of the starting zone because concentration of discharge does not occur at (a) and (b). In path B all the released snow is conveyed through the confined track at (a) and (b). Therefore, the runout distance, S, in path B depends on the size of the starting zone (Mears, 1976, after Salm, 1975).

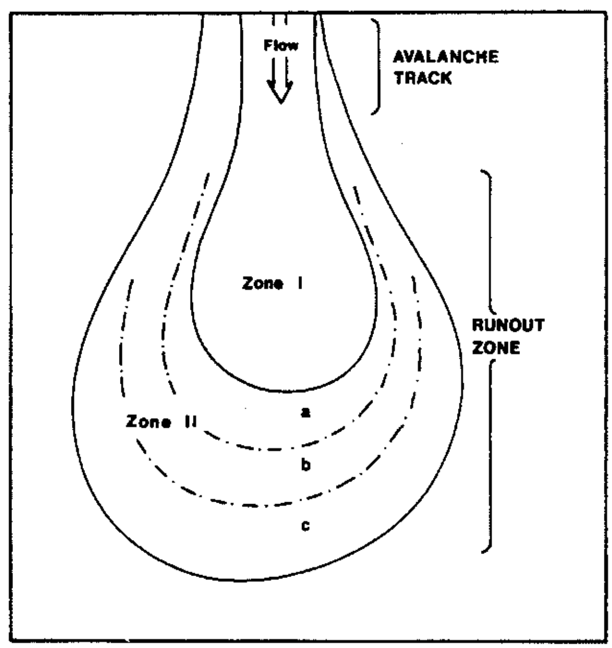


FIGURE 8.27 Runout zones of an avalanche path. Zone I is high hazard affected by avalanches with either short return periods or large impact pressures. Zone II is affected by both longer return periods and lesser impact pressures than Zone I. Hazard level decreases toward the outer margin of Zone II (Mears, 1976).

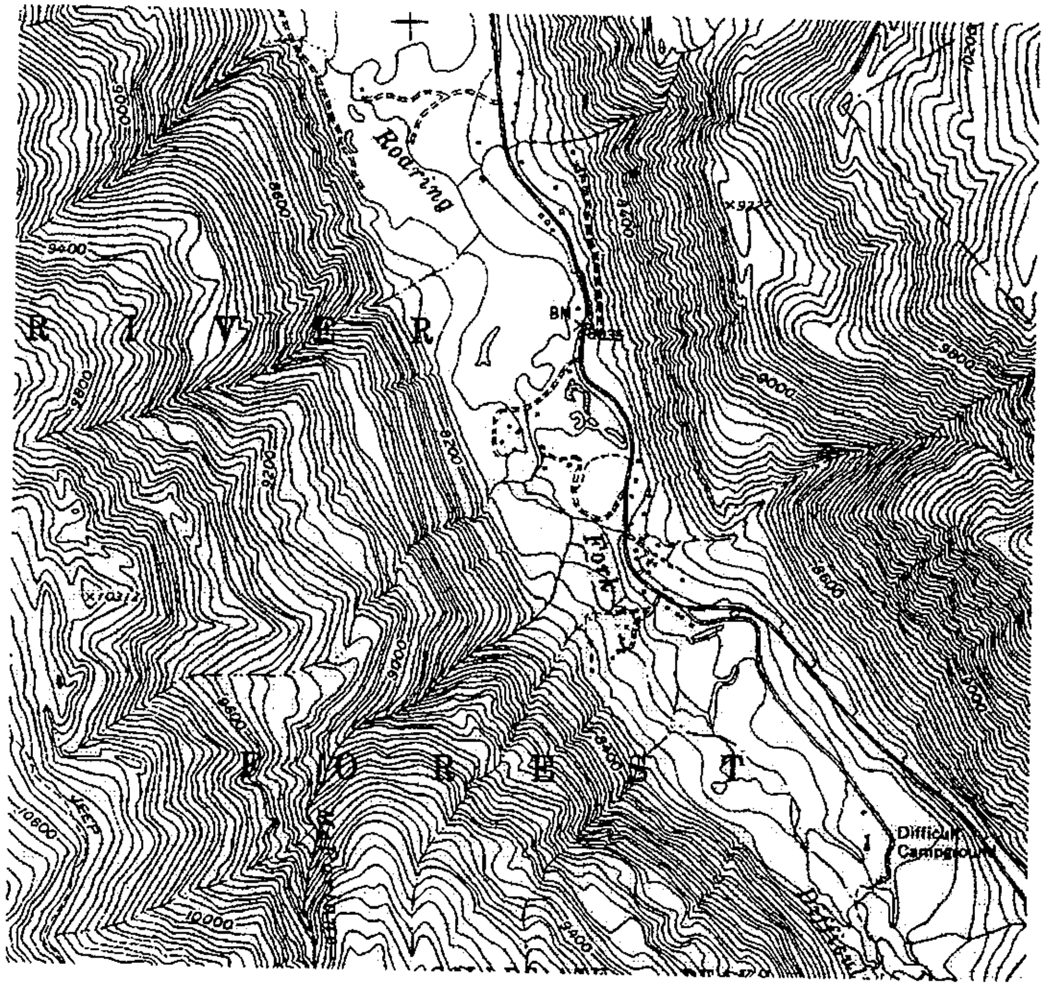


FIGURE 8.28 Topographic map of part of the Aspen, Colorado, quadrangle.

map of the area. Figure 8.29, in the maps section at the back of the book, shows avalanche paths near Aspen. You must first measure the area of the starting zone in square feet or meters and convert this measurement to hectares. Outline your starting zone on the map of Aspen. Also outline the beginning and end of the runout zone. Show your calculations.

Runout zone length _____

5. a. How does the runout distance you calculated for the McFarlane Creek runout zone compare with the length of the runout zone shown on the map?

b. Do the results suggest any changes for the map?

6. Notice that the contours at the mouth of McFarlane Creek bend away from the range front out into the valley. They represent a debris fan or alluvial fan. Are there other debris fans along the valley of Roaring Fork that could be related to avalanche activity? If so, where are they?

7. What evidence would you look for in the field to determine whether debris fans, such as at the mouth of McFarlane Creek, is related to stream deposition or avalanches?

8. The colored map of the Aspen area was published in 1972. Did McFarlane Creek avalanches present a hazard to people at that time? Explain your answer.

9. Compare Figures 8.28 and 8.29 (the colored map). Identify changes in human use of the land at the base of McFarlane Creek that occurred between 1972 (the date of the original base map used in compiling Figure 8.29) and 1987, the date of the revised map in Figure 8.28.

10. How have changes in human use of the land at the base of McFarlane Creek increased or decreased hazards from avalanches since 1972?

Alta, Utah

11. First, let's look at a typical small-avalanche site on the Alta map (Figure 8.30). Carefully identify, in the general area

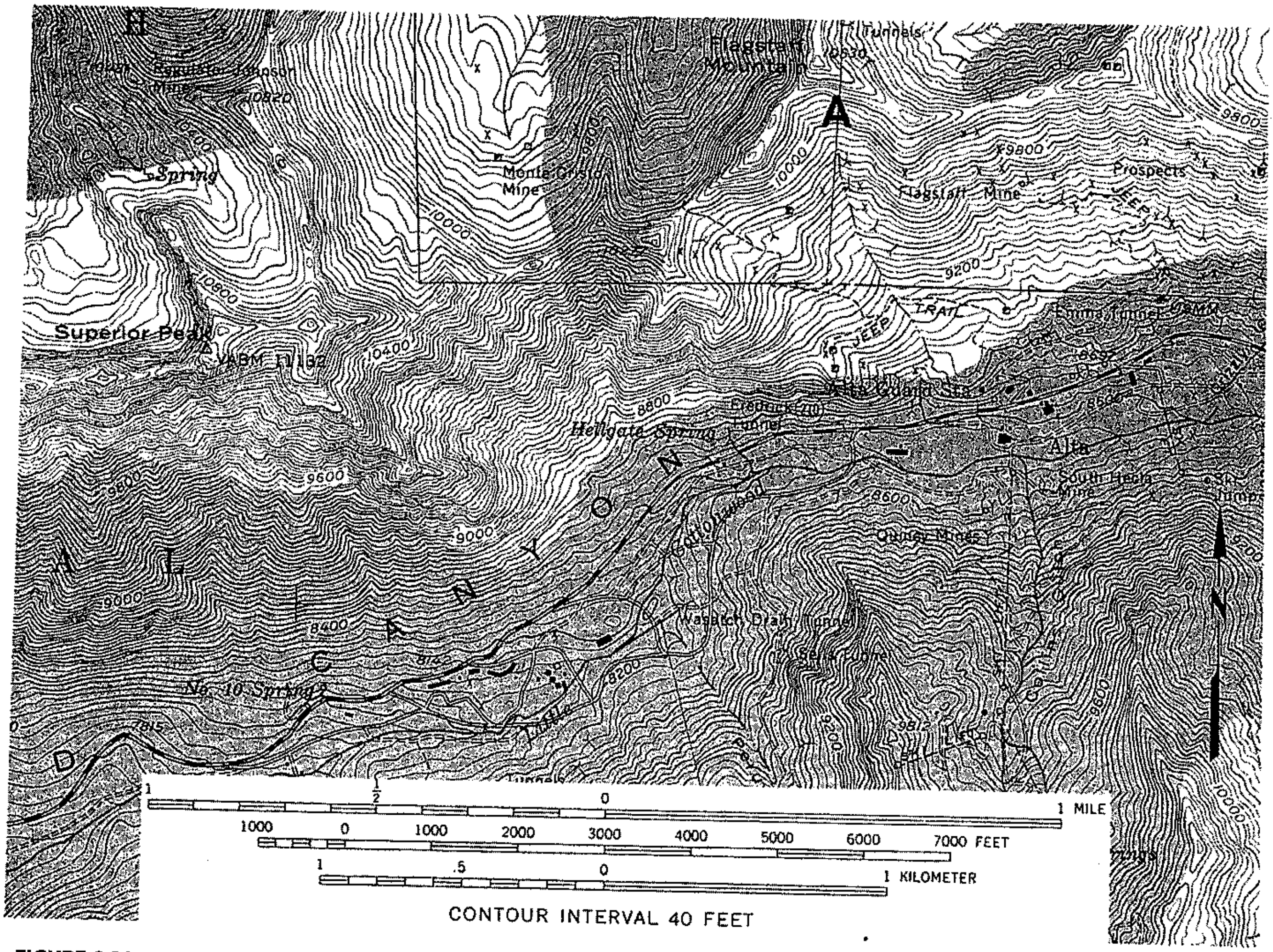


FIGURE 8.30 Topographic map of Alta area, Utah (Dromedary Peak, Utah, 7.5-minute quadrangle).

marked *A* (the gully west of the Flagstaff Mine, on the southeast side of Flagstaff Mountain), a starting zone for an avalanche that might travel down the gully. Also mark the track and identify a runout zone. Determine the slope angle for the track and calculate the length of the runout zone, based on your data and using the formula given in Question 4. (The formula may not really apply here, but it gives an approximation.) Show your work.

Slope ____

Runout zone length ____

12. The Alta Guard Station and other buildings are shown along the road. Are these buildings at risk for a small avalanche? Explain.

13. Now let's look at the risk of an unconfined avalanche on the same map. From the east side of peak 10277, which is north of Hellgate Spring and southwest of Flagstaff Mountain, draw a line along the 10,000 ft contour for 1 mile east. Refer to Figure 8.24 as a guide, and mark clearly on the map about how far you think that the runout zone from an unconfined avalanche with a mile-long starting zone might have gone. Was the town of Alta at risk for this type of an avalanche? Explain.

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