EXERCISE 11

GROUNDWATER AND KARST TOPOGRAPHY

OBJECTIVE
To recognize the distinctive landforms produced by groundwater and to understand how landscapes are formed by solution activity.

MAIN CONCEPT
The solution activity of groundwater is a significant agent of erosion in regions underlain by soluble rocks such as limestone, gypsum, and rock salt. Where solution activity dominates, it commonly develops a distinctive landscape, karst topography, which is characterized by sinkholes, solution valleys, disappearing streams and, in tropical regions, by residual conical hills.

SUPPORTING IDEAS
1. Karst topography in a given region commonly evolves through a series of stages until the soluble rock is completely removed.
2. The style of karst topography depends on climate and the characteristics of the bedrock.
3. Tower karst is a distinctive type of karst topography common in humid climates.

KARST TOPOGRAPHY
Karst topography develops in humid climates where there is abundant water free to circulate through a soluble limestone terrain. Arid regions are not susceptible to extensive karst development because of low rainfall, and in the cold regions of the arctic and subarctic, groundwater is permanently frozen and not free to circulate. Therefore, tropical, humid regions provide the ideal combination of abundant water and high temperature to enhance the chemical reactions that drive the solution process conducive to the development of karst topography.

Landforms of Karst Topography
The most characteristic landforms of a karst terrain are closed depressions, called sinks, or sinkholes, that range from small pits a few feet in diameter to large basins more than a mile wide. Two main mechanisms are involved in the development of sinks: (1) the roof collapse of near-surface caves and (2) accelerated solution and subsidence in areas of closely spaced fractures.

A second major landform in karst regions is a solution valley, which typically forms where sinks enlarge and merge into a single elongate depression. As a result, a karst region generally lacks a well-integrated surface drainage system. Tributaries are few and are generally very short. Many minor streams appear suddenly as springs in blind valleys, flow for a short distance, and then disappear into sinkholes, so that much of the drainage is underground. Only major streams flow in defined, open valleys.

Karst in Semi-arid Regions
In arid to semi-arid regions, there is a limited amount of water to circulate in the subsurface, so that karst topography is rare or poorly developed. Sinks are typically small and widely separated and are commonly associated with short disappearing streams.

Karst in Humid Temperate Regions
An idealized sequence of stages in the evolution of a karst topography in temperate regions is shown in Figure 11.1. In the early stage (Figure 11.1A), solution activity forms a system of underground caverns that enlarge until, eventually, the cavern roof collapses, thus producing a sinkhole. As the sinkholes increase in number and size, some merge to form solution valleys. When solution valleys become numerous and interconnect, the area is considered to have reached the intermediate stage of development (Figure 11.1B). Continued solution activity removes most of the limestone, so that only scattered, rounded hills and knolls remain into the late stage (Figure 11.1C).

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Tower Karst
The most spectacular type of karst topography is developed in humid tropical regions where abundant rainfall and high temperatures promote rapid solution activity of the surface and subsurface water. The general landscape of tower karst is dominated by residual hills, some more than 1000 ft high.

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A. Early Stage: (1) Surface is nearly flat with a few small, scattered sinkhole depressions. Subterranean caverns are numerous. (2) Throughout the early stage, sinkholes become more abundant and increase in size.

B. Intermediate Stage: (1) Individual sinkholes enlarge and merge to form solution valleys with irregular branching outlines. (2) Much of the original surface is destroyed. There are many springs and disappearing streams. (3) Maximum relief, although not great, is achieved. Differences in elevation between the rim and floor of a sinkhole rarely exceed 200 to 300 ft.

C. Late Stage: (1) Solution activity has reduced the area to the base of the limestone unit. (2) Hills formed as erosional remnants are few, widely scattered, and generally reduced to low, conical knolls.

FIGURE 11.1
Idealized Evolution of a Karst Topography
PROBLEMS

1. The Water Table
The block diagram above shows a hypothetical terrain with its major surface features such as valleys, streams, and lakes. The subsurface is homogeneous except for a small lens of clay near the right margin. Complete the diagram by showing the configuration of the water table and show the direction of groundwater movement with a series of arrows.
2. Mammoth Cave, Kentucky

The pockmarked surface of the Mammoth Cave area of Kentucky is a classic example of karst topography. Many sinks are aligned along joint systems and thus form linear depressions. Some sinks south of Park City are more than 60 ft deep. North of Park City, the number of sinks per unit area diminishes, but a vast underground network of caverns is here, including Mammoth Cave.

a. Study the area carefully and outline the large solution valleys.

b. Locate a stream and trace its course on the photo. Does this stream show characteristics of a typical river system (a network of branching tributaries, a trunk stream, or a valley system, for example)? What features of karst drainage patterns are unique?

c. Is there evidence to indicate that the development of sinkholes is an ongoing process, or did they all form during one particular period of time?

d. How does a sinkhole change with time?

e. What geologic hazards are most likely to be encountered in this area?

f. What particular problems of waste disposal and pollution does a karst area present to a city or to industrial development?
3. **West Texas**

   **a.** Compare the characteristics of the sinkholes in this area with those in Puerto Rico (the photographs below) and with those in the Mammoth Cave area (photographs on the previous page). Consider such features as number, size, shape, and depth.

   **b.** If the areas in all three figures are underlain by limestone, why is the topography of each so different?

   **c.** Trace the drainage system. How does it differ from the drainage in the area shown in the photographs below?

4. **Manati, Puerto Rico**

   The sinkholes in this region are as much as 150 ft deep, and the hills are up to 300 ft high. This is an area of classic tower karst, in which the residual hills have steep sides or are nearly vertical. Many hills are conical, whereas others form elongate ridges. The sinks are star-shaped, elongate, or hemispheric depressions. One is so nearly a perfect hemisphere in cross section that it has been used as the foundation for a giant radio telescope.

   **a.** List the evidence indicating that this topography was not produced by stream erosion.

   **b.** Explain the origin of the elongated hills in this region.

   **c.** Study the area shown in stereo and map the major drainage patterns.

   **d.** How does this type of karst topography differ from that in the Mammoth Cave area?

   **e.** What major factors control the development of tower karst?
The Tower Karst of China

In striking contrast to the sinkhole plains of Indiana and Kentucky, the tower karst topography of southern China presents some of the most spectacular limestone scenery on Earth (see photo below). This area of thousands of square kilometers, once covered by thick layers of limestone, is in an advanced stage of dissection by groundwater. The region consists of a "forest" of hills that rise abruptly from the surrounding terrain. These hills are remnants between sinkholes and solution basins and stand like clusters of towers. These strange mountains, shaped like upended loaves of French bread, form an intricate system of precipitous slopes and overhanging cliffs, with caves, arches, and strange landforms made by solution activity.

Classical Chinese art is noted for portraying these bizarre and exotic landforms, which appear unreal to the foreign eye. Western artists believed that the Chinese masters who painted these landforms were impressionists, but anyone fortunate enough to visit the region realizes that the artists were not visionaries; the shapes they painted were nature's own.
5. **Nanning, China**

This image shows China's Nanning karst area. Although local details are not apparent on satellite imagery, the regional texture of the surface is exceptionally well expressed.

- **a.** What karst landforms (sinkholes, solution valleys, or erosional remnants, for example) dominate the area?

- **b.** What evidence indicates that a fracture system in the bedrock has influenced this area's karst topography?

- **c.** Would the karst landforms in this area be more similar to those of Kentucky, Puerto Rico, Florida, or Texas? Explain the basis for your answer.
Contouring a Water Table

The elevation of the lakes in a region provides important information about the groundwater conditions. The surface of each lake is essentially the surface of the water table. Because the lakes are control points for the elevation of the water table, we can construct a generalized contour map showing the configuration of the water table from those data.

For example, on the map in Figure 11.2, the elevation of Dark Lake is between 120 and 130 ft, the elevation of Glass Lake is between 140 and 150 ft, and the elevation of Clear Lake is between 100 and 110 ft. For convenience, assume that the lake levels are 125, 145, and 105 ft, respectively.

The water table can be contoured by applying the same principles used in contouring the land surface. The 140- and 130-ft contour lines would be located between Dark Lake and Glass Lake, and the 120- and 110-ft contour lines would be located between Clear Lake and Dark Lake. We thus observe that the water table slopes to the east.

FIGURE 11.2
Contouring a Water Table
In the figure, brown lines represent surface contours and blue lines are contours on the surface of the water table.
6. Southern Florida

a. Determine the elevation of most of the large lakes in this area, and construct a contour map of the surface of the water table. (Refer again to Figure 11.2 and the discussion of how to contour the surface of a water table.) Use CI = 10 ft.

b. Construct a topographic profile along line A-A'. Draw the water table with a blue line. Be sure to show how Gum Creek influences the water table.

c. Use a series of arrows to indicate the general direction of groundwater movement on the map.

d. How deep would you have to drill to obtain water if the well site were located at the road intersection 1 mi west of Interlachen?

e. Many farms, small industries, and urban centers dump all of their untreated liquid waste into the subsurface. What happens to this waste? In what direction would the waste contaminants move in this area?

f. What natural hazards (floods, landslides, subsidence, earthquakes, or erosion) have the most geologic significance in terms of influencing construction work in this area?
7. Southern Florida

In recent years, the rapid urban development of Florida’s Dade County has posed a serious threat to the environment, despite the efforts of some residents to maintain environmental quality. Most of the land surface in south Dade County is fewer than 10 ft above high-tide level, and the highest areas are only 25 ft above sea level. Water is the primary environmental concern here. For this reason, Dade County and its adjacent counties are part of a regional water control system developed to conserve and protect both the surface water and groundwater and to control freshwater and saltwater flooding. The water-control measures include management of the drainage canals as well as water conservation and management of storage areas.

The major drainage ways shown on this Landsat image include patterns of water movement in natural drainage ways, the Everglades Swamp, and canals. The canals form a system designed to reduce flood damage from storms and tides and to conserve fresh water.

A limestone sequence underlying the area contains two aquifers. The upper one, the Biscayne Aquifer, extends from the surface to a depth of 120 ft and is the source of the area’s fresh water. The other aquifer, the Floridan Aquifer, is more than 800 ft below the surface and contains only brackish and salt water.

Water problems now being faced by south Dade County are saltwater intrusion into the Biscayne Aquifer, contamination of the aquifer by recharge from canal and surface waters, and depletion of the aquifer. The demand for water to serve the residents of the community has lowered the water table in the Everglades and threatens the natural flora and fauna there.

In an area of such low-lying topography, drainage problems are serious as well. Flooding is always a potential hazard. Drainage canals have helped to control the flooding, but the canals adversely affect the ecosystem of the Everglades by diverting the swamp’s freshwater source. To prevent drainage problems in urban areas, building codes that require a minimum elevation for lots and streets have been established. The consequent storm runoff, which results from urbanization, increases the flooding from the high tides caused by hurricanes.

South Dade County faces the environmental problems that plague all urban areas, plus the problems created by the county’s particular physical characteristics. Changes are occurring rapidly, as the natural forests and the Everglades are being converted to agricultural use and eventually to commercial and residential development.

a. Use a series of arrows to show the natural surface drainage patterns in southern Florida on the photograph.

b. What effect has the construction of canals had on this drainage?

c. What areas would be most susceptible to damage from hurricanes and heavy rainfall?

d. What effect would the Florida Keys have on hurricanes approaching from offshore?

e. What particular problems need to be considered before building on a limestone terrain?

f. Why has most of the urbanization of this area been concentrated in its present location near the east shore?

g. How would you expect the pattern of urbanization to appear 20 years hence?

h. What would be the best sites for the disposal of solid waste? Why?

i. What problems are likely to result from excessive pumping of groundwater?