CHAPTER 10

GLACIATION

Better quality images can be found at http://www3.nd.edu/~cneal/PlanetEarth/Lab-Glaciation/index.html

MATERIALS NEEDED

- Pencil and eraser
- Colored pencils
- Ruler
- Calculator
- Stereoscope (provided by instructor)

INTRODUCTION

Glaciers are slow-moving, thick masses of ice that form when low temperatures and sufficient snowfall allow winter snow and ice to survive the summer. Where glaciers occur, they dramatically shape the landscape by their ability to erode, transport, and deposit huge quantities of sediment. Glaciers are currently found on many tall mountains around the world as well as across most of Antarctica and Greenland. In the geologically recent past (before about 10,000 years ago), vast ice sheets also covered much of Canada and the northern parts of the U.S., Europe, and Russia. In this lab, you will learn to recognize and analyze on aerial photographs and topographic maps erosional and depositional features of glaciers. You will also learn how measurements taken over a period of years can be used to monitor the activity of a glacier in response to changes in climate.

There are two main types of glaciers: *alpine* and *continental*. **Alpine glaciers** occur in mountains. They typically begin at high elevations and flow down preexisting stream valleys to lower elevations, where they melt, as shown in Figure 10.1. As ice moves downhill, it erodes the valley and imparts a character to it that is unmistakable: a glaciated valley is straighter, deeper, and wider than the original stream valley, and has a U-shaped, rather than V-shaped, cross profile. Should the ice melt and the glacier recede from the valley, evidence of its presence is etched into the landscape.

Continental glaciers are thick, broad ice sheets that spread out to cover virtually the entire landscape (Fig.10.2). They may reach thicknesses of 4000 m or more, and they are not confined by valley walls. Present-day continental glaciers cover most of Antarctica and Greenland, but during the Pleistocene Epoch of the Quaternary Period, approximately 2 million to 10,000 years ago, much of the land area in the northern hemisphere was covered.

Material eroded by glaciers is transported by the moving ice and by meltwater. Deposition occurs when the ice melts or the running water slows. The depositional features of alpine glaciers, formed in valleys or at valley mouths, are distinctive when young. However, because they are in areas of active erosion, they largely disappear within a few tens of thousands of years, geologically a very short period of time. Continental glacier deposits, on the other hand, may be several hundred meters thick and impart a distinctive character to the landscape that remains for many tens of thousands of years. Some glacier deposits have been converted to sedimentary rock and have survived for more than two billion years.

FORMATION, MOVEMENT, AND MASS BALANCE

As snow accumulates over years at high elevations or high latitudes, the lower parts of the snow mass compact and eventually recrystallize to ice. When thich enough (about 60 m), the ice begins to flow under its own weight. Alpine glaciers flow downhill until they melt or hit the ocean. Continental glaciers flow outward from where they are thickest, usually areas of highest snow accumulation, and continue until they cross into warmer climates or hit an ocean. In both cases, a great deal of rock is frozen into the ice where it is in contact with the ground. As the ice moves, it picks up this rocky debris and carries it along.

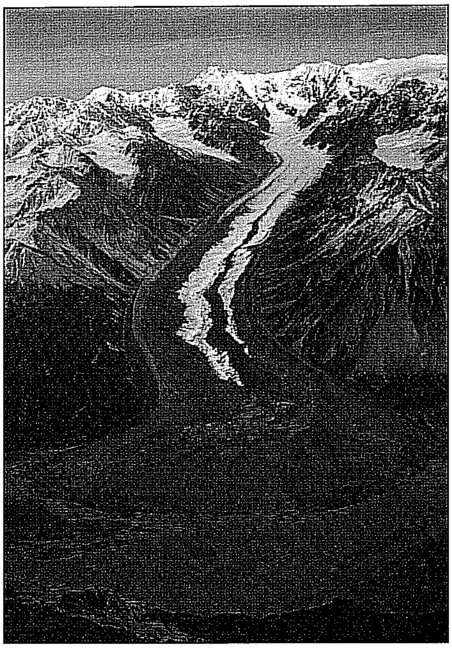

FIGURE 10.1
Oblique aerial photograph of a retreating alpine glacier near Mt. Spurr, Alaska, taken in late summer. The glacier starts in a cirque and flows down the valley to its terminus, which is marked by a prominent end moraine. The sides are marked by lateral moraines, and medial moraines occur within the glacier. The snow line is at the elevation where the medial moraines disappear; it approximates the equilibrium line.

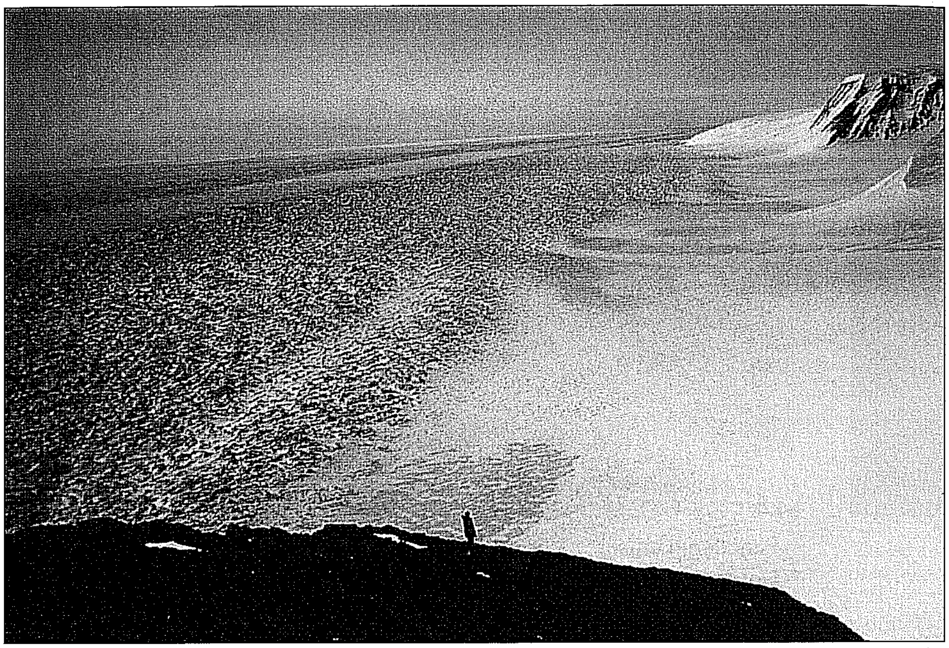

FIGURE 10.2
Oblique aerial photograph of Antarctica, illustrating the vast sweep of a continental glacier.

Figure 10.3 shows a longitudinal (lengthwise) cross section of an alpine glacier. Snow accumulates in the **zone of accumulation.** As old snow is buried, it moves downward and is converted to ice. Eventually it flows downhill until finally at lower, warmer elevations, the surface ice melts away in the **zone of wastage** (or **ablation**). The boundary between these two zones is the **equilibrium line.** Continental glaciers also have these zones.

The **mass balance** of a glacier is the annual difference between the mass of glacier ice added to the zone of accumulation and that lost from the zone of ablation. In perfect equilibrium, the mass balance is zero and the front edge of a glacier neither advances or retreats. A **positive mass balance** means an excess of accumulation over loss, which means that the front of the glacier will **advance** farther down the valley. A **negative mass balance** means more melting than accumulation and thus that the glacier front will **retreat** up the valley. In both cases, gravity ensures that the ice *within* the glacier is always moving forward. Whether a glacier front advances or retreats depends on the rate of forward movement of ice within the glacier, which is driven by accumulation, compared to the rate at which summer melting removes ice at the front edge.

Alpine glaciers are very sensitive to climate change. Many glaciers in Europe and western North America advanced substantially during the Little Ice Age, a cold spell lasting from about 1350 to 1850, and most alpine glaciers around the world are retreating in response to global warming over the past few decades. Continental glaciers also respond to climate change, but over the longer timescales of centuries and millenia. During the Pleistocene Epoch (1.8 million to 10,000 years ago), climatic fluctuations caused continental glaciers to advance and retreat as many as 21 times. Clearly, the study of glaciers is important to our understanding of the causes and effects of past and future climate change.

Erosional Landforms

A mountainous area that is or has been occupied by alpine glaciers has distinctive erosional landforms, as shown in Figure 10.4.

A **cirque** is an amphitheater-shaped depression high on a mountain, which either is or was filled with glacial ice (Fig. 10.3). If it does not contain ice, the bottom may be the site of a bedrock-basin lake, a **tarn.** The upper end, or headwall, of a cirque is very steep, and erosion by frost and glacial action causes it to migrate headward with time. *Cirque glaciers* are no larger than the cirque itself, but for many *valley glaciers,* the cirque is simply the head of the glacier; cirque and valley glaciers are types of alpine glaciers.

Headward erosion of cirques from opposite sides of a ridge may eventually cause them to join and carve a low point, or *pass,* in the ridge called a **col.** The intersection of three or more cirques may result in the formation of an isolated high peak called a **horn.**

Valley glaciers reshape preexisting stream valleys with V-shaped cross profiles into **U-shaped valleys.** (Fig. 10.4) Depressions left in the upper part of such valleys may be occupied by several small lakes connected by a stream; when viewed from the air or on a map, they look like a string of beads and are called **paternoster lakes.** The divides or ridges between adjacent glaciated valleys are commonly sharp, jagged features known as **arêtes** (a rets´). Small tributary glaciers are unable to erode

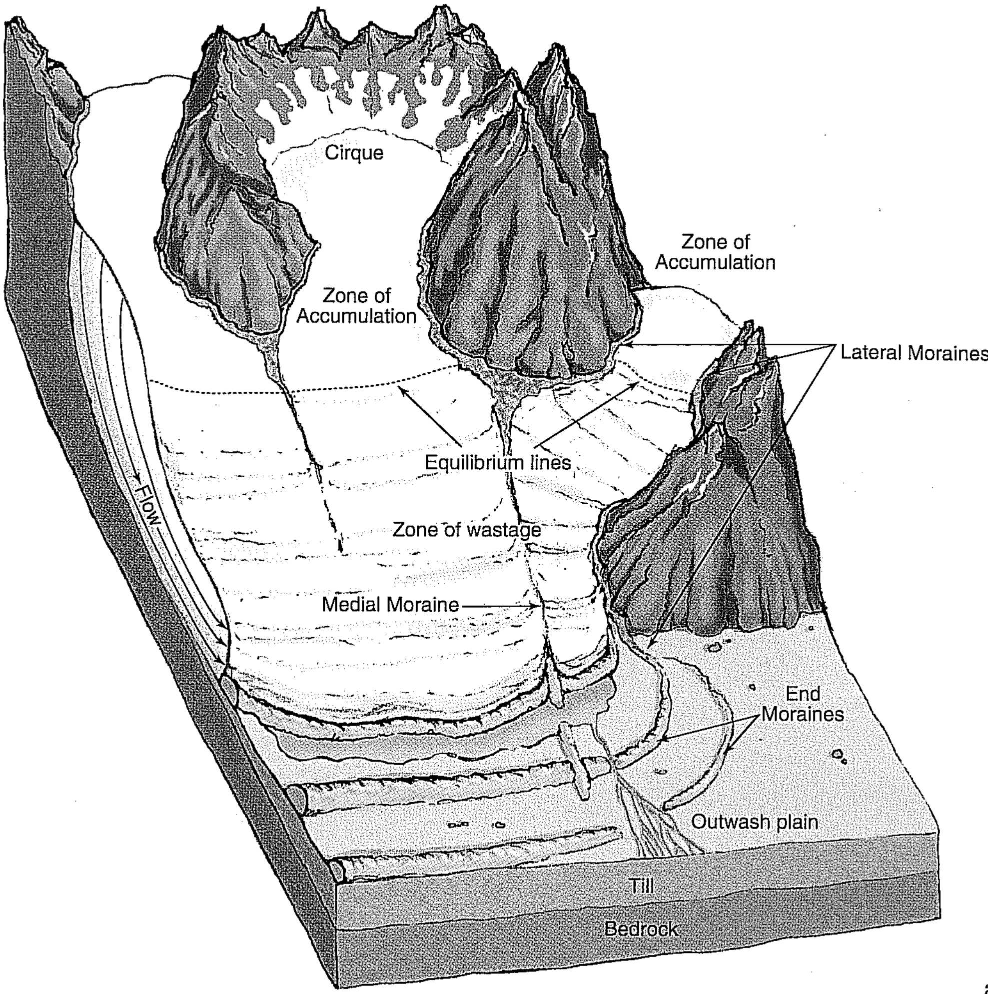

FIGURE 10.3
Glacier cross section illustrates how ice flows from the zone of accumulation, past the equilibrium line, to the zone of wastage. An end moraine forms during a pause in the retreat of the front edge, which allows flowing ice to bring sediment forward to a single stationary line. A cirque, lateral and medial moraines, and a braided outwash stream are also shown.

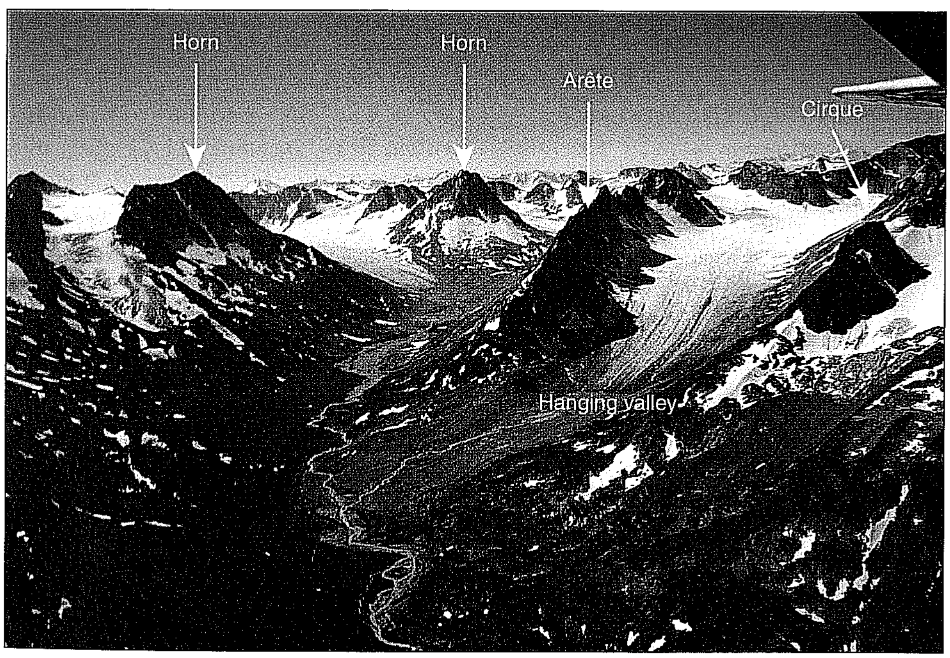

FIGURE 10.4
Oblique aerial photograph of the eastern side of the Juneau icefield, British Columbia. The U-shaped valley in the foreground was carved by an alpine glacier. Cirque and small valley glaciers are still present in the background. Other features characteristic of alpine glaciation are labeled.

as deeply as the large glaciers they join. As a result, the junction of such former glaciers is marked by a **hanging valley,** a U-shaped valley at a higher elevation than the one it joins, commonly with a waterfall. **Fiords** (or *fjords*), which are narrow, steep-sided inlets of the sea, are submerged valleys once occupied by valley glaciers.

Erosion by continental glaciers generally smooths and rounds topography by shaving down hills. Because distinctive erosional features like those formed by alpine glaciers are not left behind, past continental glaciations are best known by their deposits.

Depositional Landforms

Glaciers pick up huge volumes of loose sediment ranging in size from clay to massive boulders and transport it to the zone of wastage (Fig. 10.3). There it can be dropped straight from the melting ice or transported some distance by running meltwater or wind.

The material deposited in association with a glacier is called **glacial drift.** Two

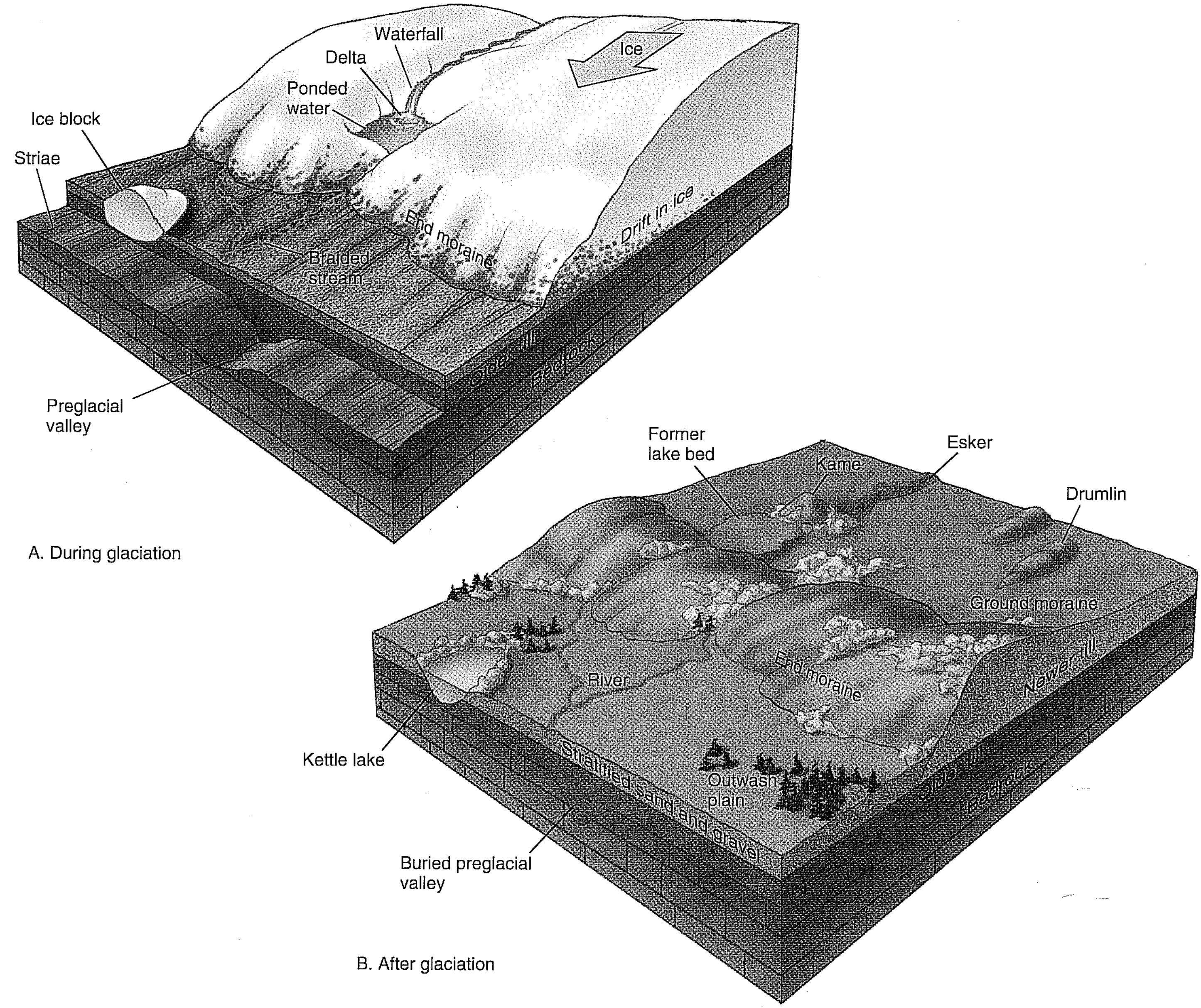

FIGURE 10.5
A. Terminus of continental glacier. B. Same area several thousands of years after retreat. Bedrock is solid rock that underlies soil and loose sediment.

kinds of drift are **till** (unsorted, unstratified debris deposited directly from ice) and **stratified drift** (sorted and stratified debris deposited from glacial meltwater).

Moraines are landforms composed mostly of till that form on or within a glacier, or are left behind when the ice melts. Figures 10.1 and 10.3 illustrate moraines on alpine glaciers that are named on the basis of their position. **Lateral moraines** are low ridges that form on each side of a glacier largely from rocks falling from valley walls. A **medial moraine** is a ridge that forms in the middle of a glacier when two valley glaciers merge and combine lateral moraines (Fig. 10.3). **End moraines** are ridges that form when a glacier achieves equilibrium for a period of time before retreating: the front edge remains stationary while the ice conveyor continues to bring sediment to the zone of ablation (Fig. 10.3). A glacial advance will destroy an end moraine. Continental glaciers form long, curved end moraines that reflect the main lobes of ancient retreating ice sheets. **Ground moraine** is the uneven blanket of till between the other moraines.

Stratified drift deposits are most prominent at the end of the glacier, where they consist of **outwash**—sand and gravel washed out of the glacier by running water. Outwash deposited in a valley forms a **valley train.** An **outwash plain** forms where braided meltwater streams deposit sediment over a wide area. Outwash plains are common features in areas of continental glaciation, as illustrated in Figure 10.5, but also form where alpine

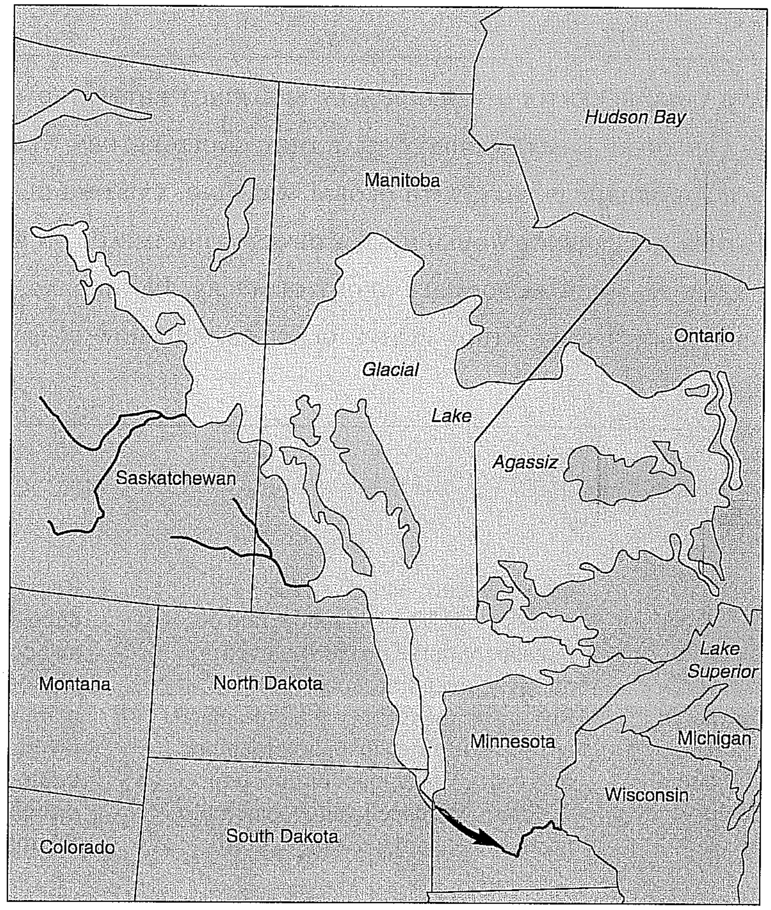

FIGURE 10.6
Maximum extent of Glacial Lake Agassiz (purple area). Blue areas within Glacial Lake Agassiz are present-day lakes. Arrow indicates drainage of Glacial River Warren; the valley is now occupied by the Minnesota River.
Source: Data from illustration by J.A. Elson, in Mayer-Oakes, *Life, Land and Water,* 1967. University of Manitoba Press, Winnipeg, Manitoba, Canada.

glaciers flow out of a valley and spread out (Fig. 10.1). Some outwash plains, formed during glacial retreat, contain abundant, undrained depressions called **kettles** or, if filled with water, **kettle lakes,** which form by the melting of buried blocks of ice (Fig. 10.5). Deposits of stratified drift that form beneath or within a glacier include **eskers** and **kames,** as shown in Figure 10.5. An esker is a long, narrow, winding ridge formed by deposition from a stream flowing within or at the base of the ice. A common type of kame is a steep-sided mound formed where meltwater flowed into a depression or hole in the ice. Eskers and kames are common features of continental glaciation in some areas, but are usually destroyed by erosion in alpine settings.

Figure 10.5 also illustrates **drumlins,** which are streamlined, elongated hills that are steeper on one end. The steeper end faces the direction from which the ice advanced. Typical drumlins are 400 to 800 m long and 8 to 60 m high. They form in swarms near the outer edge of continental glaciers and appear to have been molded from glacial drift by the advancing ice.

The effects of continental glaciation extend beyond the ice itself. Abundant meltwater may pond to form large **proglacial lakes** on the perimeter of the melting glacier, as illustrated in Figure 10.6. Sedimentation in such lakes results in a flat surface, recognizable long after the water has drained away. In some lakes, drainage occurred in stages, and *former shorelines* are left to record these stages.

Rivers draining these lakes may carve large valleys, which are later occupied by much smaller rivers. Such *underfit* streams are obviously too small to have carved the valley they now occupy. An example is the present-day Minnesota River, which occupies a broad valley cut by Glacial River Warren as it drained Glacial Lake Agassiz (Figs. 10.6 and 8.14).