ice-walled lakes to drain, and their sediments, which had accumulated layer upon layer to a considerable thickness, were left high and dry as flat-topped hills (fig. 8.4c). By the end of the melting period, at about 9k B.P., a reversal of the original topography had taken place, so that the fossils of lake-dwelling organisms are found on what are now hill tops.²⁴

The Great Proglacial Lakes

The melting of the great ice sheets naturally produced enormous volumes of meltwater; the meltwater formed extensive proglacial lakes dammed on one side by cliffs of ice (see chapter 1). Many of the lakes were vast, and all of them changed their shapes and positions continuously as the ice front itself shifted. These great freshwater lakes were second in importance only to the ice sheets themselves as components of what may be called the geographical scenery (the view as it would have appeared from a satellite) during the late Pleistocene and early Holocene. The period of the great proglacial lakes lasted from about 15k B.P. when the first, comparatively small lakes began to form, until about 8k B.P., by which time, although large remnants of the ice sheets still existed, their margins no longer dammed any sizable lakes.

The lakes were of tremendous ecological importance in a number of ways. The aquatic ecosystems that developed in them were as much a part of the postglacial biosphere as the terrestrial ecosystems on dry land; the lakes also influenced the neighboring terrestrial systems by forming barriers to migrating land plants and animals for part of the time and then, when a lake shifted its position or drained away, by leaving a tract of newly exposed lake mud ready for colonization. The presence of huge bodies of water adjacent to the ice affected the climate. The lakes were also junction points in a drainage network whose pattern changed repeatedly as the ice sheets wasted away; for example (see Glacial Lakes Agassiz and McConnell in this chapter), rivers that had drained to the Gulf of Mexico at glacial maximum subsequently changed course and drained first into the Arctic Ocean and then into the Atlantic. Lastly, some of the rivers flowing out of the lakes came into existence abruptly and spectacularly in a way that has no parallel in the modern world (see following section).
This chapter outlines the history of these great proglacial lakes over the 7,000 years (approximately) of their existence. The time interval covered crosses the Pleistocene/Holocene boundary, which most geologists put at 10k B.P. This date is not arbitrary, in spite of its being such a satisfyingly (and suspiciously) round number. The millennium centered on 10k B.P. was marked by rapid and profound changes in the terrestrial biosphere, as we shall see in chapters 11 and 12, making the date a useful boundary point in the paleoecological history of the land. But there was no correspondingly abrupt change in the progress of the lakes.

Progress is the appropriate word: the earliest, comparatively small lakes formed in the west, south of the Cordilleran ice sheet; they were followed by lakes on the western and southwestern sides of the Laurentide ice sheet. With the passage of time, as Laurentide ice—the dam that retained them—wasted away, these latter lakes migrated eastward, growing enormously. To follow the story, therefore, we shall proceed forward through time and simultaneously forward (from west to east) through space.

Glacial Lakes Missoula and Columbia
The two greatest western lakes, Glacial Lake Missoula and Glacial Lake Columbia, formed immediately to the south of the Cordilleran ice sheet some time before 15k B.P.¹ (fig. 9.1). As already noted, they were comparatively small as proglacial lakes go, but this does not mean they were small by modern standards. At its maximum, Lake Missoula was about 300 kilometers long, and its volume was about equal to that of modern Lake Ontario, somewhat over 2,000 cubic kilometers.

What makes Lake Missoula remarkable is that it alternately filled and emptied in a cycle that was repeated more than forty times in a period of perhaps 1,500 years. The cycle operated as follows.²

The lake was contained by rising ground to the southwest and by the ice sheet to the northeast. There was also, at its extreme western end, a relatively narrow ice dam formed by a southward-pointing tongue of ice known as the Purcell trench lobe; the tip of the lobe filled the valley now occupied by Lake Pend Oreille in northern Idaho. It was the behavior of this lobe that governed the lake’s cycles. Let us trace one cycle from the moment when the lake had last emptied.

The climate was gradually warming, and the ice sheet steadily melting. Therefore, accumulating meltwater slowly filled the lake basin. The process continued in orderly fashion for several years. Fi-

nally, however, the lake became so deep that the ice dam at its western end began to float; the rising water lifted the buoyant ice clear of the lake floor, so that it no longer functioned as a dam, and the outcome was a catastrophic flood as Lake Missoula’s waters suddenly flowed out under the ice, first into Lake Columbia and then in tremendous torrents that swept over the land and into the Columbia River valley. The whole lake probably drained away in less than two weeks.⁴ Such a flood, caused by the failure of an ice dam, is known as a jökulhlaup (the Icelandic name, pronounced yo-kul-hape), or a glacial outburst. After each one, surging ice formed a new dam, Lake Missoula refilled, and the cycle repeated. There are believed to have been at least forty of these floods at intervals of between twenty and sixty years. They created the so-called channeled scablands of eastern Washington.

The evidence for these spectacular events is geological. There are channels where the floodwaters flowed out, of which the greatest

![FIGURE 9.1: Glacial Lakes Columbia and Missoula south of the Cordilleran ice sheet at about 14k B.P.](image-url)

The swarm of arrows mark the Channeled Scablands, across which floodwater flowed when a jökulhlaup emptied Lake Missoula. GC, Grand Coulee; P, Purcell Trench lobe; S, M, respectively, sites of the modern cities of Spokane, Washington, and Missoula, Montana.
is the Grand Coulee. And there are sediments left by the floods in lakes downstream of Lake Missoula. Fine-grained sediments accumulated on the floors of these lakes in the years between floods, but each succeeding flood from Lake Missoula deposited a bed of boulders, pebbles, and coarse gravel. As a result, alternating layers of fine and coarse sediments are now found in the downstream lakes.

It is also possible to discover the duration of each quiescent period between one flood and the next. The sediments laid down during a quiescent period formed clearly distinct annual layers, which can be counted. Annual layers of sediment (known as varves) accumulate in any still lake fed by streams that freeze in winter. In spring and summer, while the streams are flowing, they bring in sand and silt; for the rest of the year, while they (and the lake surface) are frozen, the only material settling on the lake floor is clay fine enough to remain suspended in the lake water for long periods. Thus a varve—one year's sediments—has a lower layer of sand and silt and an upper layer of clay.

The retreat of the Cordilleran ice sheet was thus the very opposite of uneventful, at any rate to begin with. It was marked by a series of cataclysmic jokulhlaups. These spectacular happenings did not take place in a lifeless world, and it is worth contemplating their ecological effects. The floods were obviously violently destructive, so the effects must have been negative. Each time Lake Missoula began to fill after one jokulhlaup, an aquatic ecosystem no doubt began to establish itself in the lake, but it could not have developed much before being entirely wiped out by the next jokulhlaup. The same must have been true of all the lakes and rivers that served as channels for the floods. Thus most bodies of fresh water in the region—in what is now the eastern half of the state of Washington—would have been noticeably lacking in aquatic life and probably differed conspicuously from waters that the floods bypassed.

The first jokulhlaups must also have swept away large quantities of terrestrial vegetation and the soil in which it was growing. The devastated region, the unattractively named channeled scablands, was initially covered with a thick deposit of loess. Pollen studies show that it probably supported a patchwork of woodlands and grasslands. Sagebrush was abundant in the grassy patches; the woodlands contained spruces, firs, and pines. The pine pollen is believed to be that of species of five-needle pines; assuming that the climate was much cooler and wetter than it is now, whitebark pine and western white pine are the most likely possibilities.

This was the land over which the jokulhlaups from Lake Missoula flowed periodically. The first floods eroded deep channels, which later floods followed. Huge quantities of soil, subsoil, and weathered rock were swept away, to be deposited downstream as outwash. The channel floors now have only thin soil and scanty vegetation over the basal bedrock. Elongated "islands" of undamaged land, with the vegetation intact, were left between the runoff channels. Later, perhaps between 12k and 8k B.P., some tracts of the scoured land developed into patterned ground (see The Starting Conditions, chapter 4) because of frost action. Fossil patterned ground is widespread in the area at present, especially in the northern half of the scablands, and there may well have been more in the past that has since been obliterated by the growth of trees.

Jokulhlaups continue to be fairly common occurrences in glaciated mountains, but modern jokulhlaups are orders of magnitude smaller than those of Glacial Lake Missoula. They also happen where glaciers reach the sea. Cases are known (for example, the Hubbard Glacier in Alaska) in which a surging glacier has closed the mouth of a fjord, turning it into a lake. Such a lake consists of pure sea water initially, but inflowing rivers gradually dilute it. After a time, the ice dam fails, and the lake and the sea outside suddenly become one again. If the dam lasts long enough for the lake to become fresh, both the marine ecosystem that was originally trapped, and later the freshwater ecosystem that developed in place of it, are destroyed. This sequence of events must have happened again and again on the west coast of British Columbia while the Cordilleran ice sheet was retreating. The ecological effects must have been devastating in individual fjords but would not have had widespread consequences for either marine or freshwater life.

**Migration from Beringia**

It was not easy for plants and animals to invade newly ice-free environments when the great ice sheets began to melt. Conditions were harsh and habitats inhospitable, at least to begin with. This was true for both terrestrial and aquatic organisms. Many aquatic organisms faced an additional difficulty: they required continuous water routes for their migrations. Not all kinds of aquatic life require water routes if they are to spread; for example, the seeds of water plants and the eggs of aquatic snails are unharmed by drying and can be carried in a viable state across dry land. But other kinds, especially fish, are completely unable to migrate from one drainage basin to another so long as the basins remain isolated. If a fish population is to spread, links must form, joining its "home" lakes and rivers to others.

The spread of aquatic organisms that had survived the Wiscon-
sin glaciation in Beringia are good examples; they illustrate both the way migrations are begun and the way they are halted. At least six species of fish now living in the drainage basins of both the Yukon and Mackenzie rivers are believed to have survived the Wisconsin glaciation in the Yukon drainage, that is, in Beringia; among them are arctic grayling, northern pike, and lake whitefish. They evidently managed to migrate from their refugium in the Yukon drainage into the Mackenzie drainage, even though the two drainages are now separated by a height of land.

They are believed to have made the crossing in the following way. At glacial maximum, the northern part of the Laurentide ice sheet had spread right across the valley of the Mackenzie River. When the ice started to melt, two proglacial lakes formed (fig. 9.2a), which filled and, in time, overflowed. The upper (southern), Lake Bonnet Plume, flowed into the lower (northern), Lake Old Crow, which flowed in its turn, via the Porcupine River, into the Yukon River. Aquatic organisms of the Yukon River drainage thus had access to the two proglacial lakes, and many migrated into them. Conditions were no doubt bleak. The land around the lakes was probably covered with scanty, high-arctic tundra, and the lakes would have been frozen for nine or ten months of the year.

This drainage pattern was only temporary. When the melting ice front had receded far enough to uncover the Mackenzie valley, the levels of both lakes fell and the channel linking them dried up. The lower lake (Old Crow) continued to empty westward, via the Porcupine. But the upper lake (Bonnet Plume) drained away eastward into the Mackenzie River; it ceased to exist as a lake and became the Peel River (fig. 9.2b).

This explains how species that had survived the Wisconsin glaciation in the Beringian refugium managed to invade the Peel River and its tributaries (which are now part of the Mackenzie drainage) when the ice sheets melted. But once they had reached it, they failed to spread very far. For example, the descendants of the lake whitefish stock that migrated into Lake Bonnet Plume from Beringia are now entirely confined to Margaret Lake (M in fig. 9.2b), a little lake in the valley of one of the Peel's tributaries.

Most of the fish in the Mackenzie River today, except for those in its tributary the Peel, are descended from immigrants that came from the southeast, ultimately from the Mississippi drainage basin, in the southern, unglaciated half of the continent. We return in the following section to the topic of how they made the journey. Before that, two other questions remain. First, how is it known that several fish stocks currently living in the Mackenzie River are descended from

FIGURE 9.2: The drainage reversal that allowed fish of the Yukon drainage to reach the Mackenzie drainage. (a) The early stages of melting: LOC, Lake Old Crow; LBP, Lake Bonnet Plume. Together the lakes drained westward. (b) The modern drainage pattern: the Porcupine River, draining the Old Crow basin flows west; the Peel River, draining the Bonnet Plume basin, flows east. F, the site of the waterfall that blocked upstream migration (it has now disappeared). GBL, Great Bear Lake; GSL, Great Slave Lake; M, Margaret Lake; Mac, Mackenzie River; Porc, Porcupine River.
Mississippian ancestors? Second, why did the Beringian immigrants' descendants fail to spread farther?

The answer to the first question is that the fish stocks in the Peel drainage differ genetically from their relatives in the rest of the Mackenzie drainage. It is clear that they are much closer, genetically, to Beringian stocks than to those in the rest of North America. In other words, they belong to distinct geographical races of their respective species. This is true, for example, of lake whitefish, northern pike, arctic grayling, and also the lake trout discussed in chapter 3. The geographical races differ from each other in such traits as numbers of vertebrae, gill rakers, fin rays, and scales on the lateral lines.

Now for the second question. The failure of the Beringian immigrants to advance farther than they did probably has a geographical explanation. When these migrations were going on, there was a high waterfall (F in fig. 9.2b) in the Mackenzie, only a short distance upstream from the point where the Peel joined it. The waterfall no longer exists because erosion has worn down the ridge over which the river plunged, but while it lasted it must have formed an impassable barrier to fish. Before the waterfall disappeared, fish from the southeast had taken possession of most of the Mackenzie and were able to crowd out any attempted invasions from the north when the route finally became passable, which it did about 6K B.P. How the southerners arrived is the subject of the next section.

Glacial Lakes Agassiz and McConnell

The northward spread of fish—indeed of all aquatic organisms—from the unglaciated half of the continent south of the ice is bound up with the history of two great freshwater lakes: Glacial Lake Agas-
siz and Glacial Lake McConnell. Figure 9.3 shows them at their largest, at about 10K B.P.

The larger of the two, Lake Agassiz, came into existence about 12k B.P. and lasted for about 4,500 years. (It should be noted that experts disagree about these dates.) Its shape, size, and location changed continually (fig. 9.4) before it finally drained away, leaving as remnants only the modern Lakes Winnipeg, Manitoba, and Winnipegois. It was the largest proglacial lake in North America; at its greatest, its area was about 350,000 square kilometers, which is more than four times the area of modern Lake Superior, now the largest freshwater lake in the world.10

The other giant lake, Lake McConnell, came into existence at about the same time as Lake Agassiz; like Lake Agassiz, it reached its greatest extent about 10k B.P. At its longest, 1,100 kilometers, it was longer than any freshwater lake in the modern world. In its early stages it was smaller, and the early version is known as Lake Peace. As it enlarged to its 10k B.P. maximum, it engulfed other ice front lakes. Then, as the ice front drew away northeastward, it separated again, this time into three "daughter" lakes that were left behind by the ice. These lakes were Great Bear Lake, Great Slave Lake, and Lake Athabasca, which have persisted more or less unchanged to the present day. So, in a sense, Lake McConnell still exists.

The two great lakes, McConnell and Agassiz, and the numerous lesser lakes that formed at the ice front, changed continuously in shape, size, and location. The changes were caused in part by the uncovering of new ground and the formation of new drainage patterns as the ice receded and in part by changes in the topography of the land itself, which underwent gradual isostatic adjustments as the weight of the overlying ice was removed. As the lakes changed, their drainages changed too. The arrows in figure 9.3 show some of the links that formed.

Both Lake McConnell and Lake Agassiz switched drainage directions several times over. Lake McConnell (or its smaller predecessor, Lake Peace) is believed to have drained first into Lake Agassiz, then into the Arctic Ocean via the Mackenzie River, then back into Lake Agassiz, and then back to the Arctic Ocean.12

Lake Agassiz, too, shifted its drainage direction four times.13 Initially it drained south into the Mississippi valley. Then, at about 10.7k B.P., the ice front receded, opening up a spillway into the basin of the modern Lake Superior; Lake Agassiz's waters then flowed out to the east, and the level of the lake dropped. The old, southern spillway was left high and dry. Next, at about 10k B.P., lobes of the ice sheet surged southward in a temporary readvance that dammed the
Figure 9.3: Glacial Lakes McConnell and Agassiz at 10k BP. The lightly outlined modern lakes are GBL, Great Bear Lake; GSL, Great Slave Lake; LA, Lake Athabasca; LN, Lake Nipigon; LS, Lake Superior; LW, Lake Winnipeg. The rivers draining Lake Agassiz are Minn, Minnesota River; Miss, Mississippi River. The double-headed arrows show where rivers formed at various times and through which fish could migrate.

The eastern outlet once more; the level of the lake rose until it again overflowed southward to the Mississippi. Finally (about 9.5k B.P.) the ice wasted away for the last time, opening a new outlet to the east; the new eastern outlet was some 500 kilometers farther north than the old, north of the modern Lake Nipigon (see fig. 9.3). At this time Lake Agassiz became joined to a younger, more easterly proglacial lake, Lake Cibbway (to be discussed in the following section), through which it drained away.

It seems likely that the majority of fishes living anywhere in the interior of Canada and the northern United States today have ancestors that, at one time or another, lived in Lake Agassiz. The lake was the hub of migration routes leading from the unglaciated southern half of the continent into most of the drainage basins once covered by the Laurentide ice sheet. Lake Agassiz received most of its immigrants from the south: first from the upper Missouri and its tributaries in the western Great Plains, to which it was linked by superglacial streams flowing across the tracts of stagnant ice southwest of the lake in the Missouri Coteau area; and later from the Mississippi valley, to which it was joined by the Minnesota River. Moreover, Lake Agassiz was sometimes linked, through Lake McConnell, to the Beringian refugia. As a result, fish species that survived the glaciation in refugia both to the south and to the northwest of the ice are now widely spread.

Two such wide-ranging species are burbot and northern pike. Both can withstand the cold of high latitudes. Burbot spawns in late winter, under lake ice; pike in the spring, when the ice is breaking up. Burbot is now spread throughout all the glaciated area except for parts of the Atlantic, Pacific, and Arctic coasts. Pike has nearly the same range, except that it is not found in British Columbia west of the Rockies. The two species survived in both refugia and invaded from both; however, stocks from the two regions differ genetically and it is known that fish of southern ancestry took possession of a far greater area than those from Beringia. The northwestern forms of burbot and pike are found only in Alaska and northern Canada west.
of the Mackenzie River; throughout the rest of their ranges, only the southern forms occur.

Today, there are 106 species of fish in the basin of glacial Lake Agassiz,\(^4\) and all of them must have managed to migrate by at least one of the routes shown in the map in figure 9.3. Successful migrations were by no means assured. The rivers were only occasionally hospitable for fish. At other times they were raging torrents caused by jokulhaups.

For example, between about 12k and 11k b.p. (before Lake McConnell grew big), a row of three ice front lakes existed west of Lake Agassiz that are believed to have drained eastward in domino fashion\(^5\); catastrophic overflow of the first sent huge volumes of water into the second, causing it to overflow catastrophically, and so on. Great abandoned spillways (i.e., coulees) still remain (see the drawing in Ice and Fresh Water, chapter 1); they are believed to have been eroded by floods flowing at as much as 100,000 tons per second.

There were similar catastrophic floods when Lake Agassiz finally drained away eastward\(^6\) at about 9.5k b.p. At one stage, the eastern shore of Lake Agassiz was separated from the western shore of Lake Nipigon (which was somewhat larger then than now) by a strip of land a scant ten kilometers across at its narrowest (see fig. 9.3). Numerous channels crossed the strip, draining Agassiz into Nipigon; they were the routes of spectacular torrents. A fire in 1980 burned away the forest and peat concealing the floor of the aptly named Roaring River channel and exposed a field of enormous boulders deposited by the floods; many were more than a meter in diameter.

The evidence for these dramatic events is geomorphological. Boulder fields show the routes, and the force, of torrential floods; old lake shores, river deltas, and lake bottom deposits, datable by the carbon 14 technique, show where proglacial lakes formed and how they migrated in the wake of the ice front. Ecological data enable us to visualize the settings in which these events occurred and discover their ecological consequences.

First, the settings. At present the region occupied by early Lake Agassiz in 12k b.p. is covered with prairie grassland. The vegetation that first took possession of the ground as the lake migrated northward was entirely different. It was probably an open woodland of

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**FIGURE 9.4:** Some of the changes of Lake Agassiz. (a) The ice front and Lake Agassiz (stippled) at 10k b.p. The solid outline shows the modern Lake Winnipeg for reference. The dashed outline is that of Lake Agassiz at 12k b.p. (b) The ice front and Lake Agassiz (stippled) at 8.4k b.p. The long narrow lakes near its southwestern shore still exist; they are the modern lakes Winnipegos and Manitoba (to north and south, respectively). The dashed outline is that of Lake Agassiz at 10k b.p.
spruce, poplar, paper birch, and ash, with sagebrush-covered clearings providing good habitat for woolly mammoths. Subsequently, the spruce woods were replaced by pine woods, then by oak savanna, and finally by prairie (these events are described below in chapter 11).

The most unusual (to modern eyes) ecological phenomenon of the Lake Agassiz period was the abrupt appearance of an enormous expanse of freshly exposed lake bottom every time a glacial lake was suddenly drained by a jökulhlaup. Huge tracts of wet mud must have stretched as far as the eye could see (possibly there were a few human witnesses). As shown by pollen analysis, the contemporary "weeds" that invaded the newly available land were chiefly sagebrush and ragweed, with marsh vegetation in the wetter spots.

The Precursors of the Great Lakes and Glacial Lake Ojibway

The Great Lakes as they exist now form a single unit, draining into the Saint Lawrence River and out into the Atlantic. At glacial maximum there were no Great Lakes; their basin was completely covered by a lobe of the Laurentide ice sheet, the Michigan lobe. The precursors of the modern lakes were, of course, proglacial (ice front) lakes, and their geography changed continuously. The first two to form, at about 14k B.P., have been given the names Lake Chicago and Lake Maumee. Lake Chicago filled what is now the southern tip of Lake Michigan, and Lake Maumee was a larger version of modern Lake Erie; both drained south, into the Mississippi.

As the ice front retreated, more and more of the basin of modern Lake Michigan was uncovered (equivalently, Lake Chicago grew longer), and meltwater filled the basin of modern Lake Huron. These two bodies of water became joined and are known as Lake Algonquin (fig. 9.5). What had been Lake Maumee was left behind by the ice as a nonglacial lake, the precursor of Lake Erie; a new ice front lake, Lake Iroquois, more than filled the basin of modern Lake Ontario. These lakes drained into the Atlantic via the Hudson River.

Figure 9.5 shows the geography at about 12k B.P., at a time when terrestrial and aquatic ecosystems were rapidly diversifying. Tundra was giving way to spruce forests on the land south of the ice, and aquatic life began to flourish in the glacial lakes. Molluscs of many species became far more abundant than they had been in earlier glacial lakes; there must have been algae and diatoms for them to feed on, and fish to support the clams' glochidia. The map in fig. 9.5 shows two fossil mollusc sites. The fossil collections differ slightly
in age, and the older, Lake Iroquois site yielded only half as many species as the younger, Lake Algonquin site. Perhaps new immigrants doubled the number of resident species in the interval. Trying to draw conclusions from the absence of certain fossils is not wholly convincing, of course; later studies may show that some species were not really absent after all. Even so, fossils provide firmer evidence of past life than do present-day geographical ranges.

The first proglacial lake to form in the basin of modern Lake Superior appeared about 12k B.P. or soon after. It was a comparatively small lake and is known as Lake Duluth; its position coincided with the western tip of Lake Superior, and it was separated by ice from Lake Algonquin and the lakes farther east (fig. 9.6). Like Lake Agassiz and other western lakes, it drained into the Mississippi, thus, it

FIGURE 9.6: (a) The ice front lakes at about 11k B.P., with the Saskatchewan River (Sask. R) connected to Lake Duluth (LD) and the Mississippi (Miss. R). LA, Lake Agassiz. (b) The modern drainage, with the Saskatchewan River flowing into Hudson Bay. Left, mayfly nymph. Right, stonefly nymph.
was a precursor of Lake Superior only in the sense that it occupied the same space (or part of it). But it was not a member, like the modern lake, of a connected set of lakes all draining eastward.

The drainage pattern shown in fig. 9.6a had effects that persist to this day: it almost certainly explains the geographical ranges of many aquatic insects. Numerous species of mayfly and stonefly common in the southeastern United States are also found all across southern Canada from western Lake Superior to the foothills of the Rockies; their ranges include the valley of the Saskatchewan River, which now drains (via Lake Winnipeg) into Hudson Bay (fig. 9.6b). Today these insects would not be able to migrate from one drainage basin to the other. Their immature forms are aquatic nymphs, confined to water; the adult insects are feeble flyers and would be most unlikely to travel from the Mississippi basin to the Saskatchewan basin given the modern drainage pattern, in which the two rivers are separated by a height of land. When they were linked by a chain of ice front lakes, migration must have been easy, however.

No doubt many fish species found their way from the Mississippi refugium into Lake Duluth. Northern pike is believed to be one of them. Several rivers flowing into Lake Superior from the south go over barrier falls (falls impassable to fish). In these rivers, northern pike are found only below the falls in stretches of river accessible to fish swimming upstream from the lake. Muskellunge living in the same rivers are found only above the falls. A possible explanation for the separation of these two closely related fish species is that northern pike did not enter the rivers until after the ice had disappeared and the water level had fallen low enough to make the falls impassable; they were therefore confined to lower stretches of the rivers. Muskellunge, which presumably lived both below and above the falls originally, were crowded out of the lower reaches by the invading pike (there is independent evidence showing that this can happen) and now live only above the falls.

The last of the giant proglacial lakes, comparable in size with Lakes McConnell and Agassiz, was Lake Ojibway (fig. 9.7), which was at its largest about 8.5 k.y. B.P. It lay east of Lake Agassiz and was probably continuous with it. The north shore of the combined lakes, where they were walled by ice, must have been over 3,000 kilometers long. Lake Ojibway was separated from Lakes Superior and Huron (which had approximately their present form) by a height of land, but like them it drained into the Ottawa River, a tributary of the Saint Lawrence, whereas the two lower lakes (Lakes Erie and Ontario) drained into the Saint Lawrence directly.

The position of Lake Ojibway's southern shore is inferred from the present-day ranges of various aquatic animals, especially the...
four-horned sculpin and the opossum shrimp. The opossum shrimp was the sculpin's most abundant food supply. Both species are believed to have migrated into the lake from the south and to have lived in it for as long as it existed. Then, when the lake drained away, the animals were left in the scattering of ponds and small lakes that are all that now remains of Lake Ojibway. They are assumed to have persisted where they survived, but not to have spread, so that a line separating ponds that now contain them from ponds that now lack them represents the ancient shoreline.

Another Lake Ojibway fish was goldeye. It does not occur in the modern Great Lakes, and its main range is to the west of them. But it also occurs in a small disjunct region south of the modern James Bay (the southern “finger” of Hudson Bay) in waters that were once part of Lake Ojibway. The only reasonable explanation for this curious range is that goldeye moved north from the Mississippi basin into Lake Agassiz, and then east into Lake Ojibway, after the link between Lakes Agassiz and Superior had been broken, thus bypassing the Great Lakes.

Lake Ojibway came to a spectacular end about 8.3 k a.p. The ice covering Hudson Bay had weakened along a north-south line, and the northwest arm of the lake, shown in fig. 9.7 as just reaching James Bay, lengthened northward. At the same time an arm of the
sea on the north side of the ice sheet lengthened southward, along the line of weakness. The ice separating sea and lake became a steadily narrowing isthmus. The lake surface was 250 meters higher than sea level. Consequently, the isthmus acted as a high dam, and when it finally gave way, Lake Ojibway emptied into the sea with catastrophic suddenness. Thus ended the last of the giant ice front lakes. To the north of it appeared a "new" sea, which we consider in the next chapter.

10

The Rising Sea

Directly or indirectly, the meltwater from the thawing ice sheets reached the sea. When the thaw began, a large proportion of the ice sheet margins were cliffs of ice rising out of the sea; the cliffs calved off ice bergs that melted as they floated away. Later in the thaw, when the ice sheet margins lay mostly inland, meltwater accumulated in proglacial lakes as described in chapter 9. It flowed out from these lakes through the continent's great rivers: the Columbia and Fraser rivers to the Pacific; the Yukon River to the Bering Sea; the Mackenzie River to the Arctic Ocean; the Mississippi River to the Gulf of Mexico; the Saint Lawrence and Hudson rivers to the Atlantic; and the Saskatchewan, Nelson, and Churchill rivers to Hudson Bay, when the bay finally became ice free. The valleys of these impressive rivers owe their existence to glacial meltwater.

The water itself raised the worldwide level of the sea. Ice sheets in Europe and Asia were thawing at the same time, and contributed some meltwater, but they yielded a much smaller volume than did the North American ice sheets. The rising sea submerged big tracts of shoreline land, converting them from coastal plains to continental shelves. Many ice age refugia became, and remain, inundated. Other low-lying regions were temporarily inundated by the sea but are now high and dry.

The tremendous volume of water involved defies the imagination; at one time or another during the melting period about one-fourth of the whole area of Canada was under fresh or salt water. We have already considered the fresh water; this chapter deals with the expanding sea and the ecological consequences of its expansion.