The southern limit of Cordilleran ice in the Colville and Pend Oreille valleys of northeastern Washington during the Late Wisconsin glaciation

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Abstract: The southern limit of the lobes of the Cordilleran ice sheet in the Colville and Pend Oreille valleys of northeastern Washington during the Late Wisconsin (Fraser) glaciation has been placed at widely different positions by various investigators. The confusion that resulted in these different positions is due to the fact that both lobes, at times, terminated in glacial lakes and much of the terminal area of the Pend Oreille River lobe was swept by floods from glacial Lake Missoula. Evidence, presented in this paper, of the southern limit of these two lobes during the Late Wisconsin glaciation consists of (*i*) the southern limit of Late Wisconsinan till, (*ii*) the southern limit of lateral meltwater channels, (*iii*) meltwater channels whose headward areas coincide with the southern limit of Late Wisconsinan till, and (*iv*) reconstructed ice-surface profiles. This evidence suggests that the southern limit of the Colville lobe is represented by a moraine near the town of Springdale, whereas that of the Pend Oreille River lobe is near the town of Newport. The timing and extent of Late Wisconsinan deglaciation in the Colville Valley are provided by radiocarbon ages and Late Pleistocene tephras at sites upglacier from the terminal position. These data demonstrate that the Colville lobe had retreated at least 50 km by about 12 450 BP. In the Pend Oreille Valley, the presence of a Glacier Peak tephra layer near the town of Ione indicates that the Pend Oreille River lobe had retreated at least 70 km prior to deposition of the tephra.

Résumé : La limite méridionale des lobes de l'Inlandsis de la Cordillère, dans les vallées de Colville et de Pend Oreille du nord-est de l'État de Washington, durant la glaciation du Wisconsinien tardif (Fraser), a été tracée à différentes positions selon les auteurs. La confusion qui en résulte au sujet de ces positions divergentes est due au fait que les deux lobes, à certaines périodes, aboutissaient dans des lacs glaciaires, et qu'en plus la majeure partie de la région frontale du lobe de la rivière Pend Oreille fut balayée par des inondations occasionnées par les débordements du lac glaciaire Missoula. Les arguments invoqués ici pour préciser la position de la limite méridionale de ces deux lobes durant la glaciation du Wisconsinien tardif sont fondés sur (*i*) la limite méridionale du till d'âge Wisconsinien tardif; (*ii*) la limite méridionale des chenaux d'eau de fonte latéraux; (*iii*) les chenaux d'eau de fonte dont les aires de dispersion en aval coïncident avec la limite méridionale du till d'âge Wisconsinien tardif; et (*iv*) les profils reconstruits des glaciers de surface. Ces données suggèrent que la limite méridionale du lobe de Colville est marquée par une moraine localisée près de la ville de Springdale, tandis que celle du lobe de la rivière Pend Oreille est positionnée près de la ville de Newport. La période et l'étendue de la déglaciation au Wisconsinien tardif dans la vallée de Colville sont divulguées par les datations au radiocarbone et par la présence de tephras d'âge Pléistocène sur les sites en amont de la ligne frontale du glacier. Ces données révèlent que le lobe de Colville avait reculé d'au moins 50 km, il y a environ 12 450 ans avant le Présent. Dans la vallée de Pend Oreille, la présence du lit de tephra de Glacier Peak, près de la ville d'Ione, indique que le lobe de la rivière Pend Oreille avait déjà reculé d'au moins 70 km avant le dépôt de ce lit de tephra.
[Traduit par la rédaction]

Introduction

This report documents the southern limit of lobes of the Cordilleran ice sheet in the Colville and Pend Oreille valleys of northeastern Washington during the Late Wisconsin (Fraser) glaciation and the timing and extent of deglaciation in these valleys. Because both glaciers, at times, terminated in glacial lakes (Waitt and Thorson 1983; Atwater 1986; Richmond 1986), and much of the terminal area of the Pend Oreille River lobe (the Little Spokane lobe of Richmond et al. 1965 and Richmond 1986) was swept by outburst floods from glacial Lake Missoula, the southern limit of these ice lobes during the Late Wisconsin glaciation has been placed by various investigators at widely different positions, discussed briefly in this paper (see Weis and Richmond 1965, for a more detailed discussion).

The Colville Valley is a flat-bottomed valley, 2–5 km wide, that trends north and northwest for about 75 km from near the town of Springdale, at an altitude of about 600 m, to its junction with the Columbia River valley, at an altitude of about 400 m (Fig. 1). The Colville Valley is bounded on the west by Huckleberry Mountain, a north-trending ridge, with peaks ranging in altitude from about 1000 to 1750 m. On the east, the valley is bounded by a ridge trending north,

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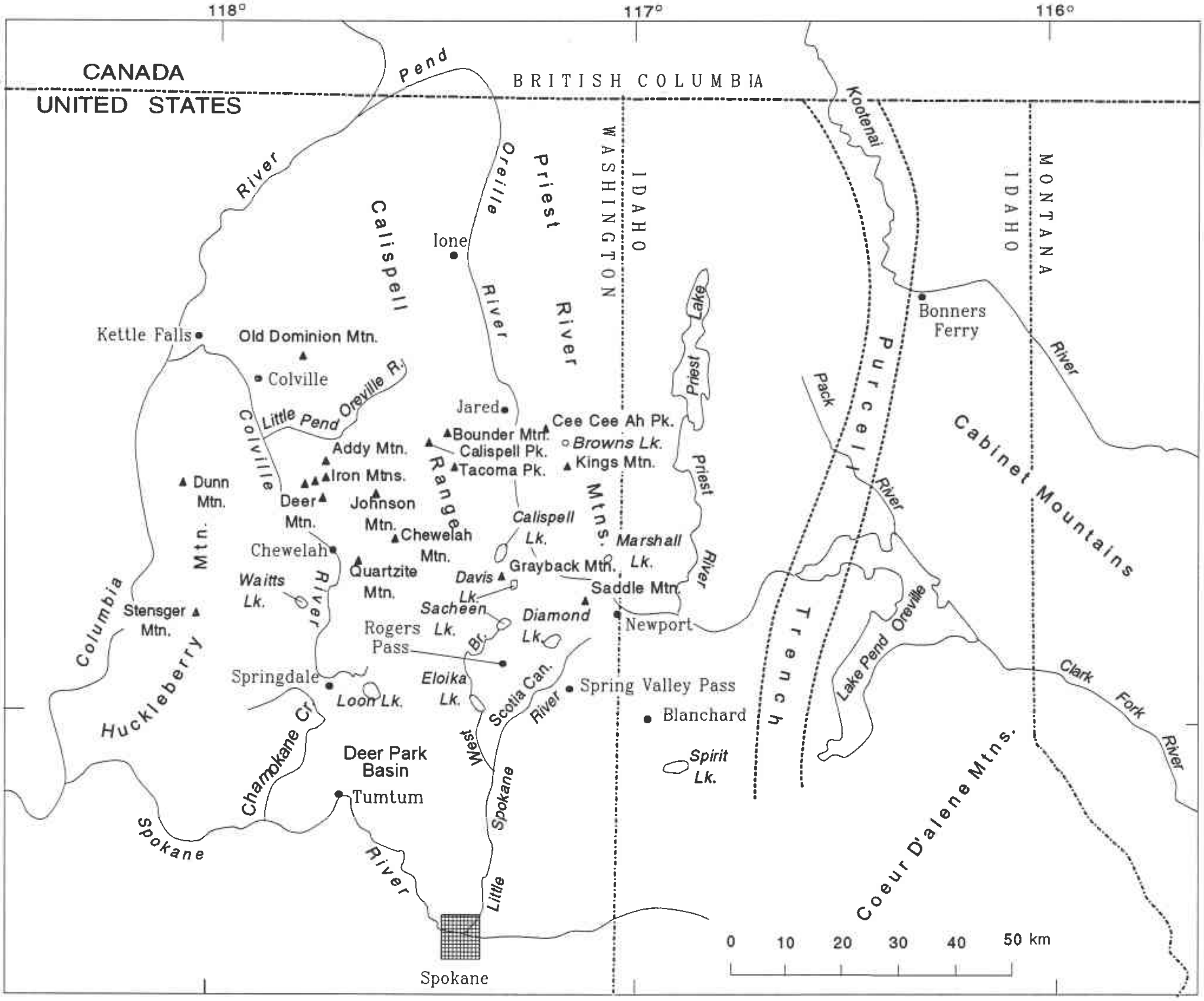
Fig. 1. Location map of northeastern Washington, northern Idaho, and northwestern Montana, showing place names mentioned in text.



informally referred to in this report as the Calispell range, with peaks ranging in altitude from about 1400 to 2090 m. To the south, the low divide between the north-flowing Colville River and the south-flowing Chamokane Creek is underlain by outwash, till, and Holocene alluvium (McLucas 1980). These unconsolidated deposits form an anomalous drainage divide in an otherwise broad, continuous valley. A preglacial Columbia River probably flowed south through the present-day Colville and Chamokane valleys to the Spokane River (Willis 1887).

The Pend Oreille Valley, like the Colville Valley, is also a broad, flat-bottomed valley for much of its length in northeastern Washington. The valley is bounded on the west by the Calispell range (Fig. 1). On the east the valley is bounded by a ridge, informally referred to in this report as the Priest River mountains, with peaks ranging in altitude from about 1200 to 2230 m. Many streams flowing from these mountain ranges north of the town of Newport flow generally southward, suggesting that at one time the Pend Oreille River also flowed to the south. Today the Pend Oreille River flows westward for about 35 km from its source, Lake Pend Oreille, at an altitude of about 630 m, then flows north for about 100 km into Canada, where it turns west for another 30 km to its junction with the Columbia River (Fig. 1).

Quaternary surficial deposits mantle large areas of the valley floors and lower hillsides of both the Colville and Pend Oreille valleys (McLucas 1980; Waggoner 1990; Stoffel et al. 1991; Carrara et al. 1995). Much of the area is covered by till and outwash deposited by lobes of the Cordilleran ice sheet that entered these valleys from the north during the Late Wisconsin glaciation. Glacial lake sediments occur in both the Colville and Pend Oreille valleys, and flood deposits from glacial Lake Missoula mantle large areas south and west of the town of Newport.

Southern limit of Cordilleran ice in the Colville and Pend Oreille valleys during the Late Wisconsin glaciation

The Cordilleran ice sheet and Lake Missoula floods in northeastern Washington

During the climax of the Late Wisconsin glaciation much of northern Washington, including the Colville and Pend Oreille valleys, was covered by lobes of the Cordilleran ice sheet. This large ice sheet was formed by the coalescence of valley glaciers in the mountains of British Columbia (Fulton 1991) and flowed south, filling valleys and overriding low mountain ranges in northern Washington, northern Idaho, and northwestern Montana. At that time a sublobe of ice from the Columbia River lobe flowed south into the Colville Valley, while another lobe flowed south into the Pend Oreille Valley. These lobes covered the flanks of the adjacent mountains and sent distributary glaciers up many of the side valleys (Kiver and Stradling 1982; Waitt and Thorson 1983; Richmond 1986; Carrara et al. 1995).

The area of the terminal position of the Pend Oreille River lobe, near the town of Newport, during the Late Wisconsin glaciation was swept over by outburst floods from glacial Lake Missoula (Bretz 1923*a*, 1923*b*; Waitt 1980) and was buried by its deposits in some places. This large lake, nearly 10 000 km^2 in extent, in the Clark Fork valley of Montana (Fig. 1), was dammed by the Purcell Trench lobe (Waitt 1984, 1985) of the Cordilleran ice sheet, which flowed south, along the Purcell Trench, through the Kootenai River valley and into the Pack River drainage (Pardee 1910). Lake Missoula is thought to have existed for about 2000–2500 years sometime between about 12 700 and 15 300 BP (Waitt 1985) when lobes of the Cordilleran ice sheet would have been near their maximum Late Wisconsinan position. Large catastrophic floods occurred periodically when the ice dam failed (Waitt 1980, 1985; Waitt and Thorson 1983; Atwater 1986; Breckenridge 1989). In the Priest Lake area, east of the study area (Fig. 1), Waitt (1984) found evidence of at least 14 floods with a recurrence interval of two to six decades. These same floods would surely have swept into the area of the present-day town of Newport.

In the area of the terminus of the Pend Oreille River lobe, the pathway of floodwaters from glacial Lake Missoula is indicated by (*i*) the morphology of giant current dunes (megaripples), (*ii*) the orientation of pendant bars, and (*iii*) the dip of foreset beds in flood deposits. A portion of these floodwaters was deflected near the Spirit Lake area into the Blanchard channel and northward beyond the present site of the town of Newport into the Calispell Lake area (Fig. 1) (Kiver and Stradling 1982; Waitt 1984). Floodwaters spilled (*i*) west over Spring Valley Pass and Rogers Pass, (*ii*) south through the channel occupied by Davis Lake to Sacheen Lake, and (*iii*) southwest through Scotia Canyon (Figs. 1, 2). These floodwaters flowed down both the Little Spokane River and the west branch of the Little Spokane River into Deer Park Basin. Giant current dunes northwest of Loon Lake also demonstrate that floodwaters in the Deer Park Basin were sometimes of sufficient magnitude to spill over a narrow pass north of Loon Lake into Colville and Chamokane valleys (Kiver and Stradling 1982).

The northernmost Lake Missoula flood spillway used during the Late Wisconsin glaciation is the narrow channel now occupied by Davis Lake (Kiver and Stradling 1982; Waitt 1984, Fig. 2) (Figs. 1, 2). Absence of flood features farther north and the apparent need for an ice obstruction to cause a drainage reversal of the Pend Oreille River support Connors' (1976, p. 341) suggestion that there was a recessional or stagnant ice mass in the Calispell Lake area at the time of the Missoula floods.

Previous work

Most early workers (Leverett 1917; Large 1922; Pardee 1922; Freeman 1926; Bryan 1927; Flint 1935, 1936, 1937), unaware or unconvinced of outburst floods from glacial Lake Missoula, confused deposits from these floods with those of the Cordilleran ice sheet (Weis and Richmond 1965). Hence, these workers placed the "maximum" and (or) the Wisconsinan position of the Cordilleran ice sheet in northeastern Washington on the Columbia Plateau south of the Spokane River (Fig. 1). Later workers, aware of the flood, still had trouble distinguishing the southern limit of Late Wisconsinan till in northeastern Washington (Richmond et al. 1965).

In the last few decades, investigators have placed the terminal position of the Colville and Pend Oreille River lobes during the Late Wisconsin glaciation far to the north of the Spokane River at or near the positions advocated in this paper (Connors 1976; Kiver and Stradling 1982; Waitt and Thorson 1983; Richmond 1986; Stoffel et al. 1991; Stradling and Kiver 1994). Several earlier investigators had also recognized these positions. Although not ever mentioning the age of the glacial boundary traced, Salisbury (1901) placed the glacial limit in the Colville Valley at the Springdale moraine and the glacial limit in the Pend Oreille Valley about 12–15 km north of the town of Newport (Fig. 1). In addition, Alden (1953, p. 147), whose fieldwork in the area was conducted between 1927 and 1938, and Connors (1976, p. 164) located the Late Wisconsinan glacial limit in the Pend Oreille Valley near the town of Newport.

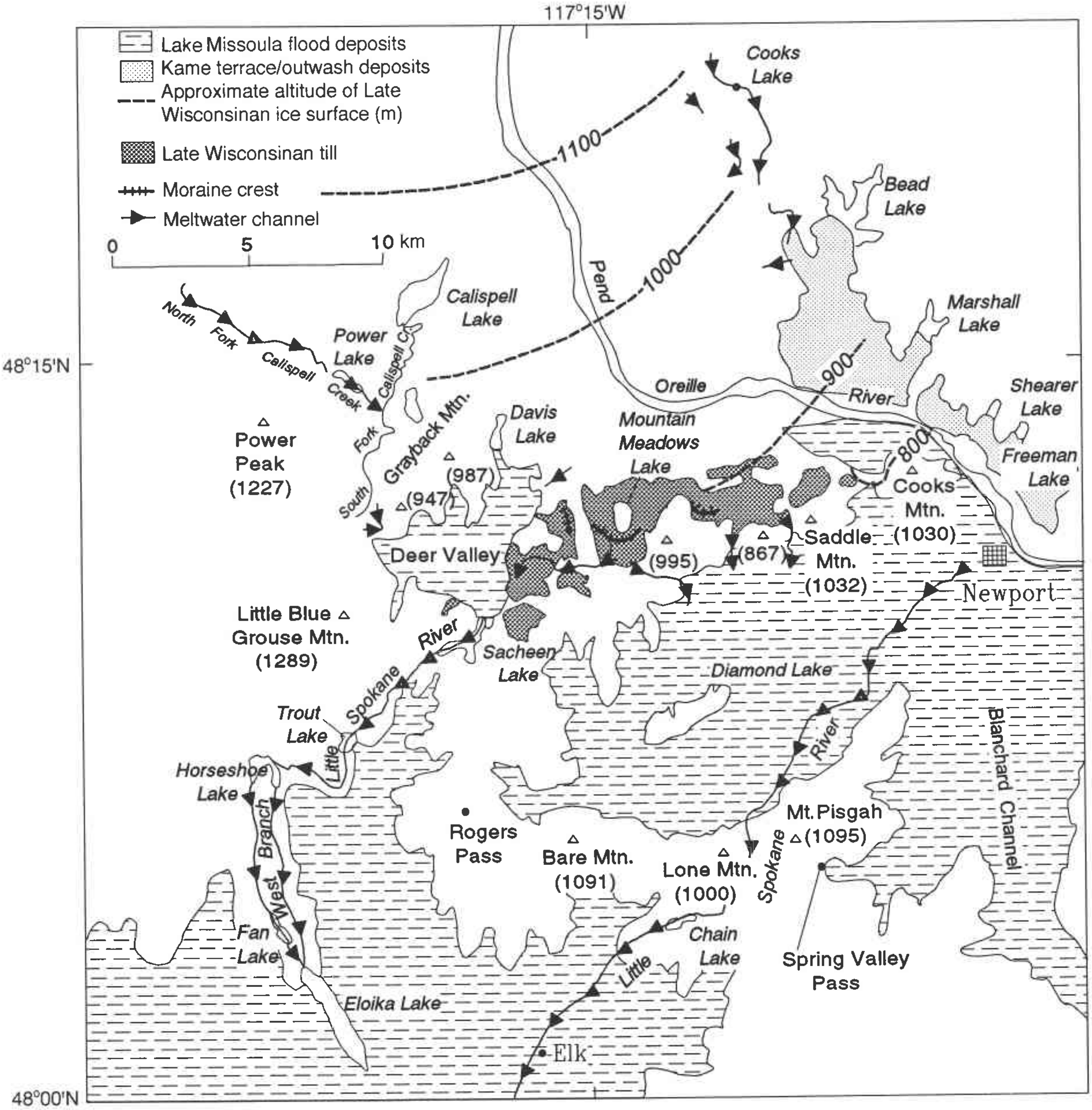
Evidence for the southern limit of Cordilleran ice in the Colville and Pend Oreille valleys during the Late Wisconsin glaciation

In the course of mapping Quaternary deposits in the Colville Valley and in the Pend Oreille Valley north of the town of Newport, evidence of the Late Wisconsinan glacial limit was noted. This evidence consists of (*i*) the southern limit of Late Wisconsinan till, (*ii*) lateral meltwater channels that form an arcuate pattern whose southern limit coincides with the southern limit of Late Wisconsinan till, (*iii*) meltwater channels whose heads coincide with the southern limit of Late Wisconsinan till, and (*iv*) reconstructed ice-surface profiles of these former glaciers based on the height of till on the valley sides and the summits of surrounding peaks.

Colville Valley

In the Colville Valley, the southern limit of the ice lobe during the Late Wisconsin glaciation is marked by a well-developed terminal moraine about 3 km west of the town of Springdale, referred to as the Springdale moraine (Flint 1936). The relatively unmodified morphology of the Springdale moraine suggests a Late Wisconsinan age. The moraine extends from near the town of Springdale west across the Colville Valley to the eastern flank of Craney Hill, a distance of about 5 km (Fig. 3). From its distal front near Chamokane Creek, the moraine extends north for about 4 km, where it is overlapped by lake sediments. The moraine has several prominent crests and contains numerous kettle ponds and closed depressions. The southern end of the moraine stands about 60 m above Chamokane Creek, which was diverted south by the moraine into a narrow channel at the

Fig. 2. Map of the Pend Oreille Valley, showing the location of Late Wisconsinan-age till, kame, outwash, and Lake Missoula flood deposits, and glacial meltwater channels (after Carrara et al. 1995). Elevations in parentheses are given in metres above sea level.

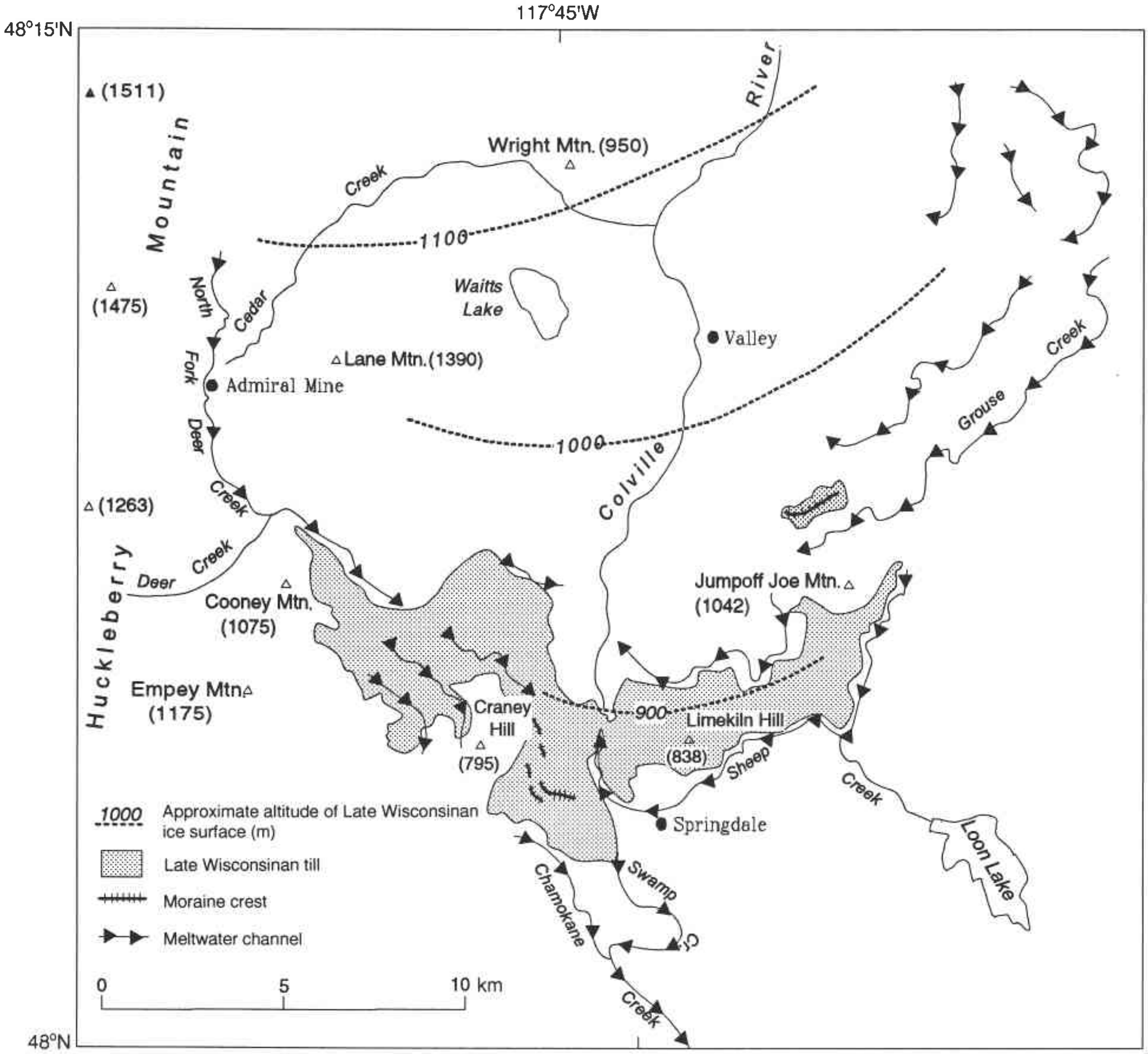


northern base of a basalt-capped mesa. The moraine is composed of mainly unstratified and unsorted, pale-yellow to brown clay, silt, and sand containing about 10–30% subangular to rounded pebbles, cobbles, and occasional boulders of mostly granitic and Belt Supergroup rocks. Many of the clasts derived from fine-grained sedimentary rocks are striated. Stratified glaciofluvial sediments are also present in some areas on the moraine.

Till of Late Wisconsinan age has not been found south of the Springdale moraine. Two locations of poorly exposed, highly oxidized, reddish-brown, sandy gravel containing scattered boulders have been identified about 3 km south and southwest of the Springdale moraine (McLucas 1980; Carrara et al. 1995). Other isolated exposures of till exist just south of Deer Park Basin (Fig. 1). However, because of the high degree of oxidation of these deposits and lack of morphology, they are believed to be pre-Late Wisconsinan in age.

Lateral meltwater channels outline a broadly arcuate pattern whose southern limit coincides with the southern limit of Late Wisconsinan till (Fig. 3). In some instances, these lateral meltwater channels beheaded preglacial drainages. For instance, Cedar Creek was beheaded by the north fork of Deer Creek. Glacial ice from the Colville lobe filled the valley of Cedar Creek along the northern side of Lane Mountain. The channel of the north fork of Deer Creek north of the Admiral mine was developed as a lateral meltwater channel. At the Admiral mine, because the drainage was

Fig. 3. Map of Colville and Chamokane valleys, showing the location of the Late Wisconsinan-age Springdale moraine and glacial meltwater channels (after Carrara et al. 1995). Elevations in parentheses are given in metres above sea level.



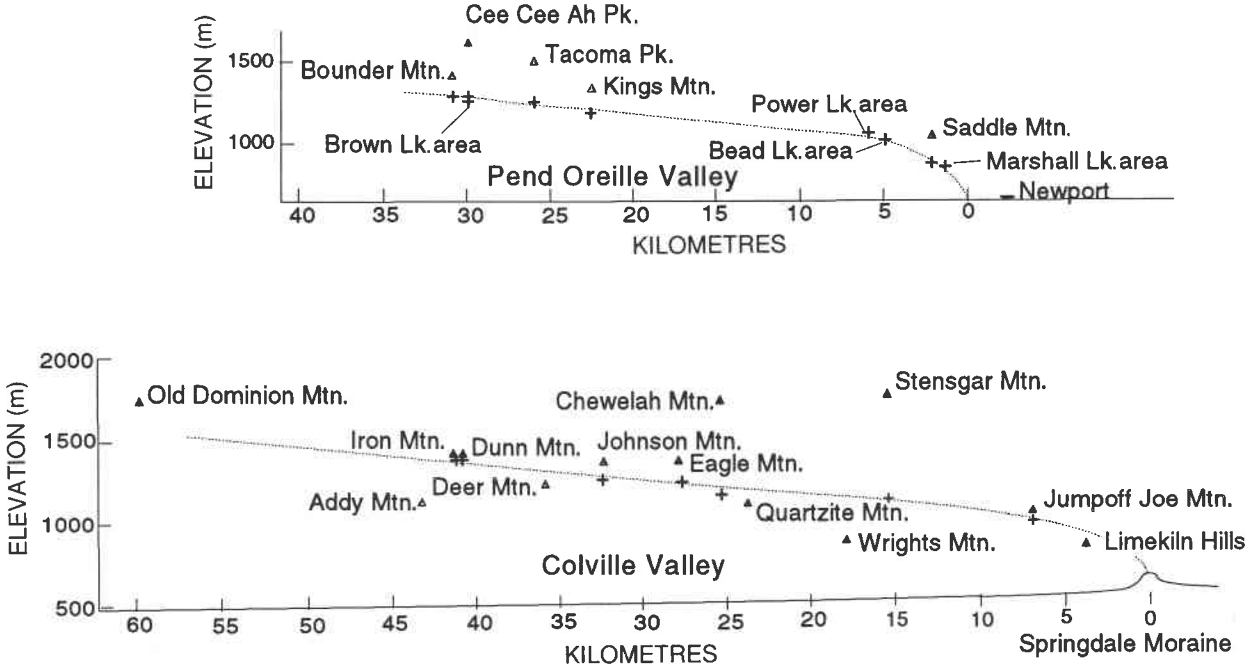
blocked to the east by an ice dam, the meltwater spilled through a gap and excavated a narrow gulch into the western flank of Lane Mountain, about 225 m lower than the surrounding ridge that initially separated these two drainages. Presently, the north fork of Deer Creek and Deer Creek form an arcuate drainage pattern for about 12 km that generally marks the southwestern margin of the former Colville lobe at its terminal position.

Two other lateral meltwater channels, which outline an arcuate pattern that coincides with the Springdale moraine, are found to the northwest of Craney Hill (Fig. 3). These meltwater channels, each about 3 km in length, emptied into a lake to the west of the moraine, formed when the Colville lobe dammed Chamokane Creek (Kiver and Stradling 1982).

East of Springdale the eastern and southeastern Late Wisconsinan margin of the Colville lobe is well defined by the lower reaches of Sheep Creek and an intermittent unnamed tributary channel (Fig. 3). Sheep Creek was also used as a channel for Lake Missoula outburst floods. Together these channels mark the outer margin of the Colville lobe for a distance of about 12 km. To the north and west of these meltwater channels the area is mantled by till; south and east of these channels the area is covered by outwash sands and gravels, which are, in places, mantled by flood deposits from glacial Lake Missoula. Other lateral meltwater channels that generally outline the margin of the southern end of the Colville lobe are also shown in Fig. 3.

Although lateral meltwater channels are common features in the Colville Valley north of the Springdale moraine, none have been found south of the moraine in Chamokane Valley (Fig. 3). This lack of lateral meltwater channels south of the Springdale moraine further suggests that the moraine represents the southern extent of the Colville lobe during the Late Wisconsin glaciation.

Fig. 4. Ice surface profiles (broken lines) of the Colville and Pend Oreille River lobes based on the altitude of peaks with till on their summits (triangle below projected ice surface) and upper altitudinal limit of till on the sides of the valleys and summits (crosses and crosses below summit triangles, respectively).



A former meltwater channel that heads at the Springdale moraine is represented by Swamp Creek (Fig. 3). The outwash south of the moraine is dissected by a channel, 350–450 m wide and 25 m deep at the deepest point, that slopes south. This channel, presently occupied by Swamp Creek, served as a meltwater channel for the Colville lobe when it stood at the Springdale moraine, and continued to drain the ice-dammed lake in the Colville Valley for some time after the Colville lobe retreated north (downvalley) (Flint 1936).

A reconstructed ice profile of the Colville lobe based on the upper altitudinal limit of till on the sides of the valley and the altitude of surrounding peaks with till and erratics on their summits is consistent with an ice mass that extended as far south as the Springdale moraine (Fig. 4). Ice-limit altitudes at seven sites and the altitudes of five peaks overtopped by ice were noted in the course of field investigations. The ice thickness in the northern part of Colville Valley was about 900 m at that time, as based on the upper limit of till on Dunn Mountain, and on the Iron Mountains (Carrara et al. 1995) (Fig. 4). These ice limits are believed to represent the ice height during the Late Wisconsin glaciation, because soils associated with the till lack a significant clay buildup in their B horizons and rock clasts are virtually unweathered.

An anomalously high till was found on the summit of Old Dominion Mountain (1750 m) (Figs. 1, 4). The associated soil profile and lack of clast weathering seem to suggest a Late Wisconsinan age. However, if Old Dominion Mountain was overridden by Late Wisconsinan ice, then the ice-surface profile shown in Fig. 4 would have to steepen sharply to the north of the Iron Mountains. Such a steep slope would require a basal shear stress of almost 3 bars (1 bar = 100 kPa), an unusually high value well beyond reported estimates (Pierce 1979). Therefore, the authors suggest that an older preexisting soil may have been stripped from the surface by periglacial processes during the Late Wisconsinan, when Old Dominion Mountain would have been a nunatak, so soil-forming processes had to begin anew at that time.

Pend Oreille Valley

In the Pend Oreille Valley, the southern limit of the ice lobe during the Late Wisconsin glaciation is difficult to determine because, not only did the lobe terminate in glacial Lake Clark (Atwater 1986), but also much of the terminal area was swept by Lake Missoula floods (Fig. 2). However, the height and position of till and morainal remnants on surrounding hills, the pattern of glacial meltwater channels, and the height and position of a graded kame terrace along the northern side of the Pend Oreille River suggest that the southern limit of the Pend Oreille River lobe formed a broad lobe approximated by a line of hills that stretches from near the town of Newport west for about 22 km to Grayback Mountain.

South of the Pend Oreille River, near the headwaters of the Little Spokane River, the southern limit of the ice lobe is indicated by patches of till banked up against the northern side of a line of hills stretching from Cooks Mountain west, for about 12 km, to the Mountain Meadows Lake area (Fig. 2). This till is composed of mainly unstratified and unsorted, pale-yellow to brown clay, silt, and sand containing about 10–50% subangular to rounded pebbles, cobbles, and boulders of mostly granitic and Belt Supergroup rocks. Many of the clasts composed of fine-grained sedimentary rocks are striated. Stratified glaciofluvial sediments are also present in some areas. Well-developed moraines exist at several sites: (*i*) a moraine, about 20 m high, whose hummocky surface is littered with large unweathered granitic boulders, is present around the southern end of Mountain Meadows

Lake (Stradling and Kiver 1994); and (*ii*) about 3 km to the east of that lake, another moraine dams a small meadow to the south.

West of the Mountain Meadows Lake area the ice flowed south through a gap, presently occupied by Davis Lake, in the line of hills to a position near the north end of Sacheen Lake (Fig. 2). This ice margin is marked by patches of till near Sacheen Lake and a well-preserved lateral moraine, about 4 km southeast of Davis Lake. In addition, granitic boulders greater than 5 m in intermediate diameter are present in Deer Valley. These boulders are thought to have been deposited by the Pend Oreille River lobe and left as lag by the last of the Lake Missoula outburst floods that spilled through the Davis Lake channel (Waitt 1984).

Till of Late Wisconsinan age has not been found south of the line of hills or the Deer Valley area. However, evidence of a pre-Late Wisconsin glaciation is preserved at a number of sites in the area (Carrara et al. 1995). These older deposits are distinguished from Late Wisconsinan till by a highly oxidized, reddish-brown soil profile. Sites of pre-Late Wisconsinan till south of the Late Wisconsinan limit indicate that the pre-Late Wisconsin glaciation was more extensive than the Late Wisconsin glaciation, but because much of the evidence of older glaciation has been destroyed by subsequent Lake Missoula floods, their southern limit(s) could not be accurately determined. Eloika Lake (Figs. 1, 2) is thought to have been dammed by a pre-Late Wisconsinan terminal moraine subsequently eroded by Lake Missoula floods and then buried by flood deposits (Kiver and Stradling 1982).

North of the Pend Oreille River, the southern limit of the Pend Oreille River lobe is marked by a large kame terrace and outwash deposit (Fig. 2) and small scattered patches of till. The kame terrace deposit extends south for a distance of about 15 km from the Bead Lake area to an area near the town of Newport. The deposit consists mostly of well-sorted, and well-stratified, clast-supported, subrounded to rounded pebbles and cobbles in a light-gray to yellowish-brown sandy matrix locally overlain by Lake Missoula flood deposits (Carrara et al. 1995). This terrace, which is as much as 240 m above the Pend Oreille River, blocked various drainages in small tributary valleys to the east, forming lakes such as Bead and Marshall lakes. Above the kame terrace, patches of Late Wisconsinan till and scattered erratics occur on the hillsides between Bead and Marshall lakes up to altitudes of about 900 m.

Several lateral meltwater channels outline a broadly arcuate pattern whose southern limit coincides with the same line of hills that appears to mark the southern limit of Late Wisconsinan till in the Pend Oreille Valley (Fig. 2). For example, a meltwater channel extends from the area southwest of Mountain Meadows Lake westward for about 4 km. Another channel follows the north fork of Calispell Creek for about 10 km before joining the south fork of Calispell Creek.

The eastern margin of the Pend Oreille River lobe is well marked by a lateral meltwater channel. The channel, about 20 km north of Newport, is presently only a dry wash and trends south for a distance of about 6 km from its head near the Cooks Lake area (Fig. 2).

Several channels whose heads coincide with the southern limit of till are present in the area south of the Pend Oreille River (Fig. 2). For example, west of Saddle Mountain three streams flow through notches, generally about 100–200 m deep, in the line of hills marking the limit of the Late Wisconsin glaciation. These notches were cut by meltwater streams when the Pend Oreille River lobe stood at its maximum position at the northern side of these hills. Two other meltwater channels, cut into the southwestern end of Grayback Mountain and about 130–180 m deep (Rocky Gorge), were probably cut by drainage from an ice-dammed lake in the Calispell Creek valley.

Sacheen Lake, at the headwaters of the west branch of the Little Spokane River, is at the head of a chain of lakes (Trout and Horseshoe) that served as a major drainage channel for the Pend Oreille River lobe when it was at its maximum position. Later, this channel served as a flood path for waters from glacial Lake Missoula. In addition, the main branch of the Little Spokane River, which trends southwest from the town of Newport, may have also served as a meltwater channel for the Pend Oreille River lobe when it stood at its southern Late Wisconsinan limit (Alden 1953, p. 147). This outflow scoured a well-developed spillway that is now about 30 m above the Pend Oreille River, about 1 km west of Newport. The Little Spokane River in this spillway heads less than 2 km from the Pend Oreille River and flows through the narrow rock gorge into Chain Lake and to the wider part of the valley below the town of Elk (Fig. 2).

Several features that may be meltwater channels are present in a line of hills south of Diamond Lake (Bare Mountain, Lone Mountain, and Mount Pisgah) (Fig. 2). Here, the Little Spokane River flows through a notch, about 290 m deep, in this line of hills. However, because the Diamond Lake area has been swept over by Lake Missoula floods and the few patches of till in the area appear to be pre-Late Wisconsinan in age, the age of these channels is not clear. They may have been formed by meltwater channels of a pre-Late Wisconsinan Pend Oreille River lobe and reused and further excavated by Lake Missoula floods during the Late Wisconsin glaciation.

A reconstructed ice profile of the Pend Oreille River lobe based on the height of till on the sides of the Pend Oreille Valley also suggests an ice mass that extended to near the town of Newport during the Late Wisconsin glaciation (Fig. 4). Ice-limit altitudes at nine sites were noted in the course of field investigations. During the Late Wisconsin glaciation, the ice thickness in the Pend Oreille Valley near Cee Cee Ah Peak (Fig. 1) and Bounder Mountain was about 650 m, as based on the upper limit of till on the flanks of these mountains (Fig. 4). This ice limit is believed to represent the ice height during the Late Wisconsin glaciation in that soils associated with deposits at or below this limit lack a significant clay buildup in their B horizons and their clasts are virtually unweathered.

Timing of ice advance and deglaciation in the Colville and Pend Oreille valleys

During the Late Wisconsin glaciation, the southern limit of the Cordilleran ice sheet was north of the International Boundary as late as 17 500 BP (Clague et al. 1980). The advance of ice into the United States must have been rapid, as the Cordilleran ice sheet is thought to have attained its maximum size about 15 000 BP (Clague et al. 1980; Clague 1981). West of the study area, the Columbia River lobe probably reached its maximum Late Wisconsinan position about 15 350 ± 400 BP, while the Sanpoil Valley sublobe is thought to have been at its maximum Late Wisconsinan position about 14 490 ± 290 BP (Atwater 1986). East of the study area, the Purcell Trench lobe is thought to have reached its maximum Late Wisconsinan position between 14 750 ± 375 and 15 200 ± 400 BP (Atwater 1986). Although the timing of the maximum advance of the Colville and Pend Oreille River lobes was not dated in this study, it is suggested here that they also reached their maximum Late Wisconsinan position about 15 000 radiocarbon years ago.

Information concerning the timing and extent of the Late Wisconsinan deglaciation in the Colville and Pend Oreille valleys is given by the location of Late Pleistocene volcanic tephras of known ages and radiocarbon ages from sites north of the terminal position of the Colville and Pend Oreille River lobes.

Several sites containing a Glacier Peak tephra layer or a couplet consisting of a Glacier Peak tephra layer and an underlying Mount Saint Helens set J tephra layer have been found in the Colville and Pend Oreille valleys (Carrara and Trimble 1992; Carrara et al. 1995). In the study area, the Glacier Peak tephra is a light-gray medium sand to silt layer 5–10 mm thick. The medium sand size fraction consists of rounded pumiceous glass fragments, 0.2–0.4 mm in diameter, that contain inclusions of mafic crystals. The fine sand size fraction contains abundant mafic crystals. Glacier Peak tephras at distal sites are thought to have been deposited by closely spaced eruptions about 11 200 BP (Mehringer et al. 1984; Foit et al. 1993). Hence, the presence of a Glacier Peak tephra layer at a given site in the Colville or Pend Oreille valleys demonstrates that the site was ice free prior to 11 200 BP.

Mount Saint Helens set J tephras were erupted between about 10 500 and 12 000 BP (Mullineaux and Crandell 1981; Mullineaux 1986). In the study area, the Mount Saint Helens set J tephra is a white to gray fine sandy silt layer 5–10 mm thick. This tephra layer contrasts with the overlying Glacier Peak tephra in that its pumiceous fragments are smaller and it has a much smaller proportion of mafic crystals. Based on a comparison of major elements with other set J tephras and the occurrence of this tephra at such a distance (about 450 km) from Mount Saint Helens, the set J tephra in the study area is probably the Jy tephra (D.R. Mullineaux, personal communication, 1990; Carrara and Trimble 1992). The exact age of the Jy tephra is not known with certainty. D.R. Mullineaux (personal communication, 1990) suggested an age of about 11 700 BP; Carrara (1989) suggested an age of about 11 400 BP, based on the number of varve-like laminations between a Glacier Peak tephra layer and an underlying Mount Saint Helens set J tephra layer in the Glacier National Park region; F.F. Foit, Jr. (written communication, 1991) suggested that these two tephras may be closer in time (about 11 200 BP). Hence, the presence of a Mount Saint Helens set J tephra layer at a given site in the Colville and Pend Oreille valleys indicates the the site was ice free prior to 11 200 BP and possibly prior to 11 700 BP.

In the Colville Valley, evidence of extensive deglaciation prior to about 12 450 BP was obtained from a bog, about 6 km northwest of Addy Mountain in the drainage of the Little Pend Oreille River (Fig. 1), about 50 km upglacier from the Springdale moraine (Carrara and Trimble 1992; Carrara et al. 1995). An accelerator mass spectrometry (AMS) radiocarbon age of 12 447 ± 116 BP (AA-9531) was obtained from a wood fragment at a depth of 365 cm underlying the Glacier Peak and Mount Saint Helens set J tephra couplet. This age of deglaciation is further supported by two conventional radiocarbon ages of 11 980 ± 60 BP (USGS-2779) and 12 020 ± 60 BP (USGS-2780) of overlying peat and peat and gyttja, at depths of 345 and 350 cm, respectively, from this same site (Carrara and Trimble 1992). In addition, an apparent $^{230}Th/^{234}U$ age of 12 000 years (corrected for detrital ^{230}Th) was obtained from organic-rich sediments in the upper reaches of North Flodell Creek (Zielinski et al. 1986), a tributary of the Little Pend Oreille River, about 25 km northeast of Addy Mountain. These radiometric ages suggest that the Colville lobe had retreated at least 50 km upglacier from its Late Wisconsinan limit prior to about 12 450 BP.

The radiometric ages of deglaciation from the Colville Valley are further supported by the presence of Glacier Peak and Mount Saint Helens set J tephra layers at several sites in the valley. Although these tephras are younger than the radiometric ages mentioned above, their presence in the Colville Valley provides further independent proof of extensive deglaciation in the Late Pleistocene. A Glacier Peak tephra layer was reported from a depth of 880 cm in a bog about 100 m southwest of Waitts Lake, 15 km north of the Springdale moraine (Fig. 3) (Mack et al. 1978*a*). The Glacier Peak and Mount Saint Helens set J tephra couplet has been identified at three sites in the valley of the Little Pend Oreille River (Fig. 1) (Carrara and Trimble 1992; Carrara et al. 1995). By themselves, the presence of these ashes in the Colville Valley demonstrates that the Colville lobe had retreated at least 50 km upglacier from its Late Wisconsinan limit prior to 11 200 BP and possibly prior to 11 700 BP.

In the Pend Oreille Valley, evidence of extensive deglaciation prior to 11 200 BP was obtained from a site, about 10 km west of the town of Ione (Fig. 1) (Mack et al. 1978*b*). A Glacier Peak tephra layer was reported at a depth of about 600 cm from a bog, about 400 m above the valley floor. The town of Ione is about 75 km north of the Late Wisconsinan limit of the Pend Oreille River lobe. However, the fact that the bog is 400 m above the valley floor would allow the terminus of the Pend Oreille River lobe to extend about 5 km south of Ione (assuming an ice profile similar to that of Fig. 4). Thus the presence of the Glacier Peak tephra in this bog is interpreted as indicating that the active margin of the Pend Oreille River lobe had retreated at least 70 km from its Late Wisconsinan limit near the town of Newport prior to the deposition of this tephra about 11 200 BP.

Summary

The southern limit of the Colville lobe of the Cordilleran ice sheet during the Late Wisconsin glaciation is marked by a well-developed terminal moraine near the town of Springdale, as originally placed by Salisbury (1901). The southern limit of the Pend Oreille River lobe is approximated by a line of hills that stretches from near the town of Newport west for about 22 km to Grayback Mountain, similiar to the limits suggested by Alden (1953, p. 147) and Connors (1976, p. 164).

In the Colville Valley, an AMS radiocarbon age of 12 447 ± 116 BP (AA-9531) from a site about 50 km upglacier from the terminal position indicates that the active margin of the Colville lobe had retreated at least this amount by about 12 450 BP. This age of deglaciation is further supported by two conventional radiocarbon ages of about 12 000 BP and also by the occurrence of a Glacier Peak tephra layer (11 200 BP) and the Glacier Peak and Mount Saint Helens set J tephra (11 200 – 11 700 BP) couplet at several sites, also about 50 km north of the Late Wisconsinan ice limit.

In the Pend Oreille Valley, the occurrence of the Glacier Peak tephra in a bog near the town of Ione is interpreted as indicating that the active margin of the Pend Oreille River lobe had retreated at least 70 km prior to the deposition of this tephra about 11 200 BP. Although data in the Pend Oreille Valley are limited, because both the Colville and Pend Oreille River lobes were of similar size and in adjacent valleys, deglaciation of these valleys is thought to have been broadly synchronous.

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