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La déglaciation de l'épisode de Pinedale, les fluctuations environnementales holocènes et l'impact sur la morphologie dans les Lemhi Mountains du centre (Idaho, É.-U.)

Enteisung von Pinedale und im Holozän folgende Umweltveränderungen und geomorphologische Auswirkungen in den zentralen Lehmi Mountains, Idaho, U.S.A.

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Résumé de l'article

Dans plusieurs vallées glaciaires le long du front oriental des Lemhi Mountains, les prairies subalpines se situent le long des axes centraux, immédiatement en amont d'arcs morainiques mis en place lors d'une récurrence de l'épisode de Pinedale. Les prairies sont composées de sédiments d'épaisseur variable retenus dans des lacs derrière les moraines. Les sédiments et le pollen qu'ils contiennent ont enregistré les fluctuations complexes qu'a subi l'environnement et qui ont accompagné la déglaciation et le relèvement postglaciaire. L'épaisseur des sédiments est fonction de l'efficacité des barrages que constituaient les arcs morainiques. La présence de cendres volcaniques du type Glacier Peak B dans une des prairies démontre que le tiers inférieur de la vallée était libre de glace au moins avant 11 250 BP environ. Les cendres recouvrent plus d'un mètre de sédiments fluvioglaciaires. Les taux de sédimentation dans la prairie suggère que la déglaciation était terminée avant 11 500 BP dans les parties basses de la vallée. Les taux de sédimentation ont nettement diminué après 10 000 BP. Un épisode froid a probablement prévalu au début de l'Holocène, aux environs de 7500 BP. De gros bourrelets de congères ont été mis en place au cours de l'avancée d'lndian Basin. Plus tard, les formes néoglaciaires ne se trouvaient plus qu'aux endroits les plus ombragés et les plus propices du point de vue climatique.

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PINEDALE DEGLACIATION AND SUBSEQUENT HOLOCENE ENVIRONMENTAL CHANGES AND GEOMORPHIC RESPONSES IN THE CENTRAL LEMHI MOUNTAINS, IDAHO, U.S.A.

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ABSTRACT In several glaciated valleys along the eastern front of the Lemhi Mountains, subalpine meadows are located along the central axes of the valleys, in positions immediately upvalley of arcuate Pinedale readvance moraines. The meadows are comprised of varying thicknesses of fine-grained sediments which were impounded by the damning action of the moraines. These sediments, and pollen contained therein, record complex environmental fluctuations which accompanied deglaciation and post-glacial recovery. The thickness of sediments in each meadow is a function of the proficiency of the arcuate moraines as dams. The presence of Glacier Peak B ash in one meadow illustrates that, at minimum, the lower one-third of that valley was deglaciated prior to approximately 11,250 yr BP. Over one meter of glacial-runoff sediments underlies the ash; sedimentation rates in the meadow suggest that deglaciation in the lower portions of the valley may have been complete before 11,500 yr BP. Sedimentation rates slowed dramatically after 10,000 yr BP. A cold, early Holocene climatic episode may have occurred around 7500 yr BP. Massive protalus landforms were deposited during the Indian Basin Advance. Later Neoglacial landforms were areally restricted to the most shaded, climatically-favorable locations.

RÉSUMÉ *La déglaciation de l'épisode de Pinedale, les fluctuations environnementales holocènes et l'impact sur la morphologie dans les Lemhi Mountains du centre (Idaho, É.-U.).* Dans plusieurs vallées glaciaires le long du front oriental des Lemhi Mountains, les prairies subalpines se situent le long des axes centraux, immédiatement en amont d'arcs morainiques mis en place lors d'une récurrence de l'épisode de Pinedale. Les prairies sont composées de sédiments d'épaisseur variable retenus dans des lacs derrière les moraines. Les sédiments et le pollen qu'ils contiennent ont enregistré les fluctuations complexes qu'a subi l'environnement et qui ont accompagné la déglaciation et le relèvement postglaciaire. L'épaisseur des sédiments est fonction de l'efficacité des barrages que constituaient les arcs morainiques. La présence de cendres volcaniques du type Glacier Peak B dans une des prairies démontre que le tiers inférieur de la vallée était libre de glace au moins avant 11 250 BP environ. Les cendres recouvrent plus d'un mètre de sédiments fluvioglaciaires. Les taux de sédimentation dans la prairie suggère que la déglaciation était terminée avant 11 500 BP dans les parties basses de la vallée. Les taux de sédimentation ont nettement diminué après 10 000 BP. Un épisode froid a probablement prévalu au début de l'Holocène, aux environs de 7500 BP. De gros bourrelets de congères ont été mis en place au cours de l'avancée d'Indian Basin. Plus tard, les formes néoglaciaires ne se trouvaient plus qu'aux endroits les plus ombragés et les plus propices du point de vue climatique.

ZUSAMMENFASSUNG *Enteisung von Pinedale und im Holozän folgende Umweltveränderungen und geomorphologische Auswirkungen in den zentralen Lehmi Mountains,* Idaho, U.S.A. In mehreren glazialen Tälern entlang der Ostfront der Lehmi Mountains befinden sich subalpine Wiesen entlang der zentralen Achsen der Täler, direkt oberhalb der bogenförmigen Rückvorstoß-Moränen von Pinedale. Die Wiesen bestehen aus feinkörnigen Sedimenten unterschiedlicher Dicke, welche durch die Damm-Wirkung der Moränen festgehalten wurden. Diese Sedimente und der darin enthaltene Pollen halten komplexe Umweltveränderungen fest, welche die Enteisung und die postglaziale Hebung begleitet haben. Die Dicke der Sedimente in jeder Weise ist abhängig von der Damm-Wirkung der bogen-förmigen Moränen. Das Vorkommen von Asche des Typs Glacier Peak B in einer der Wiesen zeigt, daß zumindest das untere Drittel dieses Tals vor ungefähr 11,250 Jahren v.u.Z. enteist war. Unter der Asche liegt mehr als ein Meter von glazialen Abfluß-Sedimenten; die Sedimentierungsgrade in der Wiese lassen vermuten, daß die Enteisung in den unteren Teilen des Tals vor 11.500 Jahren v.u.Z. abgeschlossen war. Nach 10.000 Jahren v.u.Z. verlangsamten die Sedimentierungsgrade sich drastisch. Im frühen Holozän könnte wohl eine kalte klimatische Episode um 7.500 v.u.Z. eingetreten sein. Während des Vorstoßes von Indian Basin wurden massive Protalus-Landformen abgelagert. Später waren neoglaziale Landformen örtlich begrenzt auf die schattigsten, klimatisch günstigsten Plätze.

INTRODUCTION

Recent studies have suggested that deglaciation following the Pinedale Glaciation occurred earlier in the Rocky Mountains than previously believed. These studies, summarized by PORTER *et al.* (1983, p. 99), indicate that deglaciation of mountain valleys started "well before 14,000 years ago"; in locations as widely separated as the San Juan Mountains and Front Range of Colorado (BENEDICT, 1981; PORTER *et al.*, 1983), the Wasatch Mountains of Utah (MADSEN and CURREY, 1979), and the Yellowstone Plateau of Wyoming (PIERCE, 1979). The Lewis Range of northwestern Montana was apparently undergoing deglaciation by approximately 12,000 BP (CARRARA *et al.*, 1984), and the glaciers of the Canadian Rockies had receded to present limits by 10,000 BP or earlier (HENOCH et *al.*, 1979; LUCKMAN, 1981; OSBORN, 1982).

It is logical to assume that maximum paleoenvironmental information concerning the Pinedale deglaciation and the Holocene in the Rockies will be available from mountain ranges where little post-Pinedale erosional destruction of evidence occurred. This assumption has been tested in the Lemhi Mountains of eastern Idaho (Fig. 1), where a trend of decreasing areal coverage by Holocene glacial and mass-wasting deposits as the present is approached has been well documented (KNOLL, 1977; BUTLER, 1984a, 1984b, 1984c; BUTLER *et al.*, 1983, 1984). The present study examines the Pinedale deglaciation and subsequent environmental fluctuations in several central Lemhi Mountain valleys, as reconstructed from stratigraphic, geomorphic, and palynologic data collected during the field seasons of 1979-1981, and 1984.

THE LEMHI MOUNTAINS

The Lemhi Mountains rise abruptly from the northern edge of the Snake River Plain, and extend approximately 160 km in a northwesterly direction. The range crest has a mean altitude of 3,050 m. The mountains are composed of highly deformed sedimentary rocks and quartzites, with a few granitic and dioritic intrusives exposed.

Runoff from the east-central portion of the Lemhi Mountains, where the highest peaks are concentrated, drains into two major systems. North of Gilmore Summit (Fig. 1), waters drain into Texas Creek, part of the Lemhi River system. Few permanent streams drain from the range south of Gilmore Summit; those that exist flow into Birch Creek and eventually disappear into a natural sink on the Snake River Plain.

The Lemhi Mountains are incised by a system of glacially-scoured valleys which are oriented approximately perpendicular to the crest of the range. Glacial recession and deposition have produced complex patterns of moraine and kettle topography in many valleys (KNOLL, 1977; BUTLER *et al.*, 1984).

No climatic data exist for the valleys of the eastern Lemhi Mountains. It has been estimated, however, that the eastern front of the range receives about 40-45 cm of precipitation annually. Precipitation at higher elevations may total as much as 75 cm, mostly in the form of snow (GALLUP, 1962). Modern-day mean annual temperature along the front of the mountains is estimated at 4-6 degrees C.

Douglas-fir (*Pseudotsuqa menziesii*) and ponderosa pine (*Pinus ponderosa*) occupy the lower two-thirds of most valleys. These species give way to subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*), limber pine (*Pinus flexilis*), and whitebark pine (*Pinus albicaulis*) at higher elevations. Upper treeline elevation ranges from about 2,800 to 3,100 m (WINTER, 1984).

Surface soils in the valleys are thin and stony. Many Holocene glacial/boulder deposits have soil profiles with poorly developed O/A/C horizons. B-horizon development is restricted to soils forming on Pinedale-aged (and older) moraines (BUTLER, 1984c).

THE LATE WISCONSINAN-HOLOCENE TRANSITION

In several of the glaciated valleys of the east-central Lemhi Mountains, subalpine meadows are located along the central

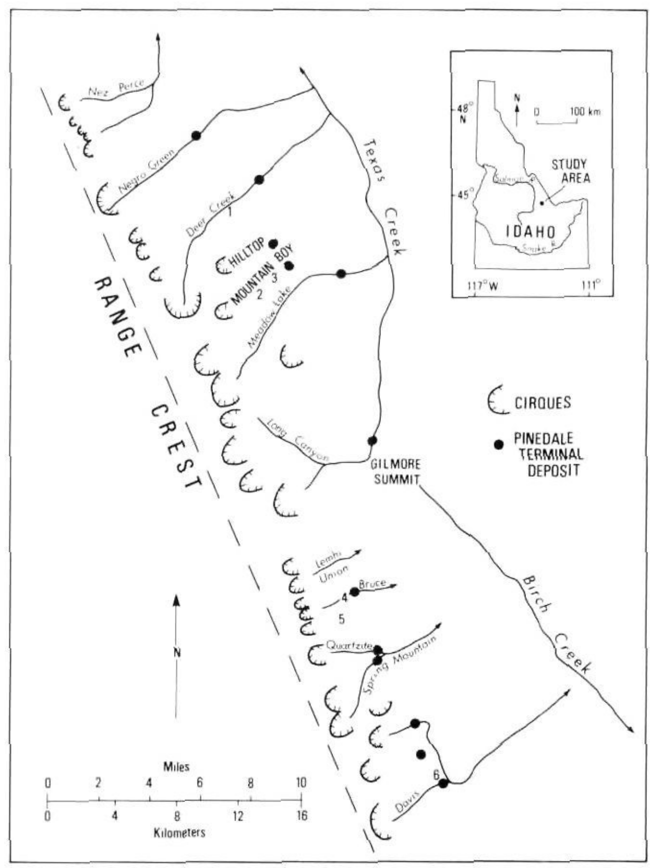

FIGURE 1. Map of the study area, with locations of cirques, Pinedale terminal deposits, and subalpine meadows (1, Deer Creek Meadow; 2, Harry's Meadow; 3, First Meadow; 4, Middle Fork, Bruce Canyon Meadow; 5, South Fork, Bruce Canyon Meadow; 6, Davis Canyon Meadow). Map based on, and modified from DORT (1962).

Carte de la région à l'étude montrant la localisation des cirques, des dépôts de la moraine frontale de Pinedale et des prairies subalpines.

FIGURE 2. Middle Fork, Bruce Canyon Meadow. View is downvalley to the Pinedale-equivalent morainal dam. Person in soil pit provides scale.

Middle Fork, Bruce Canyon Meadow. Vue en aval du barrage morainique corrélatif de l'épisode de Pinedale. Le personnage à droite donne l'échelle.

axes of the valleys, in positions immediately upvalley of arcuate mid- late-Pinedale readvance moraines (Fig. 1). The crosscutting geomorphic relationships of such moraines, indicative of readvance, have been established elsewhere (BUTLER *et al.*, 1983, 1984). The meadows are comprised of varying thicknesses of fine-grained sediments which were impounded by the damming action of the moraines. These sediments in some cases record complex environmental fluctuations which accompanied deglaciation and postglacial recovery.

Color aerial photos of excellent quality (U.S.D.A. series 24614130, numbers 680-80 through 680-101, flown 23 July, 1981) were examined and used to plot the location of every subalpine meadow between Nez Percé and Davis Canyons (Fig. 1). Meadows in Deer Creek, Mountain Boy, and the South and Middle Forks of Bruce Canyon were trenched by backhoe and shovel to determine the nature and thickness of sediments which might record late- and postglacial environmental fluctuations. Lacustrine sediments were discovered in First Meadow and Middle Bruce Meadow (Fig. 1). In all other cases, stream erosion has breached the moraines which dammed the meadows' downvalley ends. Sedimentary information concerning late- and postglacial environmental fluctuations was therefore either lost or never deposited.

Massive arcuate moraines completely blocked Mountain Boy Valley and the Middle Fork of Bruce Canyon (Fig. 2). These moraines contain large quartzite boulders, perhaps accounting for their greater resistance to erosion and breaching. Fine-grained, boulder-free, sediments were trapped behind the Pinedale-equivalent Bruce Canyon moraine to a minimum explored depth of 107 cm (Fig. 2). Studies of these sediments and efforts to determine maximum depth of deposition are continuing. Preliminary results suggest the presence of a carbonate-rich paleosol at a depth of about 80 cm, possibly resulting from warmer and/or drier conditions in the mid-Holocene.

FIGURE 3. Upper four meters of sediments in First Meadow.

Les quatre premiers mètres de sédiments, First Meadow.

Sediments in First Meadow are 8.5-9.5 m thick, and directly overlie quartzite-rich ground moraine (Fig. 3). A mid-Pinedale readvance moraine dammed the valley, producing the lacustrine environment in which sediments were deposited. Radiocarbon dates and a volcanic ash layer provide the framework for the chronology of environmental change described below.

At a depth of 700 cm, a volcanic ash tentatively identified as Glacier Peak B has been recovered (BUTLER *et al.*, 1984). Deglaciation of the meadow and the portions of Mountain Boy Valley downvalley from the moraine dam therefore took place prior to approximately 11,250 yr BP. The actual age of onset of deglaciation is unknown, because the age of the ground moraine underlying First Meadow, as well as all moraines downvalley, suffer from an absence of datable material. Nevertheless, given that 150-250 cm of fine sediments were deposited between the ground moraine and the ash, it seems reasonable to assume that deglaciation began no later than about 13,000 yr BP.

An organic-rich sedimentary unit at a depth of 160 cm in First Meadow has been radiocarbon dated at 10,130 ± 500 yr BP (Beta 3,659) (Fig. 3). In the approximately 1100 years between deposition of this unit and the underlying Glacier Peak B ash, 540 cm of fine-grained sediments were deposited, many of which occur as paired couplets resembling varves. Many of these couplets were 13 to 17 mm thick. An average rate of deposition of 4.8 mm/yr for these 1000 years indicates a period of heavy runoff into the meadow. This rate of annual sedimentation is higher than the full-glacial rate described from Colorado by LEGG and BAKER (1980), suggesting a period of runoff associated with rapid glacial deterioration upvalley. The varved nature of the sediments, however, as well as the presence of morphologic features in the sediments similar to periglacial frost wedges and involutions, suggest that the overall climate of the area was still harsh during deglaciation.

Pollen extracted from sediments between the two dated units reflects a relatively rapid change from a cold, moist spruce (*Picea*) parkland to a spruce/fir (*Abies*) forest indicative of milder climatic conditions (BUTLER, 1985). Pollen extracted from the unit dated at 10,130 yr BP definitely illustrates the onset of milder and somewhat drier postglacial conditions: the relative totals include pine (*Pinus*), 58%; spruce, 5%; fir, 17%; Douglas-fir (*Pseudotsuqa*), 3%; and sagebrush (*Artemisia*), 6% (BUTLER, 1985). Whether or not the transition from glacial to postglacial times was gradual or an abrupt step-like change cannot be determined from the pollen record (DAVIS and BOTKIN, 1985).

THE EARLY HOLOCENE

Another organic-rich sedimentary unit from First Meadow, at a depth of 91 cm, was radiocarbon dated at 7560 ± 310 yr BP (Beta 3,658) (Fig. 3). The annual average rate of sedimentation during the early Holocene was therefore much less, only 0,27 mm/yr. These lowered rates of sedimentation suggest that glacial ice had largely abandoned the valley during this period. It was during this same period that a large ice-cored rock glacier stagnated and stabilized in the adjacent Hilltop Valley (Fig. 1) (BUTLER, 1984c).

Although lower early Holocene sedimentation rates, and the stagnation of the ice-cored Hilltop Valley rock glacier, suggest drier and/or warmer climatic conditions, they do not necessarily imply that the entire early Holocene in the region was an uninterrupted period of warming. Some controversy exists as to whether or not an early Holocene cold climatic reversal occurred in the area. Evidence, both against and in support of such an interruption to the classic trend of Holocene warming toward a mid-Holocene Altithermal, has come from palynologic, paleontologic, periglacial, and glacial studies; it is briefly reviewed below.

Most pollen studies from the U.S. Pacific northwest do not reflect an early Holocene cold climatic episode (BRIGHT and DAVIS, 1982; MACK *et al.*, 1983; DORT and FREDLUND, 1984), although BARNOSKY (1985) has detected the onset of more humid climatic conditions around 8500 yr BP in south-central Washington. Advances are being made in the use and interpretation of fine resolution pollen records (GREEN, 1983), however, it is quite possible that a period of early Holocene cooling was too brief to sufficiently change forest structures and boundaries so as to be reflected in the pollen record (DAVIS and BOTKIN, 1985).

Paleontologic data from the eastern Snake River Plain (GUILDAY, 1969) and the northern margins of the Great Salt Lake (SCHAFFER, 1984) do suggest cold conditions and a possible climatic oscillation, coincidental with a rise in the Great Salt Lake (SCHAFFER, 1984). Opal phytolith data from the same Snake River Plain area, however, imply increasing aridity around 8000 yr BP (DORT and FREDLUND, 1984), so controversy remains.

The primary evidence for an early Holocene cold climatic reversal comes from glacial studies, summarized by BEGET (1983) and BUTLER (1984b). MAHANEY and SPENCE (1984), however, believe that early Holocene glacial deposits in the American west represent a halt in the retreat of Pinedale valley glaciers rather than readvances following complete or partial withdrawal of the ice.

In the Lemhi Mountains, *in situ* charcoal from a moraine in Mountain Bow Valley has been radiocarbon dated at 7100 ± 120 yr BP (Beta 2,163) (BUTLER, 1984b; BUTLER *et al.*, 1984); and pollen extracted from sediments in First Meadow which had been subjected to periglacial frost churning illustrated a vegetative assemblage representative of alpine steppe/tundra (details of the palynologic methodology and results may be found in BUTLER, 1984b). The evidence in support of an early Holocene cold climatic episode in the Lemhi Mountains continues to tentatively support the idea of an interruption to the continual post-Wisconsinan warming culminating in a mid-Holocene Altithermal. Unfortunately, no supportive evidence from other valleys in the Lemhi Mountains has as yet been described. FUNK (1976) described "late Pinedale to early Holocene moraines" near the mouths of Davis, Spring Mountain, and Lemhi Union canyons (Fig. 1). However, the location of these moraines, far downvalley from source cirques, as well as their unequivocal Pinedale-equivalent morphologic

FIGURE 4. Typical Pinedale-equivalent terminal/recessional moraine complex, Deer Creek Canyon.

Complexe morainique frontal et de récession caractéristique d'épisodes corrélatifs au Pinedale, Deer Creek Canyon.

TABLE I

Relative pollen percentages from a mid-Holocene paleosol and a surface soil

Pollen Type	Percentage of Total	
	Paleosol	Surface Soil
Gramineae	70%	5%
Pinus	8%	58%
Larix/Pseudotsuga	5%	4%
Populus	4%	—
Rosaceae	3%	4%
Ambrosia – like Compositae	—	8%
Undifferentiated Compositae	—	6%
Artemisia	1%	4%
All others	(2% each)	(<2% each)
Total known grains identified	303	306
AP/NAP Ratio	21/79	66/34

and relative-dating characteristics (determined by aerial photo analysis and field examination in 1984), belie an early Holocene-age equivalence (Fig. 4). Relative-age characteristics of the early Holocene moraine in Mountain Boy Valley (described in detail in BUTLER, 1984b), and a location very close to cirque deposits of Neoglacial age, are features totally dissimilar to those for the moraines mentioned by FUNK (1976), but are similar to characteristics described for other early Holocene deposits (BENEDICT, 1981; BEGET, 1983).

THE MID HOLOCENE

Little direct evidence exists for conditions in the Lemhi Mountains for the approximate period 7000-5000 BP. Pollen was extracted from a buried soil exposed in the First Meadow trench (and morphologically similar to the paleosol in Middle Bruce Meadow); the soil is stratigraphically located 20-40 cm over the unit dated at 7,560 ± 310 yr BP (Beta 3,658) and 30-60 cm below the modern surface soil. The relative pollen percentages extracted from this unit, combined with well-developed columnar structure in the soil, provide evidence for a warm, semi-arid environment, particularly when compared to pollen extracted from the modern surface soil (Table I). The well-developed columnar structure of the paleosol suggests an age greater than would be attributable to a Neoglacial interstade, and so is tentatively assigned a mid-Holocene age. An Altithermal of no more than about 2000 years in duration is suggested; much shorter than the "classic" Altithermal, but long enough for development of columnar soil structures under a climate conducive to a vegetative assemblage of open pine forest and grassland perhaps similar to current conditions in the Sweetgrass Hills of Montana or at the eastern foot of the Bighorn Mountains of Wyoming (McANDREWS and WRIGHT, 1969).

THE NEOGLACIAL RECORD

DORT (1962) first mapped and divided Neoglacial moraine and mass-wasting deposits in the central Lemhi Mountains into Temple Lake and Little Ice Age equivalents. His usage of the term Temple Lake was according to its generally-accepted definition at that time, a period in the early Neoglacial around 3000-5000 yr BP. He noted that these moraines occurred in close association with, and in some cases were overridden by, Little Ice Age deposits, primarily at the heads of valleys within the cirques. In the area encompassed by Figure 1, he mapped Temple Lake deposits in Nez Percé, Deer Creek, Hilltop, Mountain Boy, Meadow Lake, Long, Lemhi Union, Bruce, and Davis canyons; Little Ice Age deposits were mapped from these same valleys, as well as in cirques in Negro Green and Spring Mountain canyons.

More recently, KNOLL (1977), BUTLER (1982a, b; 1984a), and BUTLER *et al.* (1963, 1984) have described Neoglacial moraines, rock glacier, protalus, and talus deposits from Long, Meadow Lake, Mountain Boy, and Hilltop valleys. These deposits were subdivided on the basis of relative-age and dendrochronologic dating techniques into the now-accepted three stades of neoglaciation in the American Rockies; elsewhere called Indian Basin (5000-3000 yr BP), Audubon (2400-900 yr BP), and Gannett Peak/Arapaho Peak (350-100 yr BP) (BENEDICT, 1981; MAHANEY, 1984; MAHANEY and SPENCE, 1984).

Moraines, rock glaciers, and massive protalus ramparts were deposited during the Indian Basin Advance (Fig. 5). Their areal extent (KNOLL, 1977; BUTLER, 1984a) suggests that this was the most climatically severe of the three Neoglacial advances. A brief period of milder climate probably occurred during the Indian Basin Advance, temporarily halting rock glacier advance (BUTLER, 1984a) in poorly protected cirques, but not strongly affecting true glaciers in more climatically-favorable cirques.

The Audubon Stade in the central Lemhi Range was characterized by more severe climatic conditions than at present, but much milder than during the Indian Basin. This conclusion is based on the more restricted areal extent and more limited number of deposits emplaced during this period. Percent lichen cover, stability of footing, and degree of boulder implantation provide the primary methods for distinguishing these deposits

FIGURE 5. Late Neoglacial avalanche boulder tongue in Deer Creek Canyon, overriding Indian Basin protalus rampart. Note extensively-trimmed conifer on far right, indicative of occasional, modern, high-magnitude snow avalanches.

Langues de pierres du Néoglaciaire supérieur, Deer Creek Canyon, chevauchant le bourrelet de congère d'Indian Basin. À remarquer, à l'extrême droite, le conifère dégarni, témoin des importantes avalanches qui surviennent à l'occasion.

from those of Indian Basin or Gannett Peak/Arapaho Peak age (Table II). Surface soils on Audubon deposits are largely absent in the area, because of the extremely slow weathering rates of the quartzite comprising the deposits (BUTLER, 1982b). The Audubon was probably a period of minimal to no glacial conditions in this area, but with cool summers and favorable winters with enough snow to produce permanent snowbanks and associated protalus ramparts (KNOLL, 1977; BUTLER, 1984a).

The Gannett Peak/Arapaho Peak advance was characterized by a lowering of upper timberline throughout the central Lemhi Range (WINTER, 1984), as well as rock glacier advance in the most favorably-oriented cirques, snow avalanche activity (as shown by the presence of large avalanche boulder tongues, especially in Long, Meadow Lake, and Deer Creek canyons; Fig. 5), rockfall, and rather consistently narrow growth rings in trees surviving from that period (implying more severe growing conditions than at present). The stade terminated around 1905-1910 A.D. (BUTLER, 1983). Since that time, tree-ring growth has been marked by wider rings indicative of a milder climate, elevation of upper timberline has increased (WINTER, 1984), conifers have become established in subalpine meadows (BUTLER, in press), and initial stabilization and lichen colonization of avalanche boulder tongues has begun.

TABLE II

Relative-age characteristics useful in differentiating neoglacial deposits in the study area

Neoglacial advance	Percent lichen cover	Stability of footing	Degree of boulder implantation*
Indian Basin	60-85%	Barely stable	10-20%
Audubon	30-45%	Unstable to very unstable and treacherous	0-5%
Gannett Peak/ Arapaho Peak	0-10%	Very unstable and treacherous	0%

* The percentage of volume of a boulder implanted beneath the surface, determined by excavation of 10 boulders (>30 cm diameter) per deposit.

SUMMARY

The combination of glacial, mass-wasting, palynologic, and biogeographic evidence from several valleys in the Lemhi Mountains provides a picture of complexity during the Late Wisconsinan and Holocene. The complexity of the record is preserved because of the trend of decreasing severity of climate and a corresponding decrease in areal coverage of boulder-rich deposits as the present is approached. The primary necessity for future studies in the area is for clarification of the question of whether or not an early Holocene glaciation occurred, and if so, determination of its severity, spatial coverage, and duration.

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