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Résumé de l'article

La cartographie et l'identification des dépôts glaciaires et fluvioglaciaires a permis d'établir la stratigraphie locale des bassins du North Fork de la Big Lost River, du Pole Creek et du Slate Creek. Le modèle stratigraphique établi augmente la superficie déjà couverte par le modèle glaciaire de l'Idaho. Les échantillons de cendre volcanique prélevés ont été identifiés sur le plan pétrographique et mis en corrélation avec des tephras témoins provenant du Cascade Range, en se fondant sur la composition minérale et sur la géochimie du verre. On distingue quatre types de tephras: ceux de la série S du mont St. Helen's (13 600-13 300 BP), ceux de la série B du Glacier Peak (11 250 BP), ceux de la série S du mont St. Helen's (4350 BP) et ceux du mont Mazama (6600 BP). Une carotte de sédiments lacustres prélevée dans le kettle Pole Creek renferme deux tephras. L'analyse du pollen et des sédiments révèle l'existence de trois grands changements climatiques au Pleistocene supérieur et à l'Holocène: un climat frais et humide un peu avant et immédiatement après la mise en place des cendres de la série B du Glacier Peak (11 250 BP); une période de réchauffement (10 500-6600 BP); un climat chaud et sec. L'accumulation de sédiments dans le kettle prit fin vers 4350 BP. La présence du tephra de la série B du Glacier Peak à la base de la carotte donne la date minimale du retrait des glaciers de vallée (11 250 BP) à partir de leur emplacement au Wisconsinien supérieur. La date de 8450 + 85 ans BP et la présence, dans la partie supérieure de la carotte, de cendres provenant du mont Mazama (6600 BP) confirment l'identification de la série B du Glacier Peak.

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GLACIAL AND POSTGLACIAL HISTORY OF THE WHITE CLOUD PEAKS-BOULDER MOUNTAINS, IDAHO, U.S.A.*

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ABSTRACT Glacial and glaciofluvial deposits are mapped and differentiated to develop new local, relative-age (RD) stratigraphies for the North Fork of the Big Lost River, Slate Creek and Pole Creek drainages in the White Cloud Peaks and Boulder Mountains, Idaho. This stratigraphic model expands the areal extent of the "Idaho glacial model". Volcanic ash samples collected from the study area are petrographically characterized and correlated, on the basis of mineralogy and glass geochemistry, to reference samples of identified Cascade Range tephras. Four distinct tephras are recognized including; Mount St. Helens-Set S (13,600-13,300 yr BP), Glacier Peak-Set B (11,250 yr BP), Mount Mazama (6600 yr BP) and Mount St. Helens-Set Ye (4350 yr BP). A core of lake sediments containing two tephra units was obtained from a site called "Pole Creek kettle". Pollen and sediment analyses indicate three intervals of late Pleistocene and Holocene climatic change. Cool and wet climatic conditions prevailed in the region shortly before and immediately following the deposition of the Glacier Peak-Set B ash (11,250 yr BP). Climatic warming occurred from approximately 10,500 to 6600 yr BP after which warm, dry conditions prevailed. Sediment accumulation in the kettle ceased by 4350 yr BP. The presence of Glacier Peak-Set B tephra in the base of the Pole Creek kettle core provides a minimum age of 11,250 yr BP for the retreat of valley glaciers from their Late Wisconsinan maximum position. A radiocarbon date of 8450 + 85 yr BP (SI-5181), and the presence of Mount Mazama ash (6600 yr BP) up-core support the Glacier Peak-Set B identification.

RÉSUMÉ *Évolution glaciaire et postglaciaire dans les White Cloud Peaks-Boulder Mountains, Idaho, É.-U.* La cartographie et l'identification des dépôts glaciaires et fluvioglaciaires a permis d'établir la stratigraphie locale des bassins du North Fork de la Big Lost River, du Pole Creek et du Slate Creek. Le modèle stratigraphique établi augmente la superficie déjà couverte par le modèle glaciaire de l'Idaho. Les échantillons de cendre volcanique prélevés ont été identifiés sur le plan pétrographique et mis en corrélation avec des tephras témoins provenant du Cascade Range, en se fondant sur la composition minérale et sur la géochimie du verre. On distingue quatre types de tephras: ceux de la série S du mont St. Helen's (13 600-13 300 BP), ceux de la série B du Glacier Peak (11 250 BP), ceux de la série Ye du mont St. Helen's (4350 BP) et ceux du mont Mazama (6600 BP). Une carotte de sédiments lacustres prélevée dans le kettle Pole Creek renferme deux tephras. L'analyse du pollen et des sédiments révèle l'existence de trois grands changements climatiques au Pléistocène supérieur et à l'Holocène: un climat frais et humide un peu avant et immédiatement après la mise en place des cendres de la série B du Glacier Peak (11 250 BP); une période de réchauffement (10 500-6600 BP); un climat chaud et sec. L'accumulation de sédiments dans le kettle prit fin vers 4350 BP. La présence du tephra de la série B du Glacier Peak à la base de la carotte donne la date minimale du retrait des glaciers de vallée (11 250 BP) à partir de leur emplacement au Wisconsinien supérieur. La date de 8450 + 85 ans BP et la présence, dans la partie supérieure de la carotte, de cendres provenant du mont Mazama (6600 BP) confirment l'identification de la série B du Glacier Peak.

ZUSAMMENFASSUNG *Glaziale und postglaziale Entwicklung in den White Cloud Peaks-Boulder Mountains, Idaho, U.S.A.* Glaziale und glaziofluviale Ablagerungen wurden kartographiert und identifiziert, um eine neue, lokale, relative Alters-Stratigraphie der North Fork des Big Lost River, des Slate Creek und des Pole Creek in den White Cloud Peaks und Boulder Mountains, Idaho, zu entwickeln. Proben vulkanischer Asche, die im untersuchten Gebiet gesammelt wurden, werden petrographisch bestimmt und auf der Basis von mineralogischer Zusammensetzung und Geochemie des Glases in Wechselbeziehung zu Referenz-Belegen von identifizierten Tephras von den Cascade Ranges gesetzt. Es werden vier verschiedene Tephras identifiziert: von der Serie S des Mount St. Helens (13 600-13 300 v.u.Z.), von der Serie B des Glacier Peak (11 250 v.u.Z.), von der Serie Ye des Mount Mazama (6600 v.u.Z.) und des Mount St. Helens (4350 v.u.z.). Eine Probe von See-Sedimenten, der vom Pole Creek Kettle gewonnen wurde, enthält zwei Tephra-Einheiten. Die Pollen- und Sediment-Analysen lassen drei Intervalle klimatischen Wechsels im späten Pleistozän und im Holozän erkennen. Kalte und feuchte Klimatische Bedingungen herrschten in diesem Gebiet vor, kurz vor und unmittelbar nach der Ablagerung der Asche der Serie B des Glacier Peak (11 250 v.u.Z.). Eine klimatische Erwärmung trat zwischen ungefähr 10 500 bis 6600 v.u.Z. auf, nach welcher warme, trockene Bedingungen vorherrschten. Die Sediment-Anhäufung in dem Kettel endete ungefähr um 4350 v.u.Z. Das Vorkommen von Tephra der Serie B des Glacier Peak in der Basis der Probe des Pole Creek Kettle ergibt ein Minimum-Alter von 11 250 v.u.Z. für den Rückzug der Gletscher des Tals von ihrer maximalen Position im späten Wisconsin. Ein Radiokarbon-Datum von 8450 + 85 v.u.Z. (SI-5181) und das Vorkommen von Asche des Mount Mazama (6600 v.u.Z.) im oberen Teil der Probe stützen die Identifizierung der Serie B des Glacier Peak.

* Contribution du premier symposium de la CANQUA, sous la direction de René W. Barendregt.

INTRODUCTION

Glacial deposits are mapped and differentiated on the basis of multiple relative age dating (RD) techniques, including; soil properties, moraine morphology, weathering of boulders, spatial relationships of terraces and moraines, and down-valley extent of moraines. Volcanic tephra horizons, correlated to well-dated reference samples of identified Cascade Range tephras, are used for absolute age control. Sediment cores of a kettle lake are analyzed for radiocarbon, tephra, and pollen content to determine vegetation changes and a minimum age date for deglaciation.

The stratigraphic model developed for the mapping of glacial deposits in central Idaho, known as the "Idaho glacial model" (EVENSON *et al.*, 1982; COTTER and EVENSON, 1983), is a two-tiered local/regional nomenclature system. The model was established to both avoid unjustified extension of formal Quaternary stratigraphies, and unnecessary proliferation of the nomenclature. Mapping and relative age dating of glacial deposits in the White Cloud Peaks and Boulder Mountains has resulted in the establishment of three new local stratigraphies which are here correlated to the Idaho glacial model. Our work in the White Cloud Peaks-Boulder Mountains area thus extends the areal coverage of the Idaho glacial model and further emphasizes the regional applicability of this stratigraphic system. In addition, the contribution of a late-glacial absolute age pollen and tephra chronology allows the tentative correlation of Idaho glacial model to time-stratigraphic units used elsewhere in the Rocky Mountains.

LOCATION AND PREVIOUS WORK

The White Cloud Peaks and Boulder Mountains are located in central Idaho (Fig. 1). The study area includes portions of the Pole Creek, Slate Creek, East Fork of the Salmon River, and the North Fork of the Big Lost River drainages. Nearby mountain ranges include the Sawtooth Mountains (west), Smokey Mountains (southwest), Pioneer Mountains (southeast), and Lost River Range (east) (Fig. 1). Both the White Cloud Peaks and Boulder Mountains have range crests which exceed 3100 m and topographic relief of over 1300 m. Summit elevations in the region commonly exceed 3500 m, notably Ryan peak (elev. 3630 m), Castle Peak (elev. 3605 m), and Kent Peak (elev. 3565 m).

Surficial deposits of the study area are only partially mapped in detail. ROSS *et al.* (1937) and WILLIAMS (1961) mapped and described valley and glacial deposits in the Stanley Basin, the western margin of the White Cloud Peaks-Boulder Mountains area. The surficial geology of portions of the White Cloud Peaks has been mapped by ZIGMONT (1982), GAWARECKI (1983), and BLOOMFIELD (1983). Portions of the Boulder Mountains have been mapped by BLOOMFIELD (1983) and COTTER (1980). The tephra and pollen analysis of this study were restricted to samples collected in the Slate Creek drainage which joins the Salmon River 31 km east of Stanley; and the Pole Creek drainage which joins Salmon River 37 km south-southeast of Stanley (Fig. 1). No tephra or pollen studies in the area prior to the work of BLOOMFIELD (1983) have been reported, although Steen-McIntyre (personal communication) has conducted numerous reconnaissance studies.

STRATIGRAPHIC APPROACH

Due to the paucity of absolute age dates throughout the Rocky Mountains, relative dating (RD) techniques have been widely used to establish local stratigraphies. RD techniques utilize time dependent characteristics of landform, rock, and soil modification to differentiate deposits. These techniques assume that at the time of deglaciation a feature is "fresh" and that all modifications indicative of relative age have occurred since that time. As BURKE and BIRKELAND (1979) have discussed, time is not the sole factor in influencing weathering and erosion. Therefore, a multiple parameter approach to relative dating increases the reliability of differentiation on a local basis and increases the possibility of obtaining criteria useful for regional correlation. The use of any single method often does not document age difference sufficiently. Also, local factors may result in varying effectiveness of a technique at different localities.

The establishment of increasing numbers of local stratigraphies based on RD techniques (*e.g.* PIERCE *et al.*, 1976; EVENSON *et al.*, 1979; BIRKELAND *et al.*, 1979; and COLMAN

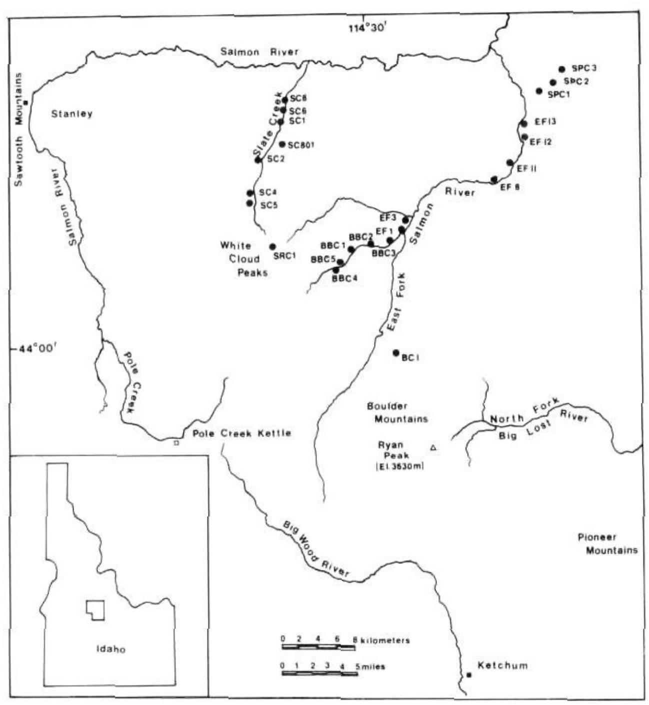

FIGURE 1. Location of major tributaries in the White Cloud Peaks — Boulder Mountains area, and the location of other areas of research discussed in text. Towns located near the study area are indicated as closed squares. Ryan Peak (open triangle) is the point of highest elevation in the study area. The pollen study site, Pole Creek kettle, is indicated by an open square. Tephra sample site locations are indicated by closed circles and identification numbers referred to in the text.

Localisation des principaux affluents des White Cloud Peaks, région des Boulder Mountains et des autres régions dont on discute dans le texte. Les villes situées près de la région à l'étude sont indiquées par des carrés noirs. Ryan Peak (triangle blanc) est le point le plus élevé de la région. Le site d'échantillonnage pollinique, le kettle de Pole Creek, est identifié par un carré blanc. Les sites d'échantillonnage des tephras sont indiqués par des cercles noirs accompagnés d'un numéro.

and PIERCE, 1981) has resulted in both the over-extension of regional nomenclature (*i.e.* Pinedale and Bull Lake) and the formal (or informal) naming of deposits differentiated by more than one RD parameter. The former — over-extension — is problematic because of regional variation of post-depositional modification processes. Problems arise with the latter — local formal nomenclature systems (as discussed by BIRKELAND *et al.*, 1979) — because the previous "Stratigraphic Code of Nomenclature" (AMERICAN COMMISSION ON STRATIGRAPHIC NOMENCLATURE, 1970) made no provision for defining glacial units on the basis of multiple physical RD parameters.

The nomenclature problem has been discussed previously (COTTER, 1980; COTTER and EVENSON, 1983; EVENSON *et al.*, 1982; 1985). These authors have concluded that because of distance, and the inability to explicitly correlate deposits in Idaho with the type sections in Wyoming, the continued use of the "Pinedale-Bull Lake" nomenclature system in central Idaho is not justified stratigraphically. The use of these terms implies demonstrated correlation with the type areas in the Wind River Range, Wyoming that cannot be substantiated using relative dating techniques. The alternative, the definition of new formal stratigraphic units for each area studied, is cumbersome, confusing and leads to an unnecessary proliferation of stratigraphic names.

EVENSON *et al.* (1982) and COTTER and EVENSON (1983) *advocate the adoption of an informal, two-tiered local/* regional nomenclature system: the "Idaho glacial model". This system prevents unjustified extension of the Pinedale/ Bull Lake nomenclature and avoids unnecessary proliferation of formal nomenclature while allowing communication between workers unfamiliar with local nomenclature systems. Under this system, deposits of first-order glacial episodes (called "advances") which are separable by absolute- and/or relative-dating (RD) techniques are assigned local, informal names (*e.g.* North Fork advance, or Rainbow Creek advance; Table I); and second order episodes (subdivisions of advances) are called "events" and given Roman Numeral designations (*e.g.* Rainbow Creek II; Table I).

A single advance (*e.q.* deposits of the Rainbow Creek advance) includes deposits within a small area, where correlations are explicit and demonstratable. Local systems are in turn correlated to a set of regional stratigraphic names (called "glaciations") that are not formally tied to a specific locality or deposit (Table I). At this time the Idaho glacial model includes three glaciations: Pothole, Copper Basin, and Pioneer (oldest).

Under the newly adopted Stratigraphic Code (NORTH AMERICAN COMMISSION ON STRATIGRAPHIC NOMENCLATURE, 1983) it is possible to elevate this nomenclature to formal status, with "advances" and "events" redefined as Alloformations and "glaciations" redefined as Diachrons. However, we are inclined to resist the addition of a formal nomenclature until the regional extent of the Idaho glacial model warrants this status.

RESULTS

GLACIAL GEOLOGY

BLOOMFIELD (1983) and COTTER (1980) have demonstrated that RD techniques can be used to differentiate the glacial deposits in the White Cloud Peaks — Boulder Mountains area of central Idaho. In these investigations the following RD criteria proved most useful:

TABLE I

Stratigraphic system and nomenclature of the White Cloud Peaks-Boulder Mountains area, after COTTER, 1980 (Big Lost River stratigraphy) and BLOOMFIELD, 1983 (Pole Creek and Slate Creek stratigraphies); the Idaho glacial model (EVENSON et al., 1982; 1985); and possible correlatives in the Wind River Range, Wyoming.

Idaho Glacial Model EVENSON et al., 1982	North Fork Big Lost River COTTER & EVENSON 1983	Pole Creek THIS PAPER	Slate Creek THIS PAPER	Wind River Range, Wyoming
Glaciation	Advance	Advance	Advance	
Potholes	North Fork IV III II I	Rainbow Creek V IV III II I	Silver Rule	Pinedale
Copper Basin	Kane	Boulder Mountain	Slate Creek	Bull Lake
Pioneer	Not Recognized	Not Recognized	Not Recognized	Pre-Bull Lake

A) *Extent of moraine complexes*: older moraines are preserved further down valley and/or higher on the valley sides than deposits of younger advances in the same canyon.
B) *Grading and cross-cutting relationships of glaciofluvial deposits*: glaciofluvial terraces grade to moraines and other terraces of the same age, and dissect older terraces. Terraces prove particularly useful for correlation of deposits from valley to valley.
C) *Moraine morphology*: morphologic variation in constructional topography, degree of development of drainage, percent undrained hollows, and surface boulder percentage are locally indicative of relative age.
D) *Till weathering*: pedologic characteristics (soil depths, color, horizonation, and ped development) and weathering of till clasts.

The glacial history of the study area includes two distinct episodes of extensive glacial expansion and end moraine deposition. In the drainage of the North Fork of the Big Lost River, COTTER (1980) assigned the local names "Kane" (older) and "North Fork" (younger) to the deposits of these two advances (Table I). We herein propose the local names "Slate Creek" (older) and "Silver Rule", respectively, for their correlatives in the Slate Creek drainage and "Boulder Mountain" (older) and "Rainbow Creek", respectively, for their proposed correlatives in the Pole Creek drainage. The Kane, Slate Creek, and Boulder Mountain advances are correlated with the Copper Basin glaciation while the North Fork, Silver Rule, and Rainbow Creek advances are correlated with the Potholes glaciation of the Idaho Glacial Model (Table I).

The Kane, Slate Creek, and Boulder Mountain advances (Copper Basin Glaciation) are represented by isolated, but clearly recognizable moraine remnants (COTTER, 1980; COTTER and EVENSON, 1983; BLOOMFIELD, 1983). The reconstruction of ice lobe geometry and provenance analysis suggest that these moraines were deposited synchronously, however, the absence of recognizable terrace levels graded to these older moraines has inhibited further stratigraphic subdivision.

Multiple, well preserved, recessional moraines of the North Fork, Silver Rule, and Rainbow Creek advances (Potholes Glaciation) indicate that there were from 3 to 5 "events" during this episode of glaciation (COTTER, 1980; BLOOMFIELD, 1983). Deposits of the three oldest events (North Fork I-III and Slate Creek I-III) are correlated principally on the basis of down-valley extent and stratigraphic association with glaciofluvial terraces. Deposits of the final events (North Fork IV and Slate Creek IV-V) are deposited up-valley from older moraines in both tributary and trunk stream valleys. Because of their isolated nature, it is unknown wheather deposits of these events formed synchronously or represent local interruptions of deglaciation of varying extent and duration.

No Pre-Kane, or Pre-Boulder Mountain advance deposits (Pioneer glaciation correlative) are recognized in the study area. Principal valleys are narrow and deposits may have been destroyed or covered by subsequent glacial and glaciofluvial activity. Deposits of a younger phase, designated Neoglacial, consist of rock-glaciers and talus debris indicating extensive periglacial rather than glacial activity. Evidence of an "intermediate" age glacial advance (between Copper Basin and Potholes glaciations) recognized in western Idaho (COLMAN and PIERCE, 1981; 1983) has not been documented in the White Cloud Peaks-Boulder Mountains area.

TEPHROCHRONOLOGY

Volcanic ash horizons are found in association with dissected alluvial fan complexes and fine grained lacustrine sediment at twenty-four sites in the study area (Fig. 1; Table II). Field characterization of samples included; depth below surface, horizontal extent and color of tephra unit, description of upper and lower contacts, and nature of over- and underlying units (sediment type, grain size distribution, and sorting). During laboratory processing, samples are passed through a 1.0 phi (500 um) dry sieve to remove any large, locally-derived rock fragments prior to cleaning and analysis. All samples are treated with 0.01 N Sodium Hypochlorite to remove organics and 0.01 N Hydrochloric Acid for removal of calcium carbonate, as described by STEEN-McINTYRE (1977). Samples are then washed in distilled water and air dried at 80°C.

Petrographic characterization of heavy mineral separates and glass shards, along with geochemical analysis of selected samples, are employed to both identify distinctive units in the study area, and correlate Idaho samples with known, well dated Cascade Range deposits. Mineral proportions are determined by point counting up to 300 Fe-Mg mineral grains per slide. Hornblende, hypersthene, augite, mica, cummingtonite, and Fe-Ti oxides are the most common mineral species encountered. The refractive index of the glass shards is determined using the central masking technique of Cherkavak (in McCRONE *et al.*, 1967), as described by STEEN-McINTYRE (1977). The 4-phi size fraction is mounted in Cargille refractive index oils at intervals of $N = 0.004$ from $N = 1.488$ to $N = 1.516$. One hundred shards are counted per mount. Refractive index range is defined by the lowest and highest index oils in which the refractive index of at least one shard match. Mean refractive index is determined by calculating the sum of the weighted average of glass shards with a matching refractive index for each index interval, divided by the total number of shards matched (STEEN-McINTYRE, 1977; BLOOMFIELD, 1983).

Correlation of the Idaho samples with known Cascade Range reference samples is based on our petrographic characterization of all samples (Fig. 2 and 3) and electron microprobe geochemical analysis of 5 Idaho samples (Fig. 4). Four distinct tephra units have been identified from exposures in the White Cloud Peaks — Boulder Mountains region of Idaho. These are; Mount St. Helens — Set S (13,600 — 13,300 yr BP), Glacier Peak — Set B (11,250 yr BP), Mount Mazama (6600 yr BP), and Mount St. Helens — Set Ye (4350 yr BP).

Two samples collected from shallow stream cuts (SC1, BBC4; Fig. 1), and one sample from a bog in Slate Creek (SC801; Fig. 1) are petrographically similar to Mount St. Helens-Set Ye tephra (4350 yr BP) (Fig. 2). These samples contain

TABLE II

Tephra samples, tephra identification, sample site location, geomorphic setting and petrographic characterization (see Figure 1 for sample site locations)

Sample	Location	Physiographic setting	R.I. Mean	Glass (N) range	HB	Heavy mineral suite-(1) HY	AU	MICA	OP	CU	Sample ID
S-1	T7N R14E	Kettle Lake	1.500	1.496-1.504	A(2)	S	R	S	S	NF	G.P.-SetB
*SRC-1	T10N R16E	Road-cut colluvium	1.501	1.500-1.504	C	NF	NF	R	C	S	MSH-SetSo
BC-1	T8N R17E	Dissected alluvial plain	1.504	1.500-1.508	C	R	NF	S	C	S	MSH-SetYe
IA-1	T10N R16E	Alluvial plain bog	1.503	1.496-1.504	C	NF	NF	NF	C	C	MSH-SetYe
BBC-4	T9N R17E	Dissected alluvial fan	1.503	1.500-1.508	C	R	S	R	S	C	MSH-SetYe
*BBC-1	T9N R17E	Road-cut alluvial fan	1.508	1.500-1.508	A	S	R	S	C	NF	Mazama
BBC-2	T9N R17E	Road-cut alluvial fan	1.508	1.500-1.512	S	S	C	NF	C	NF	Mazama
BBC-3	T9N R17E	Road-cut alluvial fan	1.508	1.500-1.512	C	C	S	NF	C	NF	Mazama
BBC-3B	T9N R17E	Road-cut alluvial fan	1.508	1.504-1.512	C	R	S	S	A	NF	Mazama
BBC-5	T9N R17E	Road-cut alluvial fan	1.507	1.500-1.512	C	S	NF	S	C	NF	Mazama
EF-1	*T9N R17E*	*Road-cut alluvial fan*	*1.508*	*1.500-1.512*	*C*	*S*	*C*	*R*	*C*	*NF*	*Mazama*
EF-3	T9N R17E	Road-cut alluvial fan	1.507	1.500-1.508	C	C	S	S	C	NF	Mazama
EF-8	T10N R18E	Road-cut alluvial fan	1.507	1.500-1.512	C	S	NF	S	C	NF	Mazama
EF-11A	T10N R18E	Dissected alluvial fan	1.508	1.500-1.508	S	NF	C	S	C	NF	Mazama
*EF-11B	T10N R18E	Dissected alluvial fan	1.508	1.504-1.508	S	S	C	C	C	NF	Mazama
EF-11C	T10N R18E	Dissected alluvial fan	1.508	1.504-1.512	C	S	C	S	C	NF	Mazama
EF-12	T11N R18E	Road-cut alluvial fan	1.508	1.500-1.512	C	S	C	S	S	NF	Mazama
EF-13	T11N R18E	Road-cut alluvial fan	1.507	1.500-1.512	S	S	C	C	C	NF	Mazama
SC-1	T10N R16E	Road-cut alluvial fan	1.507	1.500-1.512	S	S	R	C	C	NF	Mazama
SC-2	T10N R16E	Road-cut alluvial fan	1.507	1.500-1.512	C	S	C	R	C	NF	Mazama
SC-4	T10N R16E	Road-cut alluvial fan	1.507	1.504-1.508	C	C	NF	NF	C	NF	Mazama
SC-5	*T10N R15E*	*Road-cut alluvial fan*	*1.507*	*1.500-1.512*	*C*	*S*	*NF*	*S*	*C*	*NF*	*Mazama*
SC-6	T10N R16E	Road-cut alluvial fan	1.508	1.500-1.512	C	S	C	NF	C	NF	Mazama
*SPC-1	T11N R19E	Dissected alluvial plain	1.508	1.504-1.512	C	S	C	R	C	NF	Mazama
SPC-2	T11N R19E	Dissected alluvial plain	1.508	1.504-1.512	A	S	NF	NF	C	NF	Mazama
SPC-3	T11N R19E	Dissected alluvial plain	1.508	1.500-1.512	C	C	S	NF	C	NF	Mazama
WA-1	T7N R14E	Kettle Lake	1.506	1.504-1.512	C	C	S	NF	C	NF	Mazama
WA-2	T7N R14E	Kettle Lake	1.508	1.504-1.512	A	S	NF	NF	C	NF	Mazama
MA-1	T7N R14E	Kettle Lake	1.507	1.500-1.508	C	C	S	NF	C	NF	Mazama
VA-1	T7N R14E	Kettle Lake	1.507	1.500-1.512	C	C	S	R	S	NF	Mazama
VA-2	T7N R14E	Kettle Lake	1.508	1.504-1.512	C	C	S	S	S	NF	Mazama
EA-1	T10N R16E	Alluvial plain bog	1.507	1.500-1.512	C	S	S	S	C	NF	Mazama
EA-2	*T10N R16E*	*Alluvial plain bog*	*1.508*	*1.500-1.508*	*C*	*S*	*R*	*R*	*C*	*NF*	*Mazama*

(1) HY-hypersthene; HB-hornblende; CU-cummingtonite; MICA-biotite; AU-augite

(2) A-abundant, >50%; C-common, 20-49%; S-sparse, 5-19%; R-rare, 1-5%; NF-not found

* Elemental analysis by Idaho Bureau of Mines and Geology

hornblende, hypersthene, and the distinctive mineral cummingtonite in the following proportions; 55-72% hornblende, 0-4% hypersthene, and 22-42% cummingtonite. The samples also have a glass refractive index mean of N = 1.503-1.504, *indicative of Mount St. Helens-Set Ye, and display the wide* glass refractive index range characteristic of incompletely hydrated middle to late Holocene Cascade Range tephra. In comparison, the reference samples of Mount St. Helens — Set Ye contain hornblende/hypersthene/cummingtonite proportions of 74/2/24, with a mean refractive index of N = 1.504. The Mount St. Helens-Set Ye tephra was not found in the Pole Creek kettle core.

Volcanic ash characteristic of the middle Holocene eruption of Mount Mazama (6600 yr BP) is widespread throughout the study area and much of Idaho. Twenty-eight Idaho samples identified as Mount Mazama tephra contain from 28-90% hornblende, 0-45% hypersthene, and 0-50% augite. Mount Mazama reference samples contain 43-68% hornblende, 16-43% hypersthene, and 16-17% augite (Fig. 3). Cummingtonite is absent from all Mount Mazama samples. The Idaho samples display the wide glass refractive index range characteristic of middle Holocene tephra and have an index of refraction mean of N = 1.507-1.508, in agreement with both published data (BLINMAN *et al.*, 1979) and with the refractive index values from Mount Mazama reference samples. Microprobe geochemical characterization of four samples identified as Mount Mazama indicate $CaO/FeO/K_2O$ proportions of Idaho samples plot within, or adjacent to reported ranges (Fig. 4).

Tephra derived from a late Pleistocene eruption of Glacier Peak is present in sediment cores of Pole Creek kettle. The ash sample, obtained from near the base of the Pole Creek kettle core is petrographically similar to the Glacier Peak-Set

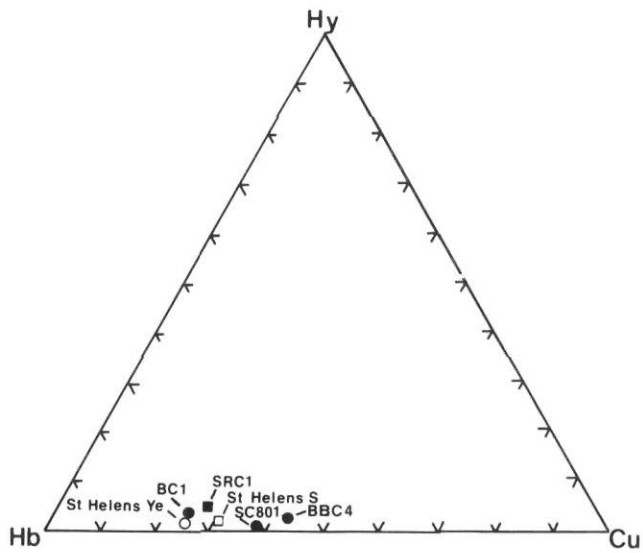

FIGURE 2. Petrographically determined proportions of Hornblende, Hypersthene and Cummingtonite of Cummingtonite bearing tephras found in the White Cloud Peaks — Boulder Mountains study area and correlative Cascade Range Reference samples. Including: Mount St. Helens — Set Ye (Reference sample = open circle, Idaho samples = closed circles); and Mount St. Helens — Set S (Reference sample = open square, Idaho sample = closed square) tephras. See Figure 1 for tephra sample site locations.

Déterminations pétrographiques des proportions de hornblende, d'hypersthène et de cummingtonite contenues dans les tephras (contenant de la cummingtonite) trouvés dans les White Cloud Peaks, région des Boulder Mountains et dans les échantillons corrélatifs de référence du Cascade Range: tephras de la série Ye du mont St. Helen's (échantillon de référence = cercle blanc; échantillon de l'Idaho = cercles noirs) et de la série S du mont St. Helen's (échantillon de référence = carré blanc; échantillon de l'Idaho = carré noir). La figure 1 donne la localisation des sites d'échantillonnage de tephras.

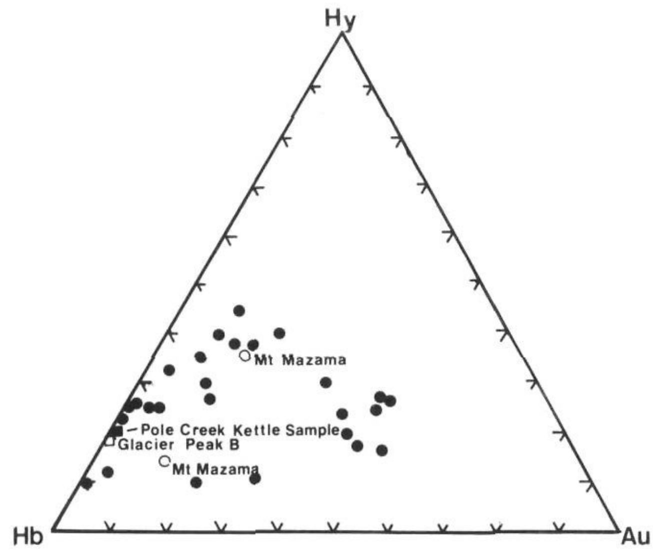

FIGURE 3. Petrographically determined proportions of Hornblende, Hypersthene and Augite of non-Cummingtonite bearing tephras found in the White Cloud Peaks — Boulder Mountains study area and correlative Cascade Range Reference samples. Including: Mount Mazama (Reference samples = open circles, Idaho samples = closed circles); and Glacier Peak — Set B (Reference sample = open square, Idaho sample = closed square) tephras.

Déterminations pétrographiques des proportions de hornblende, d'hypersthène et d'augite contenues dans les tephras (ne contenant pas de cummingtonite) trouvés dans les White Cloud Peaks, région des Boulder Mountains, et dans les échantillons corrélatifs de référence du Cascade Range: tephras du mont Mazama (échantillon de référence = cercle blanc; échantillons de l'Idaho = cercles noirs) et de la série B de Glacier Peak (échantillon de référence = carré blanc; échantillon de l'Idaho = carré noir).

B tephra (11,250 yr BP). Th Idaho sample has a glass refractive index mean of N = 1.500, and the hornblende/hypersthene/augite ratio of 79/20/1 is nearly identical to the 80/20/0 ratio of the Glacier Peak-Set B reference sample (Fig. 3). The refractive index range for glass shards is narrow in both the reference and the Idaho ashes, this is as expected for completely hydrated late Pleistocene tephras.

A single tephra sample, collected from slope wash deposits (SRC1; Fig. 1), is correlated with Mount St. Helens-Set S (13,600-13,300 yr BP). The sample is both geochemically (Fig. 4) and petrographically (Fig. 2) similar to Mount St. Helens-Set S tephras. Elemental proportions of $CaO/FeO/K_2O$ reported by MULLINEAUX *et al.* (1978) for Mount St. Helens-Set So and Set Sg tephra are similar to those obtained from electron microprobe analysis of the Idaho sample. However, petrographic characterization supports a Mount St. Helens-Set Sg origin for the Idaho sample. Mount St. Helens-Set Sg reference samples have a narrow glass refractive range, a refractive index mean of N = 1.500, and hornblende/hypersthene/cummingtonite proportions of 71/03/27 and 75/03/22. In comparison, the Idaho sample has a narrow refractive index range, a refractive index mean of N = 1.500-1.501, and a hornblende/hypersthene/cummingtonite proportion of 69/00/31.

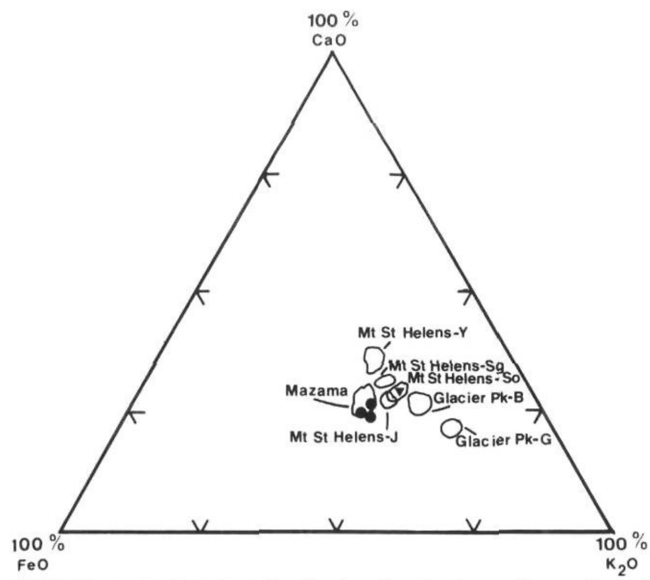

FIGURE 4. $CaO/FeO/K_2O$ ratios in volcanic glasses from selected Cascade Range tephra units (circled areas) and for White Cloud Peaks — Boulder Mountains identified as Mount Mazama tephra (closed circles) and Mount St. Helens-Set S (SRC1; closed triangle).

Pourcentages de CaO de FeO et de K_2O compris dans le verre volcanique provenant de certaines unités de tephras (zones encerclées) du Cascade Range et des tephras des White Cloud Peaks: mont Mazama (cercles noirs) et de la série S du mont St. Helen's (SRC1; triangle noir).

PALYNOLOGY

Reconstruction of Holocene vegetation and climatic changes is based on pollen analysis of a sediment core obtained from a site, here called Pole Creek kettle. The site is a kettle lake situated on a Slate Creek II moraine (BLOOMFIELD, 1983), near the mouth of Pole Creek Canyon (Fig. 1) [Alturas Lakes Quadrangle (7.5′); 43°53′15″ N latitude, 114°45′30″ W longitude]. Pole Creek kettle, at 2225 m, is within a Sagebrush Steppe community but less than 20 m of elevation below a mixed conifer community ("lower tree line"). Upper tree line is approximately 2700 m in the White Cloud Peaks — Boulder Mountains area.

The site was cored in the summer of 1983 and 1984. A Davis-type corer (length 25 cm, diameter 2.5 cm) was used to obtain sediments in 25 cm segments. Successive core samples were collected from adjacent core holes, leaving at least 25 cm of intervening sediment between sampling levels, and thus eliminating contamination due to core hole collapse. Due to the relatively small size of the core barrel, multiple core sections from the same depth and within a 1.0 sq m area were pooled for each radiocarbon sample. Qualitative field description of core samples included sediment type, color, organic content, degree of compaction, macrofossil content, and sedimentary features.

Core sections for pollen analysis were extruded into 25 cm test tube in the field, then sealed and stored for laboratory analysis. Radiocarbon samples were stored in heavy weight aluminum foil and refrigerated until submitted for dating.

Prior to the chemical treatment of core sub-samples, three-10,850 count, *Lycopodium clavatum* tablets are added to a 1 cm^3 core subsample to document loss of pollen and determine rates of pollen influx (STOCKMARR, 1971). Chemical preparation of pollen samples includes defloculation with potassium hydroxide, leaching of silicates with hydroflouric acid, and acetolyzation of organics using glacial acetic and a fresh mixture of acetic anhydride and concentrated sulfuric acid (ERDTMAN, 1943). Pollen concentrates with *Lycopodium* spikes are then suspended in glycerin gelatin, stained with gentian violet, and mounted on slides (SIRKIN, 1967).

Identification of pollen grains was aided by reference keys of ERDTMAN (1952), FAEGRI and IVERSEN (1964), McANDREWS *et al.* (1973), MOORE and WEBB (1978), and BASSET *et al.* (1978). Pollen counts were made at a magnification of 400x with detailed examination of individual grains at 1000x with an oil immersion leans.

Pollen percentages are based on counts of at least 300 grains of arboreal pollen (AP) and non-arboreal pollen (NAP) in most samples.

The basal sediments of the Pole Creek kettle core consist of fossiliferous, calcareous silts and clays (1.79-1.54 m), with interbedded volcanic ash (1.67-1.64 m; Fig. 5). A transitional unit consisting of gradational light brownish-gray calcareous clays, brownish-gray organic clays, and dark grayish-brown clayey peat (1.54-1.50 m) separates the basal sediments from a massive black peat (1.50-0.78 m) with ash horizons at 0.86 and 0.81 m. The uppermost sediments consist of: a reworked ash horizon (0.78-0.74 m), dark brown organic silts (0.81-0.59 m) and poorly compacted dark grayish-brown organics (0.59 m-surface).

Tephra samples collected from the Pole Creek core are petrographically correlated to Cascade Range reference samples derived from the late Pleistocene eruption of Glacier Peak, and the Holocene eruption of Mount Mazama (Fig. 5). The lowermost volcanic ash (1.67-1.64 m) is identified as Glacier Peak-Set B (11,250 yr BP), while the upper ash unit, consisting of multiple samples from 0.86 to 0.74 m is identified as Mount Mazama (6600 yr BP). The Mount Mazama section in the core (Fig. 5) represents a combination of multiple, closely spaced eruptive events followed by reworking and redeposition. Mount Mazama tephra frequently occurs as a doublet or multiple layer horizon, however the thickness of the Pole Creek Mount Mazama tephra (19 cm) suggests that reworking has occurred. A radiocarbon date of 8450 + 80 yr BP (SI-5181) obtained from peat at a depth of 1.19 to 1.24 m is stratigraphically consistent with the positions of the Glacier Peak — Set B ash (11,250 yr BP) and the Mount Mazama ash (6600 yr BP) in the core (Fig. 5). Neither the Mount St. Helens-Set S or Set Ye were found in the Pole Creek kettle core.

Three pollen zones can be distinguished in the Pole Creek kettle core (Fig. 5). The basal horizon (1.79 to 1.50 m), Pole Creek Kettle zone 1 (PC-1), contains the highest percentages of *Pinus* (pine) (84%) and *Picea* (spruce) (9%) pollen in the core, and the lowest percentages of Compositeae (composites) (6%), Chenopodiaceae (chenopods) (0-2%), and Cyperaceae (sedge) (0-2%).

The second pollen zone, PC-2 (1.50 to 0.76 m), contains significantly less pine (30-50% *vs* 66-84%) and more non-arboreal taxa, including percentage maxima of: Gramineae (grass) (4%), composites (41%) chenopods (9%) and sedge (33%). Percentages of arboreal taxa other than pine, including spruce, *Abies* (fir) and *Pseudotsuga-Larix* remain relatively unchanged in PC-2.

In the uppermost zone, PC-3 (0.76 to 0.63 m), pine increases (50-67% *vs* 30-50%), while sedge decreases (1-5% *vs* 10-23%). Percentages of *Artemisia* (sage), chenopods and spruce remain relatively unchanged from PC-2.

The absence of Mount St. Helens-Set Ye from the uppermost sediments of the Pole Creek kettle core indicates continuous sediment accumulation ceased prior to 4350 yr BP. Low pollen recovery from .63 m to the core surface may be due in part to slowing rates of accumulation and the oxidation of pollen grains.

DISCUSSION

Deposits of the Copper Basin glaciation; the Kane, Boulder Mountain, and Slate Creek advances, are the oldest, well-preserved moraines and terraces in the study area. Deposits of this glaciation are morphologically subdued and well weathered, and on the basis of morphology alone, cannot be differentiated as "events". Moraine geometry suggests ice deployment was similar during both the Copper Basin glaciation and the younger, Potholes glaciation, but the extent of glaciation (ice advance) was greater during the Copper Basin glaciation.

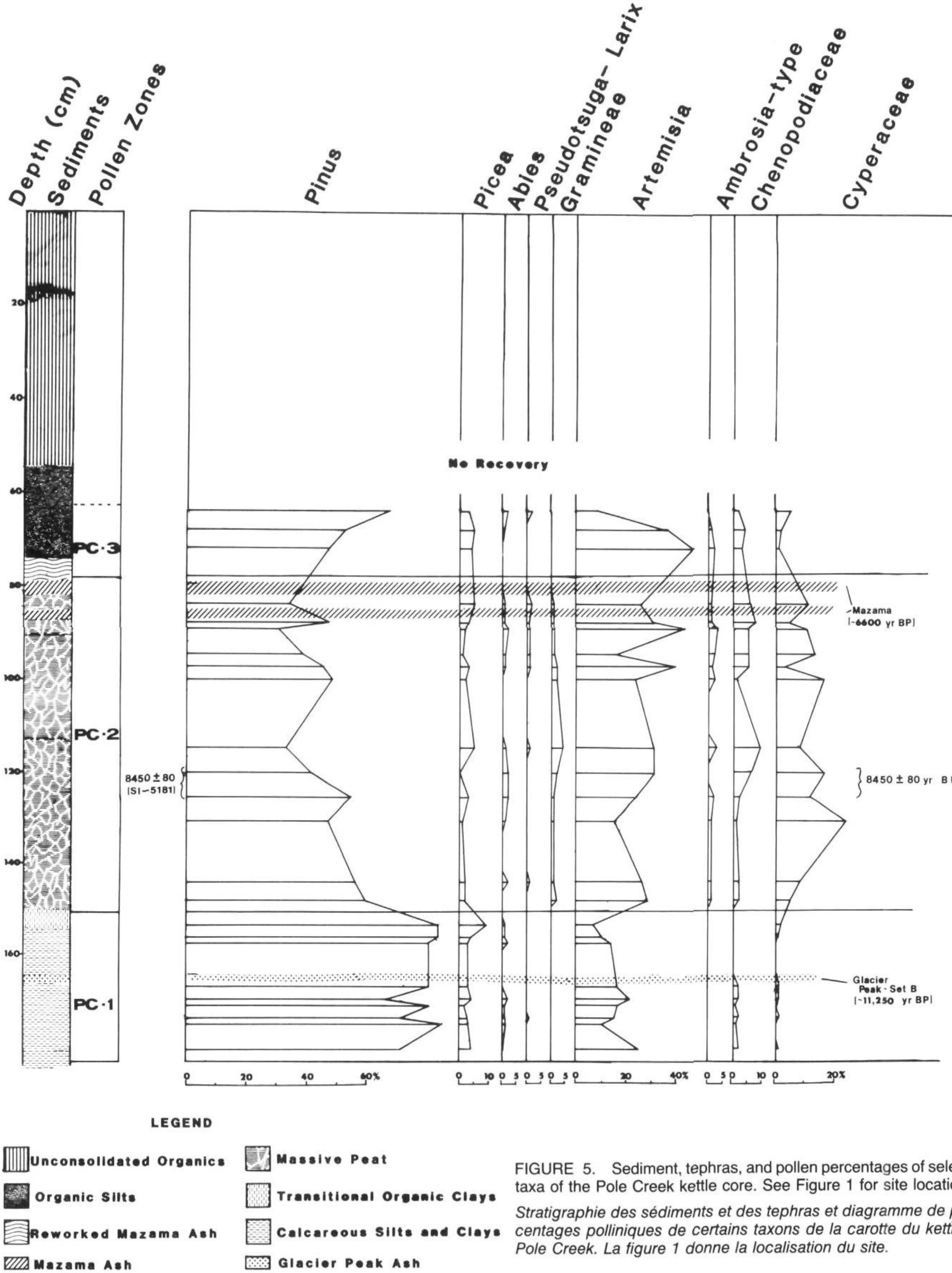

FIGURE 5. Sediment, tephras, and pollen percentages of selected taxa of the Pole Creek kettle core. See Figure 1 for site location.

Stratigraphie des sédiments et des tephras et diagramme de pourcentages polliniques de certains taxons de la carotte du kettle de Pole Creek. La figure 1 donne la localisation du site.

Deposits of the North Fork, Rainbow Creek and Silver Rule advances (Potholes glaciation) are morphologically fresh and little weathered. On the basis of these and other RD-dating parameters, deposits of the Potholes glaciation are considered to be distinct (younger) from the deposits of the Copper Basin glaciation. Although moraines of the Potholes glaciation are indistinguishable from each other on the basis of morphological characteristics, they can be diferentiated on the basis of down-valley extent and their relationship to terrace levels. Four events (North Fork I-IV) are recognized in the drainage of the North Fork of the Big Lost River (COTTER, 1980) and 5 events (Rainbow Creek I-IV) are recognized in the Pole Creek drainage (BLOOMFIELD, 1983). Because of the poor preservation of moraines and terraces in the Slate Creek drainage, the Silver Rule advance is undifferentiated (ZIGMONT, 1982).

No other morainic deposits are recognized in the White Cloud Peak, Boulder Mountains area. In particular, no evidence is found of a depositional event correlatable to the "Intermediate" or "Williams Creek" deposits recognized in the Long Valley area by COLMAN and PIERCE (1981, 1983).

Petrographic characterization of tephra appears to be an effective technique. The petrographic characteristics determined for the reference collection of late Pleistocene and Holocene Cascade Range volcanic ashes are in close agreement with published properties. Assessment of Fe-Mg phenocryst proportions and glass refractive index values serve as a quantitative data base to which unidentified tephra deposits can be correlated. Correlation of samples collected from the study area in central Idaho has enabled the identification of four major tephra units; Glacier Peak — Set B, Mount St. Helens — Sets S, and Ye, and Mount Mazama. Additional geochemical characterization of selected tephra samples support these correlations.

Deposits of the Rainbow Creek advance (Potholes glaciation) represent the last advance of extensive valley glaciation in the Pole Creek drainage. The presence of the Glacier Peak — Set B ash in a kettle lake situated on a Rainbow Creek II moraine (Pole Creek kettle) indicates that the Late Wisconsinan deglaciation in the White Cloud Peaks-Boulder Mountains area, had begun some time before 11,250 yr BP.

Pollen in the basal sediments of the Pole Creek kettle core (PC-1) indicate cool, but not extremely cold climatic conditions. Either lacustrine deposition in the kettle began after significant climatic amelioration had occurred, or sediments containing pollen representative of alpine-tundra were not retrieved during coring. The dominance of low-organic, carbonate-rich deposition suggests a nutrient-rich, but low productivity lacustrine ecosystem, this is again indicative of cool, postglacial conditions. On the basis of tephrochronology and extrapolation, pollen zone PC-1 was probably deposited from about 12,500 yr BP to 10,400 yr BP.

The higher percentages of non-arboreal taxa that characterize PC-2 document the replacement of conifer forest by an Artemisia-steppe community in association with the establishment of warmer climatic conditions. The deposition of organic-rich sediments and the higher percentages of sedge pollen indicate that the kettle lake had developed a productive ecosystem, another indication of warmer climate. This pollen zone was deposited from approximately 10,400 yr BP to 6600 yr BP.

During the deposition of PC-3 drier conditions prevailed in the region. Increased pine and sage, decreased sedge, and increased clastic sediment deposition in the kettle lake suggest less available water. This was followed by a decrease and then a cessation of sediment accumulation in Pole Creek Kettle indicating lower water levels then at present in the kettle. The onset of this dry interval occurred after 6600 yr BP and prior to 4350 yr BP (deposition of Mount St. Helens-Set Ye).

CONCLUSIONS

Two major episodes of glacial advance and moraine deposition have been recognized in the White Cloud Peaks-Boulder Mountains area. The older advances have been named the Boulder Mountain, Slate Creek and and Kane advances, and the younger advances are the Rainbow Creek, Silver Rule and North Fork advances. These advances have been correlated to the Copper Basin glaciation (older) and the Potholes glaciation of the Idaho glacial model and are tentatively correlated with the Bull Lake and Pinedale Glaciations of western Idaho (COLMAN and PIERCE, 1981; 1983).

The petrographic characterization of widespread volcanic ash horizons and identification of four distinctive Cascade Range-correlative units in the White Cloud Peaks — Boulder Mountains region contributes to the development of a late Pleistocene and Holocene absolute-age chronology in central Idaho. Identified tephra units include; Mount St. Helens — Set S (13,600-13,300 yr BP), Glacier Peak — Set B (11,250 yr BP), Mount Mazama (6600 yr BP), and Mount St. Helens — Set Ye (4350 yr BP).

The Late Wisconsinan deglaciation began before 11,250 yr BP and the deposition of the Glacier Peak — Set B ash. Cool, but not tundra, conditions characterized by a pine-mixed conifer forest vegetation existed in the area from approximately 11,250 to 10,500 yr BP (extrapolated age). After 10,500 yr BP warmer conditions prevailed and an Artemisia-steppe community was established. After the deposition of the Mount Mazama ash (6600 yr BP) a drier climate resulted in a decrease of wetland taxa (sedge), and increase in clastic deposition in Pole Creek kettle. Eventually, these dry conditions resulted in a cessation of sediment accumulation in the kettle just prior to the deposition of Mount St. Helens-Set Ye (4350 yr BP) elsewhere in the study area.

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