



The stratigraphy, depositional processes, and environment of the late Pleistocene Polallie-period deposits at Mount Hood Volcano, Oregon, USA

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Abstract

The Polallie eruptive period of Mt. Hood, Oregon, is the last major episode of eruption and dome growth, before the late Holocene activity which was centered at Crater Rock. A volume of 4–8 km³ of Polallie deposits forms an apron of ca. 60 km² on the east, northeast and southeast flanks. The Polallie deposits can be divided, stratigraphically, into four groups: Group I rockslide avalanche and pyroclastic-flow deposits; Group II debris-flow and pyroclastic-flow deposits that suggest some explosive activity and remobilization of pyroclastic debris in a glacial environment; Group III block-and-ash flow deposits that attest to summit dome growth; Group IV alternating debris-flow deposits, glacial sediments, and reworked pyroclastic-flow deposits that indicate a decrease in dome activity and an increase in erosion and transport. Group III clearly indicates frequent episodes of dome growth and collapse, whereas Groups II and IV imply increasing erosion and, conversely, decreasing volcanic activity.

The Polallie period occurred in the late Pleistocene during and just after the last Alpine glaciation, which is named Evans Creek in the Cascade Range. According to four K–Ar age dates on lava flows interbedded with Polallie deposits and to published minimum ¹⁴C ages on tephra and soils overlying these deposits, the Polallie period had lasted 15,000–22,000 years between 28–34 ka and 12–13 ka. From stratigraphic subdivisions, sedimentary lithofacies and features and from the grain-size and geochemical data, we infer that the Polallie depositional record is a result of the interplay of several processes acting during a long-lasting period of dome growth and destruction. The growth of several domes near the present summit was intermittent, because each group of sediments encompasses primary (pyroclastic) and secondary (volcaniclastic and epiclastic) deposition. Direct deposition of primary material has occurred within intervals of erosion that have probably included meltwater processes from snow and ice fields. Interactions of hot pyroclastic debris with glacier ice that capped the mountain at that time contributed to release meltwater, enhancing the remobilization of primary deposits.

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1. Introduction and geologic setting

A study of the stratigraphy, chronology and sedimentology of the volcanoclastic and glacial deposits that were emplaced during the “Polallie eruptive period” (Crandell, 1980) was carried out on the E, NE and SE flanks of the fumarolic, ice-clad Mt. Hood volcano (High Cascades, Oregon, Fig. 1). This study aims to understand depositional processes and environment, reconstruct the chronology of the eruptive period, and explore the relationships between dome eruptive activity, inter-depositional erosion, and snow–ice fluctuations.

The ice-clad Mt. Hood (3425 m asl) is a mainly andesitic volcano of Pleistocene age that has been built by a succession of lava-flow and lava-dome eruptions (Wise, 1969; Crandell, 1980; Keith et al., 1982; Scott et al., 1997a,b). The products cover an area of 235 km², with lava fields representing 70% of the approximate total volume of 50 km³ (Sherrod and Smith, 1990). The eruptive history of the composite andesitic and dacitic Mt. Hood stratovolcano began between 0.5 and 0.8 m.y. ago, with products overlying late Miocene volcanoclastic rocks with interbedded andesite lava flows of the Rhododendron and Chenoweth Formations (The Dallas Group), which themselves overlie the late Miocene Colombia River Basalt Group (Wise, 1969; Beeson and Moran, 1979; Keith et al., 1982, 1985; Scott et al., 1997a,b). Several pre-Mt. Hood vents were buried by the Mt. Hood eruptive products, for example, the Sandy Glacier volcano (1.3 Ma; Keith et al., 1982; Scott et al., 1997a,b), which underlies the west flank of Mt. Hood.

The upper part of the stratovolcano comprises large andesitic or basaltic andesite lava flows gently dipping (10°) in all directions away from the summit. The age of these flows is known to be younger than 0.6 Ma (Scott et al., 1997a,b) or 0.7 Ma (Keith et al., 1985) and older than 58–29 ka. Several recent vents existed before the Mt. Hood summit domes, including Cloud Cap 5 km NE of the summit (0.42 Ma) and Pinnacle to the north (0.128 Ma) (Scott et al., 1997a,b). Lava flows as young as 58–56 to 29–28 ka have been dated on the west and east flanks, and to the south near the present summit (Scott et al., 1997a,b; this study).

Most volcanic activity has been explosive since 50–30 ka when a cluster of domes extruded at the

summit of Mt. Hood. Stubby lava flows have also erupted on the uppermost flanks. Repeated dome growth and collapse, during and just after the last major Pleistocene Evans Creek glaciation (Porter et al., 1983), fed pyroclastic flows and lahars. Three eruptive periods occurred during the late Pleistocene and Holocene (Crandell, 1980; Cameron and Pringle, 1986, 1987; Scott et al., 1997a,b): Polallie (20–13 ka, Scott et al., 1997a,b; 34–28 ka to 13–12 ka, this study); Timberline (1830 ± 50 to 1440 ± 155 years B.P.); and Old Maid (A.D. 1790–1800). In contrast to Cameron and Pringle (1986), Scott et al. (1997a,b) do not consider Zigzag (550–455 years B.P.) an eruptive period, but rather episodes of large non-eruptive lahars emplaced between 1000 and 500 years ago. Activity at Mt. Hood continued into historical time following the Old Maid eruptive period, with three minor explosive events in 1792, 1859 and 1865, and there may also have been activity in 1907. Fumaroles are presently active adjacent to the ca. 200-year-old Crater Rock dome in the crater. Mt. Hood is ice-clad with 0.4 km³ of ice covering 13.5 km² (Driedger and Kennard, 1986).

2. Aim, methods and terminology of deposits

This paper aims to describe the distribution and characteristics of Polallie deposits on the east flank of Mt. Hood; discuss the stratigraphy and the chronology of Polallie deposits and their lateral variations; differentiate a range of primary and secondary deposits; interpret depositional processes; and enhance our understanding of the relationships between the Mt. Hood eruptive activity and snow–ice fluctuations.

We have used three methods to study the Polallie deposits. First, measured stratigraphic sections help to distinguish and define the thicknesses and extent of major units and to correlate these across several valleys. Stratigraphy and geomorphology help relate the Polallie deposits to the upper part of the volcano’s lava flow pile and its summit domes. Secondly, field sedimentology and laboratory analyses (grain size, petrography) distinguish three groups of facies: primary pyroclastic deposits; secondary debris-flow deposits; and glacial and fluvial deposits. Thirdly, three lava flows interbedded within and below the Polallie deposits were dated by ⁴⁰K–³⁹Ar method by

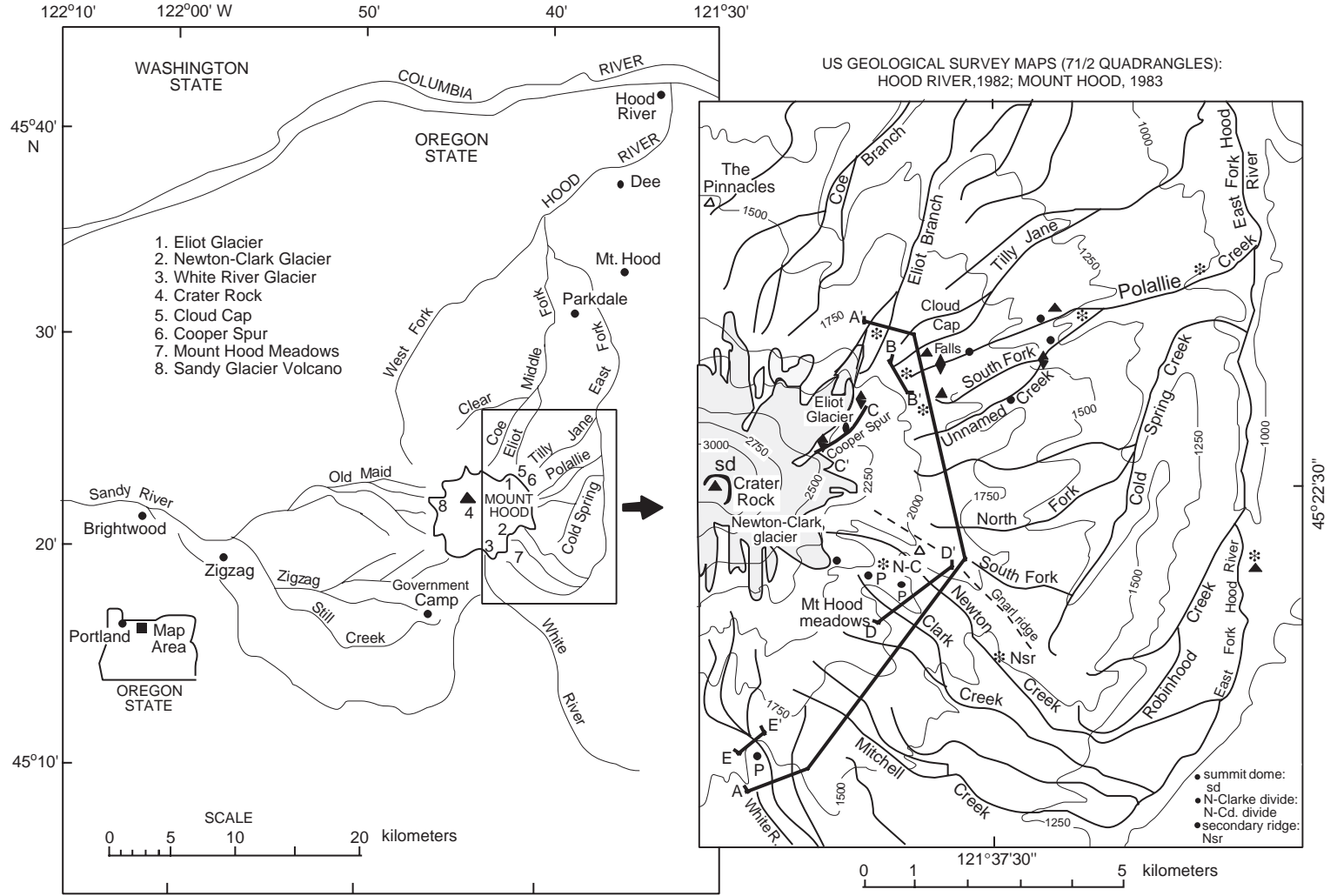


Fig. 1. Location of Mt. Hood and the area studied. Symbols: Lines AA', BB', CC', DD', and EE' are cross sections (see Figs. 2 and 4); *=measured stratigraphic sections; black triangles=¹⁴C dated samples; black diamonds=K/Ar dated samples; p=pumice sampling; open triangle=flank vents; dashed lines=ridge.

P.-Y. Gillot (personal communication, 1993). These dates provide maximum ages for the Polallie deposits.

Terminology used in this paper follows the nomenclature of Fisher (1966), Cas and Wright (1987), Fisher and Schmincke (1984), Smith (1986, 1991), Smith and Lowe (1991), and McPhie et al. (1993). Pyroclastic rocks encompass syn-eruptive deposits of block-and-ash pyroclastic flows, scoria flows, pyroclastic surges, and tephra fallout. Volcaniclastic aggregates include lahars or volcanic debris flows that contain very poorly sorted sediment. Epiclastic deposits are produced by normal surface processes of fragmentation such as gravitational rockslide or are re-mobilized by surface processes. We refer to group as a thick (tens of meters) sequence comprising several units having relatively similar sources or origins; and unit as a homogeneous deposit of a single pyroclastic flow or debris flow (one to a few meters, one to a few beds).

3. Distribution and volume of Polallie deposits

Polallie deposits are found mostly on the east, southeast and northeast flanks of Mt. Hood, but Crandell (1980) reported scattered deposits on other

flanks. They cover an area of about 60 km². The bulk of the Polallie deposits are well preserved on the east flank of Mt. Hood, where eruptive products were preferentially shed from the summit domes during that period. Polallie deposits occur in three topographic positions (Fig. 2): (1) infilling relatively large and deep pre-existing valleys, where the radial drainage is now cutting through them; (2) mantling ridges or crests, the thin deposits forming inverted relief; and (3) deposited on valley sides, probably having once filled gaps between ice bodies and valley walls. The ridge-top and valley-side deposits were interpreted by Crandell (1980) as resulting from thick glacier ice in the valley when the deposits were sedimented.

Measured sections reach thicknesses of at least 150 m in proximal areas, 50–70 m in medial areas, and as much as 20 m in distal areas 9 km from the source (Figs. 2–4). The thickest proximal sections on large, flat ridges are less than 100 m wide and tens of meters thick because lava bedrock or till deposits form the core of these ridges. Lava flows crop out on the valley flanks of Polallie, Newton and Clark Creeks and White River (Fig. 3), where Polallie deposits have been removed. The most voluminous sections are located upstream in large and deep valleys (Figs. 2 and 4). Infilling deposits have concealed the bedrock

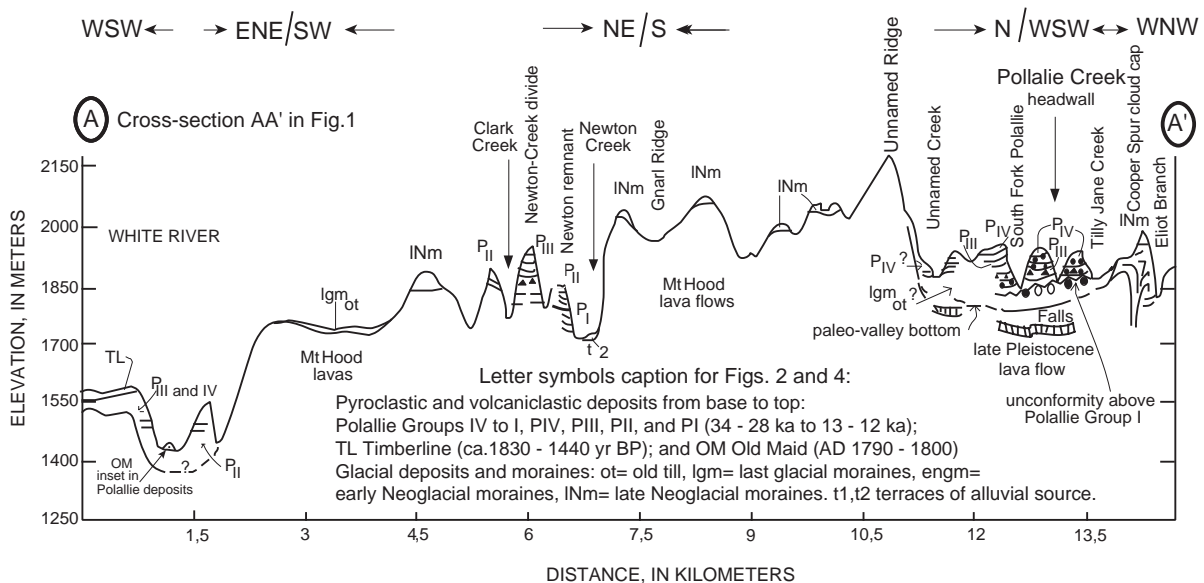


Fig. 2. Distribution and topographic position of Polallie deposits along AA' (Fig. 1) on Mt. Hood's eastern flanks from White River (SE) to Eliot glacier (NNE). Caption of letter symbols is shown in Figs. 2 and 4.

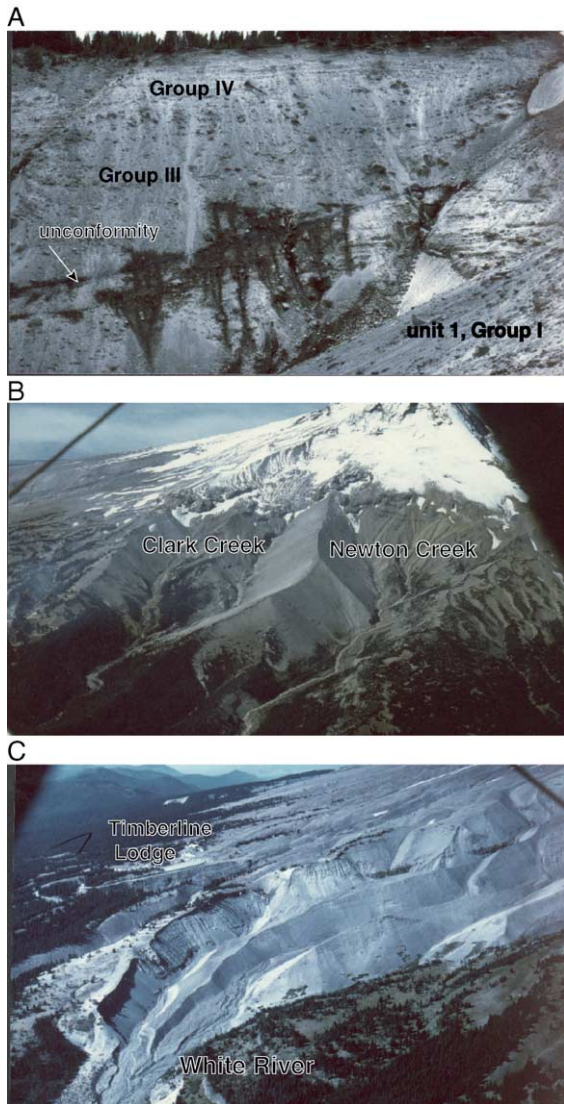


Fig. 3. (A) View of section of Polallie Creek headwall looking SSW, showing unconformity between Group I and Group III; (B) view of Newton Creek and Clark Creek valleys and divide looking WSW; (C) view of White River valley looking SW.

between Cloud Cap and Polallie Creek toward the north and the ridge between South Fork and Lamberston toward the south. We infer that 50–150-m-thick Polallie deposits once filled all the pre-existing valleys. Presently exposed sections are, therefore, deposits which filled canyons with the remaining deposits still on steep valley flanks. The geometry of the remaining deposits can be traced in most measured

sections, because they were not deformed during the Polallie eruptive period. The total bulk volume of Polallie deposits on the ca. 60-km² east flank of Mt. Hood is 4–8 km³ (deposits thickness ranging 0.05–0.15 km, width 0.2–2 km, length 5–9 km in four drainage systems; Fig. 2). This is a minimum figure owing to uncertainty in tracing the top surface of Polallie deposits at the end of the eruptive period.

4. Stratigraphy and lithofacies of Polallie deposits

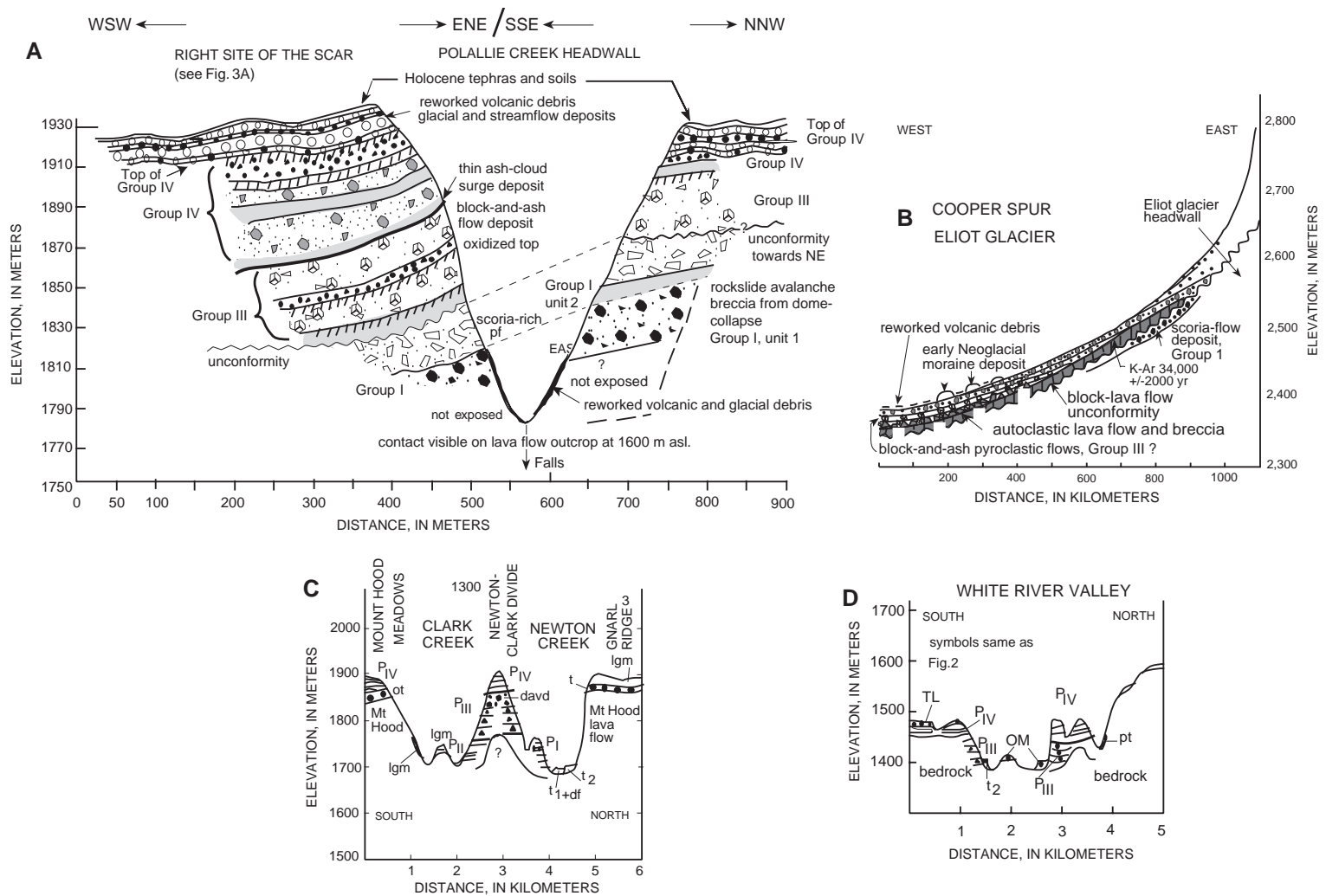
A 130–150-m-thick sequence of volcaniclastic deposits (Figs. 2–5) crops out on the scar of the Polallie Creek valley head (Figs. 3A and 4), on the ridge dividing Newton from Clark Creek (2200–1900 m asl, Figs. 3B, 4 and 5A), and in the valleys of Newton Creek, 1700 m asl, and of White River, 1500 m asl (Figs. 3C, 4 and 5B). We subdivide the Polallie deposits into four groups in proximal (≤ 3 km), medial (3–8 km) and distal (8–15 km) settings: Group I with two volcaniclastic units; Group II with two types of pyroclastic and epiclastic unit; Group III with three pyroclastic units; and Group IV with two types of volcaniclastic and epiclastic unit.

4.1. Proximal Polallie deposits

4.1.1. Polallie Group I

Group I crops out at the Polallie Creek headwall at about 1980 m asl (Figs. 3A, 4A and 5A). Group I is separated from overlying groups by an angular and erosional unconformity dipping 15–20° south-south-east (Fig. 3A).

- (1) The lowest unit consists of about 10 m of heterolithologic breccia, whose base is unexposed. The unsorted breccia is clast supported and fines depleted (Fig. 6A). Large blocks, 1–5 m across, of hornblende-bearing andesite are angular and broken, with a dense pattern of open fractures. Dark-colored, highly vesiculated blocks are abundant between poorly sorted sand matrix. Two thin layers of fine ash separate the beds. The breccia overlies pre-Pollallie andesitic lava flows that crop out at Polallie Creek Falls, in South Fork Polallie and Unnamed Creek (1600–1650 m asl, Figs. 1 and 4).



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Fig. 4. Cross sections at (A) Polallie Creek headwall (BB' in Fig. 1); (B) Cooper Spur, eastern bank of Eliot glacier (CC' in Fig. 1); (C) Newton Creek and Clark Creek valleys (DD' in Fig. 1); and (D) White River valley (EE' in Fig. 1).

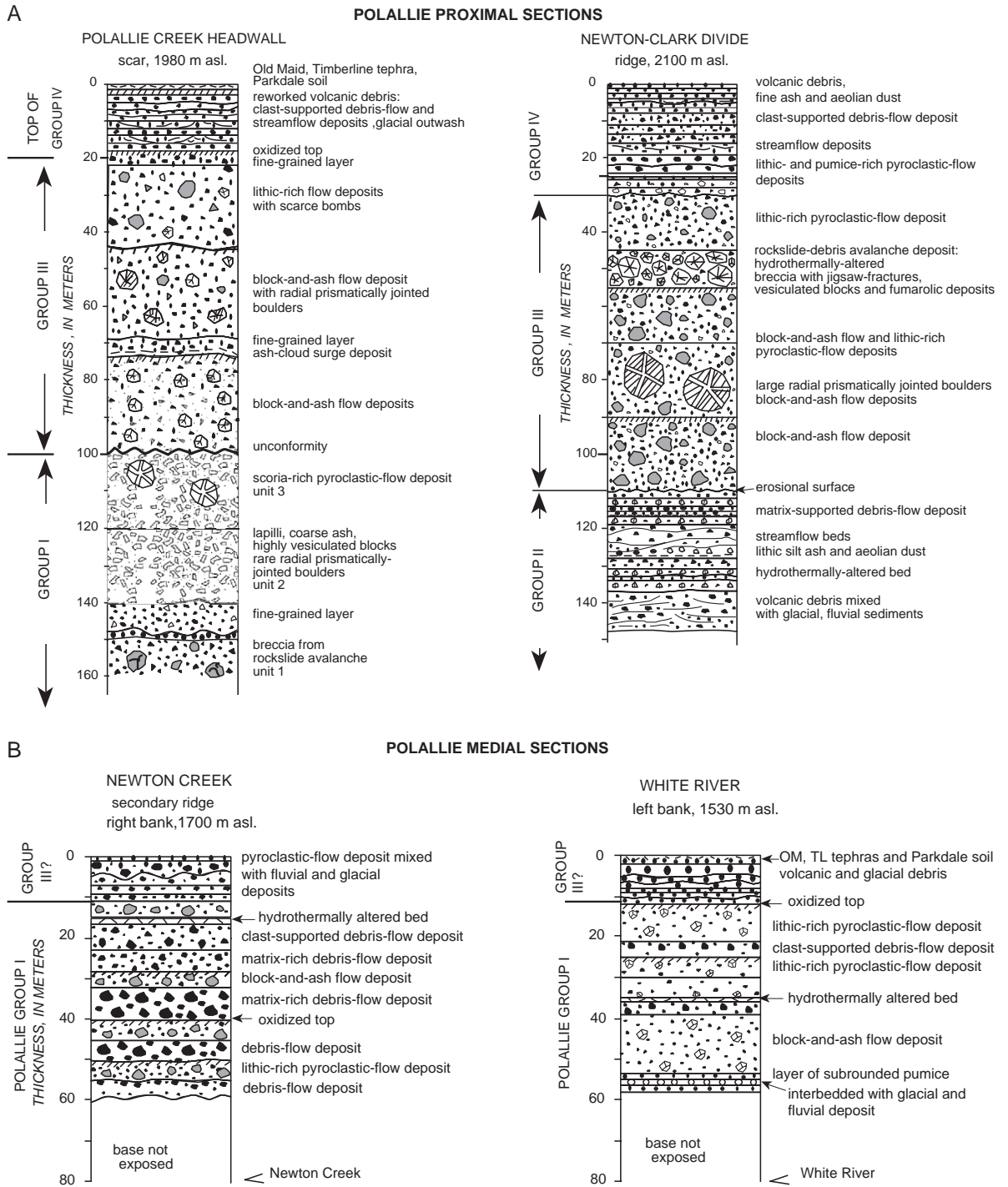
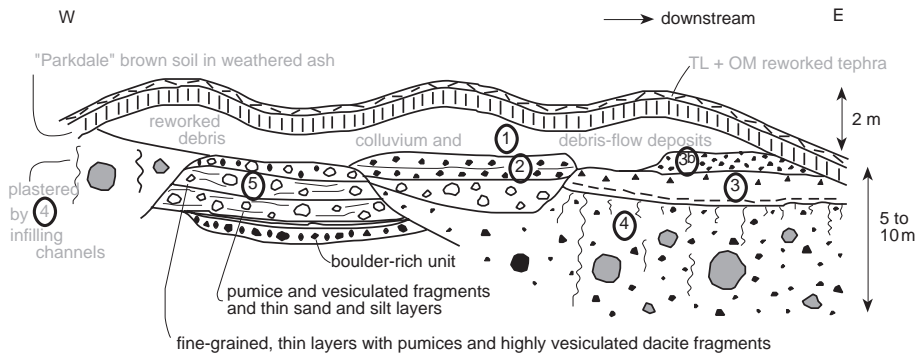


Fig. 5. Measured stratigraphic sections of Polallie Groups I to IV: (A) proximal sections of Polallie Creek headwall (1900 m asl) and Newton–Clark divide (2000 m); (B) medial sections of Newton Creek ridge (1700–1550 m) and White River ridge (1500–1450 m); (C) distal sections upstream of the Polallie Creek mouth (1000 m) and on the eastern bank of Highway 35 between Sherwood and Robin Hood campgrounds (1000 m).

C

POLALLIE DISTAL SECTIONS

POLALLIE CREEK, left bank, 1 070 m asl.(+70 m above channel)
1 km upstream of the East Fork Hood River confluence



- 1 debris-flow deposits and colluvium
- 2 streamflow deposit
- 3 debris-flow deposit (with sole layer) 3b hyperconcentrated-streamflow deposit
- 4 secondary pyroclastic-flow deposit and/or hot lahar deposit { degassing pipes
dark purple colored top
unsorted, massive, yellowish
large polymict boulders and cobbles
- 5 streamflow deposits forming a paleodivide: boulder-rich and fine-grained beds with subrounded pumices

HIGHWAY 35, right bank, 1 035-1 050 m asl.
between Sherwood and Robin Hood Campground

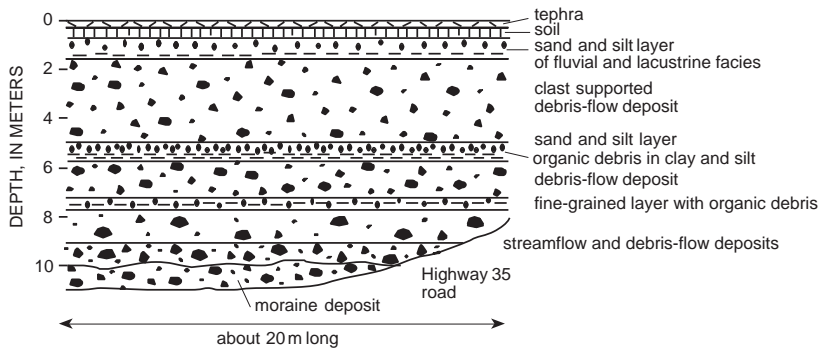


Fig. 5 (continued).

(2) Units 2 and 3 are composed of 50-m-thick block-and-ash or scoria-rich flow deposits (Fig. 6B) that include highly vesiculated andesite blocks or large scoriae. The crudely stratified, meter-scale deposits with oxidized tops are separated by thin layers of fine sand to silt.

Rare blocks, as large as 1 m, are radial prismatically jointed, poorly vesiculated and surrounded by a vitreous crust in abundant matrices of coarse sand and pebbles. Toward the base, a dark sandy layer contains less coarse sand and gravel but also small scoriae.

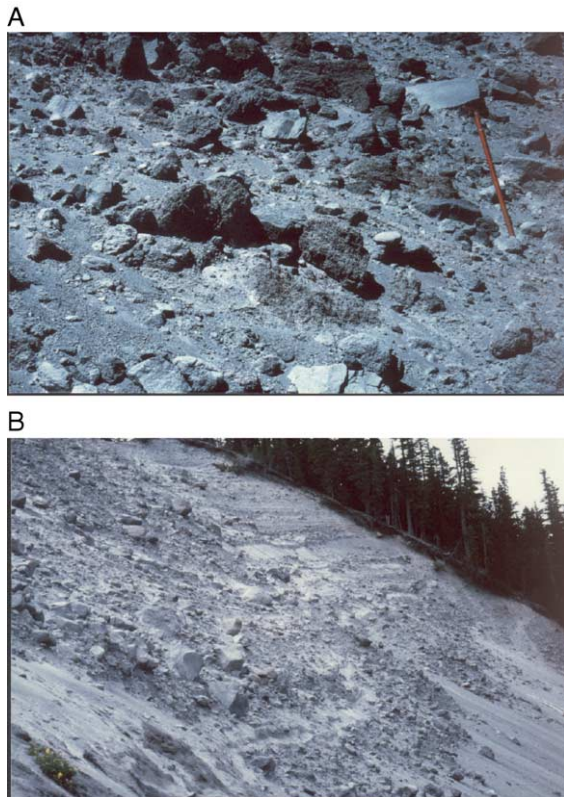


Fig. 6. (A) Polymict breccia of unit 1, Group 1 (Polallie Creek headwall), interpreted as rockslide debris avalanche (ice axe 80 cm long for scale); (B) crudely stratified, meter-scale deposits 50 m thick of unit 2, Group I (South Fork Polallie), including vesiculated andesite blocks or scoria, oxidized tops with thin fine sand to silt layers, interpreted as block-and-ash or scoria-rich flow deposits.

Several lines of evidence suggest that the present Polallie Creek cuts down through the northern edge of a large pre-Polallie valley, whose axis lies farther south between Unnamed Creek and South Fork Polallie Creek (Figs. 2 and 4). In the headvalley of Polallie Creek, the south-southeast dip of Group I deposits suggests pyroclastic debris shed from a dome near the Cloud Cap vent. Contacts between Group I and Groups II–IV also suggest a source near Cloud Cap. At the headwall of Polallie Creek, an unconformity cuts out Group II deposits (Figs. 4A and 5A).

4.1.2. Polallie Group II

Group II, 50–60 m thick, consists of two units of alternating coarse and sand-sized beds of volcani-

clastic deposits. The first type is 1–4-m-thick clast-supported beds that contain angular dense cobbles and boulders as large as 1 m in a gravel matrix. Some have an oxidized top. The second type consists of 2–4-m-thick beds of medium to fine sand and gravel that include a few dacite pumice or vesiculated, angular dacite fragments, and lithic lapilli. These massive, matrix-supported beds also show channels filled in by subangular cobbles and angular pebbles. Silt laminae separate the fine-grained beds.

4.1.3. Polallie Group III

Group III, 60–80 m thick, consists of a series of deposits of monolithologic dense dacite cobbles and boulders with abundant ash. The 5–10-m-thick units contain angular to subangular, poorly vesiculated blocks of dacite (Fig. 7A). Dense blocks up to 2 m and large radial prismatically jointed blocks of dome rock as much as 10 m across are densely packed in coarse matrix of angular cobbles and coarse sand of similar composition. Every bed fines toward the base or toward the top. The oxidized tops contain vesiculated blocks, bombs and lithic fragments, with rare degassing pipes. By contrast, towards the top of Group III, a 5–10-m-thick hydrothermally altered, polymictic breccia shows vesiculated blocks up to 10 m with jigsaw fractures (Fig. 7B).

At the head of the Polallie Creek (Figs. 3A, 5A and 7C), Group III consists of a 60–75-m-thick pile of crudely stratified beds of dense dacite boulders, cobbles and coarse ash, which dip 6–8° east. Inside each series, 3–7-m-thick block-rich beds are separated by 1–5-m-thick block-depleted beds containing sand, pebbles and cobbles. Every massive bed is covered by a thin layer of fine sand and silt. The homogeneous clast composition and radial prismatically jointed boulders point to primary deposition of block-and-ash flows resulting from dome collapses (e.g., at Soufrière Hills or at Unzen volcanoes; Freundt et al., 2000).

A composite stratigraphic section at Cooper Spur above Eliot Glacier (2600–2400 m asl) 2.2 km upstream of Polallie Creek's headwall (Fig. 2) consists of three units that grade laterally and downward along the Cooper ridge (Fig. 7C): (1) an autoclastic dacite lava flow that grades into auto-breccia and block-and-ash flows; (2) a block-and-ash flow; and (3) a flow deposit rich in scoriae and

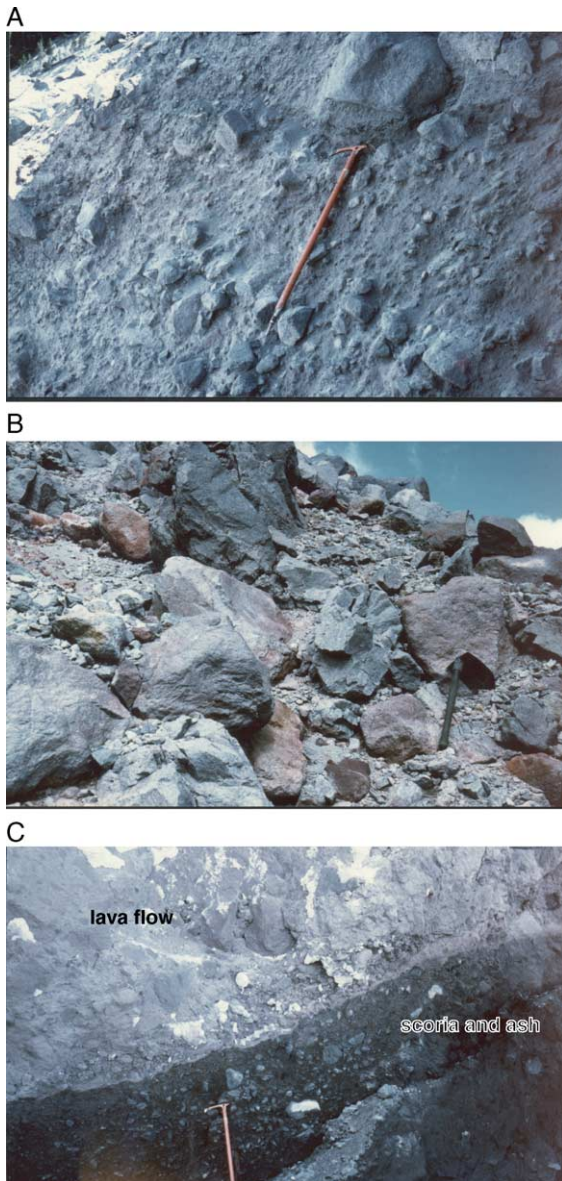


Fig. 7. (A) Grey bed 1–2 m thick with oxidized top, showing dense, angular or vesiculated clasts in coarse ash matrix, interpreted as pyroclastic-flow deposits of Group III (Polallie Creek, ice axe for scale); (B) top unit of Group III (Newton–Clark divide, shovel for scale): 5–10-m-thick polymict breccia of hydrothermally altered and vesiculated blocks 1–2 m across in coarse matrix; (C) Dark bed 2 m thick of scoria in ash (Eliot Glacier headwall, 2400 m asl, ice axe for scale), interpreted as scoria-flow deposit of Group I. This is overlain by an autoclastic lava flow from the northern summit dome, which was K–Ar dated at $34,000 \pm 2000$ years B.P.

vesiculated blocks in a dark matrix of coarse ash and lapilli. Lateral and vertical gradations from autoclastic lava to breccia suggest how block-and-ash flows were formed (Fig. 4B). Similar thick vesiculated and oxidized lava flows crop out at similar elevations at Mt. Hood Meadows in the Clark Creek catchment between 2500 and 2300 m asl.

4.1.4. Polallie Group IV

The 20–30-m-thick Group IV encompasses a series of two types of stratified, unsorted deposits (Newton–Clark divide, 2200–2000 m asl, White River, 2000 m asl, Polallie Creek: Figs. 3A and 4). (1) 3–5-m-thick massive beds comprise heterolithic, unsorted, subangular dense andesite cobbles and boulders up to 1 m across (Fig. 8A). Fine-grained 4–10-cm-thick layers of subrounded pumices and highly vesiculated lithic lapilli are intercalated (Fig. 8C). (2) About 1-m-thick, fine-grained beds contain subangular to subrounded cobbles, pebbles and coarse sand. The beds commonly include a thin layer of fine sand and silt ash (Fig. 8D). Laminae and pinch-and-swell lenses in these beds suggest some process of runoff. At the Polallie Creek headwall, Group IV is thinner than 20 m and contains less pumice and scoriae. Fine-grained, stratified, unsorted units 1–2 m thick encompass sand and a few subrounded cobbles. Intercalated thin silt layers are not confined to channels or topographic lows.

4.2. Medial to distal lithofacies

Medial Polallie debris deposited on the flanks of Mt. Hood has formed volcanoclastic aprons as thick as 100 m as far as 5–8 km downvalley of Polallie Falls (Figs. 1 and 2). Two ridges on the southern Newton–Creek’s side at 1600 m asl and on the northern White River’s wall at 1530 m asl display three lithofacies totalling 70 m in thickness (Figs. 3BC, 5B and 8C):

- (1) At the base of sections (Newton Creek, Fig. 5B), fine-depleted or fine-rich beds 1 m thick of dense blocks in ash, probably resulting from block-and-ash flows, overlie a 5-m-thick coarse heterolithic deposit, probably emplaced by a debris flow. In turn, these overlie unsorted morainic cobbles and boulders

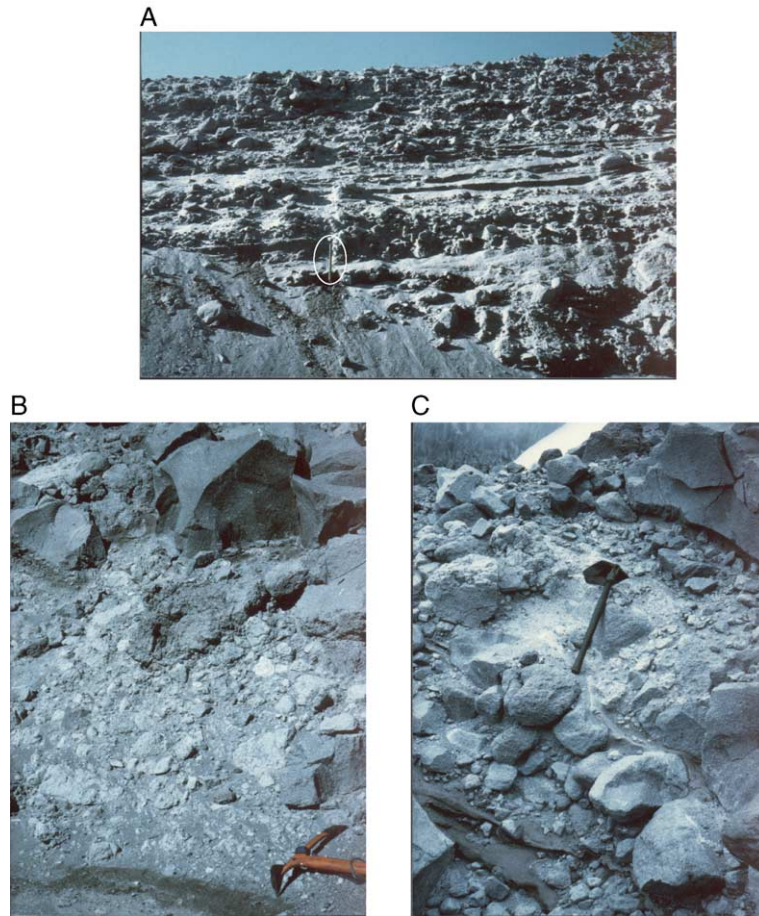


Fig. 8. (A) Beds of heterolithologic, unsorted, subangular dense cobbles and boulders up to 1 m across separated by fine-grained layers of sand and silt (Group III, upstream of White River; ice axe for scale); (B) medial to distal massive matrix-supported debris-flow deposits of unsorted, subangular clasts to subrounded pumices and vesiculated dacitic fragments (top of ice axe for scale); (C) finer grained beds contain subangular to subrounded cobbles, pebbles, and coarse sand (top of Group IV, Newton–Clark divide). Note thin brownish layers of fine sand and silt ash toward the base and laminae and pinch-and-swell lenses in the bed (below shovel).

as large as 1 m in silt and sand matrices (ca. 1700 m asl).

- (2) The middle section encompasses block-and-ash and debris-flow deposits and also crudely stratified, inversely graded pumice-rich flow deposits 1 m thick where layers of subrounded pebbles are intercalated (White River, Figs. 5B and 8C). Towards the top (Newton Creek section), a 1.5-m-thick yellowish sand bed contains angular, oxidized and hydrothermally altered blocks.

- (3) Alternating with the uppermost 1–4-m-thick debris-flow beds, crudely stratified deposits 1

m thick in sand matrix contain lenses of rounded pumices and lithic fragments (Newton Creek section, Fig. 5B).

Polallie deposits, as thick as 70 m, were further channelled 8–15 km in ENE, E and ESE draining valleys (Fig. 1). Four types of distal beds are exposed in Polallie Creek northern bank 10 km downvalley at 1050 m asl (Figs. 5C and 9) and in the southern wall of White River at 1700 m asl (Fig. 8).

- (1) Crudely stratified, clast-supported deposits 1–4 m thick include dense and vesicular subangular

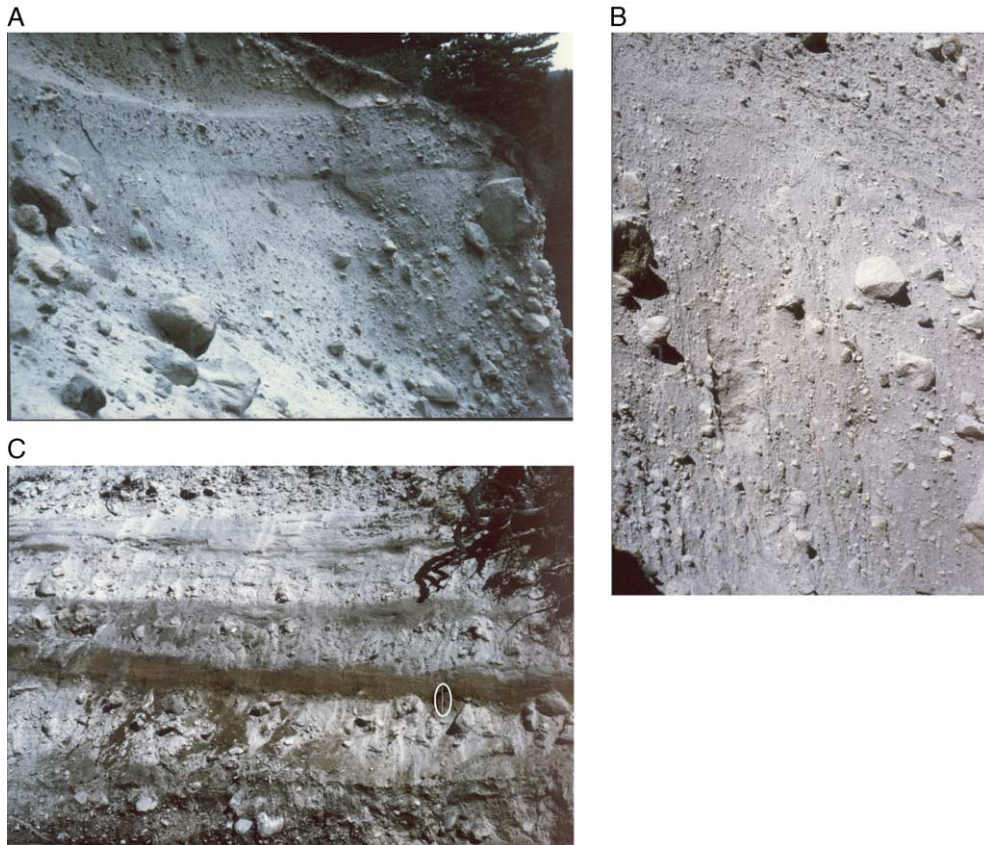


Fig. 9. (A) Massive debris-flow beds of pebbles and cobbles in fine-grained matrix, showing a fine-grained sole layer and a tabular top (section 5–10 m thick, Polallie Creek's mouth); (B) Deposit 6 m thick showing commonly stained clasts in a sand matrix and degassing pipes towards the colored top; (C) distal section 10–20 m thick of debris-flow beds and volcanic sandstones and mudstones (East Fork Hood River's southern bank, 1050 m asl, Highway 35; shovel for scale).

cobbles and blocks up to 1 m across in poorly sorted coarse sand matrices. These block-and-ash flow deposits have probably been reworked because they contain poorly to moderately rounded clasts of heterogeneous textures and compositions.

- (2) The deposits are intercalated with debris-flow beds 0.5–2 m thick of pebbles, cobbles and boulders in fine-grained matrices, showing a fine-grained sole layer and a tabular top (Fig. 9A). A 10-m-thick deposit consisting of large dense, subangular blocks, commonly stained in a sand matrix shows degassing pipes emerging at the purple-colored top (Fig. 9B). Such sedimentologic characteristics resemble those of hot lahar deposits described at

Mayon volcano by [Rodolfo and Arguden \(1990\)](#).

- (3) The few massive sand and gravel beds contain scattered subangular cobbles, which sometimes segregate to form subhorizontal lenses or clots. They are interpreted as hyperconcentrated streamflow deposits.
- (4) Small matrix-supported beds show layers of coarse sand and small cobbles and fine sand and silt layers. A bed, 1 m thick, is composed of subrounded pumice and vesiculated dacite clasts in a loamy matrix of weathered pumice (northern wall upstream of Polallie Creek's mouth). Because these uniform beds show no pinch-and-swell or deep-angle traction layers, and clasts are neither inversely graded nor

imbricated, the streamflow deposits are thought to have filled low-energy shallow channels.

4.3. Distal lithofacies

A 10–20-m-thick distal section comprises several debris-flow beds and volcanic sandstones and mudstones. They crop out on East Fork Hood River's southern bank upstream of Polallie Creek confluence at 1050 m asl along Highway 35 (Figs. 5C and 9C), and also 1–2 km upstream on the southern side of Polallie Creek's mouth 1050 m asl. The 0.5–1-m-thick crudely stratified layers of fine sand and silt, including laminated fines and organic debris, reflect deposition on poorly drained flattish areas. Voluminous Polallie deposits probably choked all western tributaries to East Fork Hood River but clasts belonging to the East Fork Hood River eastern tributaries suggest that Tertiary material from eastern catchments mixed with Mt. Hood deposits to temporarily dam the East Fork Hood River.

5. Interpretation of Polallie deposits

The Polallie eruptive period probably yielded the largest amount of volcanoclastic debris at Mt. Hood during the late Pleistocene.

5.1. Methods used to interpret Polallie deposits and environment

In addition to lithofacies, two main components of Polallie deposits, i.e., juvenile pumice, scoria, and vesiculated lithics as opposed to non-juvenile lithics, enable us to distinguish pyroclastic deposits from secondary volcanoclastic deposits. Amongst sedimentary criteria (e.g., channeled or cross-stratified beds, tractional bedforms, asymmetrical layers), clast grading, roundness and sorting help to identify the primary or secondary origin of apparently homogeneous deposits. Grain size plots ($Md\phi$ vs. $\sigma\phi$ in Fig. 10A and B) point to nine groups, which in part overlap: block-and-ash flow deposits with debris flow and streamflow deposits in proximal to medial settings (Fig. 10A) are separated from reworked

pyroclastic-flow deposits and ash layers with debris-flow and streamflow deposits, glacial outwash and silt layers in medial to distal settings (Fig. 10B). In addition, major element geochemistry of 31 lavas point to a slight increase in silica and alkalis contents through time (Fig. 10C). Pre-Polallie lavas are less silica-rich than Polallie lavas. Polallie Group I, pre-Polallie lavas and Pleistocene Mt. Hood's lavas are medium-K andesites, whereas the pyroclastic deposits of Groups II–IV belong to the medium-K dacite field.

5.2. Polallie Group I: rockslide avalanching and explosive activity

Polallie Group I encompasses two units, which overlie the young lava flows of Mt. Hood's summit at the base of Polallie headvalley, in South Fork Polallie, and the Unnamed Creek (Figs. 1, 2 and 4A).

In the lowermost unit, the unsorted, coarse breccia 10 m thick with large polymict broken blocks points to a gravitational rockslide avalanche (Figs. 5A and 6B). The uppermost 50-m-thick scoria-rich and block-and-ash flow beds with oxidised tops and radial prismatically jointed blocks are of medium-K andesite composition (Figs. 6A and 10C). These pyroclastic-flow deposits reflect repeated collapses of vertical eruption columns, or low-pressure boiling over a vent north of the present summit (Hoblitt, 1982). The pyroclastic flows of Group I suggest that a sustained explosive activity preceded the dome-building Groups II–IV.

An important question is why the deposits of Polallie Group I are apparently restricted to the Polallie Creek area. A preserved rockslide-avalanche breccia located ENE of the summit domes is in agreement with the interpretation of (1) the Eliot glacier–Cooper Spur unconformity as a scar formed by the failure of pre-Polallie or Polallie Group I summit domes and (2) a 2-km-wide and 200-m-deep pre-Polallie valley between Cloud Cap–Polallie Creek toward the north and Unnamed South Fork–Lamberson Ridge toward the south (Fig. 2). Conversely, we cannot preclude that Group I deposits may exist at the base of thick Polallie sections in Newton–Clark Creek and White River.

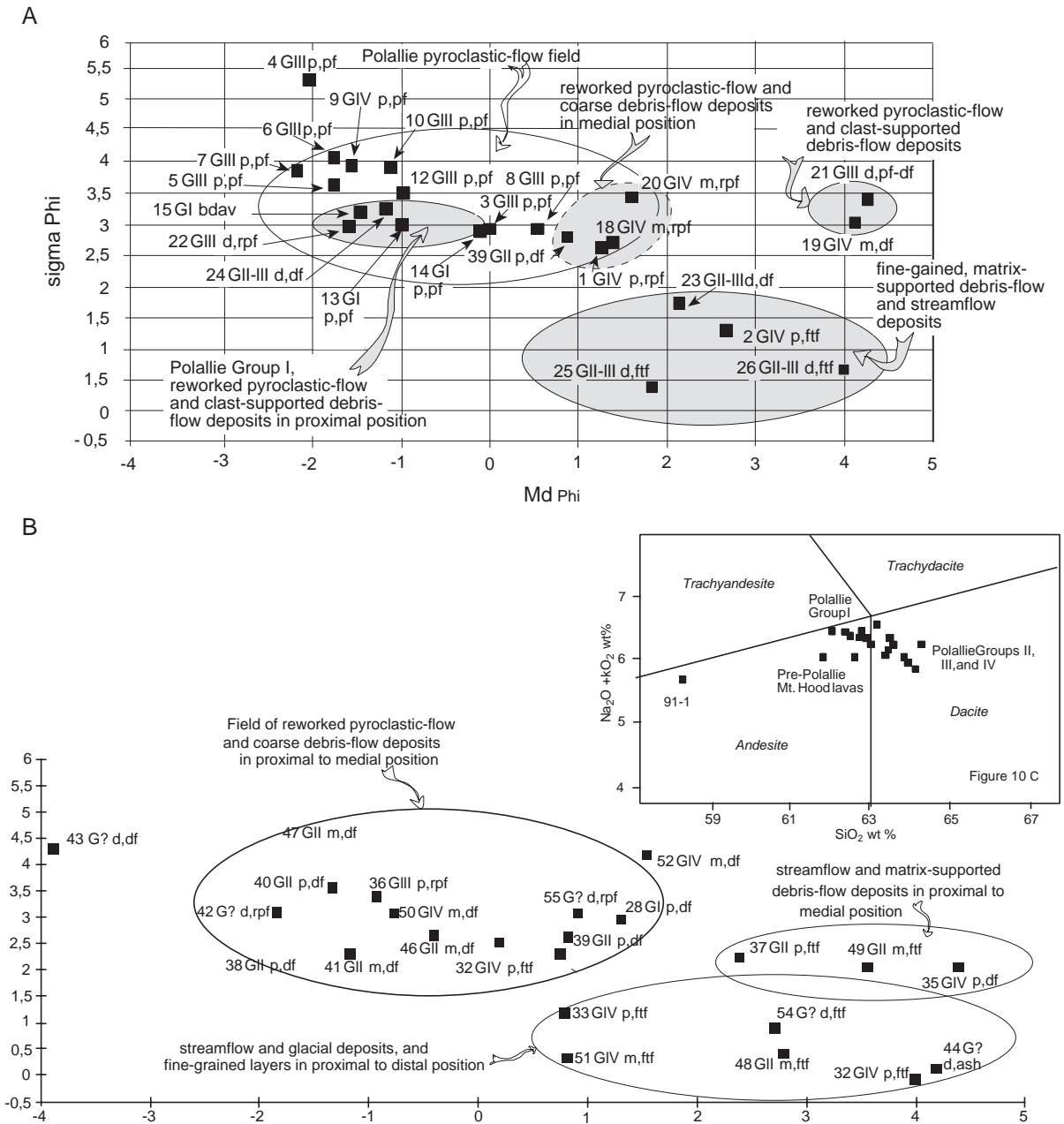


Fig. 10. (A) $\sigma\phi$ vs. $Md\phi$ plot showing grain-size characteristics of representative pyroclastic and volcanoclastic deposits of Groups I–IV (fields enclosed by contours). Numbers represent deposit sample; letters p (proximal), m (medial), and d (distal) indicate sample position with respect to the source; attached symbols indicate groups. Additional symbols meaning: pf=pyroclastic-flow deposit (spf when scoria-rich); df=debris-flow deposit (mdf when matrix-supported); dav=debris avalanche breccia; r=interpreted as reworked. (B) $\sigma\phi$ vs. $Md\phi$ plot showing grain-size characteristics of representative volcanoclastic and epiclastic deposits of Groups I–IV in proximal-to-distal positions, whose fields are enclosed by contours. Additional symbols as in Fig. 10. (C) (inset) Classification of Polallie lavas with respect to pre-Pollalie Mt. Hood lavas in a total silica–alkali $SiO_2/Na_2O + K_2O$ plot (after Le Bas et al., 1986).

5.3. Polallie Group II: reworking of pyroclastic deposits

Two sources may have fed two types of Group II deposits (Fig. 7A–C).

- (1) Block-and-ash flow deposits, including juvenile dacite clasts and lapilli and poorly sorted and angular boulders, form a thick pile of ungraded beds which suggests a rapid emplacement of pyroclastic deposits. Silt layers <1 cm thick between beds result from ash which settled from pyroclastic flows or from aeolian activity; these layers are the best sorted material among Polallie Groups ($Md\phi=4$, $\sigma\phi=0-0.5$; Fig. 10A). Block-and-ash flow deposits of Group II provide evidence for dome growth, although their volume may not exceed $2 \times 10^6 \text{ m}^3$ (maximum 25 m thick and 2.5 km long in three draining valleys). Hence, the eruptive activity of Group II summit domes was moderate to weak. Alternatively, any dome growing on Mt. Hood volcano was too far from the eastern flank to have shed substantial pyroclastic debris towards that direction.
- (2) Massive matrix-supported debris-flow deposits consist of poorly sorted subangular clasts to subrounded pumice and vesiculated dacitic fragments (Fig. 8B). Thinner streamflow beds, finer grained and moderately sorted, were deposited in low-energy channels for they show neither complex stratigraphy nor clast imbrication.

Meltwater contributed to transport based on the following observations. First, subrounded pumices or vesiculated dacite clasts in debris-flow deposits and in streamflow layers suggest that meltwater removed tephra. Secondly, thin beds of crudely stratified, normally graded, subangular to subrounded pyroclastic debris point to glacier runoff. As moraine is preserved at the base of Clark Creek's left wall (Fig. 4), pyroclastic material was probably dumped in shallow-water bodies between the valley wall and the glacier margin nearby.

5.4. Polallie Group III: dome growth and collapse

Lithofacies of block-and-ash flow deposits, which form Group III, the thickest Polallie group

(Figs. 5, 7A), suggest that they originated from gravity-driven dome collapse. Dense cognate lithics are much more abundant (about 70%) than vesiculated dacite fragments (20–25%) and pumice (5–10%) in these deposits. When gravity-driven, the flow deposits contain scarce radial prismatically jointed blocks, but abundant coarse ash matrix resulting from particle–particle interactions and clasts comminution during transport. When explosively induced and emplaced while hot, the flow deposits are more fragmented, inversely graded with oxidised tops and include more radial prismatically jointed blocks.

A volume of $6 \times 10^5 \text{ m}^3$ pyroclastic flows (60 m thick and 3 km long on average in four drainages) reflect a sustained growth of summit domes during Polallie Group III. Dome growth was interrupted at times by sizeable avalanches. Because tephra-fall layers are scarce, explosive activity at the vent was much less frequent than gravity-driven dome collapses. Toward the top of Group III, a thick hydrothermally altered breccia displays large jigsaw-fractured, vesiculated blocks mixed with fumarolic deposits (Fig. 5A) in coarse yellowish orange matrix. The radial prismatically jointed blocks (Fig. 7B) indicate that the avalanche was emplaced hot when a fast-growing dome collapsed.

Based on lack of glacial debris in Group III, glaciers had probably retreated or disappeared during this eruptive episode. Alternatively, a given glacier could have been scoured and eventually buried by pyroclastic-flow deposits that would have stacked up in gullies carved in the ice. This is a situation similar to the 1990 eruption at ice-clad Mt. Redoubt (Waitt et al., 1994; Pierson and Janda, 1994).

5.5. Polallie Group IV: volcanoclastic and epiclastic sedimentation

A series of stratified volcanoclastic and epiclastic deposits form the two types of units of Group IV (Figs. 4A and 8A).

The first coarse unit that comprises unsorted subangular cobbles and boulders is interpreted as reworked of pyroclastic flows or clast-supported debris-flow deposits. The homogeneous juvenile clasts, including some quenched bombs, point to the primary source of the material, but thin layers of

subrounded pumice and vesiculated fragments suggest that the pyroclastic material was remobilized.

The second unit of fine-grained beds points to streamflow and glacial outwash. These poorly stratified beds of small subangular cobbles and coarse sand show lamination, traction features, asymmetrical pinch and swell lenses and non-tabular bedforms of variable thickness. The beds commonly include continuous silt layers <1 cm thick, which consist of well-sorted wind-blown fine ash ($Md\phi$ 4, $\sigma\phi=0-0.5$, $Mz\phi=3.65-4.15$). Low-energy sedimentation probably took place in channels in front of, or in contact with, ice bodies.

The top of Group IV (Polallie Creek headwall, uppermost Newton–Creek and White River sections: Figs. 5B and 8C) is a pile of clast-supported debris-flow deposits and lithic-rich pyroclastic-flow deposits. Pyroclastic flow beds are small in size. Juvenile and non-juvenile clasts are mixed, and thin layers of fine ash between beds may be wind-blown material. Also interbedded are subrounded and moderately sorted cobbles in a coarse sand matrix that point to glacial outwash and streamflow deposits. Hence, eruptive activity at Mt. Hood was probably weak and decreased toward the end of Group IV. At the same time, the pile of debris flows and streamflow deposits interbedded with glacial outwash reflect an increase in meltwater fed either by glaciers or by outwash of debris dumped near glacier tongues. Some of the thin beds of fine-grained, unsorted pumice and scoriaceous fragments with a minor amount of heterolithologic clasts display a mixed avalanche lithofacies (Pierson and Janda, 1994) that may result from tephra-laden ice-and-snow avalanches, as described after the 1985 eruption of Nevado del Ruiz (Pierson et al., 1990; Thouret, 1990).

The lithofacies support the contention that the top of Group IV was stacked up while glaciers were extensive and yielded meltwater (Fig. 11B) at least in the Newton, Clark and White River valleys. In contrast, the top of group IV at the head of Polallie Creek, although similar, thins down and contains less primary material. The broad Polallie Creek headvalley has probably been deglaciated throughout the Polallie eruptive period and remained separated from the glacier, which the Cooper Spur ridge diverted towards the north. In contrast, the headvalleys of Newton–Clark Creeks and of White River were probably in

contact with ice bodies and retain fresh glacial moraine deposits lying against the deposits of Group IV. We assume that these moraines represent a minor glacial advance, or pause, following the Group IV deposition. The top of Group IV in headvalleys are less weathered with respect to similar sections in broad valleys away from glaciers (e.g., Polallie headvalley and Lamberson ridges). Limited weathering may be due to the fact that the Newton Creek, Clark Creek and White River catchments probably sheltered glacier tongues well into Late Glacial time (Fig. 11B).

6. Chronology of the Polallie eruptive period

Crandell (1980) stated that the Polallie deposits occur on all sides of Mt. Hood, thus indicating a vent at or near the summit. Many Polallie deposits are restricted to ridge tops and valley sides, positions that were probably determined by the thickness of glacier ice in a given valley. Polallie deposits thin down or are even absent on high ridges and in the glaciated valleys, whereas they are 70–100 m thick on the gentle slopes and in depressions that were not occupied by glaciers.

6.1. Data and uncertainties in dating the Polallie eruptive period

Although the age of Polallie deposits is not precise, two chronological limits constrain the eruptive period. On one hand, Polallie deposits are older than the brown ‘Parkdale soil’ ^{14}C dated at ca. 12,000 years B.P. (Harris, 1973), which overlies the Polallie sequence. But the 15,000–12,000-year-B.P. age (Crandell, 1980) is a rough estimate due to the uncertainty in inferring the degree of weathering and the relationship of the Parkdale soil (ash-cloud surge deposits?) to Polallie deposits on Mt. Hood. On the other hand, Polallie deposits cannot be older than ca. $58,200 \pm 2400$ years B.P., i.e., the K–Ar age (Gillot, personal communication, 1993) of a lava flow underlying Group I on the northern wall of South Fork Polallie Creek and on the southern side of Polallie Falls (Fig. 2).

Three lava flows related to the Polallie deposits were dated using the K–Ar method by Gillot (personal

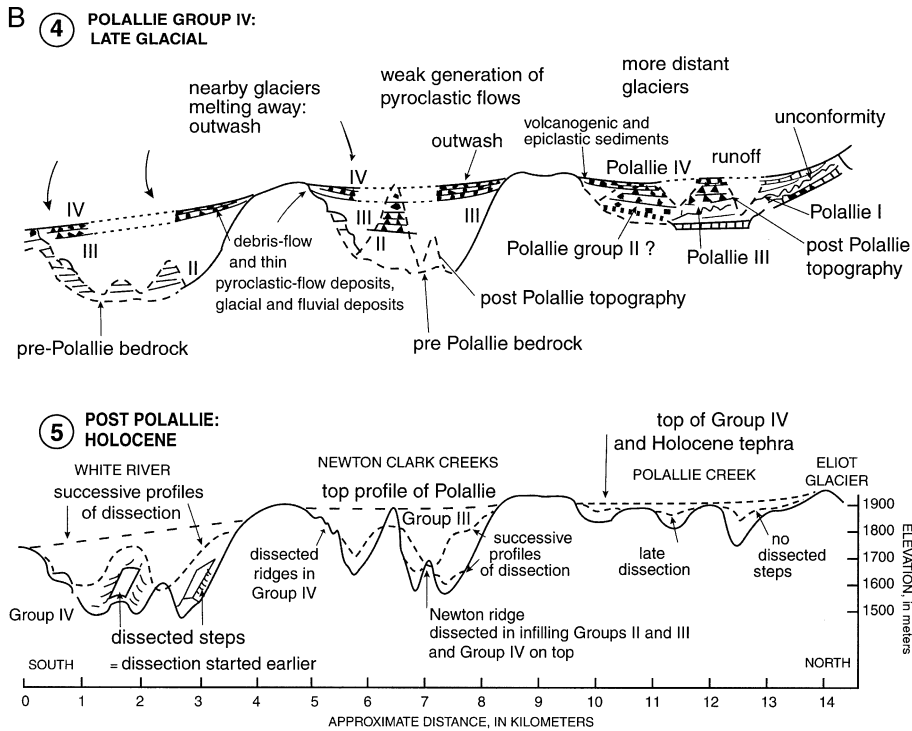


Fig. 11 (continued).

Polallie eruptive period (at least Group I or II) may have overlapped in part the Evans Creek stage of the last Fraser glaciation (ca. 28,000–22,000 years BP: [Armstrong et al., 1965](#); [Easterbrook, 1986](#); [Porter, 1981](#)). However, because the Evans Creek moraines do not contain a significant proportion of Polallie clasts, the majority of Polallie deposits were emplaced toward the end and immediately after the Evans Creek glacial stage, as assessed by [Keith et al. \(1985\)](#).

How long did the Polallie period last? Based on the above dates, it may have lasted about 10,000–25,000 years, but eruptive activity was clearly episodic. Four eruptive and non-eruptive episodes are distinguished, although the stratigraphic record shows no significant gap. The exception is the unconformity above Group I at Polallie Creek headwall and near Eliot Glacier. Despite the difficulty in tying up the unconformity between the two sections, we suspect that previous domes near the present northern Mt. Hood summit were removed by a sizeable flank collapse (during Group III) and that

a significant erosion interval occurred between Group I and Group III.

6.2. Polallie period and glacier fluctuations: data and hypothesis

In order to explain the observed changes in thickness throughout the Polallie sections, we need *not* conclude that the deposits were shed on to the surface of large glaciers. [Crandell's interpretation \(1980\)](#) may be challenged on the basis of two lines of evidence. First, the top surface of Polallie deposits is not irregular and the Group IV, broadly recognizable throughout most drainage systems ([Figs. 2 and 4](#)), was not deposited on top of glaciers. Secondly, large and shallow valleys that existed before the Polallie period, such as Polallie Creek head and its tributaries on the northeast flank, have probably remained out of reach of any glacier advance during the Polallie eruptive period. Eliot Glacier was diverted by Cooper Spur ridge toward the north, while the uppermost slopes of Cooper Spur show moraines not

older than the early Neoglacial advance (Lawrence, 1948).

Thus, the changes in thicknesses of Polallie deposits result from the burial of an uneven pre-existing relief, the reworking of deposits immediately after deposition, and a recent stream incision within volcanoclastic aprons. We argue that downcutting in the Polallie aprons on the eastern flank of Mt. Hood probably started late (in the Holocene?) based on two lines of evidence: the weak weathering of the deposits of Group IV is similar to the weathering of post-Polallie tephra and soils; the lithofacies of the top Group IV provide evidence for glacial outwash which has acted at elevations ranging from 1800 to 2100 m asl. This implies that meltwater was active in the altitudinal zone occupied today by the timberline forest. The timberline decreased by 300–400 m with respect to the present forest limit during cold and wet periods such as the Late Glacial.

7. Conclusions

The Polallie eruptive period yielded the largest amount of pyroclastic and volcanoclastic debris of any period during the late Pleistocene at Mt. Hood. Polallie deposits mantle about 60 km² on the eastern flanks with a volume of 4–8 km³. New K–Ar age dates suggest that the Polallie period took place between 34,000–28,000 years B.P. and 15,000–12,000 years B.P. The period can be divided into Groups I to IV: Group I contains three units: a breccia that probably resulted from a gravitational rockslide avalanche, a scoria flow deposit, and block-and-ash flow deposits. Group II includes reworked pyroclastic deposits and debris-flow deposits. The thickest Group III encompasses block-and-ash flow deposits and rockslide-avalanche deposits generated by dome collapses. Group IV comprises pyroclastic-flow and debris-flow deposits interbedded with debris transported by runoff, streamflow, and glacial outwash. In turn, Group IV is overlain by deposits of Late Glacial and Holocene age, which mantle the volcano's flanks.

The pre-Polallie topography has not been exhumed, but present dissection is in thickest Polallie infilling. Downcutting on the eastern flank of Mt. Hood probably started late, pointing to a rapid incision rate

owing to a dense stream network fed by meltwater from decaying ice fields. Downcutting of Polallie deposits was not steady but intermittent, as shown by stepped terraces cut into Polallie infilling, e.g., in White River valley (Fig. 3C).

Groups I–IV record four eruptive and non-eruptive episodes, because each Group encompasses primary and secondary deposits. The depositional record results from the interplay of dome growth and destruction. Group I was probably deposited while Mt. Hood was largely glaciated. Group II suggests a decrease in the eruptive activity with respect to that reflected in Group I. The pyroclastic-flow deposits of Group III clearly point to a sustained dome growth. Group IV reflects a decrease in the eruptive activity while glaciers were melting away on Mt. Hood. In addition, Groups II and IV suggest increasing erosion during inter-eruption intervals, probably enhanced by snow and ice meltwater. Meltwater is due to extensive glacier ice and/or to interactions between hot eruptive debris and snow and ice. To sum up, Groups II and IV contrast with Group III in that Group III clearly reflects recurrent dome-building eruptions and dome collapse, whereas Groups II and IV imply increasing erosion and, conversely, decreasing volcanic activity. Hence, three categories of processes have prevailed during the Polallie period (Fig. 11): eruptive activity/dome growth and collapse, and subsequent pyroclastic generation; inter-eruption erosion and transport; and glacier fluctuations, ice-snowmelt and runoff.

Repeated dome growth during the Polallie eruptive period indicates that the most likely future eruption at Mt. Hood will include growth and collapse of summit domes, probably at or near Crater Rock. A large volume of unconsolidated volcanic debris would be transported to all river systems, which drain the eastern flanks where the majority of Polallie deposits now lie. Thus, the volcano poses a direct threat to communities nearby and to densely inhabited valleys and lowlands as much as 20 km further downstream.

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