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Geomorphic History of the Lower Blue River-Lookout Creek Area, Western Cascades, Oregon

Abstract

The landscape of lower Blue River and Lookout Creek has been formed by glacial, alluvial, and mass wasting processes. More than 40,000 radiocarbon years b.p. a glacier moved up into the Blue River drainage from the main McKenzie River valley. In the process, the mouth of Blue River valley was choked with ice and glacial sediment, forcing the river to establish a new, westerly course. The ice dam also formed a lake in which fine-grained sediments were deposited.

After retreat of the pre-40,000 years b.p. glacier, Blue River began to erode the valley fill. However, during the latest Wisconsin glaciation and deglaciation the rivers again aggraded. Subsequent downcutting resulted in the development of a prominent terrace. Terrace sediments are topped by Mazama ash, indicating that this surface was abandoned as a floodplain by about 7000 radiocarbon years b.p. The modern floodplain forms a lower surface cut into glacial sediments.

Alluvial fans from tributary watersheds have been constructed onto the landforms of the valley floor. The size, degree of dissection, and internal make-up of the fans is directly related to terrace-floodplain width and watershed characteristics, especially area, relief, and bedrock geology. Fans at the mouths of larger watersheds (about 40 to 200 ha) are deeply dissected by the tributary stream and had stopped growing by Mazama-ash time. Many smaller watersheds, on the other hand, continue to construct small fans in which Mazama ash may be buried up to 4 m deep.

Introduction

The Western Cascade Range of Oregon is an area of heavily forested, steep, and somewhat unstable terrain. Studies by Anderson (1954), Dyrness (1967), Fredriksen (1970), and others have shown that forest management practices on these timber lands have had an important impact on rates of soil erosion and therefore on forest productivity. For this reason the U.S. Forest Service and the Coniferous Forest Biome of the International Biological Program have been conducting studies of erosion in the H. J. Andrews Experimental Forest 80 km east of Eugene.

This paper describes a part of the work focusing on the alluvial and glacial history in the vicinity of five research watersheds. Our purpose has been to understand better the geomorphic setting of the watersheds and to delineate and date geomorphic surfaces for soil studies now in progress. A long-range aim of the project is to develop means of estimating geologic rates of erosion and to compare them with contemporary erosion rates in areas influenced by timber management activities. The fact that no previous detailed geomorphic work had been done in the region necessitated this background study.

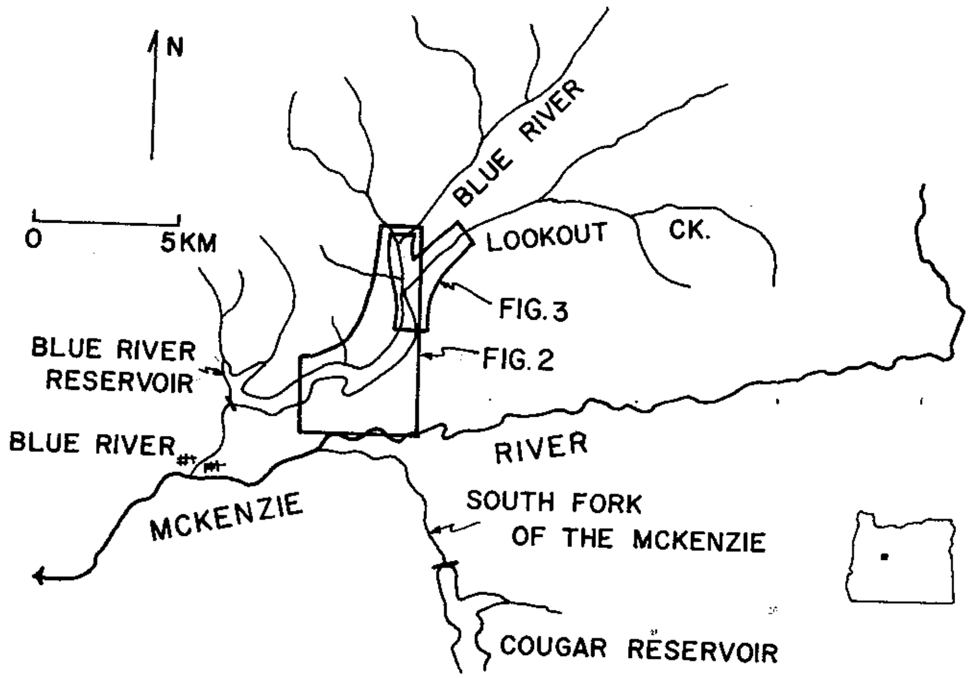

Figure 1. Index map of the lower Blue River area about 80 km east of Eugene, Oregon.

General Geologic and Geomorphic Settings

The earliest known history of the present Blue River area (Fig. 1) began in Oligocene and Miocene time with the eruption of volcanic rocks of the Little Butte and Sardine Formations (Peck *et al.*, 1964). In post-Sardine time there was a hiatus of several million years before eruption of Pliocene-age pyroclastic rocks and lava flows, which erased the earlier topography (E. M. Taylor, Oregon State University, and A. R. McBirney, University of Oregon, personal communications).

Thus the geomorphic history of the modern Blue River drainage began about four million years ago. Since that time the landscape has been carved out by the combined forces of tectonic uplift, stream erosion, mass wasting, and glaciation. Although the rapid erosional processes have removed most evidence of the geomorphic history of the area before late Quaternary time, more recent glacial and alluvial processes have clearly left their marks in the sedimentary record and on the drainage pattern of lower Blue River.

Glacial and Physiographic History

Both sedimentary and physiographic evidence indicates that during one or more periods of glaciation, glaciers from the McKenzie River valley moved several kilometers up into the Blue River drainage (Fig. 1). The primary path of ice movement was upstream through the low divide (410 m elevation) now occupied by the saddle dam of the Blue River reservoir (in the vicinity of section A-A′ in Fig. 2). There are also indications that ice from the McKenzie valley spilled into Blue River through a 640-m-elevation saddle in Lookout Ridge east-southeast of location 1 in Figure 2.

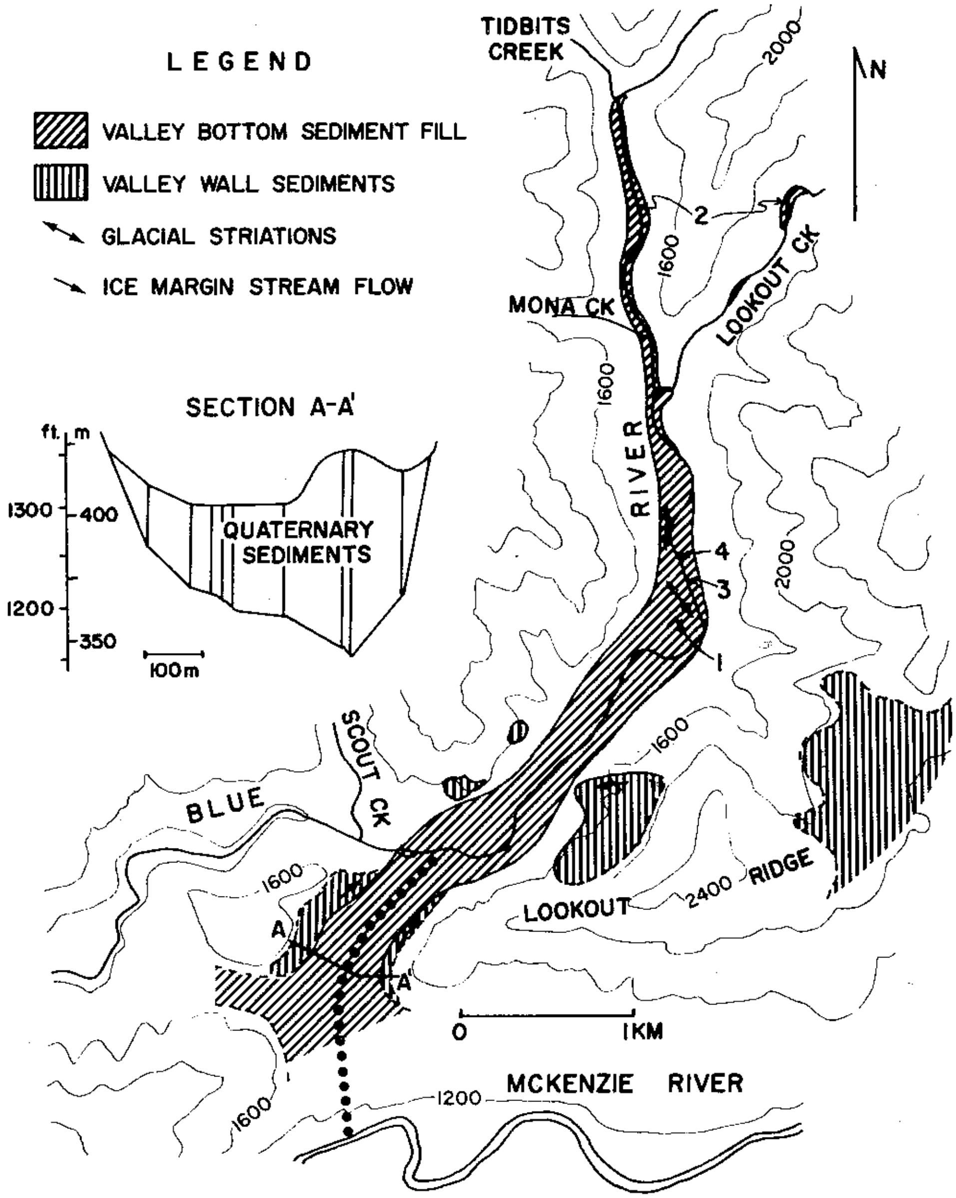

Figure 2. Map showing distribution of fluvial and lacustrine sediments related to glaciation of lower Blue River. Location 1 notes the occurrence of N25W-trending glacial striations. Location 2 marks sedimentary sections in the upper end of the lake, while at location 3 there are good exposures of sediments deposited in the lower portion of the lake. Wood collected from glacio-lacustrine sediments at location 4 was dated at >40,000 years b.p. Dotted line shows former course of Blue River. Contours (interval = 400 ft) from U.S. Geological Survey Blue River and McKenzie Bridge 15-ft quadrangles. Cross-section was drawn from U.S. Army Corps of Engineers' data.

Excavations by the U.S. Army Corps of Engineers at location 1 have exposed a glacially striated bedrock surface with patches of till plastered on it. The striae trend N25W, directly in line with the Lookout Ridge saddle, rather than parallel to the south to south-southwest orientation of the valley axis. Further evidence that ice may have flowed over the ridge has been observed during field reconnaissance in the main McKenzie valley, where patches of weathered till and kame terrace deposits indicate that ice probably reached at least as high as the 2400-ft contour (732 m).

Till is observed in scattered exposures along Blue River for a distance of 1.3 km upstream from location 1 (Fig. 2). The till occurs in several beds up to 2 m thick which are interbedded with fluvial sand and gravel and quiet water silt and clay deposits. In several instances the sediments appear to have been overridden by glacial advance in the upstream direction. The stratigraphy of this section records at least three upstream advances and downstream retreats. Absence of any old weathering surfaces suggests that these ice-front fluctuations occurred over a relatively short period of time, probably during a single glacial epoch.

While glaciers were present in the lower Blue River valley, stream drainages developed along the margins of the ice and resulted in the accumulation of river gravel in kame terraces deposited against the valley walls. Remnants of these deposits are located as "valley wall sediments" in Figure 2, and arrows indicate direction of stream flow based on stone imbrication and cross-bed orientation.

Ice in the mouth of Blue River also dammed up a lake which reached an elevation of at least 425 m (1400 ft) and extended 1.5 km up into the Lookout Creek drainage and along Blue River to a point just above the mouth of Tidbits Creek. Sections up to 7 m thick of fine-grained, quiet-water sediments are exposed in the upper and lower ends of the lake basin (locations 2 and 3, respectively, in Fig. 2).

The shape of Blue River valley before it was partially filled with sediment may be roughly determined from subsurface information gathered by the Corps of Engineers during construction of the reservoir. They drilled a series of holes across the saddle (shown as profile A-A′ in Fig. 2), which penetrated up to 78 m of semiconsolidated sediments before reaching bedrock. Other exploratory drilling and back-hoe trenching by the Corps have determined that this sedimentary fill forms a wedge which thins upstream from the saddle dam area until it pinches out near the mouth of Mona Creek (Fig. 2).

These observations indicate that Blue River formerly flowed through a canyon where the saddle dam is now located (Fig. 2) and joined with the McKenzie about 5 km upstream from their present confluence (Fig. 1). A shift of the drainage pattern occurred when glaciers filled the main McKenzie valley and ice pushed up into the Blue River drainage. Blockage of the channel diverted the course of Blue River over a low divide into the next drainage to the west. After retreat of the ice sufficient glacial debris and fluvial and lacustrine sediments filled the old channel to prevent re-establishment of the earlier stream pattern.

The physiography of Blue River valley reflects this glacial history. The river flows over bedrock at the head of the reservoir and near the mouth of Scout Creek, where it makes a westward turn at the beginning of the ice-barrier-diverted section of the river. Between these points the channel and older alluvial landforms of Blue River are cut into the soft Quaternary sediment which is in part preserved because the river is graded to the lower bedrock bench. Consequently the valley is broad and flat along this reach of the river and narrows into the bedrock channels both up and downstream.

The ice which filled the McKenzie valley and changed the course of lower Blue River was derived principally from the High Cascade plateau and the South Fork drainage. The distribution of cirques and glacial deposits in upper parts of the Blue River and Lookout Creek watersheds suggests that during the period for which there is a sedimentary record, these relatively low elevation catchments did not supply glaciers of sufficient size to extend into the map area of Figure 2. However, one cannot rule out the possibility that earlier glaciations may have inundated all of these valleys and that the evidence was subsequently eroded from the steep valley walls.

With the use of radiocarbon dating of wood fragments it is possible to place some limit on the age of glaciation of lower Blue River. One sample of Pacific yew (*Taxus brevifolia*) collected from fluvial sediments interbedded with till (location 4, Fig. 2) was dated at more than 40,000 years b.p. A second sample, western hemlock (*Tsuga heterophylla*) or incense cedar (*Librocedrus decurrens*), was collected from a probable debris torrent deposit immediately underlying glaciofluvial sediments exposed in the bank of Lookout Creek 1.2 km from its mouth. The age of the wood is greater than 35,500 radiocarbon years b.p. These dates indicate that the movement of glaciers into lower Blue River from the main McKenzie River valley occurred before 40,000 radiocarbon years ago.

Alluvial History of the Blue River-Lookout Creek Area

After the pre-40,000 years b.p. glaciation and the resulting aggradation of the lower Blue River valley, the river began to exhume its old channel. We have no record of the geomorphic history of the valley for an unknown period during the early history of this excavation. However, since the time of the latest Wisconsin glacial maximum, various alluvial landforms have preserved a clear history of alluviation, subsequent downcutting, and the construction of alluvial terraces and fans.

The task of unraveling this history has been greatly assisted by the occurrence of a volcanic ash layer on top of, or buried within, some landforms. The ash serves as an excellent time horizon because it can be correlated by petrographic methods with known Mazama airfall tephra, which were erupted approximately 7000 radiocarbon years ago (Kittleman, 1973). That eruption blanketed the Blue River region with about 1 cm of pumiceous ash.

Fluvial Terrace and Floodplain History

In the mapped area a distinct terrace surface (the "fluvial terrace" in Fig. 3) stands 6 to 10 m above the present channel. The base of the terrace is cut onto the glacial deposits and Tertiary bedrock. Terrace deposits are typically composed of up to 5 m of well-rounded, imbricated cobbles and boulders with minor fine gravel and sand interbeds which generally grade upward to a meter or so of unstratified silt to coarse sand overbank material. In some exposures a layer of Mazama ash occurs within or immediately overlies overbank sediments, and these units may be buried beneath subangular to subrounded, poorly sorted gravels from tributary watersheds. Therefore we can infer that mainstream deposition on the terrace surface was completed about 7000 radiocarbon years b.p. and that by that time Blue River and Lookout Creek were incising deeper channels.

A minimum age of 7000 years for the fluvial terrace suggests that it may be correlative with the Winkle geomorphic unit mapped by Balster and Parsons (1968) in the Willamette Valley. They report Mazama ash in the upper meter of alluvium under the Winkle surface and obtained a radiocarbon age of 5250 ± 270 years for an Indian hearth under a soil on the surface. Although correlations of geomorphic surfaces may be tenuous, it does seem reasonable that the Blue River terrace and the Winkle surface in the Willamette Valley were developed as floodplains in response to a single, but not necessarily synchronous, regional adjustment of fluvial regimens to climate and vegetation changes after retreat of the latest Wisconsin glaciers. Subsequent downcutting by local streams has caused the Winkle-age surface to be abandoned as a floodplain.

The modern vegetated floodplains of Blue River and Lookout Creek form a geomorphic surface 1 to 2 m above present low water level. In most cases this surface has been cut onto glacial sediments. In fact, the presence of the easily eroded, older Quaternary sediments appears to control the geographic distribution of the surface. Several Douglas-fir trees (*Pseudotsuga menziesii*) more than 400 years old have recently been cut from one segment of the floodplain, suggesting a minimum age for the floodplain of 400 to 500 years and indicating that the modern channel has been in its present position for at least that length of time. The floodplain characteristics and age are similar to those of the Ingram geomorphic unit of Balster and Parsons (1968), which they dated at 550 to 3200 years b.p.

The presently active channels of Blue River and Lookout Creek are mapped in Figure 3 as "modern channels." The two streams flow on bedrock and modern alluvium above their confluence, and below that point the channel is cut into the glacial sediments. The modern channels correspond to the Horseshoe surface of Balster and Parsons (1968).

Alluvial Fan History

In the Blue River-Lookout Creek area alluvial fans have been constructed onto the floodplain and terrace surfaces from the mouths of tributary watersheds. The general morphology of two types of fans is sketched in Figure 4. Upper surfaces of the fans dip radially 5° to 10° from their apex.

The fans have been constructed by two types of stream-channel processes. Sediment is deposited from bedload and from suspended load during high discharge events of recurrence intervals ranging upward from several per year. Fans may also accumulate sediment by deposition from episodic debris torrents which may flush large masses of rocks, mud, logs, and sticks from channels in a matter of seconds or minutes (Fredriksen, 1963). Debris torrents may be triggered by mass movements into the channel or the breakup of pre-existing debris dams in the channel during exceptionally high peak discharges. The average recurrence interval of such events is not known, but, judging from Fredriksen's (1965) observations, 50 to 200 years seems to be a reasonable estimate.

The characteristics of individual fans, in terms of their size, morphology, internal stratigraphy, and extent of erosion by the tributary and mainstreams, are functions of floodplain width and watershed variables such as area, channel length, relief, and slope stability. Within the mapped area it is possible to delineate two types of fans on the basis of probable history and present stage of development. However, there is

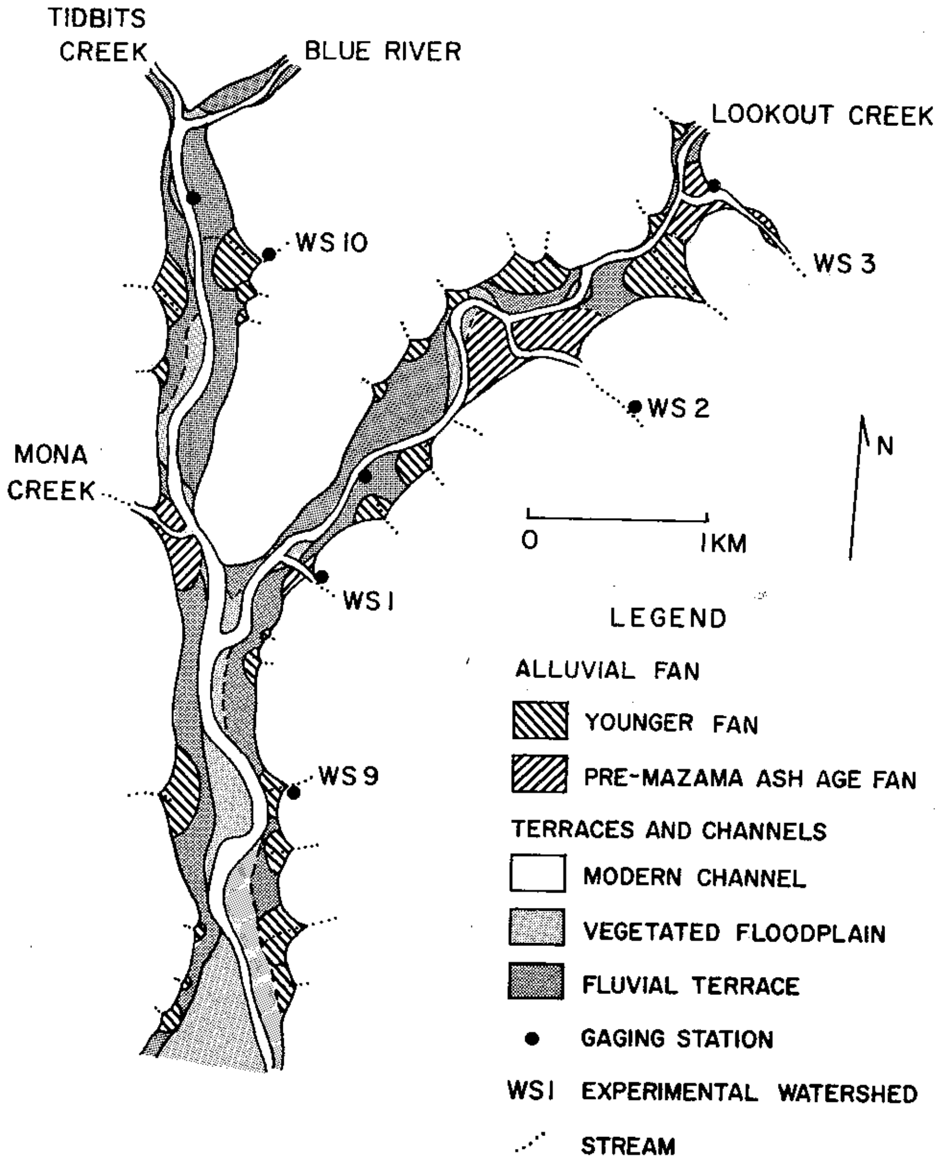

Figure 3. Map of post-glacial geomorphic surfaces near the confluence of Blue River and Lookout Creek.

a continuum of fan characteristics and, therefore, distinguishing fan types is somewhat subjective.

Alluvial fans labeled as "pre-Mazama ash age" in Figure 3 were constructed at the mouths of larger tributary watersheds (approximately 40 to 200 ha) primarily by the accumulation of debris torrent material. This is most clearly seen in the case of watershed 3, where a roadcut exposes a 15-m, vertical section of the fan interior composed of a series of beds up to several meters in thickness. Individual depositional units are made up of subangular, unsorted mineral material, ranging from clay size

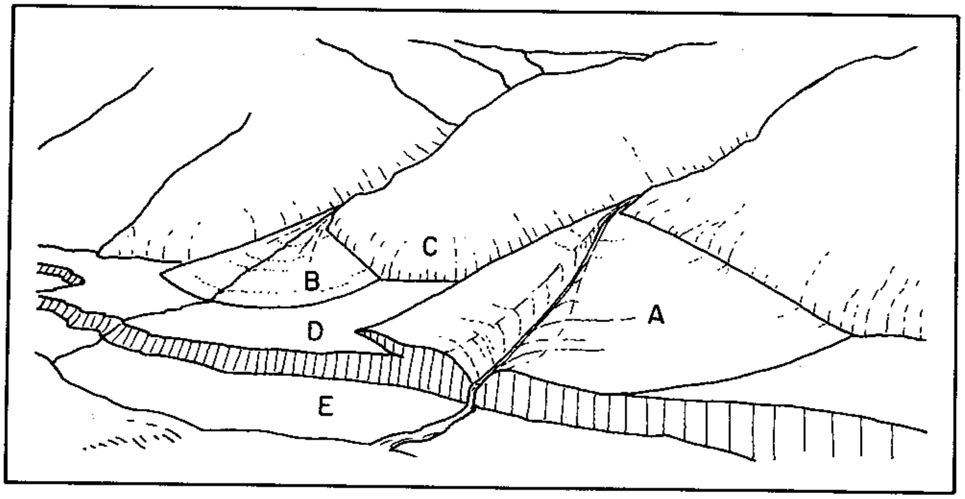

Figure 4. Sketch of two types of alluvial fans. A = dissected pre-Mazama ash age fan; B = young, active fan; C = hillslope; D = fluvial terrace; E = floodplain. Sketch by Ray Wells.

to blocks 1.7 m long, but with a notable absence of woody matter. Scattered patches of Mazama ash are found on or near the fan surface.

This internal stratigraphy indicates that the fans were formed by periodic debris torrents before about 7000 years ago. The paucity of wood in the old deposits contrasts strikingly with modern, log-filled, debris torrent material (Fredriksen, 1963, 1965). The difference may in part be related to an increase in the amount of organic debris in stream channels because of logging activities or may be due to a natural bias in the sample, such as loss of organic material by decomposition. However, this difference in wood deposits may also reflect the presence of much sparser vegetation during the period of deposition—possibly scattered groves of lodgepole pine (*Pinus contorta*) with only minor amounts of Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) (Heusser, 1960).

Morphology of pre-Mazama ash age fans was greatly modified during and after fan construction by mainstream overbank flow on the terrace surface and by downcutting of both mainstream and tributary channels (Fig. 4). In larger watersheds drained by perennial streams, channels were cut into the fans between debris torrent events. As the fan surface aggraded and downcutting by the tributary stream continued, the channel eventually became so deeply incised that fan construction ceased. This had occurred by the time of the Mazama ash fall, and subsequent debris torrents passed directly through the fan area and into the mainstream channel. The process of fan dissection was accelerated by downcutting of the mainstream channel which served to lower local base level.

Fans built at the mouths of smaller watersheds (less than about 40 ha) are generally composed of better sorted and finer sediments than the pre-Mazama ash age fans. An additional important distinction is that where the floodplain is broad enough to contain much of the fan, the surface of a fan from a small watershed is still aggrading or is gullied to a depth of no more than 1.5 m by the tributary stream.

In the small watershed fans, beds of stream-transported Mazama ash up to 25 cm in thickness are buried as much as 4 m below the fan surface. Such a stratigraphy indicates that these fans continued to accumulate sediment long after the pre-Mazama ash fans had stopped growing. For this reason small watershed fans are designated "younger" in Figure 3. Some of the alluvial fans containing ash layers offer a rather complete record of the erosional debris removed from a watershed for a time period extending back more than 7000 years. Future study of these fans will yield information about long-term processes and rates of erosion.

The finer grained, better sorted characteristics of sediment composing small watershed fans indicate that the fans were constructed by deposition of material transported as bedload or suspended load. On some of the fans, debris torrents have deposited coarse, unsorted material which has been reworked on the fan surface by more frequent, lower-magnitude alluvial events. In this manner sediment characteristics may offer a somewhat biased record of the processes transporting material to the fans.

The apparent contrast in the primary constructional processes for younger fans (annual scale events) and older fans (infrequent catastrophic debris torrents) is mainly a consequence of differences in watershed characteristics; but this contrast may also be related to a change in the relative rates of geomorphic processes about 7000 radiocarbon years ago, due to changing vegetation and climate in post-glacial times. A further complicating factor is that the older fans probably do not preserve a record of much of the alluvium which was carried in sediment transport events of low to moderate magnitude. Most of this material appears to have been transported directly through the stream channel cutting across the fan.

However, there are a number of reasons for believing that larger watersheds are more susceptible to massive debris torrent events. Geological considerations appear to be the major factors. Dyrness (1967), Fredriksen (1970), and others have pointed out that mass movements often initiate debris torrent events in channels. Dyrness (1967) has further shown that within the Andrews Experimental Forest there is a marked tendency for mass soil movements to occur at elevations between 610 and 800 m. This altitudinal band is the zone of transition from predominantly deeply weathered and altered volcanoclastic rocks below to relatively fresh lava flows at higher elevations. The underlying volcanoclastic rocks are much more susceptible to erosion by mass movements and stream cutting. The capping effect of the more resistant flow rocks prevents the establishment of a stable slope profile. As a result the clastic rocks are left in a highly unstable, over-steepened condition, and the contact zone is consequently the site of numerous shallow and deep-seated earth failures and the initiation point for debris torrents. In this way the geological setting contributes substantially to landscape instability and the initiation of debris torrents in the upper parts of the large watersheds. Headwaters of smaller watersheds in the study area do not extend high enough to reach critical exposures of the ridge capping flows.

Several other aspects of watershed size also appear to influence sediment discharge characteristics. One factor is that longer channels offer a greater chance for the development of debris dams, which may fail and trigger debris torrents at times of high peak flows during storms. Streams in larger watersheds are also subjected to extreme peak discharges, great enough to break up debris dams and flush the channels. In addition there may be meteorological factors such as greater chance of snowmelt runoff at higher elevations, which would tend to increase the probability of periodic scouring of channels in larger watersheds. However, at this time we do not have sufficient data for detailed analysis of these hypothetical relationships.

Summary

The interplay of glacial, alluvial, and mass movement processes has determined the geomorphic history of the lower Blue River and Lookout Creek valleys. More than 40,000 radiocarbon years b.p. a glacier from the McKenzie River valley moved up into the Blue River drainage, depositing as much as 65 m of sedimentary fill in the former mouth of the river and forcing Blue River to establish a new, westerly course. The ice dammed Blue River, backing a lake up the main stream and into its tributary, Lookout Creek, to approximately 1.5 km above the confluence of the two. Below the mouth of Lookout Creek the river is cut into glacial, lacustrine, fluvial, and till deposits.

After retreat of the glacier the river began to cut down through the valley fill. However, there was a fresh influx of sediment during, and just after, the latest Wisconsin glaciation of upper Lookout Creek and Blue River which resulted in channel aggradation. The subsequent period of downcutting led to the deveolpment of a prominent terrace. Fluvial sediments making up the terrace deposits are topped by Mazama ash, indicating that this surface was abandoned as a floodplain about 7000 radiocarbon years b.p. The modern floodplain, a lower surface, was cut into glacial sediments and appears to have maintained its present configuration for at least the past 400 to 500 years.

Alluvial fans from the tributary watersheds have been constructed on the floodplain and terrace surfaces. The size, degree of dissection, and internal make-up of the fans are directly tied to terrace-floodplain width and watershed characteristics, especially area, relief, and bedrock geology. Fans at the mouths of larger watersheds (approximately 40 to 200 ha) were constructed primarily from deposition by debris torrents before the Mazama ash fall occurred. Since that time these fans have been deeply incised by the tributary and main streams. In smaller watersheds more frequent, less catastrophic alluvial events have been the dominant agents of fan construction. Surfaces of many of these fans are still aggrading and the Mazama ash is buried up to 4 m within them.

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A Pleistocene Low-Elevation Subalpine Forest in the Western Cascades, Oregon

Abstract

A boulder diamicton exposed in the low Lookout Creek valley, western Cascades, Oregon, contains fossil wood, needle, and pollen material representative of a Pleistocene flora > 35,500 radiocarbon years in age. The deposit was probably formed by a debris torrent from a tributary watershed. Some of the wood fragments are abraded and randomly oriented, suggesting transport from upslope areas. *Abies* sp., *Pseudotsuga menziesii*, and *Thuja plicata* are represented in these wood specimens. Other materials, including unabraded wood, needles, and pollen occur in a continuous, horizontal layer that may represent a small piece of locally formed forest floor litter. This valley bottom flora contained abundant *Picea* cf. *englemannii* and *Abies* cf. *lasiocarpa*. These fossils suggest the occurrence of *Picea englemannii*/*Abies lasiocarpa* forest in a cold valley bottom with more xeric forest communities on adjacent hillslopes.

Present arboreal vegetation at the site is dominated by *Tsuga heterophylla*, *Thuja plicata*, and *Pseudotsuga menziesii*. Modern examples of the community represented by the fossil assemblage occur at elevations over 1000 m higher than the Lookout Creek site. The Lookout Creek assemblage probably represents a flora of an early Wisconsin or previous glaciation under conditions significantly drier than those prevailing during late Wisconsin glaciation.

Introduction

Preservation of Pleistocene plant fossil material of pre-late Wisconsin age is rather rare, particularly in the steep, rapidly eroding mountainous terrain of the Pacific Northwest. Previous work on materials of this age in western Washington has centered in the Puget Lowland (Hansen, 1938; Hansen and Mackin, 1940, 1949; Easterbrook *et al.*, 1967; Hansen and Easterbrook 1974) and along the coast of the Olympic Peninsula (Heusser, 1964, 1972; Florer, 1972) in areas where the stratigraphy is well known. There have been no reports of known pre-late Wisconsin Pleistocene assemblages in western Oregon, although several undated samples (Hansen and Allison, 1942; Hansen, 1947) may represent this period. We use the term late-Wisconsin to indicate the

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time period between approximately 10,000 and 35,000 years before present (B.P.) when extensive glaciation was occurring in the Northwest, as indicated by the Evans Creek (Crandell and Miller, 1974), Cabot Creek (Scott, 1977), and other drifts. The term early-Wisconsin is used to indicate earlier Wisconsin time, which may be represented in part by Hayden Creek (Crandell and Miller, 1974), Jack Creek (Scott, 1977), and other drifts.

During geomorphic studies in the vicinity of Lookout Creek, H. J. Andrews Experimental Forest, western Cascades, Oregon, we have located an assemblage of wood fragments, conifer needles, and pollen more than 35,000 radiocarbon years in age. In this report we offer an analysis of this assemblage and its implications regarding the magnitude of vegetation displacement in response to major episodes of climatic change. Species identification of the plant material is aided by the presence of both macro- and microfossils.

Location, Nature, and Age of the Deposit

The Lookout Creek assemblage is exposed in a streambank at an elevation of 425 m along Lookout Creek, about 1.2 km upstream from its confluence with Blue River (NW ¼ SE ¼ Sec. 31 T15S R5E). The site is within the H. J. Andrews Experimental Forest approximately 55 km east of Eugene, Oregon (Fig. 1). The general geologic and geomorphic settings of the site have been described by Swanson and James (1975a, b).

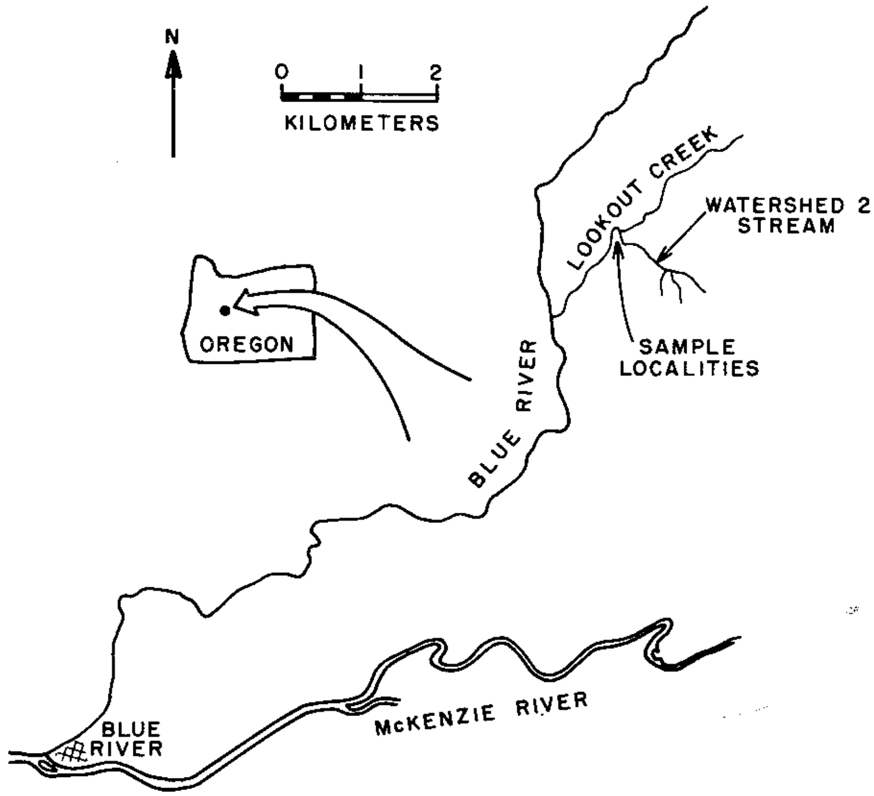
Plant fossil material is contained within the dense clayey matrix of a bouldery diamicton up to 4.5 m in thickness which is overlain by varved lacustrine sediments (Fig. 1). The lake sediments were presumably deposited in the lower Blue River drainage while the mouth of the river was dammed by glacial ice in the McKenzie River valley (Swanson and James, 1975b). Coarse well-rounded gravel deposited by Lookout Creek rests on both the lacustrine sediments and the diamicton.

The diamicton is exposed at the distal end of a massive debris fan constructed at the mouth of experimental Watershed 2 (Swanson and James, 1975b). Fans constructed of debris torrent deposits occur commonly at the mouths of 5 to 100 ha watersheds in the study area (Swanson and James, 1975b).

Clasts within the diamicton are subangular and up to 80 cm in diameter. No evidence of striations or faceting was observed. The matrix material is a dense compact of blue-gray clay and angular to subangular, unsorted rock fragments. The proportion of rock types in the deposit indicates a source area in nearby watersheds tributary to Lookout Creek, probably Watershed 2. Modern gravel in Lookout Creek includes a variety of rock types not observed in Watershed 2 or in the fossil bearing deposit.

The probable origin of the deposit was a debris torrent which originated at a middle to upper elevation site (600 to 900 m) in Watershed 2. Glaciation would be an alternative means of forming such a deposit. However, the lack of glacial landforms and striations and facets on stones argues against glacial processes as the mode of origin of the deposit. There is no clear evidence of the presence of glaciers along this section of valley floor anywhere within a kilometer of the site.

The fossil material occurs in two different patterns within the diamicton. At locality LOK-1 (Fig. 1), a matted, irregular but continuous layer of twigs, needles, and wood fragments up to several centimeters in thickness extends for more than 4 m



SAMPLE LOCALITIES IN STREAMBANK EXPOSURE

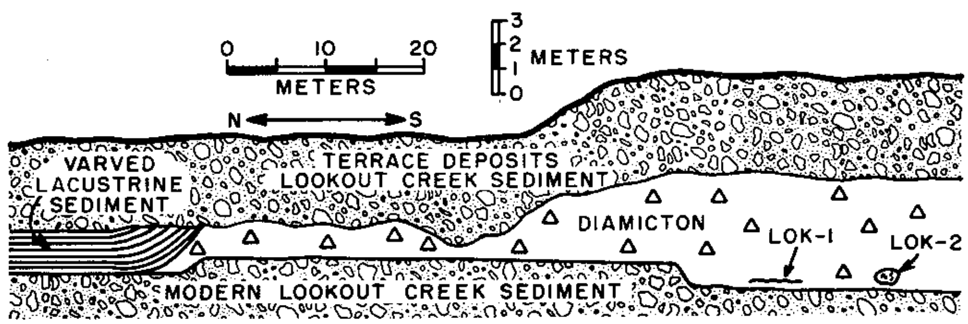


Figure 1. Location of sample localities and sketch of Lookout Creek streambank exposure showing LOK-1 and LOK-2 sites. The modern Lookout Creek sediment is deposited against the base of the exposure which shows terrace deposits unconformably overlying varved lacustrine and diamicton deposits.

horizontally. This fossil bearing horizon does not occupy a noticeable break in lithology or a weathered zone. However, the thin, continuous, horizontal nature of the band, the occurrence of needles arranged along twigs as they were in life, and lack of abrasion and rounding of the wood fragments suggest that the deposit represents a piece of intact forest floor which was not subjected to transport in a mass movement event.

Locality LOK-2 (Fig. 1) yields isolated pieces of wood scattered through a zone about 1 m thick within the diamicton. These wood fragments are randomly oriented and rounded and abraded, indicating possible transport in a mass movement event from an upslope area.

Based on these observations and geomorphic studies in Watershed 2 (D. N. Swanston and F. J. Swanson, unpubl. map), we hypothesize that the following sequence of events led to preservation of plant materials at LOK-1 and LOK-2. A debris torrent originated in Watershed 2 at an elevation between 600 and 900 m. In its downstream movement the torrent entrained, transported, and then deposited wood at LOK-2. The wood, twigs, needles, and pollen in LOK-1 appear to have been directly deposited by litterfall onto fresh debris torrent material and soon thereafter covered with similar material. Small scale slumping of debris torrent material, perhaps at a bank eroded by high stream flow, may have covered and preserved the LOK-1 material.

A sample of wood from the diamicton (I-7287) was C^{14} dated at > 35,500 years [B.P.]. The exact stratigraphic position of this specimen relative to the two sample localities is uncertain, but it probably derives from LOK-2. The presence of these deposits at the base of a deeply incised, rapidly eroding watershed suggests that they are not older than Pleistocene and are probably of late Pleistocene age.

Analysis of Macrofossils

On 3 June 1976 wood samples, needles, and bulk maceration samples were collected from locality LOK-1, and on 3 June and 7 December 1976 wood samples were collected from locality LOK-2. Ten wood samples from LOK-1 have been determined as *Abies* sp. by Allan Doerksen (Forest Research Lab, Oregon State Univ., Corvallis). The specimens include large diameter stems as well as branches as small as 1 cm. Examination of the leaf material discloses matted needles draped over numerous small twigs. Many of the needles are arranged in parallel clusters or along small twigs. Preservation of the needles is excellent and three dimensional. Disaggregation of the matrix with detergent solution allows intact needles to be separated from the matrix. Bulk maceration of several kilograms of material has not yielded any plant material not referable to *Abies*.

The needles are stomatiferous above and below, shallowly depressed to mildly convex above, flattened, with revolute margins and blunt apices, some of which are minutely notched. The needles are commonly falcate and short, and most are bent at the petiole. The twigs have conspicuous leaf scars. Comparison of these needles and twigs with all species of northwestern *Abies* shows they are clearly referable to *Abies lasiocarpa*. Examination of additional material from LOK-1 by Art McKee (School of Forestry, Oregon State Univ.) disclosed small amounts of *Tsuga heterophylla* and *Picea* sp. (cf. *englemannii*) needles in addition to abundant *Abies lasiocarpa* material.

The wood specimens from LOK-2 appear abraded and rounded. Specimens are referable to *Thuja plicata* (4 specimens), *Pseudotsuga menziesii* (2 specimens), and *Abies* sp. (1 specimen). The *Pseudotsuga* specimens are fragments of large diameter stems and are unusual in their minute growth increments, 0.14 and 0.10 mm/year

(0.005 and 0.004 inch/year). The C^{14} date of > 35,500 B.P. reported above is based on a specimen determined as *Tsuga heterophylla* (or *Libocedrus decurrens*).

Analysis of Microfossils

Abundant but generally compressed and poorly preserved pollen and spores have been recovered from locality LOK-1. A pollen count of 250 grains is given in Table 1. Percentages are calculated excluding indeterminate grains, which are those too poorly preserved for positive identification. Shown in Table 2 is a pollen count of 500 grains from a modern stand several hundred meters upslope from the Lookout Creek locality. The modern pollen rain was sampled by collection of 1 cc fragments of five moss polsters within the 50 m x 50 m of Reference Stand 7 (Dyrness *et al.*, 1974; Zobel *et al.*, 1976). These polsters were collected on logs of decay class 4, which have a mean residence time on the forest floor of 82 years (P. C. MacMillan, pers. comm., 1977).

In the pollen counts, *Pinus* species have been provisionally separated using a technique similar to Hansen and Cushing (1973). The basic separation is by cappula ornamentation. Among the diploxylon pines (types with smooth cappulae), the separation of *Pinus ponderosa* from *Pinus contorta* by morphology and size is believed to be reasonably reliable. The separation of haploxylon pines (rough cappulae) *Pinus*

TABLE 1. Pollen analysis of sample from LOK-1. Percentage figures calculated on basic sum, excluding indeterminate grains. Total count = 250 grains. Basic sum = 195.

Abies lasiocarpa type	10.8%
Abies procera-amabilis type	3.1%
Abies concolor-grandis type	2.6%
Abies indet.	5.1%
Total **Abies**	21.5%
Picea	7.7%
Pinus diplox. (**contorta** type)	6.1%
Pinus haplox. (**monticola** type)	3.6%
Pinus haplox. (**albicaulis** type)	5.6%
Pinus indet.	8.2%
Total **Pinus**	23.6%
Cupressaceae	5.1%
Tsuga heterophylla	2.1%
Tsuga mertensiana	2.1%
Quercus?	5.6%
TOTAL ARBOREAL POLLEN	67.7%
Artemesia	4.6%
Ribes	0.5%
Alnus	0.5%
Acer circinatum	0.5%
Compositae, hi spine	6.1%
Compositae, low spine	6.1%
Cruciferae	3.6%
Cruciferae, cf. **Erysimum**	0.5%
Umbelliferae	1.5%
Saxifragaceae?	1.0%
Rosaceae	0.5%
Malvaceae?	1.5%
Cyperaceae	0.5%
Other herbs	3.0%
Unknown	2.1%
Total shrubs	6.1%
Total herbs	24.1%
TOTAL NON-ARBOREAL POLLEN	30.2%

TABLE 2. Pollen analysis and stand data for Reference Stand 7, H. J. Andrews Experimental Forest (Zobel et al., 1974). Pollen analysis based on count of 500 grains. Stand data are in percent cover for mature (M) and reproduction (R) tree species (G. M. Hawk, pers. comm.).

Pollen Analysis-Reference Stand 7		
Tsuga heterophylla		35.4%
Pseudotsuga menziesii		24.2%
Abies spp.		0.2%
Pinus diplox. (**contorta** type)		1.4%
Pinus haplox. (**monticola** tyye)		2.4%
Pinus indet.		0.8%
Total **Pinus**		4.6%
Cupressaceae		5.6%
Taxus		1.2%
Alnus		2.8%
Acer circinatum		0.4%
Acer macrophyllum		0.2%
Ceanothus		0.2%
TOTAL ARBOREAL POLLEN		70.0%
TOTAL SHRUBS		5.0%
Polystichum munitum		15.8%
Polypodium glycyrrhiza		0.2%
Athyrium?		0.2%
Other fern		5.0%
Liliaceae		1.2%
Malvaceae		0.2%
Graminae		0.2%
Compositae		0.8%
Cheno-Am		0.2%
Unknown		1.2%
Indet.		0.6%
TOTAL NON-ARBOREAL POLLEN		26.6%
Stand Data-Reference Stand 7		
Tsuga heterophylla	M	55.0%
	R	30.0%
Pseudotsuga menziesii	M	25.0%
Thuja plicata	M	30.0%
	R	10.0%
Total Tree Cover		150.0%
Acer circinatum		8.3%
Cornus nuttallii		2.9%
Vaccinium parvifolium		1.8%
Taxus brevifolia		1.3%
Total Shrub Cover		14.3%
Gaultheria shallon		1.5%
Rubus ursinus		1.3%
Berberis nervosa		0.5%
Rubus nivalis		present
Total Low Shrub Cover		3.3%
Oxalis oregana		24.4%
Polystichum munitum		6.7%
Linnea borealis		5.1%
Coptis laciniata		2.0%
Tiarella unifoliata		2.0%
Viola sempervirens		0.6%
Goodyera oblongifolia		0.1%
Vancouveria hexandra		0.1%
Galium triflorum		0.1%
Total Herb Cover		41.1%

albicaulis, *P. monticola*, and *P. lambertiana* is more difficult, but with care seems practical. Although the reported percentages may be open to some question, both *Pinus monticola* and *P. albicaulis* are represented in the LOK-1 pollen sample. A grain referable to *Pinus lambertiana* was observed scanning the modern comparative material from Reference Stand 7 near the Lookout Creek locality.

Abies species determinations are more perplexing than those of *Pinus* largely because of the apparent great variability of pollen morphology among species of *Abies* and the difficulty of securing adequate comparative material. Most distinctive of the six northwest *Abies* species is *Abies lasiocarpa*. It is characterized by a relatively thin cappa with fine infrastructure and conspicuous proximal thinning, finely reticulate sacci, and relatively small overall size (Hansen, 1947; Heusser, 1964). *Abies amabilis* and *A. procera* are also distinguishable by their greatly thickened cappae and characteristically thick and dense saccus infraornamentation.

Pollen tentatively determined as *Quercus* (Table 1) resembles the pollen of modern *Q. saddleriana* and *Q. vaccinifolia*, but is considerably larger, generally 45-55 μ, and may represent some other taxon.

Pollen of Cupressaceae in Reference Stand 7 is likely from *Thuja plicata*. Cupressaceae in LOK-1 may be from *Chamaecyparis nootkatensis*, *Thuja plicata*, *Juniperus communis*, or perhaps *J. occidentalis*. More probably one or several of the first three species are represented.

Reference Stand 7 typifies the *Tsuga heterophylla/Polystichum munitum-Oxalis oregana* (TSHE/POMU-OXOR) community of Dyrness *et al.* (1974) and may be taken as representative of the modern vegetation of the Lookout Creek locality. Species composition data for the stand (Table 2) are available for comparison with the pollen count. Observations of Zobel *et al.* (1976) indicate that this community occupies the warm moist extreme of environments in the central western Cascades of Oregon as shown by indirect (Dyrness *et al.*, 1974) and direct (Zobel *et al.*, 1976) gradient analysis.

Interpretation and Discussion

The fossil assemblage from the diamicton at Lookout Creek stands in sharp contrast to the present vegetation. Today the site is at the warm moist extreme of the spectrum of forest community environments in the central Oregon Cascades. The modern pollen rain reflects the present vegetation composition fairly well (Table 2). The rank order of dominant trees, *Tsuga heterophylla*, *Pseudotsuga menziesii*, *Thuja plicata*, is repeated in the pollen frequencies. Among the shrubs, *Acer circinatum* and *Taxus brevifolia* are found in the pollen sample. *Alnus rubra* grows in an area near Reference Stand 7. The importance of *Polystichum* is duplicated in the pollen assemblage; however, other herbaceous species are not present at detectable levels. Present at low levels in Reference Stand 7 are *Trillium ovatum*, *Disporum hookeri*, and *Smilacina stellata*, probable sources of the Liliaceae pollen type, and *Bromus* sp., a possible source of the Graminae pollen.

The LOK-1 pollen assemblage is characterized by a low pine component (24 percent), compared to other glacial period records, high *Abies* (22 percent), moderate *Picea* (8 percent), low *Tsuga* spp., and no *Pseudotsuga*. Comparable Pleistocene pollen assemblages are not common. Only the basal layers of the Scotts Mills and Lake

Kachess cores reported by Hansen (1947) approach that of the Lookout Creek assemblage. The Lake Kachess core from the Central Washington Cascades has much higher *Picea* and *Abies*, about 40 percent pine, and some *Pseudotsuga* and both species of *Tsuga* in low abundance. The basal levels of the Scotts Mills core also contain higher pine and high *Abies* (40-60 percent) and *Tsuga mertensiana* is apparently absent. These cores were studied before the advent of radiocarbon dating and the precise chronological position of their lowermost levels can only be inferential. Here they are interpreted as late Glacial.

The absence of *Pseudotsuga* pollen in the LOK-1 sample is noteworthy. It is generally believed that *Pseudotsuga* pollen is greatly underrepresented in pollen assemblages. However, the sample from Reference Stand 7 indicates that in at least some stands in the Cascades, *Pseudotsuga* pollen is represented in proportion to its coverage. The high settling velocities of *Pseudotsuga* pollen result in impact of virtually all of the pollen within a few hundred meters of the source tree. However, its complete absence in the LOK-1 sample probably indicates that it was not important or vigorous in the area at that time interval. The climate on surrounding upland slopes may have been too extreme for abundant pollen production by *Pseudotsuga*. The extremely low growth rate of the *Pseudotsuga* specimens favors this interpretation. Furthermore, there is some evidence from modern stands to suggest that *Pseudotsuga menziesii* is proportionally underrepresented in the pollen rain in higher elevation stands as compared with low elevation stands (A. S. Gottesfeld and L. M. J. Gottesfeld, unpubl. data).

The fossil assemblage contains macrofossil material of subalpine fir, and the pollen assemblage, containing 8 percent *Picea*, suggests that stands including *Picea englemannii* were nearby. Jonassen (1950) reports that the proportion of *Picea excelsa* pollen in Denmark drops from 59 percent to 7 percent within 200 m of the edge of a spruce forest. *Picea englemannii* wood has been collected 1.8 km south of the LOK locality in glacio-fluvial deposits probably correlative to the varved sediments which overlie the LOK diamicton. The *Picea* wood occurs with wood of *Taxus brevifolia* and *Pinus* cf. *contorta*. *Picea englemannii* wood has also been recovered from a diamicton similar to the LOK sediments 1 km north of the sample locality. The LOK-1 pollen assemblage contains other indicators of subalpine conditions; e.g., *Pinus contorta*, *P. albicaulis*, *Tsuga mertensiana*, and high levels of non-fern herbaceous pollen (21 percent in LOK-1 vs. 2 percent in Reference Stand 7).

Today *Picea englemannii* is generally rare in subalpine communities of the western Cascades, being more characteristic of the eastern slopes of the Cascades and interior ranges. Franklin and Mitchell (1967) find *Picea englemannii* as an important associate of *Abies lasiocarpa* only on the eastern slope of the Washington Cascades, where the forests are transitional to the spruce-fir subalpine forests of the Rocky Mountains. In this area, *Tsuga mertensiana* is generally only a minor associate of *Abies lasiocarpa*, a situation similar to that shown in the LOK-1 pollen assemblage. On the east side of the Cascade Range, especially in Washington, *Abies lasiocarpa* and *Picea englemannii* are also important constituents of forests of deep glaciated valley floors and frost pockets, particularly at elevations above 800 m (Franklin and Mitchell, 1967; Franklin and Dyrness, 1973; Daubenmire and Daubenmire, 1968). In such sites, well developed *Abies lasiocarpa-Picea englemannii* stands may exist below slopes supporting trees of higher temperature requirements (topographic reversal of vegetation zonation).

This finding may be analogous to the situation at LOK-1 where the LOK-2 wood specimens indicate proximity of trees with higher thermal requirements.

The occurrence of pollen of *Picea englemannii* in the western Cascades as well as pollen of *Quercus?*, *Artemsia*, and Compositae at levels much higher than at present suggests a relatively dry as well as cold climate during this glacial event. Pollen records of the Willamette lowland such as those of Lake Labish, Onion Flats, Fargher Lake (Hansen, 1947; Heusser, 1965), show a major expansion of *Picea sitchensis* during the last glacial period, which suggests moist and cold conditions at that time. Such conditions are also proposed by Heusser (1964) for the corresponding late Glacial of the Olympic Peninsula. However, it is possible that *Picea englemannii* spread to the west side of the Cascades during the last glacial as well, as Hansen (1947) has identified this as the species of *Picea* abundantly represented in the basal levels of the Scotts Mills profile in the Cascade foothills east of Salem, Oregon, and at Lake Kachess in the central Washington Cascades at an elevation of 670 m. Heusser (1964) interpreted the high grass levels of his GL-2 Zone at Humptulips, Washington, which probably represents early Wisconsin glaciation, as being indicative of cold, dry conditions. This zone is interpreted by Heusser as marking the most intense glacial conditions of the past 50,000 years. It seems likely that the LOK-1 assemblage derives from this event or one of similar magnitude, since geomorphic and palynological observations together indicate an intense glacial event accompanied by probable drier climatic conditions.

The record of *Quercus?* pollen is problematic. Its occurrence in a spectrum otherwise clearly subalpine may be explained either as a) *Q. garrayana*, which normally occupies lowland dry sites such as Willamette Valley, but is also found at elevations up to about 1500 m on dry south facing cliffs and rocky slopes near the top of Lookout Mountain (G. M. Hawk and J. F. Franklin, pers. comm.) approximately 15 km east of the LOK-1 site; or b) as evidence for past occurrence in the Cascades of one of the subalpine oaks, *Q. saddleriana* or *Q. vaccinifolia* now restricted in Oregon to the Siskiyou Mountains; or c) as representing another taxon.

Gold Lake Bog Research Natural Area (Franklin, 1972) at 1463 m elevation in the Willamette Pass area of the central eastern Cascades may provide a modern analogue of the type of vegetation which produced much of the pollen rain to LOK-1. This *Abies lasiocarpa-Picea englemannii* dominated stand is located approximately 60 km south of the Lookout Creek drainage. Low lying forests bordering marshes and bogs are typically dominated by *Picea englemannii* and *Abies lasiocarpa*. However, reproduction is mostly *Abies amabilis* (J. F. Franklin, pers. comm.) and adjacent upland sites (1650 m elevation) are mixed with *Tsuga mertensiana, Abies magnifica* var. *shastensis, Pseudotsuga menziesii*, and *Pinus monticola* (Franklin and Dyrness, 1973).

Although the forest at Gold Lake Bog differs in several respects from a forest which would yield a pollen assemblage like that of LOK-1, such as the low importance of *Pinus contorta* and *P. albicaulis* and the high importance of *Tsuga mertensiana* in that area, it is useful as a site for evaluation of minimum vegetation displacement in the central Cascades of Oregon. This site, which is low in the subalpine zone (*Tsuga mertensiana* Zone of Franklin and Dyrness, 1973), is 1040 m above the LOK locality.

Carver (1973) and Scott (1977) present data for changes in equilibrium line altitude (ELA) during the late Quaternary glaciations in the Cascade Range based on study of glacial deposits and landforms. They conclude that the maximum late glacial ELA depression was 950-1000 m in the Mt. Jefferson area (Scott, 1977) and 1025 m in the Mt. McLoughlin area (Carver, 1973). The more extensive presumed early Wisconsin glaciation depressed the ELA 1100 to 1150 m in these areas. These data are in good agreement with the magnitude of altitudinal displacement of vegetation inferred from analysis of the Lookout Creek assemblage.

Summary

In the valley of Lookout Creek, a diamicton of presumed debris torrent origin contains a variety of plant macro- and microfossils representative of valley bottom and upslope Pleistocene forests. Locality LOK-1 within the deposit appears to have preserved a small piece of forest floor litter consisting of abundant leaves, twigs, and wood of *Abies lasiocarpa.* It has yielded a pollen and spore assemblage rich in *Picea* cf. *englemannii* and *Abies* cf. *lasiocarpa.* Dispersed in the deposit at locality LOK-2 are other wood specimens, some of which show abrasion and rounding indicative of transport. These have been determined as *Abies* sp., *Pseudotsuga menziesii*, and *Thuja plicata*, the latter two being species of generally warmer requirements than the other species represented in the deposit. These fossils suggest the occurrence of *Picea englemannii/Abies lasiocarpa* forest in a cold valley bottom surrounded by more xeric communities on adjacent hillslopes. Similar ecological situations commonly occur today in the eastern slopes of the Washington Cascades.

A somewhat similar localized association in the Oregon Cascades is found in the Gold Lake Bog Research Natural Area at an elevation 1040 m above the Lookout Creek localities. This estimate of vegetation displacement is consistent with estimates of maximum equilibrium line altitude depression during glaciations in the Oregon Cascades. The Lookout Creek assemblage is probably of Late Pleistocene age and may have formed during Early Wisconsin or a previous glaciation under conditions significantly drier than those prevailing during late Wisconsin glaciation.

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