Geologic Setting of the Glacier Peak and Mazama Ash-Bed Markers in West-Central Montana

GEOLOGICAL SURVEY BULLETIN 1395-H

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By R. W. LEMKE, M. R. MUDGE,
RAY E. WILCOX, *and* H. A. POWERS

CONTRIBUTIONS TO STRATIGRAPHY

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Describes how ash beds can be used as stratigraphic markers in correlating deposits of late Pleistocene and Holocene age in west-central Montana

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GEOLOGIC SETTING OF THE GLACIER PEAK AND MAZAMA ASH-BED MARKERS IN WEST-CENTRAL MONTANA

By R. W. LEMKE, M. R. MUDGE, RAY E. WILCOX, and H. A. POWERS

ABSTRACT

The Glacier Peak and Mazama ash beds are informally named stratigraphic markers that assist in interpreting the age and environment of deposits of late Pleistocene and Holocene age in west-central Montana. There are only three known exposures in the area that contain both ash beds. The one bed is distinguished from the other petrographically by the habit and range of refractive index of its glass shards and the refractive indices of the hornblende phenocrysts, and chemically by the composition of the glass. In the field, identification is aided by the younger Mazama ash bed generally occurring higher in the exposure, commonly within a few feet of the top, and generally being somewhat thicker and more extensive than the Glacier Peak ash bed.

The Glacier Peak ash, dated radiometrically at approximately 12,500 years B.P. (before present), occurs as light-gray to tan-gray lentils and pods, mostly in beds of silt that commonly overlie deposits of the middle stade of Pinedale Glaciation and underlie deposits of the Altithermal interval. In one exposure the ash bed is interlayered in glacial lake beds of Pinedale age. Exposures of this ash bed are not as common as those of the Mazama ash bed, and have not been found as far east.

The Mazama ash, radiometrically dated at about 6,600 years B.P., occurs near the base of the deposits of the Altithermal interval as distinct but discontinuous light-gray to tan beds that range in thickness from 0.1 foot (3 centimetres) to as much as 2.5 feet (76 centimetres). It commonly overlies a distinct fossil soil and locally is overlain by a less distinct fossil soil.

INTRODUCTION

Beds of volcanic ash resulting from eruptions of volcanoes in the Cascade Range of Washington and Oregon occur in Quaternary deposits over a wide area of the Northwestern United States and southwestern Canada. Two of these ash beds (fig. 1), informally named the Glacier Peak and Mazama beds, are particularly widespread and have distinctive characteristics which make them useful stratigraphic

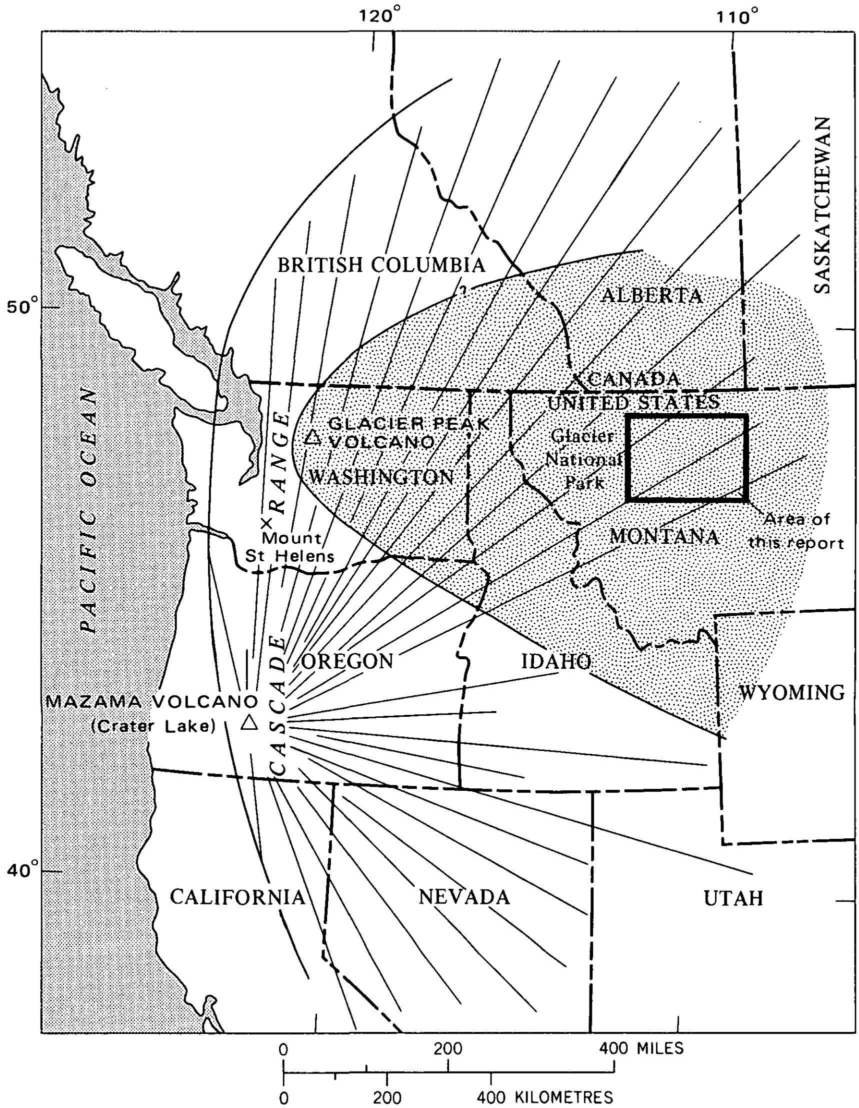


FIGURE 1. — Distribution of Glacier Peak and Mazama ash falls in Northwestern United States and Canada and location of area described in this report. Dotted pattern shows distribution of Glacier Peak ash fall; radial line pattern shows distribution of Mazama ash fall.

markers. The purpose of this paper is to describe briefly the geologic settings in which the ash beds are found, how to identify the ash beds, and how the beds are useful as stratigraphic markers in upper Pleistocene and Holocene deposits in west-central Montana.

The ash localities described in this paper are shown in figure 2. Some additional ash localities in the study area are not shown because their stratigraphic relations are essentially the same as other described ones, or because the exposures are poor and stratigraphic relations are obscure. The known ash localities that are shown are limited chiefly to areas where detailed geologic studies have been made or to areas along main highways. Therefore, it is likely that many ash localities are yet to be discovered. Additional exposures probably occur along the main valleys and tributary valleys of the Missouri, Teton, Marias, and Sun Rivers.

Only three localities (RWL-3, RWL-13, and HS-91) have been found where both the Glacier Peak and Mazama ash beds are present in a single exposure. These three localities are particularly important because they provide a fairly complete stratigraphic sequence of deposition during the past 12,500 years, or since near the close of the middle stade of the Pinedale Glaciation in the region.

REGIONAL LATE PLEISTOCENE AND HOLOCENE GEOLOGIC HISTORY

No glacial deposits older than Wisconsin age have been identified in the Plains area of west-central Montana (Lemke and others, 1965). Also, pre-Wisconsin drift has not been identified in the mountains immediately to the south and west of the study area, although pre-Wisconsin alpine glacial deposits long have been recognized to the northwest in Glacier National Park (Alden and Stebinger, 1913). More recently, Richmond (1957, 1960, 1965) described three pre-Bull Lake alpine tills from that area, separated by deeply weathered interglacial soils.

Most of the Plains area, to about as far south as Great Falls, was covered twice by continental glaciers during Wisconsin time (fig. 3). The earlier of these ice sheets merged in north-central Montana with alpine ice of the Bull Lake Glaciation and the later ice sheet merged in the same general area with alpine ice of the Pinedale Glaciation (Richmond, 1965). Because of these established correlations by Richmond (1965), the glaciations of the Plains area are referred to as the continental Bull Lake Glaciation and the continental Pinedale Glaciation rather than by the less firmly correlated midwestern nomenclature of Frye and Willman (1963).

During the continental Bull Lake Glaciation, Glacial Lake Great Falls was impounded along the southern edge of the ice front. This lake was of wide areal extent, was more than 600 feet (182 metres) deep in places, and reached a maximum surface altitude of approximately 3,900 feet (1,188 m) (Colton and others, 1961). Glacial Lake Choteau and Glacial Lake Cut Bank were formed at the same time along the western edge of the ice.

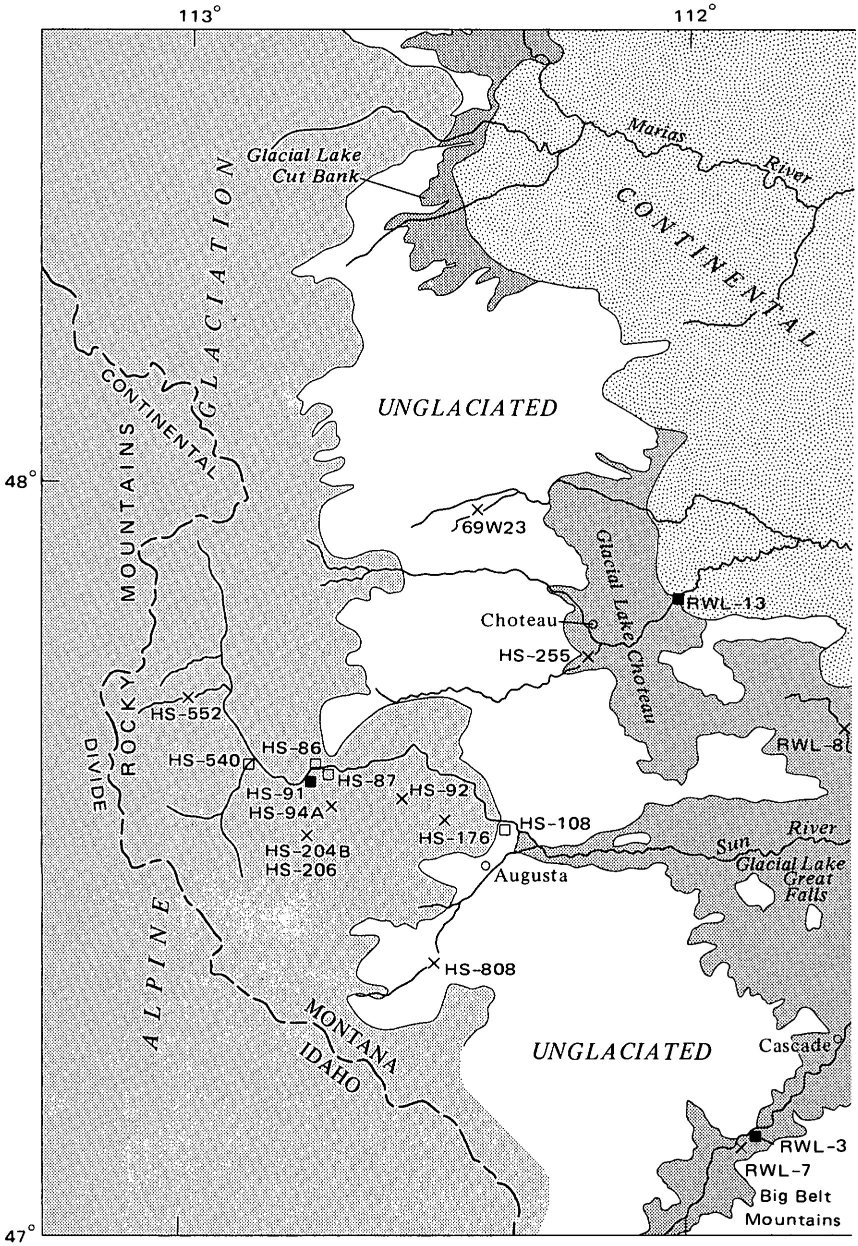
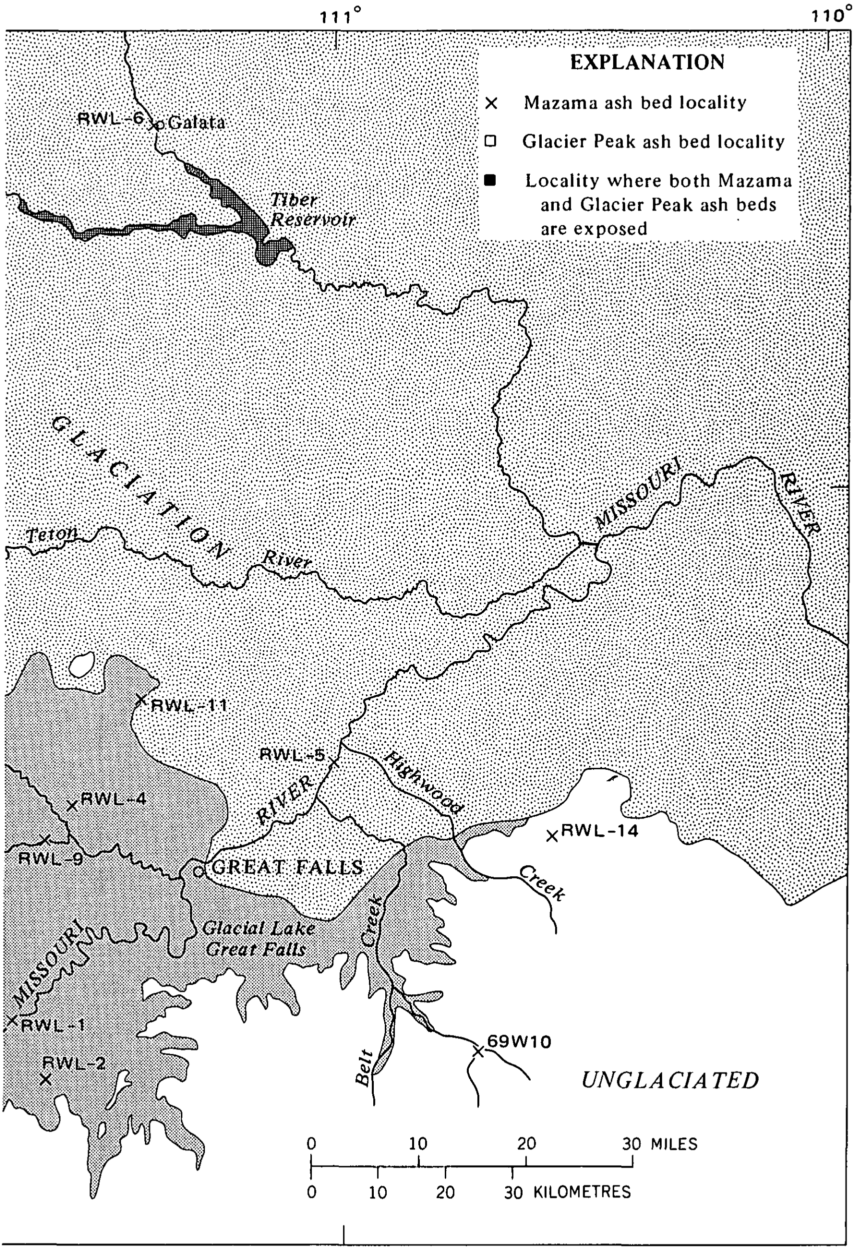


FIGURE 2. — Glacier Peak and Mazama ash-bed localities and major elements Lindvall

Ice of continental Pinedale Glaciation is estimated to have advanced into the region more than 20,000 years ago and to have persisted until



of glaciation in west-central Montana, as modified from Colton, Lemke, and (1961).

about 12,500 years ago (end of the middle stade). Glacial Lake Great Falls, Lake Choteau, and Lake Cut Bank again were impounded during

SERIES	GLACIATION AND POST-GLACIATION SEQUENCE		YEARS B.P.	VOLCANIC ASH BEDS
Holocene	Post-Altithermal (Neoglaciation)			
			4,000	
Holocene	Altithermal		6,600	Mazama ash
			7,500	
Holocene	Pre-Altithermal			
			12,000	
Pleistocene	Pinedale Glaciation	Middle stade	12,500	Glacier Peak ash
Pleistocene	Pinedale Glaciation	Interstade		
Pleistocene	Pinedale Glaciation	Early stade		
Pleistocene	Interglaciation		>29,000 (C^{14} date)	
Pleistocene	Interglaciation		70,000 (K-Ar date)	
Pleistocene	Bull Lake Glaciation	Late stade		

FIGURE 3. — Glaciation and postglaciation sequence during late Pleistocene and Holocene time in west-central Montana. Taken in part from Richmond (1972). Chart not to scale below part showing Pinedale Glaciation.

Pinedale time, south and west of the ice front. In one locality (RWL–13), the Glacier Peak ash bed is intercalated with deposits of the upper part of Glacial Lake Choteau of Pinedale age.

The Rocky Mountains in west-central Montana were glaciated several times during the Wisconsin. Extensive deposits of alpine till and outwash were laid down during Bull Lake time in the main mountain canyons and in places in the adjacent foothills at the mouths of the canyons. The Pinedale interval was marked locally by even more extensive glaciation in the mountains, which persisted until about the end of the middle stade. A mature zonal soil developed on the alpine Bull Lake deposits during the interglacial stage following the Bull Lake Glaciation, and a somewhat less mature soil was developed on the surface of the deposits of the alpine Pinedale Glaciation (Richmond, 1965). Gerald M. Richmond and R. W. Lemke are using these zonal soils in differentiating the continental drift of the Bull Lake Glaciation from the continental drift of the Pinedale Glaciation in current studies of the Plains area of north-central Montana. However, nowhere in the Plains area has Bull Lake soil been found buried beneath the younger Pinedale drift, as can be found in the alpine deposits. Also, no buried soil profile has been found in the study area south of the drift borders that separate lake deposits of continental Bull Lake Glaciation from those of continental Pinedale Glaciation. However, in exposures along the Sun River north of Augusta there is an alpine Bull Lake soil on outwash gravel overlain by alpine Pinedale Till.

As used by Richmond (1972) and followed in this paper, the Holocene is arbitrarily defined as beginning at the end of the last abrupt deterioration of Pinedale glaciers (end of the middle stade) in the mountains in the western part of the area and of glacial lake filling along the edge of the continental Pinedale ice. This deterioration of Pinedale glaciers occurred about 12,000 years ago and is approximately marked stratigraphically by the Glacier Peak ash bed.

Holocene deposits in the Plains area commonly consist of an intermixture of alluvial, colluvial, and eolian deposits that were laid down in the larger stream valleys and their tributaries. The alluvial deposits are mostly fine grained (clay, silt, and sand) and seem to represent, in large part, slack water deposits. In places they attain thicknesses of 50 feet (15 m) or more, but thicknesses of 10–20 feet (3–6 m) are more common. These deposits, particularly those in the secondary and tertiary tributaries, are now being actively incised headward by stream erosion.

A variety of Holocene deposits is present in most mountain valleys in the eastern part of the northern Rocky Mountains; the deposits include till, outwash gravel, stream alluvium, alluvial fan deposits, terrace alluvium, talus, landslide deposits, and rockfall and rockslide avalanche deposits (Mudge, 1967, 1972). In general, the materials are more coarse than alluvial and colluvial deposits in the Plains. Till and rockfall deposits are as much as 200 feet (60 m) thick; other deposits are commonly 20–50 feet (6–15 m) thick. Nearly all the deposits have been incised by stream erosion.

For purposes of discussion in this paper, the Holocene Epoch is divided into three time subdivisions: (1) pre-Altithermal interval, (2) Altithermal interval, and (3) post-Altithermal interval. Identification of deposits laid down during these three intervals is facilitated by use of the Mazama ash bed as a key marker.

The Altithermal interval began in west-central Montana approximately 7,500 years ago and ended about 4,000 years ago (Richmond, 1972). The beginning of the interval was marked by total disappearance of glaciers from the mountains in the area and by distinct soil formation in places on the Plains. As pointed out by Haynes (1968) and Richmond (1972), an episode of erosion beginning between 5,000 and 4,000 years ago is believed to be associated with climatic cooling that probably marked the end of the Altithermal and led to the onset of Neoglaciation about 4,000 years ago.

On the basis of the preceding discussion, the pre-Altithermal deposits of Holocene age in the region are those postglacial deposits that were laid down between about 12,000 and 7,500 years ago. Although glacier ice had largely or completely disappeared from the mountains in west-central Montana during this interval, it still existed in places in Alberta as the late stade of the Pinedale. The alluvial sequence representing the pre-Altithermal deposits commonly consists of a clayey silt to a silty clay with lesser amounts of sand. Coarser grained clasts, including gravel, cobbles, and boulders, commonly constitute many of the deposits in areas of high relief, such as in the Rocky Mountains and the Belt Mountains, as well as along parts of some main stream channels. The finer grained alluvial deposits generally can be distinguished from the overlying Altithermal deposits by being somewhat more compact, by having a fairly blocky texture, and by commonly being partially iron stained or containing white blebs of calcium carbonate. Indistinct soil profiles are discontinuously present, and snails, clams, and other fossils are present locally. At locality RWL–1, clams from near the top of the interval were dated (W–594) at 8,800±300 years.

In the Plains area the alluvial deposits of the Altithermal interval commonly consist of silty clay to clayey silt with lesser amounts of sand. The alluvium is generally somewhat less compact than the pre-Altithermal deposits, contains little or no iron staining and no white blebs of calcium carbonate, and commonly has a less blocky texture. A fairly conspicuous fossil soil is present in places at the base of the interval. At locality RWL–1, snails in the lower part of this soil were dated (W–902) at 7,460±250 years. That the fossil soil is of Altithermal age is supported by the studies of Richmond (1965), who found that, throughout western Montana, Oregon, and Washington, the Mazama ash bed occurs in or on soil of Altithermal age. The Mazama ash, where present, directly overlies the lowermost Altithermal soil and forms a clearly distinguishable marker horizon. Above the ash bed, other less distinct soil profiles are present locally. Freshwater snail shells are sparse to locally abundant throughout the interval, but freshwater clam shells have not been found.

In and near the mountains, terrace alluvium, alluvial fan deposits, and lacustrine deposits were laid down during the Altithermal interval. The terrace alluvium at localities HS-92, -255, -552, and -808 (table 4) consists of silt and clayey silt with some sand and gravel. The alluvial fan deposits at locality HS–94a consist of poorly sorted gravel with some silt. The lacustrine deposits at localities HS–176, –204, and –206 consist mostly of silty clay. In many of the deposits, disseminated calcium carbonate is in beds above and below the Mazama ash bed. Snails from lake beds below the Mazama ash bed at locality HS–176 yielded a carbon-14 age of 7,870±200 years, and snails above the ash were dated at 4,740±250 years. Peat within the Mazama ash at locality 204B–206 was dated by carbon-14 methods at 7,280±400 years (Mudge, 1967). In and near the mountains, a fossil soil is present beneath the Mazama ash bed only at localities HS–91 and 69W23. No evidence of a poorly developed soil was recognized above the ash bed in the exposures in the mountains.

In the Plains area it is not yet possible to distinguish, with confidence, the post-Altithermal deposits from the Altithermal deposits. It appears, however, that the post-Altithermal deposits may be thin (probably less than 5 feet (1.5 m) in most places) and, in the fine-grained alluvial sequence, may be represented in large part by the modern soil profile. More studies of fossils, pollen, and radiocarbon dating may help to differentiate these deposits.

In the mountainous area there were two periods of glaciation that resulted in deposits of till in the upper reaches of some valleys and deposits of glacial outwash and terrace deposits in the lower reaches. These deposits are dated mostly by their stratigraphic relationships to the periods of glaciation. Locally, peat deposits in alluvial fans have been dated by carbon-14 methods (Mudge, 1967, 1972). Other types of deposits shown by Mudge (1967, 1972) have been dated only by inference or relationship to older deposits. Most deposits are less than 50 feet (15 m) thick.

IDENTIFICATION OF THE ASH BEDS

In early work in Washington State, no petrochemical distinction was made between Glacier Peak and Mazama ash beds, and many occurrences of ash now known to be of Mazama origin were erroneously assigned to a Glacier Peak source (Rigg and Gould, 1957). A striking characteristic of the Glacier Peak ash in a zone, located 50–100 miles (80–160 km) from the source, is its resemblance to tapioca in color, size, and roundness of the particles. The shards are vesicular but not finely pumiceous, as are those of the powdery Mazama ash, and they are crowded with microphenocrysts and microlites. These distinctions persist downwind to the east and into the area described in this paper, where the tapiocalike aspect of the Glacier Peak shards can be seen in washed material with the aid of the stereomicroscope. Phenocrysts are relatively abundant in the Glacier Peak ash as compared with the Mazama ash and include intermediate plagioclase, green-olive hornblende, orthopyroxene, and opaque oxide. In the Mazama ash, phenocrysts are present only in moderate amounts and include the same species as the Glacier Peak plus scattered clinopyroxene and apatite. Specific properties of the individual constituents are listed in table 1.

TABLE 1. — *Physical properties and shard habits of three upper Quaternary ash beds of Northwestern United States*

	Mazama	Glacier Peak	Mount St. Helens "J"[1]
Glass shards:			
Habit	Mainly finely pumiceous stretched "silky" shards.	Predominantly vesicular "tapioca" granules.	Some vesicular granules, some stretched pumice.
Dominant refractive index.	1.499–1.511 (bimodal).	1.499-1.502	(a) 1.501–1.503 (b) 1.503–1.507
Phenocrysts:			
Plagioclase n_x	1.545–1.553	1.545–1.555	(b) 1.548–1.557
Hornblende n_x	1.658–1.665	1.645–1.653	(b) 1.646–1.655
Orthopyroxene n_x	1.688–1.692	1.689–1.695	(b) 1.693–1.697
Clinopyroxene n_x	[2]1.686–1.689	None	None.
Opaque oxides	Abundant	Abundant	Abundant.
Apatite	Sparse	None	None.

[1] Properties for Mount St. Helens "J" based on examination of only four samples of near-source lump pumice: (a) three samples, (b) one sample.
[2] Only sparsely present.

The Glacier Peak ash is distinguishable from the Mazama ash not only by the habit of the glass shards, but also by the range of the refractive indices of the glass and by the refractive indices of the hornblende phenocrysts (Powers and Wilcox, 1964). There is, however, another ash bed that might possibly be present in the region that closely resembles the Glacier Peak ash. This is the equivalent of the "J" pumice, erupted from Mount St. Helens volcano, Washington, sometime between 12,000 and 8,000 years ago, according to Mullineaux, Hyde, and Rubin (1972). Preliminary work on samples of this pumice from near the volcano shows that the "J" ash downwind should be expected to contain the same phenocryst suite as that of the Glacier Peak ash, and that even the refractive indices of the individual constituents should be very similar.

Chemical compositions of the individual constituents, both glass and phenocrysts, serve to distinguish the Glacier Peak ash from the Mazama, and on the basis of preliminary work, apparently also from the Mount St. Helens "J" ash. Major-element analyses by standard chemical methods (Peck, 1964) have been published for glass of the Mazama ash and the Glacier Peak ash (Powers and Wilcox, 1964). In the case of the Glacier Peak ash, however, results by these methods are significantly affected by the presence in the shards of abundant microphenocrysts and microlites, which are not removable by the usual separation procedures. The results by use of the electron microprobe are believed to provide values closer to the true amounts, because the microphenocrysts can be avoided. The probe results have a further advantage in that they reveal differences in glass composition from shard to shard, a characteristic more marked in the Mazama glass than in the Glacier Peak glass.

Electron microprobe analyses of the glass of these three ashes are given in table 2, which shows that the Glacier Peak glass is higher in Si and K and lower in Al, Ti, Fe, Mg, Ca, and Na than the Mazama glass. Fewer elements distinguish the Glacier Peak glass from the Mount St. Helens "J" glass, but comparison with the two available analyses of "J" (John A. Westgate, written commun., 1972) suggests that the distinction may be possible on the basis of the higher K and lower Fe, Mg, and Na in the Glacier Peak glass. Obviously, more samples of known "J" material must be analyzed.

GLACIER PEAK ASH BED

The Glacier Peak ash bed is the fallout from a major eruption of Glacier Peak volcano in the northern Cascade Range, about 50 miles (80 km) east of Everett, Wash. (fig. 1). Buried remnants of this ash fall have been found over a broad fan-shaped area extending eastward some 500 miles (800 km) from the volcano (Powers and Wilcox, 1964; Fryxell, 1965; Westgate, 1968); the suggestion has been made (Wilcox, 1969; Westgate and others, 1970) that the eruption consisted of two pulses, but that the pulses were not separated by any geologically significant interval of time.

The age of mollusk shells in the Glacier Peak ash bed at Lower Grand Coulee (about 95 miles (153 km) east-southeast of Glacier Peak), Wash., was reported by Fryxell (1965; see also Chatters, 1968, p. 494) as 12,000±310 years and that of snails in the Glacier Peak ash bed at Diversion Lake, Sun River, Mont. (loc. HS-87 of this report), was reported by Ives, Levin, Oman, and Rubin (1967, p. 517) as 12,750±350 years (Mudge, 1967). The difference between these two results is not considered important for the present purpose, and an arbitrary value of 12,500 years will be used in this report.

TABLE 2. — *Electron microprobe analyses of glass of upper Quaternary ashes (recast to total 100 percent)*

Glass	Mazama		Glacier Peak			Mount St. Helens "J"	
Area	Source	Montana	Source	Montana		Source	
Spec. No.	60-7-29R	HS-92	68W48	HS-87	68W20	3-22-71-13	8-22-71-15
SiO_2	73.0	72.7	77.1	76.6	77.1	75.9	75.3
Al_2O_3	15.7	15.6	13.7	13.2	12.9	13.7	14.0
TiO_2	.38	.38	.17	.18	.20	.19	.21
Fe as FeO	1.85	1.87	.95	.99	1.03	1.30	1.44
MgO	.46	.45	.29	.22	.22	.34	.39
CaO	1.91	1.67	1.15	1.26	1.35	1.33	1.47
Na_2O	4.17	4.60	3.21	3.94	3.50	4.79	4.97
K_2O	2.79	2.77	3.40	3.62	3.72	2.37	2.31
Total	100	100	100	100	100	100	100
Other (mostly H_2O)	3.4	3.2	5.4	5.1	5.3	No data	No data

DESCRIPTION OF SAMPLES

60-7-29R.	Mazama airfall pumice lump, SW¼ sec. 5, T. 28 S., R. 8 E., about 20 miles (32 km) NE. of Crater Lake, Klamath County, Oreg.
HS-92.	Mazama ash, NE¼SW¼ sec. 12, T. 21 N., R. 8 W., Barr Creek quad., Lewis and Clark County, Mont.
68W48.	Glacier Peak airfall pumice lump, Trinity (abandoned), about 12 miles (19.3 km) E. of Glacier Peak volcano, Holden quad., Chelan County, Wash.
HS-87.	Glacier Peak ash, NW¼SW¼ sec. 36, T. 22 N., R. 9 W. (unsurveyed), Sawtooth Ridge quad., Lewis and Clark County, Mont. (Age 12,750±250 C-14 years (Mudge, 1967).
68W20.	Glacier Peak ash, NE¼SW¼ sec. 8, T. 24 N., R. 3 W., New Rockport Colony, Teton County, Mont.
8-22-71-13.	Mount St. Helens "J" airfall pumice lump, upper part of a 3-foot (0.9-m) bed. Center sec. 25, T. 9 N., R. 5 E., Mount St. Helens quad., Skamania County, Wash. Analyzed by John A. Westgate.
8-22-71-15.	Mount St. Helens "J" airfall pumice lump, lower part of the 3-foot (0.9-m) bed. Same locality as -13. Analyzed by John A. Westgate.

GEOLOGIC SETTING

Known exposures of Glacier Peak ash in west-central Montana, although widespread (table 3), are not nearly so common as exposures of Mazama ash. Only three exposures of Glacier Peak ash (HS-108, RWL-3, and RWL-13) have been found on the Plains in the area shown in figure 2. The easternmost exposures, localities RWL-3 and RWL-13, are at approximate longitude 112°, or about 65 miles (104 km) farther west than the easternmost known exposure of Mazama ash in west-central Montana. Locality RWL-3 is along the Missouri River on the north flank of the Big Belt Mountains. Locality RWL-13 is in the Plains area along the south wall of the Teton River valley. The western exposures shown in figure 2 are along the Sun River, both within the mountains and on the Plains to the east. The two outcrops where the stratigraphy is best exposed are at localities HS-91 and HS-87.

TABLE 3. — *Glacier Peak ash-bed localities and descriptions*

Locality No.	Specimen No.	Location	Thickness of ash (ft)	Thickness of ash (cm)	Type of deposit in which ash is present	Underlying material	Overlying material	Depth of ash below surface (ft)	Depth of ash below surface (m)	Remarks
RWL-3	69W15	SW¼NW¼ sec. 21, T. 16 N., R. 2 W., 5 miles (8 km) NW. of Craig, Cascade County.	0–0.1	0–3.0	Alluvial gravel fan along Missouri River.	Gravel	Gravel	30–40	9–12	Mazama ash (68W126 and 69W16) also present in gravel about 30 feet (9 m) stratigraphically above this ash.
RWL-13	69W21	NW¼SE¼ sec. 8, T. 24 N., R. 3 W., New Rockport (Hutterite) site, Teton County.	0– .05	0–1.5	Lacustrine deposits of Glacial Lake Great Falls.	Lacustrine clay.	Lacustrine clay.	11.0	3.4	Mazama ash (69W20) also present 5.5 feet (1.7 m) above this ash. Stratigraphic section described in text.
HS-86	68W136	SE¼NW¼, sec. 3, T. 21 N., R. 9 W., Teton County.	0– .2	0–6.1	Alluvial fan, silt	Fine-grained sand.	Silt	4.0	1.2	North side of Sun River canyon.
HS-87	68W21 and 68W137.	NE¼SE¼ sec. 35, T. 22 N., R. 9 W., Lewis and Clark County.	0– .2	0–6.1	do	Gravel	Gravel	9.4	2.9	Stratigraphic section described in text.
HS-108	68W141	SE¼NW¼ sec. 27, T. 21 N., R. 6 W., Lewis and Clark County.	.2	6.1	Colluvium, silt	Silt	Silt	2.0	.6	
HS-540	68W147	SE¼SW¼ sec. 27, T. 21 N., R. 10 W., Lewis and Clark County.	.2	6.1	do	Silty clay	do	3.0	.9	
HS-91	69W19	SW¼NW¼ sec. 3, T. 21 N., R. 9 W., Lewis and Clark County.	.2	6.1	do	Gravel	do	7.5	2.3	Ash bed is 3.7 feet (1.1 m) below Mazama ash (HS-91). Stratigraphic section described in text.

DESCRIPTIONS OF SELECTED LOCALITIES

Three Glacier Peak ash-bed localities will be described in detail to show their stratigraphic relations and to show how the ash bed can be used as a marker bed. These are localities RWL–13, HS–91, and HS–87.

LOCALITY RWL-13

New Rockport (Hutterite) site in the NW¼SE¼ sec. 8, T. 24 N., R. 3 W., Teton County

[Measured and sampled at north end of conspicuous landslide scarp by R. W. Lemke, M. R. Mudge, and Ray E. Wilcox, 1969]

Unit No.		*Thickness (feet)*	*Thickness (cm)*
15.	Windblown(?) deposits. Clay, silty, medium-dark-gray; massive; no apparent bedding except at south end of scarp, which contains foreset beds that have a NE. apparent dip. No pebbles	5.1	155
14.	Mazama ash (specimen No. 69W20), light-gray, silty; fairly distinct lens of impure ash that thickens and thins laterally. Rodent burrows	0.2–0.5	6–15
13.	Windblown(?) deposits. Clay, silty. Same as unit 15	2.3	70
12.	Glacial lake beds, continental Pinedale. Clay, silty. Laminae 0.05–0.1 ft (about 1 cm) thick, alternating light gray with dark gray; distinctly laminated	2.5	76
11.	Glacial lake beds, continental Pinedale. Clay, medium-gray; prismatic structure; dark-brown iron stains on fracture surfaces	.7	21
10.	Glacier Peak ash (specimen No. 69W21), white, pure, silt-size, in a distinct lens	0.05	1.5
9.	Glacial lake beds, continental Pinedale. Clay. Same as unit 11	.8	24
8.	Sand, medium-fine to silt-size, clean, light-gray; distinct bed	0.15–.4	4.6–12.2
Unconformity.			
7.	Glacial lake beds, continental Pinedale(?). Clay, light-gray; upper 1.0 ft (30 cm) iron stained along exposed faces; unit grades down into hard gray laminae with some partings 0.05–0.15 ft (about 1–3 cm) thick; little oxidation along less well developed prismatic surfaces; sand lenses as much as 8 in. (20 cm) thick and 1.0 ft (30 cm) long extend diagonally up to the unconformity	7.1	216
6.	Sand, silty, medium-grained; thickens and thins laterally; partly crossbedded in lower part; a few pebbles 1 in. (2.5 cm) long at base, some of which consist of quartzite	0.4–0.6	12–18
Unconformity.			
5.	Glacial lake beds, continental Bull Lake(?). Clay, megalaminae of light-gray clayey silt as much as 1.0 ft (30 cm) thick alternating with dark-gray silty clay laminae 0.1–0.3 ft (2-8 cm) thick that have sublaminae of light-gray clayey silt. Periglacial(?) convolutions in upper 0.5–1.0 ft (15–30 cm); two or three mauve-colored laminae of clayey silt, 0.02 ft (about 1 cm) thick, in upper 1.0 ft (30 cm)	8.2	250

Unit No.		Thickness (feet)	Thickness (cm)
	(Section description continued at large slide block west of scarp. Bed correlation established.)		
4.	Till, continental Bull Lake(?). Mostly silty clay, light-gray, oxidized; contains subrounded pebbles that are mainly quartzite, 1½–3 in. (4–8 cm) across	2.3	70
3.	Silt, clayey, light-gray, compact	1.9+	58+
	(Section continued at another slide block farther to the west. Bed correlation established between exposures.)		
2.	Reworked shale fragments, dark-gray; fissile, with some pebbles	1.0	30
1.	Till, continental Bull Lake(?); clayey, bluish gray, with a few pebbles, grading down into yellowish-brown water-reworked till (indistinct banding)	2.3	70
	Approximate total thickness	35.8+	1,091+

Locality RWL–13 is important, because the two well-exposed ash beds provide key markers in helping to unravel the rather complex Pleistocene stratigraphy of the area. The site lies about 1 mile (1.6 km) northeast of the drift border of the continental Pinedale Glaciation. Lacustrine deposits of Glacial Lake Choteau of that glaciation constitute the uppermost glacial deposits at the site. The observation of the Glacier Peak ash near the top of these lacustrine deposits establishes for the first time a close date for the end of the continental Pinedale Glaciation in the region. Likewise, it allows the inference to be made that the lowermost exposed lacustrine deposits are of Bull Lake age and that the till exposed in the basal part of the section (units 1 through 4) also can be assigned to the continental Bull Lake Glaciation. Some or all of this till may have been water reworked or ice rafted and, therefore, may not have lateral continuity. Certainly unit 2, consisting of shale fragments, has been reworked by glacial melt-water streams from nearby outcrops of Cretaceous shale. However, outcrops along the Teton River, about a quarter of a mile (400 m) downstream, expose 35–40 feet (10–12 m) of hard, compact till believed to belong to the continental Bull Lake Glaciation.

If, as seems likely, the glacial lake beds of unit 5 belong to the continental Bull Lake Glaciation, the question then arises as to whether the unconformity at the top of this unit or the unconformity at the top of unit 7 marks the end of deposition of the Bull Lake lake beds. Inasmuch as it is believed that there was more than one interval of alpine Pinedale Glaciation in the region, it seems reasonable to assign the upper unconformity to one of the time breaks in the Pinedale.

Lake beds in units 8 through 12 are assigned to the continental Pinedale Glaciation. The fact that only about 3 feet (90 cm) of lake beds overlies the Glacier Peak ash, dated at approximately 12,500 years, indicates that the ice-marginal lakes of the region were in existence only a short time (perhaps tens of years or at most a few hundred years) after that date. Also, by 12,500 years ago major recession of the continental Pinedale ice was well underway in the region. However, continental ice still was in existence 12,000 years ago in southeastern Alberta, where Glacier Peak ash has been found on ablation deposits of the ice sheet (Westgate, 1972).

The presence of the relatively thick and very homogeneous silt deposits (units 13 and 15) that overlie the lacustrine deposits and that appear to be eolian in origin is puzzling. The occurrence of the dated Mazama ash in the lower third of this silt sequence suggests uniform climatic conditions of deposition during at least the last 6,600 years, and if there is no time break between the silt deposits and lake beds (between units 12 and 13), then uniform climatic and depositional conditions prevailed during approximately the last 12,000 years. This does not appear to accord with the environmental conditions indicated from other described localities in the area.

LOCALITY HS-91

Borrow pit on the south side of the Sun River in the SW¼NW¼ sec. 3, T. 21 N., R. 9 W., Lewis and Clark County

[Measured by M. R. Mudge and R. W. Lemke, 1969. Color designations are from "Rock-Color Chart" (Goddard and others, 1948)]

Unit No.		*Thickness (feet)*	*Thickness (cm)*
6.	Talus and colluvium topped with a 4-in. (10-cm) humic-rich soil; pebble- to cobble-size angular fragments of carbonate and chert with a light-grayish-brown silt matrix	2.2	67
5.	Colluvium, with Mazama ash matrix (specimen no. 69W18). Angular fragments of carbonate and chert. Light-gray ash constitutes about one-third of unit	2.0±	60±
4.	Colluvium, angular fragments of carbonate and chert, unsorted; finer grained than above units	1.6	49
	Unconformity.		
3.	Clay, silty (B horizon of paleosol), moderate-reddish-brown (5*YR* 4/4), granular; few angular pebbles; lower half contains disseminated $CaCO_3$ blebs	.7	21
2.	Silt (C? horizon of paleosol), calcareous; with disseminated $CaCO_3$. Pale yellowish brown; sparse pods of Glacier Peak ash 1 in. (2.5 cm) thick and 2 in. (5 cm) long, mainly silt size (speciman no. 69W19), occur near middle of unit. Angular to subrounded pebbles near base; some blocks 10 in. (25 cm) across	2.0	61

Unit No.		Thickness (feet)	Thickness (cm)
1.	Gravel (alpine Pinedale outwash), poorly bedded; fragments less than 4 in. (10 cm) across; rounded to subrounded carbonate rocks and Precambrian sandstone	3.0	91
	Covered by talus.		
	Total amount exposed	11.5±	350±

NOTE: At west end of exposure, units 1, 2, and 3 are overlain unconformably by unit 4.

The Glacier Peak ash at locality HS–91 was deposited on alluvium, and its occurrence is very similar to that of locality HS–87, about 2 miles (3.2 km) downstream. The ash occurs as small pods in a bed of silt, about 1 foot (0.3 m) above outwash gravel of the alpine Pinedale Glaciation. Here and at locality HS–87 the silt bed beneath the ash and above the outwash gravels represents alluvium deposited by the Sun River after the Pinedale alpine glacier had completely retreated to the cirque areas. The thickness of the silt bed indicates a very short period of deposition prior to the Glacier Peak ash fall. Thus, these data further substantiate the dating of the end of a major deterioration of Pinedale glaciers (about 12,000 years ago), as cited by Richmond (1972) and Lemke, Laird, Tipton, and Lindvall (1965). At this locality, the Altithermal soil was developed on the overlying silty clay (unit 3), and part of the B horizon is preserved. The overlying colluvial deposit (unit 4) lies unconformably on the fossil soil in the center of the exposure, but at the west end of the exposure it overlies units 1, 2, and 3 on an angular unconformity. The talus and colluvial deposit in the upper part of the exposure contains the Mazama ash.

LOCALITY HS–87

South shore of Diversion Lake, 100 yards (91 m) west of Madison Limestone exposure in NE¼SE¼ sec. 35, T. 22 N., R. 9 W.

[Measured by M. R. Mudge, 1959. Fossils identified by D. W. Taylor (written commun., 1959). Color designations are from "Rock-Color Chart" (Goddard and others, 1948)]

Unit No.		Thickness (feet)	Thickness (cm)
	Alluvial fan:		
11.	Soil, grass-root zone, silt with clay, noncalcareous; dusky yellow brown (10*YR* 2/2); massive, with many fragments of chert, limestone, and shale; many burrows, one filled with the following land snails: (USGS Cenozoic loc. 21825) *Pupilla* and *Vallonia cyclophorella* Sterki	1.6	49
10.	Silt, sandy (oxidized zone), calcareous; moderate brown (5*YR* 4/4); composition same as above	.8	24

Unit No.		Thickness (feet)	Thickness (cm)
	Alluvial fan — Continued		
9.	Silt, sandy (caliche zone), very calcareous, with disseminated carbonate; many rock fragments of shale, limestone, and chert; pale yellowish brown (10*YR* 6/2); massive	2.6	79
8.	Silt, calcareous, with small nodules and stringers of disseminated carbonate; contains smaller rock fragments than above; pale yellowish brown, darker than above; massive. Land snails (USGS Cenozoic loc. 21824) *Pupilla, Vallonia gracilicosta* Reinhardt, and *Oreohelix*	2.4	73
7.	Gravel, mostly shale and limestone fragments, up to pebble size; calcareous; same color as above; silty matrix	.7	21
6.	Silt, calcareous, with stringers of shaly gravel; moderate yellow brown (10*YR* 5/4); massive. Insect burrows. Land snails (USGS Cenozoic loc. 21823) *Pupilla muscorum* (Linnaeus), *Vallonia gracilicosta* Reinhardt, cf. *Succinea, Euconulus fulvus* (Müller), and *Oreohelix*	.8	24
5.	Gravel, mainly small limestone and shale fragments, less than pebble size; moderate yellow-brown; oriented	.1–.5	3–15
4.	Silt, with thin 0.1- to 0.3-ft (3- to 8-cm) lenses of Glacier Peak ash (specimen nos. 68W21 and 68W137) mainly silt size, calcareous, lighter than moderate yellow brown (10*YR* 5/4). Land snails (USGS Cenozoic loc. 21822) *Pupilla muscorum* (Linnaeus), *Vallonia gracilicosta* Reinhardt, and cf. *Succinea.* Carbon-14 age, 12,750±350 years (specimen no. W-1644)	.7	21
3.	Gravel, limestone and shale fragments up to pebble size, flattened and subangular; oriented; calcareous; moderate yellow brown	.7	21
	Unconformity.		
	Terrace deposits (alpine Pinedale outwash):		
2.	Silt, grading down into very fine grained sand; calcareous; same color as unit 4 except slightly darker in sandy part. Land snails (USGS Cenozoic loc. 21821) *Pupilla muscorum* (Linnaeus), *Vallonia cyclophorella* Sterki, and cf. *Succinea*	.6	18
1.	Gravel, mostly angular to subangular fragments of limestone and shale with some pebbles of erratics, poorly oriented, some angular cobble-size limestone and sandstone; calcareous; moderate yellow brown	4.0±	122±
	Waterline of Diversion Lake.		
	Total section exposed	15.0–15.4±	457–469±

The Glacier Peak ash bed at locality HS–87 is within an alluvial fan deposit that was formed by an unnamed stream which is a southern tributary to the Sun River. The ash-bearing silt bed contains small snail shells that were dated by Carbon-14 methods at 12,750±350 years B.P. (Mudge, 1967; Ives and others, 1967). The silt bed overlies a thin gravel bed of limestone and shale fragments (unit 3), derived locally from the north-flowing unnamed tributary of the Sun River. The gravelly bed represents the first development of the alluvial fan on the alpine Pinedale terrace deposits; therefore, an unconformity exists at the base of the bed. The silt bed (unit 2) beneath the gravel was very likely deposited after the Pinedale glacier had melted back upvalley, and probably correlates with the lower part of unit 2 of locality HS–91. The underlying coarse outwash gravel was deposited during the retreat of this glacier, and is present in almost all exposures of known Glacier Peak ash within and near the mountains.

An Altithermal soil above the ash is not recognized at this locality. If it formed on the fan, it was subsequently eroded, possibly prior to the deposition of gravel unit 5 or 7.

MAZAMA ASH BED

The Mazama ash bed is the fallout from the cataclysmic eruption that resulted in the formation of the Crater Lake collapse caldera, located in the Cascade Range some 50 miles (80 km) north-northwest of Klamath Falls, Oreg. (Powers and Wilcox, 1964). Like many eruptions of this type, it consisted of an initial stage of repeated explosive eruptions (from which came the major part of the Mazama ash fall), then a culminating eruptive stage in which the predominant action was the effusion of copious vesiculating and fragmenting magma that flowed down the flanks and valleys, terminating with the caldera collapse. The ash bed called Mazama, therefore, actually consists of several ash falls spaced at intervals of weeks to perhaps hundreds of years, carried by winds into different quadrants from Crater Lake but generally in the eastern 180° semicircle. The occurrences of Mazama ash described in the present report are some 500–600 miles (800–965 km) from the source. They are part of a major ash-fall lobe which extends northeast from Crater Lake into Alberta and Saskatchewan (fig. 1).

In view of the complex and possibly prolonged nature of the Mazama eruption, the downwind ash identified as Mazama may be of slightly different ages in different areas, and this may account for part of the range in the ages that has been inferred from radiometric determinations on carbonaceous materials in deposits associated with the ash. Among the occurrences of Mazama ash in the area of this report, age determinations have been made on deposits above and below the ash at locality HS–176 (see table 4 and description of stratigraphic section), but these deposits only serve to bracket the age of the ash at sometime between 7,850±200 and 4,740±250 years. Many determinations have been made on peat associated with the Mazama ash in Oregon, Washington, and British Columbia; age limits for the peat range between 7,000 and 6,000 years. Several workers have determined the age of charcoal lumps in the ash that flowed west from Crater Lake

TABLE 4. — *Mazama ash-bed localities and descriptions*

Locality No.	Specimen No.	Location	Thickness of ash (feet)	Thickness of ash (cm)	Type of deposit in which ash is present.	Underlying material	Overlying material	Depth of ash below surface (feet)	Depth of ash below surface (m)	Remarks
RWL-1	68W124 and 69W11.	NE¼ sec. 24, T. 18 N., R. 1 W., 2½ miles (4 km) NE. of Cascade, Cascade County.	0–1	0–30	River alluvium	Fossil soil	Fossil soil	4.1	1.2	Stratigraphic section described in text.
RWL-2	68W125	C. sec. 10, T. 17 N., R. 1 E., 5 miles (8 km) E. of Cascade, Cascade County.	1.7	52	Alluvial terrace	Silt, sand	Silt	3.3	1.0	In terrace about 15 ft (4.5 m) above flood plain of Bird Creek.
RWL-3	68W126 and 68W16.	SE¼NW¼ sec. 21, T. 16 N., R. 2 W., 5 miles (8 km) NE. of Craig, Cascade County.	0–0.8	0–24	Alluvial gravel fan along Missouri River.	Gravel	Gravel	10–15	3–4.6	Probable Glacier Peak ash (69W15) present about 30 ft (9 m) stratigraphically below Mazama ash.
RWL-4[1]	68W127	NE¼SE¼ sec. 12, T. 21 N., R. 1 E., 2 miles (3.2 km) N. of Vaughn, Cascade County.	.2	6	Alluvial terrace	Silt	Silt	18	5.5	28 ft (8.5 m) of deposits exposed in creek channel.
RWL-5	68W128	SE¼NW¼ sec. 19, T. 22 N., R. 6 E., 5 miles (8 km) E. of Portage, Cascade County.	.3	9	Colluvium	Clayey silt	Clayey silt	15	4.6	30 ft (9 m) of colluvium (partly windblown) exposed in stream channel on E. side of Missouri River.
RWL-6	68W129, 69W24, 69W25	NW¼ sec. 4, T. 31 N., R. 3 E., 0.6 mile (1 km) W. of Galata, Toole County.	1–2.5	30–76	Alluvial channel fill	Silty clay	Fine sand	0–9	0–2.7	Stratigraphic section given in text.

RWL-7	69W130	NW¼NW¼ sec. 29, T. 16 N., R. 2 W., 4½ miles (7.2 km) NE. of Craig, Lewis and Clark County.	0–1	0–30	Alluvial gravel fan along Missouri River.	Gravel	Gravel	10	3.0	40 ft (12 m) of alluvial deposits exposed similar to those at locality RWL–3.
RWL-8[1]	68W131	SE¼NW¼ sec. 14, T. 22 N., R. 1 W., 10 miles (16 km) NW. of Vaughn, Teton County.	.5	15	Stream alluvium	Mixed gravel and clay.	Silty clay	4	1.2	12 ft (3.6 m) of alluvial deposits exposed along Spring Coulee.
RWL-9[1]	68W132	SW¼NE¼ sec. 27, T. 21 N., R. 1 E., 2 miles (3.2 km) SW. of Vaughn, Cascade County.	.4	12	Deltaic deposits related to Glacial Lake Great Falls.	Fossil soil	Silty clay to silty sand.	7.5	2.3	28 ft (8.5 m) of deposits exposed; basal 7 ft (2 m) is Glacial Lake Great Falls deposits.
RWL-11	68W134	NE¼NE¼ sec. 30, T. 23 N., R. 3 E., 16 miles (25.6 km) NW. of Great Falls, Choteau County.	.1	3	Alluvium	do	Modern soil	1.2	0.4	Ash mixed with silt.
RWL-13	69W20	NW¼SE¼ sec. 8, T. 24 N., R. 3 W., New Rockport (Hutterite) site, Teton County.	0.2–0.5	6–15	Eolian-colluvium deposits.	Silty clay	Silty clay	5.1	1.5	Stratigraphic section described in text.
RWL-14	69W105	SE¼ sec. 17, T. 21 N., R. 9 E., 4 miles (6.4 km) S. of Shonkin, Choteau County.	.1	3	Stream terrace	Clayey silt (fossil soil?).	Fine gravel	1.5	0.5	A little ash mixed with silt. Easternmost Mazama ash described in paper.
HS-91	68W138 and 68W18.	SW¼NW¼ sec. 3, T. 21 N., R. 9 W[2] Lewis and Clark County.	.3	9	Colluvium, silt	Silt and gravel.	Silt	1.0	0.3	Stratigraphic section described in text.
HS-92	68W139	NW¼SW¼ sec. 12, T 21 N., R. 8 W., Lewis and Clark County.	0–0.3	0–9	Alluvium, silt	Gravely silt	Silt with lenses of gravel.	5.0	1.5	31 feet (9.4 m) of section exposed in streambank. Section is upstream from locality HS–176.
HS-94a	68W140	SW¼SW¼ sec. 13, T. 21 N., R. 9 W.[2] Lewis and Clark County.	.2	6	Alluvial fan, silt	do	Gravelly silt	3.0	0.9	About 10 feet (3 m) of section exposed in streambank.

See footnotes at end of table.

TABLE 4. — *Mazama ash-bed localities and descriptions* — Continued

Locality No.	Specimen No.	Location	Thickness of ash (ft)	Thickness of ash (cm)	Type of deposit in which ash is present.	Underlying material	Overlying material	Depth of Ash below surface (ft)	Depth of Ash below surface (m)	Remarks
HS-176	68W143	SW¼NE¼ sec. 27, T. 21 N., R. 7 W., Lewis and Clark County.	0–0.8	0–24	Lacustrine deposit	Silty clay	Silty clay	.5	0.2	Lentil in lake bed. Stratigraphic section described in text.
HS-204B	68W144	C. sec. 3, T. 20 N., R. 9 W.[2], Lewis and Clark County.	3.5±	106±	Lacustrine deposit clay	Peat, clayey	None	Top		A lentil of peat separates this ash bed from ash of HS-206.
HS-206	68W145	C. sec. 3 T. 20 N., R. 9 W.[2] Lewis and Clark County.	1.5	46	do	Gravel	Peat, clayey	3.5	1.7	About 5 feet (1.5m) in old stream channel now covered by beaver pond.
HS-255	68W146 and 68W22.	NE¼NE¼ sec. 11, T. 23 N.,· R. 5 W., Teton County.	.4	12	Alluvium, clay	Silty clay	Silty clay	4	1.2	About 3 feet (90 cm) of section exposed in streambank.
HS-522	68W148	C. NE¼ sec. 34, T. 23 N., R. 11 W.[2], Lewis and Clark County.	.4	12	Alluvium, silt	Silt	Gravel	4	1.2	About 5 feet (1.5 m) of section exposed in streambank.
HS-808	68W149 and 69W17.	NE¼ sec. 32, T. 19 N., R. 7 W., Lewis and Clark County.	.2	6	do	Clayey silt	Clayey gravel	4	1.2	About 7 feet (2.1 m) of section exposed in roadcut.
	69W23	SE¼SE¼ sec. 20, T. 26 N., R. 6 W., Teton County.	0–0.3	0–9	Alluvium	Silty clay	Silty clay	3.4	1.0	About 8.5 feet (2.5 m) of section exposed in streambank.
	69W10	SW¼ sec. 32, T. 18 N., R. 8 E. Judith Basin County.	0–0.2	0–6	do	do	do	2.5	0.8	Do.

[1]Geologic descriptions based upon field notes taken by Edwin K. Maughan, U.S. Geological Survey (written commun., 1953-56).

[2]Unsurveyed. Data from U.S. Forest Service maps.

down Rogue River, Oreg., and oddly enough, these results, too, range in age from 7,010±120 to 6,453±250 years. In the present paper, a value of 6,600 years will be used arbitrarily for the age of the Mazama ash.

GEOLOGIC SETTING

As discussed previously, the Mazama ash is widespread in postglacial deposits in the earlier part of the Altithermal interval. It is found in alluvial, colluvial, lake, and bog deposits. In alluvial deposits it commonly is found from about 3 feet (90 cm) to as much as 18 feet (5.5 m) below the surface, whereas in colluvial or lakebed deposits it is generally less than 4 feet (1.2 m) below the surface. It commonly occurs in distinct but discontinuous beds ranging in thickness from less than 0.1 foot (3 cm) to 2.5 feet (76 cm), and in short lenses 1–2 feet (30–60 cm) long and as much as 1 foot (30 cm) thick. Contacts commonly are sharp to moderately sharp. Where pure, the ash is white to grayish white; where impure (mixed with silt) it commonly is tan. Size analyses were made of five ash samples (localities RWL–1, RWL–2, RWL–3, RWL–4, and RWL–5). Although the analyses were made on field samples and some of the grains represent the non-ash fraction, it is evident that most of the ash fragments are less than 300 mesh.

The Mazama ash was deposited near the beginning of the Altithermal interval, during a time when a prominent thick soil was being formed. The best section, containing fossil soil above and below the ash, is at locality RWL–1. Here a well-developed soil is present on the silty clay below the ash. Soil also directly overlies the ash bed. At locality HS–91, a fossil soil underlies the ash bed. At locality 69W23, lenses of Mazama ash overlie a possible fossil soil on a silty clay unit 1.5 feet (45 cm) thick. These few localities indicate that the position of the ash bed in reference to the Altithermal soil varies, depending on the environmental conditions at each locality.

DESCRIPTIONS OF SELECTED LOCALITIES

Three localities of the Mazama ash bed will be described in detail to show the stratigraphic relations between ash and enclosing sediments and to show how the ash bed can be used as a marker bed. These localities are RWL–1, RWL–6, and HS–176.

LOCALITY RWL–1

In undercut bank of the Missouri River, 2½ miles (4 km) northeast of Cascade, Mont., in SE¼NE¼ sec. 24, T. 18 N., R. 1 W.

[The section described here is based upon descriptions made in 1956 by R. W. Lemke, E. K. Maughan, and E. B. McKee, with additions by R.W. Lemke in 1957, 1958, and 1963. When examined again in 1969 by R. W. Lemke, M. R. Mudge, and Ray E. Wilcox, the bank had been further undercut and the basal part of the exposed section was somewhat different from that described herein]

Unit No.		Thickness (feet)	(cm)
11.	Soil, modern profile. Upper 0.5 ft (15 cm) is dark-gray silty clay; remainder is light-gray clayey silt with a porous texture (probably largely eolian), except that the basal part is slightly reddish brown. Contains snail shells, mostly broken fragments	4.0	122
10.	Soil, weak fossil profile. Silty clay, dark-gray, calcareous. Locally abundant freshwater snails identified by D. W. Taylor (written commun., 1963, USGS Cenozoic loc. 23362) as follows: *Lymnaea caperata* Say, *Promenetus umbilicatellus* (Cockerell), *Helisoma trivolvis* (Say)	1.0	30
9.	Mazama ash (ash Nos. 68W124 and 69W11), grayish-white. Size analysis: 6.1 percent held on No. 200 sieve, 3.7 percent held on No. 300 sieve, and 90.2 percent passing No. 300 sieve. Wedges out along eastern part of exposure. Sharp undulating lower contact. Upper contact less sharp; core of bison horn found at this contact. Noncalcareous in lower 0.4 ft (12 cm), where ash is pure; upper 0.6 ft (18 cm) is impure, with much silt, is calcareous, and contains freshwater snails, identified by D. W. Taylor (written commun., 1963, USGS Cenozoic loc. 23363) as follows: *Lymnaea elodes* Say, *Nasonia cockerelli* (Pilsbry and Ferriss), *Gyraulus parvus* (Say), *Helisoma trivolvis* (Say), *Promenetus exacuous* (Say), *Promenetus umbilicatellus* (Cockerell), *Physa gyrina* Say, *Physa skinneri* Taylor	1.0	30
8.	Soil, strongly developed; early Altithermal. Silty clay, dark yellowish brown grading to moderate yellow brown toward base; blocky texture with nodules of impure selenite. Sharp upper contact. Snails, fairly abundant in basal part, submitted for radiocarbon determination (W–902), gave age of 7,460±250 years (Meyer Rubin, U.S. Geol. Survey, written commun., Nov. 22, 1960). Shells identified by D. W. Taylor (written commun., 1963, USGS Cenozoic loc. 23364) as follows: freshwater clam, *Pisidium*; freshwater snails, *Valvata lewisi* Currier, *Lymnaea elodes* Say, *Nasonia cockerelli* (Pilsbry and Ferriss), *Gyraulus parvus* (Say), *Helisoma trivolvis* (Say), *Promenetus exacuous* (Say), *Promenetus umbilicatellus* (Cockerell), *Physa gyrina* Say; land snail, cf. *Succinea*	1.6	48
7.	Clay, silty, grayish-brown; may be an immature fossil soil. Contains a few snails	.8	24
6.	Clay, silty, pale-yellowish-brown. Very lenticular. Contains freshwater snails identified by D. W. Taylor (written commun., 1963, USGS Cenozoic loc. 23365) as follows: *Lymnaea*, *Helisoma trivolvis* (Say), *Promenetus umbilicatellus* (Cockerell), *Physa gyrina* Say	0.0–0.8	0–24
5.	Sand, silty, light-gray	.0–.5	0–15
4.	Silt, sandy, indistinctly bedded. Clam shells, 3 in. (8 cm) long, submitted for radiocarbon determination (W–594), gave an age of 8,800±300 years (Meyer Rubin, U.S. Geol. Survey, written commun., 1957). Shells identified by D. W. Taylor (written commun., 1963, USGS Cenozoic loc. 23366) as		

Unit No.		Thickness (feet	(cm)
	follows: freshwater clams, *Sphaerium striatinum* (Lamarck), *Pisidium compressum* Prime; freshwater snails, *Lymnaea*, *Gyraulus parvus* (Say); land snail, cf. *Succinea*. A skull collected from middle portion of unit (at same horizon as clam shells for radiocarbon determination) was identified by G. E. Lewis (U.S. Geo. Survey, written commun., 1957) and C. B. Schultz and L. G. Tanner (Univ. Nebraska, written commun., 1968) as *Bison antiquus* Leidy ----------	1.7–2.0	52–60
	Unconformity(?)		
3.	Silt and sand, interbedded. Very calcareous. Grades eastward within 150 ft (45 m) to mostly gray silty clay (lacustrine), faintly laminated. Contains clam and snail shells and bone fragments in upper 1–2 ft (30–60 cm). Sharp but irregular upper contact ----------------------------	3.5	107
	Unconformity.		
2.	Sand, medium to coarse, clean, well-bedded; conspicuously crossbedded. Thickens westward in the exposure. Contains about 5 percent black, green, and red grains representing minerals with a specific gravity greater than 2.85. Includes some silt interbeds about 0.1 ft (3 cm) thick --------	3.0–10.5	90–320
	Unconformity(?)		
1.	Glacial Lake Great Falls deposits, continental Pinedale(?). Clay (70 percent) and silt (30 percent); well laminated, locally distorted; noncalcareous. (Base of section is at normal river level; glacial lake deposits extend at least 3 ft (90 cm) below water level.) --------------------------	3.0+	90+
	Approximate total thickness of described section ------	26.0	790

The fairly complete alluvial and fossil soil sequence exposed in relation to the dated Mazama ash bed at locality RWL–1, coupled with supporting radiocarbon dates and identification of fossils from different horizons, makes this exposure a particularly valuable one for interpreting late Pleistocene and postglacial events.

Although some uncertainty exists as to whether unit 1 represents deposits of Glacial Lake Great Falls laid down during Bull Lake time or during Pinedale time, the topographic position of the deposits indicates one of the latest glacial lake levels in the area. Therefore, unit 1 is likely of Pinedale age.

Unit 2 is clean sand, probably representing regular stream deposits of the Missouri River. An erosional unconformity marks the top of the unit and probably also the base. If, as supposed, the underlying lacustrine deposits are of Pinedale age, then the unconformities mark only short hiatuses of time.

It is not clear whether unit 3 represents lacustrine deposits of

Holocene age or of Pinedale age. The sharp but irregular upper contact suggests a time break between unit 3 and unit 4. The faintly laminated gray silty clay into which unit 3 grades laterally may be either lacustrine deposits of a large glacial lake or those of a local postglacial pond.

Unit 4 is assigned to the pre-Altithermal interval of the Holocene on the basis of clam shells in the unit dated (W–594) at 8,800±300 years B.P. A nearly complete skull, identified as *Bison antiquus* Leidy by G. E. Lewis of the U.S. Geological Survey (written commun., 1957) and later by Lewis with C. B. Schultz and L. G. Tanner of the University of Nebraska (written commun., 1957), also was collected from the middle part of the unit. In answer to an inquiry concerning the late age for this type of bison in the region, G. E. Lewis (written commun., 1968) stated: "We would still retain the original identification, i.e. *Bison antiquus*. In the range 4,500 to 7,500 B. P. we get *Bison* remains which are intermediate between *B. bison* and *B. antiquus,* but of course we should expect this."

As indicated from radiocarbon dates for units 4 and 8, units 5, 6, and 7 were all deposited within about 1,500 years, just prior to the beginning of the Altithermal. D. W. Taylor (written commun., 1963) gave the following information on the depositional environment of fossil snails and clams found in these three units as well as in units 4 and 8:

> These assemblages are all similar in general composition. So far as we know, all of the fossils may represent species living locally. There is evidence for a slight change in the immediate environment of deposition through the section sampled. The species of perennial stream habitat (*Sphaerium striatinum, Pisidium compressum*) occur only at the base of the section [unit 4]. The freshwater snails indicate perennial water (*Valvata lewisi*) [unit 8] to seasonal ponds (*Nasonia cockerelli*) [unit 8] and probably come from backwaters and sloughs that dried up to varying extents in the summer.

It is likely that the indicated environmental differences between the units are more a reflection of immediate local conditions than of regional climatic changes during deposition of the units.

The well-developed fossil soil of unit 8 provides nearly as recognizable a marker bed as the ash bed. It is particularly valuable where the ash bed is absent. The radiocarbon date (W–902) of 7,460±250 years B.P. for snail shells collected from the basal 0.5 foot (15 cm) of the unit indicates that soil formation began about 7,500 years ago — the date that we believe approximately marks the beginning of the Altithermal in the region. Thus, the fossil soil forms a convenient marker for the beginning of this interval. Inasmuch as the overlying Mazama ash was deposited about 6,600 years ago, the fossil soil unit was formed during an interval of only about 1,000 years.

On the basis of the age of the Mazama ash of unit 9 and the assumed length of the Altithermal, it seems likely that the weak soil of unit 10 was developed during the latter part of the Altithermal.

Unit 11 probably was formed mostly or entirely during Neoglaciation time. If so, the deposits, including the modern soil profile, apparently were formed under cooler climatic conditions than prevailed during the Altithermal (Richmond, 1972).

LOCALITY RWL–6

The Mazama ash bed at locality RWL–6, 0.6 mile (1 km) west of Galata in the NW¼ sec. 4, T. 31 N., R. 3 E., was first described by Horberg and Robie (1955). They designated it the type section for several ash-bed localities in southern Alberta and northwestern Montana, having similar stratigraphic relations, and named it the Galata ash. The cross section constructed by them to show the stratigraphic relations at the Galata site was redrawn and redescribed by R. W. Lemke in 1956 (fig. 4).

The till (unit 1) at the base of the section probably was laid down during the close of continental Pinedale Glaciation in the region. Sometime after the deposition of the till (presumably about 12,000 years B.P.) and before deposition of the Mazama ash bed (approximately 6,600 years B.P.), the channel in which the ash is found was cut. Inasmuch as several beds (units 2, 3, 4, and 5) were deposited on the till before channel cutting occurred and the uppermost of these beds shows a faint soil horizon, the indication is that channel cutting did not occur immediately after the close of continental Pinedale Glaciation. On the other hand, some evidence suggests that channel cutting did not immediately precede deposition of the ash bed: (1) several beds (units 6, 7, 8, and 9) underlying the Mazama ash bed were deposited after channel cutting started, and (2) the uppermost of these beds appears to be the fossil soil that we interpret to be at the base of the Altithermal. These interpretations suggest that the cutting probably occurred in the pre-Altithermal interval of the Holocene, between approximately 10,000 and 7,500 years ago. Pronounced channel cutting during this interval has not been recognized elsewhere in the region.

The Mazama ash bed (unit 10) attains the greater than normal thickness of 2.5 feet (76 cm) in the filled channel. The bed is fairly clean and is characterized by undulating but sharply defined upper and lower contacts. The fact that the bed is relatively thick in the channel but that it thins to extinction a short distance outside the channel suggests: (1) the ash was concentrated in the channel largely by fluvial and eolian processes — probably in standing water or in a very slowly moving stream that would not have eroded away the ash, and (2) the ash that was deposited originally on the flat surfaces outside the channel was removed by wind and water erosion. These assumptions help explain why the ash beds in most of the described localities are found in alluvial deposits adjacent to streams and are not found in the uplands of the region. The fine-grained nature of the ash probably makes it particularly susceptible to removal by wind on exposed dry surfaces.

LOCALITY HS-176

Located in streambank in northwesterly tributary of Willow Creek, just northwest of Sawtooth Ranch in the SW¼NE¼ sec. 27, T. 21 N., R. 7 W., Lewis and Clark County.

[Carbon-14 age determination by Meyer Rubin (written commun., 1959 and 1964)]

Unit No.		Thickness (feet)	Thickness (cm)
3.	Clay, silty, calcareous, blocky; medium gray with dark-gray lenses; massive; A horizon, 0.2 foot (5 cm) thick; no B horizon. Gravel lens locally at base. Mazama ash bed, 0–8in. (0–20 cm) thick, is present about 6 in. (15 cm) below ground surface. Snails and clams (loc. F-209a[1]) collected from below ash bed were dated (W–765) at 7,870±200 years B.P. Snails above ash bed dated (W–1416) at 4,740±250 years B.P. Bison bones common in lower part	2.6	79
2.	Clay, calcareous, blocky, tough; medium gray mottled with moderate yellow brown; a 0.7-ft (21-cm) dark-gray slightly calcareous clay bed locally overlies this unit; beneath a dark-gray lens there is a disseminated $CaCO_3$ zone about 0.4 ft (12 cm) thick	1.7	52
1.	Clay (lacustrine beds), very tough and plastic; calcareous, dark gray; wood (F-210-C) collected from this locality contained modern roots which gave it an erroneous carbon-14 age (W–774) of 3,060±200 years	3.0+	90+
	Total section exposed	7.3	222

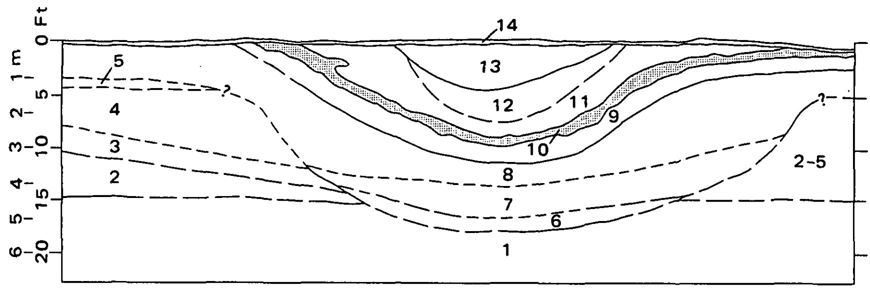
Base of stream.

[1]The mollusks from F-209a were identified by D. W. Taylor (written commun., 1959) as:

Freshwater clams:
- *Pisidium casertanum* (Poli)
- *Pisidium obtusale* Pfeiffer

Freshwater snails:
- *Valvata lewisi* Currier
- *Stagnicola palustris* (Müller)
- *Stagnicola caperata* (Say)
- *Lymnaea stagnalis jugularis* Say
- *Fossaria dalli* (Baker)
- *Fossaria parva* (Lea)
- *Gyraulus circumstriatus* (Tryon)
- *Gyraulus parvus* (Say)
- *Armiger crista* (Linnaeus)
- *Helisoma subcrenatum* (Carpenter)
- *Promenetus exacuous* (Say)
- *Promenetus umbilicatellus* (Cockerell)
- *Physa gyrina* Say
- *Physa skinneri* Taylor
- *Aplexa hypnorum* (Linnaeus)

Land snail:
- *Oxyloma* sp.



Unit	*Description*
14	Soil, modern
13	Clay, silty, dark-gray, indistinctly bedded
12	Silt, sandy; bedding approximately parallel to the contacts
11	Sand, fine; bedding approximately parallel to the contacts
10	Mazama ash bed; sharp but irregular contacts
9	Fossil soil; clay, silty, faintly bedded
8	Silt, sandy, to silty sand; obscure bedding; probably eolian-colluvial in origin
7	Sand, medium, clean, crossbedded, stream-deposited
6	Gravel, fine, stream-deposited
	Unconformity
5	Fossil soil; very poorly developed
4	Clay, silty, medium-gray; probably eolian-colluvial in origin
3	Clay, silty, dark-gray; faint soil horizons; very incomplete bison skull found near base
2	Sand, fine, thinly bedded
1	Till; silt, clay, and sand intermixed with a few pebbles

FIGURE 4. — Stratigraphic relations of Mazama ash bed with glacial and postglacial deposits at locality RWL–6. Located 0.6 mile (1 km) west of Galata, Toole County, in the NW¼ sec. 4, T. 31 N., R. 3 E. Galata ash locality of Horberg and Robie (1955).

The Mazama ash at locality HS–176 was deposited in the upper part of lacustrine beds that range in age from middle Pinedale time to about 4,500 years ago. The lake formed behind a dam created by the end moraine of the second advance of Pinedale glaciers. The lake clays are more than 90 feet (27 m) thick in the middle of the deposit, as determined from a hole drilled by a power auger. Although most of the deposit accumulated during the latter part of middle Pinedale time, locally 2–4 feet (60–120 cm) of the upper part accumulated during the Holocene (fig. 5).

SUMMARY

As examples given in this paper illustrate, the Glacier Peak and Mazama ash beds are useful stratigraphic markers in subdividing deposits of late Pleistocene and Holocene age in west-central Montana. Using these stratigraphic markers as a basis, the capability to make

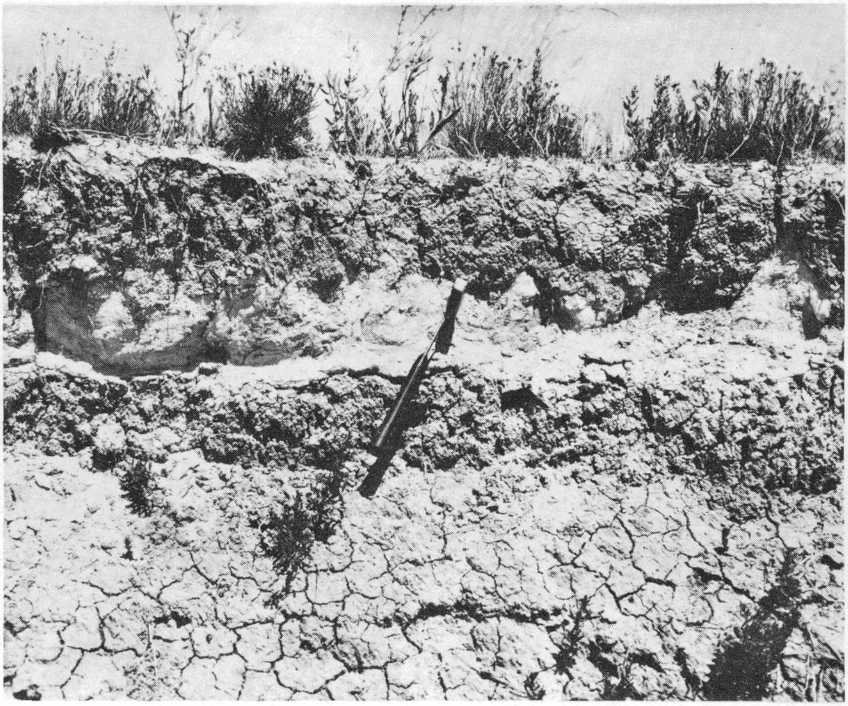


FIGURE 5. — Locality HS-176, showing Mazama ash bed (head of pick) overlying lacustrine clays deposited during the last recession of the alpine Pinedale glacier in the area. Alluvium overlies the ash bed. Radiocarbon age determinations of snail shells by Meyer Rubin (written commun., 1959 and 1964) are 7,870±200 years on shells below the ash, and 4,740±250 years on shells above the ash.

further subdivisions by recognition and regional correlation of associated beds should be enhanced. This, in turn, should provide a real impetus for future stratigraphic, ecological, climatic, and other related studies.

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REFERENCES CITED

Alden, W. C., and Stebinger, E., 1913, Pre-Wisconsin glacial drift in the region of Glacier National Park, Montana: Geol. Soc. America Bull., v. 24, p. 529–572.

Chatters, R. M., 1968, Washington State University natural radiocarbon measurements, I: Radiocarbon, v. 10, no. 2, p. 479–498 (WSU-155, p. 494).

Colton, R. B., Lemke, R. W., and Lindvall, R. M., 1961, Glacial map of Montana east of the Rocky Mountains: U.S. Geol. Survey Misc. Geol. Inv. Map I-327.

Frye, J. C., and Willman, H. B., 1963, Development of Wisconsinan classification in Illinois related to radiocarbon chronology: Geol. Soc. America Bull., v. 74, no. 4, p. 501–505.

Fryxell, Roald, 1965, Mazama and Glacier Peak volcanic ash layers — Relative ages: Science, v. 147, no. 3663, p. 1288–1290.

Goddard, E. N., chm., and others, 1948, Rock-color chart: Natl. Research Council (repr. by Geol. Soc. America, 1951, 1970), 6 p.

Haynes, C. V., Jr., 1968, Geochronology of late-Quaternary alluvium, *in* Means of correlation of Quaternary successions — Internat. Assoc. Quaternary Research, 7th Cong. USA, 1965, Proc., v. 8: Salt Lake City, Utah Univ. Press, p. 591–631.

Horberg, C. L., and Robie, R. A., 1955, Postglacial volcanic ash in the Rocky Mountain piedmont, Montana and Alberta: Geol. Soc. America Bull., v. 66, no. 8, p. 949–955.

Ives, P. C., Levin, Betsy, Oman, C. L., and Rubin, Meyer, 1967, U.S. Geological Survey radiocarbon dates, IX: Radiocarbon, v. 9, p. 505–529.

Lemke, R. W., Laird, W. M., Tipton, M. J., and Lindvall, R. M., 1965, Quaternary geology of northern Great Plains, *in* The Quaternary of the United States: Princeton, N.J., Princeton Univ. Press, p. 15–27.

Mudge, M. R., 1967, Surficial geologic map of the Sawtooth Ridge quadrangle, Teton and Lewis and Clark Counties, Montana: U.S. Geol. Survey Geol. Quad. Map GQ–610.

——1972, Surficial geologic map of the Castle Reef quadrangle, Teton and Lewis and Clark Counties, Montana: U.S. Geol. Survey Geol. Quad. Map GQ–991.

Mullineaux, D. R., Hyde, J. H., and Rubin, Meyer, 1972, Preliminary assessment of upper Pleistocene and Holocene pumiceous tephra from Mount St. Helens, southern Washington [abs.]: Geol. Soc. America Abs. with Programs, v. 4, no. 3, p. 204–205.

Peck, L. C., 1964, Systematic analysis of silicates: U.S. Geol. Survey Bull. 1170, 89 p.

Powers, H. A., and Wilcox, R. E., 1964, Volcanic ash from Mount Mazama (Crater Lake) and from Glacier Peak: Science, v. 144, no. 3624, p. 1334–1336.

Richmond, G. M., 1957, Three pre-Wisconsin glacial stages in the Rocky Mountain region: Geol. Soc. America Bull., v. 68, no. 2, p. 239–262.

——1960, Correlation of alpine and continental glacial deposits of Glacier National Park and adjacent High Plains, Montana, *in* Geological Survey research 1960: U.S. Geol. Survey Prof. Paper 400–B, p. B223–B224.

——1965, Glaciation of the Rocky Mountains, *in* The Quaternary of the United States: Princeton, N.J., Princeton Univ. Press, p. 217–230.

——1972, Appraisal of the future climate of the Holocene in the Rocky Mountains: Quaternary Research, v. 2, no. 3, p. 315–322.

Rigg, G. B., and Gould, H. R., 1957, Age of Glacier Peak eruption and chronology of postglacial peat deposits in Washington and surrounding areas: Am. Jour. Sci., v. 255, no. 5, p. 341–363.

Westgate, J. A., 1968, Surficial geology of the Foremost-Cypress Hills area, Alberta: Research council Alberta Bull. 22, 121 p.

——1972, Recent advances in the Quaternary tephrochronology of western Canada: Geol. Soc. America Abs. with Programs, v. 4, no. 3, p. 259–260.

Westgate, J. A., Smith, D. G. W., and Tomlinson, M., 1970, Late Quaternary tephra layers in southwestern Canada, *in* Early man and environments in northwest North America — Calgary Univ. Archaeol. Assoc. Paleo-Environmental Workshop, 2d Ann. Proc.: Students' Press, p. 13–34.

Wilcox, R. E., 1969, Airfall deposits of two closely spaced eruptions in late glacial time from Glacier Peak Volcano, Washington: Geol. Soc. America Abs. with Programs 1969, pt. 5, p. 88–89.

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