Volcanic Ash from Mount Mazama (Crater Lake) and from Glacier Peak

Abstract. *New petrographic and chemical data indicate that the great Mount Mazama eruption at Crater Lake, Oregon, about 6600 years ago was the source of most ash which has been called "Glacier Peak" and of some ash called "Galata." Glacier Peak volcano in Washington was itself the source of an older ash deposit, perhaps very late glacial or early postglacial in age.*

Layers of volcanic ash are sufficiently common in young deposits in northwestern United States and adjacent Canada to serve as horizon markers in geological and archeological stratigraphy, provided they can be identified and correlated.

To this end, taking advantage of recently developed techniques, we made a detailed petrographic and chemical study of samples of ash that we and others collected from layers in late glacial and postglacial deposits in the region, and a parallel study of samples of lump pumice from specific Cascade volcanoes (*1*) that might be considered likely sources. This report deals only with the widespread ash of the great eruption of Mount Mazama at the site of present Crater Lake in Oregon (*2*) and the criteria for distinguishing it from the ash of Glacier Peak volcano in Washington.

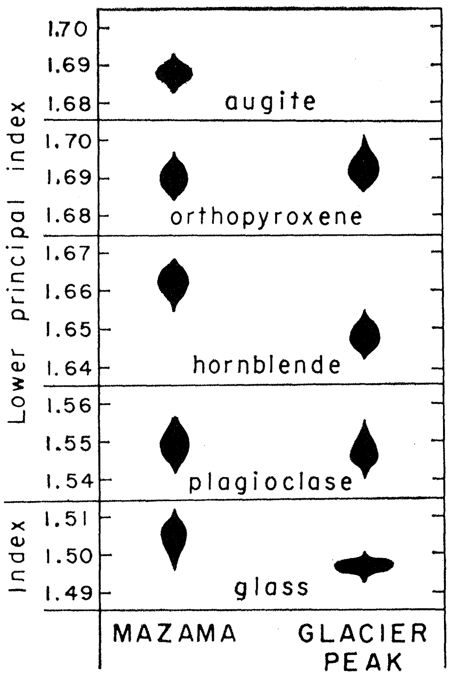

Fig. 1. Refractive indices (range and dominant values) of constituents in six samples each of Mazama and Glacier Peak pumices. Phenocrystic augite and apatite are sparingly present in Mazama material but lacking in the Glacier Peak material. Magnetite is present in both.

After a general microscopic examination in bulk, the sample of pumice or ash to be studied was scrubbed ultrasonically and, for convenience of further petrographic examination, separated into heavy, intermediate, and light fractions. To obtain a fraction of pure glass for chemical analysis, the light fraction was further manipulated with the aid of the Frantz separator and by other means. The many determinations of refractive index of the glass shards were made with the "focal-making" technique (*3*), which is well suited for rapid work with such inhomogeneous material. This technique also was used in conjunction with the spindle stage (*4*) for rapid determination of principal indices of phenocrysts. To increase confidence that the crystals measured were truly phenocrysts, only those were chosen that carried adherent glass.

The lump pumice of Glacier Peak is at once distinguishable from that of Mazama by the greater proportion of phenocrysts. Because this proportion may have been changed radically however in the ultimate deposit of fine ash at a distance, through winnowing by air and possibly water, we have attached more importance to the specific optical and chemical properties of the individual constituents in making correlations.

Figure 1 compares the ranges of refractive index found in the constituents of a half-dozen samples of lump pumice from the Mount Mazama eruption at Crater Lake, Oregon, and a similar number from the flanks of Glacier Peak volcano, Washington. The higher indices of the glass and hornblendes serve to distinguish the material of Mazama from that of Glacier Peak. The absence of clinopyroxene in the Glacier Peak material is less useful as a criterion, since it is only sparingly present in most Mazama material. Chemical analysis of the glasses (Table 1, columns I and III) shows a typical general relationship, namely, the Mazama material contains slightly less silica and lime and slightly more soda, yttrium, ytterbium, and zirconium than the Glacier Peak material.

Samples of ash from localities marked *M* on Fig. 2 have petrographic characteristics matching those of the Mazama lump pumice in Fig. 1. Of the lump pumices studied to date from the dozen or so other Cascade vents that might conceivably have been sources, none possess this particular set of characteristics. The chemical composition of the glass fraction of one sample of this ash from Montana (Table 1, column II) is typical and corresponds closely to that of the lump of Mazama pumice (column I). We

Table 1. Examples of chemical compositions (percent) of glass from typical pumice and ash.

	I. Mazama pumice *	II. Unknown ash†	III. Glacier Peak pumice‡	IV. Unknown ash§
	Major oxides, recast volatile-free			
SiO_2	72.39	72.29	73.01	74.67
Al_2O_3	14.79	14.79	15.08	14.54
TiO_2	0.43	0.46	0.30	0.23
Fe_2O_3	0.58	0.73	0.65	0.35
FeO	1.27	1.32	1.14	0.65
MnO	0.06	0.05	0.05	0.03
MgO	0.52	0.61	0.73	0.45
CaO	1.58	1.83	2.30	2.32
Na_2O	5.21	4.90	3.72	3.68
K_2O	2.77	2.95	2.89	3.05
P_2O_5	0.09	0.07	0.13	0.03
Sum	100.00	100.00	100.00	100.00
	Volatiles and selected minor elements			
H_2O^+	2.01	3.17	3.49	2.94
H_2O^-	0.10	0.26	1.23	0.31
CO_2	0.00	0.01	0.01	0.00
Y	0.003	0.003	0.001	0.0007
Yb	0.0003	0.0003	0.0001	0.0001
Zr	0.024	0.030	0.012	0.016

* Pumice lump (Spec. 61P1) from Mazama ash flow, sec. 3, T29S, R4E, upper Rogue River valley, Garwood Butte quadrangle, Oregon. Collected by R. V. Fisher. USGS analysis No. E 3464 by Dorothy F. Powers, Vertie C. Smith, and P. R. Barnett. † Fine ash (Spec. HS–92) in alluvium in irrigation ditch, sec. 12, T21N, R8W, Barr Creek quadrangle, Montana. Collected by M. R. Mudge. USGS analysis No. E 2085 by Dorothy F. Powers, P. R. Barnett, Nancy M. Conklin, and J. C. Hamilton. ‡ Pumice lump (Spec. 56P24) from young alluvium on Chiwawa River at mouth of Phelps Creek, Holden quadrangle, 19.2 km east of Glacier Peak summit, Washington. Collected by H. A. Powers. USGS analysis No. H 3463 by Dorothy F. Powers, Vertie C. Smith, and P. R. Barnett. § Fine ash (Spec. HS–87) in colluvial and alluvial fan material, sec. 35, T22N, R9W, Sawtooth Ridge quadrangle, Montana. Collected by M. R. Mudge. USGS analysis No. E 2084 by Dorothy F. Powers, P. R. Barnett, Nancy M. Conklin, and J. C. Hamilton.

conclude therefore that these samples are parts of a once continuous ash blanket from the Mazama eruption. The age of this ash layer, as inferred by various investigators from radiocarbon determinations of closely associated carbonaceous materials, is roughly 6000 to 7000 years, in adequate agreement with the radiocarbon age of about 6600 years given for charred wood in the ashflow of the Mazama eruption (*5*).

"Glacier Peak ash" came into common use as a name for a marker bed of apparent Altithermal age occurring in many bogs of northern Washington, after Hansen's (*6*) suggestion that its source might have been Glacier Peak volcano. Rigg and Gould (*7*) concluded that such an origin was consistent with the trends in particle size and sorting coefficients of the samples they studied. Upon examination of a representative suite of their samples kindly supplied by Gould, we have found, however, that the mineralogic and chemical characters correspond to the Mazama lump pumice of Crater Lake rather than to the Glacier Peak lump pumice. We therefore attribute this ash in northern Washington to the Mazama eruption, noting that the C^{14} age of about 6700 years previously suggested (*7*) is consistent with that found for known Mazama material, and that similar ash is found in similar stratigraphic situations southward to the point where it can be traced with increasing coarseness into the Mazama deposit at Crater Lake.

Samples of "Galata ash" collected at the type locality of Horberg and Robie (*8*) near Galata, Montana, and at Locality 7 on Oldman River near Lethbridge, Alberta, although very fine grained and containing detrital contaminants, were likewise found to have the same chemical and petrographic characters as the Mazama material. We have not examined material from the other localities listed but note that the refractive indices reported (*8*) for the glass of their Localities 3, 6, and "Johns Lake" are significantly above the range we have found in the Mazama material. This suggests that ash from more than one eruptive source may have been grouped under the name "Galata."

As for eruptive material from Glacier Peak volcano itself, ash which corresponds petrographically to the lump pumice on the flanks of Glacier Peak (and not to that of any other Cascade vent so far examined) has been found stratigraphically below Mazama ash at three outlying localities, marked *M/G* on Fig. 2. One of these is at Creston Bog (*9*), 200 km east southeast of Glacier Peak, where fine ash having the Mazama petrographic characteristics was penetrated at 1.2 m depth (in peat) and coarse ash having the Glacier Peak characteristics at 2 m depth (at the base of the peat). Another is in extreme northeastern Washington at Big Meadow Lake (*10*), where the ash at 2.3 m depth (in peat) has the Mazama characteristics and that at 5.9 m depth (in basal marl) has Glacier Peak characteristics. The third is at Bison Cave (Idaho State College Museum Archeological Site No. 10-Cl-10) (*11*) in eastern Idaho about 675 km southeast of Glacier Peak, where the upper ash has Mazama characteristics and the lower has Glacier Peak characteristics.

Other occurrences of ash having the characteristics of Glacier Peak material are shown by *G* on Fig. 2. Those in western Montana were collected in the course of field work by M. R. Mudge of the Geological Survey, who judged the deposits in which they occur to be appreciably older than nearby deposits containing Mazama ash. Chemical analysis of the glass of one of these samples is given in Table 1, column IV.

We conclude that these samples of older ash are parts of an ashfall or ashfalls from an eruptive episode at Glacier Peak in very late glacial or possibly early postglacial time. The

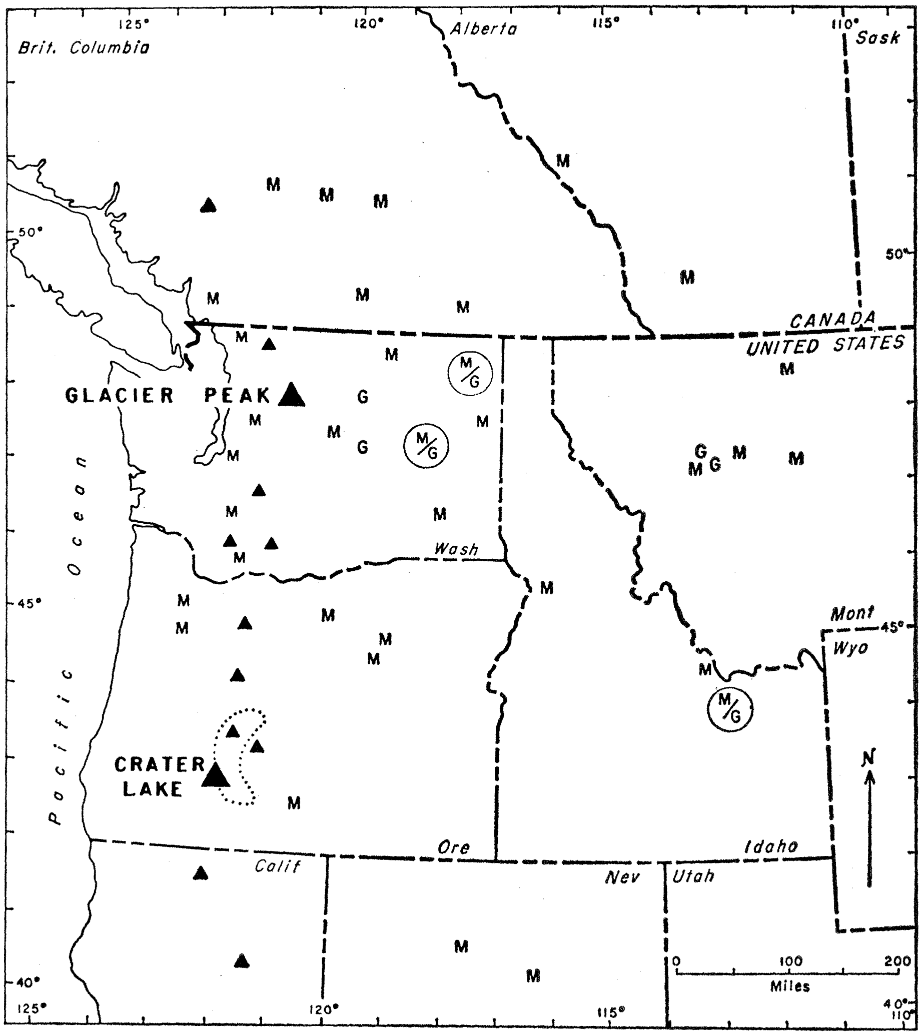

Fig. 2. Location map. *M* denotes location of sample identified as Mazama ash. *G* denotes location of sample identified as ash from Glacier Peak. *M/G* denotes place where Mazama ash has been found above Glacier Peak ash in the same stratigraphic section. Dotted line denotes approximate position of the 3-foot thickness of Mazama ashfall, according to Williams (*2*). Solid triangle denotes location of recently active vent in the Cascades.

possibility that this ash fell not only on the unglaciated area, but also on the ice itself and on ground recently abandoned by the ice, encourages search for further occurrences and age determination by radiocarbon methods (*12*).

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12. Publication authorized by the director, U.S. Geological Survey. We are indebted to many persons for stratigraphically documented samples of ash, for collections of lump pumice from recently active Cascade volcanoes, and for helpful discussion of the field and laboratory problems.

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Temperature Regime of Deep Lakes

Abstract. *New data concerning the temperature of maximum density of fresh water under pressure have been obtained in Great Bear Lake, in the Northwest Territories of Canada. Previous theoretical determinations are discussed; Strøm's empirically determined figures are in agreement with these data.*

In the north of Canada, Great Bear Lake is situated with its northern arms cutting across the Arctic Circle; it is the fourth largest lake in North America, and also the fourth deepest. It is still comparatively little known limnologically, although a comprehensive survey, with the motor vessel *Radium Gilbert*, was started in the summer of 1963. The greatest depth recorded was 427 m (1410 feet) in McTavish Arm, 8.5 km west of Port Radium in an extensive region of very deep water. The water is extremely clear in this locality, a Secchi disc reading of 30 m (98.5 feet) having been obtained; the dissolved solids amounted to 78 parts per million.

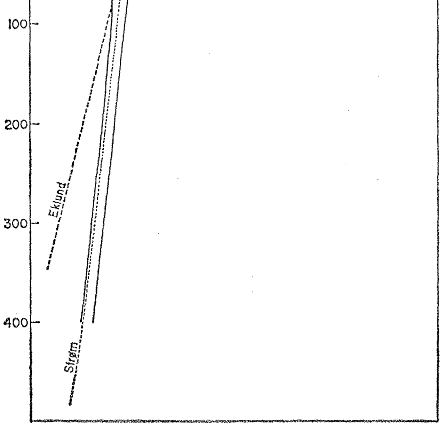

Fig. 1. Temperature series, Great Bear Lake, Canada.

The conditions in Great Bear Lake appear to come as close as possible to the requirements stipulated by Strøm (*1*) for a lake in which to measure the temperature of maximum density: "If a holomictic lake (a lake with seasonal circulations extending to the bottom) is cooled sufficiently down before vernal full circulation, temperatures in the deep must immediately after the establishment of incipient summer stratification very nearly correspond to the temperature of maximum density at the various depths."

Two temperature series were taken in the area of deep water with protected reversing thermometers in Nansen water bottles. The thermometers were calibrated by the National Research Council of Canada within 3 months of the time the readings were made. Bathythermograph traces were obtained at the same time. The first series was taken at the end of July as the surface waters approached their temperature of maximum density (3.94°C), and the second recordings were made at the end of August at about the time of maximum heat absorption. The surface temperature at this time was 6.87°C; the corresponding temperature at 50 m was 3.97°C. These series are plotted in Fig. 1; also included on the graph are the lines deduced by Strøm and Eklund (*2*). Strøm's line appears to provide an exceptionally good fit to the data; neither the early nor the late profile crosses the theoretical line; at 400 m on 26 July the observed value of 3.48°C is almost identical with that of 3.49°C deduced by Strøm, and this is well within the standard deviation of the instrument used (± 0.02°C).

Although minimum winter temperatures are not yet available, it appears that Great Bear Lake is dimictic in this deep-water region. In July there appeared to be no trace of stagnation in the deepest water, the *p*H, nitrate, and phosphate values being very close to those obtained on the surface. Miller and Kennedy (*3*) found that the water was between 85 to 91 percent saturated with oxygen at depths up to 346 m (1134 feet). It can therefore be assumed that circulation is taking place, probably at a temperature slightly below that of maximum density. When the bottom temperature reaches 3.48°C relative stability is attained. This stability is largely maintained until the fall. Its maintenance is doubtless assisted by the relatively narrow and deep section of McTavish Arm and the calm weather at this time of the year. Unfortunately no chemical data are available for the August temperature series. Such data might have indicated summer stagnation, although biological activity is so slow, even on the surface, that very sensitive methods might be required to determine any effects of this deep stagnation.

The theoretical values deduced in a most ingenious manner by Eklund from the compressibility of water have no relationship to the data from Great Bear Lake, although there is a very slight point of inflection on the bathythermograph slide at about the depth at which Eklund's line would cross the trace.

It seems apparent that Strøm's "envelope" has some physical reality, and it must therefore be connected in