μ observations of a star or of the moon for an air mass close to that of Mars. It is expected that the observations planned for the 1965 opposition, when this technique will be used, will permit positive conclusions to be drawn about Martian absorption features in the 3.5- to 3.8-μ region (*11*).

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11. Moroz [V. I. Moroz, *Astron. Zh.* **41**, 350 (1964)] also reports detection of absorption in the 3- to 4-μ region on Mars. We do not have data on water abundance for his observing site and so cannot make the appropriate analysis. However, we suggest that telluric HDO is also the source of the features he observed.
12. We thank D. M. Gates for the loan of his solar spectra and for discussion of the vagaries of absorption by our own atmosphere. Supported in part by NASA contract NAS r 220.

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Mazama and Glacier Peak Volcanic Ash Layers: Relative Ages

Abstract. *Physiographic and stratigraphic evidence supports the regional correlation of two volcanic ash layers with extinct Mount Mazama at Crater Lake, Oregon, and Glacier Peak in the northern Cascade Range of Washington. A radiocarbon age of 12,000 ± 310 years confirms geological evidence that ash derived from the Glacier Peak eruption is substantially older than ash from the Mazama eruption of 6600 years ago.*

The potential use of widespread volcanic ashfalls as time-stratigraphic marker horizons in the Pacific Northwest is great, for lenses of volcanic ejecta are present locally, and in some cases regionally, in sediments from early Pleistocene to Recent age. The best preserved, most widespread, and consequently most valuable as tools in the development of a postglacial regional chronology, are the pumice and ash from eruptions of Mount Mazama at Crater Lake, Oregon, and Glacier Peak in the northern Cascade Range of Washington.

Powers and Wilcox (*1*) recently have provided techniques for petrographic correlation of the pumice deposits from these and other (*2*) eruptions. My own field studies have yielded stratigraphic and radiocarbon data indicating the age and distribution of these deposits. It now is possible to reconfirm an age of about 6600 years for the Mazama eruption; to place an age of about 12,000 years for the Glacier Peak eruption; and to estimate the minimum areas of fallout for Mazama ash at about 900,000 km² and for Glacier Peak at more than 260,000 km² (Fig. 1).

Wide distribution of pumice from the destruction of Mount Mazama was demonstrated by Williams (*3*) within Oregon, and ash deposits as far north and east as Walla Walla, Washington were correlated with the Mazama blast by Moore and Carithers (*4*). Hansen (*5*) reported the presence of several pumice and ash horizons in bog sediments throughout the northwest, and noted the almost universal presence of a layer of volcanic ash in sediments thought by him to have been deposited during the "Thermal Maximum" (Altithermal) climatic interval between 8000 and 4000 years ago. Included in Hansen's field studies and those of Rigg (*6*) were many bogs in northeastern Washington and the Puget Sound area, nearly all of which included ash layers of Altithermal age. Rigg and Gould (*7*) adopted Hansen's earlier suggestion as to the source of the ash, and correlated these lenses of ash with an eruption of Glacier Peak known from thick deposits of pumice on its flanks and in the Entiat and Methow valleys.

Radiocarbon dates placed the age of the Mazama eruption at about 6500 years (*8*); those associated with volcanic ash attributed to the Glacier Peak eruption indicated an age of about 6700 years (*7*). Thus it became evident that the Altithermal ash deposits represented either two almost contemporaneous ashfalls or a single blanket of ash mistakenly attributed to two sources. I found late Wisconsin ash, too coarse to have been derived from Mount Mazama and stratigraphically lower than the Altithermal ash, at several localities reported by Carithers (*4*) and at the Nat Cave and Park Lake archeological sites in Lower Grand Coulee, Washington.

Most recently, Powers and Wilcox (*1*) have used petrographic and chemical characteristics to correlate the Altithermal ashfall throughout the Pacific Northwest with the catastrophic Mazama eruption and to correlate the older, coarser ash with Glacier Peak. These two ash layers were found superposed at Creston Bog by R. E. Wilcox and me during the summer of 1963, and by others as far southeast as Birch Creek Valley, Idaho (*1*, *9*).

The coarse pumice of the immediate Glacier Peak area thins rapidly eastward, grading to grains of about 0.25 mm maximum diameter at Creston Bog. Although this size still is coarse enough and distinctive enough, because of its "tapioca-like" appearance, to be megascopically distinguishable from Mazama ash in this area, remnants of the older Glacier Peak ash disappear for the most part beneath the accumulation of younger sediment and the blanket of more recent Mazama ash. Thus in a transect from Glacier Peak eastward across the Columbia Plateau, the obvious thick deposits of Glacier Peak pumice and coarse ash appear to grade smoothly to those of the finer Mazama ash blanket, which provides the most prominent series of ash deposits east of the Okanogan and Columbia rivers. Without detailed stratigraphic information, the transition from prominent exposures of Glacier Peak ash to prominent exposures of the Mazama overlay is not apparent.

At least ten radiocarbon dates, including some obtained from wood buried by the Mazama eruption (*8*, *10*), place the age of the Mazama eruption at about 6600 years. Shells of freshwater molluscs collected from an abandoned quarry in Glacier Peak ash at the east wall of Lower Grand Coulee about 8 km north of Soap Lake have been determined by radiocarbon analysis to be 12,000 ± 310 years old (WSU-155) (*11*). All shells collected at the site are fragile, but few are broken and many remain articulated; all occur within a deposit of interbedded fine sand, silt, and small pellets of Glacier Peak ash which accumulated in the slackwater area between a broad, low-lying gravel bar and the Coulee wall. Thus the age of 12,000 years obtained for the shell is a minimum

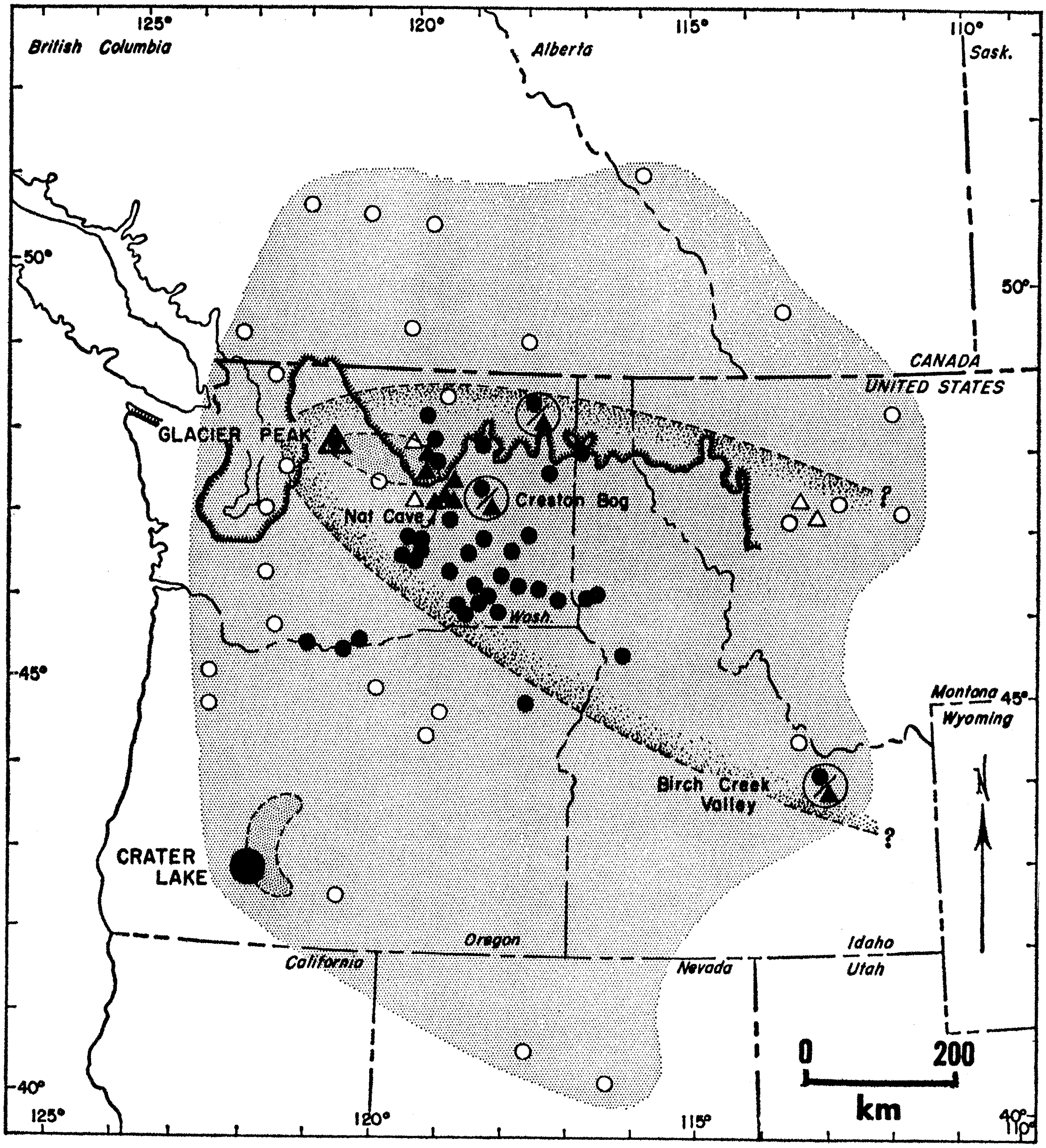

Fig. 1. Location map, showing inferred extent of minimum areas affected by fallout of volcanic ash from eruptions of Mount Mazama at Crater Lake (grey area) and Glacier Peak (broken, stippled line). Areas of irregular stippling at each volcano outline distribution of pumice deposits mapped by Williams (*3*) and Carithers (*4*). Open symbols (circles for Mazama ash, triangles for Glacier Peak ash) mark sites studied by Powers and Wilcox (*1*). Solid symbols (circles for Mazama ash, triangles for Glacier Peak ash) mark representative sites at which detailed stratigraphic information has been collected. Maximum extent of the Cordilleran Ice Sheet during Wisconsin time is shown by hachured line, adapted from several authors (*20*).

Table 1. Geologic occurrence of Mazama and Glacier Peak volcanic ash layers in the northern Columbia Plateau of Washington.

Deposit or topographic feature	Mazama ash	Glacier Peak ash
Present stream channels	Absent	Absent
Post-Altithermal loesses and flood-plain deposits	Absent	Absent
Post-Altithermal rockfall or talus	Absent	Absent
Altithermal loess	In	Absent
Altithermal cave and talus debris	In	Absent
Pre-Altithermal terraces and stream gravels	On	Absent
Osoyoos terrace and younger Columbia River outwash gravel	On	Absent
Late Wisconsin rockfall and talus	On	In
Late Wisconsin lacustrine sediments	On	In
Late Wisconsin till, Great Terrace, and earlier Columbia River outwash gravel	On	On
Scabland gravel and all older materials in the area	On	On

date but probably does not greatly postdate the time of the ashfall.

Because the age of 12,000 years fits well with other evidence for the age of the Glacier Peak ashfall, it seems reasonably certain that the eruption occurred early during the interstade following the late Wisconsin maximum advance of the Okanogan lobe of the Cordilleran Ice Sheet (Fig. 1), at a time correlated with the Everson Interstade of the Puget Sound–Fraser River area of the coastal northwest (*12*). The more widespread, better preserved, and more frequently exposed Mazama ashfall occurred just prior to the warmest part of the Altithermal climatic interval. In Lower Grand Coulee, Mazama ash occurs in talus which did not accumulate until after the late Wisconsin lake (into which Glacier Peak ash fell) had dwindled to the series of disconnected pools present today.

Often it is possible to distinguish between Glacier Peak and Mazama ash layers in the field. Geologic and physiographic evidence for the difference in the relative ages of these two ashfalls is clear-cut; they occur in unlike positions in cave sediments throughout the Columbia Plateau area (*13*), and occupy distinctively different positions in the landscape. Glacier Peak ash has not been found in any deposit known to be younger than about 10,000 years, in contrast to the widespread inclusion of Mazama ash in or on virtually every known type of sediment found in the area except those of Post-Altithermal age (Table 1). Shells used for dating the Glacier Peak eruption, and the volcanic ash from which they were collected, had been deposited in the bottom of a lake (*14*) which extended almost the entire length of Lower Grand Coulee. The existence of such a lake requires the presence of at least a vestigial ice dam on the Columbia River, though by this time the Columbia itself no longer was diverted down Grand Coulee (*15*) and probably was escaping over and under stagnant ice at the mouth of the Okanogan Valley. Certainly the Okanogan Ice Lobe had retreated that far, because coarse Glacier Peak ash occurs on the Great Terrace (*16*) of the Okanogan and Columbia rivers north of Brewster, Washington. It has not, however, been found on younger terraces in the Okanogan Valley, presumably because these terraces lie in central portions of the valley still occupied by ice at the time of the Glacier Peak eruption.

Paleontological evidence for the relative ages of these ashfalls is provided by the direct association of more than a dozen genera of freshwater molluscs with Glacier Peak ash at several sites within Lower Grand Coulee, well above the level of any possible standing water in postglacial time, in one of the most arid portions of the Columbia Plateau; mammoth and extinct bison remains also are common in deposits having stratigraphic positions similar to that of the Glacier Peak ash. Vertebrate remains in direct association with Mazama ash at archeological sites are, without exception, species which have been extant in the area historically, and at the Marmes Rockshelter archeological site include human skeletons both above and below the Mazama ash (see *17*).

Sequences of cultural material in direct association with Mazama ash at archeological sites in the Columbia Plateau (*17, 18*) are sufficiently distinctive to be of considerable use in correlating exposures of Mazama ash. Stemmed or bipointed lanceolate projectile points are dominant in deposits underlying the Mazama ash; deposits overlying the ashfall include heavy side-notched points of basalt, large corner-notched points with barbs, and smaller corner-notched points and side-notched points in that succession. Except for the large side-notched points, cryptocrystalline silica is the material most commonly used for manufacture. The entire sequence of cultural material postdates the Glacier Peak ashfall; except at Birch Creek, where nondiagnostic artifacts have been found beneath Glacier Peak ash (*9, 19*), no human occupation in the Pacific Northwest at a time earlier than about 11,000 years ago has yet been demonstrated (*15*).

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