Newfoundland off the southeastern United States does not prove the existence of a (continuous) current such as a geostrophic current or a "contour current" per se, as has been postulated (*13*). Currents resulting from internal wave motions also could transport sediment particles over that distance.

Valleys and ridges obliquely crossing deep submarine slopes may be analogous to troughs and banks near the shore, not only in morphology but also with respect to mode of origin—essentially a function of wave interaction with the sea floor. The currents causing the movement of sediment may be generated not by simple sinusoidal waves but by interference of waves having different phases and periods, or by the sum of periodic water motion and a steady current.

Channels and gullies that incise deep-water slopes may have been cut by wave-induced internal currents, analogous to channels carved by rip currents in shallow water. If size and direction of internal waves change less frequently than those of their wind-generated counterparts, the position and size of the rip channels, which are controlled by them (*14*), also may be more stable on deep-water slopes than on shallow-water slopes. Eventually, rip channels on deep submarine slopes may be modified by turbidity currents.

In attempting to draw analogies between nearshore and offshore slopes I am aware of major differences between shallow-water and deep-water provinces. Some processes in either province may enhance these differences: for example, greater variability of topographic forms in time and space, to be expected in the nearshore zone, may contrast with potentially greater dimensions in the offshore zone.

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Mazama Ash in the Northeastern Pacific

Abstract. *Volcanic glass in marine sediments off Oregon and Washington correlates with continental deposits of Mount Mazama ash by stratigraphic position, refractive index, and radiocarbon dating. Ash deposited in the abyssal regions by turbidity currents is used for tracing of the dispersal routes of postglacial sediments and for evaluation of marine sedimentary processes.*

The cataclysmic eruption of Mount Mazama 6600 years ago (*1, 2*) spread pumice and ash to the north and northeast over at least 900,000 km^2 (*2*) (Fig. 1, inset). Volcanic glass from this eruption is found in the postglacial marine sediments younger than 12,500 years (*3*) of Willapa Canyon, Astoria Canyon, Astoria Fan, Astoria Channel, Cascadia Channel, Cascadia Abyssal Plain, and Blanco Valley (Fig. 1). We now discuss the origin, stratigraphic significance, and relation to submarine topography of the deep-sea layers of ash, and their significance in processes of deposition.

Piston cores taken off Oregon and Washington show that the deep-sea sediments generally are terrigenous and derived from the extensive drainage area of the Columbia River (*3–6*). The marine deposits consist of layers of sand and silt turbidity-current deposits, interbedded with hemipelagic silty clays; volcanic glass is a major component of the layers and a minor component of the interbeds (Fig. 2).

The sand fraction (coarser than 0.062 mm) of the ash-bearing layers can be so classified (*7*): vitric ash (more than 75 percent glass), tuffaceous sand or silt (25 to 75 percent glass), and terrigenous sand or silt (less than 25 percent glass). Tuffaceous sand and silt layers are the most common type in all depositional environments. Only a few of the ash beds in the interchannel areas (regions between channels) and in the upper portions of some of the thick layers in channels on Astoria Fan are classified as vitric ash (Fig. 2).

Generally the marine ash is mainly distributed in the submarine valleys (Fig. 1); it occurs in the sediments of Astoria Canyon and its tributaries and in Willapa Canyon (*8*). On Astoria Fan all ash layers are within 60 km of the apex of the fan in the interchannel regions, but they occur throughout the 160 km of Astoria Channel. Cascadia Channel has appreciable quantities of volcanic glass between its head, near the base of the continental slope, and points at least 400 km down the channel. Ash is found also in cores taken in Blanco Valley off southern Oregon and northern California.

The vertical distribution of volcanic glass varies from distinct coarse beds to ash-rich zones of clayey silt in the different marine environments. Postglacial sediments in Astoria Canyon contain many thin layers of tuffaceous and terrigenous clayey silt (*4*); the deepest layer occurs more than 300 cm below the surface of the sediment (Fig. 2, core 1); tuffaceous sand layers at its mouth are the thickest (thicker than 35 cm) and coarsest in the area studied, containing pebble-sized fragments of pumice (*5*). In Astoria Channel the ash is found in two closely spaced layers of tuffaceous sand or silt 10 to 30 cm thick; the lower occurs at a depth between 125 and 190 cm (Fig. 2, core 2) and is thicker and contains more glass than the upper. Both layers are graded, ash being more abundant in the upper portions of each. In the interchannel areas of Astoria Fan, one and occasionally two closely spaced ash layers may occur in the middle of the upper 1 m of sediment (Fig. 2, core 3). Interchannel ash layers generally are only a few centimeters thick and contain more glass than do the ash layers in the channels of the fan. Cascadia Channel resembles Astoria Canyon in containing many thin tuffaceous and terrigenous layers of coarse silt in the thick postglacial sedimentary sequence (Fig. 2, cores 5 and 6). Only one prominent tuffaceous silt layer is found in the piston cores from the vicinity of Blanco Valley off southern Oregon and northern California (Fig. 2, core 4).

Volcanic glass in the postglacial marine sediments correlates with the continental deposits of Mount Mazama glass by comparison of refractive indices, by radiocarbon dating, and by stratigraphic position. Indices of refraction of representative samples of the deep-sea glass prove to be mainly between 1.502 and 1.509 ± 0.001 (*9*). Our determinations of refractive index from the glass shards show that in more than 50 cores the modal values of samples lie between 1.505 and 1.507 ± 0.002—similar to those reported (*10*) for Mount Mazama ash. Pumiceous glass shards were believed (*11*) to have the physical characteristics and also the range of the indices given by Steen and Fryxell (*12*) for Mazama ash.

Radiocarbon ages and the stratigraphic position of the deepest marine ash layers indicate that the deep-sea ash first occurred about midway through the postglacial period—6600 years ago—about when Mount Mazama erupted (Fig. 2). Radiocarbon dates, determined from two cores from Cascadia Channel and one core each from Astoria Canyon and Blanco Valley (Fig. 2), show that the first ash was emplaced between 9700 and 5600 years ago. If one assumes a constant rate of sedimentation in postglacial time, the lowest ash layers in cores 4 and 6 are 7300 and 6200 years old, respectively. Similar reasoning (*8*) led to a date of 7360 ± 300 years ago for the ash layer in Willapa Canyon. These ages are comparable with the 6600-year radiocarbon age of Mazama ash in continental areas in view of the inaccuracies inherent in assumption of a linear rate of sedimentation.

Ash-bearing deep-sea deposits contain the diagnostic phenocrystic suite of heavy minerals found in the Mazama ash (*10*), as well as many other heavy minerals not associated with the suite (*9*). Most heavy-mineral assemblages in the marine ash-bearing layers derive from the drainage area of the Columbia River, but ash layers in Blanco Valley derive from the Klamath Mountain Province which is drained by the Klamath, Rogue, and Umpqua rivers in southern Oregon and northern California (*3–5*).

In addition to the foreign heavy minerals and the generally appreciable quantities of other detrital minerals, most ash layers contain displaced shallow-water benthonic Foraminifera and plant fragments (*4, 5*). These contaminants, together with the grading of texture and ash content in layers (Fig. 2), geographic distribution of marine ash, and general lack of pyroclastic ash in the interbedded hemipelagic sediments, indicate that the volcanic glass slumped with debris from the continental shelf and slope and was distributed through, or deposited in, submarine valleys by turbidity currents.

The continental distribution of Mazama ash (Fig. 1, inset) shows that the pyroclastic outfall from the Mazama eruption blanketed the Columbia River and the coastal drainage areas with large quantities of ash. The bulk of the deep-sea Mazama glass is believed to derive from the Columbia River drain-

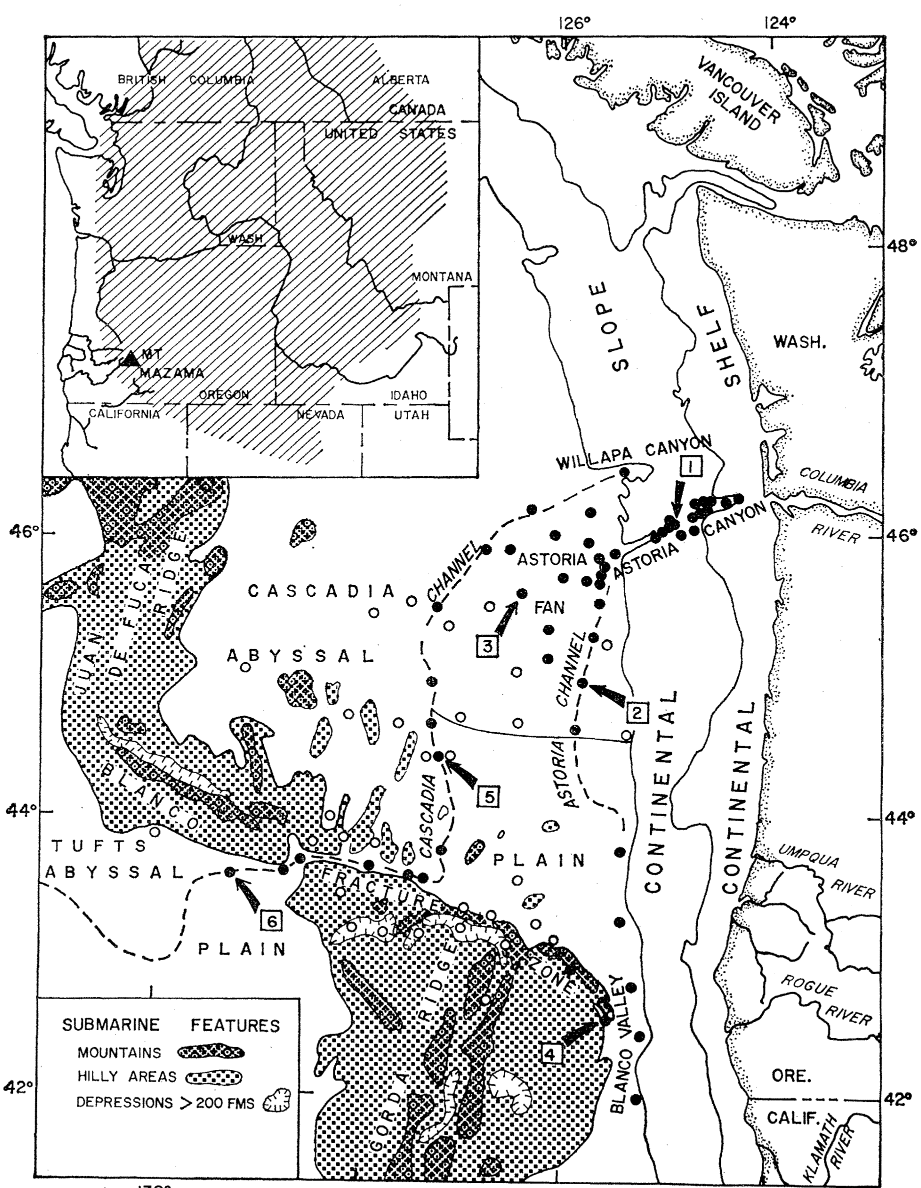

Fig. 1. Areal distribution of Mount Mazama ash. (Solid circles) Sources of piston cores containing volcanic glass; (open circles) sources of cores devoid of ash. Inset: continental area affected by pyroclastic fallout of Mazama ash [modified from Fryxell (*2*)].

turbidity currents (*14*). The size and the amount of tuffaceous material deposited in channel and interchannel regions indicate that the density of the turbidity currents must have been relatively high in the channel and low in the interchannel regions.

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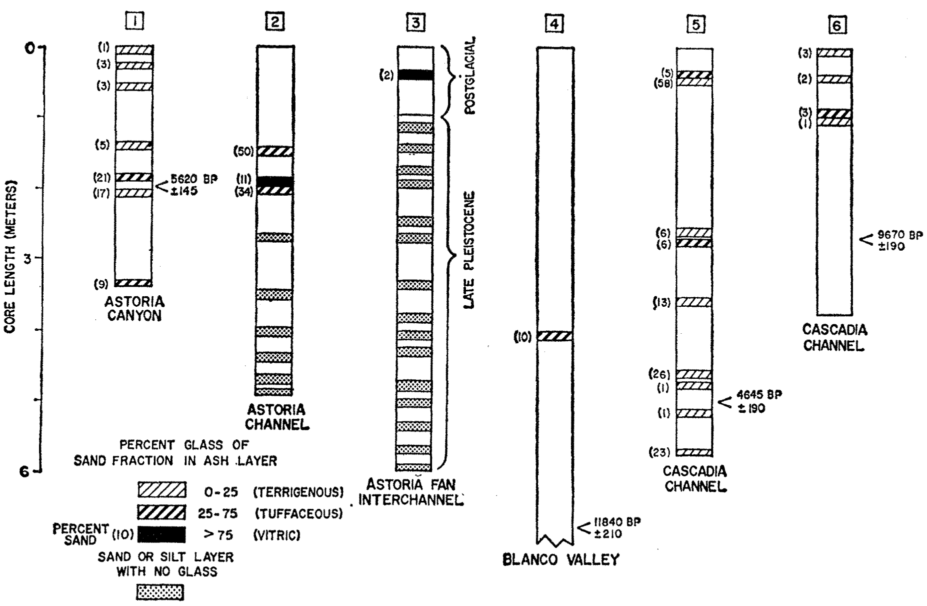

Fig. 2. Vertical distribution and age correlation of Mazama ash in selected cores; see Fig. 1 for sources. All cores shown are postglacial in age except core 3, which includes late Pleistocene deposits. Radiocarbon dates are given for four cores.

age area because (i) the continental ash fall covered most of this area; (ii) the river's heavy-mineral suite predominates in the marine ash; and (iii) the ash layers in Astoria Fan and Channel have the highest ash content, the largest pumiceous debris, and the thickest ash layers found in the marine sediments. The volcanic glass was carried first to the continental shelf by the Columbia River and smaller coastal streams and then by turbidity currents through submarine canyons to the sea floor.

Since all radiocarbon dates suggest that the first ash-bearing turbidity current occurred shortly after the Mazama eruption, the lowest ash horizon can be used (with caution) as a stratigraphic time marker to outline postglacial sedimentary history and processes. On Astoria Fan the average rates of postglacial sedimentation since the Mazama event, if one assumes a 6600-year age for the lowest ash layer, are 10 cm/1000 years in the interchannel areas and 22 cm/1000 years in the main channels (*5*). In Astoria Canyon the rates range from 50 to 78 cm/1000 years (*13*); in Cascadia Channel, from 15 to more than 104 cm/1000 years (*6*). The higher rates in the channels may be explained by channelized flow of turbidity currents. The texture and composition of the ash layers, as well as the long transportation of ash in the deep-sea channels, indicate that the main part of a turbidity current flows in the channels and deposits sedimentary layers varying little in grain size, thickness, and composition over long distances (*5*.) Thin vitric layers of fine silt in the interchannel regions of the fan, similar to vitric silt in the upper part of channel layers, suggest that fine material from a turbidity current flows beyond the channels throughout the interchannel areas of the upper and middle fan; that it lags behind and does not travel as far from the source as the coarse material in the channels. On Astoria Fan the lack of layers of sand and silt above the two closely spaced ash-bearing layers indicates that few if any turbidity currents have occurred on the fan during the past few thousand years. On the other hand, tuffaceous silts near the surface in Cascadia Channel indicate that it is still an active channel for turbidity currents.

The size of turbidity currents containing Mazama ash can be estimated from the distribution of the tuffaceous materials. To carry ash from Astoria Canyon throughout the interchannel regions of the upper fan, the turbidity currents were apparently thick enough to spread beyond the upper reaches of Astoria Channel which has a relief of nearly 200 m (*5*). On Astoria Fan the volume of sediment containing significant amounts of ash can be estimated from the areal distribution of the tuffaceous deposits (7×10^3 km^2) and from the thickness of the ash layers. A computed volume of 2.6×10^5 m^3 of tuffaceous material falls within the range of estimates of the size of slumps (10^4 to 7×10^{10} m^3) that generate turbidity currents (*14*).

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Prehistoric Use of Fur Seals: Evidence from the Olympic Coast of Washington

Abstract. *Archeological excavations on the Olympic Coast of Washington provide evidence that marine mammals, particularly fur seals, constituted a major source of food for inhabitants of this region for more than 2000 years. A recent change in the migratory pattern of the fur seals is suggested by the high percentage of mature males present in prehistoric populations.*

Archeological, geochronological, and biological investigations undertaken during the summers of 1966 and 1967 at Cape Alva, site of the former Ozette Indian village on the Washington coast (*1*), have yielded a collection of more