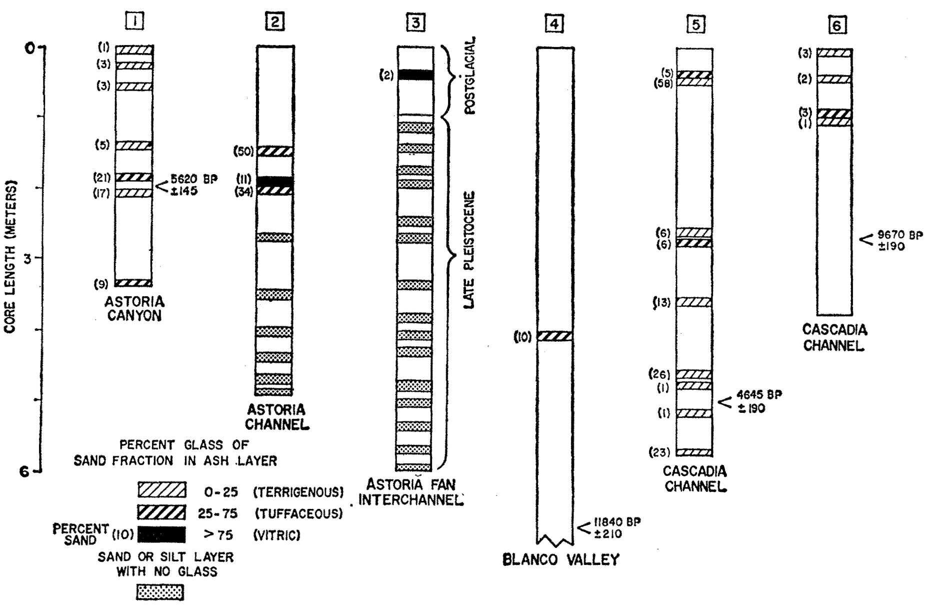

Fig. 2. Vertical distribution and age correlation of Mazama ash in selected cores; see Fig. 1 for sources. All cores shown are postglacial in age except core 3, which includes late Pleistocene deposits. Radiocarbon dates are given for four cores.

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*). 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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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

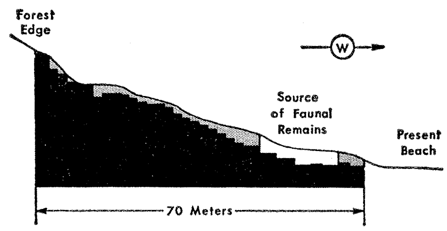

Fig. 1. Longitudinal section of the main trench excavated at the Ozette Village site, showing the area from which faunal remains were analyzed in detail. Stratification here is essentially horizontal, and geologically this is the most easily differentiated area of the main trench.

than 80,000 mammal bones. Quantitative estimates based on a sample of 1140 individual mammals demonstrate that well over 90 percent of the mammal bones recovered are from marine mammals, and that nearly 80 percent are from a single species, *Callorhinus ursinus*, the northern fur seal.

Three significant results became apparent through analyses of these remains: first, the tradition of hunting sea mammals, including fur seals, continued with little detectable change for at least 2000 years; second, archeological evidence at the site reflects no major change in local utilization of fur seals as a food source even after pelagic sealing became a profitable commercial enterprise in which Northwest Coast Indians were deeply involved; and finally, the sex and age ratios of the migratory fur seal herd along the Washington coast have changed notably in recent times.

Sea mammal hunting has long been

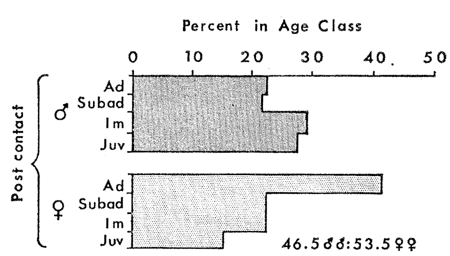

Fig. 2. Age and sex distribution of fur seals in midden at Ozette. A minimum of 286 individuals is represented in the postcontact (with Euro-Americans) period, compared with a minimum of 622 individuals in the precontact period. Abbreviations: *Ad*, adult; *Subad*, subadult; *Im*, immature; *Juv*, juvenile.

recognized as a distinctive economic activity of Northwest Coast cultures (*2*, *3*), but until now little was known concerning its antiquity. Four radiocarbon age determinations (*4*) and stratigraphic interpretation (*5*) provide evidence that the midden at the Ozette Village site represents over 2000 years of occupation. Throughout this time marine mammals comprised a major food source. The artifact inventory—containing harpoon parts, fish hooks, and related gear—as well as fish and marine invertebrate remains, supports the view of continued emphasis on maritime economy inferred from mammal remains.

The faunal assemblage is virtually the same in all excavated areas of the site. Laboratory analyses presented here include data from nine contiguous squares (comprising 103 m^3 of midden) in the deepest part of the main trench through the site (Fig. 1). Northern fur seals, the predominant mammal in all excavation levels, were identified by direct comparison of cranial elements with known specimens of *Callorhinus ursinus*.

I determined the minimum number of individuals for each 20-cm vertical excavation level by matching pairs of canine teeth belonging to single individuals. Although it is sometimes possible to match incorrectly teeth from different individuals and tally them as one, a single individual will almost never be counted twice. My calculations, therefore, are based conservatively on the least possible number of individuals in each 20-cm excavation level.

Studies conducted during the last 75 years have established the migratory route of the northern fur seals (*6, 7*) and have shown that these mammals are usually found relatively close to shore in the vicinity of Umatilla Reef, 3 miles (5 km) west of Cape Alava (*8*). Therefore, it is not surprising to find their bones in middens along this part of the Olympic Coast. However, their consistent numerical dominance as a food source was unanticipated.

The continuous emphasis on fur seal hunting had not been demonstrated previously, and ethnographic accounts (*3, 9*), as well as early reports on pelagic sealing (*6*), imply that fur seals were not hunted extensively until after Euro-American contact and the introduction of pelagic sealing for furs around 1880. Actually, data from the Ozette Village site suggest that Euro-American contact did not alter either the num-

Table 1. Criteria used for estimating ages of fur seals from midden of the Ozette Village site.

Condition of root canal	Relative maturity	Inferred age of individual
Canal open; virtually no dentine present	Juvenile	< 3 years
Canal open; extends well past base of enamel	Immature	3 to 6 years
Canal open; does not extend past base of enamel	Subadult	6 to 10 years
Canal completely or nearly closed	Adult	> 10 years

ber or character of the local fur seal population. Despite the economic incentive provided by the fur trade, fur seal bones do not increase during the historic period.

On average, 6.2 individuals in each 2-m square were identified per level of postcontact deposits, compared with an average of 7.8 individuals in each level of precontact deposits. Thus, if any real difference in vertical distribution exists, it would appear that fewer fur seals were utilized after contact than before. Certainly these people routinely hunted fur seals long before the beginning of European fur trade there, less than 200 years ago.

It should be noted, however, that after about 1880 the Indians hunted from sealing fleets (*6, 9*), removed the pelts, and left the carcasses at sea. Therefore, bones found in the site probably do not reflect the reported increase in pelagic sealing for furs, but instead record animals harvested primarily for food.

Concomitant with the reported reduction of the fur seal herd through extensive pelagic sealing around 1900 (*6*), my data suggest a marked change in the sex and age ratios of the migratory herd. Sex can be determined easily in *Callorhinus ursinus* because the size and shape of canine teeth differ greatly between males and females. Age determinations can be made by examination of annual growth rings in the canines (*10*), and samples have been submitted to the Bureau of Commercial Fisheries, Division of Marine Mammals, for exact age determinations. Because this detailed information is not yet available, I constructed relative age categories based on the size of the root canal, which becomes smaller as dentine is deposited with increasing age (Table 1). Preliminary analysis of growth rings (*11*) shows that the inferred ages given in Table 1 are reasonably accurate estimates of actual age categories.

Figure 2 gives the relative age and sex distribution of fur seals brought to the site before and after Euro-American contact. About half the males (that is, all adults and subadults) fall into the age class of 5 years and older. Today, mature males do not normally migrate south of the Gulf of Alaska (*12*). During the last 50 years, only four mature males were collected off the coasts of Washington and British Columbia (*13*), and one was collected off the coast of California. Fiscus (*14*) reports that he knows of no earlier records of mature males for the vicinity of Cape Alava.

Because the Ozette Indian village was abandoned shortly after 1900, it is presumed that the uppermost cultural deposits, which contain numerous items of Euro-American manufacture intermixed with fur seal bones, are about that age. The relatively constant high percentages of older males in the midden, compared with the virtual absence of older males in recent populations found locally, indicates that a major change in age composition of males has occurred sometime since approximately 1900. Because mature males still occur in more northerly populations, I can conclude only that there has been a change in the migratory pattern of male fur seals. Speculations about the reasons for this change would be premature, but the evidence is undeniable and it certainly correlates in time with the last major pelagic sealing.

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Band Gap of Forsterite

Abstract. *Optical absorption and reflectivity measurements on synthetic forsterite show that this silicate has a wide band gap of the order of 8.4 electron volts; thus it resembles other pure insulating oxides such as MgO. For natural olivines, in which divalent cations, mainly Fe^{2+}, can replace Mg^{2+}, all the optical absorption bands between the lattice overtones in the infrared and the first excitonic transition at 8.4 electron volts are due to the presence of iron.*

A good electrical insulator is characterized by a wide band gap; that is, between a virtually empty conduction band and an almost filled valence band there is an energy range greater than 3 to 4 ev in which traveling-wave electron states are forbidden.

Unless impurities or defects introduce energy levels within the forbidden gap, the full energy of the band gap must be made available for creation of occupied conducting states. Optical absorption and reflection measurements on iron-free synthetic forsterite, Mg_2SiO_4, demonstrate that it is a wide-gap insulator. When iron, mainly ferrous, is substituted for magnesium as in the mineral olivine, $(Mg,Fe)_2SiO_4$, such optical measurements show that the iron produces energy levels lower than the forsterite band gap. Furthermore, because excitations involving these impurity levels have energies lower than the band gap, impurity effects are probably the dominant conduction processes in natural crystals.

The synthetic forsterites were single crystals produced by the flame-fusion method (*1*), the largest being of centimeter size. It was possible to vary iron content [Fe : (Mg + Fe)] from 0.007 to 1 percent molecular. Furthermore the low iron content permitted the Fe^{3+}:Fe^{2+} ratio to be varied over a wider range than is possible in natural crystals without damage to the crystal; because the crystals were grown in an oxidizing flame, this ratio was rather high in the as-grown crystals but could be lowered by heating in a reducing atmosphere. The crystals were transparent, and samples containing more than about 0.3 percent Fe were lightly tinted; stoichiometry was higher than that listed for natural olivines, and the measured density equalled that calculated from the lattice parameters (*1*).

At energies greater than about 3.3 ev, natural olivines containing Fe of the order of 10 percent molecular show strong absorption that blocks transmission of ultraviolet light through samples thicker than about 0.1 mm. Once it was felt that the apparent absorption edge at 3.3 ev represented the onset of fundamental transitions between valence and conduction bands in the olivine lattice (*2, 3*) and thus defined the band gap. However, Fig. 1 clearly demonstrates that the apparent absorption edge is simply a result of iron in the crystal: the progressive increase of iron doping progressively increases absorption. The ultraviolet transparency of iron-free forsterite has also been noted for sintered material (*4*) and for single crystals synthesized by the Bridgman method (*5*).

Figure 2 compares transmission by a very thin natural olivine and a synthetic sample (No. 2Lc) of comparable thickness; the iron-free crystal transmits light for another 3 ev beyond the cutoff in the natural crystal. Fundamental transitions in pure Mg_2SiO_4 set in only beyond 7.5 ev, at which point the absorption intensity becomes too great to permit the transition to involve iron and still give reasonable values of oscillator strength. Thus the minimum energy separation for states associated with valence and conduction bands must be greater than 7.5 ev, and absorptions below this energy must be due to impurities.

Figure 2 also shows that heating of a synthetic sample in a reducing atmosphere dramatically decreases the absorptions at 4.6 and 6.2 ev. Because the 4.6- and 6.2-ev bands are strongest in crystals that have been heated in an oxidizing atmosphere, the bands must involve mainly Fe^{3+}. The transitions due to Fe^{3+} are so much stronger than those due to Fe^{2+} that the residual Fe^{3+} in natural crystals could account for the strength of the observed near-ultraviolet cutoff (*6*). However, the facts that the near-ultraviolet absorption in natural olivines is a superposition of bands hav-