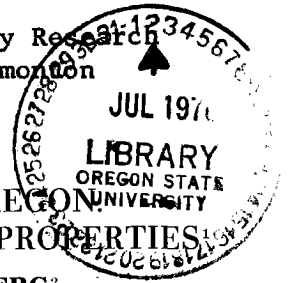


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SOILS FROM MAZAMA ASH IN OREGON. IDENTIFICATION, DISTRIBUTION AND PROPERTIES

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ABSTRACT

Ejecta from Mt. Mazama form the most extensive surficial deposit of volcanic ash in the area. The present occurrence on the landscape is dependent on elevation, topography, aspect, and vegetation as well as distance from Crater Lake. Soil textures range from coarse gravels close to the source to fine ash at distances over 300 km. A particle size discontinuity occurs in the profiles with coarser materials overlying finer materials. This is most pronounced in the coarse pumice area but it extends into the medium or fine ash areas. Soil colors depend upon depth of weathering but generally are yellowish brown to light grey in lower horizons and somewhat darker in surface horizons. A striking feature of the soils is the relatively fresh and unweathered appearance even after almost 7,000 years.

Several other recent ash deposits overlap the Mazama ash within the study area. One which occurs below the Mazama in northeastern Oregon is presumed to be from Glacier Peak. An ash younger than Mazama also occurs in the same area and is believed to be St. Helens-Y. Localized deposits of pumice from Newberry and Devils Hill as well as from numerous cinder cones overlie the Mazama material in central Oregon.

Instrumental neutron activation analysis provides a means of distinguishing different ash deposits. Twenty-one nuclides have been determined on separates of volcanic glass; many of them distinguish the Mazama ash from Newberry, St. Helens, and Glacier Peak.

The clay size fractions of soils developed from Mazama ash consist predominantly of amorphous components. They also contain complex suites of 2:1 and 2:2 type phyllosilicates. There is a general uniformity in the clay mineral suites across a climatic transect in the coarse pumice area. However, the relative amounts of individual components vary with climate and depth in the profile. The formation of the 2:1 type phyllosilicates may be associated with alternate wetting and drying in the solum and with the poorly drained matrix of the pumice particles.

Parameters relating to porosity of pumice have been determined by mercury intrusion. The median pore diameters for coarse sand-size particles of Mazama ash are in the range 7.2-7.4 μ . The total pore volumes are in the range of 0.8-1.0 ml/g. The percentage volume pores between 30 and 0.2 μ range from 78-85 per cent. To a large degree, the internal

1 Special Report No. 268, Oregon Agr. Exp. Sta., Corvallis. Partial support of the AEC, contract AT(45-1)-2062, and the NSF, Grants No. GP2449 and No. GA1355, for different phases of investigation are gratefully acknowledged.

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porosity of soils developed on Mazama pumice determines the physico-chemical properties of the systems. Unsaturated vapor flow, thermal conductivities, and rates of exchange with solutions are all low in these soils.

INTRODUCTION

The recent geologic history of the northwestern United States is intimately related to volcanism. Numerous vents exist in the area from which volcanic ejecta have been widely distributed. One of the principal sources was Mt. Mazama, site of Crater Lake, Oregon. Other prominent sources include Glacier Peak, St. Helens, Rainier, and possibly Mt. Adams in Washington and Newberry Crater and Devils Hill in Oregon. There are also a number of recently active cinder cones in Oregon which were sources of locally distributed ash falls.

The occurrence of pyroclastic deposits is of interest to all branches of soil science as well as to the related sciences of geology, oceanography, anthropology, and archeology. Yet, we lack detailed information on sources, chronology, distribution, and influence of volcanic ash on soil processes and properties. In this respect we lag behind other areas of the world such as Japan and New Zealand. There are, however, encouraging developments in Quaternary volcanology of the region (Czamanske and Porter, 1965; Fryxell, 1965; Powers and Wilcox, 1964; Steen and Fryxell, 1965; Wilcox, 1965).

The distribution of volcanic ash over the landscape has undoubtedly had considerable influence on the soils. Dominant soils in large areas east of the Cascades are developed from pumice. Other regional soils developed from alluvium, colluvium, lacustrine sediments, and loess probably contain ash in varying degrees. It may be taken as a first approximation that all of the soils of Oregon have been influenced by volcanic ash. In spite of this, previous pedological studies have not been specifically oriented to soils developed from volcanic ash. The exception to this is work by C. T. Youngberg and associates (1959, 1964, 1966). They have contributed to our knowledge of properties of coarse pumice from Newberry and Mazama in relation to forest vegetation.

An expanded research program on soils from volcanic ash has recently been initiated at Oregon State University. The deposit from eruption of Mt. Mazama is receiving major emphasis for the following reasons:

1. It represents the largest surficial deposit of ash in the state.
2. The time of soil forming processes is known; Mt. Mazama erupted about 6,600 years ago (Allison, 1966).
3. In comparison with other sources in the area, more information is available in the literature; the coarse deposit has been mapped and characterized (Williams, 1942).
4. It was possible to obtain samples of soil profiles which were relatively unmixed. This is important to studies on weathering

products. After establishing our techniques and obtaining data on the relatively pure deposits, we hope to extend the investigations to more complex mixed systems.

The research currently being pursued consists of several related lines of investigation. One study concerns the stratigraphy, redistribution and mixing of ash in local environments. Another critical investigation involves identification of deposits and determination of source on the basis of trace element composition. Another project is concerned with the crystalline and amorphous clays in fine volcanic ash from Mt. Mazama. We wish to relate the weathering products to factors and processes of soil genesis. A study involving characterization of porous matrices in pumice and the relationships of porosity to distribution and movement of ions between solid and solution phases is also being pursued.

The purpose of this paper is to review the research program in progress, to outline the problems and the approaches, and to present some of the preliminary results. It is to be stressed that the projects to be discussed are cooperative and represent contributions from a number of other individuals who should be recognized. These include G. A. Borchardt, F. W. Chichester, W. H. Doak, E. G. Knox, J. A. Norgren, D. Rai, R. A. Schmitt, and A. A. Theisen.

DISTRIBUTION AND STRATIGRAPHY

Williams and Goles (1968) estimated that the total volume of pumiceous fragments and glass shards resulting from eruption of Mt Mazama was in the order of 8-14 cubic miles. Our studies indicate that this volume of ash is probably underestimated. This great volume of material was deposited on the landscape generally to the east and northeast of Crater Lake. Williams' (1942) isopachytes diagram shows 2 or 3 lobes with the axis of the main lobe extending to the northeast from the source. Recent evidence has suggested that the area covered by Mazama ash includes much of Oregon, Washington, Idaho, eastern Montana, and the southern parts of British Columbia and Alberta (Powers and Wilcox, 1964; Fryxell, 1965; Westgate and Dreimanis, 1967).

Sampling Transect

The studies on soils from Mazama ash involve a sequence of samples extending from the coarse pumice area near the source to the fine ash deposits in northeastern Oregon, 450 kilometers from Crater Lake. Emphasis has been placed on a northeast trending transect corresponding to the axis of the main lobe. Movement and redeposition has occurred in many areas of the deposit since there is thickening downslope and alluvial fans of ash along stream channels. The sample sites were chosen on high plateaus and broad ridges in order to minimize contamination by mixing. One difficulty encountered was mixing of ash with the buried solum by tree throw. This required examination of a number of profiles in an area and selection of sites where this was minimal.

Occurrence on the Landscape

Uplands

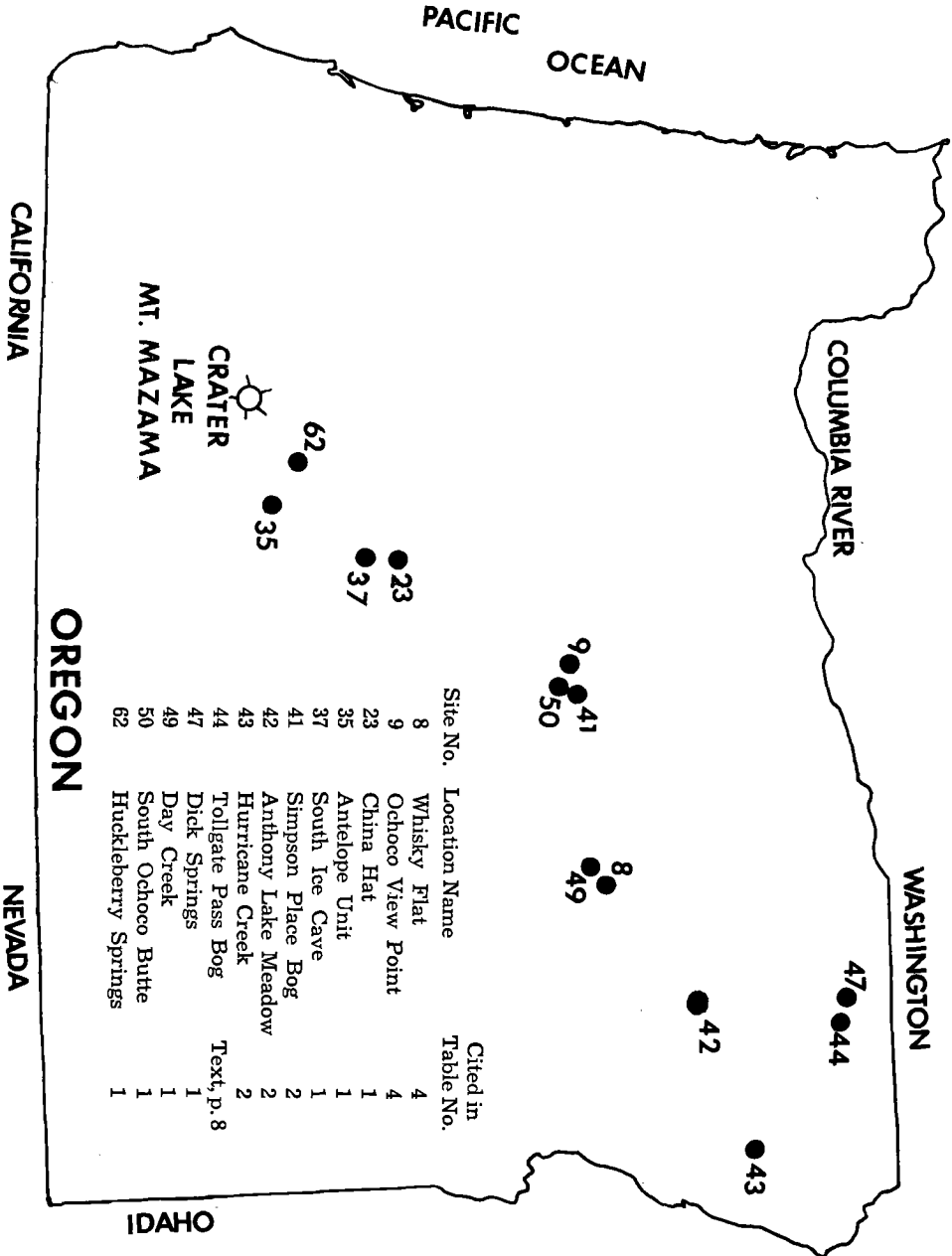


Figure 1. Sample Locations Discussed in Text

In the coarse pumice area the thickness of the deposit decreases fairly markedly as the distance from the source increases. The isopachytes diagram of Williams (1942) shows a depth of 10 ft. (3 m) at 29 miles (46 km) and 2 ft. (60 cm) at 76 miles (121 km) measured along the northeastern lobe. The depths of the deposit in relation to distance along the sample transect are shown in Table I. In the fine ash area the decreases in thickness with the distance are not marked. In some cases the thickness of fine ash exceeds that in the coarse pumice area closer to the source. The thickness measurements on level topography were surprisingly reproducible in a number of different areas in central and northeastern Oregon even though 100-300 kilometers apart.³ A high percentage of particles in the deposits of northeastern Oregon appear to be accretionary lapilli which are presumed to be formed by collection of dust in rain drops^{3, 4}. Apparently other factors such as wind and rainfall were involved in the fallout patterns. This may account for greater thickness of deposits than anticipated in some areas.

Table 1. Thickness of Volcanic Ash on Uplands in Relation to Distance from Crater Lake, Oregon.

Site	Distance (km)	Thickness (cm)
Huckleberry Springs (Sec. 36, T.27S, R.9E.)	50	224
Antelope Unit (Sec. 1, T.28S, R.10E.)	54	223
South Ice Cave (Sec. 13, T.23S, R.13E.)	107	68
China Hat (Sec. 9, T.22S, R.14E.)	117	56
South Ochoco Butte (Sec. 11, T.13S, R.20E.)	222	85
Day Creek (Sec. 24, T.11S, R.30E.)	304	72
Dick Springs (Sec. 11, T.3N, R.37E.)	445	68

The rather sharp decrease in thickness over a relatively short distance (50-60 km) is a reflection of the influence of gravity on coarse sand and gravel size particles which are dominant in the profiles as far out as the China Hat sample site. The very fine sand and silt particles were carried much farther by the prevailing winds and were thus subject to the rainfall effects mentioned above. The South Ochoco Butte, Day Creek and Dick Springs profiles are all finer textured than those closer to the source.

The previous discussion on thickness is based on observations made at sites in which movement and redeposition is believed to be minimal. The deposit is not continuous across the transect. The presence of ash and its thickness is affected by elevation, topography, aspect, and vegetation.³ These factors become increasingly important with increasing distance. Close to the source, the deposit blankets the landscape. In other areas, the ash is absent on many south and west slopes but present on many north and east slopes as well as on broad ridge tops and plateaus. The deposits may thicken downslope. Some slopes have a complex

3 D. Rai, Unpublished data for Ph.D. Thesis, Oregon State University, 1970.

4 W. H. Doak, Unpublished M.S. Thesis, Oregon State University, 1969.

pattern of ashy and non-ashy materials; the ash deposits are often associated with dense vegetation. Prominent alluvial fans of ash are common; apparently there has been a lot of movement of ash into drainage systems soon after deposition. Layers of Mazama ash have been found in the Columbia fan off the Oregon coast (Nelson *et al.*, 1968).⁵

Bog Sites

Hansen (1947) used ash layers in bog sites as a marker for pollen analyses of sedimentary columns. He has shown the influence of the pumice mantle from Mt. Mazama upon forest succession. Layers of volcanic ash in bog sites are useful in pedologic investigations since they provide a means of identifying and tracing deposits. They have been useful in developing the stratigraphy, in separating different falls in the area, and as a reference for correlation with upland sites.

Samples obtained from bog sites along the transect are generally consistent with the upland sites. The Simpson Place bog (Table 2) is near the South Ochoco Butte site (Table 1) and has an ash layer 33 cm thick. The ash layer in a bog on Tollgate Pass near the Dick Springs upland site is 34 cm thick. The lack of significant change in thickness over a distance of 200 km is consistent with the observations on upland sites. The thickness of layers in bog sites is generally less than on uplands by about a factor of two. This is due at least in part to density as the layers in the bogs are more compact. However, the differences do suggest the need for caution in interpretation of upland thicknesses. The possibility of thickening on uplands by wind deposition is in the process of evaluation⁵.

Table 2. Age Dates (C^{14}) for Bogs Containing Volcanic Ash⁷.

Bog (Location)	Dist. from Crater Lake (km)	Sample	Age (yrs. B.P.)	Correlating Ash
Simpson Place (Sec. 32, T.12S, R.21E.)	232	Peat below ash	6,500 \pm 130	Mazama
Anthony Lake Meadow (Sec. 7, T.7S, R.37E.)	338	Peat below upper ash	6,910 \pm 140	Mazama
		Peat above lower ash	9,460 \pm 130	Glacier Peak?
Hurricane Creek (Sec. 13, T.2S, R.44E.)	478	Peat above upper ash	2,430 \pm 100	} St. Helens-Y
		Peat below upper ash	3,120 \pm 105	
		Peat below lower ash	7,420 \pm 160	Mazama

An ideal bog site would reflect the aerial deposition and the sequence of shower activity. Stratification of ash layers in bogs is common and

⁵ G. A. Borchardt, Unpublished data for Ph.D. Thesis, Oregon State University, 1970.

this leads to speculations on a sequence of showers during eruption of Mt. Mazama. Stratification could also be due to sorting in water, wave action and deposition by erosion from uplands. Some stratification has been observed on upland sites but it is not as apparent as in bog sites, possibly because of mixing by tree throw, etc. An exception to this is a road cut through a deposit of Mazama ash in which the stratification is striking. The laminae follow the contours of the old land surface. Critical observations on sites such as this or on properly chosen bog sites may demonstrate the sequential nature of eruptions of volcanic ash from Mt. Mazama.

Nature of Profiles

General

Soils from Mazama ash usually show an A1, AC, C1, or A1, AC, C1, C2 type of sequence. Weakly podsolized profiles may be found in the higher rainfall areas under forest vegetation. Although the soil colors depend on the depth and extent of weathering, they generally range from yellowish brown (10YR 5/4) to light grey (2.5Y 7/2) for the lower horizons. The A1 and AC horizons are darker (10YR 4/4 - 10YR 3/3) due to the presence of organic matter and oxidation of iron. Soil textures are very much dependent upon distance from the source. Soils 80 km from Crater Lake still have gravelly textures. The percentage of fine silt increases with distance up to about 320 km and then remains constant. Perhaps the most striking feature of soils on Mazama pumice is the relatively fresh and unweathered appearance even after almost 7,000 years. This contrasts with many of the soils of Japan and New Zealand where considerably more weathering has taken place in less time.

C1-C2 Discontinuity

The Mazama deposit is characterized by a particle size discontinuity (C1-C2 horizons) at a number of locations where coarser materials overlie the finer. The mean weight diameters for samples taken 50 km from the source range from 1.02 to 1.65 mm for the C1 horizon and from 0.29 to 0.58 mm for the C2 horizon.⁴ The C1-C2 horizon boundary is abrupt and either smooth or wavy except where it has been disturbed. The Mazama deposit contrasts with the pumice deposit from eruption of Newberry Crater about 2,000 years ago (Libby, 1955) which may be taken as typical of a single eruption. In this case the particle size increases with depth. Samples taken from a site within a few miles of the source had mean weight diameters of 1.1 mm in the AC horizon, increasing to 2.7 mm at the base of the C horizon.⁴

The Mazama C1-C2 discontinuity is most apparent in the coarse pumice area of central Oregon. Examination of profiles across our sampling transect reveals that the discontinuity also extends into the medium or fine ash deposits. The relative thickness of C1 and C2 horizons varies with location (Chichester, 1967) and may be related to the different lobes on the isopachytes diagram (Williams, 1942).

Williams (1942) called attention to the larger particles above the finer material in the Mazama deposit. He gives no indication, however, that he is aware of the sharpness of the boundary. His interpretations involve increasing violence of the eruption associated with a wind shift from easterly to northeasterly directions. Fisher (1964) pointed out that a single contour map may represent more than one volcanic outburst of varying intensity in a field of changing wind direction. He assumed that each lobe was formed by a single eruption or series of eruptions within a short time interval. Some of us have also speculated on the possibility of two or more eruptions. Part of the soil sampling and laboratory analyses have been directed to this question. The data are not yet complete but it appears that if different periods of eruption are established, they will have to be on the basis of critical field mapping and morphology of the deposit. Although the question on the nature of C1-C2 discontinuity has implications to pedology, the reason for its presence is dominantly one for the geologist to solve.

Relation to Other Ash Falls

The pedologist must be conscious of overlapping deposits. Ejecta from Mt. Mazama forms the most extensive recent deposit in the area. However, by no means, is it the only one. The Cascade Range has a sequence of volcanic peaks and a number were active during the Quaternary. Deposits from some of these overlap our transect of the Mazama deposit.

The distribution of Glacier Peak ash was to the southeast of the source (Powers and Wilcox, 1964; Fryxell, 1965). The fallout pattern is presumed to include the northeastern corner of Oregon. The Glacier Peak ash occurs stratigraphically below the Mazama ash in eastern Washington and Idaho (Powers and Wilcox, 1964). Fryxell (1965) has suggested a date of about 12,000 years for Glacier Peak. Bog sites at the northeastern end of our transect contain an ash layer below the Mazama and we suspect this layer to be ash from Glacier Peak. On the basis of the thickness of the layer and the lower position in the stratigraphic column, it does not appear to be overly important in present day soils in Oregon.

Bog sites in northeastern Oregon have also revealed the presence of another ash younger than Mazama. The layer is about 2-5 cm thick with more yellowish brown colors and coarser textures than Mazama in this area. The stratigraphic occurrence above the Mazama ash is consistent with previously observed differences in horizons of the Tolo series⁶. Preliminary data⁷ based on field studies, mineralogy, and C¹⁴ dates suggest that this ash is St. Helens-Y (nomenclature of Crandall *et al.*, 1962). The occurrence of St. Helens-Y in this area is considerably south of the previously projected distribution of this ash (Crandall *et al.*, 1962).

6 Norgren, J. A. 1962. Thin-section micromorphology of eight Oregon soils. Unpublished M.S. Thesis, Oregon State University.

7 Unpublished data. J. Norgren, M. E. Harward, and G. A. Borchardt. Oregon State University; manuscript to be submitted.

Other localized deposits occur stratigraphically above the Mazama in central Oregon. These include pumice from Newberry Crater and Devils Hill (Williams, 1942) and basaltic cinders erupted from scores of cones in the area (Taylor, 1965, 1968).

IDENTIFICATION

A study of the weathering products and properties of soils formed on Mazama ash assumes the ability to recognize the deposit and distinguish it from others. Methods previously used to identify volcanic ash include stratigraphy, age dating, kind and amount of primary minerals, index of refraction of the glass, and chemical compositions.

Radiocarbon

Stratigraphic information was discussed in the previous section. It was possible to obtain C^{14} dates from bogs in some areas along the transect for correlation with stratigraphy and upland sample sites. Peat samples taken just below the predominant ash layers at all 3 sites have dates which correspond to Mazama (Table 2). A date of 6,600 years is commonly accepted for this deposit (Allison, 1966). These data are consistent with the initial hypothesis that the predominant source of ash along the sample transect is Mt. Mazama.

The Anthony Lake site contains two ash layers. Hansen (1947) observed a layer of volcanic ash in the bogs of this region and suggested the area to us⁸. The selected sample site was near the edge of a broad bench some distance from higher slopes. Topographic position of the site and apparent absence of stratification in the layers suggest that the 18 cm thickness of upper ash represents aerial deposition from Mt. Mazama. The lower ash layer of 10 cm thickness was separated from the Mazama ash by 127 cm of peat. This ash is stratified and rests directly on unoxidized silts and clay. On the basis of stratigraphic position and the work by Powers and Wilcox (1964) and Fryxell (1965), it was assumed that the lower ash was from Glacier Peak. Fryxell (1965) has suggested an age of 12,000 years for Glacier Peak which he regards as minimal. The C^{14} data for peat above the lower ash at Anthony Lake (Table 2) indicates an age greater than 9,500 years for the ash layer. We can only speculate on the time between the ash deposition and encroachment of peat above it. Dates from above and below an ash layer at Hurricane Creek differ by 700 years. A difference of 2,500 years between the date by Fryxell and our sample may be too large to account for on the basis of our sample being above the ash. Fryxell's date was based on C^{14} in shells of fresh water molluscs which were interbedded in a deposit of fine sand, silt, and small pellets of ash in a slackwater area. Since the shells were in a mixed deposit, the correlation of shell dates with the ash may not be entirely valid. The possibility of an over estimation of age exists. Both verifications of the source of the lower ash at Anthony Lake Meadow and other age dates for Glacier Peak are needed to resolve the problem.

⁸ Personal communication. H. A. Hansen, Oregon State University, Corvallis, Oregon.

The age of the ash at Anthony Lake Meadow has implications to the time of glaciation of the area. The lower ash at Anthony Meadow lies above the silt and clay deposit which is believed to be of glacial origin. These observations suggest that the ash was deposited subsequent to glaciation. The glaciers had receded above this elevation (7,100 ft) sometime prior to 9,500 years B.P. This is consistent with the suggestion by Powers and Wilcox (1964) that Glacier Peak ash is very late glacial or early postglacial in age.

The data for peat samples which bracket the upper ash at Hurricane Creek correlate with St. Helen-Y. Crandall *et al.* (1962) suggested a date of 3,200 years for this deposit. They obtained radiocarbon ages of 2,500 and 3,000 years on samples taken above and ages of 3,500 and 4,000 years on samples from below the ash layer. The present data narrow this range of time but do not significantly change the date of eruption.

Chemical Composition: Instrumental Neutron Activation Analysis

Radiocarbon dates greatly aid in establishing the identity of ash deposits. Unfortunately, reliable samples are not always available for this purpose. There are also problems in projecting from bogs to upland sites, particularly if they are some distance apart. For example, we have not located good bog sites for the area of our transect around John Day, Oregon. There are advantages to methods of identification based on samples at the specific site under investigation. Kinds and amounts of primary minerals, index of refraction of glass, and chemical composition have been used for this purpose (Crandall *et al.*, 1962; Powers and Wilcox, 1964; Czamanski and Porter, 1965; Steen and Fryxell, 1965). Chemical analyses generally have been restricted to the more common major elements. Trace element composition by wet chemical methods has not been extensively used due to laborious techniques and limits of detection. Each of the different approaches have some limitations due to overlapping parameters, bimodal frequency distributions and problems of mixing or contamination. There is no single method which will determine source. Rather, several methods are used to complement each other.

Activation analysis has been successfully applied to analysis of meteorites and other geologic material (Schmitt *et al.*, 1965; Gordon *et al.*, 1968). Although not previously used for distinguishing volcanic ash deposits, activation analysis should offer considerable promise for this purpose. The merit for the approach lies in the ability to obtain analyses for a large number of trace elements more rapidly than is possible with wet chemical procedures. A "finger print" of many elements should increase the reliability of identification.

A preliminary study indicated the potential usefulness of instrumental neutron activation analysis (INAA) in distinguishing different deposits of volcanic ash (Theisen *et al.*, 1968). Ash samples of known origin were used to develop the general methodology, the elements detectable and the magnitude of differences between samples.

It was recognized that contamination of layers of pyroclastics by primary minerals and possible differences due to mineral sorting might contribute to geochemical variability and confound the interpretations. Therefore, glassy components were isolated from fine sand size (125 to 63 μ) fractions using bromoform-bromobenzene, $\rho = 2.4 \text{ g/cm}^3$. An additional separation at 2.2 g/cm^3 may be used to remove fragments of plant residues. The separates were then irradiated in the Oregon State University TRIGA Reactor and analyzed using the method of Gordon *et al.* (1968). The counting equipment initially consisted of a 3.6 cm^3 Ge(Li) semi-conductor detector and a 4096 Nuclear Data Multi-channel analyzer. Counting statistics and precision were later improved by the use of a 30 cm^3 Ge(Li) detector.

Analysis of the energy spectra emitted from the irradiated sample and comparison with suitable standards yield elemental abundances down to the range of parts per million. The glassy separates yielded 21 nuclides measurable directly with these techniques. These include the alkali and alkaline earth elements Na, Rb, Ca, and Ba; the rare earth elements La, Ce, Nd, Sm, Eu, Tb, Yb, and Lu; and the transition elements Th, Hf, Ta, Co, Fe, Sc, and Cr.

Table 3. Abundances of Nuclides in Known Volcanic Ash Samples relative to Mazama C1 (Theisen *et al.*, 1968).

Activity Ratio for:	Mean Ratio	Coef. of Var. (%)
Mazama C2/Mazama C1	1.18	16
Newberry/Mazama C1	1.26	38
Glacier Peak/Mazama C1	0.58	56

Table 4. Activity Ratios of Nuclides for Unknown Ash Relative to Known Sources (Theisen *et al.*, 1968).

Activity Ratio for:	Mean Ratio	Coef. of Var. (%)
Ochoco View Point (OVP), AC horizon		
OVP/Mazama C1	0.92	21
OVP/Newberry	0.87	56
OVP/Glacier Peak	1.94	48
Whisky Flat (WF), AC horizon		
WF/Mazama C1	0.91	23
WF/Newberry	0.72	75
WF/Glacier Peak	1.93	54

The basic assumption in this approach is that the elemental compositions of various sources differ. The extent to which compositions differ can be expressed in terms of relative concentrations. The data in Table 3 summarize the differences between samples of known origin. The means (column 1) were obtained from the ratios of each of the 21 elements determined. For a sample like Mazama C1, the activity ratio for a given element should be near 1. The mean ratio for all elements

in the sample should also be near 1 and the coefficient of variations (% C.V.) should be low. The data show that Mazama C2 sample is most like Mazama C1 while the Glacier Peak sample differs most from it.

The technique has been tested by comparing values for known sources with samples of AC horizons from two locations near the center of the sample transect (Theisen *et al.*, 1968). The data suggest Mazama as the source of the volcanic ash at both locations (Table 4).

Detailed investigations of volcanic ash deposits using INAA are now in progress.⁵ Attention is being given to the following factors:

1. variability within deposits and between different sources in order to establish confidence intervals for composition of the different elements in a deposit;
2. variation with distance across a transect of the Mazama deposit using soil horizons and preserved ash layers in bogs;
3. variation with depth to determine the effects of weathering;
4. variation across the particle size discontinuity (C1-C2 horizon boundary);
5. effect of heavy minerals in the sample in order to determine the possibilities for use of element ratios regardless of crystalline form;
6. changes in elemental composition upon clay mineral formation in Mazama ash;
7. elemental compositions of overlapping ash deposits in north-eastern Oregon; and
8. analyses of samples of regional interest such as the Mazama ash in the vicinity of Edmonton (Westgate and Dreimanis, 1967) and the ash in ocean sediments on the Astoria fan (Nelson *et al.*, 1968).

CLAY COMPONENTS AND WEATHERING

The nature of clay size ($<2 \mu$) components in the coarse pumice from Mt. Mazama has been determined (Chichester, 1967; Chichester, Youngberg and Harward, 1969). The analyses were made on samples taken across a climatic transect in central Oregon in which the estimated annual precipitation ranges from 50 to 150 cm (20 to 60 in).

Amorphous Components

Amorphous components dominate the clay fraction of these soils. Weight losses as a result of treatment for dissolution of amorphous materials exceed 70 per cent of original oven-dry weight. The importance of amorphous materials was also indicated by the nature of X-ray diffraction patterns, differential thermal analyses, and specific surface measurements by N_2 adsorption. The amounts of amorphous materials were higher in C horizons than in upper horizons and they were also higher at sites at the drier end of the transect. It was not possible to differentiate amorphous components. Rather, they were regarded as an amorphous complex including discrete colloidal hydrous oxides of aluminum, silicon, and iron as well as the various solid solutions of silica, alumina, and water referred to as "allophane".

Crystalline Components

The phyllosilicates consisted of complex suites of 2:1 and 2:2 type layer silicates. These included chloritic intergrades, beidellite, chlorite, vermiculite, montmorillonite, and a micaceous mineral. Other minerals in the $< 2 \mu$ fractions were gibbsite, plagioclase feldspars, and quartz.

There was general uniformity in the clay mineral suites across the transect. However, some variations in individual components occurred between horizons and across the transect. Chloritic intergrades were most abundant and occurred in all samples. The occurrence of beidellite was also fairly uniform. Montmorillonite was identified at all sites, generally in the lower horizons. The relative amount of chlorite decreased with depth. Vermiculite was not observed in samples from the driest site. Gibbsite was found in the more strongly weathered surface horizons toward the wet end of the transect and especially in transitional horizons. The micaceous components occurred more frequently in samples from upper horizons and the drier end of the transect.

Weathering and Genesis of Clays

Although the amorphous components predominate in the systems studied here, the occurrence of the phyllosilicates is of particular interest from the standpoint of clay formation during the early stages of soil genesis. Schemes which have been proposed for the weathering of volcanic ash involve the initial formation of amorphous hydrous oxides and aluminosilicates of an allophanic nature. The type of phyllosilicate formed from this amorphous phase depends upon the nature of the parent material and the environment. Most weathering sequences have been depicted for situations in which silica and metallic bases are readily removed from the system by leaching. Under these conditions halloysite and finally kaolinite are believed to form from the allophanic precursors. The transformation of amorphous alumina and silica to montmorillonite is recognized for poorly drained environments.

The Mazama pumice deposit of central Oregon is very coarse in nature and has a high water permeability. One might expect such systems to favor the formation of kaolinitic minerals over the smectites. The data obtained (Chichester, 1967; Chichester, Youngberg and Harward, 1969), however, show a complex suite of 2:1 type phyllosilicates among the predominant amorphous components. Two factors were hypothesized to be effective in the retention of silica and metallic bases at concentrations requisite to the formation of 2:1 type phyllosilicates. The first is alternate wet and dry conditions due to the distribution of annual precipitation. The lack of rainfall during the summer months causes extreme moisture depletion in the surface horizons of these soils. The second factor is the retention of soil solutions by internal capillary channels of the vesicular pumice particles. The porous matrix results in a poorly drained micro-environment and unsaturated flow of water in these soils is very slow.

POROSITY

A number of previous observations have indicated that the physico-chemical properties of soils on Mazama pumice involve the internal pores in the particle matrix. We are ultimately interested in the relationships of porosity to ion equilibria and movement as well as to clay mineral formation. These studies first require that the porous media under investigation be defined. A related question involves the differences in porosity of materials ejected from different sources. The internal vesicularity of pumice is a function of gas pressure, volatile content, temperature, cooling rates, and viscosity of the original melt. Differences in materials have implications on choice of samples for future diffusion studies. The characteristics of porosity will also be of value as an aid in distinguishing deposits on the landscape.

Characterization

Previous studies demonstrated the use of Hg intrusion techniques for determining the pore-size distribution in pumice (Cochran, Boersma, and Youngberg, 1967; Borchardt, Theisen, and Harward, 1968). Essentially, the pressure required to force Hg into a pore is related to the limiting diameter of that pore. The volume of Hg intruded under a given increment of pressure is related to the volume of pores in that corresponding size range.

Detailed studies on the qualitative and quantitative nature of porosity in volcanic ash are being conducted by Doak.⁴ Preliminary conclusions for the Mazama ash indicate median pore diameters are in the range of 7.2-7.4 μ for coarse sand-size particles. Mean volume diameters (weighted means for pore diameter in relation to volume intruded at a given pore size) are in the order of 17-21 μ . The importance of these capillary pores is illustrated by also considering the volumes. The total pore volumes in coarse sand size Mazama pumice are in the order of 0.8-1.0 ml/gm. The percentage of this volume intruded by Hg in pores between 30 and 0.2 μ amounts to 78-85 per cent. The limits of 30 and 0.2 μ have significance in that they correspond to pores that could retain H₂O at a negative pressure of 0.1 bar (field moisture capacity) and 15 bars (permanent wilting point) respectively. There is a decrease in vesicularity with decreasing particle size. However, for the same particle size of pumice the parameters are independent of distance from the source. For the Dick Springs site at the northeastern end of the transect (445 km from the source), the coarse sand-size fractions appear to be aggregate lapilli. The predominant effects of weathering in surface horizons are reduction in mean weight diameter and reduction in pore volume (ml/g) as a result of filling of the pores with weathering products. The weathering processes fill the larger pores to a greater extent than the smaller pores. Microscopic examination indicates the filling of pores extends about 200 μ into the larger vesicular particles.

Implications to Properties

A number of observations have been made which indicate the strong relationship of physico-chemical properties to the internal porosity in soils developed from Mazama pumice. Chichester (1967) observed that the entry of salt solution into the capillary pores was a sluggish process once the particles had dried to low moisture levels. Apparently, air was trapped in the capillaries by the added solution and had to be displaced by dissolution. Once the salt solutions entered the pores, they resisted replacement by repeated washing with alcohol, water, or salt solutions. Exchange equilibria were not obtained even after a period of 7 days. Cochran (1966) has shown that unsaturated flow rates in samples of a pumice soil are 2 to 5 times lower than for a non-pumiceous loam. Thermal conductivities of pumice materials are also very low (Cochran, Boersma and Youngberg, 1967). The thermal properties are believed to be associated with low bulk density of the material and the arrangement of the pore space. It is apparent that the nature of the porous matrix in soils of Mazama pumice has a great deal to do with the properties of these soils.

LITERATURE CITED

- Allison, I. S. 1966. Fossil Lake, Oregon: Its geology and fossil faunas. Oregon State Univ. Press, Corvallis, Oregon.
- Borchardt, G. A., A. A. Theisen, and M. E. Harward. 1968. Vesicular pores of pumice by mercury intrusion. *Soil Sci. Soc. Amer. Proc.* 32:735-737.
- Chichester, F. W. 1967. Clay mineralogy and related chemical properties of soils formed on Mazama pumice. Ph.D. Thesis, Oregon State Univ., Corvallis, 152 pp. (Diss. Abstr. 27:3749-B).
-, C. T. Youngberg, and M. E. Harward. 1969. Clay mineralogy of soils formed on Mazama pumice. *Soil Sci. Soc. Amer. Proc.* 33:115-120.
- Cochran, P. H. 1966. Heat and moisture transfer in a pumice soil. Ph.D. Thesis, Oregon State Univ, Corvallis, 165 pp. (Diss. Abstr. 27:3-B).
-, L. Boersma, and C. T. Youngberg. 1967. Thermal properties of a pumice soil. *Soil Sci. Soc. Amer. Proc.* 31:454-459.
- Crandell, D. R., D. R. Mullineaux, R. D. Miller, and M. Rubin. 1962. Pyroclastic deposits of recent age at Mount Rainier, Washington. *U.S. Geol Surv. Prof. Paper* 450-D, pp. 64-68.
- Czamanske, G. K., and S. C. Porter. 1965. Titanium dioxide in pyroclastic layers from volcanoes in the Cascade Range. *Science* 150:1022-1025.
- Dyrness, C. T. and C. T. Youngberg. 1966. Soil-vegetation relationships within the ponderosa pine type in the central Oregon pumice region. *Ecol.* 47:122-138.
- Fryxell, R. 1965. Mazama and Glacier Peak volcanic ash layers: Relative ages. *Science* 147:1288-1290.
- Gordon, G. E., K. Randle, G. G. Goles, J. B. Corliss, M. H. Beeson, and S. S. Oxley. 1968. Instrumental activation analysis of standard rocks with high-resolution X-ray detectors. *Geochim. Cosmochim. Acta.* 32:369-396.
- Hansen, H. P. 1947. Postglacial forest succession, climate, and chronology in the Pacific Northwest. *Trans. Amer. Philos. Soc.*, Vol. 37, part 1, 130 pp.
- Higgins, M. W. and A. C. Waters. 1968. Newberry caldera field trip. In *Andesite Conference Guidebook*, Bull. 62, State of Oregon, Dept. of Geology and Mineral Industries.
- Libby, W. F. 1955. *Radiocarbon Dating*. 2nd Ed. Univ. of Chicago Press, Chicago.

- ✓ Powers, H. A., and R. E. Wilcox. 1964. Volcanic ash from Mount Mazama (Crater Lake) and from Glacier Peak. *Science* 144:1334-1336.
- Schmitt, R. A., R. H. Smith, and G. G. Goles. 1965. Abundances of Na, Sc, Cr, Mn, Fe, Co, and Cu in 218 individual meteoritic chondrules via activation analysis, I. *J. Geophys. Res.* 70(10):2419-2444.
- Steen, V. C. and R. Fryxell. 1965. Mazama and Glacier Peak pumice glass: Uniformity of refractive index after weathering. *Science* 150:878-880.
- Taylor, E. M. 1965. Recent volcanism between Three Fingered Jack and North Sister, Oregon Cascade Range. *The Ore Bin* 27:121-147.
- 1968. Roadside geology Santiam and McKenzie Pass highways, Oregon. In *Andesite Conference Guidebook*, Bull. 62, State of Oregon Dept. of Geology and Mineral Industries.
- Theisen, A. A., G. A. Borchardt, M. E. Harward, and R. A. Schmitt. 1968. Neutron activation for distinguishing Cascade Range pyroclastics. *Science* 161:1009-1011.
- ✓ Westgate, J. A., and A. Dreimanis. 1967. Volcanic ash layers of recent age at Banff National Park, Alberta, Canada. *Canad. Jour. Earth Sci.* 4:155-161.
- Wilcox, R. E. 1965. Volcanic-ash chronology. In *The Quaternary of the United States*, VII INQUA Congress, Princeton Press.
- Williams, H. 1942. *The geology of Crater Lake National Park, Oregon*. 162 pp. Carnegie Institute of Washington, Publication No. 540. Washington, D.C.
- Youngberg, C. T., and C. T. Dyrness. 1959. The influence of soils and topography on the occurrence of lodgepole pine in central Oregon. *Northwest Sci.* 33:111-120.
- ✓, and C. T. Dyrness. 1964. Some physical and chemical properties of pumice soils in Oregon. *Soil Sci.* 97:391-399.