Ecological and Topographic Features of Volcanic Ash-Influenced Forest Soils

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Abstract

Volcanic ash distribution and thickness were determined for a forested region of north-central Idaho. Mean ash thickness and multiple linear regression analyses were used to model the effect of environmental variables on ash thickness. Slope and slope curvature relationships with volcanic ash thickness varied on a local spatial scale across the study area. Ash distribution and aspect showed weak correlation. Elevation and ecologically based plant associations accounted for about 54 percent of the observed variation in volcanic ash thickness. Climax plant associations moister than grand fir/queen cup beadlily (*Abies grandis/Clintonia uniflora*) had consistently thick ash mantles and soils that would be classified as either Andisols or andic subgroups using Soil Taxonomy. The statistical model error of 10.7 cm was significantly lower than the >20 cm variation often found in local soil series. This model quantitatively assesses ash distribution and can be integrated into other local ecological models.

Introduction

Volcanic ash from eruptions along the Pacific Northwest Cascade Range has significantly influenced forest soils of the Inland Northwest, U.S.A. (Mullineaux 1986; Shipley and Sarna-Wojcicki 1983). The Holocene era eruption of Mt. Mazama (now Crater Lake, OR) distributed >116 km^3 of volcanic tephra across this region (Bacon 1983; Zdanowicz and others 1999). Soils influenced by the deposition of Mt. Mazama tephra can be found throughout the western United States and into southwestern Canada (fig. 1). Soils formed in, or influenced by volcanic ash are important to forest management. Volcanic ash-influenced soils have lower bulk density, higher porosity, and higher water infiltration and retention than soils less influenced or unaffected by ash (McDaniel and others 2005; Nanzyo and others 1993; Nimlos 1980; Warkentin and Maeda 1980). Among the benefits of these properties is the reduction in drought stress on plant communities during extended summer dry periods.

Figure 1—Estimated spatial distribution of Mt. Mazama volcanic ash across the western United States and southwestern Canada. The study area for this research project is located within the boxed area of north-central Idaho (Mt. Mazama ash distribution adapted from Williams and Goles 1968).

Regional deposition following the eruption of Mt. Mazama was estimated at approximately 15-20 cm thick in eastern Washington, with thinning in areas more distal to the eruption (Busacca and others 2001). The current distribution pattern of volcanic glass derived from the Mazama event is much different than this original deposition pattern. A map depicting the prevalence of volcanic glass in modern surface soils of Eastern Washington indicates only weak tephra influence in soils of the southwest Columbia Plateau even though these areas are closest to the volcanic source of the tephra (fig. 2) (Busacca and others 2001). Instead, glass content of the surface soils increases with increasing downwind distance from the source volcano. Also, none of the modern tephra-influenced surface soils are composed of pure volcanic ejecta. Soils of the Blue Mountains, OR, and Clearwater Mountains, ID, have some of the best-expressed andic soil properties
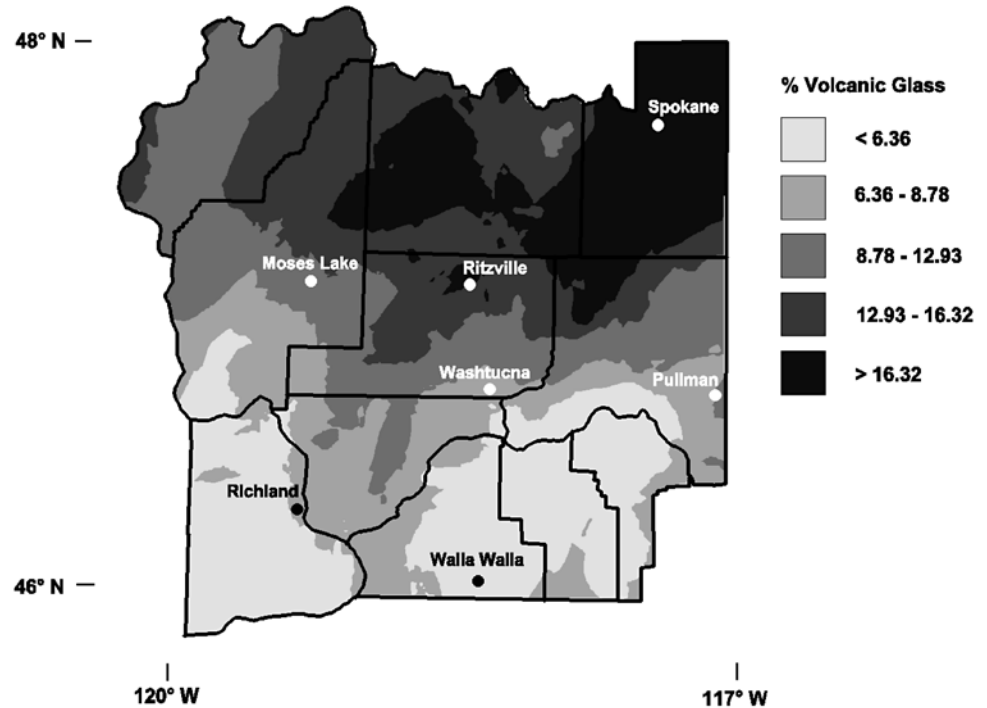
Figure 2—Volcanic glass content of modern surface soils in eastern Washington (from Busacca and others 2001).

in the region, yet these soils generally have glass contents of 20 to 50 percent in their surface layers.

Several mechanisms have been proposed as factors in the transformation of the original tephra sheet into the mixed distribution patterns that we see. These include: 1) a partial re-entrainment of ash by wind with resulting redeposition further downwind (i.e. to the northeast); 2) burial of ash material by subsequent episodes of loess deposition; 3) bioturbation of the tephra by soil fauna, which served to mix the volcanic glass into the surrounding soil mass; and 4) reduced erosion loss and enhanced capture of remobilized air-fall material under coniferous vegetation such as is found at the northern and eastern margins of the Columbia Plateau (Busacca and others 2001; Hunter 1988).

Recent Natural Resource Conservation Service (NRCS) soil surveys have extensively mapped volcanic ash-influenced forest soils in portions of the Inland Northwest. From these surveys, ash distribution and ecological/topographic relationships can be assessed. However, these soil survey relationships are often presented as a range in ash thickness. For example, volcanic ash thicknesses in Hugus and Bouldercreek soil series commonly found in our study area have mapped variations >20 cm (Soil Survey Division 2006). As more information is gathered on the role of volcanic ash in forest productivity and management, forest managers may need finer resolution of ash distribution than a range in ash thickness. The inherent variation of soil surveys may not provide the level of accuracy needed for decision support systems. A potentially workable alternative is a statistical re-analysis of individual soil-site descriptions created during local NRCS soil surveys.

Based on the above rationale, our objective was to select a relatively small geographic region within the Inland Northwest for which extensive soil and environmental data was available to 1) develop a dataset of volcanic ash depths, habitat types, and terrain features; 2) conduct statistical analyses to assess relationships between ash thickness and selected vegetative and topographic features; and 3) determine the precision and fit of a statistical model to estimate the thickness of volcanic ash across a landscape.

Materials and Methods

Study Area

The area chosen for this study is the NRCS ID-612 soil survey region of north-central Idaho (fig. 1). This survey area encompasses about 336,250 ha of diverse climatic factors, habitat types, and complex terrain attributes. Landscapes of this region are generally characterized as mountainous in the north and east, while the south and west are characterized as basalt plateaus/benchland incised with deep canyons. Elevation ranges from 300 m in the southwest to >1700 m in the north and east. Mean annual precipitation (MAP) roughly follows the elevational gradient, with <300 mm MAP in the southwest and >1500 mm in the northeast. Ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) habitat types dominate the southern regions of the soil survey. Western redcedar (*Thuja plicata*) and western hemlock (*Tsuga heterophylla*) dominate the warm, moist upland regions; with Subalpine fir (*Abies lasiocarpa*) and mountain hemlock (*Tsuga mertensiana*) predominant in the colder, higher elevations (Cooper and others 1991).

Data Analysis

Nine hundred and twenty-one soil-site descriptions and their XY coordinates were obtained from the Orofino, ID, NRCS field office. Field records composed of volcanic ash thickness, terrain attribute, and habitat type observations were entered into a database. The effective number of observations available for analyses varied since it was not unusual for certain field observations to not be recorded on the field form. A summary of the field descriptors and their potential influence on volcanic ash distribution is presented in table 1.

The continuous variables elevation (ELE), slope (SLP), and aspect (ASP) were grouped into discrete classes to facilitate the comparison of incremental changes in ash thickness with terrain attributes. ELE was classed into 200-m intervals, SLP at 10 percent breaks, and ASP in 45-degree quadrants. Curvature values were derived from a United States Geological Survey (USGS) 30-m digital elevation model (DEM) using grid algebra in a geographic information system (GIS). The numerical curvature values were then grouped into their respective linear (L), concave (C), and convex (C) classes.

Average ash thickness by class was computed for each of the variables described above. Standard errors were computed and *t*-tests performed to test for significant differences in ash thickness using an α-level of 0.1. Variables that showed significant class differences in volcanic ash thickness were subsequently tested for use as predictor variables in a volcanic ash distribution model. A stepwise variable

Table 1—Selected ecological and topographic features used in this study and their potential significance in determining volcanic ash distribution patterns (Cooper and others, 1991; Gallant, 2000).

Ecological/Topographic Features	Significance
Elevation (meters): ELE	Climate, vegetation type, potential energy
200-400	
400-600	
600-800	
800-1000	
1000-1200	
1200-1400	
1400+	
Slope (%): SLP	Overland and subsurface flow, velocity, and runoff
0-10	
10-20	
20-30	
30-40	
40-50	
50-60	
60+	
Aspect (°): ASP	Solar irradiation, wind erosion/deposition
Flat	
N (342.6-27.5)	
NE (27.6-72.5)	
E (72.6-117.5)	
SE (117.6-162.5)	
S (162.6-207.5)	
SW (207.6-252.5)	
W (272.6-297.5)	
NW (297.6-342.5)	
Up/Across Slope Curvature: PRCU/PLCU	Flow acceleration, erosion/deposition rate, converging/diverging flow, soil water content
Linear	
Concave	
Convex	
Plant Associations:	Climate, topography, site productivity, disturbance
Vegetation Series: VS	
Pinus ponderosa (PIPO)	
Pseudotsuga menziesii (PSME)	
Abies grandis (ABGR)	
Thuja plicata (THPL)	
Tsuga heterophylla (TSHE)	
Tsuga mertensiana (TSME)	
Abies lasiocarpa (ABLA)	
Habitat Type: HT	
Festuca idahoensis (FEID)	
Physocarpus malvaceus (PHMA)	
Symphoricarpus albus (SYAL)	
Linnaea borealis (LIBO)	
Clintonia uniflora (CLUN)	
Asarum caudatum (ASCA)	
Adiantum pedatum (ADPE)	
Gymnocarpium dryopteris (GYDR)	

selection procedure was used within the framework of a general linear model (GLM) to assess which variables explained the greatest variation in volcanic ash thickness. Variables that were within the upper 0.1 percentile of a Type III sums-of-squares F-distribution were retained within the model. The prediction equation was deemed reliable if it produced a high coefficient of determination (R^2) and low root mean square error (RMSE).

Results

Topographic and *Vegetative* Indicators

Volcanic ash is highly correlated with ELE (fig. 2). Each 200-m increment is significantly different up to 1200 m ($p <0.1$). Above 1200 m, there is no significant difference in mean ash thickness. Forest soils below 600 m in elevation have ash thicknesses ≤10 cm. Many low elevation soils exhibit significant mixing of the shallow ash mantle with underlying soil material. These lower elevation forest soils are classified as vitrandic subgroups of a soil order (Soil Survey Staff 1999). Forest soils located at elevations between 600 m and 1200 m have mean ash thicknesses 24 to 35 cm. These soils are classified as andic subgroups. Volcanic ash mantles have a mean thickness of about 45 cm above 1200 m elevation. Ash mantles deeper than 36 cm that meet several other NRCS criteria are considered members of the order Andisols (Soil Survey Staff 1999) or Andosols of the World Reference Base (FAO/ISRIC/ISSS 1998).

Mean ash thickness showed no significant decrease with increasing slope gradient (fig. 3). Mean ash thickness showed relatively little variation with a small range of 25 to 34 cm across all slope classes. Slopes <10 percent showed significantly less volcanic ash than all classes except the 60 percent class. Ash depth increases up
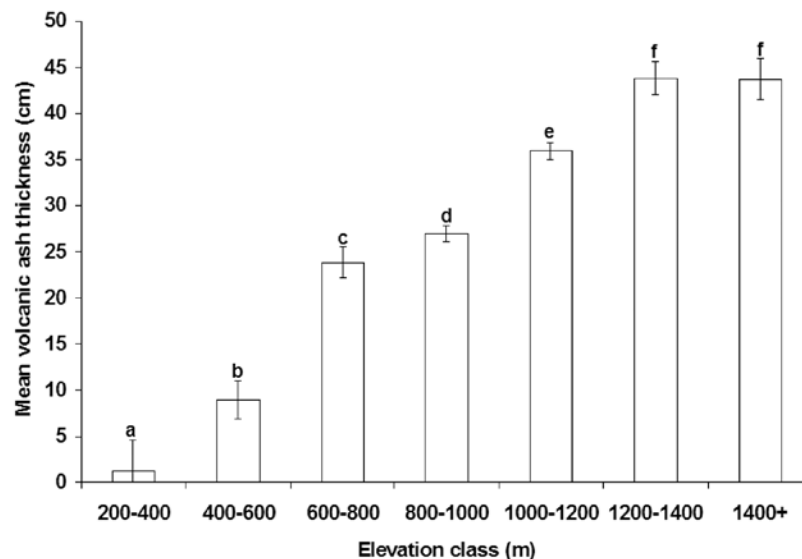

Figure 3—Mean volcanic ash thickness as a function of elevation (ELE) class. Y-axis bars represent standard errors, with letters indicating significant differences ($p < 0.1$).

to the 20 to 30 percent SLP class; after which, there are no significant differences in ash thickness by SLP class. The 20 to 30 percent class had significantly greater ash depths than all slope classes and was marginally greater than the 40 to 50 percent class ($p = 0.12$).

North aspects generally exhibit thicker ash mantles than south facing aspects (fig. 4). N, NW, and SE aspects show mean ash depths >32 cm. NE and W facing aspects have thinner ash caps (~30 cm), but are not significantly different than N, NW, or SE aspects. S, SW, and E aspects have significantly thinner ash mantles of about 27 cm.
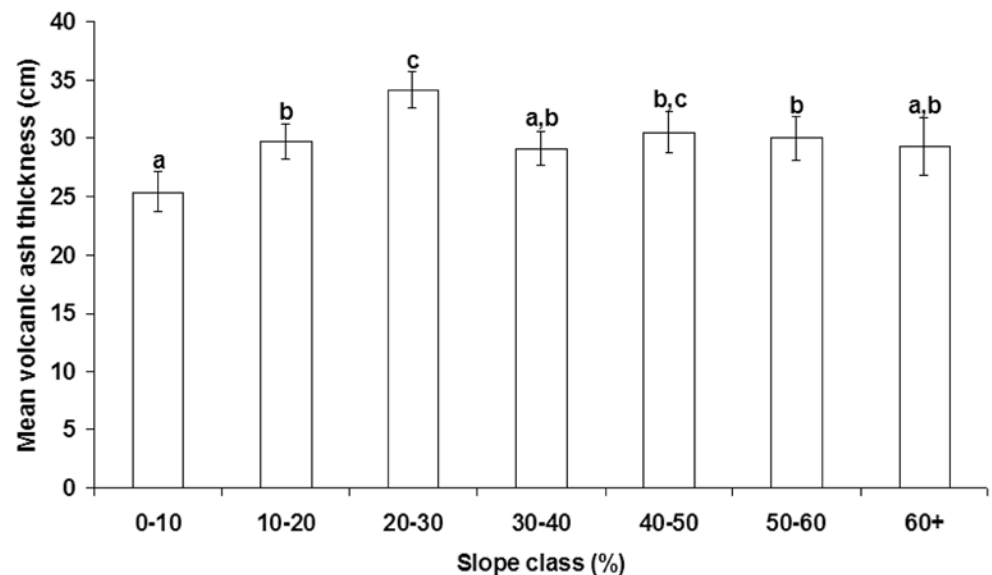

Figure 4—Mean volcanic ash thickness as a function of slope (SLP) class. Y-axis bars represent standard errors, with letters indicating significant differences ($p < 0.1$).

Slope curvature shows that nonlinear surfaces retain a greater thickness of volcanic ash compared to linear surfaces (fig. 5). Concave and convex surfaces show mean ash depths >30 cm for both upslope (PRCU) and across slope (PLCU) surface curvature. Linear surfaces in both PRCU and PLCU are significantly lower (<25 cm) than either convex or concave surfaces. There was no statistical difference between concave and convex in either PRCU or PLCU slope curvature.

Vegetation series and habitat type plant associations showed the strongest relationship with volcanic ash thickness (fig. 6). Overall, the ponderosa pine (PIPO) and Douglas-fir (PSME) vegetation series have very thin volcanic ash mantles (<3 cm) and show no significant change by habitat type within series. Grand fir (*Abies grandis* – ABGR) has the widest range in ash-influence of all vegetation series. Mean ash thickness ranges from 0 to 40 cm depending on the underlying habitat type within series. The moist twinflower (*Linnaea borealis* – LIBO) habitat
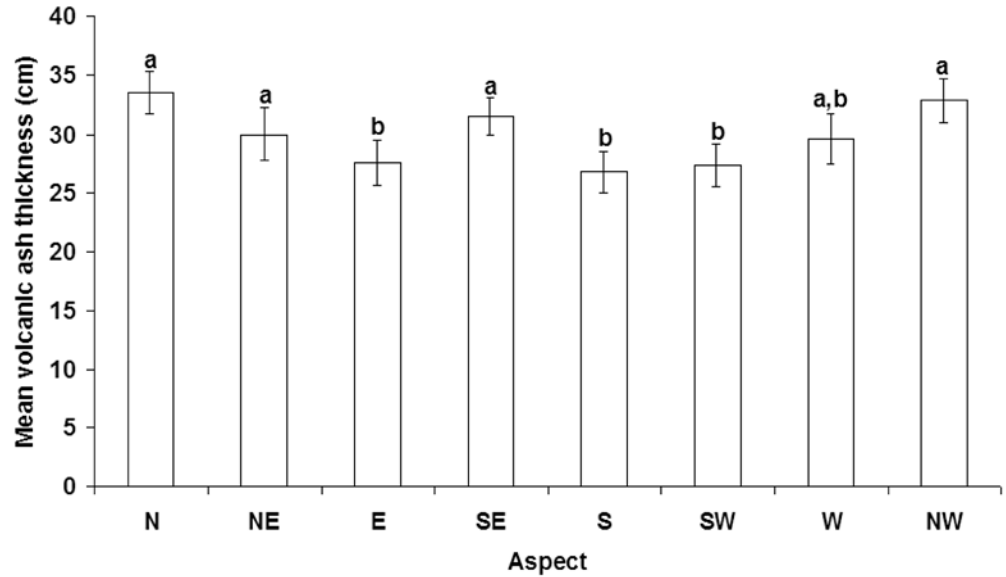
Figure 5—Mean volcanic ash thickness as a function of aspect (ASP) class. Y-axis bars represent standard errors, with letters indicating significant differences ($p < 0.1$).
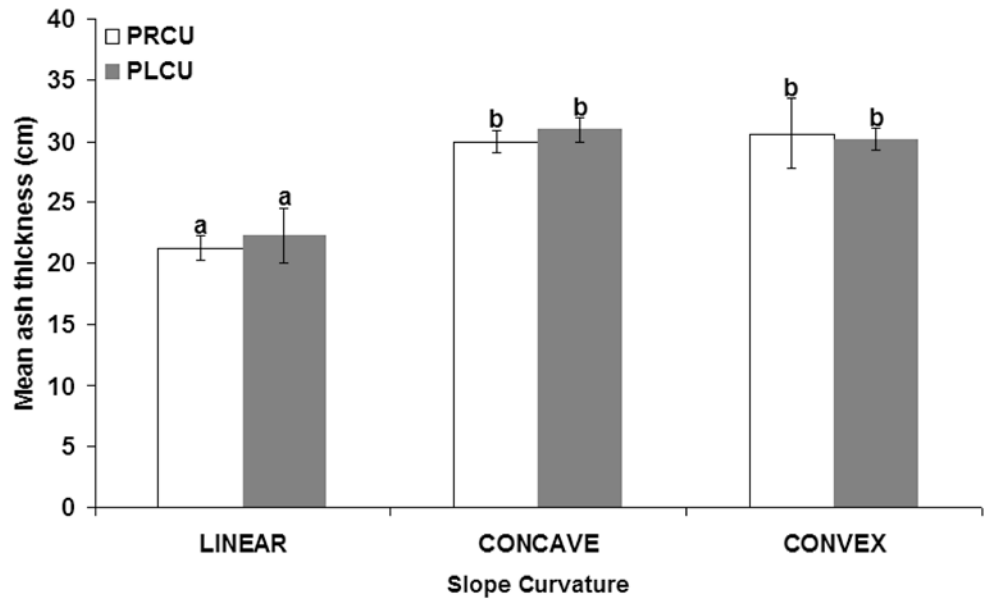

Figure 6—Mean volcanic ash thickness as a function of upslope curvature (PRCU) class. Y-axis bars represent standard errors, with letters indicating significant differences ($p < 0.1$).

type of the ABGR vegetation series surprisingly shows no significant ash mantle (mean = 0 cm). Ash thickness in ABGR habitat types can be described as a function of increasingly moist understory indicator species, with the exception of LIBO. Habitat type rankings for volcanic ash thickness would be *LIBO < PHMA/SYAL < CLUN < ASCA*, where PHMA, SYAL, CLUN, and ASCA represent ninebark (*Physocarpus malvaceus*), snowberry (*Symphoricarpus albus*), queen-cup beadlily (*Clintonia uniflora*), and wild ginger (*Asarum caudatum*), respectively. These rankings suggest that vitrandic intergrades would be more prevalent on PHMA/SYAL and LIBO habitat types, andic intergrades on CLUN, and Andisols on ASCA.

Changing from an ABGR to a western redcedar (THPL) vegetation series is accompanied by a 5-cm increase in mean ash thickness when comparing across CLUN habitat types. This shift is not evident for the ASCA habitat type, which shows no significant differences between ABGR and THPL vegetation series. Maidenhair fern (*Adiantum pedatum* – ADPE) and oak-fern (*Gymnocarpium dryopteris* – GYDR) habitat types show a reduction of >7 cm in mean ash thickness over ABGR/THPL-ASCA. Mean ash thickness for CLUN and ADPE/GYDR habitat types suggest that andic intergrades would be most common, with Andisols (in other words, ash mantle >36 cm) occurring primarily under an ASCA habitat type. Based on these observations, understory rankings of habitat type by increasing ash thickness would be *CLUN = ADPE/GYDR < ASCA*.

The western hemlock (TSHE) series displayed the largest difference in volcanic ash thickness between CLUN and ASCA habitat types (about 28 cm). TSHE-CLUN habitat types show at least a 6-cm decrease in mean ash thickness when compared to THPL-CLUN; however, a TSHE-CLUN habitat type would still fall within the andic intergrade classification associated with other CLUN habitat types. Ash thickness in the ASCA habitat type is significantly greater for TSHE vegetation series than for any other series with observed ASCA habitat types. Mean ash depths on TSHE-ASCA are 54 cm, which would place them well within the Andisol soil order.

Mountain hemlock (TSME) and subalpine fir (ABLA) series are typically found at higher elevations where air temperatures are relatively low and annual precipitation high. The warmer, moister ASCA habitat was not observed. Mean ash thickness is greater on TSME-CLUN than ABLA-CLUN, but the difference is insignificant. Volcanic ash-thickness on these vegetation series is >36 cm, thus placing them into the Andisol order.

Volcanic Ash Distribution Modeling

The class variables listed in table 1 were added stepwise into a multiple linear regression equation. Variables were assumed to be independent and normally distributed. The final model, with selected variables acting as fixed effects on volcanic ash thickness, is:

$$AT_{jklmno} = \mu + PRCU_j + ASP_k + SLP_l + ELE_m + VS*HT_n + \varepsilon_{jklmno}$$

where,

AT_{jklmno} is the predicted value for observation o with vegetation series*habitat type interaction n at elevation m on slope l with aspect k and upslope curvature j,

µ is overall volcanic ash thickness mean,

$PRCU_j$ is the fixed effect of upslope curvature (concave, convex, or linear),

ASP_k is the fixed effect of aspect (N, NE, E, SE, S, SW, W, NW, or FLAT),

SLP_l is the fixed effect of percent slope (0-10, 10-20, 20-30, 30-40, 40-50, 50-60,or 60+),

ELE_m is the fixed effect of elevation in meters (200-400, 400-600, 600-800, 800-1000, 1000-1200, 1200-1400, 1400+),

$VS*HT_n$ is the fixed effect of vegetation series*habitat interaction (where, VS are ponderosa pine, Douglas-fir, grand fir, western redcedar, western hemlock, mountain hemlock, or subalpine fir; and HT are Idaho fescue, ninebark/ snowberry, twinflower, queen-cup beadlily, wild ginger, or maidenhair fern/ oak-fern),

ε_{jklmno} is the error term;

where, $j = 3$ for upslope curvature, $k = 9$ for aspect, $l = 7$ for slope, $m = 7$ for elevation, $n = 13$ for vegetation series*habitat type interaction, and $o = 1$ for number of observations per location.

All class variables, except PLCU, explained a significant portion of variation in volcanic ash thickness ($p < 0.1$) (table 2). Variables ranked from least to most in variance explained are $PRCU < ASP < SLP < ELE < VS*HT$. The interaction term, VS*HT, accounted for the largest percentage of explained variance at 71.2 percent. ELE was the second largest at 18.2 percent. SLP and ASP accounted for 8.9 percent combined, and PRCU explained the least at 1.7 percent. The overall model was significant ($p < 0.001$) and accounted for 60 percent of the observed variation in ash thickness. A model RMSE of 10.7 cm and CV of 36 percent indicate that there is a significant amount of variation still unaccounted for; however, the predictive error is significantly lower than the variation found in local soil series.

Table 2—General linear model variables retained in an ash prediction analysis. Partial variance indicates the percent of the model R2 explained by each retained variable.

	Elevation	Slope	Aspect	Upslope Curvature	Vegetation Series* Habitat Type
Partial Variance (%)	18.2	4.7	4.2	1.7	71.2
Significance[a]	<0.0001	0.006	0.04	0.03	<0.0001

[a]Significance level tested at α = 0.1.

Discussion

Ecological and Topographic Indicators

It is evident from the broad relationships presented that volcanic ash distribution is strongly associated with vegetation patterns and less dependent on terrain attributes. Elevation, although a topographic feature, shows strong collinearity with local precipitation gradients and vegetative cover (data not shown). This situation suggests that elevation serves locally as a proxy variable for interactions between precipitation and vegetation patterns and their subsequent effect on ash distribution.

Slope class did not have a negative impact on mean ash thickness with slopes >60 percent showing no significant decline in ash depths (fig. 3). This result supports other research on slope stability of volcanic ash. In a review of volcanic ash soils, Warkentin and Maeda (1980) note that volcanic ash on free-standing slopes up to 70 degrees are common in regions of high rainfall. They attribute this high degree of stability to the unique permeability of volcanic ash.

The significantly lower mean ash thickness in the 0-to-10 percent slope class may be due to the geographic location of these observations. A majority of these observations for nearly flat terrain were on the benchlands of the south and southwest portion of the study area. This region is characterized by low elevation PSME and ABGR vegetation series, which often exhibit thin or mixed volcanic ash mantles.

The prevalence of thicker ash mantles on north aspects may be attributable to several factors (fig. 4). North aspects typically support moister plant communities in our study area (Cooper and others 1991). These moist plant communities may provide greater soil surface cover, which would decrease the impact of precipitation and overland water flow on volcanic ash redistribution. Additionally, the moisture retained within the soils after precipitation events would be less susceptible to evaporation from solar radiation. Giest and Strickler (1978) found volcanic ash soils of Oregon to be susceptible to wind erosion once in a dry state. Assuming that current southwesterly prevailing wind patterns were similar to historic post-eruption patterns, dry volcanic ash on south-facing slopes would be expected to be more susceptible to redistribution by wind than north aspects. The significant increase in ash thickness on southeast slopes is anomalous to this theory and suggests that the overall effect of aspect on ash distribution is local and intricately tied with surrounding topographic and environmental factors.

The significant decrease in ash thickness on linear surfaces shown in figure 5 is partially correlated with the slope class these observations share. A review of the dataset shows that about 67 percent of the linear surfaces occur on slopes <10 percent with the remainder unevenly divided among several steeper slope classes. As detailed in the previous discussion of slope classes, observations with gradients <10 percent are found primarily in the drier benchland portions of the study area. The correlation between slope steepness and slope surface curvature within the dataset may mask local effects of slope curvature on ash thickness. Surprisingly, convex surfaces in both upslope and across slope positions displayed no significant decrease in mean ash thickness over concave surfaces. Other research on volcanic ash deposition after the eruption of Mt. St. Helens has shown that concave surfaces support thicker ash mantles than convex (Zobel and Antos 1991). Our conflicting results may be due to the level of variation found within these classes. Standard errors were small because of large sample sizes, but the standard deviations were often large within the surface classes, reflecting significant variation within the data.

Cooper and others (1991) associate shifts in climax plant associations to distinctive soil and/or topographic microclimate features. Habitat type shifts and differing soil ash depth are evident across the broad habitat type associations observed in our study area (fig. 7). These strong relationships may be attributed to many combinations of topographic, climatic, or edaphic factors. Steele and others (1981) noted that the influence of volcanic ash contributed to distinct shifts in Idaho plant communities. However, it is still an open question as to whether
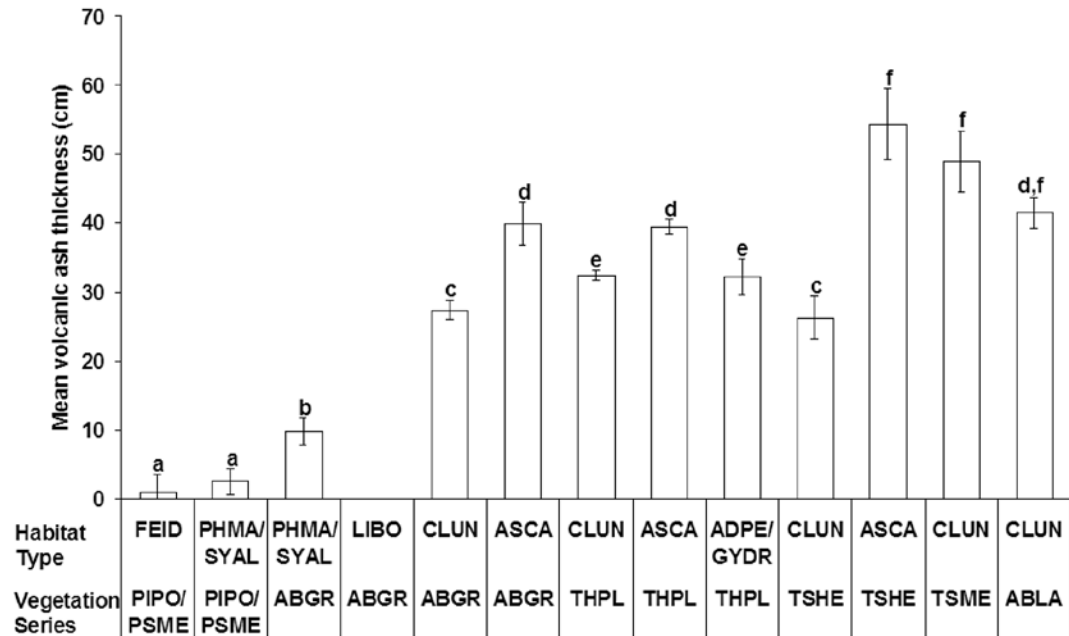
Figure 7—Mean volcanic ash thickness as a function of overstory (VS) and understory (HT) indicator plant species. Y-axis bars represent standard errors, with letters indicating significant differences ($p < 0.1$) (Cooper and others 1991).

the presence of volcanic ash is responsible for shifts in plant associations, or that variations in plant community were responsible for differential ash retention. Despite this uncertainty, volcanic ash thickness is highly correlated with plant associations and can be used to assess ash distribution patterns.

PSME and PIPO vegetation series show the least ash thickness within our data. Shifts to moister habitat types within these vegetation series show no significant dependence on volcanic ash. It has been suggested that these vegetation series now reside on landscapes that, post-Mazama eruption, were drier and did not support forest vegetation cover. Lack of overstory cover and dry climatic conditions prevented these landscapes from retaining volcanic ash mantles subsequent to the eruption.

Volcanic ash thickness in ABGR communities is highly variable. Unlike successively moister plant associations, an ABGR vegetation series does not always indicate the presence of significant volcanic ash influence. This variability is partly attributable to the transition zone that ABGR inhabits between xeric and udic soil moisture regimes. Near the dry end of the spectrum, ABGR plant communities would be associated with minimal to no ash influence. This suggests that an increase in plant available soil moisture would shift the understory plant community towards moister habitat types. Thus, drier habitat types (PHMA/SYAL) often exhibit less ash influence in the soil than the CLUN and ASCA types.

An exception to this pattern is the ABGR-LIBO association. LIBO is considered to inhabit moister environments than PHMA, suggesting that volcanic ash might be present on this habitat type. The absence of volcanic ash on LIBO habitat types may be attributable to the fact that only five observations were collected

within this habitat type, providing for a poor representation of the range in ash thickness.

All remaining plant associations moister than ABGR show significant ash influence in the soil. The presence of a thick ash mantle is often identified by the presence of these climax species. Increasing ash thickness in the soil is evident in the habitat type gradients within the THPL series; however, habitat type differences are minimal.

The TSHE vegetation series occupies a narrow ecological range in north Idaho forests and primarily inhabits moist, moderate temperature sites and are intolerant to drought, excess moisture, and frost (Cooper and others 1991). The narrow ecological range suggests that other edaphic and climatic factors might play a larger role in TSHE distribution than volcanic ash influence in the soil. Such factors may also explain why TSHE-CLUN plant associations have thinner ash mantles than THPL-CLUN. TSHE-ASCA sites do show significant increases in volcanic ash thickness. This result suggests that volcanic ash is associated with a shift to moister understory plant communities within the TSHE vegetation series.

TSME and ABLA plant communities occupy high elevation sites with up to 1500 mm of annual precipitation within our study area. Vegetation series within these zones are probably not dependent on the presence of volcanic ash for their establishment. The high precipitation and dense vegetative cover of these plant communities retained volcanic ash subsequent to original ash deposition.

Volcanic Ash Distribution Modeling

The strength of the relationships between elevation, plant communities, and volcanic ash produces a strong predictive ability for our ash distribution model. An R^2 value of 0.6 is considered an excellent improvement over the limited regional volcanic ash modeling attempts (Nimlos and Zuuring 1982). Predictions from this model allow quantitative ash assessments with a known error within the study area. Forest managers can use this model to integrate the predictions into a geographic information system (GIS). One motivation behind developing a quantitative ash distribution model was to overcome the variation inherent within mapping units generated through a soil survey. Volcanic ash thicknesses in Hugus and Bouldercreek soil series commonly found in our study area have mapped variations >20 cm (Soil Survey Division 2006). The predictive model's RMSE of 10.7 cm significantly improves on this level of variation, thus providing a finer resolution support tool for local forest soil management.

Further research should be conducted to determine local affects of topographic features on ash distribution despite the significant improvement this model provides in predicting ash depth and distribution. Global statistical procedures such as multiple linear regression may mask local topographic influence. Adjusting a statistical model to perform a more local analysis may yield improved results. A more costly, but perhaps informative method, would be a detailed survey of a finite landscape. Research at local levels may reveal topographic and volcanic ash relationships otherwise masked by large conventional soil surveys. Regardless of which approach is used, modeling ash distribution seems to be inherently a local exercise. The extrapolation of model results outside a study area is not recommended. The concepts behind the model presented in this paper may be applicable elsewhere, but the relationships as reflected in the model parameter estimates are unique.

Summary

This study's findings suggest that volcanic ash distribution is intricately linked with elevation and plant community associations. Elevation increases precipitation, which in turn supports different climax plant communities. Increasing plant density at each successive climax community may serve to retain ash deposits subsequent to volcanic eruptions and entrap wind-transported volcanic ash from drier, lower elevation sites. Topographic variables show relatively little impact on ash thickness patterns. Several of the terrain attributes showed clustering by geographic location within our study area. Gentler slopes, which were predominately found at drier, lower elevations, supported thinner ash mantles. The slope curvature variable was also linked to geographic location. Nonlinear slopes were most often found in the mountainous region of the study area. The strong effect of elevation and vegetation habitat type series reduced the ability to distinguish mean ash thickness differences between convex and concave surfaces.

Statistical modeling accounted for 60 percent of the observed variation in ash thickness and returned an RMSE of 10.7 cm. These model statistics indicate a significant development in the prediction capability of volcanic ash thickness. Model error is significantly lower than the variation of >20 cm often observed in local ash-influenced soil series. However, it became evident during our analyses that ash distribution and thickness is heavily influenced by local ecological and topographic attributes that cannot be assumed to affect ash depth uniformly across a study area. Future ash modeling efforts must focus on assessing local environmental influences and account for nonstationarity in the independent variables. Such an analysis may clarify the ecological and topographic effects on ash distribution and thickness that are otherwise generalized in a global regression analysis.

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