SEIZE THE DAY: OPPORTUNISTIC UNDERGRADUATE RESEARCH OF VOLCANICLASTICS COLLECTED DURING A FIELD TRIP TO CRATER LAKE NATIONAL PARK, OREGON

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Abstract

A student research opportunity arose during a field trip to the US Pacific northwest at a site along OR230 in the Rogue River valley due west of Crater Lake National Park, Oregon. A fresh roadcut offered a chance to describe characteristics and depositional structures of 2 volcaniclastic units, collect samples for microscopic and macroscopic examination of clasts for insights to deposition, write a funding proposal for C^{14} age determinations, and to hypothesize about modes of emplacement for the strata and rates of post-eruption incision of the Rogue River. Unit 1, at the base of the roadcut, was identified as an ignimbrite based on field and lab observations and the literature (Bacon and Wright, 2017). Unit 1 lacks bedding, extends below the road, possibly to the river, consists of a mixture of fine-ash to bomb-size clasts, including glass shards, lithic fragments, and pumice, and large (25-100 cm) chunks of charred wood. Unit 2 overlies Unit 1 and is similar in clast composition but is distinguished by an erosional contact with Unit 1, north to south trending planar beds, graded-bedding, cross beds, and lenses of coarse clasts up to a meter thick. While volcanic surge deposits have been reported near this location (Bacon and Wright, 2017), characteristics of clasts and depositional structures within Unit 2 strongly resemble those associated with fluvial deposits. Both units have C^{14}-dates of 7,700 ± 30 yr BP, consistent with origins from the climactic Mount Mazama eruption. Volcaniclastics exposed in mass-wasting scars and cutbanks along the east side of the Rogue River valley, coupled with topographic profiles across the valley, indicate infilling by volcanics from the current valley floor to at least road level, a 68 m elevation difference. Assuming Unit 2 represents streams immediately reforming and reworking volcanic fill, a simple calculation yields an 8.8 mm/yr average incision rate.

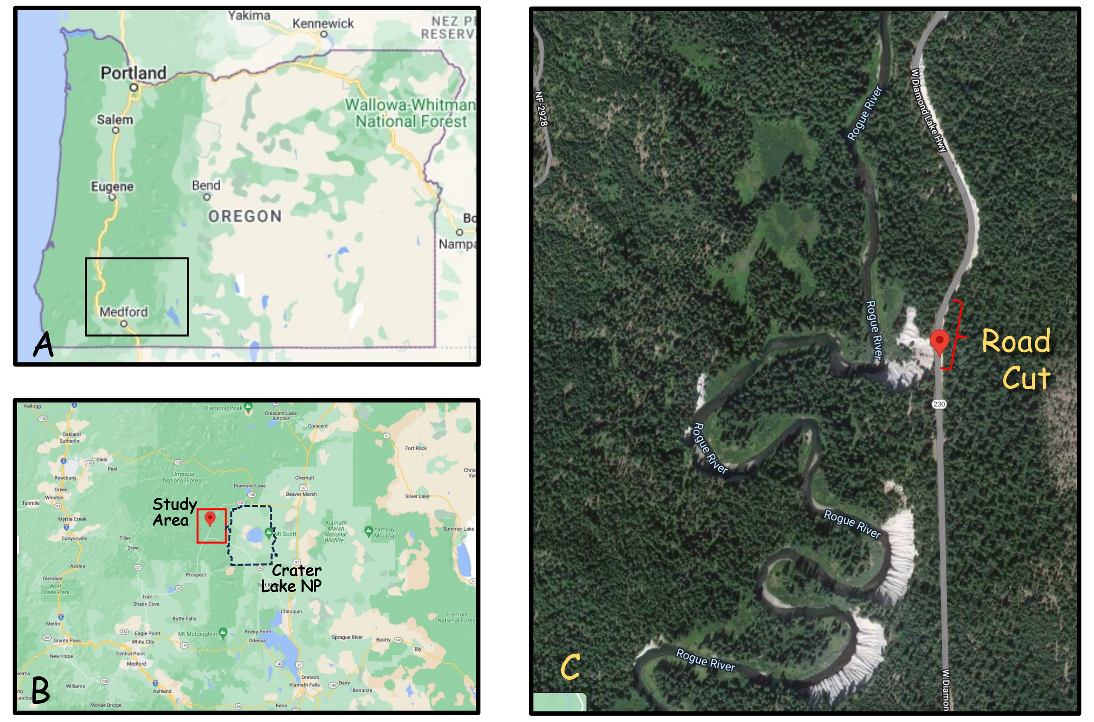

Figure 1. Location of the study area in relation to A) Oregon; B) Crater Lake National Park; and C) The Rogue River and OR230. *Images from Google Maps and Google Earth, accessed 2024.*

Introduction

Opportunities for student research can occur unexpectedly, thus it is important to remain adaptable, allowing learning to occur even when data collection were not anticipated. During a regional geological field trip to the Pacific Northwest, we observed a roadcut created by recent repairs on a stretch of OR230 within the Rogue River valley (see Fig. 1A-C). Previous research in the area (Bacon and Wright, 2017) interpreted similar lithologies and sedimentary features as forming due to the early to mid-Holocene climactic eruption of Mount Mazama that formed Crater Lake. Numerous roadcuts exist along the highway, but almost all had degraded due to weathering processes. As the probability of returning was very low, and numerous roadcuts on the highway showed signs of erosion, deposition, and vegetation growth, we seized the opportunity to describe and photograph the exposure, take some measurements, and collect sediment and carbon samples for analysis and age dating at the University of Southern Indiana. Once back home, students wrote, applied for, and were awarded an internal grant that funded C^{14} age determination of charred logs from the strata. We hypothesized the volcaniclastics at road level were from the eruption of Mount Mazama, but that observed sedimentary structures in layers higher up could be fluvially reworked volcanic materials deposited during rapid post-eruption reestablishment of drainage networks. The fluvial hypothesis was based upon the particle sizes and bedding characteristics of the materials in units 3 and 4, the orientation of the planar- and cross-bedding indicating sediment transport from north to south, and the proximity of the deeply incised valley of the Rogue River.

Background

Mount Mazama/Crater Lake is part of the more expansive Cascades volcanic arc wherein shield and stratovolcanoes formed as upper mantle magmas along the western edge of the Basin and Range extensional setting pushed to the surface (Bacon, 1990; Bacon et al., 1994).

The study area is 12.5 mi (20 km) due west of the caldera, outside National Park boundaries, in the upper reach of Rogue River drainage basin. Highway OR230 follows the Rogue River valley, which along this reach of the stream (north of Prospect, OR) is filled with volcanic materials from the massive eruption and collapse of Mount Mazama that formed Crater Lake 7700 yr BP (Bacon and Wright, 2017). South of Prospect, the valley cuts into older lavas that underlie the pyroclastics (Bacon and Wright 2017). Previous research (Bacon, 1983) produced C^{14} ages from samples collected nearby that indicate deposition during the initial eruption and/or soon afterwards. The sedimentary structures visible in strata in highway roadcuts, stream cutbanks, and mass wasting scars have been interpreted as base surge ignimbrites and ash fall associated with secondary steam explosions caused by eruption materials encountering water within the Rogue River valley (Bacon and Wright, 2017).

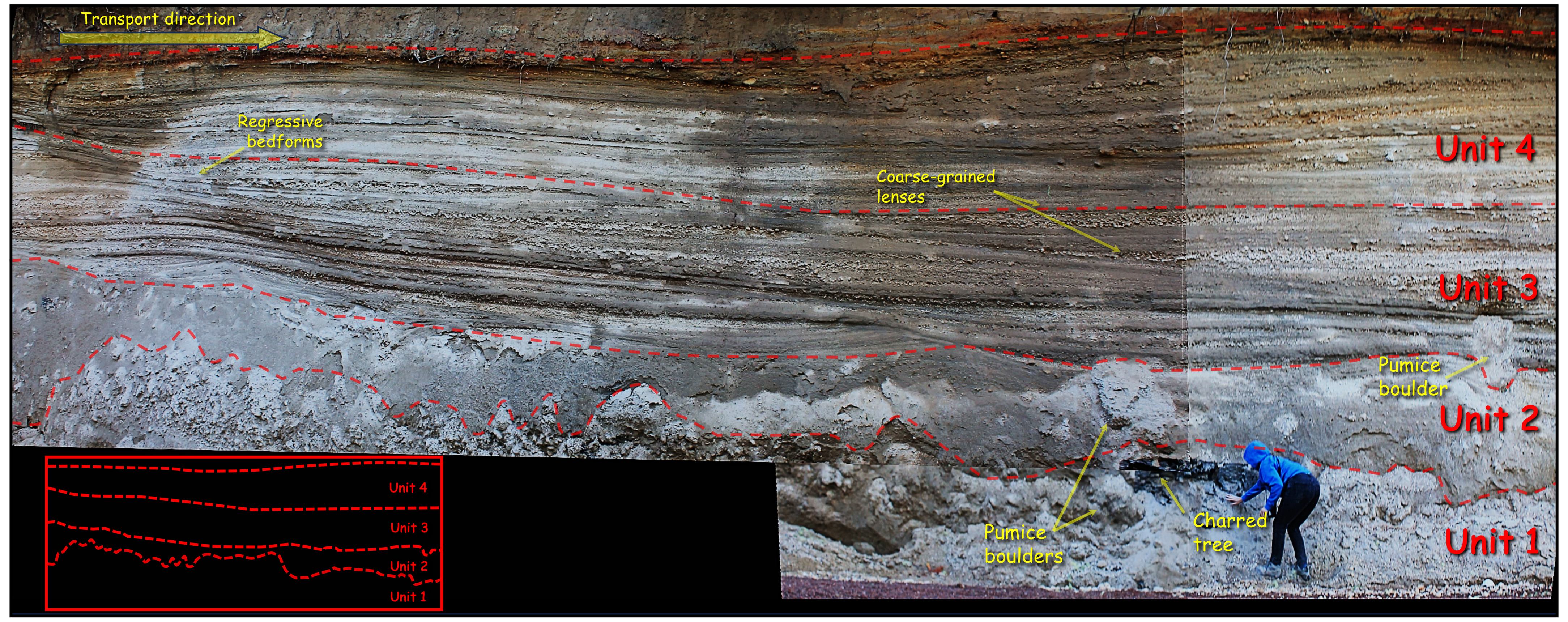

Figure 3. A composite photograph of a portion of the roadcut looking due East along OR230 (W. Diamond Lake Highway). Note the massive strata of Units 1 and 2, with clast size used to differentiate the two. The overlying Units 3 and 4 have numerous planar-beds, cross-beds, graded beds, and coarse-grained bedforms dipping from the left to right (North to South).

Figure 2. Students examining part of the north-south trending roadcut along the east side of OR230 in the Rogue River valley. The dashed red line marks the boundary between a lower ignimbrite (Units 1 and 2) and the upper planar- and cross-bedded strata (Units 3 and 4). Charred wood (circled areas) and samples of volcaniclastic sediments/rock were collected from all four units. The exposure segment shown is 20 m long (66 ft) long by 6 m tall (20 ft) and is located near the midpoint of the roadcut that extends ~160 m (550 ft) in total.

Methods

The sediments in the roadcut were measured, described and sampled over a span of about 5 hours, during which time strata were divided into 2 main layers, each with an upper and lower unit (Units 1-4; see figs. 2 and 3). Sedimentary characteristics such as clast size, composition and bedding were the basis for separation. Carbon and sediment samples were bagged and labeled for lab analysis back at the University of Southern Indiana. Charred wood from each of the 4 units was sent to Beta Analytic, Inc. for radiocarbon age determination.

In the lab, samples from the 4 units were mechanically sieved to isolate sand-sized fractions (250 - 63mm) because that size was visually abundant and could be viewed under a microscope to determine if there were quantifiable differences in composition and clasts shapes between the units. Sand fractions were then mounted to a glass microscope slide with clear double sided sticky tape. Rather than quantifying overall shape, we examined the degree to which "points" were present or absent on clasts to see if there were differences in transport distance, duration or mode between units (Manga et al., 2011). Point counts were made on 30 randomly chosen pumice clasts (e.g., see fig. 5E). If clasts in Units 3 and 4 were fluvially reworked rather than emplaced by volcanic activity, points on clasts would be reduced by rounding associated with water transport. Additionally, post-eruption fluvial reworking should result in a higher percentage of pumice clasts compared to higher density lithic and crystalline particles. Plots of these data were made to see if differences were apparent.

Field observations of valley wall and fill materials, and cross-valley topographic profiles were used to identify any topographic indications of the extent of volcanic-origin valley fill and post-eruption stream incision. In addition, the hypothesis that Units 3 and 4 could be related to stream reworking of volcanic materials could be used to calculate an average rate of incision by measuring the change in elevation from the road level to the stream channel below divided by the years since the valley was filled 7700 yr BP.

Data

The strata: Unit 1 was identified at road level and Unit 4 at the top of the roadcut (fig. 3). All 4 units vary in thickness and height above the road surface depending on where in the exposure measurements are taken (Table 1). Unit 1 consists of unstratified to weakly stratified, poorly sorted clasts of volcaniclastics that range from boulders (diameter > 25 cm) to fine silt (diameter 0.002 to 0.063 mm) size clasts with the larger clasts held by the finer matrix. All the larger clasts were pumice, whereas smaller particles were pumice, with minor amounts of mineral crystals and lithic fragments, presumably from eruptions prior to the caldera collapse. Unit 2 has an irregular (non-linear) contact with Unit 1 and consists of poorly stratified planar- and cross-bedded pebble- to silt-sized clasts, with relatively uncommon cobble sized pieces mixed in (fig. 3). The clasts consist of mostly pumice, with lesser amounts of lithics and mineral crystals. Unit 3 has a clear linear contact with Unit 2 and consists of strongly cross bedded sand- to cobble-sized volcaniclastic sediments with lenticular beds of pebble to cobble sized particles and graded bedding. The linear boundary between Unit 3 and 4 is clear, with little topography. Unit 4 has planar-beds and rare cross-beds, but fewer lenticular gravel beds than Unit 3. It too, consists of predominantly pumice, with lesser amounts of lithic fragments and mineral crystals.

Radiocarbon dates: All 4 units contained large (> 1 m) pieces of charred tree trunks and branches near the center of the roadcut (fig. 2). All four samples were within the margin of error for the climactic eruption and caldera collapse of 7700 yr BP (see Table 2).

Volcaniclastic materials: Materials between 63 mm and 250 mm sieves, when viewed under petrographic microscopes (fig. 5), showed consisted of 40 to 50% pumice versus lithics + mineral crystals, with a minimum percentage of 39.5% in Unit 4, and a maximum of 50.2% in Unit 3. Units 1 and 2 combined for an average of 45.68% pumice clasts and units 3 and 4 combined yielded a similar result of 45.03% clasts (fig. 4). In addition to clast composition, point counts on individual clasts produced very similar results, with a range of average point count values between 7.35 and 10.63 points/clast. Combining units 1 and 2 for comparison to units 3 and 4 produced average point values per clast of 8.99 and 8.88 points/clast. Many pumice clasts showed signs of melt films (Fig. 5E; Klug et al., 2002).

Topographic profiles and elevation differences: Topographic profiles constructed perpendicular to the gradient of the Rogue valley showed a distinctive surface trend incised by valleys (fig. 6). Field observations indicate the Rogue River, and its tributaries are downcutting into volcaniclastic materials, which at this location in the valley were emplaced during the Mount Mazama eruption and caldera collapse (fig. 6). The elevation of the road occurs at 3756 ft and the Rogue River at the bottom of the valley is 3536, yielding 220 ft of relief between the two.

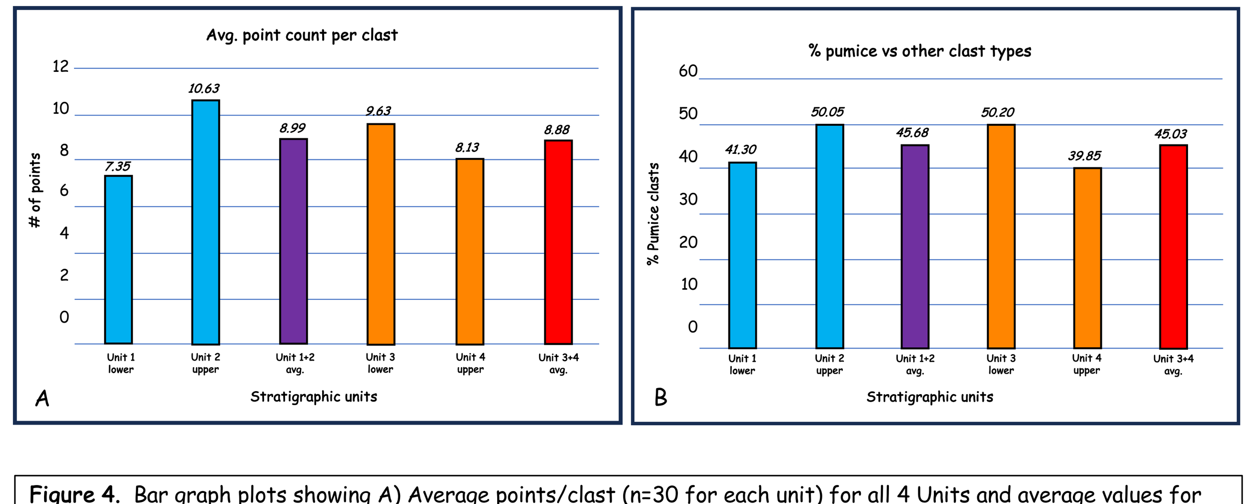

Figure 4. Bar graph plots showing A) Average points/clast (n=30 for each unit) for all 4 Units and average values for combined Units 1+2 and Units 3+4; and B) Percentage of pumice clasts compared to lithic fragments + mineral crystals for all units and averages for Units 1+2 compared to Units 3+4.

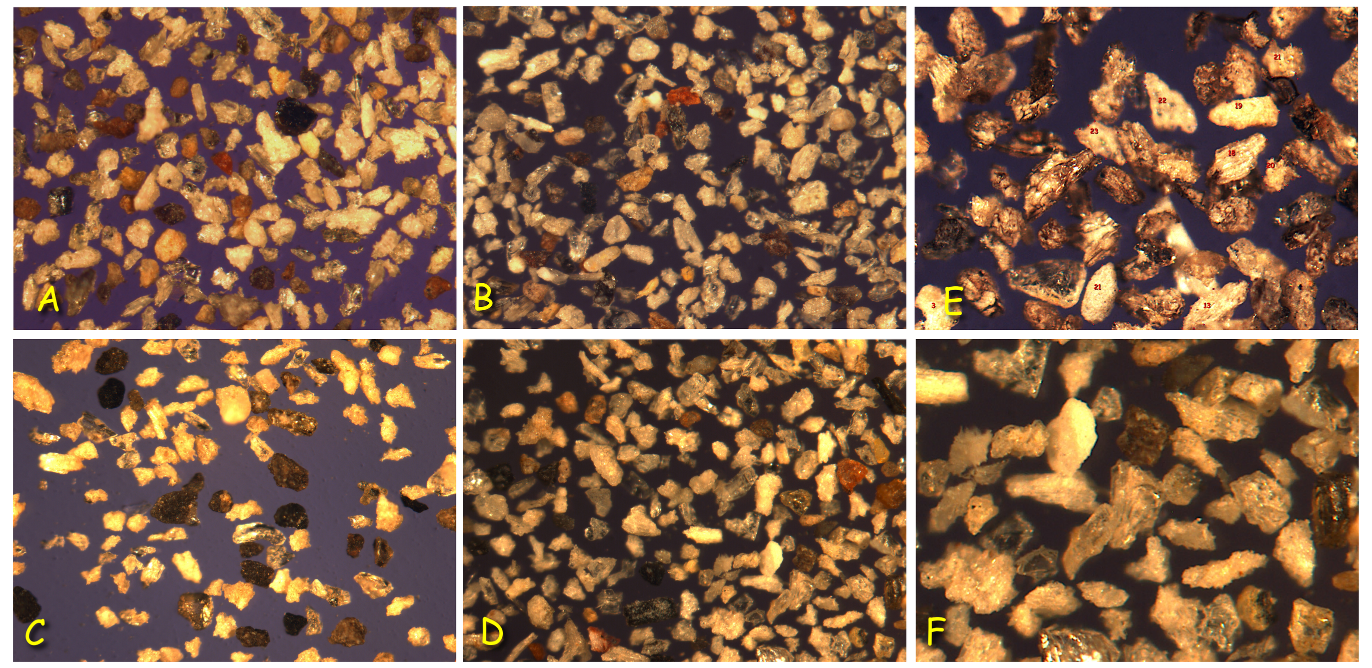

Figure 5. Photographs of sieved (250-63 μm) volcaniclastic sediments under non-polarized light placed onto clear double-sided tape. A) A sample (S1) showing pumice fragments with some mineral crystals from the lower-most part of the roadcut in Unit 1, identified as an ignimbrite; B) A sample (S2) from Unit 2; C) A sample (S3) from the lower-most part of Unit 3; D) A sample (S4) from Unit 4; E) enlarged portion of image of A, showing what are interpreted as melt films on Pumice clasts and examples of clast counting and point counting; and F) Enlarged portion of image D showing the abundance of pumice clasts compared to lithic fragments and mineral crystals.

Discussion

From a volcanologist's perspective, the materials appeared to be solely due to volcanic events, most notably pyroclastic surge and density currents. The scale was somewhat perplexing, given the size of bedding, the thickness of materials and the coarse particles. From a geomorphologist perspective, the Units 3 and 4 had characteristics of stream deposits, with planar- and cross-beds indicating transport direction, coarse grains arranged in gravel bar bedforms, graded beds and dune bar forms. Both interpretations could form the features observed (Fisher and Schmincke, 1984). The presence of charcoal within the 4 units indicates pyroclastic flows ripped trees up while burning them, which is expected for eruptions with pyroclastic events. However, it is also common for wood to be transported by streams as burned logs are blown into channels, or as previously emplaced volcaniclastics are reworked following an eruption. Little variation in C^{14} ages from the 4 units, suggests that either the charcoal-laden volcaniclastics were emplaced during multiple phases of the same eruptive event, or the lower 2 units were from volcanic eruptions, whereas the 2 upper bedded units were created as streams reworked charcoal-laden pyroclastics and drainage networks reestablished after the eruption and caldera collapse. Whereas the pyroclastic interpretation is the accepted one (e.g., Bacon and Wright, 2017), the fluvial option seemed plausible. The orientation of Unit 3 and 4's bedding indicates transport from north to south, perpendicular to the presumed direction of the volcanic blasts (east to west; Bacon, 1983). However, the chaotic nature of pyroclastic flow events could account for localized variations in flow direction (Fisher and Schmincke, 1984). Both circumstances could produce the data observed.

Our fluvial hypothesis excluded lahars for Units 3 and 4, as the bedding was too atypical compared to that associated with other lahar events (e.g., Scott, 1988). Fluvial transport of soft rock like pumice should produce rounded rather than angular clasts (e.g., Scott, 1988; Turbeville, 1991; Manga et al., 2011). Additionally, lower density pumice should be more abundant in alluvium as its more easily transported than denser lithic fragments or mineral crystals (Gran and Montgomery, 2005).

Table 1

Unit #	Thickness (m)	Initial Interpretation
4	2.0 -4.0	Stream deposits (?) finer grained with fewer bar forms throughout than Unit 3 below. Extensive planar beds, cross beds with north to south dip direction; ***Likely pyroclastic flow origin***. Possible paleosol at top
3	1.5 - 3.5	Stream deposits (?) alternating layers of coarser grained (sand to cobble sized clasts) and finer grained layers. Common pebble to cobble lenticular bedforms throughout. Extensive planar beds, cross beds with north to south dip direction; ***Likely pyroclastic flow origin***.
2	1.0 - 3.0	Ash bed; ash layer topping ignimbrite; classic appearance of pyroclastic density current (PDC); rare boulder size pumice clasts (pyroclastic bombs?)
1	0.25 - 2.5	Breccia ignimbrite, reverse graded beds uncommon, 2 - 50 cm angular clasts in an ashy matrix, uncommon 85 cm+ boulders, poorly defined planar beds and cross beds near top of unit, lower boundary not discernable (below road surface), upper boundary irregular and non-linear

Thickness and initial interpretation of units observed during our investigation. See fig. 2 for reference. Bold italicized in interpretation column is the final interpretation after our analysis.

Table 2

Unit 1		Unit 3	
Lat/Long coordinates	42°58'50.34" N; 122°23'52.61" W	Lat/Long coordinates	42°58'50.52" N; 122°23'52.87" W
C^{14} Age determination		C^{14} Age determinations	
Convention age BP	6840 ± 30 BP	Convention age BP	7030 ± 30 BP
95.4% age cal BC	5794 - 5656 BC	95.4% age cal BC	5987 - 5841 cal BC
95.4% age cal BP	7743 - 7605 cal BP	95.4% age cal BP	7936 - 7790 cal BP
Unit 2		**Unit 4**	
Lat/Long coordinates	42°58'50.52" N 122°23'52.87" W	Lat/Long coordinates	42°58'50.34" N; 122°23'52.61" W
C^{14} Age determination		C^{14} Age determinations	
Convention age BP	6890 ± 30 BP	Convention age BP	6910 ± 30 BP
95.4% age cal BC	5844 - 5716 BC	95.4% age cal BC	5845 - 5724 BC
95.4% age cal BP	7793 - 7665 cal BP	95.4% age cal BP	7794 - 7673 cal BP

Radiocarbon age-dates and locations obtained from charred wood found within the 4 units from the roadcut.

Discussion (continued)

A comparison of point counts and composition data from clasts analysis (figs. 4 and 5) showed little difference between the lower two and upper two units. The surface character of the pumice clasts in Units 1 and 2 exhibited fluid melt films, a wrinkly appearance related to vesicle coalescence during fall events (Klug at al., 2002) whereas 3 and 4 had fewer clasts with that trait (see fig. 5E and 5F).

Topographic profile evidence, such as terraces, incised valleys, or sloping surfaces, showed deeply incised rivers formed as the streams down cut through volcaniclastic fill (fig. 6). No terraces were observed while looking over a nearby precipice created by mass wasting of the valley wall (fig. 1C), and topographic profiles lacked terraces too (fig. 1C). These data are interpreted as indicating the Rogue River and its tributaries incised to their current levels with limited to no pauses for the channel to migrate laterally before continuing to incise. Such circumstances would result in continuous downcutting through the valley fill, the speed of which would be limited by the resistance of the fill. Interestingly, topographic profiles perpendicular to the valley axis were concave-up slopes with notable fluvial incision on an otherwise continuous surface (fig. 6). The surface trend is interpreted as the effect of volcanic materials from the eruption filling any previous valleys, followed by rivers reestablishing a drainage pattern in the partially filled valleys. Regardless of whether Units 3 and 4 are fluvial or not, the presence of the fill above the valley floor means the river would have to incise 67 m (220 ft) down to its current elevation. A maximum fill age of 7700 yr BP allowed calculation of an average post-eruption incision rate of 8 mm/yr ($^5/_{16}$ in/yr). It is unlikely that the Rogue River had consistent incision rates over the last 7700 years, as research at Mount St. Helens and elsewhere indicate rapid initial rates of post-eruption incision before stabilizing at some elevation determined either by local base level or changes in the resistance to erosion of underlying sediments and lithologies (Zheng, et al., 2023; Meyer and Martinson, 1988).

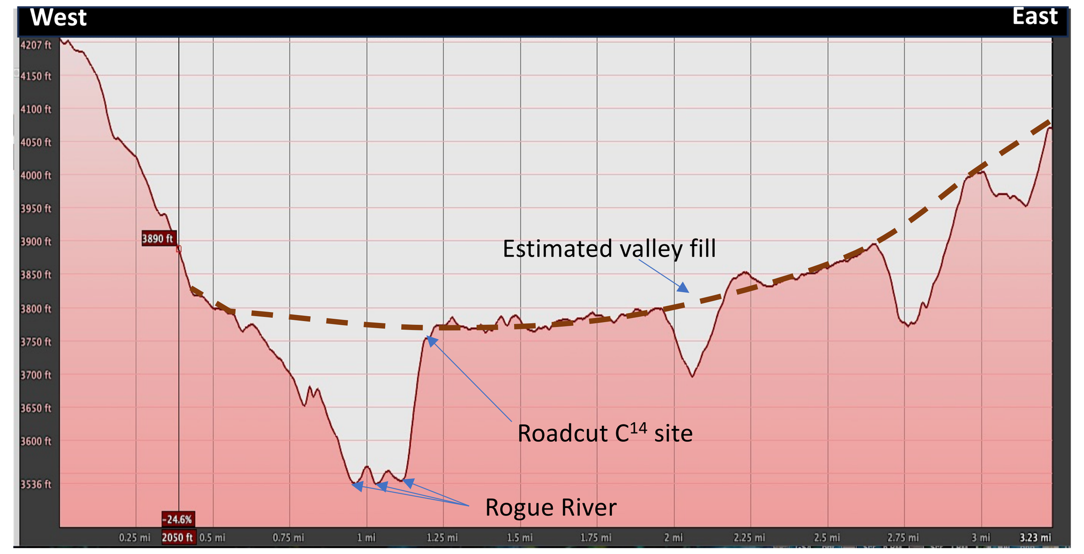

Figure 6. Cross-sectional topographic profile (VE = 12x) looking north up the Rogue River valley. The road sits an an elevation of 1144.5 m (3756 ft) above sea level, and 67 m (220 ft) ft above the river. The dashed line represents a surface trend line based on the topography.

Conclusions

The hypothesized fluvial origin of the planar- and cross-bedded strata observed in Units 3 and 4 is not supported by our data analysis. The bedding is too distinctive to be lahars (Fisher and Schminke, 1984), and fluvial reworking is not supported by clast composition or point count analysis. Textbooks have entire chapters on pyroclastic rocks discussing and showing examples of particle composition and bedding features formed due to surges and flow events like those we observed (Fisher and Schmincke, 1984; Cas and Wright, 1992). Still the rejection of our hypothesis formed a teachable moment, albeit a somewhat discouraging one; that some hypotheses fail, must be discarded and learned from. That said, other data discovered during the project related to rates of valley incision. Topographic profiles across the valley axis show that pyroclastic valley fill extends up to at least the elevation of Units 3 and 4, at 7700 yr BP. The fill has since been eroded by the Rogue River down to the current elevation, 67 m (220 ft) below the road. With deposition of the volcanic fill at 7700 yr BP, an average incision rate of 8 mm/year ($^5/_{16}$ in/yr) was calculated. Based upon research of modern eruptions (e.g., Zheng et al., 2023), large variations in post eruption incision rates likely occurred.

Ultimately, this project provided valuable learning experiences for the students and faculty alike, the most notable of which is "carpe diem" or seize the day! You should always be ready to learn when the opportunity presents itself.

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