THE GEOLOGIC SOURCE OF THE MAZAMA "MIMIC" MYSTERY TEPHRA: A GEOCHEMICAL REASSESSMENT OF VOLCANIC TEPHRA FROM VINE ROCKSHELTER (35LA304), CENTRAL WESTERN CASCADES, OREGON

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ABSTRACT

Previous neutron activation analyses of volcanic ash from two Western Cascades archaeological sites, Vine Rockshelter (35LA304) and nearby 35LA51, suggested that the source of the tephra at these sites was not the expected climactic eruptions of Mount Mazama about 6,850 ^{14}C years ago. The tephra was very similar in appearance to the ejecta from the Mazama event, however, and the ash was termed the Mazama Mimic tephra. Archaeological evidence suggested that the eruption that produced this tephra was post-Mazama in age. Because a new tephra horizon would have significant tephrochronological implications in Western and High Cascades archaeological research, instrumental neutron activation studies were initiated to further investigate the tephra and its possible sources. A resampling and reanalysis of the archaeological tephra and potential tephra sources revealed that Mount Mazama was clearly the source of the archaeological tephra, after all. The initial misidentification is attributed to unexpected geochemical variation during the correlation of the samples. The positive identification of Mazama tephra at Vine Rockshelter also indicates that the span of human occupation at this site may be considerably longer than was initially thought.

Vine Rockshelter is located in the central Western Cascades of Oregon immediately south of the Middle Fork of the Willamette River and about 20 km west of the Cascade Divide (Figure 1). During excavations in 1983, a thick primary deposit of silicic volcanic ash and pumice lapilli was found near the bottom of the deposits in front of the rockshelter. Pumice lapilli were also found scattered throughout the lower part of the rockshelter deposits. The tephra was initially thought to have originated from the violent 6,845 B.P. climactic eruptions of Mount Mazama - the resultant caldera, located 65 km south of Vine Rockshelter, later filled with water to form Crater Lake. Surprisingly, neutron activation analysis (INAA) by Dr. Gordon Goles, University of Oregon, of a pumice sample from a test pit in front of the rockshelter suggested that Mount Mazama was not the source of the tephra (Figure 2). When graphically compared

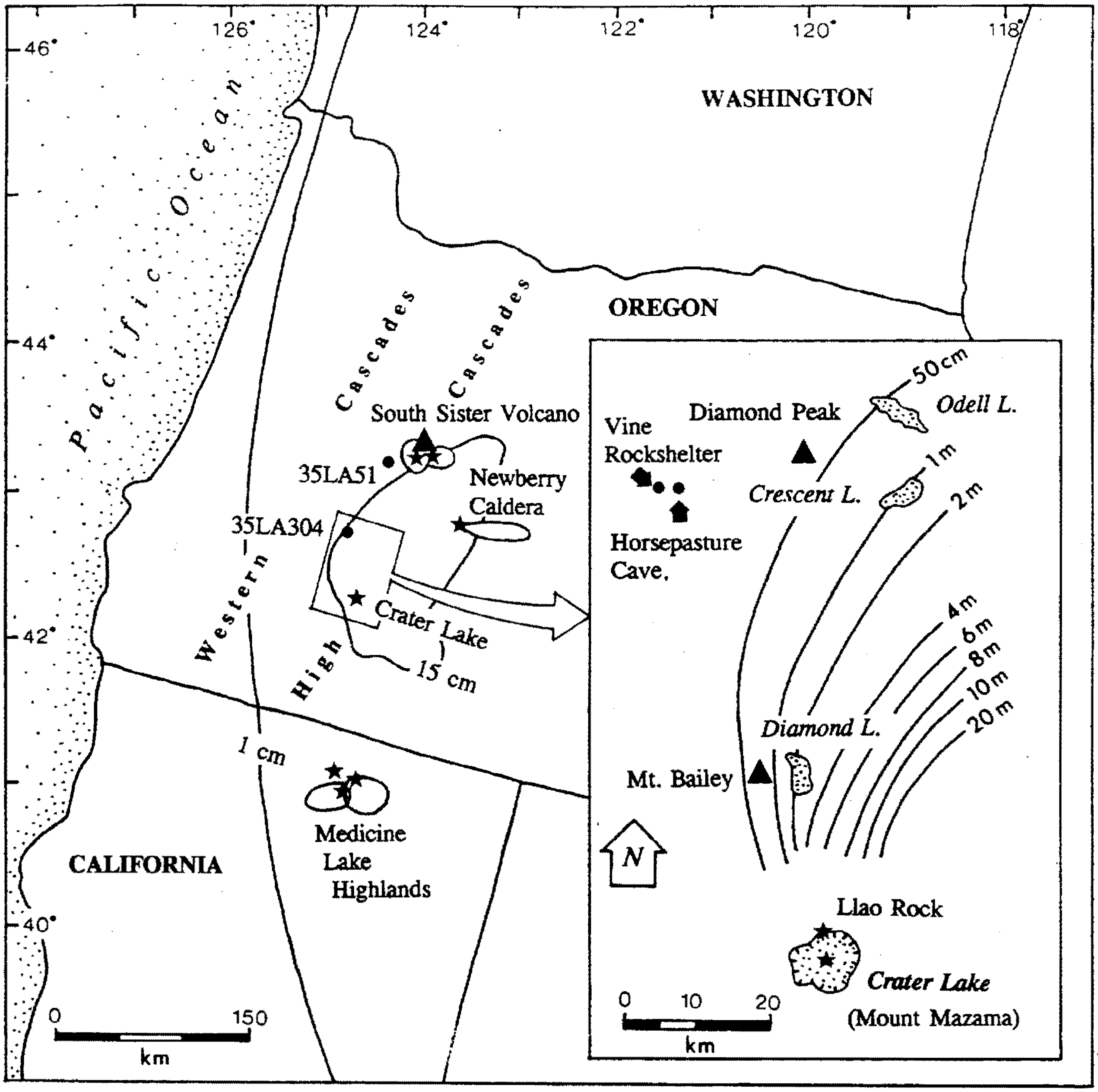

Figure 1. Location of archaeological sites and volcanic tephra sources mentioned in the text. Mazama isopachs are from Sherrod, 1986:101. The solid line surrounding each tephra vent marks the 1 cm isopach for ash deposits originating from that vent. The 15 cm designation refers to the approximate 15 cm isopach of Mazama tephra. Base map is adapted from Sarna-Wojcicki et al. 1983.

with published INAA literature values, the archaeological samples fell outside the range of known Oregon tephra sources. The Vine Rockshelter tephra was very similar in color, lapilli-size, and mineralogical characteristics to Mazama ash, however, and became known as the Mazama Mimic tephra. Tephra from another archaeological site located about 50 km NNE of Vine Rockshelter, 35LA51, was characterized at the same time and was also found to have originated from the same source. Although chronologic evidence from Vine Rockshelter was limited, the cross-dating of projectile point frequencies at this site with nearby Horse Pasture Cave (35LA39) suggested that the Mazama Mimic tephra might be as much as several thousand years younger than the Mazama tephra (Baxter and Connolly 1985:19-21,73-74; Baxter 1986a:67-69).

Materials suitable for radiocarbon dating are relatively uncommon in archaeological sites in the Vine Rockshelter region and archaeological chronologies in the central High and Western Cascades are still poorly-known. The identification of a new tephra horizon in the Oregon central Cascades would provide an important chronostratigraphic horizon for archaeologists working in the region. Additionally, a tephra horizon would prove of considerable value for geological, volcanological, geomorphological, and palynological research in this region. A new source of volcanic tephra would also call into question all previous archaeological (and geological) conclusions that had been based on the unquestioned assumption of the presence of Mount Mazama as the source of any silicic volcanic ash that had been found in the central Western and High Cascades. Any former archaeological studies that had assumed that silicic ash originated from Mount Mazama would have to be reevaluated (see Skinner and Radosevich 1991, for a summary of archaeological research). The resolution of the Mazama Mimic problem, as pointed out by Baxter and Connolly (1985:20), was essential to the development of Western Cascades archaeological chronologies.

The presence of a new source of volcanic ash in the geologically well-known central Cascades, however, would be quite unexpected. Was the Mazama Mimic tephra from a new and previously unidentified source or was it from an already known source? Could the source of the ash be Mount Mazama, after all? Was the problem a real or an analytical one? Only a reinvestigation of the tephra could provide evidence that would answer these questions.

RESEARCH OBJECTIVES

In an attempt to solve these nagging questions, we initiated a new study of the Mazama Mimic tephra in 1989 (Skinner and Radosevich 1989; Skinner and Radosevich 1991). Our research objectives were to resample and recharacterize, once again using neutron activation analysis, both the known geologic sources of tephra in the Cascades and the tephra in question from the Vine Rockshelter and 35LA51 archaeological sites. By including all analyzed samples in one experiment, the effects of laboratory analytical variation could be minimized. If the archaeological pumice could be correlated with a

GEOCHEMICAL CHARACTERIZATION OF THE TEPHRA

Sources of Volcanic Tephra

Samples of volcanic tephra were gathered from airfall tephra deposits that were clearly associated with the three most likely known source areas of silicic volcanic tephra in the central and southern Cascades region of Oregon (Table 1). For comparative purposes, samples of volcanic ash were also collected from three late Holocene tephra sources located in the Medicine Lake Highlands of Northern California (Heiken 1978; Sarna-Wojcicki et al. 1983).

Table 1. Holocene geologic sources of volcanic tephra that were geochemically characterized in the current investigation.

Tephra Source	^{14}C Age	Reference
Medicine Lake Highlands[1]		
Crater Glass Flows	Undated; probably coeval with other eruptions	Donnelly-Nolan, et al. 1990; Heiken 1978
Glass Mountain	~1000 yrs BP; overlies Little Glass Mountain	Donnelly-Nolan, et al. 1990; Heiken 1978
Little Glass Mountain	~1065 yrs. BP	Donnelly-Nolan, et al. 1990; Heiken 1978
Mazama Climatic Eruption[2]	~6850 yrs. BP	Bacon 1983
Newberry[3]	~1350 yrs. BP	Jensen 1988
South Sister Volcano[4]		
Devil's Hill	~2000 yrs. BP	Scott 1987
Rock Mesa	~2100 yrs. BP	Scott 1987

1-Northern California; 2-Oregon Southern High Cascades; 3-Newberry Caldera, Central Oregon; 4-Oregon Central High Cascades

Mazama Eruptions. The most widespread Holocene deposits of volcanic tephra in Oregon originated during several eruptive events that culminated in the construction of the Crater Lake caldera. Two of these events, the Llao Rock eruption of 7015 ± 45 radiocarbon years ago and the much larger climactic eruption of 6845 ± 50 years ago (Table 1), resulted in significant volumes of airfall ash deposits (Figure 1; Bacon 1983). Tephra from the Llao Rock eruption is compositionally very similar to the ash from the climactic eruption and the two ashfall units are geochemically indistinguishable from one another (Bruggman et al. 1987). The airfall ash deposits of the climactic eruptions are widely distributed in the Western United States, particularly to the east and northeast of the vent, and have been identified in Alberta, Canada, more than 1500 km from Crater Lake.

South Sister Volcano. Tephragenic eruptions occurred along the southern and high northern flanks of South Sister Volcano during three related eruptive events that took place about 2,000 radiocarbon years ago (see Table 1). These three events, the Rock Mesa episode, the Devils Hill Dome Chain episode, and the Carver Lake episode, are today marked by groups of obsidian-rhyolite domes that were extruded shortly after the eruption of the volcanic ash. Tephra from the two most widespread and best-dated episodes, Rock Mesa and Devils Hill Dome Chain, were collected for the present investigation. Tephra from all three eruptions has been reported to be virtually geochemically indistinguishable (Scott 1987).

Newberry Volcano. Approximately 1,350 radiocarbon years ago, a Newberry Volcano Caldera vent was the source of a locally extensive deposit of silicic volcanic tephra (Jensen 1988). The Big Obsidian Flow, a prominent caldera obsidian source, was later extruded from this same vent. The main axis of the ashfall lies east-northeast of its source and can be easily identified for several tens of kilometers from the vent (Figure 1).

Medicine Lake Highlands. Late Holocene silicic volcanic tephra is associated with three eruptive episodes at Medicine Lake Volcano, a large shield volcano located in northern California. These eruptions were followed by the extrusion of obsidian flows: Little Glass Mountain, Glass Mountain, and the Crater Glass flows (Heiken 1978; Sarna-Wojcicki et al. 1983; Donnelly-Nolan et al. 1990). All are thought to be about 1000 years old (see Table 1).

Tephra Preparation and INAA Trace Element Analysis

Sample preparation of the volcanic tephra for neutron activation analysis was kept to a minimum. Individual pumice lapillus clearly associated with each eruptive event were used to characterize the geologic sources of volcanic tephra. As recommended by Steen-McIntyre (1977:13), samples of medium-grained (2-64 mm) tephra pyroclasts were chosen for characterization. The weathered exterior of each lapillus was removed and the clean interior used for analysis. The smaller lapilli from the two archaeological sites were ultrasonically cleaned in a water bath to remove contaminants and iron stains. After initial cleaning, each sample was gently crushed and any visible crystals were removed. A magnet was used to remove the magnetic fraction from the tephra. Tephra samples were then crushed to a fine powder with a mullite mortar and pestle and immediately stored in sealed plastic vials.

Following preparation, the samples were characterized ("fingerprinted") with trace element abundances provided by instrumental neutron activation analysis (INAA). Irradiation and subsequent data analysis of all samples was carried out at the Oregon State University Radiation Center in Corvallis, Oregon. The analytical uncertainty for all elements is reported in percent and reflects the relative standard deviation (using one standard deviation) obtained for each element, based on repeated counts of standards containing that element. The analytical uncertainties reported in Table 2 are not related to the sample counting error. The net counts in some photopeaks were relatively high and the resultant counting errors shown for the corresponding analytical results were comparatively small. Used as the only measure of confidence, these counting error values would indicate a misleadingly large degree of accuracy. (The counting error values, not listed in Table 2, are available from the authors). The principles of INAA methods are discussed in more detail elsewhere (Goles 1978).

Correlation, Clustering, and Statistical Methods

The ideal element for characterizing a tephra source is one which exhibits a small degree of intrasource variability, a large degree of intersource variation, a small amount of analytical uncertainty, and relative compositional stability in post-depositional environments. Prior to examining the data set for clusters, we eliminated elements that did not meet these criteria.

The coefficient of variation (CV%; standard deviation/mean x 100) was used to quantitatively ascertain the extent of intraunit compositional variability for the analyzed Mazama samples (Table 1). A small CV% indicates a small degree of intrasource variation. Elements with a CV% of less than 15 were used in the characterization of the tephra sources. The CV% for all tephra samples was also computed so as to provide us with an estimation of those elements that were likely to show adequate inter-source variability for tephra characterization, i.e., those with a large CV%. Elements such as Na, K, and U which are known to be susceptible to mobility through post-depositional weathering processes were also eliminated from consideration (Fisher and Schmincke 1984:327-345). Elements that met the preceding criteria and which exhibited an analytical uncertainty of five percent or less were chosen to characterize the tephra.

Because of the small size of the data set, graphical correlation and clustering methods (scatterplots and ternary diagrams) were initially used to identify geochemical clusters and to correlate the archaeological samples and the geologic source groups. Cluster analysis methods served to independently confirm the results of the graphical analysis of the sample data (Figure 3). All cluster analyses were performed with the MVSP 2.0 multivariate statistical package using the Euclidean distance coefficient and the unweighted pair-group method. When applied to the INAA data set, different clustering algorithms yielded almost identical results.

Results of INAA Analysis

The results of INAA studies of tephra from the six sampled geologic sources and the two archaeological sites are presented in Table 2.

When selected trace element ratios or pairs are plotted on bivariate scatterplots, individual geologic tephra sources are distinguishable as discrete visual clusters. The four tephra samples from the two archaeological sites consistently fall into the cluster defined by the Mazama pumice lapilli. When plotted with the new INAA data, the same trace element ratios that initially suggested the existence of a Mazama Mimic tephra source now point to a different and less surprising conclusion (Figure 4).

Cluster analysis results of the INAA data set (Figure 4) were consistent with the results of the graphical correlation of the data. The volcanic ash samples from Vine Rockshelter and 35LA51 clearly fall within the same groups as those originating from the climactic eruptions of Mount Mazama.

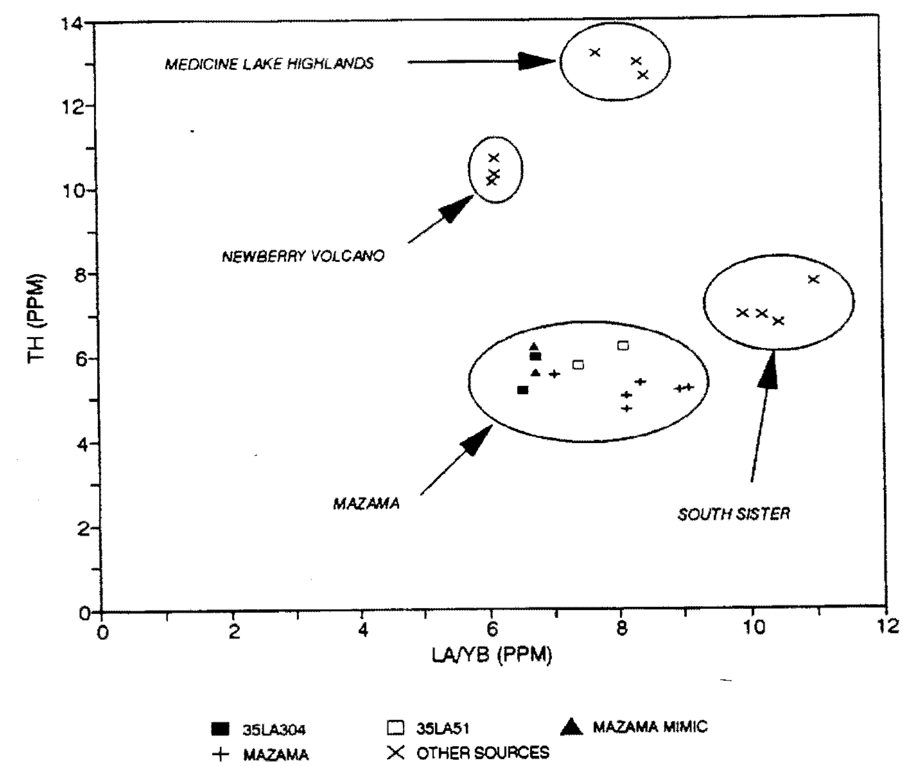

Figure 3. Scatterplot of the Lanthanum/Ytterbium ratio versus Thorium, the same elements and archaeological tephra samples that were illustrated in Figure 2. These results are from the current reanalysis of the samples.

	FEO	NA2O	SC	CO	SB	RB	CS	SR	BA	LA	CE	ND	SM	EU	TB	YB	LU	ZR	HF	TA	TH	U
VINE-1	2.46	3.74	11.7	3.1	0.3	39	2.0	419	510	14.5	35.2	17.8	4.3	1.2	0.6	2.1	0.3	206	7.0	0.5	5.9	2.4
VINE-2	2.27	3.89	10.4	3.1	0.3	26	1.7	440	508	13.4	26.2	16.2	3.9	1.2	0.6	2.1	0.3	200	5.9	0.4	5.2	1.7
LA51-1	2.29	3.99	7.3	2.3	0.5	37	2.3	286	534	15.8	36.0	19.8	4.2	1.0	0.6	2.0	0.3	225	7.3	0.5	6.2	2.6
LA51-2	2.21	3.99	6.9	2.3	0.5	43	2.4	260	549	15.7	34.3	20.4	4.2	0.9	0.6	2.1	0.3	267	7.1	0.5	5.7	2.5
MAZA-2	2.86	4.15	7.7	4.7	0.5	43	2.5	300	566	17.7	42.5	21.4	4.6	0.9	0.6	2.5	0.3	239	6.7	0.5	5.5	2.6
MAZA-4	2.05	3.78	6.0	3.0	0.5	51	3.7	376	676	18.3	40.0	18.6	4.1	0.7	0.6	2.0	0.3	185	5.9	0.5	5.2	2.4
MAZA-5	2.28	4.73	6.4	3.6	0.4	55	3.0	422	699	17.9	40.0	19.3	4.3	0.9	0.6	2.2	0.3	191	5.7	0.4	4.7	1.9
MAZA-7	2.70	4.75	7.0	4.8	0.5	49	3.0	431	678	19.6	46.2	18.6	4.6	1.0	0.7	2.2	0.3	230	5.9	0.4	5.2	2.4
MAZA-8	2.24	4.56	6.8	3.3	0.5	49	2.8	349	692	19.1	45.2	22.1	4.6	1.0	0.6	2.3	0.3	201	6.3	0.4	5.3	2.3
MAZA-9	2.23	4.37	6.6	3.9	0.4	47	2.6	384	646	18.6	44.8	21.1	4.7	1.0	0.7	2.3	0.4	187	6.0	0.4	5.0	2.2
NEWT-1	2.01	4.94	5.8	1.1	0.5	109	4.7	104	728	29.9	58.5	30.4	6.5	0.8	1.1	4.9	0.7	276	8.6	1.5	10.3	4.4
NEWT-2	1.99	4.61	5.8	1.4	0.5	119	4.6	99	741	30.1	60.4	26.8	6.5	0.8	1.1	4.9	0.7	320	8.5	1.4	10.7	4.3
NEWT-3	2.01	4.85	6.0	1.0	0.5	107	4.3	111	748	29.9	60.1	27.4	6.5	0.8	1.3	4.9	0.7	305	8.8	1.4	10.1	4.1
DOME-1	1.92	4.19	4.0	3.2	0.3	70	2.8	224	656	19.0	37.1	14.3	3.3	0.7	0.5	1.9	0.3	213	4.6	0.8	6.9	2.9
DOME-2	1.75	4.05	3.7	2.8	0.4	78	3.0	208	693	19.4	37.6	16.8	3.2	0.6	0.4	1.8	0.3	194	4.6	0.9	7.7	3.3
ROCK-1	1.78	4.32	3.8	2.7	0.3	69	2.7	204	678	18.7	36.1	13.9	3.1	0.7	0.6	1.8	0.3	168	4.3	0.8	6.7	2.8
ROCK-2	1.77	4.05	3.9	3.3	0.3	70	2.6	222	670	18.3	37.3	19.9	3.2	0.7	0.4	1.8	0.3	171	4.6	0.8	6.9	2.9
CRGT-1	1.67	3.89	4.5	2.1	0.7	139	9.5	102	713	21.8	42.0	19.0	4.6	0.6	0.7	2.8	0.4	235	5.5	0.9	13.2	5.7
LGMT-1	1.74	3.96	4.8	2.3	0.7	143	9.4	133	688	22.0	43.1	23.1	4.7	0.6	0.7	2.6	0.4	198	5.4	0.9	13.0	5.6
LBT-1	1.69	3.62	4.8	2.3	0.7	139	9.0	139	700	21.6	42.7	22.9	4.6	0.6	0.7	2.6	0.4	213	5.6	0.9	12.7	5.6
UNCERTAINTY	5%	3%	3%	5%	5%	10%	5%	12%	10%	3%	7%	12%	5%	5%	5%	5%	5%	15%	5%	5%	5%	7%
CV% MAZAMA	12	8	8	18	7	7	13	12	7	3	6	7	4	12	5	7	6	10	5	10	5	9
CV% ALL	15	9	33	36	26	50	61	46	11	23	20	20	22	22	32	39	38	19	21	47	37	39

VINE: VINE ROCKSHELTER (35LA304) TEPHRA
LA51: TEPHRA SAMPLES FROM 35LA51
MAZA: MAZAMA TEPHRA (CRATER LAKE)
NEWT: NEWBERRY TEPHRA
DOME: SOUTH SISTER DOME CHAIN TEPHRA
ROCK: ROCK MESA TEPHRA
CRGT: CRATER GLASS FLOW TEPHRA
LGMT: LITTLE GLASS MOUNTAIN FLOW TEPHRA
LBT: GLASS MOUNTAIN FLOW TEPHRA

UNCERTAINTY = REALATIVE STANDARD DEVIATION FOR ELEMENT BASED ON REPEATED COUNTS OF STANDARDS (UNRELATED TO SAMPLE COUNTING ERROR)

Table 2. Results of instrumental neutron activation analysis of silicic pumice lapilli from Vine Rockshelter (35LA304), 35LA51, and known Oregon and Northern California Holocene tephra sources.

The Solution to the Mystery

The solution to the mystery of the Mazama Mimic tephra is, of course, that the tephra originated from the climactic eruptions of Mount Mazama. There is no Mazama Mimic source. Neutron activation analysis and correlation of tephra from Vine Rockshelter, 35LA51, and the Oregon and Northern California tephra sources indicated that Mount Mazama was clearly the source of the so-called Mazama Mimic tephra. Unexpected analytical variation between published values and those determined by the earlier Vine Rockshelter study was responsible for the initial misidentification of the source of the tephra samples. The problem was, in other words, strictly an analytical one.

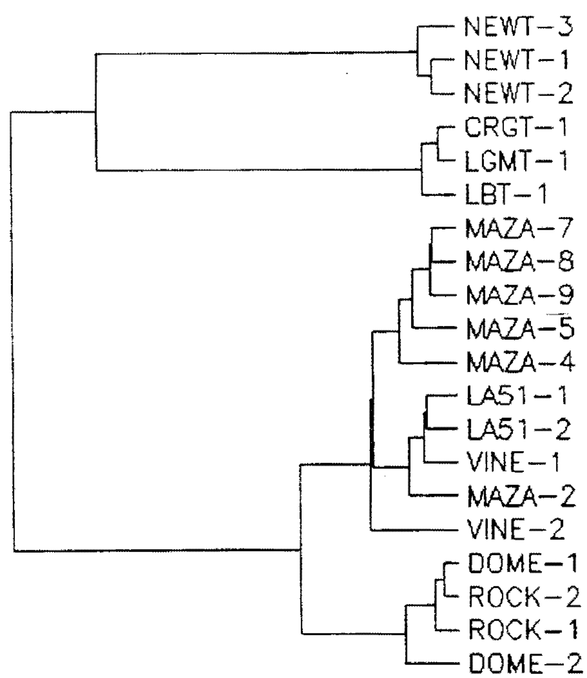

Figure 4. Dendrogram illustrating the results of the trace element cluster analysis classification of the geological and archaeological tephra samples. Sample names are defined in Table 2.

CONCLUSIONS

The identification of Mount Mazama as the source of the Vine Rockshelter and 35LA51 tephra effectively solves the mystery of the Mazama Mimic tephra - the mystery source simply did not exist and was only an analytical fiction. Using INAA characterization methods and minimal sample preparation techniques, the Mazama tephra is easily distinguishable from other Oregon Holocene Cascades sources. It is still safe to assume that silicic tephra deposits found at most southern and central Western and High Cascades archaeological sites, unless they are located in the South Sister vicinity, are almost certainly from Mount Mazama.

The correct identification of the source of the tephra does suggest that the initial occupation of Vine Rockshelter may have begun at an earlier date than was previously thought. The cultural sequence at Vine Rockshelter is potentially considerably longer than was initially hypothesized on the basis of the artifact assemblage and limited radiocarbon dates. The presence of Mazama tephra near the bottom of the rockshelter deposits suggests a possible span of seasonal occupation lasting nearly 7,000 years.

This investigation demonstrates that great care must be taken when published literature values are used for geochemical tephra correlation studies. The tale of the Mazama Mimic mystery tephra clearly illustrates the dangers that may be encountered.

Tephrochronological research such as that carried out at Vine Rockshelter can play a very important role in chronologically and stratigraphically dating and linking archaeological sites within a geographic region. The central Western and High Cascades of Oregon are just such a region and contain deposits from numerous Holocene tephragenic silicic and basaltic volcanic events. The availability of these tephrochronologic possibilities can provide Oregon archaeologists with a chronologic opportunity that should not be overlooked in future regional geoarchaeological research.

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