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ARCHAEOLOGICAL SURVEY OF ALBERTA

OCCASIONAL PAPER NO. 36

Geochemical characterization of tephra deposits at archaeological and palaeoenvironmental sites across south-central Alberta and southwest Saskatchewan

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ABSTRACT

The Mazama Ash is one of the mostly widely distributed tephra units in North America, present as a visible ash in sediments of early Holocene age (ca. 7600 cal yr BP) from Oregon, across to Wyoming and north into central Alberta. It is considered one of the most important stratigraphic markers across this region and is commonly used to ascribe age control to sites. In archaeological projects it is often identified simply on the basis of field characteristics or light microscopy. This can be problematic in sites with low accumulation rates and poor radiocarbon chronologies because several visible tephra are present in Alberta. These include Glacier Peak G (ca. 13,500 cal yr BP), Mount St. Helens Yn (ca. 3600 cal yr BP), and Bridge River (ca. 2500 cal yr BP). Here we present new major-element geochemical analyses from archaeological and sedimentary sites across south-central Alberta and Saskatchewan. We confirm Mazama at most sites, but the presence of Bridge River (and potentially Mount St. Helens Yn) indicates that major-element geochemical data is an important, if not necessary, component to identifying tephra in this region. We also provide the first Bayesian modelled age estimate for Mount St. Helens Yn of 3780-3480 cal yr BP.

KEYWORDS

tephra, geochemistry, Mazama, Bridge River, Glacier Peak, Mount St. Helens, radiocarbon, archaeology, calibrated ages

1. Introduction

Studies examining archaeological and sedimentary sites across central and southern Alberta have often relied on the Mazama Ash, sourced from Crater Lake in Oregon (Figure 1), for chronologic control. This widely distributed volcanic ash has a GISP2 ice-core age of 7627±150 yr BP (Zdanowicz et al. 1999) and a new Bayesian age estimate of 7682–7584 cal yr BP (Egan et al. 2015). However, this tephra is only one of several that have been described since the 1960s at sites across south-central Alberta and southwest Saskatchewan. These include Glacier Peak G (GP-G; 13,710-13,410 cal yr BP), Mount St. Helens Yn (MSH Yn; ca. 3400 ^{14}C yr BP), and the Bridge River tephra (2349-2704 cal yr BP), the latter sourced from Mount Meager in British Columbia (Figure 1) (e.g., Westgate and Dreimanis 1967; Osborn 1985; Beaudoin and King 1986; Luckman et al. 1986; Zoltai 1989; Clague et al. 1995; Beaudoin et al. 1996; Kuehn et al. 2009). In a geological context, tephra identifications have usually been confirmed by geochemical analysis, generally through electron microprobe analysis of volcanic glass or phenocrysts. In an archaeological context, the use of geochemical methods has been much less common. Many past tephra identifications have been based on field criteria, sometimes assisted by light microscopy, and occasionally supplemented by radiocarbon dates.

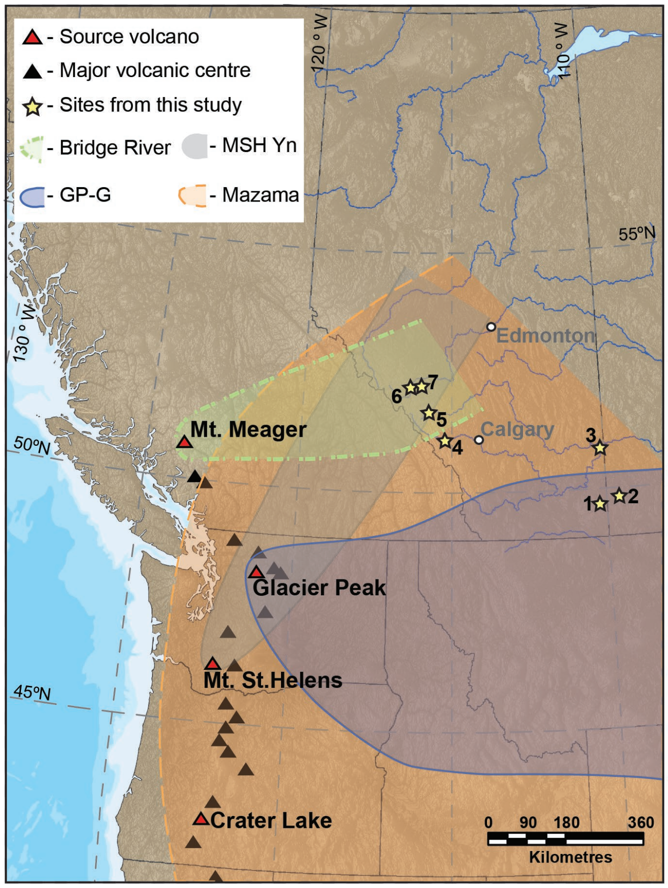

Figure 1. Locations of tephra analyzed for this study, including the approximate distribution of visible deposits of the four main tephras present in Alberta. Distribution of ash to the north of the Athabasca River along the British Columbia border may be limited due to a lack of sites . 1 - Stampede Site; 2 - Friday's Site; 3 - Saskatchewan Outlook; 4 - Lacs des Arcs/Bow River sites (e.g., EgPs-48); 5 - James Pass; 6 - Abraham Lake/White Rabbit and Brian's Creek sites; 7 - Nordegg Bridge and Transmission line sites.

Although Mazama has relatively unique glass morphology in comparison to other tephras found in Alberta, the other tephras have a similar appearance to each other under the microscope, and to the untrained eye, all four could be easily mistaken for one another (Figure 2).

We reanalyzed several samples from archaeological and sedimentary sections across Alberta and into Saskatchewan to provide new geochemical evidence for the tephra collected. Included are archaeological sites at Lac des Arcs and on the Bow River (Newton 1991), the Stampede site in south-east Alberta (Klassen 2004), Friday's site in southwest Saskatchewan (Vreeken 1999), and James Pass in Jasper National Park (Beaudoin et al. 1996). Sedimentary sections included are largely along the North Saskatchewan River in the foothills from Abraham Lake to the Nordegg area, with one on the South Saskatchewan River (Figure 1; Table 1). Several stratigraphic logs representing typical site stratigraphy are presented in Figure 3.

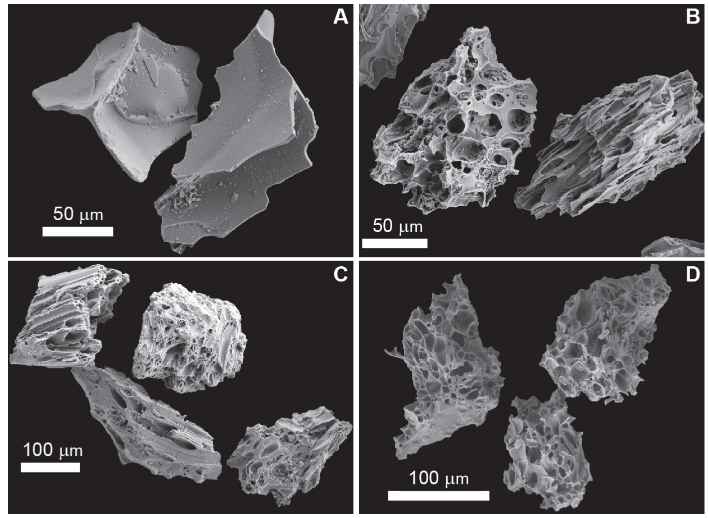

Figure 2. Scanning electron microscope (SEM) images of the Mazama (A,B), Bridge River (C), and MSH Yn (D) tephras. Mazama contains pumiceous grains similar to Bridge River, MSH and GP-G, but platy, bubble-walled and tricuspate shards (A) are common in Mazama and rare or not present in the other three.

Table 1. Site Summary.

Accession Number	Collection Year	Site	Details
UA 2701	1994	James Pass, AB	Archaeological site, horizon 4
UA 2702	1994	James Pass, AB	Archaeological site, 29-33 cm depth
UA 2703	-	Saskatchewan Outlook, AB	Cutbank, S. Sask. River, 1.6 m depth, 4-5 cm thick
UA 2704	2003	Friday's Site, SK	Section
UA 2705	1997	Abraham Lake Lookout Point, AB	Road cut
UA 2815	1987	White Rabbit Creek, near Abraham Lake, AB	Cutbank on creek, tributary to the N. Sask. River
UA 2816	1987	Nordegg Bridge, AB	N. Sask. River cutbank on Hwy 734, 11 km south of intersection with David Thompson Hwy
UA 2817	1987	Nordegg Bridge, AB	N. Sask. River cutbank on Hwy 734, 11 km south of intersection with David Thompson Hwy
UA 2818	1987	Brian's Creek (informal name), AB	Cutbank on tributary of Upper N. Sask. River; 52°0'26" N - 116°33'11" W.
UA 2819	1987	Nordegg Transmission Line, AB	Road cut just north of Nordegg Bridge
UA 2820	1988	Bow River, AB	Archaeological site, tephra on paleosol ~175 cm below surface, dated (see Newton 1991)
UA 2821	1988	Bow River, AB	Archaeological site, tephra on paleosol ~175 cm below surface, dated (see Newton 1991)

Table 1. (*continued*)

Accession Number	Collection Year	Site	Details
UA 2822	1988	Lac des Arcs, AB	Archaeological site. Tephra 69 cm below surface (see Newton 1991)
UA 2823	1988	Lac des Arcs, AB	Archaeological site. Tephra immediately above scraper 12 m west of site profile
UA 2824	1988	Lac des Arcs, AB	Archaeological site. Lower tephra samples west of profile area
UA 2825	-	Stampede Site, AB	Archaeological site.
UA 2831	1987	Lac des Arcs, AB	Archaeological site. Noted as "volcanic ash". Sample looked like carbonate unit, treated with HCl revealed tephra.
UA 2852	2016	James Pass, AB	Archaeological site. From soil peel archived at the Royal Alberta Museum

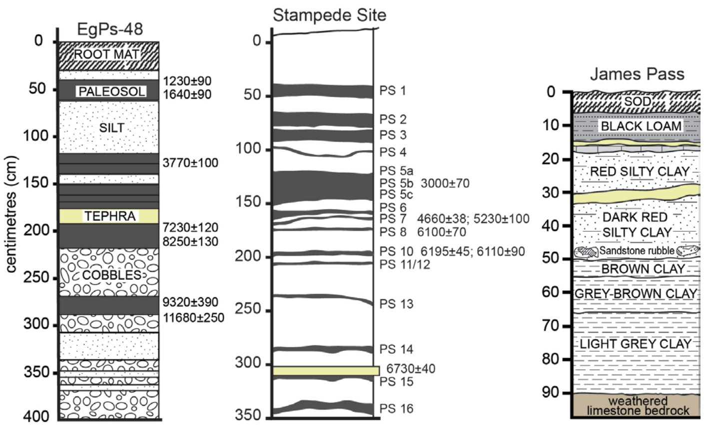

Figure 3. Examples of stratigraphic profiles from several sites in Alberta. EgPs-48 is redrawn from Newton (1991) and is a site on Lac des Arcs, the tephra is UA 2820/21 and is identified as Mazama. The Stampede site stratigraphic log is a composite log redrawn from Klassen (2004). The tephra is UA 2825 and is identified as Mazama. The James Pass stratigraphic log is redrawn from Ronaghan (1993). The upper tephra is thin and discontinuous and no sample survives from this original work, therefore sample UA 2852 was collected from the site peel stored at the Royal Alberta Museum, and was identified as Bridge River. UA 2702 is the lower thick tephra at ~30 cm depth and is identified as Mazama. All ages presented in the figure are in ^{14}C years BP.

In addition to new geochemical data, we have compiled radiocarbon dates that have been reported in association with MSH Yn (Table 2). Although Mazama, Bridge River and GP-G have all had relatively recent re-assessments of their ages, the age of MSH Yn has not been reviewed since 1990 (Vogel et al. 1990). Using these compiled ages we have developed an improved age estimate of the tephra using Bayesian age modelling techniques provided in OxCal v.4.2 (Bronk Ramsey 2009).

2. Methods

All tephra samples were sieved into multiple size fractions (> 125 µm, 125-75 µm, and 75-45 µm) and examined by light microscopy to confirm the presence of glass. Several samples contained abundant carbonates that masked the presence of glass and were treated with 10 percent HCl. Any samples containing abundant organic material were treated with 30 percent H_2O_2. Most samples were predominantly glass and were bulk mounted in acrylic pucks with epoxy, although several required density separation using lithium heteropolytungstate (LST) with a density of ~2.44 grams per cubic centimetre to float the glass component.

Single grain glass-analyses for major and minor elements were carried out by electron probe microanalyses (EPMA) on a JEOL 8900 superprobe by wave-dispersive spectrometry (WDS) at the University of Alberta. Analytical conditions were set at 15KeV, with a 6 nA current and 10 micrometre beam to minimize alkali migration. Two secondary glass standards of known composition, a Lipari obsidian ID 3506 and Old Crow tephra, were analyzed at the start, after every ~100 points, and at the end of each analytical run to track the accuracy and stability of the calibration. For more details on methodology see Jensen et al. (2008) and Kuehn et al. (2011). All data are normalized to 100 percent and are presented in weight percent (wt%) oxides.

The radiocarbon dates for MSH Yn were input into a Bayesian model utilizing the Tau_Boundary function in OxCal v.4.2 (Bronk Ramsey 2009). Dates were calibrated using IntCal13 (Reimer et al. 2013). To test the sensitivity of the model to the exclusion of certain radiocarbon dates (i.e., dates associated with MSH Yn samples identified strictly by field criteria and age), and how the dates were placed into the model, eight different runs were carried out.

3. Results and discussion

3.1. Geochemistry

All tephra samples analyzed were either Mazama or Bridge River tephras (Figure 4). Mazama was ubiquitous across all sites while Bridge River was consistently found in the foothills and towards the eastern edge of Abraham Lake, farther from the mountains than previously reported. It is important to note that several sites throughout the foothills discussed here, including the Nordegg Bridge section, have unpublished reports of MSH Yn, although no samples remain of that tephra. However, the stratigraphic descriptions placing it between confirmed samples of Mazama and Bridge River suggest the identification is correct.

Table 2. Previously reported radiocarbon dates associated with MSH Yn samples. All ages are conventional.

Location	Dates above	Dates below	Stratigraphic Notes	Reference
Proximal MSH	3350±50 (W-2549)	3510±80 (W-1752)	W-2549 is above both Yn and Ye, although erupted close in time this date may be somewhat young. W-1752 is charred wood at the base of Yn.	Crandell et al. 1981; Mullineaux 1996
Otter Creek, BC	3220±70 (GSC-1946)	3390±130 (GSC-298)	Both samples approximately within 2 cm of tephra. Dates on slices of peat from Otter Creek bog.	Westgate 1977
Oldman Creek, BC	3460±140 (GSC-1461)	-	Wood (*Picea* or *Larix*) directly above tephra in bog cross-cut by Trans-Canada highway	Blake and Lowdon (1976)
Pemberton Creek, BC	-	3410±110 (GSC-345)	Charcoal directly below tephra	Blake et al. 1966
Tonquin Creek, BC	3140±70 (Beta-13559)	3680±80 (Beta-13558)	Wedges of peat in contact with the upper and lower boundaries of the tephra	Luckman et al. 1986
Entwistle, AB	3550±65 (WIS-343)	-	Peat wedge containing tephra	Westgate et al. 1969
"Location 7c", AB	3350±100 (AECV-451C)	-	Peat wedge containing tephra. From peat core that appears to have been collected off the Yellowhead highway, east of Edson.	Zoltai 1989
Sunwapta Pass, AB	-	3370±110 (Beta-4676)	Charcoal directly below tephra	King 1984

Geochemically, Mazama has a much greater range in composition than any of the other four tephras examined here. Previous geochemical descriptions of distal Mazama ash deposits tended to present only means and standard deviations, providing limited information. Deposits analysed for this study display a broad compositional range that classify it as a rhyodacite rather than simply a rhyolite, which is evident in the geochemical plots (Figure 4). This is consistent with proximal descriptions of the climactic Mazama eruption that include a dacitic component (e.g., Bacon et al. 2006). Although Bridge River overlaps somewhat with Mazama, its higher SiO_2 wt% and variable Cl and K_2O wt% clearly distinguish the two tephra.

Bridge River, MSH Yn and GP-G are physically similar-looking tephras that can be readily distinguished based on their major element geochemistry (Figure 4; Table 3). GP-G is the highest SiO_2 wt% tephra, with a relatively limited geochemical composition. MSH Yn is the most distinct tephra, generally off the broad compositional trends shared by the other tephra, particularly in terms of Al_2O_3 and K_2O wt%. A full summary of the geochemical averages and standard deviations is provided in Table 3.

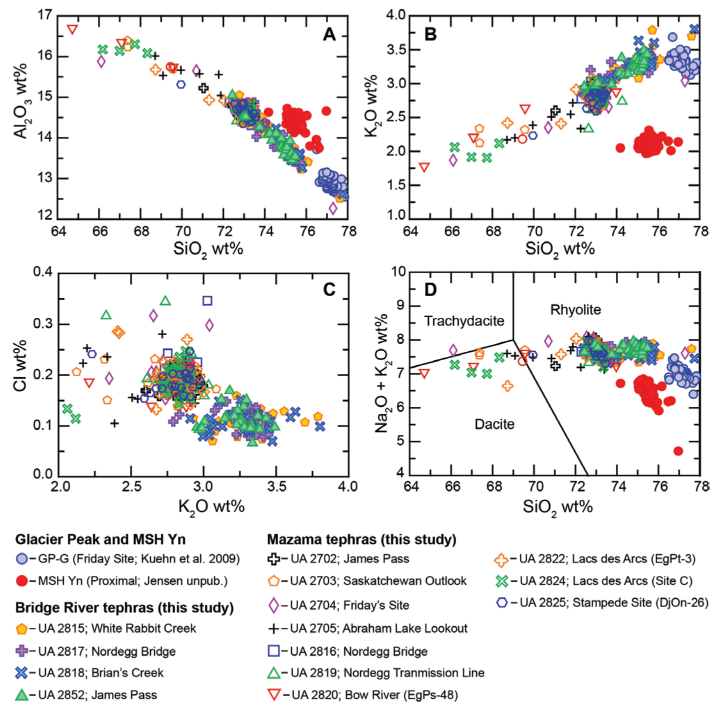

Figure 4. Summary of geochemical data of analyzed tephra. A – All tephra analyzed in this study including reference material from GP-G and MSH Yn; B – All three tephra are readily distinguished through geochemistry with SiO_2 and K_2O being particularly effective; C – Mazama and Bridge River tephra, commonly found together, are readily separated by Cl and K_2O wt%; D – A total alkali-silica diagram (TAS; Le Bas et al. 1986) showing the geochemical classification of the tephra, with Mazama being the only one with a dacitic component.

3.2. Mount St. Helens Yn age modelling

The new age estimates for MSH Yn were obtained using a Bayesian model with a Tau_Boundary function. The Tau_Boundary function assumes that the dates being incorporated into the model cluster near the boundary being dated (Bronk Ramsey 2009), in this case, the boundary being the tephra itself. This is a safe assumption because the compiled ages presented in Table 2 are all within several centimetres of the tephra; the one exception is the upper date in the proximal material that lies above Ye, the eruption that closely followed Yn. However, the Tau_Boundary function does contain a distribution tail that allows for some leeway in distance from the boundary. Additionally, while this date is above Ye, the eruptions following Yn are considered to have occurred over a short period of time. Therefore, the time represented by the distance between the top of Yn and the radiocarbon date is likely relatively small.

Table 3. Summary of normalized geochemical data collected in this study. FeOt - Total as FeO. H_2Od = water content by differnece (100-analytical total, n= number of analyses. The lighter shaded rows are of Bridge River tephra.

Sample	Statistic	SiO_2	TiO2	Al_2O_3	FeOt	MnO	MgO	CaO	Na_2O	K_2O	Cl	H_2Od	n
UA 2701	Mean	72.53	0.44	14.76	2.09	0.06	0.48	1.75	4.95	2.74	0.20	3.23	29
Mazama	StDev	1.66	0.10	0.47	0.53	0.04	0.19	0.44	0.25	0.27	0.04	1.94	
UA 2702	Mean	72.94	0.43	14.59	1.96	0.06	0.42	1.62	5.01	2.80	0.18	2.63	26
Mazama	StDev	0.41	0.06	0.16	0.15	0.03	0.04	0.18	0.14	0.10	0.02	1.24	
UA 2703	Mean	72.49	0.45	14.74	2.07	0.04	0.47	1.75	5.04	2.77	0.19	3.66	31
Mazama	StDev	1.50	0.07	0.47	0.42	0.03	0.19	0.43	0.18	0.20	0.02	1.48	
UA 2704	Mean	72.79	0.45	14.60	2.01	0.06	0.45	1.67	5.00	2.77	0.20	3.32	30
Mazama	StDev	1.57	0.08	0.54	0.41	0.02	0.18	0.46	0.25	0.21	0.04	1.91	
UA 2705	Mean	72.52	0.45	14.77	2.05	0.04	0.47	1.78	4.97	2.74	0.19	3.04	32
Mazama	StDev	1.20	0.08	0.42	0.33	0.03	0.16	0.35	0.21	0.21	0.03	1.09	
UA 2815	Mean	74.84	0.34	13.86	1.48	0.04	0.32	1.39	4.35	3.28	0.11	4.34	29
Bridge River	StDev	1.04	0.07	0.52	0.21	0.02	0.09	0.26	0.20	0.20	0.02	1.19	
UA 2816	Mean	72.97	0.44	14.60	1.96	0.05	0.44	1.61	4.90	2.84	0.20	4.51	28
Mazama	StDev	0.23	0.04	0.12	0.07	0.02	0.03	0.06	0.17	0.08	0.03	2.18	
UA 2817	Mean	74.67	0.33	13.90	1.50	0.05	0.32	1.41	4.45	3.26	0.11	3.90	29
Bridge River	StDev	0.95	0.06	0.49	0.24	0.03	0.06	0.23	0.16	0.16	0.02	1.37	
UA 2818	Mean	74.85	0.35	13.85	1.51	0.04	0.33	1.38	4.32	3.28	0.11	4.12	27
Bridge River	StDev	1.10	0.07	0.51	0.25	0.02	0.10	0.25	0.20	0.21	0.02	1.11	
UA 2819	Mean	73.06	0.44	14.55	1.94	0.04	0.44	1.62	4.87	2.83	0.20	3.22	26
Mazama	StDev	0.31	0.04	0.14	0.10	0.03	0.03	0.12	0.14	0.14	0.04	0.96	
UA 2820	Mean	72.41	0.46	14.79	2.15	0.06	0.53	1.80	4.84	2.75	0.19	3.54	24
Mazama	StDev	2.18	0.12	0.60	0.65	0.03	0.30	0.65	0.19	0.25	0.02	0.68	
UA 2821	Mean	72.55	0.45	14.77	2.09	0.06	0.51	1.72	4.94	2.72	0.19	3.37	23
Mazama	StDev	1.60	0.08	0.55	0.49	0.03	0.20	0.39	0.20	0.20	0.03	0.87	
UA 2822	Mean	72.76	0.46	14.70	2.01	0.05	0.48	1.73	4.84	2.78	0.20	3.89	22
Mazama	StDev	1.01	0.07	0.26	0.35	0.04	0.14	0.41	0.21	0.15	0.04	1.91	
UA 2823	Mean	73.03	0.44	14.64	1.98	0.05	0.44	1.63	4.81	2.79	0.19	3.08	24
Mazama	StDev	1.03	0.08	0.37	0.29	0.03	0.11	0.25	0.17	0.13	0.02	1.16	
UA 2824	Mean	72.13	0.49	14.89	2.23	0.06	0.56	1.89	4.89	2.67	0.19	3.35	23
Mazama	StDev	2.29	0.16	0.61	0.73	0.02	0.30	0.69	0.20	0.32	0.03	1.38	
UA 2825	Mean	72.92	0.46	14.65	1.99	0.05	0.45	1.61	4.87	2.80	0.19	3.27	23
Mazama	StDev	0.69	0.06	0.21	0.21	0.04	0.09	0.19	0.20	0.16	0.02	1.14	
UA 2832	Mean	72.84	0.44	14.73	2.01	0.05	0.47	1.64	4.88	2.77	0.18	3.03	21
Mazama	StDev	0.93	0.07	0.34	0.28	0.02	0.11	0.25	0.16	0.16	0.03	0.78	
UA 2852	Mean	74.61	0.32	13.90	1.51	0.04	0.35	1.42	4.50	3.23	0.11	3.37	24
Bridge River	StDev	0.81	0.07	0.38	0.16	0.02	0.07	0.21	0.16	0.15	0.02	1.32	

The model was run using eight different combinations of dates and the placement of dates, summarized in Table 4. Final age estimates were not affected greatly by the inclusion or exclusion of certain dates (that is, dates associated only with geochemically confirmed samples as opposed to all dates), but there was a relatively notable difference between including or excluding the radiocarbon dates that were from peat wedges containing the tephra. Because these two samples contained tephra, they were initially placed in the model within the boundary itself, which could cause them to be weighed too heavily in this particular model. Placing these dates either before or after the boundary caused similar variation, but WIS-343 was rejected by the model when placed post-eruption because the date was considered too old. Overall, we feel the best age range is presented by model run 6b of 3740-3480 cal yr BP with a median age of 3620 cal yr BP, using only geochemically confirmed samples and excluding the remaining enclosed date of WIS-343 (Figure 5). We chose to exclude this date because it may be skewed older as shown by its rejection

Table 4. Calibrated age ranges for models. Model 6b is considered the most reliable age estimate for MSH Yn.

Model run	Details on dates included/ excluded	Calibrated age range (cal yr BP)	Median age (cal yr BP)
1	Includes all dates reflecting stratigraphy	3825-3605	3705
2	Includes all dates, excluding dates enclosed ages	3790-3485	3625
3	All ages, but enclosed ages placed pre-eruption	3785-3500	3635
4	*All ages, but enclosed ages placed post-eruption	3840-3610	3730
5	All ages, AECV-451C placed post-, WIS-343 pre-eruption	3800-3505	3645
6a	**Geochemically confirmed Yn samples	3835-3610	3725
6b	Geochemically confirmed Yn samples, no enclosed ages	3780-3480	3620
6c	As above, no AECV-451C but WIS-343 placed pre-eruption	3850-3490	3660

* Low agreement index with WIS-343, model rejects placement of date post-eruption

** Confirmed samples include Proximal, Otter Lake, Sunwapta, and Entwistle (enclosed sample)

when placed in the post-eruption phase, and its nature as a bulk peat date. Additionally, the model run where WIS-343 was placed pre-eruption creates a similar age range (3785-3500 cal yr BP).

A complication with MSH Yn is the presence of another MSH tephra of similar composition that has been reported in the Obed and Hinton area and towards Jasper National Park (e.g., Westgate, 1977). Radiocarbon dates associated with this tephra reported by Westgate (1977) and Luckman et al. (1986) suggest this tephra predates MSH Yn by several hundred radiocarbon years, with estimates ranging from ca. 4400-3900 ^{14}C yr BP. A peat site reported by Zoltai (1989) due south of this region contains several ash beds; the upper bed has a radiocarbon date of 3350±100 ^{14}C yr BP, with the lower ash beds containing dates of 3860±150 and 3820±110 ^{14}C yr BP. It is unclear how undisturbed these peat deposits are despite assurances by the author, but the ages suggest that if there are indeed two MSH set Y tephras present in Alberta, their distributions could overlap. However, more geochemical analyses and radiocarbon dates are necessary to clarify this issue.

4. Conclusion

Archaeological sites in Alberta can contain up to four major visible tephra units. The geochemistry of each is unique, but their other characteristics greatly overlap. In general, the careful use of light microscopy, stratigraphy and age control has been largely successful in positively identifying visible deposits of Mazama. However, we suggest that geochemical characterization is necessary to positively confirm the identity of any visible ash in Alberta. This applies particularly in sites with poor chronologic control, lower sedimentation rates, and in the Rocky Mountains and foothills between Calgary and Hinton, where Mazama, Bridge River and MSH Yn can occur at the same site. We recommend that geochemical characterization be a routine component of verification of tephras across Alberta.

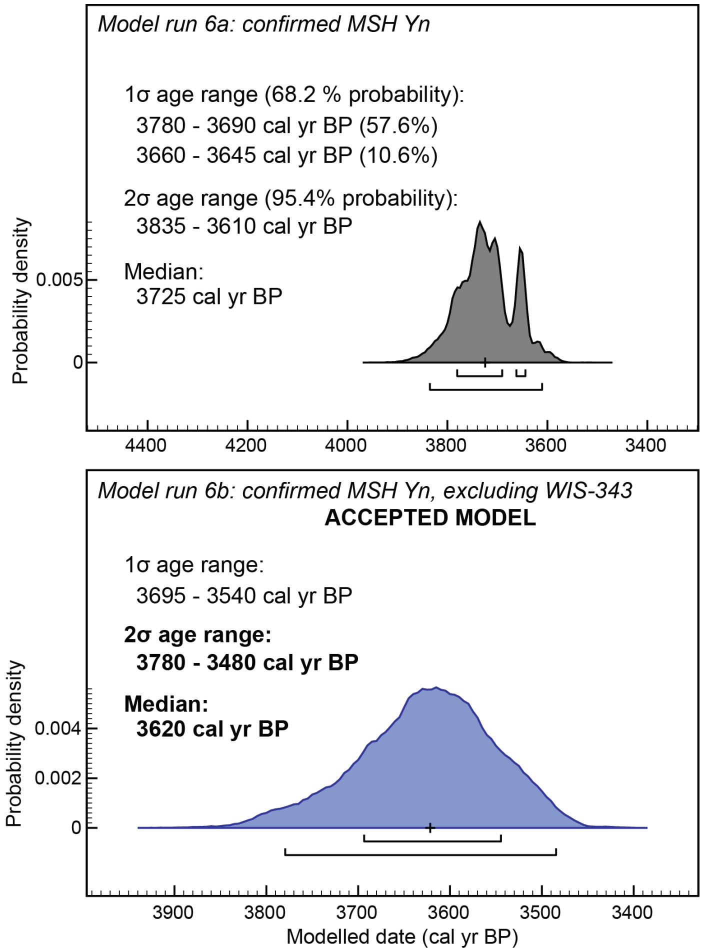

Figure 5. Probability density function plots derived from radiocarbon dates related to MSH Yn samples that have had their identity confirmed through geochemical studies. The upper plot includes WIS-343, a sample of peat that contained the tephra. Including this date creates a tighter calibrated range and older median age. The lower plot excludes this age, extending the younger portion of the calibrated age range and slightly lowering the median age. The latter age estimate is a more conservative estimate, and should be the age used considering the origin (largely bulk peat and charcoal) and age (all pre-1988) of the radiocarbon dates.

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