Variations in the depth and thickness of the White River Ash in lakes of the southwest Yukon

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ABSTRACT

The purpose of this study is to document the depth and thickness of the White River Ash in lakes across the southwest Yukon for use in paleoenvironmental impact studies. Sediment cores were sampled from seven lakes located within the plume of the eastern lobe of the White River Ash (1147 cal. years BP). Site locations are between 92 and 254 km from Mount Churchill, Alaska, the probable source for the White River Ash. Based on magnetic susceptibility measurements, the depth of the sediment above the ash layer in the lakes ranges between 38 and 98 cm; these differences are due to factors associated with sedimentation rates. The thickness of the ash ranges between 0.1 and 32 cm and typically increases with proximity to the source vent. These results can be used in paleoenvironmental studies to assist in the interpretation of the impact of volcanic ash events.

RÉSUMÉ

Le but de cette étude est d'obtenir des données sur l'épaisseur des centres de la rivière White dans les lacs du sud-ouest du Yukon aux fins d'utilisation dans le cadre d'études d'impact paléoenvironnemental. Nous avons examiné les carottes de sédiments prélevées dans sept lacs situés dans le panache du lobe est des cendres de la rivière White (1147 cal. BP) afin de déterminer les différences de profondeur et d'épaisseur de la couche de cendres. Les sites d'échantillonnage sont situés entre 92 et 254 km du mont Churchill (Alaska), une source possible des cendres de la rivière White. Selon des mesures de la susceptibilité magnétique, la profondeur des sédiments au-dessus de la couche de cendres dans les lacs varie entre 38 et 98 cm et dépend de facteurs liés au taux de sédimentation. L'épaisseur des cendres varie entre 0,1 et 32 cm et augmente habituellement à proximité de la source. Ces résultats peuvent être utilisés dans les études paléoenvironnementales pour faciliter l'interprétation des répercussions des épisodes de cendres volcaniques.

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INTRODUCTION

THE WHITE RIVER ASH EVENT

The eastern lobe of the White River Ash is the result of a volcanic eruption that deposited an enormous volume of tephra over southern Yukon 1147 cal. yrs. BP (Fig. 1; Clague *et al.*, 1995; West and Donaldson, 2001). Evidence of the eruption occurs in peat profiles as far east as Great Slave Lake, Northwest Territories (Robinson, 2001), and recent work suggests that traces can be found northeast to Great Bear Lake (Lerbekmo, 2008). Early studies of the widespread tephra layer suggested different possible sources for the tephra, such as Mount Natazhat (Hayes, 1892), Mount Bona (Hanson, 1965), or a vent under the Klutlan Glacier (Lerbekmo and Campbell, 1969; Fig. 2). More recently, Mount Churchill, Alaska, a stratovolcano in the Wrangell volcanic field 40 km from the Yukon-Alaska border was determined to be the likely source (McGimsey *et al.*, 1992; Richter *et al.*, 1995). However, Lerbekmo (2008) recently reprised the idea that a vent under the Klutlan Glacier is the source.

Explosive volcanic eruptions such as the White River Ash event eject large quantities of ash into the atmosphere that become deposited in both terrestrial and aquatic environments. Tephra is incorporated into lake sediments by falling directly on the lake surface, and through deposition within the watershed and transportation to the lake via runoff. Evidence suggests the eruption that produced the White River Ash occurred in late autumn or early winter (West and Donaldson, 2001), therefore, the tephra would have been deposited on frozen lake surfaces and would not have been incorporated into the

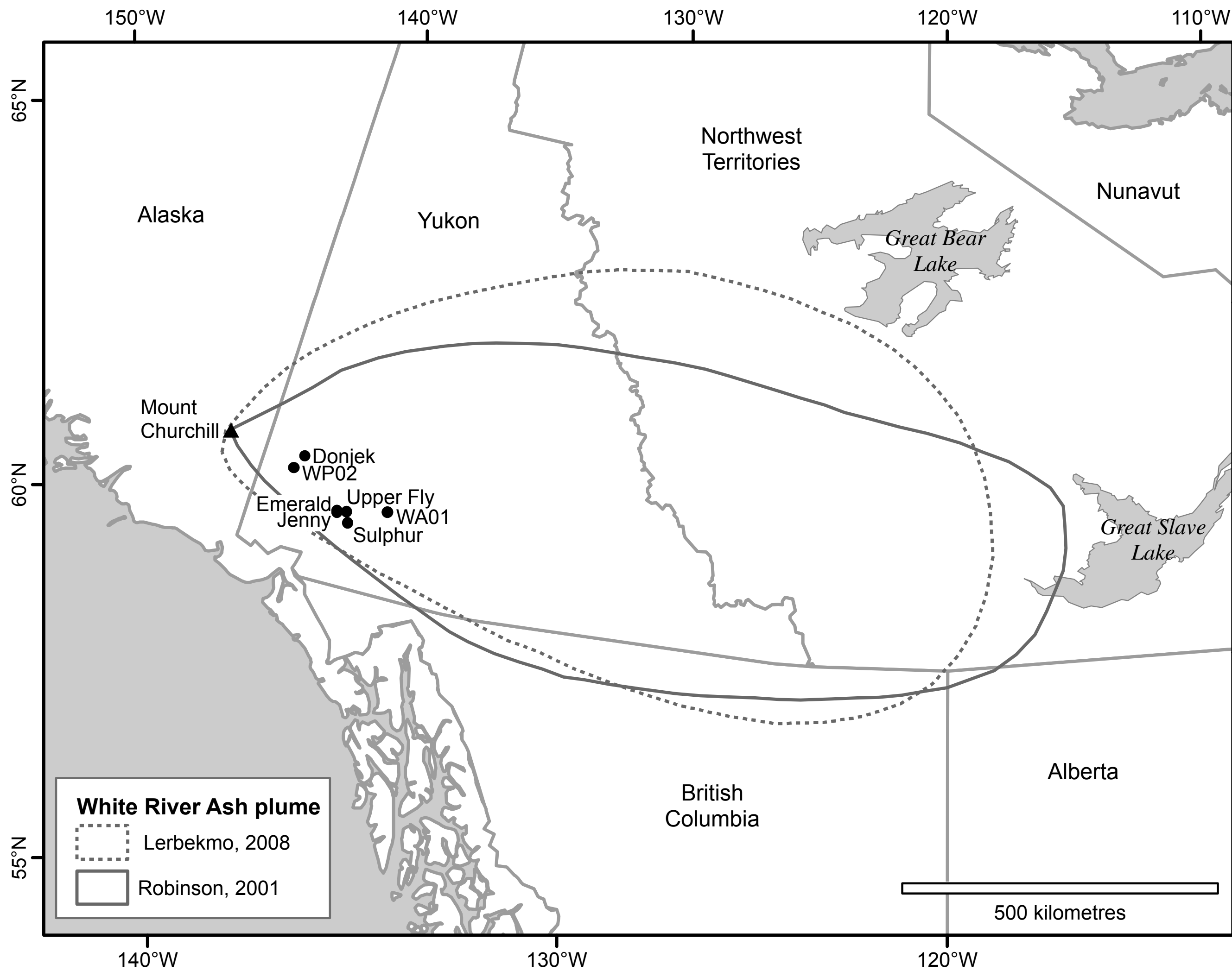

Figure 1. *The extent of the eastern lobe of the White River Ash after (Robinson, 2001) and (Lerbekmo, 2008). Location of the seven study lakes and Mount Churchill are provided for reference.*

sediments until the spring melt. The ashfall would have impacted both the aquatic and terrestrial communities in the region, though the extent of the impact would be a function of the quantity of ash deposited in a given site. Therefore, this event provides a 'natural experiment' to evaluate the impact of this catastrophic event on ecosystems through the analysis of fossils in lake sediments.

The objective of this study is to assess the variations in depth and thickness of the White River Ash from seven lakes in southwest Yukon. The results from this study can then be used in paleoenvironmental studies to aid in the interpretation of the impact of these types of events on terrestrial and aquatic ecosystems.

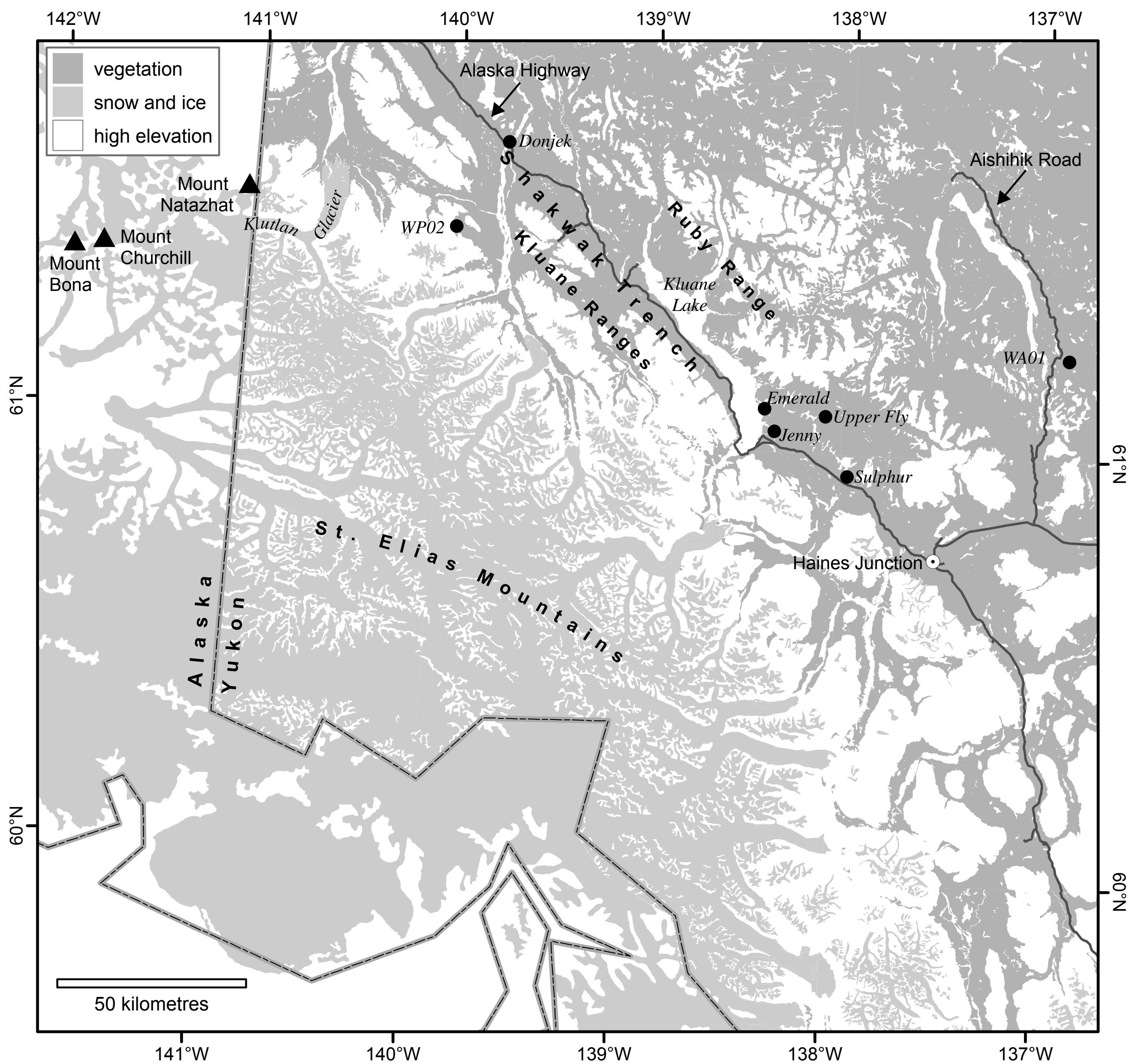

Figure 2. Map showing more detailed locations of the seven lakes. Mount Churchill, Mount Natazhat, Mount Bona and the Klutlan Glacier are provided for reference.

REGIONAL SETTING

The southwest Yukon is located in the rainshadow of the St. Elias Mountains resulting in a semi-arid climate with total precipitation values <300 mm annually (Environment Canada, 2004). Mean annual daily temperatures are below 0°C, and discontinuous permafrost is widespread throughout the region, particularly at higher elevations (National Atlas Information Service, 1995). Dominant trees in this part of the boreal forest are white spruce (*Picea glauca*), balsam poplar (*Populus balsamifera*) and trembling aspen (*Populus tremuloides*; Johnson and Raup, 1964); bogs with stands of black spruce (*Picea mariana*) can be found further north. Natural grasslands are interspersed with open forest stands, particularly in the vicinity of Kluane Lake and in the Aishihik Lake region (Vetter, 2000). Alpine-tundra types including dwarf birch (*Betula*), willow (*Salix* spp.), grasses (Gramineae) and sedges (Cyperaceae) are found at higher elevations.

The region is geologically complex and is underlain by a variety of bedrock types including intrusive bodies composed of granodiorite, quartz diorite, quartz monozite and granite. Gneiss and volcanic rock are also present, and till is abundant, particularly in the Kluane Lake region (Gabrielese *et al*., 1977; Fulton, 1995).

Seven sediment cores recovered from lakes located within the eastern lobe of the White River Ash plume were used for this study (Figs. 1, 2). Lakes vary in their ionic composition, but are generally bicarbonate rich and dominated by either calcium or magnesium, with higher ionic concentrations occurring near Kluane Lake. Surface areas of the lakes vary between 0.1 and 143 ha, and core collection depth ranged between 2.5 and 11 m (Table 1). Both Sulphur Lake (Sulphur) and Upper Fly Lake (Upper Fly) lack an obvious inflow, yet both have a stream outflow, whereas the other sites are kettle lakes with only groundwater inputs. Vegetation surrounding the lakes varies. Sulphur Lake WA01 (WA01), Emerald Lake (Emerald), Jenny Lake (Jenny), and Donjek Kettle (Donjek) are situated in the boreal forest; Upper Fly is in the forest-tundra transition zone; and Lake WP02 (WP02) is located in alpine tundra.

Table 1. *Location, surface area, core collection depth, and distance from Mount Churchill for the seven study lakes.*

Lake	Latitude (°N)	Longitude (°W)	Elevation (m)	Surface area (ha)	Core collection depth (m)	Distance from Mount Churchill (km)
WP02	61.48	140.00	1463	0.65	4.0	92.6
Donjek	61.69	139.76	732	0.6	6.0	110.1
Emerald	61.07	138.37	820	8.4	7.0	181.6
Jenny	61.04	138.36	817	19.9	4.0	183.0
Upper Fly	61.09	138.09	1326	10.5	4.0	196.2
Sulphur	60.95	137.98	854	142.6	11.0	205.7
WA01	61.25	136.93	991	0.1	2.5	254.7

METHODS

FIELD METHODS

Lake sediment cores were collected from Emerald and Donjek in August 1996; Sulphur and Upper Fly in July/August 1997; Jenny in May 2003; WP02 in July 2006; and WA01 in July 2008. All sediment cores were retrieved using a modified Livingstone piston sampler and the unconsolidated uppermost sediments were extruded into plastic bags in the field. The length of the core that is extruded in this manner depends on the cohesiveness of the sediments and varies from site to site (Fig. 3). The remainder of the cores were extruded, wrapped in plastic wrap and aluminum foil and transported back to Ottawa where magnetic susceptibility was measured. Only the uppermost sections of the lake sediment cores are discussed in this study.

LABORATORY METHODS

Magnetic susceptibility

Magnetic susceptibility is a non-destructive sediment logging technique that measures the ability of the sediments to be magnetized; values typically reveal the amount of magnetic minerals that are present within the sediments (Dearing, 1994). Increases in concentrations of magnetic minerals in lake sediment cores are generally interpreted as periods of increased erosion in the watershed. For example, greater precipitation would transport inorganic allochthonous material to the lake, which would then become incorporated into the sediments (Lowe and Walker, 1997). Other material that causes high magnetic concentrations in lake sediments includes volcanic ash, due to the presence of magnetite, a common mineral that dominates magnetic

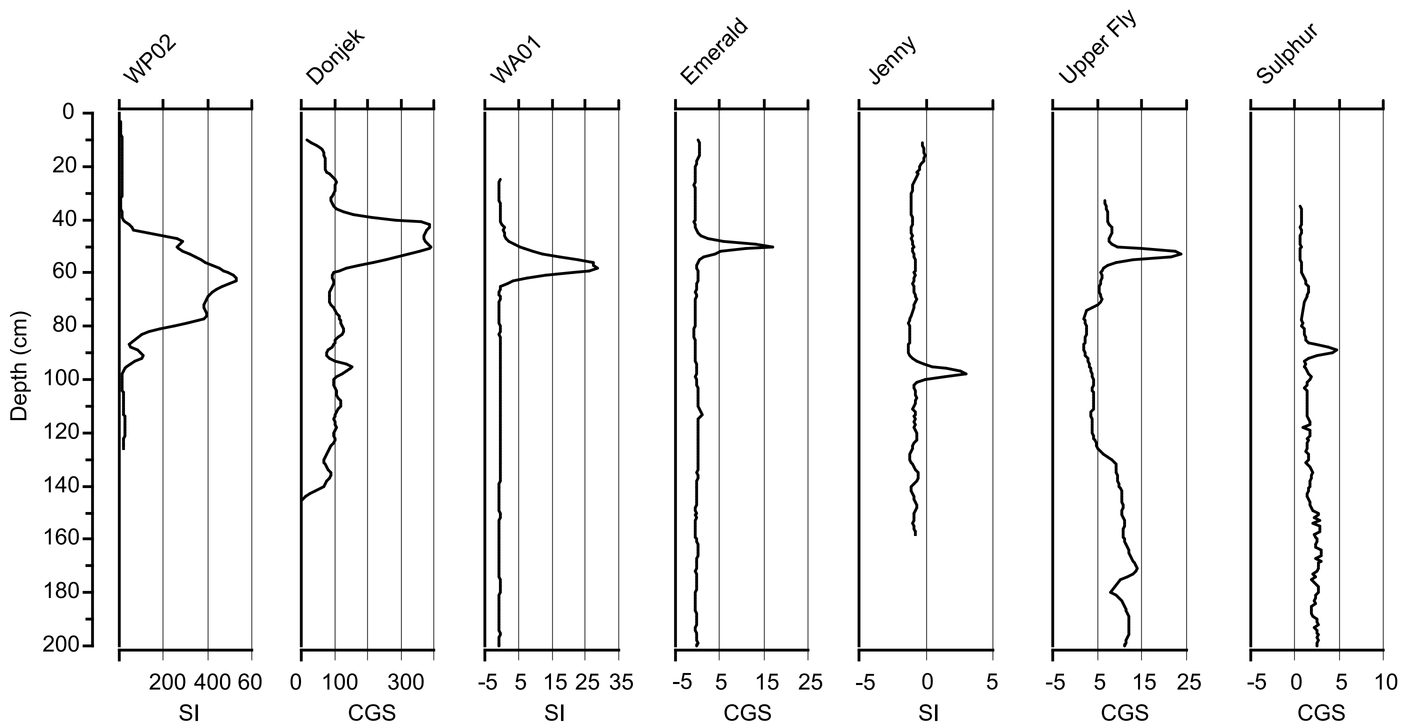

Figure 3. *Magnetic susceptibility profiles for the seven study lakes. Note that different units were used.*

susceptibility measurements when present in a sample (Dearing, 1994).

A Bartington MS2C Core Sensor with a 6 cm-internal diameter was used to measure magnetic susceptibility at 1 cm intervals on the seven lake-sediment cores. Whole cores were fed through a loop sensor and the meter computed susceptibility values as a weighted mean of the individual measurements (Nowaczyk, 2001). Units are dimensionless and the base units are either in centimetres, grams, seconds (CGS) or metres, kilograms, seconds (International System of Units; SI). Although the values are slightly different, for the purposes of this study the interpretation of the results is not affected.

RESULTS

MAGNETIC SUSCEPTIBILITY OF SEDIMENT IN SOUTHWEST YUKON LAKES

In all seven lake-sediment cores, maximum values of magnetic susceptibility occur where the White River Ash is present (Fig. 3). Both WP02 and Donjek have very high maximum values (533 SI units and 392 CGS units, respectively), followed by more moderate maximum values at WA01 (28.7 SI units), Upper Fly (23.7 CGS units) and Emerald (17 CGS units), and low maximum values at Sulphur (4.81 CGS units) and Jenny (2.97 SI units). All sites have low magnetic-susceptibility values in the portions of the cores where there is no volcanic ash. WP02 and Donjek have the highest minimum values (6.7 SI units and 6.2 CGS units, respectively), Upper Fly and Sulphur have small, positive values (1.9 CGS units and 1.6 CGS units, respectively), whereas Jenny, Emerald, and WA01 have negative values (-1.4 SI units, -0.7 CGS units and -0.8 SI units, respectively). Prior to the ash deposition, magnetic concentrations appear more variable throughout the cores from Donjek and Upper Fly, whereas the remaining sites show stable, low magnetic concentrations aside from where the White River tephra is present.

WHITE RIVER ASH DEPTH IN SOUTHWEST YUKON LAKES

The White River Ash layer is shallowest in Donjek with only 38 cm of sediment accumulation over the past 1200 years (Table 2). Comparable sediment accumulation rates above the ash are found at Upper Fly (54 cm), Emerald (51 cm), WP02 (50 cm), and WA01 (51 cm), whereas Sulphur (90 cm) and Jenny (98 cm) have almost twice the accumulation.

WHITE RIVER ASH THICKNESS IN SOUTHWEST YUKON LAKES

The thickest layers of White River Ash found in lake sediments from these sites are at WP02 (32 cm) and Donjek (27 cm; Table 2). WA01 has 11 cm of ash, whereas Jenny, Emerald, and Upper Fly all have less than 1 cm (0.3, 0.3 and 0.1 cm, respectively). Sulphur has no visible ash layer, however the magnetic susceptibility values indicate an increase coinciding with the timing of the White River Ash (Lacourse and Gajewski, 2000). Note that the estimate of ash thickness is not exact due to the averaging of the magnetic signal by the sensor.

Table 2. *Depth and thickness of the White River Ash found in the sediment cores of the seven lakes. Ash depth is based on magnetic susceptibility measurements (1 cm resolution) and ash thickness is based on magnetic susceptibility measurements and visual inspection.*

Lake	Ash depth (cm)		Ash thickness (cm)
	Start	Finish	
WP02	50	82	32.0
Donjek	38	61	27.0
Emerald	50	51	0.3
Jenny	98	99	0.3
Upper Fly	53	54	0.1
Sulphur	89	90	Not visible
WA01	51	62	11.0

DISCUSSION

MAGNETIC CONCENTRATIONS IN LAKE SEDIMENTS

Carbonate lake sediments at Jenny, Emerald and WA01 result in weak, negative magnetic susceptibility values due to the diamagnetic behaviour of calcium carbonate (*e.g.*, precipitated calcite, ostracodes and molluscs) found in the sediment (Fig. 2; Dearing, 1994). The weak, positive values throughout the cores at the other sites suggest paramagnetic sediments that include minerals that contain iron (*e.g.*, biotite, olivine; Dearing, 1994).

The White River Ash is ferrimagnetic based on the strong, positive susceptibility values at all sites; this is due to the presence of the mineral magnetite that comprises 2.1% of the weight of the White River Ash (Lerbekmo and Campbell, 1969). Very high (*i.e.*, >300 regardless of unit) magnetic concentrations at Donjek and WP02 are the result of the volume of White River Ash that occurs in the sediments at those sites (Fig. 3), as large bulk samples record higher values than small samples of the same material (Dearing, 1994). Magnetic concentrations of the White River Ash at the other sites are lower and are a reflection of the reduced amount of ash in those sediments. The particularly low values at Jenny and Sulphur lakes may be a result of the large surface area at those two sites, where the ash becomes more diluted in the sediments than it would at the lakes with a smaller surface area.

WHITE RIVER ASH THICKNESS AND DISTANCE FROM THE SOURCE

The thickness of the White River Ash layer in lake sediments is expected to decrease with increasing distance from the source. This holds true for six of the seven lakes, but not for WA01, which has an 11 cm thick ash layer and is located the furthest from the source in this study (Tables 1, 2). WA01 is a bowl-shaped kettle lake with a very small surface area (0.1 ha) surrounded by steep slopes. As the tephra was deposited it would have become concentrated in a small area at the bottom of the lake (referred to as sediment focusing). In addition, as the snow on the surrounding slopes melted in the spring, any ash within the basin would have been washed into the lake, thereby increasing the amount accumulated in the sediments. A lake sediment core collected from a slightly larger lake with less steep slopes across the Aishihik Road from WA01 revealed no visible ash layer, suggesting the importance of the morphology of the lake and surrounding basin to the ash layer thickness at WA01.

WHITE RIVER ASH DEPTH AND SEDIMENTATION RATES

The amount of lake sediment that has accumulated above the White River Ash is comparable at five of the seven sites, indicating similar sediment accumulation rates over the past 1200 years (Fig. 3 and Table 2). Greater sedimentation rates have occurred at both Jenny and Sulphur since the White River Ash event, and may be due to larger sediment input to the sites as well as sediment focusing. The steep-sided bathymetry of Sulphur Lake causes accumulated material within the sediment to move downslope to the bottom of the lake where the core sample was collected within an 11 m-deep section. A similar situation exists at Jenny Lake, however it is more likely the result of the steep slope alongside the lake close to the area where the core was collected. During periods of increased precipitation or snowmelt, inorganic allochthonous material becomes entrained and deposited in the lake and eventually forms part of the sediments.

CONCLUSIONS

Magnetic susceptibility in lake sediments is highest where the White River Ash is present, and greater volumes of ash result in much higher magnetic susceptibility measurements. The thickness of the White River Ash typically decreases with increasing distance from the source vent, and lake sedimentation over the past 1200 years is fairly consistent between the sites. However, sediment focusing can increase the amount of ash incorporated into the sediments of a given site. The findings from this study will be considered in a paleoenvironmental study exploring the impact of the White River Ash event on aquatic ecosystems in the region.

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