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The variegated (VT) tephra: A new regional marker for middle to late marine isotope stage 5 across Yukon and Alaska

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ABSTRACT

The Variegated (VT) tephra, likely sourced from the eastern Aleutian arc, has a geographic distribution that places it amongst the most widespread tephra beds in eastern Beringia. First identified in the Fairbanks area of interior Alaska, it has been identified at eight additional sites ranging from Togiak Bay in southwestern Alaska, to the Klondike area of west-central Yukon. Correlation of these occurrences is established through the equivalence of glass major and trace-element geochemistry, Fe-Ti oxide geochemistry, stratigraphy, and independent age data. In Yukon and Alaska, VT tephra has a minimum bulk tephra volume estimate of $\sim$32 km^3. Previous age estimates for VT tephra have varied, ranging from a glass fission-track age of 125 $\pm$ 30 ka to a weighted mean thermoluminescence (TL) age of 77.8 $\pm$ 4.1 ka from bracketing ages on loess. A new infrared stimulated luminescence (IRSL) age of 106 $\pm$ 10 ka, paleoenvironmental data, and several TL and IRSL ages from Togiak Bay suggest that the time of deposition is more likely between these previous age estimates: post-marine isotope stage (MIS) 5e but underlying a prominent soil likely associated with MIS 5c, placing it within late MIS 5d.

1. Introduction

Widely dispersed tephra beds, such as the Vedde Ash in western Europe and the Old Crow tephra in Yukon and Alaska, play an important role in correlating and dating regionally distributed paleoenvironmental and stratigraphic records (e.g. Westgate et al., 1983; Mangerud et al., 1984; Reyes et al., 2010a). Tephrochronology plays a fundamental role in interpreting stratigraphic records in the non-glaciated regions of Yukon and Alaska, collectively eastern Beringia. This region and its geological archives are critical to understanding the evolution of the Arctic by providing an opportunity to examine terrestrial paleoenvironmental records. Restricted glaciation in this region has resulted in the preservation of long, near-continuous sedimentary records that frequently contain exceptional paleobotanical and faunal records by virtue of their common association with permafrost (e.g. Westgate et al., 1990; Matheus et al., 2003; Zazula et al., 2007; Froese et al., 2009). Sedimentary records of this age are often difficult to date and correlate since much of the material is too old for commonly used dating techniques such as radiocarbon dating. Fortunately, one of the most unique aspects of sedimentary records in eastern Beringia is the common presence of distal tephra beds (e.g. Preece et al., 1999, 2000; Jensen et al., 2008; Péwé et al., 2009). Each tephra bed has unique geochemical, petrologic and morphologic components that allows correlation of sediments across hundreds to thousands of kilometers, and some can be directly dated by either glass fission-track or ^{40}Ar/^{39}Ar methods (e.g. Kunk, 1995; Sandhu and Westgate, 1995; Sandhu et al., 2000).

The majority of tephra studies in eastern Beringia have focused on establishing individual records at specific locales (e.g. Preece et al., 1999, 2000; Schaefer, 2002; Matheus et al., 2003; Jensen et al., 2008). There has been limited success in correlating disparate sites to one another through recognition of regionally

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Table 1
Summary of sample locations.

Sample	Location	Latitude and Longitude	Summary of stratigraphic context of VT
UT 1435	Togiak Bay-1, Alaska	58.903 N, 160.748 W	50 cm thick occurrence within a 19 m thick diamicton (Kaufman et al., 2001)
UT 1409	Togiak Bay-2, Alaska	58.967 N, 160.260 W	At the base of a peat unit containing a *Picea* peak (Kaufman et al., 2001)
UA 1425	Halfway House, Alaska	64.705 N, 148.502 W	Within inorganic silt, 40 cm below a paleosol
UT 822	Gold Hill I/Ib, Alaska	64.856 N, 147.929 W	Within inorganic silt, near base of paleosol (Preece et al., 1999; Berger, 2003)
UA 1344	Gold Hill IV, Alaska	64.856 N, 147.929 W	Gold Hill 4: within B-horizon of paleosol
UA 1097	Chester Bluff, Alaska	65.335 N, 142.732 W	Within inorganic silt, ~10 m above Old Crow
UA 1100	Little Montauk, Alaska	65.104 N, 141.417 W	Within inorganic silt, below a ~1 m thick organic-rich silt
96TOK-1-5	Tetlin Junction, Yukon	63.198 N, 142.178 W	Base of paleosol (Schaefer, 2002)
UT 1562, 1637, UA 1580	Jackson Hill, Yukon	64.023 N, 139.361 W	Within inorganic silt with some organic blebs
UA 1579	Hunker Creek, Yukon	64.017 N, 139.147 W	Within frozen organic-rich silt
UT 1813	Thistle Creek, Yukon	63.067 N, 139.317 W	Within frozen organic-rich silt

extensive tephra beds. To date, the Old Crow tephra (124 ± 10 ka) is the only bed that has been established firmly as a regional marker horizon across eastern Beringia (e.g. Westgate et al., 1985; Preece et al., in press). Recognizing widely distributed tephra beds is an important aspect of tephrochronology as it facilitates correlation, dating and comparison of paleoenvironmental records (e.g. Lowe, 2001; Muhs et al., 2001; Newnham et al., 2003). This study presents the geochemistry, stratigraphic setting, and refines age constraints on the regionally distributed Variegated or VT tephra.

First described by Preece et al. (1999) at the Halfway House and Gold Hill sites near Fairbanks, VT tephra has since been collected and analyzed, although not necessarily identified as VT tephra, at several other sites across Alaska and Yukon. This paper establishes the widespread distribution of VT tephra at ten sites ranging from western Alaska through central Yukon using stratigraphic, geochemical, petrographic, and chronological data. Further, it argues that the VT tephra is an important regional stratigraphic marker in eastern Beringia, with an areal distribution and bulk tephra volume that places it among the largest eruptions in Yukon and Alaska.

2. Methods

2.1. Stratigraphy

Previously reported stratigraphic sections at Gold Hill, Halfway House and Jackson Hill were re-examined, and in the case of Gold Hill, a new site several hundred meters from the original was logged and sampled. All other sites were sampled and logged in detail, with the exception of Togiak Bay and Tetlin Junction, which were not accessible and overgrown, respectively. Stratigraphic information at these sites relies on previously published data.

2.2. Major-element geochemistry

All major-element geochemical analyses are grain discrete and, with the exception of the Tetlin Junction sample and the Fe-Ti oxide analyses for Togiak Bay-1 and Gold Hill I samples, were carried out on a JEOL superprobe 8900 at the University of Alberta by wavelength dispersive spectrometry. Glass analytical conditions are as follows: 15 keV accelerating voltage, 6 nA beam current, and a beam diameter of 10 μm. A well-characterized Lipari obsidian and Old Crow tephra were analyzed concurrently as secondary standards. Reported data are a compilation of multiple analyses (see

Table 2
Major-element glass geochemistry.

Sample		SiO_2	TiO_2	Al_2O_3	FeO_t	MnO	MgO	CaO	Na_2O	K_2O	Cl	H_2O_{diff}	*n*
Togiak Bay-1	MEAN	70.90	0.57	14.73	3.04	0.11	0.62	2.35	4.59	2.94	0.16	3.94	28
(UT 1435)	STDEV	0.21	0.04	0.17	0.08	0.03	0.04	0.07	0.16	0.06	0.03	1.74	
Togiak Bay-2	MEAN	70.75	0.57	14.78	3.10	0.10	0.63	2.39	4.56	2.95	0.16	2.42	53
(UT 1409)	STDEV	0.39	0.05	0.29	0.17	0.02	0.06	0.12	0.15	0.08	0.03	1.81	
Halfway House	MEAN	70.51	0.58	14.83	3.17	0.10	0.69	2.47	4.57	2.92	0.16	2.52	79
(UA 1425)	STDEV	1.36	0.08	0.41	0.49	0.03	0.20	0.42	0.21	0.21	0.04	1.66	
Gold Hill I	MEAN	70.64	0.56	14.66	3.24	0.10	0.71	2.49	4.54	2.91	0.16	2.68	18
(UT 822)	STDEV	1.28	0.07	0.36	0.43	0.02	0.20	0.41	0.18	0.19	0.03	1.34	
Gold Hill IV	MEAN	70.76	0.57	14.72	3.11	0.10	0.65	2.41	4.58	2.94	0.16	2.73	70
(UA 1344)	STDEV	0.92	0.06	0.33	0.30	0.04	0.12	0.27	0.23	0.20	0.04	1.93	
Chester Bluff	MEAN	70.42	0.59	14.86	3.21	0.11	0.70	2.48	4.56	2.92	0.15	3.31	49
(UA 1097)	STDEV	1.12	0.06	0.38	0.39	0.04	0.16	0.31	0.20	0.16	0.02	1.77	
Little Montauk	MEAN	70.11	0.59	14.87	3.34	0.11	0.74	2.63	4.57	2.88	0.16	2.77	64
(UA 1100)	STDEV	1.33	0.06	0.36	0.49	0.03	0.21	0.43	0.18	0.20	0.04	1.72	
Tetlin Junction[a]	MEAN	70.16	0.63	14.89	3.30	–	0.74	2.32	4.78	3.01	0.17	–	16
	STDEV	0.39	0.13	0.15	0.20	–	0.07	0.13	0.14	0.11	0.03	–	
Jackson Hill	MEAN	70.48	0.59	14.75	3.22	0.10	0.70	2.52	4.57	2.90	0.17	2.65	72
(UA 1580, UT 1562, 1637)	STDEV	1.02	0.05	0.27	0.38	0.03	0.16	0.31	0.21	0.17	0.03	1.36	
Hunker Creek	MEAN	70.17	0.59	14.82	3.33	0.10	0.73	2.72	4.53	2.83	0.17	2.13	27
(UA 1579)	STDEV	1.48	0.06	0.33	0.54	0.03	0.22	0.54	0.13	0.21	0.03	1.21	
Thistle Creek	MEAN	70.15	0.60	14.82	3.35	0.09	0.72	2.60	4.66	2.86	0.16	3.21	23
(UT 1813)	STDEV	1.65	0.08	0.57	0.53	0.04	0.21	0.55	0.12	0.24	0.03	1.72	

n = number of analyses; FeO_t = total Fe as FeO; averages include zero values; H_2O_{diff} = water by difference; STDEV = standard deviation. Standardization by mineral and glass standards. Normalized on a water-free basis.

[a] Analyzed at the University of Alaska, Fairbanks, microprobe laboratory, using the same analytical protocals and secondary standard Old Crow tephra.