Glass-fission-track ages of Late Cenozoic distal tephra beds in the Klondike district, Yukon Territory

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ABSTRACT

A distinctive and widespread tephra bed is a very useful stratigraphic tool, especially if its age is accurately and precisely known. However, distal tephra beds, like those in the Klondike region of the Yukon, are difficult to date because of their fine grain size and contaminated character. Grain-specific methods, such as the fission-track and $^{40}Ar/^{39}Ar$ techniques, are essential for reliable results.

Three rhyolitic tephra beds, each with a homogeneous glass composition, have been dated by the glass-fission-track method. Mosquito Gulch tephra is 1.42 ± 0.16 Ma and dates an intermediate-level terrace on Bonanza Creek. Quartz Creek tephra is 3.00 ± 0.33 Ma and confirms a late Pliocene age for the upper part of the White Channel gravel. Furthermore, the presence of the Quartz Creek tephra in an ice-wedge cast indicates that permafrost conditions must have existed in west-central Yukon at this time. The Jackson Hill tephra is 0.13 ± 0.03 Ma.

RÉSUMÉ

Une strate distincte et étendue de tephra est un outil stratigraphique très utile, en particulier si l’on connaît son âge exact et précis. Toutefois, les strates de tephra distales, comme celles de la région du Klondike au Yukon, sont difficiles à dater en raison de leur faible granulométrie et de leur contamination. Des méthodes propres au grain, comme la datation à partir des traces de fission et la technique $^{40}Ar/^{39}Ar$, sont essentielles pour obtenir des résultats fiables.

Trois strates de tephra rhyolitique, chacune ayant une composition vitreuse homogène, ont été datées à partir des traces de fission du verre. Le tephra du ravin Mosquito date de 1,42 ± 0,16 million d’années et a permis de déterminer l’âge d’une terrasse de niveau intermédiaire sur le cours d’eau Bonanza. Le tephra du cours d’eau Quartz est vieux de 3,00 ± 0,33 millions d’années et confirme que la partie supérieure du gravier de White Channel remonte au Pliocène supérieur. En outre, la présence de tephra du cours d’eau Quartz dans une fente de glace fossile indique qu’il a dû y avoir du pergélisol dans le centre-ouest du Yukon à cette époque. Le tephra de Jackson Hill date de 0,13 ± 0,03 million d’années.

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INTRODUCTION

The Klondike region (Fig. 1) is located within the influence of volcanoes in the Wrangell Mountains and the more distant Alaska Peninsula-Aleutian arc. As a result, the late Cenozoic sediment of the Klondike region contains a large number of distal tephra beds. This situation holds promise for the eventual development of a comprehensive tephrochronological record, which, in turn, will facilitate the assembly of a reliable, regional, time-stratigraphic framework for the late Cenozoic deposits of the Klondike region. This type of time record would help to improve strategies for gold exploration, as well as greatly support other geoscience projects, especially those studies aimed at elucidation of the nature and timing of late Cenozoic environmental change.

With this objective in mind, tephra studies in the Klondike district began in earnest a few years ago. The authors' findings, based on tephra samples collected by them and received from others prior to 1996, have recently been detailed (Westgate et al., 2000; Preece et al., 2000). During the last two years, the authors have collected and received — especially from A. Duk-Rodkin, Geological Survey of Canada, Calgary — many tephra samples, all of which have been carefully documented as to location and stratigraphic setting. Many of these samples have already been characterized, but a large number await study.

The value of a tephra bed as a stratigraphic tool is considerably enhanced if its age is accurately and precisely known. However, the age of distal tephra beds is not easily determined because of their fine grain size and contaminated character. The application of grain-specific geochronological methods is essential for reliable results. We have developed two fission-track (ft) dating methods suited to distal tephra beds, both of which involve the use of the hydrated glass shards (Westgate et al., 1997). The isothermal plateau fission-track (ITPFT) method requires a thermal pretreatment to correct for partial fading of fission tracks and can be applied to tephra beds whose glass shards are larger than 125 µm (Westgate, 1989; Sandhu et al., 1993). The second method uses the mean diameter of the spontaneous and induced fission tracks to correct for this track-fading effect and can be used for tephra beds whose glass shards are as small as 60 µm (Sandhu and Westgate, 1995).

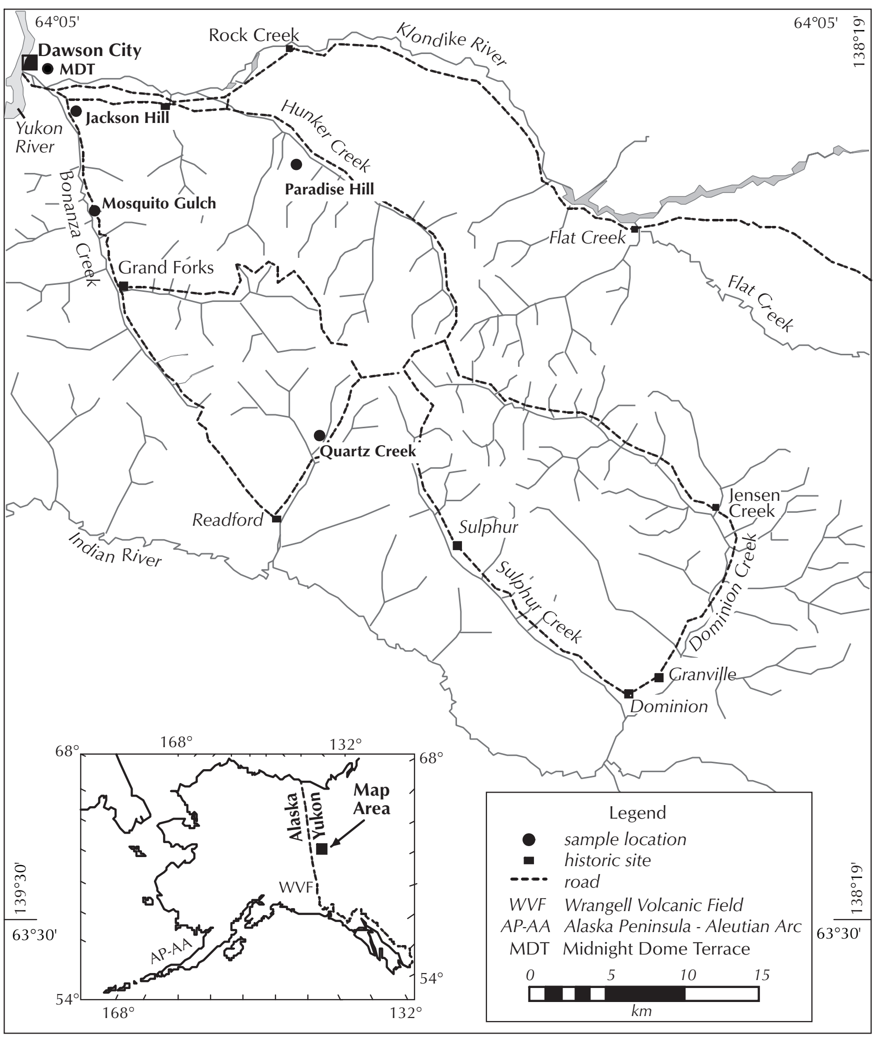

Figure 1. *Location of tephra samples dated by the glass-fission-track method.*

Distal tephra beds in the Klondike region that are derived from volcanoes in the Alaska Peninsula-Aleutian arc (type I tephra beds in the terminology of Preece et al., 1999), all contain abundant bubble-wall glass shards and are readily dated by glass-ft methods. Tephra beds related to volcanoes in the Wrangell Mountains (type II beds) are very pumiceous and not well suited to dating by glass-ft methods. However, some type II beds contain very small amounts of bubble-wall and chunky glass which allow their age to be determined by these methods, but large samples must be processed in order to recover the required amount of glass.

This report presents the results of the application of the diameter-correction-fission-track (DCFT) dating method to three tephra beds in the Klondike region: Mosquito Gulch, Jackson Hill, and Quartz Creek tephra beds (Fig. 1).

LITHOSTRATIGRAPHIC AND GEOMORPHIC SETTING OF TEPHRA BEDS

Mosquito Gulch tephra (UT19) occurs as a 2-cm-thick, discontinuous bed within alluvium on an intermediate terrace of Bonanza Creek (Naeser et al., 1982; Preece et al., 2000). This terrace, called Archibald's Bench, is approximately 37-42 m above present-day river level, on the right bank, and is about 8 km upstream from the confluence with the Klondike River (Fig. 1). It was formed subsequent to deposition and extensive dissection of the White Channel gravel (Milner, 1976). Unfortunately, the exposure containing Mosquito Gulch tephra was destroyed a few years ago during placer mining operations. The tephra occurred in silty clay overbank deposits that covered 1 m of gravel, which, in turn, rested on a well developed strath terrace. The overbank sediment was about 1 m thick and was unconformably overlain by 10 m of gravel and sand. The age of Mosquito Gulch tephra dates formation of Archibald's Bench on which it sits and provides a minimum age for the Klondike gravel, deposited during the first major expansion of the Cordilleran Ice Sheet (Froese et al., 2000).

Jackson Hill tephra (UT1637) takes its name from Jackson Hill, located 5 km east of Dawson City (Fig. 1). Forty metres of White Channel gravel are covered by up to 50 m of Klondike gravel at this site (Figs. 2, 3). The tephra is present in the upper part of a 2-m-thick gully-fill deposit, the gully being incised about 10 m into the Klondike gravel, close to the level of the highest terrace along the

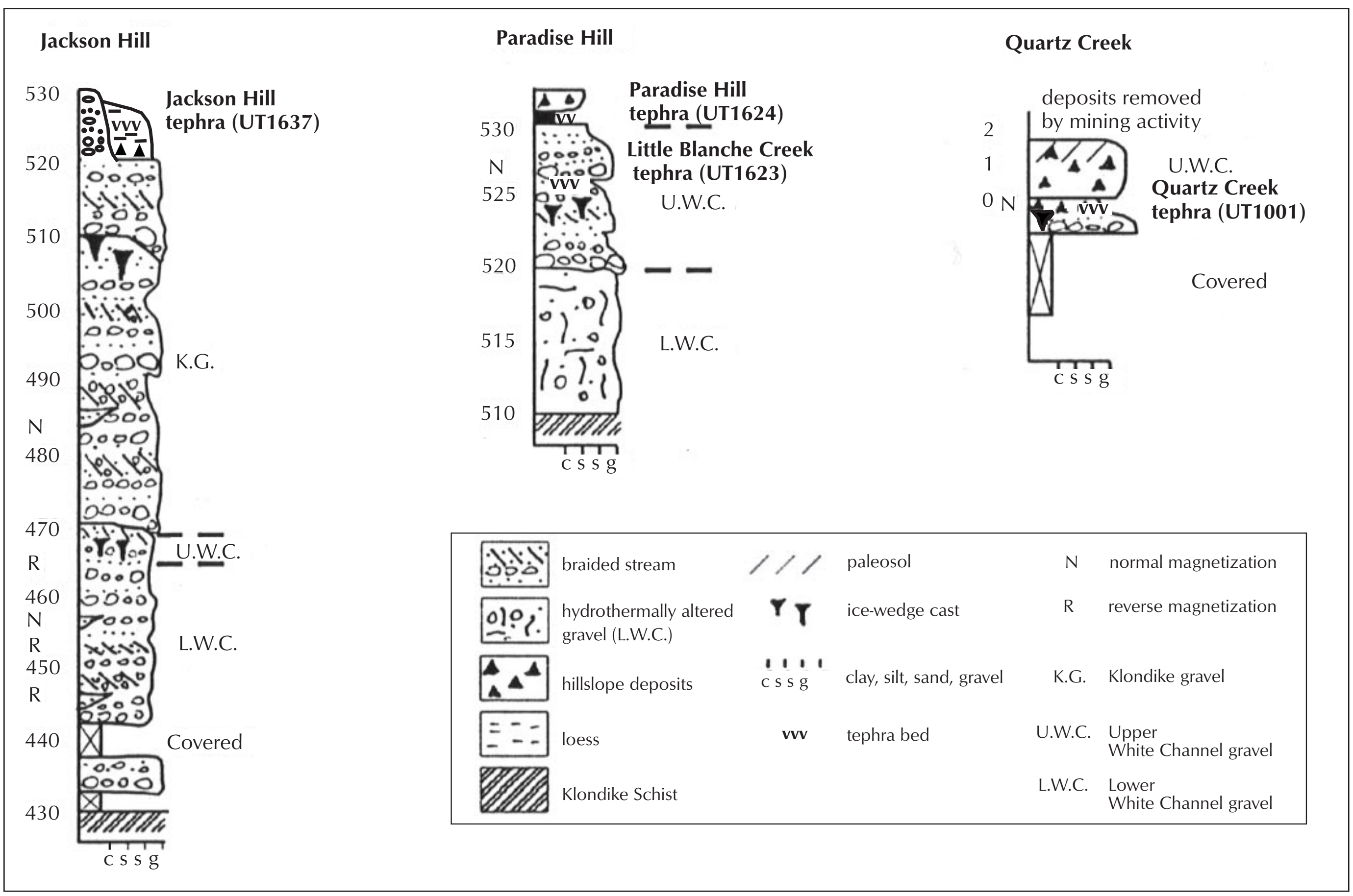

Figure 2. *The lithostratigraphic setting of tephra beds at Jackson Hill, Paradise Hill and Quartz Creek sites. Elevation in metres is given for the first two localities, but only the thickness is given for the Quartz Creek site.*

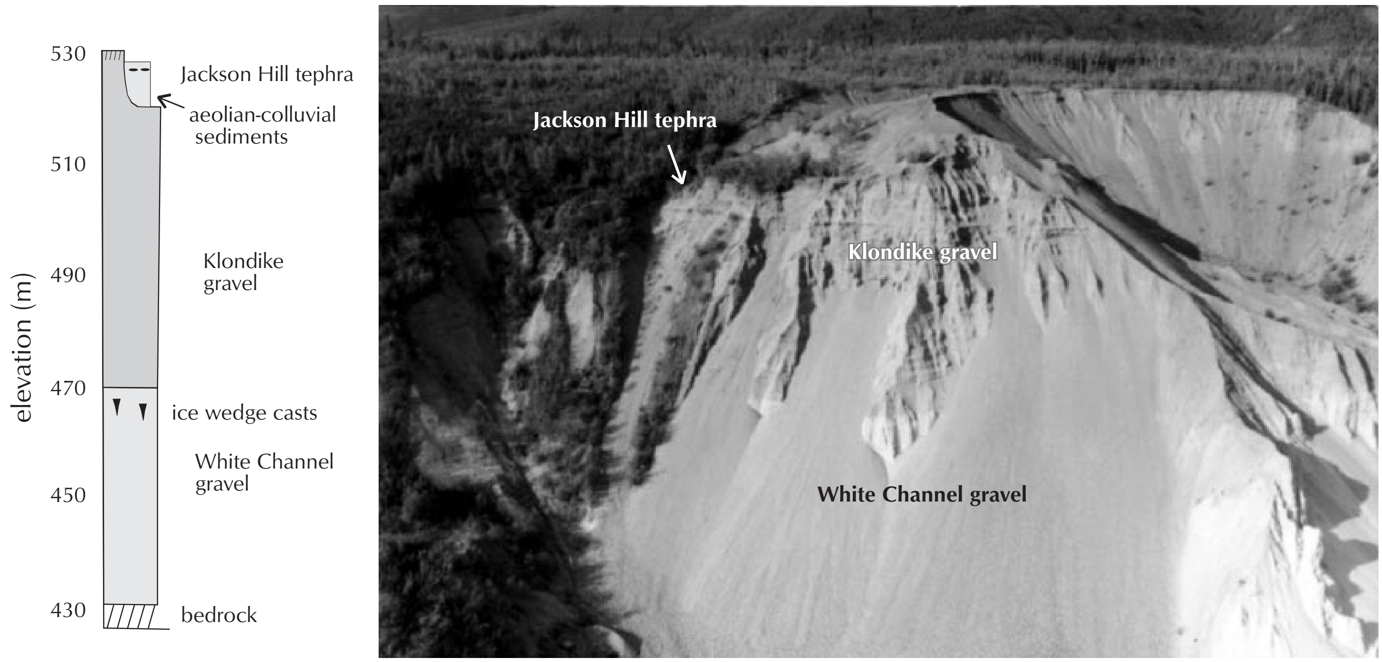

Figure 3. *The geomorphic and stratigraphic setting of Jackson Hill tephra.*

Klondike River (Fig. 3). The gully-fill sediments consist of 0.5 m of matrix-supported gravel overlain by 1.5 m of massive to crudely stratified, organic-rich silt. Discontinuous pods of Jackson Hill tephra, up to 3 cm thick, occur 50 cm below the surface in this silt. The lower diamict is interpreted as a hillslope deposit derived from downslope movement of the Klondike gravel into the gully, while the overlying silt is thought to represent retransported loess. The age of this tephra bed will offer another minimum age for the Klondike gravel. Its fine grain size places it at the very limit of tephra that we can date by our glass-ft methods.

Quartz Creek tephra (UT1001) occurs in a colluviated facies of the Upper White Channel gravel (Froese et al., 2000) at a site located 35 km southeast of Dawson City near the confluence of the Little Blanche and Quartz creeks (Fig. 1). Mining activities have exposed 2 m of massive fluvial gravel that is separated by a bedrock high from the more extensive, and slightly lower, colluviated facies (Fig. 4). Locally, the tephra has been preserved in an ice-wedge cast (Fig. 4). Hence, its emplacement must have shortly preceded thawing of the ice wedge, a feature that can only form in the continuous permafrost zone. The age of Quartz Creek tephra would not only date the Upper White Channel gravel but give the timing of the onset of permafrost conditions in west-central Yukon.

Other tephra beds have been found in the Upper White Channel gravel and in the overlying sediments, and offer the potential for additional age control. Little Blanche Creek tephra has been discovered in the Quartz Creek (UT1054, UT1455, Preece et al., 2000) and Hunker Creek drainage basins (UT1623, Fig. 2) but 'chunky glass' has not been found in this pumiceous unit, therefore it is not datable by our glass-ft methods. However, it likely can be dated by the $^{40}Ar/^{39}Ar$ technique because of its abundant hornblende. Fortunately, Paradise Hill tephra (UT1624) is only 5.5 m above Little Blanche Creek tephra at Paradise Hill (Fig. 2) and contains good chunky glass. It occurs in fluvial sand above the Upper White Channel gravel and is overlain by organic-rich silt and colluvial deposits (Fig. 2). Its age is not determined as yet.

DESCRIPTION OF TEPHRA BEDS

The mineralogical and chemical characteristics of Jackson Hill and Mosquito Gulch tephra beds prove them to belong to the type I group, whose source volcanoes are located in the Alaska Peninsula-Aleutian arc region (Fig. 1). Quartz Creek tephra, on the other hand, is of the type II variety and comes from a volcano in the Wrangell volcanic field (also in Fig. 1; Preece et al., 1999; Preece et al., 2000).

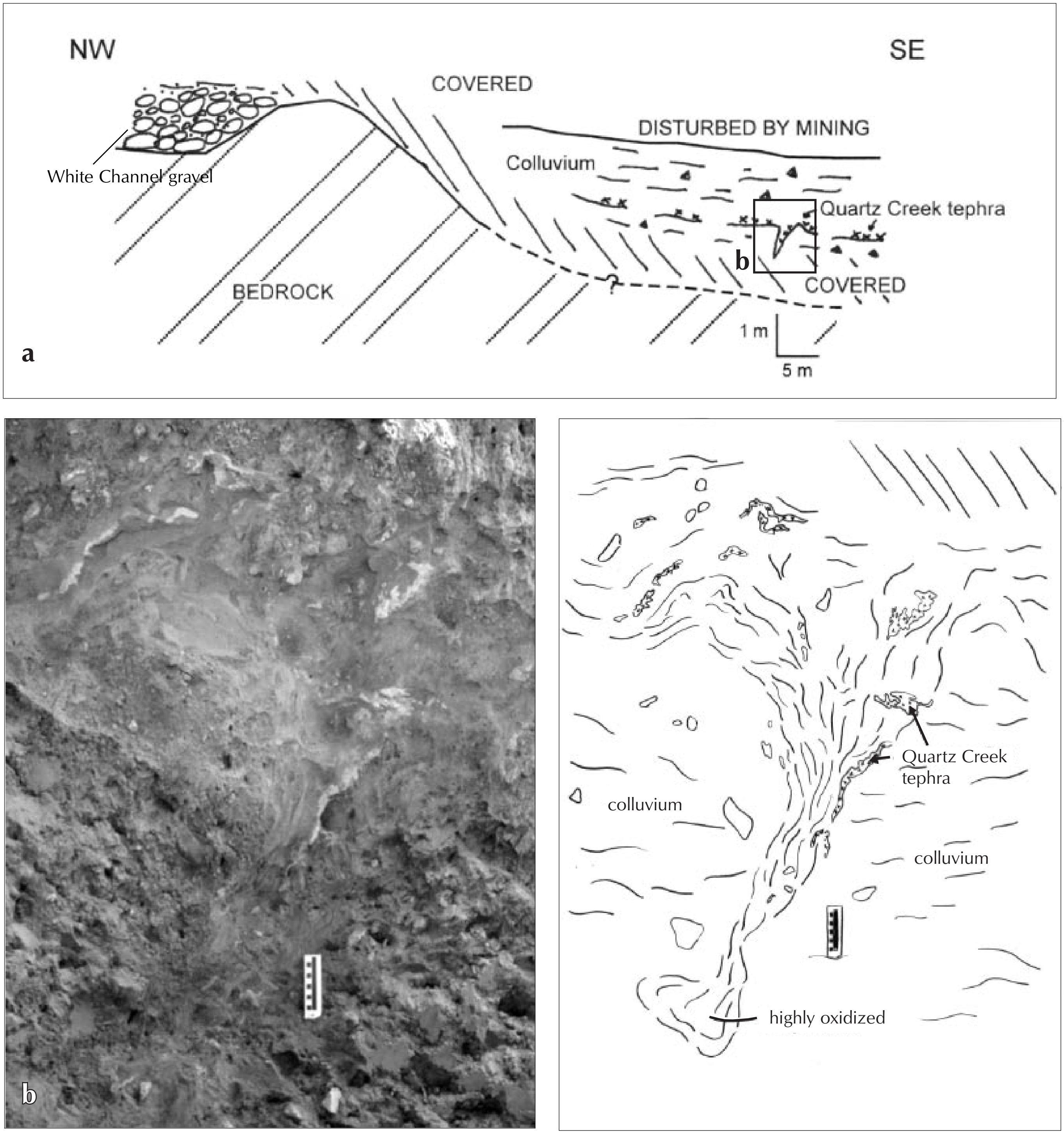

Figure 4. *(a) Generalized stratigraphic relationship between Quartz Creek tephra, colluvial sediments, and White Channel gravel at site along Quartz Creek (Fig. 1); (b) Photograph and sketch of Quartz Creek tephra draped within an ice-wedge cast at Quartz Creek site. Dated at 3.00 ± 0.33 Ma, Quartz Creek tephra provides a minimum age for the White Channel gravel in the Klondike region and a late Pliocene age for the first occurrence of permafrost in the Yukon Territory.*

Jackson Hill tephra has a cream colour, whereas Mosquito Gulch tephra is grey. Both consist mostly of bubble-wall glass shards with feldspar, orthopyroxene, clinopyroxene and minor amounts of green or red amphibole, titanomagnetite, ilmenite, apatite and zircon. The white Quartz Creek tephra is very pumiceous and rich in phenocrysts of mostly feldspar, orthopyroxene, green amphibole and iron-titanium oxides; apatite and zircon are rare. All three beds have glass shards of a rhyolitic composition and a homogeneous glass population, although Jackson Hill tephra has the rare dacitic outlier (Table 1, Fig. 5). A unimodal glass composition is an essential prerequisite for glass-ft dating. The trace-element composition of the glass shards is shown in Table 2, where it can be seen that the concentration levels of the rare-earth elements are much lower in Quartz Creek tephra than in the other two units.

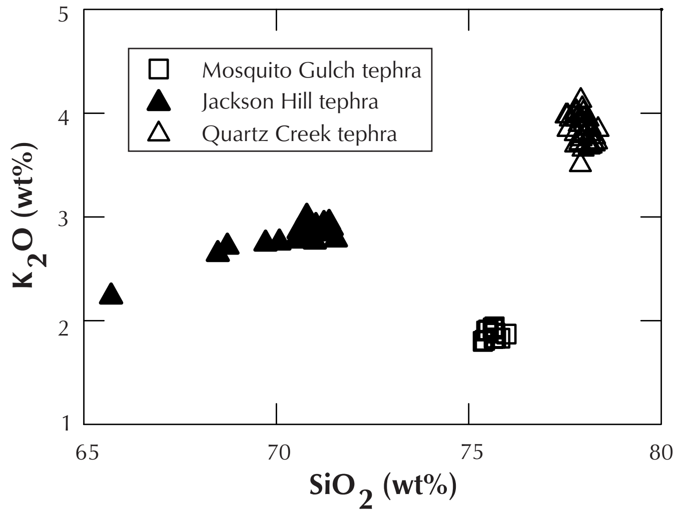

Figure 5. *K_2O/SiO_2 plot showing the homogeneous composition of glass shards in the three tephra beds dated by the glass-ft method.*

FISSION-TRACK DATING

The glass-DCFT method (Sandhu and Westgate, 1995) was used to date the tephra beds, all of which have suffered partial fading of fission tracks in their glass shards (Fig. 6). Correction for this fading effect must be made when determining the glass-ft age of these tephra beds.

An internal standard is included in each irradiation in order to monitor the accuracy of the age determinations. The glass-ft age of Huckleberry Ridge tephra, our internal standard, is very similar to its $^{40}Ar/^{39}Ar$ age (Table 3) and shows that our age estimates are of acceptable accuracy.

Table 1. *Average glass major-element compositions of tephra beds.*

	Quartz Creek		Jackson Hill			Mosquito Gulch	
			pop. 1	pop. 2			
SiO_2	77.96	(0.21)	65.71	70.62	(0.84)	75.63	(0.17)
TiO_2	0.17	(0.06)	0.79	0.61	(0.08)	0.31	(0.09)
Al_2O_3	12.52	(0.16)	15.58	14.74	(0.26)	13.27	(0.09)
FeO_t	0.83	(0.06)	5.24	3.23	(0.26)	1.83	(0.08)
MnO	0.03	(0.02)	0.13	0.11	(0.04)	0.08	(0.04)
CaO	0.93	(0.05)	4.06	2.54	(0.31)	1.34	(0.05)
MgO	0.16	(0.03)	1.62	0.68	(0.13)	0.26	(0.02)
Na_2O	3.52	(0.13)	4.53	4.49	(0.22)	5.24	(0.10)
K_2O	3.84	(0.13)	2.23	2.83	(0.09)	1.87	(0.05)
Cl	0.04	(0.02)	0.11	0.16	(0.03)	0.17	(0.04)
H_2Od	5.06	(0.93)	1.38	2.14	(1.70)	4.97	(1.24)
n	**37**		**1**	**19**		**12**	

Notes: All analyses done on a Cameca SX-50 wave-length dispersive microprobe operating at 15 kV accelerating voltage, 10-15 mm beam diameter, and 6nA beam current. Standardization achieved by use of mineral and glass standards. Analyses recast to 100% on a water-free basis. n = number of analyses, FeO_t = total iron oxide as FeO, H_2Od = water by difference, pop. 1 = population 1, pop. 2 = population 2. Average composition based on non-zero values for the following samples: Quartz Creek (UT1001, UT1053, UT1544), Jackson Hill (UT1562, UT1637) and Mosquito Gulch (UT19). Numbers in brackets are standard deviation.

Table 2. *Average glass trace-element composition of tephra beds.*

	Quartz Creek	Jackson Hill	Mosquito Gulch		Quartz Creek	Jackson Hill	Mosquito Gulch
Rb	70	67	35	Gd	1.87	6.26	5.43
Sr	234	177	77	Tb	0.23	1.03	1.03
Y	7	36	37	Dy	1.21	6.31	6.24
Zr	94	256	199	Ho	0.23	1.30	1.34
Nb	4.0	6.3	4.3	Er	0.68	3.83	4.11
Cs	1.91	3.97	1.53	Tm	0.11	0.62	0.71
Ba	873	721	595	Yb	0.75	3.99	4.65
La	17.39	18.29	14.69	Lu	0.10	0.50	0.57
Ce	30	37	29	Hf	2.93	6.56	5.39
Pr	3.39	5.38	4.51	Ta	0.40	0.31	0.26
Nd	11.1	22.6	19.2	Th	6.9	6.0	2.9
Sm	1.69	5.73	5.12	U	2.84	3.17	1.57
Eu	0.62	1.40	1.22	**n**	**6**	**2**	**2**

Notes: Samples were analyzed at the University of Wales, Aberystwyth. Fully quantitative solution ICP-MS analyses were performed using a VG Elemental ICP-MS PlasmaQuad II+ with a modified high sensitivity interface and calibration was achieved using multi-element synthetic standards. Details of the analytical procedures and standards are given in Pearce et al. (1997).
n = number of analyses. Average composition based on the following samples: Quartz Creek (UT1001, UT1053, UT1544), Jackson Hill (UT1562), Mosquito Gulch (UT19).

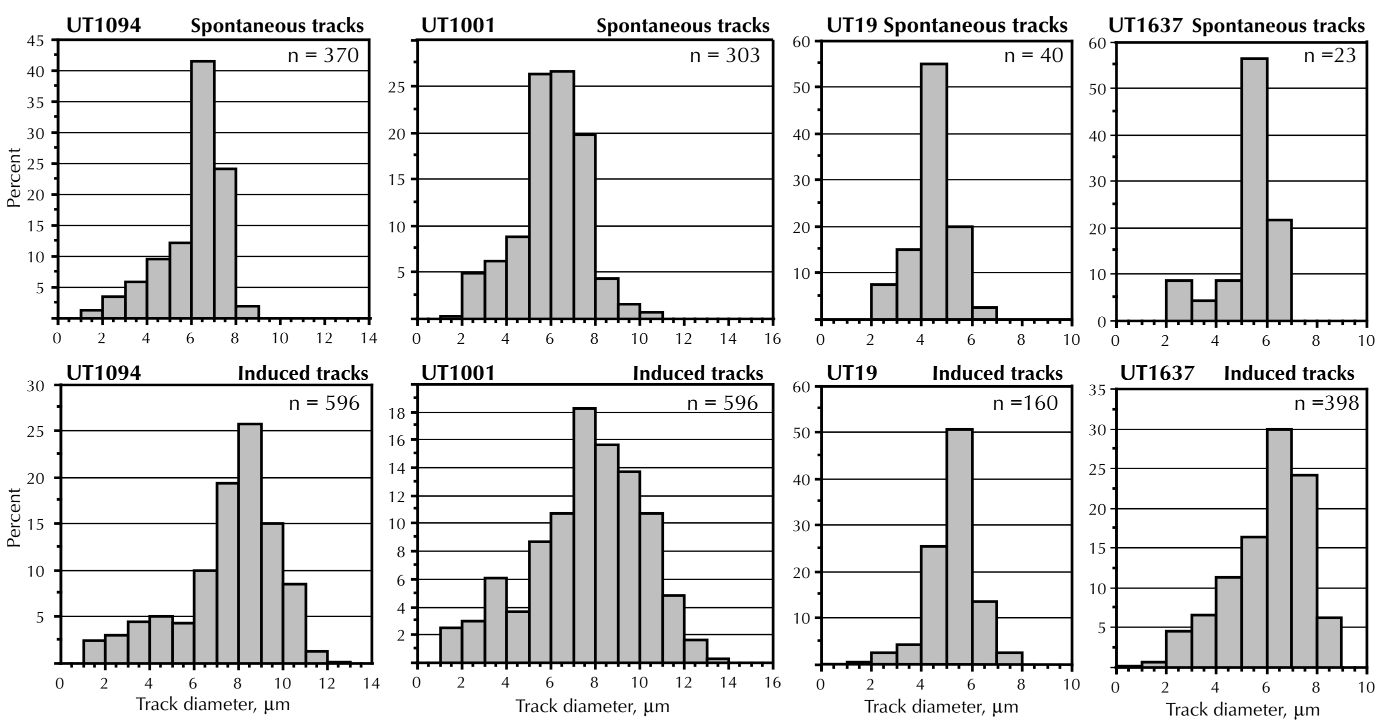

Figure 6. *Size distributions of spontaneous and induced fission tracks in glass shards of dated tephra beds. All samples have experienced partial fading of their spontaneous tracks. Note variation in the vertical scale. UT1094, Huckleberry Ridge tephra, the internal standard; UT1001, Quartz Creek tephra; UT19, Mosquito Gulch tephra; UT1637, Jackson Hill tephra. 'n' is the number of measurements made on each sample.*

Table 3. *Glass-fission-track ages of late Cenozoic distal tephra beds in the Klondike district, Yukon Territory.*

Sample number, Date irradiated, (Analyst)	Spontaneous track density 102 t/cm^2	Corrected spontaneous track density 102 t/cm^2	Induced track density 105 t/cm^2	Track density on muscovite detector over dosimeter glass 105 t/cm^2	Etching conditions HF:temp:time %: O C : s	D_s µm	D_i µm	D_s / D_i or D_i / D_s(#)	Age 10^6 yr
Mosquito Gulch tephra									
UT19 16/05/77 (NN)	3.24 ± 0.64 (26)		0.40 ± 0.02 (635)	4.76 ± 0.05 (9617)	26: 24: 65	nd	nd	nd	1.23 ± 0.25
UT19*		3.86 ± 0.76 (26)	0.40 ± 0.02 (635)	4.76 ± 0.05 (9617)	26: 24: 65	nd	nd	1.19 ± 0.04#$	1.46 ± 0.29*
UT19 16/05/77 (JAW)	3.96 ± 0.67 (35)		0.56 ± 0.01 (2218)	4.76 ± 0.05 (9617)	26: 24: 70	nd	nd	nd	1.06 ± 0.23
UT19*		4.71 ± 0.80 (35)	0.56 ± 0.01 (2218)	4.76 ± 0.05 (9617)	26: 24: 70	nd	nd	1.19 ± 0.04#$	1.26 ± 0.28*
UT19 09/10/98 (AS)	4.25 ± 0.60 (50)		0.57 ± 0.01 (2346)	5.44 ± 0.05 (13889)	24: 23: 70	4.40 ± 0.13	5.23 ± 0.07	0.84 ± 0.03	1.30 ± 0.24
UT19*		5.06 ± 0.72 (50)	0.56 ± 0.01 (2346)	5.44 ± 0.05 (13889)	24: 23: 70	4.40 ± 0.13	5.23 ± 0.07	1.19 ± 0.04#	1.55 ± 0.28*
						Corrected Weighted Mean Age			1.42 ± 0.16*
Quartz Creek tephra									
UT1001 31/01/00 (AS)	39.30 ± 1.96 (401)		2.69 ± 0.02 (14637)	5.01 ± 0.04 (12744)	24: 22: 110	6.01 ± 0.09	7.61 ± 0.10	0.79 ± 0.02	2.36 ± 0.26
UT1001*		49.75 ± 2.5 (50)	2.64 ± 0.02 (14637)	5.01 ± 0.04 (12744)	24: 22: 110	6.01 ± 0.09	7.61 ± 0.10	1.27 ± 0.02#	3.00 ± 0.33*
Jackson Hill tephra									
UT1637 31/01/00 (AS)	1.04 ± 0.23 (21)		1.45 ± 0.02 (5867)	5.06 ± 0.04 (12744)	24: 22: 70	5.31 ± 0.23	6.08 ± 0.08	0.87 ± 0.04	0.12 ± 0.03
UT1637*		1.20 ± 0.26 (21)	1.45 ± 0.02 (5867)	5.06 ± 0.04 (12744)	24: 22: 70	5.31 ± 0.23	6.08 ± 0.08	1.15 ± 0.05	0.13 ± 0.03*
Huckleberry Ridge tephra: internal standard									
UT1094 31/01/00 (JAW)	43.23 ± 1.42 (931)		4.21 ± 0.03 (25152)	4.87 ± 0.04 (12744)	24: 21: 120	6.09 ± 0.07	7.54 ± 0.09	0.81 ± 0.01	1.59 ± 0.17
UT1094*		53.57 ± 1.76 (931)	4.20 ± 0.03 (25152) (12744)	4.87 ± 0.04	24: 21: 120	6.09 ± 0.07	7.54 ± 0.09	1.24 ± 0.02#	1.97 ± 0.21*

Notes

The population-subtraction method was used.

* Samples corrected for partial track fading by the track-size method (Sandhu and Westgate, 1995); uncorrected age is given for the other samples.

Ages calculated using the zeta approach and $\lambda D = 1.551 \times 10^{-10}$ yr^{-1}. Zeta value is 318 ± 3 based on 6 irradiations at the McMaster Nuclear Reactor, Hamilton, Ontario, using the NIST SRM 612 glass dosimeter and the Moldavite tektite glass (Lhenice locality) with an $^{40}Ar/^{39}Ar$ plateau age of 15.21 ± 0.15 Ma (Staudacher et al., 1982).

Error (± 1σ) is calculated according to Bigazzi and Galbraith (1999). Area estimated using the point-counting technique (Sandhu et al., 1993).

D_s = mean spontaneous track diameter and D_i = mean induced track diameter; nd = not determined. Number of tracks counted is given in brackets.

$ Samples corrected for partial track fading by data from UT19 (AS) because all UT19 age estimates are based on glass shards from the same tephra sample.

Data on UT19 (NN) taken from Naeser et al., 1982. The single-crystal (sanidine) laser-fusion $^{40}Ar/^{39}Ar$ age of Huckleberry Ridge tephra, the internal standard, is 2.003 ± 0.014 Ma (2σ error) (Gansecki et al., 1998).

\# = D_i/D_s

The glass-ft age estimates are given in Table 3. Three separate age determinations were made on Mosquito Gulch tephra and its weighted mean age is 1.42 ± 0.16 Ma. The younger mean age given in Naeser et al. (1982) reflects the fact that no correction was applied for partial track fading, the date being considered as a minimum value. Therefore, Archibald's Bench was formed about 1.4 million years ago, an age that strongly supports correlation to the Midnight Dome Terrace on the Klondike River, just east of Dawson City, given the magnetostratigraphic-based chronology of Froese et al. (2000). The recent identification of Mosquito Gulch tephra near the base of the loess sequence at the Midnight Dome Terrace (Fig. 1) confirms this correlation.

The glass-ft age of Quartz Creek tephra is 3.00 ± 0.33 Ma, which is in agreement with hornblende $^{40}Ar/^{39}Ar$ ages that range from 2.64 Ma to 3.01 Ma (Kunk, 1995) and is compatible with the normal magnetization of the enclosing sediments (Fig. 2, Froese et al., 2000). The authors are currently determining a glass-ITPFT age (Westgate, 1989) for Quartz Creek tephra, which will provide additional control on its age and considerably reduce the relative standard error associated with it. A late Pliocene age for the upper part of the White Channel gravel is confirmed and the presence of Quartz Creek tephra in an ice-wedge cast (Fig. 4) indicates that permafrost conditions existed in west-central Yukon at this time.

Jackson Hill tephra is much younger than was anticipated, given its position near a high-level terrace along the Klondike Valley. It is 0.13 ± 0.03 Ma. Corroborative evidence for this young age comes from its petrographic and chemical attributes that suggest a correlation to VT tephra, which occurs 5 m above Old Crow tephra at Halfway House in central Alaska (Preece et al., 1999).

CONCLUDING STATEMENT

Tephrochronological studies of the late Cenozoic deposits in the Klondike area have only just begun in earnest. The region lies within the fallout zone of large-magnitude volcanic eruptions from the Wrangell Mountains and the Alaska Peninsula-Aleutian arc and already a large number of distal tephra occurrences have been documented, although most await careful study. The results presented in this report give a glimpse of the eventual rewards that tephra studies can confer on our understanding of the late Cenozoic geologic history of the Yukon Territory, namely, the development of a comprehensive, reliable time-stratigraphic framework.

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