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Research paper

OSL dating of loess deposits bracketing Sheep Creek tephra beds, northwest Canada: Dim and problematic single-grain OSL characteristics and their effect on multi-grain age estimates

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Geochemically-fingerprinted tephra beds provide unique chronostratigraphic markers for comparing Quaternary sedimentary records across eastern Beringia (Alaska and Yukon Territory). Establishing reliable numerical age control on these tephra horizons enables them to be placed within firm temporal frameworks and increases their potential as correlative tools for regional palaeoenvironmental reconstructions. To this end we present new single-grain and multi-grain quartz optically stimulated luminescence (OSL) chronologies for loess deposits bracketing three well-documented and regionally significant variants of the Sheep Creek tephra (SCt) at two sites in west-central Yukon Territory (Ash Bend and Quartz Creek). Single-grain OSL ages bracketing the SCt-A and SCt-K reveal that these tephras were deposited during late Marine Isotope Stage (MIS) 5 or early MIS 4. The SCt-C variant and associated organic-rich bed at Ash Bend were likely deposited during late MIS 5, based on a single-grain OSL age of ~81 ka for the overlying sediments. The single-grain OSL ages obtained for these deposits are in stratigraphic order and in broad agreement with a fission track age estimate of ~77 ka for the SCt-K. In contrast, comparative chronologies obtained using multi-grain aliquots are stratigraphically inconsistent and unexpectedly young when compared with the independent SCt-K age. Detailed examination of the single-grain OSL datasets reveal a range of unfavourable luminescent properties that could have contributed to the multi-grain aliquot age discrepancies; including, very low yields of luminescent grains, weak OSL signal sensitivities and large populations of aberrant grains (particularly 0 Gy grains and 'dim' grains with a tendency to sensitise during the equivalent dose (D_e) measurement sequence) that have similarly sized OSL signals as grains used for D_e analysis. Synthetic aliquot D_e datasets constructed from single-grain OSL measurements reveal that the large proportional light sum contributions of 0 Gy and dim grains could possibly account for multi-grain age underestimations in some of the Ash Bend samples. In light of these potentially problematic averaging effects, we do not consider the multi-grain OSL ages to be reliable and suggest that single-grain approaches may be preferable for dating sediments with similar quartz luminescence behaviours across this region.

1. Introduction

The well-preserved distal tephra beds of eastern Beringia (Alaska and the Yukon Territory) represent a series of invaluable marker horizons that have provided correlative, chronostratigraphic frameworks for key terrestrial proxy records across the region (Westgate et al., 1990; Preece et al., 1999; Zazula et al., 2006; Froese et al., 2009; Péwé et al., 2009). The use of such tephra beds as robust stratigraphic markers is, however, dependent on both accurate geochemical characterisation (e.g., Preece et al., 1992, 2000; Westgate et al., 2005) and the provision of reliable age control at reference localities. Various absolute and relative dating techniques have been applied to distal tephras and tephra-bearing deposits from eastern Beringia to constrain their depositional chronologies, including fission track dating of glass shards (Westgate et al., 1990; Preece et al., 2011), $^{40}Ar/^{39}Ar$ dating (Kunk, 1995), luminescence

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dating (Berger, 2003; Demuro et al., 2008), radiocarbon dating of associated plant macrofossils (Froese et al., 2006; Demuro et al., 2008) and palaeomagnetism (Westgate et al., 1990). Optically stimulated luminescence (OSL) dating is well-suited for this purpose as it can provide direct depositional ages on bracketing sedimentary horizons, it produces numerical ages that do not require subsequent calibration on the calendric timescale, and it is applicable over an age range that extends well beyond the limits of radiocarbon dating (e.g., Wintle and Murray, 2006; Lian and Roberts, 2006).

OSL dating of individual quartz grains (so-called single-grain dating) can offer significant advantages over traditional multi-grain luminescence dating techniques in complex sedimentary environments, particularly glaciogenic contexts (e.g., Duller, 2006; Bateman et al., 2010; Arnold et al., 2011), but it has yet to be widely applied to eastern Beringian deposits despite major developments in related instrumentation, measurement protocols and analytical techniques over recent years (e.g., Bøtter-Jensen et al., 2000; Galbraith et al., 1999; Jacobs et al., 2006a; Duller, 2008; Arnold and Roberts, 2009). Moreover, there have been few detailed methodological studies of quartz grains extracted from tephra-bearing loess deposits in this region, and few assessments of their suitability for routine OSL dating applications. Previous research on known-age loess deposits bracketing the Dawson tephra (Klondike district, Yukon Territory) by Demuro et al. (2008) has, however, revealed that multi-grain aliquot OSL measurements (~80 and ~800 grains per aliquot) can result in broad equivalent dose (D_e) distributions and significant age underestimation in this depositional context, while single-grain OSL dating may be more apt to produce ages in agreement with independent age control. This study also showed that the luminescence signal intensities of quartz grains derived from the Klondike loess deposits were generally low, and that many of the individual grains produced aberrant OSL behaviours (e.g., 0 Gy grains and dose-response curves that show early onset of saturation). Importantly, the causes of multi-grain OSL age underestimation observed for these dim samples have not been empirically explained and require further investigation. This paper offers new insights into the causes of such age offsets through comprehensive analysis of single-grain OSL data obtained from additional tephra-bearing loess deposits in the region.

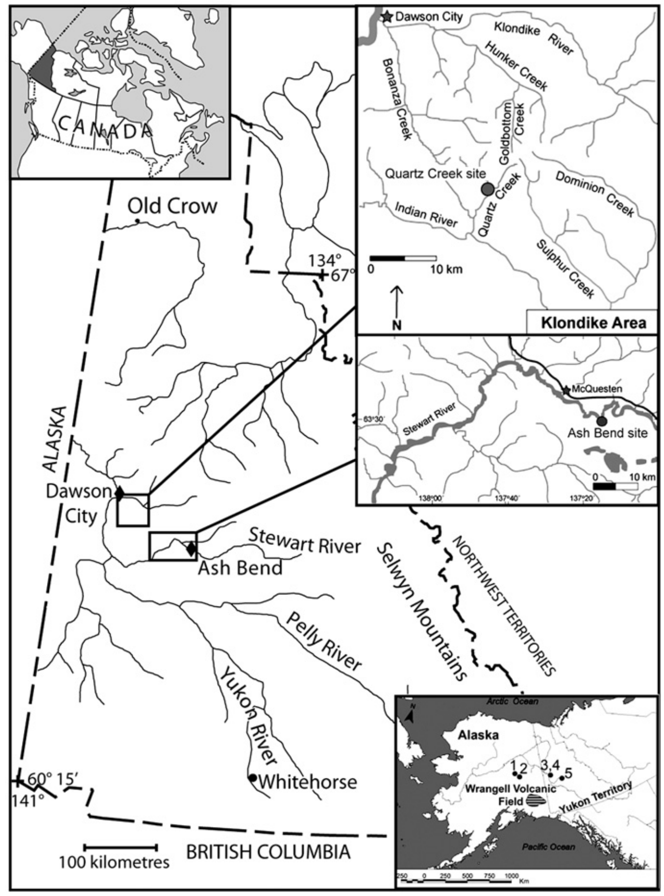

Fig. 1. Map of the Yukon Territory, Canada, showing the study sites of Ash Bend and Quartz Creek (Klondike district). Inset (bottom right) indicates sites at which the different Sheep Creek tephra (SCt) variants were originally found: 1-Fairbanks (SCt-F); 2-Canyon Creek (SCt-CC); 3-Klondike (SCt-K); 4-Christie Mine (SCt-C), 5-Ash Bend (SCt-A). Also shown is the location of the source area for the SCt (the Wrangell volcanic field).

2. SCt classification and previous chronological work

Prior to the recent study of Westgate et al. (2008), the various SCt horizons found at sites in central Alaska (Fairbanks, Canyon Creek site), eastern Alaska (Lost Chicken Creek) and in west-central Yukon Territory (Klondike district, Sixty Mile district and Stewart River) were assumed to represent a single, correlative marker bed with a depositional age of ~190 ka (based on the thermoluminescence (TL) results of Berger et al. (1996)). However, comprehensive re-assessments of the geochemistry and petrography of SCt horizons from different locations across eastern Beringia have revealed that beds classified formerly as SCt encompass a series of distinct tephras deposited at different times during the Pleistocene (Westgate et al., 2008). Five variants of SCt have now been identified and named according to the site at which they were originally found (Fig. 1); namely, SCt-F (Fairbanks, Alaska), SCt-CC (Canyon Creek, Alaska), SCt-C (Christie Mine, western Yukon), SCt-K (Klondike, western Yukon) and SCt-A (Ash Bend, western Yukon). SCt-C, SCt-K and SCt-A have a common compositional relationship and shared source at Mount Drum in the Wrangell volcanic fields, and appear in close stratigraphic relationship at the Ash Bend site studied by Westgate et al. (2008).

Following reclassification of the SCt in eastern Beringia, the TL age of ~190 ka obtained by Berger et al. (1996) is now ascribed to variant SCt-F found in the Fairbanks area of Alaska where it is present below the widespread ~124 ka Old Crow tephra (Preece et al., 2011). The age of the SCt-CC remains unclear owing to contradictory geomorphic, mineralogical and geochemical evidence – though its association with deposits that also host the ~124 ka Old Crow tephra and its close association with Delta Glaciation deposits in central Alaska suggest a MIS 6 age (Begét and Keskinen, 2003; Westgate et al., 2008; Demuro et al., 2012). Fission track dating of the Dominion Creek tephra found immediately above the SCt-K bed at the Dominion Creek site in the Klondike district produced an age of 82 ± 9 ka (Westgate et al., 2008). However, the $^{40}Ar/^{39}Ar$ age of the Moldavite tektite glass calibration standard used in this fission track study has recently been re-evaluated (discussed in Preece et al. (2011)) and indicates that the Dominion Creek tephra should actually be ~5% younger than the originally published age. On the basis of the revised fission track chronologies at Dominion Creek, the age of the SCt-K is expected to be around 77 ± 8 ka (Preece et al., 2011). An additional pilot OSL dating study performed on two loess samples found immediately above and below the SCt-K bed at the same site has also yielded ages of 69 ± 11 and 84 ± 9 ka, respectively (Westgate et al., 2008). However, only three multi-grain aliquots were used to derive the burial dose estimates for each of these samples, and D_e determination was performed using very large aliquots containing ~4400 quartz grains. In light of the preliminary nature of this earlier OSL study – and the problems we detail here for multi-grain D_e analysis performed in similar contexts – we have cautiously used the fission track age