

# Loess, bioturbation, fire, and pedogenesis in a boreal forest – grassland mosaic, Yukon Territory, Canada

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## Abstract

Calcareous Holocene loess forms a surface veneer in soils of the topographically-controlled boreal forest – grassland mosaic near Kluane Lake, southwestern Yukon Territory, Canada. B horizons formed in Late Pleistocene / early Holocene loess have been buried by the continuing deposition of Neoglacial loess. These materials have been mixed in varying degrees with the underlying sandy glaciofluvial deposits by bioturbation and post-fire redistribution on slopes, creating a diversity of microstructures in the upper mineral and organic horizons. Contrasting soil types occur in close proximity under adjacent grassland and forest vegetation: Chernozemic (Kastanozem – WRB) and Brunisolic (Cambisol – WRB), respectively. The distribution of radiocarbon dates for soil charcoal preserved in toeslope colluvium suggests that fire activity diminished in the mid-Holocene.

## Key Words

Loess, boreal forest, grasslands, fire, bioturbation, soil micromorphology

## Introduction

Loess deposition has contributed to soil parent materials across the Beringian region of northwestern North America during the Quaternary (Muhs *et al.*, 2003; Sanborn *et al.*, 2006). Accessible opportunities to study soil formation in relation to contemporary loess deposition are available in relatively few areas in this region (Muhs *et al.*, 2004). This paper reports on the pathways of Holocene soil formation in relation to vegetation and natural disturbance processes in a complex boreal landscape in which loess deposition is currently active.

## Study Area

The lower slopes of the Ruby Range on the southeastern shore of Kluane Lake (61° 3'N, 138° 21'W; Figure 1) are mantled by gravelly glaciofluvial deposits with up to 50 m of local relief and slopes up to 60%. Soils in the Kluane L region usually have a 10-30 cm thick veneer of calcareous loess, locally over-thickened to > 100 cm in depressions or on toeslopes. Loess accumulated in two phases: late Pleistocene / early Holocene and Neoglacial (Denton and Stuiver 1966). These deposits are often separated by a reddish-brown paleosol ("Slims soil") that forms the non-calcareous B horizon of many soils (Figure 2). Neoglacial loess can contain a 1-2 cm thick layer of the 1147 cal. yr BP White River tephra (Clague *et al.*, 1995). Rapid progradation of the Slims River delta after ca. 1700 AD (Clague *et al.*, 2006) created a closer dust source that likely accelerated loess deposition near Kluane L. The study area has a cold, dry climate, based on data for Haines Junction, 60 km southeast of the study area (mean air temperature -2.9°C, mean annual precipitation 306 mm) (Environment Canada 2007). Slope aspect strongly influences microclimate and vegetation patterns. South- to west-facing aspects are usually occupied by *Festuca-Artemisia* grassland (Laxton *et al.*, 1996), with abrupt transitions to boreal forest dominated by white spruce (*Picea glauca*), with lesser amounts of trembling aspen (*Populus tremuloides*) (Figure 3). The base-rich loessal grassland soils were designated as Melanic and Eutric Brunisols in the Canadian soil classification system (Laxton *et al.*, 1996; Soil Classification Working Group 1998), but those with organic matter-rich A horizons (Figure 4) are more appropriately placed in the Chernozemic order (Sanborn 2009), equivalent to Kastanozems (IUSS Working Group WRB 2006). Loessal soils on adjacent forested sites are predominantly Brunisolic (WRB – Cambisol), with Cryosols in some depressions and on north-facing toeslopes.

## Methods

To examine soil property variation across vegetation boundaries, 31 pedons were described and sampled by pedogenic horizon (Soil Classification Working Group 1998) at 5- or 10-m intervals along three surveyed transects oriented perpendicular to the long axes of esker ridges, along slope segments with contours that were linear in plan view. Thin sections were prepared from epoxy-impregnated intact samples of selected

horizons. Soil samples were analyzed for particle size distribution by pipetting (Gee and Bauder 1986), and for organic and inorganic carbon before and after carbonate removal by HCl (LECO CHN-600 Elemental Analyzer). Charcoal was collected from toeslope colluvium at an additional 13 sites between Silver Creek and Cultus Bay (Figure 1), and was dated by accelerator mass spectrometry (Jull 2006), with radiocarbon ages converted to calendar years BP (cal. yr BP) using OxCal (Oxford Radiocarbon Accelerator Unit 2009) and the probability density function plotted.

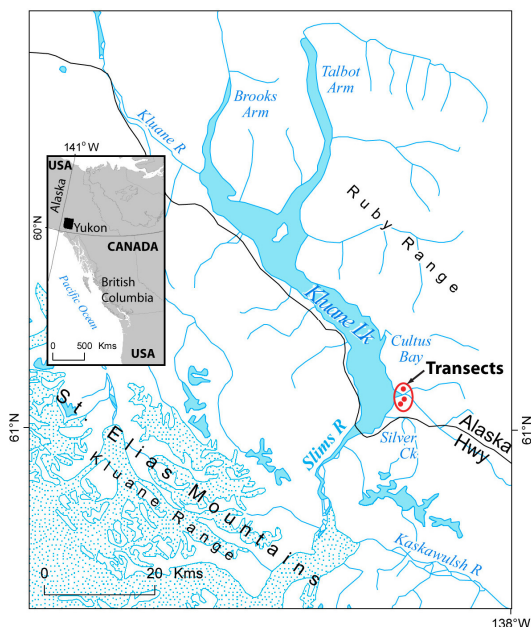


Figure 1. Study area location.

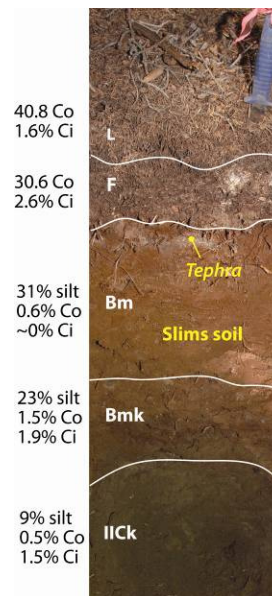


Figure 2. Brunisolic (WRB – Cambisol) forest soil, with high inorganic C (Ci) content in forest floor. (Co = organic C; knife handle = 11 cm long).

## Results and Discussion

The three transects (45-82 m long, relief 12-20 m) were located ~9-11 km from the Slims River delta (Figure 1). Grass-dominated vegetation occupied the upper 2/3 of slopes with aspects ranging from 230° to 260°, while boreal forest occupied all other slope positions. Controlling for slope steepness, pedons on upper- and midslope positions did not differ significantly between forest and grassland in the thickness-weighted silt content of the uppermost 50 cm of mineral soil (t-test:  $p=0.42$ ,  $df=6$ ). Although forest should intercept and retain dust more efficiently than low herbaceous vegetation (Muhs *et al.*, 2003), our sample size may have been too small to detect such an effect. This comparison also did not attempt to estimate the amounts of aeolian material retained in forest floors.

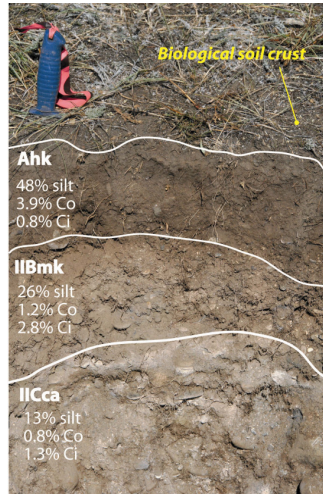
For a majority of transect pedons, some degree of mixing of parent materials has occurred, as indicated by coarse fragments and/or sandy loam textures in the uppermost mineral horizons (e.g. Figures 2,3). The White River tephra, associated with the Neoglacial loess, was present as a recognizable marker layer (e.g. Figure 2) in only 50% of the transect pedons, and displayed > 50 cm of lateral continuity in only one case. Bioturbation was likely responsible for this morphological disruption and variability, with different agents predominating under different vegetation types: arctic ground squirrels (*Spermophilus parryii*) in grasslands (Zazula *et al.*, 2006) (Figure 5), and tree-throw in forests. The extent of bioturbation influenced microstructure formation (Figures 6a,b), with silt-rich B horizons displaying platiness created by seasonal ice lens formation (Van Vliet-Lanöe 1985), while there was little or no aggregation in A and B horizons with coarser textures that resulted from mixing of loess with underlying glaciofluvial sands and gravels.

The fate of Neoglacial loess in surface horizons differed between forest and grassland soils. Forest floors resembled mor humus (Figure 2), but with L and F horizons that were visibly enriched in silt (Figures 6c,d) and detrital  $\text{CaCO}_3$  (mean inorganic C concentrations: L – 2.2%,  $n=11$ ; F – 1.4%,  $n=13$ ). Grassland soils lack surface organic horizons, but loess inputs appeared to be initially incorporated in biological soil crusts (Figure 4) (Marsh *et al.*, 2006), except in areas disrupted by recent squirrel burrowing (Figure 5). Reworking of loess on forested slopes during the Holocene may have also occurred after fires, based on the association between charcoal and buried soils in toeslope colluvium. The exact mechanism of post-fire

redistribution is uncertain, given the dry climate that would make water erosion unlikely. The cumulative probabilities of the calibrated radiocarbon dates for soil charcoal suggested a mid-Holocene decline in fire activity (Figure 7). This was consistent with the record of charcoal accumulation rates in a small pond within 5 km of the sites examined in this study (Whitmire 2001). However, the absence of soil charcoal dates between ~ 3000 and 6000 cal. yr BP could also reflect reduced loess deposition during a period of diminished glacial sediment production, and hence, less potential for burial and preservation of soil charcoal by colluviated loess.



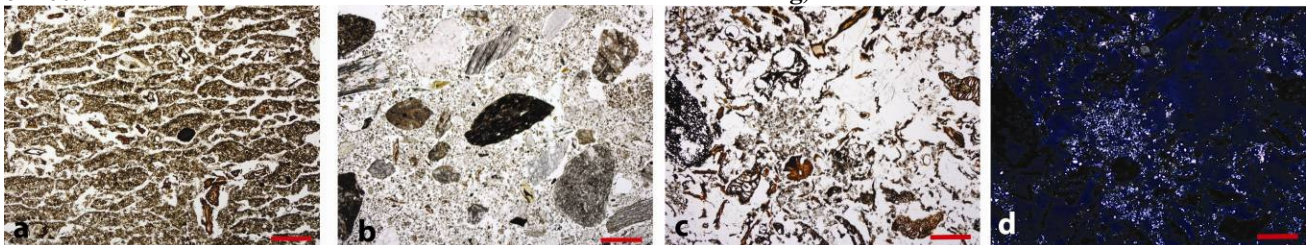
**Figure 3.** Intermingled grassland and boreal forest vegetation on esker ridges, between Ruby Range and Kluane L. Grassland in foreground has slope aspect of 260°.



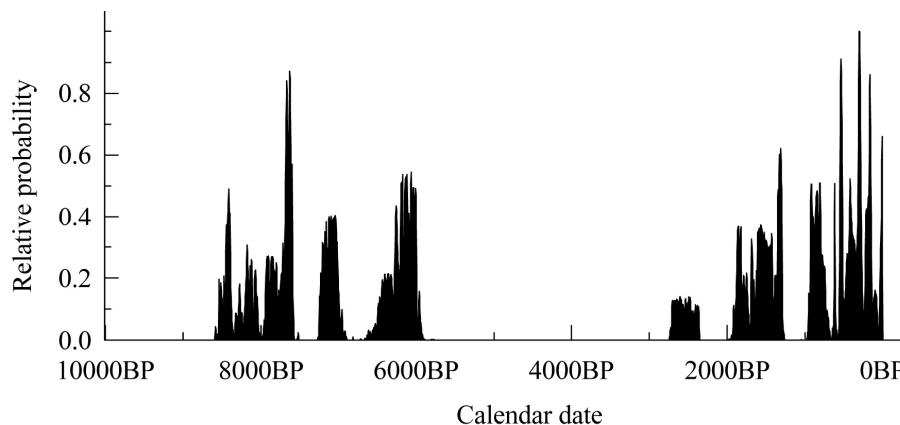
**Figure 4.** Chernozemic (WRB – Kastanozem) soil on crest of esker ridge. (Co = organic C; Ci = inorganic C; knife handle = 11 cm long)



**Figure 5.** Recent soil disturbance by arctic ground squirrels (*Spermophilus parryii*) in grassland.



**Figure 6.** Thin section views (plane light, except as noted): (a) platy structure in silt-rich B horizon of forest soil (depth ~ 20 cm), (b) weakly aggregated B horizon of grassland soil, (c) forest organic surface horizon with high silt content, (d) same view as (c), but with crossed polarizers. Scale bar = 1 mm.



**Figure 7.** Cumulative probabilities of calibrated accelerator radiocarbon dates for soil charcoal (n=23).

## Conclusions

Pedogenic modification of Holocene loess has followed diverging pathways in topographically-controlled forest-grassland mosaics in southwestern Yukon. Calcareous surface horizons of grassland soils displayed varying degrees of mixing of loess with the underlying glaciofluvial sands and gravels. Arctic ground squirrels (*Spermophilus parryii*) have been a major agent of soil bioturbation in these grasslands. In contrast, forest soils had mor-like surface organic horizons that were visibly enriched in calcareous silt. Redistribution of loess on forested slopes likely occurred through a combination of bioturbation by treethrow and episodic soil movement after fire. Variable mixing of these parent materials has created a diversity of microstructures in upper mineral horizons. Radiocarbon dating of soil charcoal preserved in toeslope colluvium suggests that fire activity diminished in the mid-Holocene.

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