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Invited review

150,000 years of loess accumulation in central Alaska

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ABSTRACT

The Halfway House site in interior Alaska is arguably the most studied loess deposit in northwestern North America. The site contains a complex paleomagnetic and paleoenvironmental record, but has lacked the robust chronologic control that would allow its full potential to be exploited. Detailed reexamination of stratigraphy, paleomagnetics and tephrostratigraphy reveals a relatively complete marine isotope stage (MIS) 6 to Holocene record constrained by the Old Crow (124 ± 10 ka), VT (106 ± 10 ka), Sheep Creek-Klondike (ca. 80 ka), Dominion Creek (77 ± 8 ka) and Dawson (ca. 30.2 cal ka BP) tephras. We show two well-developed paleosols formed during Marine Isotope Stages (MIS) 5e and 5a, while MIS 5c and 5b are either poorly represented or absent. The new tephrostratigraphy presented here is the most complete one to date for the late Pleistocene and indicates MIS 5 sediments are more common than previously recognized. A magnetic excursion within the sediments is identified as the post-Blake excursion (94.1 ± 7.8 ka), providing independent age control and adding to the increasing body of evidence that Alaskan loess is a detailed recorder of variations of the Earth's magnetic field over time. A high-resolution magnetic susceptibility profile placed into this new chronostratigraphic framework supports the hypothesis that wind-intensity is the main variable controlling fluctuations in susceptibility. Correlation of the susceptibility record to global marine $\delta^{18}O$ records is complicated by highly variable accumulation rates. We find the lowest rates of accumulation during peak warm and cold stages, while abrupt increases are associated with periods of transition between marine isotope (sub)stages. Building on previous accumulation models for Alaska, surface roughness is likely a leading variable controlling loess accumulation rates during transitions and peak cold periods, but the negligible accumulation during MIS 5e and 5a suggests that loess production was exceedingly low, negating the role of surface roughness. This interplay of variables leads to optimal conditions for loess accumulation during transitions between isotope stages, and to a somewhat lesser extent, stadials and interstadials.

1. Introduction

Large areas of Yukon and Alaska remained unglaciated during the Quaternary, but the proximity to major ice sheets has provided the conditions to create and preserve a loess record spanning more than 3 million years (e.g. Westgate et al., 1990). In this region, commonly known as eastern Beringia, loess deposits are often roughly divided into two main types: valley-bottom and upland loess. Valley-bottom loess is commonly perennially frozen and may be interbedded with retransported loess and organic material related to the growth of syngenetic permafrost and periods of degradation. Sediments are organic-rich, and alluvial and colluvial material may be locally present. These valley-bottom deposits tend to preserve the rich floral and faunal records for which Beringia is famous (e.g. Froese et al., 2006, 2009; Guthrie, 1968, 1990; Péwé, 1975a; Péwé et al., 1997, 2009; Zazula et al., 2007). Upland loess is generally comprised of primary air-fall loess that was, or is, perennially frozen, but has been relatively ice-poor for most of its existence. Most primary deposits have experienced periods where permafrost may have completely thawed (e.g. Péwé, 1975a,b; Péwé et al., 1997), and these fluctuations have caused some reworking and erosion through thaw slumping and cryoturbation. Regardless, this 'upland' loess is more comparable to 'classic' loess deposits, such as the Chinese loess plateau, where dry, organic-poor loess contains numerous paleosols (e.g. Liu et al., 1986; Kukla, 1987; Begét and Hawkins, 1989; Begét, 2001; Muhs et al., 2003, 2008; Jensen et al., 2008). Modern loess deposition is limited, but does

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continue in parts of Alaska, with estimated deposition rates at 0.2–2 mm/year in the Fairbanks area (Pewe, 1955, 1975a).

These extensive deposits, originally referred to as the "Yukon silts," have been mapped since the late 1800s (e.g. Russell, 1890; Spurr and Goodrich, 1898; Gilmore, 1908). The origins of the silt were unclear, with most workers suggesting a number of different processes, although by the 1950s, Taber's (1943, 1953) hypothesis of *in situ* production by frost-shattering was in vogue. However, subsequent detailed work by his contemporary Troy Péwé (1955) presented a compelling argument that the silts were aeolian deposits. Péwé (1955) noted that these silts were thickest along or near the major silt-rich and glacially-fed rivers of Alaska, and tended to thin away from them, both laterally and with elevation. Most importantly, he also noted that the mineralogy of the loess differed from the underlying bedrock, effectively disproving Taber's *in situ* hypothesis. This alternative hypothesis was not without controversy but was largely accepted not long after it was first presented.

Péwé went on to formalize the stratigraphic nomenclature for these silts in the Fairbanks region (Péwé, 1975b). Valley-bottom retransported loess was thought to be primarily post-last interglacial (i.e. marine isotope stage (MIS) 5) in age, and was divided into the Wisconsinan Goldstream Formation (MIS 4–2) and Holocene Ready Bullion (MIS 1) Formation. Primary loess deposits, which tend to mantle mid-slope and upland portions of central Alaska, can also occur stratigraphically below or laterally to the Goldstream and Ready Bullion Formations, and were named the Engineer Loess (Holocene) and Gold Hill Loess (>last interglacial). Undifferentiated upland primary loess deposits were known simply as the Fairbanks Loess (e.g. Péwé, 1955, 1975b; Péwé et al., 1966). Since Péwé's initial work, detailed geochronologic and paleomagnetic studies have helped differentiate units present in Fairbanks Loess locales (e.g. Westgate et al., 1990; Oches et al., 1998; Berger, 2003; Lagroix and Banerjee, 2004a; Péwé et al., 2009). Present usage of Péwé's nomenclature finds the terminology generally limited to the Engineer (Holocene; MIS 1), Goldstream (Wisconsinan; MIS 4–2) and Gold Hill (>MIS 5) Formations, but application of the formal names is based on chronology rather than whether the loess is primary or secondary, or present in valley-bottoms or slopes, since the spatial distribution and age of deposits have proven to be more complex (e.g. Begét, 1990; Berger, 2003; Muhs et al., 2003; Lagroix and Banerjee, 2004a,b). The Eva Creek Formation is the formal name Péwé et al. (1997) designated to the forest bed/thaw unconformity that is thought to represent MIS 5e; sediments attributed to other stages of MIS 5 have not been clearly identified in Alaska (e.g. Reyes et al., 2010a). Terminology in this paper will follow recent applications of Péwé's (1975b) formal stratigraphic nomenclature, where divisions are based on the age of the loess rather than location or sedimentology.

The Halfway House site (64.708 N, 148.503 W) is a mid-slope loess deposit mapped as Fairbanks Loess by Péwé et al. (1966) (Fig. 1). Located ~47 km west of Fairbanks, this exposure was created during the construction of the George Parks Highway in the 1960s, and is one of the most extensively studied loess sites in Alaska and the Yukon (e.g. Westgate et al., 1983, 1985; Begét and Hawkins, 1989; Begét, 1990; Begét et al., 1990; Oches et al., 1998; Preece et al., 1999; Vlag et al., 1999; Berger, 2003; Lagroix and Banerjee, 2002, 2004a,b; Muhs et al., 2003, 2008). Collectively, this research indicated that Halfway House is mostly comprised of the Goldstream Formation, and contains a stratigraphic and paleomagnetic record that has regional paleoenvironmental significance. However, poor chronologic control has hindered the interpretation of the record, and made it difficult to compare it to other regional and global paleoenvironmental records. Here we present a tephrostratigraphic framework for Halfway House that provides new chronologic control to this section by identifying several dated tephra beds from other locations in Yukon and Alaska. High-resolution paleomagnetic data provide additional age constraints that support the correlations and new age estimates. Magnetic susceptibility measurements and detailed stratigraphy allow direct correlation of our record to previous studies, placing that research into this new chronologic framework, and provide new insight into Alaskan loess accumulation models.

2. Previous research

2.1. Tephrostratigraphy

Westgate et al. (1983, 1985) first described Halfway House and identified two paleosols and tephra beds across the section. The lowest tephra was correlated to the regionally extensive Old Crow tephra (Fig. 2; OCt; 124 ± 10 ka; Preece et al., 2011a). Preece et al. (1999) describe the second tephra, as well as two additional beds, all stratigraphically above OCt, naming them the Halfway House (HHt), VT and SD tephra beds. At the time, none of these beds had independent age estimates. Muhs et al. (2003) re-examined Halfway House and identified an "unnamed" tephra approximately 1.5 m below OCt and provided several new ages estimates for the Halfway House tephra that suggested an early Wisconsinan age.

2.2. Magnetic susceptibility

Unlike Chinese loess, magnetic susceptibility (χ) in Alaskan loess deposits is lower in paleosols and higher in inorganic loess (e.g. Begét and Hawkins, 1989; Vlag et al., 1999; Liu et al., 2001). There are several generally accepted assumptions that can guide interpretations of changes in magnetic susceptibility in Alaskan loess. First, the dominant fluctuations in susceptibility reflect the size and concentration of magnetic grains present in the loess, although experimental studies examining susceptibility suggest concentration may be more important (e.g. Heider et al., 1996). The amount and size of magnetic grains present in the loess is driven by changes in wind intensity, with highest wind intensities entraining more and/or larger magnetic grains, and carrying them further (e.g. Begét, 1990, 1996, 2001; Vlag et al., 1999). These highest wind intensities may be a result of katabatic winds from ice sheets (Muhs and Budahn, 2006), but may also reflect differences in synoptic climatology during the cold stages (e.g. Mock et al., 1998). These observations indicate that magnetic susceptibility highs occur during cold stages with extensive glaciation, while the lows are associated with intervals of decreased glacier coverage and wind intensity during interglacials or interstadials (e.g. Begét et al., 1990). Second, loess in Alaska is largely glaciogenic, produced by comminution and transported via glacially-fed rivers such as the Tanana, Nenana and Yukon (e.g. Péwé, 1955; Begét, 2001; Muhs et al., 2003; Muhs and Budahn, 2006). High elevation areas of the Alaska Range through St. Elias Mountains host extensive modern glaciers and production and transportation of silt continues today, albeit in a more limited manner (e.g. Muhs et al., 2003, 2004). Therefore, accumulation of loess can be continuous through interglacial–glacial cycles, and paleosols in loess represent periods in time when loess accumulation was sufficiently low that pedogenesis exceeded loess input (e.g. Muhs and Bettis, 2003; Muhs et al., 2004).

Further examination of magnetic mineralogy suggests little pedogenic enhancement of ferrimagnetic content and evidence for some destruction and alteration of magnetic grains, contributing to the lower susceptibility within paleosols (Vlag et al., 1999; Liu et al., 1999, 2001; Begét, 2001). This model of susceptibility variation is also seen in some Siberian loess deposits (e.g. Chlachula et al., 1998;