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Invited review

Late Pleistocene and Holocene tephrostratigraphy of interior Alaska and Yukon: Key beds and chronologies over the past 30,000 years

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ABSTRACT

The Aleutian Arc-Alaska Peninsula and Wrangell volcanic field are the main source areas for tephra deposits found across Alaska and northern Canada, and increasingly, tephra from these eruptions have been found further afield in North America, Greenland, and Europe. However, there have been no broad scale reviews of the Late Pleistocene and Holocene tephrostratigraphy for this region since the 1980s, and this lack of data is hindering progress in identifying these tephra both locally and regionally. To address this gap and the variable quality of associated geochemical and chronological data, we undertake a detailed review of the latest Pleistocene to Holocene tephra found in interior Alaska and Yukon. This paper discusses nineteen tephra that have distributions beyond southwest Alaska and that have the potential to become, or already are, important regional markers. This includes three ‘modern’ events from the 20th century, ten with limited data availability but potentially broad distributions, and six that are widely reported in interior Alaska and Yukon. Each tephra is assessed in terms of chronology, geochemistry and distribution, with new Bayesian age estimates and geochemical data when possible. This includes new major-element geochemical data for Crater Peak 1992, Redoubt 1989–90, and two andesitic tephra from St Michael Island (Tephra D), as well as revised age estimates for Dawson tephra, Oshetna, Hayes set H, Aniakchak CFE II, and the White River Ashes, northern and eastern lobes.

1. Introduction

Volcanic ash deposits (tephra) are a key chronostratigraphic component of late Quaternary palaeoenvironmental reconstructions, as seen, for example, in the North Atlantic region (e.g. Abbott and Davies, 2012; Blockley et al., 2014; Davies et al., 2014). This is largely because individual tephra deposits allow a level of precision and accuracy in dating and correlation that is unachievable through other means (e.g. Lane et al., 2013). Methods such as radiocarbon dating have been used to construct chronologies, but have accompanying errors that can limit the comparison of widely distributed palaeoenvironmental records. Radiocarbon dating can also be affected by issues of sample selection, taphonomy, contamination, and stratigraphic integrity (e.g. Olsson, 1974; Lowe and Walker, 2000; Nilsson et al., 2001; Oswald et al., 2005; Brock et al., 2010). In particular, high latitude regions with an abundance of ‘old’ carbon on the landscape, because of slow rates of decomposition, are particularly susceptible to producing complicated radiocarbon chronologies (e.g. Karrow and Anderson, 1975; Nelson et al., 1988; Abbott and Stafford, 1996; Zimov et al., 1997; Kennedy et al., 2010; Reyes and Cooke, 2011). The development of detailed tephrostratigraphic frameworks can help overcome barriers in interpretation that are created by the inherent uncertainty in age models that constrain many depositional records and their associated palaeoenvironmental data.

The use of tephra deposits as a tool for stratigraphy and chronology has been enhanced in recent decades (e.g. Braitseva et al., 1997; Davies et al., 2012; Kaufman et al., 2012; Lowe et al., 2013; Moriwaki et al., 2016). In practice, tephrostratigraphy and -chronology relates to the use of visible (macro) beds, or non-visible, microscopic deposits known as ‘cryptotephra’. In northwestern North America the majority of tephrostratigraphic studies have been limited to areas where visible tephra are present (e.g. Péwé, 1975; Miller and Smith, 1987; Westgate et al., 1970; Beget et al., 1991; Clague et al., 1995; Foit et al., 2004; Kuehn et al., 2009a; Jensen et al., 2011; Preece et al., 2011a), and only a few studies

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have identified cryptotephra (e.g. Zoltai, 1989; de Fontaine et al., 2007; Lakeman et al., 2008; Payne et al., 2008). Additionally, while detailed Plio-Pleistocene syntheses of tephra in the Yukon and Alaska exist (e.g. Preece et al., 1999, 2011b; Jensen et al., 2008, 2016; Péwé et al., 2009), Holocene syntheses are largely missing. There are a number of individual records for specific volcanic sources from proximal settings (e.g. Stelling et al., 2005; Larsen et al., 2007; Schiff et al., 2008, 2010), or study areas focused in southwest Alaska and the eastern Aleutian arc (e.g. Riehle, 1985; Miller and Smith, 1987; Riehle et al., 1999; Carson et al., 2002; Fierstein, 2007; de Fontaine et al., 2007; Kaufman et al., 2012). However, there are no broad overviews of Holocene and latest Pleistocene tephra extending to distal sites.

The Late Quaternary tephra record of northwestern North America is increasingly important not just for researchers within western North America, but also further afield. On modern timescales, the distribution of volcanic ash is of significant interest for local hazard assessment and also at a regional level for aviation safety (e.g. Casadevall, 1994; Bull et al., 2011). Cryptotephra play an important role in developing tephrostratigraphic frameworks and understanding eruptive histories because they can greatly expand the known distribution of previously identified tephra (e.g. Turney et al., 1997; Davies et al., 2001) and result in the discovery of new eruptions (Wastegård, 2002; Davies et al., 2003; Pyne-O'Donnell, 2007; MacLeod et al., 2015). Cryptotephra studies also have great potential for chronological applications such as linking and comparing disparate palaeoenvironmental records if the tephra is well characterised and dated (e.g. Lowe et al., 2007; Lowe et al., 2012; Lane et al., 2013; Streeter and Dugmore, 2014). The recent discovery of Pacific northwest tephra more than 5000 km from their source in eastern Canada (Pyne-O'Donnell et al., 2012), Europe (Jensen et al., 2014a) and the eastern United States (Jensen et al., 2014b; Mackay et al., 2016; Pyne-O'Donnell et al., 2016), demonstrates the excellent potential for developing a cryptotephra framework across northern North America.

In order to more fully utilise the currently available Alaska eruption records, a baseline of well-characterised and dated tephra - the foundations of a regional tephrostratigraphy— is required. The aim of this review is to provide an assessment of available tephra data for this region as a starting point to achieve this goal. This review is restricted to tephra from the latest Pleistocene and Holocene as sedimentary records from this time period are commonly studied, but tephra records younger than the Dawson tephra (~30,000 cal yr BP) are not always well documented. This paper focuses on tephra found within eastern Beringia, the unglaciated region of Alaska and Yukon, and reassesses their geographical distribution, geochemical characterisation and age estimates, to update the regional tephrostratigraphy.

1.1. *Regional setting*

The study region for this review is limited to the interior of Alaska and Yukon (Fig. 1) for several reasons — this area preserves late Pleistocene sedimentary records that normally would have been removed by glaciation elsewhere, and captures the distal record of large magnitude eruptions from sources in the Wrangell volcanic field (WVF) and Aleutian Arc-Alaska Peninsula (AAAP). By choosing this more distal area we are attempting to reduce the "background noise" created by the large number of small eruptions that have deposited hundreds of tephra in locations proximal to the source volcanoes. Tephra found in the interior are the most likely to be significant for both a regional tephrostratigraphy, and one that may be applied more broadly across North America. The northern limit of the North American Cordillera is a significant topographic barrier within the region and the prevailing winds that flow around it create a natural break in the landscape. These conditions have restricted the distribution of visible tephra in the area, for example tephra from the Cascades or southern volcanic sources that are found in central and southern Canada (e.g. Zoltai, 1989; Westgate et al., 1969; Lakeman et al., 2008) have not been reported in this region. Hence, this study area can be thought of as preserving tephra from Alaska, and potentially sources further upwind, such as Kamchatka.

The Alaska Volcano Observatory reference library (Alaska Volcano Observatory, 2014) documents the long-term activity of volcanoes in the area. Of Alaska's 130 volcanoes and volcanic fields, 96 have been active either historically or within the Holocene (Miller et al., 1998). From historical observations since ~ 1760 CE more than 50 volcanoes have been active, and the eruption database currently catalogues 177 tephra plumes and falls from 27 volcanoes (Alaska Volcano Observatory, 2014). These eruption records give us an indication of the high level of volcanic activity and tephra production occurring, but not necessarily how many tephra have been preserved distally. The transport distances of the eruptive ejecta are related to factors such as the height of the eruption column, duration of the event, and prevailing winds at the time of the eruption (e.g. Turner and Hurst, 2001; Watt et al., 2009; Bull et al., 2011). As many of the eruptions documented were relatively small events with limited transport potential, the actual number of tephra preserved distally will be significantly less even before factoring in additional issues influencing the preservation and taphonomy of tephra layers within sedimentary records (e.g. Dugmore et al., 1996; Beierle and Bond, 2002; Davies et al., 2007; Payne and Gehrels, 2010; Pyne-O'Donnell, 2010; Watson et al., 2015).

The Kamchatka Peninsula can also be considered here as a potential source of distal cryptotephra in this region given the large number of active volcanoes present and their favourable position in terms of prevailing wind direction. However, while Yalcin et al. (2003) report finding shards from the Ksudach 1907 eruption in the Eclipse ice core (see section 3 for details), there have been no published occurrences of visible deposits of Kamchatkan tephra within eastern Beringia.

2. Materials and methods

We reviewed the literature to assess which tephra have been identified within the study area and collated available information on those tephra, particularly with respect to stratigraphy, glass geochemistry, and chronological control. One additional radiocarbon date and new electron probe microanalysis (EPMA) data produced at the University of Alberta, Edmonton, have been included here. The datasets used within this review are detailed in the Supplementary Data (Tables S1—S7).

A full characterisation of tephra deposits also describes attributes such as glass morphology, mineralogy, and trace-element composition of whole rock or glass samples. These can be particularly useful, or even necessary, for distinguishing between different tephra or identifying complex volcanic histories (e.g. Westgate et al., 2008, 2013; Preece et al., 2011a,b, 2014; Smith et al., 2011). However, when working with distal samples, and cryptotephra in particular, these observations are not always possible (e.g. if only the glass fraction is deposited) or undertaken (e.g. if EPMA data appear sufficient for a project, or if the required analytical equipment is not available). For this study we focus on assessing the attributes most commonly utilised in tephra studies: major-element glass geochemistry, chronology and stratigraphy. Additional information on glass morphology, mineralogy and trace element geochemistry that is available is summarised in Table S1.

Tephra identified within the study area are split into three