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A new Holocene record of geomagnetic secular variation from Windermere, UK

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ABSTRACT

Paleomagnetic secular variation (PSV) records serve as valuable independent stratigraphic correlation and dating tools for marine and terrestrial sediment sequences, and enhance knowledge of geomagnetic field dynamics. We present a new radiocarbon-dated record (WINPSV-12K) of Holocene geomagnetic secular variation from Windermere, updating the existing 1981 UK master PSV curve. Our analyses used continuous U-channel samples taken from the center of four sediment cores retrieved from Windermere in 2012. The natural remanent magnetization (NRM) of each U-channel was measured before and after stepwise alternating field (AF) demagnetization on a superconducting rock magnetometer at intervals of 0.5-cm or 1-cm. The NRM data reveal a stable and well-defined primary magnetization.

Component declinations and inclinations estimated using Principal Component Analysis (PCA) of NRM data from the four Windermere cores correlate well on their independent radiocarbon age models. The four records were stacked using a sliding window bootstrap method, resulting in a composite Holocene PSV record (WINPSV-12K).

On millennial timescales WINPSV-12K correlates well with other records from Western Europe and the northern North Atlantic to a resolution of ~1 kyr, given age uncertainties and spatial variability between records. WINPSV-12K also compares well to the CALS10k.2 and pfm9k.1a model predictions for Windermere. Key regionally-significant PSV inclination features of WINPSV-12K which correlate with other North Atlantic records include peaks at 5–6, 8.5, and 10 cal ka BP, and a trough at 7 cal ka BP. Key PSV declination features include the eastward swing from 5.5–2.3 cal ka BP followed by a major westward excursion at 2.3 cal ka BP, peaks at 1.1 and 7 cal ka BP, and troughs at 5.4 and 8.2 cal ka BP, with the caveat that an estimated magnetic lock-in delay of at least 100–200 yr is present. PSV variations on 1–3 kyr timescales are interpreted to represent strengthening and weakening of the North American versus the Siberian and European–Mediterranean high-latitude flux lobes, based on the close similarities between the North Atlantic regional records and the antiphase existing in the East Asian Stack record and the North East Pacific inclination stack. WINPSV-12K provides a regionally-important new PSV reference curve whose prominent features may serve as stratigraphic markers for North Atlantic paleo-records.

1. Introduction

Paleomagnetic secular variation (PSV) describes the variation in the Earth's geomagnetic field on timescales of a hundred years or longer in periods of stable magnetic polarity, and exhibits substantial variation throughout the Holocene (Turner et al., 2015; Turner and Thompson, 1981; Zheng et al., 2014). Fine magnetic particles in marine and lacustrine settings often preserve the direction and intensity information of the Earth's magnetic field during and shortly after deposition, forming a continuous PSV archive. Lake sediments are conducive to paleo-record preservation due to relatively high sedimentation rates, good accessibility, and little influence from currents, waves, and macrofaunal bioturbation. PSV records reconstructed from marine and lacustrine sediments have become increasingly utilized over the last few decades (Mackereth, 1971; Ojala and Saarinen, 2002; Snowball et al., 2007; Stoner et al., 2013, 2007; Turner et al., 2015; Zheng et al., 2014). These records provide continuous informa-

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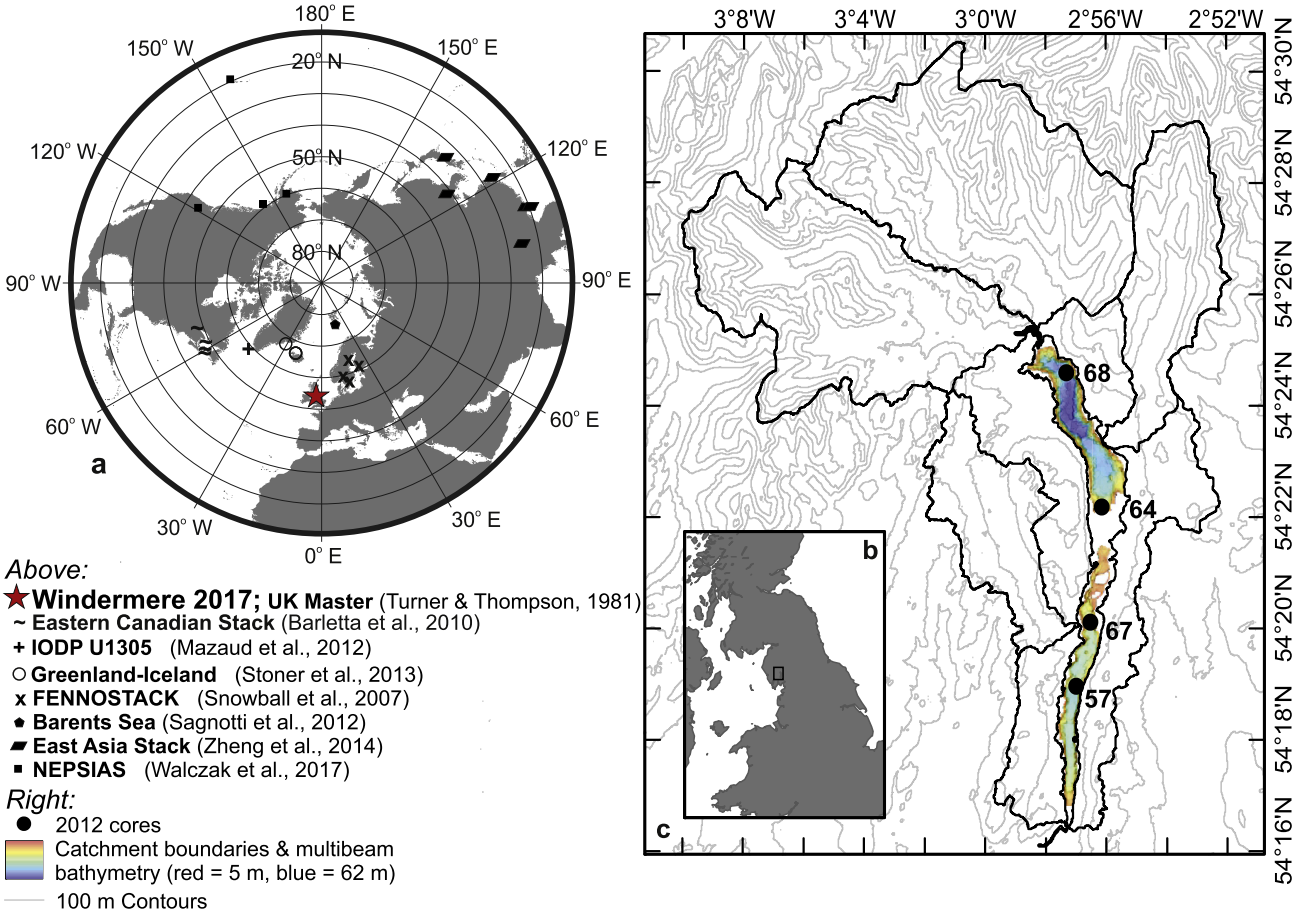

Fig. 1. Above: Map of the 10–90°N latitudes, showing the locations of both Windermere (red star) and comparative records (other markers). Right: Map of the catchment of Windermere with 100 m contour lines, multibeam lake bathymetry, and core locations. Inset: Location of Windermere in the British Isles (black box).

tion on geomagnetic field dynamics beyond historical observations and archaeological measurements (Batt et al., 2017; Jackson et al., 2000), and provide data to inform and improve geomagnetic field models (Brown and Korte, 2016; Constable et al., 2016; Nilsson et al., 2014) while serving as a valuable stratigraphic correlation and dating tool that is independent of climate and ecological systems (Ólafsdóttir et al., 2013). In sediment cores exhibiting high sedimentation rates and little bioturbation, PSV records are particularly suitable for dating and improving the correlation of sedimentary records even over large regions (Zheng et al., 2014), and are thus valuable in developing understanding of rapid changes and diachroneity in the Earth System at high temporal resolution. There is a need across locations used in the study of late Quaternary climate variability to produce and utilize more PSV records using reliable dating methods, high measurement resolution (1 cm or better), and continuous sampling and measurement techniques. Having an independent dating and stratigraphic tool other than tephra layers enables the correlation of more spatially distributed records, especially between locations with no common tephra horizons.

The location of Windermere, UK, provides an opportunity to link continental Europe with Icelandic and Greenlandic records (Fig. 1). Measurement of declination in the UK demonstrated the potential for the use of PSV as a dating method (Mackereth, 1971). The UK PSV master curve constructed in 1979–1981 (Thompson and Turner, 1979; Turner and Thompson, 1981) has been used both to date other PSV records from around Europe (Saarinen, 1999; Vigliotti, 2006) and also in the construction of several paleomagnetic field models, thus furthering understanding of the geomagnetic field (Constable et al., 2016). There has been little study of UK-based Holocene paleomagnetic records since the development of the existing UK master curve, which was largely dated using 20 cm thick bulk radiocarbon samples using older radiocarbon processing methods (Thompson and Turner, 1979; Turner and Thompson, 1981). New piston cores from Windermere provide the opportunity to update the UK master curve (which was constructed partially from cores from Windermere, along with Llyn Geirionydd and Loch Lomond) using modern dating and paleomagnetic analyses. The new cores span the length of Windermere, whereas the Windermere cores collected by Turner using a 'Mackereth' corer were all from a location similar to that of our Core 57 (Fig. 1) (Turner and Thompson, 1981).

In this study, we construct a composite Holocene PSV record (WINPSV-12K) using four sediment cores from Windermere, UK (Fig. 1), with a view to updating the UK PSV master curve (Thompson and Turner, 1979; Turner and Thompson, 1981). The accelerator mass spectrometry (AMS) radiocarbon-dated record is high-resolution, with core sedimentation rates of 20–50 cm/kyr and paleomagnetic measurements every 0.5–1 cm. WINPSV-12K is compared to well-dated records from the North Atlantic (Mazaud et al., 2012; Stoner et al., 2013), Scandinavia (Sagnotti et al., 2012; Snowball et al., 2007), the existing UK master PSV curve (Turner and Thompson, 1981), the UK archeomagnetic curve (Batt et al., 2017), eastern Canada (Barletta et al., 2010), East Asia (Zheng et al., 2014), and the North East Pacific (Walczak et al., 2017). WINPSV-12K serves as a valuable new curve for synchronization of Holocene marine-terrestrial records across the northern North Atlantic (NNA) geomagnetic region.