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COMMENT

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In praise of archives (and an open mind)

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A recent study dating Viking presence in America to a precise year was only possible thanks to long-term conservation of archaeological finds. It also arose from curiosity, interdisciplinarity and recognition of emerging techniques. These factors highlight the importance of archiving materials and asking the right questions in research on the entanglements of climate and history.

Annually-resolved radiocarbon (^{14}C) measurements of wooden remains from Newfoundland have recently established a European presence in North America (Vinland) in 1021 CE[1]. This precision greatly exceeds what had been achieved with conventional radiocarbon techniques in earlier decades[2] and sheds new light on Viking transatlantic travel[3]. But beyond the revelation that Norsemen crossed the Atlantic 471 years before Columbus, the study exemplifies the importance of conservation: The new high-resolution ^{14}C analyses of α-cellulose of four wooden artifacts from the archaeological site of L'Anse aux Meadows were possible because the original samples had been stored appropriately for decades. While archiving sounds trivial and should be common practice, long-term conservation is a challenge for many universities and institutions owing to the recurrent costs of specialist facilities. In many archives across the world, wood and other biological materials are poorly catalogued and preserved: Had the finds from L'Anse aux Meadows rotted away, they would not have been available to exploit advances in accelerator mass spectrometry[4], identification of exceptional cosmogenic ^{14}C anomalies in 774 and 993 CE[5], and wider improvements in radiocarbon age calibration (IntCal20)[6].

With an exact date of 1021 CE for Viking presence in Newfoundland, Norse transatlantic expansion can now be contextualised in light of historically-dated narratives and high-resolution paleoenvironmental proxies (Fig. 1A). Strikingly, comparison with an annually-resolved and absolutely-dated temperature reconstruction[7] reveals the voyages between Greenland and Vinland took place during the warmest pre-industrial summer of the past millennium. The mean June–August temperature in 1020 CE was 0.75 °C warmer than the 1961–90 reference period[7]. Likewise, the Viking discovery of Greenland in the late-10th century was achieved in the warmest decades of the medieval period. The summer of 990 CE was the warmest in the past 2000 years, +1.22 °C relative to modern climatology. Moreover, the initial Norse occupation of the Faroe Islands, possibly in 825 CE[8], as well as the beginning of the Viking Age itself in the 790s[9], both follow remarkably warm summers over the North Atlantic and Europe[7] (Fig. 1A).

The succession of mild summers is likely to have facilitated transatlantic navigation, for instance by improving visibility of low islands[10]. Arctic seafaring and coastal settlement surely further depended on favourable sea-ice extent, predictable ocean current dynamics and continuous driftwood supply. Driftwood was, and remains essential for fuel, construction timber, boat building, and other routine needs across the treeless high-northern latitudes[11]. Both too much and little annual pack ice limit the supply of driftwood to Arctic and subarctic coastlines due to requirements of open water for transport and the limited floating time of wood.

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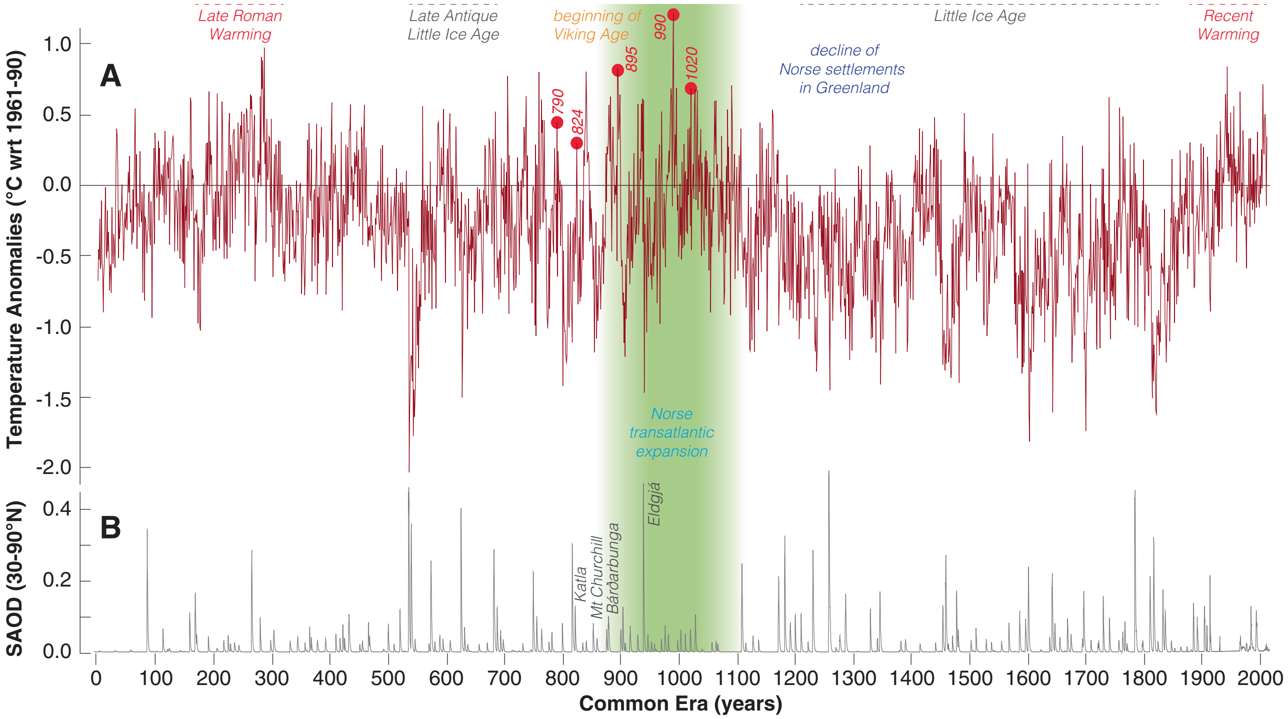

Fig. 1 Climate and volcanism in the Viking Age. A Summer temperature reconstruction for the North Atlantic/European sector[7], revealing peak warming from the beginning of the Viking Age in the 790 s throughout the Norse occupation of the Faroes, Iceland, Greenland, and Vinland from the 9th to the 11th century CE. **B** Stratospheric Aerosol Optical Depth (SAOD) for the Northern Hemisphere extra-topics associated with volcanic dust veils and estimated from ice core records[14].

The medieval warmth may be attributable, in part, to subdued volcanic forcing spanning the early-8th to mid-12th centuries (Fig. 1B). This period also coincides with *landnám*, the first permanent Icelandic settlements that were established by the 870s[12]. A cluster of high-latitude Northern Hemisphere volcanic eruptions, including those of Katla and Bárðarbunga in Iceland in 822/3 and circa 870 CE, respectively, and Mount Churchill, Alaska in 852/3 CE may have had limited climate impacts (Fig. 1B), but the colossal sulphur output of the Eldgjá eruption in Iceland from 939 to 940 CE evidently led to the depression of summer temperatures over much of the Northern Hemisphere[7]. Of course, the Norse could have no knowledge that ameliorated North Atlantic climate might reflect decline in large-scale volcanic forcing but once in Iceland, they soon gained direct experience of the effects of eruptions. It has been argued that the Christianisation of Iceland in 999/1000 CE was influenced by severe experiences of the Eldgjá eruption[13].

The case of Norse expansion across the Atlantic identifies four ingredients that can contribute to successful paleoenvironmental research: archive materials, keep chronologies under review, bridge disciplines, and challenge paradigms. The global radiocarbon spikes in 774 and 993 CE can surely anchor other hitherto floating tree-ring chronologies, thereby providing firm dates for natural and historical events. A forensic approach that integrates evidence from high-precision radiocarbon and stable isotope measurements, paleoenvironmental proxies, archaeology, philology, and other branches of the humanities, promises fresh insights into the entanglements of climate variability and human history. We should connect our epistemological silos, ask the right questions, and let the data speak.

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Competing interests
The authors declare no competing interests.

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