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Rapid Communication

Evidence for the occurrence of Vedde Ash in Sweden: radiocarbon and calendar age estimates

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ABSTRACT: A tephra layer of rhyolitic composition has been recorded in sediments from Lake Madtjärn, southwestern Sweden. Geochemical analyses have shown that the tephra is identical to the rhyolitic component of the middle Younger Dryas Vedde Ash. A series of AMS radiocarbon measurements places the radiocarbon age of the tephra within a ^{14}C plateau at 10 400–10 300 ^{14}C y BP. Based on a linear Younger Dryas sedimentation rate and assumptions about the apparent synchroneity of changes in lake sediments, tree rings and ice-core records, the calendar year age of the tephra concentrations is estimated at 12 045–11 975 yr BP, which accords well with the age of the equivalent tephra in the GRIP core. © 1998 John Wiley & Sons, Ltd.

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KEYWORDS: Madtjärn; microtephra; Younger Dryas; radiocarbon age.

Introduction

The Vedde Ash is a well-documented time-synchronous marker horizon around the North Atlantic. It has been found in marine cores from the North Atlantic Ocean, as one of the constituents of North Atlantic Ash Zone I (e.g. Kvamme *et al.*, 1989; Bard *et al.*, 1994; Austin *et al.*, 1995; Lacasse *et al.*, 1995), in the Greenland GRIP ice-core (Grönvold *et al.*, 1995), and in lake sediments from Norway, Iceland and Scotland (e.g. Mangerud *et al.*, 1984; Björck *et al.*, 1992; Birks *et al.*, 1996; Turney *et al.*, 1997). The easternmost record reported so far is from a varved clay from Lake Mullsjön in southern Sweden, although this has not been confirmed geochemically (Wohlfarth *et al.*, 1993).

Two geochemically distinct components have been recognised in the Vedde Ash, one basaltic and one rhyolitic. In some areas, however, only the rhyolitic component has been recognised, indicating an irregular geographical distribution or different preservation mechanisms (Long and Morton, 1987; Turney *et al.*, 1997). The possibility of two simultaneous eruptions from different volcanic systems has been proposed to explain the different components of the tephra horizon (Norðdahl and Hafliðason, 1992), although others prefer a single source (the Katla volcano; Lacasse *et al.*, 1995).

The main importance of the Vedde Ash lies in the potential it offers for the correlation of climatic events recognised in different archives, i.e. ice-cores, marine cores and terrestrial stratigraphies. Efforts are being made presently to link the Swedish clay-varve chronology, i.e. the Swedish Time Scale to other chronologies, such as the GRIP ice-core record, using the Vedde Ash as a marker feature.

This paper presents the first geochemically analysed record of Vedde Ash glass shards from Sweden. The ash horizon occurs within a well-dated lacustrine sediment sequence from southwestern Sweden, Lake Madtjärn (Björck and Digerfeldt, 1991; Björck *et al.*, 1996), and the radiocarbon measurements were obtained from samples of terrestrial plant macrofossils (see Björck *et al.*, 1996).

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Methods

New techniques for the extraction of invisible tephra particles ('microtephra') from lacustrine sediments have been developed recently (Rose *et al.*, 1996; Turney, in press). A sediment core from Lake Madtjärn (Fig. 1) was chosen to test for the occurrence of the Vedde Ash in Sweden, by using the technique developed by Turney (in press). The Younger Dryas sequence from Lake Madtjärn, 800–832.5 cm (Fig. 2; see Björck *et al.*, 1996) was sampled contiguously in 1 to 2 cm intervals. Samples of 1 cm^3, mostly consisting of clay gyttja, were treated by burning for 4 h at a temperature of 650°C, soaked overnight in 10% HCl to reduce the organic and carbonate content and were then sieved through mesh diameters of 24 and 75 μm. Thereafter the size fraction 24–75 μm was enriched by using a heavy liquid, sodium polytungstate, $Na_6(H_2W_{12}O_{40})H_2O$, with relative densities of 2.4 and 2.5 g cm^{-3}, which allowed the microtephra to float and the bulk of mineral particles (e.g. quartz, feldspar) to sink. The tephra concentration was estimated by counting all tephra shards in the fraction between 2.4 and 2.5 g cm^{-3}. A search for the basaltic component of the Vedde Ash was undertaken in the fraction between 2.7 and 2.8 g cm^{-3}, but no shards were found.

Tephra shards from a sample taken at 812–813 cm depth were analysed geochemically on an electron microprobe at the University of Edinburgh. This sample was treated by a combination of acid digestion (e.g. Dugmore, 1989) and density-separation methods (Turney, in press). The sample was not ashed because this is known to alter the geochemical composition of the tephra shards (Dugmore *et al.*, 1995). This resulted in a very clean sample, with more than 50% of the particles identified as tephra shards. The preparation for microprobe analysis and subsequent analytical procedures follow Dugmore *et al.* (1995).

Results and discussion

The highest concentrations of tephra are recorded as two tephra peaks at 812.5 cm and at 814.5 cm (Fig. 2). Because the Vedde Ash fallout is believed to have been the result of a geologically instantaneous event (cf. Norðdahl and Hafliðason, 1992), the double peaks in tephra shard concentration are probably a result of reworking and/or bioturbation. A small number of shards were found up to at least 806 cm, indicating a minor reworking of glass shards by bioturbation and by inwash from the drainage area. No shards were found below 816 cm. The shards are colourless or pale brown and are often three- or four-winged, which is typical of the Vedde Ash (Mangerud *et al.*, 1984; Long and Morton, 1987). The high concentration of shards discovered in this sequence suggests that the Vedde Ash may be present throughout the whole of south Sweden, and even further east in the Baltic region. This is also suggested by recent findings of the Vedde Ash in a Younger Dryas sequence from Högstorpsmossen (J. Björck and Wastegård, in preparation), ca. 250 km southeast of Lake Madtjärn (Fig. 1).

A summary of the microprobe analyses is shown in Table 1. The results are compared with the results of microprobe analyses of Vedde Ash from terrestrial sites in Norway (Kråkenes; Birks *et al.*, 1996) and Scotland (Whitrig Bog, Turney *et al.*, 1997) as well as the Vedde Ash stratotype

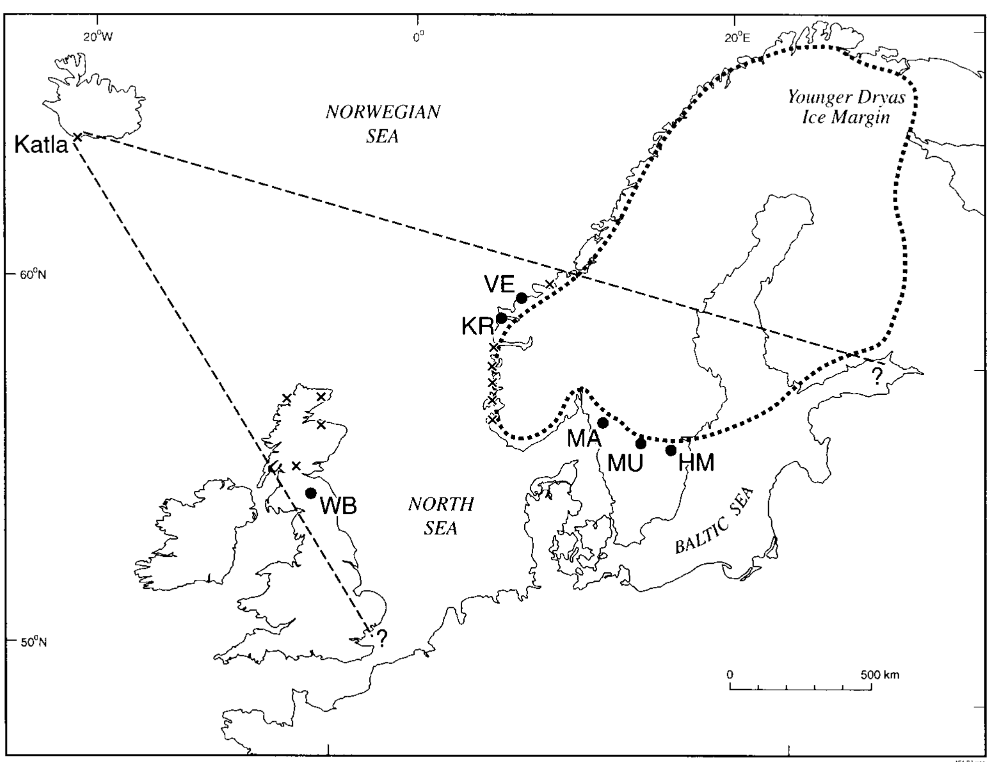

Figure 1 Map of northwest Europe showing the location of Lake Madtjärn (MA) and of other sites discussed in the text: Whitrig Bog (WB), Kråkenes (KR), Vedde (VE), Lake Mullsjön (MU) (Wohlfarth *et al.*, (1993)) and Högstorpsmossen (HM) (J. Björck and Wastegård, in preparation). Other terrestrial sites in Scotland and Scandinavia with confirmed occurrences of the Vedde Ash are marked with crosses. Data from Roberts (1997) and Turney *et al.* (1997) for sites in Scotland and from Mangerud *et al.* (1984), Bard *et al.*, (1994) and Birks *et al.*, (1996) for sites in Norway. The possible plume of wind-transported Vedde Ash to northwestern Europe is indicated.

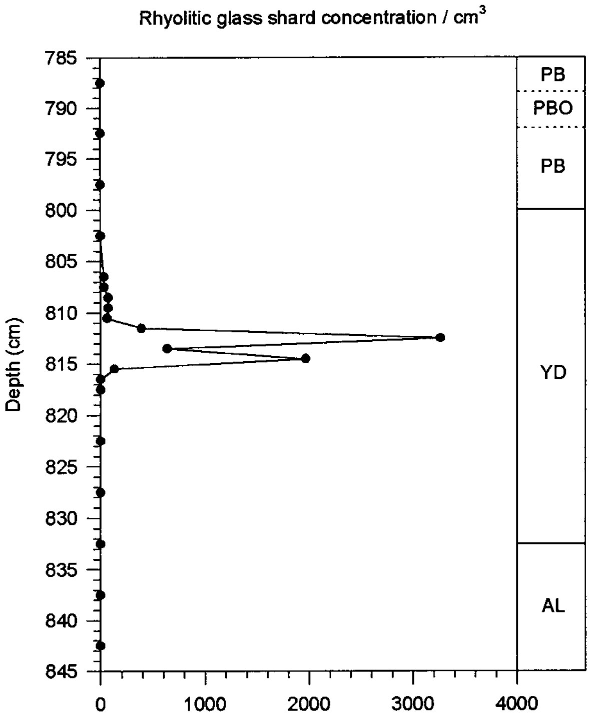

Figure 2 Concentration of tephra shards (24–75 μm) against depth at Lake Madtjärn. The climatostratigraphic boundaries between Allerød (AL), Younger Dryas (YD), Preboreal (PB) and the Preboreal oscillation (PBO) are shown (after Björck *et al.*, 1996).

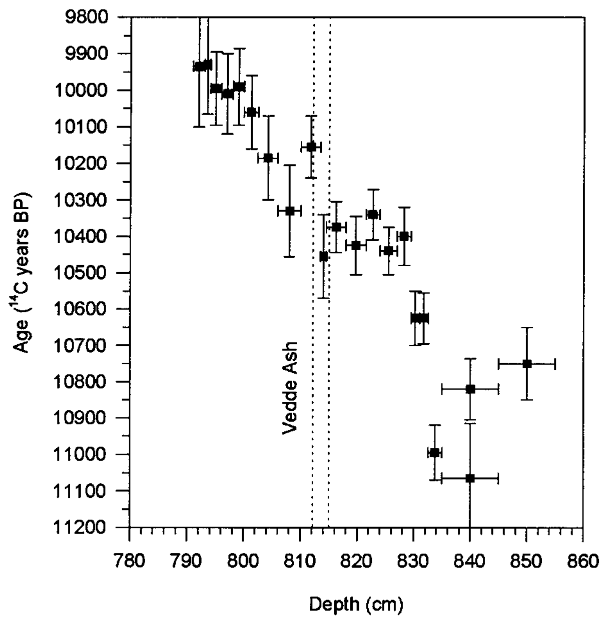

Figure 3 Radiocarbon dates versus depth in the Younger Dryas sequence from Lake Madtjärn. All dates are based on terrestrial macrofossils (see Björck *et al.*, 1996). Horizontal bars are the depth spans of each sample, vertical bars show one standard deviation of activity measurement.

Table 1 Composition of rhyolitic tephra shards from Lake Madtjärn (depth 812–813 cm), determined by electron microprobe analysis. Total iron is expressed as FeO*. Analyses were performed on a Cambridge Instruments Microscan V, with an accelerating voltage of 15 kV, a beam current of 15 nA and a beam diameter of 1 μm. The results are compared with analyses of rhyolitic Vedde Ash shards from Kråkenes (Birks *et al.*, 1996), Whitrig Bog (Turney *et al.*, 1997) and the Vedde Ash stratotype (Mangerud *et al.*, 1984). The latter shows low totals in sodium content, probably as a result of mobility of sodium during microprobe analysis (Mangerud *et al.*, 1984).

	Madtjärn ($n = 31$)		Kråkenes ($n = 11$)		Whitrig Bog ($n = 30$)		Vedde Ash Bed ($n = 21$)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
SiO_2	69.94	0.93	70.46	0.88	70.32	1.05	72.87	0.97
TiO_2	0.28	0.04	0.29	0.03	0.28	0.03	0.31	0.14
Al_2O_3	13.25	0.16	12.95	0.21	13.10	0.25	13.25	0.28
FeO*	3.70	0.11	3.63	0.28	3.69	0.12	3.79	0.16
MnO	0.13	0.03	0.17	0.08	0.13	0.03	0.15	0.09
MgO	0.24	0.02	0.20	0.02	0.20	0.02	0.21	0.04
CaO	1.28	0.05	1.38	0.09	1.23	0.07	1.23	0.12
Na_2O	4.48	0.23	4.64	0.39	4.51	0.26	2.11	0.39
K_2O	3.41	0.12	3.34	0.10	3.54	0.11	3.21	0.38
Total	96.69	1.10	97.06	1.16	97.01	1.26	97.13	

in western Norway (Mangerud *et al.*, 1984). The results confirm that the shards analysed from Lake Madtjärn are identical to the rhyolitic component of the Vedde Ash.

Four AMS radiocarbon dates based on fossils obtained from deposits between 818 and 806 cm give a mean radiocarbon age of 10 330 ± 65 ^{14}C yr BP (Fig. 3), which is in agreement with the date reported from Kråkenes, west Norway (10 310 ± 50 ^{14}C years BP; Birks *et al.*, 1996). However, a radiocarbon plateau is indicated at 10 400–10 300 ^{14}C years BP in both the Lake Madtjärn (Fig. 3) and the Kråkenes data, so that the tephra layer cannot be dated more precisely.

The Younger Dryas interval at Lake Madtjärn spans 32.5 cm (832.5–800 cm), and if a duration of 1150 calendar years for the Younger Dryas cold phase is assumed (e.g. Johnsen *et al.*, 1992; Goslar *et al.*, 1995), then a mean sedimentation rate of 0.28 mm yr^{-1} can be inferred for this part of the sequence. Based on the uniform Younger Dryas sediments (clay gyttjas) we can assume a fairly constant sedimentation rate. By this means, the tephra peak at 814.5–812.5 cm is dated to 515–445 years before the Younger Dryas–Preboreal transition at Lake Madtjärn. The onset of this transition is clearly identified in lake sediments, tree rings and in the GRIP ice-core, and is considered synchronous, with a date of 11 450 calendar yr BP (AD 1950) (Björck *et al.*, 1996). A recent match between the German oak and pine chronologies (B. Kromer and M. Spurk; pers. comm.), however, shows that ca. 80 yrs should be added to these

11 450 yr, which gives an almost perfect correlation between the tree-ring width increase in the German pines (cf. Björck *et al.*, 1996) and the $\delta^{18}O$ rise in the GRIP core (Johnsen *et al.*, 1992). With this correction, the Vedde tephra peak in Lake Madtjärn dates to 12 045–11 975 calendar yr BP, which compares with Grönvold *et al.*'s (1995) dating of the Vedde Ash in the GRIP ice-core to 11 980 ± 80 ice yr BP (AD 1950). It might be profitable, therefore, to examine varves in Sweden that are estimated to ca. 12 000 varve yr BP in the preliminary adjusted Swedish Time Scale (cf. Wohlfarth, 1996), to establish whether the Vedde Ash can be detected. If the Vedde Ash can be located within the Swedish Time Scale, then the error margins of the varve chronology can be determined independently.

Conclusions

The Vedde Ash has been found in sediments from a site in southwestern Sweden. This is, so far, the easternmost geochemically proved record of this marker horizon. The ash is dated to 10 300–10 400 ^{14}C yr BP based on an AMS dating series. Based on the synchronisation between lake sediments, tree rings and the ice cores (Björck *et al.*, 1996), including a recent overlap between the German oak and pine chronologies (B. Kromer and M. Spurk, pers. comm.), we estimate the calendar age of the Vedde Ash at this site to 12 045–11 975 yr BP. The presence of the Vedde Ash in south Sweden provides an opportunity for linking this well-dated marker horizon to annually laminated sequences in south Sweden, and for estimating possible errors in the Swedish Time Scale (cf. Wohlfarth, 1996). It also opens new possibilities for correlation of terrestrial sequences in Scandinavia and the British Isles and, for the first time, there is the possibility of correlating a lacustrine sequence in Sweden with marine cores from the North Atlantic and ice cores from Greenland.

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