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Tephra analysis of sediments from Midge Lake (South Shetland Islands) and Sombre Lake (South Orkney Islands), Antarctica

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Abstract: Lake sediment cores from Midge Lake, Livingston Island, South Shetland Islands and Sombre Lake, Signy Island, South Orkney Islands were analysed for volcanic tephra using light microscopy and magnetic susceptibility. Cores were dated using published ^{14}C and ^{210}Pb chronologies. Electron probe microanalyses of discrete tephra glass shards were undertaken to characterise the tephra geochemically in order to identify possible source volcanoes and refine tephrochronological data for the region. Results identified five tephra horizons in a core from Midge Lake. Four of these tephra at 3–4 cm, 8–9 cm (*c.* 450 yr BP), 15–16 cm (*c.* 755 ± 105 yr BP) and 21–22 cm (*c.* 1340 ± 100 yr BP) consisted of sodic basaltic to basaltic-andesitic glasses, containing abundant labradoritic feldspar inclusions, and a single 'acidic' tephra was found at 2–3 cm. Seven tephra horizons were identified in the Sombre Lake core including three basaltic tephra at 3–9 cm (30 ± 4 yr BP to 125 ± 25 yr BP), 31–32 cm and 44–46 cm (1325 ± 50 ^{14}C yr BP) and four acidic tephra at 21–22 cm and 24–25 cm, 33–36 cm (*c.* 1021 ^{14}C yr BP) and 54–56 cm (*c.* 1450 ^{14}C yr BP). These are the first tephra to be identified from the South Orkney Islands. Geochemical and grain size analysis indicated that the analysed Midge Lake tephra were derived from the Quaternary Deception Island volcano. Smaller grain sizes, congruent geochemical data and prevailing wind directions also indicate this volcano as the likely source of Sombre Lake tephra. Results highlight the importance of establishing geochemical consistency between tephra deposited across wide geographical areas, during apparently synchronous time periods, if they are to be used in a regional tephrochronology.

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Introduction

Sedimentary tephra horizons are widespread in Antarctic lakes due to the large numbers of eruptions from Antarctic volcanic centres active during the Late Quaternary, and the ease with which large eruptions of volcanic ash can be transported and deposited over large areas (Smellie in press). Distinctive tephra deposits may form valuable isochrones, and thereby facilitate the correlation of tephra-laden stratigraphies over very large distances (Westgate & Gorton 1981). As a result tephrochronology may be used to assist in the establishment of accurate chronologies in a region where ^{14}C dating has often proved ambiguous (Björck *et al.* 1991a).

Previous studies of visible tephra horizons within Midge Lake sediments, Livingston Island, South Shetland Islands, together with ^{14}C dating of associated moss remains, has led to the construction of a preliminary tephrochronology for the northern Antarctic Peninsula. These tephra horizons have been related to similar horizons from "lake Åsa" and "Chester Cone lake", Livingston Island (Björck *et al.* 1991b), Hidden Lake, James Ross Island, Lake Boeckella, Hope Bay and a moss bank on Walker Point, Elephant Island (Björck *et al.* 1991b, 1991c, Björck & Zale 1996). Deception Island, South Shetland Islands, *c.* 45 km away from Midge Lake, has been identified as the most likely source of these tephra (Björck *et al.* 1991b, 1991c, 1991d) (Fig. 1).

The present study aimed to refine and extend this tephrochronology by re-examining the tephra from Midge Lake and examining sediment cores from Sombre Lake, Signy Island (*c.* 800 km distant). The first part of this study was to examine microscopically cores from Midge Lake and Sombre Lake for evidence of tephra and to classify tephra glass shards into size groups. Second, magnetic susceptibility was evaluated as a means of rapidly identifying tephra in these lake sediments (cf. Björck *et al.* 1991b). Third, tephra glass shards from both lakes were analysed by electron probe microanalysis (EPMA) to determine their geochemical characteristics. Tephra glass shards are homogeneous quenched pyroclasts which show little or no crystallization of mineral phases and are not subject to density sorting. Their composition should not vary with distance from source. Consequently, shard geochemistry will be representative of parent magma composition (unless the reactive glass has not retained its chemical integrity) (Dugmore *et al.* 1992). Analysis of discrete shards also eliminates the contamination risks associated with bulk sediment analyses and therefore

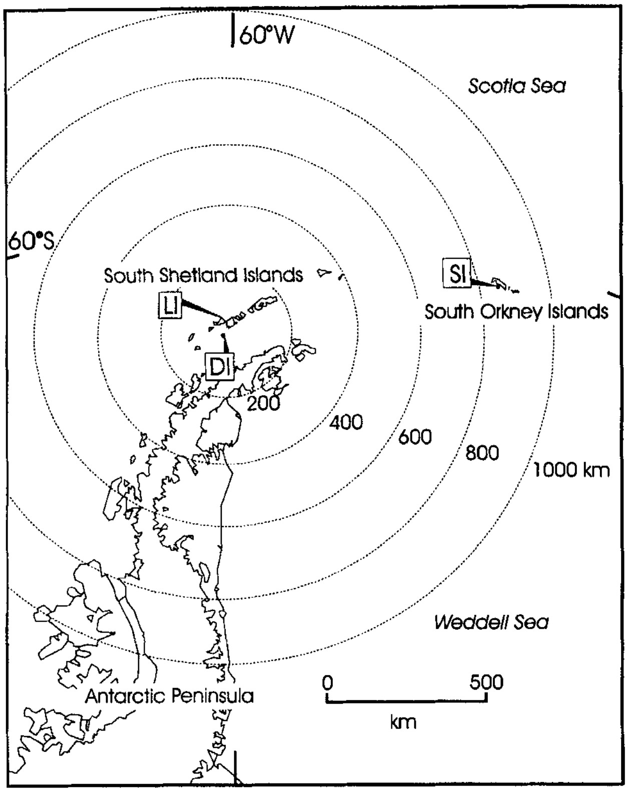


Fig. 1. Sketch map of the Antarctic Peninsula region showing the location of Livingston Island (LI), Deception Island (DI) and Signy Island (SI). Dashed circles illustrate dispersal distances for tephra erupted at Deception Island, an active volcano.

addresses the ambiguity associated with cross-correlation of the same tephra layers in different lake sediment cores (Björck *et al.* 1991d). Finally, both cores were examined to determine if there was any consistent pattern of shard size distribution and geochemical characteristics, to assess if any tephra present could be related temporally and geochemically with previously described tephra from Deception Island, or other likely volcanic sources, and whether these could contribute to the regional tephrochronology. These studies should improve the applicability of tephra as a regional dating tool by permitting tephra horizons to be traced reliably over long distances using their geochemical properties and shard size distributions.

Methods

Site descriptions

Midge Lake, Livingston Island (*c.* 62°38'S, 61°06'W), South Shetland Islands (Fig. 1), is the largest lake on Byers Peninsula, the only major part of the island not presently covered by glaciers. The lake covers an area of 65 000 m^2, has a maximum depth of 9 m and is ice covered for 9–11 months each year. The palaeolimnology of Midge Lake is described by Björck *et al.* (1991d) and the local geology and geomorphology by Smellie *et al.* (1984), Crame *et al.* (1993) and López-Martínez *et al.* (1996). Midge Lake sediments are rich in visible tephra layers and have been integrated into a regional tephrochronology based on ^{14}C dated moss remains (Björck *et al.* 1991d).

Sombre Lake, Signy Island (60°41'S, 45°37'W), South Orkney Islands (Fig. 1) is situated in a coastal valley plain. The lake covers an area of 24 300 m^2, has a maximum depth of 11.2 m and is ice-covered for *c.* 8 months each year. The lake is described by Heywood *et al.* (1980) and the geology by Storey & Meneilly (1985). There are no visible (macroscopic) tephra in Signy Island lake sediments.

Sample analyses

A 26cm long sediment core from the deepest point of Midge Lake was sampled at 1 cm intervals and a 60 cm long sediment core from the deepest point of Sombre Lake was sampled at a higher resolution of 0.5 cm intervals from 0–40 cm, at 1.0 cm intervals from 41–45 cm and at 2 cm intervals from 45–60 cm.

For microscopical analyses tephra glass shards were extracted from weighed subsamples of sediment which were reduced via stepwise chemical attack, using H_2O_2, NaOH and HCl (Rose *et al.* 1995). The technique is designed to remove up to 85% of biogenic silica, carbonate and organic fractions. Tephra were examined at 400x magnification and identified by their vesicularity (where evident), morphology and isotropy under cross-polarized light (Hunt & Hill 1993). Tephra were counted along slide transects, measured by their long axis, and classified in frequency groups of <20 µm, 21–40 µm, 41–60 µm, 61–80 µm, 81–100 µm and >100 µm. The concentration of shards per gram dry mass of sediment was calculated following Rose *et al.* (1995).

Magnetic susceptibility of individual core samples (of known dry weight) was measured using a Bartington Instruments MS2 magnetic susceptibility meter. Magnetic measurements of the Signy lake core were previously made by Wilson (1993).

The geochemical composition of individual tephra glass shards was analysed using EPMA (Larsen 1981, Dugmore *et al.* 1992). Residues for EPMA were passed through a 20 µm sieve, to remove shards that would be too small to analyse. Residues containing the >20 µm fractions were prepared following Hunt & Hill (1993). Electron probe microanalysis was conducted using an automated Cambridge Instruments MICROSCAN V at Edinburgh University operated with an accelerating voltage of 20 kV, a probe current of 15 nA, and a focused beam diameter of 1 µm. Standard calibrations were carried out for K, Ca, Ti, Mn, Mg, Fe, Na, Al and Si and andradite was used as the internal standard. Suspected tephra glass shards were first analysed qualitatively using Energy Dispersive Spectrometry (EDS) and then quantitatively via Wavelength Dispersive Spectrometry (WDS). Total exposure time for each shard was kept to a minimum of *c*. 50 s by excluding the beam from the sample between counts, a measure to reduce Na mobilization. Where possible, at least 15 shards from each tephra were analysed in order to improve statistical significance.

Tephra were dated with reference to an established ^{210}P and ^{137}Cs and AMS ^{14}C chronology for Sombre Lake (Appleby *et al.* 1995, Jones unpublished). Sixteen radiocarbon dates (AMS ^{14}C) from Sombre Lake were used to construct an age vs. sediment depth model. AMS ^{14}C dates of aquatic moss remains were used in the model on account of the low carbon content of the sediment and because these have been found to provide the most reliable dates in Antarctic lakes which do not have a hardwater effect (Björck *et al.* 1991a). Midge Lake tephra were dated using published chronologies of Björck *et al.* (1991b, 1991d) and compared with regional tephrochronologies (see Orheim 1972, Björck *et al.* 1991b, Smellie 1990).

Results

Midge Lake, Livingston Island

Two distinct types of tephra were identified on the basis of colour, vesicularity and morphology. Most common were pale brown, platy, non-vesicular, 'basaltic' shards. Under cross-polarized light, the shards were isotropic. However, small lath-like areas showing grey interference colours were observed in some of the larger specimens. Under reflected light, these areas appeared as colourless inclusions of moderate reflectivity, within the high reflectivity glass shards. The second tephra type consisted of colourless shards which were highly vesicular and isotropic under cross-polarized light. These shards were provisionally termed 'acidic' (cf. Hunt & Hill 1993). Tephra counts showed four distinct basaltic tephra peaks, at 3.0–4.0 cm, 8.0–9.0 cm, 15.0–16.0 cm and 21.0–22.0 cm (Fig. 2). A single acidic tephra was found at 2.0–3.0 cm (Fig 2). Tephra peaks are asymmetrical with abrupt increases followed by gradual declines up the core (Fig. 2). Dates for these tephra are presented in Table I.

Basaltic tephra glass shard sizes were predominantly in the 20–60 μm size range with a few shards >80 μm (Fig. 3). Shard size distributions in the four basaltic tephra peaks were significantly correlated with each other (Table II). In the single acidic tephra shard size distributions were: 20–40 μm (42%), 40–60 μm (33%) and 60–80 μm (25%). Unlike the basaltic tephra, there were no shards over 80 μm in length.

Mass specific magnetic susceptibility (Fig. 2) revealed four distinct peaks at 0.5–1.0 cm (156 x 10^{-8} m^3 Kg^{-1}), 3.0–4.0 cm (152 x 10^{-8} m^3 Kg^{-1}), 8.0–9.0 cm (228 x 10^{-8} m^3 Kg^{-1}) and 19.0–20.0 cm (135 x10^{-8} m^3 Kg^{-1}). There were coincident peaks in basaltic tephra concentration at 3.0–4.0 cm and 8.0–9.0 cm. However, there was no significant statistical relationship between magnetic susceptibility and tephra concentration (r^2 = 0.757, n =25, P = 0.05).

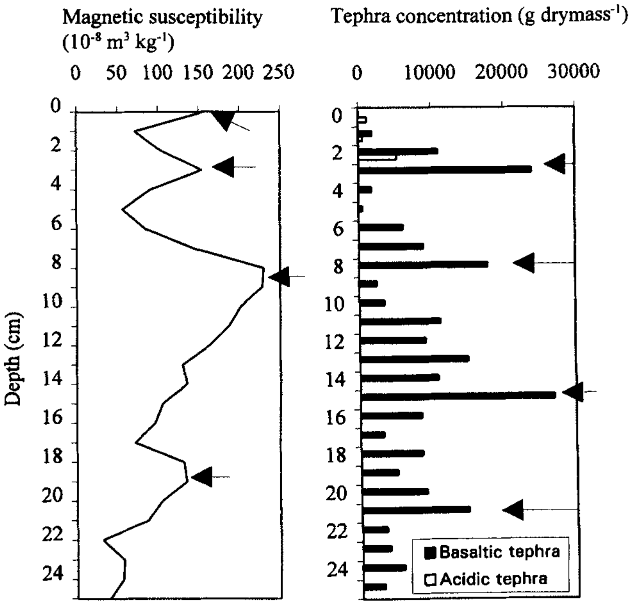


Fig. 2. Midge Lake mass specific magnetic susceptibility and tephra concentration. Arrows indicate magnetic susceptibility peaks and tephra horizons.

Quantitative geochemical analyses by WDS were carried out on ≤15 basaltic tephra shards from each of the peaks at 3.0–4.0 cm, 8.0–9.0 cm and 21.0–22.0 cm. They were found to be Na-rich basalts, with mean SiO_2 percentages between 52.18% and 53.90%, and mean Na_2O between 4.54% and 5.05%. Low standard deviations show that all the glasses have similar chemical compositions (Table III). Numerous lath-like inclusions were observed within the shards. Analyses

Table I. Midge Lake and Sombre Lake tephrochronology.

Age yr BP	Midge Lake Björck *et al.* (1991a)	Midge Lake Present study
H (1967 1969, 1970[4])		2–3 ac
H 1912–1917[1] (1842[5])		3–4 ba
**450[6]	7–7.1 ba	8–9 ba
*755 ± 105[1]	12–13 ba	15–16 ba
*1340 ± 100[1]	20–20.3 ba	21–22 ba
		Sombre Lake (cm)
◊30 ± 4[3]–125 ± 25[3]		3–9 ba
**685–718[2]		21–22 ac
**768–795[2]		24–25 ac
**949–973[2]		31–32 ba
**997–1068[2]		33–36 ac
*1325 ± 50 [2]		44–46 ba
**1437–1473[2]		54–56 ac

References: [1]Björck *et al.* (1991a), [2]Jones (unpublished), [3]Appleby *et al.* (1995), [4]Smellie (1990), [5]Orheim (1972), [6]Björck *et al.* (1991b).
Dates: H = historic documentation, * = AMS ^{14}C, ** = AMS ^{14}C model, ◊ = ^{210}Pb
Tephra: ba = basaltic; ac = acidic. Depths in cm.

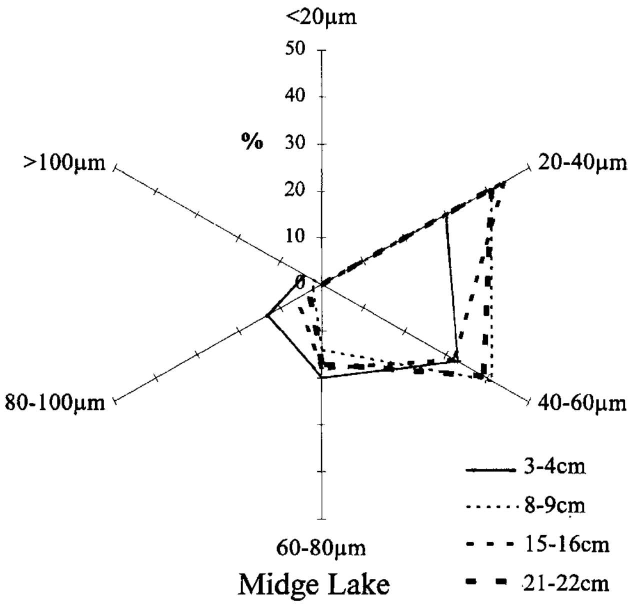


Fig. 3. Shard size distributions (%) in each of the four 'basaltic' tephra peaks from Midge Lake.

Table II. Correlation coefficients (r) of tephra glass shard size distributions between tephra layers.

Midge Lake (basaltic) $n = 5, P = 0.05$				
	3–4 cm	8–9 cm	15–16 cm	21–22 cm
3–4 cm	1			
8–9 cm	0.9461*	1		
15–16 cm	0.9071*	0.9531*	1	
21–22 cm	0.9842*	0.9967*	0.9674*	1
Sombre Lake (basaltic) $n = 6, P = 0.05$				
	7–8 cm	31–32 cm	44–46 cm	
7–8 cm	1			
31–32 cm	0.7117	1		
44–46 cm	0.3162	0.8590*	1	
Sombre Lake (acidic) $n = 6, P = 0.05$				
	21–22 cm	24–25 cm	34–35 cm	54–56 cm
21–22 cm	1			
24–25 cm	0.8058	1		
34–35 cm	0.8856*	0.9729*	1	
54–56 cm	0.1952	-0.1247	-0.1370	1

(* = statistically significant)

of one of these inclusions showed it to be labradoritic plagioclase feldspar, with a composition similar to the anorthite (Ca-rich) end member.

Sombre Lake, Signy Island

Tephra identification was complicated by the high proportion of mineral matter remaining after chemical treatment but both basaltic and acidic tephra were present in low concentrations in the Sombre Lake core. Tephra counts showed evidence of three basaltic tephra peaks at 3–9 cm, 31–32 cm and 44–46 cm. Although acidic tephra concentrations were low, slide counts indicated the presence of four acidic tephra horizons at 21–22 cm, 24–25 cm, 33–36 cm and 54–56 cm (Fig. 4). Dates for these tephra are presented in Table I.

Tephra glass shard size distributions in the three basaltic tephra peaks show that shards were predominantly 20–40 µm in size and rarely over 80 µm (Fig. 5a). The four acidic tephra peaks also contained shards of predominantly 20–40 µm (Fig. 5b). However shard sizes in the lower peaks (33–36 and 54–56 cm) were irregular and absent in some size categories eg. 40–60 µm (Fig. 5b). There were a few significant correlations of shard size distributions between the four

Table III. Wavelength dispersive spectrometry (WDS) analyses of Midge Lake tephra and a single Sombre Lake tephra.

Mean percentages Element (oxide)	Midge 3–4 cm (n = 13) mean	 s d	Midge 8–9 cm(n = 15) mean	 s d	Midge 21–22 cm (n = 14) mean	 s d	Sombre 3–4 cm (n = 1) mean
SiO_2	53.84	0.62	53.9	2.41	52.18	1.47	50.42
TiO_2	1.88	0.55	2.3	0.26	2.34	0.18	2.7
Al_2O_3	16.48	0.57	14.34	0.51	14.6	0.61	15.85
Fe_2O_3	8.16	0.81	9.72	0.2	9.98	1.14	12.33
MnO	0.2	0.03	0.22	0.01	0.23	0	0.21
MgO	3.43	0.61	3.7	0.94	4.34	0.74	3.49
CaO	7.97	0.31	7.31	1.61	8.24	1.15	7.53
Na_2O	5.05	0.05	4.54	0.07	4.57	0.17	3.7
K_2O	0.65	0.12	0.77	0.26	0.62	0.21	0.35

Correlation coefficients

	Midge 3–4 cm	Midge 8–9 cm	Midge 21–22 cm	Sombre 3–4 cm
Midge 3–4 cm	1.0000			
Midge 8–9 cm	0.9983	1.0000		
Midge 21–22 cm	0.9984	0.9996	1.0000	
Sombre 3–4 cm	0.9947	0.9966	0.9973	1.0000

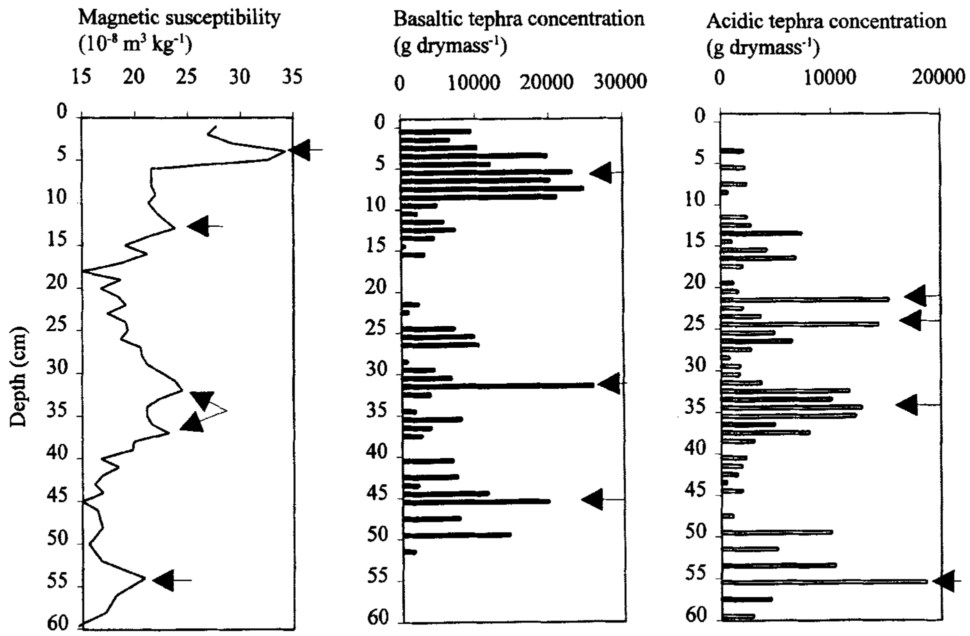


Fig. 4. Sombre Lake mass specific magnetic susceptibility and tephra concentration. Arrows indicate magnetic susceptibility peaks and tephra horizons.

Sombre Lake tephra peaks, but correlations were predominantly non-significant (Table II).

Mass specific magnetic susceptibility revealed four distinct peaks at 4 cm (34 x 10^{-8}m^3 Kg^{-1}), 13 cm (23 x 10^{-8} m^3 Kg^{-1}), 32–37 cm (23 x 10^{-8} m^3 Kg^{-1}) and 54 cm (22 x 10^{-8} m^3 Kg^{-1}) (Wilson 1993, fig. 4). There was no significant relationship between magnetic susceptibility and basaltic tephra concentration ($r^2 = 0.1405$, $n = 52$, $P = 0.10$) or acidic tephra concentration ($r^2 = 0.0190$, $n = 52$, $P = 0.10$), or the sum of both ($r^2 = 0.1373$, $n = 52$, $P = 0.10$). However, a small subset of the Sombre Lake data (1–6 cm) did reveal a significant relationship for the basaltic tephra peak at 3–4 cm ($r^2 = 0.918$, $n = 6$, $P = 0.005$).

Quantitative geochemical analyses of Sombre Lake shards by WDS was complicated by a high percentage of mineral matter (95%) which EDS identified as fragments of quartz, pale green hornblende, orthoclase and rare garnet. Acidic tephra were differentiated from the surrounding quartz and feldspar by their highly vesicular surfaces. However, their surfaces were difficult to analyse and a repeatable quantitative analysis was not possible. Basaltic shards were easier to detect, but were typically so thin that the excitation volume included the underlying resin and only one shard (core depth 3–4 cm) proved thick enough to analyse. WDS analysis showed the geochemistry of this shard to be a high-sodium basalt (Table III), and its composition highly significantly correlated ($r = 0.994$–0.997, $n = 9$, $P = 0.001$) with the mean composition of samples from the three tephra horizons from Midge Lake.

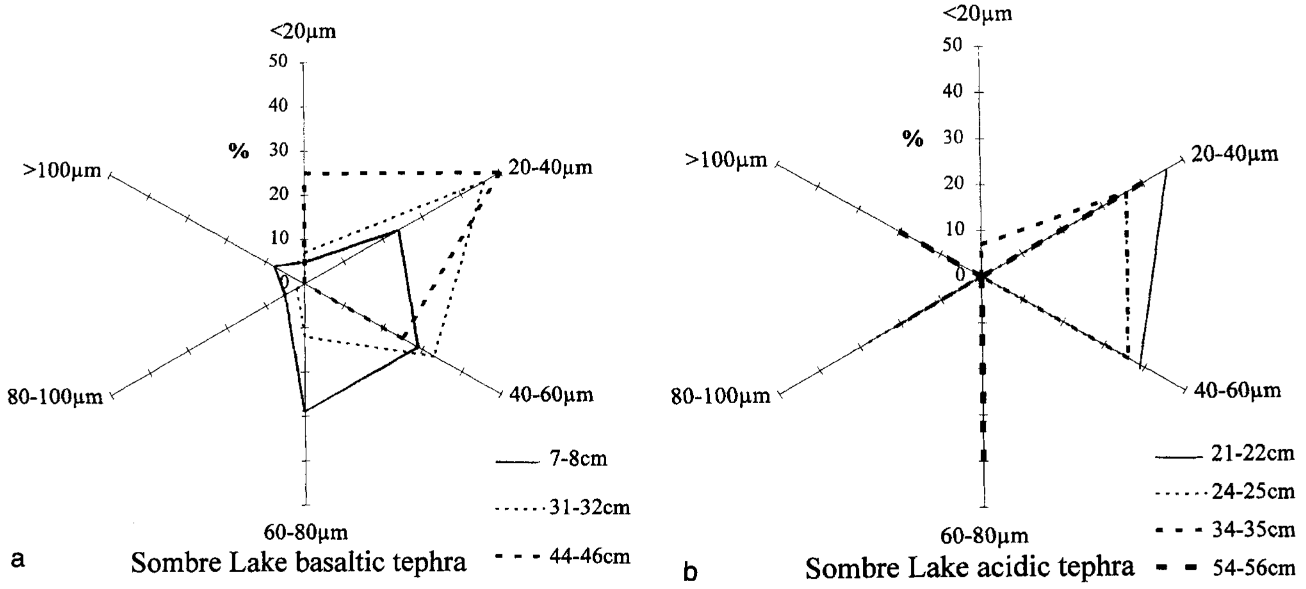
Discussion

Identification of tephra glass shards

Using microscopic analysis two previously undetected tephra have been found in Midge Lake and six tephra have been identified in the South Orkney Islands for the first time. The hitherto unsuspected abundance of tephra in lake sediments examined in this study is in sharp contrast to the paucity of tephra encountered in marine cores. For example, only one Holocene (≤10 ka) tephra layer was discovered in marine cores from the Scotia Sea adjacent to Signy Island, even though they should have been a repository for all of the tephra encountered in Sombre Lake (Moreton & Smellie, in press).

Previous studies by Björck *et al.* (1991d) reported three visible tephra horizons within the top 26 cm of sediment from Midge Lake, at 7–7.1 cm, 12–13 cm and 20–20.3 cm (Table I). Allowing for variations in the rate of sediment deposition within the lake, these tephra horizons occur at similar depths to the lower three layers detected during in the present study; i.e. 8–9 cm, 15–16 cm and 21–22 cm. However, two further tephra horizons were identified in the present study at 2–3 cm (basaltic) and 3–4 cm (acidic). Thus, although the majority of tephrological studies have examined sediments in which fallout is readily visible, laboratory analysis of cores may reveal the presence of microscopic tephra and thus extend tephrochronological studies to regions beyond where fallout is visible. The microscopic analysis also allows tephra from Midge Lake and Sombre Lake to be classified into acidic and basaltic categories so better defining individual eruption events.

In the Sombre Lake core three basaltic tephra and four acidic tephra were identified. Tephra peaks in both cores were typically asymmetrical with abrupt increases followed by gradual declines up the core (Figs 2 & 4). This diffuse



a Sombre Lake basaltic tephra

b Sombre Lake acidic tephra

Fig. 5. Shard size distributions (%) in each of the three 'basaltic' tephra peaks and four acidic tephra peaks from Sombre Lake.

upper boundary of tephra horizons is indicative of tephra being deposited directly into the lake followed later by surface runoff reworking deposits from the catchment (cf. Björck *et al.* 1991b).

Size characterization of tephra glass shards

The size distributions of tephra glass shards from Midge Lake are relatively constant between tephra layers (Fig. 3, Table II) which suggests a constant distance from the source volcano and predominant input by direct ash fall, with only minor reworking. In Sombre Lake there is greater size differentiation between and within tephra layers (dispersed shards) and there is also a greater percentage of shards <20 µm. This is possibly a result of more prolonged and/or intensive secondary aerological and catchment sorting processes than those affecting the Midge Lake tephra (Fig. 5a & b). Tephra glass shard size distributions are therefore a likely product of the distance from the source volcano and secondary aerological and catchment sorting processes.

Magnetic susceptibility

Despite previous research demonstrating a correlation between high tephra counts and high mass specific magnetic susceptibility (Oldfield *et al.* 1980, Thompson *et al.* 1980), this study indicated no significant correlation in either Midge or Sombre Lake. A small subset of the Sombre Lake data (1–6 cm) did reveal a significant correlation and there are coincident peaks in basaltic tephra concentration in the Midge Lake core. Therefore mass specific magnetic susceptibility generally appears not to be a good indicator of tephra in cores from these lakes although the High Induced Remnant Magnetisation (HIRM) magnetic susceptibility technique has proved successful in other Antarctic studies (Björck *et al.* 1991b). A possible reason for the inability of mass specific magnetic susceptibility to identify accurately tephra peaks is that the lake sediments contain hornblende, a magnetic mineral, which may be responsible for drowning out the signal from the tephra. Magnetite may also be present in the lakes but has not been measured. In Midge Lake there are some coincident peaks which may indicate a lower hornblende content than Sombre Lake sediments. The uppermost tephra in Midge Lake is acidic and not detectable using mass specific magnetic susceptibility.

EPMA and volcanic sources of tephra

EPMA enabled tephra glass shards from Midge Lake to be geochemically characterized. Analysed Midge Lake tephra have mean SiO_2 abundances of between 52.18 and 53.90% (Table III) suggesting basaltic to basaltic-andesitic compositions within the range of those analysed by Björck *et al.* (1991b), which had SiO_2 abundances of 52–63%. However, in the Sombre Lake sediments the use of EPMA was hindered by the high minerogenic content of the sediment which was not substantially reduced by the chemical processing. In addition, the thinness of Sombre Lake tephra glass shards also made EPMA difficult to carry out. In contrast, extraction from peats is relatively simple using acid digestion (Dugmore 1989, Dugmore *et al.* 1992).

Na_2O/K_2O ratios in tephra and lavas from Holocene volcanic centres throughout the region (Smellie, unpublished data) show that Deception Island (63°00'S, 60°40'W) is the most likely source for the analysed Midge Lake tephra (Fig. 6). The similarity of shard sizes between the different tephra from Midge Lake also suggests a local volcanic source. The

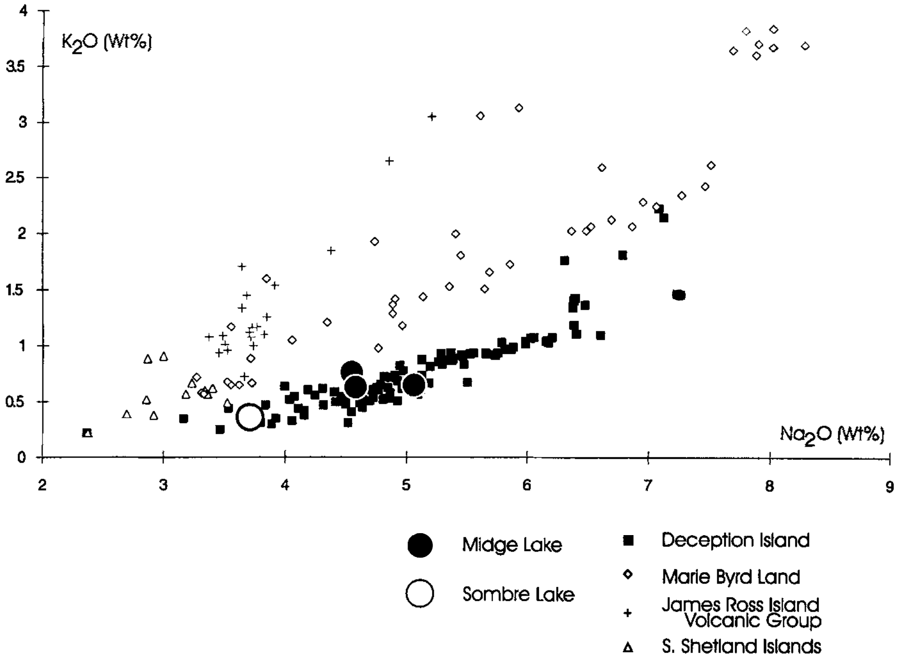


Fig. 6. Plot of Na$_2$O vs.K$_2$O for three Midge Lake tephra and a single Sombre Lake tephra compared with analysed samples from Holocene volcanoes throughout West Antarctica. Data sources: Palais *et al.* (1988), LeMasurier & Thomson (1990), and Smellie (unpublished).

single shard analysed from Sombre Lake also most closely resembles Deception Island magmas from *c.* 850 km away but it cannot be confidently assigned a source volcano on the basis of a single sample. The highly significant correlation between WDS results from Sombre Lake and Midge Lake tephra (Table III) strongly suggests that Deception Island is the most likely source volcano. Without further analyses, we are unable to identify unambiguously the provenance of the acidic tephra at the two lake sites. However, evolved tephra petrographically similar to those in this study have been described from Bransfield Strait, Scotia Sea and Deception Island (Matthies *et al.* 1988, Moreton & Smellie in press, unpublished data of J.L. Smellie) and a Deception Island provenance is also likely.

Tephrochronology

Radiocarbon dates corresponding to tephra described in Björck *et al.* (1991b) were used as the basis for a tephrochronology of the Midge Lake core (Table I). The two upper tephra horizons (2–3 and 3–4 cm) were not detected by Björck *et al.* and are therefore not dated. These horizons may correspond to documented eruptions on Deception Island in 1967, 1969 or 1970 or to earlier eruptions in 1842 or 1912–17 (Orheim 1972, Smellie 1990) as suggested in Table I. However, despite all the analysed Midge Lake tephra having a distinctive composition indicative of a single source volcano, the tephra compositions of each individual layer are very similar. Therefore individual tephra layers from a single lake cannot always be easily distinguished from one another (Fig. 6). This can limit their use for unambiguous regional correlation and tephrochronology as it is important not only to establish geochemical consistency between tephra deposited across wide geographical areas, but also to be able to distinguish between individual tephra layers in the same lake sediment.

Despite these limitations this study has shown that the microscopic differentiation of basaltic and acidic tephra, shard size distributions and geochemical data may enable individual tephra layers to be distinguished. Analysis of trace elements and accurate radiometric dating may further improve the potential of such tephra both as a regional dating tool and in permiting the geographic extent of tephrochronologies to be extended (cf. Dugmore *et al.* 1992).

Whilst many tephra in this study remain most useful in local studies (e.g. cross correlation of cores from a single lake, or cores from lakes in geographically close areas (such as the South Orkney Islands)), the temporal similarity between dates for the Midge Lake tephra horizon at 21–22 cm (1340 ± 100 yr BP) and the Sombre Lake tephra horizon at 44–46 cm (1325 ± 50 yr BP) indicates that this horizon is a possible indicator of a sequence of eruptions during a similar time period (possibly influenced by different wind directions). As such, this horizon has the potential to be incorporated into a regional tephrochronology.

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