

An initial palaeosalinity history of Jaw Lake, Bunger Hills based on a diatom–salinity transfer function applied to sediment cores

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Abstract: Two sediment cores taken from Jaw lake (Bunger Hills, East Antarctica) were analysed for diatom composition and abundance. A diatom–salinity transfer function developed for the nearby Vestfold Hills was used to determine palaeosalinity reconstructions from the assemblages preserved in each of the cores. There is a large step-wise decrease in salinity in the second core from at least *c.* 4000 to *c.* 2000 uncorrected ¹⁴C yr BP. The salinity record from the first core starts at *c.* 3000 uncorrected ¹⁴C yr BP and is comparable with the salinity of the second core between *c.* 3000 and *c.* 2000 uncorrected ¹⁴C yr BP. Sudden lake water dilution in both cores at *c.* 1900 uncorrected ¹⁴C yr BP is followed by brief increases in lake water salinity between *c.* 1900 and *c.* 500 uncorrected ¹⁴C yr BP, after which gradual dilution to present occurs. This analysis of the local environmental history of this saline lake reveals a mid–late Holocene evolution of the lake basin similar to that documented from earlier marine and freshwater lacustrine sediments in the Bunger Hills. The high coherence of the independent sediment records suggests a robust general palaeosalinity reconstruction of the lake is achieved in addition to providing evidence for the fidelity of single sediment cores as useful and adequate representation of the palaeolimnological histories of Antarctic lakes.

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Introduction

Antarctic lakes are emerging as important archives of climate change. Several lake-rich areas or “oases” on the east Antarctic coastline are yielding excellent limnological records of previous regional climatic conditions (e.g. Larsemann Hills: Burgess *et al.* (1994), Vestfold Hills: Roberts & McMinn (1999a), Roberts *et al.* (1999), Bunger Hills: Kulbc (1997)). Saline lakes and their sedimentary biological communities are particularly well suited as sources of palaeoclimatic information in the Antarctic due to the sensitivity of lake water chemistry to even small changes in the climate of these regions.

The community composition of fossil diatom assemblages is a particularly useful proxy of palaeolimnological conditions (Juggins *et al.* 1994). Diatoms are highly responsive to water chemistry and have been used as indicators of many lake water properties throughout the world, with most attention focussed upon factors such as pH (e.g. Cumming *et al.* 1994), nutrients (e.g. Bennion 1994), and salinity (e.g. Fritz *et al.* 1994). The significant relationship that exists between diatoms and lake water salinity in Antarctic lakes (e.g. Roberts & McMinn 1996) can be taken a step further, with fossil diatom assemblages in Antarctic lake sediments providing palaeolake water salinity estimates (e.g. Roberts & McMinn 1999a).

Here we use a diatom–salinity transfer function derived for lakes within the Vestfold Hills (Roberts & McMinn 1998) to determine palaeolake water salinity estimates from two lake sediment cores from a lake in the nearby Bunger Hills.

Materials and methods

Site description and coring

The Bunger Hills (*c.* 66°S, 101°E) form one of the largest ice-free areas of East Antarctica. The climate of the Bunger Hills area is relatively mild, characterized by a mean annual air temperature of -9.1°C, a positive annual radiation balance and a potential annual evaporation of 450–600 mm yr⁻¹ (which is nearly three times higher than the annual precipitation of 200 mm yr⁻¹) (Vcrkulich & Melles 1992). The local geology and geomorphology of the hills is described in detail by Augustinus *et al.* (1997). A striking feature of these hills are the numerous lakes that fill the valleys and depressions. The total area of the lakes is *c.* 36 km², covering 6–7% of the oasis bedrock (Klokov *et al.* 1990). The freshwater lakes (up to 14.3 km², Algae Lake) are concentrated in the southern hills and around the periphery while most of the lakes on the islands and to the north are saline (Kaup *et al.* 1993).

Jaw lake (66°12'S, 100°58'E) [unofficial name] is a *c.* 300 m long saline lake (*c.* 23‰ surface water salinity) situated on Fuller Island in the Bunger Hills. It is at an elevation of 8 m a.s.l and is separated from Cacapon Inlet by ridges of *c.* 10 m a.s.l. As Jaw lake is a simple closed system with no groundwater or surface stream in/outflows it will have responded particularly rapidly to climate-driven hydrological change, with fluctuations in the balance between precipitation and evaporation resulting in both changes in lake level and the concentration or dilution

of dissolved salts. As such, the diatom community preserved in the sediments of Jaw lake will reveal the climate regime acting on the lake basin at the time of their sedimentation.

Two separate cores were taken from a 1.5 m thick ice platform in the middle of the lake (7 m deep) on 29 December 1995. A 55 mm diameter impact corer (Neale & Walker 1996) retrieved 53 cm from the first core attempt (Jaw-1) and 45 cm from the second core attempt (Jaw-2). The impact corer was unable to penetrate any further. Both cores were subsampled on site resulting in a sample set comprised of 1–5, 5–13, 13–18, 18–21, 21–26, 26–31, 31–36, 36–43, 43–43.5, 43.5–48 and 48–53 cm from Jaw-1, and 1–5, 5–10, 10–15, 15–20, 20–25, 25–30, 30–35, 35–40 and 40–45 cm from Jaw-2. Care was taken to ensure the retrieval of the surface sediment as the topc. 0–5 cm, particularly in Jaw-1, tended to collapse upon core extrusion.

Sediment dating

A single radiocarbon age of 2700 ± 80 ^{14}C yr was determined for the 43.5–48 cm sediment section of the Jaw-1 core and 3150 ± 80 ^{14}C yr was determined for the 30–35 cm sediment section of the Jaw-2 core. Assuming the core tops were retrieved, sedimentation rates of 0.02 cm yr^{-1} and 0.01 cm yr^{-1} respectively were derived from the linear extrapolation of the single radiocarbon ages determined for each core. No attempt to correct these dates for reservoir effects was made as the influence of the reservoir effect in saline lakes in the Bunger Hills is, as yet, unknown. There are no determinations of the reservoir effect in the freshwater lake sediment of the Bunger Hills (Melles *et al.* 1994, 1997, Kulbe 1997) and the reservoir effect of the marine sediment in the Bunger Hills is known to be both dependent upon the degree of dilution with meltwater (as detailed in Melles *et al.* 1994) and irregular (between 770 (Melles *et al.* 1997) and 8100 yr (Kulbe 1997)). As no more sediment is available to determine additional radiocarbon ages for either lake core we are hesitant to convert the single radiocarbon date we have for each core into a reservoir corrected and calibrated chronology, particularly in light of the reservoir effect uncertainty in saline lakes in the Bunger Hills. Consequently, dates referred to for Jaw lake sediment throughout the remaining text are uncorrected radiocarbon ages.

Diatom analysis of the sediment cores

Each sample was treated with 10% H_2O_2 for three days to remove the organic fraction of the sediment. Following three centrifuge treatments (2000 rpm for 5 min), samples were washed in distilled water. Prepared residues were mounted in Naphrax. Diatoms were then identified using a Zeiss Standard 20 light microscope with 100x oil immersion objective and phase contrast illumination. For each sample, the percentage of each taxon was evaluated by counting 400 frustules. Diatom species were then expressed as relative abundances (% total

diatoms) of the 400 frustules counted per sample. Those species occurring $\geq 2\%$ abundance in any core section were included in the numerical analyses. Identification and taxonomy of the diatom species was based principally on Roberts & McMinn (1999b).

Palaeosalinity analysis of the sediment cores

The Bunger Hills (*c.* 66°S , 101°E) are located about 1000 km to the east of the Vestfold Hills (*c.* 68°S , 78°E) and all of the species found in the cores taken from Jaw lake (25 in total) are members of the Vestfold Hills diatom flora (see Roberts & McMinn 1999b). It is assumed that the salinity preferences demonstrated by these species in the lakes of the Vestfold Hills (see Roberts & McMinn 1998) are maintained in the lakes of the Bunger Hills. Therefore, an established diatom-salinity transfer function previously developed for the Vestfold Hills (Roberts & McMinn 1998) was used to calculate the epilimnetic salinity of the Jaw lake sediment.

Results and discussion

Diatom stratigraphy and palaeosalinity reconstruction

A total of 25 diatom taxa were observed throughout the Jaw lake cores. All 25 were found in Jaw-1 and 22 of the 25 were found in Jaw-2. The diatom stratigraphy and transfer function diatom-inferred salinity reconstruction for both cores is shown in Fig. 1. Distinct changes in species dominance from the base of each core to the top of each core are discernible.

The base of Jaw-1 is almost completely dominated by *Navicula directa*. This taxon is often dominant in sea ice diatom assemblages and is known to thrive in hypersaline conditions in the Vestfold Hills with an estimated salinity optimum of 77.5‰ (Roberts & McMinn 1998). Below 30 cm this species accounts for more than 45% of each sample. Above 30 cm the change in dominance from *Navicula directa* to *Navicula cf. salinarum*, *Stauroneis* sp. a and other less saline species is marked. *Navicula cf. salinarum* alone accounts for more than 10% of each of the samples above 30 cm. *Navicula cf. salinarum*, *Amphora* sp. a, *Stauroneis* sp. a and *Nitzschia lecontei* Van Heurck all prefer much less saline conditions than *Navicula directa* (with optima of 26.7, 36.8, 37.5 and 48.4‰ respectively; Roberts & McMinn 1998). The abundance of *Navicula cf. seminulum* above 30 cm attests to the sudden dilution of the lake at this time as this species has a salinity optimum of only 8.3‰ (Roberts & McMinn 1998).

The diatom community preserved in the sediment of Jaw-1 reveals that Jaw lake went through a highly saline ($> 100\text{‰}$) state until a sudden lakewater dilution of the order of *c.* 70‰ took place at *c.* 30 cm. Following this sudden dilution, salinity stabilized (at *c.* 35‰), interrupted briefly by a relatively small increase (to *c.* 50‰) between 5 and 13 cm before returning to current levels (*c.* 30‰).

The diatom flora at the base of Jaw-2 is also dominated by

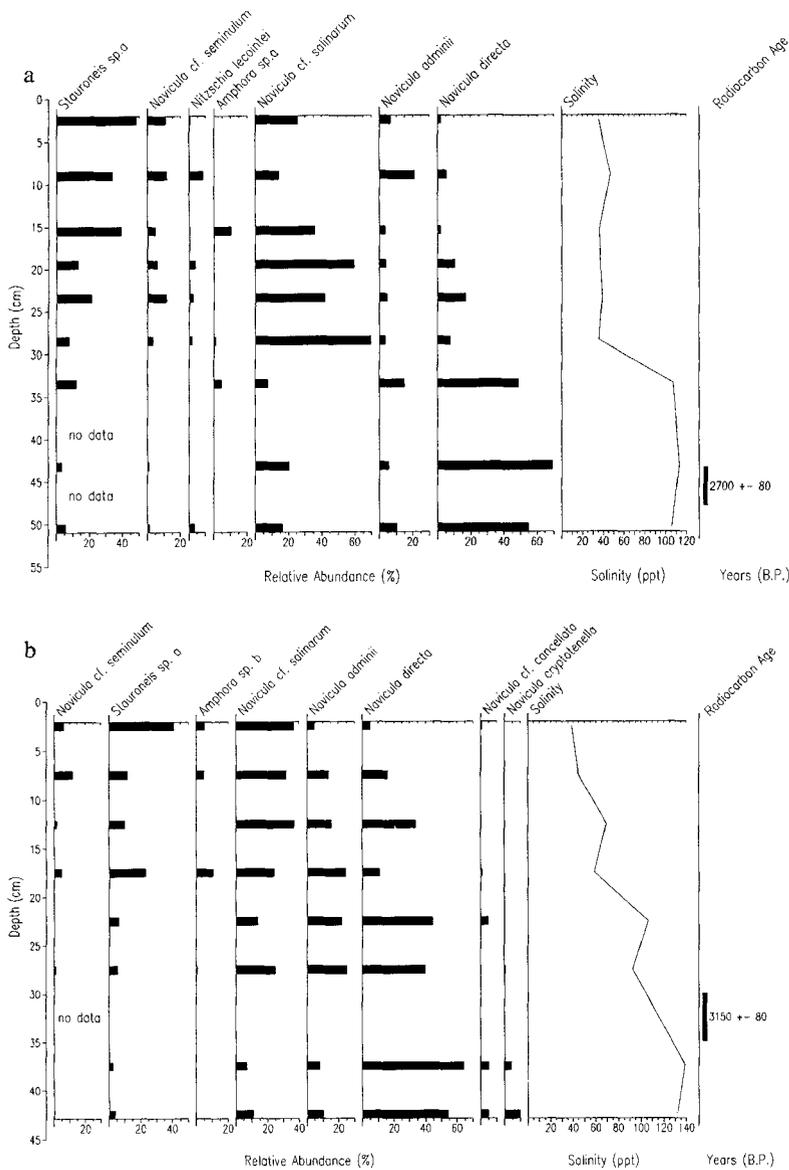


Fig. 1. a. Diatom stratigraphy and diatom-inferred salinity for Jaw-1. Relative abundances of major (> 5%) diatom taxa are shown in order of decreasing salinity optimums. A single radiocarbon age of 2700 ± 80 ¹⁴C yr was determined for sediment between 43.5 and 48 cm. Note: 36–43 cm sample was lost in transit for additional radiocarbon dating. b. Diatom stratigraphy and diatom-inferred salinity for Jaw-2. Relative abundances of major (> 5%) diatom taxa are shown in order of decreasing salinity optimums. A single radiocarbon age of 3150 ± 80 ¹⁴C yr was determined for sediment between 30 and 35 cm.

the hypersaline *Navicula directa*. In the very lowest samples (>30 cm) this species accounts for more than half of the total diatoms counted. The change in dominance from this species to species with lower salinity optima (such as *Amphora* sp. b: 39.6%, *Stauroneis* sp. a: 37.5% and *Navicula* cf. *seminulum*: 8.3%) is more gradual than the same transition in Jaw-1 (see Fig. 1). Nevertheless, the palaeosalinity signal preserved in the sediment of Jaw-2 reveals a similar trend to that preserved in Jaw-1.

The diatom community preserved in the sediment of Jaw-2 reveals that Jaw lake maintained a highly saline (> 90‰) state in the mid to lower core samples (> 20 cm) and became gradually diluted (of the order of *c.* 45‰) in the upper core samples (< 20 cm). Following this dilution of the lakewater from > 90‰ to *c.* 60‰, salinity briefly rose to *c.* 70‰ between 10 and 15 cm after which dilution continued to present day.

Statistical comparison of the palaeosalinity records of the

two cores reveals similar trends (Fig. 2). A piecewise linear interpolation curve correlation reveals a correlation between the two palaeosalinity reconstructions to be 0.85 (0 = no correlation, 1 = perfect correlation). Both cores show a very high original salinity, a relatively sudden dilution of the lakewater and a subsequent relative stabilization of the lakewater salinity to present (Fig. 2). Over the timeframe involved (mid-late Holocene) the two cores show statistically similar general trends. These trends can now be interpreted as a function of the climatic regime of the Jaw lake basin throughout the mid-late Holocene.

Palaeoecological interpretation

Jaw lake was probably formed by the marine transgression of the Bungar Hills during the earliest Holocene (Adamson & Colhoun 1992), after which the inlet became isolated from the

ocean due to postglacial isostatic uplift of the basin, and the original seawater became gradually concentrated as a result of the negative water balance in the basin. Since the cores penetrated into mid-Holocene deposits only, the diatom-palaeosalinity signals derived from both lake cores investigated here begin in the mid-Holocene and therefore the palaeoecological interpretation of the lake sediment sequences is limited to the mid to late Holocene.

The diatom communities preserved in the sediment of the two Jaw lake cores (Fig. 1) reveal a similar climate pattern to that documented from marine and freshwater lacustrine sediments in the Bunger Hills for the mid-late Holocene by Kulbe (1997). Kulbe (1997) identified a warm phase that began in the Bunger Hills around 4500 calibrated ^{14}C yr BP with climatic conditions becoming optimal between 2500 and 2000 calibrated ^{14}C yr BP. In the following 100 yr Kulbe (1997) describes a period of rapid climate change followed by a cooler period from 1900 to c. 500 calibrated ^{14}C yr BP before the current warmer climate to present. The step-wise decrease in salinity in Jaw-2 from c. 4000 to c. 2000 uncorrected ^{14}C yr BP coincides with Kulbe's (1997) warm climate at this time. Lake water dilution results from increasing precipitation in times of warming in coastal Antarctic lake environments. The salinity record from Jaw-1 starts at c. 3000 uncorrected ^{14}C yr BP but is comparable with the salinity of Jaw-2 at the time of Kulbe's (1997) optimal climate (i.e. c. 2500 and 2000 ^{14}C yr BP). A sudden lake water dilution is evident in both Jaw-1 and Jaw-2 at c. 1900 uncorrected ^{14}C yr BP. This rapid dilution in Jaw lake is coincident with the rapid climate change recorded at a similar time by Kulbe (1997). Following this rapid dilution of the lake water, we see increases in lakewater salinity in both cores between c. 1900 to c. 500 uncorrected ^{14}C yr BP. A c. 15‰ rise in salinity at c. 500 uncorrected ^{14}C yr BP for Jaw-1 and a c. 10‰ rise in salinity immediately following the rapid dilution at c. 1900 uncorrected ^{14}C yr BP for Jaw-2 are observed. These increases can be attributed to brief periods of less precipitation, consistent with Kulbe's (1997) cooler period from 1900 to c. 500 calibrated ^{14}C yr BP, after which gradual dilution to present occurs, again consistent with current climate warming trends resulting in increasing coastal Antarctic precipitation.

Conclusion

The lake water salinity history of Jaw lake has been successfully recorded in the two lake sediment cores via the diatom community. The similarity of diatom species between the Vestfold Hills and the Bunger Hills allows the diatom-salinity transfer function developed for the Vestfold Hills to be used successfully for the Bunger Hills region. In the absence of a Bunger Hills diatom-salinity training dataset this Vestfold Hills diatom-salinity training set provides a useful tool for the initial palaeosalinity reconstructions of cores from lakes in this region.

Analysis of the changes in the diatom communities of both

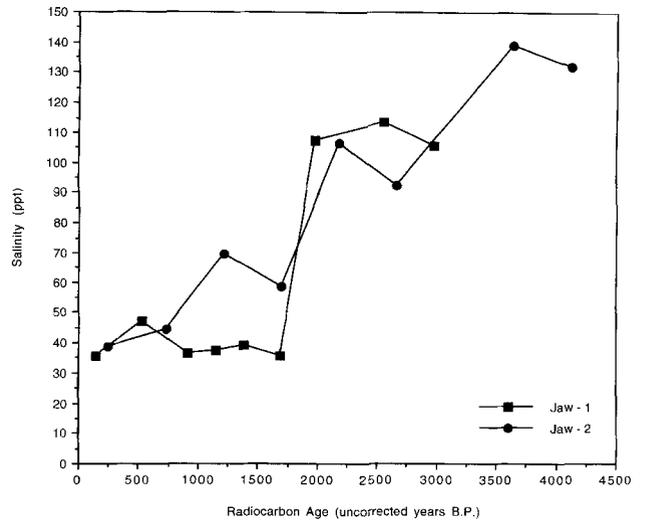


Fig. 2. Comparing palaeosalinity estimates from Jaw-1 (Fig. 1a) and Jaw-2 (Fig. 1b) using a simple linear chronology derived from single radiocarbon ages reveals a piecewise linear interpolation curve correlation = 0.85 (0 = no correlation, 1 = perfect correlation).

sediment cores and the resulting palaeosalinity reconstructions reveals a local environmental history of this saline water basin consistent with marine and freshwater lacustrine sediments in the Bunger Hills for the mid to late Holocene. The high coherence of the two independent sediment records suggests a robust palaeosalinity reconstruction of the lake is achieved. It also attests to the value of both using diatoms as reliable proxies of lake conditions in areas with simplified lake dynamics, such as coastal Antarctic oases, and the potential of a single sediment core as general representation of the palaeolimnological/palaeoclimatic history of an Antarctic lake.

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