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Phil. Trans. R. Soc. Lond. B 1990 **327**, 227-232
doi: 10.1098/rstb.1990.0056

Phil. Trans. R. Soc. Lond. B **327**, 227–232 (1990)
Printed in Great Britain

The Surface Water Acidification Project (SWAP) Palaeolimnology Programme

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Improvements in techniques of lake-sediment analysis over the last two decades have enabled palaeolimnologists to reconstruct changes in water acidity and atmospheric contamination with high resolution. In the Surface Water Acidification Project (SWAP) Palaeolimnology Programme these techniques have been used to trace the history of a range of specially selected study sites and to evaluate alternative causes for lake acidification. At the same time further improvements in some of the techniques, especially diatom analysis, have been made.

Introduction

Palaeolimnology is concerned with the study of lake history as recorded by lake sediments. In the past two decades palaeolimnologists have developed sampling, dating, and analytical approaches that now enable the sediment record to be deciphered with precision and accuracy over timescales of relevance to contemporary environmental problems, taking advantage of the relatively rapid accumulation rate (1–10 mm a^{-1}) of most recent lake sediments.

Lake sediments also contain a record of catchment and atmospheric history (figure 1), and

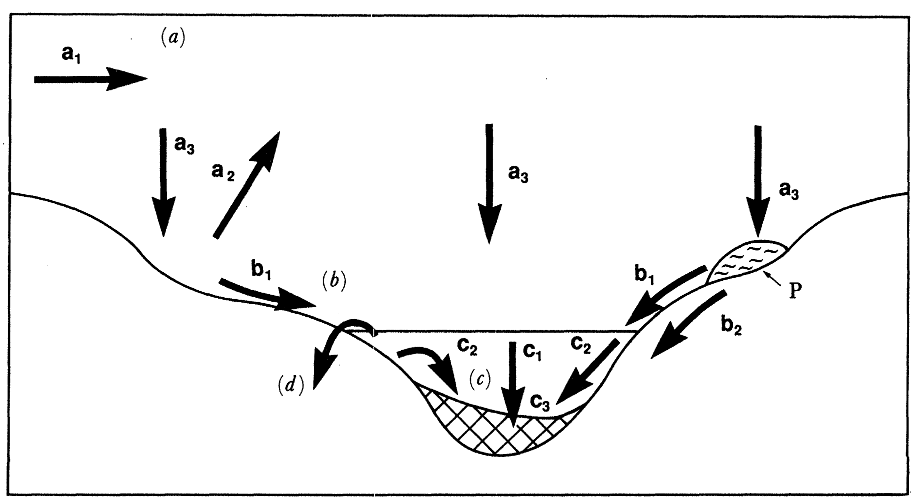

Figure 1. Diagrammatic cross-section of sources and pathways for lake sediment. (*a*) Atmospheric inputs; a_1, sources outside catchment; a_2, sources within catchment; a_3, wet and dry deposition to lake and catchment surface (radioactive nuclides, S, PAH, trace metals, fly ash and carbonaceous particles, pollen and spores). (*b*) Catchment inputs; b_1, inflow streams (silts, clays, organic detritus, pollen and spores, solutes); b_2, groundwater (precipitates, e.g. Fe, Mn). (*c*) Lake inputs; c_1, plankton (diatoms, chrysophytes, cladocera); c_2, littoral flora/fauna (diatoms, macrophyte spores and pollen, chydorid cladocera, chironomidae); c_3, benthic flora/fauna (diatoms, chironomidae). (*d*) Outflow losses; (P, peat bog.)

comparisons of these with records of lake history through time and between sites often allow the causes, as well as the timing and rate, of historical changes to be inferred.

Unlike other sources of historical scientific information, lake sediments usually provide a record that is continuous, covers a full range of timescales, is available at all sites and is amenable to standard methods of analysis. At some sites difficulties with dating, sediment conformability and fossil preservation are encountered but such problems can be recognized and poor sites avoided.

Palaeolimnological techniques are hence ideally suited to problems of lake acidification. Initial claims that these problems were caused by acid deposition were poorly supported because of the lack of high quality historical data and the need to differentiate between naturally acid and recently acidified waters. Almost all countries with acid waters and high S deposition have now adopted palaeolimnological methods to address this issue. Papers in this volume by Kingston & Birks, Davis *et al.*, Meriläinen & Huttunen and Charles are examples of such studies.

The palaeolimnology programme

When the Surface Water Acidification Project was set up in 1983 the Management Committee identified palaeolimnology as a key area of research with a dual remit.

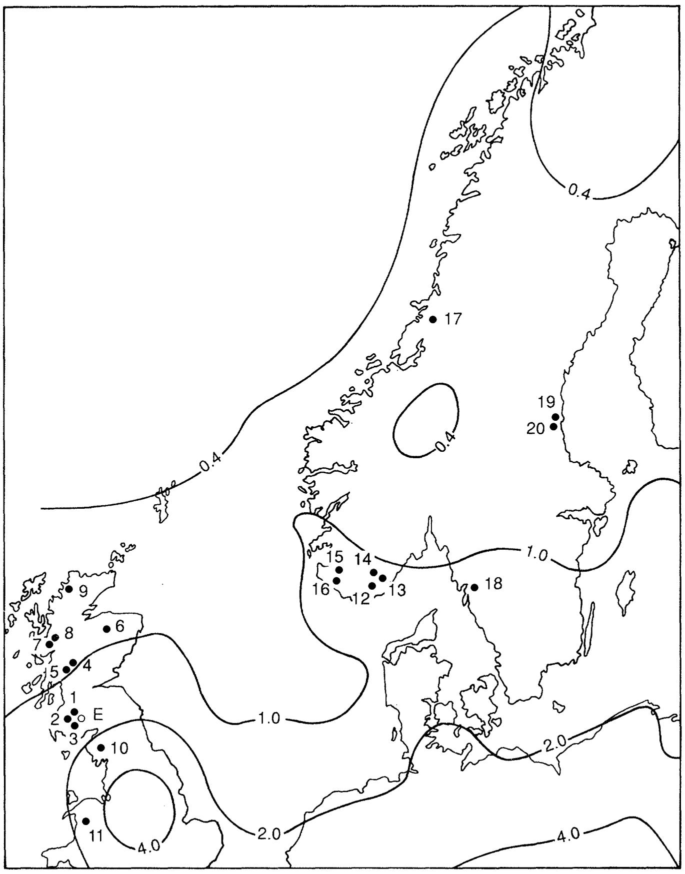

FIGURE 2. Map of N.W. Europe showing location of sites (table 1) and isolines of S deposition (g m^{-2} a^{-1}) (from Eliassen *et al.* 1988). 1, The Round Loch of Glenhead; 2, Loch Grannoch; 3, Loch Fleet; 4, Loch Tinker; 5, Loch Chon; 6, Lochan Uaine; 7, Loch Doilet; 8, Lochan Dubh; 9, Loch Sionascaig; 10, Devoke Water; 11, Llyn Hir; 12, Verevatn; 13, Gulspettvann; 14, Holmevatn; 15, Holetjörn; 16, Ljosvatn; 17, Röyrtjörna; 18, Lilla Öresjön; 19, Sjösjön; 20, Lill Målsjön; E, Ellergower Moss.

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1. To carry out detailed integrated studies of lakes in areas of high and low acid deposition, choosing sites that had similar catchment characteristics and that were adjacent to the instrumented stream catchments studied by others in the main SWAP programme. For example, Verevatn (figure 2) was chosen because of its proximity to the Birkenes catchment study in southern Norway. Other sites in this category include Round Loch of Glenhead and Lochan Dubh in Scotland, Röyrtjörna in Norway and Lilla Öresjön in Sweden. Cores from each of these sites were subjected to diatom, chrysophyte, cladoceran, chironomid, pollen, trace metal, sulphur, carbonaceous particle, magnetic mineral and polycyclic aromatic hydrocarbon (PAH) analysis. The cores were dated by ^{210}Pb analysis and land-use history surveys of the catchments were made. The results of these studies are presented by Berge *et al.*, Jones *et al.* and Renberg *et al.* (this symposium).

2. To evaluate a range of alternative hypotheses for lake acidification. Although by 1983 there was already abundant palaeolimnological evidence available to support the acid deposition hypothesis, the role of long-term acidification and changes in land-use and land management was unclear. In this programme the long-term acidification question has been addressed by Atkinson & Haworth (this symposium) and Renberg *et al.* (this symposium) by using data from Loch Sionascaig, Devoke Water and Lilla Öresjön (figure 2, table 1), and various versions of the land-use hypothesis have been considered by Patrick *et al.* (this symposium), Birks *et al.* (this symposium), Anderson & Korsman (this symposium), Renberg *et al.* (this symposium)and Kreiser *et al.* (this symposium), by using data from many sites, including Holetjörn, Ljosvatn in Norway, Sjösjön and Lill Målsjön in Sweden, and Lochs Tinker, Chon, Doilet and Lochan Dubh in Scotland (figure 2, table 1). The palaeolimnological evidence supporting the acid-deposition hypothesis is presented by Battarbee (this symposium).

Techniques

To fulfil the objectives of the programme, many techniques have been used. The bases of the techniques and examples of their application to problems of lake acidification are also presented. The biological techniques used include diatom analysis (Birks *et al.*, Munro *et al.*, Round and Smith, all this symposium) chrysophyte analysis (Cronberg, this symposium), chironomid analysis (Brodin, this symposium) and cladoceran analysis (Nilssen & Sandøy, this symposium). Of these techniques, most developmental work has been devoted to diatom analysis, the central method for pH reconstruction. A SWAP calibration data-set of over 160 sites from Norway, Sweden and the U.K. has been created by using a standard approach to diatom taxonomy and water chemistry (Munro *et al.*, this symposium). New methods of pH reconstruction and error estimation have been developed from the data-set (Birks *et al.*, this symposium) and have been applied routinely to all sediment-core sequences within the project.

Techniques used to trace atmospheric contamination include trace metal, sulphur and PAH chemistry (Rippey, this symposium), carbonaceous particle analysis (Wik & Natkanski, this symposium) and mineral magnetic analysis (Oldfield & Richardson, this symposium). Clymo *et al.* (this symposium) describe a study evaluating the atmospheric deposition record of an ombrotrophic mire. The chronological framework for most studies has been provided by ^{210}Pb dating (Appleby *et al.* and El-Daoushy, this symposium) although ^{14}C wiggle-match dating has also been used (Clymo *et al.*, this symposium).

TABLE 1. SWAP SITES WITH MAJOR LAKE AND CATCHMENT CHARACTERISTICS

	United Kingdom										
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
name	Round L. of Glenhead	L. Grannoch	L. Fleet	L. Tinker	L. Chon	L. Uaine Lochnagar	L. Doilet	Lochan Dubh	L. Sionascaig	Devoke Water	L. Hir
latitude	55° 05′ N	55° 0′ N	55° 0′ N	56° 13′ N	56° 12′ N	57° 4′ N	56° 44′ N	56° 46′ N	58° 10′ N	54° 20′ N	52° 17′ N
longitude	4° 27′ W	4° 15′ W	4° 10′ W	4° 30′ W	4° 33′ W	3° 40′ W	5° 35′ W	5° 26′ W	4° 75′ W	3° 23′ W	3° 46′ W
altitude/m	295	210	344	420	100	950	10	230	73	233	435
catchment/ha[a]	95	1290	107	112	1570	28	3290	157	4000	305	23
geology	granite	granite	granite	micaschist	micaschist	granite	quartzite schists	quartzite schists	gneiss/ sandstone	volcanics/ granite	mudstones/ shales
land-use/ vegetation	moorland	forest	forest/ moorland	moorland	forest/ moorland	alpine heath	forest/ moorland	moorland	moorland	moorland	moorland
lake area/ha[a]	12.5	114.3	17.3	11.3	100	4.0	53	8.8	517	34	4.9
maximum depth/m	13.5	20.5	19	9.8	25	21	16.8	9	66	14	8.8
pH	4.77	4.6	4.5[b]	6.0	5.2	5.8	5.9	5.6	6.6	6.2	4.8[b]
Ca^{2+}/ (μeq l^{-1})	41	47	39	78	79	69	47	33	73	118	47
SO_4^{2-}/ (μeq l^{-1})	89	110	124	62	85	82	68	40	71	138	120
S deposition/ (g m^{-2} a^{-1})	1.24	1.29	1.29	1.36	1.36	0.84	0.78	0.78	0.5	2.0	1.81

	Norway						Sweden		
	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
name	Verevatn	Gulspettvann	Holmevatn	Holetjörn	Ljosvatn	Röyrtjörna	Lilla Öresjön	Sjösjön	Lill Målsjön
latitude	58° 23′ N	58° 40′ N	59° 09′ N	58° 28′ N	58° 24′ N	64° 40′ N	57° 33′ N	61° 42′ N	61° 53′ N
longitude	8° 12′ E	9° 05′ E	9° 05′ E	6° 48′ E	6° 42′ E	12° 10′ E	12° 20′ E	16° 53′ E	17° 09′ E
altitude/m	268	56	588	485	385	163	107	79	82
catchment/ha[a]	60	190	2750	5	22	2400	400	230	30
geology	granite	granite/ gneiss	granite/ gneiss	granitic migmatite	granitic migmatite	granite	gneiss	granite/ gneiss	granite/ gneiss
land-use/ vegetation	forest	forest	forest/ heath	forest	forest/ heath	forest	forest	forest	forest
lake area/ha[a]	9	32	100	1.6	11	26	61	32	8
maximum depth/m	13.9	25	> 15	17	25	15.8	17	16	4
pH	4.4	4.8	4.7	4.57	4.47	6.6	4.6	5.7[b]	5.5[b]
Ca^{2+}/(μeq l^{-1})	—	160	22	26	23	70	124	na	na
SO_4^{2-}/(μeq l^{-1})	—	175	—	75	79	28	210	na	na
S deposition/ (g m^{-2} a^{-1})	1.8	1.3[c]	1.3[c]	1.3[c]	1.3[c]	0.15	1.8	0.5	0.5

[a] 1 ha = 10^4 m^2. [b] Pre-liming. [c] Estimated from Eliassen *et al.* (1988).

Post-1970 change and modelling

In addition to work within SWAP on long (post-glacial) and medium (post-1800) timescales, Flower *et al.* (this symposium) consider very recent (post-1970) timescales to assess the evidence for lake responses to decreasing acid deposition, liming and other changes in the catchments of acidified lakes. A final paper (Jenkins *et al.*, this symposium) compares the diatom-based pH reconstructions for the main study sites with reconstructions based on the use of the catchment acidification model, MAGIC.

The SWAP project has been funded by a grant from the Central Electricity Generating Board (U.K.) and the National Coal Board (U.K.) to the Royal Society. Most of the work presented here has been financed from this source but additional support has also been received: for U.K. work from the Department of Environment (DoE), the Natural Environment Research Council (NERC) and the Central Electricity Generating Board (CEGB); for Norwegian work from the Norwegian Council for Science and the Humanities (NAVF), and for Swedish sites from the Swedish Natural Science Research Council (NFR) and the Swedish National Environmental Protection Board (SNV).

We thank the SWAP Management Committee, especially Sir John Mason, Hans Martin Seip, Lars Walløe, Sir Richard Southwood, Carl-Olof Tamm, Jack Talling and Tom West for their help and encouragement, Ron Harriman, Ron West, for water chemistry, John Kingston, Sheri Fritz, Keith Camburn for help with diatom taxonomy, John Line for computer programming, Cajo ter Braak for statistical assistance, Karin Olsson for help with ^{210}Pb analyses, Dick Derwent and Jimi Irwin for data on S deposition, and Stuart Phethean, Don Monteith and Paul Raven for help with fieldwork. We are grateful to John Kingston and John Birks for their help with the editing of several papers in this volume.

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