

## **The influence of catastrophic floods on water quality as recorded in the sediments of Blagdon Lake, England**

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**ABSTRACT** Studies of the relation between water quality and sediment in Blagdon Reservoir, southwest England, are discussed in the context of varying sources and rates of supply of sediment. Magnetic, chemical and sedimentological results are presented. Early deposits in the lake are contrasted with later sediments some of which are derived from a major flood in 1968. The effect of this event on water quality is outlined, and the methods used are shown to provide the basis for further quantitative study of the lake.

*L'influence d'inondations catastrophiques sur la qualité de l'eau telle qu'elle ressort par les sédiments du lac Blagdon, Angleterre*

**RESUME** Des études sur la relation entre la qualité de l'eau et les sédiments de la retenue de Blagdon, au sud-ouest de l'Angleterre, sont discutées dans le contexte des diverses sources et taux d'apport en sédiments. Des résultats portant sur les aspects magnétiques, chimiques et sédimentologiques sont présentés. Des dépôts anciens diffèrent d'autres plus récents, dont certains proviennent des grandes inondations de 1968. L'effet de cet événement sur la qualité de l'eau est souligné, et les méthodes utilisées sont indiquées en vue de fournir une base pour une étude quantitative ultérieure du lac.

### **INTRODUCTION**

The quality of surface water is largely controlled by its interaction with sediments, both within the water column and at the bed of lakes and reservoirs. Chemical species are present in solution, sorbed onto colloids, precipitated, as weathered minerals, or bound to organic material. Complex processes take place at the sediment-water interface as the system moves towards chemostasis (cf. Mortimer, 1942). In particular, sediments effectively buffer the concentration of soluble metals. Clays, colloidal iron-manganese oxides and organic materials sorb metals strongly (Förstner & Wittmann, 1981), and thus

in water the concentration of heavy metals in solution is intimately related to the sediment present. In addition to the characteristics of the sediment, its rate of supply may be important. Fresh sediment may offer more exchange sites or increase the load in solution by the import of unweathered substrate. Conversely, previously active sediment may become buried and chemically inaccessible. Both character and supply in turn depend upon the source of the sediment and the hydrological processes in operation. (Loucks, 1975).

In order to study these relationships, sediments were analysed from a eutrophic, hardwater reservoir near Blagdon in the Mendip area of southwest England (Fig.1), which was completed in 1905. The area has been worked for lead, zinc and copper since Roman times (Woodward, 1872; Gough, 1930) and the most recent phase of metal extraction (1850-1900's) has concentrated on the reworking of older slags. Soils

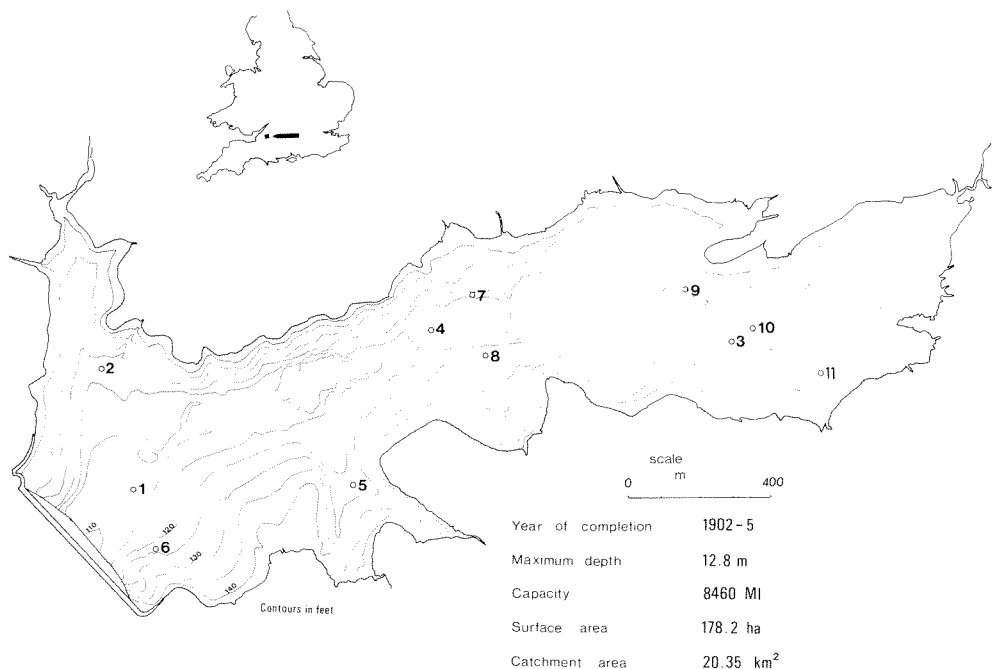


FIG.1 Blagdon Reservoir, Mendip, England.

of the district are contaminated by lead, zinc and cadmium (Thornton, 1981), and enhanced levels of cadmium have been detected especially in the area of Shipham (Thornton et al., 1979). Under normal flow conditions the majority of sediments are carried to the reservoir by its feeder streams, from soils and subsoils developed on Keuper bedrock or Keuper-derived Pleistocene deposits. Local sources include materials eroded from the margin of the reservoir. The Rickford spring, which drains mineralized Carboniferous limestone of the Mendip pericline, substantially contributes to solute levels. Blagdon Reservoir also has experienced several intense rainfall events, and severe flooding occurred in 1925 and 1968. During the

flood event of 10-11 July 1968 sediment sources which are normally inactive, including most notably an extensive network of limestone dry valleys, contributed solutes and sediments to Blagdon Reservoir (Hanwell & Newson, 1970). The study site, therefore, offers an opportunity to investigate the influence of changing source and rate of supply of sediments upon their chemical make-up and to estimate the likely effect upon water quality. A variety of experimental methods have been employed to distinguish between the influence of long term and pulsed events, and between sources contributing to the sediments in the lake.

## EXPERIMENTAL METHODS

Sediment cores were taken from Blagdon Reservoir using a Mackereth 1-m corer (Mackereth, 1969). The cores were extruded; 2 cm slices were taken, dried at 40°C and disaggregated prior to analysis.

### *Magnetic measurement*

Specific low field initial susceptibility ( $\chi$ ) was measured using a Bartington susceptibility meter and employing aliquot portions (9 g) of sediment. Saturation isothermal remanent magnetization (SIRM) was measured on the same samples using a Molspin (Minispin-1A) spinner magnetometer after the samples had been packed into their holders with foam. The saturating field was 8000 Oe (0.8 T). The samples were remeasured after being placed in a reverse field of 1000 Oe (0.1 T). The ratio SIRM/ $\chi$ , and the parameter "S" (Walling *et al.*, 1979) were calculated for each sample. The ratio dry mass:wet volume was estimated by completely filling pre-weighed plastic pots (11 cm<sup>3</sup>) with lake sediment in its field state, drying, and re-weighing.

### *Chemistry*

Subsamples (1 g) were analysed for total metal concentrations by refluxing the sediment with 90 HNO<sub>3</sub>:10 HCl (15 cm<sup>3</sup>), evaporating to dryness and making samples up to 25 cm<sup>3</sup> with 0.1 M HNO<sub>3</sub> (Sinex *et al.*, 1980). A selective sequential extraction was also used to separate the following fractions:

- (a) exchangeable metal ions (1 M magnesium chloride);
- (b) surface oxide and carbonate-bound metal ions (1 M sodium acetate);
- (c) metals bound to Fe-Mn oxides (0.04 M hydroxylamine hydrochloride);
- (d) organically bound metals (hydrogen peroxide);
- (e) residual metal ions (90 HNO<sub>3</sub>:10 HCl).

Heavy metal concentrations were determined using a Philips SP2900 double beam atomic absorption spectrophotometer with SP9 computer, and employing background correction where necessary.

### *Sediment analysis*

A portion of dried sediment (3-5 g) was taken from each slice of core, suspended in calgon solution (250 cm<sup>3</sup>, 5% w/v), and shaken overnight.

The sample was then wet-sieved through a 63  $\mu\text{m}$  (4.0 phi) mesh. The fraction retained (sand) was dried, weighed and expressed as a percentage of the dry weight of the original sample. An aliquot portion (5  $\text{cm}^3$ ) of the suspension which passed the sieve (silt and clay) was collected for the determination of particle size. Grain size distributions for silt sized sediments were determined on a model TA II Coulter Counter using a 140  $\mu\text{m}$  aperture. This gave an effective particle size analytical range of between 63  $\mu\text{m}$  (4.0 phi) and 2  $\mu\text{m}$  (9.0 phi). Graphical measures for phi skewness, sorting and kurtosis (after Folk & Ward, 1957) were calculated for all samples using the grain size curves produced by Coulter Counter analysis.

## DISCUSSION

### *Magnetic measurements*

The magnetic signature from core 3 (Fig.2) is similar in all 11 cores from Blagdon Reservoir, and provides an acceptable means of inter-core correlation which will be used in subsequent quantitative work on sedimentation rates and material fluxes. In addition, the similarity between the cores attests to the fact that the changes illustrated in Figs 2 and 4, for core 3 and 5 respectively, are synchronous basinwide phenomena. The marked change at 58 cm in core 3 (Fig.2) identifies the boundary between limnic sediment above, and former topsoil, *in situ*, below. Similar magnetic changes have been used to estimate the depth of limnic sediments across the lake even where no lithological changes are visible in the core. Between 38 and 58 cm in core 3 the magnetic characteristics suggest that topsoil-derived material forms an important constituent of the accumulating lake sediment. This early phase of topsoil enrichment could well represent the combined effects of topsoil erosion around the margin of the lake and the adjustment of inflowing channels and slopes to the creation of the reservoir. In core 5 the same feature is present and topsoil enriched sediment lies between 26 and 48 cm. This can be related to the sediment chemistry (Fig.4). At depths >38 cm in core 3 (Fig.2), subsoil or channel-scour-derived material is more important with lower  $\chi$  and "S" values (Oldfield *et al.*, 1979). This fall in  $\chi$  and "S" values is very marked in some cores. The peak in  $\chi$  and SIRM at a depth of 10-12 cm in core 3 is tentatively correlated with the 1968 flood although on the basis of magnetics alone this remains uncertain until further work has been completed.

### *Sediment analysis*

Blagdon lake sediments can be classified as poorly sorted muds (Folk, 1974) with a sand content ranging from 0.34 to 5.38%. A plot of the percentage of sand (Fig.2) reveals two prominent sand-rich horizons, one at the base and the other at the top of the core. The former (54-68 cm) is clearly the pre-reservoir soil. The latter, which is centred at 8-10 cm but extends from 2 to 12 cm, is interpreted as sediment deposited in the July 1968 flood.

Using sample skewness, sorting, kurtosis and sand percentage values, a cluster analysis (Ward, 1963) was carried out and three clusters identified (Fig.3). Cluster 3 sediments (pre-reservoir) are distinguished from cluster 1 (later limnic sediments) and cluster 2

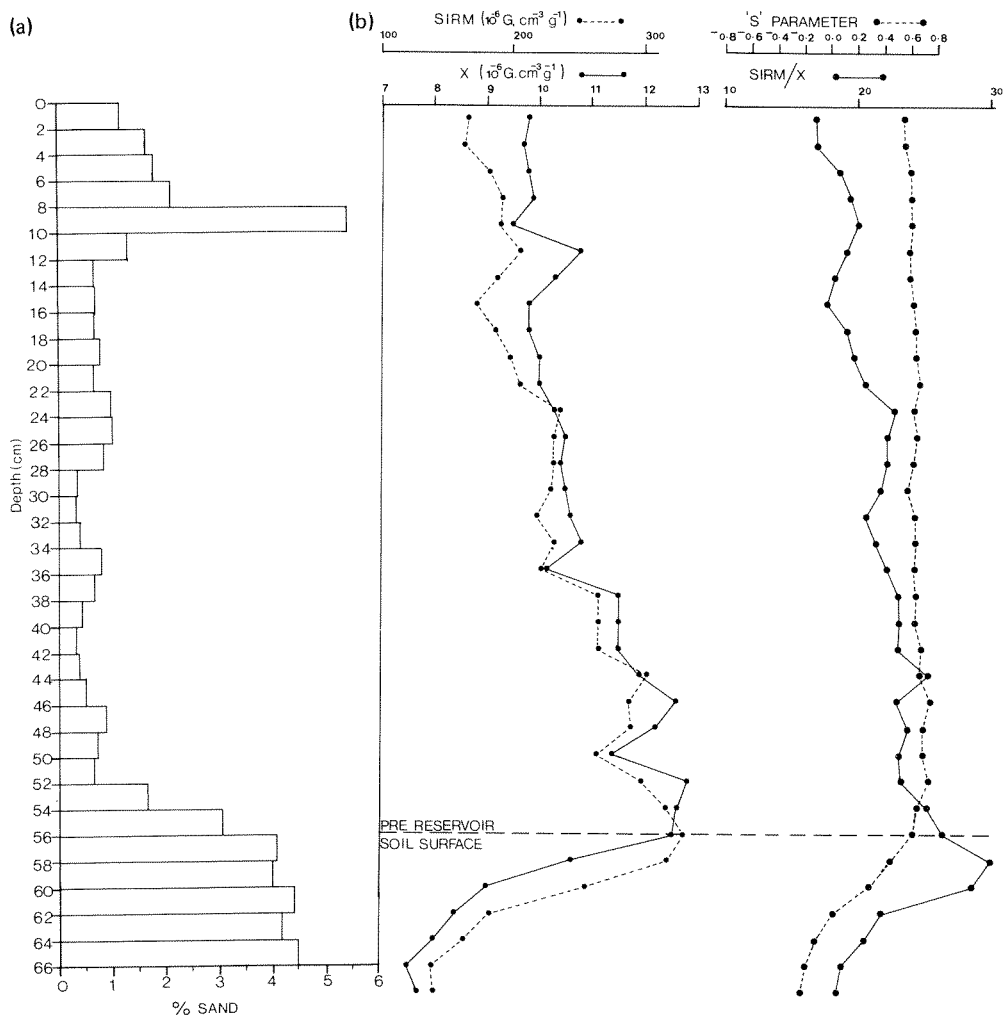


FIG.2 Downcore records for site 3: (a) % sand, (b) magnetic measurements.

(early limnic sediments) by poor sorting and low kurtosis values (Fig.3). Samples at 14-16 cm have grain-size characteristics similar to pre-reservoir sediments but with lower sand contents. They may represent a period of reservoir drawdown in 1964 (Wilston *et al.*, 1975) which resulted in exposure and subaerial reworking of limnic sediments. Cluster 1 and 2 sediments have similar sorting and kurtosis values but cluster 2 has lower sand percentages and is more positively skewed. Initially, sediments of cluster 2 type characterized sedimentation in the reservoir, but from 34 cm to the surface, sediments represented by cluster 1 became more important. This may reflect a long term change in the calibre of sediment available in the catchment or, as is more likely, an increase in the energy of sediment transport processes. The sand content provides a useful measure of the competence or magnitude of past depositional events within the reservoir.

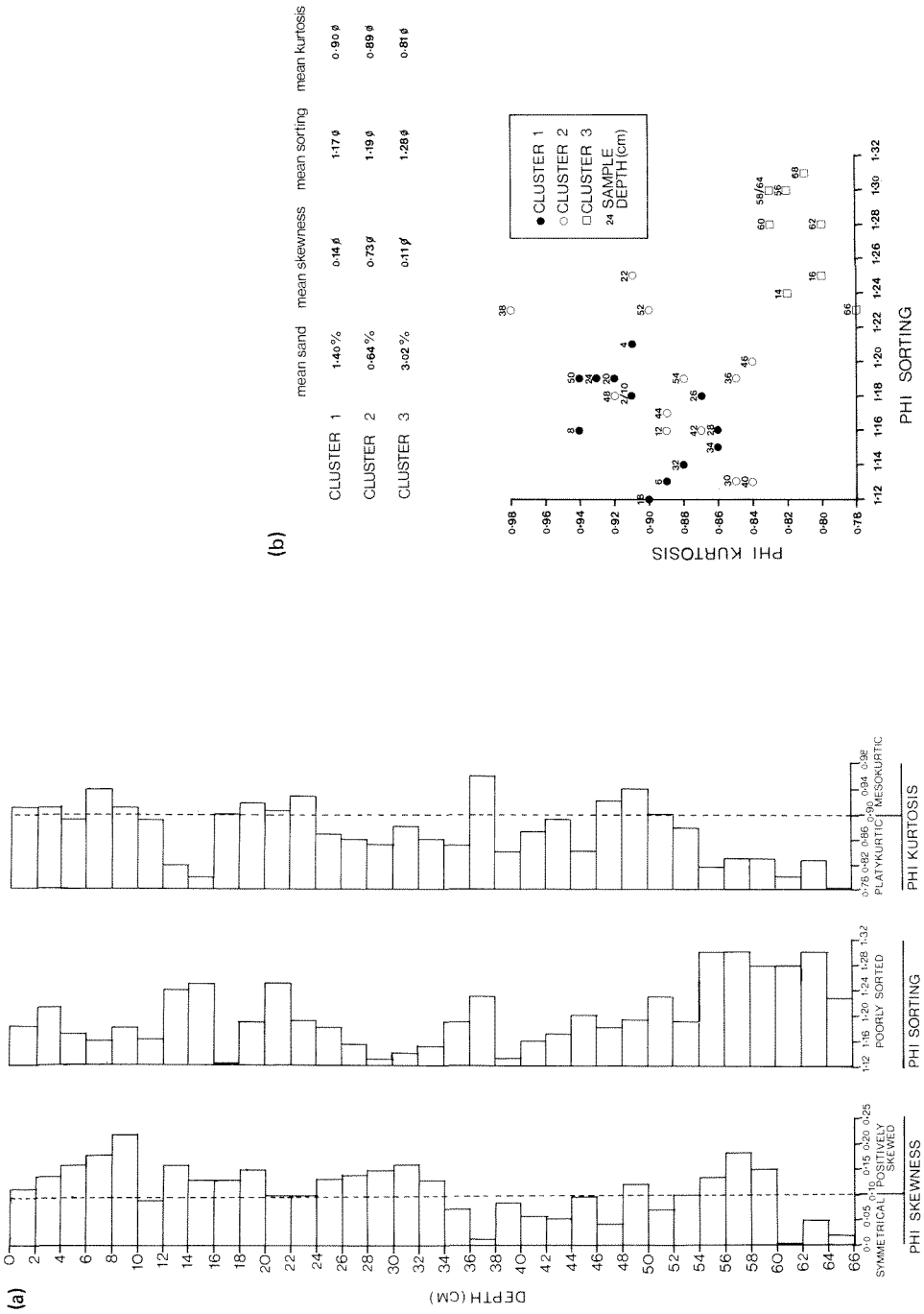


Fig. 3 Downcore records for site 3: (a) grain-size parameters, (b) results of cluster analysis.

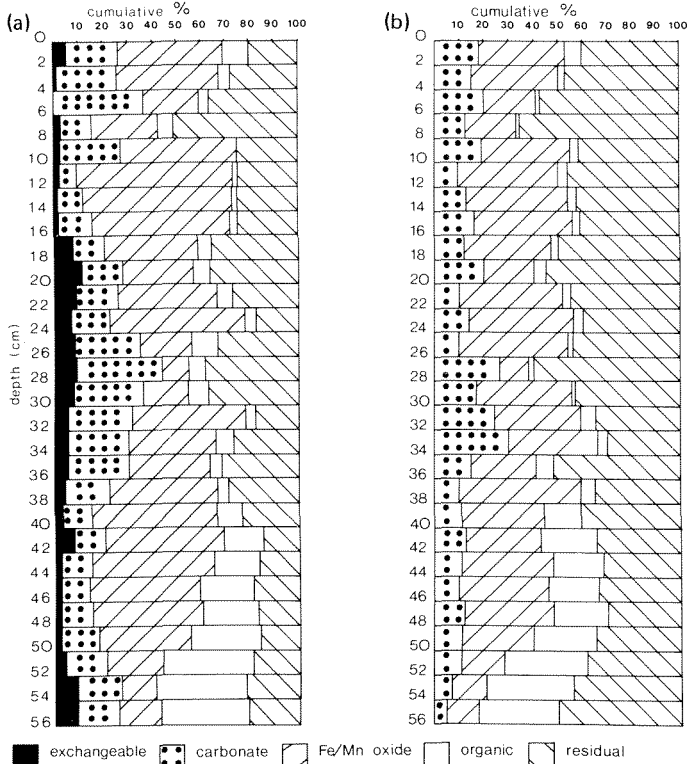


FIG.4 Downcore record of sequential selective extraction for site 5: (a) lead, (b) zinc.

Heavy metal chemistry

The data for total metal concentrations (Table 1) reveal greater concentrations in core 5 than core 3. Mean Pb concentration in core 5 was 171 mg kg<sup>-1</sup> in comparison with 117 mg kg<sup>-1</sup> in core 3, and equivalent figures for Zn are 300 and 225 mg kg<sup>-1</sup>. The piped flow from Rickford spring, which enters the reservoir near the site of core 5, has generally enhanced metal concentrations. Selective extraction provides a sensitive measure of variations in sediment source. The lowest samples (48-56 cm) represent pre-reservoir soil and have high levels of lead and zinc in the organic fraction, while metal associated with iron-manganese oxides decreases down the profile (Fig.4). Above this level, local reworked topsoil was probably the dominant source for early sediments. These sources became less significant higher up the profile (36-38 cm) since more distance sources contributed a greater proportion of the sediment. As topsoil was washed into the lake, its nutrient loading would have increased productivity. Aquatic molluscs efficiently incorporate heavy metals from solution into their shells (Bryan & Hummerstone, 1978), and this phenomenon is discernible in the sediments from the increase in carbonate associated metal which later declines as the lake aged and nutrient levels fell (Fig.4).

The 1968 flood, identified at 6 to 12 cm from sedimentological

TABLE 1 Total metal concentrations in selected cores

Blagdon 3						Blagdon 5				
Depth (cm)	Pb	Zn (mg kg <sup>-1</sup> )	Cd (mg kg <sup>-1</sup> )	Mn	Fe (%)	Pb	Zn (mg kg <sup>-1</sup> )	Cd (mg kg <sup>-1</sup> )	Mn	Fe (%)
0-2	149	295	0.39	1121	0.12	151	290	0.37	1149	1.8
2-4	82	191	0.14	753	0.03	145	284	0.36	695	1.5
4-6	100	192	0.17	584	1.3	144	271	0.16	596	1.4
6-8	90	203	0.17	464	1.1	148	268	0.43	660	1.6
8-10	95	203	0.20	509	1.3	142	286	0.66	637	1.6
10-12	108	231	0.13	540	1.5	150	296	0.45	635	1.7
12-14	110	229	0.38	495	1.7	153	297	0.19	657	1.5
14-16	89	226	0.13	466	1.4	101	31	0.22	696	1.1
16-18	126	208	0.12	437	1.3	156	360	0.58	689	1.8
18-20	99	198	0.14	436	1.3	134	293	0.28	597	1.6
20-22	127	232	0.18	511	1.5	145	301	0.30	526	1.6
22-24	130	209	0.13	464	1.3	170	361	0.75	649	1.9
24-26	94	230	0.11	455	1.5	156	333	0.23	643	1.8
26-28	112	204	0.14	516	1.5	174	333	0.34	582	1.6
28-30	126	251	0.16	532	1.7	161	321	0.29	645	1.9
30-32	121	244	0.10	543	1.6	116	314	0.57	663	1.8
32-34	108	231	0.09	540	1.5	216	320	0.55	713	1.9
34-36	89	215	0.08	528	1.4	231	350	0.41	795	2.3
36-38	126	218	0.21	551	1.5	198	314	0.55	698	1.8
38-40	91	231	0.20	535	1.1	167	321	0.51	770	2.2
40-42	99	232	0.17	541	0.01	187	317	0.77	685	2.2
42-44	128	220	0.13	602	2.1	221	303	0.79	802	2.0
44-46	97	207	0.11	688	1.3	199	329	0.80	930	2.0
46-48	105	233	0.14	701	1.5	279	309	0.77	1014	2.0
48-50	85	166	0.14	582	1.4	192	338	0.80	722	2.1
50-52	136	246	0.10	652	1.8	200	326	0.68	503	2.2
52-54	106	214	0.13	681	1.6	167	266	0.53	423	1.8
54-56	78	248	0.17	533	1.6	191	273	0.46	491	1.8
56-58	135	247	0.18	464	1.1					
58-60	155	225	0.15	386	0.98					
60-62	151	247	0.22	398	1.2					
62-64	140	214	0.22	372	0.95					
64-66	165	231	0.29	393	1.1					
66-68	217	274	0.22	413	2.0					

evidence, is reflected in the lead profile by the absence of organic-fraction metal between 8 and 10 cm. In both the lead and zinc profiles (Fig.4), the residual fraction becomes less important from the 6 cm level to the sediment surface and represents the mobilization of minerogenic sediments by a large flood event.

## CONCLUSIONS

(a) Selective chemical extractions are shown to be highly effective in discriminating between the binding sites of heavy metals.



in lake sediments and thus allow the formulation of clearly defined hypotheses about water quality/sediment relationships for Blagdon Reservoir.

(b) The sedimentological techniques used distinguish between styles of sedimentation in a way that complements and confirms the reality of changes suggested by chemical and magnetic techniques. They may also suggest ways in which pulsed storm events may be set within the framework of longer term, time-dependent (ageing) processes within lakes.

(c) Magnetic methods, which are relatively rapid and are non-destructive, enable detailed study of a single core to be extrapolated across a lake basin and provides, in the case of Blagdon, the possibility of investigating sediment chemical and mineralogical characteristics in quantitative sediment influx and deposition rate terms. In addition the mineral magnetic studies enable sediment sources and styles of erosion to be identified.

(d) The Blagdon site offers good opportunities for quantitative studies on sediment/water quality relationships, and further work is in progress to this end.

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