Trace metal distribution in the sediments of the whole lake basin for Lochnagar, Scotland: a palaeolimnological assessment

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Abstract
Analyses of trace metals on multiple sediment cores from the whole-lake basin of Lochnagar, Scotland, show that the depth of departure from stable values towards a rapid increase of the Pb/Ti and Hg concentration profiles provides a good dating feature for the 1860s. In relatively shallow areas of the lake, inferred sediment accumulation rates and the trace metal inventories change with water depth, but in the deep water area, sediment accumulation rates are lower than in most other areas of the lake. Mercury, Pb, Cu and Zn inventories in the sediments accumulated since 1860 in the deepest area are 61%, 64%, 73% and 56% of the corresponding average inventories for the whole sediment area of the lake, respectively. This is mainly due to low sediment accumulation in the deep basin. This finding differs from the expected sediment focusing pattern and makes quantitative interpretations of palaeolimnological features using sediments from the deep area of this lake difficult. The influence of sediment focusing from the north-eastern side, the largest portion of the sediment area of the lake basin, on the deepest area of the lake may be limited, so the sediments in the north-east could be difficult to be transported to the deepest area through sediment focusing. Therefore, the sediments in the deepest area of the lake may not represent the whole-lake basin well for the relative abundances of different types of fossils.

Introduction
Lake sediments provide a good archives for storing important information about past conditions of a lake and its watershed, and have been used to reconstruct the historical record of contamination (Renberg et al., 1994; Engstrom & Swain, 1997) and changes in other environmental aspects such as climate, acidification and entrophication (e.g., Battarbee et al., 1985; Jones et al., 1993). However, sediment distribution within a lake basin is not even, and many studies have shown that the sediment accumulation rate changes with water depth, caused by sediment focusing processes (Evans & Rigler, 1980; Davis & Ford, 1982; Blais & Kalff, 1995). Sediment focusing is the term used to describe the resuspension of sediments in shallower areas by waves and water currents with subsequent transport to, and settling in the deeper areas of the lake. Since the distribution of sediment is uneven within a lake, the selection of coring location is very important.

It is generally assumed that settling sediment particles are well mixed in the deep area of a lake, and for palaeolimnological studies, one sediment core is usually taken from the deepest area of a lake and used to represent the whole lake (Brezonik et al., 1990; Paetzel et al., 1994; Von Gunten et al., 1997). But can one sediment core from the deep area of a lake truly represent the whole lake? Bindler et al. (2001) has reported an exceptional case, and argued that acidification may influence on sedimentation processes, although it is not adequate to fully describe the pollution Pb sedimentation pattern.

Lochnagar is a relatively remote mountain lake which has not been influenced directly by human activity, it has been used for studying trace metal and organic pollution deposition and its effects (Rose et
al., 2001; Yang et al., 2002a, b). It is also part of the U.K.’s Acid Waters Monitoring Network (AWMN) and Environmental Change Network (ECN) and the UNECE’s International Cooperative Programme on Assessment and Monitoring of Acidification of Rivers and Lakes. Consequently it is one of the most intensely studied and monitored freshwater sites in the U.K.

In order to estimate trace metal inventories in Lochnagar, we investigated sediment distribution in the whole lake basin, 17 sediment cores were taken from different areas of the lake to analyse trace metal distribution in order to put contemporary sediment concentrations into an historical context for trace metal inventory calculations.

Study site

Lochnagar is a cirque lake that lies to the southeast of the Cairngorm Mountains in Scotland, at an altitude of 785 m in the centre of a granitic massif. The lake is roughly pear-shaped and occupies an area of 9.8 ha with a precipitous catchment of 92 ha. The lake basin is relatively simple. The littoral area is covered by sands and boulders, whilst the whole central basin (6.1 ha) is covered by soft sediment. The lake floor slopes quite sharply to a deep basin with the deepest point (26 m) offset from the centre of the lake towards to the backwall of the corrie (Fig. 1). No distinguishable inflow feeds the lake. The lake drains to the north-east through a series of small pools to the stream of Lochnagar Burn which feeds the larger Gelder Burn. In the catchment, the bedrock is biotite granite overlain in places on the lower slopes by blanket peats. Of these localised areas of peat, certain areas, notably along the eastern shore, are severely eroded.

Methods

Sediment sampling and analyses

Sixteen sediment cores (Nag9–Nag25) mainly along five transects radiating from the central area of the lake and one core (Nag26) from the nearest outflow pool to the lake body were taken with a gravity corer filled with a 7.7 cm inner diameter polycarbonate core tube between 28th June and 2nd July 1997. The sediment cores were sectioned using a stainless steel slicer at 0.5 cm intervals from the surface to 7 cm depth, and then at 1 cm intervals from 7 cm to the bottom of the cores. Wet density measurements of samples were determined using a 2-cm³ container. Water content was determined by heating sub-samples at 105 °C for 24 h and loss-on-ignition (LOI), a proxy for organic matter content, was determined by heating dried samples at 550 °C for 4 h. The remainders of the samples were all freeze dried.

Two sediment cores were dated using the 210Pb method (Yang, 2000). All the sediment cores were analysed for spheroidal carbonaceous particles (SCPs), and the SCP profiles of the cores were matched with the dated sediment cores so that dates could be applied to all sediment cores and they could be stratigraphically cross-correlated (Rose et al., 1995; Yang, 2000).

All the sediment samples were analysed for Hg, Pb, Zn and Cu. Samples were digested using concentrated HNO₃. Mercury was measured using cold vapour atomic absorption spectrometry (CV-AAS) following reduction with SnCl₂ (Engstrom & Swain,