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Differential sedimentation *versus* coring artifacts: a comparison of two widely used piston-coring methods

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Abstract

In order to compare two widely used piston-coring techniques, parallel cores were taken with both a Kullenberg and a Livingstone corer in the deepest part of Soppensee (25 m), a small eutrophic Swiss lake containing varved sediments. The cores were taken within a horizontal distance of 3 m and yield comparable stratigraphic records. Differences in millimetre-scale microstructure are attributed to primary sedimentation processes at the water/sediment interface. Sediment thin-sections, as well as sediment x-radiograph investigations, reveal no difference in microstructure that could unequivocally be attributed to one of the coring methods used. The differences in deposition are therefore thought to reflect the inherent variability of lacustrine sedimentation in Soppensee.

Major differences in overall core recovery do occur, however, in organic-rich, highly porous sediments. These variations are primarily attributed to differential gas expansion. Actual sediment-accumulation rates can therefore only be correctly estimated if the sedimentary record can be constrained within a high-resolution temporal framework, e.g. by annual laminations.

Introduction

Studies of lake and mire deposits by use of biostratigraphic and geochemical analyses provide proxy data which may help to reconstruct past environmental perturbations induced by factors such as climate change, human impact on the landscape, or pollution. The sampling of the lake sediment during fieldwork represents the initial phase of a labour-intensive investigation. Because a substantial amount of time, and hence money, is invested in laboratory analyses it is necessary to analyse only those sediments that are of unambiguous quality. The reliability of the coring method used during fieldwork is consequently crucial. To obtain long (>2–3 m) sedimentary records, several techniques have been developed. They either sample the sediment core as a monolith (e.g. Kullenberg, 1947; Mackereth, 1958) or as several consecutive core segments (e.g. Livingstone, 1955; Wieckowski, 1989). Each of these methods has its advantages, but direct comparisons between different methods (see, e.g., Ross & Riedel, 1967; Schneider, 1974; Hongve & Erlandsen, 1979; Blomqvist, 1985; Crusius & Anderson, 1991) are rarely carried out.

In the course of an interdisciplinary project concerning the late-Quaternary environmental dynamics of Soppensee (596 m a.s.l., 8°05′E, 47°05′30″N), a small lowland lake in Central Switzerland, over 70 sediment cores were collected. The deepest part of the basin has water depths from 25 to 27 m and encloses a small area of approximately 50 × 50 m (Figure 1). Prominent differences in sediment thickness between various well-defined stratigraphic marker horizons were detected in the sedimentary record (Sturm & Lotter, in prep.; Figure 2). This observation has led the authors to suspect that the observed differences might have been produced as a result of the coring technique used to sample the lake sediments. In the present study we have therefore compared the results of two different, widely used piston coring methods in order to test whether these observed differences have been produced as an artifact of the coring operation or are the result of depositional processes operating in Soppensee.

Methods

In autumn 1991 two sets of parallel cores were taken, each within a horizontal distance of 3 m in the deepest part of the lake, at a water-depth of 25 m. Cores SO91-19 and SO91-21 were taken with the Kullenberg system whereas a Livingstone corer was used for the parallel cores SO91-20A + B and SO91-22A + B. Because both sets of duplicated cores show similar evidence, we shall concentrate our discussion on cores SO91-21 (Kullenberg) and SO91-22A + B (Livingstone).

Both Kullenberg and Livingstone coring systems were deployed from a floating 8 × 4 m platform equipped with a 6.5 m high tripod and a 15 hp motor winch. The Kullenberg piston coring operation used in this study is described in detail by Kelts et al. (1986). All Kullenberg cores were taken with a 9-m-long core barrel and a 1.5-m-long gravity corer. The gravity corer acted a as trigger trip-weight, preceding the main corer by 2 m. The head of the core barrel had a weight of ca 300 kg and coring was monitored with an echograph. In Soppensee this coring method usually yielded between 6 to 8 m of sediment. Immediately after core recovery, the sediment-filled plastic liner (57 mm inner diameter) was cut into segments 1 m long. The ends of these individual segments were closed with tightly fitting plastic caps, which were then firmly taped to the liner.

The Kullenberg corer, having penetrated the sediment, was used as an anchor to keep the floating platform at the same location while the Livingstone coring operation was performed. We have used a modified Livingstone corer, described in detail by Merkt & Streif (1970). The corer is made of brass tubes bolted together. It contains a replaceable plexiglass liner (46 mm inner diameter, 2 m long) which receives the sediment. The corer is coupled to aluminium rods (2.5 cm diameter, 2 m long) that are connected by bayonet catches. This version enables the coring operation to be rapidly completed, but the rods cannot withstand excessive hammering. While the device is lowered, a piston inside the core barrel is locked by a wooden dowel (4 or 6 mm diameter, depending on sediment compaction) and connected by a 3 mm steel-wire to a cable drum on the floating platform. Coring begins with the piston locked in position. By pushing the rods firmly and steadily downwards, the wooden dowel is sheared and the core barrel can now slide past the piston to cut the core segment.

The Kullenberg corer is driven by its heavy weight and the momentum of a 2 m free-fall, thereby penetrating 7–8 m into the lake-bottom deposits within a few seconds. In contrast, the Livingstone corer is pushed into the sediment by hand; thus, depending on the length of the corer barrel, several successive penetrations must be performed to recover 7–8 m of sediment. In order to relocate the coring hole and also to prevent bending of the Livingstone coring rods, a casing consisting of aluminium tubes (75 × 80 mm, 2 and 2.5 m long) is pushed into the surficial sediment after recovery of the topmost 2 m of soft sediment.

After recovery of one complete core (the A-core), consisting of a series of consecutive 2 m segments, the whole operation was repeated at a horizontal distance of 0.5–1 m to obtain a B-core with core segments that begin 50 cm higher than those of the A-core. By carefully correlating the segments of the A and B cores, a hypothetical continuous core (A + B) was constructed. This hypothetical record (Figure 3) was used to evaluate the performance of the Livingstone corer.

The core segments of both Kullenberg and Livingstone methods were opened the day after recovery. The liners were longitudinally cut with a rotating saw on two opposite sides. The core was then separated into two identical halves by means of a thin steel wire. For water saturated topmost sediments, as well as for the lowermost, sticky clayey segments, two 120 × 15 cm copper plates were used to separate the segments into halves. The cores were then photographed, lithologically described, and subsampled for sediment thin-section and textural analyses.

Results

Lithologic logs of the cores are illustrated in Figure 3. Stratigraphic correlation between the trigger gravity core and the Kullenberg core was not possible on the

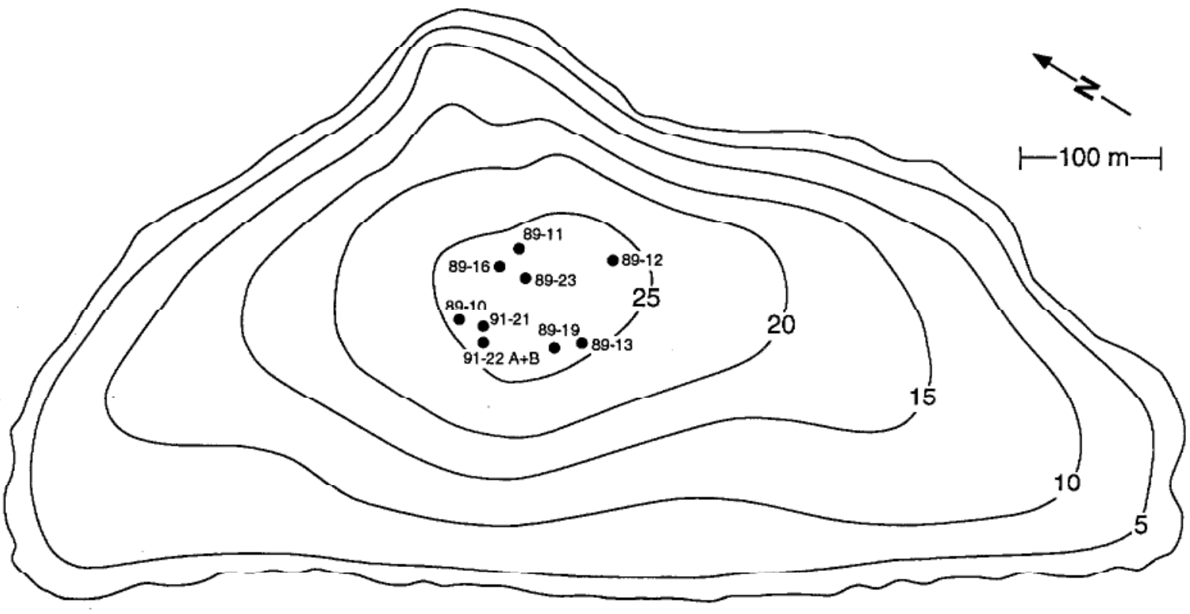

Figure 1. Bathymetric map of Soppensee, depths in metres. Only cores discussed in text are shown.

basis of conspicuous lithological features. The lithologic log for core SO91-21 has therefore been produced by combining the logs from the 63.5 cm trigger core and the 700.5 cm main core, producing a total length of 764 cm.

The parallel Livingstone cores (SO91-22A and SO91-22B), having vertical overlaps of at least 50 cm per 2 m segment were amalgamated to construct a single hypothetical core on the basis of well defined stratigraphic markers (Figure 3). The first segment of core SO91-22A could not be recovered due to its high water content. Consequently, core recovery for SO91-22A was 600 cm (150–750 cm of sediment depth), whereas SO91-22B yielded 785 cm (15–800 cm of sediment depth). The combined hypothetical core SO91-22A + B produced a total length of 815 cm.

Of the 98 marker horizons, consisting of prominent sediment layers defined in core studies from Soppensee (Sturm & Lotter, in prep., and Figure 2), 89 could be identified in at least one of the new cores. A total of 75 could be correlated between SO91-21 and SO91-22A + B. The location and dimensions of these marker horizons, in relation to core depth in each of the three cores, was measured when the cores were freshly opened. To compare differences in sediment thickness between individual marker beds, a quotient Q (Figure 3 and Table 1) was calculated by dividing the distance between two adjacent markers in SO91-21 by the distance between the same markers in SO91-22A + B.

Table 1. Comparison of the distance between the three topmost marker layers

Markers	SO91-21	SO91-22A+B	Q
Surface to H9	33.0 cm	48.0 cm	0.687
H9 to H1	91.8 cm	113.8 cm	0.807
H1 to G6	11.2 cm	10.2 cm	1.098

The stratigraphic records preserved in both cores corroborate results previously obtained from the Soppensee basin (Sturm & Lotter, in prep.). The parallel cores of the Kullenberg and Livingstone systems are macroscopically comparable. They show that identical lithologies, stratigraphic sequences, and individual marker beds can be correlated between both cores. To prove the microstructural correlation of the cores, we prepared x-ray radiographs and sediment thin-sections from different lithological units of both cores (Figure 3). Detailed examination of the radiographs and thin-sections should either reveal differences between the two coring methods or allow us to assess the extent of structural damage, if any, that either coring method might have caused.

X-radiographs (Figure 4) of epoxy-impregnated, 2 mm thick slabs of freeze-dried sediment (Mehl & Merkt, 1992) reveal an almost perfect correspon-

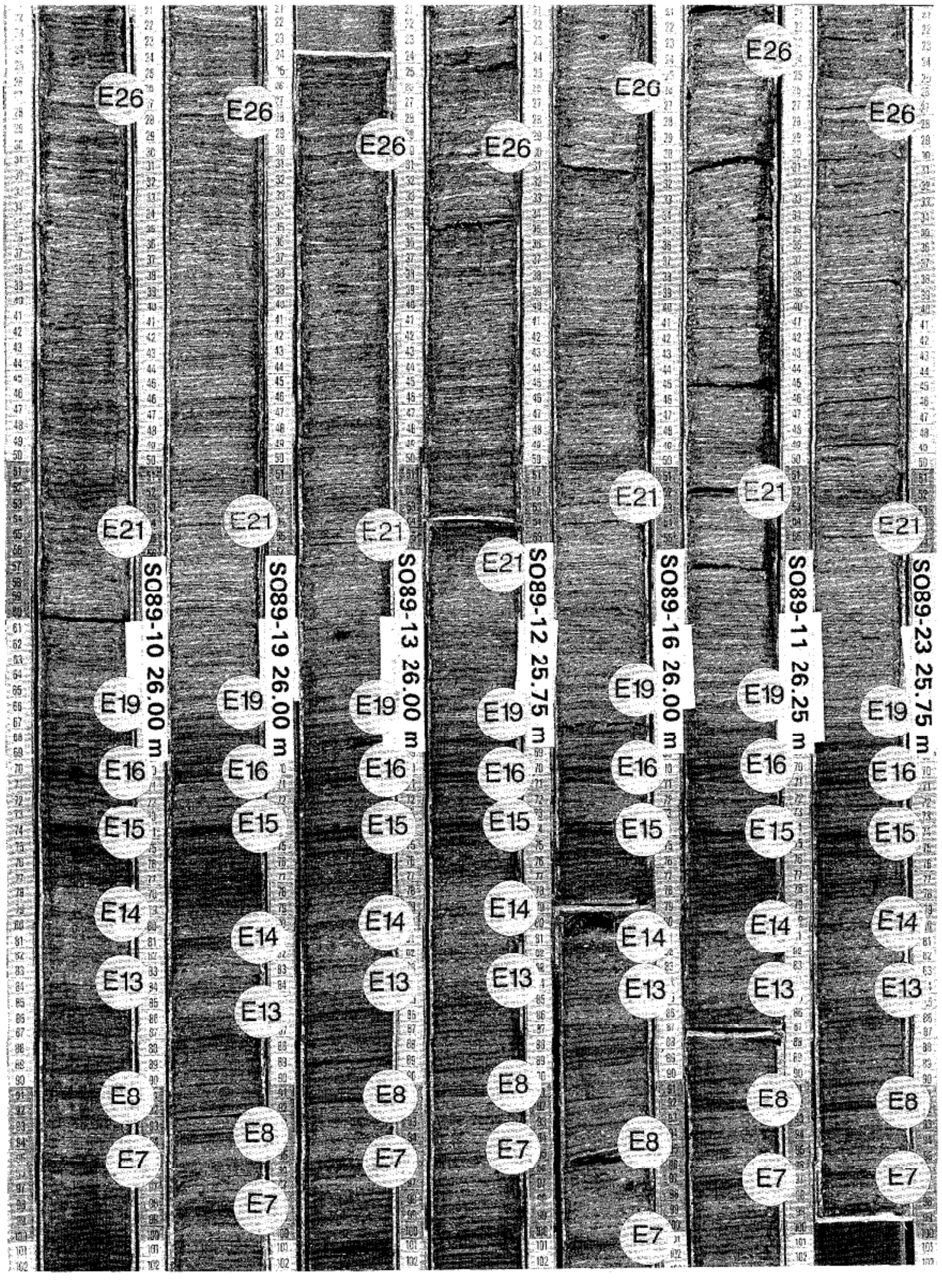

Figure 2. Photograph of different core sections from the deepest part of the Soppensee basin (for location see Figure 1). Some distinct markers in the cores are indicated. Scale in cm.

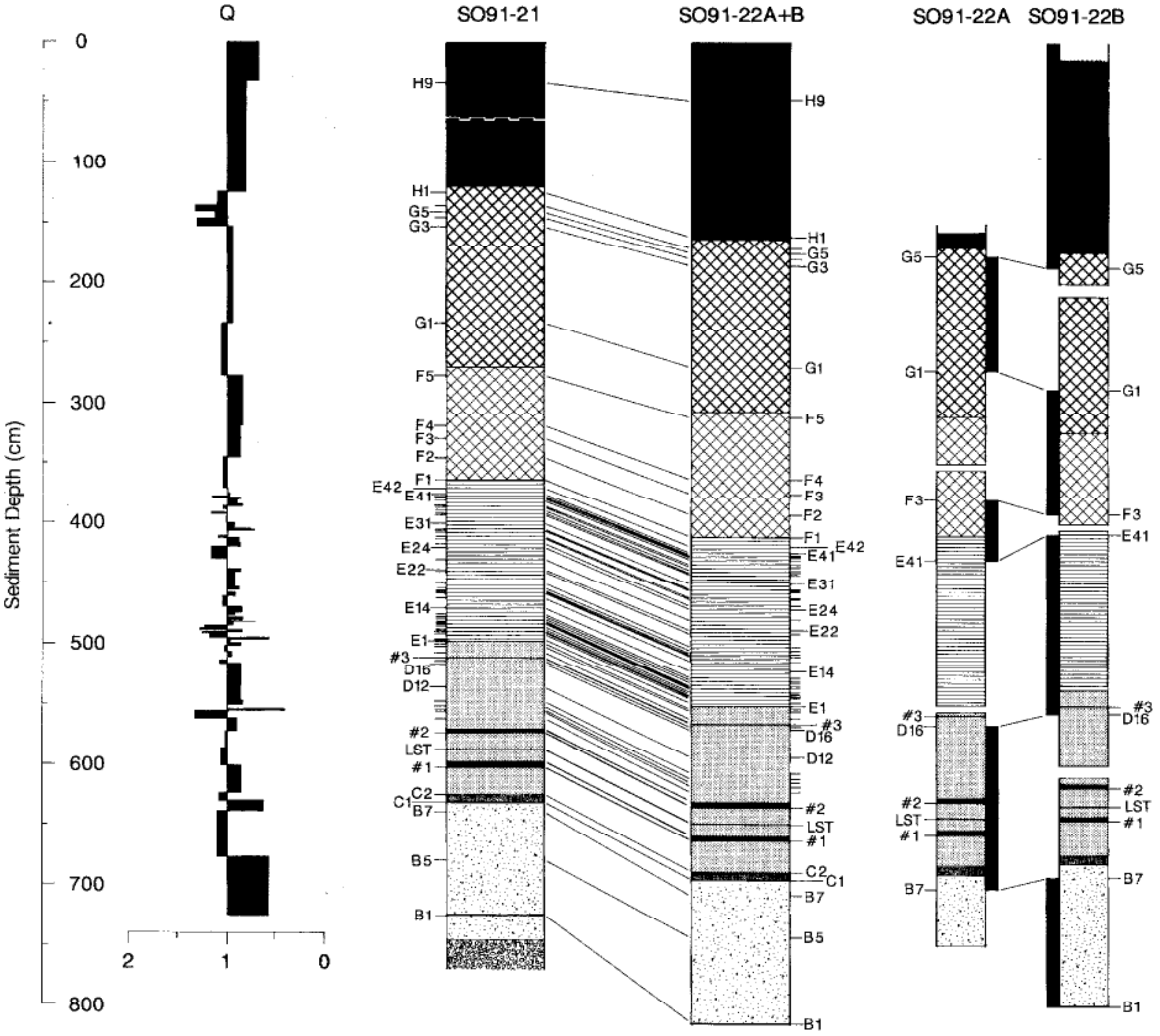

Figure 3. Lithology and position of 75 stratigraphical markers in cores SO91-21 (Kullenberg) and SO91-22A + B (hypothetical Livingstone). For graphical reasons not all markers are labelled. The black vertical bars on the actual Livingstone cores SO91-22A and SO91-22B indicate the segments used to construct the hypothetical Livingstone core. Specific stratigraphical markers used for the correlation are indicated. Q represents the quotient of the distance between two adjacent markers (for details see text).

dence between the two cores. Minor differences on a millimetre-scale, however, can be observed, both in the thickness of some of the short sequences and in the development of unique lithological features, such as the thickness of individual laminae (e.g. the pair at marker F4 in Figure 4) or the frequency of vivianite lenses (Figure 4 around marker G1).

Microstratigraphic analyses of thin-sections (Figure 5) of freeze-dried samples (Merkt, 1971; Lotter et al., in prep.) show how well sedimentary structures are preserved. There is no indication of any distortion of laminae or subunits of laminae that could be attributed to the coring techniques applied. Some disturbances of the laminations (e.g. cracks, Figure 4) can clearly be attributed to inappropriate handling during sub-sampling and/or insufficient freeze-drying. Individual layers of specific particles, such as calcite or diatoms, have not been modified by coring forces. Figure 6 illustrates the perfect preservation of small scale sedimentary structures in the thin-section samples. In this example, subtle bioturbation burrows pierce a thin layer of graded silt and clay and penetrate the underly-

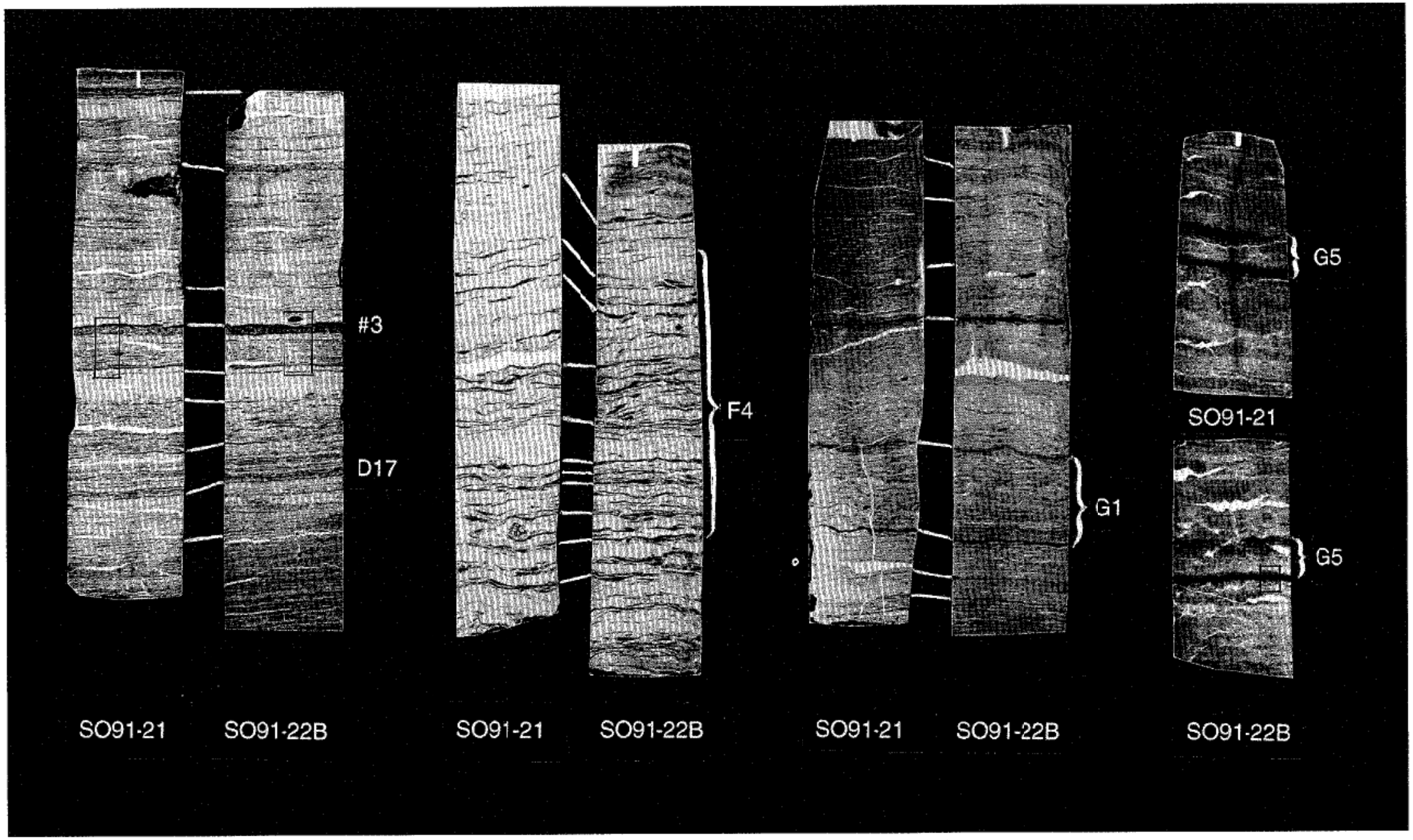

Figure 4. X-radiographs of 4 pairs of samples from Livingstone cores (SO91-22B) and Kullenberg cores (SO91-21). Characters and numbers at the right side of each pair correspond to the markers in Figure 3. The rectangles at markers #3 and G5 indicate the location of the section depicted in Figures 5 and 6. The radiographed slabs are approx. 10 cm long and 2 mm thick.

Table 2. Sediment thickness (in cm) between some markers in different cores from the deepest part of Soppensee

Marker	SO89-17*	SO89-19*	SO89-23*	SO91-21*	SO91-22A + B**	SO91-22A***	SO91-22B***
B6 to B7	34.5	34.5	32.0	38.5	34.9	34.9	34.0
C1 to C2	5.0	4.0	3.0	6.5	6.0	6.0	6.8
# 1 to LST	14.5	9.7	7.7	15.0	14.1	14.1	12.8
LST to # 2	13.5	12.7	7.5	13.7	13.5	13.5	14.5
D6 to D7	3.2	2.3	–	3.4	3.4	3.4	–
D19 to D20	4.2	4.2	3.5	5.3	5.2	–	5.2
E2 to E3	6.0	4.0	5.2	4.0	3.4	4.8	3.4
E11 to E12	2.2	1.7	1.7	1.5	1.5	1.4	1.5
E15 to E16	3.5	3.0	2.9	3.1	3.4	3.4	3.4
E17 to E18	1.5	1.5	1.3	1.6	1.6	1.4	1.6
E19 to E20	3.3	3.0	3.0	3.5	3.8	3.1	3.8
E21 to E22	3.0	2.7	2.5	2.4	2.8	2.2	2.8
E25 to E26	4.7	4.1	4.5	4.2	4.8	4.0	4.8
E29 to E30	1.3	1.3	1.0	0.9	1.2	0.9	1.2
E31 to E32	7.0	7.0	7.5	7.4	7.4	5.0	7.4
E36 to E37	1.3	3.0	4.5	3.9	4.4	4.3	4.4
E40 to E41	1.7	2.3	2.2	2.4	2.5	2.4	2.5
E42 to F1	8.5	7.7	8.2	7.7	7.5	7.5	–
F2 to F3	17.5	17.1	12.3	15.5	18.1	18.1	–
F4 to F5	–	54.9	43.0	42.0	50.4	–	50.4
G1 to G3	–	72.5	87.5	80.3	84.9	85.4	93.3
G4 to G5	5.0	4.2	4.5	5.5	4.9	4.9	–
H6 to H9	39.2	78.0	68.0	55.0	–	–	–

* Kullenberg cores.
** hypothetical Livingstone core.
*** Livingstone cores.

ing indistinct siderite and calcite layers. The burrows originate from an almost homogenized unit overlying the carbonate layers.

Discussion

Lithological, stratigraphical, and microstructural details are reproducible in cores using both coring systems. Moreover, these features can be precisely correlated from one core to the other. The main difference between the two systems is the overall length of core recovery. Although its lowermost deposits are stratigraphically younger, the combined Livingstone core SO91-22A + B appears to be 51 cm longer than the Kullenberg core SO91-21. If we correlate between the lowermost mutual marker B1 (Figure 3), which is presumed to be synchronous between the two cores, a difference of 90 cm, or slightly more than 10%, is observed between the two cores. One reason for this discrepancy is obviously the fact that it has not been possible to exactly correlate the trigger gravity core with the topmost segment of the main Kullenberg piston-core SO91-21. There must be some sediment missing from the top of the main core as indicated by the distance between sediment surface and the first marker H9 in the two cores (see Table 1 and Figure 3). We estimate this missing part between the trigger gravity core and the main piston-core to be about 20–30 cm. This hiatus, however, would still not fully compensate for the discrepancy observed between the core recovery of the two systems.

If the depths of the markers in core SO91-21 (Kullenberg) are plotted against their depths in SO91-22A + B (Livingstone), the data points lie on an almost straight line (Figure 7) with the exception of the top and the lower end of the cores. These main differences also become obvious if we look at the quotient Q (Figure 3) calculated from the distance between adjacent markers in the two cores. Values below 1 indicate longer

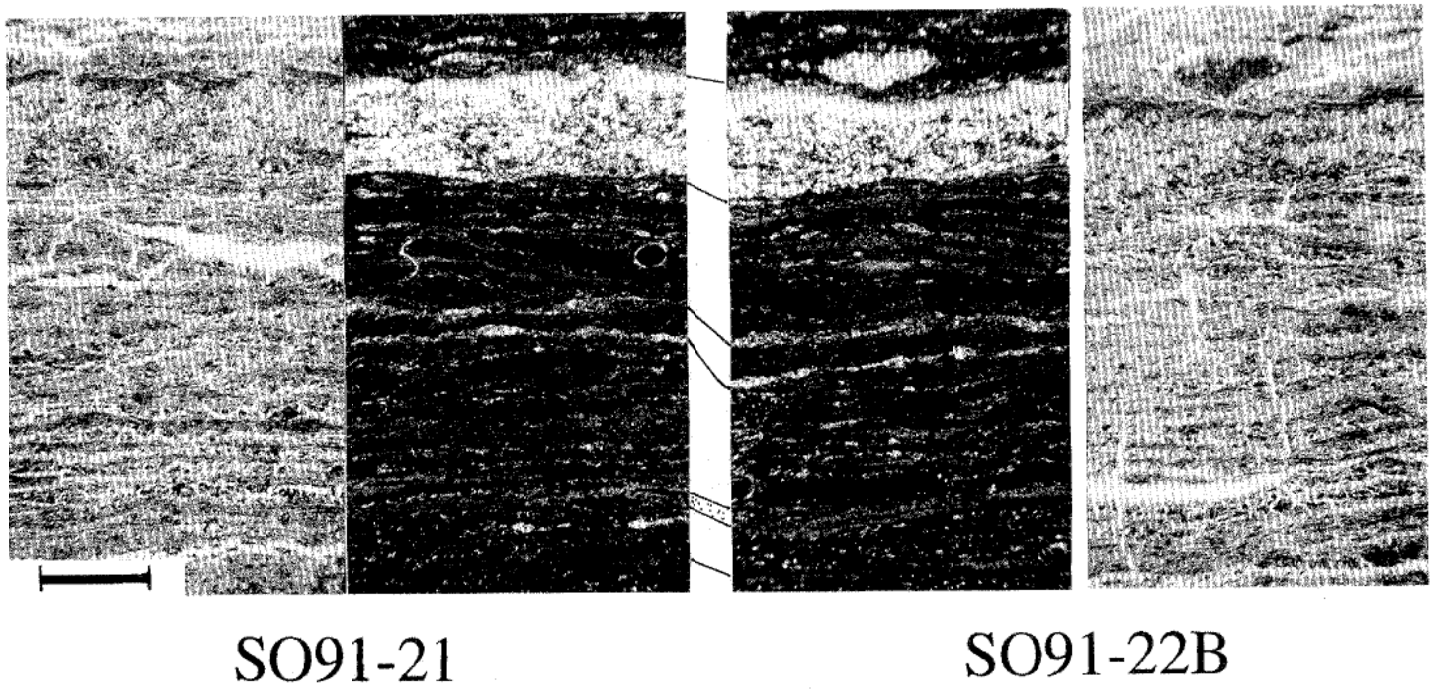

Figure 5. Thin-section photographs of marker #3 (see Figures 3 and 4). Pairs of photographs (crossed nicols and parallel nicols) of samples from the Livingstone core (SO91-22B) and from the Kullenberg core (SO91-21). Dark photographs in the centre (crossed nicols): near the top is a layer of coarse detrital calcite crystals grading upwards, with some quartz grains(marker #3); possibly a mini-turbidite. Below: lamina of fine calcite crystals with some clastic (bright) alternating lamina of minute siderite crystals (fine grey). Light photographs (parallel nicols): darker lines with organic detritus, including chrysophyte cysts and pollen interbedded with calcite and clastic grains. Light grey lines in between: unstructured, monotonous, reticulately-cracked organic matrix, containing clouds of minute siderite crystals ('summer layer'). The reticulate cracks are freeze-drying artefacts. Scale bar: 2 mm.

Figure 6. Thin-section (crossed nicols) of the lower part of marker G5 of the Kullenberg core (the position of G5 in the profile is shown in Figures 3 and 4). For explanation see text. Scale bar: 1 mm.

distances between the same markers in SO91-22A + B (Livingstone), whereas values above 1 imply longer separations in SO91-21 (Kullenberg). Out of a total of 75 correlated markers, 42 Q-values (56%) have values below 1, i.e. the distances between the markers are generally longer in core SO91-22A + B (Livingstone). Only 21 Q-values (28%) are above 1. In 12 cases (16%) the distance between the markers is identical in both cores, i.e. Q = 1. The lowest Q-values, i.e. the major discrepancies in favour of the Livingstone corer, occur in the topmost (markers H9, H1) and in the lowermost deposits (markers B1, B6, B7). One reason for the shorter upper part preserved in the Kullenberg core (SO91-21), consisting mainly of water-rich, weakly compressed, calcareous gyttja, could be that this part of the sediment column has had to pass through the entire length of the plastic liner of the piston corer. Thus, the uppermost, unconsolidated parts of the core have been partly mixed. Moreover, a hydraulic shock wave in front of the piston corer may have pushed away part of the unconsolidated surficial sediment (see, e.g., Stowe & Aksu, 1978; Blomqvist, 1991).

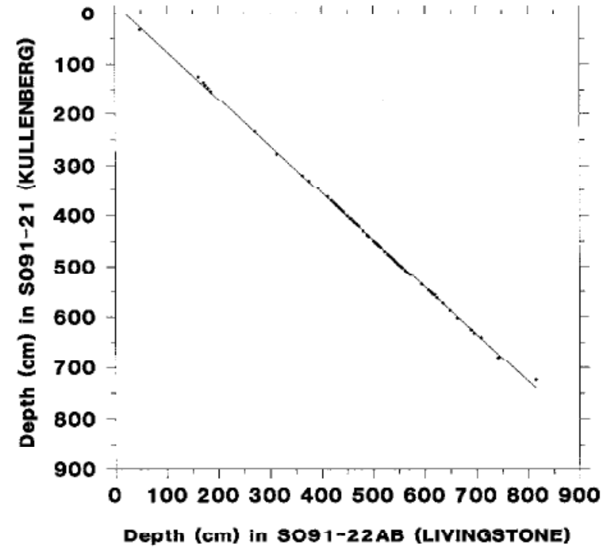

Figure 7. Depth of the 75 identified stratigraphic markers in core SO91-22A + B (Livingstone core) plotted against their depth in core SO91-21 (Kullenberg core). The line fitted through the data points is based on a linear smoother.

Another reason for the differences in thickness of sediment between the marker layers involves gas expansion within the sediments (see, e.g., Ohle, 1978). Gas expansion has often been observed when cores are raised to the lake surface. This expansion effect is due to decreases in pressure associated with decreasing water depth (1 bar per 10 m of water depth) and increases in temperature, thereby provoking a rapid expansion of gases, such as methane, that are enclosed in the sediment. This expanding gas forms bubbles which then inflate and thus may 'stretch' the sediment. Since expansion in the horizontal direction is confined by the enveloping liner tube, the sediment can only move vertically. This effect appears to be more pronounced with increasing abundance of sedimentary organic matter and with increasing porosity. The artificial 'growth' of sediment can be blocked by placing plastic caps onto the ends of the segments immediately after core recovery. Nonetheless, depending on the pressure built up inside the liners, the caps may be detached or the pressure may sometimes even burst the liners. With the Kullenberg corer the problem of gas expansion can usually be controlled, since the top and the bottom of the 9 m long liner is blocked by the piston and the core catcher, respectively. Additionally, the bottom of the sediment core is often a stiff clay. Therefore, no overall vertical sediment 'growth' can be generated using this system. In contrast, in the Livingstone system, with its shorter 2 m segments, gas expansion affects the sediment even while the core is being hauled to the water surface. In this case, while the top of each liner is blocked by the piston, the bottom end remains open, often allowing 5–15 cm of sediment to be extruded out of the corer by expanding gas. Since the Livingstone cores have been taken with a vertical overlap of 50 cm, the loss of some sediment at the bottom of each segment does usually not hamper correlation between parallel cores. Commonly, Livingstone cores are extruded and the pore volumes produced by expanded gas are eventually compressed again. Thus, with the Livingstone system, it is possible that, although a drive of 100 cm is expected according to the coring rods, core recovery of only 90 cm may be achieved. For this study, however, the 2 m Livingstone segments were not extruded, but cut open the same way as the Kullenberg segments. A growth in sediment between core recovery and the opening of the segments has been observed which accounts for some of the discrepancies between core recovery rates using the two coring methods.

An alternative explanation for the observed differences in total core recovery between the two systems may arise from system-inherent deficiencies. In both systems the piston is stationary during coring while the core barrel with the liner is pushed over the piston. Friction on the inner wall of the liner may cause the sediment core to lag behind the advance of the core barrel, while the piston builds up a vacuum which acts against this friction. Such retardation of the penetration rate of the corer will cause sediment to be pushed aside and lost. This mechanism can, however, only occur if air, or methane in the case of Soppensee, were present below the piston, because water being essentially incompressible. The effect of plugging of the corer has been mainly described from studies using gravity cores (see, e.g., Piggot, 1941; Lebel et al., 1982; Blomqvist, 1991; Cumming et al., 1993) but may also occur with piston corers (see, e.g., Wright, 1980, 1993). Yet, in our case neither x-radiographs nor thin-sections show any structural evidence for a differential loss of sediment.

Since constant Q-values do not exist, neither between the Kullenberg and the Livingstone cores, nor between the parallel A and B cores of the Livingstone sampler (see Table 2), another alternative explanation can be considered. Differential penetration of portions of the sediment into the liners of the Livingstone corer may occur due to unsteady downwards pressure applied to the rods by the coring crew. This alternative is unlikely, however, since the synchroneity of any downwards movement of the core barrel, as well as the locked position of the piston, are not affected. Yet, the Kullenberg corer operates basically with the same technology. This device will also slow down and even accelerate on its way through sediments of different penetrability, until penetration is terminated by any hard lithology. The only difference between the Livingstone and the Kullenberg systems is that the velocity of the Kullenberg device is not manually controlled but, once released, its ability to penetrate different sediment types is determined by its momentum and its own constant weight. Identical segments of Kullenberg cores taken at closely situated places in comparable sedimentary conditions are therefore expected to give constant or regular Q-values (and a near 1 to 1 ratio of core to nature). Several cores retrieved in the deepest part of the Soppensee basin, less than 50 m apart, however, have irregular Q-values (Figure 2 and Table 2). Since this occurred with an identical sampling device and within similar sediment, it is inferred that the differences in vertical distance between markers in all of these cores are mainly of primary origin and have not arisen due to coring artifacts. Moreover, varve counts between markers in different cores produce comparable time-spans between these markers, whereas the sediment accumulation rate is, of course, proportional to the amount of sediment between these markers.

Conclusions

Kullenberg and Livingstone cores taken in Soppensee, an eutrophic Swiss lowland lake, have produced comparable results with regard to lithology and sediment microstratigraphy. The Livingstone system with its shorter recoverable segments may, depending on the gas content of the sediment, produce artificially longer cores, whereas the cores obtained by the Kullenberg system are not significantly affected by interstitial gas expansion. The differences observed between well defined marker horizons (Figure 2) in Soppensee are not due to the type of coring system used. These variations seem to reflect natural sedimentary patterns, which are inherently more complex than the simple parallel-bedded units usually depicted in models of lacustrine sedimentary environments. In fact, close examination of x-radiographs and thin-sections taken from core samples often reveal undulating and wavy microstructures along the bedding planes separating laminae. This is consistent with observations of modern lacustrine water/sediment interfaces, where the lake floor is generally uneven and pock-marked and exhibits randomly distributed, centimetre-scale crests and hollows (Sturm, 1990). Sedimentary structures in heterogeneous lacustrine sediments are also influenced by complex interactions between biological and physical processes, such as methane ebullition and animal activities before, during, and after deposition. Furthermore, differential sediment compaction, as well as the fine-scale topographical patchiness of the sediment surface, might also account for the differences in sediment accumulation encountered in a lacustrine sedimentary basin (Sturm, 1990).

The comparison of the two coring methods indicates that caution must be exercised when calculating and comparing accumulation rates. Accumulation rates can only be evaluated on a sound basis if a high-resolution temporal framework can be established for the sedimentary column, e.g. by annually laminated sediments. Otherwise we may be mislead by differential 'stretching' or compression of the sediment caused by some of, or a combination of, processes outlined in this study.

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References

Blomqvist, S., 1985. Reliability of core sampling of soft bottom sediment – an in situ study. Sedimentology 32: 605–612.

Blomqvist, S., 1991. Quantitative sampling of soft-bottom sediments: problems and solutions. Marine Ecology Progress series 72: 295–304.

Crusius, J. & F. Anderson, 1991. Core compression and surficial sediment loss of lake sediments of high porosity caused by gravity coring. Limnology and Oceanography 36: 1021–1031.

Cumming, B. F., J. R. Glew, J. P. Smol, R. B. Davis & S. A. Norton, 1993. Comment on 'Core compression and surficial sediment loss of lake sediments of high porosity caused by gravity coring' (Crusius & Anderson). Limnology and Oceanography 38: 695–699.

Hongve, D. & A. H. Erlandsen, 1979. Shortening of surface sediment cores during sampling. Hydrobiologia 65: 283–287.

Kelts, K., U. Briegel, K. Ghilardi & K. Hsu, 1986. The limnogeology-ETH coring system. Schweizerische Zeitschrift für Hydrologie 48: 104–117.

Kullenberg, B., 1947. The piston core sampler. Svenska Hydro-Biol. Komm. Skr. 3: 1–46.

Lebel, J., N. Silverberg & B. Sundby, 1982. Gravity core shortening and pore water chemical gradients. Deep Sea Research 29A: 1365–1372.

Livingstone, D. A., 1955: A lightweight piston sampler for lake deposits. Ecology 36: 137–139.

Mackereth, F. J. H., 1958. A portable piston sampler for lake deposits. Limnol. Oceanogr. 3: 181–191.

Mehl, J. & J. Merkt, 1992. X-ray radiography applied to laminated lake sediments. Geological Survey of Finland Special Paper 14: 77–85.

Merkt, J., 1971. Zuverlässige Auszählung von Jahresschichten in Seesedimenten mit Hilfe von Gross-Dünnschliffen. Archiv für Hydrobiologie 69: 145–154.

Merkt, J. & H. J. Streif, 1970. Stechrohr-Bohrgeräte für limnische und marine Lockersedimente. Geologisches Jahrbuch 88: 137–148.

Ohle, W., 1978. Ebulition of gases from sediment, conditions, and relationship to primary production of lakes. Verh. int. Ver. Limnol. 20: 957–962.

Piggot, C. S., 1941. Factors involved in submarine core sampling. *Bulletin of the Geological Society of America* 52: 1513–1524.

Ross, D. A. & W. R. Riedel, 1967. Comparison of upper part of some piston cores with simultaneously collected open-barrel cores. Deep Sea Research 14: 285–294.

Schneider, R., 1974: Vergleich der Bohrmethoden Hiller und Livingstone. Pollen et Spores 16: 489–492.

Stowe, D. A. V. & A. E. Aksu, 1978. Disturbances in soft sediments due to piston coring. Mar. Geol. 28: 135–144.

Sturm, M., 1990. Die Sedimente der verschiedenen Becken des Luganersees. Archive der See-Entwicklung. Int. Symposium *Limnol. Aspects and Management of Lake of Lugano:* 11.

Wieckowski, K., 1989. A new method of coring in deep lakes with rod-operated samplers. Boreas 18: 357–358.

Wright, H. E. Jr., 1980. Cores of soft lake sediments. Boreas 9: 107–114.

Wright, H. E. Jr., 1993. Core compression. Limnology and Oceanography 38: 699–701.