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RESEARCH REPORT

No. 9

A palaeolimnological evaluation of the extent and impact of atmospheric contamination and recent environmental change in two remote highland lakes in SE Siberia

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November 1994

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Final report for the NERC small research grant GB9/1032 entitled:

A palaeolimnological evaluation of the extent and impact of atmospheric contamination and recent environmental change in two remote highland lakes in SE Siberia.

By

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NOVEMBER 1994

INTRODUCTION

Recent work on atmospheric pollution and its effects on surface waters has focused mainly on areas receiving high acid deposition. There is now increasing interest in the effects and extent of atmospheric contamination in background areas outside these regions not only to establish impacts of long distance pollutant transport but also to identify undisturbed ecosystems where responses to future climatic change might be best detected. Recent developments in the former Soviet Union (FSU) have facilitated access to remote regions of Eurasia where recent environmental change impacts on natural ecosystems are poorly known. The Khamar Daban Mountains in SE Siberia is one remote region that lies in the main trajectory paths of polluted air masses from industrialized centres in Europe. Investigation of the effects of atmospheric pollution in this region is important for several reasons but especially because it contains the world's largest undisturbed boreal wilderness area.

Recent sedimentary records from two high mountain soft-water lakes in this mountain range are used to reveal the regional extent and timing of atmospheric contamination and environmental change. This report details the first palaeolimnological investigation of sensitive mountain lakes in Central Asia and demonstrates the value of these techniques in identifying trends in environmental change over recent decades at remote, unmonitored and unsurveyed sites.

SITES, STRATEGY AND POTENTIAL OBJECTIVES

Two lakes, Lake Kholodnoye and Lake Qvadratnoye, (Fig. 1) located above the tree-line in undisturbed granitic catchments were selected for sampling in 1991 and 1992. L. Qvadratnoye is about 14 km west of the former site and is located on the edge of the highland granite zone, partially facing Lake Baikal to the north west. Because of very limited survey time due to helicopter availability and the absence of any detailed maps of the area, morphometric data are lacking. However, in size L. Qvadratnoye is about 600 x 300 m and L. Kholodnoye is a little larger but considerably deeper at 25 m compared with 8.5 m in the former. L. Qvadratnoye is located at about 1600 m altitude, some 120 m lower than the other lake.

Water samples for chemistry determinations and several short sediment cores were retrieved from each site. A master core for each site (KOL3 and QAD2) was selected for dating. Core chronologies were established by radio-isotope assay and depth-age relationships constructed according to Appleby et al. (1986).

Sediment sub-samples from each master core were used for analyses of trace metals and spheroidal carbonaceous particles (SCPs are derived from fossil fuel combustion, see Rippey et al. 1984 and Rose 1991 for descriptions and methods). Combined with sediment chronology, these data enable time trends in site contamination to be inferred.
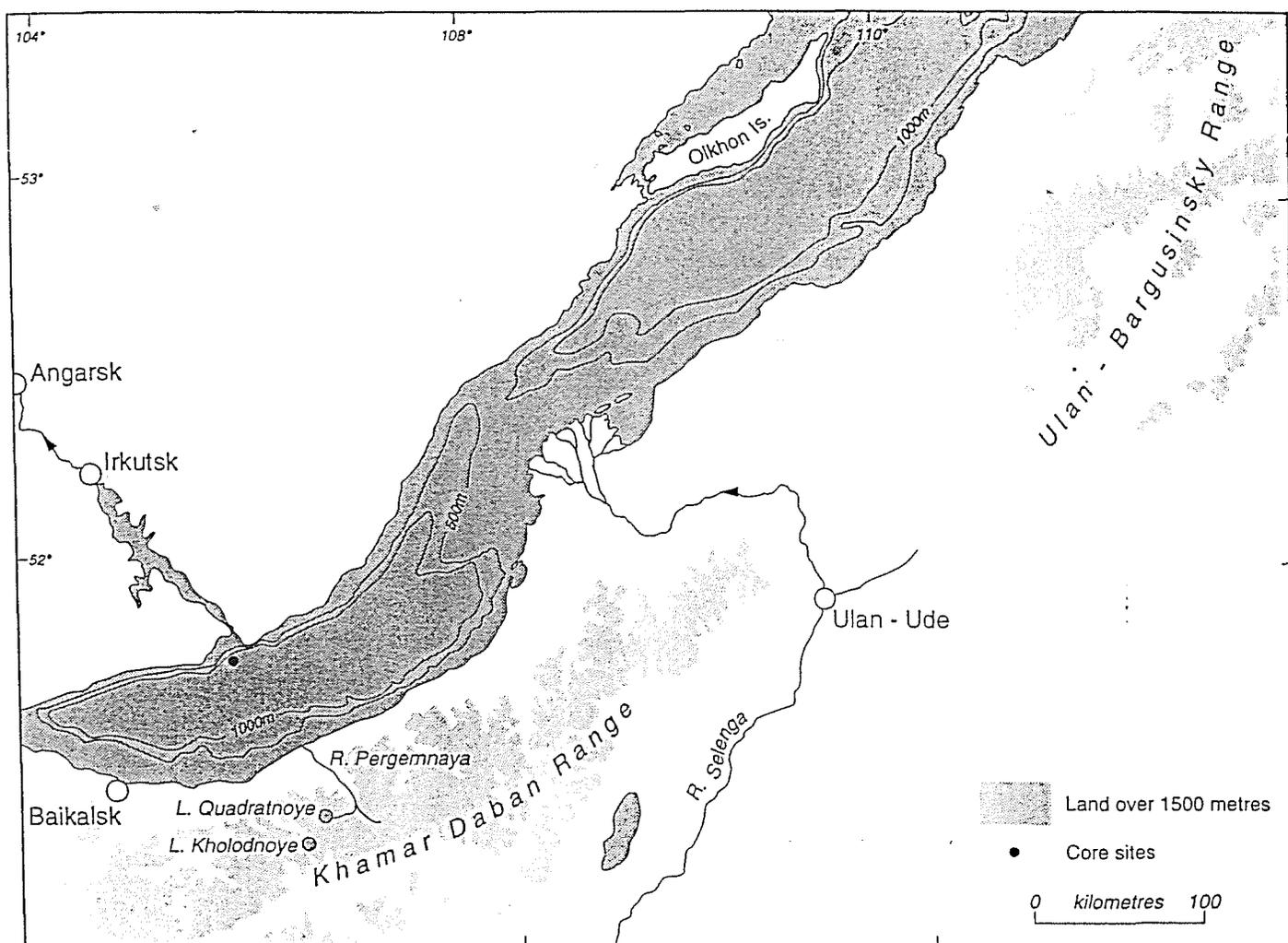
Figure 1. The locations of Lake Kholodnoye and Lake Qvadratnoye in the Khamar Daban Mountains, southeast Baikal, Siberia

Diatom analysis of each master core was undertaken to provide a record of environmental change at each site and comparison of this with geochemical evidence of pollution allows the ecological significance of any contamination to be assessed.

pH values for the past ca. 150 years were reconstructed for each site using the sedimentary diatom assemblages and the diatom pH calibration model (Stevenson *et al.* 1991, Birks *et al.* 1990).

RESULTS

Water chemistry

Water chemistry (determined at British and Russian laboratories, Table 1) shows that both sites are mildly acid and have very low concentrations of common cations. Results, particular for calcium, were inconsistent between laboratories and highlights some problems in cross laboratory comparisons of analytical results. Nevertheless, all the determinations showed Ca to be < 100 u eq l^{-1}; chloride was particularly low reflecting the continental location of the lakes and a small excess of sulphate was present at each site. Lake water at both sites was unstained by humic material and consequently the TOC value is low at < 1 mg l^{-1}.

Table 1. Water chemistry data for Lake Kholodnoye on two occasions: 14th July 1991 and 4th July 1993 as determined by the UK (A) and the Russian (B) laboratories (see text). Ionic concentrations are in u equivalents, TOC indicates total organic carbon in mg l^{-1}.

	pH	uS	ALK	Ca	Mg	Na	K	SO$_4$	Cl	TOC
1991	6.14	8	28	41	11	8	3	39	2	-
1993 A	6.14	8	25	11	8	8	3	44	2	0.8
1991	6.1	11	51	78	31	-	-	50	8	-
1993 B	6.1	11	39	80	16	-	-	52	8	-

Core lithostratigraphy and dating

Routine core measurements of sediment percentage dry weight and loss on ignition (at 550°C) for both cores (Figs. 2 & 3) show large variations with KOL3 profiles being dominated by a single major change at around 14 cm depth. There are several changes in QAD2, around 33, 19 and 10.5 cm.

Core dating shows that QAD2 has the highest and most variable sediment accumulation rate (SAR) with the top 10 cm representing 121 year of sediment accumulation, in KOL3 this depth represents 131 years. A peak in SAR in QAD2 occurs around 10.5 cm (1860) but the SAR also increases markedly in the upper 4 cm or post 1977 period. KOL3 shows only a small recent increase in SAR with highest values around 1870.

Geochemistry

Sedimentary metal concentration profiles in KOL3 (Fig. 7) show several features, peaks in Na, Mg and Ca around 15 cm depth, high concentrations of Fe and Mn at the core top, and a strong increase in Pb concentrations beginning at 9.5 cm (1860s). The marked fluctuation in alkali and alkali earth metals around 14 cm depth (early 19th century) in this core. This feature provides clear geochemical evidence of minerogenic sediment inwash and substantiates the lithostratigraphic record. In the upper 2 cm of sediment the Fe and Mn concentrations indicate re-cycling and re-precipitation of these metals caused by oxidization effects and the presence of an oxic mud-water interface. The Pb profile shows two isolated concentration peaks below 20 cm depth and a sustained concentration increase beginning at 9.5 cm and dated to the 1860s. This latter increase is not related to other geochemical changes and is suggestive of contamination from atmospheric pollution. The increases in Zn and Cu at the core top are difficult to ascribe to pollution because of possible co-precipitation effects.

Geochemical results for the Lake Qvadratnoye core are not yet available.

Spheroidal carbonaceous particles (SCPs)

The KOL3 SCP profile (Fig. 4) indicate an up-core increase in concentration, from the early 1970s to the core surface concentration of 2888 particles g^{-1} dry sediment. In QAD2 contamination begins in the early 1950s (Fig. 5); surface sediment concentrations are similar to KOL3 but the particle flux is higher.

Polychlorinated biphenyls (PCBs)

Full details of PCB analyses are given in Appendix 2 and show that in samples of the upper 1 cm of sediment collected from L. Kholodnoye and L. Qvadratnoye total PCB concentrations were 32 and 13 ng g^{-1} dry sediment, respectively. However, core bottoms, representing the pre-industrial period, show significant background concentrations of 9 and 7 ng g^{-1}, respectively. The background values probably stem from contamination during sampling procedures or from natural sources (see Appendix 2). Subtracting background from the surface sediment concentrations and assuming that the six bulked core tops from each site reflect the SARs calculated for KOL3 and QAD2, then the PCB values represent very similar fluxes of

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Figure 2. Lithostratigraphic profiles for the Lake Kholodnoye core (KOL3): percentage dry weight and organic content (loss on ignition at 550°C)
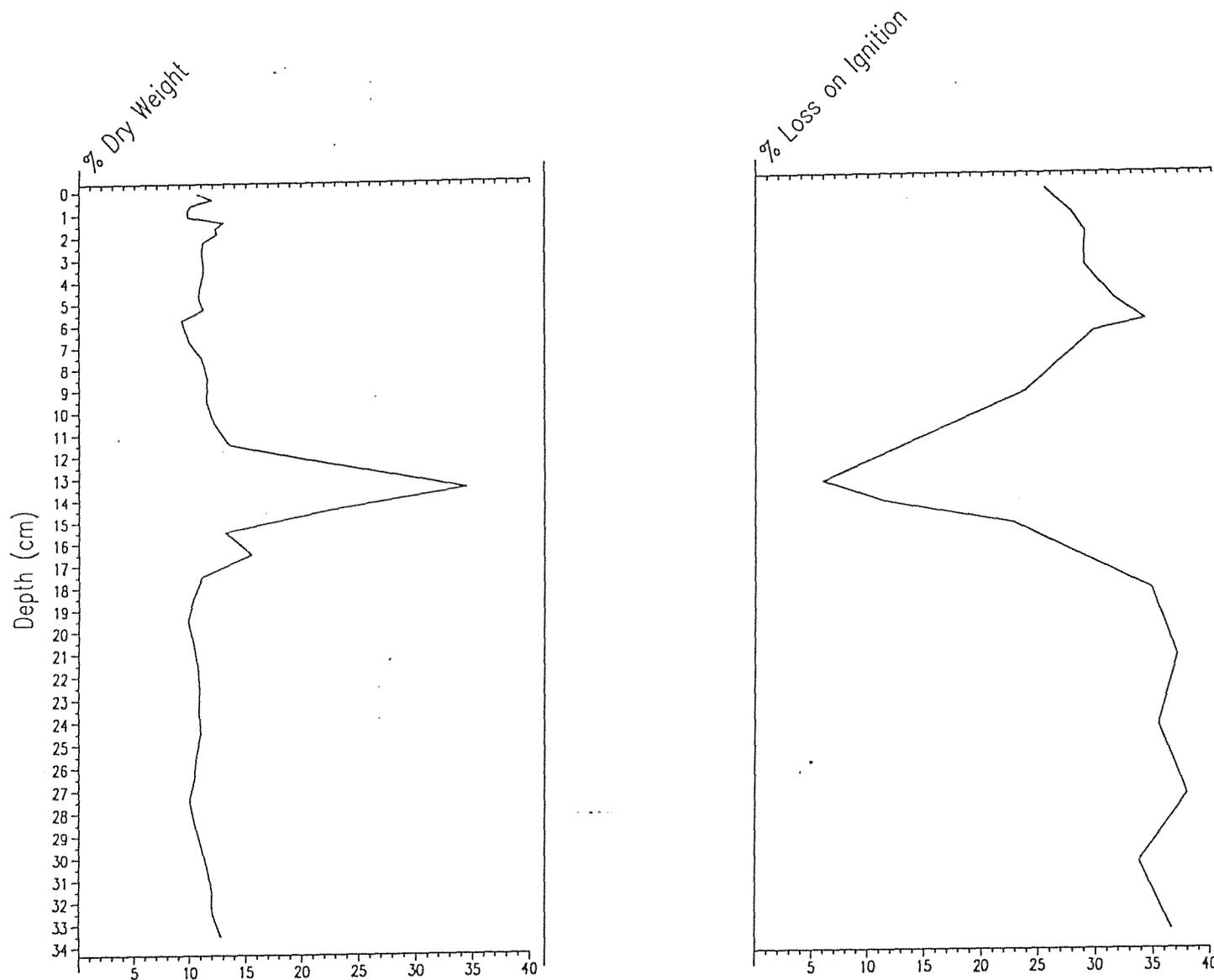
Figure 3. Lithostratigraphic profiles for the Lake Qvadratnoye core (QAD2): percentage dry weight and organic content (loss on ignition at 550°C)
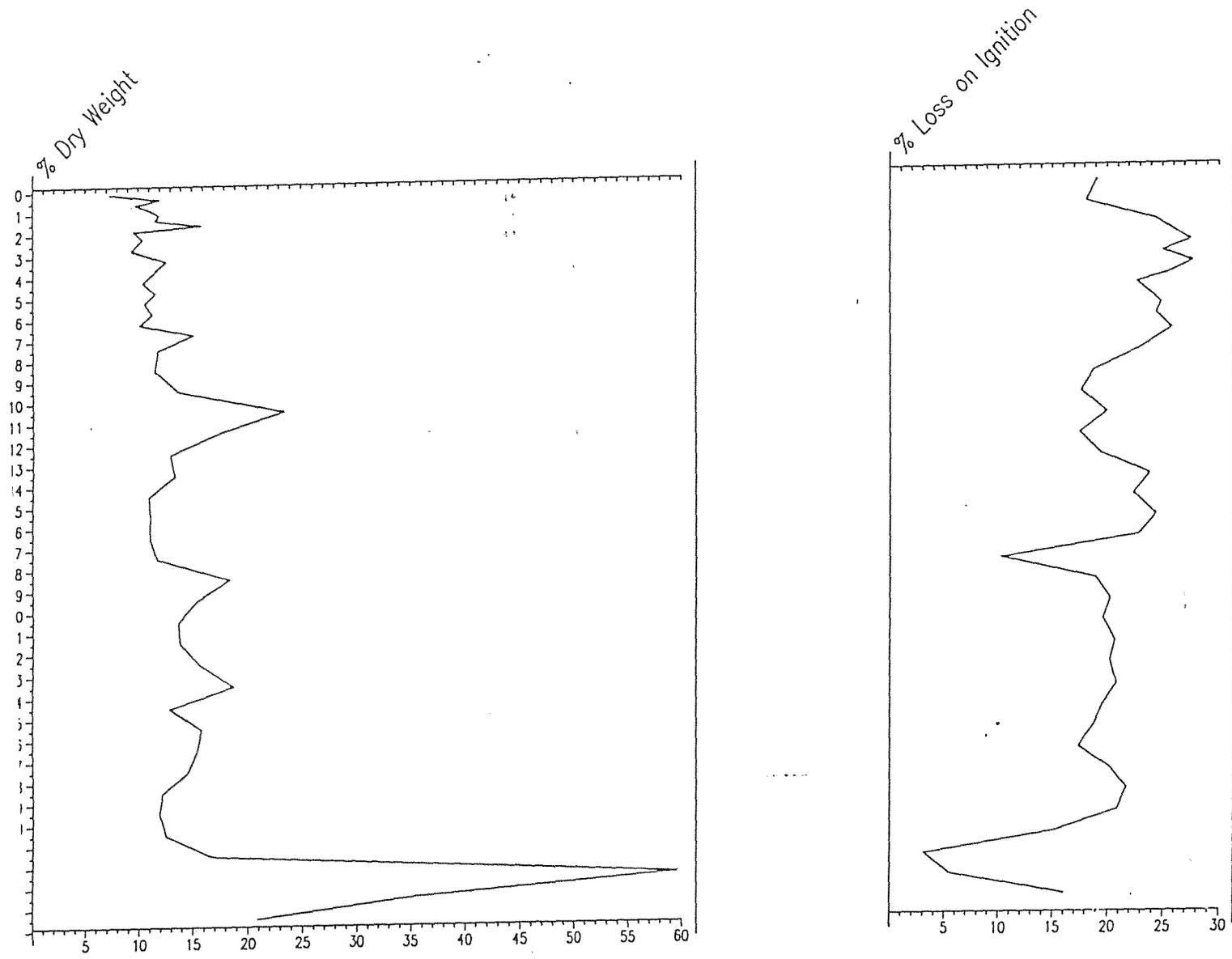
2.1 and 1.9 ng cm^{-2} yr^{-1} over approximately the last 10 years.

Diatoms

The diatom frequency diagrams for KOL3 shows that the common taxa, *Achnanthes marginulata, A. scotica, Aulacoseira distans* v. *nivalis* and *Frustulia rhomboides* v. *saxonica* are fairly uniformly distributed throughout the core. There is a tendency for abundances of *A. marginulata* and *Aulacoseira* taxa to fluctuate reciprocally.

In marked contrast, QAD2 diatom profiles show very non-uniform distributions with large changes in *F. elliptica* abundances occurring between 22-14 and 8.5-3 cm depth. These depths represent, respectively, a period ending in the 1820s and the 1890s - 1970s period.

The diatom taxa in both cores are well represented in lake floras known from soft-water sites in western Europe (cf. Stevenson *et al.* 1991). It is noteworthy however that *F. elliptica* is not normally encountered in acid highland lakes in this region and, despite the general similarity of floras, a species of *Stauroneis* in KOL3 is possibly new.

pH reconstructions

The reconstructed pH of KOL (Fig. 6a) show that lake acidity remained stable throughout the entire period spanned by the sediment core at around pH 5.2. This is despite the major lithostratigraphic fluctuation around 14 cm depth and the impact of atmospheric pollution since the mid 20th century.

Again in marked contrast, the pH curve for QAD (Fig. 6b) shows considerable change, the principal features being rises in pH values to above pH 7 around 18 cm depth and to pH 6.4 around 6 cm depth (1940s). These changes are mainly driven by increased abundances of *F. elliptica*, a species that has a relatively high optimum pH (Stevenson *et al.* 1991).

DISCUSSION

Both Lakes Kholodnoye and Qvadratnoye are inaccessible and remote and unaffected by catchment specific human activity. The sediment record at each site indicates a combination of diagenesis, catchment disturbance and atmospheric contamination but only at the latter site does the diatom record provide any evidence of water acidity changes.

Diagenesis

Diagenetic surface effects are demonstrated by the major increases in Fe and Mn concentrations in the upper 3 cm of KOL3. These result from recycling processes; Mn is converted to the soluble divalent form under less intense reducing conditions than iron so that, in the core, the peak in particulate manganese concentration is above that of iron. Although the behaviour of iron and manganese in lakes is now well known (Davison 1993), and the separation of peaks in particulate iron and manganese in the water column has been documented (Mayer *et al.* 1982, Cornwell 1986, Kawashima *et al.* 1988), there are few examples of this separation in lake sediments. In KOL3 these profiles indicate good oxygen

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Figure 4. Lake Kholodnoye summary diatom diagram, and diatom concentrations in core KOL3, 1993
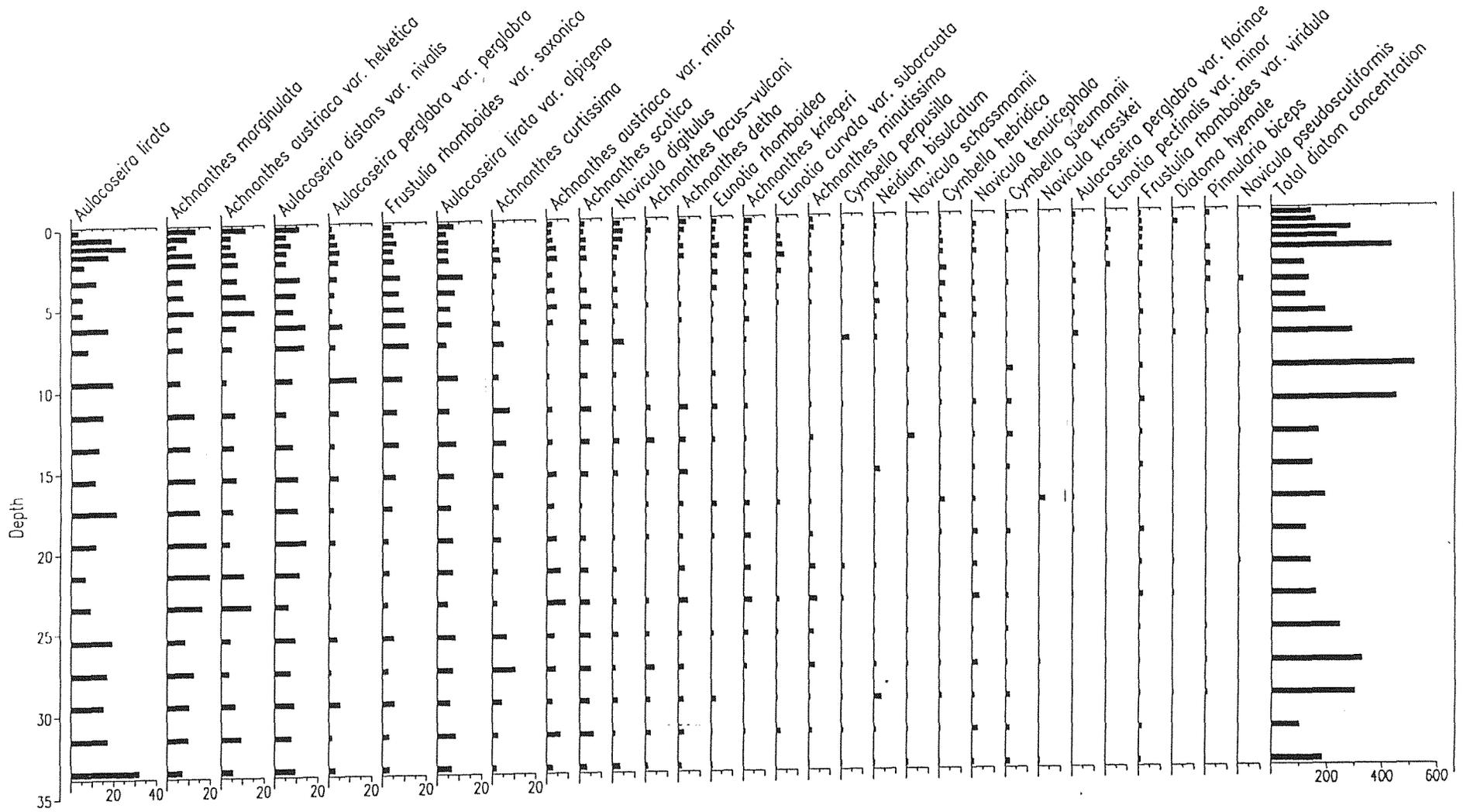
Figure 5. Lake Qvadratnoye summary diatom diagram and diatom concentrations in core Qad2, 1993
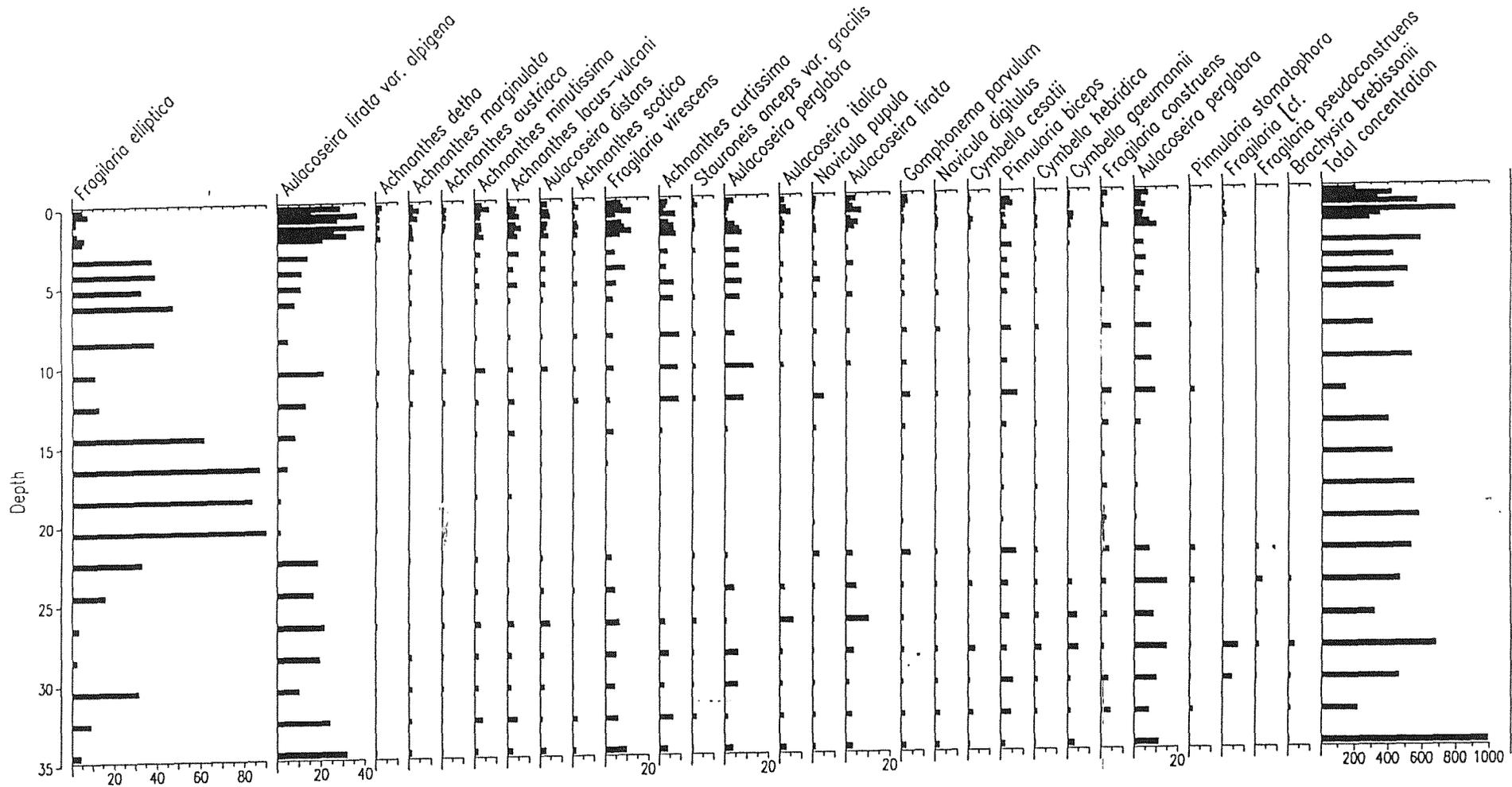
Figure 6a. Reconstructed pH profile
for the lake Kholodnoye core KOL3
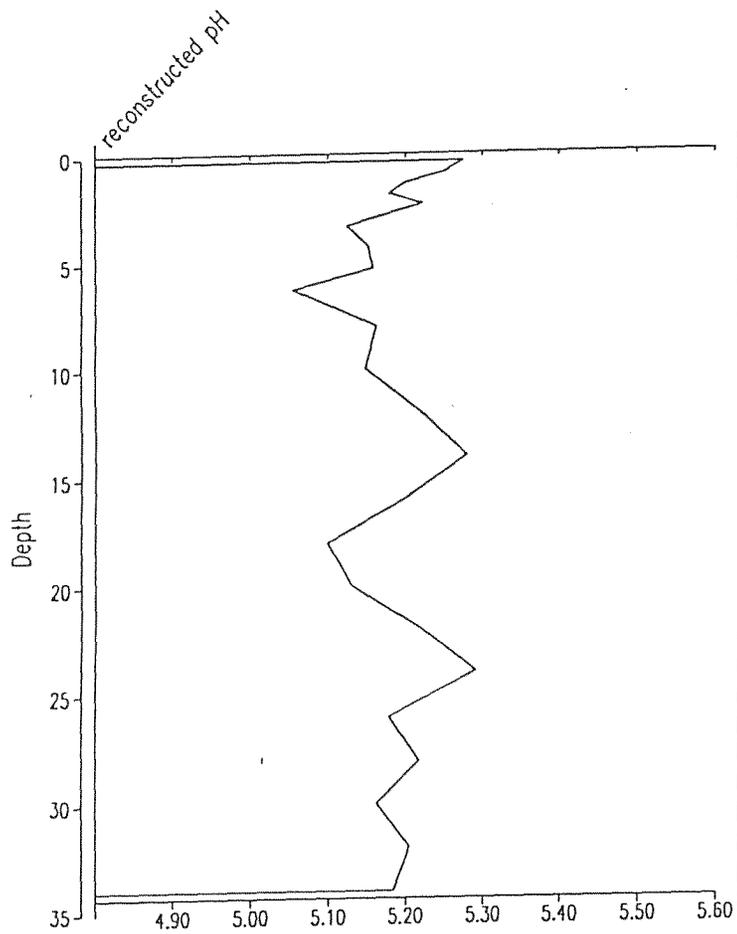
Figure 6b. Reconstructed pH profile
for the lake Qvadratnoye core QAD2
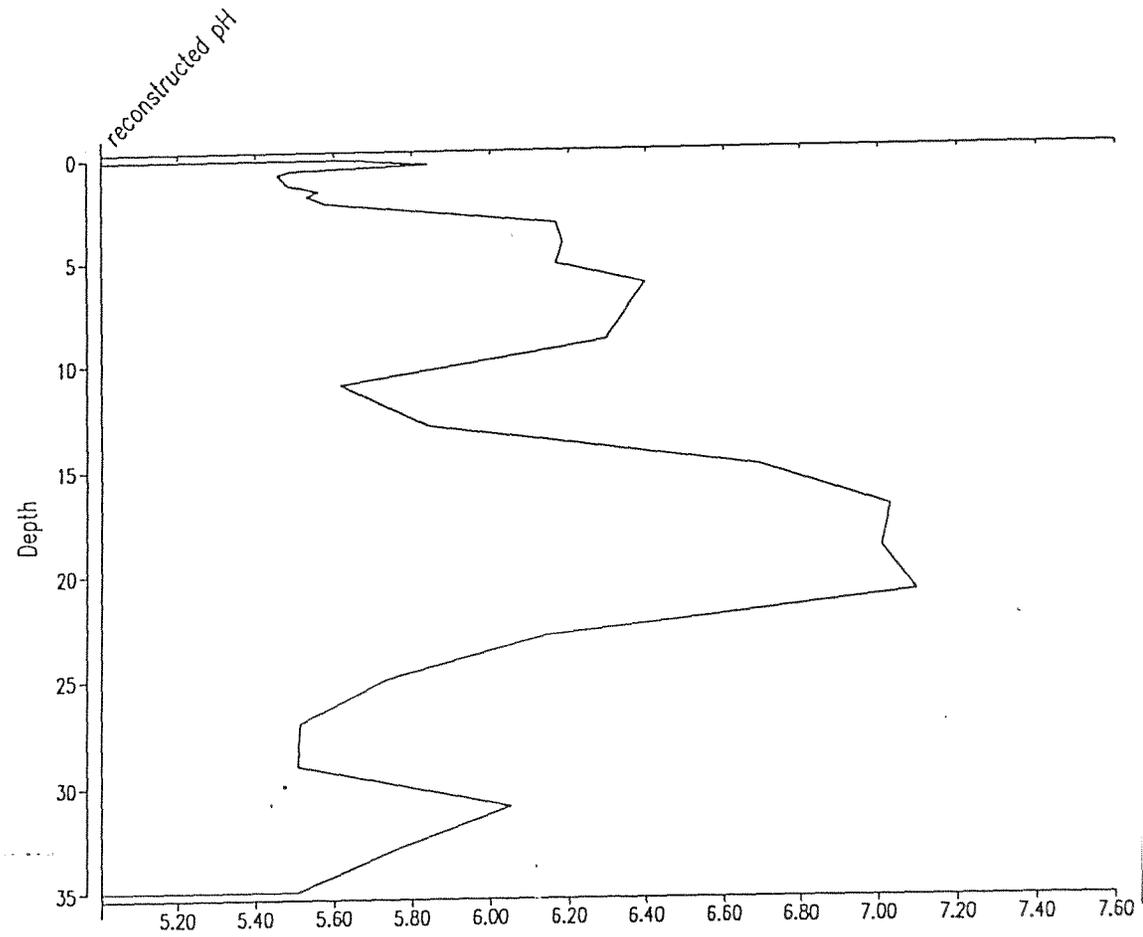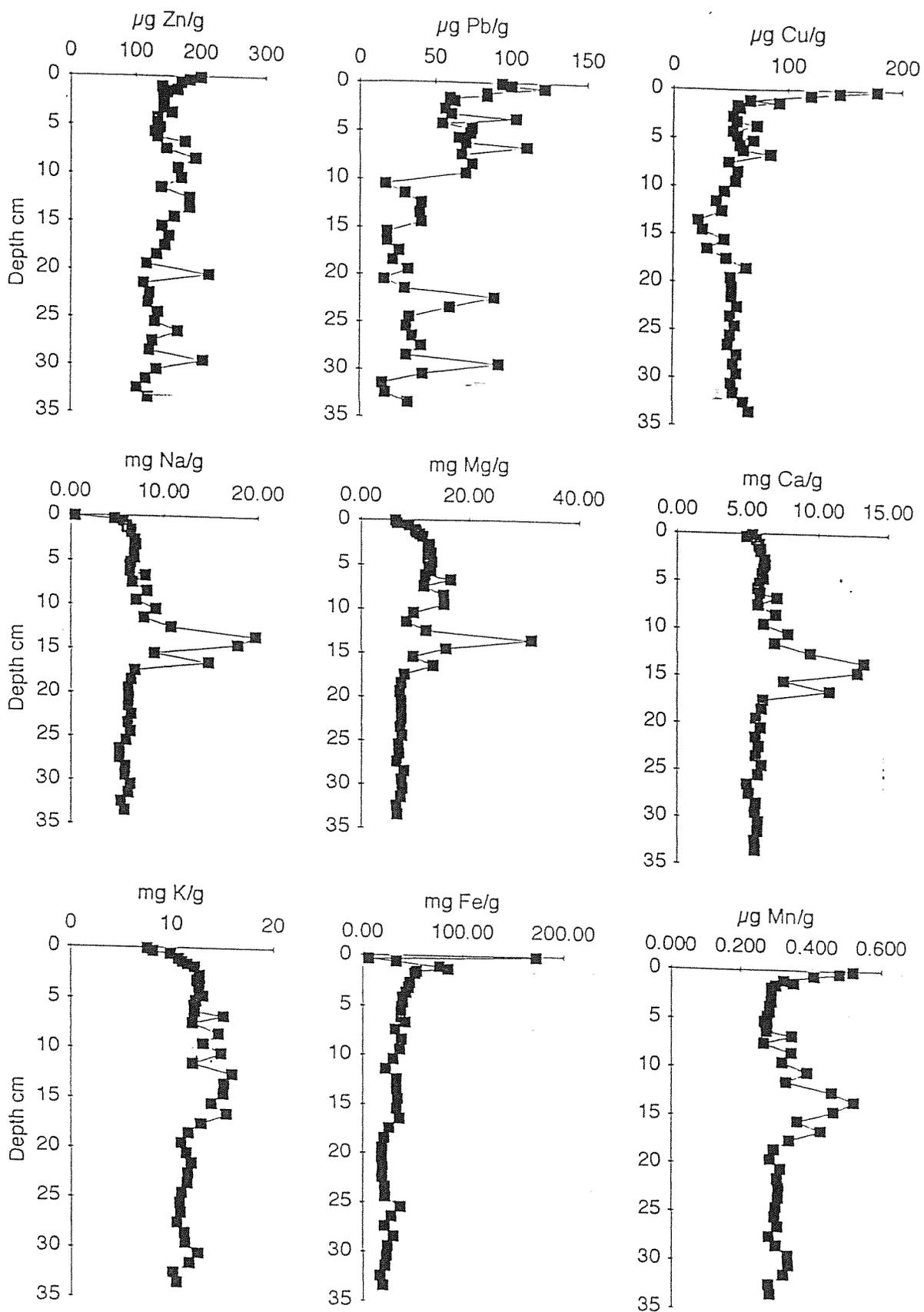
Figure 7. Geochemical profiles for the Lake Kholodnoye core (KOL3)
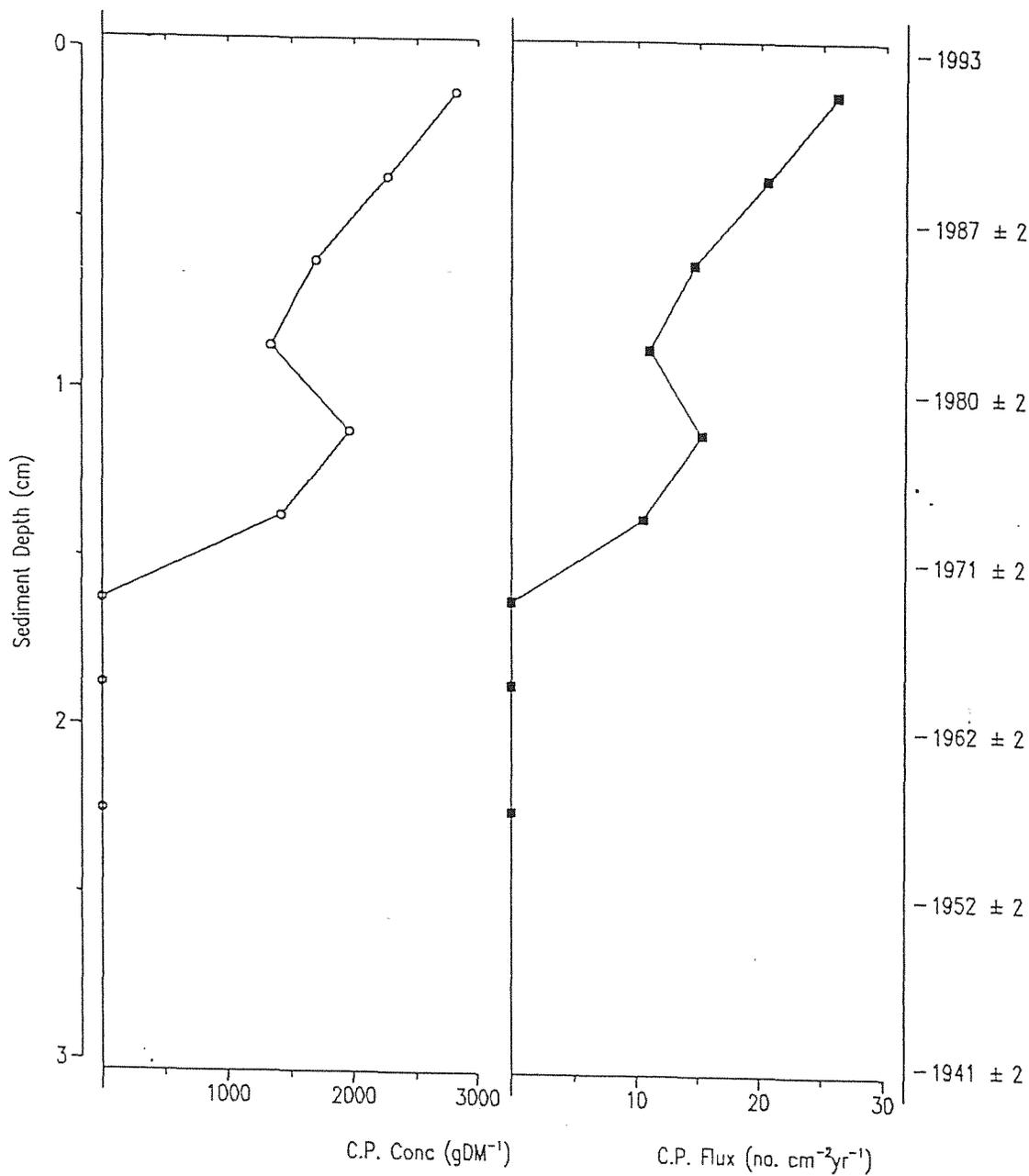
Figure 8. Spheroidal carbonaceous particle concentration and influx profiles for the Lake Kholodnoye core (KOL3)
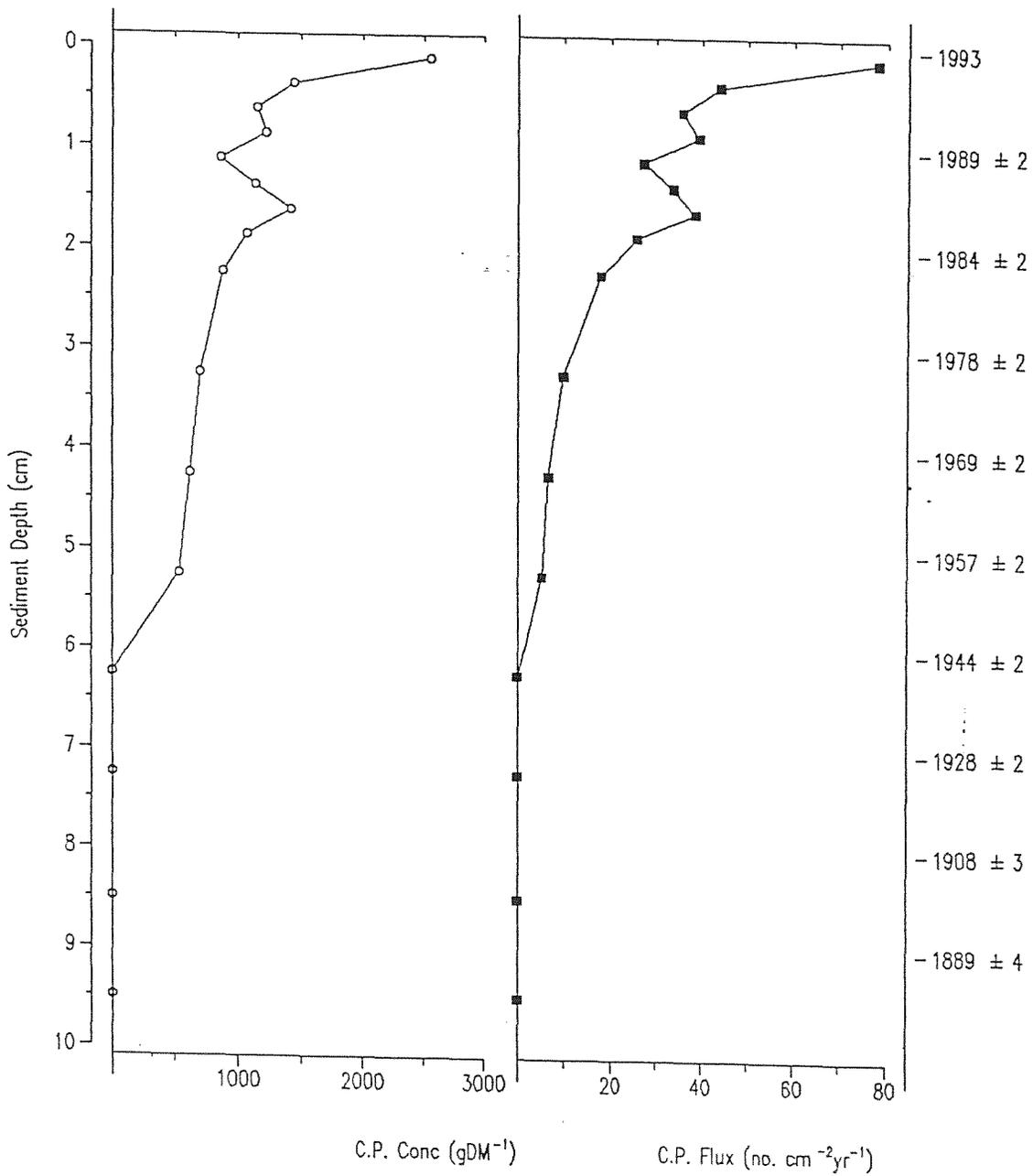
Figure 9. Spheroidal carbonaceous particle concentration
and influx profiles for the Lake Ovadratnove core (OAD2)

penetration into surface sediment combined with a low SAR and a very low level of reactive organic matter production in the lake. Other diagenetic processes such as mineral or diatom dissolution appear to be unimportant over the time scale of the cores and diatom preservation is excellent throughout each core sequence.

Catchment disturbance

Both cores show major changes in lithostratigraphy and these are almost certainly the result of changes in the nature and rate of sediment inwashed from the catchment of each lake. In KOL3 a single major event centred at 14 cm depth, dated to around 1815 AD, supplied material with high minerogenic content. In this core section, weathered granite, principally as flakes of micaceous material, was visibly recognisable. In the QAD2 core a similar, though less extreme feature, occurred at 10.5 cm which, according to the ^{210}Pb chronology, dates to the 1860s period. However, the major mica-rich inwash feature in this core occurred deeper at around 33 cm and does not correspond with any similar stratigraphic feature in KOL3.

Despite the similarity of the lake catchments, there is little synchronicity in lithostratigraphic core details between the two sites, other than the occurrence of 19th century inwash horizons. Causes of the inwash features (high % dry weight, low organic content, and high base cation concentrations) are probably responses to local catchment changes resulting from natural weathering processes and natural disturbance phenomena such as fire or rock falls. Interestingly, the region is seismically active and a major earthquake occurred in the southeast Baikal in 1861.

In KOL3 there is no diatom response to the major inwash feature, species relative abundances being unaffected by the event, indicating that water quality was unchanged at this time. Contrastingly, the sedimentary record in QAD2 is indicative of repeated disturbances in the lake/catchment as shown by major changes in the diatoms, lithostratigraphy and SAR. The low abundance of *F. elliptica* corresponds with high SAR and less organic sediment in the top 3 cm and again at around 10 - 11 cm depth. The chronology is not applicable to the deeper core sections but the section with low *F. elliptica* abundance around 27.5 cm is linked with a small decrease in organic content as is low abundance at around 33 cm depth. These observations indicate that *F. elliptica* abundance changes are linked with catchment changes.

Atmospheric contamination and acidification

The large increase lead concentration in the upper 9.5 cm of KOL3 is unlikely to be caused by 'surface effects' (cf. Duce *et al.* 1991, Davison 1993) and the only tenable explanation of this increase is atmospheric contamination since the mid 19th century. Unequivocal evidence of atmospheric contamination of both lakes is provided by SCP records and PCB measurements. The particle records indicate a significant but low level of contamination since the early 1940s. Although SCPs concentrations can vary with core location within a lake, these data indicate that L. Qvadratnoye receives higher depositions of these particles than does L. Kholodnoye. Surface particle concentrations are however all very low compared with similar lakes in areas of high deposition of atmospheric pollutants in the UK (Flower et al. 1990) but correspond with those in remote lakes on the western fringe of Europe (Rose 1991).

PCB contamination, as excess concentration, is comparable with that found in rural sites elsewhere (see Appendix 3). Despite the higher concentration in L. Kholodnoye surface sediment, the two lakes have similar annual fluxes, at about 0.2 and 0.18 ng g^{-1} cm^{-2}, respectively. These fluxes are an order of magnitude less than for a eutrophic lake in rural England (Sanders *et al.* 1992).

The high abundances of *F. elliptica* (pH optimum 6.6, see Stevenson *et al.* 1991) in the early 19th century compared with higher abundance of *Aulacoseira alpigena* (pH optimum 5.3) in the earlier and later periods indicates that lake water was more acid during these later periods. However, the unusually high abundances of *F. elliptica* in this core could indicate a major change in source of diatoms rather than a major shift in water pH. The QAD2 diatom profiles certainly indicate disturbances of some kind that are specific to this site. With the current level of analysis it is not clear what the causes are, but a major shift in diatom source communities has occurred possibly as a result of catchment erosion, lake level change or real fluctuations in lake water pH. It is noteworthy that the reconstructed pH for surface sediment for each lake is almost one pH unit lower than the measured pH (Table 1). For highland lake diatom stratigraphies the SWAP modern diatom-water chemistry calibrational data set (Birks *et al.* 1991) is probably not the most appropriate since this includes a wide range of site types. Consequently, as part of the EU funded alpine lakes research project, ALPE, a more applicable training set is currently being constructed (Cameron & Birks, in prep.) and will be applied to these cores when available.

The sedimentary diatom record of KOL3 clearly shows that, despite these regional emissions, the critical load of deposited acidity has not been exceeded. Because of the unsatisfactory nature of the water chemistry results for Ca, critical load estimations (Battarbee *et al.* 1994) for these sites cannot be made. However, the diatom stratigraphies do indicate that acid deposition does not as yet pose any major ecological problem in the area. On the other hand, diatoms in QAD2 indicate acidification since the 1820s. This acidification, if real, cannot be caused by atmospheric pollution because the timing is too early and it is inconceivable that this lake should acidify when the nearby and more sensitive (lower Ca and conductivity of lake water, Table 1) Lake Kholodnoye did not.

Sources of pollution

Although neither lake appears to be acidified by atmospheric pollution, the SCP, trace metal and PCB records indicate small but significant contamination. This immediately raises the question of the source of these pollutants. There are several regional centres of atmospheric pollution but by far the most important is the industrial city of Angarsk (Fig. 1) producing some 124,000 tonnes of sulphur dioxide annually. However, when compared with western emissions this figure is not large, a single medium sized British coal fired electricity utility produces a similar annual quantity of sulphur dioxide (National Power 1992). Regional industry in southeast Siberia has developed mainly since the 1950s but whether this is the major source of the lake contamination is unclear. The SCP records approximately correspond with this trend and also indicate that L. Qvadratnoye is more contaminated than L. Kholodnoye. Since SCPs are relatively large particles this could indicate the proximity of L. Qvadratnoye to prevailing winds from the industrial centres on the west side of L. Baikal.

Long distant pollutant transport cannot however be ruled out, contamination of lake sediments by trace metals occurs globally (Hermanson 1991, Evans & Rigler 1985) and PCB contamination is also widespread in the Northern Hemisphere (Appendix 2). The early contamination of Lake Kholodnoye by Pb in the 1860s suggests long distance transport but sources of atmospheric pollutants cannot be identified further without more field data. These

are best obtained from sampling a transect of sediment cores from highland lakes along the 700 km of mountain ridges which follow Lake Baikal's eastern shore so that any contamination gradients from regional pollution sources can be identified.

CONCLUSIONS

1. The two remote Siberian highland lakes, Lake Kholodnoye and Lake Qvadratnoye, have been contaminated by atmospheric pollutants since at least the 1860s.

2. Diatom analysis shows that lake water acidification has not occurred at Lake Kholodnoye and at Lake Qvadratnoye the apparent acidity changes are on a time scale that cannot be explained by atmospheric pollution trends.

3. Diatom and lithostratigraphic changes are not synchronous between the two sites and this suggests that they reflect local, catchment based, natural disturbance events with no direct link with climate.

4. Whether the degree of recent contamination derives mainly from background atmospheric pollution or from regional point source emissions can only be verified by testing more lakes to establish if any contamination gradient exists away from these regional sources.

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APPENDIX 1

RADIOMETRIC DATING OF SEDIMENT CORES FROM TWO SIBERIAN
HIGHLAND LAKES: LAKE KHOLODNOYE AND LAKE QVADRATNOYE.

Radiometric Dating of Sediment Cores from Two Upland Siberian Lakes

Three sediment cores from Lakes Kholodney and Bol collected in 1991 (KOL1) and 1993 (KOL3 and QAD2) were analysed for ^{210}Pb, ^{226}Ra, ^{137}Cs and ^{241}Am by gamma spectrometry using a well-type coaxial low background intrinsic germanium detector fitted with a NaI(Tl) escape suppression shield (Appleby *et al.* 1986). The results of the radiometric analyses are given in Tables 1-4 and shown graphically in Figs.1-6.

Kholodney and Bol are small upland lakes ~25 km south of the town of Tankhoy on the southern tip of Lake Baikal. The rainfall at these sites of ~1500mm per year is more than three times the figure for Baikal, and may be expected to result in much higher fluxes of atmospherically delivered radionuclides. This is confirmed by the results shown in Table 5, which compares values of a number of parameters characterising the fallout record in each core with the corresponding results from two Baikal cores. The mean ^{210}Pb flux for the upland lakes of 400 Bq m^{-2}y^{-1} is more than twice that for Baikal. There is a similar difference in the ^{137}Cs inventories, though comparisons for this radionuclide are less straightforward due to the greater influence of lake hydrology.

A feature of both Kholodney cores is the abnormally high ^{210}Pb activity in the surficial sediments. The presumption that this is indicative of very low sedimentation rates is confirmed by the steep gradient of the unsupported ^{210}Pb activity versus depth profiles (Figs.1b & 2b). ^{210}Pb activity reduces to less than 5% of the surficial value (~100 years accumulation) in just 3.25cm in KOL1 and 6.25cm in KOL2. Beneath this level, however, further reductions in ^{210}Pb activity occur at a much lower rate, radioactive equilibrium with the supporting ^{226}Ra not being reached until a depth of ca.20cm in KOL1 and ca.18cm in KOL2.

^{210}Pb activity in the surficial sediments of Lake Bol is significantly lower than in Kholodney. Further, ^{210}Pb activity varies non-monotonically with depth (Fig.3), peak activity occuring at 3.25cm. These results suggest that contemporary sedimentation rates in Bol are significantly higher than in Kholodney, though the steep decline in ^{210}Pb activity from 3.25-10.5cm indicates that this may be a recent development. Below 10.5cm, there is again a slower rate of decline, equilibrium not being reached until ca.18cm.

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Dates for each core were calculated using both the CRS and CIC ^{210}Pb dating models (Appleby and Oldfield 1978) where practicable, and the results are shown in Figs. 7-9. Although dates for the past 60-100 years are fairly unequivocal, problems do however arise with the chronology of the deeper sections near equilibrium.

Post-1900 Sedimentation Rates

In both Kholodney cores, unsupported ^{210}Pb activity in the upper sections declines more or less exponentially with depth and there is little significant difference between the CRS and CIC chronologies. Both indicate fairly uniform sedimentation rates over several decades, the mean values being:

	CRS Model $g \, cm^{-2} y^{-1}$	CIC Model $g \, cm^{-2} y^{-1}$
KOL1	0.0053±0.0004	0.0041±0.0005
KOL3	0.0066±0.0003	0.0058±0.0004

The slightly higher values given by the CRS model may an artifact of the elevated ^{210}Pb activity in the deeper sections.

Accumulations rates in these cores are too slow to allow an accurate resolution of the weapons fallout record. Maximum ^{137}Cs activity occurs in the surficial section of KOL1 and 1-1.25cm section of KOL3. Significant levels of ^{241}Am, also indicative of the 1963 fallout peak (Appleby *et al.* 1991), were detected in the top 1.5cm of KOL1 and top 3cm of KOL3. Best estimates of the 1963 level based on the distribution of the ^{137}Cs and ^{241}Am inventories are 1.0±0.3cm in KOL1 and 1.5±0.3cm in KOL3. Figs. 7 & 8 show that these are in reasonable accordance with the ^{210}Pb dates, which put the 1963 level at 0.75-1cm in KOL1 and 2-2.5cm in KOL3.

Because of the non-monotonic ^{210}Pb profile (Fig.3), only the CRS model could be used to date the recent sediments of QAD2 (Appleby & Oldfield 1983). The ^{210}Pb calculations indicate a significant increase in sedimentation rates over the past two decades from a relatively low base value similar to that at Kholodney. The ^{210}Pb chronology for QAD2 is well supported by the weapons fallout ^{137}Cs and ^{241}Am records (Fig.6) both of which have clearly defined peaks at 4.25±1.0 cm. The inferred date of

1963 for this level is in good agreement with the ^{210}Pb chronology (Fig.9). Mean accumulation rates for the periods 1900-63 and 1963-1993 are calculated to be:

	1900-63 $g\ cm^{-2}y^{-1}$	1963-93 $g\ cm^{-2}y^{-1}$
^{137}Cs		0.0169±0.0040
^{210}Pb (CRS model)	0.0080±0.0005	0.0179±0.0012

19th Century Sedimentation Rates

In KOL1, below the change in gradient of the ^{210}Pb profile at 3.25 cm there are significant divergences between the two ^{210}Pb dating models. Although both indicate higher sedimentation rates in the older sections of the core, the CRS model dates the transition to ca.1920 whereas the CIC model gives a much older date of ca.1880.

Because of the very high surficial activity and steep gradient of the ^{210}Pb profile, the elevated ^{210}Pb activity below 3.25 cm could instead be due to other causes such as downward smearing of ^{210}Pb during the coring process or downward mobility of ^{210}Pb via porewater diffusion. For most cores the effects of these processes would be scarcely detectable due to the much lower activities.

In the 1993 cores the possible influence of smearing was minimised by the trimming the peripheral material during extrusion. Figs.2 & 3 show that the anomalies are significantly lower in these cores, though they have not been eliminated altogether. The ^{210}Pb chronologies for KOL3 and QAD2 (Figs.8 & 9) both still indicate higher sedimentation rates in the mid (CRS model) to early (CIC model) 19th century.

There is some evidence from the geochemistry of KOL1 to suggest that in the past there may have been episodes of accelerated sedimentation in Kholodney due to increased catchment erosion. Above 5cm depth there is a significant drop in LOI values, falling to a minimum value at 3.25cm. In KOL3 there is an anomalous layer of dense sediment at 13-15cm recording a possible inwash event. There is a similar layer in QAD2 at 10-12cm (and a much deeper layer at 32-34cm). Both layers are associated with minor perturbations to the ^{210}Pb profiles indicative of accelerated sedimentation. As seen in the surficial sediments of Lake Bol, such

events can have an exaggerated impact on the sediment record because of the very slow accumulation rates normally prevailing in these lakes.

Core Chronologies

With the above considerations in mind chronologies for each core have been constructed according to the following procedures. The final results are given in Tables 6-8.

KOL1

There is little ambiguity above 2.1cm. The first level at which there is a significant discrepancy occurs at 3.25cm, dated ca.1920 by the CRS model and ca.1880 by the CIC model. Correlation on the basis of comparable ^{210}Pb activity suggests that this section is contemporaneous with the 6.5cm level in KOL3. Since the latter is unequivocally dated ca.1885, the CIC model date would appear to be more appropriate.

Dating the 6.75-12.5cm section by ^{210}Pb is very problematic. Using either the CRS or CIC models would imply a sustained three-fivefold increase in the ^{210}Pb flux over several decades during the 19th century. This is highly unlikely, and the most credible explanation for the elevated ^{210}Pb activity throughout this section is downsmear during coring.

The chronology given in Table 6 has thus been restricted to the top 5cm. It has been based on the CIC model, using the constant sedimentation rate of 0.0041 ± 0.0005 g cm^{-2}y^{-1} determined from the mean slope of the ^{210}Pb profile above 3.25cm.

KOL3

There is no ambiguity above 6.25cm, dated ca.1886. The first level at which there is a significant discrepancy occurs at 7.5cm. There is evidence from the ^{210}Pb profile of disturbances at 8.5cm and 13.5cm, with some dilution of ^{210}Pb activity. The latter is presumably related to the inferred inwash event at 13-15cm. Since the CIC model does not indicate accelerated sedimentation at this depth, the CRS model dates have been preferred, and these are shown in Table 7.

QAD2

The dating of this core was carried out using the CRS model. The inference of episodes of accelerated sedimentation above 4cm and below 10cm is supported by ^{210}Pb dilution, the ^{137}Cs and ^{241}Am results, and the elevated sediment densities.

4

References

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Appleby,P.G. and Oldfield,F., 1983. The assessmment of ^{210}Pb data from sites with varying sediment accumulation rates. *Hydrobiologia*, **103**:29-35

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Table 1   Lake Kholodney ^{210}Pb Data

Core KOL1

| Depth | Dry Mass | ^{210}Pb Concentration | | | | ^{226}Ra Concentration | |
| | | Total | | Unsupp | | | |
cm	gcm^{-2}	Bq kg^{-1}	±	Bq kg^{-1}	±	Bq kg^{-1}	±
0.30	0.04	3992.0	92.2	3960.7	93.4	31.3	14.9
0.90	0.13	3111.5	69.6	3048.8	71.6	62.7	17.0
1.50	0.22	1824.3	55.7	1792.8	56.3	31.5	8.1
2.10	0.31	836.2	31.8	817.5	32.5	18.7	7.0
3.25	0.46	205.8	10.3	164.3	10.7	41.5	3.0
6.75	0.93	113.8	8.4	71.3	8.8	42.5	2.8
9.50	1.31	99.3	8.6	57.9	9.0	41.4	2.7
12.50	1.70	67.1	5.9	26.6	6.3	40.5	2.4
16.50	2.24	45.5	7.0	9.0	7.2	36.5	1.5
20.50	2.80	37.1	5.3	0.6	5.5	36.5	1.4
24.50	3.32	37.7	6.7	1.0	6.9	36.7	1.5

Core KOL3

| Depth | Dry Mass | ^{210}Pb Concentration | | | | ^{226}Ra Concentration | |
| | | Total | | Unsupp | | | |
cm	gcm^{-2}	Bq kg^{-1}	±	Bq kg^{-1}	±	Bq kg^{-1}	±
0.13	0.02	4917.0	50.4	4877.2	50.5	39.8	3.7
1.13	0.13	3984.2	61.7	3951.0	62.1	33.2	6.4
2.25	0.28	2794.6	36.5	2744.2	36.6	50.4	3.6
2.75	0.34	1962.8	28.1	1924.7	28.2	38.1	2.5
3.25	0.40	1513.3	26.8	1472.3	27.0	41.0	2.8
3.75	0.46	1163.6	26.4	1119.7	26.6	43.9	3.1
4.25	0.52	655.3	19.1	615.2	19.2	40.1	2.4
5.25	0.63	368.2	17.5	328.8	17.8	39.4	3.2
6.25	0.74	249.1	13.4	207.7	13.7	41.4	2.4
7.50	0.88	101.9	5.7	60.5	5.8	41.4	1.4
8.50	1.00	75.3	7.0	30.4	7.2	44.9	1.4
11.50	1.40	84.3	11.0	43.5	11.1	40.8	1.8
13.50	1.94	42.4	4.9	10.2	5.0	32.2	0.9
15.50	2.46	45.2	6.2	7.6	6.4	37.6	1.5
18.50	2.88	34.6	5.9	4.9	5.9	29.7	1.0
21.50	3.21	28.0	4.7	-8.1	4.8	36.1	1.2
24.50	3.56	34.5	4.9	-1.2	4.8	35.7	1.1

Table 2   Lake Kholodney ^{137}Cs and ^{241}Am Data

Core KOL1

Depth	^{137}Cs Conc		^{241}Am Conc	
cm	Bq kg^{-1}	±	Bq kg^{-1}	±
0.30	2001.31	27.55	9.48	4.09
0.90	1508.91	20.25	9.43	3.37
1.50	1057.84	17.22	4.87	1.79
2.10	491.92	39.35	0.00	0.00
3.25	94.32	2.48	0.00	0.00
6.75	46.90	1.84	0.00	0.00
9.50	29.33	1.63	0.00	0.00
12.50	17.97	1.68	0.00	0.00
16.50	10.18	1.28	0.00	0.00
20.50	3.23	1.40	0.00	0.00
24.50	0.98	1.03	0.00	0.00

Core KOL3

Depth	^{137}Cs Conc		^{241}Am Conc	
cm	Bq kg^{-1}	±	Bq kg^{-1}	±
0.13	1826.71	1.55	22.23	2.15
1.13	2188.38	22.13	17.52	2.27
2.25	1003.72	10.51	9.71	1.59
2.75	595.00	7.48	7.73	1.10
3.25	428.62	6.72	6.19	1.22
3.75	306.92	6.99	0.00	0.00
4.25	165.52	4.21	0.00	0.00
5.25	106.36	5.21	0.00	0.00
6.25	55.83	3.34	0.00	0.00
7.50	22.47	1.49	0.00	0.00
8.50	11.96	1.21	0.00	0.00
11.50	8.12	1.11	0.00	0.00
13.50	1.49	0.66	0.00	0.00
15.50	3.56	0.94	0.00	0.00
18.50	3.79	0.55	0.00	0.00
21.50	0.20	0.83	0.00	0.00
24.50	0.27	0.78	0.00	0.00

Table 3 ^{210}Pb Data

Core QAD2

Depth	Dry Mass	^{210}Pb Concentration				^{226}Ra Concentration	
		Total		Unsupp			
cm	gcm^{-2}	Bq kg^{-1}	±	Bq kg^{-1}	±	Bq kg^{-1}	±
0.13	0.01	1456.0	47.1	1393.5	47.7	62.5	7.9
1.13	0.13	1098.1	31.6	1064.2	31.8	33.9	3.5
2.25	0.27	1564.1	30.0	1533.3	30.2	30.8	3.3
3.25	0.38	1779.2	33.3	1749.9	33.5	29.3	3.3
4.25	0.51	1737.3	38.7	1708.0	39.0	29.3	4.8
5.25	0.62	1247.9	26.1	1222.3	26.3	25.6	2.7
6.75	0.81	841.5	23.5	811.5	23.7	30.0	3.0
7.50	0.92	605.0	20.5	572.2	20.6	32.8	1.9
8.50	1.05	397.0	17.2	363.2	17.3	33.8	2.5
10.50	1.40	57.5	7.6	22.6	7.7	34.9	1.2
12.50	1.80	61.8	7.9	27.9	8.1	33.9	1.6
14.50	2.08	40.8	6.3	15.4	6.4	25.4	1.0
16.50	2.32	45.8	6.9	16.9	7.1	28.9	1.7
18.50	2.63	28.9	5.3	−1.0	5.4	29.9	1.1
20.50	2.99	29.3	6.4	−1.6	6.6	30.9	1.6

Table 4 ^{137}Cs and ^{241}Am Data

Core QAD2

Depth	^{137}Cs Conc		^{241}Am Conc	
cm	Bq kg^{-1}	±	Bq kg^{-1}	±
0.13	254.50	11.38	0.00	0.00
1.13	275.43	7.03	0.00	0.00
2.25	295.40	6.27	0.00	0.00
3.25	324.84	6.96	6.23	1.61
4.25	389.35	9.03	7.62	1.82
5.25	369.35	6.05	4.95	1.27
6.75	110.01	4.80	0.00	0.00
7.50	63.70	2.70	0.00	0.00
8.50	43.79	2.87	0.00	0.00
10.50	17.49	1.01	0.00	0.00
12.50	6.17	1.29	0.00	0.00
14.50	4.83	0.60	0.00	0.00
16.50	0.00	0.00	0.00	0.00
18.50	0.57	0.82	0.00	0.00
20.50	0.00	0.00	0.00	0.00

Table 5   Radionuclides Inventories of Upland Siberian Lakes

		Unsupported ^{210}Pb				^{137}Cs	
		Inventory		Flux		Weapons	
		Bq m^{-2}	±	Bq m^{-2}y^{-1}	±	Bq m^{-2}	±
	KOL1	9842	265	307	8	5467	131
	KOL3	15712	390	489	12	6494	171
	QAD2	13000	264	405	8	2773	56
Baikal	BIK6	4952	120	154	4	1277	30
	BIK22	6023	187	184	6	1246	32

Table 6   <u>Lake</u> <u>Kolodney</u> ^{210}<u>Pb chronology</u>   <u>Core</u> <u>KOL1</u>

| Depth | Dry Mass | Chronology | | | Sedimentation Rate | | |
| | | Date | Age | | | | |
cm	gcm^{-2}	AD	yr	±	$gcm^{-2}yr^{-1}$	$cmyr^{-1}$	± (%)
0.00	0.00	1991	0				
0.25	0.03	1983	8	1			
0.50	0.07	1974	17	2			
0.75	0.11	1965	26	3			
1.00	0.14	1956	35	4			
1.25	0.18	1946	45	5			
1.50	0.22	1937	54	7			
1.75	0.26	1928	63	8			
2.00	0.29	1919 72		9			
2.25	0.33	1911	80	10	0.0041	0.030	12.2
2.50	0.36	1903	88	11			
2.75	0.40	1895	96	12			
3.00	0.43	1887	104	13			
3.25	0.46	1878	113	14			
3.50	0.49	1870	121	15			
3.75	0.53	1862	129	16			
4.00	0.56	1854	137	17			
4.50	0.63	1838	153	19			
5.00	0.69	1822	169	21			

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Table 7   Lake Kolodney ^{210}Pb chronology   Core KOL3

| Depth | Dry Mass | Chronology | | | Sedimentation Rate | | |
| | | Date | Age | | | | |
cm	gcm^{-2}	AD	yr	±	$gcm^{-2}yr^{-1}$	$cmyr^{-1}$	± (%)
0.00	0.00	1993	0				
0.25	0.03	1990	3	2	0.0093	0.081	2.8
0.50	0.06	1987	6	2	0.0089	0.076	2.9
0.75	0.09	1983	10	2	0.0085	0.071	3.1
1.00	0.12	1980	13	2	0.0080	0.066	3.2
1.25	0.15	1976	17	2	0.0076	0.062	3.2
1.50	0.18	1971	22	2	0.0071	0.058	3.1
1.75	0.21	1966	27	2	0.0067	0.053	3.1
2.00	0.24	1962	31	2	0.0062	0.049	3.0
2.25	0.28	1957	36	2	0.0058	0.045	2.9
2.50	0.31	1952	41	2	0.0059	0.047	3.1
2.75	0.34	1946	47	2	0.0060	0.049	3.3
3.00	0.37	1941	52	2	0.0058	0.048	3.7
3.25	0.40	1936	57	2	0.0057	0.047	4.0
3.50	0.43	1931	62	2	0.0055	0.045	4.5
3.75	0.46	1925	68	2	0.0053	0.044	5.1 .
4.00	0.49	1920	73	2	0.0061	0.051	5.8
4.25	0.52	1915	78	2	0.0070	0.059	6.5
4.50	0.55	1911	82	3	0.0073	0.062	7.4
4.75	0.58	1907	86	3	0.0075	0.065	8.3
5.00	0.61	1903	90	3	0.0078	0.068	9.2
5.25	0.63	1899	94	3	0.0080	0.071	10.0
5.50	0.66	1896	97	3	0.0081	0.073	11.0
5.75	0.69	1893	100	4	0.0082	0.074	11.9
6.00	0.72	1889	104	4	0.0083	0.076	12.8
6.50	0.77	1884	109	5	0.0109	0.098	14.9
7.00	0.82	1880	113	5	0.0157	0.138	17.1
7.50	0.88	1875	118	6	0.0206	0.178	19.3
8.00	0.94	1873	120	6	0.0280	0.225	24.6
8.50	1.00	1871	122	7	0.0355	0.272	29.9
9.00	1.07	1868	125	7	0.0320	0.240	30.6
9.50	1.14	1865	128	7	0.0284	0.207	31.2
10.00	1.20	1862	131	7	0.0249	0.175	31.8
10.50	1.27	1859	134	8	0.0214	0.142	32.5
11.50	1.40	1853	140	8	0.0144	0.077	33.8
12.50	1.67	1838	155	10	0.0191	0.084	46.8
13.50	1.94	1823	170	12	0.0238	0.090	59.8
14.50	2.20	1808	185	12	0.0185	0.080	68.9

Table 8   Lake QAD ^{210}Pb chronology   Core QAD2

| Depth | Dry Mass | Chronology | | | Sedimentation Rate | | |
| | | Date | Age | | | | |
cm	gcm^{-2}	AD	yr	±	$gcm^{-2}yr^{-1}$	$cmyr^{-1}$	± (%)
0.00	0.00	1993	0				
0.50	0.05	1991	2	2	0.0305	0.261	3.9
1.00	0.11	1989	4	2	0.0328	0.269	3.7
1.50	0.17	1987	6	2	0.0288	0.234	3.5
2.00	0.24	1984	9	2	0.0226	0.185	3.2
2.50	0.30	1981	12	2	0.0180	0.150	3.1
3.00	0.36	1978	15	2	0.0152	0.128	3.2
3.50	0.41	1974	19	2	0.0129	0.109	3.4
4.00	0.48	1969	24	2	0.0111	0.093	3.6
4.50	0.54	1963	30	2	0.0102	0.084	3.8
5.00	0.59	1957	36	2	0.0100	0.083	4.0
5.50	0.66	1951	42	2	0.0096	0.078	4.3
6.00	0.72	1944	49	2	0.0089	0.070	4.8
6.50	0.78	1937	56	2	0.0082	0.063	5.2
7.00	0.85	1928	65	2	0.0075	0.056	6.1
7.50	0.92	1918	75	2	0.0069	0.050	7.3
8.00	0.99	1908	85	3	0.0063	0.043	9.3
8.50	1.05	1897	96	4	0.0057	0.036	11.2
9.00	1.14	1889	104	4	0.0124	0.070	18.1
9.50	1.23	1881	112	5	0.0190	0.105	24.9
10.00	1.32	1872	121	6	0.0257	0.139	31.8
10.50	1.40	1864	129	7	0.0324	0.174	38.7
11.50	1.60	1855	138	8	0.0237	0.132	38.2
12.50	1.80	1846	147	9	0.0151	0.089	37.7
13.50	1.94	1837	156	10	0.0153	0.104	46.3
14.50	2.08	1828	165	12	0.0155	0.118	54.8

Fig.1a

Lake Kholodney
Total ^{210}Pb Activity versus Depth

Core KOL1

- - - - - - - Supported ^{210}Pb

^{210}Pb Activity (Bq kg^{-1})

Depth (cm)

Lake Kholodney
Unsupported ^{210}Pb Activity versus Depth

Core KOL1
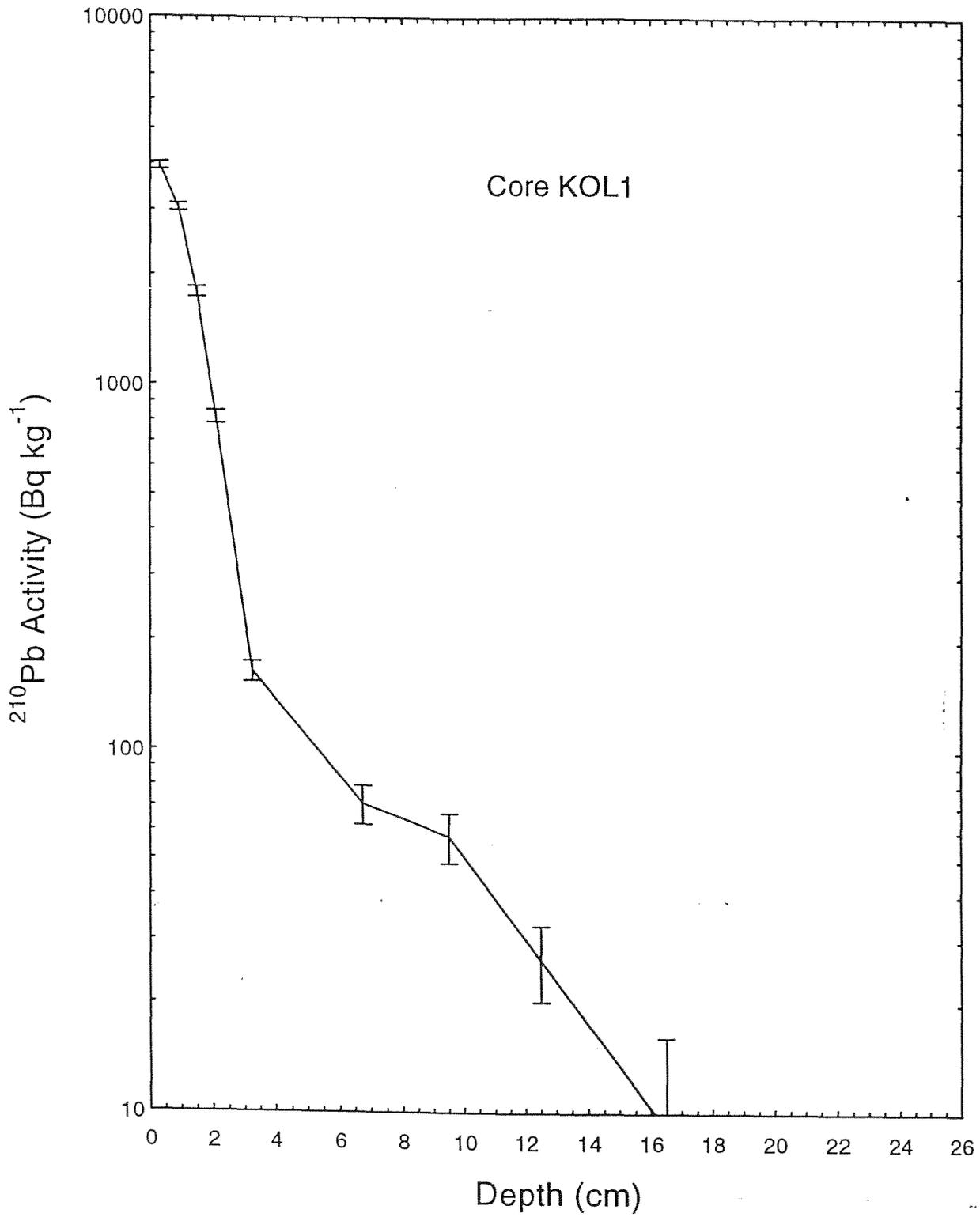
Fig.2a

Lake Kholodney
Total ^{210}Pb Activity versus Depth

Fig.2b

Lake Kholodney
Unsupported ^{210}Pb Activity versus Depth

Core KOL3

^{210}Pb Activity (Bq kg^{-1})

Depth (cm)
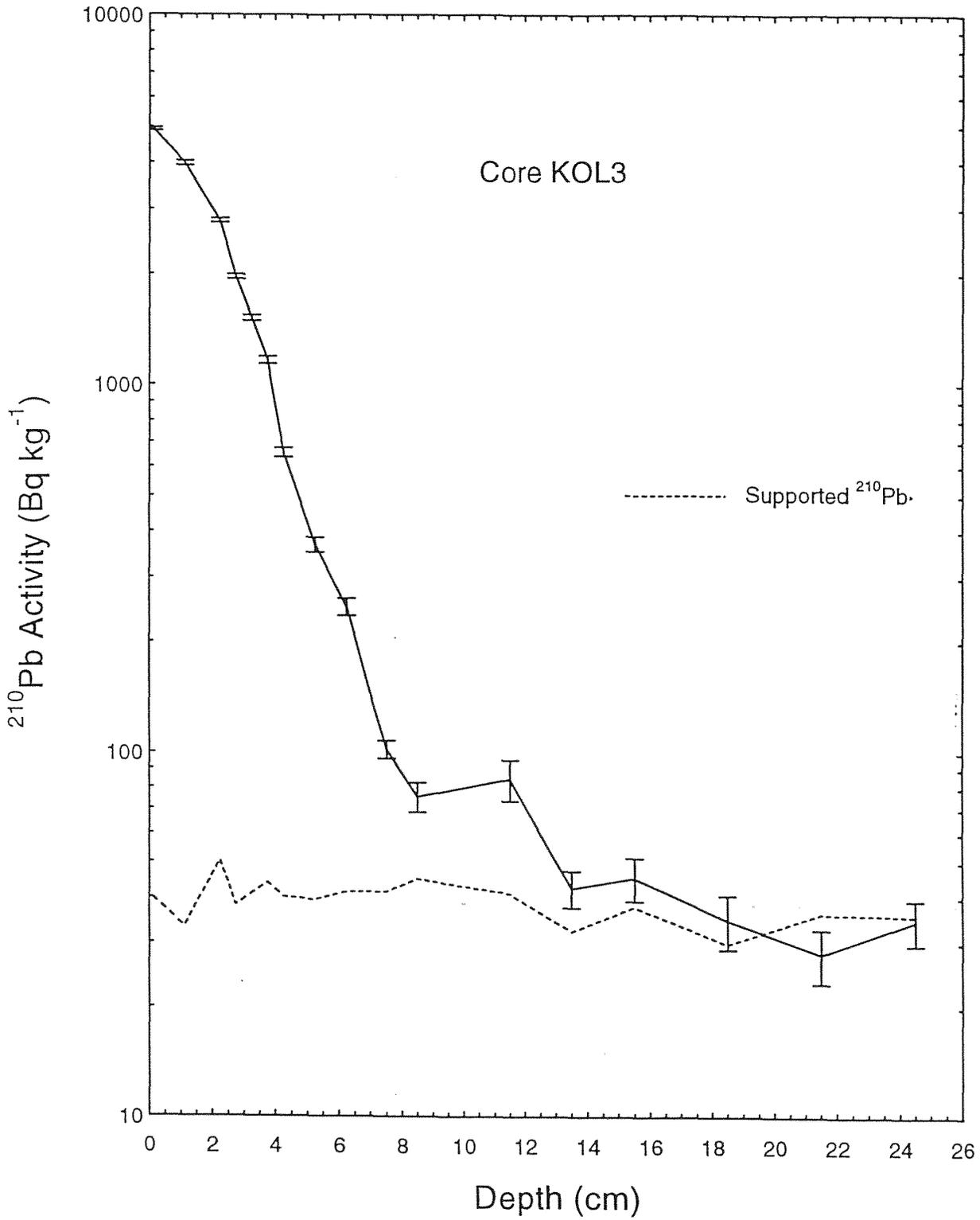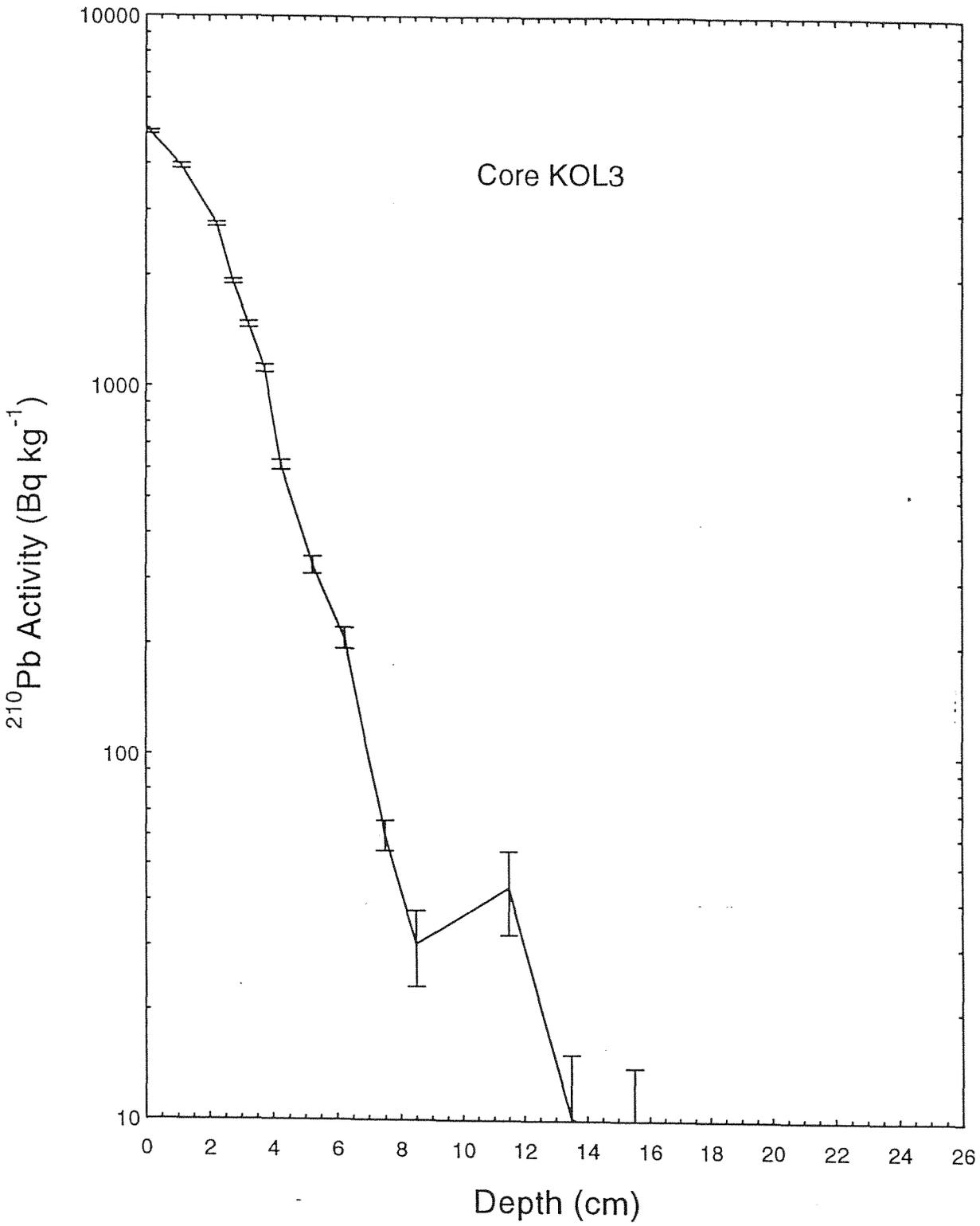
Fig.3a

Lake Qvadratnoye
Total ^{210}Pb Activity versus Depth

Core QAD2

- - - - - - - Supported ^{210}Pb

^{210}Pb Activity (Bq kg^{-1})

Depth (cm)
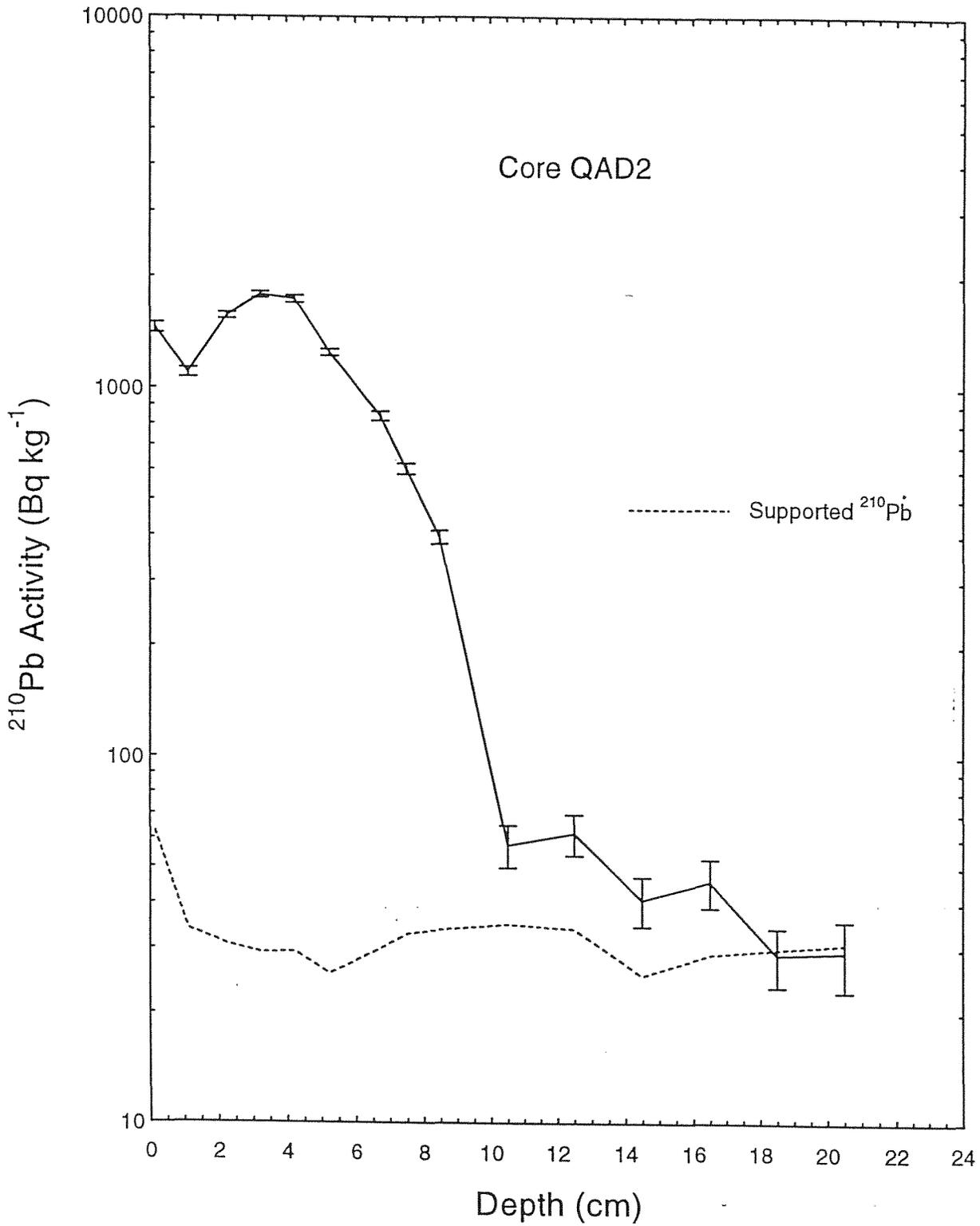
Fig.3b

Lake Qvadratnoye

Unsupported ^{210}Pb Activity versus Depth

Core QAD2
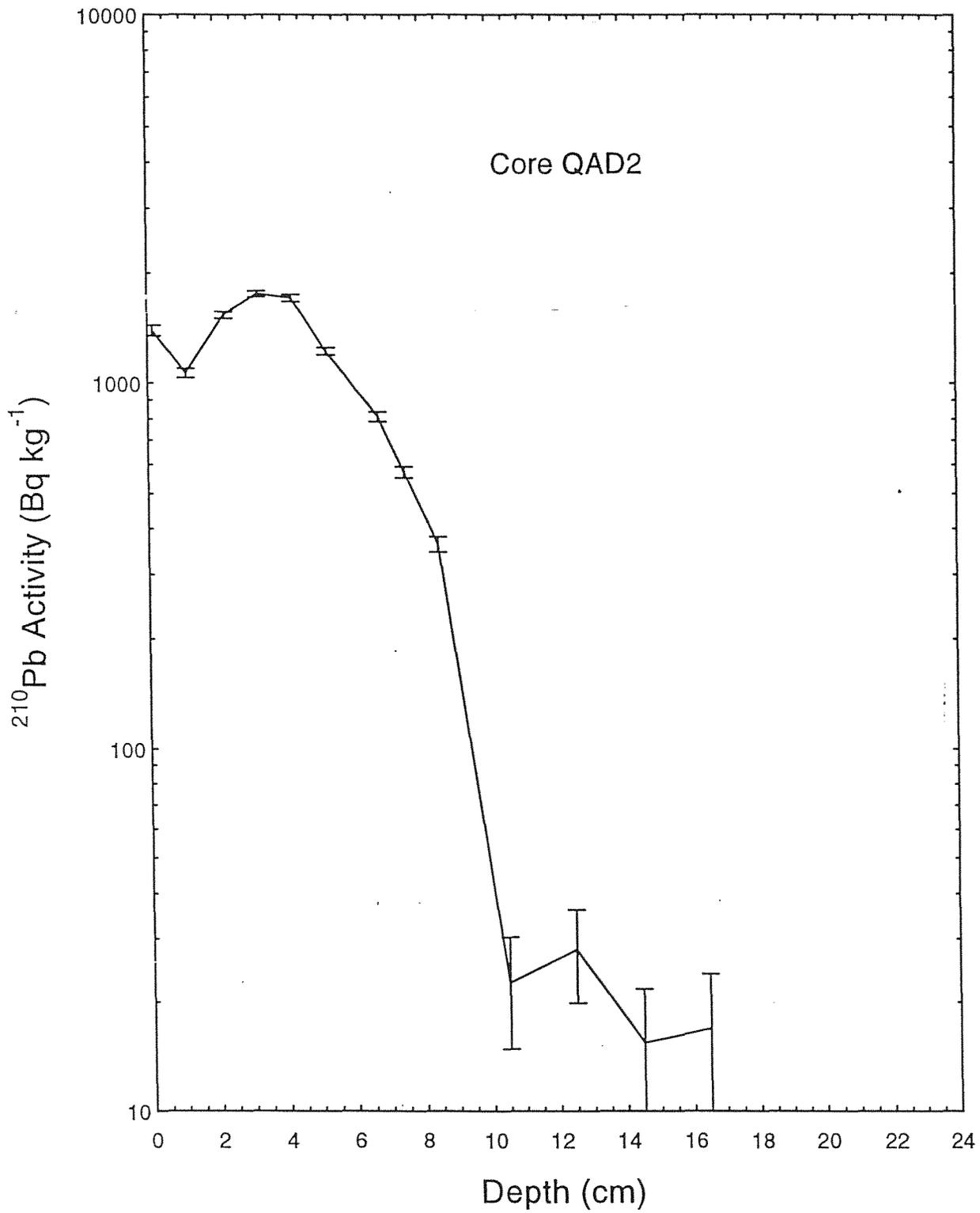
Fig.4

L. Kholodney
^{137}Cs & ^{241}Am Activity versus Depth

Fig.5

L. Kholodney
^{137}Cs & ^{241}Am Activity versus Depth

Core KOL3

^{137}Cs
^{241}Am

Radiocaesium Activity (Bq kg^{-1})

^{241}Am Activity (Bq kg^{-1})

Depth (cm)
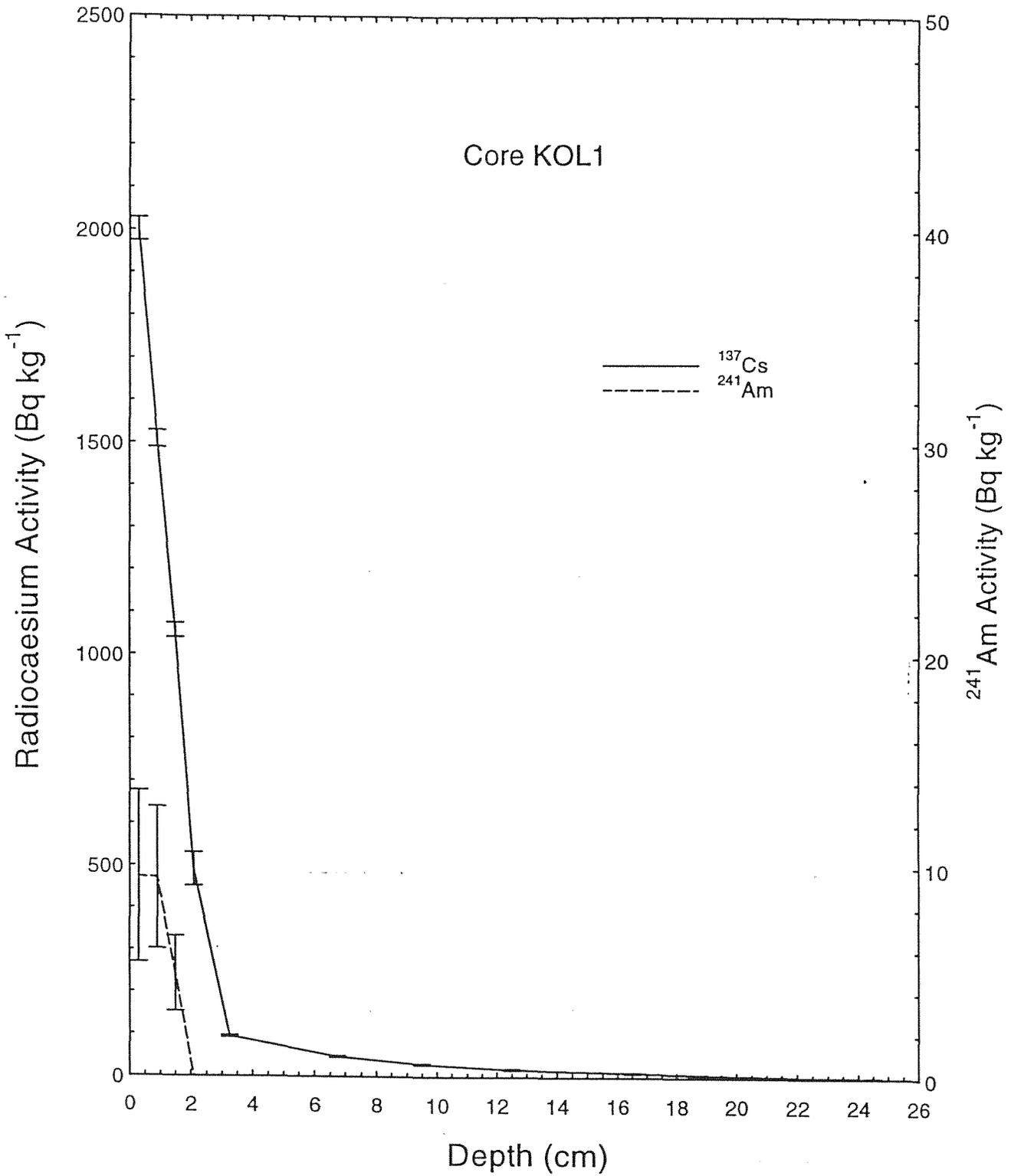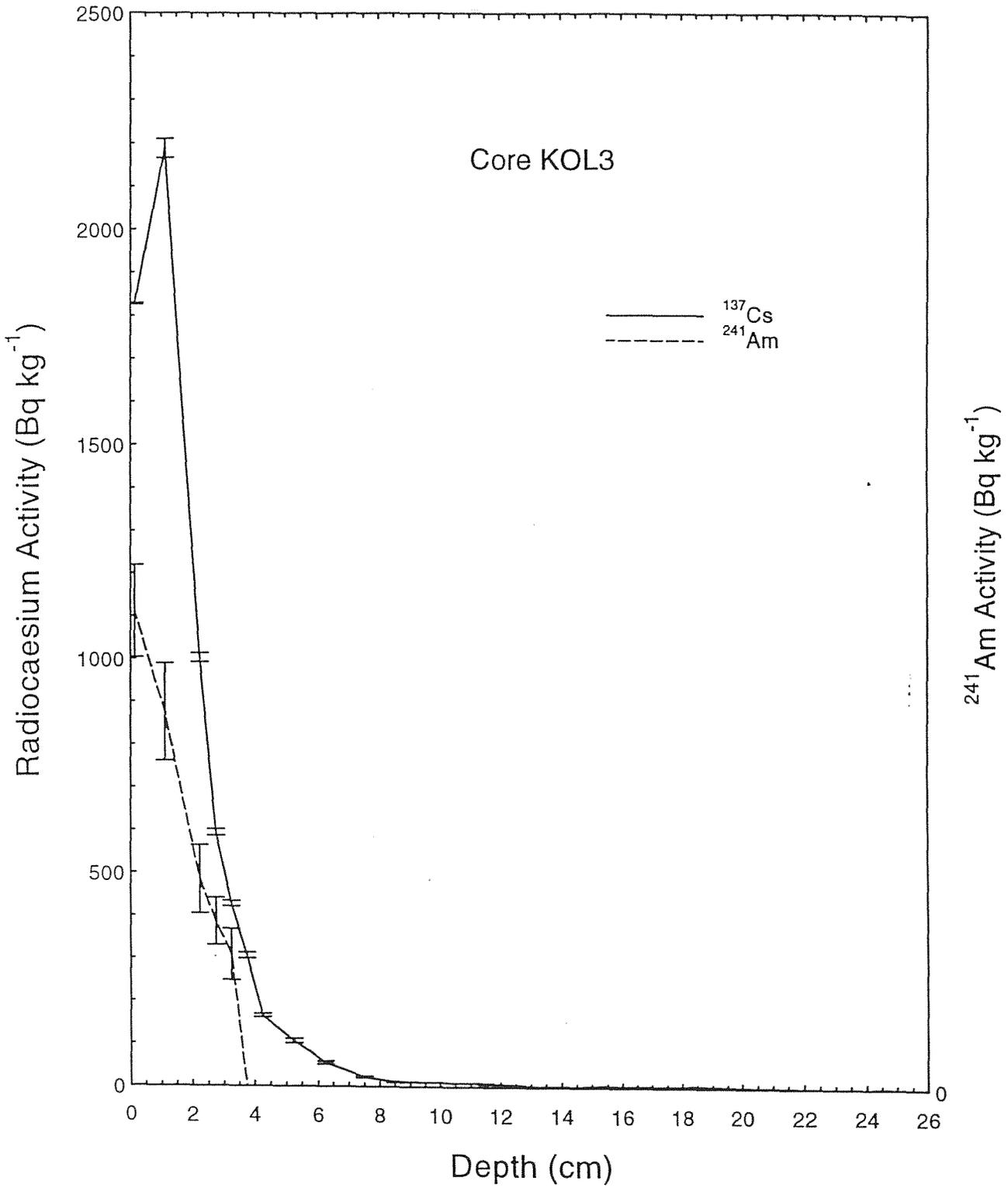
Fig.6 Lake Qvadratnoye
^{137}Cs & ^{241}Am Activity versus Depth
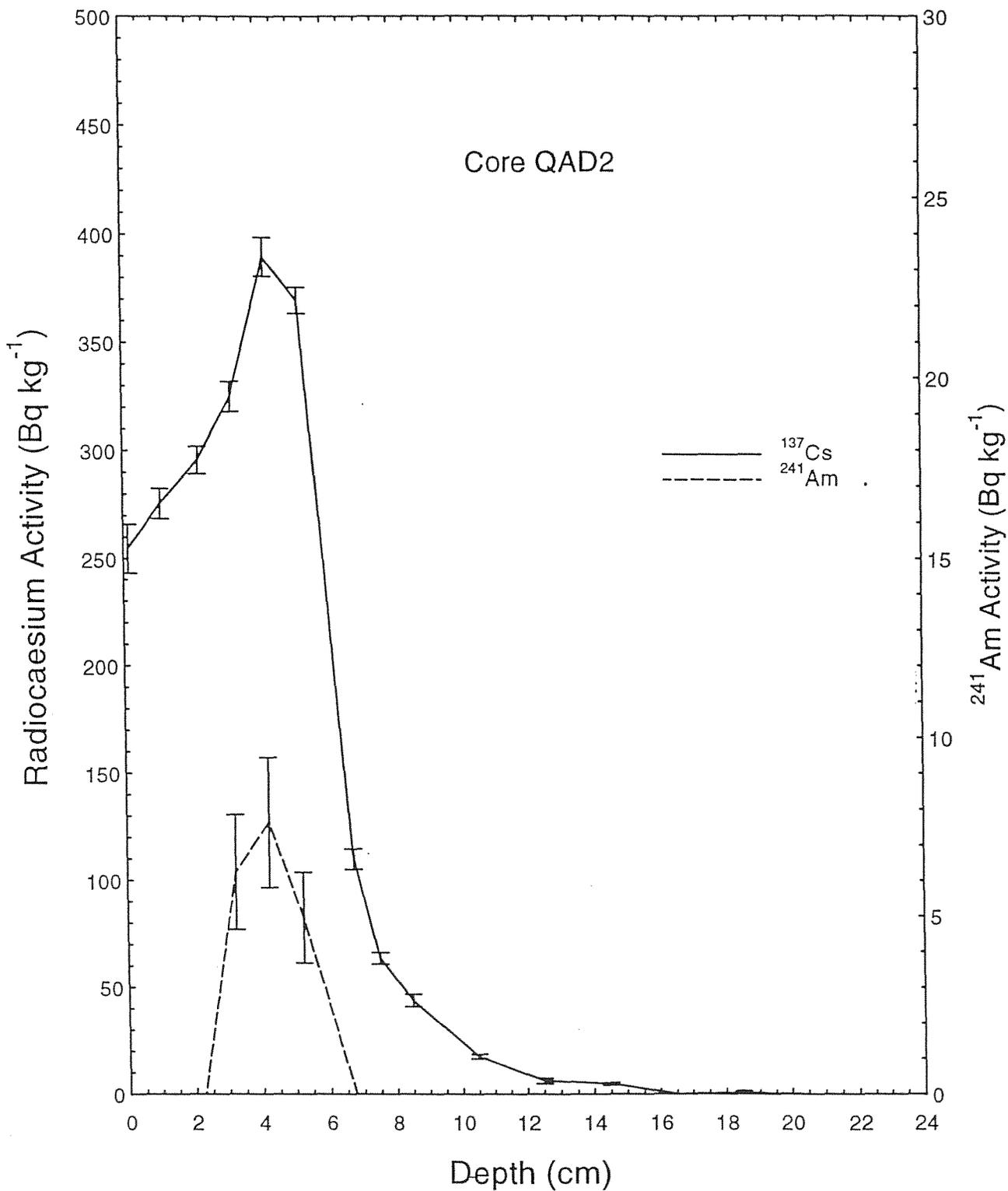
Fig.7

Lake Kholodney Core KOL1
Depth versus Age
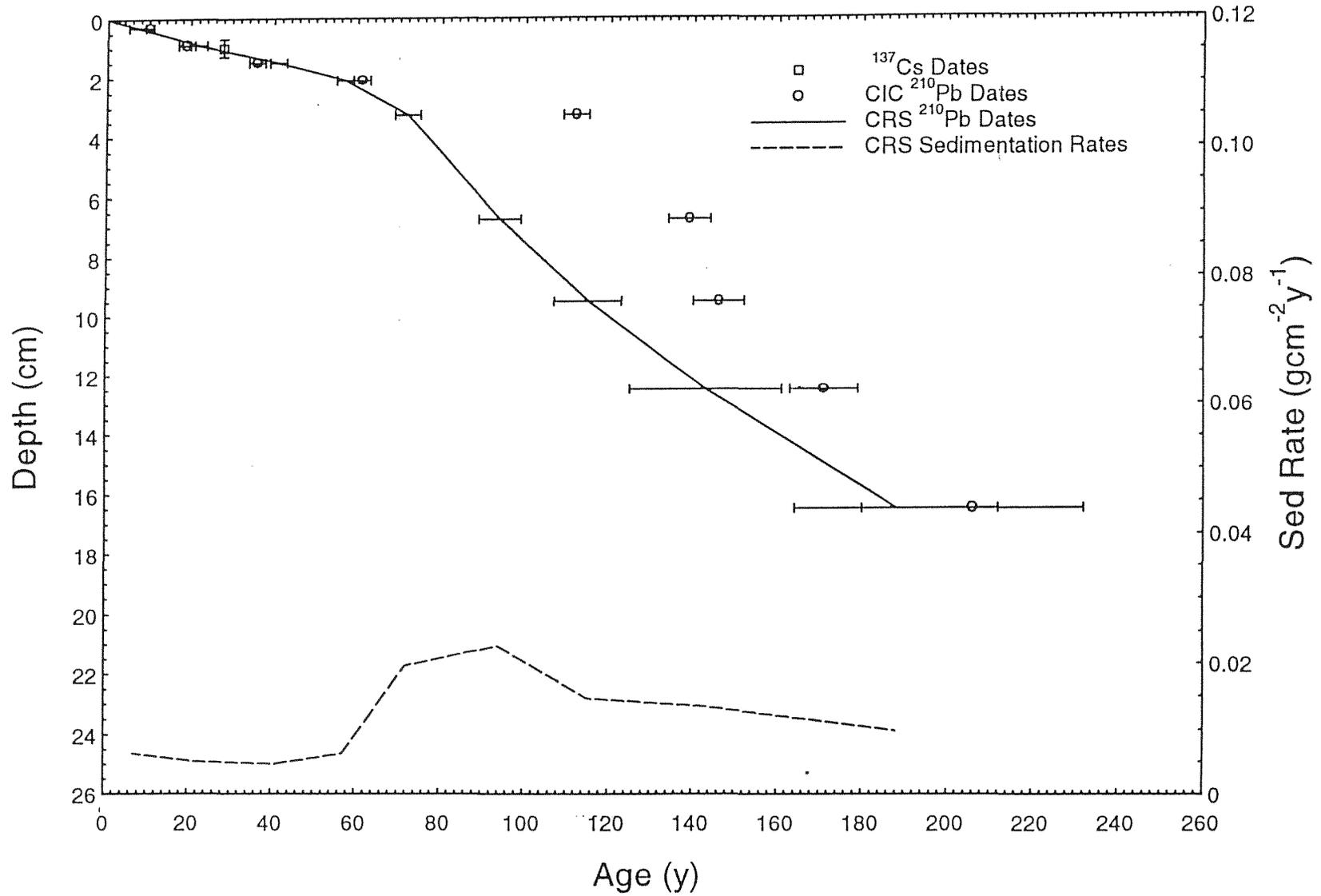
Fig.8

Lake Kholodney Core KOL3
Depth versus Age
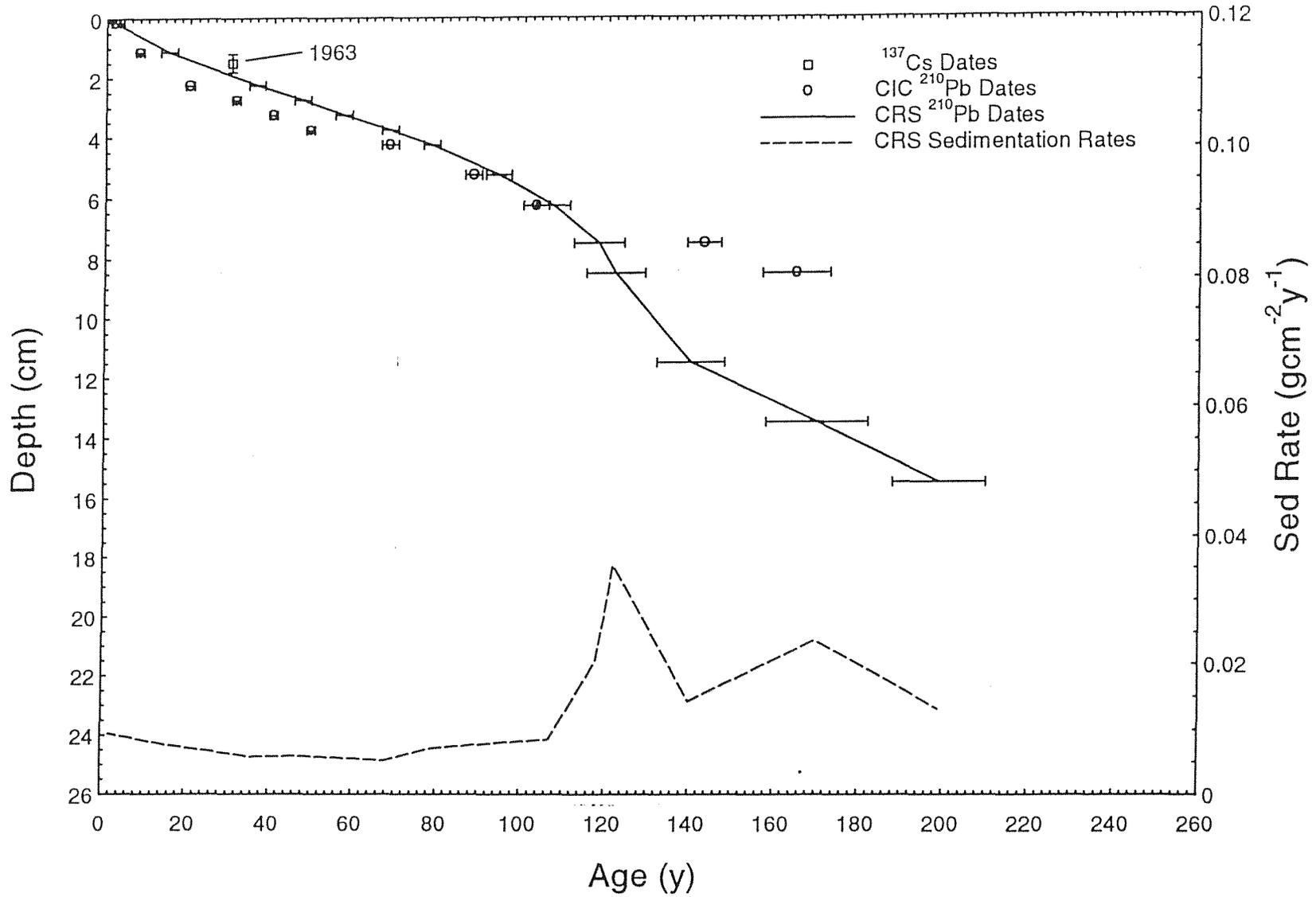
Fig.9

Lake   Core QAD2
Depth versus Age

Legend:
- □ ^{137}Cs Dates
- ○ CIC ^{210}Pb Dates
- —— CRS ^{210}Pb Dates
- – – – CRS Sedimentation Rates

Y-axis (left): Depth (cm)
Y-axis (right): Sed Rate (gcm^{-2}y^{-1})
X-axis: Age (y)
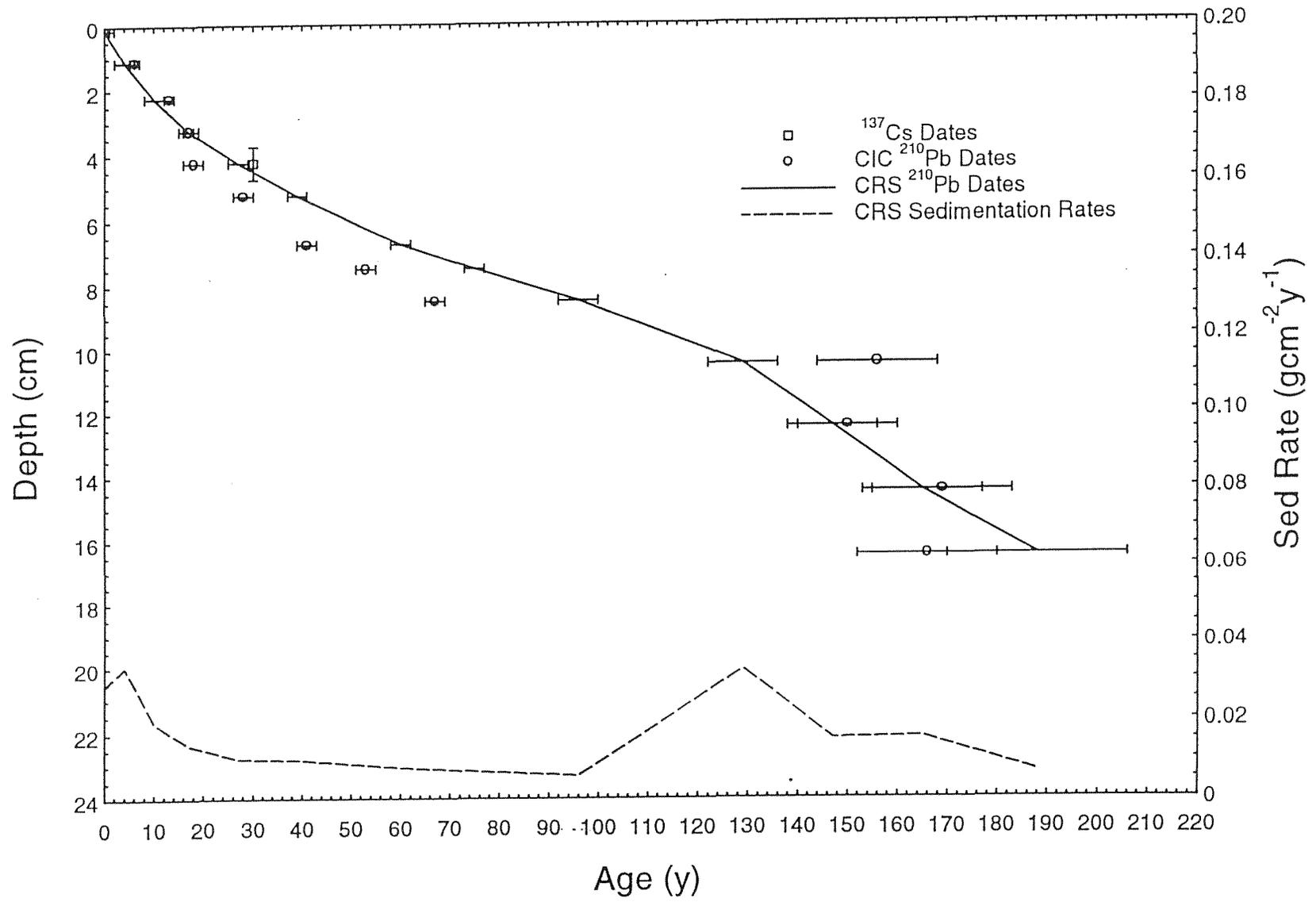
APPENDIX 2

PCBs IN SEDIMENTS FROM TWO SIBERIAN HIGHLAND LAKES: LAKE KHOLODNOYE AND LAKE QVADRATNOYE.

1.0 INTRODUCTION

Polychlorinated biphenyls (PCBs) are a group of chlorinated aromatic compounds which were first synthesised industrially in the US in 1929, and in the UK in 1954. They have a wide range of uses, including dielectric fluids in transformers and capacitors, plasticizers in paints, plastics, sealants and adhesives, and components of hydraulic fluids in gas turbines and vacuum pumps (Moore & Ramamoorthy 1984). Recently, evidence from a number of sources has shown that some PCB species form during combustion processes and are emitted from coal-fired power stations and car exhausts (Granier & Chevreuil 1991; Kocan *et al* 1991), and municipal and chemical waste incineration (e.g. Boers *et al* 1993; Wilken *et al* 1993; Sakai *et al* 1993). Theoretically, over 200 individual PCB congeners exist, depending on the number and position of chlorine atoms on the basic biphenyl molecule.

PCBs can be released into the environment in a number of ways, for example via industrial emmissions, leaching from landfills and the failure of electrical equipment (Sanders *et al* 1992). Once emitted into the environment, PCBs are very persistent. They enter the atmosphere by direct emissions or volatilisation from soil and water, and can be transported long distances before being deposited by wet or dry deposition (Jones *et al* 1991). The hydrophobic and lipophylic properties of PCBs mean that they are very insoluble in water and tend to accumulate in lipid-rich matrices. When PCBs reach a lake environment, either by direct deposition or via catchment inputs, they preferentially bind to organic-rich particulates, and can become incorporated into bottom sediments by deposition of these settling particles. Subsequent patterns of accumulation of sediment-associated PCBs will be affected by processes such as resuspension, degradation and bioturbation. The properties and behaviour of PCBs in freshwater systems can result in their bioaccumulation in the aquatic foodchain.

This report is presented in the form of a briefing note. It gives the results of PCB analysis carried out on sediment samples from two remote Siberian lakes, and provides an interpretation of these results in the context of studies carried out elsewhere in the Northern Hemisphere. Further details such as site

descriptions, and other background information have not been included within this report. The samples provided for analysis were from the top and bottom of sediment cores from two Siberian lakes and were labelled KOL Top, KOL Bottom, QAD Top andQAD Bottom. The samples are referred to by these names in the following text.

2.0 ANALYSIS AND RESULTS

The analysis of sediments for PCB determination was carried out by capillary gas chromatography using an electron capture detector (a sensitive detector for chlorine-containing species). The concentration of the seven most abundant and most commonly analysed PCB congeners was determined, along with the total PCB content (Table 1).

Table 1: Results of PCB analysis on lake sediments, giving individual congeners and total concentration (ng g^{-1}, or ppb, dry weight)

Congener Number*	KOL Top	KOL Bottom	QAD Top	QAD Bottom
28	1	<1	<1	1
52	2	<1	<1	<1
101	3	1	1	<1
118	4	<1	<1	<1
138	4	<1	2	<1
153	4	1	2	1
180	2	1	1	<1
Total PCB	32	9	13	7

* Numbered according to Ballschmitter & Zell (1980)

To determine total concentrations, samples were quantified using a mixture of Aloclor[1] standards (Aloclor 1242, 1254 and 1260).

The limit of detection for the congener-specific PCBs is 1 ng g^{-1} (ppb), and samples did not require blank correction. The analytical recovery was 80-90%, with the analytical error in the region of ±50% for total PCBs in QAD Top and Bottom and KOL Bottom, and ±30% for KOL Top.

3.0 DISCUSSION

3.1 RESULTS OF PCB ANALYSES

The analysis of the seven individual PCB congeners shows that, with the exception of KOL Top, concentrations in the sediment samples are close to or below the limit of detection of 1 ng g^{-1} dry weight. The essentially clean blank and good analytical recovery gives some confidence in the detection of congeners present at such low levels. However, given the relatively large error margin for total PCB concentrations at the lower end of the detection range (see Section 2), it is unlikely that there is a significant difference between the results given for QAD Top, QAD Bottom and QAD Bottom.

The detection of even low levels of PCBs in the bottom sediments of KOL and BOLS requires some explanation, as it is highly likely that these sediments considerably pre-date any industrial synthesis of PCBs. Low levels of PCBs have also been detected in sediments pre-dating the manufacture of PCBs by Sanders *et al* (1992) (see Table 2). Several explanations for this were suggested by these authors, and these are,

- that small traces of PCBs may be transferred from more recent sediments to deeper, uncontaminated sediments by lake processes such as diffusion, mixing or bioturbation, or by sampling and extruding methods.

- that samples may be contaminated during preparation and analysis.

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[1]Aloclor is the tradename for PCBs adopted by the US manufacturer Monsanto

- that the peaks appearing on the chromatogram which match the retention time of certain PCB congeners, may not be the PCB congeners themselves, but coeluting species from the sample matrix.

- that there are real, pre-industrial levels of PCBs in the environment.

The first and third possibilities cannot be discounted in this study, but the second seems unlikely given the condition of the blank which was run in parallel with the samples. The final possible explanation for the presence of PCBs in sediments pre-dating industrial manufacture put forward by Sanders *et al* (1992) warrents further discussion. Most studies designed to investigate the historical trend of PCBs in the environment generally do not report sedimentary levels prior to 1900, and so it is difficult to confirm the existence of pre-industrial PCBs from these reports. However, there is growing evidence that some PCB congeners are formed during combustion processes, which does not rule out the possibility of the presence of PCBs in the environment prior to industrial synthesis. The presence of some PCB species has recently been reported in emissions from combustion sources, such as coal-fired power stations and car exhausts (Granier & Chevreuil 1991; Kocan *et al* 1991), and also from chemical and municipal waster incineration plants. The PCB congeners identified in emissions from these sources are the non-ortho or coplanar species which have a similar structure, and exhibit similar behaviour, to dioxins, which are well known persistent toxic organic compounds. It is thought that the coplanar PCBs identified in emissions from incinerators are formed by the same synthesis mechanism that causes the formation of dioxins, i.e. *de novo* synthesis from particulate organic carbon (Boers *et al* 1993; Schoonenboom 1993).

3.2 A COMPARISON OF RESULTS WITH OTHER STUDIES

Table 2 compares the total PCB concentration present in KOL and QAD with results from other sediment studies in the Northern Hemisphere. The table shows that the total PCB concentrations reported in this study are in the same order as those found in other lake sediments, and much lower than in the relatively polluted Milwaukee harbour, as would be expected. The levels found in QAD Top, QAD Bottom and KOL Bottom are <15 ng g^{-1}, and according to Golden *et al* (in press) this range of values is typical of uncontaminated

ecosystems where inputs are dominated by atmospheric deposition. In a survey of Spanish reservoir sediments, Bernal *et al* (1992) showed that high mountain reservoirs contained PCB concentrations below 10 ng g^{-1}.

The total PCB concentration found in KOL Top is comparable with that found in Esthwaite Water (UK), which is a rural lake remote from major industrial or residential conurbations (Sanders *et al* 1992). The higher levels found in lakes such as Michigan and Ontario reflects the increased importance of non-atmospheric sources, or intense and localised atmospheric inputs from local industrial or urban centres (Golden *et al*, in press).

A large number of the studies quoted in Table 2 have reported higher concentrations of total PCBs in samples below the sediment surface, with rapid increases dating from about the 1950s and peak concentrations occuring in the 1960s or 1970s. These patterns generally reflect the production and use of PCBs in the Northern Hemisphere, with peak concentrations representing peak usage befor controls were placed on the use and disposal of PCBs in many countries. Depending on the rate of accumulation in KOL and QAD, it is possible that the PCB record held in the sediments of these lakes may reflect these general trends, with the maximum PCB concentrations being located further down the sediment profile.

4.0 SUMMARY

PCB analysis of seven individual congeners in Siberian lake sediments has shown that most are close to the limit of detection in QAD Top, QAD Bottom and KOL Bottom. Concentrations of these congeners are slightly higher in KOL TOP. The total PCB concentration in QAD Top, QAD Bottom and KOL Bottom is <15 ng g^{-1}, but this figure is higher in KOL Top, being >30 ng g^{-1}. These figures are consistent with concentrations found in other rural or remote areas of the Northern Hemisphere. The presence of PCBs at depth in QAD and KOL sediments may be due to an artifact of sampling or analysis, however, the presence of PCBs in the environment (and therefore in lake sediments) prior to their industrial synthesis cannot be ruled out.

Table 2:   A comparison of total PCB concentrations found in this study with those found in other locations

Sample site	Author	Sediment depth (cm)	Time interval represented	ΣPCB concentration (ng g^{-1} dry weight)
Kol (this study)		top		32
		bottom		9
Qvad (this study)		top		13
		bottom		7
Esthwaite Water, UK	Sanders et al (1992)[1]	0-2	1988	31
		10-12	1963	46
		35-38	1899	7
Dark Lake, Wisconsin	Swackhamer & Armstrong (1986)[2]	0-2	1971-1981	19
		6-8	1935-1948	2
Emrick Lake, Wisconsin	Swackhamer & Armstrong (1986)[2]	0-2	1978-1983	89
		8-10	1954-1963	13
Milwaukee Harbour, Wisconsin	Christensen & Lo (1986)[3]	0-10	1975-1980	5530
		70-80	1940-1945	1030
Lake Superior	Golden et al (in press)[4]		1990	~7
			1978	~15
			1916	~2
Lake Michigan	Golden et al (in press)[4]		1990	~130
			1978	~250
			1916	0
Lake Ontario	Golden et al (in press)[4]		1990	~200
			1978	~500
			1916	~10

~ values estimated from Figures

Notes: total PCB concentration defined as:

[1]   sum of 22 individual congeners

[2]   derived from Aroclor 1242, 1248, 1254, 1260

[3]   derived from Aroclor 1242, 1254, 1260

[4]   sum of 80-90 individual congeners

5.0 ACKNOWLEDGEMENTS

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