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A Report to the Royal Society Project Q 607/KB

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Palaeolimnological investigations of lakes on the Jianghan Plain, Central China

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A report to the Royal Society on an exchange agreement between the Royal Society and the Chinese Academy of Sciences

Project Q 607/KB

August 1994

Introduction

The project described in this report is the result of an exchange agreement funded by the Royal Society and the Chinese Academy of Sciences. The scientists involved in the exchange were based at two institutions in the U.K. (University of Liverpool and University College London) and China (Institute of Geodesy and Geophysics, Wuhan and East China Normal University, Shanghai) and ran for 3 years between 1991 and 1993.

The research focused on the central region of the Jianghan Plain, Sihu Region. Three lakes were selected for detailed study, Changhu, Donghu and Honghu (see location map), although sediment cores were taken from a total of nine lakes over the three year period. The three main lakes cover a gradient of human impact, Changhu situated in a rural area to the west of Wuhan, Donghu situated within Wuhan and subject to intensive human impact and Honghu an intermediate case. Of the other study lakes, Shahu, like Donghu is situated within Wuhan, while Liangxihu, Chixihu, Chidonghu, Wanghu and Dayehu are sited to the east of Wuhan.

Laboratory analyses of the sediment samples were undertaken by both Chinese and British scientists and included magnetic measurements, diatom and pollen analyses, particle sizing, geochemical and organic content analysis and trace metal and carbonaceous particle analyses as indicators of atmospheric deposition at the sites.

This report is a summary of the work undertaken during the study period and includes the main results and conclusions arising from it. More detailed reports on specific aspects of the project are included as appendices, along with abstracts of papers stemming directly from this work either submitted to or accepted by peer reviewed journals.

Aims of the project

The main aim of the project was for Chinese and U.K. scientists to collaborate on applying palaeolimnological techniques to large shallow lakes on the Jianghan Plain to try and determine the impact of human influence on these important water bodies.

In the absence of long-term historical water chemistry data, the sediment accumulated in lakes can provide a record of past events and past chemical conditions. Given a long enough sediment record it is possible to determine lake conditions at a time before human influence thereby allowing a baseline to be drawn from which to compare later changes. This allows human impact to be put into perspective alongside natural changes.

The techniques employed were both traditional palaeolimnological ones such as geochemical, pollen, diatom and metal analyses as well as newer methods such as nutrient reconstruction from diatom assemblages and carbonaceous particle analyses which had not been used in this region before. Using such techniques the historical record and recent changes in lake water quality can be assessed and human impact by both direct (discharge of industrial and domestic waste waters into the lake) and indirect (atmospheric deposition of pollutants) means determined.

Site descriptions of the main study lakes

Honghu and Changhu are located in the central part of the Jianghan plain, in the Sihu Region (112°00' - 114°05'E, 24°21' - 30°00'N) in the catchment of the Neijing River. The population of the region is 4.45 million and has an area of 12,120 km^2 of which 432,000 ha is farmland and 329,300 ha is wetland. It is an economically developed region with intensive agriculture and production is important for both Hubei Province and China.

The Sihu region is on the lowlands between the Dongjin River to the north and the Yangtse River to the south and forms the lowest part of the Jianghan Plain with 82% of the area between 20-35 m above sea level. There are 230 lakes in Sihu with a total area of 77,200 ha. Of these Honghu and Changhu are the largest.

Honghu (29°49'N, 113°17'E) measures 23.4 km east to west and 20.88 km north to south with a total area of 355 km^2. The bathymetry is remarkably flat and has a mean water depth of 1.35m (maximum = 2.32m, minimum = 0.40m). 98% of the lake bed is covered by aquatic vegetation with 95 recorded species. The main emergent macrophytes are wild India Rice (*Zizania latifolia*) and lotus. The recorded mean annual temperature in the Honghu area is 16.6°C and the average temperature for July, the hottest month, is 28.9°C. It is a northern sub-tropical monsoon climate with precipitation concentrated into the summer months. The mean annual rainfall is 1344 mm.

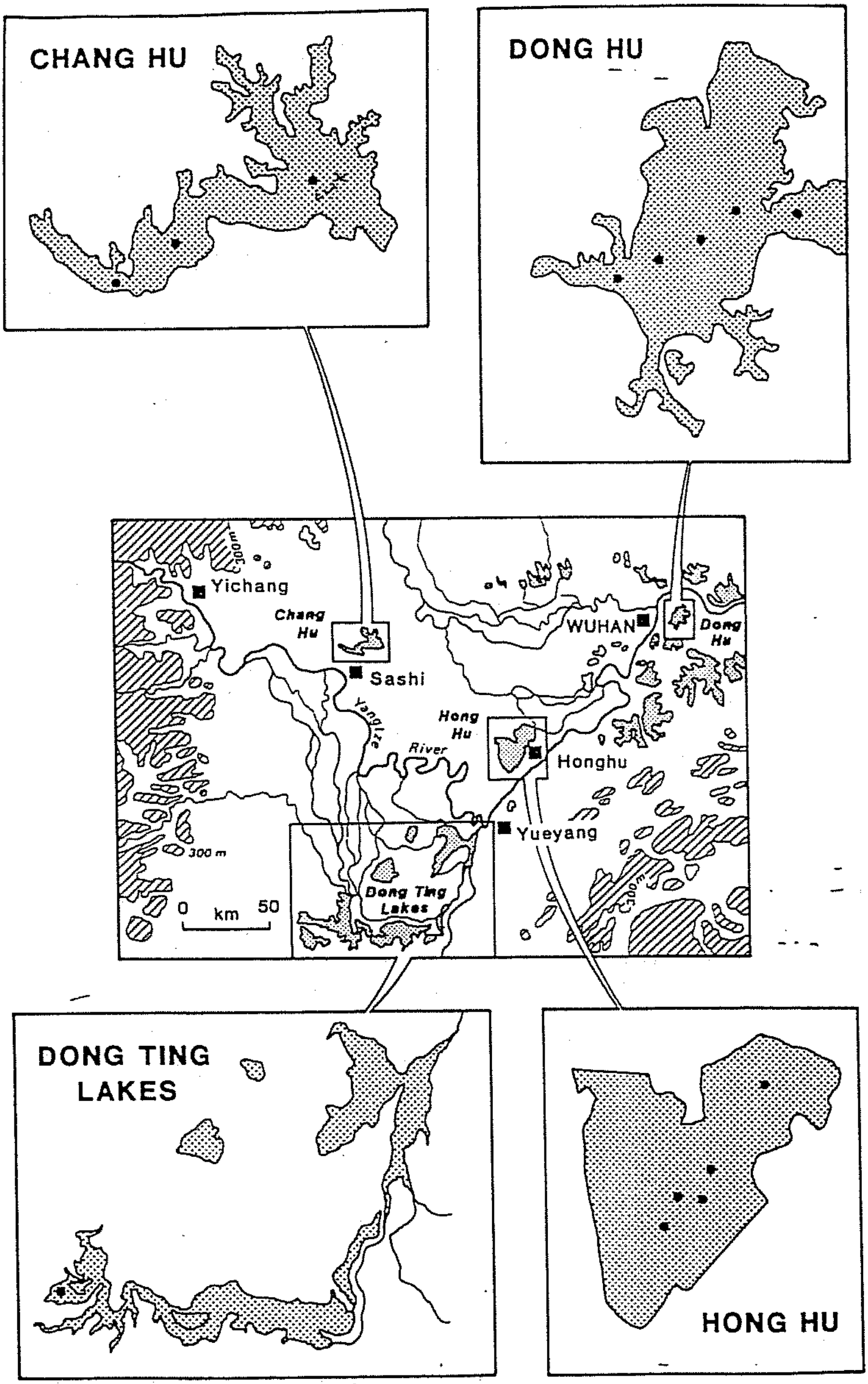
Changhu (30°28'N, 112°23'E) measures 30 km east to west, 18 km north to south and has a surface area of about 127 km^2 and a catchment area of 2265 km^2. The mean water depth is 3.9m with a maximum of 5.2m. The lake receives water from the Shihuiqiao, Hougang, Taihugang and Longhuiqiao Rivers and discharges into Hanshui via the Tianguan River. There are 40 recorded species of aquatic plant, with wetland, emergent, floating and submergent plant zones from shore to lake centre.

Donghu is located in the south of Wuchang in Wuhan city. It is a river dammed lake and consists of a series of 8 interconnected smaller lakes. It also links with Shahu via Shahugong. The surface area of the lake is 42km^2 with a shoreline of 111.5 km. The mean water depth is 2.5m with a maximum of 4.6m towards the south. Donghu is one of the most important domestic, industrial and agricultural water sources in Wuchang. One million people live in the 119 km^2 catchment and 73 factories including the Wuhan Iron and Steel Complex are located along the shore of which 28 discharge sewage into the lake.

Summary of the main results

Diatoms and ostracods

Diatoms are particularly good indicators of past limnological conditions, and their role as indicators of trophic status is well established (eg. Battarbee, 1978; Anderson, 1989). However, until recently,



CHANG HU
DONG HU
Yichang
300m
Chang Hu
Sashi
WUHAN
Dong Hu
Yangtze River
Hong Hu
Honghu
Yueyang
300 m
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Dong Ting Lakes
300m
DONG TING LAKES
HONG HU

only a qualitative interpretation of species changes in the sediments of eutrophic lakes has been possible. In the last few years quantitative approaches have been developed, which enable inferences of the past environment to be made from fossil diatom assemblages in sediment cores. These techniques are now commonly used in palaeolimnology for reconstructing past environmental variables, and models using this approach have recently been developed for reconstructing past lake phosphorus concentrations (eg. Hall & Smol, 1992; Anderson, 1993; Bennion, 1994).

At the outset of this study, the aim was to apply a diatom transfer function developed for lake phosphorus concentrations to the three Hubei lakes in order to assess the onset, causes, and development of eutrophication at each site. However, poor diatom preservation in the sediments of all the studied lakes prohibited any historical interpretation to be made, and the use of the quantitative transfer function approach to address eutrophication problems was not possible. Therefore the report in Appendix B summarises the surface sediment diatom assemblages, the epiphytic (macrophyte samples) and epilithic (littoral rock samples) diatom communities, and provides a summary of the contemporary trophic status of each lake, based on the ecology and habitats of the modern diatom floras.

Honghu

The common diatom taxa in Hong Hu are *Cymbella microcephala, Achnanthes minutissima, Epithemia adnata, Cocconeis placentula,* and *Gomphonema angustatum.* Almost all forms are non-planktonic species, and are primarily associated with epiphytic habitats. The diatom flora indicates shallow, alkaline, mesotrophic conditions. The measured total phosphorus concentration in July 1991 was 25 $\mu g\ l^{-1}$, which appears to be consistent with the trophic status as indicated by the diatoms. Diatom preservation is very poor in the sediments of Hong Hu, and therefore down-core changes cannot be explored. Preliminary ostracod analyses by Dr. Jonathan Holmes (Kingston University, UK) also reveals very poor preservation of ostracod material, with some rare monospecific shells present in a few core levels, and rare bivalve shells, gastropod shells and broken mollusc material were also occasionally observed. The poor preservation can perhaps be explained by the low organic content of the sediments and the loss of sediments from the lake system to the Yangtze River during flood episodes. In addition, the loose, flocculant nature of the surface sediments suggests that these would easily be disturbed and reworked by wave action during storms events leading to further diatom breakage and enhanced dissolution.

Changhu

The dominant diatom taxon in Chang Hu is *Aulacoseira granulata* and its finer form var *angustissima,* and common taxa include *Cocconeis placentula, Nitzschia amphibia, Cyclotella radiosa* and *Epithemia adnata.* The common taxa are indicative of alkaline, nutrient-rich, eutrophic conditions, which is consistent with the measured total phosphorus concentration in July 1991 of 96 $\mu g\ l^{-1}$. Clearly, both the chemical and biological data indicate that Chang Hu has a higher trophic status than Hong Hu. There is some spatial variability in the surface sediment diatom assemblages indicating that the eastern part of Chang Hu is less enriched than the western part. Diatom preservation in the sediments is very poor and is the poorest of all four studied sites. The ostracod data also reveals poorer preservation in Chang Hu than in Hong Hu or Dong Hu, as the samples were barren. This extremely bad preservation prohibits the exploration of down-core changes.

Donghu

The common diatom taxa in Dong Hu are *Cyclotella radiosa, Aulacoseira granulata, Aulacoseira* [sp.1], *Cyclostephanos dubius* and *Cyclostephanos invisitatus*. The common taxa are associated with alkaline, nutrient-rich, strongly eutrophic waters. The trophic status as indicated by the diatom flora is consistent with the measured total phosphorus in July 1991 of 88 µg l^{-1}, and therefore this lake is of similar trophic status to Chang Hu but is clearly more productive than Hong Hu. Analyses of the surface sediments from various locations indicates little spatial variability in diatom species composition across the lake and the diatoms are better preserved in the sediments of Dong Hu, than in either Chang Hu or Hong Hu. However, identification was only possible to a depth of 20 cm in core E2, and there is little down-core change in the floristic composition in this part of the core. The only significant change is the appearance of *Cyclostephanos tholiformis* in the surface sample, which suggests an increase in nutrient levels in recent years. At present, there is no chronology for this core and therefore it is not possible to interpret these changes in relation to time. Preliminary ostracod analyses reveals poor preservation of ostracod material, with some rare monospecific shells present in a few core levels, and rare bivalve shells, gastropod shells and broken mollusc material were also occasionally observed.

Shahu

The common diatom taxa in Sha Hu are planktonic forms, typically associated with alkaline, strongly eutrophic waters, and this assemblage is similar to those found in Dong Hu. Sha Hu is clearly a highly enriched lake but water chemistry data is not available at present. Poor diatom preservation prohibits any temporal change to be investigated.

Pollen

Honghu

The Honghu pollen record can be divided into two parts. The lower part has sediment comprising black clay and organic matter and a high total pollen count. Emergent plants such as Polygonaceae, *Typha* and Gramineae are abundant with some floating plants such as *Trapa*, *Nelumbo* and some submerged plants such as *Myriophyllum*. Spores of Zygnemaceae and *Mougeotia* which prefer highly organic shallow waters appear frequently. All these species are indicative of a shallow water body and it may be that some areas have since become swamp. The upper part of the core shows that the lake has become deeper. Sediment accumulation rate has also increased and has changed to a grey-brown to yellow-brown colour. In this upper portion pollen density is lower and some *Potamogeton* seeds have also been found.

Changhu

The lower part of the core shows local pollen types such as shrubs, herbs and aquatic plants to be relatively abundant as are spores of freshwater algae and this indicates a shallow sedimentary environment. Within the water body, emergent plants such as Gramineae, *Typha*, *Sparganium* and Polygonaceae are abundant together with *Trapa*, *Nelumbo* and *Myriophyllum*. Towards the north-west of the lake a hilly area forested with mainly broadleaf deciduous trees is represented by pollen from *Quercus*, *Castanea*, *Castanopsis*, *Ulmus*, *Pterocaryas*, *Juglans* and *Pinus*. A few peaks of *Picea* and

Abies may suggest a cool period in the higher altitude area. From the time represented by 46cm sediment depth, the lake began to deepen. The main aquatic pollen types are submerged species including *Myriophyllum*. In the upland area, human activity intensified causing a decline in broadleaf tree pollen whilst needle leaf tree pollen expands.

Carbonaceous Particle analyses

Carbonaceous particles (CPs) are produced from the high temperature combustion of fossil-fuels, which in this region of China is almost exclusively coal. Extraction and enumeration of these particles from lake sediment cores therefore gives an historical record of atmospheric deposition at lake sites. CPs are chemically robust and immobile in sediments so are a good marker for the onset and changes in other fossil-fuel derived pollutants especially where these are either not reliably recorded in sediments (e.g. sulphur) or expensive to analyse (polycyclic aromatic hydrocarbons). In addition the consistent patterns of the particle profiles allows their use as an indirect dating tool for sediments. Unfortunately this technique relies upon one core from the region to be reliably dated (using for example, radiometric techniques or varve counting). This has not been the case in the cores taken for this project and so dating is missing from all cores. However, the similarity between the CP profiles and that of metals, and combustion statistics for coal in Wuhan does suggest tentative dates for some particle profile features. This could in the future lead to a cheap, quick and reliable way of dating sediment cores in this area. This is discussed in more detail in Appendix D.

The CP results from these sites are remarkably consistent in two respects. Firstly, the shapes of the profiles are very similar suggesting that they have been affected by depositions from a single large source, probably Wuhan, throughout the time of the profile. This is supported by the similarity of this general pattern to the coal consumption record for Wuhan. This, and the lack of similarity to the national pattern, also implies that Wuhan is the sole source of pollutants for a large part of the Jianghan Plain and although other emission sources do exist they are not large enough to effect the sedimentary record of the lakes studied. This study was not exhaustive and local influences are likely to occur at other sites.

Secondly, a spatial pattern exists showing a decrease in both surface and core maximum CP concentration with increasing distance from Wuhan. This seems to support the 'Wuhan source' hypothesis, as local or other large-but-remote influences would upset this pattern which extends at least 185 km from Wuhan. Assuming this to be a radius, then Wuhan influences an area of at least 100,000 km^2. Prevailing wind directions will of course play a major part and this is only a very rough approximation.

A plot of either log maximum CP concentration or log surface CP concentration against distance from Wuhan shows a straight line suggesting that CP concentration decreases by a factor of ten with every 200-250 km from the city. As concentrations start at about 10,000-20,000 gDM^{-1} in Wuhan, a 0 gDM^{-1} value would be reached at about 850-950km from the city although of course, in practice this would not be the case. Concentrations of between 100 - 1000 gDM^{-1}, the range (depending on sediment accumulation rate) that has been attributed to a 'hemispherical background' for CPs would therefore be reached at a distance of about 250 - 300km from the city.

Magnetic measurements

Mineral magnetic measurements on sediment cores from Donghu reveal evidence for changes in the magnetic properties of the sediments. This suggests that the recent lake sediment profiles contain deposited magnetic minerals and atmospherically derived fly-ash from industrial processes starting in the 1950's and increasing in recent decades. This is supported by evidence from carbonaceous particle analyses and adds further evidence to the inferred dates attributed to the sediment cores by carbonaceous particles in Appendix D. In addition the record of haematite deposition parallels that of the influence of urban waste water input into the lake supporting the geochemical and diatom evidence for increases in the nutrient input and status of the lake.

Sediment Geochemistry

The recent sediment history of the studied lakes on the Jianghan Plain shows that human influence, especially urban development and industrialisation of the region have had a great impact, far exceeding any changes found in the early sediment record which are attributed to natural variability. Most of the lakes on the Jianghan Plain are shallow and this benefits the growth of aquatic plants. Geochemical analysis of sediments from these lakes show that the growth of these plants has caused an enrichment of C and N and a decrease of Al in surface sediments. Agricultural and domestic waste water has brought more P, C and N to the lakes and this has been seen to promote eutrophication and cause P enrichment in the sediment. This is supported by diatom evidence. With urban development and the input of industrial waste water into the lakes toxic metals are also enriched in the sediments. Lake waters in the region are extensively used for the purposes of agriculture and fisheries giving rise to the possibility that these metals could accumulate in and adversely effect the health of the local population.

In Honghu, aquatic plant growth has given rise to enrichment of some nutrient elements in the sediment surface although less enrichment has taken place where cultivation has removed nutrients from the system. However, groundwater movement is high and is increased by cultivation processes and this results in a loss of Ca, Mg, Fe and Mn in these areas.

The major influence on the sediments in Donghu is discharge of sewage and industrial effluent from the factories around the shore. This has increased since the 1960's leading to an acceleration in phosphorus loadings. The lake is now highly eutrophic. Trace metals are also found to significantly increase in surface sediments.

Trace Metals

The trace metal content of sediment in the studied lakes is controlled mostly by mineral supply from the catchments: Mn, Cu, Zn and Ni concentrations are close to that of average shale. Pb concentrations alone are significantly greater than average shale, and show up-core increases at all studied sites.

At individual sites Pb contents and carbonaceous particle concentrations are correlated indicating a common, probably atmospheric, source for these materials. Other trace metals normally associated with atmospheric pollution are not observed to increase up-core. This may be explained by the low abundance of the Pb (only 10 - 15 ppm above background). Only Zn is expected to be present in comparable amounts, and it would be masked by the high Zn background concentrations. The low concentration of atmospheric trace metals may be due to relatively small local sources, but in part is also explained by the high sediment accumulation rate, which has the effect of diluting the pollution.

Daye Hu differs from the other lakes in showing an extreme enrichment in Cu, and lesser enrichment in Zn, Pb and Fe. As no enrichment in carbonaceous particles is observed, this pollution is likely to have an origin different from that in the other lakes.

Conclusions and Recommendations

Palaeolimnological studies have shown that there has been a long term human influence on the lakes of the Jianghan Plain, central China. This impact began 1500 years ago when there was a large population movement from the mountain region to the plain, but evidence suggests that increases in population, industrialisation and urban development have, in recent decades, affected the lakes at an unprecedented rate.

This impact takes the form of both direct discharges into the lakes from local agricultural, domestic and in some cases industrial waste-waters, and indirect effects such as atmospheric deposition of pollutants from more remote sources. The accelerated increase in nutrient inputs to the lakes has been observed by both changes in diatom floras stored in the sediments as well as geochemical techniques and it is probably this change which has been most significant.

Depositions of industrially derived pollutants, transported and deposited via atmospheric pathways are much more recent, the record (determined by metal, magnetic and carbonaceous particle analyses) only really starting in the 1950's. However, increases since that time have been dramatic and with continued increasing industrialisation are likely to continue to be so. Concentrations of, for example, carbonaceous particles are at the level of many European lakes where depositions have been decreasing over the last 10-20 years. However, high sediment accumulation rates in the Jianghan Plain lakes means that loadings of atmospheric pollutants maybe higher than these figures suggest and could lead to significant impact on freshwaters in sensitive areas as has been seen throughout Europe and the United States.

This study of sediment cores from lake sites on the Jianghan Plain has shown the long-term and extensive impact of human activities on the region. In particular direct discharges into the lakes has increased the trophic status and these changes have overwhelmed any impact that may have been caused by atmospheric depositions and more subtle environmental changes.

Assessing environmental changes such as climate change and atmospheric contamination is the next logical step in this palaeolimnological study and is especially important in this region of China situated in a zone of climatic transition between sub-tropical southern China and temperate north-central China. Lake sediments could be used to study such changes but the Jianghan Plain lakes studied in this report would not be suitable as the influence of such subtle changes would be masked. However, there are upland lakes to the west of Hubei in the Shennongjia area ideally situated for studies of this nature and this will be the subject of a future proposal to the Royal Society and the Chinese Academy of Sciences.

Acknowledgements

We would like to thank the Royal Society and the Chinese Academy of Sciences for both their financial support and their continued help and encouragement.

In addition, we are grateful to Dr. Jonathan Holmes of Kingston University, London who undertook the ostracod analyses.

Appendix A

Abstracts of papers from this project submitted to and accepted by peer reviewed journals.

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The chemical structure of the ecological environment in Lake Honghu

Yang Handong and Cai Shuming
(Institute of Geodesy and Geophysics, Academica Sinica, Wuhan 430077)

Abstract

Lake Honghu is a typical shallow lake in the Middle Reaches of the Yangtse River. It is filled with aquatic plants and is an example of an important type of wetland in China. This paper reports on the chemical structure of the ecological environment in the lake.

In the lake water, Ca^{2+} and HCO_3^- are the major cation and anion respectively, the alkali capacity is rather low and the acid capacity is 1.2 - 2.0 x 10^{-3} mol/l H^+. The carbonate equilibrium is the basic control of the geochemical processes of water quality and the carbonates form easily.

Aquatic plants in the lake concentrate certain elements and the sediment profiles of C, N, S, Ca and Cd show surface enrichment. The content of Al is relatively poor in the sediment where aquatic plants grow in abundance.

Most of the C exists in the aquatic plants and most of the N, P, K, Ca and Mg exist in the sediment. The sediment compartment is a major store of nutrient elements.

Accepted by *Acta Ecologica Sinica*.

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Environmental implications of magnetic measurements on recent sediments from Lake Donghu, Wuhan.

Yang Handong [1], He Baoyin [1], Cai Shuming [1], Frank Oldfield [2] and Yu Lizhong [3]
[1] (Institute of Geodesy and Geophysics, Academica Sinica, Wuhan 430077)
[2] (Department of Geography, University of Liverpool, Liverpool)
[3] (Department of Geography, East China Normal University, Shanghai)

Abstract

Mineral magnetic measurements have been made on three sediment cores from Lake Donghu, Wuhan, and reveal evidence for changes in the magnetic properties of the sediments. It is suggested that the recent lake sediment profiles contain deposited magnetic minerals and atmospherically derived fly-ash from industrial processes. In the cores, the lake has been affected by heavy industrial processes beginning in the 1950's and increasing in recent decades. In one core the record of haematite deposition parallels that of the influence of urban waste water input.

Environmental geochemistry of sediment in Lake Donghu, Wuhan.

Yang Handong, Nang Shengwen and Cai Shuming
(Institute of Geodesy and Geophysics, Academica Sinica, Wuhan 430077)

Abstract

The distribution and role of C, N, P, Si, Al, Fe, Ca, Mg, Cu, Zn, Pb, Cd, pH and Eh in the sediment series of Lake Donghu in Wuhan are described and analysed in this paper. The processes of the sediment geochemistry in this lake have been affected mainly by human activities. Since the 1960's, the sedimentation and sediment series in the lake have been disturbed and the discharge of sewage water from multiple sources have accelerated eutrophication. A large amount of carbon, nitrogen and phosphorus have been accumulated in the sediment. The accumulation of these nutrients is considered to be the major factor resulting in the deterioration of the lake environment. In addition, the heavy accumulation of phosphorus in the sediment was found to be synchronous with disturbance from humans. Hence, the authors are of the opinion that the concentration of phosphorus in the sediment may be used as an indicator for dividing the intensity and area of pollution in the sediment of Lake Donghu.

Accepted by *Acta Hydrobiologia Sinica*

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The chemical characteristics of lake sediments in the Jianghan Plain and the relationship with the influence of human activities.

Yang Handong and Cai Shuming
(Institute of Geodesy and Geophysics, Academica Sinica, Wuhan 430077)

Abstract

This paper reports the chemical characteristics of sediments Lake Honghu, Lake Changhu, Lake Donghu and Lake Shahu, on the Jianghan Plain and discusses the evolutionary features of the lakes on the Plain as well as the ways and levels of influence on these lake environments by human activities.

Most of the lakes on the Jianghan Plain are shallow and this benefits the growth of aquatic plants. In recent changes of the lakes, human activities, especially urbanisation and industrialisation, have had greater effects on the lake environment. These changes have exceeded natural variability.

The chemical characteristics of the lake sediment profiles in the Jianghan Plain show that the growth of aquatic plants have led to enrichment of C and N and a decrease in Al in sediments. Agricultural and domestic waste water which have been input to the lakes and brought more P, C and N to take part in lake ecology, promote eutrophication and cause P enrichment in the sediment. With urban development and the input of industrial waste water into the lakes, not only C, N and P were enriched in the sediments, but also toxic metals. These effect lake ecosystems and change ecological structures. Where urbanisation and industrialisation is developed to a high degree, if lake resources are not protected, then nutrient elements and toxic metals accumulate in the sediment, lake resources are further destroyed and can cause harm to humans.

Primary research of vegetation and environmental change in the district of Honghu Lake and Changhu Lake

Zhou Xinyu
(Institute of Geodesy and Geophysics, Academica Sinica, Wuhan 430077)

Abstract

Pollen analyses have been undertaken on sediment cores from the two lakes. The core D1 from Honghu can be divided into two parts. The lower part has sediment comprising black clay and organic matter and a high absolute pollen count. Emergent plants such as Polygonaceae, *Typha* and Gramineae etc. were abundant with some floating plants such as *Trapa, Nelumbo* and some submerged plants such as *Myriophyllum*. Spores of Zygnemaceae and *Mougeotia* which prefer highly organic shallow waters appeared frequently. All these species are indicative of a shallow water body and it may be that some areas have become swamp. The upper part of the core indicates a deeper lake. At this time the sediment accumulation rate increased and grey-brown to yellow-brown sediment appeared. In this sediment, pollen density is lower and some *Potamogeton* seeds have been found.

In Changhu Lake local pollen types such as shrubs, herbs and aquatic plants are relatively abundant as are spores of freshwater algae and this indicates a shallow sedimentary environment. Within the water body, emergent plants such as Gramineae, *Typha, Sparganium* and Polygonaceae were abundant together with *Trapa, Nelumbo* and *Myriophyllum*. Towards the north-west of the lake was a hilly area with a mainly broadleaf deciduous forest with pollen from *Quercus, Castanea, Castanopsis, Ulmus, Pterocaryas, Juglans* and *Pinus* present. A few peaks of *Picea* and *Abies* may suggest a cool period in the high altitude area. From the time represented by 46cm sediment depth, the lake began to deepen. The main aquatic pollen types were submerged species including *Myriophyllum*. In the hilly area nearby, human activity intensified including a denudation of the landscape. Consequently, broadleaf tree pollen becomes less common and needle leaf trees expand because of their great vitality.

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The geochemical characteristics of cultivation processes in Lake Honghu.

Yang Handong and Cai Shuming
(Institute of Geodesy and Geophysics, Academica Sinica, Wuhan 430077)

Abstract

The geochemistry of Lake Honghu has been affected by human activities. This paper comprehensively explains geochemical characteristics of cultivation processes in the lake. It has been shown that:

(1) Owing to abundant aquatic plant growth, some elements such as S, C, N and Ca are enriched in the surface of the sediment. The concentrations of nutrient elements reduce in the process of cultivation.

(2) Because the level of the groundwater is high and the movement of groundwater is frequent in the area of cultivation, many elements such as Ca, Mg, Fe and Mn are removed. The loss of Ca is nearly 80%.

(3) In the evolution of the lake, changes in cultivation and changes in dry and wet processes of the lake have altered sedimentation processes and the order of sediment layers and the distribution of elements changed.

Accepted by *Oceanologica et Limnologica Sinica*

Other papers in preparation:

Cai, S., Oldfield, F., Battarbee R.W., et al. A palaeoecological investigation to assess recent changes to lakes on the Jianghan Plain, Hubei. To be submitted to *Journal of Ecology*

Boyle, J., Yang, H., Rose, N., et al. Temporal and spatial patterns of atmospheric deposition on the Jianghan Plain, Hubei, using the lake sediment record. To be submitted to *Water, Air and Soil Pollution.*

Zhou, X., and Bennion, H. et al. Pollen and diatom evidence for changes in nutrient status of three eutrophic lakes in central China over the last 2000 years. To be submitted to *Journal of Paleolimnology*

These manuscripts are almost complete but require ^{210}Pb dating before they can finally be published. It is hoped other papers may also be produced from this work.

In addition a book has been prepared by Professor Cai Shuming which includes the results of this study entitled 'Palaeolimnology and Holocene Environmental Changes in the Jianghan-Dongting Plain'. This book will be published in China in both Chinese and English.

Appendix B

THE DIATOM ASSEMBLAGES OF LAKES ON THE JIANGHAN PLAIN, HUBEI PROVINCE, CHINA.

Helen Bennion

Introduction

This report details the analyses of diatom (unicellular, siliceous algae) assemblages from four large lakes, Hong Hu, Chang Hu, Dong Hu, and Sha Hu, situated on the Jianghan Plain in Hubei Province, Central China. These lakes are approximately 2000-3000 years old but have experienced recent environmental change, owing principally to land-use changes in their catchments. Originally, the plain was essentially a lake and bog landscape. However, approximately 1500 years ago, there was a large population movement from the mountain region to the plain, with the first mass rice cultivation and a phase of land reclamation taking place some 500 years later. There has since been further development, with the biggest population expansion and the peak of cultivation occurring approximately 300-600 years ago, and further expansion in the early 20th century and again in the 1950s. The current high population density on the Jianghan Plain, recent industrial development and more importantly the extensive agricultural development, with increasing use of chemical fertilisers in the last 40 years, has serious implications for the water quality of the region's large lakes, particularly with regard to the problem of cultural eutrophication.

Therefore, the aim of the work presented here was to examine the extent of eutrophication in the three selected lakes by means of diatom analysis. In the absence of long-term historical water chemistry data, the sediment accumulated in lakes can provide a record of past events and past chemical conditions (Smol, 1992). Diatoms are particularly good indicators of past limnological conditions, and their role as indicators of trophic status is well established (eg. Battarbee, 1978; Anderson, 1989). However, until recently, only a qualitative interpretation of species changes in the sediments of eutrophic lakes has been possible. In the last few years quantitative approaches have been developed, which allow the generation of a 'transfer function' describing the relationship between a given diatom species and an environmental variable, and which enables inferences of the past environment to be made from fossil diatom assemblages in sediment cores. The techniques of weighted averaging (WA) regression and calibration (ter Braak & van Dam, 1989) are now commonly used in palaeolimnology for reconstructing past environmental variables, and models using this approach have recently been developed for reconstructing past lake phosphorus concentrations (eg. Hall & Smol, 1992; Anderson, 1993; Bennion, 1994).

At the outset of this study, it was the aim to apply such a diatom transfer function developed for establishing background lake phosphorus (P) concentrations from a set of shallow, eutrophic lakes in the United Kingdom (Bennion, 1994), to the three Hubei lakes, in order to reconstruct the epilimnetic P concentrations in these lakes and thus to assess the onset, causes, and development of eutrophication at each site. However, poor diatom preservation in the sediments of all the studied lakes prohibits any historical interpretation to be made, and clearly the use of the quantitative transfer function approach to addressing eutrophication problems is not possible in this study. Therefore, the following report focuses on the surface sediment diatom assemblages (short cores), and the epiphytic (macrophyte samples) and epilithic (littoral rock samples) diatom communities, and provides a summary of the contemporary trophic status of each lake, based on the ecology and habitats of the modern diatom floras.

Hong Hu

A series of samples from two sampling dates, July 1991 and October 1992, have been analysed and the data are summarised below. Only those species present in percentages greater than 5% are listed.

The number of valves counted in each sample varies according to the level of preservation, with approximately 100 valves counted in the poorest samples and approximately 300 valves counted in the live material.

Epilithon (July 1991)

Achnanthes minutissima	78%
Synedra acus	7%
Fragilaria intermedia	5%

Epiphyton (July 1991)

Epithemia adnata	29%
Nitzschia gracilis	23%
Cocconeis placentula	21%
Cymbella veneta	5%

Core A1, 0-1 cm (July 1991): water depth 4.3 m; location=NE; diatoms rare.

Cymbella microcephala	20%
Amphora pediculus	15%
Gomphonema angustatum	13%
Cocconeis placentula	10%
Achnanthes minutissima	10%
Nitzschia frustulum	10%
Epithemia adnata	8%

[NB. No diatoms observed in remainder of core A1].

Core A3, 0-1 cm (July 1991): water depth 4.3 m; location=NE; diatoms rare.

Cymbella microcephala	28%
Epithemia adnata	16%
Gomphonema angustatum	16%
Synedra acus	8%
Cymbella silesiaca	8%

Core B1, 0-1 cm (July 1991): water depth 3.5 m; location=SW; diatoms too broken to count, but species seen are the same as in A3.

Core D1, 0-1 cm (July 1991): water depth 4.3 m; location=Central N; a few broken diatom valves were seen but identification not possible throughout the whole core. Very inorganic sediment.

Core D2, 0-1 cm (July 1991): water depth 4.3 m; location=Central-N; diatoms rare.

Achnanthes minutissima	38%
Cymbella microcephala	25%
Navicula radiosa v. *tenella*	12%
Gomphonema angustatum	6%
Cymbella silesiaca	6%

Core 92/2, 0-1 cm (October 1992): water depth 1 m; location=NW; diatoms rare.

Achnanthes minutissima	32%
Cocconeis placentula	21%
Amphora pediculus	14%
Nitzschia amphibia	10%

[A few broken valves were seen in the remainder of the core, but identification not possible].

The common diatom taxa in Hong Hu are *Cymbella microcephala, Achnanthes minutissima, Epithemia adnata, Cocconeis placentula,* and *Gomphonema angustatum*. Almost all forms are non-planktonic species, and are primarily associated with epiphytic habitats, given the dense macrophyte coverage in the lake. The diatom flora indicates shallow, alkaline, mesotrophic conditions. The measured total phosphorus concentration in July 1991 was 25 μg l^{-1}, which appears to be consistent with the trophic status as indicated by the diatoms.

Diatom analysis of the surface sediments from various locations across the lake in 1991 indicates little spatial variability in the composition of the diatom assemblages. Diatom preservation is very poor in the sediments of Hong Hu, and therefore down-core changes cannot be explored. Preliminary ostracod analyses by Dr. Jonathan Holmes (Kingston University, UK) also reveals very poor preservation of ostracod material, with some rare monospecific shells present in a few core levels, and rare bivalve shells, gasteropod shells and broken mollusc material were also occasionally observed.

The poor preservation can perhaps be partly explained by the low organic content of the sediments. Loss on ignition (LOI) data shows that below about 9 cm in the core, the percentage LOI is less than 10%, and percentage dry weight (DW) is between 30-40%. Therefore, most of the core has a high mineral (clay) content. The high temperature in the summer months produces anaerobic conditions in the sediments and de-oxygenation of the water. Furthermore, biological processes such as high microbial activity and fish grazing causes carbon to be converted to carbon dioxide, resulting in low production of organic matter. A further explanation for the lack of diatom material in the Hong Hu sediments is loss from the lake system to the Yangtze River during flood episodes, so that many cells never reach the sediments. In addition, the rather loose, flocculant nature of the surface sediments suggests that these would easily be disturbed and reworked by wave action during rain storms, and this might cause diatom breakage and enhanced dissolution for those cells that do reach the sediments, and reduces the likelihood that the diatoms become permanently buried in the sediment. A combination of the above factors may explain why there is no fossil diatom record in the Hong Hu sediments, but more detailed work on sediment resuspension with traps and the impact of grazing etc is required before any firm conclusions can be made.

Chang Hu

As for Hong Hu, a series of samples from the two sampling dates, July 1991 and October 1992, have been analysed, plus samples from a long core (LL1) taken by colleagues at the Institute of Geodesy and Geophysics in November 1991, and the data are summarised below. Only those species present in percentages greater than 5% are listed. The number of valves counted in each sample varies according to the level of preservation, with approximately 100 valves counted in the poorest samples and 300 valves in the live material.

<u>Epilithon (July 1991)</u>

Aulacoseira granulata	24%
Aulacoseira granulata v. *angustissima*	15%
Nitzschia amphibia	10%
Nitzschia frustulum	8%
Gomphonema parvulum	7%

<u>Core A1, 0-1 cm (July 1991):</u> water depth 3.4 m; location=W; diatoms very broken.

Aulacoseira granulata	29%
Cocconeis placentula	16%
Aulacoseira granulata v. *angustissima*	13%
Nitzschia amphibia	8%
Stephanodiscus hantzschii	6%
Cyclostephanos tholiformis	5%

Core LL1, 0-1 cm (November 1991): water depth 2 m; location=E-Centre; diatoms very broken.

Aulacoseira granulata	34%
Cyclotella radiosa	18%
Epithemia adnata	12%
Fragilaria construens	8%

[NB. Only a few diatom fragments observed and very high clay content in remaining levels of core LL1.]

Core 92/2, 0-1 cm (October 1992): water depth 1.5 m; location=E; diatoms very badly preserved and most specimens badly broken.

Aulacoseira granulata	30%
Cocconeis placentula	15%
Cyclotella radiosa	10%
Epithemia adnata	7%
Achnanthes minutissima	6%
Rhopalodia gibba	5%

[NB. Only a few badly broken diatoms (of the same species as those in the surface sediment) observed in the next few levels, but analysis of the remainder of core 92/2 not possible.]

The dominant diatom taxon in Chang Hu is *Aulacoseira granulata* and its finer form var *angustissima*, and common taxa include *Cocconeis placentula, Nitzschia amphibia, Cyclotella radiosa* and *Epithemia adnata*. Both planktonic and non-planktonic diatom forms are present. The common taxa are indicative of alkaline, nutrient-rich, eutrophic conditions, which is consistent with the measured total phosphorus concentration in July 1991 of 96 $\mu g\ l^{-1}$. Clearly, both the chemical and biological data indicate that Chang Hu has a higher trophic status than Hong Hu.

There is some spatial variability in the surface sediment diatom assemblages. *Cyclotella radiosa* is present only in the samples from the Eastern part of the lake, whilst *Cyclostephanos tholiformis* and *Stephanodiscus hantzschii* are present only in the sample from the Western part of the lake. The former species is generally associated with mesotrophic waters, whilst the latter two are associated with strongly eutrophic waters, thus indicating that the Eastern part of Chang Hu is less enriched than the Western part. In addition, water depth may explain why planktonic forms account for a greater percentage of the total assemblage in the Western part of the lake, than in the Eastern part, where the average water depth is lower and where frequencies of non-planktonic forms are higher. Furthermore, macrophyte cover is denser in the shallower, Western part thus providing a possible explanation for the higher abundance of epiphytic taxa (*Epithemia* spp., *Achnanthes* spp., and *Fragilaria* spp.) in the Eastern samples compared to the Western sample.

Diatom preservation in the sediments is very poor and is the poorest of all four studied sites. The ostracod data also reveals poorer preservation in Chang Hu than in Hong Hu or Dong Hu, as the samples were barren. As in Hong Hu, the LOI data indicates that the organic matter content is low throughout the whole core (6-11%) and decreases rapidly with depth down core. Conversely, DW is very high (25-50%), particularly below 5 cm, and the sediments appear to have a high clay content. This extremely bad preservation prohibits the exploration of down-core changes.

Dong Hu

As for Hong Hu and Chang Hu, a series of samples from the two sampling dates, July 1991 and October 1992, have been analysed and the data are summarised below. Only those species present in percentages greater than 5% are listed. The number of valves counted in each sample varies according to the level of preservation, with approximately 100 valves counted in the poorest samples and 300 valves in the live material.

Core E2, 0-1 cm (July 1991): water depth 5 m; location=Centre; diatom preservation good.

Cyclotella radiosa	22%
Aulacoseira [sp.1]	17%
Aulacoseira granulata	10%
Cyclostephanos tholiformis	10%
Cyclostephanos dubius	9%
Nitzschia subacicularis	7%

Core E2, 4-5 cm (July 1991): as above; diatoms broken but identification still possible.

Aulacoseira [sp.1]	33%
Cyclotella radiosa	20%
Aulacoseira granulata	16%
Cyclostephanos invisitatus	11%
Cyclostephanos dubius	6%

Core E2, 10-11 cm (July 1991): as above; diatom preservation poor.

Aulacoseira [sp.1]	37%
Aulacoseira granulata	22%
Cyclotella radiosa	13%
Cyclostephanos invisitatus	7%
Cyclostephanos dubius	5%

Core E2, 20-21 cm (July 1991): as above; diatom preservation very poor.

Aulacoseira granulata	34%
Cyclotella radiosa	18%
Aulacoseira [sp.1]	16%
Cyclostephanos dubius	11%
Gyrosigma acuminatum (fine)	10%

[NB. diatom preservation too poor in remaining levels of core E2 for counting].

Core F2, 0-1 cm (July 1991): water depth 3.5 m; location=W; diatom preservation reasonable.

Cyclotella radiosa	20%
Cyclostephanos invisitatus	16%
Aulacoseira granulata	13%
Cyclostephanos dubius	10%
Nitzschia sp.	9%
Aulacoseira [sp.1]	7%

Core G1, 0-1 cm (July 1991): water depth 3.7 m; location=E; diatom preservation reasonable.

Cyclotella radiosa	23%
Aulacoseira granulata	16%
Cyclostephanos dubius	12%
Nitzschia subacicularis	8%
Cyclotella meneghiniana	8%
Aulacoseira [sp.1]	8%
Synedra acus v. *angustissima*	5%
Cyclotella pseudostelligera	5%

Core 92/2, 0-1 cm (November 1992); water depth 3.6 m; location=SW; diatom preservation reasonable.

Aulacoseira [sp.1]	25%
Cyclotella radiosa	13%
Cyclostephanos invisitatus	8%
Cyclostephanos dubius	7%

[NB. *Aulacoseira* [sp.1] belongs to the *A. alpigena* group, but the specimens here do not exactly match any published taxonomic descriptions, and hence a temporary name is assigned].

Sha Hu

A single short core was taken from Sha Hu in November 1992, and the data are summarised below. Only those species present in percentages greater than 5% are listed. Only 100 valves were counted in the surface sample owing to the low level of preservation.

Core 92/1, 0-1 cm (November 1992); water depth 2 m; location=Centre; diatom preservation poor.

Aulacoseira granulata	20%
Cyclostephanos dubius	12%
Stephanodiscus hantzschii	10%
Cyclotella atomus	7%
Cyclotella meneghiniana	6%
Aulacoseira sp.	5%

[Diatom preservation too poor in the remainder of core 92/1 for counting]

The common diatom taxa in Sha Hu listed above are planktonic forms, typically associated with alkaline, strongly eutrophic waters, and this assemblage is similar to those found in Dong Hu. Sha Hu is clearly a highly enriched lake but water chemistry data is not available at present. Poor diatom preservation prohibits any temporal change to be investigated. As for the other lakes, LOI values are low (17-19%) in the top 17 cm of the core, and the material is clay-based.

Summary

The common diatom species observed in the surface sediments of the Jianghan Plain lakes are the same as those found in shallow waters in Europe of similar water chemistry, indicating the potentially wide geographical applicability of diatom transfer functions as long as dominant taxa are adequately represented in training sets and fossil diatoms are preserved in sediment cores.

Other lakes

In November 1993, a series of lakes to the East of Wuhan city were sampled. Short sediment cores were extracted from Wang Hu, Chi Xi Hu, Chi Dong Hu and Liangxi Hu. The samples have been screened and preliminary analyses indicates that there is also a low level of preservation in these lakes. However, detailed diatom analysis has not yet been undertaken, but should be completed by October 1994.

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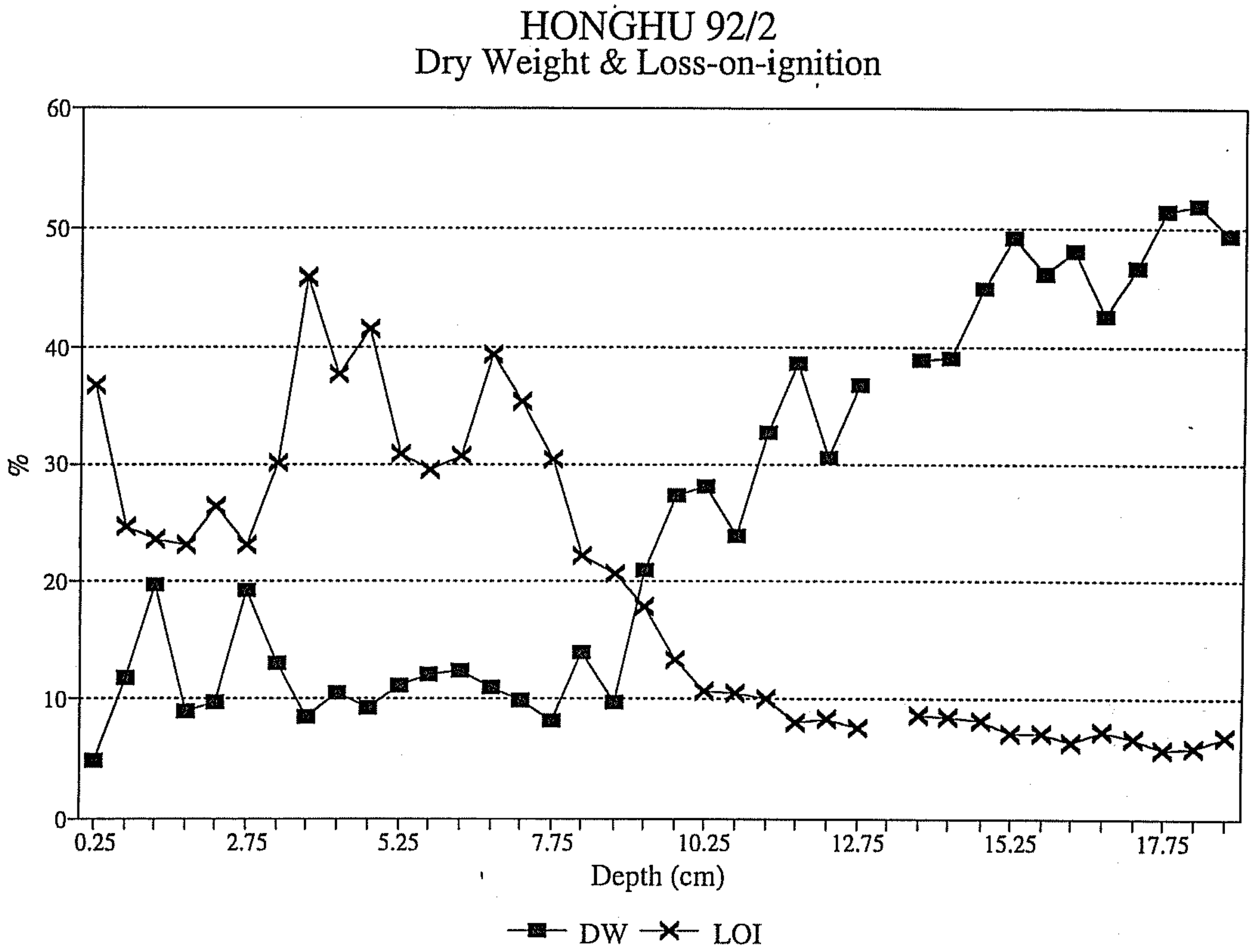
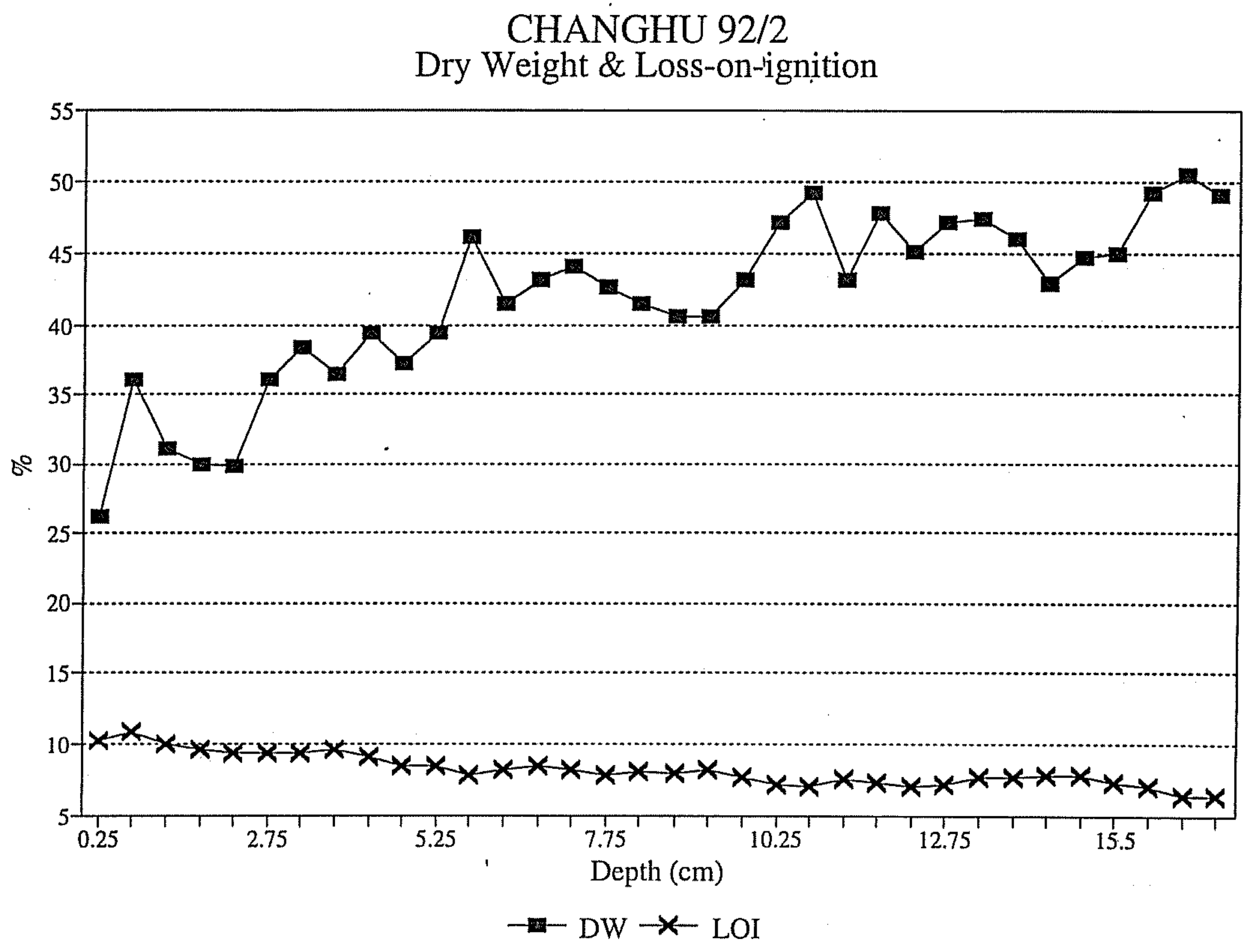
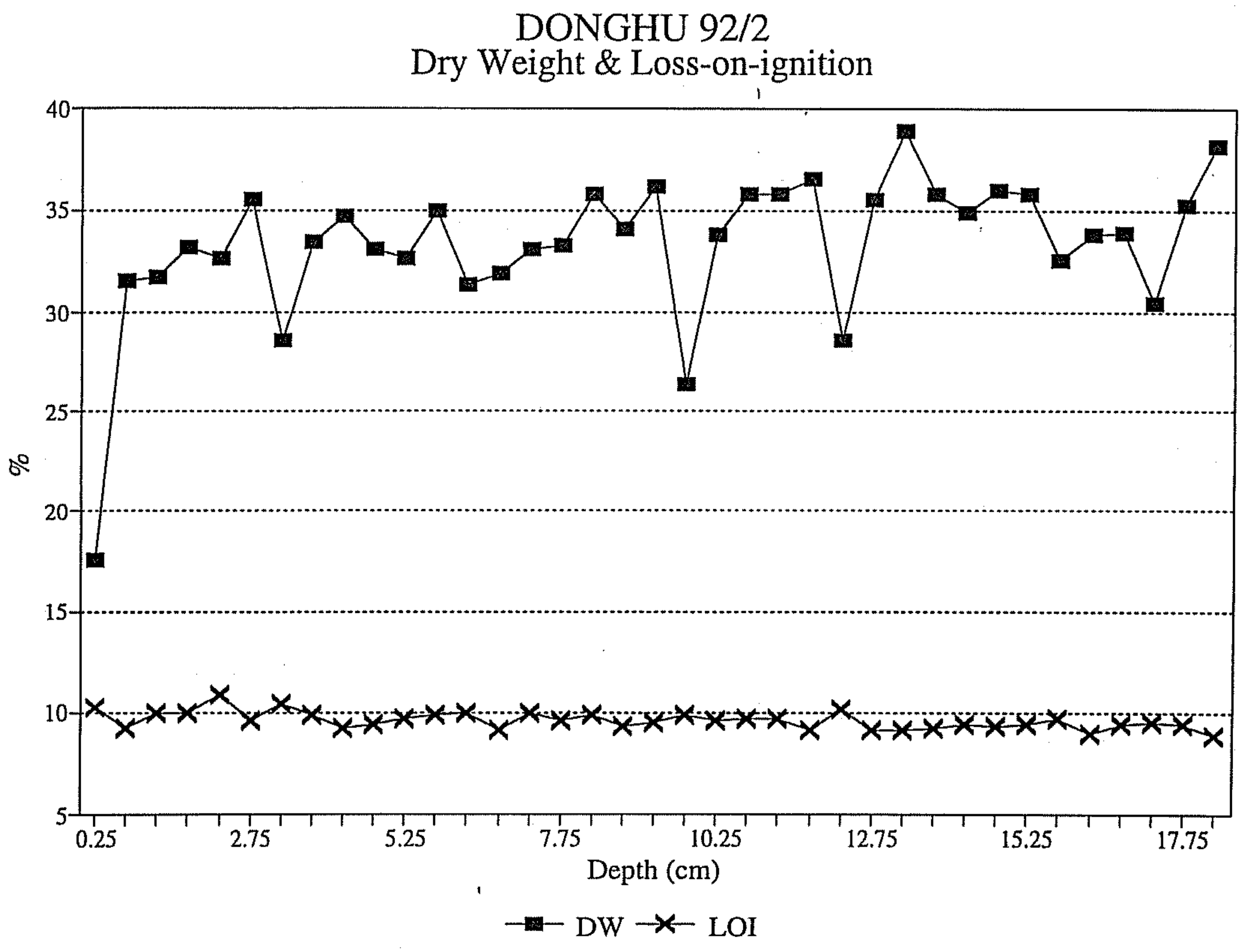
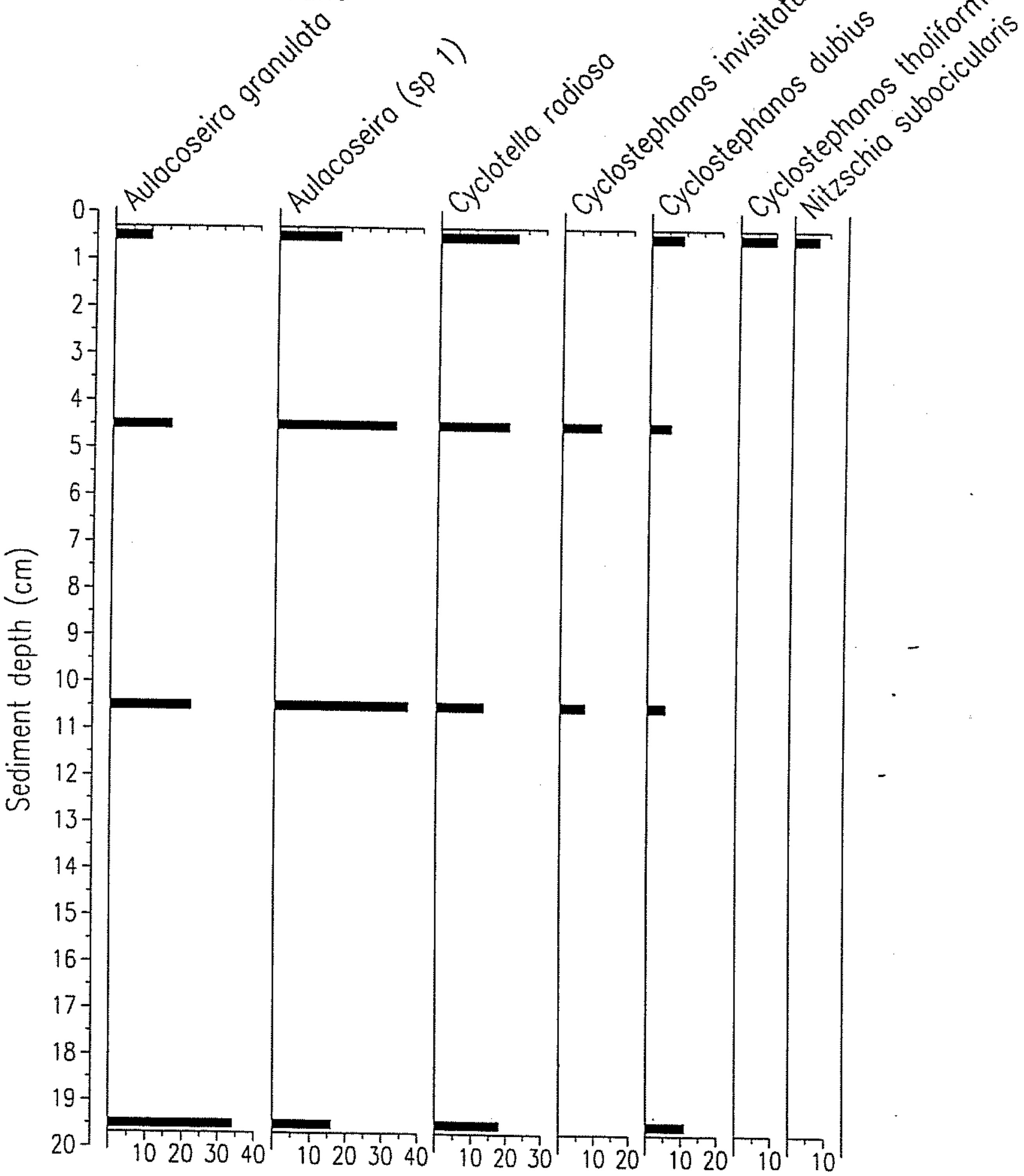

HONGHU 92/2
Dry Weight & Loss-on-ignition
%
60
50
40
30
20
10
0
0.25
2.75
5.25
7.75
10.25
12.75
15.25
17.75
Depth (cm)
DW
LOI

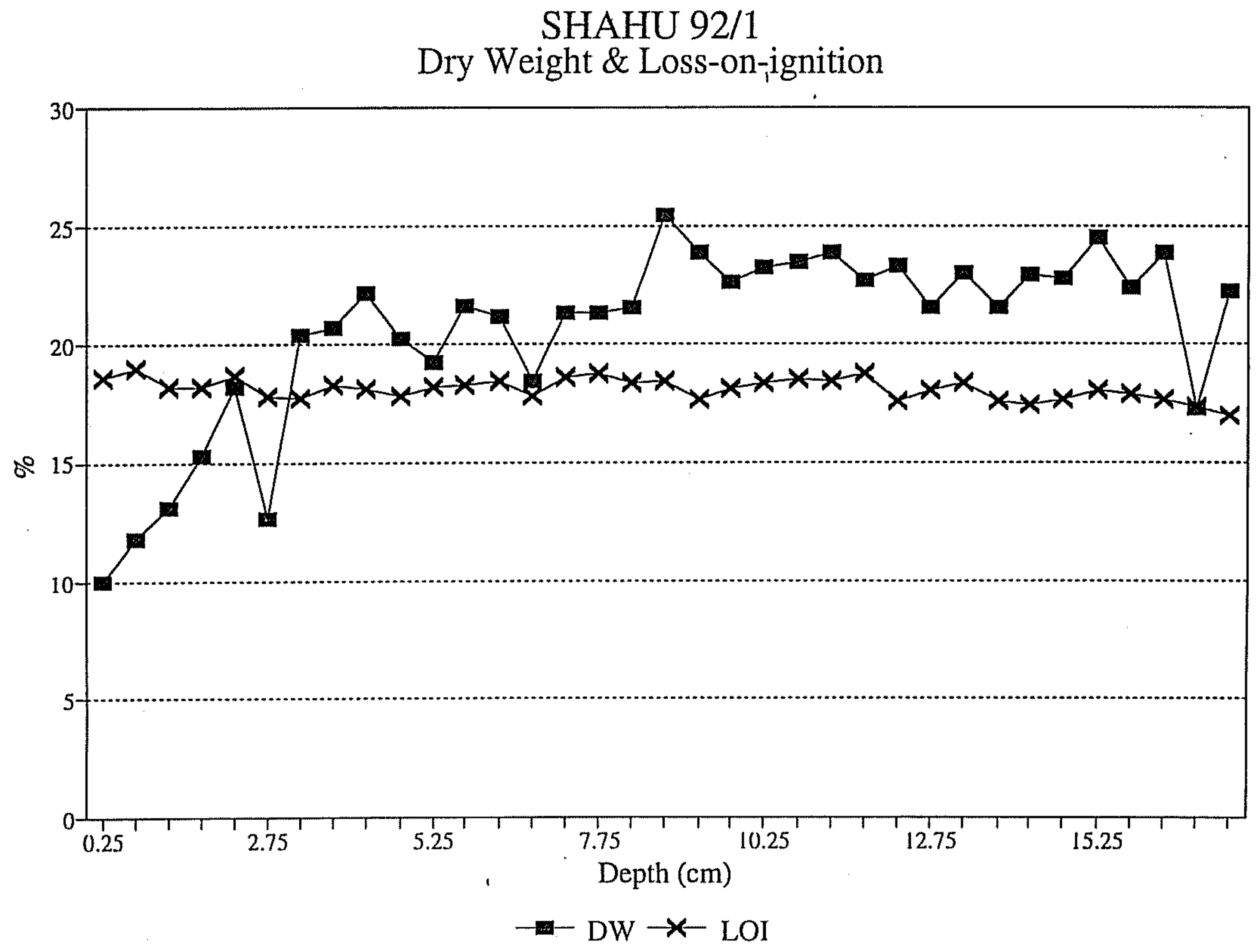

CHANGHU 92/2
Dry Weight & Loss-on-ignition
55
50
45
40
35
30
25
20
15
10
5
%
0.25
2.75
5.25
7.75
10.25
12.75
15.5
Depth (cm)
DW
LOI


DONGHU 92/2
Dry Weight & Loss-on-ignition
40
35
30
25
20
15
10
5
%
0.25
2.75
5.25
7.75
10.25
12.75
15.25
17.75
Depth (cm)
DW
LOI

Donghu E2

Common Diatom Taxa




SHAHU 92/1
Dry Weight & Loss-on-ignition
30
25
20
15
10
5
0
%
0.25
2.75
5.25
7.75
10.25
12.75
15.25
Depth (cm)
DW
LOI

Appendix C.

TRACE METAL PROFILES FOR SEDIMENT CORES FROM LAKES ON THE JIANGHAN PLAIN IN HUBEI.

John Boyle

Introduction

In 1993 four lakes to the east of Wuhan were visited; Wang Hu (WANG 1), Chi Xi Hu (CHIX 1), Chi Dong Hu (CHDG 1), and Liangxi Hu (LIGX 1). In addition, samples from Daye Hu were provided by our Chinese colleagues.

Sub-samples were digested in concentrated nitric acid, and Cu, Pb, Ni, Zn, Mn, and Fe were determined using AAS. Values were checked using Buffalo River sediment.

General results

Chemical profiles for the five lakes are shown in the Figure 1, together with the carbonaceous particle profiles. The following points are striking:-

1) Daye Hu is completely different from the other sites. Cu, Pb, and Zn are all strongly enriched compared both with other sites, and with crustal averages. This is not reflected in the Ni or carbonaceous particle profiles.

2) The remaining sites have values close to crustal averages, except for Pb which is slightly enriched.

3) Of the pollutant metals only Pb consistently increases up-profile. The Pb increases closely match those of the carbonaceous particles. There is in fact a good correlation between carbonaceous particles and Pb (Figure 2).

Sedimentation rates

There are no ^{210}Pb dates for the sediments. However, comparison of the cumulative carbonaceous particle profiles (Figures 3,4,5,6) with the cumulative coal consumption for Wuhan (Figure 7) provides a means of estimating the accumulation rates. Figure 8 shows age-depth curves based on this data.

The results indicate accumulation rates of between 2.4 and 3.6 mm/yr for Liangxi Hu, Chi Dong Hu and Wang Hu, but over 6 mm/yr for Chi Xi Hu.

These results agree well with cross correlations of peaks with the coal data, except for Chi Xi Hu, where there is some question concerning interpretation of the peaks (Neil Rose, this report).

Cu

The Cu content of average shale is 50 ppm; all sites but Daye Hu are at or below this, indicating no strong enrichment. Cu does however, tend to increase towards the surface (this is not true at Chi Dong Hu), showing some similarities to the Pb profile.

Daye Hu differs completely with Cu peaking at 1200 ppm or more than 20 times the crustal average. A major local source must be present.

Zn

In Europe and north America, Zn is either the most enriched of the pollutant metals, or a close second to Pb. These sites in Hubei have Zn concentrations only marginally above the average shale value of 90 ppm. Furthermore, only at Wang Hu is a marked up-core increase observed. Large variations in Zn are observed, which are partially mirrored by changes in the Ni content. These variations may be masking any anthropogenic metal enrichment.

Daye Hu once again differs, exhibiting concentrations more like those of European surface sediments.

Ni

Ni concentrations are at or below those of average shale (80 ppm). Only at Chi Xi Hu is a surface increase observed. Generally slight up-core decreases suggest that anthropogenic sources are not important.

This is supported by the profile from Daye Hu which shows no Ni enrichment.

Fe

Fe is more concentrated than average shale (47mg/g) at all sites. Slight surface or shallow subsurface peaks are seen at three of the sites. Some diagenetic remobilisation is thus possible.

The higher than average Fe content at Daye Hu may indicate that Fe is associated with the pollution.

Mn

Average shale contains 850 ppm Mn, which is similar to the average in these sites. Mn increases up-core at all sites but Daye Hu. At Chi Dong Hu and Chi Xi Hu (these lakes are close to each other), the Mn profile shows strong similarities to the Pb profile. The close agreement of the Pb and carbonaceous particle profiles argues against Mn having influenced Pb. It remains possible that Mn and Pb have a common anthropogenic source. Coincident diagenetic enrichment is possible but seems unlikely.

Pb

Pb increases consistently up-core, and correlates well with carbonaceous particles (Figure 2). A common source for these two materials is likely.

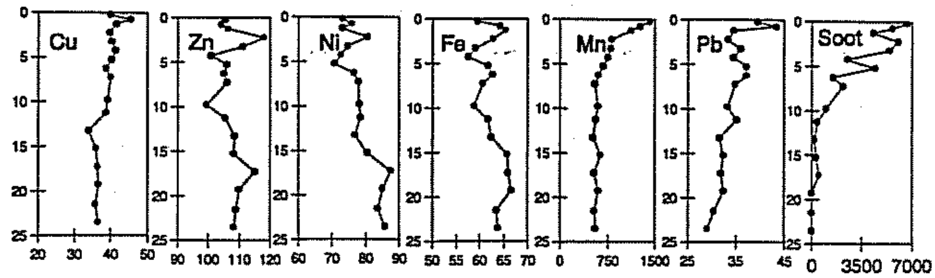
Evidence of pollution

Daye Hu is clearly strongly polluted with Cu, and to a lesser extent with Pb and Zn. This seems to be related to a local source, completely dissociated from the general Pb and carbonaceous particle combination seen in the other lakes.

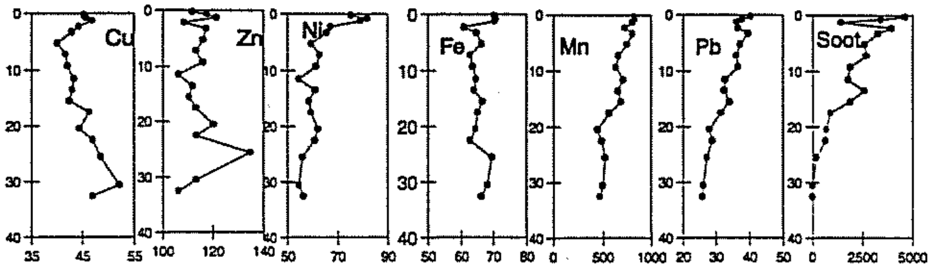
Pb increases above core-bottom values (close to the average shale value of 20 ppm) are about 10 ppm. This is extremely low compared with the several hundred ppm usually seen in Europe or north America. If, as in Europe, Zn pollution is of similar magnitude to Pb, and all other metals are far lower, its is not surprising that these metals do not show up-core increases in these lakes.

Trace metals may also have been diluted; accumulation rates of mineral matter are relatively high. Based on a wet density of 1.23, dry weight of 30%, and a sedimentation rate of 3 mm/yr, a dry mass accumulation rate of 1100 $g/m^2/yr$ is estimated. This is an order of magnitude greater than is most lakes analysed in European and North America. This has greatly contributed to the relatively low concentrations of pollutant metals and carbonaceous particles; the anthropogenic Pb flux based on this calculation (assuming an increase above background of 15 ppm Pb) is 16.5 $mg/m^2/yr$; this is not much lower than that for North America (20 - 30 $mg/m^2/yr$).

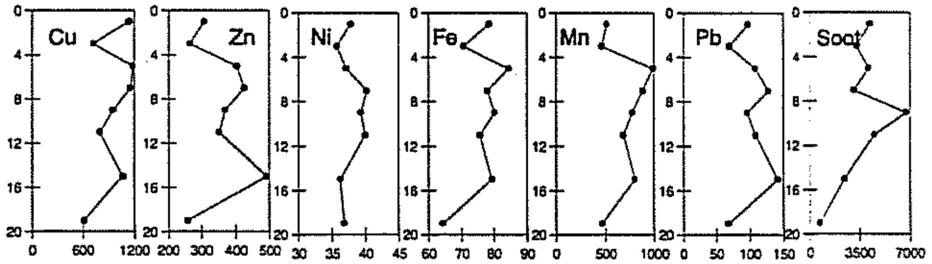
Liangxi Hu (LIGX 1)



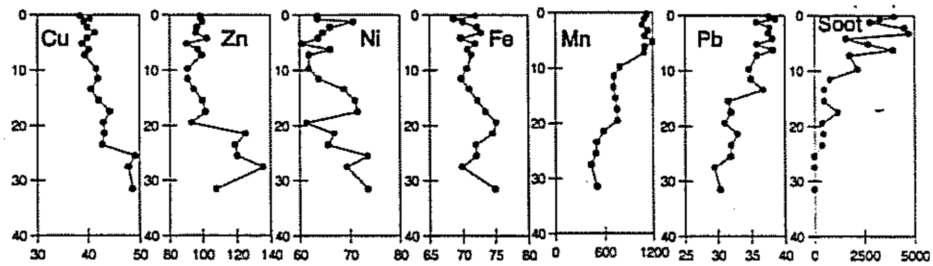
Chi Xi Hu (CHIX 1)



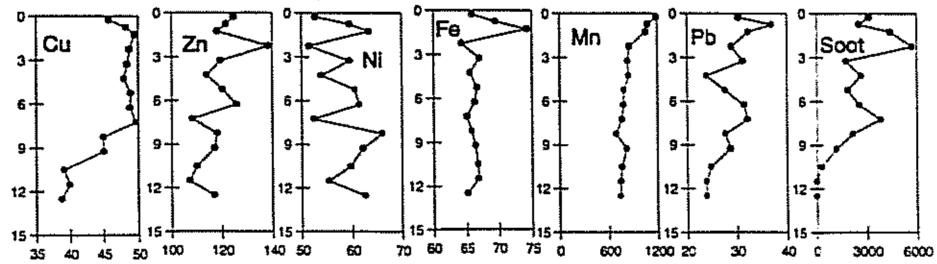
Daye Hu



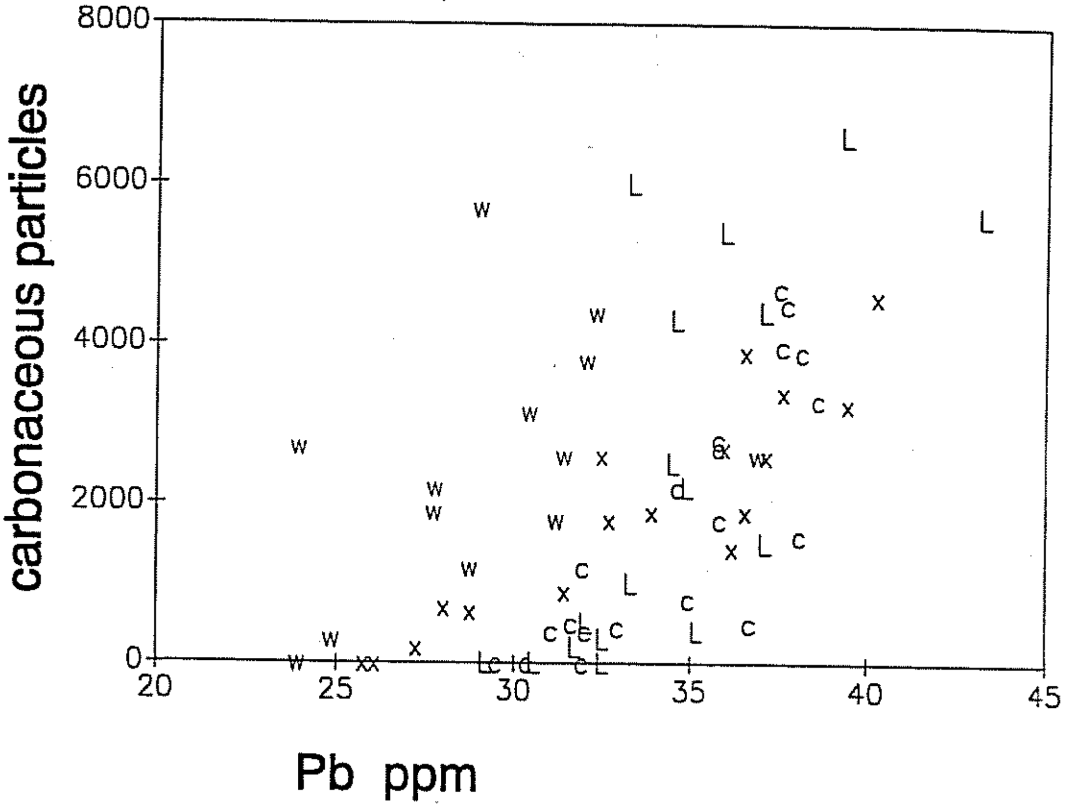
Chidong Hu (CHDG 1)



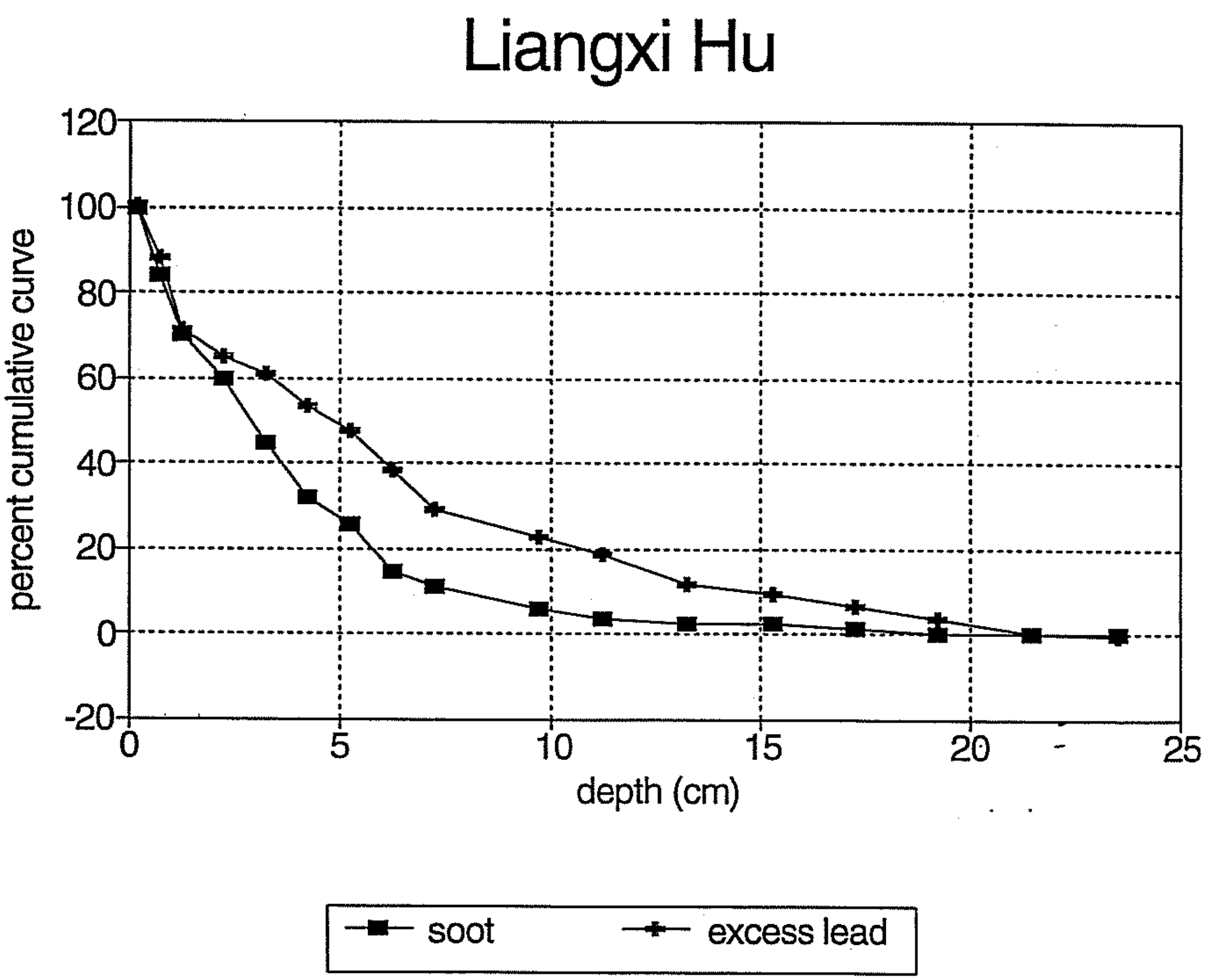
Wang Hu (WANG 1)

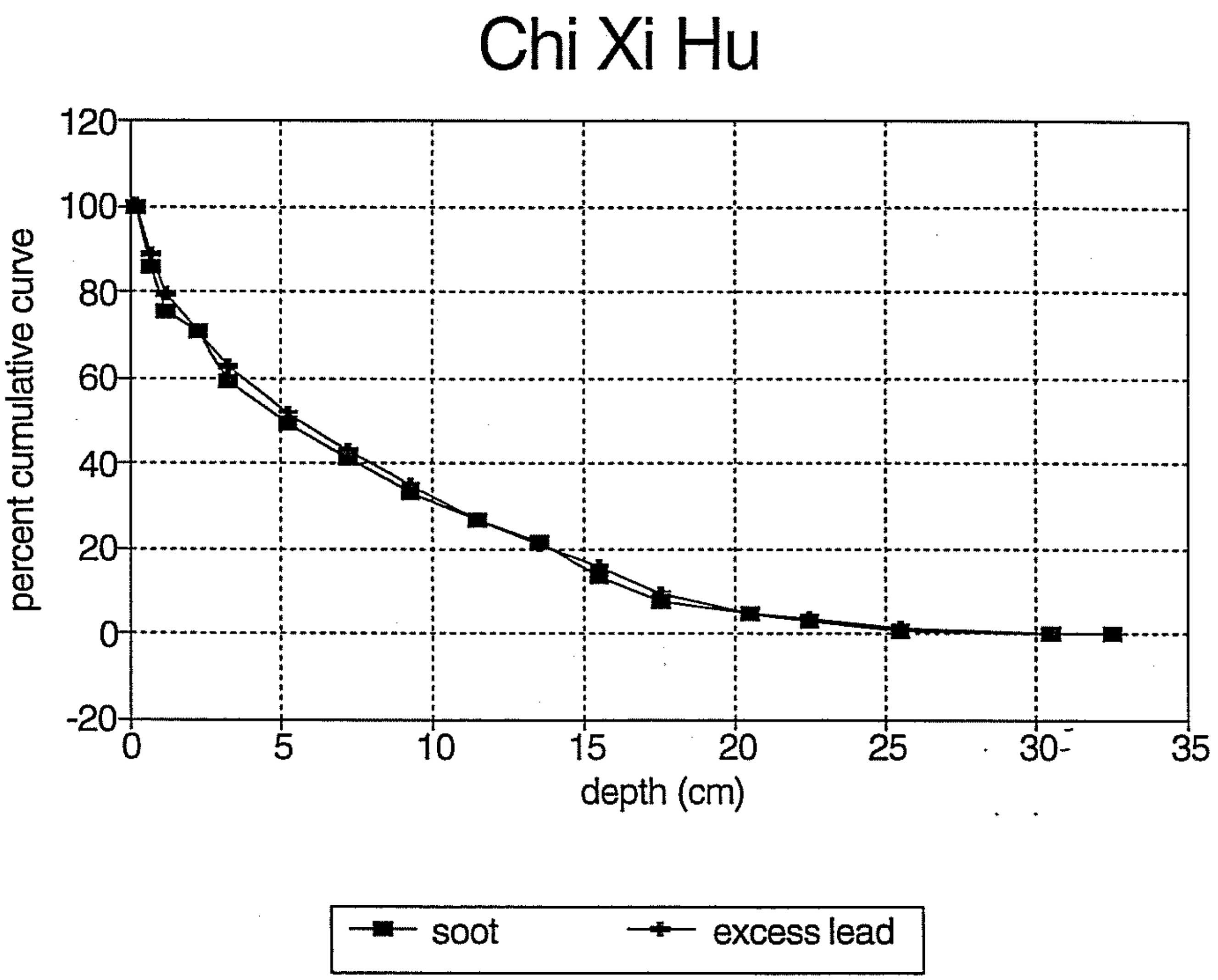


* Fe units are mg/g; all others are μg/g

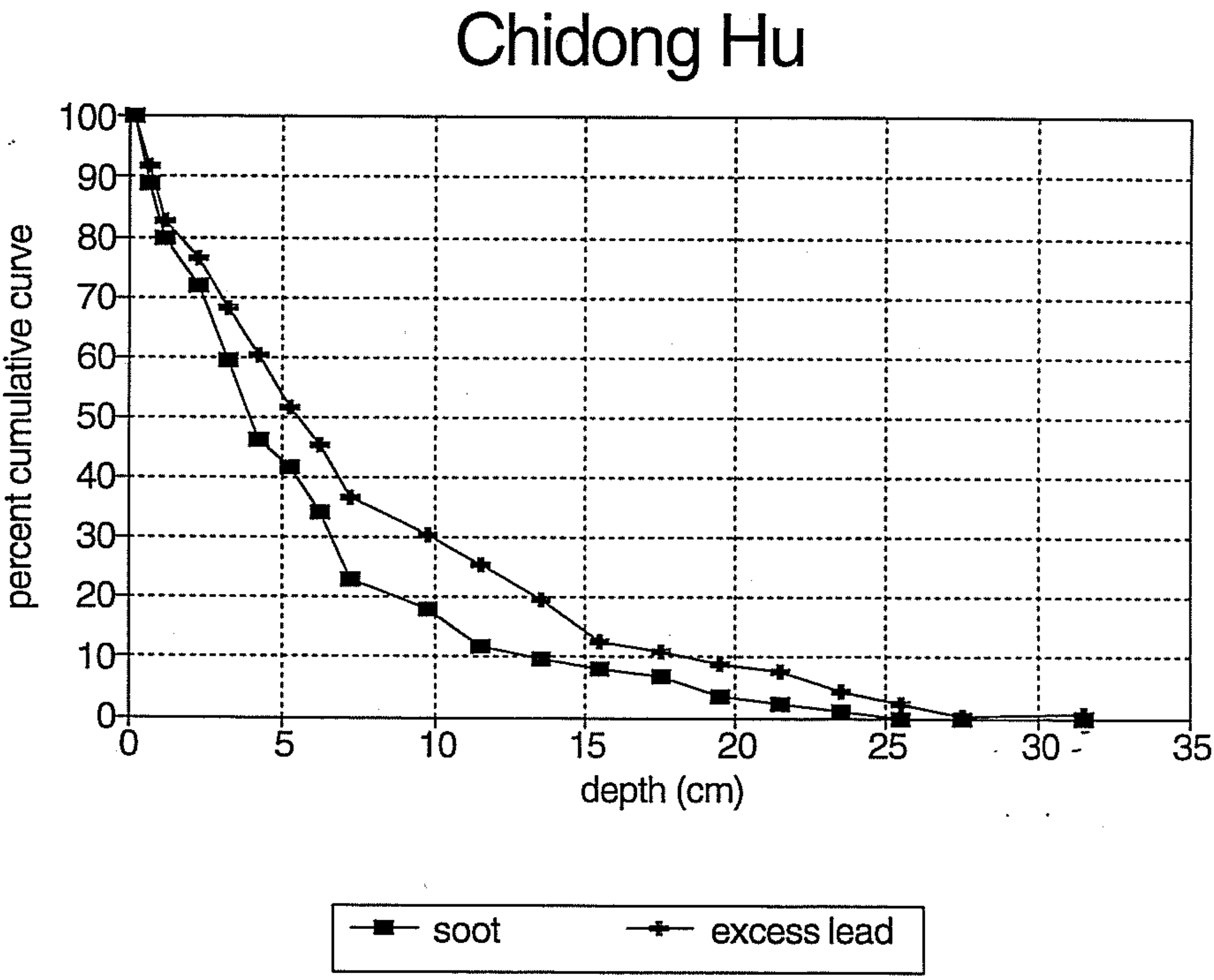


8000
6000
4000
2000
0
carbonaceous particles
20
25
30
35
40
45
Pb ppm


Liangxi Hu
120
100
80
60
40
20
0
-20
0
5
10
15
20
25
percent cumulative curve
depth (cm)
soot
excess lead

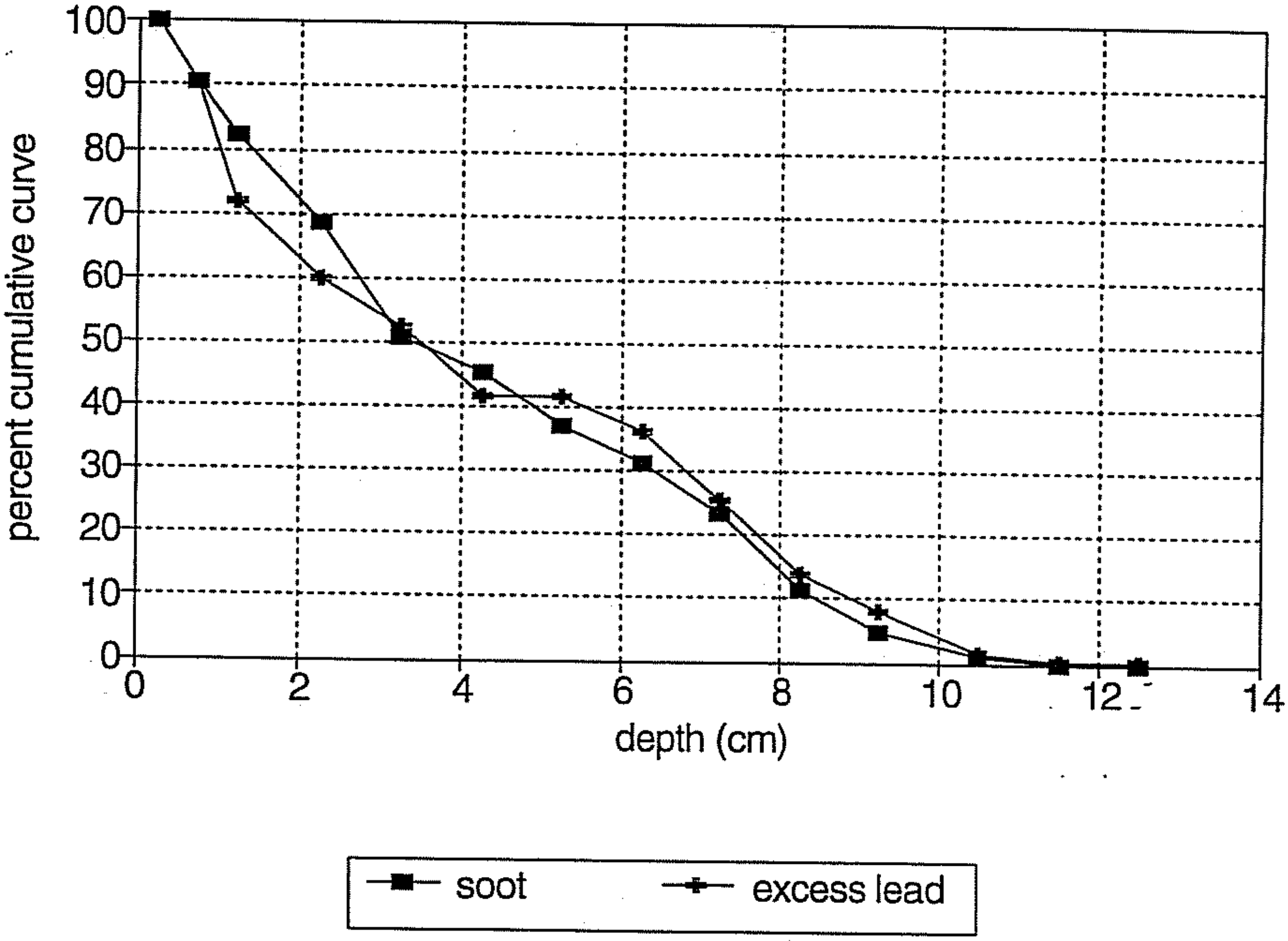


Chi Xi Hu
120
100
80
60
40
20
0
-20
percent cumulative curve
0
5
10
15
20
25
30
35
depth (cm)
soot
excess lead



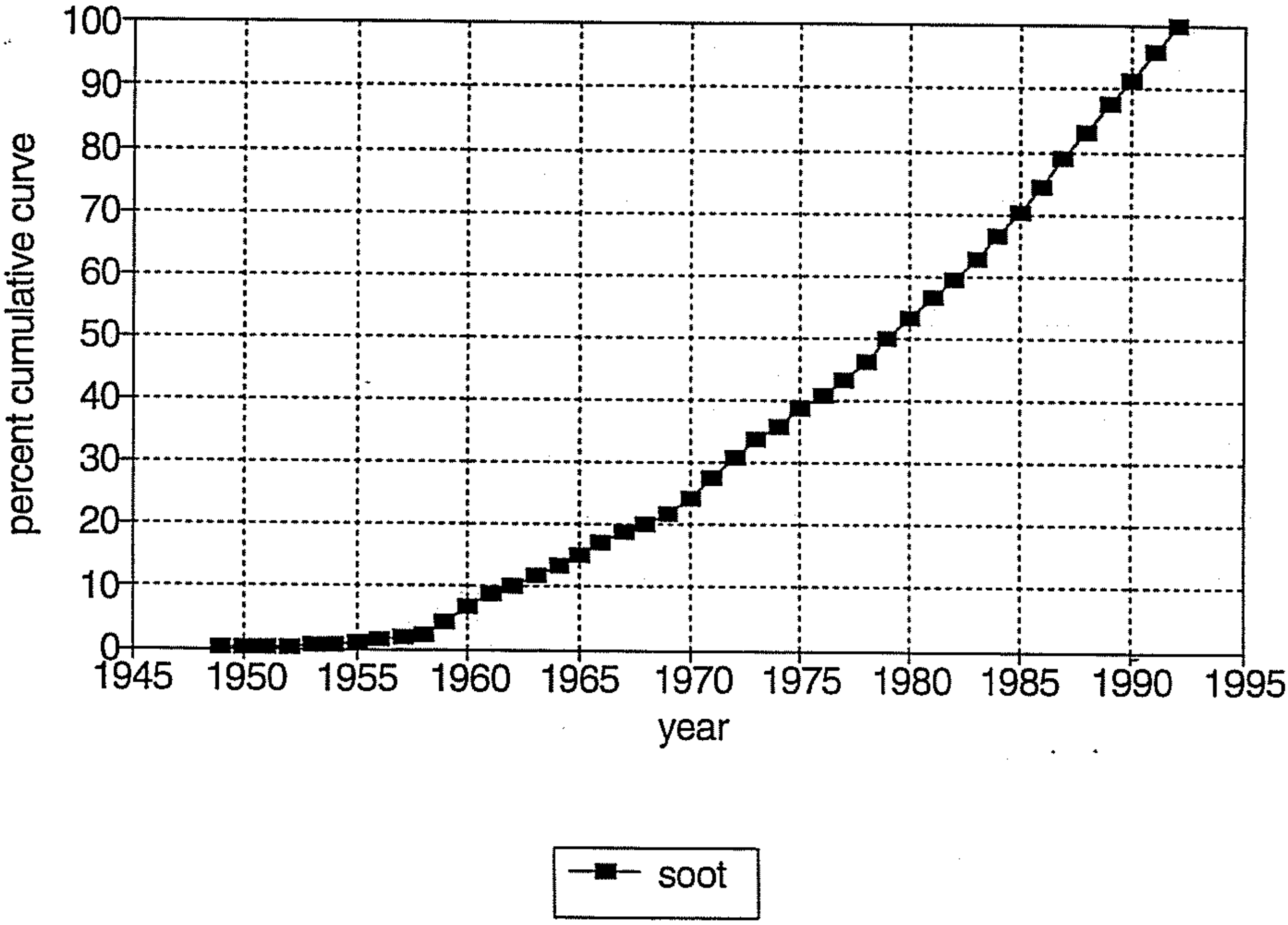
Chidong Hu
percent cumulative curve
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35
depth (cm)
soot
excess lead

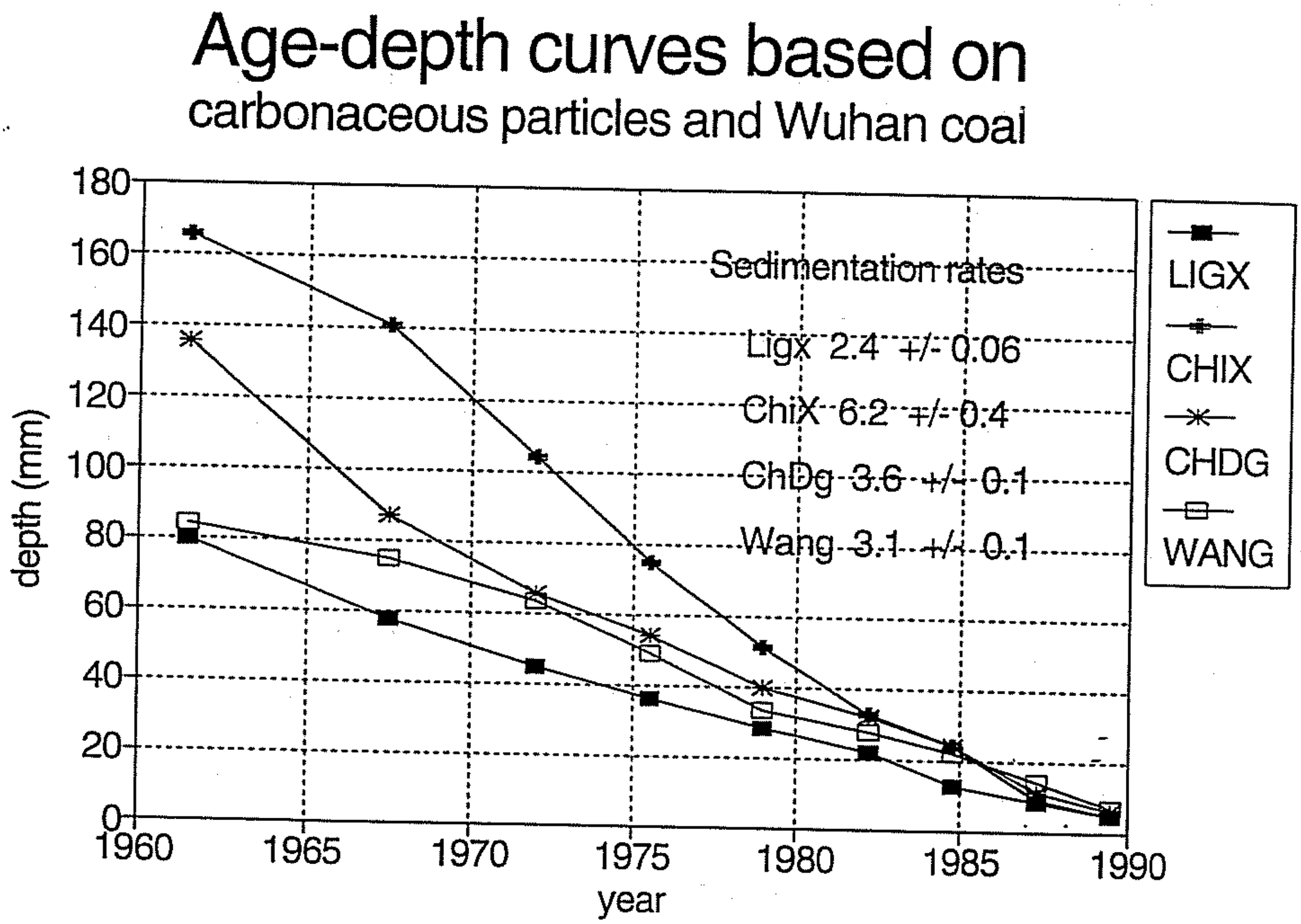
Wang Hu



100
90
80
70
60
50
40
30
20
10
0
percent cumulative curve
0
2
4
6
8
10
12
14
depth (cm)
soot
excess lead

Wuhan Coal Consumption




Age-depth curves based on
carbonaceous particles and Wuhan coal
Sedimentation rates
Ligx 2.4 +/- 0.06
ChiX 6.2 +/- 0.4
ChDg 3.6 +/- 0.1
Wang 3.1 +/- 0.1
LIGX
CHIX
CHDG
WANG
depth (mm)
180
160
140
120
100
80
60
40
20
0
1960
1965
1970
1975
1980
1985
1990
year

Appendix D.

CARBONACEOUS PARTICLE PROFILES FOR SEDIMENT CORES FROM LAKES ON THE JIANGHAN PLAIN IN HUBEI.

Neil Rose

Introduction.

The lake sediment cores discussed in this report were taken over a three year period, 1991 - 1993 inclusive, on three separate visits whilst visiting scientists at the Institute of Geodesy and Geophysics in Wuhan.

In 1991, Hong hu, the main study site and Chang hu to the west of Wuhan were cored (cores A1 and LL1 below, respectively) and Dong hu in Wuhan itself.

In 1992, Hong hu (core 92/2), Chang hu (92/2) and Dong hu (92/2 & 92/2A) were again cored along with Sha hu (Sao 1) another lake within Wuhan.

In 1993, lakes to the east of Wuhan were visited, Wang hu (Wang 1), Chi Xi hu (Chix 1), Chi Dong hu (Chdg 1) and Liangxi hu (Ligx 2). In addition samples were obtained from Daye hu which had been cored earlier in the year by our Chinese colleagues.

At present none of the sediment cores described below have been dated. It is hoped that a core from Hong hu will be ^{210}Pb dated in the near future and this will aid the interpretation of the Hong hu profiles considerably. It will also enable rough dates to be applied to the other sediment cores by means of indirect dating using carbonaceous particles.

Hong hu

Two cores have been analysed from Hong hu, A1 taken in 1991, and 92/2 taken in 1992. The former core shows a very short profile ($\leq$ 8.5cm) and also has a low concentration of carbonaceous particles (CPs) even at the surface. The sampling interval of this core was large and sediment samples from every 2cm only were available for analysis. This was a pilot study in as much as CP analyses had never been performed on Chinese lake sediments before and so it was decided to return to Hong hu the following year to take cores in different locations to confirm this first profile and to extrude the retrieved cores more finely so that a more detailed profile could be produced.

Core 92/2 shows a higher concentration of CPs at the sediment surface than A1 and also a longer profile (12 - 15 cm). This suggests that it may be from an area of Hong hu where there is better sediment accumulation than at the A1 core site. The 92/2 CP profile resembles many sediment profiles found in Europe and the USA. There is slow, steady increase in CP concentration followed by a period of more rapid increase. CP concentration is fairly constant between 8 cm and 3.5 cm and a peak is reached at 1.5 - 2 cm. There is a sharp decrease immediately above the peak and concentrations increase again in the surface (0 - 0.5 cm) level. Without dating it is impossible to interpret this core to any great extent but it is hoped that as Hong hu is the main study site, this will be the core that will eventually be ^{210}Pb dated. This will help interpret the peaks and troughs of the profile more fully. However, it is still possible to compare the CP profile with combustion statistics as these have been shown to compare very well in other parts of the world.

In many lake sites in European countries the shape of CP profiles from lake sediments compares well with national fossil-fuel consumption statistics and quite often electricity production (by fossil-fuel means) statistics for the host nation. Sometimes where lakes are situated close to international borders the profile can resemble the national statistics of the neighbouring country especially where the neighbour uses a lot more fossil-fuel than the host country or when the prevailing wind is from that direction. Particles are known to travel over hundreds and even thousands of kilometres and so the profile is quite likely to be a combination of more than one country's emissions although there is usually one dominant source.

Hong hu is situated in central China and consequently particles deposited there are unlikely to have come from outside of the country. However, the CP profile shown in 92/2 hardly resembles the national statistics for China at all which shows an almost exponential increase in fossil-fuel combustion since about 1950. Most European countries are considerably smaller than China and so it maybe that whereas a European CP profile from even a remote lake site will reflect national statistics, in China a smaller than national scale needs to be considered in order to make a comparison.

All the lake sites considered here are situated in the province of Hubei and the major population and industrial centre of this province is Wuhan. The coal consumption statistics for Wuhan since 1949 are much more similar to the Hong hu 92/2 profile than the national statistics and so it may be that this profile is reflecting emissions predominantly from Wuhan and its surrounding area. Coal consumption in Wuhan increased dramatically in 1958 when a new steel mill went into production and if this date corresponds to the rapid increase in CPs at about 11 - 12 cm then this gives a rough sediment accumulation rate for the 92/2 core of about 3 mm / yr, a rate thought to be a good average for this site (Prof. Cai Shuming, pers. comm.). This would give a date for the CP peak as 1986. ^{210}Pb dating is needed to confirm this.

It should also be noted that great sedimentary changes take place between 7 - 11 cm, and below this level the sediment becomes much more clay-like and less organic. This can be seen from the loss-on-ignition and dry weight figures. It may be that this change in sediment type effects the CP concentration in some way as this is also the region where CP concentration starts to increase more rapidly. Again, dating will help sort this out.

Chang hu

As with Hong hu, cores were taken from Chang hu in both 1991 and 1992. Also similarly to Hong hu the 1991 core (LL1) shows a much shorter profile ($\leq$ 8.5 cm) than the 1992 core (92/2 - 19 cm) but in the case of Chang hu this is accompanied by a much higher surface concentration in the shorter core. This suggests that the differences between the two cores may be due to differing sediment accumulation rates. Magnetic measurements were also done on LL1 and also on a core taken from the same location as 92/2, called 92/5. These measurements confirm that the accumulation rate in the 92/2 core area ($\equiv$92/5) is more rapid.

As the 92/2 core was analysed in more detail and appears to have approximately similar accumulation rates to the Hong hu core (the Hong hu 92/2 profile is slightly shorter and so may have a slightly slower sediment accumulation rate) it is the 1992 cores that should be compared. There are two main features that are immediately obvious:

i) The surface concentration of the Chang hu 92/2 core is less than half of the Hong hu 92/2 core. This is probably due to Chang hu being further from Wuhan than Hong hu. If this is the case then it suggests that Wuhan is the single most important emissions source over a considerable area as although Hong hu is nearer than Chang hu (185 km from Wuhan) it is still about 120 km away.

ii) Both have concentration peaks near the surface of the core followed by a sharp decline and then a recovery in the surface levels. Similar CP profile patterns also suggest that both sites are receiving depositions from the same source. It is also interesting to note that the Chang hu peak is at a slightly lower depth (2 - 2.5 cm) than that of Hong hu (1.5 - 2.0 cm) again suggesting a slightly faster accumulation rate. This could also be the reason for a second high surface concentration in Chang hu (0 - 0.5 and 0.5 - 1) compared to only one (0 - 0.5 cm) in Hong hu.

If the concentration peak in the Chang hu profile corresponds to that in the Hong hu core then it could be dated to 1986. This suggests an accumulation rate for Chang hu of about 4mm / yr.

Dong hu

Two cores from Dong hu have been analysed for CPs and both were taken in 1992 from the same location within the lake. The first core, 92/2, was short (17.5cm) and the CP record was found to start below this depth. For this reason, the second core, 92/2A, which was about 80 cm long was analysed and was found to contain the whole profile.

Both cores show a CP concentration peak at about the same sediment depth, 4 - 4.5 cm in 92/2 and 4.5 - 5 cm in 92/2A. It may be that 92/2A has a slightly faster accumulation rate than 92/2, although the peak concentration is almost double, and it is difficult to be certain. If these peaks are equivalent to those found in Hong hu and Chang hu (put at 1986) then it suggests that the sediment accumulation for Dong hu is about 7.5mm /yr, approximately double. It was suggested above that the rapid increase in the Hong hu core could be due to the start of a steel mill in Wuhan in 1958. At an accumulation rate of 7.5mm/ yr this date would occur at about 25cm down the Dong hu cores, a level which is below the start of the 92/2 core and which is just about at the start of the profile in 92/2A.

However, 20 - 25 cm is also the level at which major sediment changes take place in the Dong hu 92/2A core and similarly to the Hong hu core this could influence the CP profile.

Although the peak concentration in 92/2A is approximately double that of the 92/2 core, surface concentrations are roughly the same and about double those of Hong hu and three times those of Chang hu. This probably reflects the proximity of the site to the centre of Wuhan.

Sha hu

Like Dong Hu, Sha Hu is a lake situated within Wuhan. A single short core (17.5 cm) was taken in 1992. This lake is also within Wuhan. The CP concentration peak occurs at 3 - 3.5 cm and if this is equivalent to the other sites discussed, it suggests an accumulation rate of about 5 mm /yr. The surface CP concentration is the highest for all the sites discussed here (16,000 gDM^{-1}).

The CP profile for this core shows many similarities to that of the Dong hu 92/2 core although it may have a slightly slower sediment accumulation rate. Smaller peaks occur in both profiles either side of main peak and again lower down the cores and these may reflect other deposition events experienced locally to Wuhan but not seen in more distant sites.

Assuming accumulation rates for Dong hu and Sha hu as discussed above these depositional features occur in 1988/9, 1986 (main peak), 1980/1 and 1966-9. Where data exists (i.e. pre-1988) peaks in coal consumption for Wuhan do occur in 1966 and 1980 and this may be the reason for the peaks in the sediment cores. However, a major peak in coal consumption also occurs in 1972 for which there is no equivalent is observed in the sediment record. This may be due to an inadequate analysis interval at this period and more sediment levels may need to be analysed to identify a peak at this time.

Wang hu

Wang hu lies approximately (120km) to the east of Wuhan an intermediate distance from Wuhan than Hong hu and Chang hu are to the west. The surface sediment CP concentration is similarly intermediate.

The CP profile is short, about 12cm, and shows a peak concentration at 2 - 2.5cm. Once again, if this represents 1986, then it suggests an accumulation rate for this site of about 3 mm / yr, similar to Hong hu. Above the CP peak there is, once again, a decrease in concentration followed by an increase again in the surface level. An accumulation rate of 3 mm / yr also suggests a date of 1956-8 for the start of the particle record, similar to that of the Hong hu rapid increase and the start of the steel mill in Wuhan. Also, using this rate, a smaller peak at 7 - 7.5cm would date to about 1971 about the time of the 'missing' peak, corresponding to a peak in Wuhan coal consumption, in the lakes to the west of Wuhan.

Unlike the lakes discussed previously, the loss-on-ignition and % dry weight diagrams do not show such a dramatic change in their profiles suggesting no major sedimentary changes.

Chi Xi hu

Chi Xi hu lies approximately 100km to the east of Wuhan and is unusual amongst these cores in as much that the sediment profile has its highest CP concentration in the surface level.

There are two sub-surface CP peaks and the uppermost one is only separated from the surface maximum by a sharp dip which may correspond to that seen immediately above the peak in other cores. That being the case the uppermost sub-surface peak may correspond to the date attributed in this report to the peaks in other cores i.e. 1986. If this is so, then the accumulation rate for this core is 3 - 3.5 mm / yr.

This accumulation rate would date the lower sub-surface peak at about 1950 - 1955, earlier than the steel mill in Wuhan, and the start of the CP record to the turn of the century not seen in any other core. It is uncertain whether this is the case or whether the accumulation rate is much faster than suspected. Similarly to Wang hu the loss-on-ignition and % dry weight diagrams suggest no major sedimentary changes.

Chi Dong hu

Chi Dong Hu lies 110km to the east of Wuhan intermediate to Chi Xi Hu and Wang Hu. The surface CP concentration is similarly intermediate and like Chi Xi Hu although nearer to Wuhan than Hong Hu has a lower surface concentration (prevailing wind direction E to W??). The profile shows the now familiar sub-surface decrease and a peak at 3 - 3.5cm. Again, if this dates to 1986, then the accumulation rate at this site would be 4.5 - 5mm / yr.

Other peaks occur at 6-6.5cm, 9.5-10cm and 17-18cm. This accumulation rate would date these peaks to 1980/81, 1971-74 and 1955-59 respectively. These dates correspond quite well with peaks in the Wuhan coal consumption record, including the 1971 peak not present in CP profiles to the west of Wuhan. The particle record begins at 24-25cm which would date to the early-1940's.

Similarly to Wang Hu and Chi Xi Hu the loss-on-ignition and % dry weight diagrams suggest no major sedimentary changes in this core.

Liangxi Hu

Liangxi Hu lies approximately 55km to the east of Wuhan. Of the lakes studied outside the city, it is the nearest site to Wuhan and as might be expected shows the highest surface CP concentration of these sites.

Like Chi Xi Hu the surface concentration is also the maximum concentration, but a secondary peak at 2-2.5cm may represent the '1986 peak' discussed for the other sites. This being so, the sediment accumulation rate at this site would be about 3 mm/yr. However, the analysis interval means that this peak could be slightly higher or lower than 2-2.5cm in this core and the accumulation rate would change accordingly.

Again, other peaks occur lower down the profile at 5-5.5cm and 7-7.5cm. A 3 mm/yr accumulation rate would date these peaks to the mid-late 1970's and the late 1960's respectively. Being nearer to Wuhan, it would be expected that the peaks identified in lake cores more distant would also be present here. However, these dates do not correspond to peaks in consumption and peaks at expected dates do not occur. Therefore, the peaks in this core either relate to other, perhaps local, events or they represent the peaks seen elsewhere and the '1986 peak' is misplaced, or may be the sediment accumulation rate has varied through time at this site. From the data available there is no way to be certain.

Conclusions

Without ^{210}Pb dating the discussion of the profiles produced by CP analysis of these lake sites is purely speculative. In most cases it is fairly self-supporting, but in an area where such analysis has not been done before dating is additionally valuable as there is no previous work against which to compare.

The CP results from these sites have been remarkably consistent in two respects. Firstly, the shapes of the profiles has been very similar leading to the suggestion that they have been affected by depositions from a single large source, probably Wuhan, throughout the time of the profile. This is supported by the similarity of this general pattern to the coal consumption record for Wuhan. This, and the lack of similarity to the national pattern, also implies that Wuhan is the sole source of pollutants for an enormous area, possibly a large proportion of the Jianghan Plain and although other emission sources do exist they are not large enough to effect the sedimentary record of the lakes studied. This study was not exhaustive and local influences are likely to occur at other sites. One lake for which CP analysis was done but which is not discussed above is Daye Hu. A few and infrequent samples were taken from a core from this lake, but the profile was not complete and so is not discussed in more detail. Daye Hu is situated very close to a coal burning power station at Daye and might be expected to exhibit local influences. However, the limited data still appear to fit the pattern and a further study would need to be carried out to confirm this.

Secondly, a spatial pattern exists showing a decrease in both surface and core maximum CP concentration with increasing distance from Wuhan. This seems to support the 'Wuhan source' hypothesis, as local or other large-but-remote influences would upset this pattern which extends at least 185km from Wuhan. Assuming this to be a radius, then Wuhan influences an area of at least 100,000 km^2. Prevailing wind directions will play a part here and this is really only a very rough approximation.

A plot of either maximum CP concentration or surface CP concentration against distance from Wuhan shows an interesting pattern. It appears that there is an exponential decrease of CP concentration with distance. Dong Hu and Sha Hu are both within the city limits and so it is unclear exactly where they should lie on this diagram, however, they are both between 5-10km from the main industry in the city

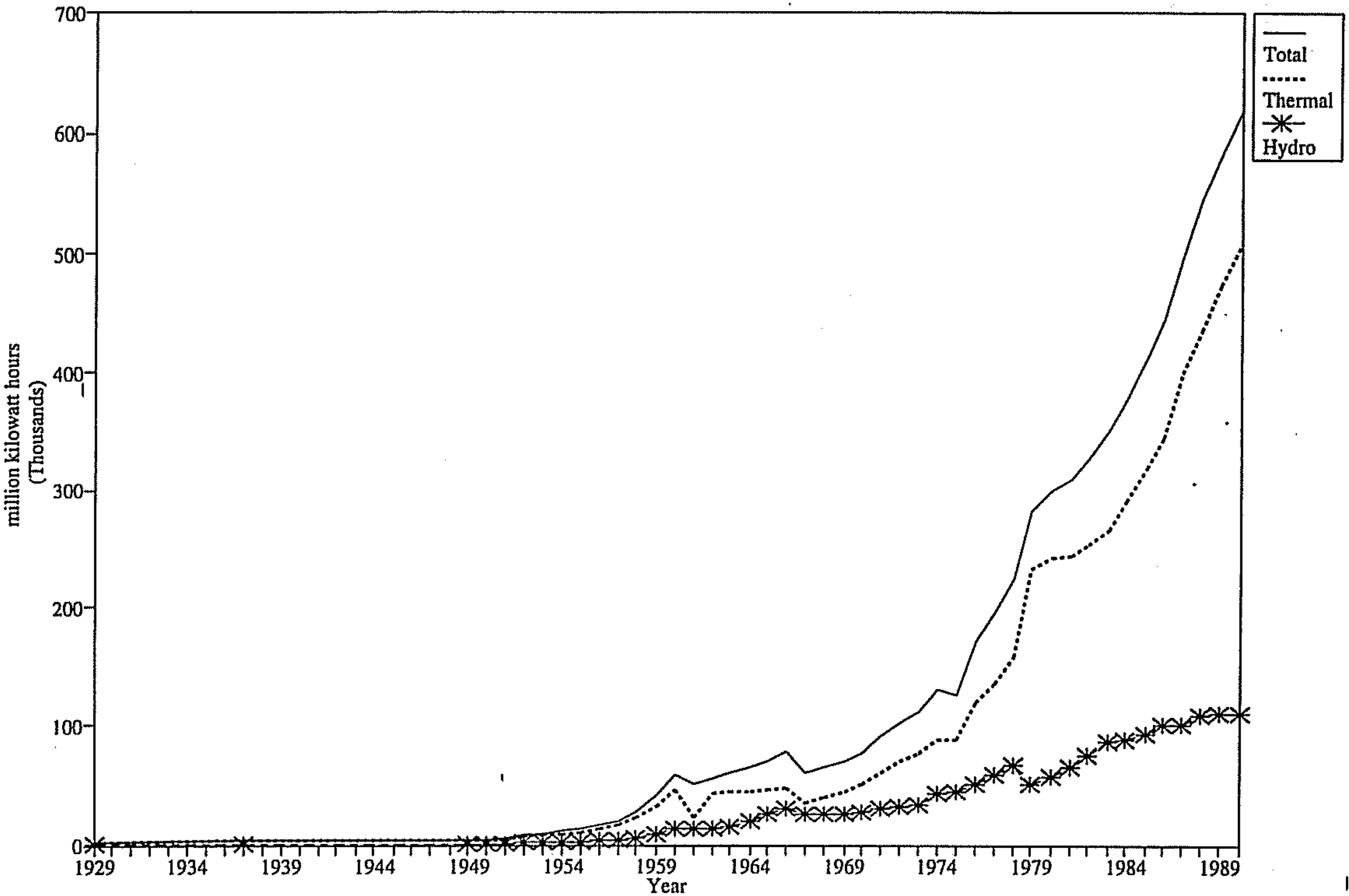
(Dr Lizhong Yu, pers. comm.). Outside the city the decrease appears to be fairly linear and continuing this trend a concentration of 0 gDM^{-1} would be reached between 250 - 300km from Wuhan. Whether this actually occurs, or whether other influences (local, other Chinese, or long range transported) prevent a zero value remains to be seen although CP's have been present in all other remote sites in the northern hemisphere studied so far giving rise to an idea of a CP 'hemispherical background'.

A graph of log CP concentration (surface or maximum) against distance from Wuhan produces a straight line suggesting that CP concentration decreases by a factor of ten with every 200-250km from the city. As concentrations start at about 10,000-20,000 gDM^{-1} in Wuhan, a 0 gDM^{-1} value is reached at about 850-950km from the city although of course, in practice this will not be the case. Concentrations of between 100 - 1000 gDM^{-1}, the range (depending on sediment accumulation rate) attributed to the 'hemispherical background', is reached at a distance of about 250 - 300km from the city.

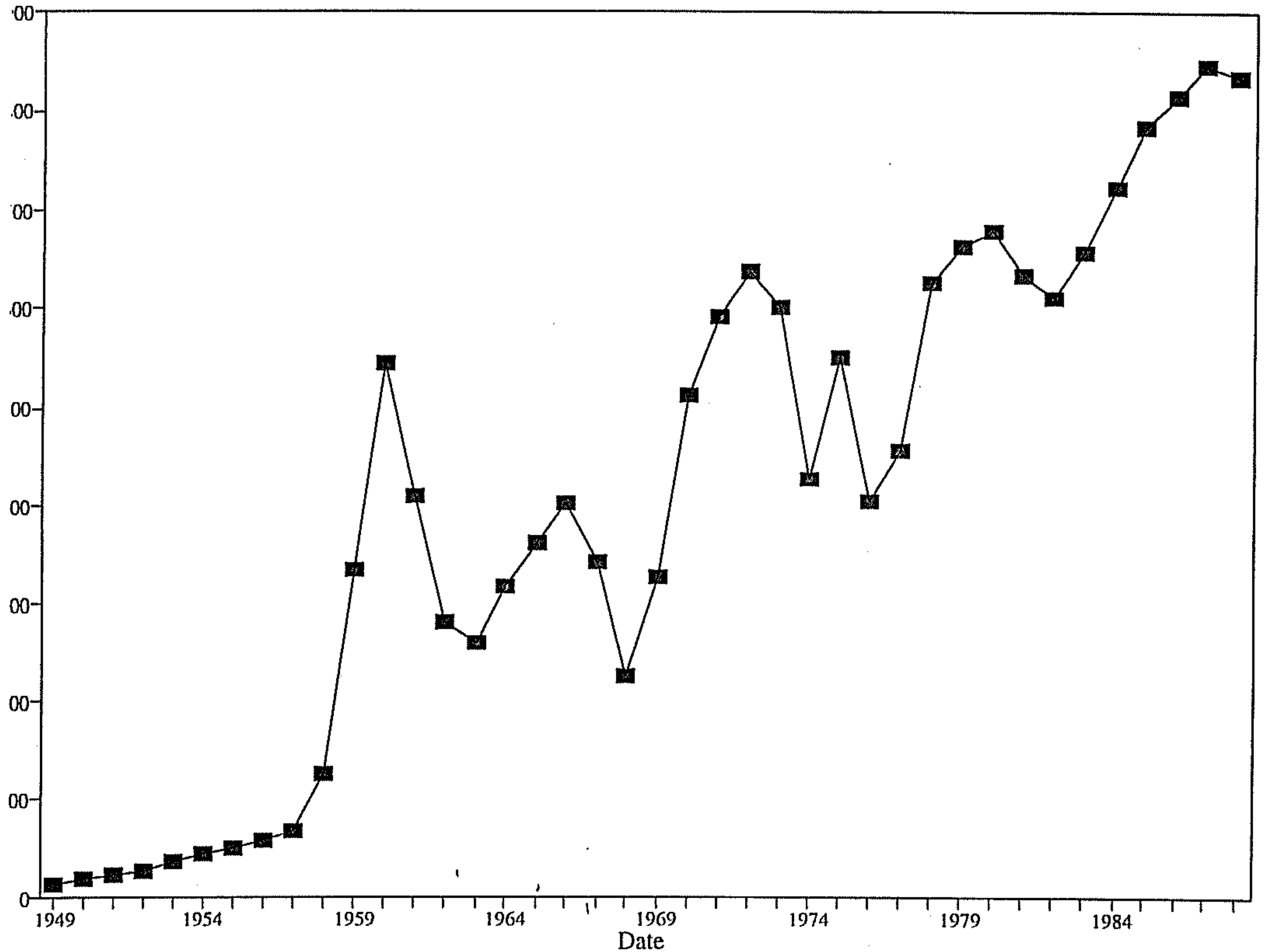
Further Research

^{210}Pb dating is now needed to confirm ideas on the temporal distribution of CP's in the Jianghan Plain. It would also be of value to see how far the influence of atmospherically deposited pollutants originating from the city of Wuhan extends spatially. This could have implications for human and environmental health and it may be that in areas of sensitive geology symptoms of surface water acidification could occur and may already be evident in the sedimentary record. The lakes considered so far have been on an east-west axis along the Yangtse River and consequently it would be of great interest to study lakes also to the north and south. Interpretation would also be aided by the use of meteorological data for the region.

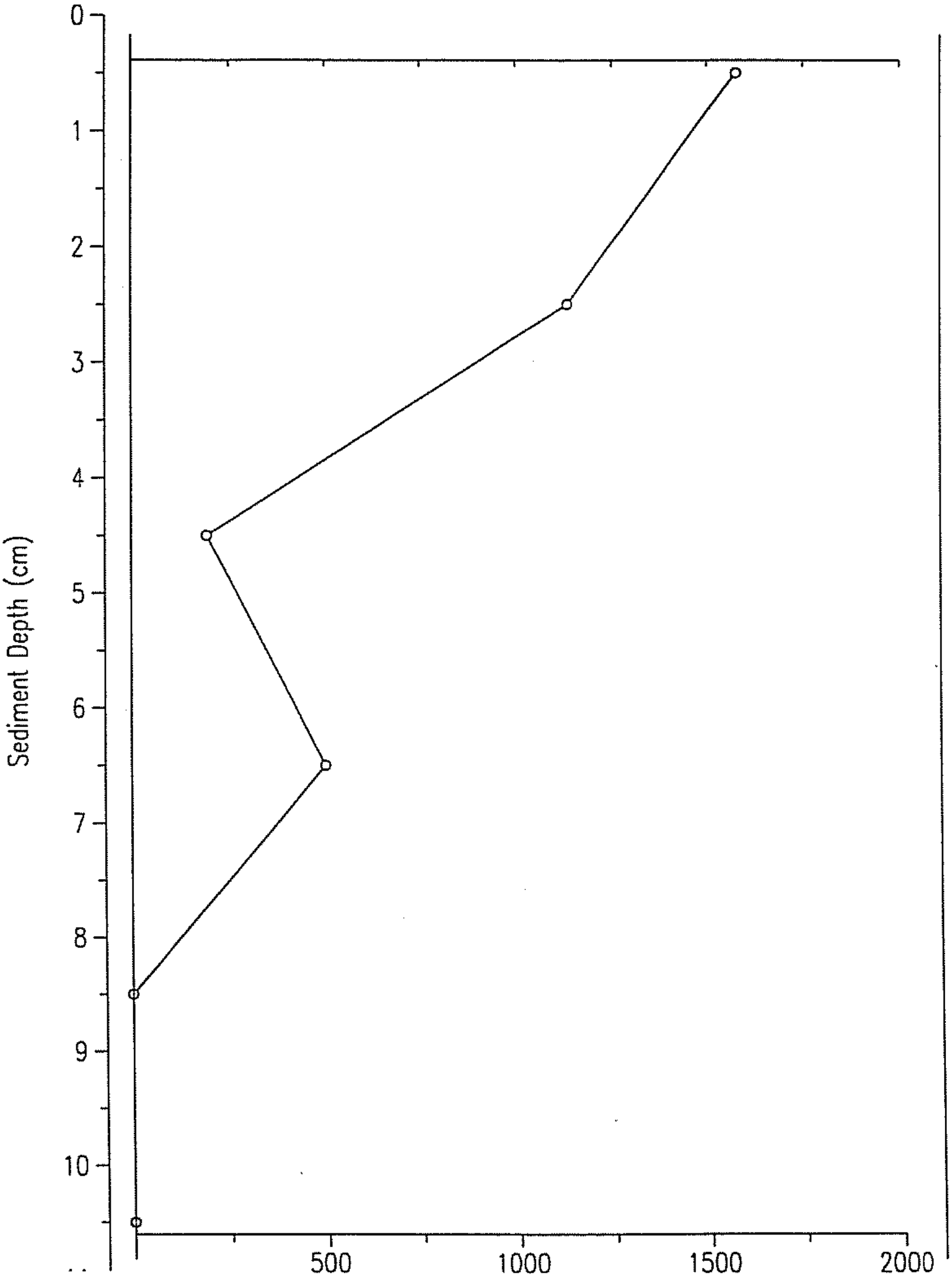
China: Production of Electricity by type



Wuhan: Coal consumption

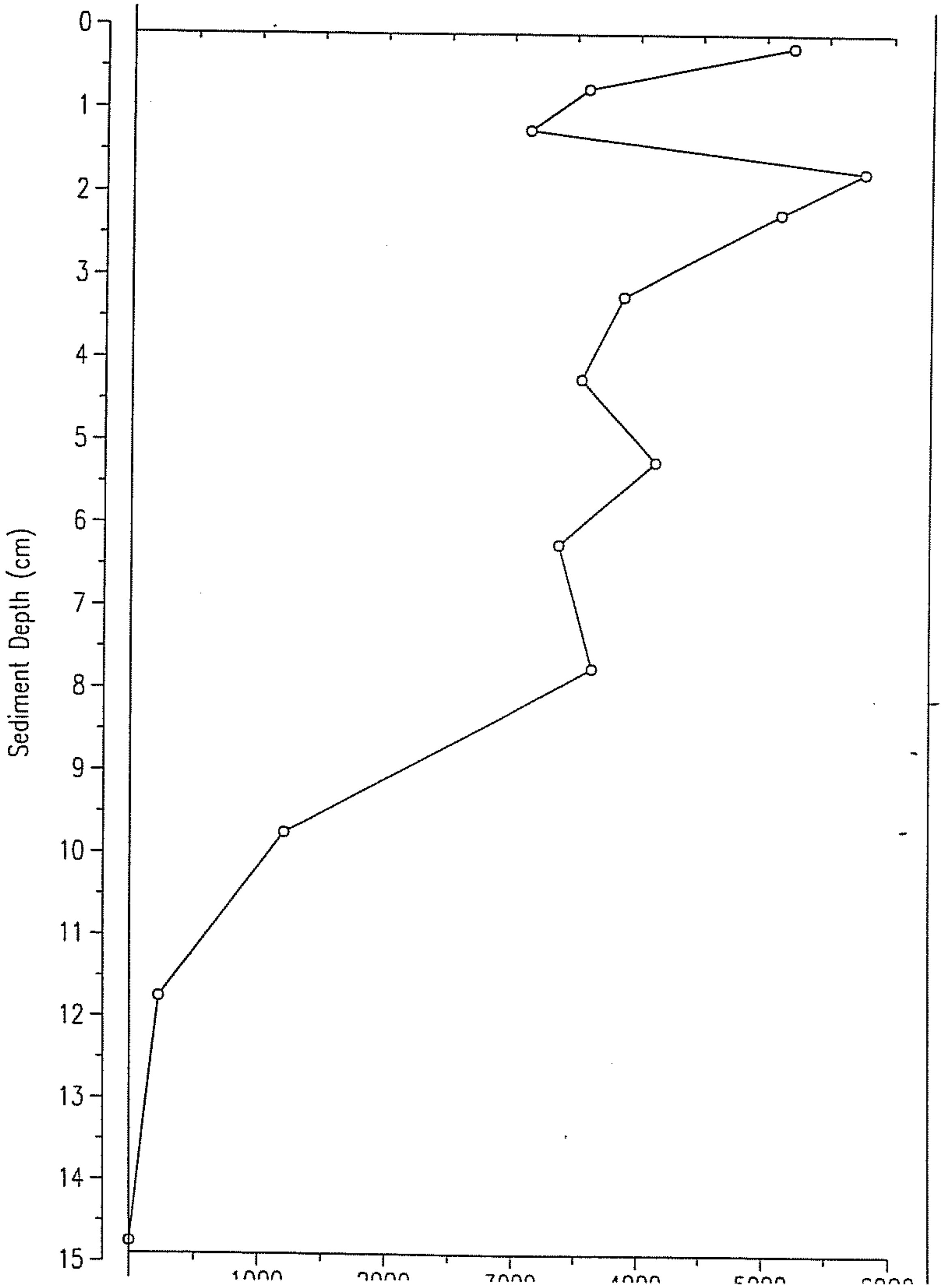


Hong Hu (A1) 1991
Carbonaceous Particle Concentration Profile

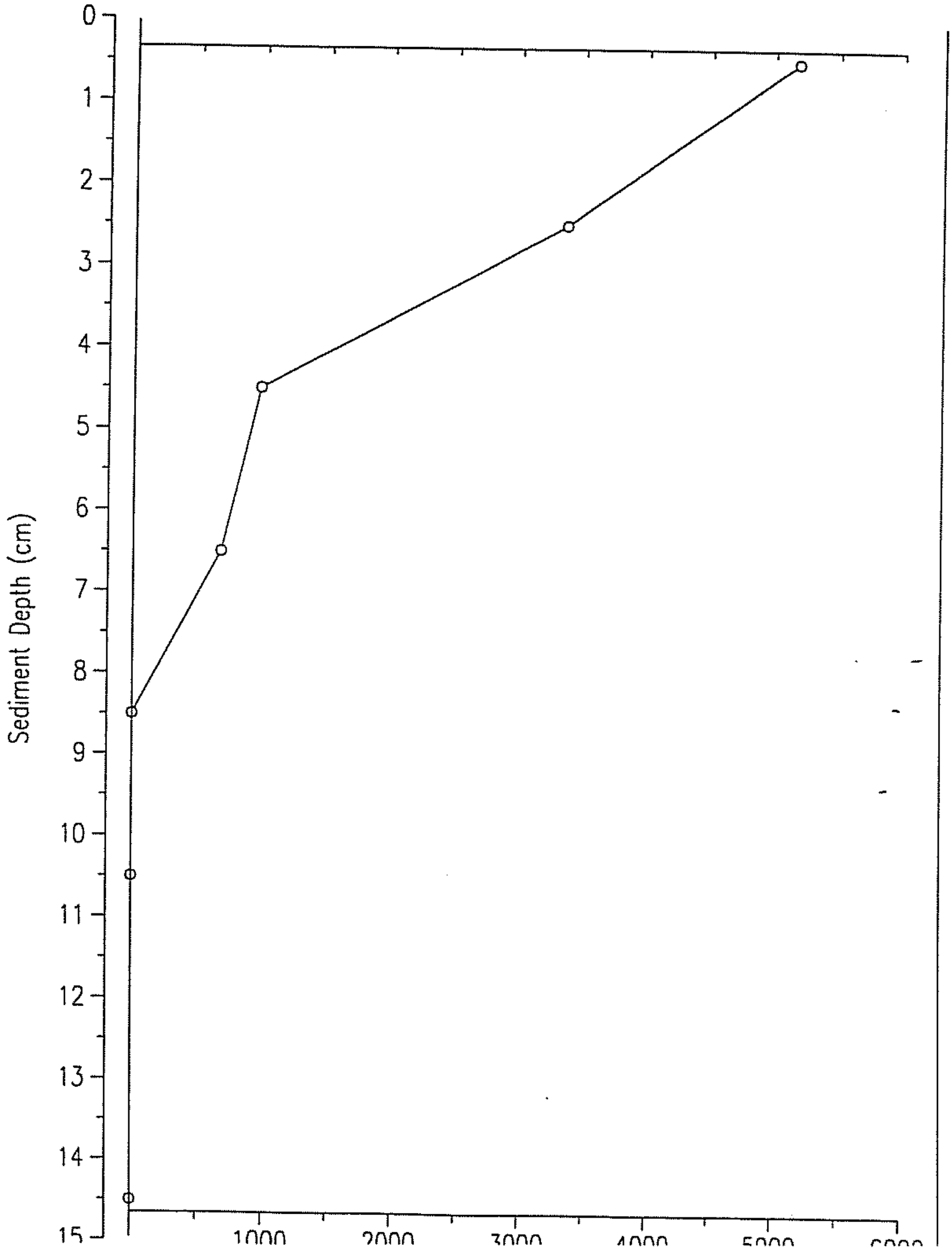


HONG HU (HONG 92/2) 1992

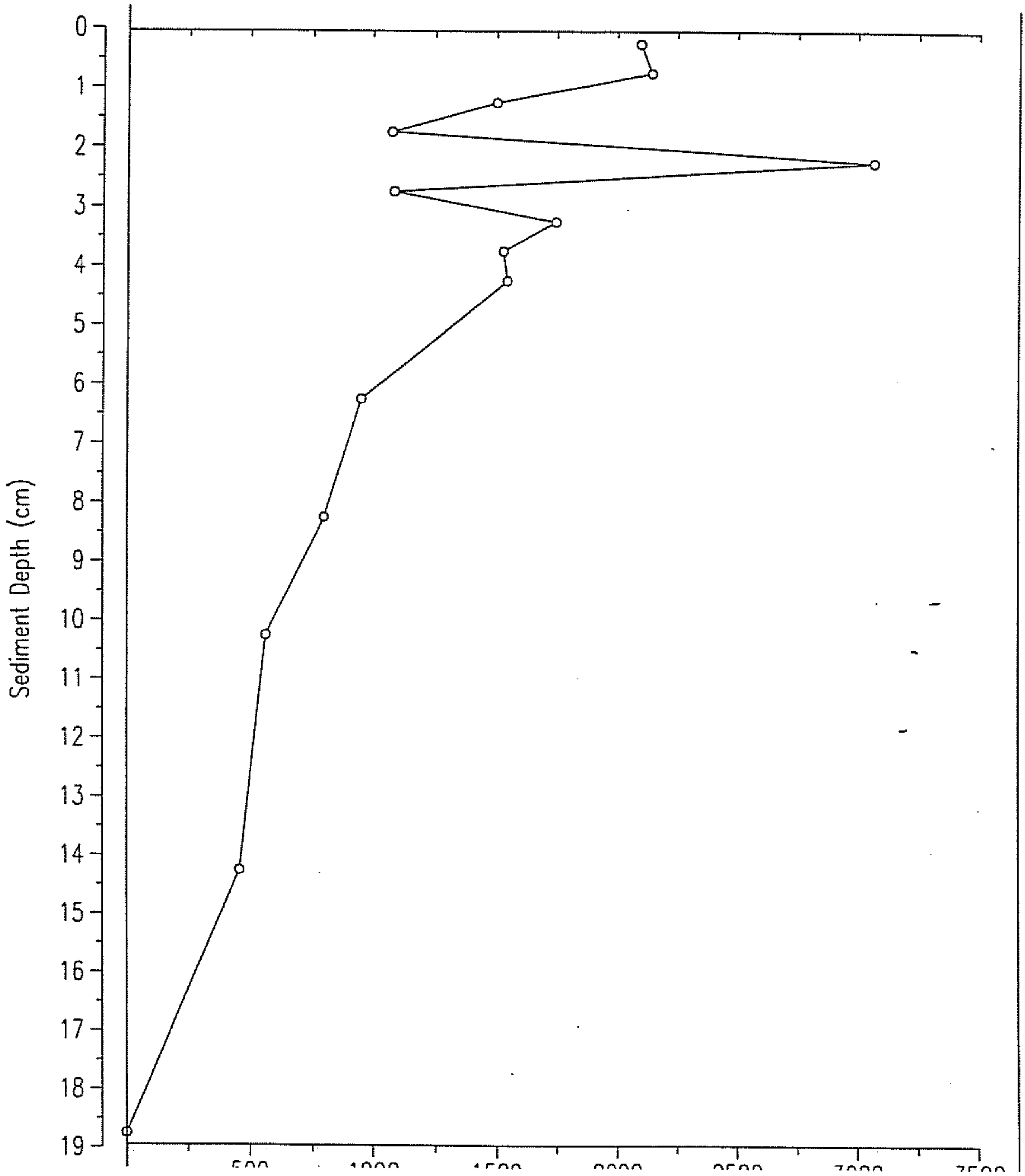
Carbonaceous Particle Concentration Profile



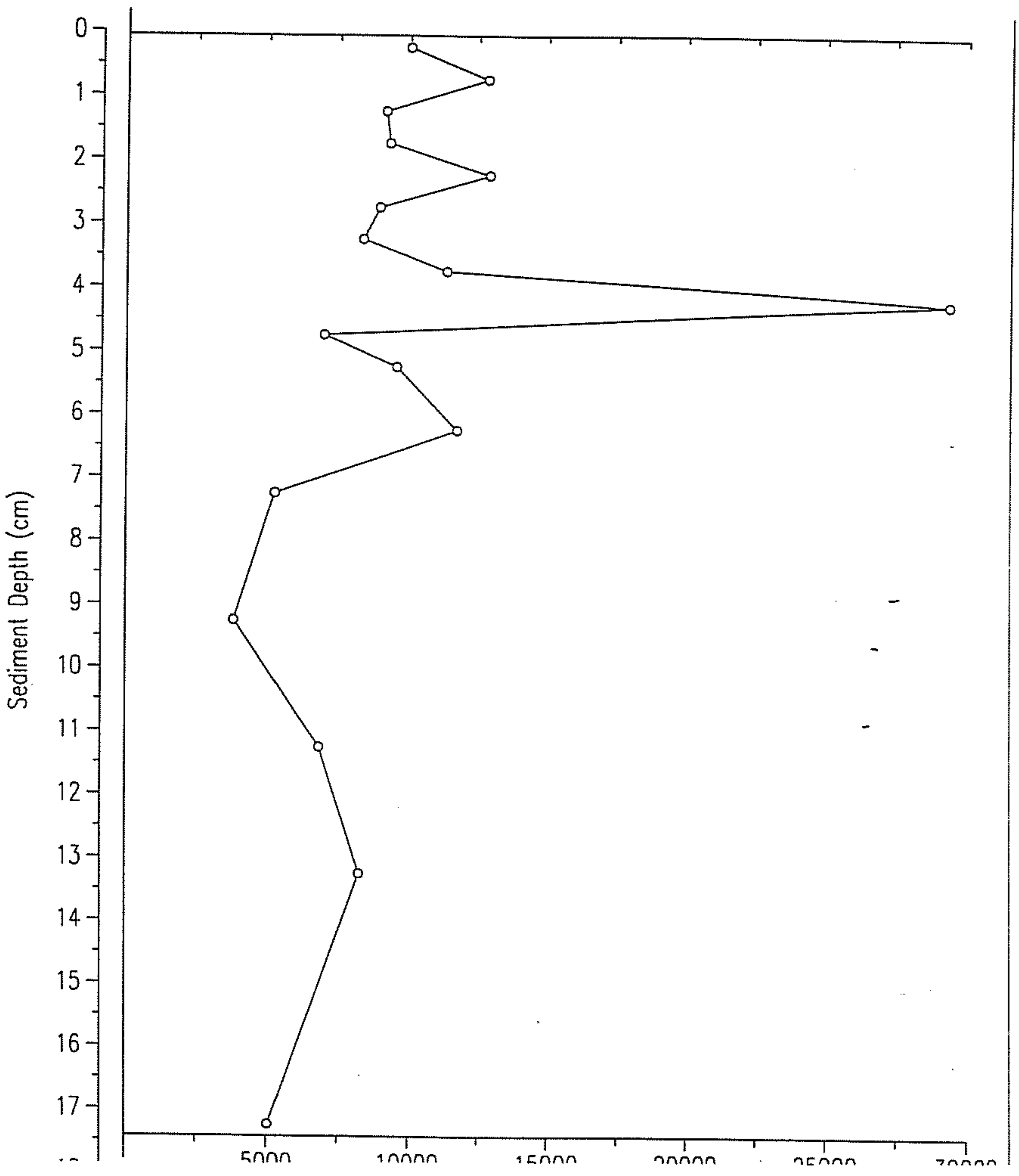
Chang Hu (LL1) 1991
Carbonaceous Particle Concentration Profile



Chang Hu (CHANG 92/2) 1992
Carbonaceous Particle Concentration Profile

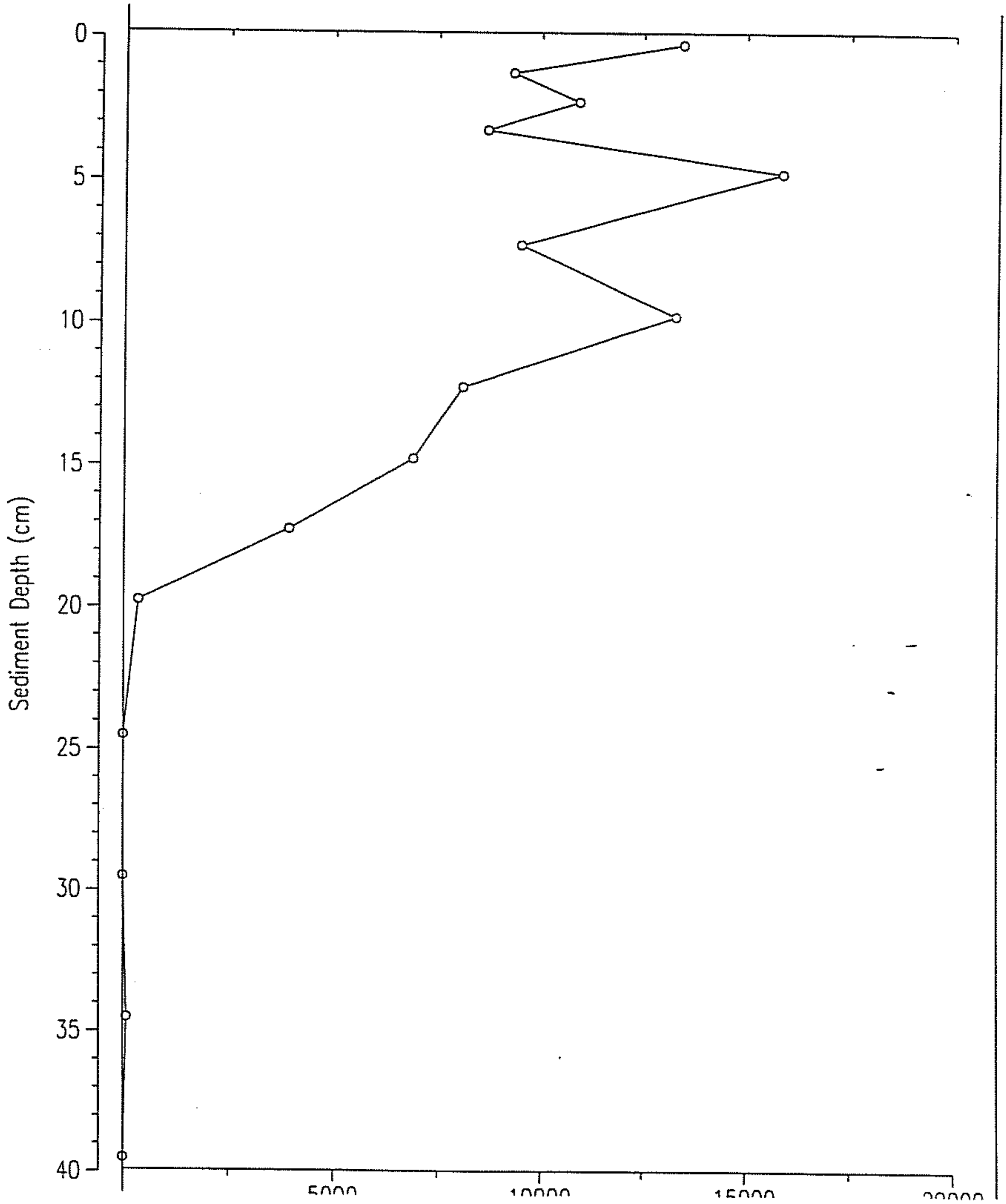


Dong Hu (DONG 92/2)
Carbonaceous Particle Concentration Profile

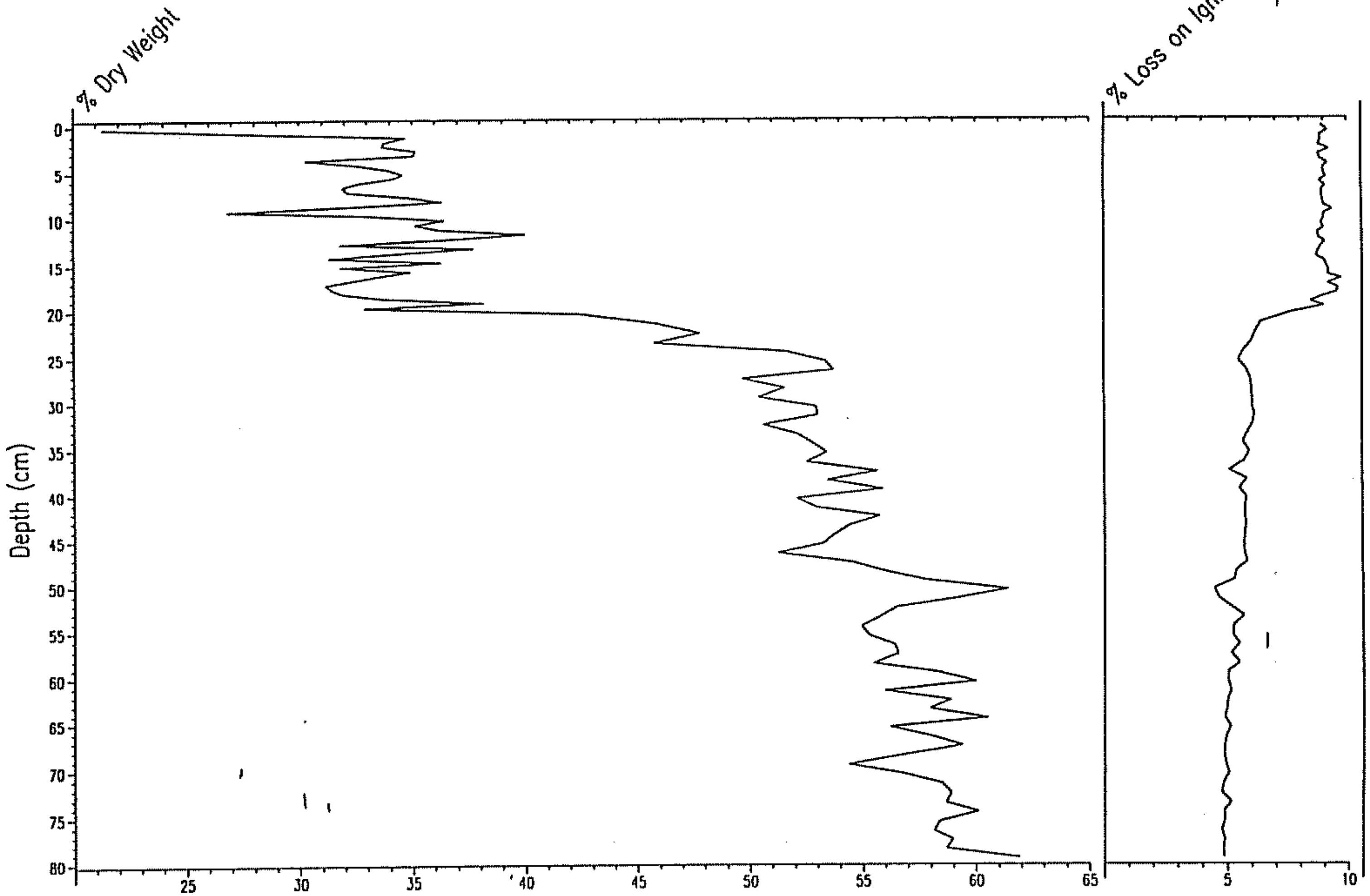


Dong Hu (DONG 92/2A) 1992

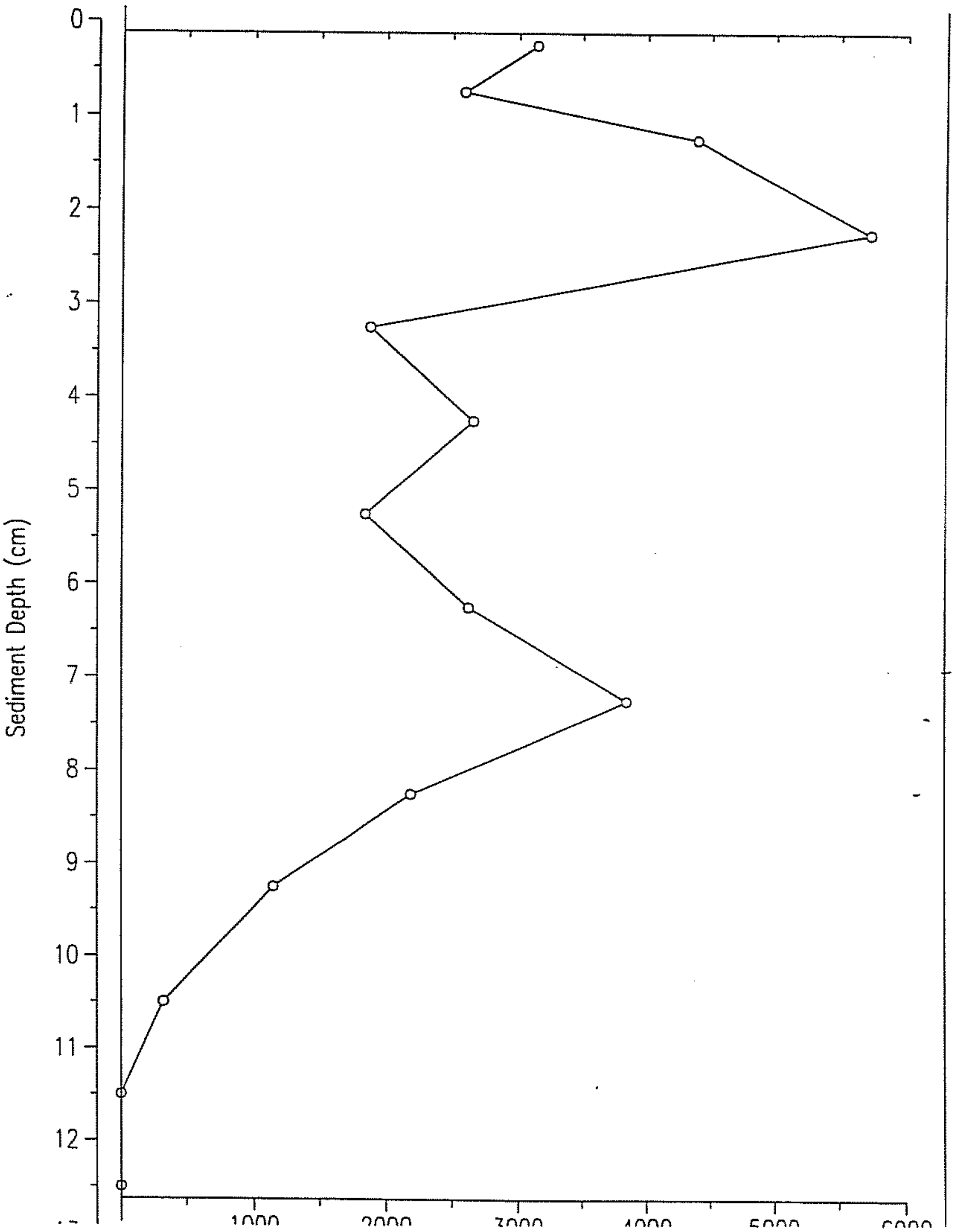
Carbonaceous Particle Concentration Profile



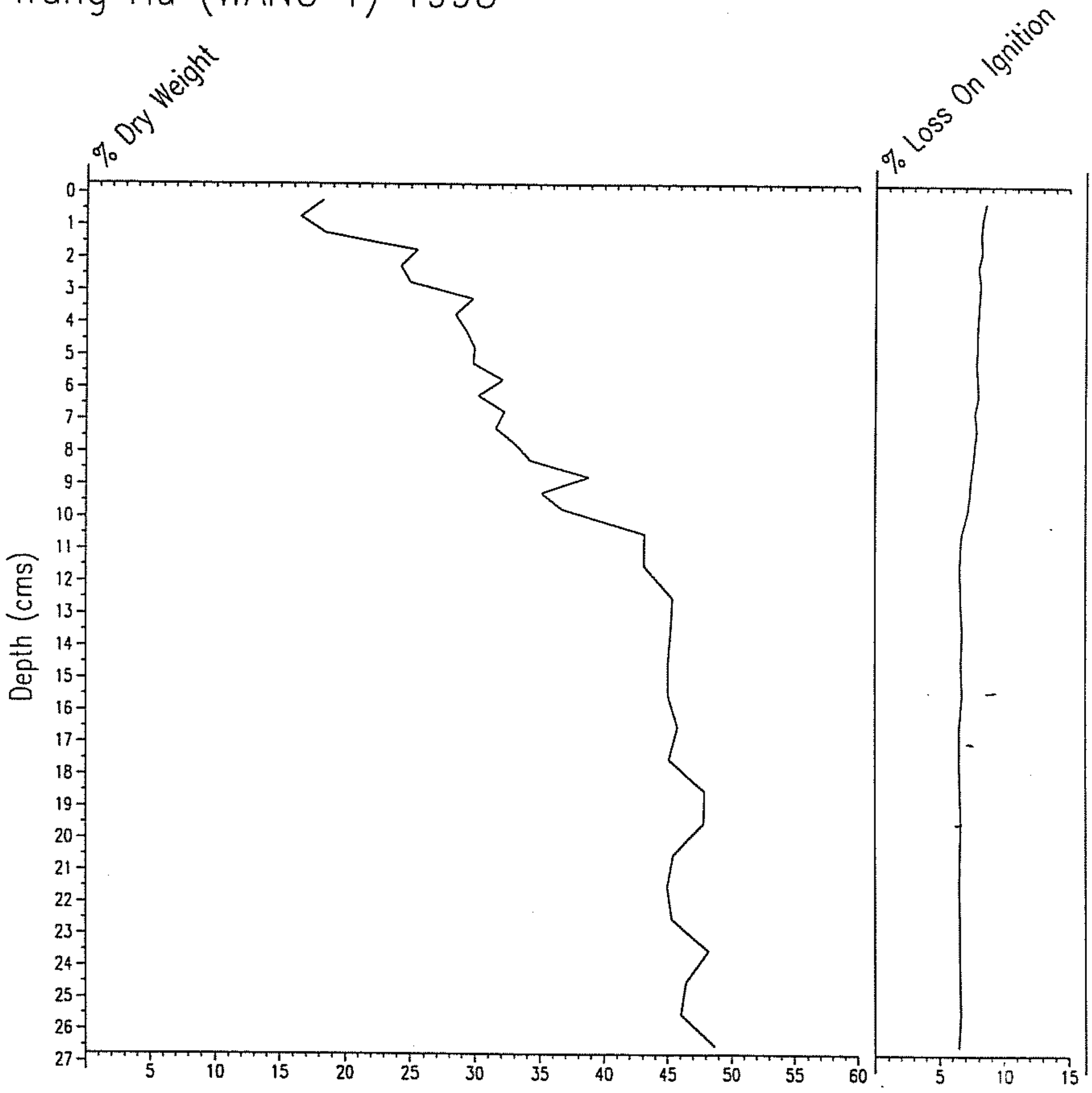
Dong Hu (DONG (92/2A) 1992



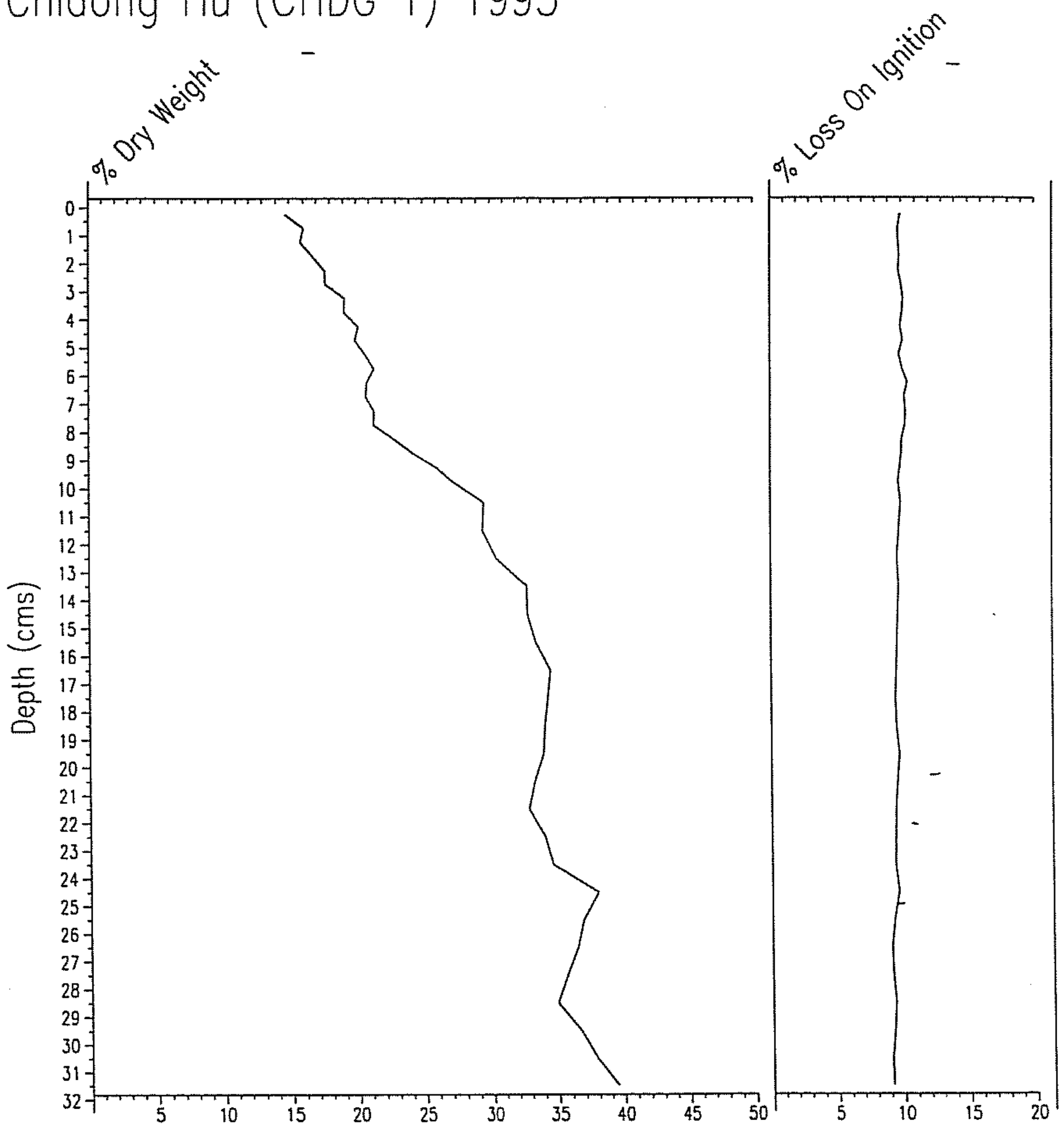
WANG HU (WANG 1) 1993
Carbonaceous Particle Concentration Profile



Wang Hu (WANG 1) 1993

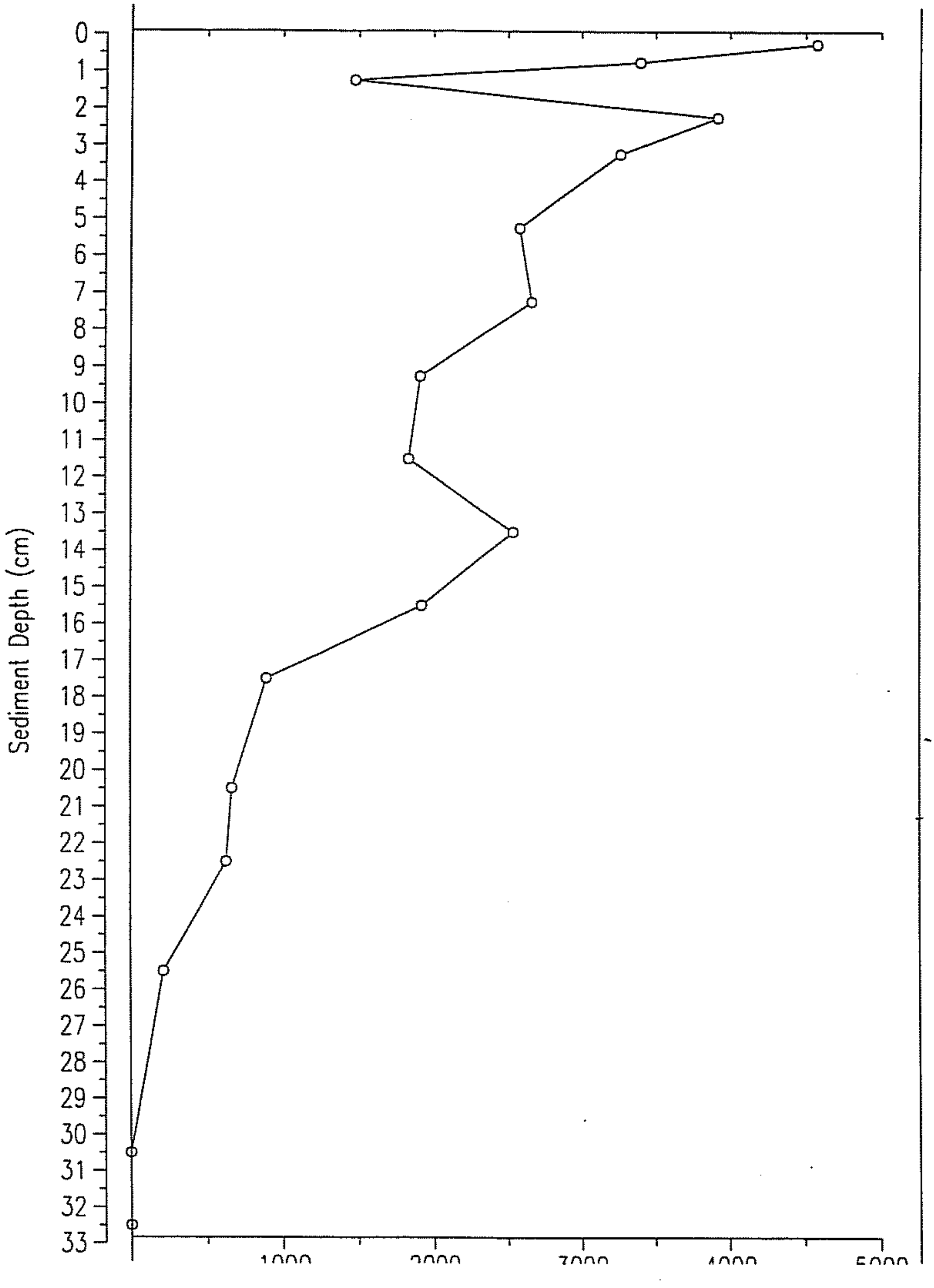


Chidong Hu (CHDG 1) 1993

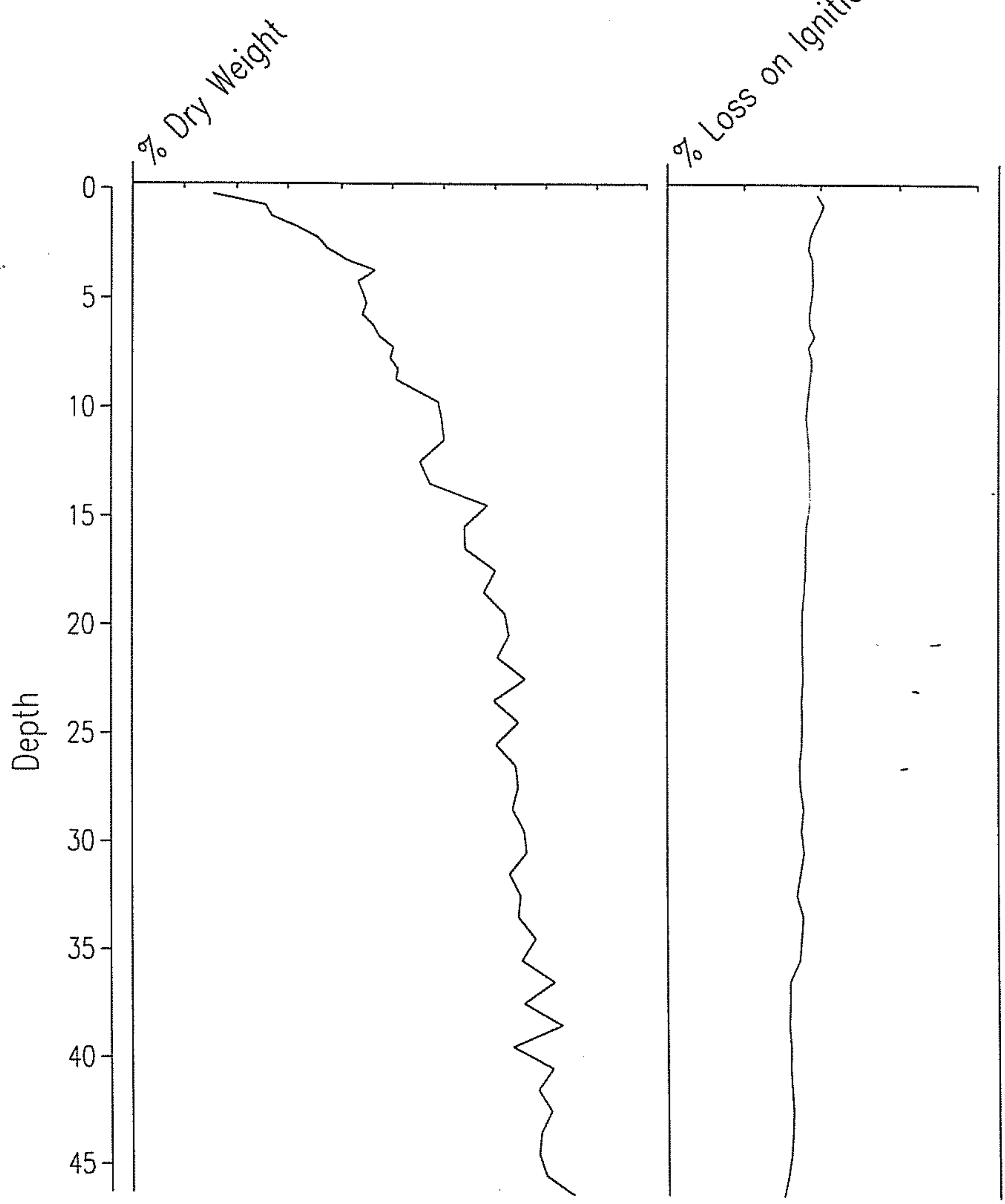


Chi Xi Hu (CHIX 1) 1993

Carbonaceous Particle Concentration Profile

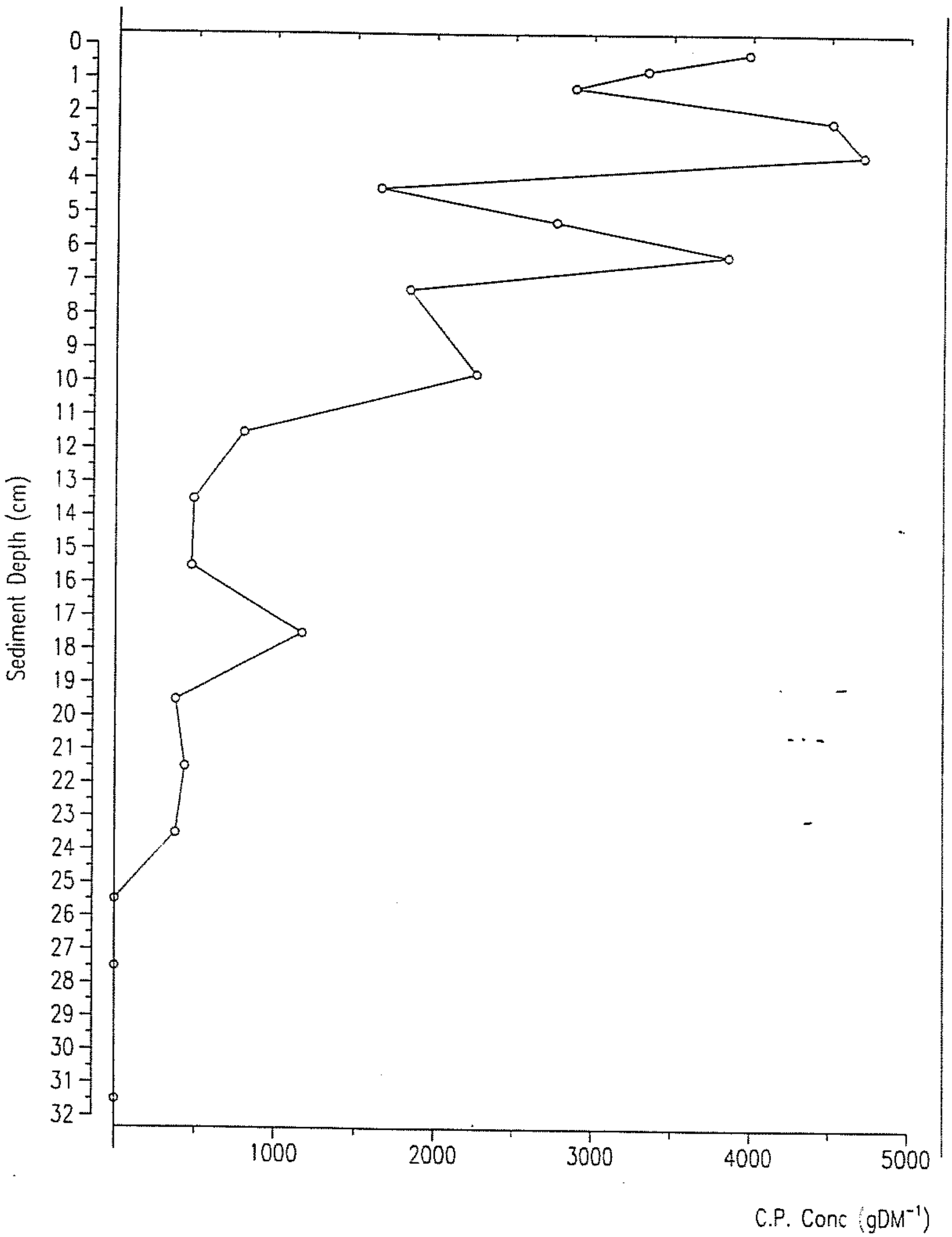


Chixi Hu (CHIX 1) 1993



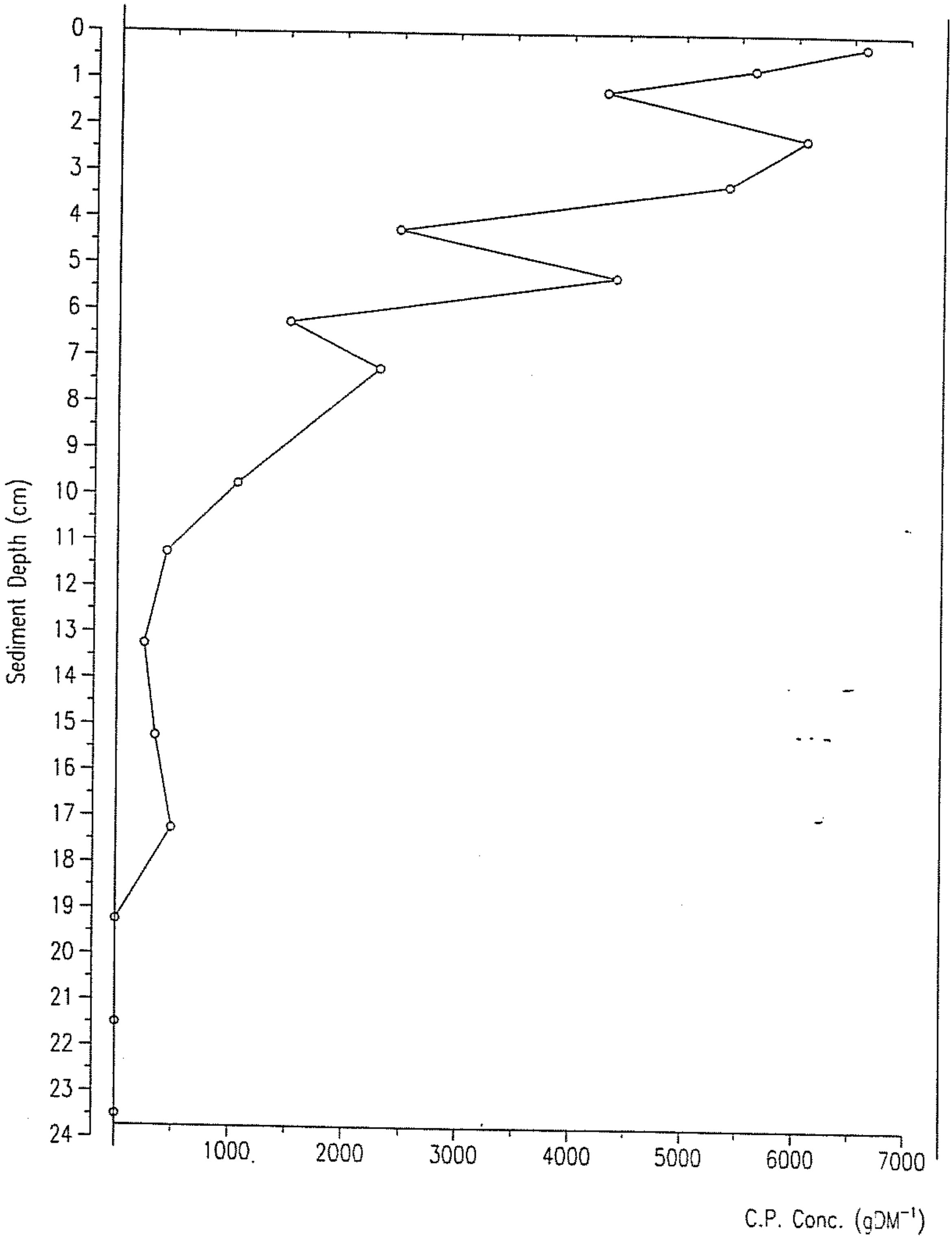
Chidong Hu (CHDG 1) 1993

Carbonaceous Particle Concentration Profile

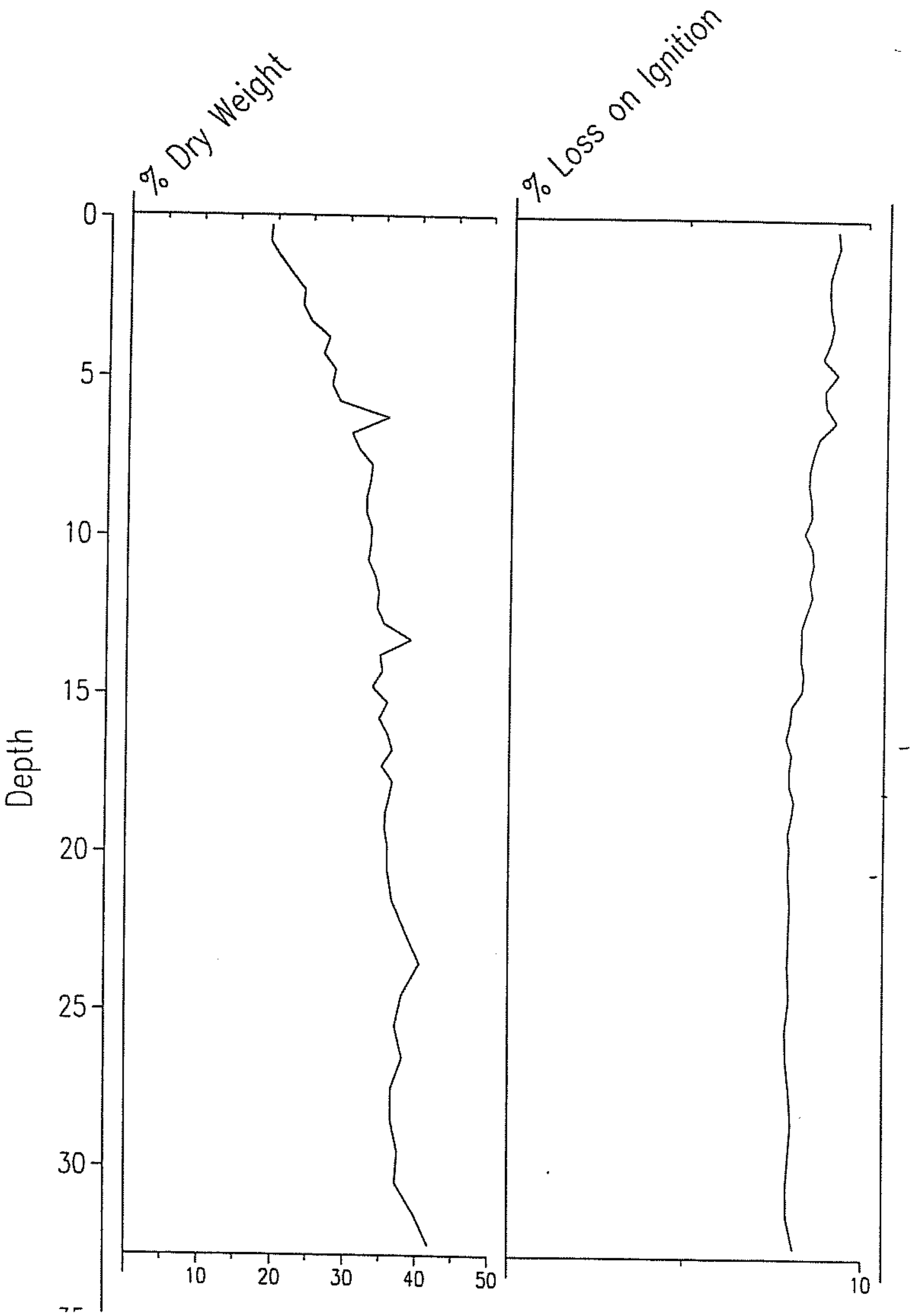


Liangxi Hu (LIGX 1) 1993

Carbonaceous Particle Concentration Profile

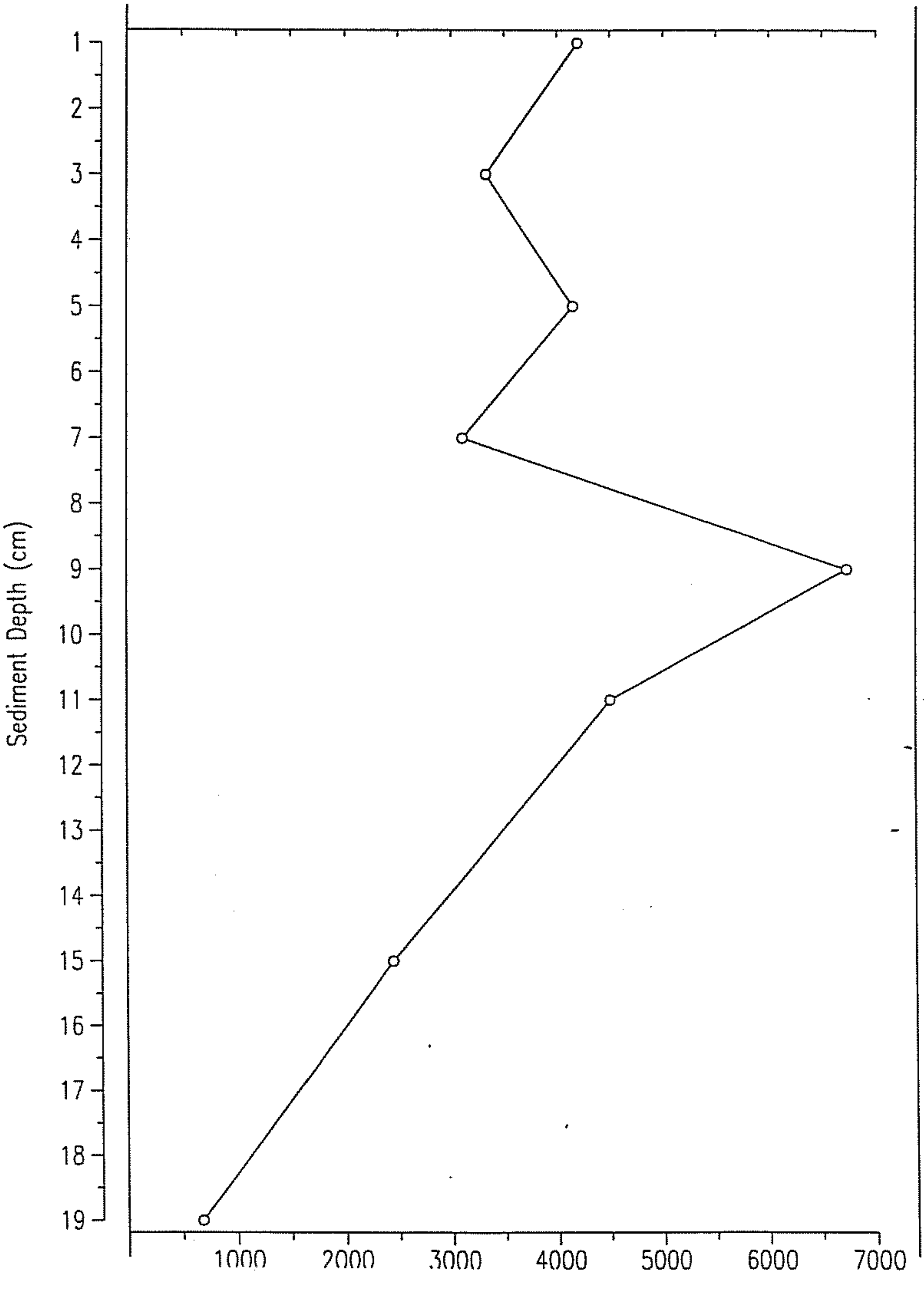


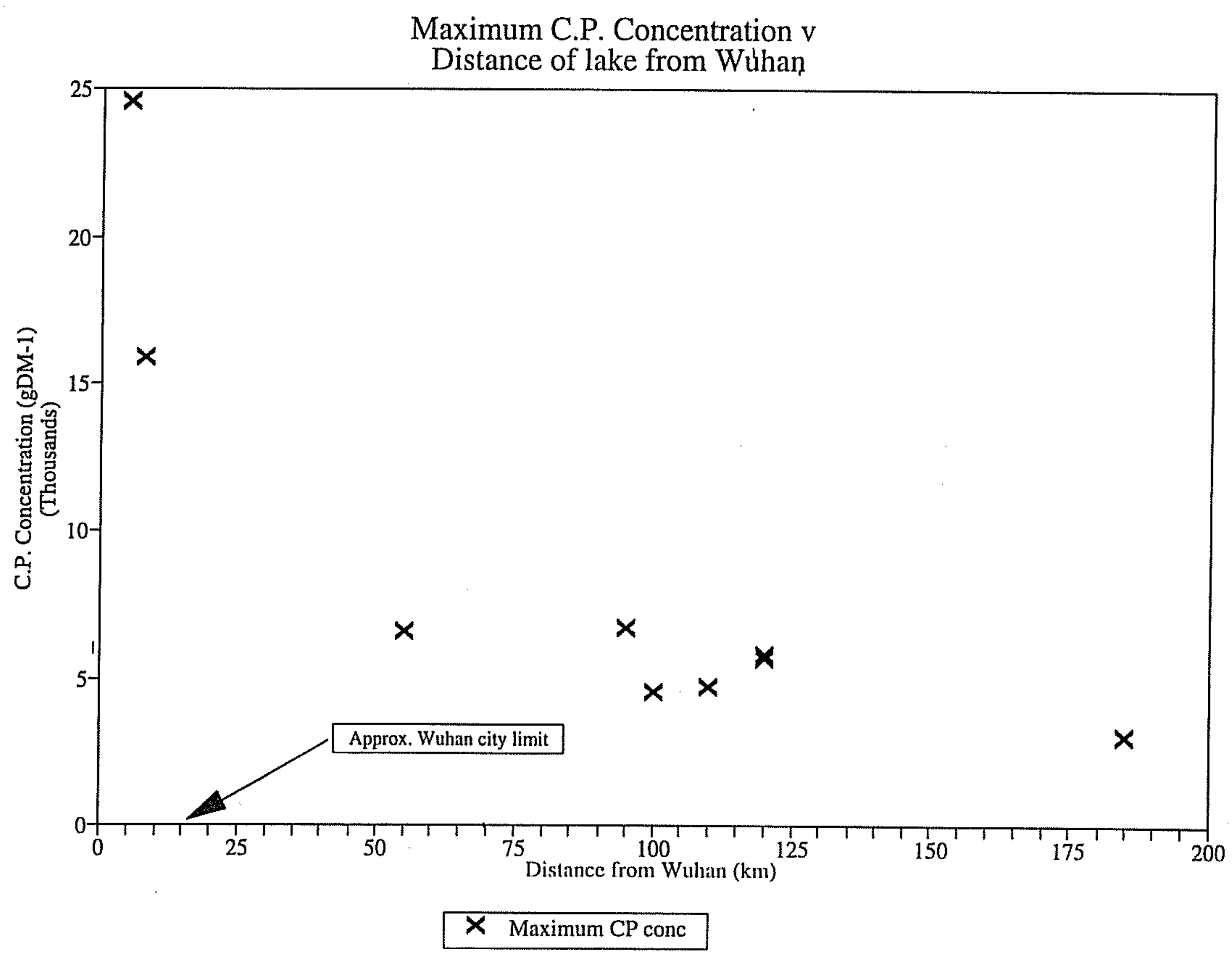
Liangxi Hu (LIGX 2) 1993



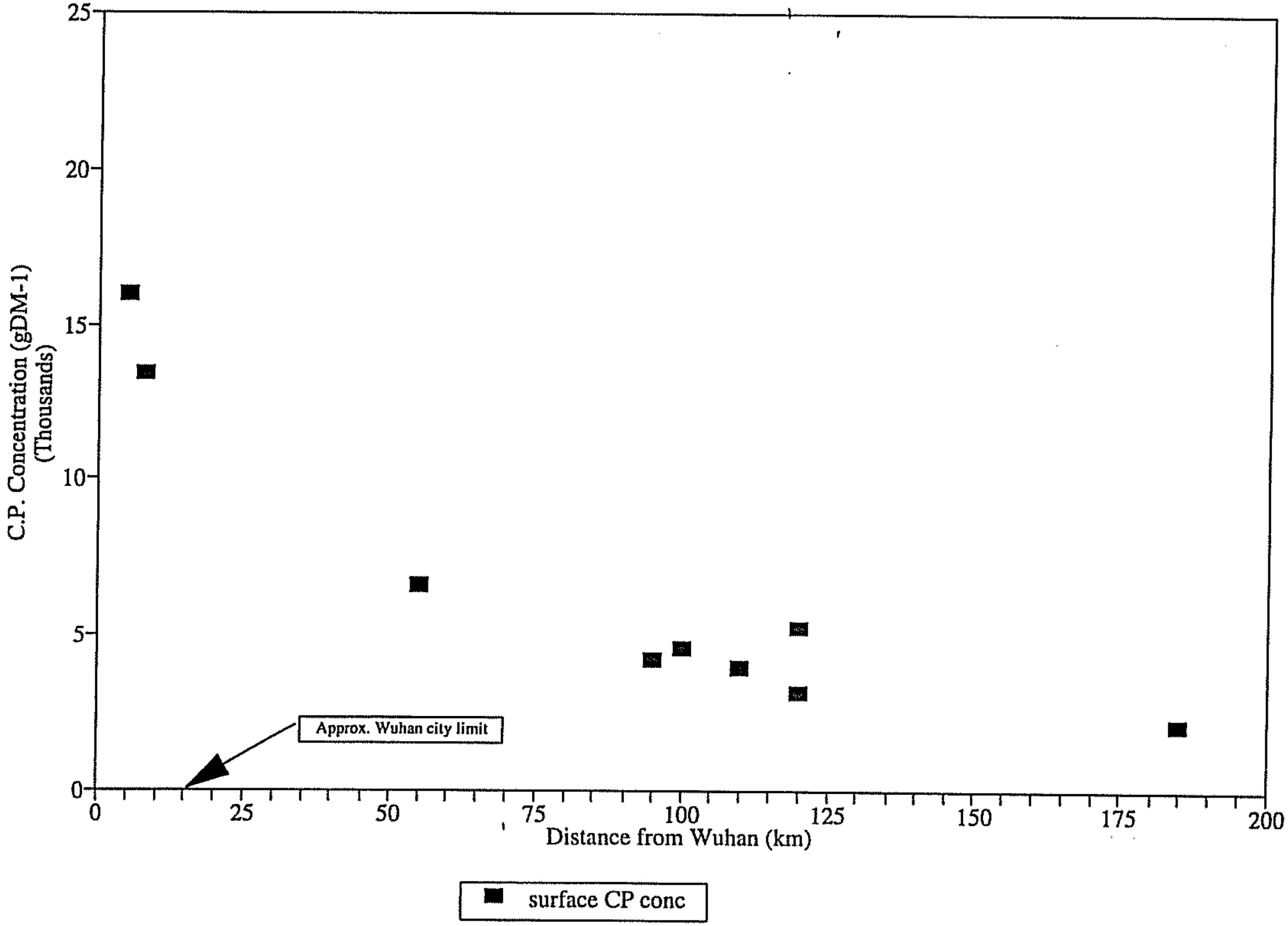
Daye Hu 1993

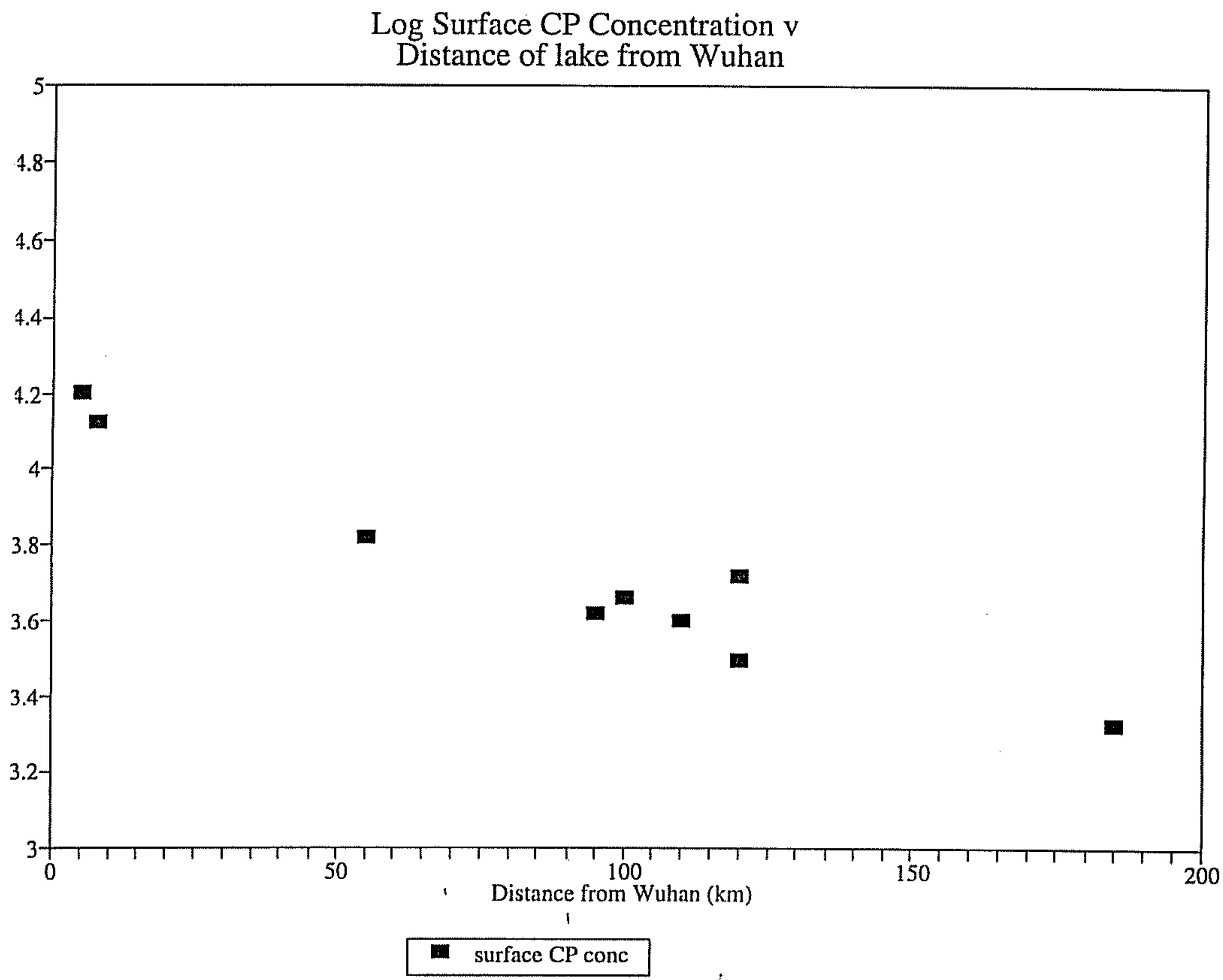
Carbonaceous Particle Concentration Profile

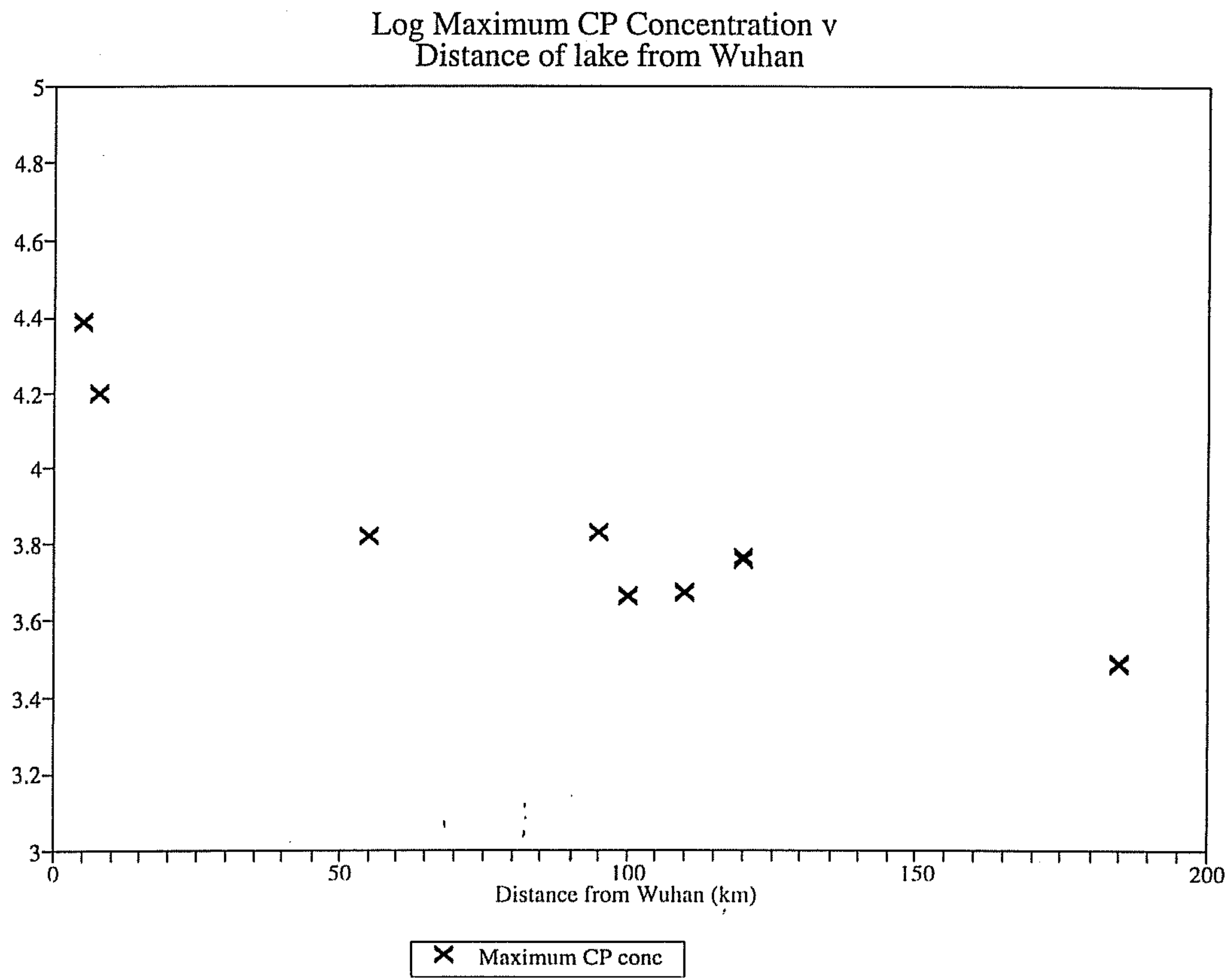



Maximum C.P. Concentration v
Distance of lake from Wuhan
C.P. Concentration (gDM-1)
(Thousands)
25
20
15
10
5
0
0
25
50
75
100
125
150
175
200
Distance from Wuhan (km)
Approx. Wuhan city limit
Maximum CP conc

Surface C.P. Concentration v Distance of lake from Wuhan




Log Surface CP Concentration v
Distance of lake from Wuhan
5
4.8
4.6
4.4
4.2
4
3.8
3.6
3.4
3.2
3
0
50
100
150
200
Distance from Wuhan (km)
surface CP conc



Log Maximum CP Concentration v
Distance of lake from Wuhan
5
4.8
4.6
4.4
4.2
4
3.8
3.6
3.4
3.2
3
0
50
100
150
200
Distance from Wuhan (km)
Maximum CP conc