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PALAEOECOLOGY OF A MEDIEVAL FISHPOND SYSTEM (VAJGAR, CZECH REPUBLIC)

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Abstract: A palaeoecological investigation of a sediment core obtained from an artificial lake – the fishpond Vajgar (40 ha) near the town of Jindřichův Hradec, southern Bohemia, has been carried out in connection with extensive multidisciplinary research preceding the removal of its sediment. Samples from selected standard profile were subjected to chemical, pollen, and palaeoalgological analyses in order to study the chronology of vegetation development, anthropogenic impact on the landscape, and the development of an artificial fishpond ecosystem. The palaeoecological record under study comprises the period of extensive change from pre-cultural, silver fir-dominated forest vegetation into managed, agricultural landscape dominated by cereal fields and pastures. After Medieval colonization, the proportion between wooded and open landscape changed, and the composition of original forests shifted to pine. Pollen spectra from the High Middle Ages are characterized by high percentages of anthropogenic indicators and closely resemble the results from urban deposits (cesspits, wells, communication horizons, etc.). This period can be subdivided into a first phase correlated with the High and Late Middle Ages and a second phase correlated with the post Medieval period and partly maybe also with the agricultural collectivization of the 20th century. The earlier phase has a rather uniform character with a significant presence of grazing indicators and cereal weeds. After the collectivization of the 1950s and later, a substantial change in agricultural practices can be detected: the large-scale use of herbicides affecting the composition of agricultural ruderal species (e.g. decline of cornflower (*Centaurea cyanus*), rye (*Secale*), etc.).

The development of the aquatic system of the fishpond Vajgar was studied by means of chemical and palaeoalgological analyses. On the basis of observed changes in the composition of subfossil algal communities, the fishpond history can be split into four distinct phases. It is assumed that the progression over individual phases was caused by changes in water chemistry that can be interpreted as shifts in water quality caused by the urbanization of the surrounding areas as well as by changes in agricultural practices. The results of the investigation of some chemical elements (especially heavy metals) show stratigraphic patterns that can be related to historical events. These results show that the mixing and bioturbation of the sediment was not so significant as might be expected.

INTRODUCTION

Pollen analyses of nontraditional materials (e.g., anthropogenic urban deposits) proved to be very useful in the effort to reconstruct past environments in the Czech Republic (e.g. JANKOVSKÁ 1988, 1995a,b, 1997, 1998, 1999). This article represents the first attempt to evaluate the palaeobotanical and palaeoalgological records of fishpond sediments in the

Czech Republic. This material can provide unusually complex palaeoecological information, as it contains not only pollen but also the remains of several aquatic organisms (e.g., algae and zooplankton) indicative of past environmental conditions. The opportunity to analyze a complete vertical profile of sediments from an artificial Medieval dam (fishpond 40 ha) was much appreciated for the following reasons.

Fishpond sediments would be expected to provide information from a biotope that palaeoecologically represents a transition between the natural biotope of peatbogs and the entirely anthropogenic deposits from various archaeological entities (cesspits, latrines, wells, etc.). In the Czech Republic up till now, pollen analyses have only been done from peat bogs and from urban archaeological sites. A study of fishpond sediments could therefore give a new perspective for palaeoreconstruction since fishpond sediment contains pollen from both the surrounding natural and seminatural vegetation as well as the entirely synanthropic vegetation of an enclosed urban environment.

Within the Czech Republic, in contrast to most other countries, no natural lakes have persisted except for a few glacial lakes in the Šumava mountains. Another aspect of the study was to see whether fishpond sediment could contain a valid pollen spectrum at all and if so would the information it contain be of value.

Another intention of the palaeobotanical analysis was to make an attempt to complete the paleoecological interpretative value of some indicator algal species. Much attention is now being given to this new branch of palaeoecology, viz. palaeoalgology (JANKOVSKÁ & KOMÁREK 2000, KOMÁREK & JANKOVSKÁ 2001).

DESCRIPTION OF THE VAJGAR FISHPOND AND ITS CATCHMENT

The Vajgar fishpond (ca. 40 ha) is situated in the town of Jindřichův Hradec (23,000 inhabitants, 49° 09′ N, 15° 0′ E, altitude 476 m) in South Bohemia in a region well known as a historical fishpond district (Fig. 1a). Fishponds are artificial lakes that were built as early as 900 years ago (KUBŮ et al. 1994, JANDA & PECHAR 1996, POKORNÝ et al. 1999). The Vajgar fishpond was part of the town fortification. The first written documents about the Vajgar fishpond come from the 13th century. The fishpond provided water and fish and acted as a recreation area. Since 1795 it has served as a recipient of the town's waste waters (TEPLÝ 1927). Until 1970, the waste water (BOD_5 200–250 $mg.L^{-1}$, P_{tot} ca. 5 $mg.L^{-1}$, N_{tot} 50 $mg.L^{-1}$) was discharged into the Vajgar fishpond at a rate of about 15 $L.s^{-1}$. In 1970, a wastewater treatment plant was built to handle about 10,900 m^3 per day. Up to 1965, the fishpond was regularly emptied to harvest fish. Then when the outlet mechanism was damaged and later also a small dam was made between the so-called "Small" and "Large" Vajgar, the pond could not be drained any more. The Vajgar fishpond serves as a sedimentation basin for the Hamerský potok, the stream that brings water from the catchment. The Hamerský potok (in its upper part called Studenský) rises from a spring 45 km northeast of Jindřichův Hradec near the hill Javořice (837 m altitude) in the Českomoravská vrchovina Mts. and flows through a system of several fishponds. The catchment area of the Studenský/Hamerský potok is about 220 km^2. The average annual precipitation (rainfall) in the 1980s was about 670 mm and the average temperature 7.3 °C. The average water flow in the Hamerský potok at Oldřiš, ca. 8 km upstream from the Vajgar fishpond was 1.2 $m^3.s^{-1}$ in the 1980s.

Hydrological data from 7 major fishponds in the catchment, ranging in area from 10 ha to 127 ha are given by POKORNÝ & HAUSER (1994). Evaluation of the sources of eutrophication in the catchment are given by POKORNÝ (1995). For a detailed description of the catchment, see PETRŮ (1999).

Dying and decomposing blooms of cyanoprokaryotes (*Microcystis aeruginosa*) in the Vajgar fishpond caused hygienical problems and had to be treated with lime and water imported by fire-engines. Therefore, in 1991–1992, the town council of Jindřichův Hradec financed the restoration of the Vajgar fishpond, meaning large-scale removal of organic-rich bottom sediments (330,000 m^3) using a suction dredger developed for this purpose (POKORNÝ & HAUSER 1994, 2002). Similar projects were done later in the town of Telč and other places in the Czech Republic in the 1990s.

MATERIAL AND METHODS

Sediment stratigraphy analysis

A steel 1 m long "russian corer" (JOWSEY 1966) with steel bars was used to acquire a sediment core. A perplex sampler was used to sample the top sediment. Water depth and thickness of black sediment were measured at 60 points (Fig. 1b) in the fishpond area. A map of black sediment was made and total volume of black sediment estimated. Sampling points were located by theodolite. In the center part of the fishpond, the deepest core was 2.5 meters thick. Subsampling of the core was carried out at intervals of 2.5 cm, but the stratigraphical resolution of 5 cm (10 cm in lower parts of the profile) was adopted for the analyses. Sampling was done in October 1990.

Description of the sediment profile (B3)

0–10 cm low-density sapropel, slightly oxidized;

10–70 cm black, anaerobic sapropel, reduced with fine particles, relatively rich in organic matter, evident gas release;

70–150 cm grey, mineralogenic sapropel, mostly clay, relatively low content of organic matter, consolidated, no evidence of gas production;

150–240 cm proportion of coarser particles increases gradually, even small pieces of gravel can be found, sediment highly mineralogenic;

240–250 cm peat layer (J3).

Pollen and palaeoalgological analyses

The samples used for pollen and palaeoalgological analyses were prepared by the standard acetolysis method (FAEGRI et al. 1964, OVERBECK 1958). As most of the samples had more or less a mineral character, they were pre-treated with concentrated hydrofluoric acid (HF) for 24 hours. Each sample was analyzed on a separate 24 × 24 mm microscopic pollen slide.

The results are presented in the form of percentage pollen diagram. The finds of subfossil algae and other microfossils are attached to the diagram at the right end. From the NAP (non-arboreal pollen) group anthropogenic indicators, both primary and secondary, are listed separately. This category consists of clear indicators of landscape synanthropization,

Fig. 1a. Location of the town of Jindřichův Hradec.

although many other anthropogenic indicators are likely included in higher taxonomic groups (e.g., *Apiaceae*, *Asteraceae*, *Brassicaceae*, *Ranunculaceae*, *Fabaceae*). Percentage values are calculated on the basis of the regional pollen sum: AP + NAP (excluding hydrophyta) = 100%. Percentage curves are exaggerated 10 times in the pollen diagram in order to increase readability. The number of spores, algae, and other microfossils are related directly to the pollen sum.

Sediment chemistry and dating

The following chemical analyses of the standard core were made: dry matter, organic matter, Al, As, B, Bi, Ca, Cd, Co, Cu, Cr, Fe, Hg, K, Mg, Mo, Na, Ni, P, Pb, S, Se, Sr, Ti, V, W, Zn. The release of phosphorus (both total and phosphate) from the upper black layer and from the lower grey layer were tested in a laboratory under aerobic and anaerobic conditions. The dating of the whole profile was made by the means of C^{14} analyses at five levels (Department of Quaternary Geology, Radiocarbon Dating Laboratory, Lund University, Sweden). The dating of upper layers was performed by Cs^{134}/Cs^{137} measurements (Institute of Landscape Ecology, České Budějovice, Czech Republic). Sediment dry matter was estimated by heating to constant weight at 105 °C, and organic matter content by loss-on-ignition of dry mass at 550 °C. The content of base cations, nutrients and heavy metals and release of phosphorus were estimated at the Swedish Water and Air Research Institute, Stockholm, in cooperation with Lund University, Sweden.

Nomenclature of plant names follows the ALPADABA database, housed at the Department of Palaeobotany, University of Bern, Switzerland.

RESULTS AND DISCUSSION

Dating of the profile

Five sediment layers were dated by C^{14} (see Table 1). The radiocarbon age of the peat underlying the fishpond sediment (240–250 cm) was determined to be 1040 ± 60 BP (Lu-3322). After calibration (see Table 1), the sediment age corresponds to the Early Middle Ages. The closest layer of the sediment above the peat layer (profile "B3") was determined to be 890 ± 60 BP (Lu-3321), and again resemble the Early Middle Ages Period after the calibration. The age of the layers 170 cm and 100 cm is 700 ± 60 BP (Lu-3320), and 670 ± 60 BP (Lu-3319) respectively. Both samples are then dated to the High Middle Ages. The age of the upper sediment layer (25 cm) is 370 ± 60 BP (Lu-3318), and resembles the Modern Period according to the calibration results. This date is considered incorrect due to the low accuracy of the C^{14} method for recent sediments.

Radiocarbon dating confirmed the biostratigraphically determined age: the oldest sediments (250 cm) can be correlated with the Early and Late Subatlantic (SA1/SA2)

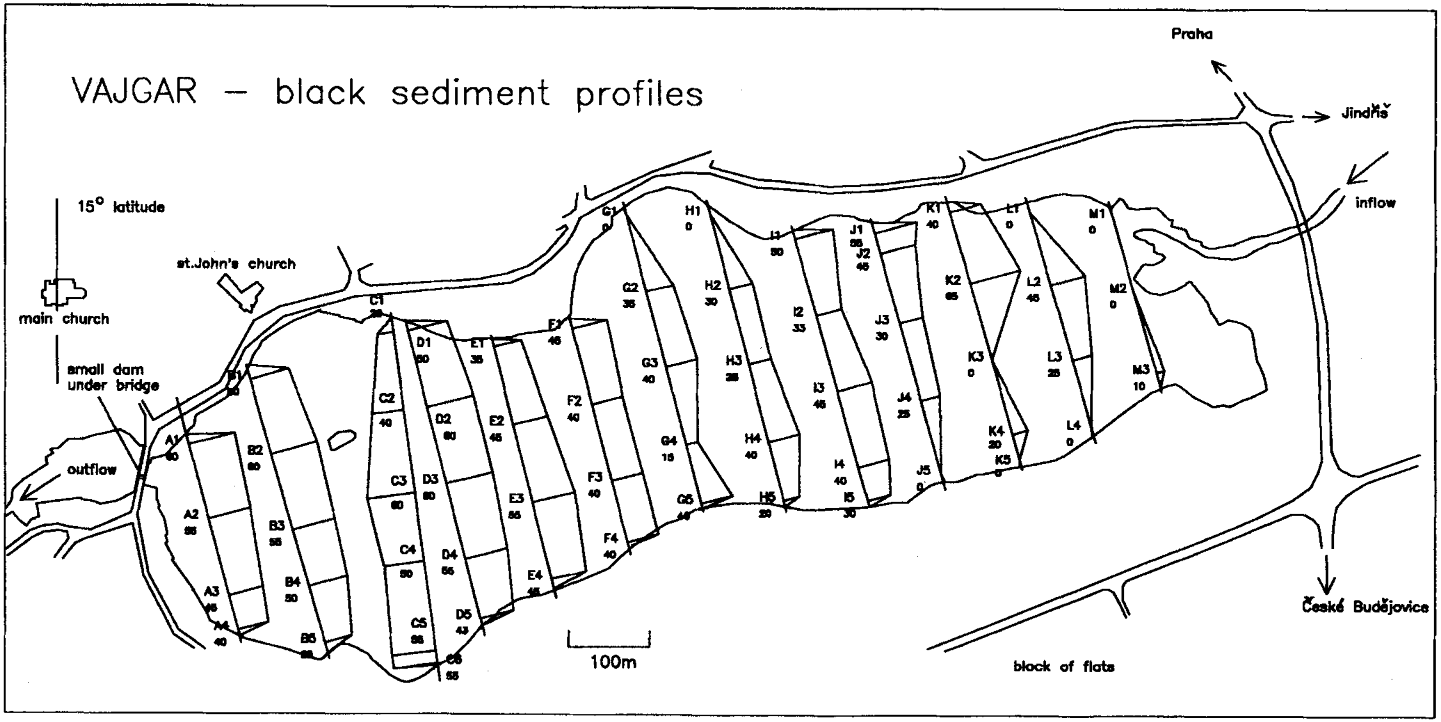

Fig. 1b. Jindřichův Hradec, Czech Republic. Scheme of the Vajgar fishpond in Jindřichův Hradec, location of individual sediment cores taken and thickness of respective black sediment layers (cm).

Table 1. Results of the radiocarbon data calibration according to STUIVER et al. (1998 a,b). Calib 4.3 computer program was used.

Radiocarbon age	Calibrated age ranges (1 sigma) and respective relative area under probability distribution	Calibrated age ranges (2 sigma) and respective relative area under probability distribution
1040±60 BP	898–921 AD (0,165) 944–1036 AD (0,825) 1144–1147 AD (0,010)	886–1159 AD (1,000)
890±60 BP	1041–1095 AD (0,378) 1117–1141 AD (0,166) 1153–1214 AD (0,456)	1025–1253 AD (1,000)
700±60 BP	1263–1315 AD (0,645) 1354–1387 AD (0,355)	1220–1332 AD (0,660) 1339–1398 AD (0,340)
670±60 BP	1282–1323 AD (0,502) 1350–1390 AD (0,498)	1256–1409 AD (1,000)
370±60 BP	1452–1523 AD (0,550) 1568–1627 AD (0,450)	1439–1641 AD (1,000)

boundary, while most of the profile is dated to Late Subatlantic (SA2, sensu FIRBAS 1949). The Late Subatlantic sediments were subdivided into two different subphases (SA2 a and SA2 b) by means of pollen analysis.

C^{14} dating showed that the Vajgar fishpond was constructed about the beginning of the last millennium. Transport of material into the fishpond was great in the 13th and 14th centuries. In 0–10 cm layer 0.18 Bq/g (dry mass) of Cs^{137} and detectable amount of Cs^{134} were found. In the layer 30–40 cm deep there was no Cs^{134} and 10 times less (0.015 Bq/g) of Cs^{137} than was found in the layer 0–10 cm.

Regional vegetation development

All sediment samples contained a rich pollen spectra in a good state of preservation. Moreover, sporopollenin-containing algal remains were abundant in the fishpond sediments. The composition of the pollen spectra significantly differed from the pollen spectra of the same age obtained from natural biotopes such as peat bogs and lakes: anthropogenic indicators are conspicuously abundant and the diversity of taxa is very high. This closely resembles pollen spectra from anthropogenic deposits from the High Middle Ages known from Bohemian towns (JANKOVSKÁ 1995a,b, 1999).

The oldest part of the profile (sample 240–250 cm; see Fig. 2) contains pollen spectra that indicate a more or less natural state of the site and its surroundings. The composition of the regional forest cover can be considered as almost natural: silver fir (*Abies alba*), spruce (*Picea abies*), and occasionally beech (*Fagus sylvatica*) were the dominant trees. The presence of *Pteridophytes* is typical for dark coniferous forests. Other tree species were most likely only subdominants: oak (*Quercus*), lime (*Tilia cordata* and *T. platyphyllos*) and occasionally elm (*Ulmus*), maple (*Acer*), ash (*Fraxinus excelsior*), hazel (*Corylus avellana*), pine (*Pinus sylvestris*) and birch (*Betula*). The analyzed sediment can be characterized as the peat that probably originated in the environment of an alder carr. Alder carrs must have been

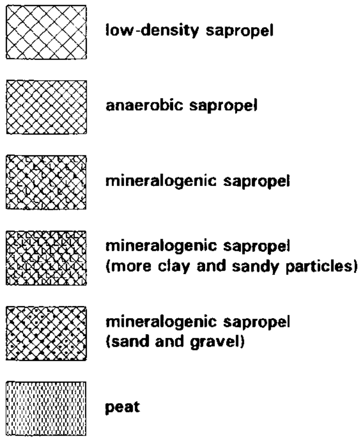

Fig. 2. Explanation to the "Lithology".

abundant in hydrologically favourable sites (e.g. river alluvia) during that time. Alder (*Alnus glutinosa*) probably grew as a component of alder-spruce forests as well.

The time of the formation of the deepest part of the profile is correlated with SA1/SA2 boundary. Although virtually no human activity is expected in the region during this time (see absence of cereal pollen), one pollen grain of *Centaurea cyanus* has been found in the sediment. The activity of man in the surrounding landscape can be inferred only from a sporadic occurrence of *Plantago lanceolata*, *Rumex acetosa* and *Cannabis-Humulus* pollen. The find of *Centaurea cyanus* is rather ambiguous as the occurrence of this cereal weed in Bohemia is confined exclusively to the High Middle Ages (JANKOVSKÁ 1995a, 1997) and the *Centaurea cyanus* pollen curve often correlates with that of *Secale* (GREIG 1991) in Central Europe.

Although the pollen curves display some changes during the subsequent period (SA2), their character allows us to distinguish only two clear phases (SA2a and SA2b), which are described and interpreted below:

SA2a : 240–55 cm

This sediment was the first to be formed in the bottom of the artificial pond. The pollen spectra of the oldest fishpond sediments differ from that of the underlying peat (250 cm) by the abundance of pollen derived from synanthropic vegetation and by the presence of algal cenobia indicating the presence of a freshwater biotope. According to the results of the pollen analysis, the duration of SA2a is from the High Middle Ages (when the fishpond was founded) to the first half of the 20th century. Although this is a long period and many significant changes in the vegetation cover are expected during that time, only indistinct changes are observed in most of the pollen curves. Redeposition and other disturbance of the sediments must be considered during that time.

The landscape surrounding the site had already been significantly disturbed by human activity in the very beginning of this phase. The decline of natural forests in favour of cereal fields, meadows, pastures, and urban areas is inferred for that time. Nevertheless, the vegetational composition of remnants of the original forests remained largely undisturbed. *Abies*, *Picea* and *Fagus* (at higher altitude) dominated in these. A moist environment of dark, coniferous forests with prevailing *Abies alba* is reflected in the regular occurrence of *Lycopodium annotinum* spores. On the other hand, the growing percentages of *Pinus* and the occurrence of *Calluna* pollen and *Pteridium* spores indicate the survival of some forests and the degradation of their soils. The abundance of different light-demanding herbaceous species indicates the increasingly open character of the landscape. Some of these herbs are clear anthropogenic indicators. The pollen of *Cerealia* (*Secale* and *Triticum* type) points to the importance of cereal cultivation. The cultivation of *Panicum* (only hardly distinguishable

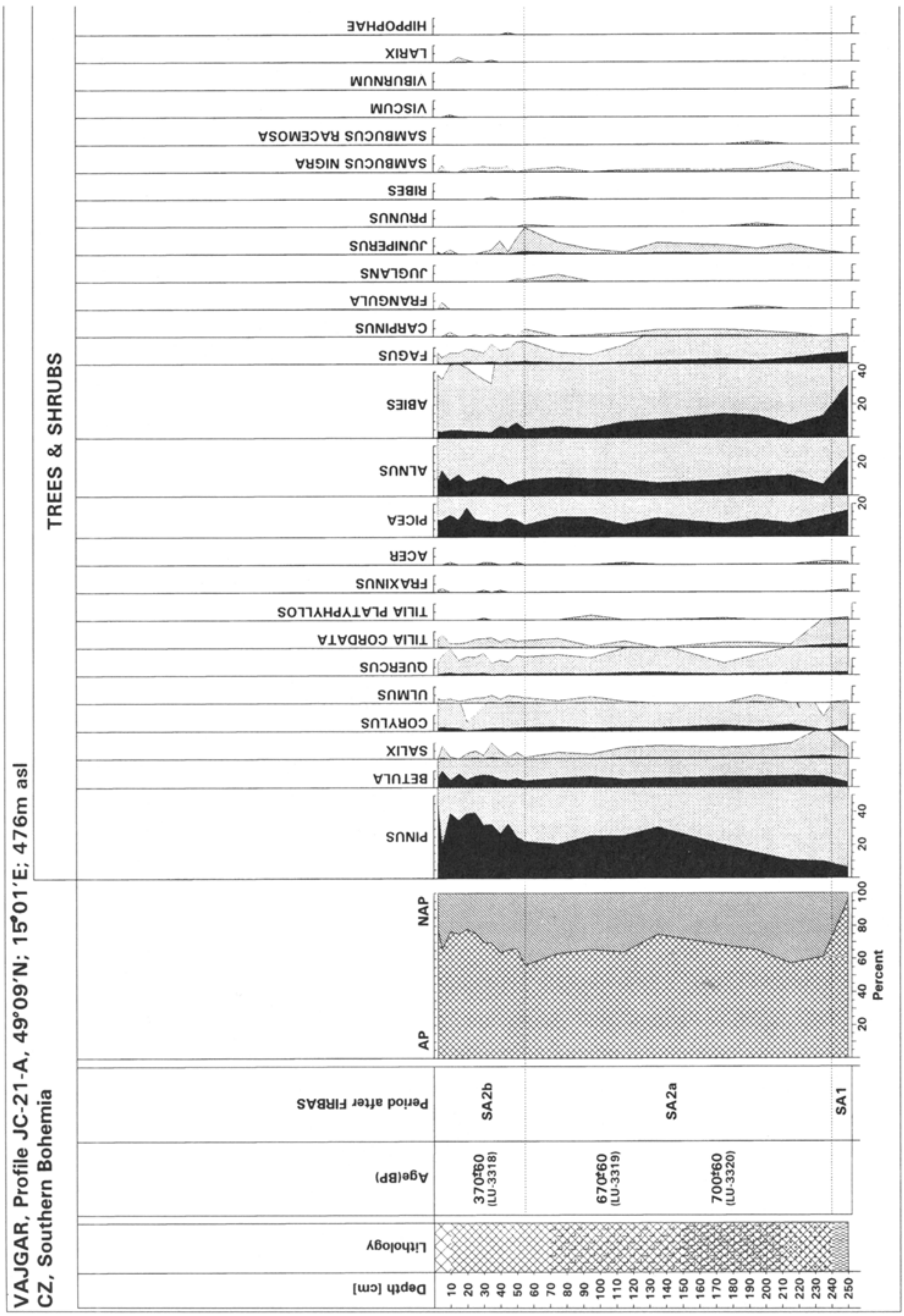

Fig. 2. Diagram showing pollen records and other microfossils.

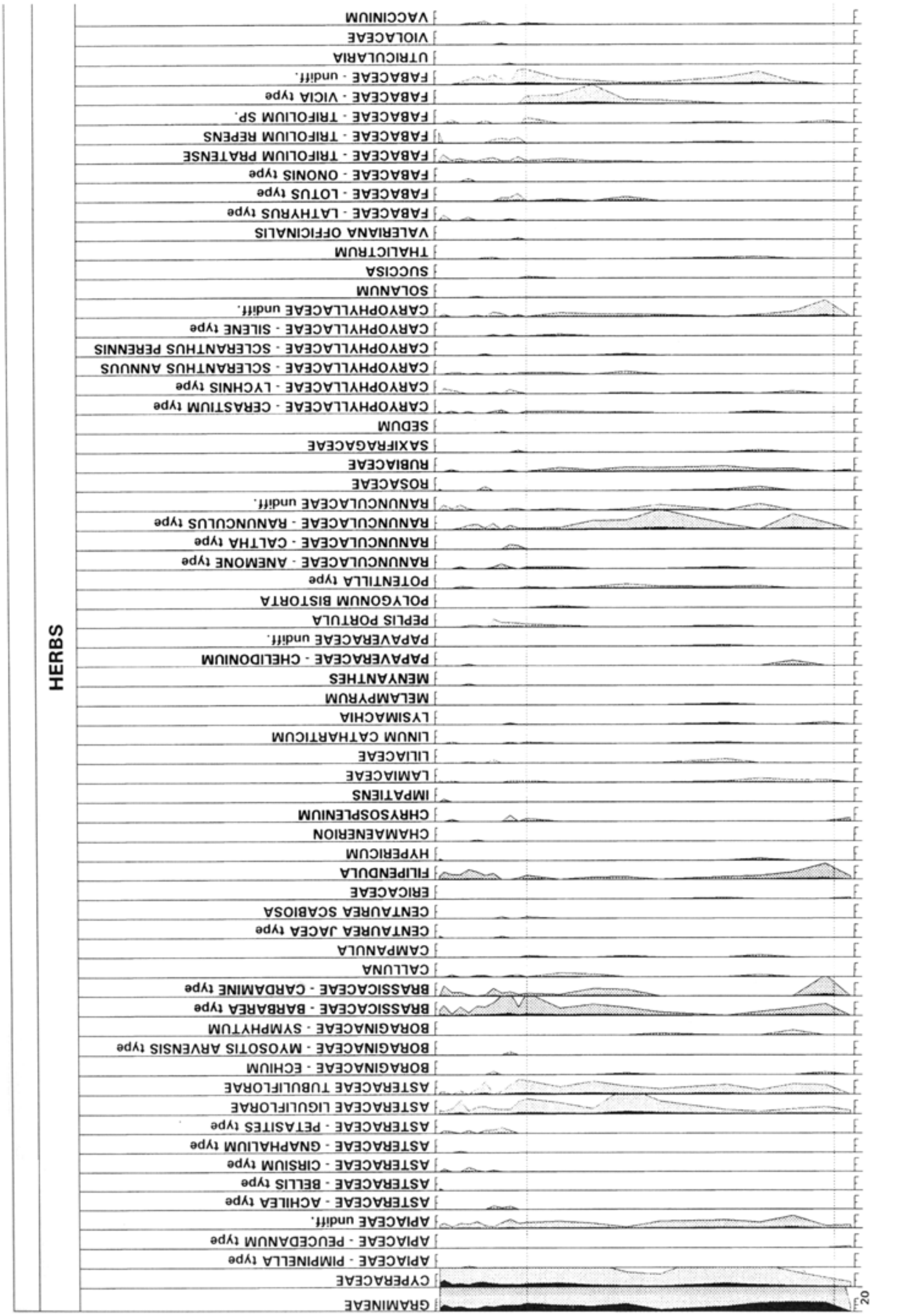

Fig. 2. Diagram showing pollen records and other microfossils (continued).

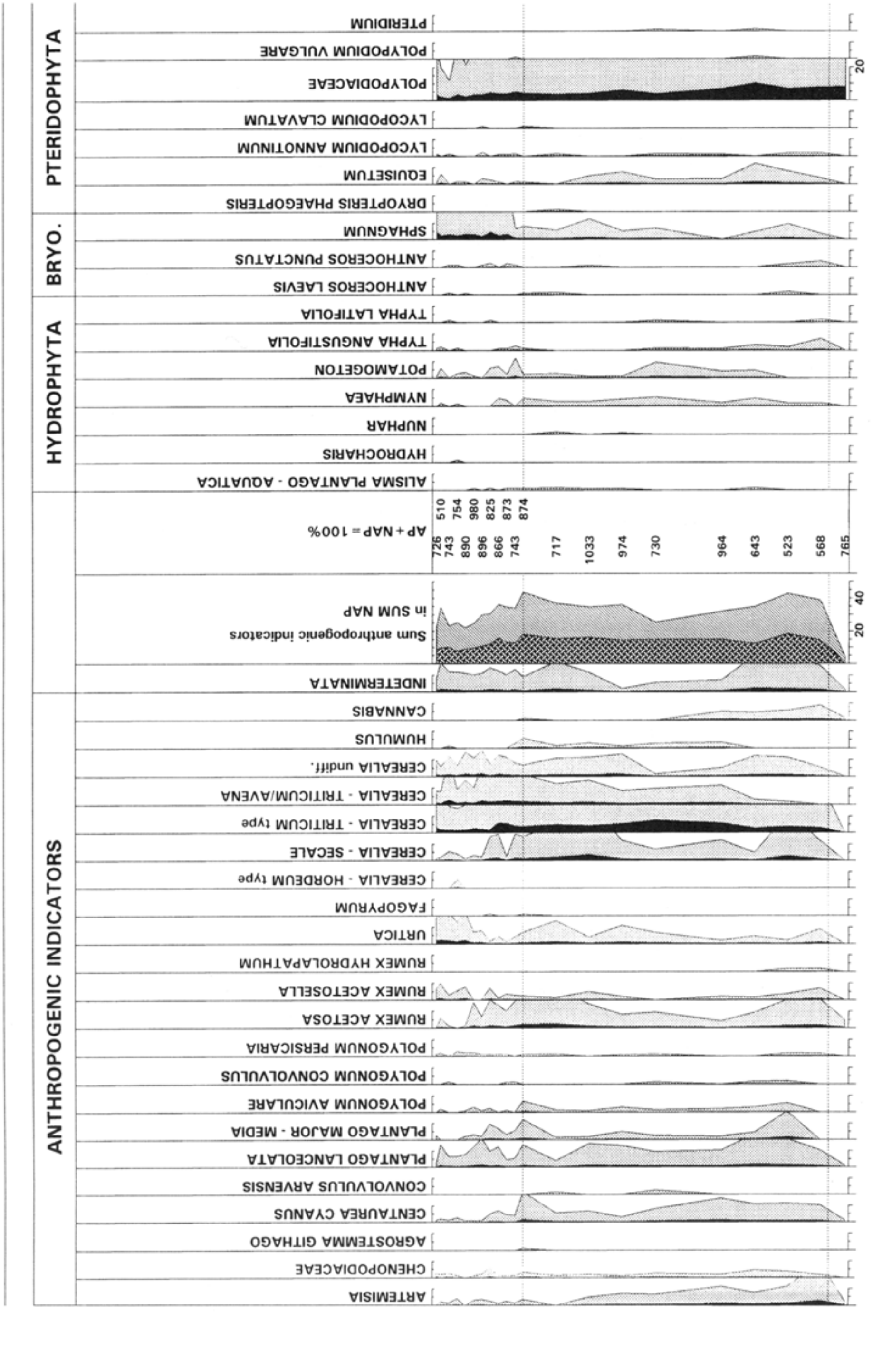

Fig. 2. Diagram showing pollen records and other microfossils (continued).

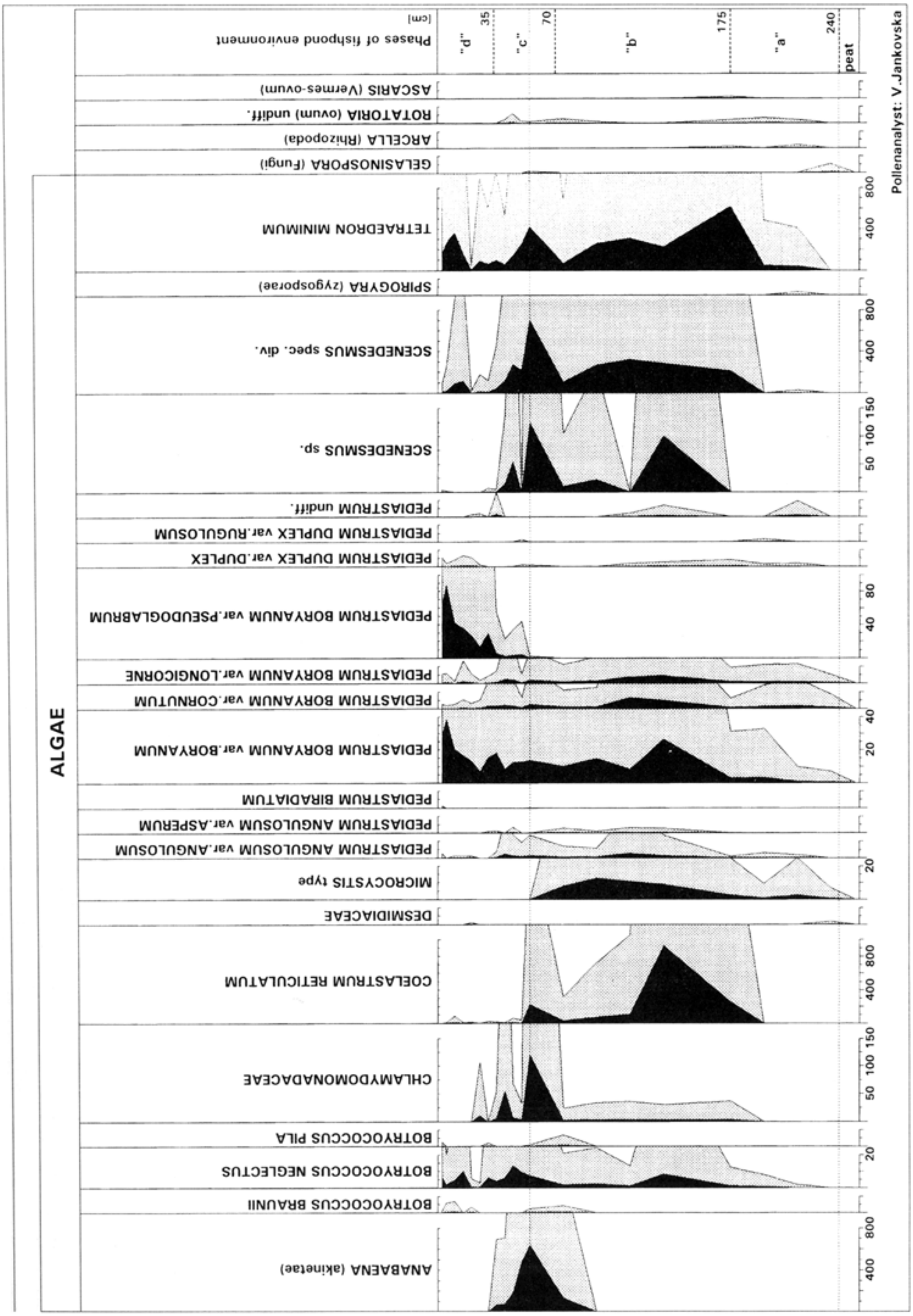

Fig. 2. Diagram showing pollen records and other microfossils (continued).

as pollen) is not out of the question, since this crop was an important part of the High Middle Ages agricultural system in Bohemia (according to macrofossil finds by ČULÍKOVÁ 1995 and OPRAVIL 1993). It is likely that also *Cannabis* was cultivated as a textile crop. Cereal weeds are present in the form of *Centaurea cyanus*, *Agrostemma githago*, *Rumex acetosella*, *Polygonum aviculare*, *P. persicaria*, *Scleranthus annuus*, *S. perennis*, and probably some *Chenopodiaceae*. Later, during the end of the SA2a, the cultivation of *Fagopyrum* is demonstrated by several pollen finds. The presence of the nearby town is reflected in the occurrence of pollen derived from ruderal plant communities growing on heavily disturbed manured soils of middens, courtyards and dumps: *Plantago lanceolata*, *P. major-P. media*, *Polygonum aviculare*, *Artemisia*, *Rumex acetosa* and *Chenopodiaceae*. It is likely, that the significant part of pollen finds of *Apiaceae*, *Asteraceae*, *Brassicaceae*, *Caryophyllaceae* and *Fabaceae* is also derived from species growing in ruderal habitats. According to our experience from palynological investigations of the High Medieval deposits from Bohemia, the pollen of *Echium* and *Trifolium* are also reliable indicators of anthropically disturbed sites. The same is true for the spores of *Anthoceros laevis* and *A. punctatus*. Both of these *Anthoceratophyta* started to spread in the High Middle Ages in connection with the emergence of the new agricultural methods.

Apart from the cereal fields, the existence of meadows and pastures is confirmed by the presence *Campanula*, *Filipendula*, *Linum catharticum*, *Polygonum bistorta*, *Thalictrum*, *Lychnis* type, *Potentilla* type, *Lysimachia*, *Poaceae* and *Cyperaceae* pollen. But the most conspicuous indicator of open areas used for grazing is *Juniperus*.

All of the above-mentioned finds clearly point to the High Middle Ages origin of the deepest fishpond sediments. Growing eutrophication in the vicinity can be inferred from the presence of *Sambucus nigra*, *Sambucus racemosa*, and *Chenopodiaceae*. If we compare the percentage of *Chenopodiaceae* with other sites of the same age and in a similar situation near the High Medieval towns (e.g., Praha, Nymburk, Most; JANKOVSKÁ 1991, 1995a, 1998), we find these relatively very low in the Vajgar sediments. *Chenopodiaceae* pollen indicate the presence of sites affected by eutrophication from accumulating animal dung and human faeces. One specimen of an oocyte originating from the presumably human intestinal parasite (*Ascaris* sp.) has been found in the sediments of the fishpond. Another parasite regularly found in the High Medieval anthropogenic sediments, *Trichuris trichiura*, was completely absent. We can speculate about the relatively clean character of the urban area of Jindřichův Hradec. However only direct investigations of medieval archaeological objects can confirm this hypothesis.

SA2b : 55–0 cm

The uppermost 0.5 m of the profile corresponds with this phase. Although changes in proportion between individual forest trees are only quantitative, some development is observed in comparison to the preceding phase. Approaching degradation of the original forests is indicated by the growing percentages of *Pinus* pollen and the decrease in *Abies* percentages. A slight increase in *Picea* and the occurrence of *Larix* pollen can indicate the period of active forest management, with artificial forest planting and the introduction of new tree species (*Larix*). The conspicuous fall in *Juniperus* percentages may indicate the destruction of original pastures and their change into cereal fields or their overgrowth by secondary forest (see increase in AP percentages). The last changes in forest composition and the decrease in grazing indicators together with a sudden fall in *Secale* and *Centaurea cyanus* pollen curves lead us to a biostratigraphical correlation of the young part of SA2b with the period of agriculture collectivization that took place in the second half of the 20th century. Unfortunately, the results of radiocarbon dating did not confirm this biostratigraphic chronology. A ^{14}C age of 370 ± 60 BP has been obtained from the depth of 25 cm. This discrepancy between the results of independent dating can be best ascribed to the effect of possible redeposition of the sediment.

A high diversity of herbaceous pollen in the sediments from the SA2b is the result of the landscape mosaic of fields, meadows and ruderal areas in the vicinity of the fishpond. Apart from the occurrence of *Lycopodium clavatum* spores indicating degraded forest soils, there are finds of *Lycopodium annotinum*, pointing to the permanence of relatively undisturbed forest biotopes with favourable habitats. The increase in *Sphagnum* spores may also indicate moist habitats in forests and meadows and their paludification. *Anthoceros laevis* and *A. punctatus* spores indicate the presence of moist and heavy soils in cereal fields, while *Sambucus nigra* points to the nitrogen enrichment of some habitats.

The development of the aquatic habitat

Thanks to the presence of pollen grains and the remains of different aquatic organisms, the history of an aquatic ecosystem can be studied by the means of palaeoecological methods. Although the redeposition of fishpond sediments, their intensive bioturbation and human disturbance can be assumed, the result of palaeoalgological analyses surprisingly revealed a relatively well-stratified and undisturbed record. This is probably due to the unusually high sediment accumulation rate.

The development of an aquatic ecosystem can be best traced by indicator values of freshwater algae. These organisms are usually ignored by palynologists, although their importance in palaeoecological reconstructions of freshwater habitats has been already emphasized by several authors (ALHONEN & RISTILUOMA 1973, BOTTEMA 1974, FJERDINGSTAD 1954, HAAS 1994, GUY-OHLSON 1992, JANKOVSKÁ & KOMÁREK 1982, 2000, JANSSEN 1986, KOMÁREK & JANKOVSKÁ 2001, NIELSEN & SØRENSEN 1992, SEBESTYÉN 1969, VAN GEEL et al. 1994, etc.). Although pollen grains of several aquatic macrophytes have been found in the sediments of the Vajgar fishpond, their value as indicators of past conditions is limited. The finds of subfossil algae much better reflect the past environment. According to these records, four principal phases of fishpond development can be distinguished and interpreted in terms of changing trophic conditions:

Phase "a" (240–175 cm)

The first sediments that were formed under waterlogged conditions in the newly constructed fishpond contain sporadic remains of algae and the pollen of water-lily (*Nymphaea*). At a depth of 215 cm, strong increase in *Tetraedron minimum*, *Scenedesmus* and *Pediastrum* species is observed. *Nymphaea* and *Potamogeton* grew at the water surface, and *Typha latifolia*, *T. angustifolia*, and *Alisma plantago-aquatica* grew in the littoral.

Equisetum limosum probably occurred in the littoral. We can infer a mesotrophic water status during this phase.

Phase "b" (175–70 cm)

During the transition from phase "a" to phase "b", a significant change in algal species composition took place. 5945 cells of *Tetraedron minimum*, 2061 coenobia of *Scenedesmus* sp. div. and 2460 coenobia of *Coelastrum reticulatum* were found "per slide". The last species occurred for the first time in this level. The number of *Botryococcus neglectus* colonies, *Pediastrum* species, and algae identified as *Chlamydomonadaceae* and *Microcystis* type also increased. The occurrence of *Coelastrum reticulatum* culminated at 135 cm (6765 coenobia; it is 900% of the total sum AP + (NAP - hydrophyta) = 100%). Also *Pediastrum boryanum* var. *longicorne*, *Pediastrum boryanum* var. *cornutum*, *Pediastrum angulosum* var. *angulosum* and *Pediastrum angulosum* var. *asperum* reached their maxima. Apart from these, *Pediastrum boryanum* var. *boryanum*, *Scenedesmus* sp.div. and *Tetraedron minimum* were found at the same level.

From the group of water macrophytes, *Nymphaea* and *Potamogeton* grew on the water surface, *Typha latifolia*, *T. angustifolia*, *Alisma plantago-aquatica*, and *Peplis portula* occurred in the littoral.

The abrupt change in the composition and quantity of algal flora in the fishpond at the boundary between phases "a" and "b" can be ascribed to eutrophication (and maybe to the warming) of the water. *Coelastrum reticulatum*, for example, has been found in southern Bohemia only in sediments of the former lake Švarcenberk (JANKOVSKÁ 1980, POKORNÝ & JANKOVSKÁ 2000), which were dated to the warm Boreal period. In Swiss lakes (research of Prof. Dr. A.F. Lotter, University of Bern), this species is limited to warmer and nutrient-rich waters (JANKOVSKÁ & KOMÁREK 2000).

Phase "c" (70–35 cm)

The occurrence of *Anabaena* akinetes is characteristic for this phase. Two distinctive types of akinetes have been observed, and one has been determined by Prof. J. Komárek as the *Anabaena berezowski* type. The abundance of these blue-green algae culminated between 50 and 55 cm together with *Scenedesmus* (some colonies of *S. ellipticus* were also found), *Tetraedron minimum*, *Coelastrum reticulatum*, and algal types determined as *Chlamydomonadaceae*. The composition of algal species indicate an increasing trophic level. On the other hand, the finds of *Botryococcus pila* indicate the inflow of acid waters from peat (KOMÁREK & MARVAN 1992) in the upper parts of the catchment and even in the littoral zone of the Vajgar pond.

No significant change occurred in water macrophytes in comparison to the underlying phase, except the *Peplis portula* has its maximum here.

Phase "d" (35–2 cm)

This last phase is characterized by the dominance of *Pediastrum boryanum* var. *pseudoglabrum* and the lack of *Anabaena* akinetes. A slight increase in *Pediastrum boryanum* var. *boryanum* and *Pediastrum duplex* var. *duplex* is also observed. Aquatic

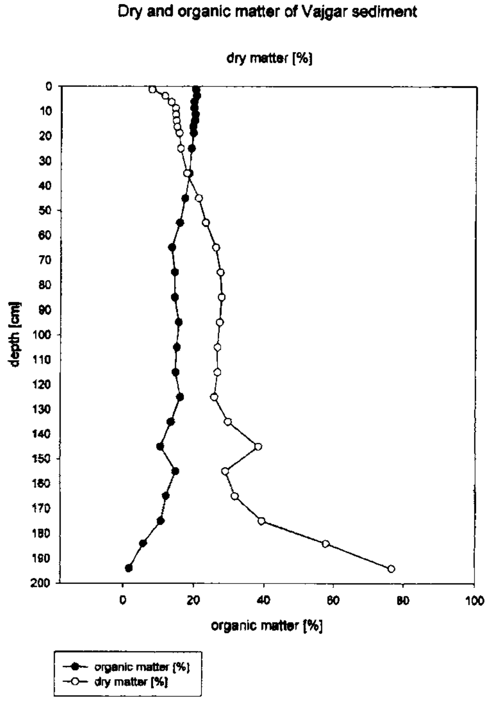

Fig. 3. Dry-matter and organic-matter content in the sediment profile of the Vajgar fishpond (October 1990).

macrophytes *Nymphaea* and *Potamogeton* were again recorded, and one find of *Hydrocharis* pollen was noted.

Phase "d" of the development of the aquatic habitat is partly synchronous with the younger part of the SA2b of regional vegetation development. This demonstrates that the effect of anthropogenic changes in the catchment (e.g., changes in agrotechnical practices, changes in waste treatment) had a profound influence also on the water habitat of the fishpond ecosystem.

Sediment composition and its interpretation

The dry-matter content in the sediment's vertical profile (Fig. 3) shows a range between 10% at the surface and 25% at about 1 m and almost 80% at a two-meters depth. The organic-matter content (expressed in % of dry matter) in the vertical profile of sediment (Fig. 3) ranges between 20% at the sediment surface to 14% at an about 1 m depth, and the organic-matter content decreases in the deeper layers.

The vertical profiles of heavy metals and nutrient concentrations in dry mass of sediment are shown in Fig. 4. The concentrations of heavy metals do not exceed limits for composts given by the Ministry of Environment of the Czech Republic. An increase in concentrations of different heavy metals in different layers of the vertical profile can be explained only by particular activities in the catchment: the concentration increase of Hg close to the sediment surface corresponds to the period when fungicides containing Hg (Agronal) were used to grain seeds. The increase of Cr at the depth of 75 cm corresponds to the time when Cr was used in the factory at the lower part of the catchment and waste water was not treated. The sudden increase in Pb between 150 cm and 100 cm is too deep to be explained by an increase in the use of Pb-containing fuel; another technological source like plumbing, or dyes was responsible. Sulphur comes from the local and remote burning of high-sulphur coal. Recently the coal has been replaced by oil, gas, and electrical heaters, which could result in a decrease of sulphur deposition in the upper layer of sediment. An increase of phosphorus and calcium concentrations in the upper 50 cm layer corresponds to the high eutrophy of the water and to the intense fertilizing and liming of both fields and fishponds in the catchment. The increase

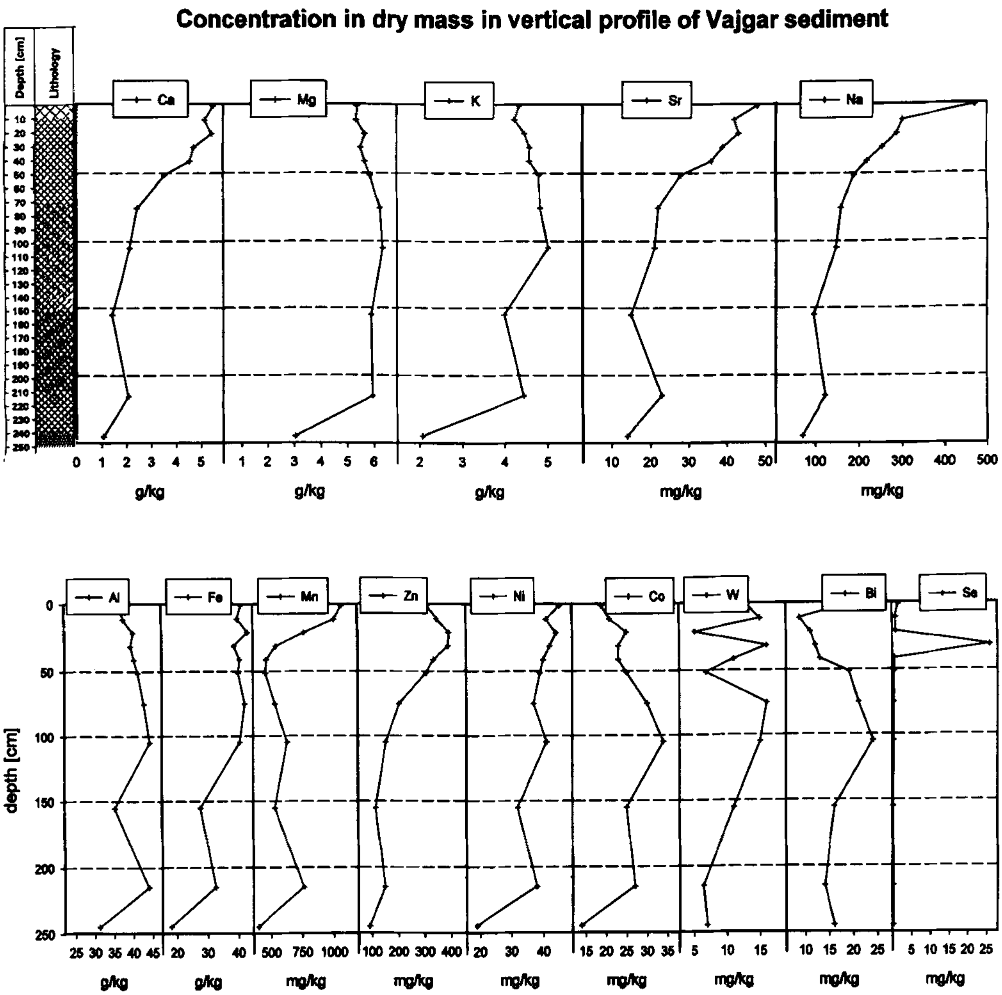

Fig. 4. Vertical profile of concentrations of selected elements in dry mass sediment of the Vajgar fishpond (October 1990).

of Na concentrations in the upper 75 cm can be explained by salting of roads in winter and by point discharge of treated wastes from a slaughter-house at Studená. Because Sr occurs together with Ca and the shapes of the concentrations curves in vertical profile are very similar, the recent increase of Sr can be explained by high input of Ca rather than by the sudden deposition of Sr after the Chernobyl nuclear accident (in 1986).

The concentration of manganese in the region is relatively high and the recent accumulation of Mn in sediment results perhaps from leaching caused by the acidification of soils and precipitation in sediment, which is alkaline due to the lime presence and anaerobic conditions.

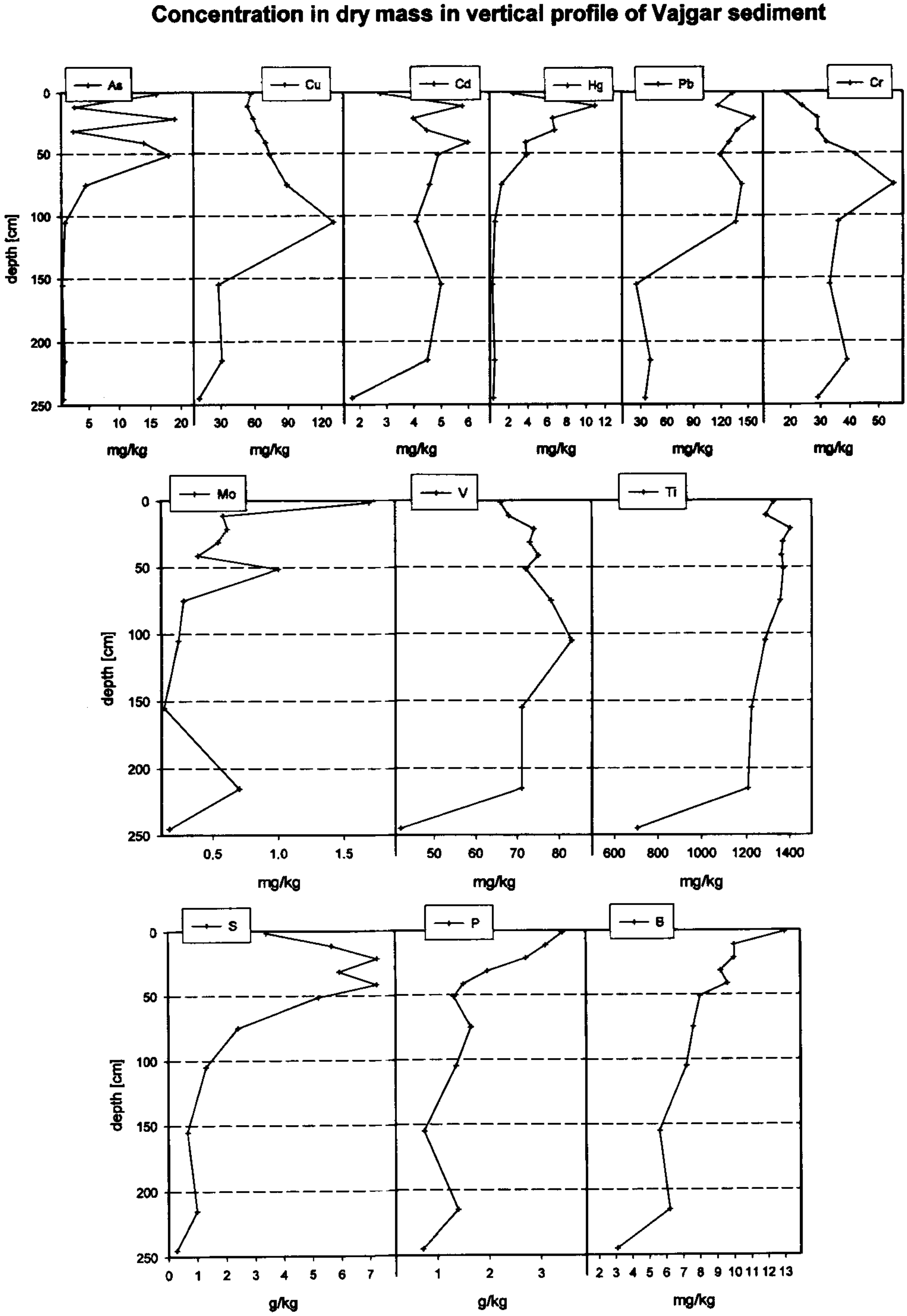

Fig. 4. continued.

In the next upper fishpond (Ratmírovský 78 ha) concentrations of heavy metals (Cu, Zn, Pb, Cd, Ni) are highest in the upper layers of sediment and decrease down from a ca. 50 cm sediment depth (KROUPA 1994). The increase of concentrations of these metals in the upper layers results from anthropogenic activity in the catchment, similar to the trends in concentrations of heavy metals in sediments of other fishponds in the catchment. In the fishponds located in the upper part of the catchment in the highland (ca. 700 m altitude), sediment concentrations of Mn, Cr and Pb are lower in the Vajgar fishpond, which can be explained by the lower organic-matter content (10%) and low alkalinity of water.

The relatively high concentration of Fe in the sediment of Vajgar (about 30 g/kg dry mass) indicates that Fe plays an important role in the binding of phosphate.

The release of total phosphorus from the upper black and lower grey layers of sediment both under aerobic and anaerobic conditions showed a release of P by the black sediment layer under anaerobic conditions and an ability of the deeper grey layer of sediment to bind phosphorus both in aerobic and anaerobic conditions. Seasonal courses of phosphorus concentrations before sediment removal (1991) and after sediment removal (1993, 1994, 1995) in the inlet and outlet of the Vajgar fishponds show an increase of phosphorous binding capacity after sediment removal. Concentrations of heavy metals and base cations were also measured in the inflow and outflow of the Vajgar fishpond in order to evaluate the effect of sediment removal on their budget (POKORNÝ & HAUSER 2002).

CONCLUSIONS

High accumulation rates together with low sediment mixing and bioturbation has enabled the reconstruction of the history of a fishpond ecosystem during the last thousand years. It was found that the sediment from an artificial dam – a fishpond – can provide valuable palaeoecological information for a historical time period unless it should have been damaged by dredging or similar human activity. A comparison of archival written documents with the results of the pollen analysis could bring an even more accurate picture of the environment of human society from the foundation of the fishpond to the present. The fishpond's pollen spectrum was found to be very rich and thus pollen analyses from fishpond sediments can represent an ideal transition between the results of analyses from natural peat bog sediments and the entirely anthropogenic deposits from cesspits, wells and latrines of the Middle Ages. The development of the aquatic habitat and the surrounding landscape was traced in detail. Anthropogenic influences were among the most important factors that altered the development of the ecosystem from its beginnings. Human impact especially accelerated during the 20th century. It had a profound influence on the surrounding landscape and on the fishpond itself, either directly or indirectly. As a consequence, black, anoxic sediment started to accumulate in the fishpond, fixing large amounts of nutrients and toxic elements and serving as an uncontrolled source of nutrients.

The eutrophication of the aquatic system, as indicated by the algal species composition in the 50 cm sediment surface layer, corresponds with the indicators of high anthropogenic activity found in the pollen spectrum in the same sediment layer. The determination of the findings of coccal green algae made possible a more detailed description of the aquatic environment for individual time periods and for the development phases of the fishpond.

Preliminary results of diatom analyses (MARVAN & ELSTER, in prep.) show a corresponding value as indicator species to that of coccal green algae.

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