

Reservoir sediments – a witness of mining and industrial development (Malter Reservoir, eastern Erzgebirge, Germany)

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Abstract. The Malter Reservoir is situated about 30 km south of Dresden (eastern Germany) in a historical mining area of the eastern Erzgebirge. It was built in 1913 for the protection from floodwaters, droughts and for generating electricity. The river Rote Weißeritz is the main source of clastic input into the lake. Geochemical and sedimentological data of gravity- and piston-cores, recovered from the deepest point of the lake, document the environmental history of the drainage area since 1963. ^{137}Cs dating gives an average sedimentation rate of ~ 2.9 cm/year. Within the whole core, heavy metals are strongly enriched (parentheses refer to enrichment factors as compared with average shale): cadmium (290), silver (140), bismuth (90), antimony (25), lead (21), zinc (14), tin (13), uranium (9), tungsten (9), molybdenum (5), copper (4), thallium (3) and chromium (2). Enrichments are detectable for the whole registered time-period of 81 years. Peaks of up to 27 mg/kg silver, 37 mg/kg bismuth, 91 mg/kg cadmium, 410 mg/kg chromium, 240 mg/kg copper, 20 mg/kg molybdenum, 14000 mg/kg

phosphorus, 740 mg/kg lead, 6.5 mg/kg antimony, 74 mg/kg tin, 52 mg/kg tungsten and 1900 mg/kg zinc reflect local events caused by human impact. Inputs from different pollution sources at different times are represented by highly variable elemental concentrations and ratios within the core. High pH values within the water and the sediment column, the large adsorption capacity of the fine-grained C_{org} -rich sediment, and the presence of low Eh-values and sulphide ions in the sediment prevent the remobilisation of the toxic elements. Erosion of these contaminated sediments during floods, channel flows or resuspension during removal of the sediments may lead to a downstream transfer of pollutants. Contents of P and C_{org} , as well as diatom abundance, indicate a change from oligotrophic to eutrophic conditions in the lake during ~ 1940 – 1950 . This was mainly caused by high agricultural activity in the drainage area. Reduced contents of Cu, Zn, Cd and Cr since the reunification of East and West Germany are obviously caused by increasing environmental protection measures, such as wastewater purification and especially the closing of contaminating industries.

Key words East Germany · Erzgebirge · Eutrophication · Heavy metals · Lake sediments · Mining · Pollution development

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Introduction

The area between the top of the eastern Erzgebirge and the Malter Reservoir is part of one of the oldest mining areas in Europe. The 104.6-km² drainage area of the Malter Reservoir (see Fig. 1) is situated ~ 30 km south of Dresden. The area is drained by the Rote Weißeritz, which flows through the reservoir. Mining activities started in the mid-13th century (Quellmalz 1966) and lasted until 1992, when the last ore mine was closed in Schmiedeberg. Mainly tin, but also copper, tungsten, molybdenum, bismuth and silver, were mined and processed. At the beginning of this century, human impact on

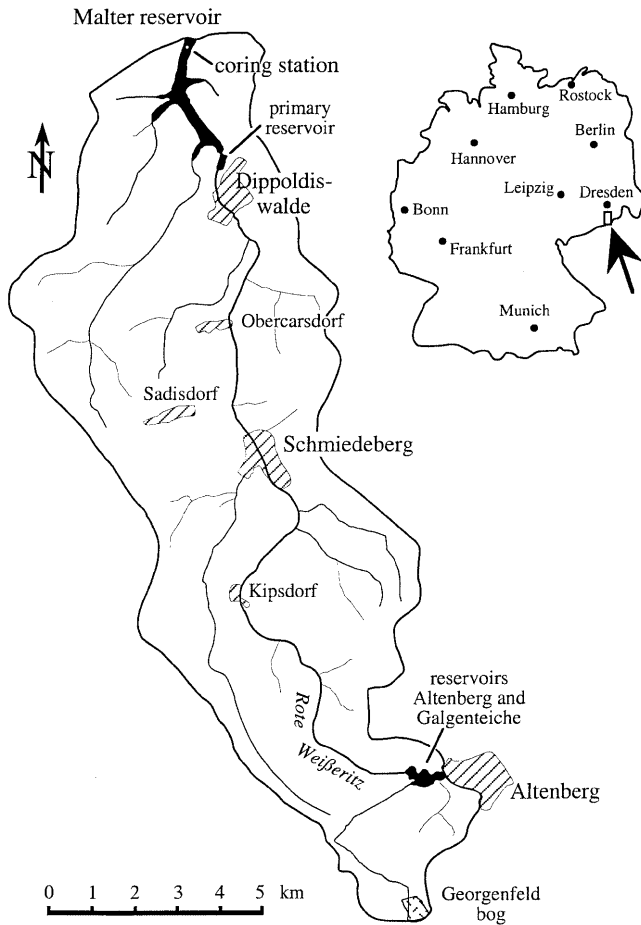
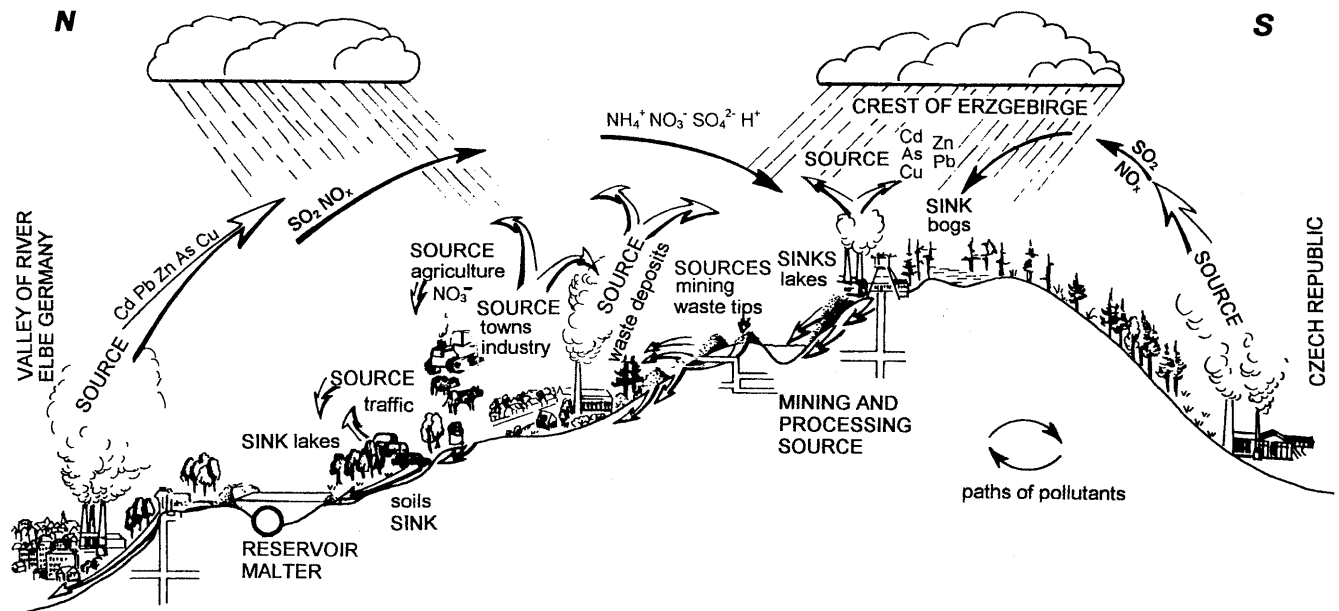


Fig. 1

Drainage area of the Malter Reservoir. (Compiled by G. Lauterbach)

Fig. 2

Sources and sinks of elements in the eastern Erzgebirge



the ecosystem was augmented by increasing amounts of industrial and mining waste, a lack of sewage purification plants or their inadequate function, the growth of agriculture (especially the keeping of cattle), and wet and dry deposition of air pollutants (acids, heavy metals). Figure 2 depicts schematically the sources and sinks of elements and their cycles in the area. Preliminary results of a supplementary study in the ecosystem of eastern Erzgebirge are summarised by Matschullat and others (1994), the composition of recent atmospheric input in the eastern Erzgebirge is described by Bozau (1995) and Matschullat and Bozau (1996). Many of the metals that were transported to the catchment area by winds could be mobilised as a consequence of the acidification of soils and rivers, especially in the higher regions of the Erzgebirge. The sediments of the Malter Reservoir reflect the contamination of the drainage area since the building of a dam in 1913. The uppermost sediments give information about the changing environmental load since the reunification of Germany in 1989.

Methodology

In April 1994, seven cores were recovered from the deepest part of the Malter Reservoir near the dam, far from the mouth of the river Rote Weißeritz and still far enough from the deep-water outlet of the dam (Fig. 1). Three cores were recovered by a gravity corer (Meischner and Rumohr 1974) to acquire an undisturbed sediment surface. Four additional cores were recovered by a piston corer (modified by R. Niederreiter, after Petterson and Kullenberg 1940), and comprised the stratigraphic sequence from 1913 to 1994. The length of the cores differed between 120 and 150 cm because of variations in relief at the bottom of the former valley. Three cores were used for biological investigations (Lessmann and

others 1996) and another three cores for geochemical analysis and ^{137}Cs -dating. The distribution of elements and of the Cs-activity within the cores are discussed in this paper.

The piston core for ^{137}Cs -dating (96 cm length) was sampled in 2-cm intervals. The samples were dried at 105 °C; their specific weight was measured with a Quantachrome helium-pentapycnometer. The activity of the ^{137}Cs isotope was analysed using a Seiko EG&G 7800 multi-channel analyser coupled with an Ortec GEM-30185 Ge-detector at the gamma-ray peak of 662 keV.

The gravity core for geochemical analysis (89 cm length) was sampled in 1-cm intervals within the first 10 cm, and then in 2-cm intervals. The piston core (122 cm length) was sampled from 64 cm depth downwards at 2-cm intervals, overlapping 25 cm with the gravity core. The samples were dried for 24 h, using a Christ Alpha 1-5 freeze dryer, and milled with an agate mortar. Sulphur and total carbon were analysed by an Eltra Metalyt CS 1000 RF apparatus. Inorganic carbon was measured in the same way after removing the organic carbon at 540 °C by oxidation. For main and trace element analysis, the dried and milled samples were dissolved using a total digestion apparatus (Ruppert 1987; PicoTrace 1997): A series of 32 solid samples was simultaneously digested in polytetrafluoroethylene (PTFE) vessels using a mixture of ultra-pure fluoric acid (40%), perchloric acid (70%) and nitric acid (65%) at elevated pressure and temperature (170 °C, all acids cleaned by sub-boiling distillation). During the evaporation step, the acid fumes were removed directly from the samples by means of a clean airflow, which circulates through an evaporation plate. The residues of the evaporation were dissolved in nitric acid and hydrochloric acid and water at 150 °C. After cooling, the clear digestion solutions were transferred into a volumetric flask (dilution factor: 1:2000). The homogenised solutions were stored in polyethylene bottles. During the whole digestion procedure, there was only a minimal risk of contamination, because ultraclean, sub-boiling distilled acids were used, and because the system was closed during the pressure phase and sheltered during evaporation. Analyses of the elements Al, Ti, Fe, Mn, Mg, Ca, Na, K, P and Ba were performed by inductively coupled plasma emission spectrometry (ICP-OES; ARL Maxim I). The elements Cu, Zn, Pb, Ba, Sn, U, Co, Mo, W, Bi, Be, Yb, La, Ce, Nd, Cd, Cr, Ag, Sb and Tl were analysed by inductively coupled plasma mass spectrometry (ICP-MS; Fisons Instruments PQ2+). In addition, radiographic pictures were taken of the piston core using an Eresco MF1 X-ray apparatus.

Study site

The Erzgebirge and the Fichtelgebirge form the large SW-NE striking Saxothuringian anticline (Franke 1989). The drainage area of the Malter Reservoir lies within the Altenberger Scholle (Pälchen and Ossenkopf 1967). The

borders of the catchment area are the Flaje-Reichstädt and the Teplice-Ulberndorf eruptive faults. The oldest rocks in the study area are Proterozoic paragneisses, meta-greywackes and meta-rhyolites, which form the crystalline basement. These rocks mainly occur in the lower part of the drainage area (Fig. 3). The grey biotite gneisses contain easily weathered lenticular amphibolites and small amounts of Cambrian mica schists and phyllites (Pälchen and others 1989). Non-metamorphic rocks consist of a few Westphalian sediments, which are mainly in the drainage area of the Pöbelbach brook (south-west of Schmiedeberg, see Fig. 1). Of much more importance are the acidic magmatites, such as the Teplice Rhyolite (Westphalian C/D) and the granites of Schellerhau, Altenberg and Sadisdorf (Autun). The latter contains Sn-W-mineralisation that is especially enriched in F, Li, Zn, Rb, Cs and As (Pietzsch 1963, Pälchen and others 1982). Within the drainage area of the Malter Reservoir mineralisations occur of cassiterite-wolframite (Sadisdorf), quartz-hematite (Schellerhau), barite-quartz-hematite (Niederpöbel and Reichstädt) and quartz-arsenopyrite-pyrite-sphalerite-galenite (Dippoldiswalde, Schmiedeberg and Niederpöbel; Pälchen and others 1989). Thus, enrichments of Sn, W, Cu, Pb, Zn, Ba and Cd are to be expected in river waters and sediments. Figure 3 shows the course of the Rote Weißeritz, the river pH, the height, and the main rock types in the study area. The height difference from the crest of the Erzgebirge to the Malter Reservoir is 540 m. The pH of the Rote Weißeritz rises from ~4 at the reservoirs 'Galgenteiche' and 'Speicher Altenberg' (see Fig. 1) to 6.6-7 at the inflow to the Malter Reservoir. The length of the Rote Weißeritz is ~20 km. Soils in the drainage area are dystric cambisols (brown podsollic soils), podsols and gleyic luvisols (pseudogley soil) with enrichments in Sn, Bi, Mo, Pb, Ag and Ba, depending on the source rocks (Pälchen and others 1991).

The Malter Reservoir

The Malter Reservoir (330 m above sea level) has a storage capacity of up to 8.78 million m³ and was built in 1913 for protection against floods, droughts and for generating electricity. However, in times of drought, the Malter Reservoir also has been used as a drinking-water supply (Sieber 1992). Seventy-seven percent of the overall water input into the reservoir is delivered by the Rote Weißeritz. A small artificial basin (a primary reservoir) between the river Rote Weißeritz and the Malter Reservoir catches the coarser particles of the bed load such as the more stable and heavy minerals of quartz and cassiterite. However, in times of drought and dredging of sediments from the primary reservoir (for example in 1974-1975), coarser material reached the profundal of the Malter Reservoir. The present trophic state of the lake is mesotrophic to eutrophic. During August to October, anoxic conditions in the hypolimnion develop, whereas in the epilimnion saturation or supersaturation of oxygen

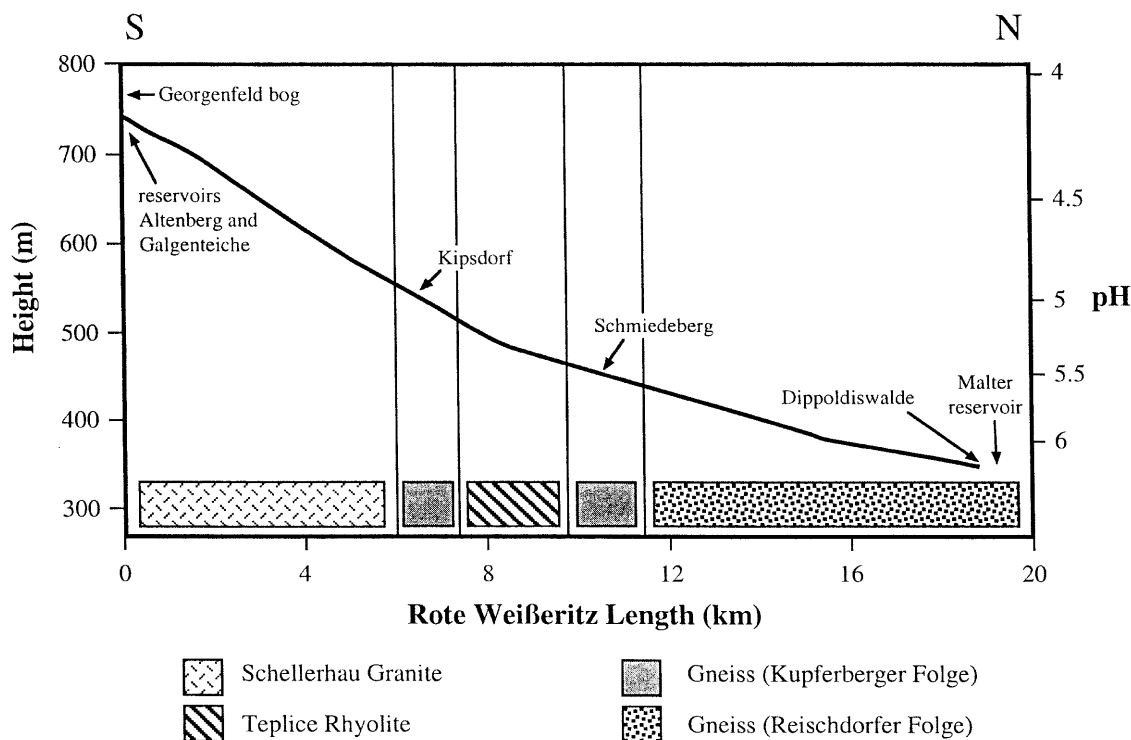


Fig. 3

Length (km) of the river Rote Weißeritz (rock types and pH gradient depending on height). (Modified after Matschullat and others 1994)

exists. The pH value in the water column ranges from 6.4 (after snowmelt in the spring) to 9.8 because of photosynthesis (during the summer). In the uppermost sediments (0–40 cm depth) pH is ~6.8 (Lessmann and others 1996). The electrical conductivity ranges from 280 to 350 $\mu\text{S}/\text{cm}$ in the water column, the Eh value in the upper sediments (0–40 cm depth) varies ~ +70 mV. Most of the profundal sediments consists of fine silt and clay (Schubert 1993). Contrary to most natural lakes, the northernmost part of the Malter Reservoir (see Fig. 1) cannot be seen as a final sink for all sediments. For example, sediments from the area near the dam can get lost through channel flows at the bottom, especially during episodic deep water discharge. Most parts of the lake bottom act as a sink for metals and nutrients that originate from the catchment area.

Element sources

The geological background of the study area (granites, rhyolites, gneisses) is generally poor in heavy metals, but contains numerous ore veins. Therefore, high natural input of heavy metals and their compounds are to be expected. Low pH values of rain (Bozau 1995) favour chemical weathering and mobilisation of elements. Acid-buf-

fering carbonates are lacking in the drainage area. Waters and soils are acidified especially within the higher regions because of acid emissions that originate from industrial processes and power plants that use brown coal in Germany and the Czech Republic (Matschullat and others 1994). During spring snowmelts and times of high precipitation, acidification of the rivers increases. Matschullat and others (1994) describe a general pH gradient of the Rote Weißeritz during spring 1992 from pH 3.8 at 800 m height to a continual increase to pH 6.6 in the Malter Reservoir (Fig. 3). However, neutralisation of the river water does not always happen before reaching the lake as the diatom studies in the lake water show (Lessmann and others 1996). The Georgenfelder Hochmoor (a bog on the top of the Erzgebirge, 870 m above sea level), which drains into the Rote Weißeritz, is a sink for atmospheric input. Organic complexing substances from the bog waters may additionally lead to a higher solubility of heavy metals (Pekdeger 1977).

Besides acidic precipitation, there are several sources of anthropogenic input of elements into the ecosystem by contaminated river waters and sediments and by atmospheric input, e.g. fly ashes (Brumsack and Heinrichs 1984), aerosols from non-ferrous metal industry etc. Because of strong forest damage by acid rain only 30% of the catchment area is still forested. However, because of the high sedimentation rate, the main part of the pollutants in the lake sediment is not delivered by direct atmospheric input but by deposition of contaminated waters, bed load, and suspended particles of the rivers reaching the lake.

Enrichments of Pb, Cd, Zn, Ni, Cu and Cr in communal sewage are high compared with the contents in natural

ivers (Knöpfel 1994). From mine waste dumps, heavy metals can be mobilised by the oxidation of sulphides followed by a decrease in pH. Local industries within the drainage area are known as possible sources of heavy metals. At Schmiedeberg, a foundry that closed in 1990, possibly emitted Fe, Mn, Ni and Co (Ossenkopf 1990). Furthermore, during the existence of the German Democratic Republic, there were paper-processing industries, a laundry and a tannery in Dippoldiswalde, as well as dye works. During the last decades, intensive agriculture has been carried out, primarily the raising of cattle in the northern part of the study area. This has decreased since the opening of the boarder between East and West Germany in 1989. Over-fertilisation caused by enrichment of nitrates and phosphates etc. in sewage waters has led to high primary production and, therefore, increasing eutrophication in the Malter Reservoir (see Section: Organic load and eutrophication).

^{137}Cs dating

Figure 4 shows ^{137}Cs activity (Bq/kg) with sediment depth. The Chernobyl accident of 1986 is clearly visible at 22 cm depth. Thus, a mean sedimentation rate of ~ 2.9 cm annually between 1986 and 1994 can be calculated, as well as for the time between 1963 and 1986. The peak of 1963 (cessation of hydrogen bomb tests), which varies in strength depending on the area (Clark and Smith 1988), is much smaller, but still discernible at

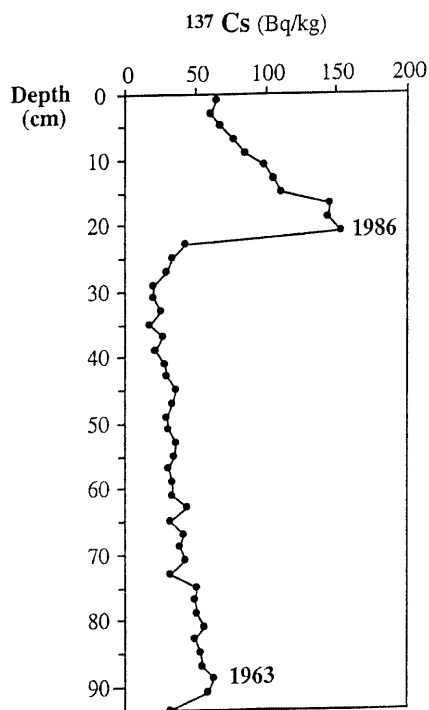


Fig. 4

Plot of ^{137}Cs activities against depth in the sediment core

88 cm depth. Assuming an overall sediment thickness of not greater than 156 cm depth (longest piston core), a mean sedimentation rate of only 1.4 cm/year can be estimated for the years between 1913 and 1963. This could be mainly explained by a smaller input and compaction of sediment, and by a smaller input of autochthonous organic matter at the early stage of sedimentation. However, radiographic pictures of the sediment core show a disturbed layer at 95-cm depth, which is probably caused by loss of sediment during a deep-water discharge out of the reservoir. This possible hiatus at 95-cm sediment depth makes time correlation difficult before 1963. A discharge event may also explain the small activity of ^{137}Cs in the years between 1953 and 1963. Parts of the sediment representing these years probably have been eroded.

Sedimentary history and metal load of the Malter Reservoir

No macroscopic changes could be found in the sediment column except for slightly varying colours that indicate oxidic (dark brownish) and anoxic (blackish) layers. Almost the whole sedimentary record of the profundal is dominated by silt and clay. The material tends to be slightly coarser only in deeper sediments (from 104 cm downwards). However, higher input of coarser material in times of floods are not macroscopically visible. Geochemical data of all analysed elements in the overlapping part of gravity and piston cores show that element contents of both cores fit very well if we shift the piston core 18 cm downwards. Thus, a sedimentological record of 140 cm can be constructed (Figs. 6, 8). Considering the hiatus at 95-cm depth, as indicated by radiographic pictures, a good correlation can be obtained for sediment depth, at least for the years between 1963 and 1994. Because the sediments are strongly reduced during the whole time of deposition, bioturbation would affect only the uppermost few centimetres of the sediment column, which corresponds to not more than 1–2 years. Resuspension of sediments from the primary reservoir (see Fig. 1) can be excluded because of its distance (>2 km) and the low flow velocity within the Malter Reservoir. The concentrations of Al, Ti, Fe, Mn, Mg, Ca, Na and K versus core depth are plotted in Fig. 5. Al, Ti, Fe, Mg, Na and K show only small variations and behave quite conservatively through time. Variations of Al and Mg in the upper parts of the core may be caused by grain-size effects. Slightly higher contents of Ti and Na in the bottom sediments can eventually be explained by the coarser material enriched in Ti minerals and albite. These sediments can be derived from the former river at the base of the reservoir. The increase in Ca from bottom to top, with a slight decrease in the upper sediment, positively correlates with P, C_{org} and S (see Fig. 8). Calcium is probably bound in the form of Ca-phosphates, which, for example are used in detergents and fertilisers. The input of P into

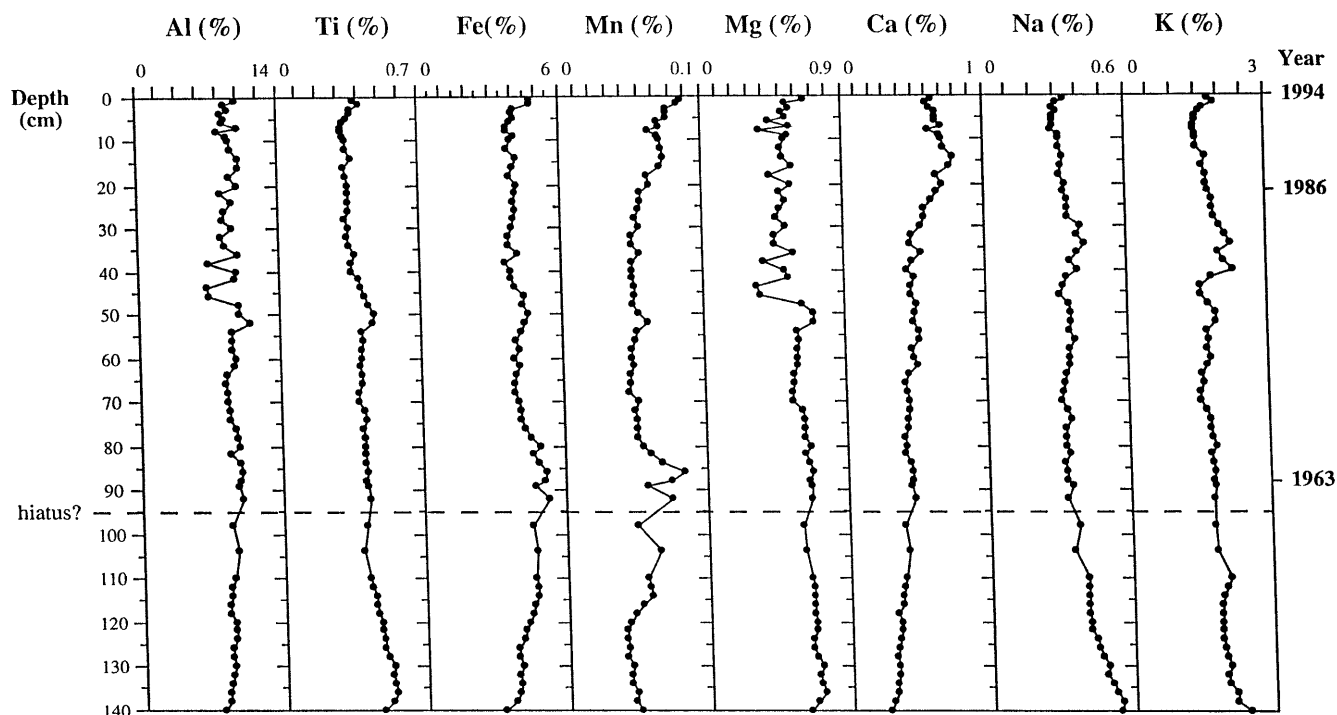


Fig. 5

Plot of main element contents against depth (concentrations in wt%)

lake waters leads to increasing organic productivity in the water column and causes eutrophication of the lake. Because of limited oxygen supply, the produced organic material cannot be completely oxidised in the water and is preserved within the anoxic sediment causing elevated contents of C_{org} and S. This trend was already visible immediately after construction of the dam (Figs. 5 and 8). The increasing Mn concentration in the upper sediment of the core is caused by reduction of deposited Mn-oxide/hydroxides in favour of soluble Mn^{2+} , its diffusion to the sediment-water interface, and its precipitation as Mn-oxide/hydroxide if free oxygen is present (Kummert and Stumm 1989). The Mn-peak in 80- to 90-cm depth (~1962–1968) cannot be explained by oxidation processes because the core sediments are strongly reduced. A number of trace elements are strongly enriched in the reservoir sediments as compared with the mean element contents of the upper continental crust and an average shale (after Taylor and McLennan 1985; Wedepohl 1991, 1995; see Table 1, Fig. 7): Cd (enrichment factor compared with average shale: 290), Ag (140), Bi (90), Sb (25), Pb (21), Zn (14), Sn (13), U (9), W (9), Mo (5), Cu (4), Tl (3) and Cr (2). Schubert (1993) analysed the uppermost sediment column of the whole reservoir and found the following enrichment factors: Cd (200), As (100), Sn (70), Zn (23) and Pb (20). This contamination is serious. However, high pH-values within the water and the sediment column, the large adsorption capacity of the fine-grained

C_{org} -rich sediment, and the reducing sulphidic environment within the sediments (formation of insoluble sulphide phases etc.), prevent the remobilisation of toxic elements. On the other hand, erosion of these contaminated sediments during floods may cause problems for waters and sediments downstream of the dam.

The fluctuations of some trace elements within the sediment core are plotted in Fig. 6. An approach to correlate concentration trends with anthropogenic activities in the drainage area is shown in Fig. 9. This scheme is far from complete because detailed official information is lacking. Maxima of up to 27 mg/kg Ag, 37 mg/kg Bi, 91 mg/kg Cd, 410 mg/kg Cr, 240 mg/kg Cu, 20 mg/kg Mo, 14,000 mg/kg P, 740 mg/kg Pb, 6.5 mg/kg Sb, 74 mg/kg Sn, 52 mg/kg W and 1900 mg/kg Zn were analysed in different depths of the core (see Table. 1). Nearly all the elements plotted in Fig. 6 are strongly enriched throughout the whole core, i.e. since 1913.

The Ba graph seems to reflect mining activities that were probably interrupted during World War II (approximately the depth between 120 and 110 cm). The Ba content at the bottom of the sediment core indicates the natural geological background, which was eventually elevated because of input of particles from fluorite-barite mineralisations from the drainage area. Decreases in Ba values from 98 cm upwards indicate the closing of ore mines (for example, Schellerhau in 1954 corresponded to ~100 cm depth).

The distribution of Sn, whose sole source is cassiterite, probably corresponds to variations in grain size. There is no technogenic Sn contribution observable. The Sn peak, as well as the Ba peak at about 5-cm depth (~1992, Fig. 6), indicate a higher input of coarser material. The building of the reservoir 'Speicher Altenberg' (see Fig. 1),

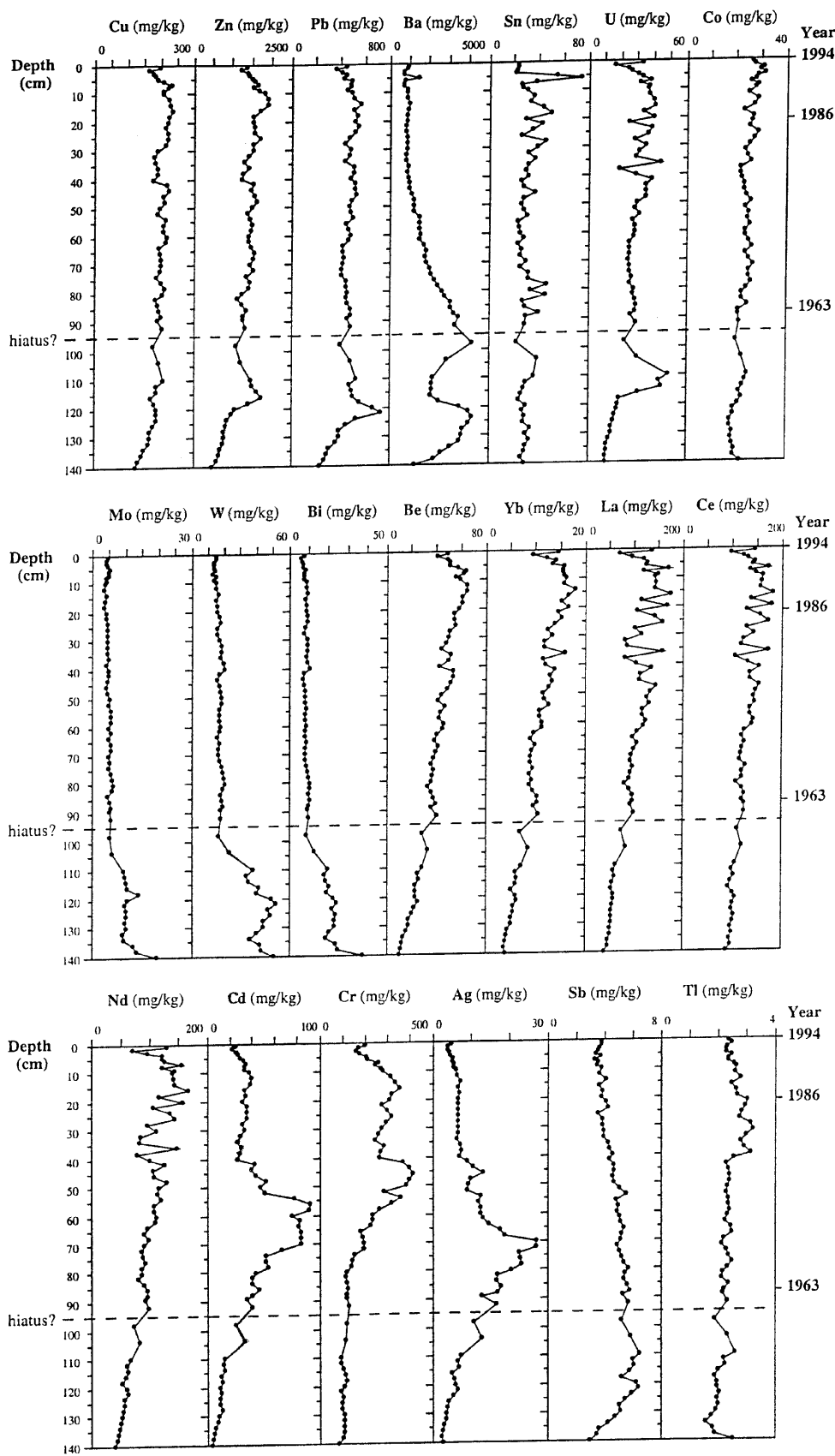


Fig. 6
Plot of trace element contents against depth (concentrations in mg/kg)

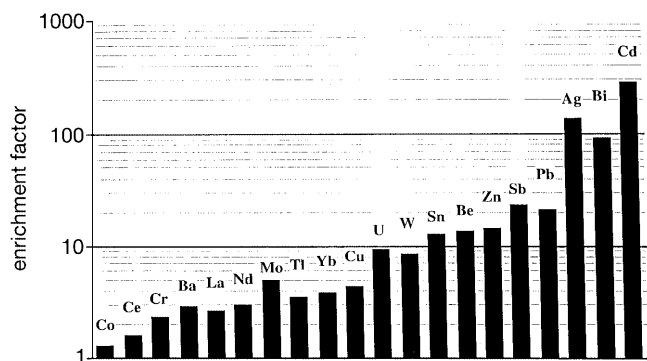


Fig. 7

Plot of C_{org} , P and S against depth (concentrations in %)

an artificial lake that drains into the Rote Weißeritz (see Figs. 1 and 3), was finished after that time and thus might reduce the input of coarser clastic material into the Malter Reservoir, thus reducing the contents of elements enriched in the coarser fraction. This dam is situated in an area with granites that contain disseminated cassiterite.

High contents of the other elements, such as Ag, Bi, Cd, Co, Cu, Mo, Ni, Pb, Sb (Sn), U, Zn, Be, Ba, Ce, Yb, Nd, and W, are only to a small extent caused by elevated concentrations within the rocks or ores of the drainage area (see Table 1). The very high concentrations of these elements and their strong fluctuations within the core se-

diments indicate, besides some geogenic input, mainly technogenic contributions from ore mining, metal smelting, and the production of special ceramics and semiconductors etc. It is astonishing that most of these enriched elements have their maxima at different depths. This indicates changing input patterns into the rivers and lake during the investigated period. The reasons may be construction, modification or closing of industrial plants, changes in production and sewage treatment processes etc. As mentioned above, with the exception of manganese, a separation of elements by mobilisation and migration within the sediments is very unlikely because the fixation capacity of the sediment is very high.

The intercorrelation of Mo, W and Bi in the bottom sediments indicates a high geological and soil background signal caused by Mo-W-Bi mineralisation (Pälchen and others 1991) as well as the intensive corresponding mining activities. A decrease in these elements above the hiatus (see Figs. 5 and 6) reflects the decrease in mining and smelting activity of the Mo-W-Bi ores. Zn, Pb and U have a strong maximum at the same time (~1940 to 1950), whereas Cd, Cr and Ag were deposited in a younger period (~1960–1980), but at different core depths. Mining activities and leaching from mine waste dumps, and release from the geological background because of acidification of the surface waters and soils, are reasons for the enrichment of Zn, Pb and U. Cd, Cr and Ag are typical elements of industrial wastewater, such as from galvanisation processes within tanneries, laundries (in Dippoldiswalde) within dye works; however, metal-work-

Table 1

Mean and median values of elements in reservoir sediments compared with the upper continental crust, an average shale, and mean element values of the local geological background in the catchment. Values of upper continental crust from Wedepohl (1995) and average shale from Wedepohl (1991), Ba,

Ce, La, Nd, U, W and Yb from Taylor and McLennan (1985), Sb after Ruppert (unpublished data). S1Granite of Schellerhau, coarse-grained; S2 same granite, fine-grained; TQ1 northern, and TQ2 southern Teplice Rhyolite, after Tischendorf (1989) and Pälchen and others (1987)

	Median (mg/kg)	Mean (mg/kg)	σ (0.66) (mg/kg)	Cont. crust (mg/kg)	Average shale (mg/kg)	S1 (mg/kg)	S2 (mg/kg)	TQ1 (mg/kg)	TQ2 (mg/kg)
Ag	6.8	9.7	6.1	0.055	0.07	n.d.	n.d.	n.d.	n.d.
Ba	1536	1862	1057	668	650	130	250	90	200
Be	42.0	41.0	14.3	3.1	3.0	n.d.	n.d.	n.d.	n.d.
Bi	9.0	12.0	6.3	0.121	0.13	n.d.	n.d.	n.d.	n.d.
Cd	34.6	37.5	22.6	0.102	0.013	n.d.	n.d.	n.d.	n.d.
Ce	125	128	23	65.7	80	101	123	24	133
Co	24	24	3	11.6	19	1.5	1.2	1	1
Cu	197	196	23	14.3	45	6	3	55	40
Cr	195	210	94	35	90	3	4	5	5
La	99	102	35	32.3	38	38	43	10	62
Mo	5.2	6.4	2.9	1.4	1.3	n.d.	n.d.	n.d.	n.d.
Nd	96	97	31	25.9	32	48	51	15	71
Pb	476	465	76	17	22	40	35	35	35
Sb	4.7	4.7	0.9	0.31	0.2	n.d.	n.d.	n.d.	n.d.
Sn	29.5	31.8	8.6	2.5	2.5	n.d.	n.d.	n.d.	n.d.
Ti	2.4	2.4	0.3	0.75	0.68	n.d.	n.d.	n.d.	n.d.
U	28.8	28.5	9.0	2.5	3.1	12.6	9.5	6	10
W	17.5	22.9	11.6	1.4	2.7	n.d.	n.d.	n.d.	n.d.
Yb	10.8	10.7	3.8	1.5	2.8	10	13	5	7
Zn	1434	1362	310	52	95	38	37	55	40

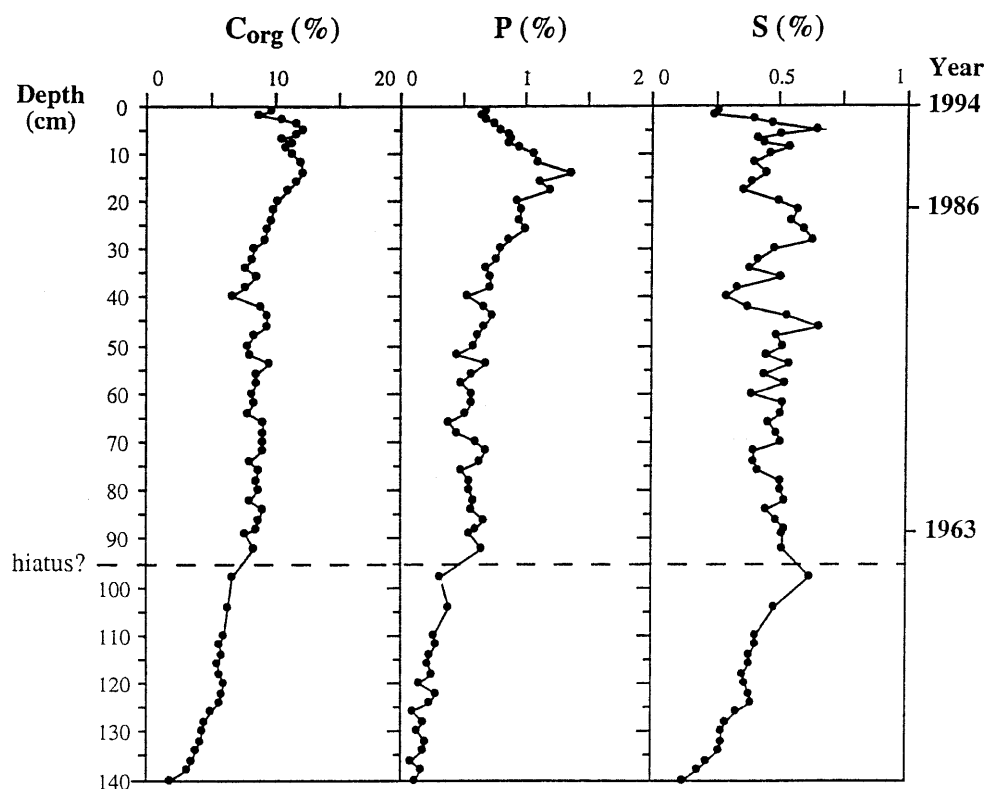


Fig. 8

Enrichment factors of heavy metals relative to their mean values in an average shale (from Wedepohl 1991; Ba, U, Sb, and W from Taylor and McLennan 1985)

ing industries (in Schmiedeberg until 1990) can be also responsible for a higher input of these elements (Förstner and Müller 1974). Sewage from photographic laboratories were enriched in silver. A decrease in Cd, Cr, Cu, Pb, U, Zn, Sn and Ag in the uppermost centimetres can be explained by the construction of a P-precipitation stage in the sewage purification plant in Dippoldiswalde in 1991/1992, but also by the closure of the industrial plant since 1989 (the year of the German reunification). The continuous upward decrease in Sb enrichment cannot be explained. The steady increase in the contents of Be, Yb, La, Ce and Nd could be caused by ceramic or by rare earth elements (REE)-producing industries. Unfortunately, it was not possible to get detailed information about the start and closure of the different industries and factories in the drainage area. Some historical facts are summarised in Fig. 9.

Organic load and eutrophication

As shown in Fig. 8, P and C_{org} values increase from the bottom sediments to the top, with a slight decrease, especially in P, in the uppermost sediments. The mean values with 0.60% P and 8.2% C_{org} , and the trend of the graphs indicate high productivity in the lake from its early stage onwards. These observations are in good agreement with the abundance of diatoms investigated in one piston core taken from the same location, which indicated that the

Malter Reservoir was a eutrophic lake from 110-cm depth upwards (Lessmann and others 1996). Only the upper few centimetres of the sediment showed slightly lower trophic conditions. That means, eutrophication of the Malter Reservoir started quite early. The building of the first mechanical purification plant in 1962/1963 (Fig. 9) did not have a measurable influence on primary productivity in the lake. This was probably because of its small capacity of only 2000 inhabitants compared with about 17,000 inhabitants in the whole drainage area (information from *Abwasserzweckverband Einzugsgebiet der Talsperre Malter* in 1997). However, lower phosphate content in the lake sediment during the last years has obviously been a result of reduced livestock, reduced fertiliser use in agriculture and to the shutdown of several local industries. Because of the loss of nutrients by deep-water discharge from the dam less nutrients reach the sediments. However, the lake is still eutrophic. The discharge of insufficiently purified wastewater into the lake water has resulted in greater phytoplankton blooms, especially those of cyanobacteria (Lessmann and others 1996). Compared with phosphorus, the decrease in C_{org} contents within the sediments is not clear. Sulphur is primarily bound to organic material. Accordingly, S shows quite a good correlation with C_{org} . However, sulphur is also bound within sulphidic compounds in the anoxic sediments. In the presence of sulphidic sulphur, chalcophile elements, such as Fe, Cu, Zn, Pb, Cd, Ag, Sb, Bi, Mo and Tl, become immobile because of their co-precipitation as insoluble sulphides.

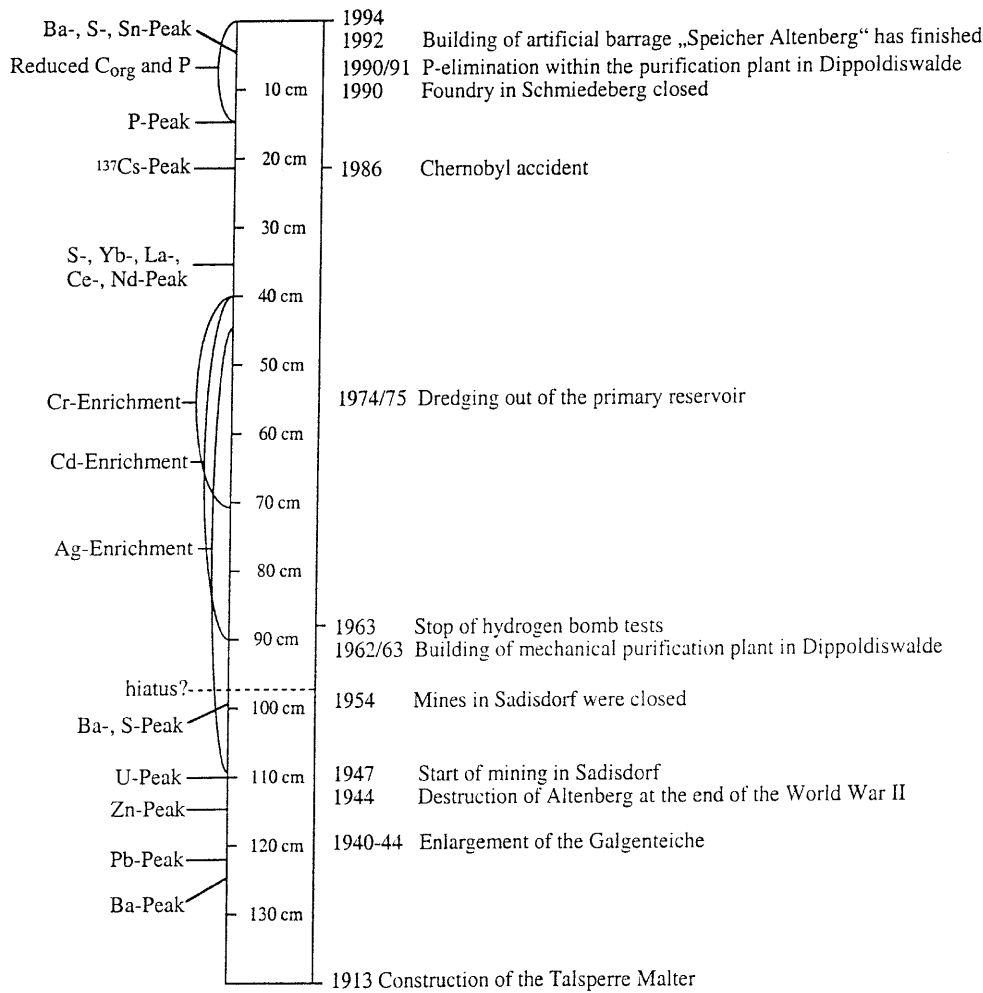


Fig. 9
Development of heavy metal load with technogenic events

Conclusions

The sediments of the Malter Reservoir mainly reflect the input of clastic and dissolved material transported by the river systems out of the drainage area of the river Rote Weißeritz and some smaller creeks. The Rote Weißeritz delivers ~77% of the water into the lake. High mean sedimentation rates of 2.8 cm/year from 1963 to 1994 is indicated by ¹³⁷Cs dating. However, the complex interaction of many element sources and a lack of official information on the economic development in the drainage area has led to difficulties in correlating element contents to specific historical events (Fig. 9). Although atmospheric element input is low compared with input by river water (suspended sediment, bed load and ions), the lowering of pH caused by acid rain has a strong effect on the mobilisation of heavy metals from the drainage area of soils, mine waste dumps, mining heaps, and local industrial and communal sewage. Thus high contents of Cu, Zn, Pb, Sn, U, Co, Mo, W, Bi, Be, Yb, La, Ce, Nd, Cd, Cr, Ag, Sb and Tl delivered by surface waters are reflected in the sediments of the lake. These enrichments are consid-

ered to be serious, especially because the Malter Reservoir has been used as a drinking-water supply in the past. A remobilisation of heavy metals (except Mn) from the sediments is unlikely. High pH values within the water and the sediment column, large adsorption capacity of the fine-grained C_{org.}-rich sediments and the presence of low Eh values and sulphide ions in the sediments prevent remobilisation of the toxic elements. However, erosion of the contaminated sediments during floods, or resuspension during removal of the sediments by deep-water discharge, may lead to a downstream transfer of pollutants. Agriculture has been intensive in the drainage area. Livestock and over-fertilisation led to an early eutrophication of the reservoir in about 1940, and reached a maximum in 1989/1990 as indicated by P and C_{org.} contents. Since the reunification of Germany, the shutdown of mining and ore-processing activities, the closure of industrial plants, the installation of sewage-treatment plants, the reduction in agricultural activities and the construction of a purification plant in Dippoldiswalde has led to a lower element input, especially of Cu, Zn, Pb, Sn, U, Cd, Cr and Ag, since 1989.

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