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SEDIMENT CORES FROM RIVER DAMS AS FLOOD ARCHIVES

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Abstract

Studies of sediment cores originating from a dam of the River Mulde near Bitterfeld (Saxony-Anhalt, Germany) confirmed that river dams act as excellent archives of flood events. The records were performed by significant changes of the composition and quality of suspended matter and sediment. To combine the investigated sediment core with a reliable time scale, suitable reference data (e.g. radionuclides, geochemical markers) were included into the study. Subsequently, flow data of the Mulde (from 1975 up to now) were used to assign specific floods (>300 m^3/s) to the event layers detected in the sediment cores. In addition to this, further time markers were inspected towards a more reliable adjustment of the time scale. In detail we made use of the ^{137}Cs activity maximum (caused by Chernobyl fallout), as well as of the drop in organic pollution (following the collapse of East Germany's industrial sector 1989/90), and finally of the decrease in the concentration levels of elements and isotopes (a consequence of the reduced activities of mines and metallurgical plants in the River Mulde catchment).

Exemplarily we present the results for a short sediment core, which originates from the Friedersdorf basin of the Mulde river dam (sampled in September 2002). The most recent such layer occurring in this sediment core was caused by the flood in August 2002. This event proved to be an outstanding flood time marker with regard to its thickness and geochemical properties.

Key words: Cesium-137, stratification, flood, lake sediment, river dam, trace element, Chernobyl impact

> *Something, which is now a rarity in scientific practice, is unselfish scientific cooperation born out of modesty and conducted eye-to-eye. Yet adopting this approach is bound to lead to joint success and friendship, especially between West and East.*

INTRODUCTION

Sediments of isolated lakes such as 'dead ice' lakes or maar lakes reflect best the medium to long-term regional and global trends of environmental and climatic changes. Therefore, they belong to the most informative and easiest accessible geological archives available for paleoclimatic and paleoecological reconstructions of the recent geological past of terrestrial and freshwater environments. However, short-term changes of the hydrological cycle with high dynamics, such as flood events, are recorded, if at all, only with low resolution by these sediments, because they are not directly connected to the surface runoff regime. In contrast to this, natural or anthropogenic river dams (e.g. Zerling *et al.* 2001), which are continuously in contact with the flowing water and also flood plain sediments (e.g. Schönfelder, Steinberg this volume), are more suitable for a detailed reconstruction of such events. But studies of river dams as flood archives are rare, if not absent. In this paper, we present a study on the sediments of a River Mulde dam (Saxony-Anhalt, Germany) and show the suitability of river dam sediments as short-term environmental archives.

Since 1975 the River Mulde, one of the most severely polluted tributaries of the River Elbe, has been redirected through the disused opencast pit of the Muldenstein lignite mine, creating the Bitterfeld Mulde river dam. Medium-term

Fig. 1. Professor B.W. Scharf (seated left) during the sampling campaign of the Bitterfeld dam in April 2002.

studies of the hydrodynamics, sedimentation, and heavy metal balance reveal that the dam (with a surface area of 6.1km^2, a volume of 118 million m^3, and a catchment area of 6170 km^2) is an important sediment and pollutant sink for the area of the lower River Mulde and the River Elbe (Zerling *et al.* 2001). Because the loads of suspended matter and pollutants entering the river dam closely depend on the flow rate of the River Mulde it is imperative to take into account the relation between flooding and deposition rate. For example, the load of a single flooding event may be several times greater than the total load even of a long-term base flow. Deposition rates have been estimated from differential measurements between the sediment load entering the river dam and that passing through it. Reliable data for the dam of the River Mulde are available on monthly and annual basis since 1991 (Jendryschik 2003). In order to verify the calculated deposition rates and to assign the suspended matter actually deposited in the river dam to individual events, detailed studies of the lakes sediment are required.

Eight sediment cores originating from both the Friedersdorf basin and the main basin of the River Mulde dam (collected in April and September 2002 during a joint drilling campaign with Professor Dr. B.W. Scharf; Fig. 1) were extracted for further studies. Short cores were obtained using a Mondsee corer, chiefly in order to study recent undisturbed lake deposits. The estimation of the thickness of the lake sediment since the flooding in 1975 is based on core borings sunk from a flooding platform. All sediment cores indicate clear stratifications, which reflect the flooding and flood events of the River Mulde since 1975.

The present paper focused exemplarily on the study of a short core collected in September 2002 in the Friedersdorf basin (Core MUL1HW: 4525600 east, 5724660 north, approximately 400 mm long). Above all, the study deals with the temporal classification of the floods documented in the sediment core using various methods (gamma spectrometry, X-ray fluorescence analysis for the elements As, Ba, Cd, Cr, Cu, Ni, P, Pb, S, Sn, Th, U and Zn, and hydrological events).

METHODS

Sample preparation

After the core had been extracted, it was packed airtight in foil and stored at 4°C until opened again. Macroscopic description, photographic documentation, and the division of the core immediately followed opening in the laboratory into individual samples. Core MUL1HW was divided into six screening samples with a lower resolution and 25 detail samples with a higher resolution for geochemical examination. The detail samples encompassed separate layers of sediment (see also Fig. 2). The screening and detail samples obtained for geochemical studies were shrink-wrapped in a noble gas atmosphere (He) in foil bags and kept in a deep freeze below 0°C until required.

Gamma spectrometry

Gamma spectrometry analysis was performed on the individual samples kept separately in plastic boxes. Measurements were taken using two n-type HPGe coaxial low-energy detectors with an active volume of 39 cm^3 and a beryllium window with a thickness of 0.5mm. The energy resolution at 122 keV (^{57}Co) was about 570 eV. Spectral analysis was aided on both detectors by the special software GAMMAW. The detectors were calibrated using certified reference material supplied by the International Atomic Energy Authority (IAEA). The reference material comprised a BL-5 uranium reference ore adjusted with SiO_2 to an uranium content of 400 (± 2.1) µg/g (IAEA-RGU-1), along with material from the Canadian Certified Reference Materials Project (reference britholite ore OKA-2), adjusted with SiO_2 to a thorium content of 800.2 (± 15.8) µg/g Th (IAEA-RGTh-1). To evaluate

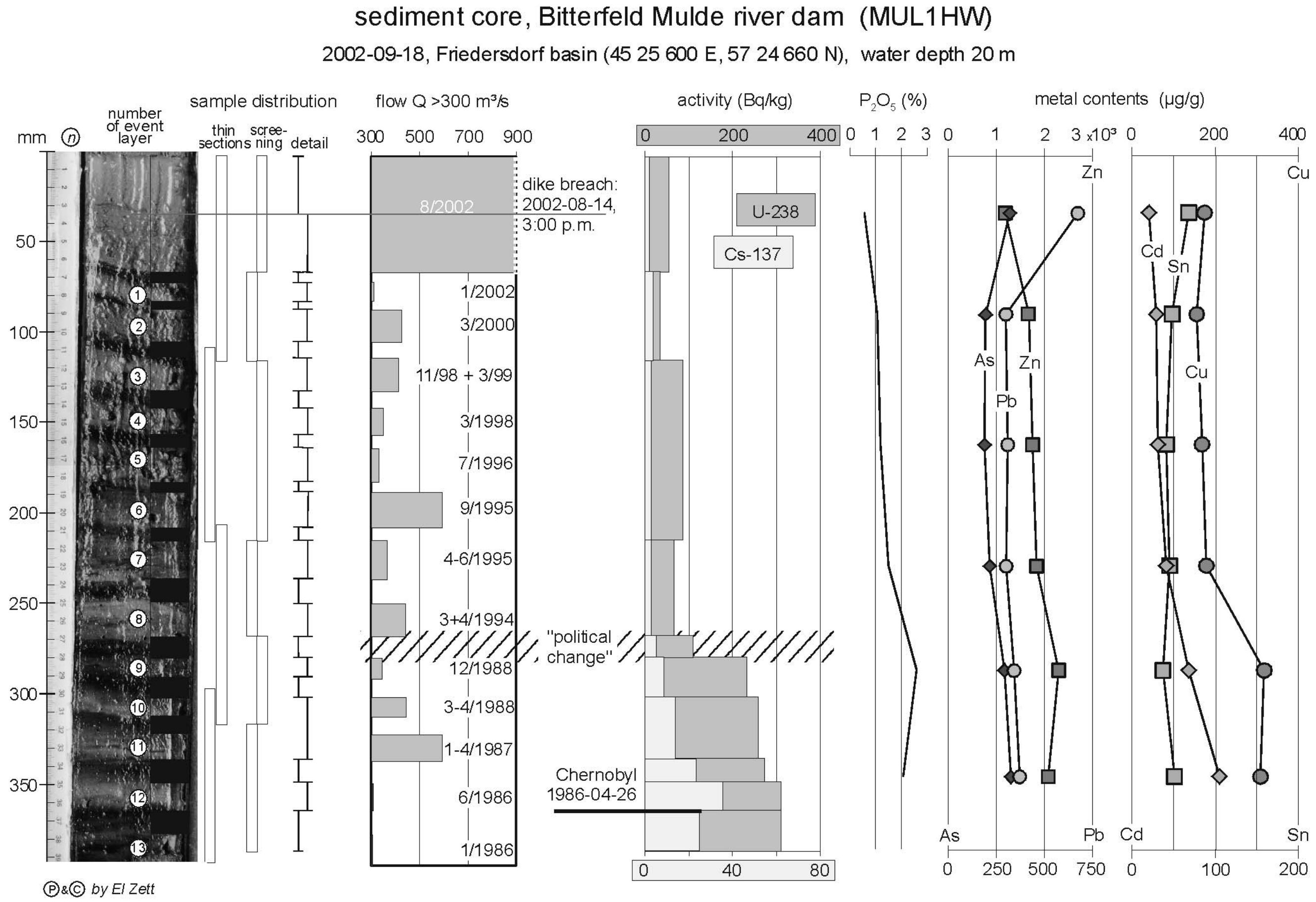

Fig. 2. Structure of the 390 mm-long core, temporal classification and distribution of selected radionuclides (^{238}U, ^{137}Cs), P_2O_5 as an indicator of organic pollution and levels of selected elements and heavy metals. The levels of elements were determined in the overall fraction (>2mm) using the X-ray fluorescence method. In the two columns on the right, the upper scales apply to Zn and Cu, while the lowers ones apply to As, Pb, Cd and Sn.

the gamma spectra, the various gamma energies were used for the identification and quantification of ^{238}U and ^{137}Cs: ^{238}U from the daughter product: ^{234}Th: 63.3 keV (3.8%); ^{137}Cs 661.6 keV (85.1%).

X-ray fluorescence analysis

To meet the requirements for analytical grade material, the collected sediments were dried at 105°C and ground using an agate ball mill. Aliquots (4 g) of the sample powder were mixed with 20% wax (Hoechst wax for XRF-analysis) as a binder, homogenized, and finally compressed into pellets.

The analytical measurements were performed by a Siemens SRS 3000 wavelength dispersive X-ray spectrometer fitted with a 3kW Rh target tube (125 µm Be), a 60kV X-ray generator, and a crystal changer for eight analyzer crystals. The measuring process and data evaluation were controlled by the spectrometer's own software (SPECTRA 3000). Measurements were taken in a vacuum using the 34 mm collimator mask with the analyzer crystals OVO 55, Ge, LIF 200, and LIF 220. For more details on the methodology used and the detection limits, see Junge *et al.* (2001).

Temporal assignment of the flood layers

The following methods were used for the temporal assignment of the flood layers documented in core MUL1HW:

1. Radiometric determination of the concentration courses of the radionuclides ^{137}Cs and ^{238}U in the sediment core. The very limited maximum ^{137}Cs activity caused by fallout from Chernobyl (26 April 1986) ought to enable a precise time marker in the period covered by the sediment core. Similarly, the abrupt drop in active uranium mining by WISMUT following the collapse of East Germany in 1989/90 ought to be reflected in a drop in the levels of ^{238}U radionuclides and overall levels of uranium in the sediment.

2. The decreasing concentration of certain elements (including As, Ba, Cd, Cr, Cu, Ni, Pb, Sn, Zn) accompanying the closure of mining and smelting plants in the River Mulde catchment area also should be reflected in the lake sediment. This drop should be significantly different from the continuous output of heavy metals from waste dumps and mine pits typical of the River Mulde catchment. Moreover, the lower organic pollution of the River Mulde since German unification should be detectable by changed composition (e.g. decreasing of phosphorus) of the lake sediment.

3. Combining the above-mentioned 'geochemical verified time markers', with the flow data measured at the river

gauge at Bad Düben we will be able to attribute the event layers occurring in the cores to specific cases of flooding of the River Mulde.

MACROSCOPIC CORE DESCRIPTION

Core MUL1HW was totally stratified with alternating 14 light and 13 dark layers comprising:

a) dark, blackish-gray to black, organic-rich layers;

b) light, yellow to yellowish-gray layers (grayer in the lower core areas) with sizeable clastic fractions.

According to the macroscopic findings, the light layers can be regarded as 'event layers' in the sequence of floods interrupting the normal, mainly biogenically controlled lake sediment formation during summer months reflected by dark layers. The light layers are frequently graduated and finely laminated.

Macroscopically, the core is divided into two distinct sections. The upper section, approximately 260 mm thick and with a lighter appearance, consists of alternated stratification containing 9 light and 8 dark, sharply delineated layers. The lower section is approximately 140 mm thick and is significantly darker owing to its higher organic fraction, the borders between the layers (5 light, 5 dark) appearing less distinct. The average thickness of the light layers (disregarding the most recent flood layer from August 2002) in core MUL1HW was 16.6 mm (±4.4; maximum: 25 mm; Fig. 2). The most recent dark layer above event layer 1 (depth 60–70 mm; Fig 2) reflects the mainly biotic sedimentation of summer 2002 (April until 12 August). In a sediment core obtained at the same position in April 2002 the event layer 1 (Fig. 2) has formed the lake surface layer.

At the top of the sediment core, a light clastic layer with a thickness of approximately 55 mm (with largely incompact stratification) had developed. This layer can be associated with the River Mulde flooding that reached its peak between 13 and 16 August 2002. In terms of color and particle size, the top layer is divided into two sections: The lower 26 mm is yellowish-gray and contains larger fractions of coarse material; the upper 29 mm is yellowish and contains fine fractions. The reason for this macroscopic and lithological division of the flood layer could be the dike breaches which occurred upstream of the Mulde dam on 14 August 2002, causing fluctuations in the transport energy and the import of suspended matter into the River Mulde.

RADIOACTIVE TIME MARKERS

In order to obtain an initial overview of the distribution of natural radionuclides from the ^{238}U decay chain and the anthropogenic ^{137}Cs, the six screening samples were studied (Fig. 2). An activity maximum in the concentrations of ^{238}U (151 Bq/kg) and ^{137}Cs (12.3 Bq/kg) was found at a depth of 310–380 mm. In order to be able to set the 1986 time marker from the ^{37}Cs distribution (the reactor accident at Chernobyl on 25/26 April, 1986) more precisely, this depth range was augmented by the detail samples. As a result, a clear ^{238}U activity maximum (309–311 Bq/kg at a depth range of 340–380 mm) and an even more pronounced ^{137}Cs activity maximum (35.2 Bq/kg) were found.

In core MUL1HW, the ^{137}Cs distribution indicates a sediment age of 16 years (Chernobyl) in the depth layers of 340–350 mm. The ^{137}Cs concentration maximum is inside a flood layer (event layer no. 12, Fig. 2), and the organic-rich dark layer beneath it also exhibits a higher activity (24.6 Bq/kg). The accident at Chernobyl took place in late spring 1986, night of 25/26 April 1986. Flood events with maximum flows of about 300 m^3/s before and directly after the reactor accident were observed on 21 January 1986 (winter flooding) and 31 May/1 June 1986 (summer flooding), respectively. This pattern results in the following event layers: during the winter flooding on 21 January 1986, the lowest event layer captured in core MUL1HW was precipitated (event layer no. 13, Fig. 2). The initial organic sedimentation in early spring 1986 (between February and the end of May 1986) is reflected by the organic-rich, dark layer above. During this period, the Chernobyl reactor accident took part with very fast washout from the atmosphere and subsequent input of ^{137}Cs into the lake sediment. Already the first atmospheric aerosols with maxima of radioactivity up to 120–160 Bq/m^2 were detected the 30th of April 1986 in West Germany (German meteorological Survey station Regensburg; Steinkopff 2002). It demonstrates that the time difference was very low between the Chernobyl accident and the ^{137}Cs input on German soils with the possibility of their transport by running waters. The subsequent summer flooding (31 May/1 June 1986) resulted in the avulsion of ^{137}Cs-contaminated soil material and hence the ^{137}Cs activity maximum observed within this flood layer deposited in the River Mulde river dam (event layer no. 12, Fig. 2). In the lowest part of the sediment core MUL1HW a layer-by-layer preparation was not possible. Therefore the lowest investigated detail sample contains two layers, the event layer no. 13 and the organic-rich, dark layer above, with the consequence that the ^{137}Cs-detection is extended up to this range (Fig. 2). More recent River Mulde flooding led to the additional, but declining input of ^{137}Cs into the sediment of the Mulde river dam. The ^{137}Cs contamination caused by the accident at Chernobyl mainly affected the uppermost organic soil layers and the humus mineral soil horizons. The water solubility of radio cesium and hence an accompanying shift can be ruled out (Böhm, Pfeffer 1990). However, owing to the tight bonding of Cs to the organic substance, during the course of the erosion processes and the related removal of soil fines, ^{137}Cs was transferred into the suspended fraction. These transfer processes of ^{137}Cs contaminated soil material through Mulde River and are reflected in core MUL1HW until the early 1990s, when Cs is at the detection limit (above event no. 8, Fig. 2). We assume that, in contrast to Cs mobility in soils probably due to colloidal transport, its mobility in the Mulde dam sediments is negligible. The disastrous flooding in August 2002 did not mobilized ^{137}Cs.

The ^{238}U radionuclide (Fig. 2) and the total uranium levels (Table 1) within core MUL1HW show an activity respectively concentration decreasing from bottom to top. In the depth range of 240–280 mm, a sharp decrease in ^{238}U activity down to the level of the mean natural concentration is observed. The upper core with only one sixth of ^{238}U activity and one half the total uranium level (20–41 µg/g compared to 60–78 µg/g U) of the lower core sections, characterizes the

Table 1

Mean levels of elements in the sediment of the Bitterfeld Mulde river dam depending on the deposition period

Period	n	As µg/g	Pb µg/g	Sn µg/g	Zn µg/g	Cd µg/g	Cu µg/g
August 2002 flood layer	2	251±96 (183..319)	537±192 (401..673)	64±6 (59..68)	1225±59 (1183..1266)	21±1 (20..22)	160±20 (146..174)
"Post-reunification" (1989/90 to August 2002)	13	171±23 (135..216)	294±16 (262..330)	44±9 (36..72)	1676±127 (1447..1885)	34±7 (27..54)	170±22 (148..173)
"Pre-reunification" (1975 to 1989/90)	9	283±90 (119..399)	340±63 (228..432)	46±8 (31..56)	2153±424 (1535..2895)	94±34 (41..145)	321±74 (216..435)
Tertiary underground	4	16±5 (11..23)	38±9 (31..50)	7±1 (6..8)	110±36 (76..155)	4±2 (2..7)	27±7 (21..36)
Total surface sediment 1991[a)]	36	225±60 (103..312)	327±44 (174..399)	n.d.	2490±430 (1160..3290)	78±19 (29..115)	286±64 (146..445)

Period	n	Cr µg/g	Ni µg/g	Ba µg/g	P_2O_5 µg/g	U µg/g	S µg/g
August 2002 flood layer	2	111±3 (107..111)	76±5 (69..76)	1112±124 (1024..1200)	5916±303 (5701..6130)	19±2 (17..20)	2276±334 (2039..2512)
"Post-reunification" (1989/90 to August 2002)	13	120±11 (107..151)	89±6 (80..102)	939±112 (721..1168)	10735±2878 (7680..17260)	30±9 (20..45)	5951±2059 (3901..10950)
"Pre-reunification" (1975 to 1989/90)	9	216±38 (158..279)	118±14 (102..137)	1372±176 (952..1564)	20931±8374 (10280.32370)	74±22 (43..119)	11504±4872 (4311..18600)
Tertiary underground	4	83±7 (77..92)	32±2 (29..34)	522±58 (465..596)	2883±565 (2400..3670)	52±55 (3..100)	6382±2136 (3179..7544)
Total surface sediment 1991[a)]	36	178±27 (117..247)	116±26 (55.186)	n.d.	n.d.	n.d.	n.d.

Notes: The table contains median level ± standard deviation (upper) and minimum and maximum values (lower) of element contents within the total fraction (<2 mm) of lake sediment determined using X-ray fluorescence analysis. The levels in the post-reunification period and the pre-reunification periods are based on the temporal assignment of the sediment core sections using the methods described in the paper. They are made up of the results from four cores from Friedersdorf basin and Main basin of the Bitterfeld Mulde river dam. The "Tertiary underground" is made of the tertiary strata below the lake sediment (former mine surface).

[a)] element contents according to Born (1996) are received also from the total fraction (<2 mm) of the surface lake sediment; n.d. = no data.

1990s that is the post-reunification period. It reflects the abrupt decline of uranium mining and treatment (Zwickau Mulde; Beuge *et al.* 1994) as well as of the smelting industry in the Freiberg mining area. The pre-reunification era (prior to 1989/90) is characterized by maximum uranium and uranium isotope concentrations. The more recent sections of the core indicate the weak mobilization of ^{238}U during the course of flooding in 1995 and 2002.

TEMPORAL MARKERS FROM ELEMENT-GEOCHEMICAL STUDIES

The levels of trace elements of the screening samples of core MUL1HW as well as the loss on ignition (Fig. 2) indicate that the core can be divided into two geochemical distinguishable sedimentation periods: one core section reflecting the pre-unification/East German period (1989 and older;

depth range: below 260 mm) and the other the post-reunification era (1990s; depth range 0–260 mm; Table 1). They differ distinctly in terms of their element levels (total particle size fraction), the sediment deposited in the Mulde river dam in East German period usually containing higher concentrations of in particular organic element indicators and heavy metals (Table 1).

The higher organic input of the lake sediment deposited until 1989 compared to the post-reunification era reflects the distinctly higher levels of total phosphorus as part of the biotic material (mean of all cores examined: about 2.1%, compared to about 1.1% in the post-reunification era), which is mainly deposited in the anaerobic sediments as vivianite caused by high phosphate concentrations of Mulde water (up to 470 ng/mL; Junge, Jendryschik 2003), sulfur (mean about 1.1% compared to about 0.6 %) as well as in the higher loss on ignition (core Mul1HW: about 19% compared to about 15% in the <20 µm sediment fraction). Conversely, the low clastic fractions within this section of the core are indicated by lower levels of SiO_2 (on average about 45% compared to about 53%), Al_2O_3 (on average about 13% compared to 14%; clay mineral fractions), and Zr (on average about 200 µg/g compared to about 226 µg/g; heavy mineral fraction).

The heavy metals and other ore-bound elements released in GDR area by the mining and smelting industries are apparent from the high concentrations of As, Pb, Sn, Zn, Cd, Cr, Ni, and Cu (cf. Table 1), as well as U (on average about 74 µg/g compared to 30 µg/g), Ba (on average about 1372 µg/g compared to about 939 µg/g) and Sr (about 158 µg/g compared to 117 µg/g).

The levels of Zn, Cd, Pb, Cu, As, and Sn document a continuous decreasing trend from bottom to top of the core (Table 1). A sharp drop in the element levels is to be observed below a depth of 260 mm (event layer no. 8, Fig. 2, for statistics, see Table 1), especially Zn, Cd, Pb, Cu, As, and Sn. Based on geochemical findings, this fixes the time marker of the political changes leading to German reunification (1989/90), which prompted an abrupt decline in the input of these elements due to the closure of mines and smelting plants in the catchment area of the Zwickau and Freiberg Mulde.

The findings from the screening samples show that the flooding documented in MUL1HW (event layers 1–13; Fig. 2) was not accompanied by any significant increase in the concentrations of heavy metals or ore elements in the lake sediment. The only exception is the flooding in August 2002, which showed a five-fold higher sedimentation at the drilling points on the bottom of the Mulde river dam. This resulted in major concentration increases of Sn, As and Pb in the surface sediment, which can probably be attributed to material being washed away from the industrial waste heap at Muldenhütten (Freiberg Mulde) during flooding (Klemm *et al.* 2003). By contrast, the levels of Zn, Cd, Cr, Ni, Cu (Table 1) and U of the flood sediment fit in with the trend of improved sediment quality generally observed since the 1990s.

RELATIONS BETWEEN FLOW DATA OF THE RIVER MULDE AND THE EVENT LAYERS IN THE LAKE SEDIMENT

The sediment of the Bitterfeld Mulde river dam consists of macroscopically visible alternation between light layers (flood layers) and dark, organic-rich layers. From experience of the amount of suspended matter in the River Mulde at higher flows, floods with an average flow of more than 300 m^3/s (about five times the average flow of the River Mulde at the gauge in Bad Düben some 15km downstream of the Bitterfeld Mulde river dam; the mean flow of the River Mulde since 1975 is about 64 m^3/s) form very likely macroscopically visible flood layers in the sediment of the Bitterfeld Mulde river dam. Depending on the varying deposition in the dam, layers up to several centimeters are built up. These layers alternate with organic-rich parts of the sediment (dark layers) reflecting intensified phases of bioproduction. The formation of the latter occurs mainly in the seasonally warmer periods of the year (early, mid- and late summer).

As a result of this pattern, a succession of flood events occurring during the same winter period will be reflected in the formation of just one macroscopically visible layer. It may vary in terms of texture depending on the number of floods and their development, but dark, organic-rich layers will not interrupt it. The specifics of winter flood situations are mainly visible in the microscopic (and only to a minor extent the macroscopic) layer structure of the corresponding event layer. Although it frequently varies in size and texture depending on the number of floods and their course, dark, organic-rich layers do not interrupt it. The particular features of the winter flood situations are visible in microscopic and to a lesser extent in the macroscopic image of the layer structure of the corresponding event layer.

In contrast to this, each summer flood leads to the formation of an independent macroscopically visible event layer in the lake sediment, if the time period between successive summer floods is sufficient to activate the lake's bioproduction resulting in sufficient sedimentation. The normal, biogenically determined summer sedimentation leading to the formation of a dark layer is not interrupted in the absence of floods in the following winter period, i.e. if winter starts with low to medium flows, a macroscopically visible, light-colored, thick clastic layer is not formed. However, these dark layers appear different when viewed microscopically.

When macroscopically assigning the flood events to the event layers occurring in the sediment of core MUL1HW, the above-mentioned seasonal effects were taken into account (Table 2).

Since 1 May 1975, when the flooding of the disused lignite mining pit at Muldenstein began using water from the River Mulde, 33 floods with an average flow of >300 m^3/s have been recorded (data from the measuring station at Bad Düben river gauge, State Department of the Environment, Leipzig). Taking into account the above explained seasonally related effects, these 33 floods (including the catastrophic flooding in August 2002) would be reflected in 22 macroscopically visible event layers with adjacent dark, organic-rich layers which all in all should be visible in the

Table 2

Temporal assignment of event layers in sediment cores from the Bitterfeld Mulde river dam to floods of the Mulde with a flow of $Q \geq 300\ m^3s$ with particular attention to core MUL1HW

Periods with flow $Q \geq 300\ m^3/s$ *Periods with flow $Q < 300\ m^3/s$*	Event layers in core MUL1HW	Flood period (date)	Daily flow flood peak; m^3/s	Maximum flow, m^3/s
Summer flooding. 2002	0	13.08.-18.08.2002	>>800	
	Light			
Summer 2002	*Dark*			
Winter flooding 2002	1	29.01.2002-30.01.2002	310 (30.01.2002)	
	Light			
Summer 2000+2001	*Dark*			
Winter flooding 2000	2	10.03.2000-20.03.2000	426 (11.03.2000),	
	Light		411 (19.03.2000)	
Summer 1999	*Dark*			
Winter flooding 1999	3	03.03.1999-07.03.1999	414 (04.03.1999)	432 (04.03.1999)
	Light			
Winter flooding 1999		03.11.1998	305	335
Summer 1998	*Dark*			
Winter flooding 1998	4	19.03.1998	344	357
	Light			
Winter 1996+Summer 1997	*Dark*			
Summer flooding. 1996	5	10.07.1996	334	350
	Light			
Winter 1995+Early summer 1996	*Dark*			
Late summer flooding 1995	6	02.09.1995-04.09.1995	588 (03.09.1995)	657 (03.09.1995)
	Light			
Summer 1995 (July/August)	*Dark*			
Early summer flooding 1995	7	03.06.1995-04.06.1995	360 (04.06.1995)	451 (04.06.1995)
Winter flooding 1995		15.05.1995	263	311
Winter flooding 1995	Light	19.04.1995-21.04.1995	363 (20.04.1995)	371 (19.04.1995)
Summer 1994	*Dark*			
Winter flooding 1994	8	14.04.1994	308	368
Winter flooding 1994	Light	16.03.1994-18.03.1994	444 (17.03.1994)	486 (17.03.1994)
Period 1989–1993	*Dark*			**← East Germany collapse**
Winter flooding 1989	9	20.12.1988-26.12.1988	311 (20.12.1988)	373 (21.12.1988)
	Light		336 (26.12.1988)	
Summer 1988	*Dark*			
Winter flooding 1988	10	22.03.1988-09.04.1988	309 (09.04.1988)	449 (28.03.1988)
	Light		441 (28.03.1988)	
Summer 1987	*Dark*			
Winter flooding 1987	11	11.04.1987-14.04.1987	547 (12.04.1987)	654 (11.04.1987)
Winter flooding 1987		28.03.1987-31.03.1987	377 (30.03.1987)	392 (30.03.1987)
Winter flooding 1987		10.02.1987-12.02.1987	365 (11.02.1987)	454 (10.02.1987)
Winter flooding 1987	Light	30.12.1986-05.01.1987	591 (01.01.1987)	620 (01.01.1987)
Late summer 1986	*Dark*			
Summer flooding. 1986	12	31.05.1986- 01.06.1986	266 (01.06.1986)	279 (01.06.1086)
	Light			
Early summer 1986	*Dark*			← "Chernobyl"
Winter flooding 1986	13	21.01.1986	292	326
	Light			
Period 1984-1986	xx *(Dark)*	Low-water period (individual flow up to max. $266 m^3/s$)		
Summer flooding. 1983	XX (Light)	06.08.1983-08.08.1983	657 (07.08.1983)	960 (6.8.83)
Summer 1982 + winter 1983	xx *(Dark)*			
Winter flooding 1982	XX (Light)	01.02.1982	368	400
Winter flooding 1982		07.01.1982	343	357
Winter flooding 1982		28.11.1981	327	
Summer 1981	xx *(Dark)*			
Winter flooding 1981	XX (Light)	11.03.1981-17.03.1981	859 (13.03.1981)	1020
		09.02.1981	301	309
Late summer 1980	xx *(Dark)*			
Summer flooding. 1980	XX (Light)	23.07.1980-25.07.1980	569 (24.07.1980)	729 (24.07.1980)
Early summer 1980	xx *(Dark)*			
Winter flooding 1980	XX	29.04.1980-04.05.1980	358 (03.05.1980)	367 (03.05.1980)
Winter flooding 1980		07.02.1980-08.02.1980	308 (07.02.1980)	339 (07.02.1980)
Summer 1978 + 1979	xx *(Dark)*	Low-water period (individual flow up to max. $279 m^3/s$)		
Early summer flooding 1978	XX	09.05.1978-11.05.1978	641 (10.05.1978)	810 (10.05.1978)
Late summer 1977 + winter 1978	xx *(Dark)*			
Summer flooding. 1977	XX	12.08.1977-13.08.1977	344 (13.08.1977)	378 (13.08.1977)
Summer 1976 + winter 1977	xx *(Dark)*			
Winter flooding 1976	XX	13.01.1976-18.01.1976	605 (16.01.1976)	636 (16.01.1976)
Summer 1975	xx *(Dark)*			
Flooding of the Mulde river dam starts: 01.05.1975				

lake sediment deposited since 1975 in the Mulde river dam (Table 2).

Core MUL1HW contains a total of 14 macroscopic event layers including the sediment layer deposited during the flood in August 2002. According to the radiometric findings (^{137}Cs), the sedimentation period can be narrowed down to the period from January 1986 until August 2002. During this period, a total of 21 flood situations (>300 m^3/s) were recorded. They include 17 winter floods distributed among 10 winter periods, and four summer floods (Table 2). This indicates that the 21 floods recorded should according to the above-explained concept be reflected in 14 event layers in the sediment. This number of event layers derived from the model is consistent with the field findings, i.e. with the macroscopically visible number of 14 event layers found in core MUL1HW (Table 2, Fig. 2).

In addition to the radiometric results, the assignment of the event layers documented in core MUL1HW to the floods registered in 1986–2002 is also confirmed by the geochemical element findings. The fall in the levels of heavy metals (including Zn, Cd, Cu, Ni and Cr) and other indicator elements (e.g. phosphorus) detected in the lake sediment of the Bitterfeld Mulde river dam and caused by the collapse of East Germany in 1989/90 occurs in the section between the floods recorded from winter 1988 (event layer no. 9) and 1994 (event no. 8; Fig. 2, Table 2). This reflects a four-year low-water period (1989–93) and is indicated by the formation of a dark, organic-rich layer. It completes the lower section of the core about 0.14m thick, which is macroscopically significantly darker owing to the higher portion of organic material and features less distinct boundaries between the layers.

CONCLUSIONS

River dams act as suitable sediment traps, which provide reliable information about the impact of past floods. The Bitterfeld Mulde river dam proved to be an instructive example to investigate such event-specific sedimentation of the suspended matter fraction reflecting the various influence factors e.g. flow and course of flooding. The findings can be used to a better assessment of the sedimentation rate and the actual deposition of fine sediment with respect to individual floods and to recover the date of origin of the event layers in other flood archives (e.g. flood sediment, floodplain loam). The latter is above all of interest when dealing with the study of floods in historical and geological periods.

With regard to the temporal assignment of layer events to specific flood situations the detected findings in the sediment core from Bitterfeld Mulde river dam also allow practical conclusions for flood precautions and management. They indicated that despite of the high effectiveness of the sediment trap of the Bitterfeld Mulde river dam (more than 90% of the entire volume of suspended matter transported by the River Mulde is deposited in the river dam), the actual sedimentation of very fine suspended matter on the lake bottom (caused by flooding) is relatively low in each case. Including phases of extreme floods it amounts only to a few centimeters. Taking into account the historical frequency of floods, it can be concluded that the Bitterfeld Mulde river dam will remain an effective sediment trap for a very long time (at least 500–700 years) in the Mulde-Elbe river district.

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