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Sediment dynamics from the drainage area into Lake Mladotice (western Czech Republic) in relation to flood events and under the influence of pre- to post-communist landscape changes

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Abstract In May 1872 a landslide occurred in the western Czech Republic, blocking the Mladoticky stream valley and creating Lake Mladotice. The 1952 and 1975 air photos document that collective farming had a great impact when balks and field terraces were removed and fields were made much larger. Because of this change in land use we expected higher soil erosion and a related increase in the sedimentation rate. Our analysis of the sedimentary record aims to identify the factors controlling sediment input, i.e. soil erosion, which is dependent on rainfall–runoff processes and land use in the drainage basin. The sediment stratigraphy, physics, chemistry, micropalaeontology, isotope content and thin sections yield a detailed temporal resolution of the sedimentation chronology. Surprisingly, the sedimentation rates only indicate a small increase from 2.2 cm/year (1954–1963) to 2.7 cm/year (1963–1978) to 2.5 (1978–1986) and 2.4 cm/year (1986–2003).

Key words change in land use; Lake Mladotice; landslide; rainfall–runoff processes; sedimentation rates; soil erosion

DRAINAGE BASIN AND LAKE EVOLUTION

Lake Mladotice is located in the western Czech Republic, about 30 km north of Pilsen. Its altitude is 413 m above sea level and its surface area is 4.74 ha. The lake receives drainage from a basin of approx. 47 km^2, about 50% of which is intensively farmed. The bedrock mainly consists of Paleozoic shale, sandstone and conglomerate, with some Proterozoic phyllite and spilite and Paleozoic granite.

On 26 May 1872 a landslide created Lake Mladotice. Construction work on the Saaz-Pilsen railway decreased the stability of the slope and, as a result, an extreme rainfall event of 237 mm within two hours (Stekl *et al.*, 2001) triggered slope failure (Janský & Urbanová, 1994). The slope failure material accumulated across an area of 300 m of the valley floor and blocked Mladoticky Creek, creating a lake about 20 m deep (Fig. 1). The first bathymetric measurements of Lake Mladotice were made in

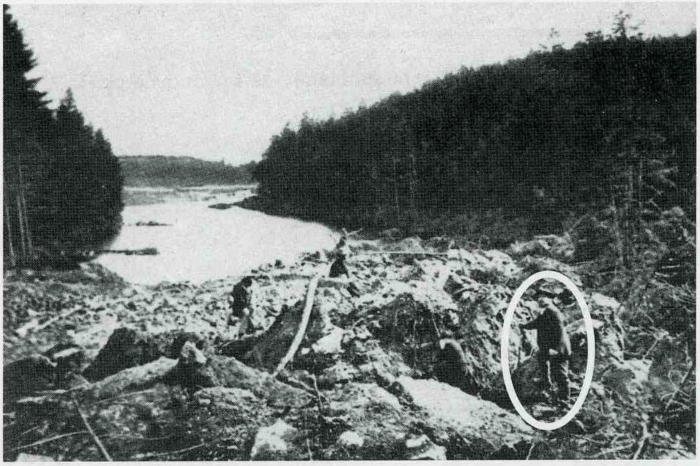


Fig. 1 Dammed valley immediately after the landslide in 1872. A man in the right-hand foreground indicates the scale; the lake is emerging in the background. Print from the SBORNIK CSZ 1912, volume XVIII (photo by C. Purkyne).

1972 and 1990 (Janský 1976, 1977; Janský & Urbanová, 1994). Between these two measurements, the lake's depth declined from 7.70 to 6.30 m. Its water volume decreased from 141 000 m^3 to 101 000 m^3. From these figures Janský & Urbanová (1994) calculated an annual sedimentation rate of about 7.8 cm.

METHODS

To reconstruct land use shifts the Military Topographical Institute in Dobruska supplied air photos taken in 1938, 1952, 1975, 1987 and 1998. Up to now only 2-D interpretation is possible, because of the lack of overlap. The air photographs document a considerable land use change with the introduction of collectivization. We anticipate that stereoscopic 3-D-interpretation of the air photos will show the removal of field terraces that accompanied field enlargement and also contributed to increased erosion (Janský, 1976, 1977; Janský & Urbanová, 1994).

To assess the influence of natural factors on erosion, transport and sedimentation rates in Lake Mladotice, rainfall data were analysed from six stations recording data since 1881. Runoff data serve to indicate the dimensions of past flood events. The nearest runoff gauge is located on the Strela River (Plasy Station), which also drains the Mladoticky creek. Daily records at this gauge date back to 1941. It is assumed that large floods recorded at the Strela River were also experienced at the Mladoticky creek and that sediments were deposited in the lake during these events.

Sediment analyses

We obtained information about the distribution of the sediments by extracting 13 short cores of about 1 m in length. Five long cores were drilled down to the bottom of the

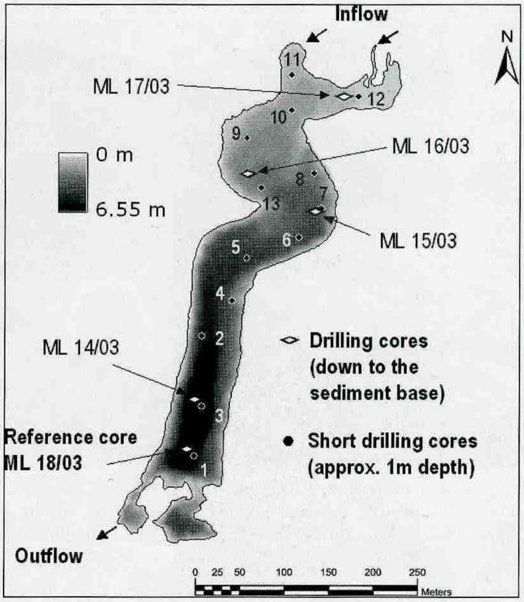


Fig. 2 Map of Lake Mladotice showing locations of short and long cores. The core ML 18/03 is located near the outflow with the maximum water depth.

sediments. The reference core ML 18/03 was extracted from the deepest part of the lake and core ML 14/03 was investigated for diatom analyses. Core sites are shown in Fig. 2.

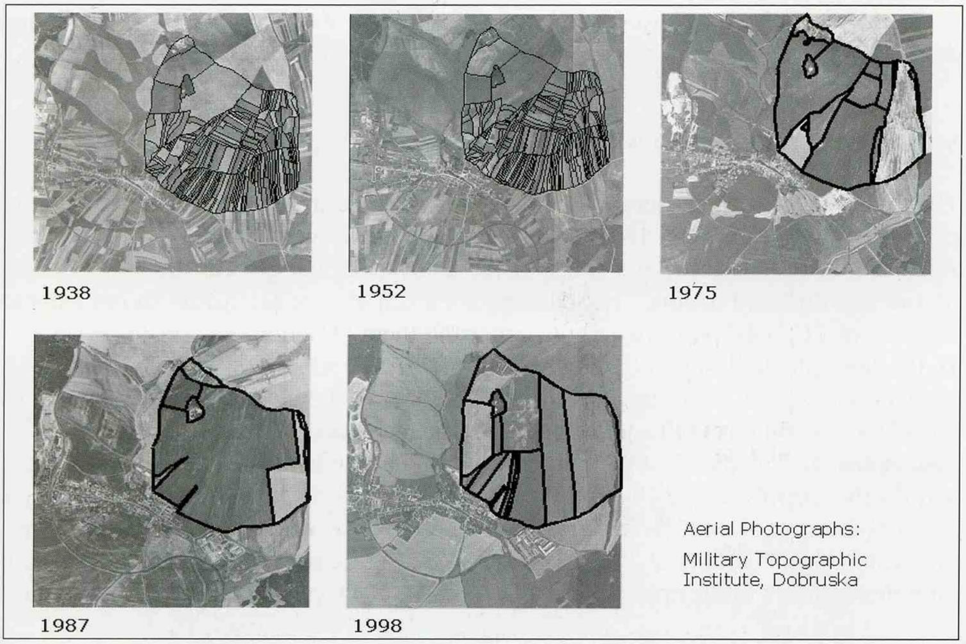
Reference core ML 18/03 comprises analyses of water content, density, grain size, total sulphur, total carbon, total phosphorus, clay mineral composition, ^{137}Cs, ^{241}Am and ^{210}Pb as well as thin sections from the entire length of the core. The upper part of the sediment core ML 14/03 was investigated for diatoms (0–160 cm core depth).

RESULTS

Changes in land use and flood discharge

This paper describes the fundamental changes in the sediment dynamics based on the investigations of Schulte *et al.* (2006). The data will be discussed in detail by Albrecht (2007). This also involves the details of bedding phenomena, grading and lamination of the sediments.

Landscape changes in the drainage basin of Lake Mladotice were reconstructed from air photos. Figure 3 shows about 1 km^2 of farmland northeast of Zihle in the drainage basin of Lake Mladotice. No changes are visible in the field patterns between 1938 and 1952. Collective farming had the greatest impact between 1952 and 1975, when fields were made much larger. A further increase in the size of some fields is visible in 1987. The photos taken in 1998 show that the size of the fields was reduced again after the political turnabout in the Czech Republic in 1990. Bigger fields facilitate soil erosion due to longer slopes and increased surface runoff.



Aerial Photographs:
Military Topographic Institute, Dobruska

Fig. 3 Air photos of a field about 1 km^2 in size, northeast of the town of Zihle in the catchment of Lake Mladotice. Collective farming had the greatest impact between 1952 and 1975.

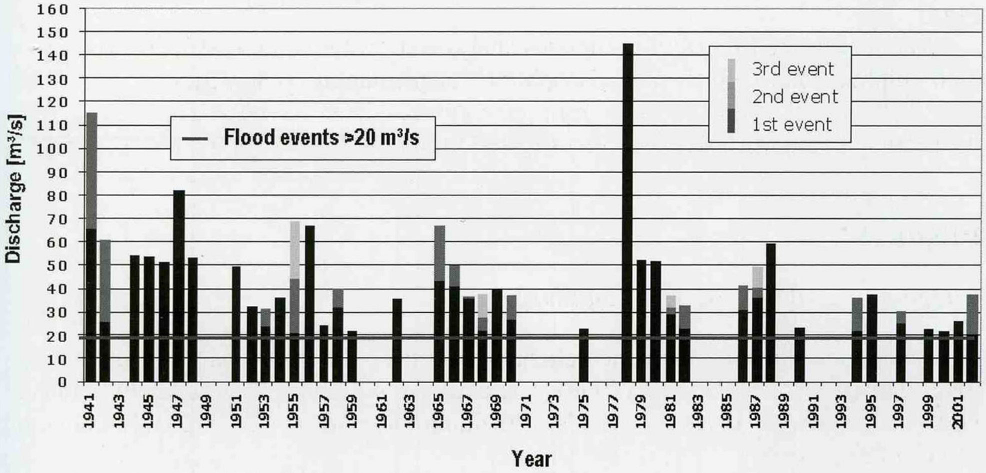


Fig. 4 Flood events of the Strela River (Plasy), 1941–2003, exceeding a maximum discharge of 20 m^3 (different grey shades represent several events in one year).

To clarify whether the system changes are due to natural or anthropogenic causes, we analysed the time series of discharge at the Strela gauge at Plasy (775 km^2), recorded since 1941. Figure 4 shows flood events of more than 20 m^3/s; various shades of grey represent several events within a year. These data give a frequency of 34 flood events within 30 years (1941–1971) which decreases to a frequency of 23 events in 24 years (1978–2003). Furthermore, trend analyses show that the magnitude of the peak discharge has been decreasing as well, especially over the past 25 years.

Stratigraphy and geochemistry of lake sediments

The lake sediments of reference core ML 18/03 are largely muddy silts. Sediment cores ML 14/03 and ML 16/03 (Fig. 2) show clear evidence of a system change. According to macroscopic and stratigraphic analyses of these cores the system change occurred at different depths. The sediment chemism of core ML 14/03 shows a distinct increase of TC and TS above a core depth of 200 cm (TS increases six-fold), core ML 16/03 shows the build-up of these elements at a core depth of 100 cm.

Concerning the chemistry of reference core ML 18/03 some of the contents of carbon (TC), phosphorus (TP) and sulphur (TS) double above a core depth of 190 cm. This system change is demonstrated even more clearly by the heavy metal levels. Pb, Cu, Ni and Zn rise sharply above 190 cm. Other elements such as calcium (Ca) show an increase only in near-surface sediments above 60 cm, which correlates with the occurrence of calcite. Also TC, TP and TS show a marked increase near the surface. Owing to the phosphate content of the open water, the lake can nowadays be classified as eutrophic.

Analyses of isotopes

The absolute chronology of the sediments is also based on available ^{137}Cs, ^{241}Am and ^{210}Pb measurements (Fig. 5). The radiation of ^{137}Cs and ^{241}Am maximum at a core

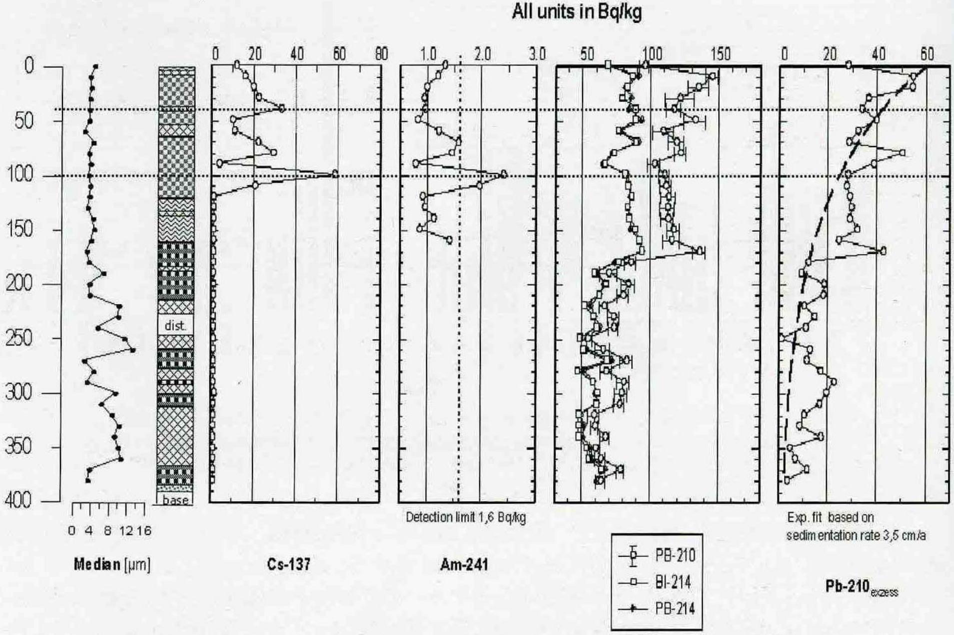


Fig. 5 Isotope contents in reference core ML 18/03 (^{137}CS, ^{241}Am, ^{210}Pb).
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depth of 100 cm is attributed to the 1963 maximum of bomb fallout which started in 1954. Americium clearly demonstrates bomb fallout because there was no emission of americium during the Chernobyl disaster. The peak at 40 cm core depth is assigned to the Chernobyl fallout in 1986.

Thin sections, temporal resolution and sedimentation rates

Thin sections give an additional chronology, in some cases with an accuracy of one year. The new sediment data on geochemistry, isotopes, diatoms and thin sections especially of core ML 18/03 and partly of core ML 14/03 (diatoms) yield the following interpretation (Fig. 6):

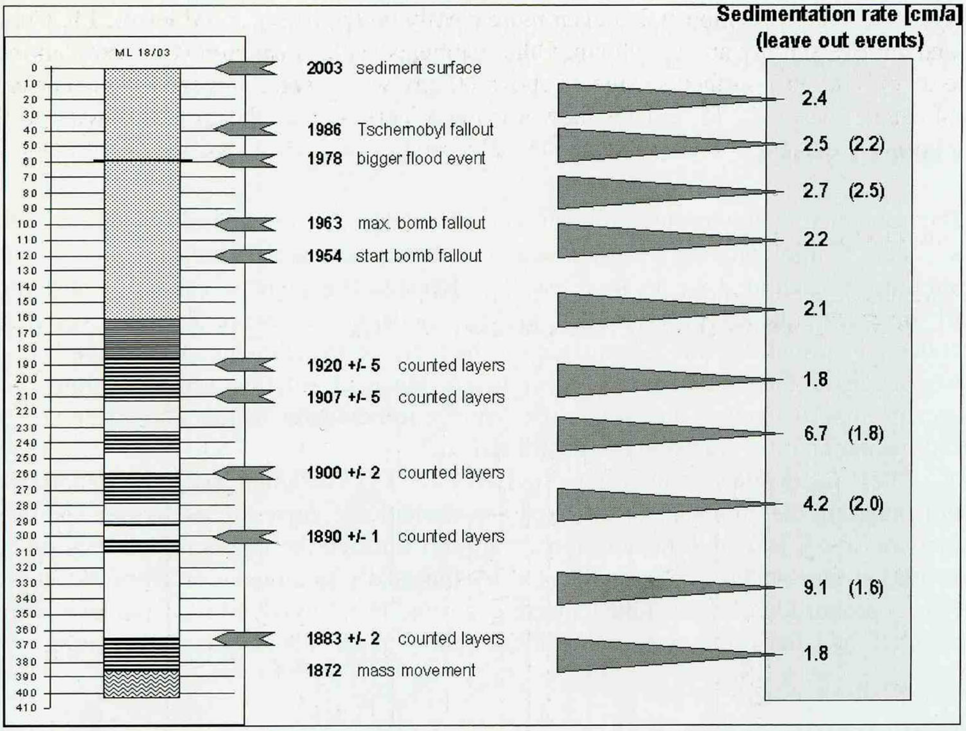

Fig. 6 Results of thin section analyses, temporal resolution and calculated sedimentation rates.

The 1872 landslide impounded the lake and sedimentation began. Thin section analyses show that clastic sediments were deposited in annual layers above the base. It was possible to count the layers up to 1883 with an error of ±2 years. The average sedimentation rate was 1.8 cm/year.

This was followed by a 50 cm thick, homogeneous sequence of unbedded sediment. We interpret this sediment as having been deposited during an event or a phase of events prior to 1890 (average sedimentation rate 9.1 cm/year). The material comes either from the still unvegetated mass failure area at the southern end of the lake (Fig. 2) or from flood input by the Mladoticky creek.

Up to 190 cm core depth, thick unbedded sequences alternate with annually bedded sediments. A layer count dated this depth to 1920. Partial blurring of the boundaries between the layers results in a possible error of ±5 years. Owing to the alternation between event-dependent high sediment inputs and annual sediment layers, there are substantial variations in sedimentation rates between 6.7 and 1.8 cm/year.

Above 160 cm core depth there is a clearly bedded diatom mud that can be dated relatively accurately by various sediment analyses. The start of bomb fallout in 1954 provides a time marker (120 cm core depth). The sedimentation rate between 1920 and 1954 was calculated at 2.1 cm/year. Maximum fallout at 100 cm core depth occurred in 1963 (sedimentation rate 2.2 cm/year). The next time marker is the flood of 1978, shown by a distinct event layer and a change in diatom composition. The sedimentation rate from 1963 to 1978 was calculated at 2.7 cm/year. Until the fallout from Chernobyl in 1986 the sedimentation rate fell only slightly to 2.5 cm/year. The rate is 2.4 cm/year between 1986 and the sediment surface (2003).

CONCLUSIONS

Data obtained from various sediment analyses yield a high temporal resolution of the sediment stratigraphy. In 1920 the sedimentation rate was 2.1 cm/year, then came a slight rise, reaching 2.7 cm/year after 1963. Because this increase cannot be attributed to greater frequency or amplitude of big floods we conclude that the switch to collective agriculture was responsible for the increase in sediment entering the lake. If we disregard the extraordinary event layers when calculating sedimentation rates, greater importance then attaches to the "change in land use" factor. The differences in sedimentation rates are smaller, but still remain.

These results may be interpreted in two ways. (1) The amount of soil erosion from the parts of the drainage basin used for agriculture corresponds to the sediment increase in the lake and the additional transport through the lake. (2) Soil erosion has increased much more than is indicated by the lake's sedimentation rates, because a (large) proportion of the sediments were deposited in colluvial, alluvial and lake inflow areas. If the latter is the case, such sinks are likely to provide relevant information.

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