Mining Subsidence-generated legacy sediments in a Mid-European low-order stream floodplain as an archive for historic human activity and flooding events

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Background

In an interdisciplinary project (with collaboration of the IWW and EMR, both RWTH Aachen University), which will be funded by the DFG (German Research Foundation) from July 2015, we investigate the human impact on the Wurm River (Fig. A) on a local scale, quantifying and evaluating marker substances from sewage disposal and coal mining in conjunction with landuse change and in particular the impact of water mills and ponds that alterate the fluvial morphodynamics. Focusing on source-specific contaminants we try to evaluate the impact of construction and abandoned water mill channels and ponds, past flooding events, remobilization of heavy metals and downstream dilution effects on a local and stream length scale.

Modern river systems in central Europe can be termed „humanized fluvial systems", as those are highly influenced by human activities. An increased impact in medieval times (forest clearing, mill ponds) changed the river systems. Since the industrialization heavy metals and other contaminants are accumulated in the flood plains. A high degree of sealing, river regulations and the immission of contaminants from industrial processes results in changing of river shape, gradient and and sedimentation rates including contaminated sediment. Alluvial sediments are suitable as an archive for this human impact. So-called legacy sediments (James 2013) are in particular rich archives, providing insight in e.g. industrial activity that occurs in the catchment of the river.

In this study, legacy sediments are determined as sediments that accumulate in sediment traps which form under the influence of mining subsidences occurring in the flood plain of the Wurm River (Fig. B). This low-order stream in North Rhine-Westphalia (Germany) near the Dutch border is notably characterized by a long coal mining history, causing subsidences and pollution (Fig. A). Local special industries (tanneries, dye works, metal working, among other) in the City of Aachen, which is located in the upper catchment, leave their marks especially for the last 200 years in the floodplain sediments.

A

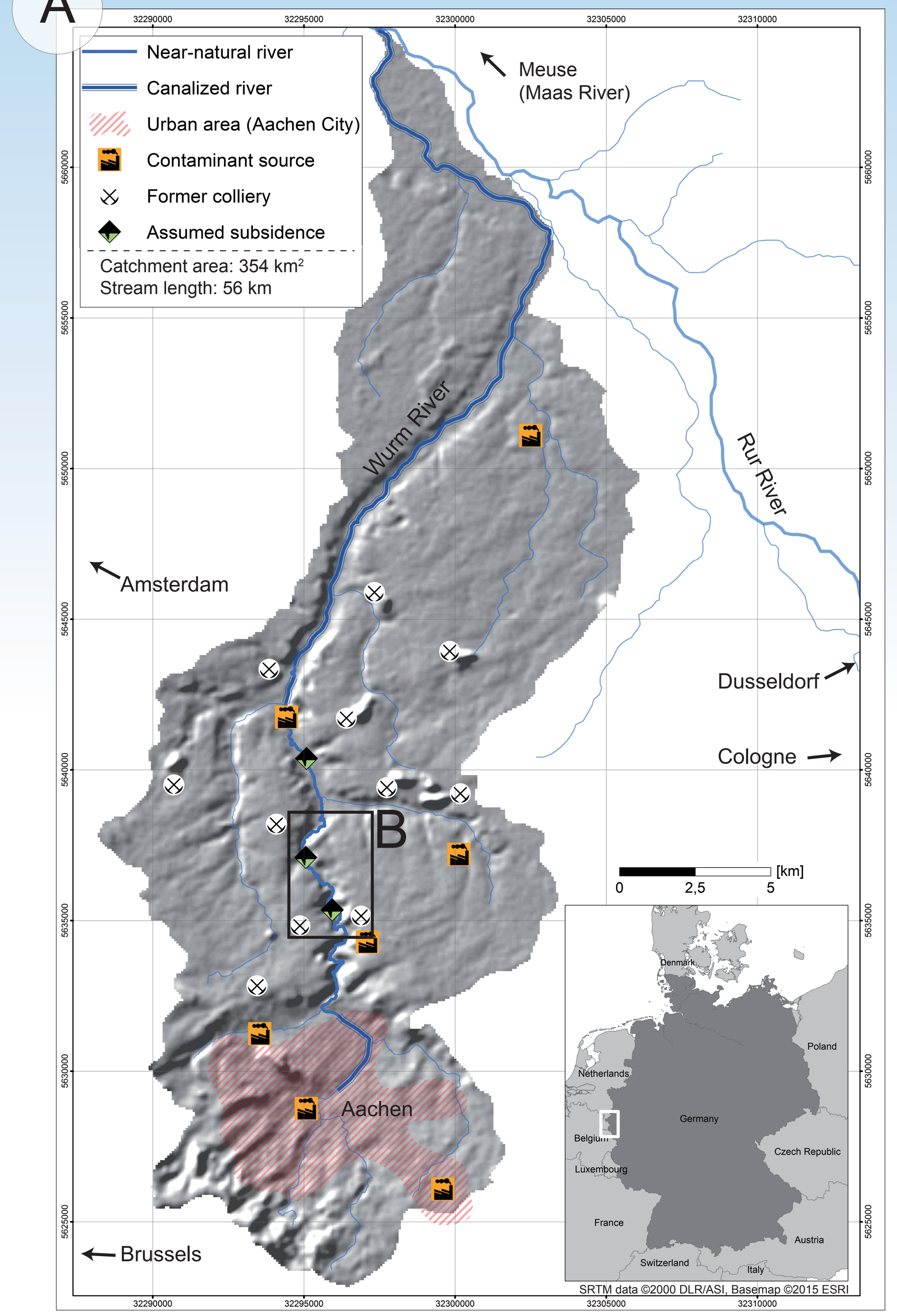
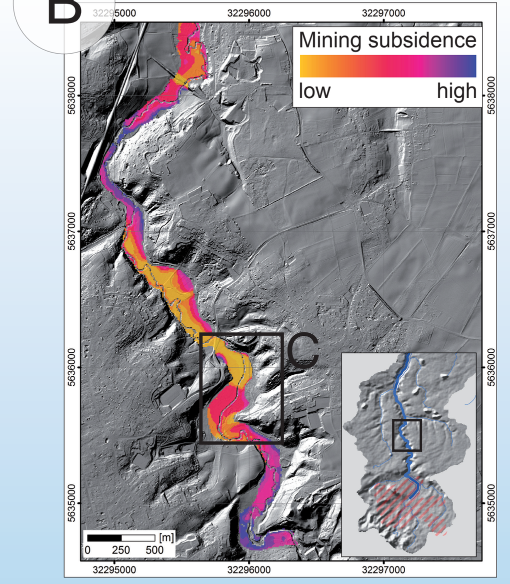


Fig. A: Study area. The Catchment of the Wurm River features several abandoned collieries and contaminant sources, causing mining subsidences in the floodplain and alluvial sediments that archive the industrial history of the area. Water mills (not visualized, count 99) are distributed along the whole river.

Fig. B: Mining subsidence derived from up-to-date DEM and historical maps. Values serve as indicator for field work since high error values occur near valley flanks

B



C

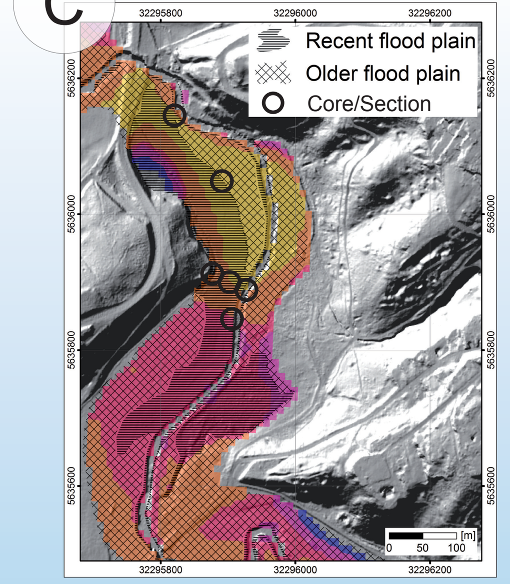
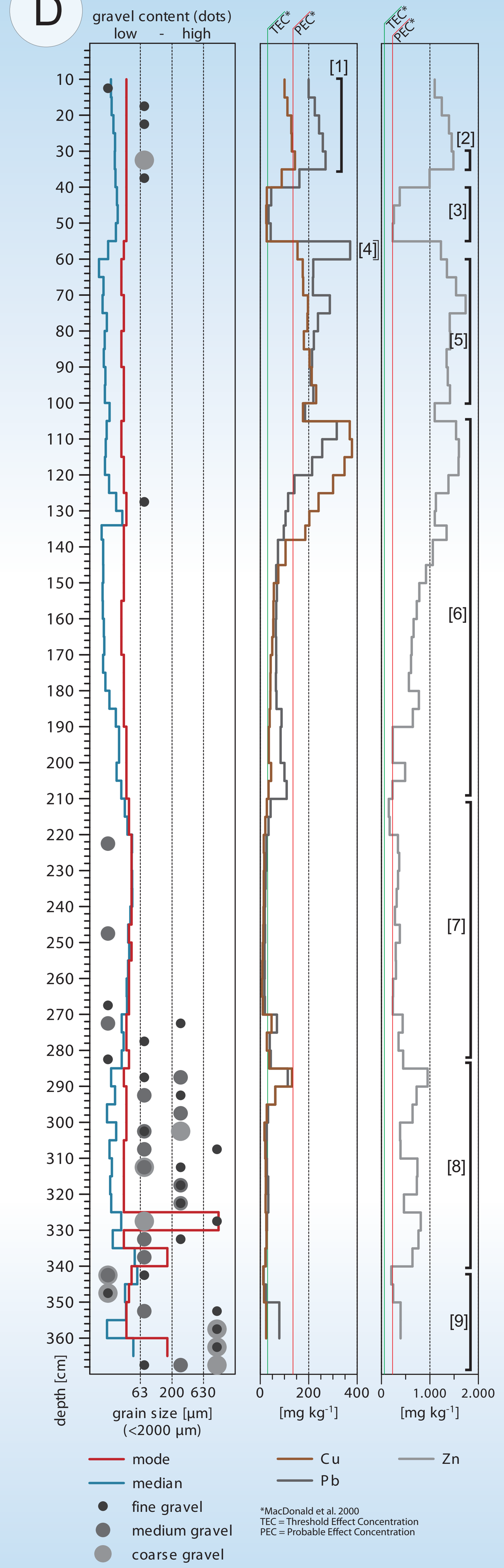


Fig. C: Location of sample sites chosen by recent flood plain geometry and subsidence occurance

D



[1] Thesis: Pb content shows switch from leaded to unleaded gasoline. Upper flood plain soil containing fining up sequences

[2] Thesis: Contaminants-bearing crust from industry due to poorly developed sewerage system, washed out by extraordinary heavy rainfall events. Most likely to be correlated with documented extreme event in 1975 (also indicated by local knowledge).

[3] filling consistent of allochthonous sediment (loess?), probably to level unevenness in pasture land. Pristine material not affected by alluvial sedimentation

[4] former flood plain surface, buried by applicated allochtonous sediment. For Pb content see [1]

[5] trace metal loaded fine material accumulated due to change of landuse and e.g. aeolian trace metal immission (?)

[6] increasing contamination sinc beginning of industrialization

[7] preindustrial sedimentation with embedded flood episodes (marked by medium gravel dots)

[8] early mining activitys respectively processing of ores from the vicinity (rich ore deposits located in a nearby catchment) in local water mills. Highly dynamic fluvial environment (stream bed)

[9] stream bed sediments, gravel dominated. Low trace metal values due to lack of fine material (probably medieval age, therefore concentrations below geogenic background anyway)

Fig. D: Sediment core (location see Fig. C) providing an continous record since medieval (?) times (Dating in prep.), containing several peaks that can be correlated to anthropogenic sources and landuse changes. Calamine-bearing carboniferous limestones can be assumed as a source for high geogenic background of Pb and Zn.

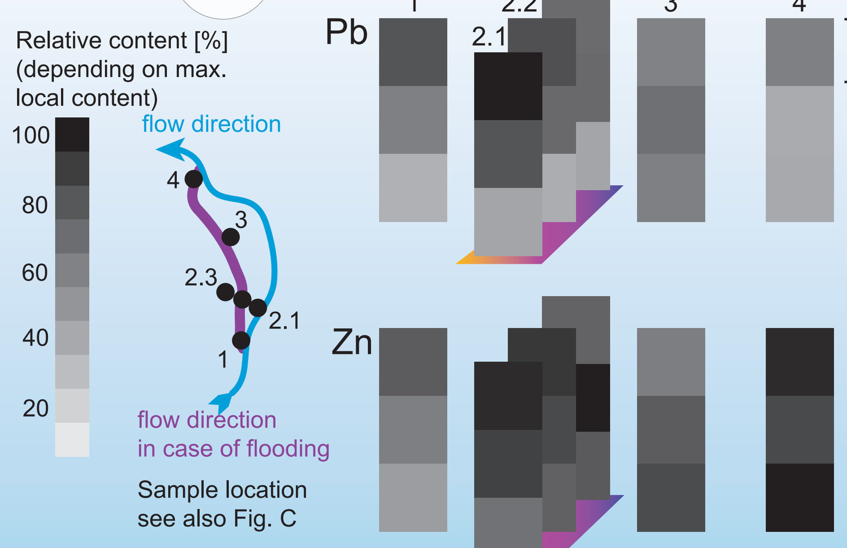
Methods/Results

We chose a combination of grain size and X-Ray fluorescence analysis for a set of sections on the riverbanks and core drillings in the flood plain. This is complemented by geochemical analyses to detect source-specific contaminants, physical and numerical modeling for evaluation of subsidence processes in the flood plain and gamma spectrometry for Cs-137 content. The latter is used as age control and thus indicator for sedimentation rates (Fig. F/G). Sedimentation rates vary from 0.6 to 1.0 cm/a in areas that are unaffected by subsidence and 1.2 to 2.6 cm/a that are obviously subsided.

The samples show multiple Cu-, Pb-, and Zn-peaks (Fig. D) as well as Cr- and Ba-peaks (Fig. F/G). Pb- and Zn-values show dilution effects on a very local scale (Fig. E), decreasing both in vertical and horizontal direction as the industrial impact changes over time and trace metal content dilutes in flooding direction with decreasing flow velocity. Local knowledge is gathered to link trace metal peaks with flooding events and contaminant sources (Fig. G). Mining subsidence effects (Fig. H) is currently modeled to evaluate its impact taking the former and recent stream channels into account. We plan to evaluate dilution effects downstream from spring to mouth as well as backwater effects. Mill impact in fluvial morphology is in preparation, using DEMs and aerial photos from different time slices.

Fig. E: Local dilution effects of Pb and Zn in directions of flood stream and subsidence. Relative content is converted to greyscales.

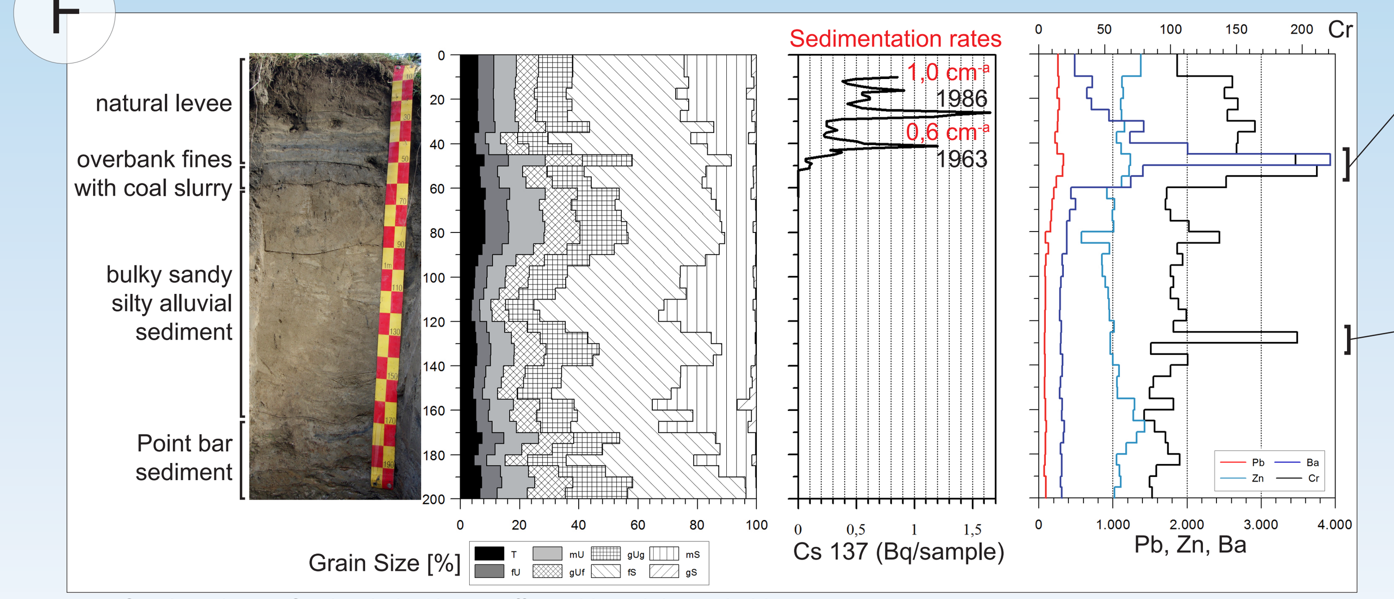
E



Pb contents range from 226 to 375 mg/kg in the upper units, 146 to 304 in the second units and 149 to 238 at the base, showing a significant decrease both in vertical and horizontal direction, indicating subsidence from section 2.1 to 2.3 and local dilution effects from 1 to 4

Zn contents range from 993 to 1539 mg/kg in the first units to 1250-1588 in the second and from 1080 to 1593 in the third, indicating subsidence from section 2.1 to 2.3 as well, besides distribution is ambivalent

F



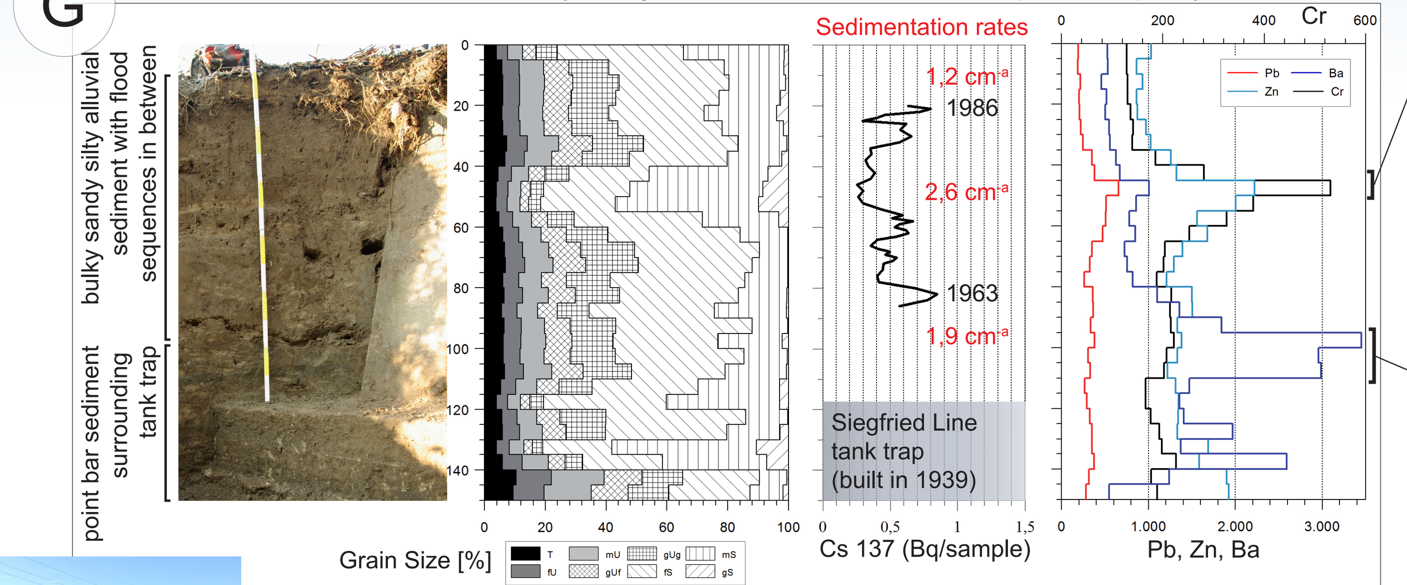
Section above: Cut bank that is not affected by mining subsidence

Barium peak probably correlated to coal washing (with barium sulfate). Decreasing Ba content in the upper part of the section supports this since the nearby coal mine was abandoned in 1969.

Most likely to be linked to local industry like tanneries or dyeworks that were active Cr sources in late 19th, early 20th century. Single peak could represent a single remobilization event.

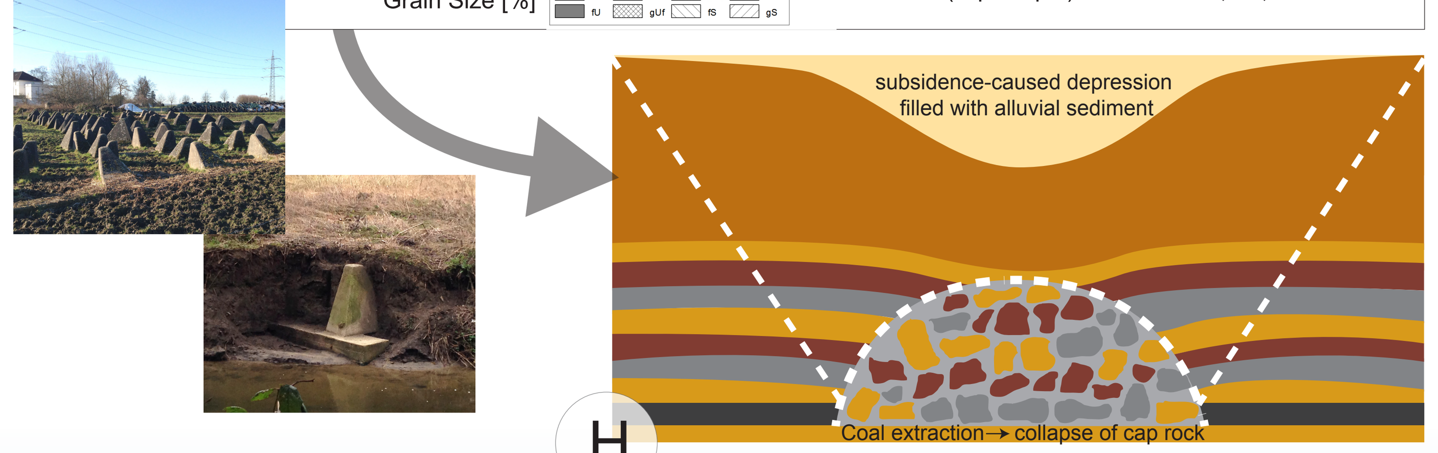
G

Section below: Cut bank that is affected by mining subsidence. World War II-Tank traps are completely sunken



Due to poorly developed sewerage system, trace metal rich crust (esp. Cr) from sewerage containing industrial wastewater matter was washed out by extraordinary heavy rainfall events (see grain size distribution).
Most likely to be correlated with documented extreme event in 1975 (indicated by local knowledge, sedimentation rates supports this dating).

Barium peak most probably correlated to coal washing (with barium sulfate). Decreasing Ba content in the upper part of the section support this since the nearby coal mine was abandoned in 1969.



H

Fig. H: Scheme of subsidence process that occurs as a result of collapsed coal mining galleries. Trough functions as sediment trap for alluvial material.
1. Picture on the left: Example for Siegfried-Line tank traps in original position
2. Picture on the left: Subsided tank trap (same as in section showed in Fig. G)

Discussion

Floodplain sedimentation (Fig. D) is based on pristine alluvial material, showing high trace metal values though because of high geogenic background. With decreasing depth, values increase, marking the initial industrialization. In the flood plain, Pb contents decrease from in- to outflow point of a 30-year flood event discharge as well as in subsidence direction. However, this is not applicable for Zn values, although a dilution towards subsidence is indicated. The top of the section provides information about industrial processes upstream. Fig. G shows a section containing a subsided tank trap of World War II's Siegfried Line. Subsidence is evidenced by Cs-137 measurements in natural alluvial sedimentation, supported by trace metal peaks that can be correlated to sources and events. A section that is not under subsidential influence locates in the vicinity (Fig. F) is characterized by significant lower sedimentation rates.

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