HOW TO FIND SEDIMENTARY ARCHIVE OF FLUVIAL POLLUTION IN A BEDROCK-CONFINED RIVER REACH

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INTRODUCTION

The Ohře River (L: 316 km, A: 5606 km^2) springs in the Eastern Bavaria (the Eger) and its confluence with the Labe (the Elbe) is in the North-West Czechia (Fig. 1).

The river has received pollution from several sources active non-coevally during the last 5 centuries, (Fig. 2). Most of those sources were in the upper and middle river reaches where the deposition/erosion patterns of the river are highly variable. The upper part of the catchment has mainly felsic rocks and the river has a broad floodplain. In the middle reach the Ohre River and its right-bank tributaries are deeply incised into the Doupovské Hory Mts., a large body of mafic volcanic rocks, while left-bank tributaries are incised in intrusive and metamorphic rocks of the Krušné Hory Mts. with several local ore regions, in particular in the Oloví and the Jáchymov areas (Ag, Pb, and U). The geologic and geomorphologic complexity has two main consequences: deposition of historical sediments in the middle reach has been limited and spatially uneven and anomalous background concentrations of risk elements are expected.

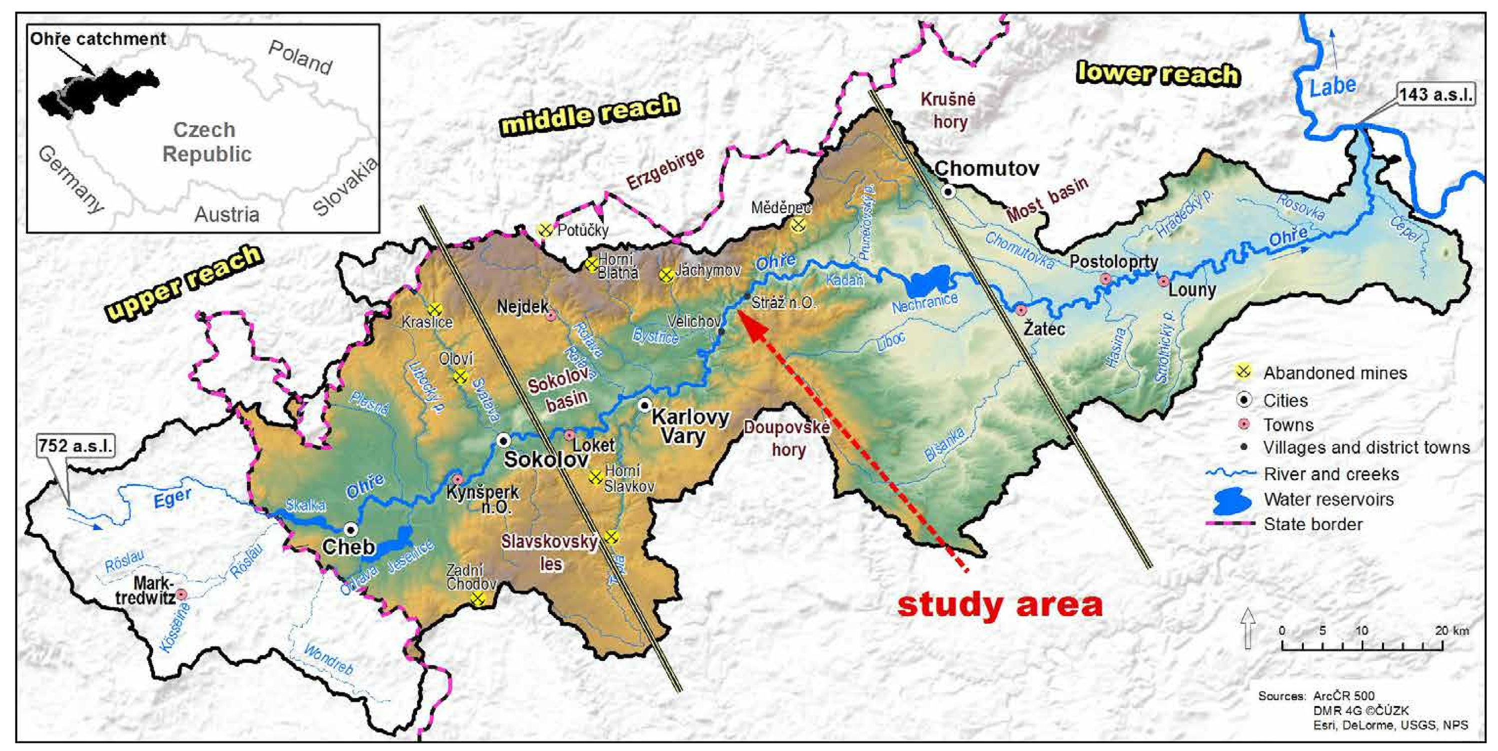
It is not easy to find a useful sedimentary archive of historical pollution in the middle reach of the river, but it would be desired for two main reasons: (1) to decipher poorly described pollution history from the Krušné Hory and Doupovské Hory Mts., mostly undocumented in written archives and (2) to better understand retention of pollutants in the transport zones of a bedrock-confined river system.

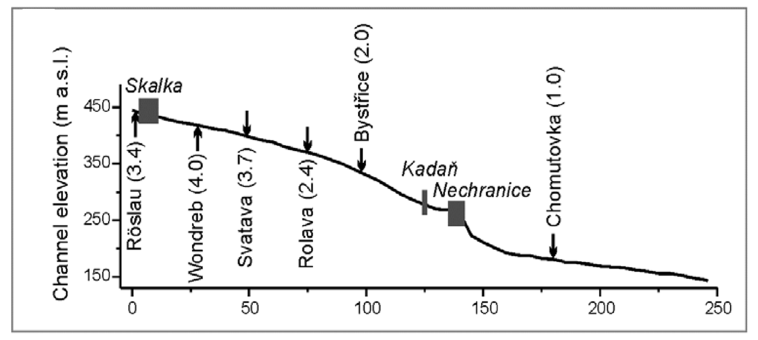
GEOINFORMATIC AND SAMPLING METHODS

Datasets for GIS analysis were purchased from the Czech Office for Surveying, Mapping and Cadastre (© ČÚZK) and Military Geographic and Hydrometeorology Office (© MO ČR). The Imperial Obligatory Imprints of the Stable Cadastre (1840s) and the topography map from 1958 were georeferenced to actual cadastre map. The historical photographs from 1938 and 1953 were orthorectified using ERDAS 2015 software and land-use changes were determined. The laser scanning dataset from 2011 (DMR 5G, © ČÚZK) was used to create a detailed digital elevation model (Fig. 5). Based on the digital elevation model and intensive field surveys a detailed geomorphologic analysis of the area (Fig. 4) was performed. Data processing, analysis and visualisation were made in ArcGIS Desktop 10.3 with extension 3D Analyst.

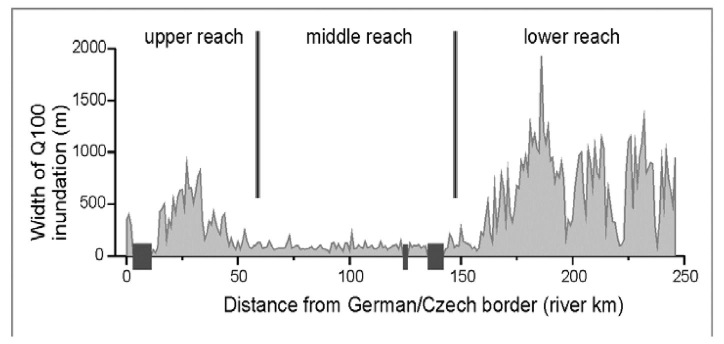
The contamination of the floodplain was analysed mainly by portable (handheld) X-ray fluorescence spectrometer (XRF) Olympus Innov-X (DELTA Premium), which provides fast analysis of more than 30 elements, such as pollutants (Cu, Pb, Sn, U, and Zn) and grain-size sensitive lithogenic elements (Al, Si, K, Rb, Zr) also suitable for sediment provenance tracking.

Fig. 1 Characteristics of the Ohře River system in the Czech Republic.





Channel elevation, position of dam reservoirs and tributaries (mean annual discharge in m^3/s in parentheses).



The width of the floodplain inundated by floods with recurrence 100 y.

Fig. 2 Possible pollution sources in the Ohře catchment

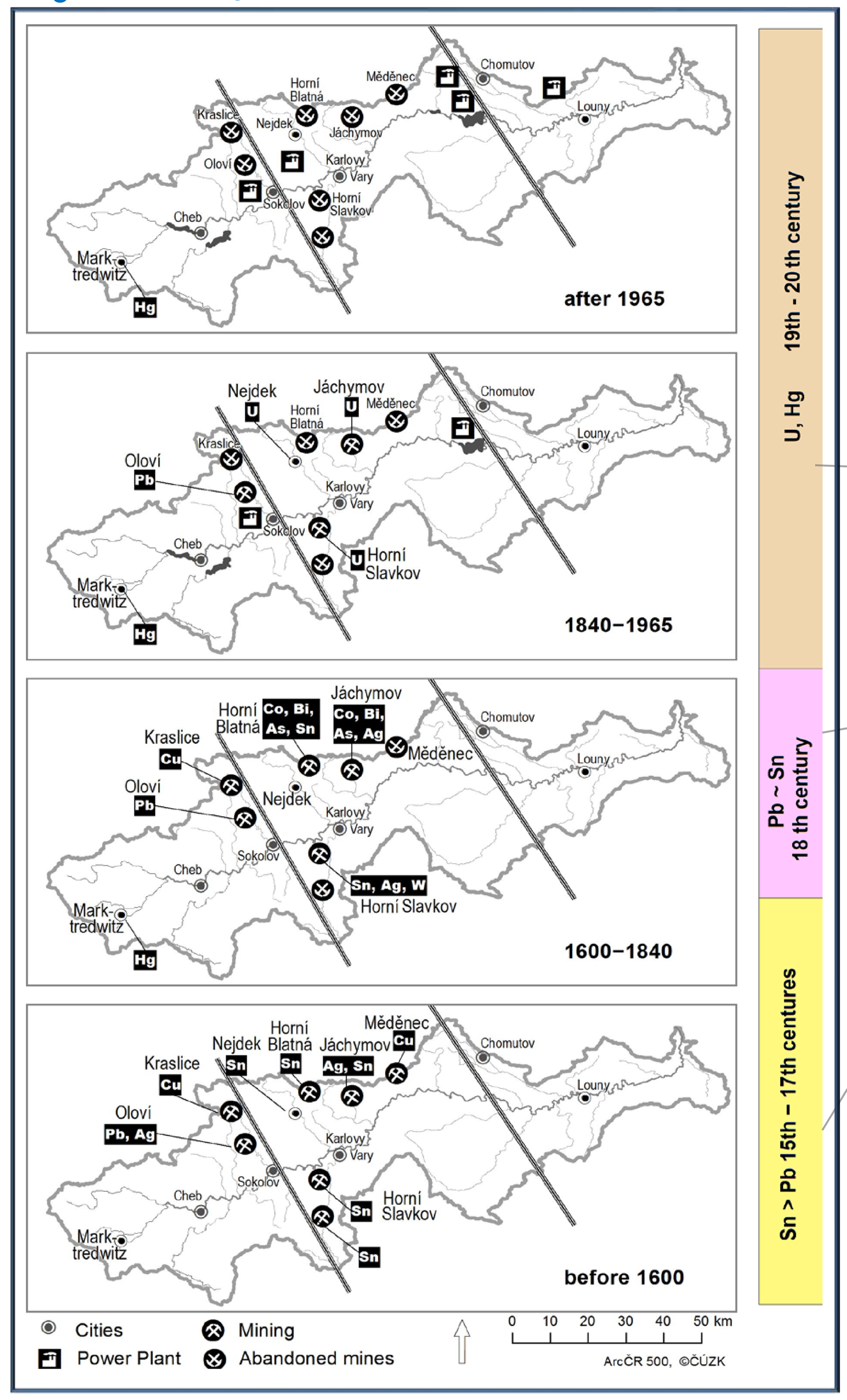
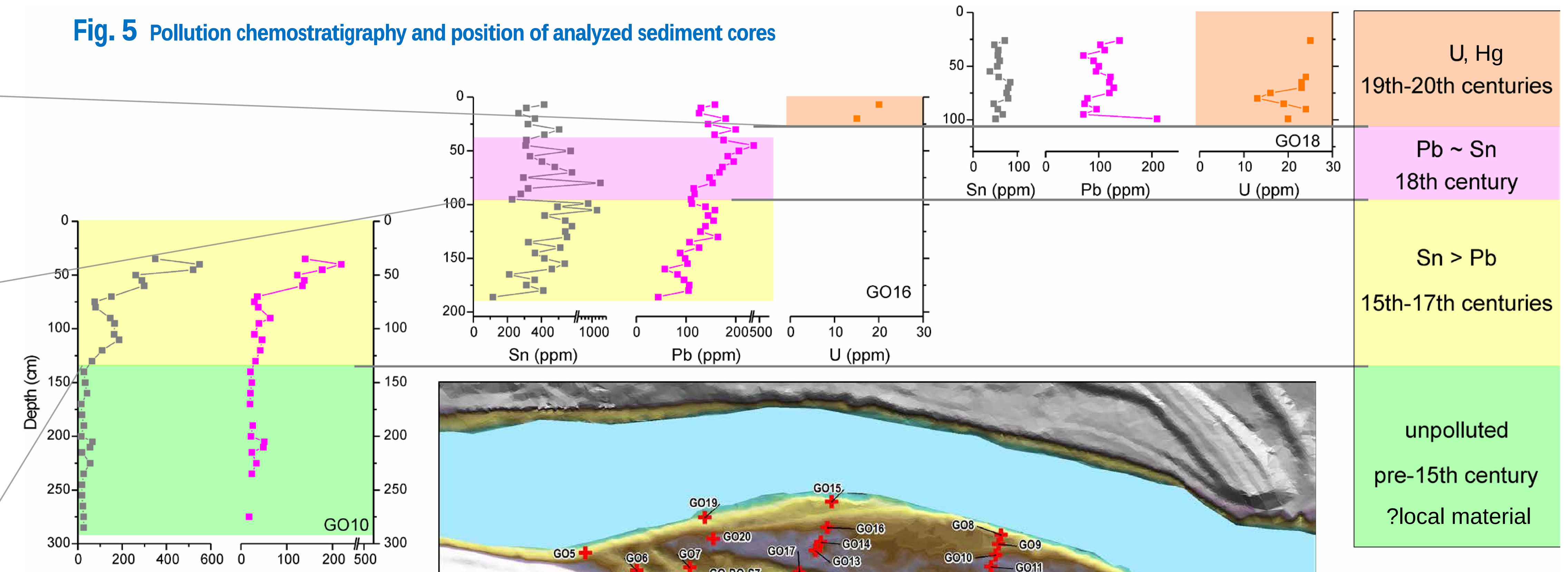
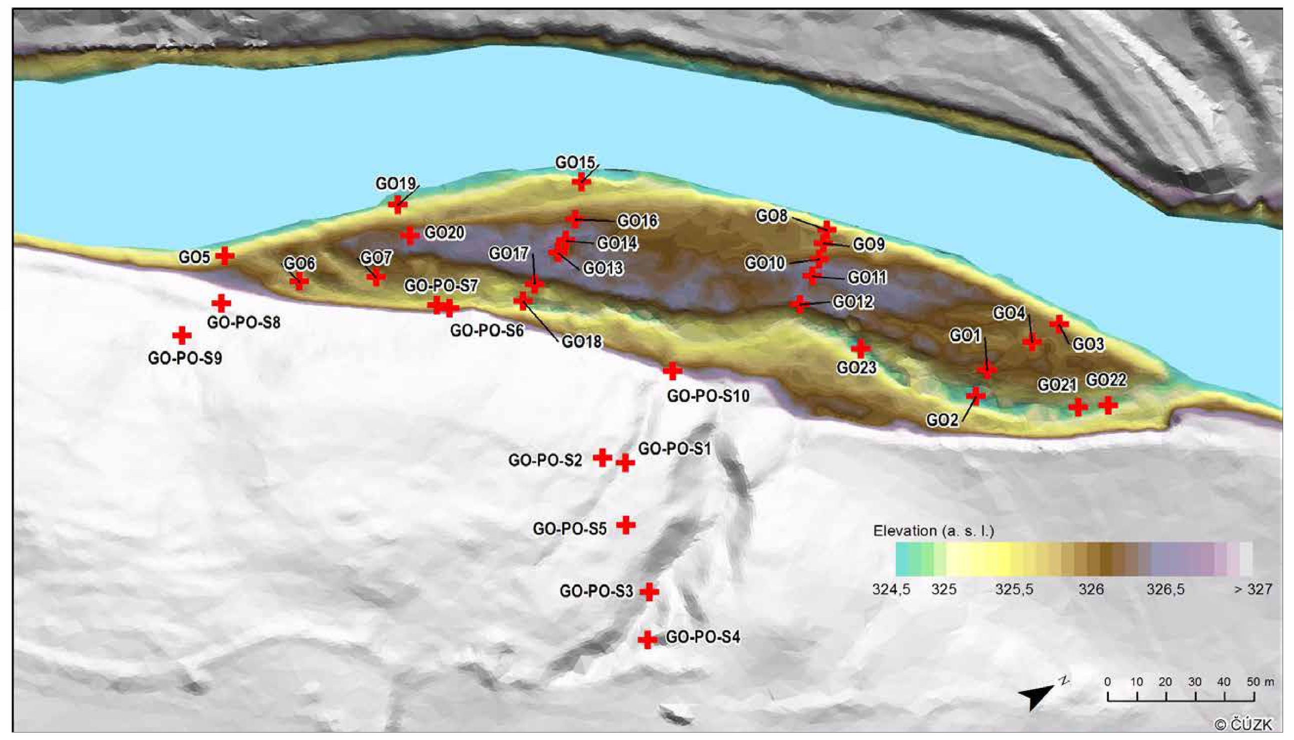


Fig. 5 Pollution chemostratigraphy and position of analyzed sediment cores





STUDY AREA

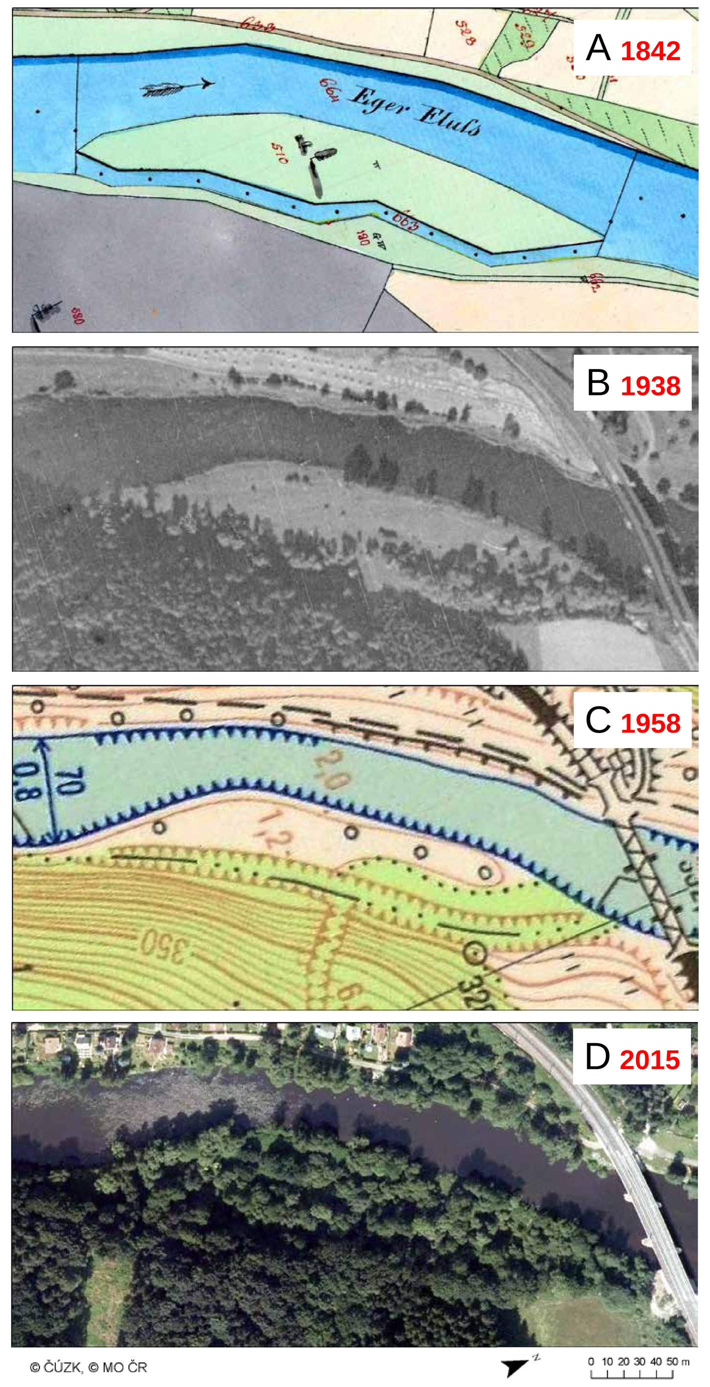
On the base of examination of historical maps we identified a bar (35x320 m in size) in the middle reach of the river near the Stráž nad Ohří and decided to describe its formation, recent erosion/deposition history and evaluate its sedimentary archive value.

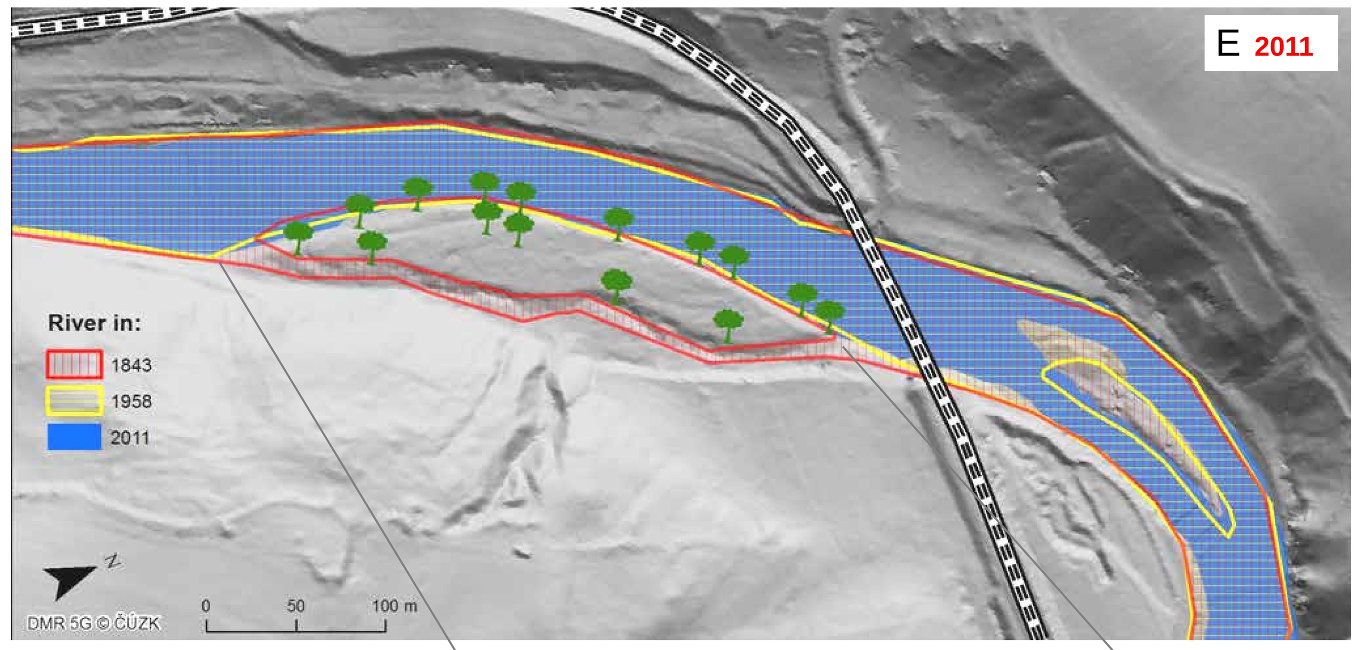
The bar, now a part of the floodplain, was an island (channel bar) according to map made in 1842 (Fig. 3A). Current topography confirms the former island (Fig 3D and Fig. 3E). It is situated in location, where the valley is widened enough to support channel aggradation; similar channels can be found also in neighbouring parts of the river reach. The side channel, which separated the island from the valley side, was no more depicted in 1958 map (Fig. 3C), and we thus assume it coalesced with the valley-side between the 1840s and 1950s. Nowadays only extreme river discharges may pass it.

DATA ANALYSIS

We evaluated the current bar by a detailed field examination of topography, description of trees growing on the bar (identification of species and dendrological dating of selected trees, see Fig.3E and Fig. 4), comparison of those results with historical photographs from 1938 to the present time (Fig. 3A to E), detailed geomorphic description of the surface microtopography (Fig. 4), and OSL dating (still in progress). We also performed in situ XRF analysis of sediment cores in the bar and revealed that most of fine sediments (mostly sand, minor silt) of the bar have been polluted by Cu and Pb mining, SnO_2 extraction, and U ore mining and hydrometallurgical processing from historical sources shown in Fig. 5.

Fig. 3 The study island in old maps and orthophotos





River development during years 1842–2010

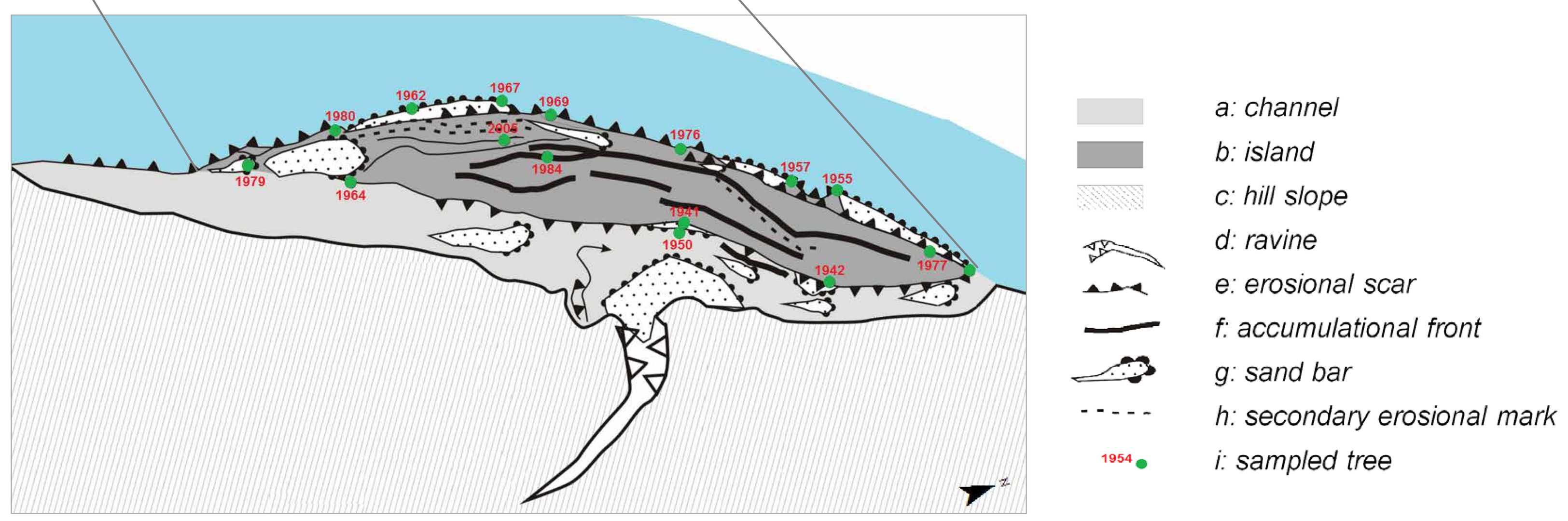


Fig. 4 Geomorphological features of the study area

RESULTS

We evaluated pollution sequence in sedimentary profiles using (1) historical information on ore mining and processing (Fig. 2) and (2) stratigraphic order in sediments from diverse parts of the island. We assumed (1) possible hiatuses in deposition in individual cores, (2) secondary pollution masking "signal of improvement" after cessation of mining (=only the first appearance of pollution has been evaluated), and (3) post-depositional stability of pollutants in sediments (reliable for Sn and Hg, probable for Pb, Cu was not evaluated). The result is shown on Fig. 5.

Unpolluted sediments (Pb and Sn <100 ppm) were found only in the central part of the island (cores GO10 to GO12). Their larges thickness is just below a ravine in the right valley edge. Beside the lack of pollution they also have larger K/Rb ratio than the rest of the bar; also soil strata at the right bank valley edge have larger K/Rb. We assume the channel bar formation was triggered by an alluvial fan formed below the gully. Weakly polluted sediments were found also in GO16.

The prevailing part of the bar has been formed in the recent centuries that is proven by considerable pollution by Sn, Pb and also Cu, of which extraction started in late Middle Ages and – in the case of Pb and Cu – and continued to about 18th century, with a stepwise shift from mainly SnO_2 extraction to Pb mining and smelting.

The youngest sedimentary sequences are found in the fill of the former side channel and in places around the channel edge of the bar (in erosional scars at the bank line) as proven by their enhanced contents of Hg and U. The Hg pollution (from Marktredwitz, Saxony) started by the end of the 18th century and U pollution (from nearby Jáchymov Ore Region) was limited to the period from mid 19th to mid 20th centuries. In the SW edge and former side channel the sediments also have larger K/Rb ratio showing larger contribution of local soil washouts as a sediment source.

CONCLUSIONS

Pollution history of the last centuries is documented in the studied bar in the Ohře River. The pollution history was so variegated that it made possible to reconstruct the development history of the bar. Alluvial fan with unpolluted local sediments was probably a nucleus of the channel deposition that lasted about half millennium as proven by firstly enhanced Pb and Sn, with stepwise change from mainly Sn to mainly Pb pollution, and finally with enhanced Hg and U. The youngest massive deposits with elevated Hg and U are in the former side channel, now nearly filled; some recent deposition is also found on top of the sediment body in SW part of the bar.

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