Sediment characterization and estimation of PCB volume and mass in a Girardon type spur dike field (Rhone): optimization by coupling core and GPR profile analyses

Caractérisation sédimentaire et estimation des volumes et quantités de PCB dans un casier Girardon (Rhône) : Optimisation par l'utilisation couplée de carottages et de profils GPR

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RÉSUMÉ

Afin d'améliorer la navigation sur le Rhône, des travaux d'aménagement fluviaux ont été entrepris au XIX siècle (casiers Girardon) dans le but de contraindre et de réduire la bande active du fleuve avec pour conséquence un stockage de sédiments contaminés par les Polychlorobiphényles (PCB). Dans un contexte de réhabilitation des marges alluviales actuelles (cadre du Plan Rhône, Schéma Directeur d'Aménagement et de Gestion des Eaux) qui intègre le démantèlement de ces aménagements, il est primordial d'estimer les volumes et masses de sédiments pollués afin d'adapter les travaux de réhabilitation. Nous présentons une méthode de caractérisation du remplissage sédimentaire, à l'aide d'un radar géologique (GPR) et de carottages, permettant une évaluation des dimensions des différentes structures sédimentaires et une estimation des stocks de pollution en PCB en place dans un tel aménagement. Le volume total des sédiments du casier étudié (102 m x 102 m) est estimé à 24 203 m^3, soit une masse de sédiments stockés d'environ 30 250 tonnes, et la masse de PCB stockés dans ce casier est estimée à 1,26 kg.

ABSTRACT

To improve navigation on the Rhone river, river development works were undertaken in the 19th century (Girardon spur dikes) in view to constrain and reduce the active channel of the river, resulting in the storage of sediments contaminated by polychlorinated biphenyls (PCBs). In the framework of restoring the current alluvial margins (programmed in the Rhone Plan, Master Development and Water Management Plan) which incorporates the dismantlement of these developments, it is vital to estimate the volumes and masses of polluted sediments deposited in them in order to adapt the restoration works. We present a method for characterizing sediment fills using ground penetrating radar (GPR) and coring to perform the assessment of the dimensions of different sediment structures and an estimation of the stocks of PCBs pollution in place in such dike fields. The total volume of sediments of the spur dike field studied (102 m x 102 m) is estimated at 24 203 m^3, i.e. a mass of stored sediment of about 30 250 tons, while the mass of PCB stored in it is estimated at 1.26 kg.

KEYWORDS

Dike field, Girardon spur dike, Ground Penetrating Radar, Polychlorinated biphenyls (PCB), River Rhone (France).

1 INTRODUCTION

To improve navigation on the River Rhone, river development works (called “casiers Girardon” or spur dikes) were carried out in the 19th century narrow the active channel of the river, resulting in the storage of sediments contaminated by polychlorinated biphenyls (PCBs). Consequently, the current alluvial margins of the Rhone are the focus of projects that incorporate the dismantlement of these dike fields. This makes it vital to estimate the volumes and masses of polluted sediments deposited in them in order to adapt the restoration works. The study highlights (i) a sediment structure linked to the filling mode revealed by geophysical investigation (Ground Penetrating Radar or GPR): (ii) the temporality of pollution storage in comparison to the spatial dimension of the structures revealed by the diachronic study of the progression of the river banks, in order to (iii) spatialize and quantify the volumes and masses of PCB present.

2 MATERIALS AND METHODS

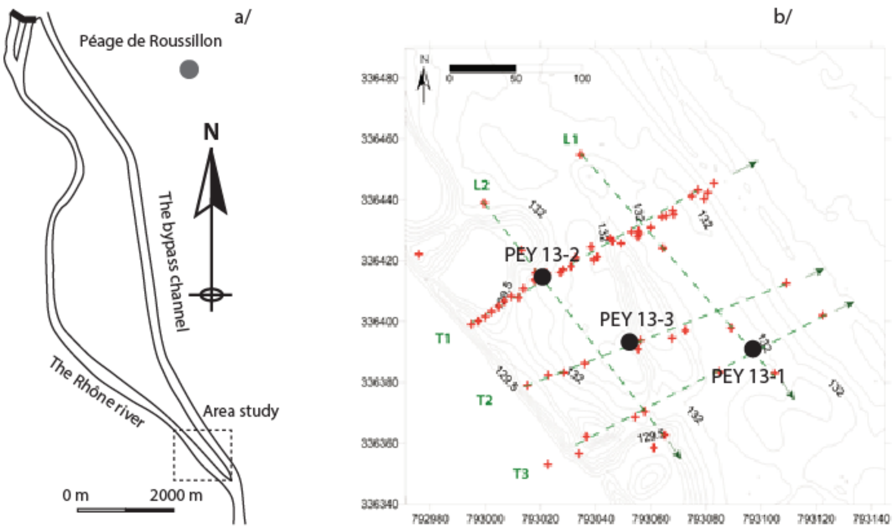

Figure 1: a/ localization of the spur dike field studied; b/: localization of transects obtained by GPR: the crosses correspond to GPS points, the black circles are the points where the cores were taken.

The site investigated is located along the Rhone Valley downstream of Lyon (France), in the municipality of Péage-de-Roussillon (figure 1.a/). The use of GPR, a geophysical method based on the propagation of electromagnetic waves, is particularly suited to the study of alluvial formations (Néal, 2004) and fill structures, but it above all provides the 3D architecture of sedimentary structures (Mumphy *et al*., 2007, Mermillo-Blondin *et al*.). To obtain this information, five transects were drawn: three transversal transects (T1, T2, T3) and two longitudinal transects (L1, L2), each with a length of 102m (figure 1.b/). Three cores, whose depth was limited by the old bed of the Rhone composed of gravel and forming the wall of sediment fill since the development works of the 19th century, were taken (PEY 13-1: 2.87 m; PEY 13-2: 1.69m; PEY 13-3: 4.50 m; Figure 1.b/). These cores were positioned in order to cross as many structures as possible. A detailed description and granulometric analyses permitted verifying the limits of the structures. Lastly, nine measures of PCB concentrations were performed.

3 IDENTIFICATION OF SEDIMENT STRUCTURES AND CHRONOLOGICAL RECONSTITUTION

The study of five radar profiles permitted the identification of eight sediment units that can be grouped into three ensembles from east to west (example of profile T2, figure 2.a/). The analysis and interpretation of the radar profiles made it possible to position the upper layer of the gravel (former bed of the Rhone before the development) and identify the major sediment structures of the fill without performing a preliminary study. The diachronic study based on aerial photographs from 1911 to 2009 was used to reconstitute a time series of spur dike field filling as a function of the different sediment structures. It was compared to the GPR results obtained. Thus it was possible to reconstitute a time series in which four periods were identified (example of profile T2 figure 2 b/): from 1911 to 1958 deposit of units I-a, I-b and I-c; from 1958 to 1972 deposit of units II-a and II-b; from 1972 to 1986 probable erosion of units I-b and I-c and deposit of unit III-a (filling of the median channel); from 1986 to 2009 deposit of units II-c and IV-a. The comparative study of the sediment structures identified on the radar profiles and their evolution over time, were used to establish the chronology of the filling of the spur dike field and reconstitute the history of the formation of these different structures.

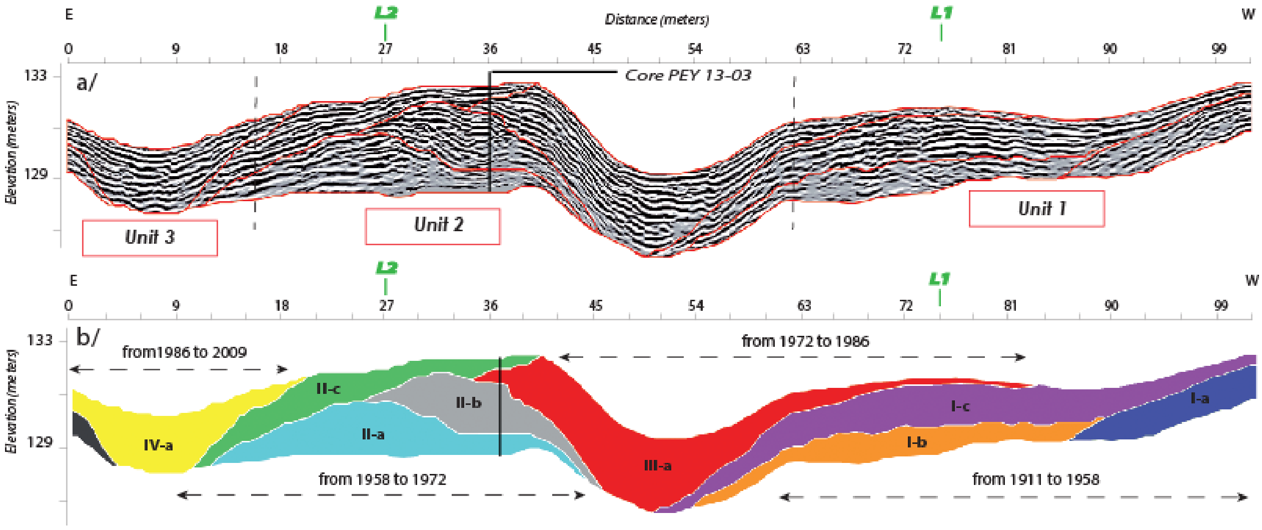

Figure 2: Example of the profile studied. a/ processed radar profile T2 (200 MHz antenna); b/ interpretation of profile T2 with a representation of the different units found and the position of core PEY 13-3.

4 MEASURE OF PCB CONCENTRATIONS AND QUANTITATIVE APPROACH BY 3D INTERPOLATION

The aim of this study was to quantify the mass of pollutants (PCBs) using a limited and sufficient number of samples. Once the sedimentary units were identified using radar profiles, the coring locations were determined in order to group as many of these units as possible (core positions shown in figure 1). Nine PCB analyses were necessary for 8 units (two units were sampled twice and the oldest unit was not analyzed). The oldest formations, deposited between 1911 and 1958, presented very low PCB concentrations: between 0.91 µg.kg^{-1} and 0.63 µg.kg^{-1}. The formations deposited between 1958 and 1972, presented higher concentrations: between 60.99 µg.kg^{-1} and 106.33 µg.kg^{-1}. Peak PCB consumption in France occurred during the filling period between 1972 and 1986, thus explaining the high concentrations found: entre 75.19 µg.kg^{-1} MS and 131.64 µg.kg^{-1} MS. Lastly, between 1989 and 2009, average concentration was 6.48 µg.kg^{-1} MS. Interpolation by 3D kriging of five profiles was performed to obtain a volume of sediments for each unit and a total volume of 24 203 m^{3} of sediment deposited in the spur dike field studied. Given that the average per volume ratio of the sediment is 1 250 kg.m^{3}, it was possible to calculate the mass of PCB contained in each unit. This led to an estimated total mass of PCB in the dike field of 1.26 kg.

Therefore the method used to investigate a stock of sediment and estimate its pollutant content, coupled with coring and GPR profiling performed on site, allowed determining the filling mode and chronology, the spatial positioning of the sediment structures and their respective volumes, the mass of PCBs contained in each sediment unit identified and, lastly, the total mass of pollutants.

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