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Dating of sediment record at two contrasting sites of the Seine River using radioactivity data and hydrological time series

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ABSTRACT

Sediment cores were collected at the outlet of the highly anthropogenized catchment of the Seine River at two contrasting sites: a flood plain of the lower Seine River and a quasi-permanently submerged harbour basin (or wet dock) in the upper tidal estuary.

Analyses of artificial radionuclides (^{137}Cs and plutonium isotopes), coupled with hydrological and bathymetric data, lead to a precise dating of the sediment cores collected at the two sites.

^{137}Cs signals originating from global fallout (early 1960s) and from the Chernobyl accident (1986) are identified, but at different levels due to the incomplete nature or variable continuity of the records. Anomalous ^{238}Pu concentrations found at both sites (1–2 Bq kg^{-1}) are attributed to unknown industrial releases originating from upstream. Interpolating ^{137}Cs sediment activities under the assumption of a constant sediment rate, those releases were dated back to 1975 ±1, thus providing a local but reliable time-marker.

Age models have highlighted a very contrasting sediment filling dynamics in these two sites. This study presents the first sediment record of alpha- and gamma-emitting artificial radionuclides obtained at the outlet of the huge catchment area of the River Seine, over a period covering the last 50 years.

1. Introduction

Long time series are valuable tools for analysing the environmental impact of the production and utilization of potentially hazardous elements or substances, and for assessing the recovery of ecosystems in response to operational and discharge limitations. Unfortunately, a number of contaminants already impacted ecosystems well before reliable analytical methods were made available to assess their concentrations for environmental monitoring or research purposes. Therefore, the long-term reconstruction of environmental contamination relies on the analysis of archives, based on sample banks or natural records (sediment or ice cores, corals, speleothems, tree rings, etc.) with updated analytical tools (e.g. Lecavalier et al., 2013; Sabatier et al., 2008, 2012; Shen et al., 2012).

In highly anthropogenic ecosystems, especially rivers and estuaries, it is always a very challenging task to identify and date suitable undisturbed sediment records. Indeed, sedimentation areas have often been disturbed by various human activities (dredging, navigation, harbour development, etc.). Once located, these sediment records need to be dated, and their continuity assessed as well. With this objective in view, natural and artificial radionuclides can be used to provide efficient time-markers. The ^{210}Pb excess method is particularly well suited for the dating of sediments deposited over the last few decades (e.g. Du and Walling, 2012; Kirchner, 2011; Le Cloarec et al., 2011; O'reilly et al., 2011; Petit et al., 1987; Sanchez-Cabeza and Ruiz-Fernández, 2012; Saravana Kumar et al., 1999), yielding accumulation rates and allowing the identification of sedimentary hiatuses. Unfortunately, different tributaries in rivers or estuaries have contrasting ^{210}Pb signatures, and also show variations with time, which prevent the efficient use of this method (Le Cloarec et al., 2011).

Artificial radionuclides are powerful chronological markers provided that they can be related to well documented events or releases. As a result, they can only be used to access sedimentation rates for intervals between dated horizons in a sediment core.

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To reconstruct the historical contamination of the Lower River Seine, sediment cores were collected in two contrasting environments: a flood plain of the lower Seine River and an old careening basin (or wet dock) in Rouen harbour (upper tidal estuary) that has not been dredged for several decades (1970s). In this study, we report the dating results obtained from these cores using artificial radionuclides (^{137}Cs, ^{238}Pu and ^{239,240}Pu), yielding a 50-year long sedimentary record of unprecedented quality, corroborated by hydrological and bathymetric considerations.

2. The Seine River and its catchment area

The Seine River is 776 km long and drains a catchment area of 78 650 km^2, including the densely populated and industrialized region of the Paris Basin. Over the last 70 years (1941–2010), its mean discharge has been 450 m^3 s^{-1}, ranging from 100 m^3 s^{-1} during low flows to 2200 m^3 s^{-1} during floods (data: Service de Navigation de la Seine). The river tide (or tidal pulse) is propagated upstream over a distance of 160 km from the mouth at Le Havre (Kp 360; the reference point Kp 0 (kilometric point) is situated at the Pont Marie in Paris) to a dam at Poses (Kp 202). The estuary is divided into three parts (Fig. 1): the upper estuary (or fluvial estuary), the middle estuary and the lower estuary. The upper estuary conveys only fresh water; although subject to the river tide, its regime is dominated by fluvial discharge.

2.1. Site on the flood plain of the lower River Seine

The first coring site is located at Bouafles (Kp 170), 30 km upstream from the Poses dam (corresponding to the anthropogenic upstream limit of the tidal estuary, Fig. 1). It is situated in an abandoned channel of the Seine River that is nowadays filled (Fig. 2), corresponding to a flood plain influenced by sedimentary inputs from the Seine River during river floods since the early 1960s. Before this period, the site was continuously submerged. Between 1990 and 1995, an embankment was built at the entry of the channel to limit flooding, but the highest floods nevertheless led to sedimentary inputs from the river. The last severe flood took place in 2004.

2.2. The upper estuary site

The second coring site is located in the upper estuary of the Seine River (Kp 251), in a disused dock at Rouen called “la Darse des Docks” (Fig. 3). Built in 1930, this dock was used intensively as a naval repair facility until the end of the 1950s, but this activity declined drastically from the 1960s onwards to cease definitively in 1988. Inspections of historical bathymetric charts permit to assume that certain parts of the dock have not been dredged since 1960. In the south-eastern part of the dock, the data provided by the Grand Port Maritime de Rouen (GPMR, Rouen harbour authority) allow us to assume that the site chosen for the coring remained undisturbed over this period of time.

3. Sampling and analytical methods

3.1. Sediment coring technique

At the on-land site of Bouafles, coring was carried out with a percussion corer. A 130-cm-long core was collected. On the submerged site of the Darse des Docks, the same corer was adapted to be used on a barge, and a 580-cm core sample of consolidated mud was collected. At this site, a long box-corer (gravity corer) was also used to collect the superficial unconsolidated mud, thus making it possible to retrieve a 105-cm-long core which included the soft surface mud. Subsequently, the two cores were combined together into a single profile. The loss of sediment at the interface and the compaction induced by the percussion corer were corrected assuming no such sampling artefacts occurred using the gravity corer, and combining water content profiles. Compaction was not estimated for deeper sediments.

3.2. Sediment and geochemical analyses

Lithological descriptions and photographs were used to characterize the cores from the two sites. A radiographic examination was carried out on each core with the SCOPIX® X-ray imaging system (University Bordeaux I) (Migeon et al., 1999). The resulting images represent the highest resolution signal that could be obtained. The cores were sampled systematically using 1 cm-thick slices in the case of Bouafles and 5 cm thick slices for Darse des Docks, respectively. The grain-size of some of these samples was determined with a laser diffraction particle sizer.

In order to determine their stable element compositions and radioisotope activities, the sediment samples were dried at 30 °C and then crushed. To measure the activity of the gamma-emitting radionuclides, the samples were conditioned in 17 or 60 mL boxes according to the quantity of sediment available.

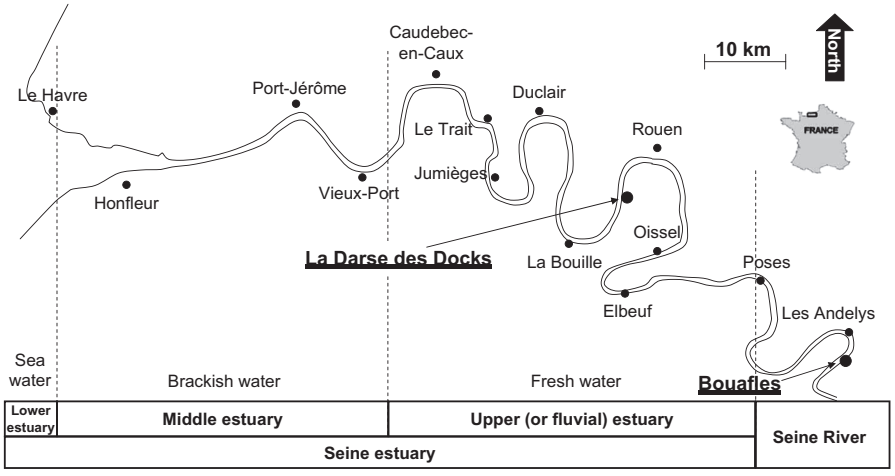

Fig. 1. Map of the lower course of the Seine River (after Deloffre et al., 2005), with location of the core sampling points.