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Tracing sediment sources using strontium isotopes in a pond draining an agricultural catchment (Loire River basin, France)

Marion Le Gall^{a*}, Olivier Evrard^a, François Thil^a, Anthony Foucher^b, Sébastien Salvador-Blanes^b, Olivier Cerdan^c, Sophie Ayrault^a

^aLaboratoire des Sciences du Climat et de l'Environnement, (LSCE), UMR 8212 (CEA/CNRS/UVSQ), Avenue de la Terrasse, F-91198, Gif-sur-Yvette Cedex, France

^bLaboratoire GéoHydrosystèmes Continentaux (GéHCO), E.A 6293, Université F. Rabelais de Tours, Faculté des Sciences et Techniques, Parc de Grandmont, 37200 Tours, France

^cBureau de Recherches Géologiques et Minières (BRGM), 3 avenue Claude Guillemin, 45060 Orléans, France

Abstract

Soil erosion in agricultural catchments leads to the accelerate supply of sediment to rivers. Here, we determine the sources contributing to the siltation of a pond in the Louroux catchment (24 km², French Loire River basin), representative of lowland agricultural environments of Northwestern Europe. Strontium isotopic ratios were determined in potential sources and sediment core samples collected in the Louroux pond, at the outlet of the catchment. These ratios were shown to provide good discrimination between different sediment sources (soil, suspended particulate matter, calcareous rock samples), and their respective contributions were calculated using mass balance equations. These results should be used to guide the implementation of soil conservation measures to limit sediment supply to the Louroux River.

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Keywords: soil erosion ; ⁸⁷Sr/⁸⁶Sr isotopic ratio ; core sediment ; end-member ; mass balance equation

1. Introduction

Soil erosion constitutes a major environmental problem in agricultural areas of Northwestern Europe. This process of detachment, transportation and deposition of soil by water is particularly intense in areas where drainage

* Corresponding author. Tel.: +33169824339.

E-mail address: marion.legall@lsce.ipsl.fr

pipes may create an additional pathway for sediment to the river network^{1,2}. When this supply of sediment reaches the river, it leads to the degradation of water quality by increasing turbidity, filling reservoirs and transporting contaminants (such as phosphorous, pesticides, persistent organic pollutants, heavy metals and pathogens) through fluvial systems^{3,4}. To limit these negative consequences, the main sources of erosion need to be identified to implement appropriate management practices to reduce erosion and the subsequent transport of sediment.

In this study, we use $^{87}\text{Sr}/^{86}\text{Sr}$ strontium isotope ratios as geochemical tracers of surface erosion processes⁵. $^{87}\text{Sr}/^{86}\text{Sr}$ variations are controlled by the rock type and its formation age, and reflect the weathering and mixing of different substrates^{6,7}. In this context, it is assumed that Sr isotopic composition varies with lithology and that it can be used to quantify the origin of different material types, such as soils, suspended particulate matter (SPM) and river waters.

Here, we investigate soil erosion and sediment transport in a small catchment, the Louroux (24 km²), located in the French Loire River basin and representative of lowland cultivated environments of Northwestern Europe. In this catchment, the modernization of agricultural practices after World War II led to the modification of land uses, to the creation of tile drain outlets and to the reshaping of river channels. As a result, soil erosion and sediment fluxes strongly increased during the last 70 years, resulting in the sedimentation and the eutrophication of the Louroux pond (52 ha), located at the outlet of the catchment. During the last decade, suspended sediment yields within the catchment were estimated between 90 and 102 t.km⁻².yr⁻¹⁸. An approach based on isotopic geochemistry was conducted to quantify the respective contributions of the sources contributing to the siltation of the river network and the Louroux pond.

2. Study area and methods

The Louroux pond catchment (24 km²) is a small agricultural catchment located in the French Loire River basin. Characterized by a flat topography (average slope of 0.4%), and by a temperate oceanic climate, the catchment is covered with arable land (78 %), grassland (18 %) and woodland (4 %). The lithology is strongly contrasted with the presence of different substrates: (1) loam in upper parts of the catchment, (2) flint clay, (3) Touraine lacustrine limestone, (4) shelly sand, (5) sand and continent gravel and (6) silicic conglomerate.

Five automatic monitoring sampling stations recorded continuously hydro-sedimentary characteristics during one hydrological year (September 2013 - September 2014). River water was collected in acid-cleaned polypropylene bottles during three flood events (30th December 2013, 29th January 2014 and 13th February 2014). SPM concentrations were determined by filtration of a given volume of river water through dried, acid-cleaned and pre-weighted filters (Whatman, QMA). A sedimentary archive, the LRX-1301 core, was collected in the Louroux pond in 2013 using a corer of 90 mm \varnothing and dated using fallout radionuclide measurements (^{137}Cs)⁸.

After mineralization (dissolution by successive addition of HF/HClO₄ and HNO₃/HCl), $^{87}\text{Sr}/^{86}\text{Sr}$ ratios were determined after chemical purification of the Sr fraction, using a Thermo Finnigan Neptune-Plus Multi-collector Inductively Coupled Plasma Mass Spectrometry (MC-ICP-MS) instrument.

3. Results and discussion

Sr isotope ratios were measured in potential sources of sediment (soil, SPM, calcareous rock samples) and in the Louroux pond sediment core (Fig. 1).

Sr signatures displayed large variations in soil samples, from 0.712763 to 0.724631 (n=19). The highest values were observed in upstream parts of the catchment whereas the lowest signatures were measured in the downstream part, along the southern tributary. Calcareous rocks were sampled in the southern part of the catchment and showed an average value of 0.708717. In SPM samples, Sr signatures ranged from 0.713660 to 0.725749. During the two first flood events generated by long and low-intensity rainfall, $^{87}\text{Sr}/^{86}\text{Sr}$ values remained similar with values ranging from 0.715484 to 0.718637. The third flood event was more intense and SPM transported in the rivers during this flood presented the highest ratios with signatures comprised between 0.717814 and 0.725749 (Table 1). In the Louroux core, Sr isotope ratios ranged from 0.710739 to 0.716864. On top of the core (0-30 cm), Sr signature

remains stable, with a mean value of 0.712785. The highest value (0.716864) is reached at 41 cm depth. From 47 cm depth to the bottom of the core, signatures tend to decrease to reach the lowest value of 0.710739 at a depth of 110 cm (Fig. 2).

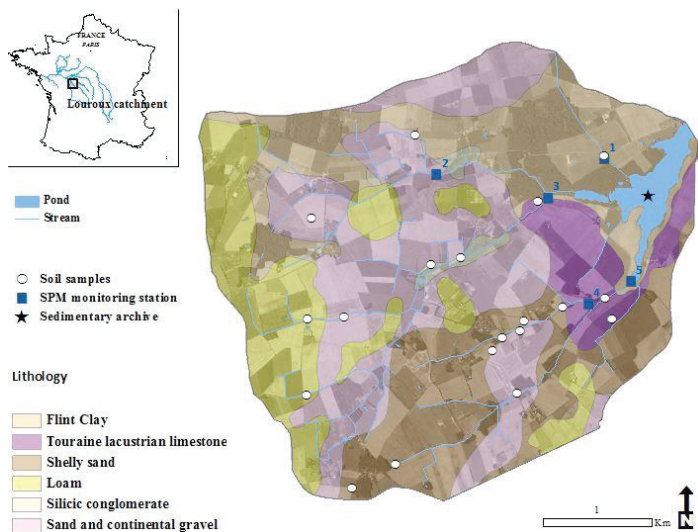


Fig. 1. Location of the Louroux catchment in France and detailed map of sample locations.

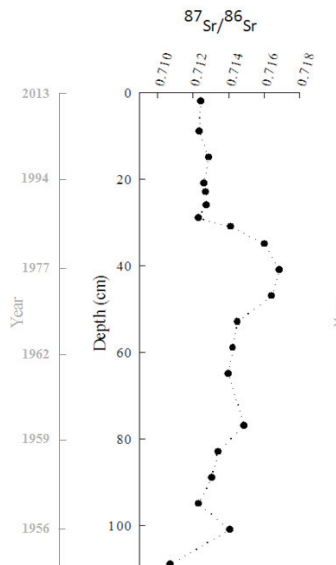


Fig. 2. Sediment ⁸⁷Sr/⁸⁶Sr ratio profile in the Louroux core.

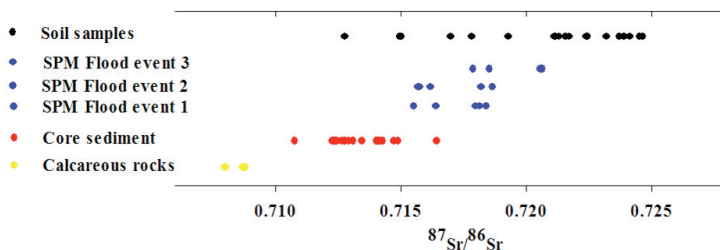


Fig. 3. Sr isotope ratios in calcareous rocks, core sediment, SPM and soil samples.

Fig.3 shows the variations of ⁸⁷Sr/⁸⁶Sr ratios in potential sediment sources and in the pond core. The isotopic signature of the core is scattered between a carbonate end-member characterized by the isotopic ratio of calcareous rocks and a SPM-soil end-member. The lowest isotopic ratio measured in the core is close to the carbonate end-member. Highest values match the signature of some SPM samples. ⁸⁷Sr/⁸⁶Sr ratios of SPM collected during the third flood event show the highest values, close to the highest ones measured in the soil samples. Sediment accumulated in the Louroux pond would then predominantly originates from a carbonate end-member and from SPM transported during flood events.

To quantify the respective contribution of the carbonate and SPM sources to the core sediment, mass balance equations were used (Eq. 1 and 2):

$$\left(\frac{^{87}\text{Sr}}{^{86}\text{Sr}}\right)_{\text{core}} = x \left(\frac{^{87}\text{Sr}}{^{86}\text{Sr}}\right)_{\text{carbonate}} + (1 - x) \left(\frac{^{87}\text{Sr}}{^{86}\text{Sr}}\right)_{\text{SPM}} \tag{1}$$

$$[\text{Sr}]_{\text{core}} = x[\text{Sr}]_{\text{carbonate}} + (1 - x)[\text{Sr}]_{\text{SPM}} \tag{2}$$

where x and $1-x$ are the mass fraction of Sr coming from the carbonate and the SPM end-members, respectively. $^{87}\text{Sr}/^{86}\text{Sr}_{\text{core}}$, $[\text{Sr}]_{\text{core}}$, $^{87}\text{Sr}/^{86}\text{Sr}_{\text{carb}}$, $[\text{Sr}]_{\text{carb}}$, $^{87}\text{Sr}/^{86}\text{Sr}_{\text{SPM}}$ and $[\text{Sr}]_{\text{SPM}}$ represent the strontium isotopic composition and concentration of the core, the carbonate and the SPM end-members, respectively.

We calculated the relative contribution of both end-members, by subdividing the pond core into four sections: (1) the bottom of the core where the lowest Sr ratio is observed (110 cm), (2) the lower part (53 cm to 110 cm) with increasing $^{87}\text{Sr}/^{86}\text{Sr}$ ratios from the bottom to 53 cm depth, (3) the medium part (35 cm to 53 cm) with the highest $^{87}\text{Sr}/^{86}\text{Sr}$ values and (4) the upper part (above 35 cm depth) with steady $^{87}\text{Sr}/^{86}\text{Sr}$ ratios. Sources were characterized by the average isotopic ratios determined in the calcareous rocks and in the SPM from the three flood events.

The results show that on the bottom of the core, sediment mainly originates from a calcareous end-member (72 %). In the lower section of the core (between 53 cm and 110 cm), sediment mainly comes from SPM, with an average contribution of 81 %. Highest $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, obtained between 35 and 53 cm, correspond to a maximal SPM contribution of 92 %. In the upper part, Sr signatures and SPM contribution decrease, reaching a steady state, with an average SPM contribution of 71 % (Fig. 4).

Dates attributed to the sediment core layers will be used in the remainder of the text to facilitate the interpretation of environmental changes in the catchment. The bottom of the core may correspond to the local signature of the pond. The lower part, dated between 1955 and 1966 corresponds to a period of changes in agricultural practices. Sediment fluxes strongly increased after the reshaping of streams and land consolidation. As a result, high soil losses led to an increase of sediment transfer to rivers⁸. Consequently, the proportion of sediment originating from SPM increased in the Louroux core. The highest inputs of SPM were observed between 1969 and 1981. This period that followed large-scale land management changes was affected by the extension of the drainage network and the creation of ditches⁸. It resulted in a massive supply of sediment to the Louroux pond which explains the dominance of the SPM source in the sediment core during this period. Sedimentary transfers tended to stabilize between 1982 and 2013. The contribution of sediment originating from SPM decreased and reached a constant proportion of 71 %, the remainder being supplied by carbonate material.



Fig. 4. Contribution of calcareous and SPM sources to sediment collected in the Louroux core.

4. Conclusions

In this agricultural catchment where sediment transfers are large and episodic, Sr isotopes measured in a sediment core collected at the outlet were shown to provide quantitative information about the origin of material accumulated in the pond. Sediment inputs to the pond appeared to be controlled by the supply of material originating from two distinct sources, carbonates and SPM, with varying contributions throughout time. Additional work is required to better constrain the carbonate end-member origin (detrital or authigenic calcite). The relatively high proportions of sediment supplied by SPM underline the necessity of implementing appropriate farming practices to reduce sediment supply to rivers and the subsequent transport of particle-bound contaminants.

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