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Record of human activities in the Pb isotopes signatures of coastal sediments from the Roman archaeological site of Cala Francese, Cape Corsica (France)

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ABSTRACT

The Mediterranean margins were characterized by intense maritime commercial exchanges since Antiquity. We conducted a lead isotope study of coastal sediments from Cala Francese, a Roman archaeological site at Cape Corsica (France) with the aim of evaluating the environmental contamination of lead over the historical period. The Pb content and isotope composition have been measured on the upper sections of three sedimentary columns. According to a radiocarbon chronological framework, the sampling interval covers the last ~3500 to 4000 years. Our results indicate that Pb enrichments in the Cala Francese sediments began during the Roman period and changes in the corresponding Pb isotope signatures are consistent with human perturbations of the local environment since the Roman period. Based on a literature compilation of the potential Pb mining districts, we discuss the sources of the Pb contamination. In addition to recording the signature of global atmospheric pollution in the upper samples, the Cala Francese site records a local contamination due to Roman occupation, as indicated by the occurrence of potsherds. The Miocene Pb mining districts from Cartagena and Mazaron in SE Spain are identified as the most probable sources of the local contamination, and are consistent with the archaeological information of the Roman trade routes.

1. Introduction

The history of Mediterranean population has been greatly influenced by the physical geography surrounding the Mediterranean Sea (Morhange, 1994). Inspite of this, coastal sediments uncovered during excavations have only recently attracted the attention of archaeologists (Marriner et al., 2010). Indeed, the study of the relationships between Mediterranean populations and their coastal environment began only in the 1990s. Today, archaeologists are increasingly aware of the importance of the environment in understanding the socio-economic and natural frameworks in which ancient societies lived. Excavations are now more likely to embrace a multidisciplinary methodology and include the fields of archaeology, geology, geography and history (e.g., Goiran and Morhange, 2001).

As underlined by Delile et al. (2014) the study of artefacts alone is not sufficient to identify the maritime trade routes. For example, the Pb isotope approach provides complementary information that can constrain the sources of ores. Because of its specific properties (corrosion resistance, malleability and low melting point), lead was widely used during the Antiquity for various purposes: plumbing, architecture, manufacture of glasses and weights measuring, welding, casting statues, shipbuilding and fishing (Lucas and Harris, 1962; Nriagu, 1983). As a result, lead is an excellent tracer for characterizing ancient industrial activities (Chow et al., 1973; Shirahata et al. 1980; Ng and Patterson, 1982; Renberg et al., 1994; Shotyk et al., 1998; Véron et al., 2006). Lead has four stable isotopes (^{204}Pb, ^{206}Pb, ^{207}Pb and ^{208}Pb). The last three isotopes are the end products of the natural decay chains of uranium and thorium. The initial content of U and Th of the primary geological reservoir thus determines the specific isotope ratios of different Pb ores (Doe, 1970). These ratios are preserved during the melting of the ore, allowing the identification of not only the geological origin of the Pb but also the sources of pollutants compared to Pb derived from the erosion of the Earth's crust. In the Mediterranean area (Fig. 1), this Pb isotopic approach was developed to differentiate the geographical

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Fig. 1. Location of Cape Corsica within the Mediterranean basin and showing the principal Pb mining districts exploited during the Antiquity: Laurion, Thasos and Chalkidiki in Greece (blue dots); South Tuscany, Apuane Alps and Sardinia for Italy (green dots); Taurus in Turkey (purple dot). In Southeastern Spain (grey dots), the following districts were grouped together: Cartagena, Almagreda and Mazaron as Miocene ores and, Sierra de Gador and Sierra de Alhamia as Triassic ores as was proposed by Arribas and Tosdal (1994). Note the color code for the Pb ores is conserved throughout the manuscript. Arrows indicate Roman trade routes (modified from Brown, 2011 and Delile, 2014). The black dots indicate the location of ancient cities, harbours or Pb districts cited in the text. The enclosed map shows the location of Cala Francese and other sites from Cape Corsica (Meria, Macinaggio, Tamarone). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

origins of Pb ores in the Antiquity (Stos-Gale et al., 1996; Yener et al., 1991; Sayre et al., 1992; Véron and Le Roux, 2004). The reconstruction of the environmental contamination was especially useful in documenting the growth and/or demise of ancient harbours (e.g., Alexandria in Véron et al., 2006, 2013; Sidon in Le Roux et al., 2003; Portus and Ephesus in Delile et al., 2014 and Delile, 2014). Geochemical sediment studies show that small variations in Pb isotope ratios may correspond to changes in the sources and/or the mineralogy of Pb (Shirahata et al., 1980; Ng and Patterson, 1982). In the study of Véron et al. (2006), the environmental impact of cities is determined by the $^{206}Pb/^{207}Pb$ ratio. In the Roman period, the range of characteristic ratios is between 1177 and 1185 and for the Greek period it is between 1187 and 1199 (Véron et al., 2006). In archaeometry, Pb isotopic analyses are widely used to determine the sources of various artefacts, such as glass (Shortland, 2006), the varnish (Wolf et al., 2003), and metals of different periods and origins (Durali-Mueller et al., 2006; Renson et al., 2011).

In this paper, we apply the Pb approach on coastal sediments retrieved from the archaeological site of Cala Francese along the Northwestern Cape Corsica margin (Fig. 1). Due to its central location in Mediterranean basin, Corsica, and especially the Cape Corsica, have been involved in many commercial exchanges (see the Roman trades reported on Fig. 1) as attested by the abundant archaeological remains founded on the islands, and in particular at the Cala Francese site, but also on the adjacent seafloor. >450 archaeological ores have been catalogued in Corsica by the DRASSM (Césari, 2010). We have used a combination of radiocarbon dating and Pb isotope and Pb concentration data from sedimentary columns of the Cala Francese, in order: 1) to document any environmental lead contamination of the site; 2) to identify the main Pb supplies and; 3) to reconstruct the historical evolution of the pollution in comparison with other Mediterranean sites.

2. Sedimentary material: coring sites and chronology

The archaeological site of Cala Francese is located at the Northern tip of Cape Corsica (Fig. 1). During the Roman period, it housed an "*oppidum*", based at Monte Bughju, a strategic location for the surveillance of the coastline and control of goods (customs). At the foot of the hill stands a swamp, which was probably connected to the sea in the past (Fagel et al., in press). This lagoon could have served as a natural harbour during the Roman period, providing a perfect shelter against the winds. This hypothesis is reinforced by the presence of numerous fragments of amphora on the surface and under the sea in the adjacent bay. The Cala Francese constitutes therefore an important site to highlight both cultural ties and relationships between Corsican and Italian societies.

Two survey campaigns were conducted in July 2010 and June 2014 at the Cala Francese lagoon (see coordinates in Fig. 2). In 2010, the cores were retrieved using a 6 cm diameter hand auger. Two cores (CF10-1, 0–360 cm and CF10-II, 0–380 cm) were taken at the entrance of the lagoon, another at its northern end (CF10-III, 0–240 cm) and a final core on its Eastern edge (CF10-IV, 0–180 cm). Samples were taken at 20 cm intervals, except for core CF10-III, which was subsampled at 10 cm intervals. All of the sedimentary columns start with a muddy base mixed with pebbles. This unit is overlain by homogeneous darker clays and the final upper unit is composed of marine sands (see Fagel et al., in press more sedimentological details). Abundant fragments of amphorae are only observed in the core CF10-III which is located at the foot of the Monte Bughju. Note that potsherds are observed between 20 and 140 cm depth, with a maximum content for samples in the 40–60 cm interval. The core samples were kept under cold conditions at AGEs laboratory (University of Liege).

In 2014, two additional continuous cores were drilled by using a 50 cm diameter motorized cobra coring system from CEREGE (Aix-en-Provence, France). CF14-1 was drilled in an intermediate location between cores CF10-I and CF10- IV, and CF14-2C was retrieved close to CF10-III (see coring locations on Fig. 2). Core CF14-1 was drilled using a manual Russian corer for the first 2 upper meters then by the cobra corer from 2 to 4.21 m. Core CF14-2C was drilled only with the cobra corer down to 4,21 m. The sedimentary columns (Fig. 2) consist of an alternation of three lithological units: 1) coarse sands with centimetric pebbles, fragments of shells and posidonia; 2) fine sands with abundant marine shells and; 3) clays with some fragments of rocks. Potsherds have been observed in the upper sections of CF14-2C (70–85 cm) as they were in core CF10-III. The cores were kept under cold conditions. CF14-2C was split for lithological description and collection of suitable material for radiocarbon dating. Sampling of core CF14-2C was performed every 5 cm for geochemical analysis.

In order to obtain a chronology of the sedimentary deposits, thirteen Cala Francese samples were sent to the Lyon laboratory for AMS radiocarbon dating (data in Table 1). Dates were obtained on 4 charcoals samples from CF10-II between 80 and 360 cm (plus 1 but modern from CF10-III), 5 *posidonia* fragments from CF14-2C between 151 and 410 cm, 1 macroremain from CF10-III at 170–180 cm, 1 shell from CF14-2C at 196 cm and 1 organic bulk sediment from CF14-2C.

3. Archaeological setting and human occupation

Our surveys take place after a long tradition of research and in a context of archaeological renewal for Cape Corsica. The Prehistory of the area is based on the excavations of Françoise Lorenzi in Guaita

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