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^{210}Pb mass accumulation rates in the depositional area of the Magra River (Mediterranean Sea, Italy)

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ABSTRACT

Nine sediment cores were collected between 2009 and 2012 in the inner continental shelf (Mediterranean Sea, Italy) mainly influenced by the Magra River, at water depths ranging from 11 to 64 m. Mass Accumulation Rates (MARs) were calculated through ^{210}Pb analysed by Gamma spectrometry. Three different dating models (single and two-layer CF-CS, CRS) were applied to clay normalised $^{210}Pb_{xs}$ profiles and ^{137}Cs was used to validate the ^{210}Pb geochronology. The maximum MAR values (>2 g cm^{-2} yr^{-1}) were found in the region adjacent to the Magra River mouth and outside the Gulf of La Spezia (0.9 ± 0.1 g cm^{-2} yr^{-1} at St. 3-C6 and 4-C4). Results from ^{137}Cs/$^{210}Pb_{xs}$ ratios calculated in Surface Mixed Layers (SMLs) evidenced the coastal boundaries of the Magra River depositional area, which is very limited towards south. Differently, in the north-west sector, fine sediments are generally driven by the Ligurian Current and move towards north-west: at the deepest and most distant station from the River mouth, the MAR value is the lowest one in the study area.

Few major Magra River floods occurred during the sediment core sampling period. By using the short-lived radioisotope ^{7}Be as a tracer of river floods, a clear ^{7}Be signature of 2009 flood is present at St. 1-SA1C. Finally, by analyzing the clay normalised $^{210}Pb_{xs}$ profiles, a decrease of its activity dating the years 1999 and 2000 is observed in four cores, corresponding to two major Magra River floods occurring in those years.

1. Introduction

Coastal areas close to a river mouth are important regions where interactions between terrigenous sediment supply and marine processes occur, determining the sedimentation rates and the extent of sedimentary deposits. River flood events together with nearshore wave climate are the driving forces in changes in sediment dynamics, which have important consequences on the state of the marine coastal environment. The chronology of recent sedimentation and the determination of Mass Accumulation Rates (MAR) are of the greatest importance (Appleby and Oldfield, 1992, 1978) for the understanding of present processes and/or the reconstruction of past conditions. Radionuclides are powerful tools that can provide information about the connections between physical, chemical, sedimentological and biological processes (Kershaw and Woodhead, 1991). They provide the time dimension of these processes, being clocks associated to the environmental system. The study of deltaic and inner shelf sediments provides a useful tool for the determination of past and recent climatic events. In general terms, understanding the mechanisms operating on the inner shelf could increase our knowledge of seaward sediment flux and help close short-term sediment budget on the continental shelves.

Moreover, the study of the modern sediment supplies and the sediment distribution on the inner continental shelf is of great importance to evaluate ecosystems vulnerability and to anticipate shelf evolution under the pressure of human activities. Dating sediments is thus an important process that can help the understanding of complex natural and anthropogenic interactions. In the NW Mediterranean, some studies dealing with metal distributions in relation to sedimentary processes have been carried out, mainly in the prodelta of the most important rivers (Alonso and Maldonado, 1986; Vernet et al., 1977) or in the most contaminated areas (Palanques and Diaz, 1994), but sedimentation rates considered in these studies were usually mean values.

The Magra River is the main Ligurian river for its mean annual discharge (40 m^{3} s^{-1}) (Rinaldi et al., 2009), therefore being the major sediment input in La Spezia and Cinque Terre coastal area (eastern Ligurian Sea, NW Mediterranean Sea). The Magra River mouth and its surrounding depositional area is then an important study site where sediments and associated radionuclides

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accumulate after flood events. In the last fifteen years main flood events occurred from November 1999 to the 25th October 2011, the latter having massively affected the touristic region of Cinque Terre, with disastrous impacts on humans, infrastructures and the environment.

Very limited data are available on Sediment Accumulation Rates (SARs, $cm\,yr^{-1}$) and Mass Accumulation Rates (MARs, $g\,cm^{-2}\,yr^{-1}$) in the eastern continental shelf of the Liguria region (Jennings et al., 1985) and radionuclide distributions (Anselmi et al., 1982; Ferretti et al., 1983). A radiometric - sedimentological study was then planned and carried out in order to define the recent (over the last century) sedimentation regime and identify possible recent changes of sediment input reaching the marine coastal environment.

The aim of the present work is to estimate the Mass Accumulation Rates in the inner continental shelf close to the Magra River, through radioactive tracers such as ^{210}Pb, ^{137}Cs, ^{7}Be and to better define the dynamics of the fine sediment fraction.

1.1. Radioisotopes (^{210}Pb, ^{137}Cs, ^{7}Be) as tracers of particle dynamics

Naturally occurring particle-reactive radionuclides, together with some anthropogenic radioisotopes, are useful tracers of sedimentation processes in the marine environment. In coastal areas, a large fraction of radionuclides and pollutants is associated with particles and fine sediments (Baskaran and Santschi, 1993; van Wijngaarden et al., 2002 and reference therein) settling through the water column and reaching the seafloor.

^{210}Pb and ^{137}Cs have half-lives of 22.23 and 30.05 yrs (Bé et al., 2010), therefore being useful to characterise events in the last 100 years, while ^{7}Be with half-life of 53.22 days is a good tool for investigating processes occurring over time scales of ca. 200 days; i.e., flood sedimentation and seasonal deposition.

The natural radionuclide ^{210}Pb of the ^{238}U radioactive chain is continuously supplied from the atmosphere by decay of gaseous ^{222}Rn exhaled from the continental crust after decay from ^{226}Ra and produced *in situ* in the water column from the decay of dissolved ^{226}Ra. ^{210}Pb is a good sediment tracer since it has a high geochemical affinity with settling particles, therefore in the water column it is readily scavenged and delivered continuously to the sea bottom (Cochran, 1990; Legeleux et al., 1994; Sanchez-Cabeza and Ruiz-Fernández, 2012). Through this process, the ^{210}Pb activity on the sea floor is "in excess" ($^{210}Pb_{xs}$) with respect to ^{226}Ra activity of sediment, that is the "supported" ^{210}Pb. While supported ^{210}Pb concentration is almost constant through the sediment column, $^{210}Pb_{xs}$ vertical profiles are controlled by sediment accumulation, mixing rates and radioactive decay. In particular, $^{210}Pb_{xs}$ has been widely used for establishing radiogeochronology in marine sediments. From its activity profile, Surface Mixed Layer (SML) thickness, SARs and MARs can be estimated, on time scales of $\sim$100 years, compatible with its physical half life (Abril and Gharbi, 2012; Alonso-Hernández et al., 2006; Appleby and Oldfield, 1978; Appleby, 1979; Corcho-Alvarado et al., 2014; Hancock et al., 2000; Koide et al., 1972; Kuzyk et al., 2013; Maiti et al., 2010; Martín et al., 2014; Miralles et al., 2005; Puig et al., 2015; Robbins, 1978; Sanchez-Cabeza and Ruiz-Fernández, 2012; Sanchez-Cabeza et al., 1999; Zalewska et al., 2015).

Differently, the input of the anthropogenic radionuclide ^{137}Cs to the oceans occurred only since the beginning of the atmospheric nuclear weapon testing in mid 1950s that peaked in 1963 and occurred later in the Mediterranean Sea as a consequence of the Chernobyl accident of April 1986 (Delfanti and Papucci, 2010). The identification of 1963 and 1986 peaks in ^{137}Cs vertical activity profiles in sediments is used for the validation of sediment dating models based on natural tracers (particularly ^{210}Pb).

Finally, ^{7}Be is produced by cosmic-ray spallation of nitrogen and oxygen in the atmosphere. It is delivered to the Earth surface through (wet and dry) atmospheric deposition and adsorbed onto terrestrial particles, that are then eroded and transported to the marine environment (Baskaran and Santschi, 1993; Olsen et al., 1986). ^{7}Be is also deposited onto the ocean surface, where it can be scavenged by particles; ^{7}Be is preferentially adsorbed to fine sediments (Palinkas et al., 2005). ^{7}Be, in conjunction with other radiochemical and sedimentological properties, is a good tracer of recent ($<$200 d) fluvial sediments (Mullenbach and Nittrouer, 2000).

So the joint analysis of ^{210}Pb, ^{137}Cs and ^{7}Be activity profiles, together with textural characteristics, can give a complete picture of sedimentation processes and deposition of flood sediments in the marine environment.

2. Regional setting

The coastal area in the eastern Ligurian Sea (NW Mediterranean Sea), limited by Punta Mesco on the northwest and by the Magra River mouth on the southeast (Fig. 1), was chosen for this study.

The Ligurian Sea is dominated by a large and well-defined anticlockwise circulation (Astraldi et al., 1995; Manzella, 1985; Pinardi et al., 2015) fed by two distinct currents: the Tyrrhenian Current and the western Mediterranean Current (inset a, Fig. 1). The circulation in the study area is influenced by the large-scale Ligurian Current (Gasparini et al., 2009; Molcard et al., 2009), which is characterised by a cyclonic boundary current modulated by seasonality and wind forcing. So the main current circulation drives sediments from the northern Tyrrhenian Sea and the Magra River mouth towards northwest; the riverine suspended particles, as they enter the sea, are transported by the prevailing currents in a north-westerly direction towards the Gulf of La Spezia and the western Ligurian Sea (Astraldi and Manzella, 1983; Esposito and Manzella, 1982; Haza et al., 2010).

The Magra River catchment is around 1700 km^2; the main tributary of Magra (which is 70 km long) is the Vara River (65 km long), with a catchment area of about 570 km^2. The mean annual precipitation is around 1700 mm, reaching a maximum of approximately 3000 mm in the upper part of the basin; the Magra River mean annual discharge at its mouth is 40 $m^3\,s^{-1}$ (Rinaldi et al., 2009). The importance of small river sediment discharge is comprehensively studied in Milliman and Syvitski (1992) and Woodward (1995), where fluvial sediment discharge is explored with respect to both basin area and elevation; the Magra River can be classified in the group "Mountain (1000–3000 m) – Alpine Europe". The Magra River total sediment load is $0.13 \times 10^6\,t\,yr^{-1}$ (Rinaldi, 2007), in general agreement with data reported in the above classification and in Poulos and Collins (2002).

In the last century the Magra, which is a gravel-bed river, experienced relevant geomorphic changes (Rinaldi et al., 2005a, 2005b; Surian and Rinaldi, 2003), especially due to human activities. Three dams were built for hydroelectric purposes in the period 1930–1950, with a total storage capacity of 5,340,000 m^3, and for sure they represent a relevant anthropogenic impact on Magra River bedload sediment fluxes being trapped by the artificial impoundments (Rinaldi, 2005), as these human impacts are recognised also on a global scale (Milliman and Farnsworth, 2011; Vörösmarty et al., 2003); few dykes were also built in the '80 s along the Magra and Vara Rivers. An intensive sediment mining occurred between 1960 and 1980; the sediment extracted from the lower reaches has been estimated to be around 24 million m^3 between 1958 and 1973 (Cavazza and Pregliasco, 1981), in comparison with an annual bedload transport estimated to be one or two orders of magnitude lower. Recent data (Surian and Rinaldi, 2004) indicate for the Magra and Vara Rivers a new phase with renewed sediment supply, promoted by a series of flood events.