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Origin and pattern of salinization in the Holocene aquifer of the southern Po Delta (NE Italy)

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ABSTRACT

The origin and patterns of groundwater salinity of a shallow coastal aquifer pertaining to a reclaimed subsiding zone of the Po Delta are examined in this study. The aim is to identify the source of the hypersaline groundwater residing in the basal portion of the aquifer and to infer the mechanism of salinization of the remaining portion of the aquifer. To disentangle the possible sources of salinity the molar ratio of environmental tracers like Cl^- and Br^- were used in combination with the classical geochemical analyses of major and minor cations ratios. High-resolution multi-level sampling (MLS) allowed obtaining a robust and self-consistent hydrogeochemical database, which was statistically analysed via factor analysis and proved to be log-normally distributed. Thus, a common origin could be inferred for the elevated salinity that characterize most of the groundwater samples, this can be recognized in the organic rich fine-grained sediments, deposited in salty back barrier and marsh environments during the last transgression phase. This study proves that a detailed analysis of groundwater geochemistry can be considered a valuable tool to assess the origin of salinity in coastal Holocene aquifers, where the traditional conceptual model of a simple fresh/seawater interface may not be adequate.

1. Introduction

The salinity distribution in many coastal aquifers shows a complex pattern, resulting not only from current processes but also from past events, including sea-level fluctuation, subsidence, climate change, mixing and human activity. In general, groundwater salinization can take place via diverse mechanisms such as actual seawater intrusion due to intense aquifer exploitation and/or sea level rise (Andersen et al., 2005; Ghiglieri et al., 2012; Werner et al., 2013), mobilization of saline paleowaters due to past transgressions, (Han et al., 2011; Sola et al., 2014), water–rock interaction, like evaporite dissolution (Cendón et al., 2008; Lucas et al., 2010), and anthropogenic contamination, like return flow (Merchán et al., 2015; Perrin et al., 2011). Independently from the salt source, its identification is often puzzled by intensive groundwater-sediment interactions amplified by the increased water ionic strength (Colombani et al., 2015a; Mondal et al., 2010) or by mixing processes enhanced by human activities as excessive pumping and land reclamation (Barlow and Reichard, 2010; Custodio, 2010). As these processes do not mutually rule out, discriminating between modern versus paleo seawater intrusion is vital to build a sound conceptual model of aquifer salinization (Chaudhuri and Ale, 2014; Werner and Gallagher, 2006).

Coastal aquifers formed over the last 10,000 yr, have been subject to multiple phases of sea-level fluctuations. These sea-level changes provoked an extensive transgression of paleo seawater into previously freshwater coastal aquifers, affecting all delta and coastal areas in the Mediterranean sea (Geriesh et al., 2015; Giambastiani et al., 2013; Sola et al., 2014) and worldwide (Wang and Jiao, 2012; Tran et al., 2012).

The aim of this study is to identify the origin and mechanism of groundwater salinization in an alluvial coastal aquifer in the northern Adriatic Sea that was broadly affected by Late Quaternary transgressive-regressive cycles. The study was performed by means of (i) a detailed reconstruction of the depositional environment that characterized this coastal aquifer in the Late Quaternary (Amorosi et al., 2015; Stefani and Vincenzi, 2005); (ii) using major elements and their molar ratios to distinguish different sources of salinity (Kim et al., 2002); and (iii) performing a statistical analysis to infer the relative relevance of different geochemical processes occurring in the coastal aquifer (Huang et al., 2013).

The established conceptual model may be applicable to a large amount of similar coastal aquifers, with a proper incorporation of the local geological environments. The present study is furthermore fundamental for the understanding and future assessment of the impact of

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projected climate change and sea-level rise on aquifers in vulnerable coastal flood plains.

2. Site description

The study area is located in the coastal floodplain of the Po River near Ferrara (Northern Italy) and covers 750 km^2 (Fig. 1). A great part of this territory are recently reclaimed lands, characterized by a flat topography and altitudes ranging from 5 to −11 m above sea level (a.s.l.). The only topographic heights are dunes, paleodunes and riverbanks.

In the Po Delta, fast subsidence and large sediment input allowed a full record of the Late Quaternary evolution (Fig. 1). The stratigraphic architecture was ruled by glacio-eustatic fluctuations. The latter gave origin to an alternation of alluvial plain deposits and coastal/shallow marine sediments. Alluvial plain deposits accumulated mainly during lowstand (Pleistocene) phases, while coastal/shallow marine sediments accumulated during transgressive-highstand (Holocene) phases (Amorosi et al., 2015).

During the last glacial lowstand, from 125 ka B.P. to the last glacial maximum (about 18 ka B.P.), the study area was characterized by the sedimentation of well-drained middle alluvial-plain sands. Deglaciation and early transgression were associated with an erosive disconformity development and the fast inland movement of a barrier-lagoon-estuary system in response to rapid sea level rise and reduced siliciclastic influx

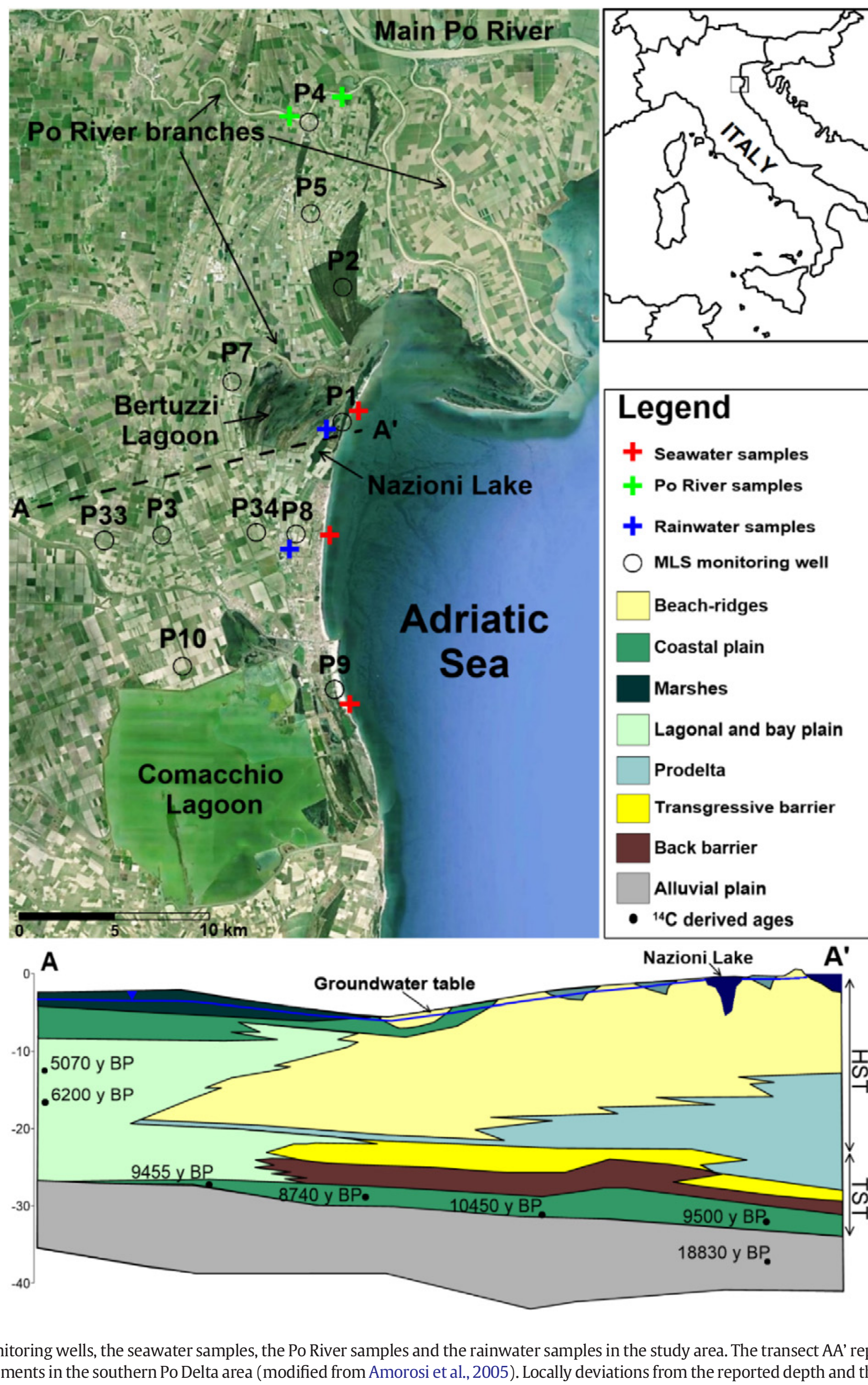

Fig. 1. Location map of the monitoring wells, the seawater samples, the Po River samples and the rainwater samples in the study area. The transect AA' reports the general distribution and age of the depositional environments in the southern Po Delta area (modified from Amorosi et al., 2005). Locally deviations from the reported depth and thickness of the facies' distribution are possible. LST stands for lowstand system tract, TST for transgressive system tract and HST for highstand system tract.