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Late Quaternary palaeoenvironmental evolution of the Adriatic coastal plain and the onset of Po River Delta

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ABSTRACT

Despite abundant geologic literature about the Po coastal plain, stratigraphic architecture beneath modern Po River Delta is virtually unknown. In this paper, combined sedimentological, micropalaeontological and geochemical investigations of three continuous cores (cores 1 to 3), about 40 m thick, enable for the first time the detailed reconstruction of subsurface stratigraphy in the Po River Delta area, along with its late Quaternary palaeoenvironmental evolution.

Lowstand deposits, formed during the Last Glacial Maximum, are expressed as a fining-upward succession of fluvial-channel and related overbank deposits, capped by a stiff, overconsolidated horizon. Above this unconformable surface, the lower post-glacial succession (transgressive systems tract or TST) is less than 7 m thick and includes a deepening-upward succession of back-barrier, shoreface and inner-shelf deposits. On the other hand, the overlying highstand systems tract is considerably thicker (up to 27 m) and comprises the bulk of recent delta progradation (*i.e.*, vertically stacked prodelta, delta front and delta-plain deposits).

Stratigraphic correlations within early transgressive, back-barrier deposits show vertically stacked, thin shallowing-upward successions, reflecting an internal subdivision of TST into small-scale parasequences.

The homogeneous shallow-marine clay that accumulated at the turnaround from transgressive to highstand conditions can be palaeontologically differentiated into two packages (*Miliolidae*-dominated and *Ammonia/Cribroelphidium*-dominated), reflecting open-marine and river-influenced conditions, respectively. Timing of maximum marine ingression (maximum flooding surface-MFS) is recorded within the open-marine clays at about 5500 calibrated yr BP by minor changes in microfauna.

Geochemical characterization of Core 1 testifies that distinct changes in sediment provenance accompanied the palaeoenvironmental evolution of the study area under changing relative sea-level conditions. At lowstand times, the study area was an alluvial plain under the influence of Adige River, as suggested by comparatively high Ba/Al values within pre-Holocene fluvial deposits. Increasing upward values of Cr/Al_2O_3 and Ni/Mg within TST suggest an increasing sediment provenance from the Po River during early stages of transgression, via the longshore drift.

The onset of modern-age Po Delta in the study area is precisely identified in Core 1 at 25.10 m depth, and has a distinctive, double signature. In terms of microfaunal assemblages, Po River sediments are clearly marked by the development of a characteristic foraminiferal association dominated by the opportunistic species *Nonionella turgida*, a taxon typically abundant in the marginal zone of present northern Adriatic Sea mud-belt. Po River deposits are also fingerprinted by a peculiar geochemical composition, corresponding to maximum Cr and Ni concentrations.

1. Introduction

The Po Plain is one of Europe's major alluvial plain, which hosts a very dense population (about one third of the Italian population) and important agricultural and industrial activities. Owing to the considerable number of continuously-cored boreholes and cone penetration tests performed in the last decade, along with the construction of a solid database including thousands of pre-existing data, the Po Plain represents today an excellent archive for developing high-resolution stratigraphic studies. The possibility of tracing stratigraphic surfaces from the basin margin to the coastal plain makes the Po Plain a natural laboratory for the construction of detailed sequence-stratigraphic models (Amorosi and Colalongo, 2005).

Although several studies have documented in detail late Quaternary stratigraphic architecture in the Po coastal plain, mostly south of modern Po Delta (Rizzini, 1974; Bondesan et al., 1995; Amorosi and Marchi, 1999; Amorosi et al., 1999a,b, 2003, 2005; Stefani and

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Vincenzi, 2005; Curzi et al., 2006), no documentation exists about subsurface stratigraphy beneath the present delta plain.

This research attempts to fill the gap, through combined sedimentological and micropalaeontological investigations of three continuously-cored boreholes (cores 1–3), 35–40 m deep, that were drilled in 2006 in the delta area, and the construction of a N–S oriented transect, roughly parallel to the coastline and perpendicular to Po River (Fig. 1). Specific objective of this paper is to examine the onset of deltaic sedimentation in the present Po Delta area, and frame it within a sequence-stratigraphic context. In this respect, detailed geochemical characterization of Core 1 is used as a tool for provenance discrimination and characterization of the key surfaces for sequence-stratigraphic interpretation.

2. Methods

The stratigraphic record was provided by three continuously-cored boreholes (cores 1, 2 and 3) performed by S.P.G. Adria through the wireline perforation system, which guaranteed very high (>90%) recovery percentages. The cores were recovered in the modern delta plain, following a roughly north–south orientation, in order to obtain stratigraphic information about the entire delta system, from Po Levante to Po Tolle channel mouths (Fig. 1).

Each core was split lengthwise, macroscopically described in terms of mean grain size, sedimentary structures, colour and accessory material content, including peat, organic matter, plant and wood fragments, calcareous nodules, mollusk shells and bioclasts. A total of 191 samples were collected for micropalaeontological analysis. Due to its relatively distal (easternmost) position, which is confirmed by a continuous record of a thick succession of marine clays, Core 1 was selected as reference core for our study, and for this reason extensively sampled. Selected stratigraphic intervals were sampled for cores 2 and 3 to refine facies interpretation (Fig. 2). Approximately 150 g of sediment were dried in an oven for 8 h at 60 °C. They were washed with water plus hydrogen peroxide (35% vol.) through sieves of 63 μm (240 mesh), and then dried again for 24 h.

The benthic microfauna (foraminifers and ostracods), encountered within the >63 μm size fraction was qualitatively analyzed. Samples containing more than 300 foraminiferal specimens were dry sieved and quantitatively analyzed in the size fraction >125 μm. The relative abundance percentage of each foraminiferal species was finally calculated within 43 countable samples.

Identification of foraminiferal and ostracod species relies upon original descriptions and several key papers (Bonaduce et al., 1975; AGIP, 1982; Jorissen, 1988; Athersuch et al., 1989; Albani and Serandrei Barbero, 1990; Henderson, 1990; Cimerman and Langer, 1991; Sgarrella and Moncharmont Zei, 1993; Fiorini and Vaiani, 2001). Ecological interpretation of species and environmental significance of microfaunal associations are inferred from comparison with modern benthic communities (Colalongo, 1969; D'Onofrio, 1969; Bonaduce et al., 1975; Breman, 1975; Jorissen, 1987; Murray, 1991; Van der Zwaan and Jorissen, 1991; Barmawidjaja et al., 1992; Yassini and Jones, 1995; Debenay et al., 2000; Ruiz et al., 2000; Donnici and Serandrei Barbero, 2002; Smith and Horne, 2002) and similar microfaunal assemblages recorded within late Quaternary coastal successions of Italy. These include Po coastal plain (Amorosi et al., 2004, 2005; Fiorini, 2004; Bondesan et al., 2006) and Ombrone and Arno coastal plains (Carboni et al., 2004; Aguzzi et al., 2007).

Geochemical analyses were also performed on 59 samples from Core 1, in order to obtain specific information about sediment provenance. Samples were oven-dried at 40 °C to complete dryness, and homogenized in an agate mortar. Chemical determinations were obtained by X-ray fluorescence spectrometry (Philips PW 1480) on pressed powder pellets, following the matrix correction methods of Franzini et al. (1972, 1975), Leoni and Saitta (1976), and Leoni et al. (1986). The estimated precision and accuracy for trace element determinations are better than 5%, except for those elements at 10 ppm and lower (10–15%). Loss on ignition (LOI) was evaluated after overnight heating at 950 °C.

Nine carbon-rich samples (organic clay, peat or well-preserved mollusk shells) were collected from cores 1 and 3 (Fig. 2) and analyzed by CEDAD laboratory (University of Lecce, Italy), providing a reliable

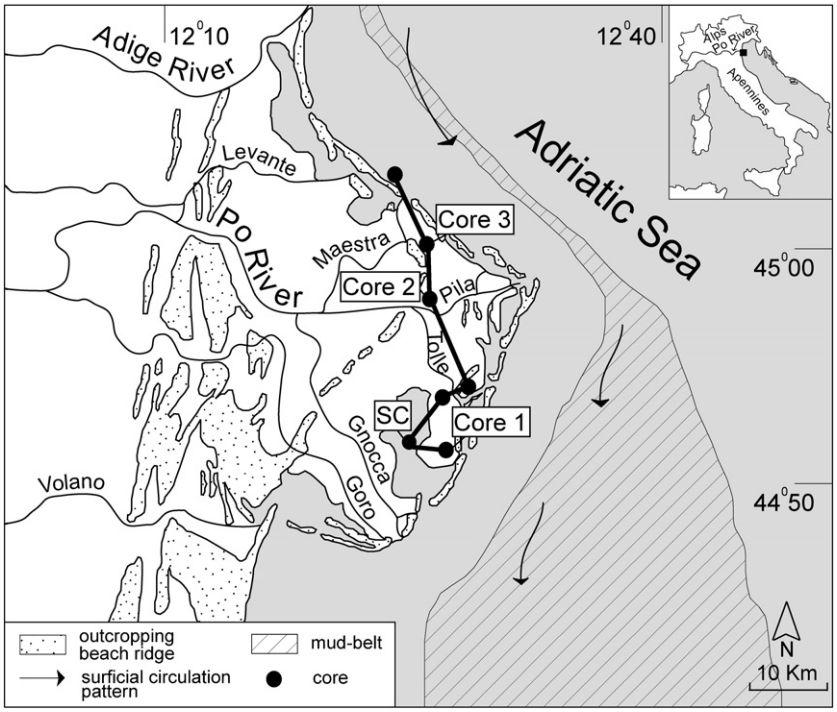

Fig. 1. Location of the study area, with indication of the three cores (1–3) investigated in this study and section trace of Fig. 6. Dots indicate outcropping beach ridges in the Po Delta area (after Ciabatti, 1967). SC=Core Scardovari (described in Correggiari et al., 2005b). The mud-belt identified offshore the present Po Delta and the Adriatic surficial circulation pattern are also shown.