Global and Planetary Change 117 (2014) 9–27

Contents lists available at ScienceDirect

Global and Planetary Change

journal homepage: www.elsevier.com/locate/gloplacha

Late-Holocene to recent evolution of Lake Patria, South Italy: An example of a coastal lagoon within a Mediterranean delta system

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ARTICLE INFO

Article history:
Received 20 May 2012
Received in revised form 28 February 2014
Accepted 7 March 2014
Available online 17 March 2014

Keywords:
coastal lagoon
Tyrrhenian Sea
Volturno River delta
Holocene
facies analysis
historical cartography

ABSTRACT

Lake Patria is a mesoaline coastal lagoon that develops along the coastal zone of the Volturno River plain (Campania, South Italy). The lagoon is a saline to brackish water body, ca. 2.0 long, and 1.5 km wide, with an average water depth of 1.5 m, reaching a maximum of ca. 3.0 m. The freshwater input into the lagoon is provided by a series of fresh to brackish water channels and small springs, landwards, while a permanent connection with the Tyrrhenian Sea is provided by a channel, 1.5 km long and a few meters wide.

Drilling data from 12 boreholes acquired in the study area indicate that Lake Patria is a man-modified remnant of a larger lagoonal area that developed during the last millennia along the Campania coastal zone within an alluvial delta system at the mouth of the paleo-Volturno River. Sedimentological and stratigraphic analyses of drill cores suggest that the lower Volturno delta plain developed in the last 6000 years. Depositional conditions during this period were dominated by flood-plain and alluvial plain settings, with transition to coastal bars and associated back-barrier coastal lagoons.

Lake Patria started evolving at an early stage of the Volturno delta plain formation as a consequence of foreshore deposits damming-up by littoral drift. The first marine layers display a radiocarbon age of ca. 4.8 ka BP and overlie a substrate represented by volcaniclastic deposits, originated by the Campi Flegrei, and associated paleosols. The lagoonal succession cored at Lake Patria may be interpreted as the result of a dynamic equilibrium between marine influence and riverine input into the lagoonal system through time, and has been tentatively correlated with the major climatic changes that occurred during Mid–Late Holocene.

Insights into the recentmost evolution of the coastal lagoon of Lake Patria are provided by the GIS-based analysis of the physiographic changes of the region conducted on a series of historical topographic maps dating back to the early XVII century. Particularly, the superposition of historical cartography reveals the secular trends in the change of coastal environments and the role of human modification of natural habitats over the last 400 years.

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1. Introduction

The coastal zone of the Mediterranean Sea is a complex, highly dynamic depositional system and environment that varies its shape and characteristics in response to environmental changes through time. During the Quaternary, along the Mediterranean continental margins, microtidal conditions coupled with relatively high rate of sediment supply by the regional river network have often favored the development of coastal lagoon/barrier systems and wetlands (Stanley, 1997; Morhange et al., 2000; Amorosi and Milli, 2001; Tesson et al., 2005; Mikhailova, 2006; Robert et al., 2006; Di Rita et al., 2010; Bellotti et al., 2011; Bernasconi and Stanley, 2011; Carmona and Ruiz, 2011; Di Rita et al., 2011; Giraudi, 2011, 2012; Amato et al., 2012). In particular, these environments typically developed towards the end of the marine transgressive phase that culminated ca. 6.5 ka BP and was characterized by a suite of backstepping barrier–lagoon system (TST), followed by large scale progradation of coastal foresets and the occurrence of alluvial delta systems (HST) (Stanley and Warne, 1993, 1994; Bellotti, 2000; Amorosi et al., 2008; Aucelli et al., 2012; Amorosi et al., 2012; Milli et al., 2013; among others).

Because of their land and sea interface location and shallow water depth, lagoons are heavily subject to natural constraints. Consequently, most of these coastal ecosystems are very dynamic and productive and are a context of primary interest when investigating the geological and biological dynamics of the coastal zone (Barnes, 1980; Kjerfve, 1994; Oertel, 2005).

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http://dx.doi.org/10.1016/j.gloplacha.2014.03.004
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Climatic/hydrographic and marine influences cause large differences and rapid changes in the physical and chemical characteristics of lagoons. Horizontal and vertical stratification of water masses is generally strongly dependent on the wind regimes whose frequency and intensity are in turn dependent on regional climate. Hydrological characteristics (e.g. salinity, nutrients) are related to the above-mentioned physical forcing, but also depend on river flows which in turn depend on climatic forcing.

The Mediterranean region is characterized by a sensibly reduced percentage (ca. 5%) of lagoonal coasts with respect to any other continent (Doody, 2001). Several deltas of this region, like the ones of Ebro, Rhone, Po, and many others along the Italian coasts, that originally developed within former lagoons enclosed by barrier–island or coastal sand bars, have been colonized and modified by human activities for at least the last 6 thousand years, and hence represent valuable sites for the understanding of the role of human activity in the modification of natural coastal habitats (Stanley and Warne, 1994; Bellotti, 2000; Amorosi and Milli, 2001; Di Rita et al., 2010; Alberico et al., 2012; Giraudi, 2011, 2012; Amato et al., 2012; among others). Critical controls on the evolution of coastal lagoons that developed close to large river mouths are also represented by the interplay between eustatic changes, subsidence and sediment supply within the associated alluvial delta system (cf. Giraudi, 2011, 2012; references therein).

To date, in spite of insightful studies concerning the coastal lagoons of the Mediterranean region (Morhange et al., 2000; Amorosi and Milli, 2001; Tesson et al., 2005; Di Rita et al., 2010; Carmona and Ruiz, 2011; Di Rita et al., 2011; Giraudi, 2011, 2012), there have been few systematic sedimentological studies on Holocene coastal lagoons of the South-Eastern Tyrrhenian Margin (e.g. Barra et al., 1996; De Pippo et al., 2007; Amorosi et al., 2012).

The purpose of the present study is to contribute to the understanding of the Late Holocene and recent evolution of Lake Patria, a remnant of the coastal lagoon–marsh area that originally developed in the southern part of the Volturno River delta system along the Campania coastal zone. The Holocene evolution of Lake Patria coastal region was characterized by the interplay of coastal and riverine dynamics and coeval volcanism through time, and hence provides an interesting case history, within the central Mediterranean region, to highlight the role of different sedimentary processes in the development of coastal lagoons.

The research work relies on integration of sedimentological and micropaleontological investigation of continuously-cored boreholes that were drilled around Lake Patria and across the Volturno delta plain. The present-day lagoon represents part of a wider marsh that was partially drained at the end of the 19th century (cf. Amorosi et al., 2012). In order to identify the causes of the environmental variations that have occurred in recent times, historical and recent maps were considered, emphasizing the coastal trend and the evolution of the different environments (lagoon and marshy systems) in the last ca. 400 years.

2. Geological setting

The Campania Plain and the Gaeta Bay are integral components of a large Quaternary extensional basin belt that formed mostly during the Quaternary between the western flank of southern Apennines and the eastern Tyrrhenian margin (Fig. 1) (Malinverno and Ryan, 1986; Mariani and Prato, 1988; Oldow et al., 1993; Ferranti et al., 1996; Casciello et al., 2006). The Volturno plain developed in the Early Pleistocene as a segment of the Campania continental shelf in response to post-orogenic extension associated with strike-slip tectonics that took place along the Eastern Tyrrhenian margin (Cinque et al., 1993; Sacchi et al., 1994; Milia and Torrente, 1999; Milia et al., 2003). Rapid tectonic subsidence dominated the geodynamic evolution of the area and the Campania Plain remained largely submerged by the sea during most of the Pleistocene.

Since Mid–Late Pleistocene, extensional tectonics was accompanied by the onset of an intense volcanic activity that developed in several places across the continental margin (Cassignol and Gillot, 1982; Di Vito et al., 1999). At ca. 39 ka the entire Campania Plain was covered by deposits, tens of meters thick of a highly explosive ignimbritic eruption, known as Campania Grey Tuff (CGT) (Barberi et al., 1978; Di Girolamo et al., 1984; Deino et al., 1994; De Vivo et al., 2001; Rolandi et al., 2003). Another eruption, dated at ca. 15 ka, caused the deposition of the Neapolitan Yellow Tuff (NYT) that is primarily exposed in the area of Campi Flegrei (Rosi and Sbrana, 1987; Scarpati et al., 1993; Deino et al., 2004).

The widespread volcanic activity that occurred along the Campania continental margin during the Late Pleistocene produced significant volcaniclastic aggradation, and was largely concomitant with an overall slowering of tectonic subsidence rates and the eustatic regression associated with the last glacioeustatic cycle between 125 ka and 18 ka. As a consequence, a seaward shift of the shoreline and the forced regression of paralic-shallow marine depositional systems concurrently occurred, while the whole plain emerged and the paleo-Volturno River likely started fluvial downcutting with formation of a major incised valley (Brancaccio et al., 1991; Romano et al., 1994; Amorosi et al., 2012).

During the Pleistocene–Early Holocene (ca. 15 ka–6 ka) the post-glacial rising of sea level caused a broadening of the inner shelf along with a rapid flooding of the lower part of the Volturno plain. Since ca. 6.5 ka the termination of the transgressive phase marked a turnaround point within the coastline retrogradation and the onset of the Late Holocene progradation (Romano et al., 1994; Barra et al., 1996; Santangelo et al., 2010; Amorosi et al., 2012). In the last 5 ka the present-day Volturno delta started to form and the whole coastal plain prograded seaward with a migration of shoreline in the order of 3–6 km (Cinque et al., 1997; Amorosi et al., 2012).

2.1. Location and physiography of the area

Lake Patria (40°56′N, 14°02′E; Italian: Lago Patria) is a man-modified coastal lagoon that developed in a topographic-depression of the Volturno River coastal plain, in the Campania region of southwest Italy (Fig. 2). The lagoon itself is a mesoaline water body ca. 2 km long, and 1.5 km wide, with an average water depth of 1.5 m, reaching a maximum of ca. 3 m. It has an outlet to the open sea, and is shielded from the wave dynamics primarily by a narrow barrier of land. The freshwater input into the lagoon is provided by three major sources represented by Canale Vico Patri to the NE, Canale Vena to the NW and a series of minor fresh to brackish water channels as well as three small springs on the eastern coast. A permanent connection with the open sea is provided by a channel, 1.5 km long and a few meters wide (Merola and Sacchi, 1964; Merola et al., 1964).

The present-day Patria Lake occupies the southernmost part of a back-barrier depression of the Volturno delta plain, that lies at an elevation between 0 and −2 m with respect to the present sea-level (Fig. 2) and it represents a remnant of a larger wetland that formed along the coastal zone at the mouths of the Volturno and Regi Lagni rivers during the last thousand years (Amorosi et al., 2012). The original shape and extent of the lagoon have been in fact significantly altered by anthropic activity. As a consequence, only Lake Patria and the Variconi marshes nowadays remain out of the formerly existing lagoon system.

3. Material and methods

This study is based on subsurface geological data and historical cartography. Sedimentological and stratigraphic analyses were conducted on 6 drill cores acquired along a NNE–SSW transect across the eastern coast of Lake Patria. Boreholes G1 to G5 reach a maximum depth of ca. 40 m below ground level (bgl) and were drilled using a thin-walled corer without circulation water added. Borehole G1b was drilled at the Lake Patria shore to duplicate the uppermost 11.20 m of the study sequence, mostly corresponding to the Late Holocene and Recent deposits of the lagoonal succession. Drilling operations at G1b site included the

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