PALEOCEANOGRAPHY INSIGHTS FROM A CHANNEL SYSTEM IN THE PLEISTOCENE FOREDEEP BASIN OF THE ADRIATIC (MEDITERRANEAN SEA)

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ABSTRACT: Three-dimensional visualization techniques were used to determine the presence of a submarine sinuous channel in the Pleistocene foredeep basin of the Adriatic Sea (Mediterranean). The channel system (Adria Channel) drains the upper slope and forms a leveed-channel system and frontal splays out onto the basin floor. Integration of geomorphic and morphometric studies applied to the seismic data set gives insights into the paleoceanography of the buried basin. In particular, the Adria Channel indicates that, besides the channelized flows, bottom currents swept the lower slope, affecting the overgrowth of levees, the deflection of sediment waves, and the progradation of sediment units draping the channel–levee system. The Adria Channel is the longest channel system recognized in the Pleistocene units of the Adriatic Sea (160 km) and one of the few sinuous channels described in a collisional margin.

KEY WORDS: channel, morphometry, geomorphology, levees, sediment waves, paleoceanography

INTRODUCTION

Increasing computing power and enhancement of visualization software in the past several years enable friendly manipulation and relatively rapid interpretation of large 3D seismic volumes. This enhanced capability allows an interpreter to achieve a broader context in the study of geomorphic features and increases the ability to visualize them in three dimensions. Subsurface studies show that depositional elements have horizontal dimensions greater than their vertical dimensions. As a result, small depositional elements often can be resolved in plan view (or surfaces) even if they can be detected only in vertical view (sections). Several techniques (flattening, slicing, spectral decomposition, etc.) contribute to improving our understanding of a particular geomorphic feature or surface of interest, providing new keys to interpret depositional elements and systems (e.g., Barnes, 2006; Gao, 2009). These new techniques allow us to integrate seismic stratigraphy and seismic geomorphology, but borehole data remain critical to the calibration of seismic facies and lithofacies.

Seismic geomorphology is developing on several fronts. Among these recent developments is the application of observations made through seismic geomorphic analysis to paleoceanography, a discipline essential to the understanding of past climate change. Paleocirculation patterns and watermass structure can be reconstructed through interpreting seismic data across contourite drifts (Knutz and Cartwright, 2003; Hohbein and Cartwright, 2006) and sediment waves (Trincardi et al., 2007a, 2007b). As seismic data coverage increases in deepwater environments along continental margins, the role of these seismic-based geomorphologic studies could become more important, enhancing our understanding of sediment dispersal patterns in deep marine environments.

This research documents how integration of geomorphic and morphometric studies, applied to 3D seismic volumes, gives insights into the paleoceanographic history of a basin. In particular, we describe a clastic system active between the upper slope and the basin floor in a Pleistocene foredeep basin. The integration of boreholes and 3D data provides for calibration of seismic facies and lithology of the depositional elements under scrutiny.

SETTING

The main Pleistocene sequences of the Adriatic foredeep basin are in the order of 100 ms thick, and consist of prograding slope deposits and sheet-like turbidites (Dondi et al., 1985). The prograding units represent the filling of the foredeep basin. A complete foredeep sediment cycle representing depositional shallowing conditions could not develop during the Pliocene because structural deformation affected the basin before the fill process was complete (Argnani and Ricci Lucchi, 2001). Pleistocene time, with respect to Pliocene time, is characterized by an averaged lower sea level, a higher sediment accumulation rate, and weaker tectonic activity (Carminati et al., 2003). Therefore, the Pleistocene units in the North Adriatic basin are an ideal place to study seismic geomorphology because morphologies are thick enough to be resolved in seismic and because they are undeformed by postdepositional tectonic activity, thus recording in their stratigraphy the result of primary sedimentary processes (Figs. 1, 2).

The North Adriatic margin presents a channel system up to 160 km long developing from the upper slope to the deep basin (Fig. 3). The main point source of sediment is the paleo–Po river system, which was the major contributor to the progradation of the continental slope along the northwest–southeast-oriented axis of the foredeep basin (Fig. 1). The paleo–Po delta developed...
in the inner shelf during transgressions and reached the edge of the wide Adriatic shelf during regressions (Correggiari et al., 1996). Secondary sediment sources were the folded and thrust Apennines Mountains, located on the western flank of the basin (Ori et al., 1986). Sea-level fluctuations in the Adriatic caused drastic modifications in oceanographic circulation during the late Pleistocene, affecting sediment distribution in these deepwater systems (Trincardi et al., 1994; Cattaneo and Trincardi, 1999; Ridente et al., 2008). In fact, the Adriatic is a land-locked, semi-enclosed basin, hence any change in sea level or in the infill of the basin by progradational sediment bodies may have altered the paleocirculation pattern substantially. However, the pattern of sea-level fluctuations and Po delta advance and retreat at the scale of the last glacioeustatic fluctuation could represent an analogue of what happened in previous cycles.

The modern Adriatic Sea presents bottom currents both cascading across strike and flowing along the continental slope (Verdicchio and Trincardi, 2006) and superficial currents having counterclockwise circulation (Sherwood et al., 2004). These flow patterns affect the late Pleistocene sediment distribution and the geometry of the prograding clinoforms both on deltas and on the continental slope. Advection determines the asymmetry of the Po
delta and the absence of pronounced prodeltas along the Apennine shelf. The modern currents in the Adriatic Sea govern a sediment dispersal system more than 500 km long (Trincardi et al., 1996, Cattaneo et al., 2004).

METHODS

This work is based on a large dataset of 3D seismic volumes and well logs acquired by eni E&P over the last decades. The 3D seismic volumes used in this study have a band width of 20–100 Hz and a wavelet with zero phase and normal polarity. Five separate data volumes were merged on a common georeferenced coordinate system combining to cover more than 4,000 km² of study area to better appreciate the spatial distribution of the channel–levee system beyond the prograding slope in the North Adriatic foredeep basin. Regional surfaces were interpreted to create maps that represent the entire structure of the basin at a glance (Fig. 1). This mapping was based on the interpretation of every other line (of the 3D seismic volumes) in order to get the highest accuracy in the measurements of the geomorphic elements. To implement horizontal-view seismic interpretation, we picked geologic-time surfaces from the 3D seismic volumes so that seismic attribute maps on these fixed-geologic-time surfaces can be analyzed in terms of depositional systems and used in determining the evolution of the channel system through time. Seismic workstation visualization software for propor-

Fig. 2.—Seismic cross sections showing Pleistocene progradational units filling the North Adriatic basin southeastward; the high-amplitude continuous reflector bag_25 displays a channel–levee system with levees up to 30 ms high and overbank deposits forming a ridge (R) tens of ms above the surrounding paleo-seafloor (see Figure 1 for locations).
tional slicing, seismic attribute extractions, spectral decompositions, and co-rendering assisted in imaging the geomorphic systems.

Three wells located proximal to the Adria Channel provided logging suites and recovered sediment samples over the interval of interest (Fig. 4). A synthetic seismogram with the same phase and polarity as the seismic data (zero phase, normal polarity) was generated for each well using the logs available in those wells. These synthetic seismograms were used to tie the horizons and picks to the seismic data. Once the synthetic wavelet matched the seismic data, we used the well logs to determine the lithologic meaning of the seismic facies within the stratigraphic framework. Furthermore, well logs allowed calculation of the average seismic velocity of the study section (2000 m/s) to convert vertical measurements on seismic profiles from milliseconds (TTWT) to metric scale.

Fig. 3.—Source-to-sink channel system (Adria Channel) developed for more than 100 km from the upper slope to the basin; A) continuity overlying RMS average amplitude extracted from a 40 ms window below surface bag_25 (red is high value, blue is low) and line drawing of distal sector of the Adria Channel; B) image derived from spectral decomposition (26 Hz) and overlying the flattened surface bag_25; C) combined image overlaying continuity to image 3b; the line drawing displays the drainage acting as source area for the channel system; D) close-up showing outer bends with levee breaches; E) close-up showing distributary channels in a frontal splay with high amplitude values.

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**OBSERVATIONS**

*Pleistocene Clinoforms in the North Adriatic*

The study area of the North Adriatic foredeep basin is filled by sheet-like deposits with high-amplitude seismic facies overlain by prograding clinoforms that rapidly consumed the accommodation space of the foredeep during the late Pleistocene (Fig. 2). These clinoforms encase a well-developed channel system that is the object of this study. The geometry of the sediment units shows that clinoforms prograde in two directions: parallel and perpendicular to the axis of the basin, the former direction related to the paleo-Po river system and the latter to the Apennine mountain chain (Figs. 1, 2). Consequently, they generate an interfingering of marine onlaps and downlaps whose specific geometry depends on the variable provenance of the sediment. These two distinct
prograding slope systems determine almost perpendicular shelf edges with a crescent-shaped area where they merge (Fig. 1). The shelf edges are linear, and no lobate features resembling shelf-margin deltas occur. Seismic facies on the slope have discontinuous low-amplitude reflectors. Commonly, these facies are intercalated with regionally continuous, high-amplitude, low-frequency reflectors (Fig. 2). It is one of these reflectors (bag_25) that defines the late Pleistocene clinoform encasing the well-developed channel system, the object of this study.

Well logs (gamma ray, sonic, acoustic impedance) define the surface bag_25 as the interface between an upper sediment with low seismic velocity (1980 m/s) and a lower deposit having high seismic velocity (2010 m/s) (Fig. 5). The passage from low velocity to high velocity defines a trough in the seismic wavelet (zero phase, normal polarity). This trough corresponds to a bright, continuous reflector with low frequency that is correlatable regionally. Sediment samples recovered fine-grained sediment in the unit with high seismic velocity and recorded a thickness of 40 m. We interpret this unit as a hemipelagite (the top of the hemipelagite corresponds to surface bag_25). The top of the hemipelagite shows extremely high values of gamma radiation.

Several seismic attributes contributed to the identification and visualization of the Adria Channel, including but not limited to root-mean-square amplitude, continuity, and spectral decomposition. By integrating the seismic attributes, we were able to visualize the complete system of the Adria Channel, identifying drainage area, leveed channel, frontal splays, sediment-wave fields, and draping unit. The Adria Channel is the longest and most evident Pleistocene channel system in the North Adriatic basin. The channel–levee system is 111 km long, reaching 151 km if frontal splays are included in its length measure. Taking into account the seismic amplitude values: relatively high values occur to the west, and low values occur to the east in the sediment-wave field. Right below the hemipelagite and parallel to it, the seismic profile of Figure 5 shows a reflector characterized by wavelet picks with high amplitude and continuity. Sediment samples recovered sand in the unit defined by this reflector. The local topography constrains the sandy unit to a subtle ponded basin.

The Adria Channel and Its Depositional Elements

The surface bag_25 was mapped along one of the above-mentioned regionally continuous, high-amplitude, low-frequency reflectors to define the uppermost unit of a long-lived channel system, here named the Adria Channel. This reflector represents the boundary between the Adria Channel system and an overlying prograding unit (Fig. 2). The surface bag_25 is present in the entire basin and extends landward up to the shelf edge, where seismic artifacts (i.e., multiples) hamper further interpretation (Fig. 2).

Figure 4 shows how the widest bend of the Adria Channel (between sections 6 and 10) divides into two areas with distinct seismic amplitude values: relatively high values occur to the west, and low values occur to the east in the sediment-wave field. Right below the hemipelagite and parallel to it, the seismic profile of Figure 5 shows a reflector characterized by wavelet picks with high amplitude and continuity. Sediment samples recovered sand in the unit defined by this reflector. The local topography constrains the sandy unit to a subtle ponded basin.

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consideration also the drainage area, the whole system has a total length of 160 km.

**Drainage Area of the Adria Channel**

The drainage patterns of the Adria Channel stand out when imaged using spectral decomposition of the seismic signal that filters part of the acoustic noise and some artifacts, as multiples. In particular, the main content of frequency in the 3D seismic volume (26 Hz) emphasizes the short, narrow, and straight gullies that erode the upper slope and converge basinward at the base of the slope (Fig. 3). These gullies have self-similar dimensions and feed a sinuous conduit that develops a channel with levees up to 20 ms high (ca. 20 m) (Fig. 2). The drainage development appears to be best expressed in a crescent-shaped upper slope area where the slope related to the Apennine Chain and the slope prograding along the axis of the Adriatic basin merge (Fig. 3).

**Leveed Channel**

Levees are best developed in the proximal sector of the Adria Channel. The accuracy of surface bag 25 is enough to distinguish the channel thalweg from the levees, and the resolution of seismic stratigraphy allows observations on the vertical evolution of the channel system (Figs. 2, 4). The channel system appears stable and laterally inactive, as evidenced by its lacking avulsions in the upper reach of the system, lacking meander growth, and lacking cutoffs. Consequently, the channel system piles up sediment units more than 100 ms thick; in particular the aggradational levees form a ridge up to 30 ms above the adjacent basin floor (Figs. 1, 2). Locally, this ridge acts to form a ponded slope microbasin (Fig. 4).

**Frontal Splays**

Toward the basin, where the channel depth decreases notably, the interpreted surface bag 25 is not accurate enough to...
image the most basinward sector of the Adria Channel (Fig. 1). Co-rendering seismic attributes (continuity and most representative frequency, 26 Hz) and projecting them on the surface bag_25 helped distinguishing the interconnected narrow and thin conduits characterizing the final sector of the channel system (Fig. 3E). These conduits form dendritic patterns with an overall cone-shaped morphology. They are associated with levee breaches in outer bends and are interpreted as avulsion channels generating frontal splays. Figure 3 shows RMS average amplitude extracted from a 40 ms window below surface bag_25. Therefore it represents the distribution of sediment during the last stage of development of the long-lived Adria Channel. Most of the frontal splays show low amplitude values. Only the southernmost frontal splay presents high amplitude, here interpreted as indicative of coarser sediment. The last channel to form across the top of this splay is the most sinuous (Fig. 3E).

**Sediment Waves**

Sediment waves occur out of two outer bends of the Adria Channel characterized by strong curvature (at sections 9 and 13) (Fig. 4). The two sediment-wave fields merge and present low values of seismic amplitude. In map view sediment waves are curvilinear and subparallel, and their crests reach 3 km in length. Shorter crests occur outward, and their geomorphic expression disappears 5 km away from the generating points. The waves closest to the generating points are parallel to the outer bends. The farthest are almost straight, north-south oriented and apparently disarticulated with the original train of sediment waves, maybe indicating a different controlling factor.

**Draping Unit**

The sediment unit overlying the surface bag_25 is a prograding clinoform of the continental slope topped by a continuous bright reflector (Figs. 2, 6). An axial transect of seismic profiles along the thalweg shows how this sediment unit progrades exactly along the thalweg, down to section 15. The progradation shows low-seismic-amplitude reflectors downlapping on the surface bag_25, forming a wedge that thins down system (Fig. 6). Beyond section 15 the sediment unit overlying bag_25 appears wavy. This unexpected geometry derives from the arbitrary cross section tracked along the thalweg and shows that deposition does not prograde along the thalweg beyond section 15. To understand the true direction of progradation in this sector we track a line parallel to bag_25 on the arbitrary cross section (dashed line in Fig. 6). The line intersects a marked wavy reflector (green reflector in Fig. 6) defining the points where the thickness of the draping unit is the same (because the dashed line and bag_25 are parallel). In map view, these points define the front of the prograding clinoforms along this sector. Assuming that the front is linear and perpendicular to the flow direction, we infer that the sediment source is to the northwest (Fig. 6).

![Fig. 6.—Cross section along the channel axis from sections 9 to 19; note the green reflector topping the unit overlying surface bag_25; in the proximal sector (sections 9–14) the overlying unit progrades along the channel, forming clinoforms; clinoforms thin out basinward around section 15. In the distal sector, the wavy geometry of the draping unit suggests provenance of sediment from the northwest.](https://pubs.geoscienceworld.org/books/chapter-pdf/4260007/9781565763043_ch14.pdf)

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Quantitative Analysis of the Adria Channel

Where Adria Channel piles up sediment forming the ridge, we analyzed 20 topographic transverse sections 2 km apart from each other and we measured slope gradient, width, depth, and sinuosity (Fig. 7). Channel width is calculated between the highest point of each levee on topographic sections perpendicular to the channel axis. Channel depth (or levee height) is calculated between the apex of the levee and the thalweg, projected on the same vertical segment. Sinuosity derives from the ratio of the conduit length (measured along the centerline of the thalweg) to the length of the line connecting the inflection points of bends. Sinuosity increases basinward, whereas slope gradient, width, and depth decrease basinward (Fig. 7). Levees are asymmetric in shape. In particular, the right levee appears higher in sections 4, 9, 10, 17, 19, and 21. These sections coincide with right bends where the right levee is considered an inner levee. A constant growth of the right levee occurs from section 6 to section 10 (where the right levee grows ca. 18 m) while a decreasing trend occurs from section 11 to 16. Although the depth of the channel decreases basinward, short segments record local subtle counterslopes (less than 1 degree). Commonly, these counterslopes occur beyond bends on straight reaches, and they were averaged out when analyzing the general slope gradient of the channel. Average values of slope gradient gradually decrease basinward. Reaches 1–5 have an average slope of 0.40°, 6–16 have an average slope of 0.27° and 17–22 have an average slope of 0.16°. Sinuosity along the same reaches is 1.2, 1.5, and 1.8, respectively (Fig. 7).

Along the uppermost sections the channel narrows from 1300 to 800 m (Fig. 7). Section 4 is located at the first slope break of the system. From section 4 to 11, width is around 800 m, then it drops to 500 m, maintaining this width downslope to section 18, where a second slope break occurs and the channel width decreases gradually. The width:depth ratio is constant along all the transverse section analyzed. Along the thalweg, root-mean-square (RMS) amplitude shows high values between section 4 and 12 and low values upstream and downstream. In particular, high amplitude appears on straight reaches and upslope of the aforementioned counterslopes (Fig. 4).

Sections 3 to 6 are on the most steeply sloping sector of the channel and display a subtly incised thalweg (Fig. 5). Sections 7 to 11, located beyond the first slope break, show a concave-upward profile with lateral wing-like structures, typical of channel–levee

Fig. 7.—Plots showing levee height, channel width, and thalweg depth with relative sinuosity and slope gradient. Bottom: topographic profiles across the channel–levee system. Arrows on sections 13, 17, and 18 indicate erosion on the left levees in the outer bends (see Figure 4 for location of sections).
systems. Topographic sections 13, 17, and 18 show erosion on the left levee—that is, on outer bends. In section 13, the outer levee is higher than the corresponding inner levee, and vice versa in sections 17 and 18, where the outer levees are lower than the corresponding inner levees (Fig. 7).

DISCUSSION

The Adria Channel and Its Paleoenvironmental Significance

The Adria Channel trends in an overall northwest to southeast direction and is developed at the base of a slope 300–400 ms high from shelf edge to basin floor (Fig. 2). Excluding the eroded drainage area, most of the slope shows no truncations or regional erosional surfaces. This lack of significant erosion suggests that the generation and evolution of the Adria Channel occurred in a submarine environment. Additional data confirming this setting are the vertical aggradation of the meanders and the downslope decrease of width and depth of the Adria Channel, opposite to what occurs in alluvial systems (Kastens and Shor, 1986; Flood and Damuth, 1987; Ethridge and Schumm, 2007) (Fig. 4). Dimensions of the depositional elements described are compatible with known examples of submarine channel systems (e.g., Kolla et al., 2007).

The self-similar converging gullies suggest that the staging area of the Adria Channel is the upper slope and that no further sediment sources occur landward on the shelf. Probably this is a factor determining the prevalence of fine-grained sediment in the channel system, and consequently the low amplitude of the seismic facies (Fig. 2, 3). The drainage area is located where the Apennine and the paleo–Po river slope prograding clinoforms merge. The converging progradation of the two slope systems seems to determine a preferential submarine erosive area along the hinge, an area where the availability of accommodation is not enough for the amount of sediment prograding from the two fronts (Fig. 3C).

The proximal sector of the Adria Channel receives unconfined flows where the gradient is highest, and no preferential erosive conduits occur (Fig. 7). The flow waxes and becomes confined beyond the first slope break where an erosive conduit forms. Possibly, a hydraulic jump determines the appearance of levees (section 7) ca. 4 km downslope of the slope break (section 5) where the channel width decreases by 60% and the levees grow with a positive trend up to 15 m.

In the main sector analyzed, the Adria Channel is stable. It lacks avulsions, lateral migration, and meander growth. The channel persists under conditions of extreme vertical aggradation because sedimentation on the overbank keeps pace with sedimentation on the channel bed (Fig. 2). Consequently, the channel system builds up, by aggradation, a continuous ridge above the adjacent seafloor. These observations suggest that flows in the channel had predominantly fine-grained suspended load. Also, the formation of two adjacent sediment-wave fields indicates that the flow in the channel was mainly dominated by fine-grained sediment continuously stripping over the outer bends. These relationships are supported by several authors (e.g., Ethridge and Schumm, 2007; Posamentier and Walker, 2006; Kolla et al., 2007).

Inferred Paleoeceanographic Processes

Flows with fine-grained sediment are generally slower than dense currents carrying coarser sediment, and the influence of the Coriolis is weaker on slow flows (Normark and Piper, 1991). We infer that the right levee is higher on the inner part of bends because of a bottom current sweeping the area southeastward. Such a current would add a southeastward vector to the dilute flow confined within the channel, thus determining an overgrowth of right levees along the inner bends (Fig. 8). In the modern Adriatic Sea, the overgrowth of levees derives from regional bottom currents flowing perpendicular to the channel (Trincardi et al., 2007b). A specific sector of the Adria Channel, between sections 11 and 17, does not show this kind of levee overgrowths. The sector between sections 11 and 17 shows typically higher levees on outer bends, as expected from flow stripping. This increase in levee height relates to the shadow effect determined by the elevation of the ridge along sections 5–10, which protects this sector from the southeastward bottom current. Shadow effects are described in the literature when reporting about comet-like features behind obstacles along a flow path (e.g., Fleming, 1984; Verdicchio et al., 2007). The shadow effect is evident also from observations on the sediment-wave fields. Overbank sediment waves develop preferentially on the outer bends of the channels by flow stripping and generate a front of crests perpendicular to the flow stripping, almost parallel to the outer bend (Migeon et al., 2001; Posamentier and Kolla, 2003). In the study area, sediment waves are parallel to the outer bend only within a certain distance (within the “shadow cone”), whereas they appear deflected farther (where the southeastward bottom current sweeps the paleo-seafloor) (Figs. 3, 4). Deflected sediment waves are reported by Verdicchio et al. (2007) along the modern Adriatic slope, where currents cascading from the upper slope affect along-strike bottom currents. Further modern analogs of strong bottom currents capable of affecting depositional elements during their formation are documented in the Adriatic Sea (Cattaneo et al., 2004) and in the Bahama Outer Ridge (Flood and Giosan, 2002).

We interpret that the southeast-flowing bottom current deposits most of the coarser sediment at the main slope break on a ponded microbasin, as documented by the high values of RMS amplitude in that area (Figs. 4, 8). We infer that the high-density part of the bottom current is less than 30 m thick because the coarse sediment is not deposited beyond the 30-m-high ridge formed by the aggradation of the Adria Channel. Therefore, the high right levee confined within the widest bend (sections 6–10) reflects the deposition of the finer sediment carried in the uppermost part of the bottom current. Hence, the current was thicker than 30 m. Based also on observations by Mohrig and Buttles (2007), the southeast-facing bottom current is unconfined, because the ratio of current thickness (>30 m) to channel depth (<15 m) is greater than 1.3, which is the threshold for channelized flows in laboratory experiments.

Flows flushing the Adria Channel had erosive capability at least down to section 18, where outer bends show the morphology of undermined levees (Fig. 7). Section 13 shows typical right inner levee lower than outer levee, vice versa in sections 17 and 18, where right inner levees are higher because they were affected by the southeast-flowing bottom current. Hence, sections 17 and 18 represent the passage between the channel sector protected by the shadow cone and the downslope sector swept again by the southeast-flowing bottom current (Fig. 8).

The shadow effect affected the depositional pattern even after the end of the Adria Channel activity. Within the shadow cone, the abandoned channel determined a preferential direction for low-energy flows depositing their fine-grained sediment. Out of the shadow cone, the stronger southeast-flowing bottom current deposited sediment disregarding the slope gradient of the abandoned channel and generating a prograding front perpendicular to the southeast-flowing bottom current (Fig. 6).
Counterslope segments along the thalweg associated with high RMS amplitudes are interpreted as scours that erode the bed of the Adria Channel where the channel widens and flow may expand, as described elsewhere by Normark and Piper (1991). Generally, authors report a decrease of width:depth ratio where sinuosity increases (e.g., Crumeyrolle et al., 2007). However, the processes generating the scours increase the efficiency of the currents flushing the channel, thus maintaining a constant width:depth ratio along the Adria Channel even where sinuosity increases.

The last frontal splay of the Adria Channel that is derived from a channel avulsion occurred upstream of the previous avulsions (Figs. 3D, E). Also, the frontal splay spread upstream with respect to the previous ones. The last channel to form across the top of this frontal splay is the most sinuous (Fig. 3E). These observations suggest backstepping of the system and decrease in sand:mud ratio in the flows and therefore representative of the waning phase of evolution of the turbidity-flow channels, as reported elsewhere by Posamentier and Walker (2006). We infer that the hemipelagite plugging the Adria Channel (whose top is represented by surface bag_25) was deposited during a transgression when the paleo-Po delta was confined in the inner shelf and sediment accumulation rate was minimum at the base of slope. The extremely wide shelf of the North Adriatic determined a condensed section also in the upper slope, which became underfilled during the transgression. In this view, the extremely high radioactivity values of the gamma log at the top of the hemipelagite may represent the maximum sediment starvation during a relative sea-level high stand, while the prograding unit overlying bag_25, with sigmoidal internal geometry and basal downlaps, may represents a regression.

Sinuous channels are typical of divergent continental margins and are underrepresented in collisional margins (Mutti et al., 2009). Considering this fact, either the Adria Channel is one of those underrepresented features or its presence suggests that the North Adriatic foredeep basin was passive during the Pleistocene. In addition, the literature reports that these channel–levee systems are unique to relatively large river systems. Instead the Adria Channel appears detached from large river systems and is fed by a submarine drainage eroding the mudstone-dominated continental slope.

CONCLUSIONS

Analyses of 3D seismic data and well logs in the Adriatic Sea determined the presence of a channel system (the Adria Channel) having a well developed submarine drainage in the modern upper-slope region, a leveed channel in the lower slope, and frontal splays in the basin. At 160 km long, the Adria Channel is the largest Pleistocene channel system documented in the Adriatic region.

The integration of geomorphic and morphometric studies applied to the Adria Channel indicates that southeast-flowing bottom currents swept the lower slope during the Pleistocene, affecting the overgrowth of inner right levees, the deflection of sediment waves, and the progradation of sediment units draping the channel–levee system. The sinuous leveed channel was stable (laterally inactive) during its time span of activity. Analyses of the seismic and lithologic facies suggest a prevalence of dilute flows operating in the environment where the Adria Channel developed. The Adria Channel appears detached from...
a large river system, and it was likely plugged during a transgression. The Adria Channel may be one of the few sinuous channel–levee systems in a foredeep basin reported in the literature.

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