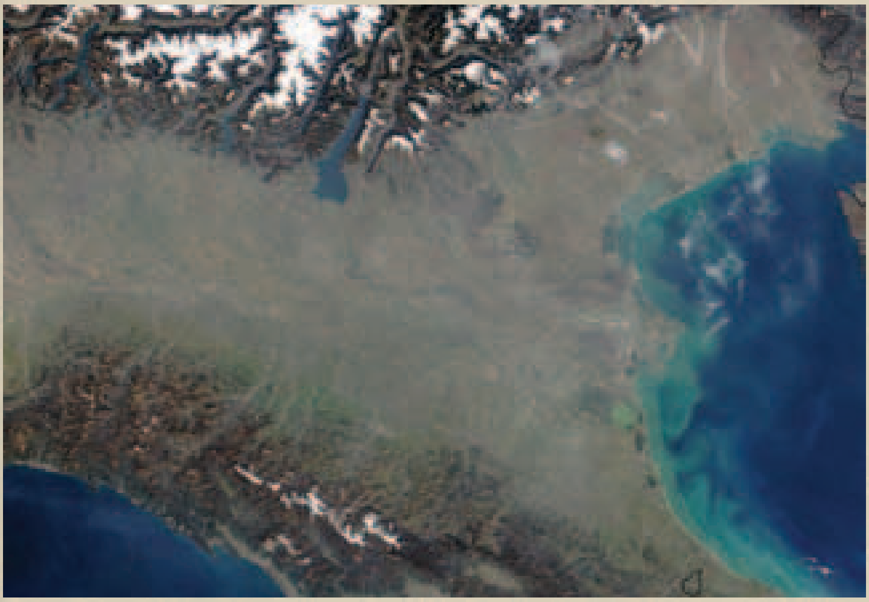
Volume n° 2 - from B16 to B33

32nd INTERNATIONAL GEOLOGICAL CONGRESS

LATE QUATERNARY EVOLUTION OF THE PO PLAIN FROM SURFACE AND SUBSURFACE DATA: A TRAVERSE FROM THE APENNINES TO THE ADRIATIC SEA



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Pre-Congress **B24**

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Front Cover:
Satellite image of the Po Plain, surrounded by the Alps and Apennines chains and by the Adriatic Sea.

LATE QUATERNARY EVOLUTION OF THE PO PLAIN FROM SURFACE AND SUBSURFACE DATA: A TRAVERSE FROM THE APENNINES TO THE ADRIATIC SEA

Leader: A. Amorosi, U. Cibin, P. Severi, M. Stefani
Associate Leaders: G. Gabbianelli, U. Simeoni, S. Vincenzi

Introduction

The depositional architecture of alluvial plain and delta deposits is quite valuable, harboring a detailed stratigraphic archive, highly sensitive to both eustatic and climatic fluctuations. Climate plays a major role by modulating both the marine dynamics and the riverine supplies; relative sea level in turn controls the river base level and the accommodation space availability. The impressive Quaternary fluctuations of these parameters broadly affected the depositional dynamics of the alluvial and deltaic units, offering a good opportunity to test the sequence stratigraphy concepts against actual case histories, framed within a high-resolution chronological context. The alluvial Po plain and delta areas provide excellent examples of such terrigenous systems, as well as being the sites of Italy’s main economic activity, despite their being subject to major environmental risks. The geological study of these deposits is therefore valuable from both scientific and applied points of view.

Since the late eighties, the Geological Survey of the Emilia-Romagna Region has being carrying out an extensive interdisciplinary research effort, aimed at understanding these complex successions, within the framework of the Geological Mapping Protocol of Italy, at the 1:50,000 scale. The research integrates outcrop and subsurface studies, both in the northern Apennines foothills and in the adjacent subsurface, in order to reconstruct the Po Basin depositional history during Pliocene and Quaternary times, through the hierarchical identification of genetically-related depositional units. Detailed surface geological mapping is integrated by shallow-subsurface 3D modeling, based on stratigraphic coring, a large number of digital cone-penetration tests, and geophysics, the latter being particularly valuable in the offshore areas.

This trip is intended to provide an introduction to the late Quaternary evolution of the Po Plain in the Emilia-Romagna region, through the examination of: (i) outcropping continental deposits and fluvial terraces near the Apennine foothills, (ii) stratigraphic cores from upper and lower Po Plain areas, (iii) outcropping Holocene sedimentary bodies in the present-day coastal plain, and (iv) modern delta bay depositional environments. This paper is a collective effort by academic and public administration geologists; individual authorship is indicated at specific paragraphs, the final editing was mainly carried out by M. Stefani.

The Po Plain is the surface expression of a peri-sutural basin, bounded to the south by the Apennines and to the north by the Alps, with its southern prolongation forming the Adriatic Sea (Fig. 1). The region therefore largely corresponds to a foredeep basin, developed during Neogene times and subject to active tectonic deformation. The active tectonic framework of the basin is characterized by ramp and flat structures, propagating toward northern areas. The subsurface geology has mainly become known through the hydrocarbon exploration of this area (Fig. 2), site of natural gas and geothermal exploitation, the latter by the town of Ferrara. Because of the active structural framework, the Quaternary deposits show a comparatively reduced thickness in the discontinuous basin margin outcrops, but they can exceed 2,000 m in the Po Plain depocentres. Great thickness variations have been identified in the subsurface, between subsiding syncline areas and ramp anticline zones. The Quaternary foredeep successions record an overall shallowing evolution, from deep marine environments to alluvial plain conditions, a trend dramatically punctuated by the Quaternary glacio-eustatic fluctuations. This evolution records the sharp predominance of the sediment influx over the accommodation increase rate. The strong sediment input was related to the fast erosion of the surrounding high relief, through glacial and interglacial phases.

The younger portions of the Po Plain stratigraphic succession are dominated by Po river sediments, grading southward into its tributaries deposits. During the first excursion day, fluvial deposits and morphological terraces will be examined in the Modena (Tiepido river valley) and Bologna (Reno river valley) areas. Some geographic and hydrologic information on these rivers is useful in helping the understanding of their depositional dynamics. We have, however, to keep in mind that these data are strongly influenced by both anthropic alteration and the present-day climatic conditions. The Tiepido river (a name literally meaning “lukewarm”) is a small stream flowing from the Apenninic argillaceous hills and reaching the Po through the Panaro river; it is almost dry in summer, but it can experience impressive floods in autumn-winter time (when lukewarm it is not!). The Reno river has presently a length of 211 km, a hydrographic basin of 1,015 km^2, and a mean discharge of about 26 m^3/sec, at its entry point into the alluvial plain. Due to the high relief and the terrigenous lithological composition of the Reno drainage basin, the river sediment load during flood episodes is very large, supporting a high sedimentation rate both along its plain course and at its wave-dominated mouth. The Reno river acted for a long period as a Po tributary, even as late as in the XVI Century, but the combined action of the Po riverbed aggradation and of large hydraulic engineering works then forced it to independently reach the Adriatic Sea, through a former Po delta distributary channel mouth.

The Po is by far the largest river of Italy, albeit being a small one if considered from a global point of view. It has a length of 652 km, a catchment area of about 70,100 km^2, displaying a very complex and heterogeneous geological framework, and a mean annual discharge estimated at about 1,515 cubic metres per second, over the 1918-1981 interval, with flood peaks of over 10,000 m^3/sec and low water levels of just a few hundreds m^3/sec. The largest floods normally take place in November, the lowest level is in late summer. The flux variations are now largely emphasized by human activity impact, such as deforestation, urban growth and continuous river embankment; they were therefore much lower during the Holocene. Throughout the Holocene, active sedimentation was nevertheless essentially confined to autumn-winter flood episodes. The Po northern tributaries, often flowing out of large glacially-induced lakes and from crystalline areas, are generally much poorer in sediment load than their southern counterparts, sourced by the flysch-dominated Apennines. The Po flows into the Adriatic Sea through a complex delta system, the modern one being the youngest out of several generations of highstand wave-dominated deltas. The delta dynamics was obviously influenced also by the oceanographic dynamics of the Adriatic Sea, a semi-enclosed basin subject to strong salinity variations and rich in continental-derived nutrients. Very calm under average conditions, the Adriatic Sea is subject to significant winter storm wave activity, and a tidal range exceeding 130 cm in the Po Delta region. The Po sedimentary evolution will be mainly examined in its historic delta area, during the second day of the trip.

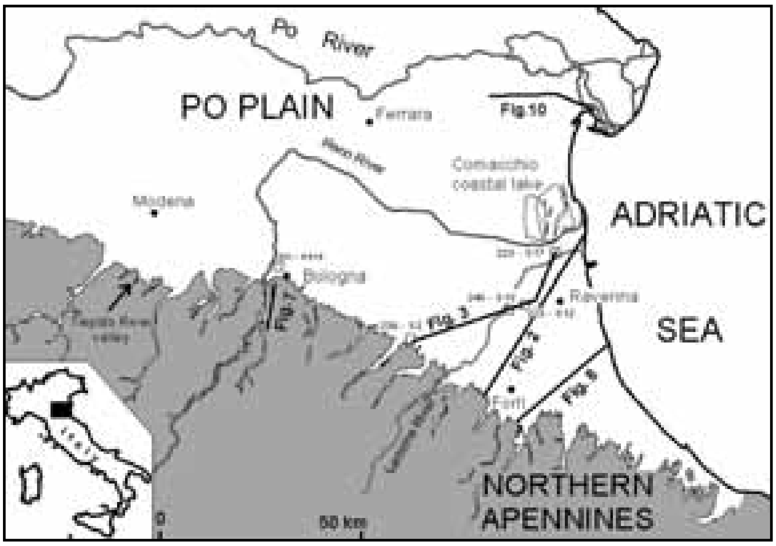

Figure 1 - Location map of the study area, showing section traces of Figures 2, 3, 7, 8 and 10.

Geological setting

The stratigraphic interpretation of the depositional units outcropping at the Po Basin margin is based upon recent field work and previously published papers (Ricci Lucchi et al., 1981, 1982; Gasperi et al., 1986; Vai & Castellarin, 1992; Pini, 1999). Subsurface research at the basin scale (Pieri & Groppi, 1981; Castellarin et al., 1985; Dondi & D'Andrea, 1986; Dalla et al., 1992; Regione Emilia-Romagna and ENI-AGIP, 1998; Regione Lombardia & Eni Divisione Agip, 2002) include: i) the analysis of 30,000 km of seismic reflection profiles provided by ENI-AGIP, ii) sedimentological-stratigraphic interpretation of over 11,000 km of continuously-cored boreholes, and iii) logging measurements (electric logs, spontaneous potential, and, where available, sonic logs) from approximately 600 boreholes.

As already pointed out, an overall shallowing-upward trend characterizes the upper portion of the Apennine foredeep basin fill (Ricci Lucchi, 1986). The distinction of two laterally-extensive stratigraphic discontinuities ("B" and "F" in Fig. 2) enables the identification of three third-order depositional sequences. These sequences coincide with the depositional cycles P2 (middle-late Pliocene), Qm

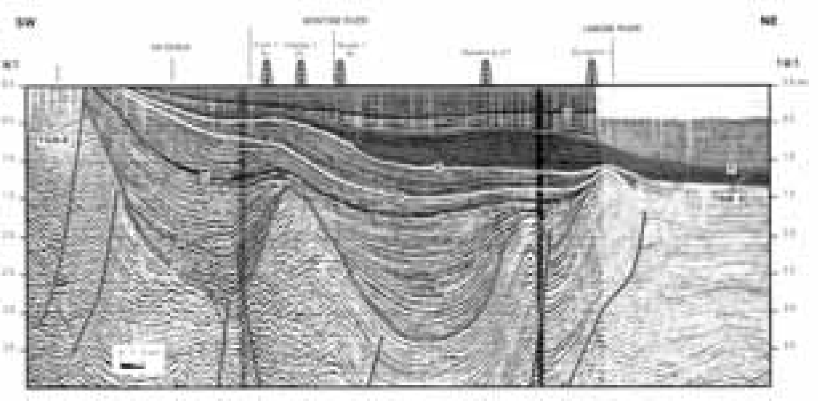

Figure 2 - Seismic line across the southern Po Plain (see section trace in Fig. 1), with sequence-stratigraphic interpretation of the Pliocene-to-Quaternary basin fill, involved into the Apennines front compressive deformation. The "F" unconformity corresponds to the lower boundary of the Emilia-Romagna Supersynthem; the "G" one separates the Lower Emilia-Romagna Synthem from the overlying Upper Emilia-Romagna Synthem. From Regione Emilia-Romagna & Eni-Agip (1998).

(Quaternary marine), and Qc (Quaternary continental), recognized at the basin margin by Ricci Lucchi et al. (1982). These discontinuities record important changes in the foredeep accommodation potential, changes generated by basin-modification events which were related to the structural framework reorganization. These structural events forced the marginal area to uplift and the depocentres to migrate northward, generating denudation surfaces, both at the basin margin and on structural highs. Basin margin tilting resulted in the formation of angular unconformities, associated with strong erosion. Diminishing accommodation triggered the development of fast-prograding units, in the central part of the basin, generating the rapid basinward shifting of the offlap breaks. The main tectonic events were separated by subsidence periods, increasing the accommodation potential. This evolution resulted in the piling up of aggrading packages, with the prominent onlap of seismic reflectors onto the sequence bounding unconformities (Fig. 2). The subsurface correlation of the thin stratigraphic packages recognized in outcrop is prevented by the reduced seismic differentiation potential in the subsurface; detailed calibration of well-log and core data, based upon micropalaeontological analysis, pollen and strontium isotope stratigraphy, however, quite often generates reliable correlation lines from proximal to relatively distal areas.

An upward transition from deep marine clays ("Argille Azzurre") to littoral sands (Imola Sands of Amorosi et al., 1998; see also Ruggieri, 1962, 1995) represents the diagnostic feature of the Qm cycle in the northern Apennines piedmont belt. The Imola Sands outcrop discontinuously, representing the last marine episode recorded in the outcropping foredeep succession, which was deformed and uplifted during Late Pliocene and Pleistocene times.

Tectonic influence progressively decreases from the strongly deformed Pliocene strata to the relatively undisturbed Late Quaternary deposits (Qc sequence, above unconformity "F" in Fig. 2). In the Geological Map of Italy at a 1:50,000 scale, the Qc cycle is referred to as the Emilia-Romagna Supersynthem. Identification of a laterally extensive unconformity within this unit ("G" in Fig. 2) allows the Emilia-Romagna Supersynthem to be subdivided into two lower-rank units (Lower and Upper Emilia-Romagna Synthems, respectively). The Lower Emilia-Romagna Synthem predominantly consists of alluvial and coastal plain deposits at the basin margin, grading basinward into delta front and shallow-marine deposits (high-amplitude, laterally continuous reflectors, Ori, 1993). This unit is capped by the Upper Emilia-Romagna Synthem, consisting entirely of alluvial fan and alluvial plain alternations in marginal areas, grading basinward into cyclic alternations of alluvial and deltaic/shallow-marine deposits. This sequence is characterized by poorly-defined subsurface reflectors, but it can be carefully studied through core analysis and geologic log interpretation.

A marked cyclicity typifies the Upper Emilia-Romagna Synthem. Beneath the present coastal plain, the repeated alternation of coastal and alluvial deposits enables the splitting up of this unit into stacked transgressive-regressive sequences (T-R), showing an average thickness of about 100 m and spanning over time intervals of about 100 ka (Fig. 3). These sequences are characterized by a peculiar internal architecture and correspond to 4th-order depositional cycles. Lower parts of T-R sequences record fast coastal-plain aggradation and rapid shoreline transgression, through the development of retrograding barrier-lagoon-estuary systems, forming thin transgressive systems tracts (TST). The transgressive deposits are overlain by characteristic shallowing-upward successions, related to delta and strandplain progradation, forming highstand systems tracts (HST). The subsequent long-lasting phases of sea-level fall are recorded by exceptionally thick (up to 60 m) successions of interbedded alluvial and coastal-plain deposits, falling-stage (FST) and lowstand (LST) systems tracts (Amorosi et al., 1999b; Amorosi and Colalongo, in press).

At landward locations, within non-marine strata, the rhythmic alternation of coarse-grained bodies and thick, locally-pedogenized, clay horizons occurs at various scales, providing the basic cyclic theme of the alluvial plain facies associations. In this framework, bounding surfaces of T-R sequences are marked by abrupt facies changes, from amalgamated fluvial-channel gravel and sand, deposited mostly at lowstand conditions, to mud-dominated floodplain sediments, with isolated channel bodies and organic-rich, paludal clays (transgressive alluvial deposits - TST). These successions grade upward into thick alluvial plain deposits, showing increased channel clustering and sheet-like geometry (regressive alluvial deposits, including HST, FST, and LST).

The sharp lower boundaries of T-R sequences, identified within the alluvial sections, can be physically traced into the transgressive surfaces recognized at seaward locations (Fig. 3). Given the unconformable nature of the basal transgressive surfaces, the T-R sequences identified within the Upper Emilia-Romagna Synthem can be regarded as subsynthems. Examining the stratigraphic architecture from top to bottom, we may observe that the base of the Ravenna Subsynthem (AES8) corresponds to the onset of the recent Flandrian transgression (Oxygen Isotope Stage 1 in the curve of Martinson et al., 1987); this unit mainly consists of Holocene deposits. The lower boundary of the underlying Villa Verucchio Subsynthem (AES7) is assigned to O.I.S. 5e, i.e. the Tyrrhenian transgression, whereas the base of the older Bazzano Subsynthem (AES6) is thought to reflect transgression at the onset of O.I.S. 7.

Pollen distribution within T-R sequences shows distinctive cyclic changes, which parallel facies architecture. Arboreal pollen (AP) displays maximum values within coastal sediments, floodplain clays, and inland swamp peats, at the base of T-R sequences, suggesting the development of mixed, broad-leafed vegetation, during warm-temperate climatic phases (Amorosi et al, 1999b; 2001). AP percentages sharply decrease in the middle and upper parts of T-R cycles, dominated by amalgamated fluvial-channel bodies, where pollen spectra record a cold-climate vegetation, dominated by NAP (non-arboreal pollen) and Pinus. Transgressive surfaces correlate with the onset of warm-temperate, interglacial phases (Amorosi et al., 2004). The close match between stratigraphic architecture and pollen distribution suggests that sedimentation in the Po Basin was predominantly driven by combined eustatic sea-level changes and climatic variations. Correlation with the marine oxygen-isotope record documents strict relationships between T-R sequences and glacial/

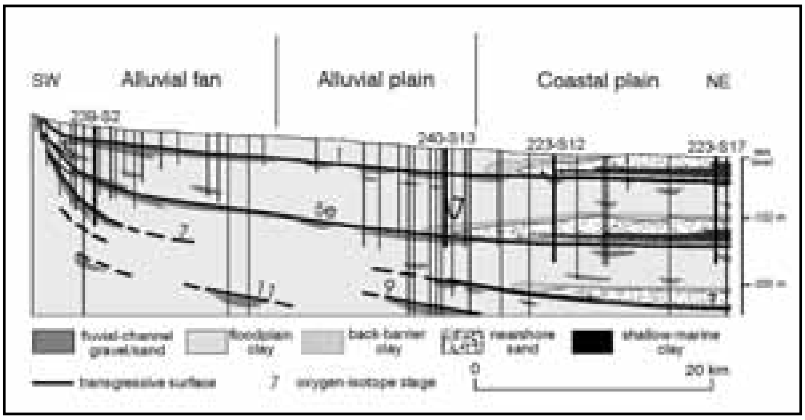

Figure 3 - Stratigraphic overview of the Upper Emilia-Romagna Synthem (see section trace in Fig. 1), showing the subdivision into transgressive-regressive sequences (subsynthems) and the geometric linkage between updip fluvial strata and downdip deltaic and coastal-marine deposits. From Amorosi & Colalongo (in press).

interglacial eustatic cycles.

A peculiar sedimentary cyclicity can also be observed within the intramontane valley deposits, at the northern Apennines margin. Individual cycles there consist of the regular alternation of sections displaying high and low terrace preservation, which are likely to reflect alternating interglacial/glacial phases. Radiocarbon dating (Amorosi et al., 1996) supports the correlation of the well-preserved fluvial terraces, spanning a few tens of metres above the present rivers (terraces 1-14 in Fig. 7), with the Ravenna Subsynthem. Dating of older units is in progress, in order to generate a detailed stratigraphic framework for the whole of the Po Basin. Refined geological mapping of the youngest terraces, together with their radiometric and archaeological dating, document a very close spacing between individual terrace sequences, in the range of 2-5 m, recording a periodicity of 1000-1500 yrs. This study enables their correlation with thin, palaeosol-bounded floodplain cycles, reflecting higher-frequency climatic fluctuations (Fig. 4).

The 3D depositional architecture of Subsynthem AES8 (Ravenna) and the Holocene sedimentary evolution in the Po delta area have been recently reconstructed through interdisciplinary integration of sedimentological, stratigraphic, palaeontological and geotechnical investigations (Amorosi et al., 1999a; 2003; Amorosi & Marchi, 1999; Bondesan et al., 1999). This transgressive-regressive cycle corresponds to the youngest fourth-order depositional sequence, related to the post-glacial eustatic rise. Several evolutionary stages can be schematically identified through the sequence, while only the youngest of these is recorded by outcropping sediments:

a) During the last glacial interval (Würmian), the present day coastal region saw the development of a comparatively-coarse fluvial sedimentation, in a cold, middle alluvial plain setting, about 300 km inland. Amalgamated sand bodies, bearing large mammal remains (e.g., Mammoth), were quite probably deposited into braided river environments, and can be correlated across the entire axial portion of the Po Plain. From a stratigraphic point of view, this unit belongs to the uppermost part of Subsynthem AES7 (Villa Verrucchio).

b) The latest Pleistocene was characterized by a non-depositional and erosional evolution, cutting a system of shallow valleys and fluvial terraces, with elevation differences in the order of 20 m. This evolution resulted in the formation of a laterally extensive hiatal surface, marking the boundary between Subsynthems AES7 and AES8.

c) During the climax of the eustatic rise (O.I.S. 1), coastal sedimentation was negligible, and transgression very fast, producing a widespread ravinement surface, which still bottoms large portions of the Adriatic Sea. Sedimentation was still spotty in the present day coastal area.

d) At about 10,000 yr B.P., the last phases of eustatic rise triggered a renewed fast sedimentation in the area, under lower alluvial plain and coastal marsh conditions. Deposition was unable to counteract the relative sea-level rise and, therefore, further transgression took place, triggering the development of a back-stepping deltaic-estuarine system, characterized by flat, laterally-extensive sand bodies, grading seawards into a condensed bioclastic clay level (TST).

e) At about 5,500 yr B.P., sedimentation managed to compensate the sea-level rise, at the maximum transgression line. This line has been identified 25 km eastward from the present coast in the visited region.

f) High sedimentation rates then took over the reduced sea-level rise, and coastal progradation started. During early highstand times, large coastal bays were closed by the lateral growth of sandy spits

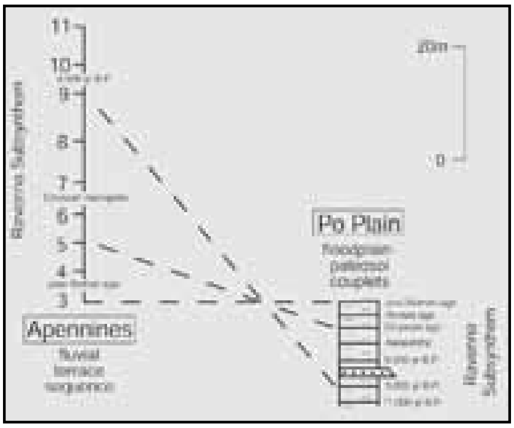

Figure 4 - Stratigraphic correlations between fluvial-terrace and floodplain deposits within the Ravenna Subsynthem. Note how single terrace sequences (numbered on left) correlate into the subsurface with floodplain units bounded by very low-maturity palaeosols (black lines on the right). The correlation line between terrace n. 3 and the post-Roman age palaeosol, based on geometric and pedologic evidence, is assumed as datum. Terraces n. 1 and 2 are not reported in the figure since they are artificial, having been produced by human activity. From Amorosi et al. (1996).

and barrier islands. An environmental innovation phase then generated a deltaic system that was to survive until the recent land reclamation works, through the development of succeeding generations of partially-overlapping delta lobes. Progradation continued to coexist with localised marine transgression onto abandoned distributary systems. The growth of the different lobe generations produced thick regressive sequences (HST). The interpretation of the last 3,000-yr interval becomes more and more accurate, being recorded by outcropping sediments. Through this period, the delta distributary channels migrated laterally, over more than 90 km (Fig. 5). The cold and moist climatic phases saw higher fluvial system instability and faster delta progradation rates than drier periods. The average shoreline migration rate over the last 3,000 yrs was in the order of 4-5 m/yr, peaking at over 100 m in a few months, during the early stages of the present day delta growth. During the same interval, delta front deposits record high sedimentation rates, with an average value of 5 mm/yr and peaks of several m/yr at the distributary mouths.

Over the last 3,000 yrs the sedimentary dynamics have been subject to an increasing anthropic impact. Delta dynamics (Fig. 5) strongly influenced the development of an affluent Etruscan port (Spina), as well as the last capital of the Roman Empire (Ravenna). Eventually, the sedimentary dynamics were totally altered by hydraulic engineering works. The present day delta is an almost artificial structure, induced in the early XVII Century by the Republic of Venice to avoid the silting up of the Venetian Lagoon. The delta is presently characterised by five active distributary channels, namely: Po di Maistra, Pila, Tolle, Gnocca, and Goro, the major one being the Pila channel. During the last 50 years erosion has largely taken over sedimentation as the dominating coastal process, and so delta progradation has ceased, due to the severe reduction of the sediment flux. At present, only large coastal protection works and artificial damming prevent the delta area, largely lying beneath sea level, from being vanquished by the sea.

The modern delta environmental framework

G. Gabbianelli & U. Simeoni

The present day delta territory has been extensively modified by human activity. Hydraulic works were carried out by the monks of the Pomposa Abbey (6th-10th Centuries AD); extensive land reclamation was performed during the XVI Century, but the reclaimed areas were soon to return to their initial marsh condition, because of the fast subsidence, the rapid coastal progradation, the strong sea storms and the river flooding characterizing the so-called “Little Ice Age”, as well as due to human heedlessness. A new cycle of reclamation works began during the second half of the XIX Century, and at the beginning of 1900 ca, 800 km^2 of marshes were reclaimed for agriculture, by means of huge water-scooping machines. The last works were carried out during the 1970s; the marshy areas were eventually reduced to their present 120 km^2 extension, less than a quarter of their 19th Century extension.

The present bowl-shaped form of the delta region, featuring higher borders seaward and a wide depression in the middle, well below sea level (Bondesan, 1989; Simeoni et al., 2000), is mainly due to the artificial subsidence and to the lengthening of the constrained delta distributary channels. During flood events, the levee-retained waters can rise up to 6-8 m above the surrounding floodplain. During the last decades, a deepening trend of the Po distributary channels was recorded, increasing the risk of piping and breaching through artificial levees, grounded on instable soils. The distributaries’ natural tendency of breaching and wandering triggered large flooding even in recent times (1951, 1957 and 1966). This dangerous situation is forcing the managing administrations to constantly reshape the hydraulic works, at a major economic cost. The reclamation works largely enhanced the natural subsidence speed of about 1-2 mm/yr, but the main accelerating factor was the extraction of methane- bearing waters from deposits, carried out between 1938 and 1961 (Bondesan and Simeoni, 1983). Caputo et al. (1970) and Borgia et al. (1982) report subsidence rates of up to 250 mm/yr in the central area of the present day delta, during the 1951-57 interval, and up to 180 mm/yr between 1958 and 1962. After the extraction stopping, subsidence slowed down to mean rates of 33 mm/yr, during the 1962-67 interval, and to 37.5 mm/yr between 1967 and 1974 (Bondesan and Simeoni, 1983). These latter data witness the fading out of the benefits derived from the ending of the water extraction, as early as the early ‘70s. Fast subsidence accelerated shoreline retreat along the delta coasts, already suffering from the sharp decrease of the sediment supply. This evolution also increased the slope angle of beaches. Both the subsidence-triggered lagoon deepening and the sediment occlusion of tidal inlets induced a sensible slackening of internal hydrodynamic energy. The result is a finer-grained sedimentation inside lagoons

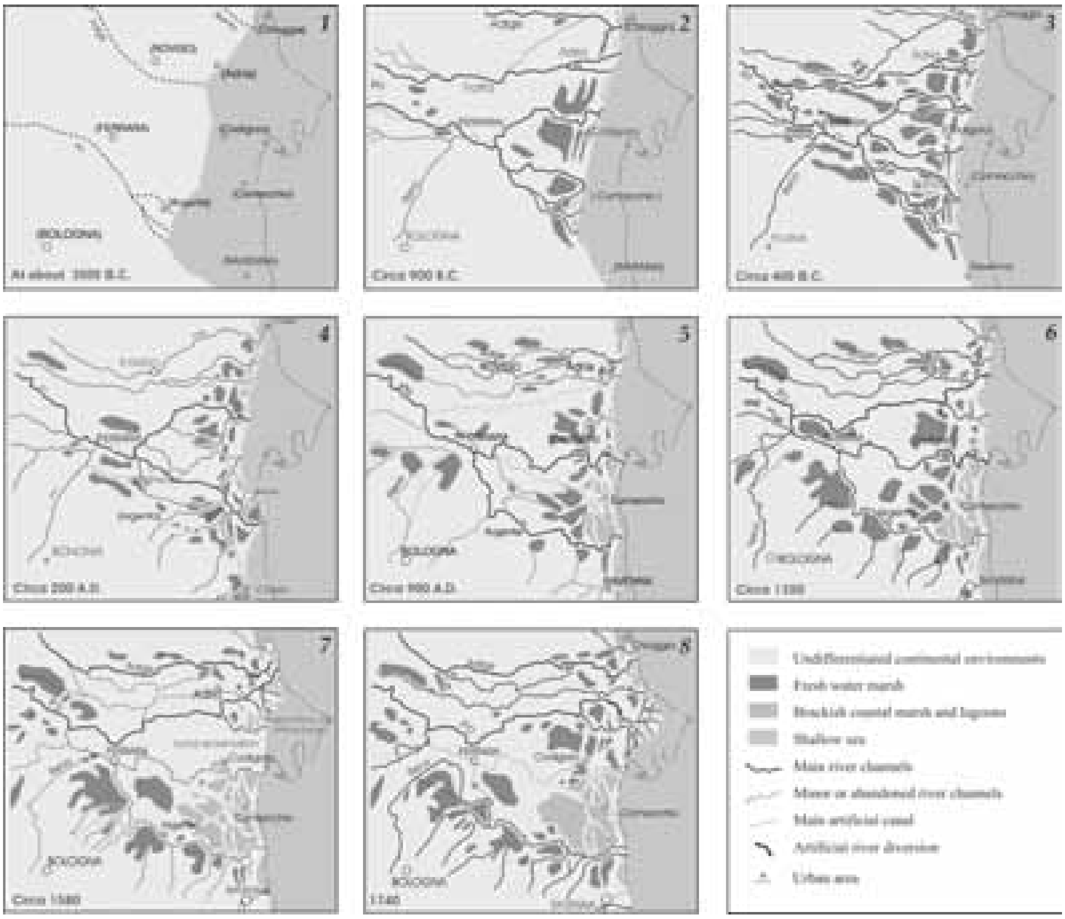

Figure 5 - The complex highstand evolution of the Po delta distributary channels. Palaeogeographic reconstruction becomes progressively more reliable and accurate for the last 3,500 ysr; during this time interval, the delta lobes migrated over more than 90 km and the coastline prograded up to 25 km to the east. The arrows indicate major man-induced fluvial diversions, which had a dramatic impact on the Reno and Po river evolution, the present-day lobe being an almost artificial structure, induced at the very beginning of the XVII Century to prevent the silting up of the Venice lagoon (Cf. Figs. 10 and 11).

and bay areas, which are subject to the progressive benthic fauna depopulation and to increasing anoxia phenomena, also supported by the increasing load of human-produced organic nutrients.

DAY 1

A. Amorosi, U. Cibin, & P. Severi

The first day of trip will be focused on the Late Quaternary deposits of the Po Basin (Emilia-Romagna Supersynthem), along a proximal to distal transect traced from surface to subsurface successions. In the morning, we will observe the fluvial sequences outcropping at the Apennine margin (Modena and Bologna piedmont area). In the afternoon, we will examine the correlative downdip sedimentary successions of the Po Basin, through detailed analysis of continuous cores. Our overall objective is to discuss a stratigraphic traverse stretching across the Po Basin, focusing our attention on the linkage between the updip fluvial strata, partly exposed at the Apennines foothills, and the downdip coastal deposits, buried beneath the Po Plain.

Stop A1:

Quaternary fluvial deposits of the Tiepido River

valley (Lower Emilia-Romagna Synthem)

Our trip will start at the southern margin of the Po Basin, in the Modena area. The lower Quaternary fluvial succession (the Lower Emilia-Romagna Synthem), which is several hundreds metres thick in the subsurface of the Po Plain, wedges out toward the basin margin (Figs. 2, 3, and 8) and is generally not exposed along the Apennine foothills, with the exception of a very few sections. In the Tiepido River valley, the Lower Emilia-Romagna Synthem crops out extensively, consisting of a cyclic alternation of fluvial-channel gravel bodies and mud-dominated floodplain deposits. The overall Quaternary succession is punctuated by two major unconformities, which are thought to reflect two distinct episodes of tectonic uplift which affected the Apennine chain. A prominent unconformity separates the Lower Emilia-Romagna Synthem from the underlying littoral Imola Sands (Qm sequence). The base of the Upper Emilia-Romagna Synthem is characterized by an angular unconformity, overlain by an almost horizontal succession of terraced fluvial deposits. As a whole, the Lower Emilia-Romagna Synthem shows a coarsening- and thickening-upward trend, marked by the progressive increase in the gravel content, leading to frequently-amalgamated gravel bodies. Mature palaeosols can be identified in the upper part of the succession.

Stop A2:

Late Quaternary fluvial terraces of Reno River valley (Upper Emilia-Romagna Synthem)

A few stops in the Reno River valley, nearby Bologna, will provide us with the opportunity to discuss the general aspects of fluvial terrace sedimentation at the Po Basin margin. In this area, a hierarchy of fluvial terrace sequences can be identified by successively thinner groupings of genetically-related fluvial terraces. Unfortunately, outcrops are rare in this area, and our discussion will therefore mainly have to follow a geomorphic approach.

A first stop, south of Sasso Marconi, will provide an overview (Fig. 6) of the entire Late Quaternary fluvial terrace succession (the Upper Emilia-Romagna Synthem). We will be standing on top of the Holocene terrace. Two groups of older, well-preserved fluvial terraces are clearly visible at higher topographic levels. In the valley landscape the various terrace groups show up, split by steep escarpments many tens of metres high, displaying very poor terrace preservation and including outcrops of much older bedrock units (Fig. 7).

A close inspection of the topographic bands displaying higher terrace preservation will be possible later in the day, south of Casalecchio di Reno, where individual terraces of Holocene age can be walked on, and minor escarpments, a few m thick, more closely observed.

The alluvial terrace deposits consist of fining-upward successions, generally 2-4 m thick, bounded by erosional basal unconformities, cut into the underlying bedrock. Channel-related facies are mainly represented by massive, horizontally- or cross-stratified gravels. The lens-shaped sand bodies topping gravel units are thought to represent lower energy deposits, formed in chutes or abandoned channels. Coarse-grained sediments are generally abruptly overlain by tabular silty and clay bodies, considered to be overbank deposits, or by localized organic-rich layers. Terrace sequences are generally capped by colluvial deposits, the thickness of which increases moving from the younger to the older units. Pedogenesis typically took place at the top of the overbank fines. Soil formation was triggered by renewed incision, preventing the further flooding of the newly formed terraces. Soils occur at various stratigraphic levels within the colluvium, reflecting distinct episodes of subaerial exposure.

Stop A3:

Late Quaternary stratigraphic architecture in the Po Plain subsurface:

Core examination and stratigraphic imaging

This stop will illustrate the subsurface stratigraphic architecture of the Emilia-Romagna Supersynthem in the Po Plain (Fig. 8), focusing on the youngest transgressive-regressive cycle, of Holocene age (the Ravenna Subsynthem), through fresh core examination. The Ravenna Subsynthem shows a complex stacking pattern of alluvial, coastal, deltaic, and shallow-marine deposits (Rizzini, 1974; Bondesan et al., 1995; Amorosi et al., 1999a). The Late Quaternary facies architecture of the Po Plain reflects the last eustatic cycle of sea-level fall and rise, from the glacial maximum to the present (Figs. 8, 10). Fluvial sedimentation characterized the long-lasting phase of falling sea level, which occurred during the last glacial period.

Lowstand fluvial deposition was restricted to broad, shallow, incised valleys, and to the basin axis, whereas soil development occurred on the interfluves. The Bølling-Allerød interstadial and the subsequent Younger Dryas cold event, were only recorded in fast-subsiding areas, and even there as scattered spots only. Transgressive sedimentation in the present coastal plain mostly started during the early Holocene. The backstepping evolution of sedimentary facies and coastal onlaps led to the landward migration of the shoreline, up to 25 km west of its present-day position. Detailed facies analysis of cores and interpretation of piezocone penetration tests provide a complex scenario of transgressive depositional environments, including coastal plain/lagoon and estuary systems, either wave-dominated or tide-influenced in nature. Highstand deposition, developed during the last 6 ka BP, was characterized by progradation of several generations of ancient, wave-dominated Po deltas, under the combined influence of climate and subsidence.

There will be ample opportunity to discuss the Late Pleistocene-Holocene depositional history of the Po Plain, through detailed examination of two continuous cores, approximately 35 m long, recovered in updip (alluvial) and downdip (coastal) areas. The comparison of the depositional evolution at proximal versus distal locations will be framed by a series of stratigraphic cross-sections and 3D images, documenting the depositional architecture of non-marine and marine sediments. Facies analysis will include close inspection of fluvial-channel sands, floodplain clays, swamp peats, lagoonal clays, transgressive-barrier sands, inner shelf or prodelta clays, and delta front sands. It will be shown how the interdisciplinary integration of the palaeoecological, pollen, petrographic and geochemical characterization of these facies greatly improves their stratigraphic understanding.

Several sequence-stratigraphic surfaces will be shown on core. The transgressive surface (TS – subsynthem lower boundary in Fig. 8) can be easily recognized as a sharp facies change, separating overconsolidated, stiff floodplain clays from overlying swamp and lagoonal (coastal plain and back-barrier), organic-rich deposits. The tidal ravinement surface (TRS) is locally identified within back-barrier, estuarine deposits of the incised-valley fill. The wave ravinement surface (WRS) is a readily-identifiable, regionally extensive surface, marking an abrupt lithological change from back-barrier clays to transgressive barrier, bioclast-rich sands.

The maximum flooding surface (MFS) is located a short distance above TS and RS, and is generally indistinguishable through conventional sedimentological techniques, but it can be placed, based upon palaeoecological information, at the turnover point of the benthic foraminifera associations. The microfaunal assemblages record a palaeoenvironmental evolution leading from open-marine to shallower water, and eventually to schizohaline environments, thus recording a shallowing trend and an increasing riverine influence.

Finally, the very high-resolution stratigraphic outline reconstructed for the Po Plain will be discussed as a nice case history for distillating a generalized sequence stratigraphy model and for testing the opportunity to use transgressive surfaces, rather than sequence boundaries, as stratigraphic bounding surfaces.

After the discussion we will begin our afternoon drive to Ferrara.

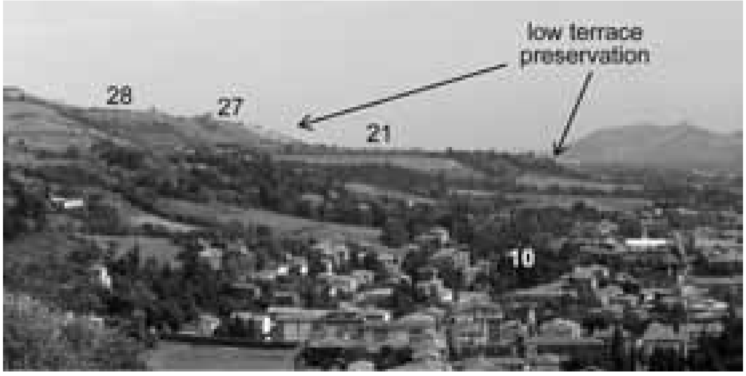

Figure 6 - Highly and poorly preserved terraces along the western flank of the Reno River valley, at Sasso Marconi (15 km south of Bologna). Highly-preserved river terraces are numbered (compare with Fig. 7). Terrace n. 10 belongs to the Ravenna Subsynthem, whereas terraces 21 and 27-28 are assigned to the Villa Verucchio Subsynthem and Bazzano Subsynthem, respectively.

Depositional history and the urban growth of Ferrara

M. Stefani

The overnight stay in Ferrara will provide us with the opportunity to discuss the dynamic relationships between a river depositional evolution and the coeval urban growth. Whereas the majority of the Italian towns shares a pre-Roman origin, Ferrara is a comparatively "new" city,

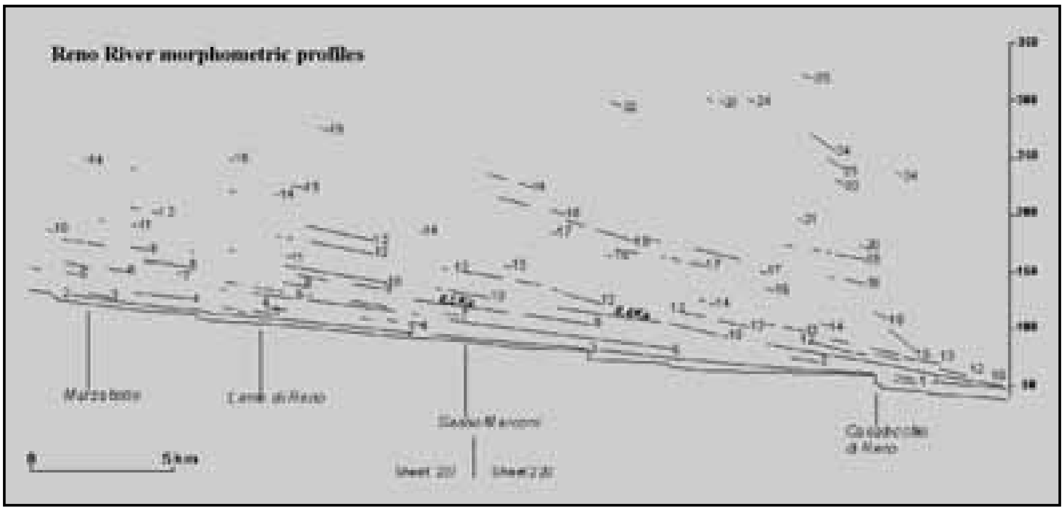

Figure 7 - Longitudinal morphometric profiles through the intramontane valley of the Reno River (see section trace in Fig. 1). Sections with high terrace preservation, corresponding to terraces 1-14, 17-21 and 22-24, are separated by steep escarpments, showing poor (terraces 15-16) or no terrace preservation (see Fig. 6). The escarpments are thought to reflect fluvial channel incision at the onset of glacial periods.

being born in early medieval times (about 1300 yrs B.P.). The early settlers elected the sandy river levees as their dwelling place of choice, since they provided drier and much firmer ground than the surrounding muddy depressions. The town nucleated at two separate sites, the southern one at the very diverging point of the two main Po distributary channels (Primaro and Volano, Fig. 9), where the first cathedral was erected, and the northern one, where a castle was built, near the border between the Byzantine and Longobard areas of influence. The ancient castle area still stands out as the "highest point", so to speak, of the old town. The southern nucleus experienced a reduced expansion, while the northern one enjoyed a steady growth, initially through a linear expansion, on top of an elongate fluvial sand body. Oxford University archeological research has revealed the repeated interbedding of crevasse deposits with anthropic surfaces. At a latter stage, the town grew northward, into the interfluvial depression, through a long series of land reclamation works and discrete town expansions. The environmental constraint, however, still forced the town to keep an elongated shape, parallel to the river. During the XII Century, the Episcopal seat was moved into the Romanesque cathedral, built at the northern limit of the growing town, in a former marsh area. From 1,000 to 500 yrs B.P., the main Po river flow progressively shifted northward, triggering the development of a new delta system (Fig. 5); the water flux at the southern border of the town therefore progressively faded out and a further urban expansion was therefore able to encompass the former fluvial island of St. Anthony. Extensive land reclamation works, starting in 1465, then supported a further huge expansion (the so-called Addizione Erculea, Herculean Addition) into northern interfluvial, morphologically depressed areas, where the poor geotechnical properties generated significant construction problems, witnessed by impressive building deformation. This town expansion started in 1492, but the new areas have still not been completely filled up by constructions (let us hope that they never will be). After a long period of economic and demographic decay, massive urban expansion restarted only after the Second World War, in a chaotic way, utterly unaware of any natural constraint, exposing the town to significant environmental hazards.

The tight scheduling constraints will prevent us from making a comprehensive tour of the town. We will, however, probably be able to get a taste of the "town stratigraphy" by walking through a north-south section, stretching from interfluvial to levee and riverbed areas, eventually reaching remnant distributary channels. We will move from a morphological depression known as Borgo di Sotto (Lower Burg), characterized by organic rich clay and by a very shallow phreatic level, to the sandy levee crest, where 1,000 old buildings are partially buried by slightly younger fluvial sands. We then

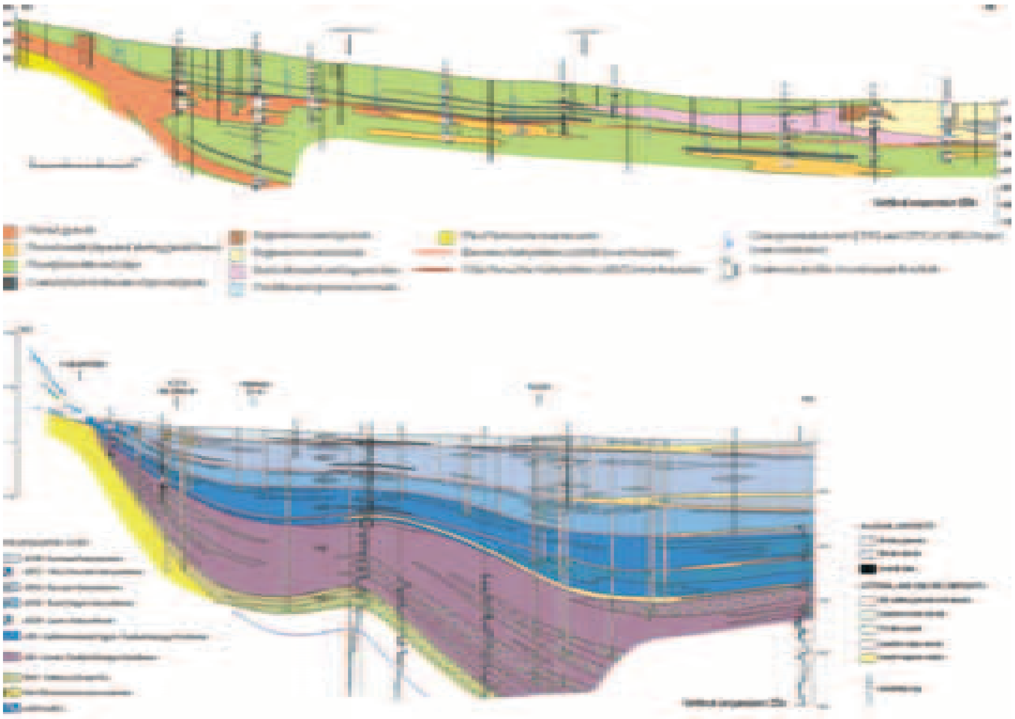

Figure 8 - Geologic cross-sections stretching from the Romagna Apennine foothills to the Adriatic Sea (see section trace in Fig. 1), depicting the subsurface stratigraphy of the Emilia-Romagna Supersynthem (below) and the facies architecture in the uppermost 40 m (above). Compare with the stratigraphic evolution illustrated in Fig. 10. Stratigraphic correlations based upon well geophysical log, core and CPTU data. From the Geological Map of Italy at scale 1:50,000, Sheet 240.

will descend into the ancient sandy river bed (Via XX Settembre), preserving a significant river flank dip (Via Porta d'Amore), and walk through the old town walls and moat, to reach the present day Volano Canal, facing the Po di Primaro distibutary channel diverging area.

DAY 2

M. Stefani and S. Vincenzi

The second day of excursion has aimed at three main goals: (i) exposing the Holocene stratigraphy of the central portion of the Po delta system (Fig. 10); (ii) examining some outcropping coastal units, showing spectacular fossil aeolian dunes, channel-levee complexes, flood erosional structures, etc.; (iii) observe modern depositional environments, during a boat trip into an interdistributary bay. The morning will be aimed at examining some outcropping examples of depositional and erosional processes, which developed over the last 3,000 yrs, a time interval subject to a growing degree of anthropic influence (Fig. 5). This prompts us to put in some remarks on human activity, even in a guide like this one essentially focused on natural processes. Due to the environmental features of the visited area, we recommend trip participants take anti-mosquito precautions.

Stop B1:

Channel-levee complex of the Volano distributary channel

We will leave the Town of Ferrara heading eastward, following for a while the Po di Volano palaeochannel, gently winding through the lower alluvial plain. The sandy palaeoriverbed morphology often stands out above the surrounding argillaceous depressions. The elevation difference is often in the order of 3-5 m and was enhanced, at a late evolutionary stage of the river, by an early artificial embankment. About 1,000 yrs ago, this was the main distributary channel of the Po system, but then it progressively faded into a minor

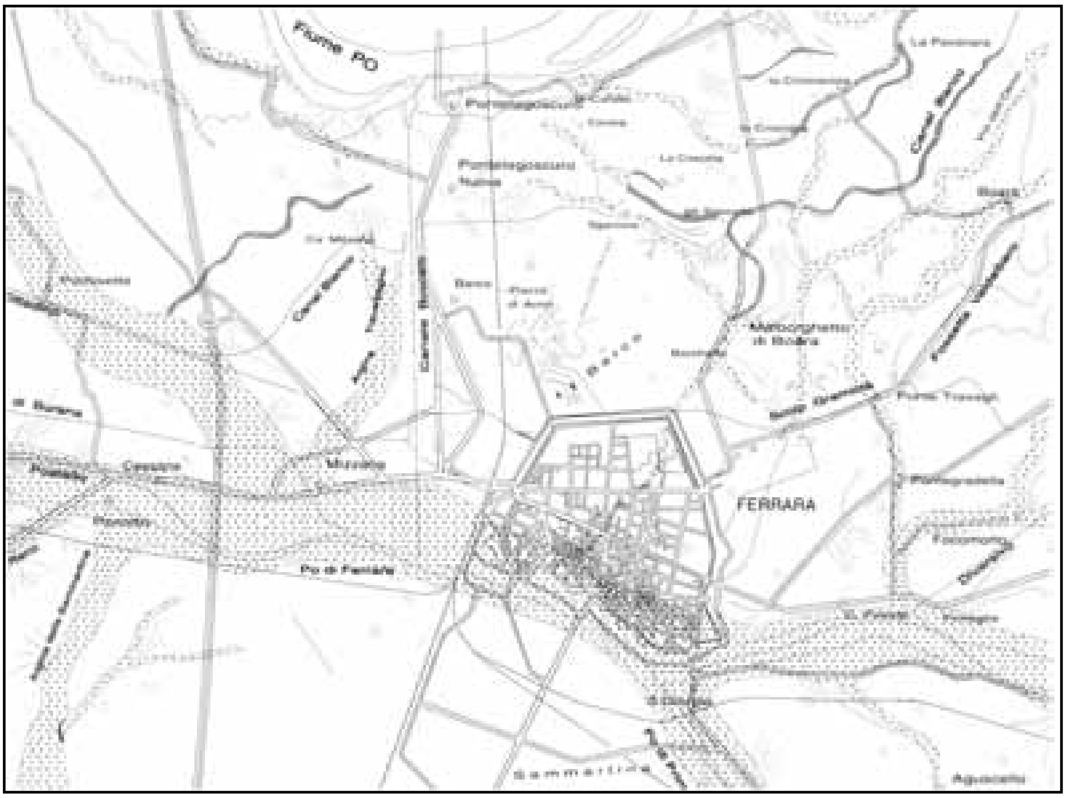

Figure 9 - The town of Ferrara has grown on the northernmost natural levee of the Po River, at the diverging point of its medieval-era distributary channels. The stratigraphic architecture strongly influenced the ancient town shape.

role, due to the northward shifting of the water and sediment fluxes. The system eventually experienced a sudden demise, because of an ill-fated attempt to force the Reno River to reach the sea through the Volano; the reduced morphological gradients and the Reno's huge sediment load suddenly choked the Po channel with sediment, preventing any further water flow. The channel axis was therefore filled up with low permeability, fine-grained organic rich sediments, resting on middle-grained fluvial sand. During the XX Century, an artificial canal was dug into the palaeoriverbeds, kept open for navigation and irrigation purposes.

Stop B2:

Reclaimed interdistributary marsh area at the east of Iolanda di Savoia

We will leave the Volano palaeochannel, to enter into a former marsh area, at Tresigallo. Sedimentological reconstruction and archaeological data suggest that the interdistributary area was mainly under subaerial conditions during Roman times, but then evolved into a broad, fresh-water, marshy zone, above sea level. The region then experienced two superimposed land reclamation phases. The first was attempted between 1564 and 1572 (Grande Bonificazione Estense), over more than 400 km^2: a large, 330-km-long canal system was dug, and waters were forced to reach the sea through two canal mouths, under purely gravitational force. Compaction of dried and oxidized peats and organic clays, however, rapidly induced a fast subsidence, which was soon to reverse the topographic gradients, making any effort to keep the region dry totally futile. It was only during the second half of the XIX Century that land reclamation was re-attempted, reaching success through the massive use of steam water pumping and a good injection of British money and know-how. The visited area now shows a completely artificial landscape, with very open spaces, always lying well below sea level. The differential compaction of sediments emphasizes the ancient sandy riverbeds and strongly deforms the rectilinear road-bed driven along during our trip.

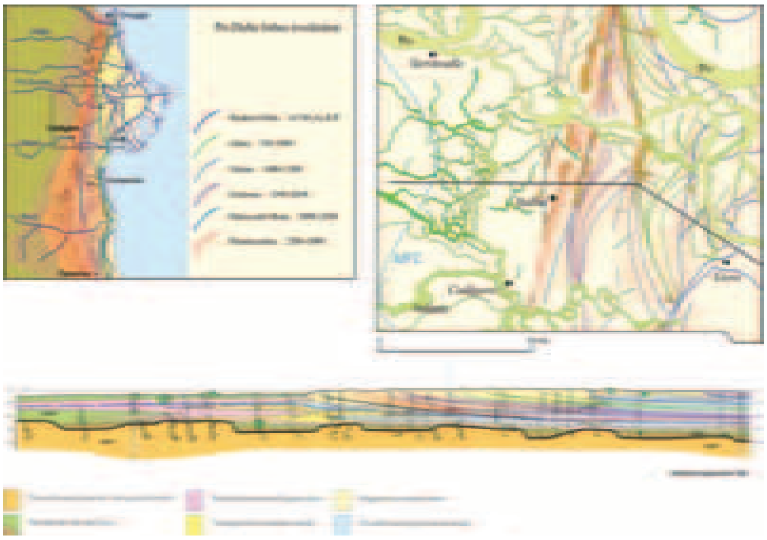

Figure 10 - The visited coastal plain area derived from the superposition of several Po delta lobe generations (a, cf. Fig. 5), the depositional evolution of which is witnessed by outcropping sediments (b) and by the depositional architecture reconstructed in the related subsurface (c, location in Fig. 1). In the profile, a vertical amplification of 1/50 is used and a selection of the analysed cone penetration tests and stratigraphic logs is depicted. While the outcropping units span over the last 3,000 yrs only, the subsurface profile records the evolution from the last glacial maximum to the present. In the stratigraphic profile, note the disconformable superposition of transgressive sediments over eroded continental sands, and the large highstand progradation; in the synthetic surface map, observe the arcuated coastal sand-ridge pattern and the complex palaeoriverbed patterns, showing up in the western portion of the area.

Stop B3:

The Holocene maximum transgression in the northeastern Ferrara Province

Even if nothing catches the eye at the surface, it is worthy to point out the area reached by the Holocene maximum transgression, at about 6,000-5.500 yr B.P., as located by the 3D reconstruction of the depositional geometry and facies (Fig. 10). The maximum transgression line is here located at about 10 m below sea level, and at 25 km to the west of the present day coast line. Such a huge progradation is really impressive, considering the shortness of the time span elapsed and the comparatively reduced dimension of the river system involved.

Stop B4:

Stratigraphic legacy and human alteration on an anomalous delta channel

The trip will perpendicularly cross a peculiar north-south striking palaeoriverbed, the Gaurus. This structure is noteworthy in its being almost perpendicular to all other distributary channels, a trend reflecting the inland wedging out of the transgressive and early highstand coastal sands. This structure was also influenced by the impact of artificial works, carried out during early Roman Empire times, in order to open a continuous navigation canal (Fossa Augusta) linking the ports of Altinum, to the north of Venice, to Classae, near Ravenna. The winding palaeoriverbed stands out above the surrounding reclaimed marsh because of the differential compaction of sand and clay, as well as due to the moistening action of the surviving canal.

Stop B5:

Fossil aeolian dune field near Massenzatica

Major dune field growth was matched with phases of delta lobe abandoning and erosive coast-line retrogradation and stabilization. Some of these aeolian sands show mineralogical features pointing to a northern Adige sediment source, even in this Po dominated area. Among the dune fields preserved throughout the entire Adriatic coast, the visited area stands out for both its good preservation and large dimensions. The dunes date back to about 3,000 yrs B.P., (early Bronze Age) since then, progradation has brought the coastline back an impressive 20 km. The dune field is overall elongated parallel to the ancient coastline, with a N 10° azimuth, but the individual dune ridge direction has a main 50° strike, recording the action of the NE winter winds, in the Adriatic known as “Bora”. The internal forsets are mainly dipping at about 230°, again pointing to the NE wind action. The development of this dune field was probably influenced by the stratigraphic inheritance, which made the area less subsiding than the surrounding ones. This site, indeed, corresponds to the seaward edge of the transgressive coastal sand body and to

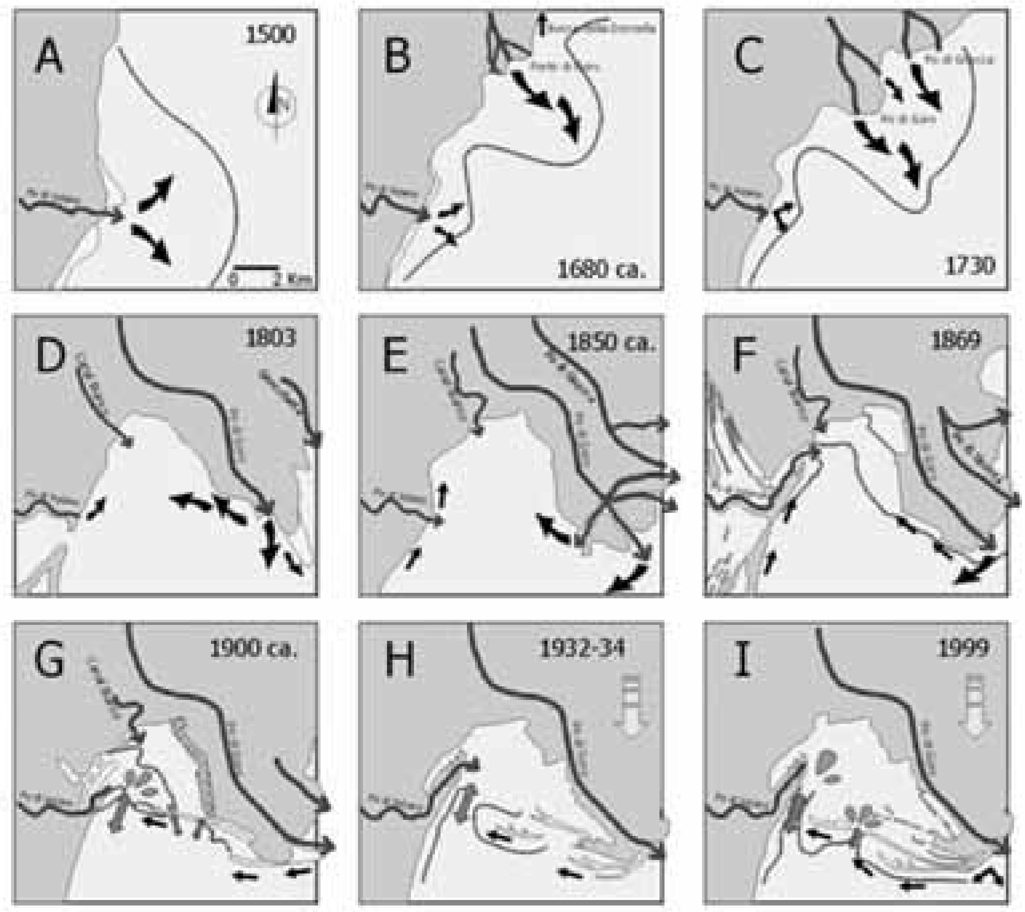

Figure 11 - Environmental evolution of the Po di Goro area from the end of the XVI century to the present day. Bathymetry is depicted by dashed lines (Fontolan et al., 2000). The former marine area was progressively enclosed by the fast modern delta progradation.

an older erosive palaeohigh, curved into Pleistocene sands. The dunes still reach an elevation of about 9 m and are colonized by peculiar xerophilous vegetation. The good preservation of the dune field is also related to the high permeability of these fine-grained, well sorted sands, which prevents rain water from eroding at the surface. At the north, the dune field is suddenly cut by the Po river erosion, near an ancient distributary mouth. At a much more recent time, the dunes barely escaped destruction through illegal sand excavation, a sad fate unfortunately shared by the majority of the surrounding aeolian fields, even where they were harboring major archaeological remains, as in the adjacent San Basilio area.

Stop B6:

Erosive depression cut by flood waters into coastal sands (Gorgo dello Stradone)

The highly turbulent flood waters pouring out from the delta channels interacted in a dramatic way with the coastal sand bodies. The dune alignments played an important role by constraining the flood flux and thus raising up the water level, but the permeable coastal sands were much easier to rework than their finer-grained cohesive marsh counterparts. The fluvial floods were therefore able to pierce through the dune bodies, producing crevasse splays and erosive depressions, locally known as Gorghi, either elongated or sub-circular in shape. The depressions were then filled by the phreatic waters, becoming the site of peculiar, isolated, pond ecosystems. The majority of these depressions was recently filled up by man, generally through their use as waste dumping sites, putting the phreatic waters to a great risk of pollution.

Figure 12 - Satellite image of the modern Po Delta area; the visited Sacca di Goro lagoon is depicted by the dot.

Stop B7:

(optional) Delta distributary palaeochannel mouth and large Renaissance hydraulic works

About 800 yrs ago, the Goro distributary channel bifurcated at Mesola and reached the sea through two independent mouths, in an actively prograding lobe. A Renaissance castle marks the diverging point of the two distributaries. During the second half of the XVI Century, the southern channel was artificially cut off from the active river flow and used as the final draining canal of the large, gravity-driven, land reclamation work, discussed in a previous stop. The interruption of the sediment influx triggered an erosional coastal retrogradation and, to prevent the high tide salty water from flooding the dried-up land, a peculiar bridge-like Renaissance building was erected, as a site of tide-operated locks.

Stop B8:

Depositional evolution of the Goro Lagoon

G. Gabbianelli & U. Simeoni

The afternoon will be mainly spent on a boat trip into the Goro interdistributary lagoon and spit. At the SW of the Goro distributary channel, the homonymous lagoon (Sacca di Goro, Fig. 12) extends over about 2,000 hectares, with an average depth of 1.2–1.5 m only. Its bottom is quite flat and largely consists of bioturbated loam muds, showing a higher clay content in the northern and central zones; sand is, on the contrary, more abundant near the southern lagoon mouth. The evolutionary phases of the Sacca di Goro are depicted in Fig. 11, deduced from ancient cartographic data.

Until the 1500s (A), the open marine area was almost exclusively supplied with sediments by the Po di Volano mouth. The large artificial canal cut in 1604 induced the modern delta formation, that was soon to generate the branches of Goro, Gnocca and Donzella (B). During the early 1700s, the delta lobes of the Po di Goro and of Gnocchetta began to delimitate a protected interdistributary bay (C), which further developed through the following century (D, E). During the second half of the XIX Century (F), a distributary channel mouth deviated into the bay, building up a small deltaic apparatus and feeding sandy spits. At the beginning of the last century (G), the bay was therefore largely occluded by a growing system of sandy spits, turning itself into a semi-enclosed lagoon; the hydraulic exchanges with the sea were mainly supported by tidal currents (bi-directional arrows), through a few remaining tidal mouths. At around 1930 (H), the renewed “sea-flooding” of the Sacca di Goro began, due to the rapid human-induced subsidence (vertical arrow). The deepening evolution still continues today, even if at a reduced speed (I).

The visited lagoon is quite significant from both economic and naturalistic points of view. Following the Ramsar Convention on nature conservation, in 1971, the Goro lagoon was classified as wetland of international importance; in 1982 it was declared a natural reserve, and in 1988 it was included into the Po Delta regional park. These conservation efforts, aimed at enhancing the environmental value of the area, have to unfortunately cope with the strong economic exploitation and ecological degradation of the lagoon: activities connected to clam fishing in the areas involve about 1,000 people, generating an income largely exceeding 50 million Euros per annum. In the last decades, the frequency of eutrophication and anoxia phenomena has had a strong economic impact; the fishery crisis gave rise to an ill-conceived intervention policy, purposely aimed at improving the hydraulic exchanges between the lagoon and the surrounding river and sea waters. The works carried out, however, were performed without any respect for the natural morphodynamics, thus compromising the sedimentary evolution of the area and jeopardizing

Figure 13 - BW reproduction of the nice 1814 watercolour topographic map of the Codigoro area. Before the massive XIX Century land reclamation works, the fluvial and coastal sand ridges spectacularly stood out as emerging topographic highs between fresh water (NW) and brackish (SE) marshes.

the very survival of the Scanno di Goro spit, which provides the only natural protection of the lagoon from the winter sea storms. The impressive lack of sedimentological knowledge showing up in this project was soon to make it utterly useless, because of the lack of any forecasting of the morphological scenario it would trigger.

Stop B9:

Coastal sand ridges in the Mesola Wood

In our way back to Ferrara, we will cross Bosco Mesola, a mesophyll ilex-dominated wood, grown on well-preserved coastal ridges, largely formed by small, back-beach aeolian dunes. The arcuated and elongated coastal bodies accurately record the prograding evolution of two interfering wave-dominated delta lobes, which developed between 800 and 600 yrs B.P. These ridges record a very high-frequency sedimentary cyclicity, reflecting the climate-driven flood amplitude variations. The careful morphological study of these sedimentary bodies was made more complex by the thick vegetation cover, making the use of GPS and trigonometric techniques difficult.

We will then follow the Romea Road, built on a beach sand ridge, marking the late Roman coastline, at about 1700 yrs B.P. Passing by the Romanesque bell tower of the Pomposa Abbey, we will turn eastward, perpendicularly crossing prograding coastlines formed between 2,000 and 3,000 yrs ago.

Stop B10:

(optional) Subsidence impact at Codigoro

The visited region is subject to a fast natural subsidence, recorded by very thick Quaternary successions (see Introduction). The subsidence has lately been much accelerated by the combined effect of widespread land reclamation works and massive subsurface water pumping. A graphic depiction of the high subsidence speed and of the problematic management of this fragile coastal area is provided by the Po di Volano bank, within the small town of Codigoro. 50 years ago the high tide level was well below the foot path and boats freely docked at the pavement's edge; now two superimposed generations of walls try to barely protect the town from the combined effects of the large subsidence, high autumn and winter tides and the massive water influx, brought in by the largest water-scooping plant of Italy. The nearby plant delivery peaks of over 120 m^3/sec, making it one of the largest river of Italy, albeit a completely artificial one.

Leaving Codigoro, we will follow the northern natural levee of the Volano distributary channel, until entering a freeway near Migliarino. The trip will end in Florence, after driving through the northern Apennines, via Motorway A1.

Acknowledgements

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References

Amorosi A. and Marchi N., 1999. High-resolution sequence stratigraphy from piezocone tests: an example from the Late Quaternary deposits of the SE Po Plain. Sedimentary Geology, 128, 69-83.

Amorosi A. and Colalongo M.L, in press. The linkage between alluvial and coeval marginal-marine successions: evidence from the Late Quaternary record of the Po River Plain, Italy. In: M. Blum and S. Marriott (Eds.), IAS Special Publication.

Amorosi A., Farina M., Severi P., Preti D., Caporale L. and Di Dio G., 1996. Genetically related alluvial deposits across active fault zones: an example of alluvial fan-terrace correlation from the upper Quaternary of the southern Po Basin, Italy. Sedimentary Geology 102, 275-295.

Amorosi A., Caporale L., Cibin U., Colalongo M.L., Pasini G., Ricci Lucchi F., Severi P. and Vaiani S.C., 1998. The Pleistocene littoral deposits (Imola Sands) of the northern Apennines foothills. Giornale di Geologia 60, 83-118.

Amorosi A., Colalongo M.L., Pasini G. and Preti D., 1999a. Sedimentary response to Late Quaternary sea-level changes in the Romagna coastal plain (northern Italy). Sedimentology 46, 99-121.

Amorosi A., Colalongo M.L., Fusco F., Pasini G. and Fiorini F., 1999b. Glacio-eustatic control of continental-shallow marine cyclicity from Late Quaternary deposits of the south-eastern Po Plain (Northern Italy). Quaternary Research 52, 1-13.

Amorosi A., Forlani L., Fusco F. and Severi P., 2001. Cyclic patterns of facies and pollen associations from Late Quaternary deposits in the subsurface of Bologna. GeoActa, 1, 83-94.

Amorosi A., Centineo M.C., Colalongo M.L., Pasini G., Sarti G. & Vaiani S.C., 2003. Facies architecture and latest Pleistocene-Holocene depositional history of the Po Delta (Comacchio area), Italy. Journal of Geology, 111, 39-56.

Amorosi A., Colalongo M.L., Fiorini F., Fusco F., Pasini G., Vaiani S.C. and Sarti G., 2004. Palaeogeographic and palaeoclimatic evolution of the Po Plain from 150-ky core records. Global and Planetary Change, 40, 55-78.

Bondesan M., 1989 Geomorphological hazards in the Po Delta and adjacent areas. Geografia Fisica e Dinamica quaternaria, Sup. 2, 25-33.

Bondesan M. and Simeoni U., 1983. Dinamica ed analisi morfologico-statistica dei litorali del Delta del Po e delle foci dell'Adige e del Brenta. Memorie di Scienze Geologiche, v. 36, 1-46.

Bondesan M., Favero V., and Viñals, M.J. 1995. New evidence on the evolution of the Po-delta coastal plain during the Holocene. Quat. Int. 29/30: 105-110.

Bondesan M., Calderoni G., Cattani L., Ferrari M., Furini A.L., Serandrei Barbero, R., and Stefani, M. 1999. Nuovi dati stratigrafici, paleoambientali e di cronologia radiometrica sul ciclo trasgressivo-regressivo olocenico nell'area deltizia padana. Annali dell'Università di Ferrara, 8: 1-34.

Borgia G.C., Brighenti G., Vitali D., 1982, I giacimenti di gas del Delta del Po: criteri per una nuova valorizzazione. Atti Convegno sui fluidi caldi e le risorse energetiche marginali-Piacenza1.10.1982.

Caputo M., Pieri L., Unguendoli M., 1970. Geometric investigation of the subsidence in the Po Delta, Bollettino di Geofisica Teorica ed Applicata, v. 12 (47), 187-207

Castellarin A., Eva C., Giglia G., Vai G.B., Rabbi E., Pini G.A. and Crestana, G., 1985. Analisi strutturale del Fronte Appenninico Padano. Giornale di Geologia, 47, 47-75.

Dalla S., Rossi M., Orlando M., Visentin C., Gelati R., Gnaccolini M., Papani G., Belli A., Biffi U. and Catrullo D., 1992. Late Eocene-Tortonian tectono-sedimentary evolution in the western part of the Padan basin (northern Italy), Paleontologia i Evoluciò 24-25, 341-362.

Dondi L. and D'Andrea M.G., 1986. La Pianura Padana e Veneta dall'Oligocene superiore al Pleistocene. Giornale di Geologia 48, 197-225.

Fontolàn G., Covelli S., Bezzi A., Tesolin U., Simeoni U., 2000. Stratigrafia dei depositi recenti della Sacca di Goro. Studi Costieri, V. 2, 65-79.

Gasperi, G., Cremaschi, M., Mantovani Uguzzoni, M.P., Cardarelli, A., Cattani, M. and Labate, D., 1987. Evoluzione plio-quaternaria del margine appenninico modenese e dell'antistante pianura. Note illustrative alla carta geologica. Mem. Soc. Geol. It., 39, 375-431.

Martinson, D.G., Pisias, N.G., Hayes, J.D., Imbrie, J., Moore, T.C. and Shackleton, N.J. (1987) Age dating and the orbital theory of the ice ages - development of a high-resolution 0 to 300,000 year chronostratigraphy. Quaternary Research, 27, 1-29.

Ori G.G., 1993. Continental depositional systems of the Quaternary of the Po Plain (northern Italy). Sedimentary Geology 83, 1-14.

Pieri M. and Groppi G., 1981. Subsurface geological structure of the Po Plain, Italy. Pubbl. 414 P.F. Geodinamica, C.N.R., 23 pp.

Pini G.A. 1999 - Tectonosomes and Olistostromes in the Argille Scagliose of the Northern Apennines, Italy. Geological Society of America, Special Paper, 335: 70 pp.

Regione Emilia-Romagna and ENI-AGIP, 1998. Riserve idriche sotterranee della Regione Emilia-Romagna. A cura di G. Di Dio. S.EL.CA., Firenze, 120 pp.

Regione Lombardia and Eni Divisione Agip, 2002. Geologia degli acquiferi Padani della Regione Lombardia. A cura di C. Carcano e A. Piccin. S.EL.CA., Firenze, 130 pp.

Ricci Lucchi F., Colella A., Ori G.G., Ogliani F., Colalongo M.L., (with the collaboration of Padovani A., Pasini G., Raffi S. & Venturi L.), 1981. Pliocene fan deltas of the Intra-appenninic Basin, Bologna. In Ricci Lucchi F. (ed.), International Association of Sedimentologist, 2nd European Regional Meeting. Excursion Guidebook: 79-138. Tecnoprint, Bologna.

Ricci Lucchi F., Colalongo M.L., Cremonini G., Gasperi G., Iaccarino S., Papani G., Raffi I. and Rio D., 1982. Evoluzione sedimentaria e paleogeografica del margine appenninico. In: Cremonini G. and Ricci Lucchi F. (eds.) Guida alla geologia del margine appenninico-padano. Società Geologica Italiana, Guide geologiche regionali, Pitagora Tecnoprint, Bologna, 17-46.

Ricci Lucchi F., 1986. Oligocene to Recent foreland basins of northern Apennines. In: Ph. Allen & P. Homewood, eds., Foreland Basins, IAS Special Publication No. 8, 105-139.

Rizzini A., 1974. Holocene sedimentary cycle and heavy mineral distribution, Romagna-Marche coastal plain, Italy. Sedimentary Geology, 11, 17-37.

Ruggieri G., 1962. La serie marina pliocenica e quaternaria della Romagna. Camera di Commercio, Industria e Agricoltura Forlì. 76 pp.

Ruggieri G., 1995. Sull'età delle "sabbie di Imola". Naturalia Faventina, 2, 79-81.

Simeoni U. (2000). "Studi costieri, Dinamica e difesa dei litorali- Gestione integrata della fascia costiera", N 2, La Sacca di Goro.

Vai G.B. and Castellarin A. 1992. Correlazione sinottica delle unità stratigrafiche nell'Appennino Settentrionale. Studi Geol. Camerti vol. spec. 1992/2, CROP 1-1A, 171-185.

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