THE IMPORTANCE OF 3D GEOLOGICAL MAPPING IN THE STRATIGRAPHIC INTERPRETATION, DEPOSITIONAL RATE ESTIMATION AND ENVIRONMENTAL MANAGEMENT OF THE PO DELTA REGION (FERRARA PROVINCE, NORTHERN ITALY)

Ubaldo Cibin (1) and Marco Stefani (2)

(1) Dipartimento di Scienze della Terra, Via Saragat 1, 44100, Ferrara. Italy. stm@unife.it
(2) Servizio Geologico, Sismico e dei Suoli, Regione Emilia-Romagna, Viale Silvani, Bologna. ucibin@regione.emilia-romagna.it

KEY WORDS: Geological Mapping, Sedimentology, Stratigraphy, Delta, Holocene, Quaternary

The geological mapping of a delta-plain area developed at the south-western border of the modern Po Delta lobe (Fig. 1) provided important data for both the reconstruction of the stratigraphic evolution and the environmental management of this fragile coastal area. Research on the late Quaternary evolution of the region integrates surface investigation with the three dimensional reconstruction of the first 50 m of subsurface. Understanding of this central area was achieved through the study of the whole of the Po Delta regional, stretching from Ravenna to the Venice Lagoon (Fig. 1). In this region, fast subsidence and large sediment input supported a comprehensive registration of the late Quaternary transgressive-regressive evolution. Holocene may exceed 40 m in thickness. Transgressive units are buried beneath younger sediments, whereas highstand delta-top facies outcrop widely and can be correlated with upstream and offshore successions, to provide a regional picture of the depositional evolution.
Analysis of the outcropping units was mainly based on remote sensing techniques, integrated by the interpretation of the topographic microrelief and of historical maps, produced over the last five centuries (e.g. Fig. 3) and recording the modern delta lobe growth in its making. Interpretation of these data was enhanced through GPS assisted field reconnaissance and sampling. Chronological interpretation of outcropping units derived from the examination of archaeological findings, ancient building dating and literary sources, the later dating back to the ancient Greek period and particularly detailed over the last 500 yr. The surface data were stored and synthesised within a geographic information system (Arcview 8.1).
The main tool for the stratigraphic understanding of the upper 50 m of subsurface was provided by about 200 digital cone-penetration tests, calibrated through continuous stratigraphic coring (Fig. 2). Dissipation tests were also performed.

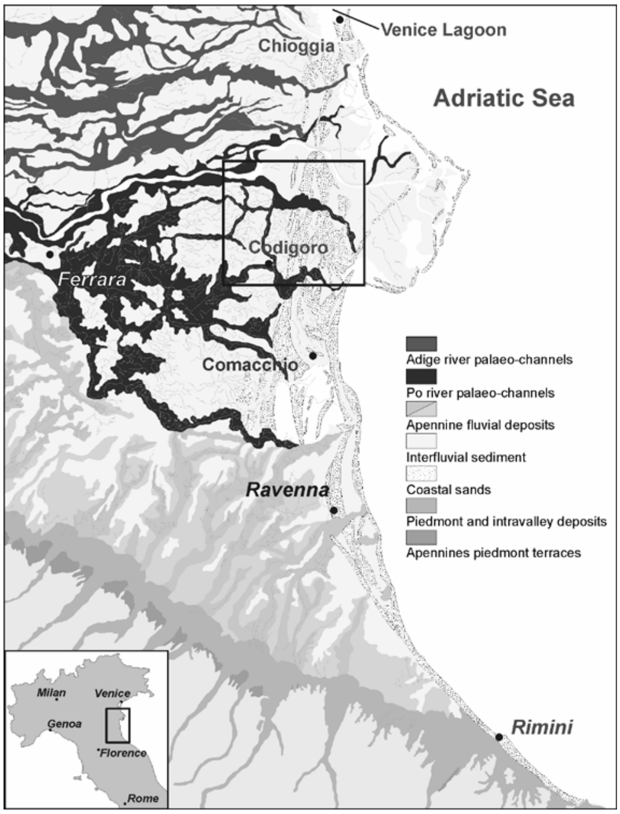

Figure 1 - The mapped area (rectangle) within the regional framework of Apennines, Po and Adige river deposits.

The average depth of penetration tests was 35 m; continuous wire-line coring reached levels as deep as 200 m. Sedimentary facies description was performed on the cores, together with micro- and macro- palaeontological determination, palynology, sand petrography and grain-size analysis. Further subsurface information was provided by gamma and resistivity logging in wells and by the critical examination of several hundred previous technical investigations, showing a highly variable level of accuracy and reliability.

Subsurface chronology was investigated through ^{14}C dating. Interpretation of the highstand subsurface stratigraphy was greatly enhanced by correlation with the outcropping geological evidence. Subsurface data were synthesised to produce stratigraphic profiles and trimetric projection fence diagrams (Fig. 3). A vertical stratigraphic resolution of about 20-30 cm was generally achieved and the chronological accuracy varies from thousands of years, in the oldest units, to a few years, in modern deposits. The role of autocyclic mechanisms and eustatic, climatic, tectonic and anthropogenic influences was evaluated. Eustatic and climatic fluctuations appear to have dominated the depositional history. Tectonic and compaction subsidence also provided a significant contribution to the relative sea level increase, especially during the “eustatically stable” highstand interval.

The last glacial time period (Wuermian) is recorded by middle alluvial plain coarse sand bodies (Fig. 2). Depositional hiatuses were common, but individual fluvial bed accumulated rapidly. Average sedimentation rate was in the order of 1 mm/yr. Deglaciation and early transgression were associated with an erosive disconformity. In the modern coastal area, transgressive accumulation started between 10 and 9 000 yr BP. Back-stepping fluvial and brackish marsh deposits were followed by delta-estuarine sand bodies, influence by the last important eustatic rise pulses. The fast coastline retrogradation speed was probably of 20-30 m per year or more. During late transgression times, the sediment input was able to sustain high coastal plain aggradation rates, in the order of 4 mm/yr after compaction (depositional values of 8-10 mm/yr). Transgression climaxed at about 5 500 yr BP, during a warm climate phase. Early highstand saw the growth of large sand spits and barrier islands, progressively turning the previous bays into confined lagoons. The highstand progradation was marked by the growth of different delta lobe generations, which was correlated with the fluvial drainage history. During the highstand, aggradation was mainly supported by subsidence and delta plain sediments accumulated at the average rate of 2-3 mm/yr. The coastal progradation speed and the sand/mud ratio were largely variable, reflecting both climatic modification and human alteration. At about 3 500 – 3 000 yr BP, a particularly active meteo-marine regime profoundly affected the depositional dynamics. Etruscan and Roman times were characterised by a warm climate and by fluvial stability, associated with the development of a large delta lobe. Anthropogenic effects were already important during Roman Empire times, when the main delta lobe prograded with an average velocity of about 30 m/yr and the delta top area grew at a speed of about 0.40 km^2/yr. At around 1 500 yr BP, transition toward moister and cooler conditions and the abandoning of the Roman Empire hydraulic works coincided with important drainage network instability. The modern delta lobe was induced 400 years ago by an artificial fluvial mouth cut commissioned by the Republic of Venice. At 350-300 yr BP, distributary mouths prograded with a speed of roughly 200 m/yr, the delta top area increased at a velocity of about 3 km^2/yr.

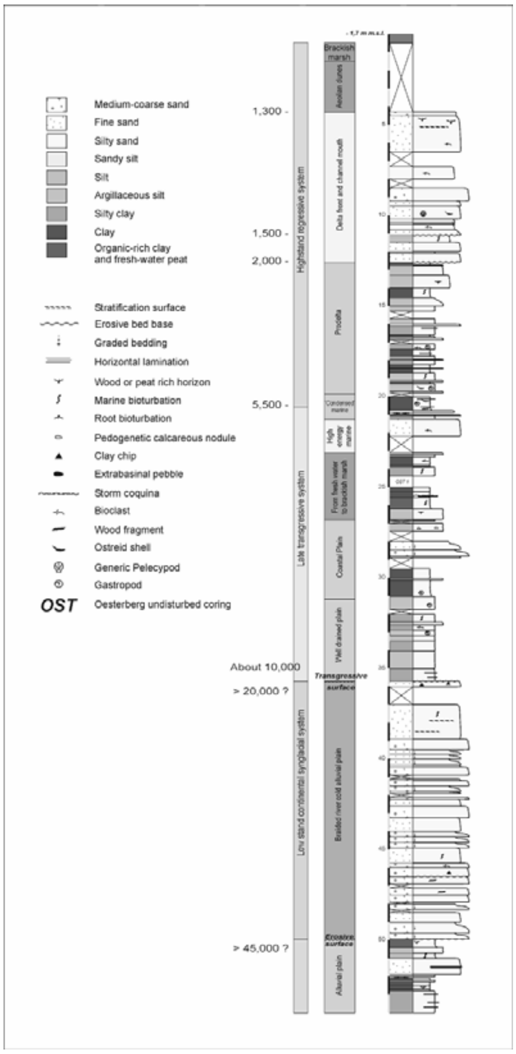

Figure 2 - The upper portion of the stratigraphic core 187S1, recording the last 50.000 years of depositional evolution, from synglacial alluvial plain sedimentation to transgression and highstand progradation.

During the last 150 years, water scooping supported the widespread land reclamation of almost the whole of the delta top region. Continuous river embankments were built, forcing rivers to become suspended over reclaimed areas, well bellow sea level. Wetland drying and methane water exploitation induced subsidence of 3-4 m per century, with top speed exceeding 25 cm/yr.

The average Po sediment flux to the delta system probably exceeded 12 · 10^6 m^3/yr during the first half of the 20th Century but the granular sediment input to the coastal environments has almost completely stopped anthropogenic alteration of rivers, such as dam construction, soil protection and massive river-bed excavation. Coastal erosion is presently strong throughout the region. Climatic change, accelerated subsidence, interruption of the fluvial sand input, river and coastline artificial rigidity, water pollution and eutrophication combine to make the environmental management of the fragile coastal area difficult. A retreat of the human activity from delta top areas looks unavoidable in any foreseeable future.

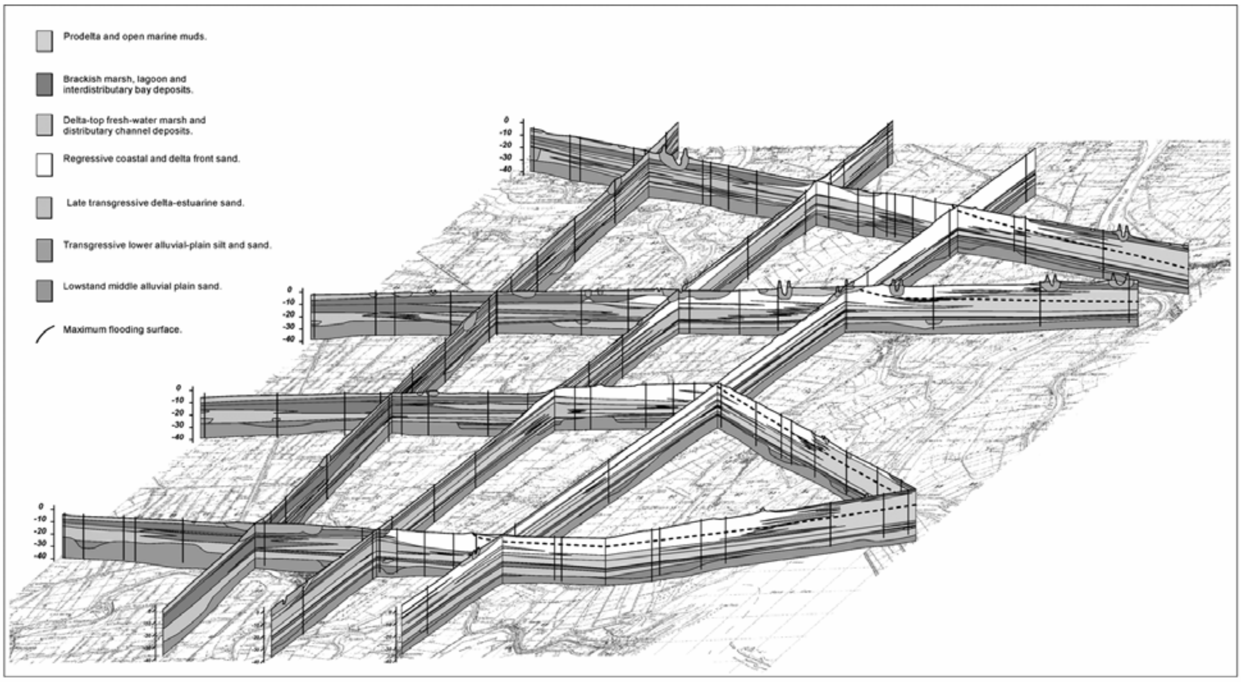

Figure 3 - Fence diagram synthesising the three dimensions Holocene depositional architecture of the mapped area, recording a complex transgresive-regressive evolution.