APAT
Agenzia per la protezione dell'ambiente e per i servizi tecnici
SERVIZIO GEOLOGICO D'ITALIA
Organo Cartografico dello Stato (legge n. 68 del 2. 2. 1960)
DIPARTIMENTO DIFESA DEL SUOLO

MEMORIE
DESCRITTIVE DELLA
CARTA GEOLOGICA D'ITALIA

VOLUME LXXXIII

Areas of the Lagoon of Venice on the Official Geological Map of Italy:
Sheet 128 *"Venezia"*, Sheets 148-149 *"Chioggia-Malamocco"*

Le aree di laguna nella Carta Geologica Ufficiale d'Italia:
Foglio 128 "Venezia", Fogli 148-149 "Chioggia-Malamocco"

Editor
REGIONE VENETO
DIREZIONE GEOLOGIA ED ATTIVITÀ ESTRATTIVE
SERVIZIO GEOLOGIA

SYSTEMCART - Roma - 2008

II - GEOLOGICAL SETTING AND HISTORICAL OUTLINE

Due to the environmental and historical importance of the Lagoon of Venice and the city of Venice itself, numerous studies have been conducted in the past, with the aim of establishing the geological setting of the area (ZANETTIN 1955). To avoid a long list of references, the most important works are cited appropriately in the following sections. In particular, due to the precarious nature of the Venetian soil, notoriously associated with subsidence and soil compaction, several geotechnical, hydrogeological and altimetric surveys have been carried out.

Initial stimuli towards basic studies occurred in the 1970s, as a result of the disastrous flood of 1966.

The drilling of the *Venezia 1 – CNR* boreholes was essential for more information on the geology of the area, and was carried out by the continous boring method to a depth of 947 m. The *Venezia 2 – CNR, Lido 1* and *Marghera 1* boreholes, which reached depths of 400, 1,333 and 602 m respectively, produced several undisturbed samples.

Knowledge on the deepest subsoil until the Mesozoic was acquired in adjacent areas with the drilling of exploration boreholes in the search for hydrocarbons (*Assunta 1* (4,747 m), *Jesolo 1* (1,804 m), *Eraclea 1* (2,502 m), *S. Donà di Piave 1* (3,081 m) and *S. Angelo 1* (2,036 m)). A series of seismic surveys was also carried out by AGIP (national hydrocarbon company).

Also in the 1970s, the Committee for the Study of Defence Measures of the City of Venice (CSP-DV) created several multidisciplinary surveys, which yielded an initial complete framework of the geology of the Venice area.

Several researches covered both the deep subsoil and surface sediments, leading to the detailed descriptions of the Holocene evolution of the area. It should be noted that, as they act as bases for the creation of the Geological Map of Holocene and Late Pleistocene deposits, studies in the 1970s and 1980s provided an initial large-scale description of the geological evolution of the surface cover (GATTO & PREVIATELLO, 1974; ALBEROTANZA *et alii*, 1977; BORTOLAMI *et alii*, 1977; FAVERO & SERANDREI-BARBERO, 1978, 1980, 1983; GATTO & CARBOGNIN, 1981; BORTOLAMI *et alii*, 1984; GATTO, 1984).

In the 1980s and 1990s, a series of targeted, "strategic" projects was started by the ITALIAN RESEARCH COUNCIL (CNR), updating geological knowledge acquired during the previous twenty years.

1. - GEOLOGICAL EVOLUTION AND STRUCTURAL FRAMEWORK

1.1. - PRE-QUATERNARY EVOLUTION

The Venice area lies in the centre of the Neogene-Quaternary foreland, which is shared between the NE-verging northern Apennine thrust belt and the S-verging eastern Southalpine chain (Fig. 2). In a wider regional framework, this foreland is situated at the north-eastern edge of the Adriatic microplate, and a long succession of sedimentary, magmatic and tectonic events are also recorded in the subsurface of the area surrounding Venice and offshore. These events have been brought to light not only by hydrocarbon research surveys and geophysical surveys carried out by AGIP in the second half of the 20th century, but also by the more recent work by the Transalp and CROP-mare Projects.

The oldest records go back to the Palaeozoic and Triassic, and information comes from the stratigraphic log of the *Assunta 1* borehole, integrated with aeromagnetic survey data (CASSANO *et alii*, 1986). Granite (448±18 Ma) found at a depth of 4,711 m, locates the plate boundary between two Palaeozoic microplates (Carnic-Dinaric and

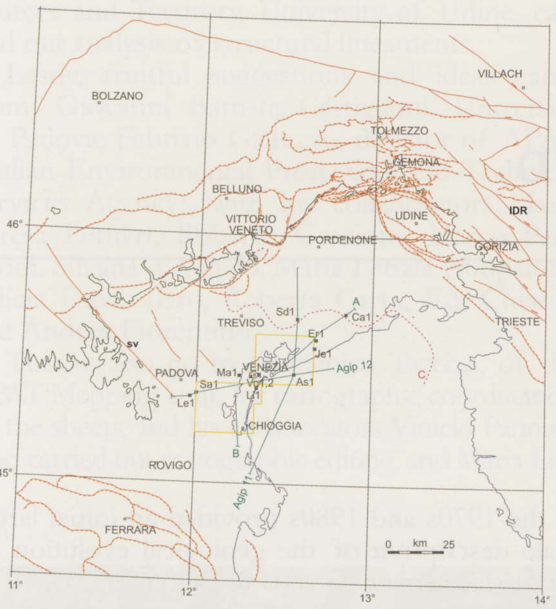

Fig. 2 – *Area of Venezia and Chioggia-Malamocco Sheets in Neogene-Quaternary tectonic framework, characterised by oblique convergence between northern Apennine and eastern Southalpine thrust belts. The latter is kinematically released westwards by Schio-Vicenza fault system (SV) and eastwards by Idrija fault system (IDR). AGIP boreholes: Le1-Legnaro, Sa1-S. Angelo di Piove di Sacco, As1-Assunta, Je1-Jesolo, Er1-Eraclea, Sd1-S. Donà, Ca1-Cavanella, Ce1-Cesarolo, Li1-Lido, Ma1-Marghera; CNR boreholes: Ve1, Ve2-Venice; reflection seismic cross-sections: A, B; geological cross-sections: AGIP 11, 12; dotted line C: buried margin of Friulian Carbonate Platform versus Belluno Basin, situated westwards. Active - and seismogenic - tectonic systems surrounding Venice area are (clockwise): front of eastern Southalpine chain (from Schio-Vicenza fault to Idrija system), dextral strike-slip fault system of Idrija (western Slovenia), part of front of northern Apennine chain (Ferrara), Schio-Vicenza system (west of Padova).*

Austroalpine-Southalpine) between the granite itself and the Variscan metamorphic core of Recoaro. This plate boundary extends NE-SW from Venice to Forni Avoltri (western Carnic Alps). The deeply dismantled structural high of *Assunta 1* (Fig.3), which is characterised by Carnian successions overlapping the plutonic body, suggests that this area was one of the sources of clasts for the Permo-Triassic terrigenous units which now outcrop in the Recoaro Pre-Alpine area.

An aeromagnetic survey also identified a thick body of Ladinian volcanites (Fig. 3), found in other deep boreholes in the Veneto-Friuli plain and related offshore environs. Rhyolite, dacite and andesite with intercalated minor volcanoclastics and terrigenous deposits of Early Permian age were also found in the *Legnaro 1* borehole (Fig. 2). These volcanites represent one of the effects of the intensive extensional and strike-slip tectonics which developed in the Southalpine realm during the Permo-Mesozoic.

The depositional architecture and framework of the overlying crust, from the Norian "Dolomia Principale", which testifies to relative tectonic stasis, to the Quaternary units, are clearly reconstructed by the network of industrial seismic lines covering the Veneto plain and the northern Adriatic Sea, calibrated with many boreholes.

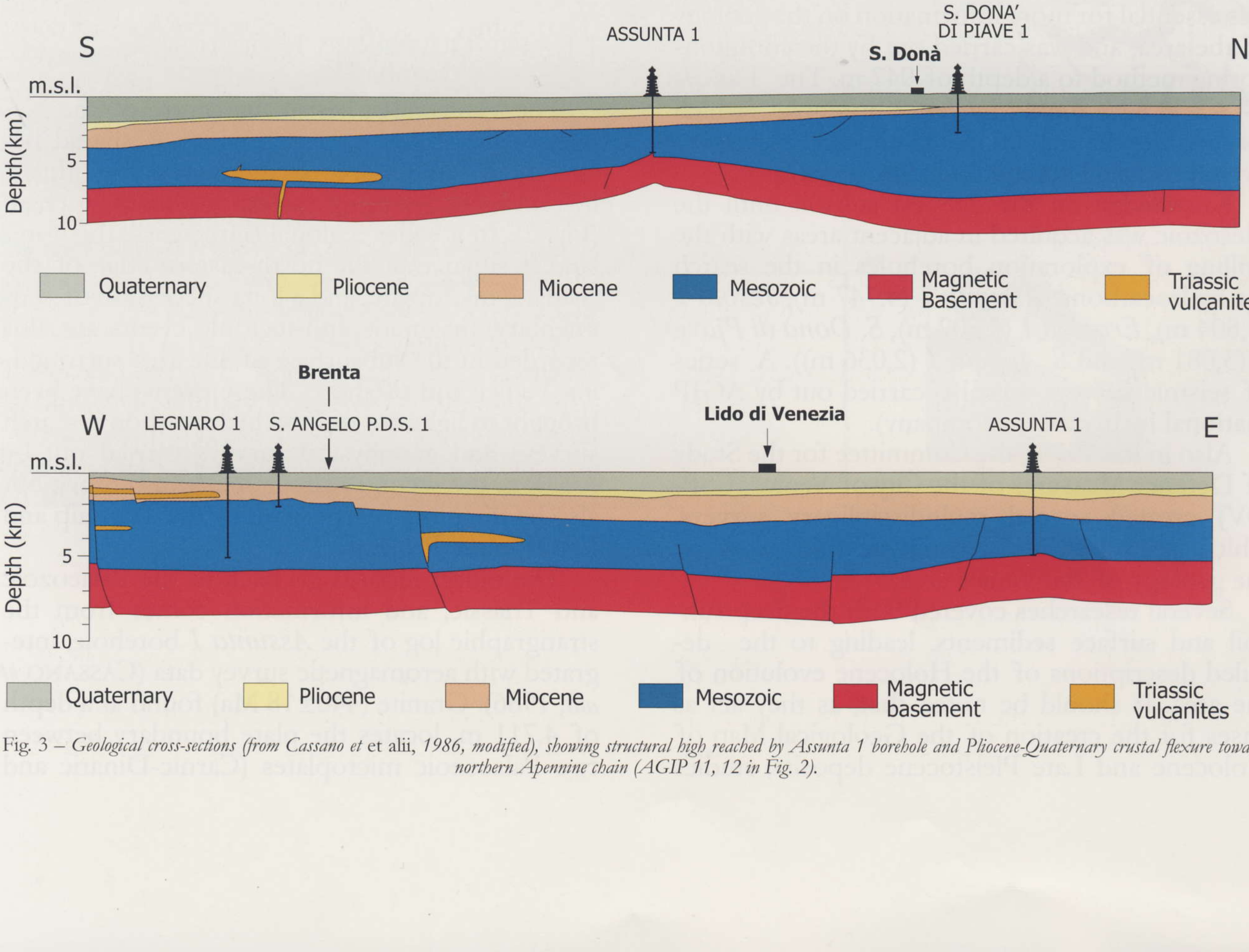

Fig. 3 – *Geological cross-sections (from Cassano et* et alii, *1986, modified), showing structural high reached by Assunta 1 borehole and Pliocene-Quaternary crustal flexure towards northern Apennine chain (AGIP 11, 12 in Fig. 2).*

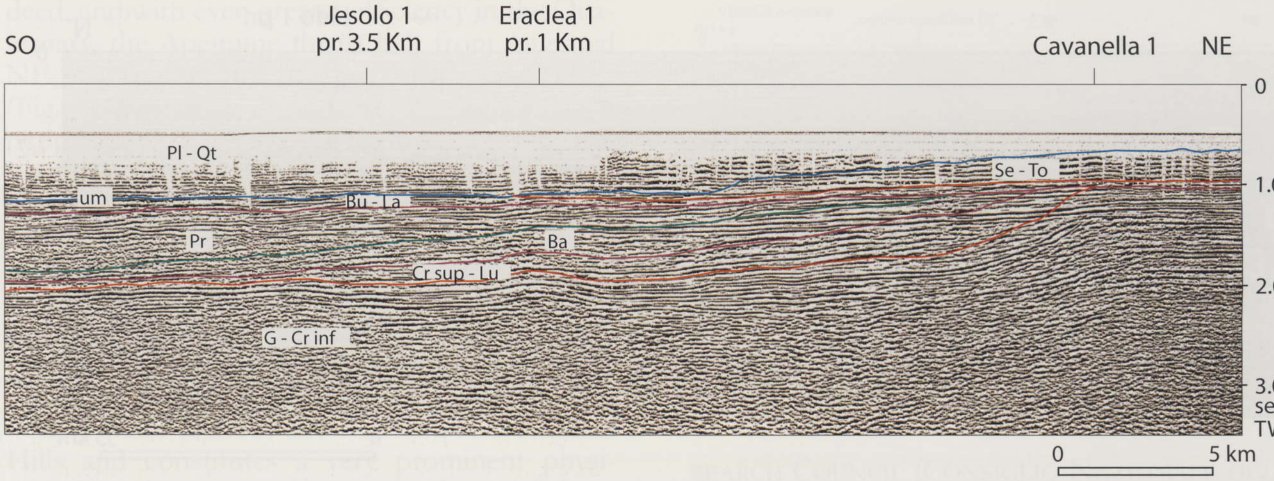

Fig. 4 – *Seismic reflection cross-sections (A in Fig. 2, from* FANTONI et alii*, 2002, modified), showing relationships between western margin of FCP and Belluno Basin, depositional geometries on the slope, filling of basin first by hemipelagic successions of Late Cretaceous-Lutetian (Cr sup-Lu: Scaglia Rossa, interfingered with resedimented bodies from FCP) and Bartonian (Ba: the Scaglia cinerea), then by distal turbidites (Jesolo Flysch), and lastly by deltaic mudstones (Possagno Marl) of Priabonian age (Pr). "Gruppo di Cavanella" platforms (here Burdigalian-Langhian: Bu-La) prograded on both Eocene successions and eroded top of FCP. Shape of Messinian erosional surface (um) highlights deep fluvial valleys linked to fall in sea level of Mediterranean during Messinian; palaeotopography was then sealed by terrigenous deposits of Pliocene and Pleistocene age (Pl-Qu).*

Throughout the Jurassic and Cretaceous, the palaeogeographic setting is represented by the system of the Belluno Basin-Friulian Carbonate Platform (FPC), starting from the Early Jurassic in an extensional and strike-slip framework linked to the opening of the Alpine Tethys.

The surface projection of the margin of the FCP, which was repeatedly involved by progradations and retrogradations (CATI *et alii*, 1989), is shown in Fig. 2, and is clearly defined by a series of exploration boreholes. Its typical stepped pattern shows the arrangement of the Belluno Basin-FCP system in a tectonic framework, dominated by extensional faults running NW-SE, segmented by NE-SW strike-slip or transtensive faults.

According to PICOTTI *et alii* (2002), the FCP developed from the Early Jurassic on less subsident blocks (mean subsidence rate: 0.05 mm/y), with marginal drowning at the Early-Middle Jurassic boundary; this fact produces undersupply of the basin, which then achieved its first maximum depth. A second subsidence peak occurred between the Late Oxfordian and the Early Kimmeridgian (0.25 mm/y), and caused rapid aggradation - almost 1 km - of the FCP and strong undersupply of the Belluno Basin, which reached a palaeobathymetry of approximately 1,400 m (FANTONI *et alii*, 2002). During the latest Jurassic-earliest Cretaceous, the speed of subsidence decreased again, to 0.02 mm/y, with a sedimentation rate of 0.01 mm/y. This evolution, which continued into the Late Cretaceous, produced an overall thickness of approximately 4 km of Jurassic-Cretaceous carbonates in the FCP. In the Belluno Basin, and therefore in the subsurface of the Venice area, a palaeobathymetry of over 1,200 m was reached at the end of the Cretaceous, and was subsequently annulled by Palaeogene deposits (Fig. 4).

During the Dinaric event (Late Cretaceous-Late Eocene), which built up the External Dinarides in Friuli and also in the central-eastern Dolomites (DOGLIONI & BOSELLINI, 1987; POLI, 1995; 1996; POLI & ZANFERRARI, 1995), the area of the present Veneto plain became the peripheral bulge of the WSW-verging thrust system of the Dinaric front. In the Venice subsurface, the effects of this event are recorded only in the form of palaeobathymetric and depositional variations, evident in the western sector of the FCP, which was extinguished by uplift. The effects of karst processes, which are visible in the Carnic Pre-Alps, and intense subaerial erosion throughout the Palaeogene, caused the uplift of the FCP. In time, erosion reached the Lower Cretaceous carbonates, as shown by the logs of the *S. Donà di Piave 1* and *Cesarolo 1* boreholes and taken those at the Pre-Alpine margin (*Nervesa 1, Arcade 1, Merlengo 1*; Fig. 2).

Instead, the space inherited by the Mesozoic subsidence in the Belluno Basin (Fig. 4) was filled during the Palaeocene and Eocene by deposits coming from N and NE: at first hemipelagic (Scaglia Rossa: Maastrichtian-Lutetian; Scaglia cinerea: Bartonian) and then by distal turbidites up to deltaic deposits (respectively Jesolo Flysch and Possagno Marl: Priabonian).

During the Oligocene, the subaerial erosion of the western sector of the old Mesozoic FCP continued. At the same time, in the area of the present Veneto plain, located NW of Venice, a depocenter with terrigenous, volcanic and volcano-

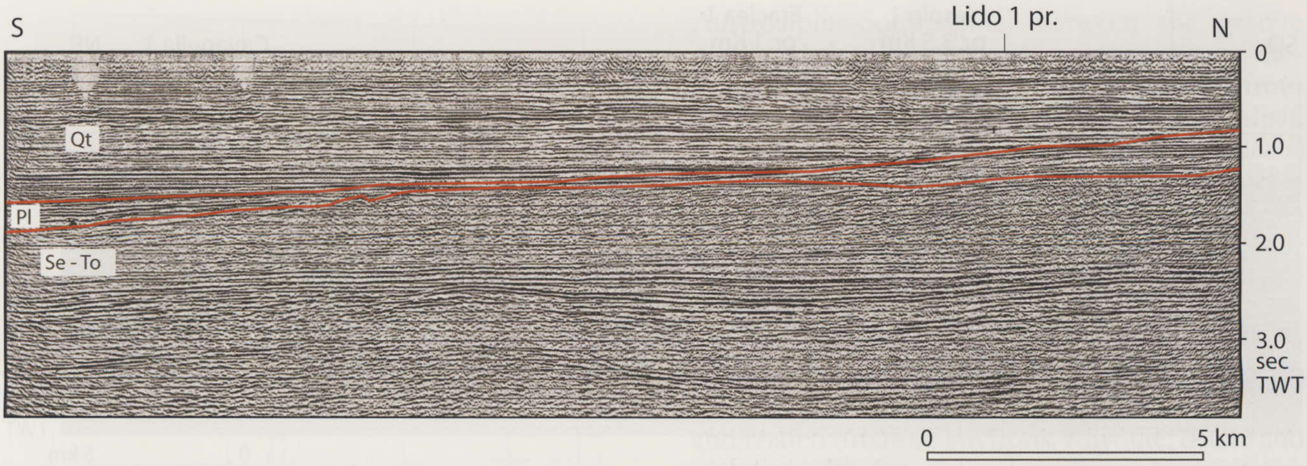

Fig. 5 – *Seismic reflection cross-section (B in Fig. 2; from* FANTONI et alii, *2002, modified), showing southward progradation of Serravallian-Tortonian terrigenous platforms (Se-To) and complex shape of Messinian erosional surface, on which Pliocene terrigenous successions were deposited with onlap geometry southwards. Top of Pliocene platform carbonates were reached at bottom of Lido 1 borehole. Note Quaternary clastic wedge (Qt) and thickness of Pleistocene sediments, at times turbiditic, prograding on subsident ramp of Apennine foreland.*

clastic deposits formed (about 700-800 m thick) (*Legnaro 1, S. Angelo di Piove di Sacco 1* and *Villaverla 1*). The basin was bounded by NW-SE extensional faults: the NW-SE-striking *Schio-Vicenza* fault and its related system may have started in this extensional stage.

Between the latest Chattian and the Langhian, the area surrounding Venice was also involved by the Insubric event, like the whole subsurface of the present eastern Veneto and Friuli plain (MASSARI, 1990), which first became a peripheral bulge and later part of a foreland basin. A weak crustal flexure of less than 1° to the NNE (FANTONI *et alii*, 2002) was the response to the topographical load induced by remote uplift in the Eastern Alps. Uplift and erosion of Austroalpine nappes are testified by the composition of the arenite deposited in the foreland basin (STEFANI, 1987). This basin gradually extends SSW, so that the system of thin terrigenous-carbonate platforms of the "Gruppo di Cavanella" (*sensu* AGIP) reached the present coastal area only in the Burdigalian (Fig. 4). Here, the old Oligocene topography was sealed by sediments with thicknesses of the order of tens of metres, as opposed to hundreds in the Veneto-Friuli hills.

From the Serravallian to the Messinian, rapid SE migration of the eastern Southalpine thrust belt (main Neoalpine tectonic phase) caused the formation of a trough, with its depocenter in the eastern Veneto and Friuli Pre-Alpine area. The clastic wedge, over 3 km thick in the Pre-Alps, rapidly becomes thinner towards the Adriatic coast (Fig. 4: 225 m in *Cavanella 1* borehole). The composition of the clasts, with the strong prevalence of carbonates, shows provenance from Southalpine areas (STEFANI, 1987).

A very important event also for the Venice subsurface occurred in the Messinian, in response to the drop in sea level of the Mediterranean. The whole area reached continental conditions, with widespread erosional processes and the creation of new drainage basins. One of the largest and deepest palaeovalleys in the Venice area was the Messinian valley of the palaeo-Piave (BARBIERI *et alii*, 2004), which eroded the Miocene deposits and reached the "Gruppo di Cavanella" (Fig. 4).

In the Lower Pliocene, the Messinian catchment area influenced marine ingression in the Venice area, with proximal marine deposits and then silty and sandy deltaic ones (*Jesolo 1* and *Eraclea 1*: Fig. 4). Starting from the Pliocene, the Venice area became part of the Apennine foreland, and small Pliocene carbonate platforms formed in this sector (*Lido 1* and *Assunta 1*: Fig. 5). At that time, in-

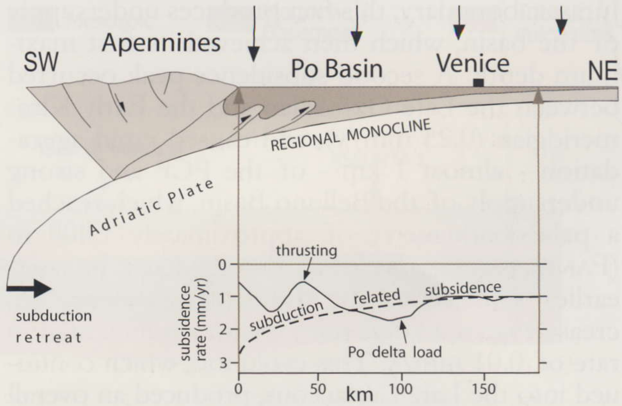

Fig. 6 – *Sketch of present northern Apennine thrust-belt - Po-Veneto plain foredeep system: Venice area is located on foreland ramp (from* CARMINATI et alii, *2003). Insert: contribution to lagoon subsidence due to Apennine subduction, representing over half of total subsidence in Pleistocene.*

deed, and with even greater efficiency in the Quaternary, the Apennine thrust belt front migrated NE, causing flexure of the Veneto-Friuli crust (Fig. 6). Therefore, during the Lower Pliocene, a peripheral bulge in the Venice area formed, followed by rapid drowning and the establishment of epibathyal conditions in the Early Pleistocene. The subsidence caused by the tectonic load of the north Apennine thrust belt produced over half (at least 500 m) of the total subsidence recorded in the Venice area in the Pleistocene (BARBIERI & GARCIA-CASTELLANOS, 2004).

The Schio-Vicenza fault, which borders the Veneto plain towards the Lessini-Berici-Euganei Hills and constitutes a very prominent physiographic element, was reactivated many times with varying kinematics linked to the stress fields that involved the area during the Cenozoic. In the Neogene, the fault was the release boundary between the eastern Southalpine chain and the less shortened Lessini region, acting as a pivotal fault with a throw that is annulled near the Venetian area. According to PELLEGRINI (1988), it was also active in the Late Pleistocene.

With regard to the Pliocene-Quaternary evolution of the north Apennine chain, the Schio-Vicenza fault separates the peripheral bulge of the Lessinian block from a foreland sector that also underwent the evolution of the Southalpine front: the latter partly contrasts the flexure of the Veneto foreland towards the SW, produced by the load of the north Apennine thrust belt.

Further tectonic features of regional importance have been hypothesised in the subsoil of the eastern Veneto plain by various authors (ZANFERRARI *et alii*, 1980a; ZANFERRARI *et alii*, 1980b; SLEJKO *et alii*, 1989; CARULLI *et alii*, 1990; CASTALDINI).

1.2. - QUATERNARY EVOLUTION

Due to the effect of foreland subduction under the Appennine front, the clastic wedge gradually thins to the NE in the direction of the northern portion of the Friuli plain, within which the actual South Alpine front is buried. Fig. 7a and 7b show both the NE migration of the onlap of flexured Pleistocene deposits on the flexured Pliocene substratum to the SE and the thinning-out of the same Pleistocene horizons to a wedge.

Biostratigraphic and chronostratigraphic knowledge of the deep deposits of the Venetian area were acquired until the 1970s by in-depth surveys (*Venice 1 - CNR*, 947 m, and *Venice 2 - CNR*, 400 m) undertaken by the ITALIAN RESEARCH COUNCIL (CONSIGLIO NAZIONALE DELLE RICERCHE, 1971; FAVERO *et alii*, 1973; SERANDREI-BARBERO, 1975; FAVERO *et alii*, 1979; FAVERO & PASSEGA, 1980; BELLET *et alii*, 1982; MÜLLENDERS *et alii*, 1996).

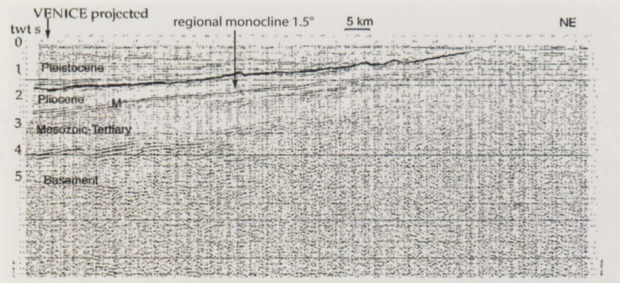

Fig. 7a – *Seismic reflection profile of Crop M-18, in northern Adriatic between Po Delta and Gulf of Trieste, where Pleistocene clastic wedge protrudes (from* CARMINATI et alii, *2003). Pliocene/Pleistocene boundary and Messinian erosional surface are highlighted (M).*

Some exploration boreholes are included in the Chioggia-Malamocco Sheet (*Lido 1, S. Angelo di Piove di Sacco* 1, *Codevigo* 1, *Civè* 1), which yielded some information on Quaternary deposits. Conversely, the quoted in-depth surveys *Venice 1 - CNR* (947 m) and *Venice* 2 - *CNR* (400 m) provided extremely detailed information on Plio-Pleistocenic deposits, even those located in the historical city centre of Venice and slightly north of the northern limit of the Sheet.

The Pleistocene stratigraphic successions in the area of the two Sheets have recently been updated as part of the biostratigraphic and chronological profiles of KENT *et alii* (2002) and MASSARI *et alii*

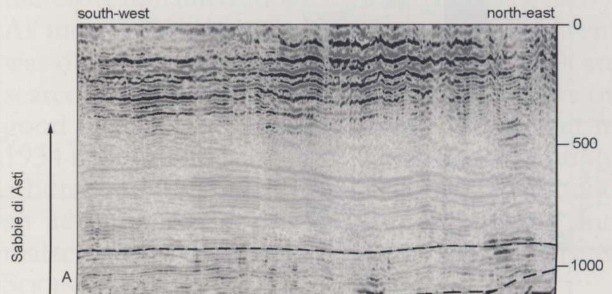

Fig. 7b – *NNE-SSW seismic section off Chioggia, showing setting of Plio-Pleistocene deposits of blue clay (Argille del Santerno) and Asti sands, separated by well-marked discontinuity (from* TEATINI et alii, *2000).*

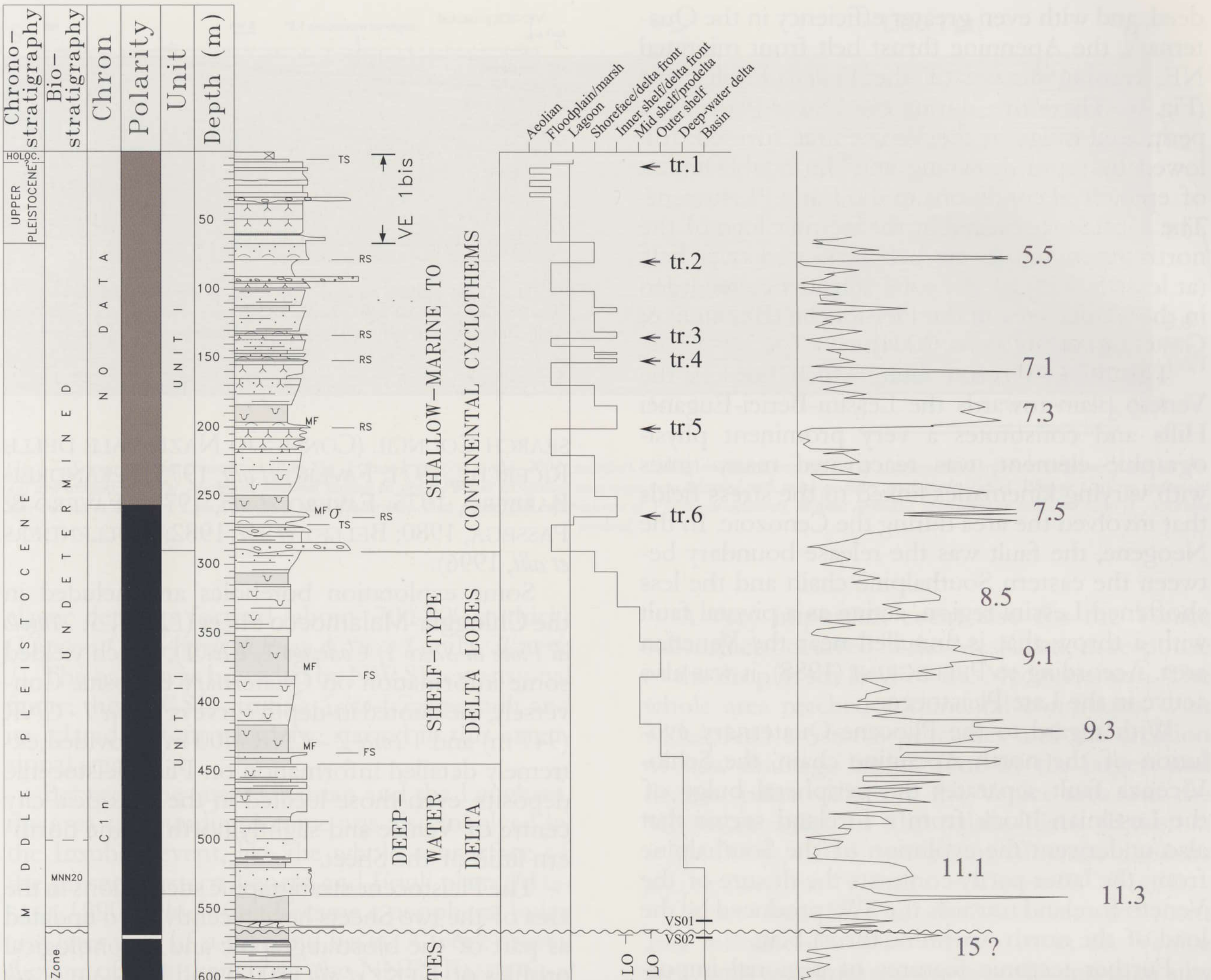

Fig. 8 - *Stratigraphy of Venice 1 – CNR and Venice 1b – CNR boreholes, drilled in historical centre of Venice (from* MASSARI et alii, *2004). Magnetic polarity analysis is from* KENT et alii *(2002).*

(2004). These authors used biomagnetostratigraphy and stratigraphy of the sapropel, together with analysis of *facies* and *biofacies*, to prepare a detailed reconstruction of the evolution of the Venetian basin in the last 2.15 Ma, partly with the aim of correlating continental chronology with what is defined in the oceanic deposits in this marginal area (MASSARI *et alii*, 2004). This new survey of the Venetian stratigraphic sequence used different approaches - in particular, study of nannofossils, magnetostratigraphic setting of the succession, and comparison of stratigraphic records with astrochronological data.

The results of this research may be summarised as follows (Fig. 8):

(1) In the late Gelasian (late Pliocene), the area was a highly subsident shelf, whose depth was almost reduced to sea level;
(2) During the Lower Pleistocene, after a gap that lasted for at least 0.2 Ma and corresponded to most of the Olduvai Subchron, the shelf sank rapidly to bathyal depth (biozone from MNN 19a to MNN 19e: 1.947 to 0.96 Ma). This interval was characterised by greatly reduced sedimentation rates (less than 10 cm/Ky), represented by interstratified hemipelagic mud interbedded with sapropel layers;
(3) During most of the period of the MNN 19f biozone (zones with *Pseudoemiliania lacunosa*, 0.96-0.42 my), there was a thick layer of basin sludge as a result of considerable terrigenous contributions from the south-eastern Alpine sector;
(4) In the middle of Chron 1n (Brunhes), deltaic sedimentation, mainly linked to the progradation of the palaeo-Po system, caused progressive replenishment of the basin. This episode, which represents the most important construction stage, ended with the first disappearance of continental sediments, tentatively correlated with the marine oxygen isotope substage (MIS) 8.4;
(5) The upper part of the succession shows cyclic organisation, with an upward increase in marginal marine and continental deposits subjected to subaerial exposure. In this interval, the Venetian area was below sea level during the highstand glacio-eustatic tract, but emerged during the successive lowstand conditions.

Some of the stratigraphic layers identified by KENT *et alii* (2002) in the first 300 m of subsoil match the arrangement of acquifers/aquitards, whose development model was processed by analysis and interpretation of the stratigraphies of hundreds of boreholes and calibrations in the 1970s by study of the *Venice 1 - CNR* borehole. As these aquifers/aquitards have good lateral

Fig. 9 – *Map of depth contours (a.m.s.l.) of top of 2nd aquifer, which may correspond to tr.3 described by* KENT et alii *(2002).*

continuity, an attempt was made to extend knowledge of depositional events identified in the surrounding areas to this survey too (BRAMBATI *et alii*, 2003). One example is the map of the second aquifer, which may correspond to the tr.3 described by KENT *et alii* (2002) (Fig. 9).

During the Tyrrhenian transgression, the position of the coastline moved further from its current position, but did not reach the areas now occupied by the cities of Padova and Treviso, which therefore remained above sea level (FAVERO, 1987). As most of the knowledge concerning this event was obtained from wells drilled for water, data are scarce in terms of quantity and are not always of good quality. An historical survey, carried out in 1934 near Correzzola (Padova) deserves mention: a borehole was drilled to a depth of 185 m, and an accurate description of the microfauna and malacofauna found were reported by ACCORDI & SOCIN (1950).

Sources of information increase progressively towards the shallow sediments. In particular, many surveys and multidisciplinary studies conducted on data from hundreds of boreholes drilled for various purposes, with average thrusts of 25-30 m, have documented the depositional events of the last 30,000 years in detail.

Three main depositional stages are recorded in the last 30 m of sediments, which represent the environmental situations established in the Late Pleistocene and following Holocene, due to global changes in sea level: the deposits of the Lowstand Systems Tract (LST), Holocene Transgressive Systems Tract (TST) and Highstand Systems Tract (HST).

During the LST, related to the last glaciation (Last Glacial Maximum; LGM), the area in question appeared as a vast alluvial plain furrowed by watercourses, the palaeobeds of which, now buried, have been identified by high resolution seismic surveys (STEFANON, 1984; MC CLENNEN *et alii*, 1997). In that period, as the sea level was approximately 110-120 metres lower than it is now (MOSETTI & D'AMBROSI, 1966; VAN STRAATEN, 1967; D'AMBROSI, 1969; LEONARDI, 1970; TRINCARDI *et alii*, 1994; CORREGGIARI *et alii*, 1996a; CORREGGIARI *et alii*, 1996b), the coastline was located near the present-day city of Pescara and almost coincided with the edge of the Fossa del Pomo, where it met the deltaic apparatus of the palaeo-Po.

The main deposits of the LGM are those related to the flow of the rivers Piave, Brenta, Bacchiglione, Adige and Po, whose alluvial fans overlapped locally, creating overall sedimentary successions. The changing dynamics of the alluvial environment processes gave rise to energy gradients responsible for complex lateral-vertical organisations of facies. Therefore, channel deposits of flood plains and lake and marsh basins are currently found arranged in vertical layers or lateral heteropy.

As a consequence of the dry, glacial, and subsequently arid climate, a considerable lowering of the base level (BORTOLAMI *et alii*, 1977) caused erosion and deepening of river beds.

The top deposits of this stage, dated to about 18,000 years BP, show clear signs of pedogenesis developing in conditions of prolonged sub-aerial exposure. A discontinuity surface, representing a stratigraphic gap with a time-frame varying between 7,000 and 13,000 years depending on area, separates these deposits from the overlying ones. This gap, which includes the Post-Glacial and part of the lower Holocene, mainly seems to be due to a lack of deposition and also to local erosion caused by intense fluvial dynamics (GATTO & PREVIATELLO, 1974). The latter was reinforced by an increase in river loads. Therefore, the boundary with the subsequent Holocene deposits is marked by a surface, sometimes eroded, at the top of a Pleistocene clay known locally as *caranto*, which is regarded by some writers as a palaeosoil subjected to overconsolidation due to subaerial exposure and the dry, cold climate.

The *caranto* has been studied and described in many works, including those by MATTEOTTI (1962), GATTO & PREVIATELLO (1974), GATTO (1980; 1984), TOSI (1993; 1994a; 1994b;1994c), BONARDI & TOSI (1994a; 1995a; 1997; 1999; 2000b; 2000c; 2001), BONARDI *et alii* (1997), BRAMBATI *et alii* (2003) and MOZZI *et alii* (2003).

The *caranto* varies in thickness from a few centimetres to 2 m and is generally composed of clayey silt or highly compacted silty clay. It is pale grey in colour, with ochre pressure marks, and contains carbonatic nodules a few millimetres in diameter. These levels generally accumulated between 20,000 and 18,000 years BP, although younger ages cannot be excluded as regards the upper limit. BINI *et alii* (2003) and SERANDREI-BARBERO *et alii* (2005b) dated small roots and peaty branches with the Accelerator Mass Spectrometry (AMS) technique, demonstrating the existence of a vegetal cover and occasional sedimentary flows in the Late Glacial and Holocene in the subsoil in the historical centre of Venice. These levels accumulated between 12,000 and 7,000 years BP. Dating of the overlying sediments indicates that the latter mainly belong to the medium-upper Holocene layer (MOZZI *et alii*, 2003). Recent studies place pedogenesis and overconsolidation within the stage corresponding to the stratigraphic gap or the reduced sedimentary flow that occurred between 14,500 years BP and the beginning of the Holocene transgression.

The *caranto* represents an excellent guideline level to identify the boundary between the Pleistocene and Holocene deposits, mainly in the marine and eastern lagoon sectors, where it is macroscopically evident, thanks to the differing sedimentological properties of the upper and lower deposits. Instead, towards the margin of the central lagoon and towards the hinterland, identification may require more exhaustive examination, particularly in cases of contact with continental environments.

Unfortunately - despite its regional extent, not

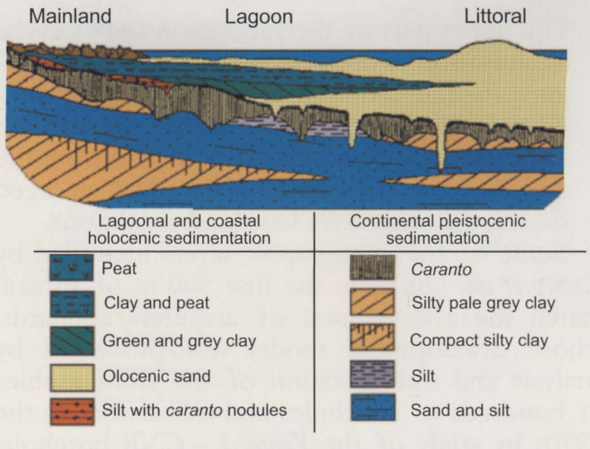

Fig. 10 – *Late Pleistocene and Holocene stratigraphic sequence of central part of Lagoon of Venice (after GATTO & PREVIATELLO, 1974).*

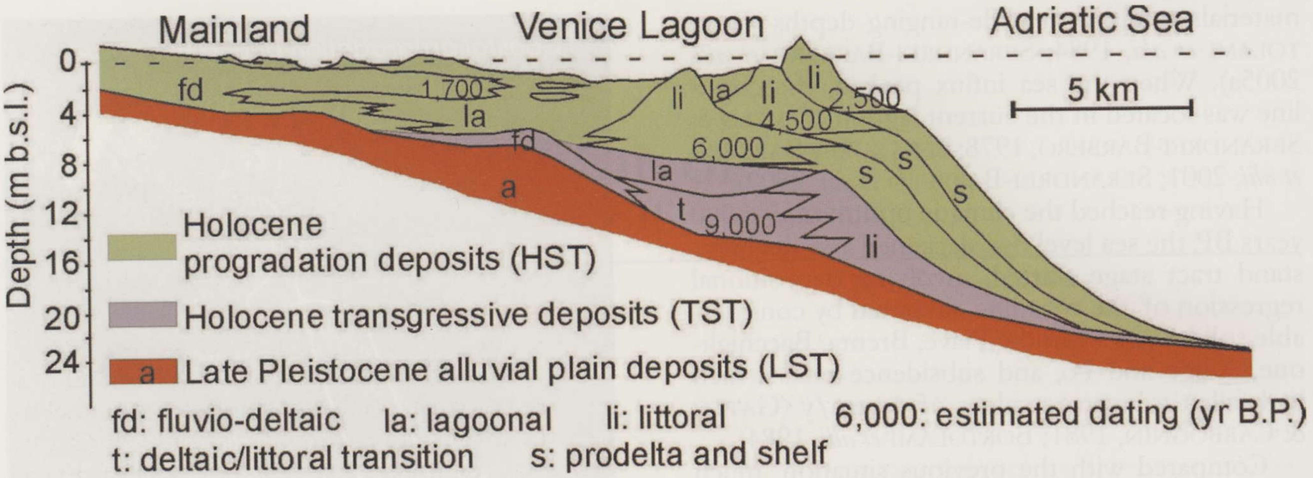

Fig. 11 – *Sketch of depositional systems in southern sector of Lagoon of Venice (from* BONARDI et alii, *2006).*

only in the Adriatic area, but also in other coastal areas around the world - this overconsolidated layer shows more or less wide-ranging and localised lateral discontinuities. In heteropy with the silty-clayey level of *caranto*, there are facies made up of markedly clayey sediments originating from lakes and marshes that were not overconsolidated, due to their particular textural and depositional properties, and also from sandy deposits, probably from the fluvial ridge, which often show traces of pedogenesis and cementation. Some authors have recently adopted the definition of *caranto* to include non-overconsolidated coeval sediments.

Lastly, interfingerings with marine and lagoon deposits, indicating the presence of palaeo-river beds or replenished channels, which occasionally occur.

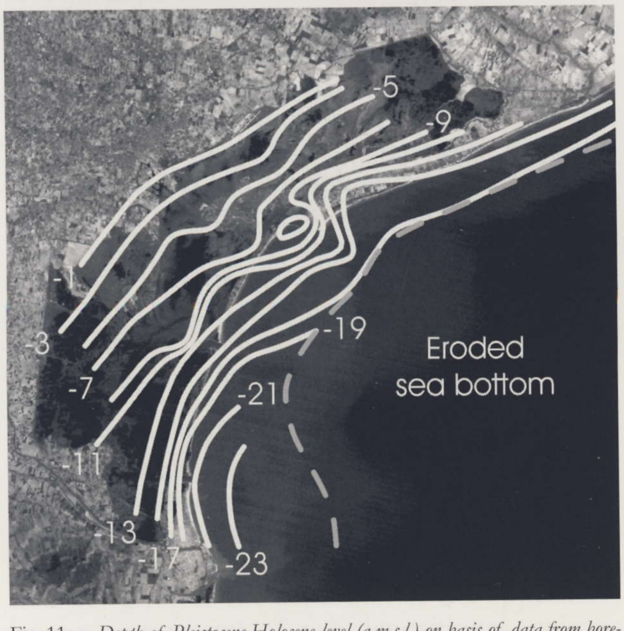

Fig. 11a – *Depth of Pleistocene-Holocene level (a.m.s.l.) on basis of data from boreholes and high resolution seismic analysis (from* BRAMBATI et alii, *2003). This surface matches that of tr.1 of* KENT et alii *(2002), and shows marine area where Holocene deposits are not found or have been eroded.*

An initial reconstruction of the trend of the Pleistocene-Holocene surface boundary in the lagoon was proposed by GATTO & PREVIATELLO (1974) (Fig. 10).

Subsequent updates by GATTO (1984) and TOSI (1994c) have also identified and characterised this discontinuous surface in the coastal sector, emphasising the lateral variability and identifying two low areas, separated by a morphological high near the present-day Bocca di Lido. These studies have also defined an initial architectural model of the depositional systems from the mainland to 5 km offshore (BONARDI *et alii*, 2006) (Fig. 11).

BRAMBATI *et alii* (2003) recently created a model of the state of this lagoonal surface and the offshore area, revealing the morphological setting of the palaeoplain during the lowstand marine tract (Fig. 11a).

During the initial stage of the Holocene transgression, erosional river furrows were filled with transgressive sea sand (FONTES & BORTOLAMI, 1973) and formed littoral apparatuses (primordial lagoons probably developed behind them), which gradually moved further north. Local levels of reworked sandy silt of uncertain origin, with chaotic structure and containing Pleistocene clay breccias are defined as overflow deposits, as it is hypothesised that they are the result of particularly intense dynamic processes (fluvial channel fill following deglaciation or marine transgression). Transgressive deposition, which lasted approximately 5,000 years, took place in conditions of rapid sea level rise and reduced sedimentary flow, accompanied by a subsidence rate which may have reached 3 mm/y, as estimated by radiodating on organic materials sampled at wide-ranging depths (BORTOLAMI *et alii*, 1984; SERANDREI-BARBERO *et alii*, 2005a). When the sea influx peaked, the coastline was located in the current lagoon (FAVERO & SERANDREI-BARBERO, 1978; SERANDREI-BARBERO *et alii*, 2001; SERANDREI-BARBERO *et alii*, 2002).

Having reached the climatic optimum, 5-6,000 years BP, the sea level rise slackened and the highstand tract stage started, involving depositional regression of the coastline, favoured by considerable solid flows from the Piave, Brenta, Bacchiglione, Adige and Po, and subsidence rates which had fallen to average values of 1 mm/y (GATTO & CARBOGNIN, 1981; BORTOLAMI *et alii*, 1984).

Compared with the previous situation, much more complex and differentiated environments started to develop in the transition area between sea and land, in turn characterised by various types of subenvironments.

According to the evolutionary model of the coastline proposed by TOSI (1994c) (Fig. 12), obtained with data from palaeo-ecological and radiometric surveys on coastal subsoil sediments, the transgressive marine trend prevailed in the central-northern area until total replenishment of the morphological high identified at the Lido inlet. Aggradation of deposits was associated with gradual exhaustion of a large branch of the Brenta, of which traces still remain today.

To the south, once the maximum marine influx had peaked, progradation of the littoral began, favoured by abundant solid flows from the Adige, Brenta and Bacchiglione, not balanced by the rise in sea level.

Near the margins of the inner lagoon, which were not directly involved in detritic flows, geological subsidence caused the enlargement of lagoonal basins shorewards.

Within the Holocene sequence, oscillations due to the reduced sea level were recorded by secondary transgressive-regressive depositional events, probably the consequence of minor climatic changes, which were however able to influence the flow and accumulation of sediments and eustatism. The clearest example is the finding of ancient salt marsh on highstand tract Holocene lagoon deposits, on which man-made settlements of Roman age have been found. There follow younger deposits of the lagoonal environment, in which evidence of salt marsh is often found again in the upper part (SERANDREI-BARBERO *et alii*, 1997; BONARDI, 1998; BONARDI *et alii*, 1998; SERANDREI-BARBERO *et alii*, 2004). The top of the Roman level coincides with a discontinuity which extends laterally throughout the Venetian area and may correspond to findings from the Ravenna area, attributed here to the IV-VI centuries AD, which identifies a surface of fluvial erosion correlated laterally with soils (AMOROSI, 1999; REGIONE EMILIA-ROMAGNA, 1999).

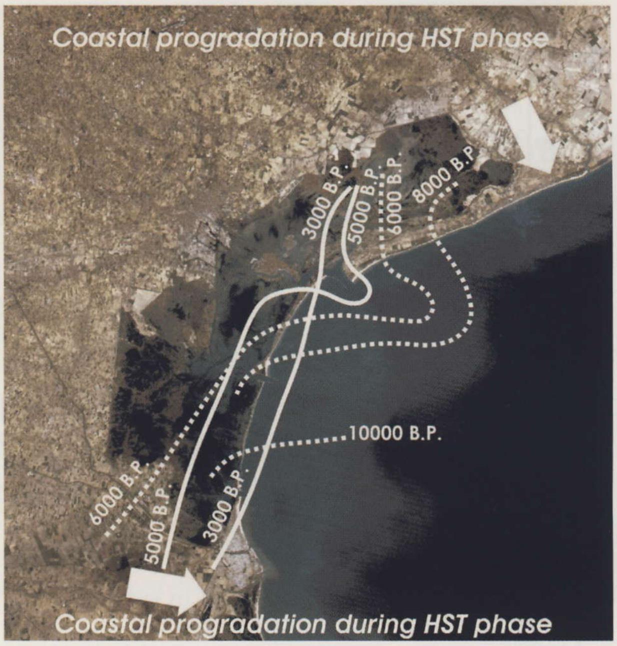

Fig. 12 – *Model of Holocene evolution of coastline (from* TOSI, *1994c, modified). Arrows: direction of advance of coastline, caused by progradation of river mouths during highstand tract stage.*

The historic evolution of the Venetian area has been considerably influenced by anthropic interventions, particularly from about 1000 AD. The most evident transformations are due to direct diversions of rivers from the lagoon, which is otherwise subjected to infilling, partly due to increased solid flows and partly to a reduction in the rate of sea level rise. While limiting replenishment of the lagoonal basin, these operations involved deepening and expansion shorewards, especially because geochemical processes caused an increase in subsidence rates due to salinisation of deltaic areas, which had previously been characterised by freshwater environments.

Man's activities in the last century - for instance, the construction of tidal barriers - have considerably changed coastal and lagoonal hydrodynamics and therefore the processes of resuspension, transport, and deposition of sediments.