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STRATIGRAPHY, PALAEOPEDOLOGY AND PALYNOLOGY OF LATE PLEISTOCENE AND HOLOCENE DEPOSITS IN THE LANDWARD SECTOR OF THE LAGOON OF VENICE (ITALY), IN RELATION TO THE CARANTO LEVEL

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ABSTRACT
The present investigation brings new stratigraphic, palaeopedological and palynological data deriving from the study of 4 cores, bored to a maximum depth of 15 m in the central sector of the Lagoon of Venice, along the inner shores, between the mouth of the Dese river and Porto Marghera.
In agreement with the general stratigraphy known from previous studies, the lowermost deposits in the cores are fluvial, radiocarbon dated to 21,000 – 18,000 BP. The correlation to the stratigraphic framework of the central Veneto plain shows that they belong to the Late Pleistocene fluvial sedimentary system of the Brenta river, the Bassano megafan. The pollen record of this alluvium is characterized by typical hydrophilous plants (*Typha, Potamogeton, Nymphaea*...), which are referred to swampy environments during the Last Glacial Maximum and the Late Glacial. The compact level known as *caranto*, located at the top of the fluvial sediments at a depth of some metres from the ground surface, has been recognized as consisting of a set of pedogenetic calcic and gley B and C horizons. This palaeosol formed on the alluvial plain of the distal reaches of the Bassano megafan, in the time span comprised between the deactivation of fluvial processes, which took place after 14,500 BP and probably before the beginning of the Holocene, and the lagoon transgression. As the latter apparently interested the study area only in post roman times, pedogenesis could act for 8000 – 12,000 years. The definition of the pedogenetic nature of the weathering features is based on macro- and micromorphological observations, associated with physico-chemical analyses. The palynological analysis shows that the *caranto* level is characterized by a very low pollen content. The Late Holocene lagoonal deposits which cover the *caranto* palaeosol have dominant subtidal / intertidal mud flat and salt marsh facies, within a context of varying water salinity probably related to river inputs. The presence of a slightly pedogenized level developed in a salt marsh environment, indicates a hiatus in the deposition of the lagoonal sediments. Two radiocarbon datings of the organic O horizons of this soil in two cores show that this discontinuity is of medieval age. Furthermore, they provide a reliable chronostratigraphic support to the determination of the recent relative sea level rise. This latter has been estimated 2.3 m since 1055 – 954 cal BP to present day in Porto Marghera, EniRisorse area, and 1.1 m since 640 – 592 cal BP to present day in Porto Marghera - Fusina, ABIBES area.

RIASSUNTO
Nel corso di questa ricerca sono stati studiati dal punto di vista stratigrafico, paleopedologico e palinologico le carote provenienti da 4 sondaggi ubicati al margine interno del settore centrale della Laguna di Venezia, tra la foce del F. Dese e Porto Marghera, per una profondità massima di 15 m dal piano campagna.
*In accordo col contesto stratigrafico generale già definito in numerosi studi precedenti, i depositi lagunari olocenici ricoprono qui, con spessore esiguo, una serie fluviale datata 21.000 – 18.000 BP. Il record pollinico di questi sedimenti è caratterizzato da piante idrofile (*Typha, Potamogeton, Nymphaea *...), tipiche di ambienti palustri riferibili all'ultimo pleniglaciale e al tardiglaciale. Inquadrando i depositi fluviali nell'ambito della pianura veneta centrale, si evince che il sistema sedimentario attivo nell'area di studio era quello tardopleistocenico del Brenta (megafan di Bassano), in aggradazione fino al tardiglaciale. Al tetto dei depositi alluvionali è presente il livello alterato, sovraconsolidato, con screziature e noduli carbonatici, conosciuto nell'area lagunare con il nome di "caranto". Mediante uno studio paleopedologico, e comparando i risultati con le caratteristiche dei calcisol presenti sulle superfici distali del megafan di Bassano in prossimità della laguna, è stato possibile confermare la natura pedogenetica delle figure di alterazione che lo contraddistinguono. Il "caranto" è stato dunque interpretato come un suolo sepolto, che si è sviluppato sui depositi di esondazione del tratto distale del megafan di Bassano. L'arco temporale per la sua formazione è compreso tra la cessazione dei processi fluviali, avvenuta successivamente a 14.500 BP e, probabilmente, prima dell'inizio dell'Olocene, e l'ingressione lagunare. Nell'area di studio quest'ultima è attribuibile al periodo post romano, e dunque l'intervallo complessivo durante il quale la pedogenesi ha potuto agire è di 8000 – 12.000 anni. L'analisi palinologica ha mostrato che nel "caranto" il contenuto in polline ha valori estremamente bassi, probabilmente a causa della distruzione dei granuli durante la pedogenesi.*
I depositi lagunari indagati, riferibili all'Olocene recente, presentano prevalentemente facies di fondo lagunare / piana intertidale e di palude salmastra (barena / salt marsh), con evidenza di fluttuazioni nella salinità dell'acqua, probabilmente dovute all'alterno influsso dei fiumi che sfociavano in laguna. La presenza di un livello debolmente pedogenizzato in ambiente di palude salmastra, indica l'esistenza di una lacuna stratigrafica all'interno della serie lagunare indagata. Due datazioni al radiocarbonio degli orizzonti organici di questo suolo in due diverse località, indicano che tale hiatus ricade in età medievale. Questi dati cronostratigrafici permettono, inoltre, di fornire una stima del recente innalzamento relativo del livello marino, pari a 2.3 m da 1055 – 954 cal BP al presente nell'area EniRisorse di Porto Marghera, e 1.1 m dal 640 – 592 cal BP al presente nell'area ABIBES di Porto Marghera - Fusina.

Key words: Venice, Last Glacial Maximum, Late Glacial, palaeosol, palynology, alluvial plain, lagoon.

Parole chiave: Venezia, Last Glacial Maximum, tardiglaciale, paleosuolo, palinologia, pianura alluvionale, laguna.

1. INTRODUCTION

The lagoon-and-barrier sedimentary system of the lagoon of Venice (Fig. 1) is the result of a long-term history of delicate equilibrium between sea and land, that is, between coastal and fluvial processes. During the Holocene, the sea level has been continuously rising, as a result of the combined effect of the post glacial eustatic sea level rise and local land subsidence. Meanwhile, the Piave and Brenta rivers have been delivering large volumes of sediments to the Adriatic Sea. These materials, due to redistribution along the coast, have been providing the sands for the upbuilding of the barrier islands. On the other hand, these large alpine rivers repeatedly had their mouths within the lagoon itself, together with smaller rivers such as the Musone, Marzenego, Dese and Sile. In Fig. 1a, it is possible to perceive how a further south-western expansion of the Piave sedimentary system, in connection with the Sile system, would imply the infilling of the northern lagoon, as much as a progradation of the Brenta system would bring about a forced regression in the southern lagoon. The only area in which there has been no important fluvial activity is in the central lagoon, where the distal fringes of the Late Pleistocene Bassano megafan and Nervesa megafan *pro parte*, reach the lagoon shores. In the underground, these Late Pleistocene continental deposits represent the bed on which the lagoon-and-barrier sediments lie (Fig. 1b).

Rivers freely choose their way to the lagoon just until the beginning of the second millenium A.D., when human control on the hydrographic network became progressively stricter. In fact, rivers brought about a lowering of the salinity near their mouths, because of the mixing of fluvial fresh-water with salty sea water. They also enhanced sedimentation, as they delivered alluvial sediments into the lagoon. Both these tendencies were regarded as negative, and strongly contrasted by the Venetians, for both sanitary (prevention of malaria) and economic (navigation in the lagoon) reasons. Between the 11th and 17th century A.D., the main rivers were artificially driven out of the lagoon by the Venice Republic, and only the minor watercourses were let in.

In order to investigate the complex relations between the alluvial and lagoon sedimentary systems during the Upper Pleistocene and Holocene, the inner shores of the central lagoon of Venice, between the mouth of the Dese river and Porto Marghera, have been

a)

b)

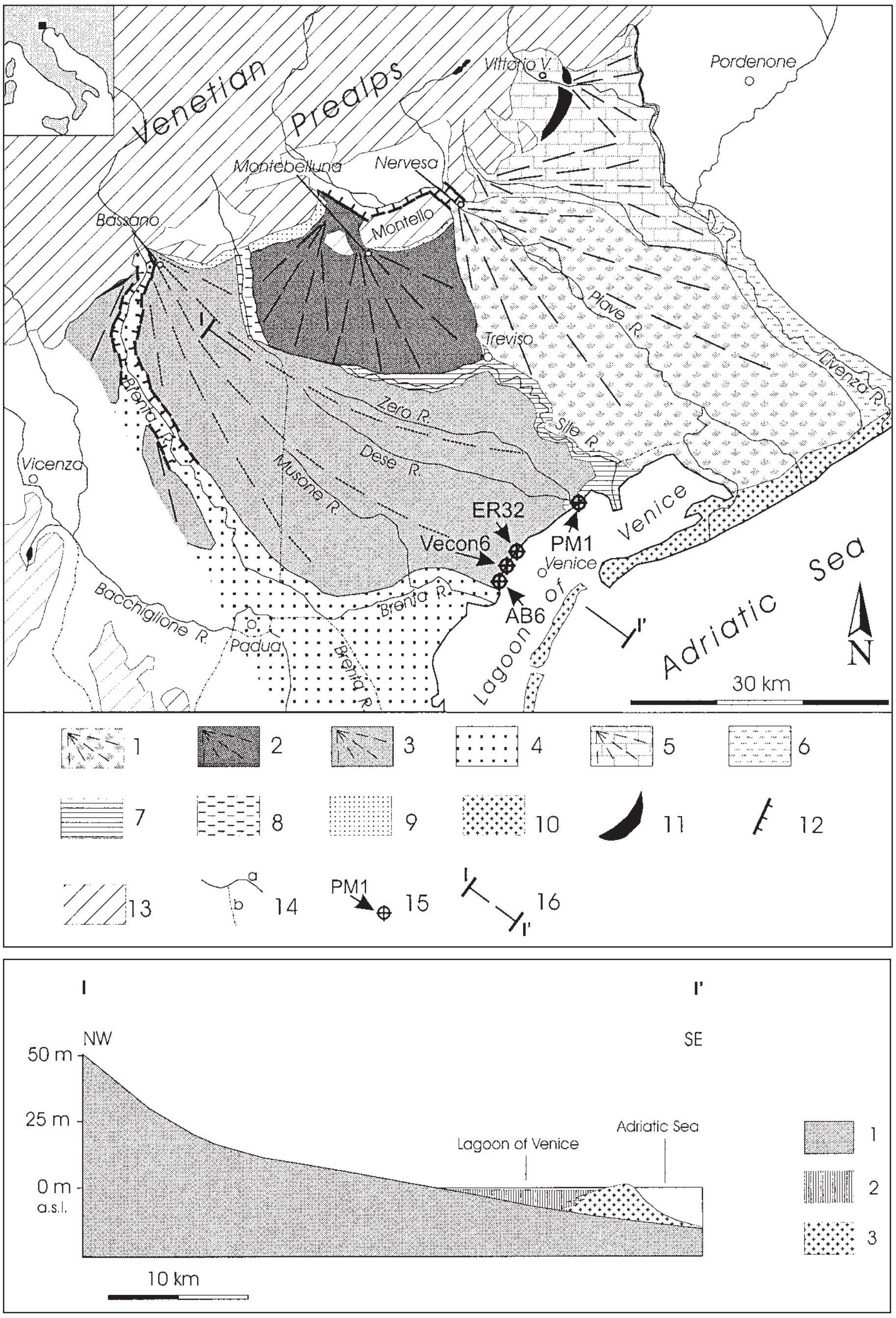

Fig. 1a - Geomorphological sketch of the Central Veneto plain (modified from Bondesan *et al.*, 2002). 1. Nervesa megafan (Late Pleistocene, Holocene); 2. Montebelluna megafan (Late Pleistocene); 3. Bassano megafan (Late Pleistocene); 4. Brenta alluvial plain (Holocene); 5. Monticano, Cevada and Meschio fans (Holocene); 6. Livenza alluvial plain (Holocene); 7. Sile, Dese and Zero alluvial plain (Holocene); 8. Musone alluvial plain (Holocene); 9. piedmont fans (Holocene); 10. littoral sandy deposits (Holocene); 11. moraines (Late Pleistocene); 12. fluvial erosive scarps; 13. hills and mountains; 14. natural (a) and artificial (b) hydrography; 15. core location; 16. location of the geological cross section of Fig. 1b.
Fig. 1b - Geological cross section (modified from Broglio *et al.*, 1987). 1. alluvial deposits of the Bassano megafan (Late Pleistocene); 2. lagoonal deposits (Holocene); 3. littoral deposits (Holocene).

chosen as a study area. Particular attention has been devoted to the firm, mottled horizon locally known as caranto, widespread in the underground of the central lagoon, with the aim of understanding its genesis and evaluating its stratigraphic importance.

2. THE GEOLOGICAL FRAMEWORK

The Holocene lagoon-and-barrier sedimentary complex of the lagoon of Venice started forming most probably around 7000 - 6000 BP (Bortolami *et al.,* 1977); the oldest radiocarbon datings of organic materials at the base of the lagoonal deposits are 7210±40 BP (depth of ca. 4.00 m below mean sea level) in the island of S. Erasmo (Schiozzi & Brambati, 2000), 5090±100 BP (depth of 5.95 m below mean sea level) in the northern lagoon (Serandrei Barbero *et al.*, 2001), 4670±70 BP in the underground of Piazza S. Marco, Venice (depth of 5.80 m below mean sea level) (Serandrei Barbero *et al.*, 2001). In general, in the central lagoon the deposits have an average thickness of around 5 m, progressively thinning towards the mainland (Fig. 1b), but the scours of the tidal channels can be more than 10 m deep (Alberotanza *et al.*, 1977; McClennen *et al.*, 1997). In the underground of the city of Venice, the lagoonal deposits, consisting of both silty - clay sediments and sandy infillings of tidal channels, have a thickness of between 2 and 6 m. The sandy littoral deposits of the barrier islands, which separate the lagoon of Venice from the Adriatic Sea, reach a maximum thickness of ca. 15 m (Gatto, 1980; Tosi, 1994).

The accomodation space of the lagoon-and-barrier deposits has been provided by the coupled post glacial eustatic sea level rise and local land subsidence, that together constitute the relative sea level rise. Considering the last 6000 years, the sea level changes derived from coral dating in Tahiti (Bard *et al.*, 1996) and speleothemes dating in the Thyrrhenian Sea (Alessio *et al.*, 1997) are consistent in indicating an eustatic sea level rise between 2 and 3 m. These trends, based on a reliable record for the last 12,000 years (Antonioli & Silenzi, 1998), may be taken as an indication also for the northern Adriatic Sea. The average subsidence rate in the lagoon of Venice during the Holocene has been estimated to be ca. 1.3 mm/year (Bortolami *et al.*, 1977; Bortolami *et al.*, 1984; Serandrei Barbero *et al.*, 1997, Serandrei Barbero *et al.*, 2001). Altogether, this would suggest a theoretical relative sea level rise for the lagoon of Venice of ca. 10 m during the last 6000 years (8 m due to land subsidence and 2 m to eustatic sea rise). Available levelling measurements for the 1908–1930 period give a much lower subsidence rate of about 0.5 mm/year in the lagoon of Venice (Gatto & Carbognin, 1981; Carbognin *et al.*, 1984; Carbognin & Tosi, 2003). These measurements were carried out before the peak of man-induced subsidence, related to over-pumping of underground water for industrial use in Porto Marghera during the mid- 20th century, and are thus indicative of the natural trend. Based on this latter subsidence rate, the theoretical relative sea level rise for the lagoon of Venice during the last 6000 years, before human impact, would only be ca. 5 m (3 m due to land subsidence and 2 m to eustatic sea rise). For comparison, we recall that the relative sea level rise since 6000 BP has been estimated to be about 4 m in the lagoon of Caorle, 30 km to the east of the lagoon of Venice, and 8 - 9 m in the lagoon of Marano, 15 km farther east (Galassi & Marocco, 1999). These differences may be due to different rates of land subsidence in different locations and time intervals.

The lagoon-and-barrier sediments lie on top of Late Pleistocene alluvium (Fig. 1b). In Venice, the overall thickness of the fluvial deposits posterior to the last interglacial (marine isotopic stage 5e) is about 60 m (Mullenders *et al.*, 1996; Kent *et al.*, 2002). The topmost, radiocarbon dated, peat levels indicate that fluvial sedimentation was still active in the lagoon area during the Last Glacial Maximum (Bortolami, *et al.,* 1977; Tosi, 1994; Serandrei Barbero *et. al.*, 2001); the latter is here intended as the period extended from about 22,000 to 15,000 BP, within the marine isotopic stage 2, during which the last maximum expansion of ice sheets and mountain glaciers took place in the northern emisphere (Crowley & North, 1991, p. 47; Orombelli & Ravazzi, 1996). In the central lagoon these deposits mainly belong to the Pleistocene Brenta sedimentary system, which formed a megafan with the apex at the mouth of the Brenta valley near Bassano del Grappa, elongated in a SE direction (Bassano megafan, Fig. 1a) (Mozzi, 1995; 1998; Bondesan *et al.,* 2002). The aggradation of the distal portions of this megafan was continuous until ca. 14,500 BP, after which the deactivation of the distributary system took place, due to fan-head trenching in the piedmont sector. This probably happened in response to the deglaciation of the alpine area, a crucial environmental change which occurred at the Pleistocene – Holocene transition. In any case, the presence of Mesolithic (Sauveterrian) sites at the surface in the distal Bassano megafan, near the lagoon shores (Broglio *et al.*, 1987), indicates that sedimentation had already stopped by the Early Holocene. In the lagoon and in the mainland, these Late Pleistocene fluvial sediments consist of scarcely interconnected, few-metres-thick, sandy channel deposits embedded in laminated, silty clay overbank deposits, with common, few-centimetres-thick peaty levels with lateral extension up to a few kilometres (Favero *et al.*, 1973; Serandrei Barbero *et. al.*, 2001; Iliceto *et al.*, 2001; Bondesan *et al.*, 2002; Bondesan & Mozzi, 2002).

At the top of the continental series is a compacted, mottled, 1 – 3 m thick level, with common millimetric to centimetric carbonatic nodules. Gatto & Previatello (1974) called this level a palaeosol, but they did not support this statement with any analytical or morphological assessment. It is regarded as rather continuous in the underground of the central lagoon, mantling the slightly undulated, gently southwards dipping unconformity surface positioned between the Late Pleistocene continental series and the overlying, mid-Holocene barrier-and-lagoon deposits (Gatto, 1980). It is locally known as *caranto*, a word which was introduced in the scientific literature by the early geotechnical studies concerning the underground of Venice (Matteotti, 1962); the foundations of the city of Venice rest on wood bearing piles which are driven in the resistant *caranto*. In fact, *caranto* is a word in Venetian dialect with which peasants in the mainland traditionally indicate hard, cemented horizons, often forming few centimetres thick crusts, outcropping in the fields during tillage. Soils with such horizons are the typical calcisols widespread in the Venetian plain, having Late Pleistocene, fine silty alluvial deposits as parent material (Giandon *et al*., 2001).

Much palynological research has been carried out on the Quaternary deposits of the Lagoon of Venice (Bertolani Marchetti, 1967; Horowitz, 1967; Paganelli, 1967; Buurman, 1970; Bandini Mazzanti *et al*., 1974; Calderoni *et al*., 2000). These studies evidence the occurrence of a continental environment during the glacial period, characterized by Pine forests, particularly constituted by *Pinus sylvestris* or *P.mugo*, and other microthermic plants. In the Holocene, the area was dominated by mixed oak woods. The withdrawal of the arboreal plant pollen and the appearance of grains of hygro-hydrophytes record the development of wet environments. Pollen grains which may be referred to a typical lagoon flora have been detected in most surface levels.

3. METHODS

During this investigation the sedimentary series have been cored continuously to depths ranging between 5 and 15 m, in four different locations on the inner shores of the lagoon (Fig. 1a): core PM 1, Punta Montiron, at the mouth of the Dese river, depth 0 - 15 m; ER 32, Porto Marghera, EniRisorse area, depth 0 - 8 m; Vecon 6, Porto Marghera, VECON area, depth 0 - 10 m; AB 6, Porto Marghera - Fusina, ABIBES area, depth 0 - 5 m. The deposits have been described in order to recognize the sedimentary and pedological features. ^{14}C datings have been carried out by G. Calderoni of the University of Rome "La Sapienza" (Bondesan *et al*., 2002; Bondesan & Mozzi, 2002). Radiocarbon dates have been calibrated with the calibration program CALIB REV 4.3, based on Stuiver & Reimer, 1993 (probability distribution, 1 sigma).

Palynological and palaeopedological analyses have been carried out just on cores PM 1, Vecon 6 and AB 6, in the interval centred on the main unconformity between the continental and lagoon deposits. The sediment samples used for chemical and physical analyses have been air-dried and crushed to pass through a 2 mm sieve. Standard laboratory methods have been carried out on the fraction <2mm, and included particle size distribution (clay, silt and sand content) by pipette method, organic carbon content according to Walkey and Black method, and pH (1:2.5 soil water ratio). Cation exchange capacity (CEC) and total acidity have been determined by titration after extraction with triethanolamine and $BaCl_2$ buffered at pH 8.2. Total carbonates have been determined by gas-volumetric method using Dietrich-Fruehling calcimeter. Micromorphology has been carried out on selected undisturbed samples, impregnated with resin and cut to obtain thin sections ca. 30 μm thick. Description of thin sections has been carried out following Bullock *et al.,* 1985.

For palynological analyses, the available sediment samples have been treated with cold HCl and HF, hot HCl and Na-hexametaphosphate, sieved (250 μm), treated with hot NaOH, stored in a water/glycerol solution 50% v/v. Pollen percentages are calculated on the total of pollen grains and spores.

4. CORES STRATIGRAPHY AND PALAEOPEDOLOGY

Core PM 1

Stratigraphy

Between 15.00 m and 12.60 m two main sand bodies, with erosive lower boundaries, are present (Fig. 2). Both show fining upward sequences, the lower one (14.90 ÷ 14.50 m) from medium sand to fine sand, the upper one (13.80 ÷ 12.60 m) from fine sand to sandy silt. Between the two is a set of thinly laminated silt and silty sand, with a 15-cm-thick layer of silty clay at the bottom. On top of the upper sandy layer is a 10-cm-thick layer of peat, radiocarbon dated 20,630±240 BP (Rome-1188; Bondesan *et al*., 2002), followed by 65 cm of silty clay which grades upwards to sandy silt. Above lie a set of laminated alternances of silt and very fine sand, capped by 20 cm of silty clay. Between 10.65 and 10.55 m there is another peat level, dated 18,720±200 BP (Rome-1187; Bondesan *et al*., 2002), 22,630 – 21,810 cal BP. The peat is covered by 2.25 m of clay silt, with evident millimetric planar bedding, containing common remnants of canes. Three peaty layers are present within this sequence: the upper, and thicker one, at a depth of 8.55 ÷ 8.45 m, has an age of 18,200±190 BP (Rome-1186; Bondesan *et al*., 2002), 22,010 – 21,130 cal BP; these peat layers, as the others present in the core, show abrupt upper boundaries, while the lower boundaries are transitional in 2 - 4 cm. On top lie two thin sandy layers, separated by a clay silty loam interval between 7.80 and 7.50; the lower one shows positive grading from fine sand to very fine silty sand, the upper one consist of silty fine sand. The stratigraphic sequence is interrupted at the depth of 7.00 m, as the core has been damaged during drilling operations, and starts again at 6.00 m. Between 6.00 and 4.50 m, the sediment is mainly silty; above 5.30 m, this interval is characterized by a firm consistence (pocket penetrometer test on the core give values of 3.50 kg/cm^2), a massive structure, the presence of many hard carbonatic nodules several millimetres large, and abundant greyish and yellowish mottles. Between 4.50 and 4.00 m is an organic rich silty loam, followed by thinly laminated, centimetric and decimetric alternances of fine sand, with varying percentages of silt and clay, and silty loam. Many broken shells are present in the 4.00 – 2.30 m interval. The top 1.5 m are anthropogenic, and consist of urban garbage, as the borehole is located in an abandoned waste. See also Tab.1 for details.

Textural and pedological analyses

The uppermost samples (PM 1/1 to 5) are sandy, though in varying percentages, while the lower ones are more silty (Fig. 3). All the samples examined show neutral to subalkaline reaction, and low carbonate percentage in the upper layers (samples PM 1/1 to 4); carbonate tends to disappear in the intermediate levels (samples PM 1/5-6-7), and to increase at the bottom. Cation exchange capacity (CEC) is medium to low, and decreases with depth; organic matter presents variable contents (range 1.5 – 6.5%) at the surface, decreasing with depth.

Micromorphology

Thin section examination of selected samples from

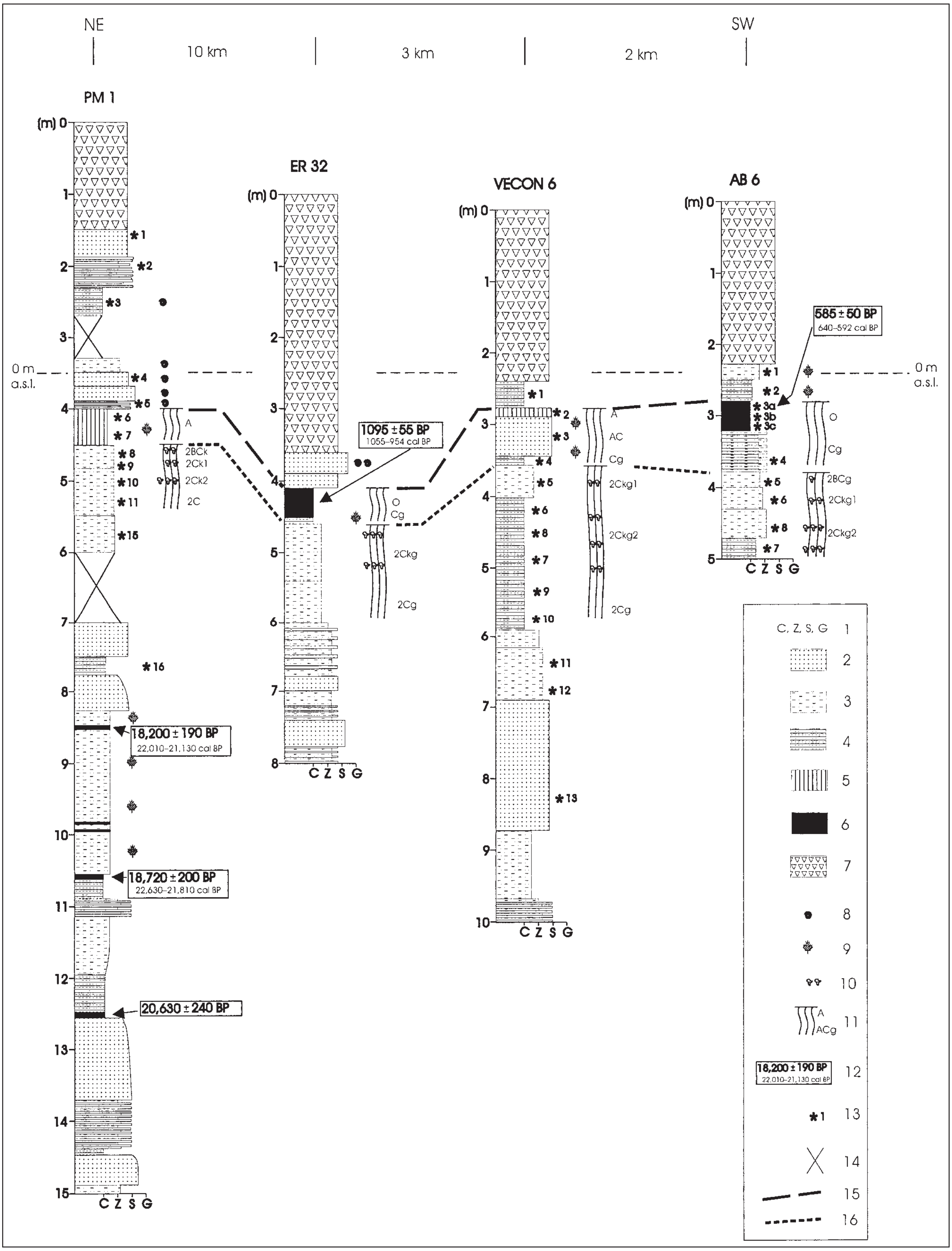

Fig. 2 - Stratigraphic logs (see also Tables 1, 2 and 3 for facies description and interpretation). 1. C: clay, Z: silt, S: sand, G: gravel; 2. sand, silty sand; 3. silt, sandy silt, clay silt; 4. clay, silty clay; 5. organic loam; 6. peat; 7. anthropic deposits; 8. shells; 9. plant remains (leaves, canes, wood, rootlets); 10. carbonatic nodules; 11. buried soil, with horizons; 12. ^{14}C date; 13. sample; 14. core gap; 15. tentative correlation of the top of the medieval organic horizons; 16. tentative correlation of the top of the *caranto* palaeosol.

this core indicates these prominent features. Sample PM 1/7 presents a close porphyric microstructure, with high coarse/fine (c/f) ratio and few interconnected pores. Blackish-brown undifferentiated organic components (undecomposed tissue fragments) are scarce. The coarse fraction consists of medium and fine sand, and coarse silt. Quartz grains dominate, followed by mica flakes. The groundmass is greyish and the birefringence in the fine fraction results from small mica flakes and from randomly distributed clay domains. No calcitic features have been observed. The sample beneath (PM 1/8) is a yellowish-brown clayey-silt with greyish mottles. The microstructure is laminated, with graded subhorizontal laminae; coarser material is found at the bottom, and is constituted by fine quartz grains in a calcareous, silty groundmass. In this calcareous silt, carbonate nodules and semi-continuous crusts form in the bottom part of the layer. The samples underneath (PM 1/9, PM 1/10) present finer texture with thin laminations, alternatively oxidized (silty) and reduced (sandy), in a clayey-calcareous matrix; the thinner laminations tend to aggregate in calcareous nodules, similar to those of the above described horizon.

Core ER 32

Stratigraphy

Between 8 and 6 m, the series is characterized by centimetric to decimetric alternances of fine sand and silt (Fig. 2). The thicker sandy layer in this interval, between 7.70 and 7.40 m, is coarser (medium sand) and better sorted. From 6.00 to 4.60 m the sediment is a silty clay loam, firm, with up to 50% greyish (5Y 6/1) and yellowish (2.5Y 6/8) mottles, 2 – 10 mm large; between 5.45 and 4.60 m, there are up to 25% hard and soft $CaCO_3$ nodules, 2 – 4 mm large. Above there are 10 cm of grey (10Y 5/1) silty clay, with many cuticles of canes, passing gradually (in 3 cm) to a dark grey (5Y 5/2) peat (4.50 ÷ 4.05 m), dated 1095±55 BP (Rome-1206), 1055 – 954 cal BP. This organic layer is covered by a 15-cm thick layer of very fine sand (abrupt boundary), which in turn lies under 30 cm of medium sand, well sorted, containing many *Cardium* shells; the boundary between the two is erosive. On top there are more than 3-m thick anthropogenic deposits (landfill of the industrial area of Porto Marghera).

Core Vecon 6

Stratigraphy

The lowermost sediments in the core (Fig. 2), between 10.00 and 9.70 m, consist of 1 – 3 mm thick alternances of fine sand and silt, overlain by 1 m of laminated clay silt. Above, between 8.70 and 6.90 m, is a rather thick layer of silty fine sand, which grades upward to sandy silt (6.90 ÷ 6.20 m), and is covered, through an abrupt boundary, by silt (6.20 ÷ 5.90 m). Between 5.90 and 3.45 m the series is rather homogeneous from a grain size point of view, spanning from silty clay to silty loam, but the general characteristics differ much in the various levels. Between 5.20 and 3.55 the sediments are firm (up to 4.5 kg/cm^2 with the pocket penetromer), massive, stained by many yellowish and greyish mottles, with up to 7% hard $CaCO_3$ nodules. Underneath (5.90 ÷ 5.20 m), the sediments are grey and less firm; the same applies to the 3.55 ÷ 3.45 m interval, which in addition contains common millimetric plant remains

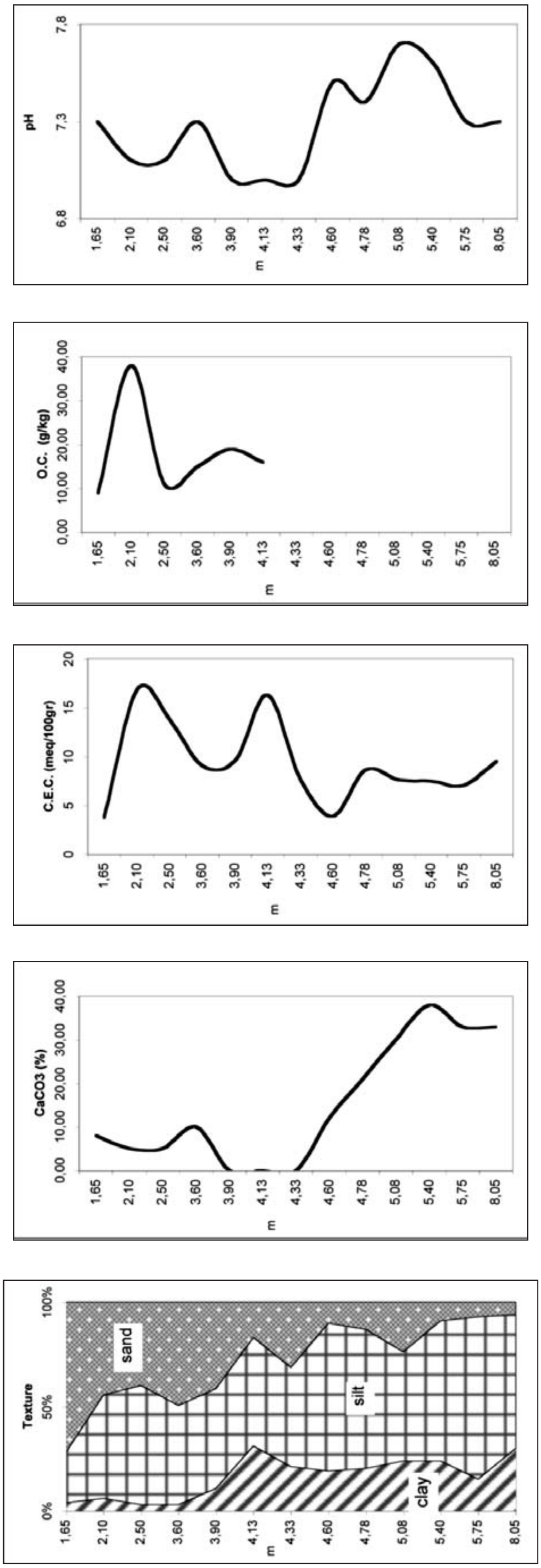

Fig. 3 - Pedological analyses of core PM 1

(wood, cuticles). Between 3.45 and 2.80 m the silty sand sediments contain many, partly decomposed, wood fragments and much dispersed organic matter, the latter showing a peak in the top 10 cm. The 2.80 ÷ 2.40 m layer consists of laminated silty clay. The topmost deposits are anthropogenic (landfill of the industrial area of Porto Marghera). See also Tab. 2 for details.

Texture and pedological analyses

The analysed portion of the core is characterized by marked variations (Fig. 4). The upper sample (Vecon 6/1) is a subalkaline silty clay; carbonate and organic matter contents are moderately high, and CEC is moderate. Underneath there are two coarser levels (samples Vecon 6/2, 6/3), loamy to loamy sand, decarbonated and acid, with high organic matter content and CEC. Further underneath (sample Vecon 6/4) a change occurs, with a marked decrease in sand content (<10%); in this subacid silty-clay level carbonates are absent, organic matter and CEC are low. The samples beneath this one (Vecon 6/5 to 6/12) present rather uniform characteristics. Texture is clay silty, with sand contents ranging from 1% to 10%. Reaction is overall subalkaline; carbonates are abundant and organic matter content is very low or absent, CEC is low. The deepest sample (Vecon 6/13), instead, is a subalkaline sandy loam, calcareous, with very low CEC.

Micromorphology

Sample Vecon 6/3 presents coarse texture with high porosity (>20%) determined by interconnected chambers and channels. The mineral fraction in the groundmass is greatly masked by abundant, reddish brown organic matter fragments (mostly roots and undecomposed tissue fragments). Remnants of calcareous shells are frequent too.

Underneath, a layer (Sample Vecon 6/4) with fine texture, uniformely distributed throughout, occurs. The groundmass is prevalently silty-calcareous, with a few sand-size quartz relicts. In the top part of this layer organic fragments are still present, while in the bottom part these disappear; ferrugineous nodules and yellow mottles occur in a grey matrix. Microstructure is apedal with very low porosity (total pores <5%); calcareous features are absent.

The previously described layer shades off gradually in a set of fine silty, calcareous levels with a grey colour and pale yellow fine sand laminations. Calcareous material in the matrix is arranged into cryptocrystalline nodules of septaria type (sample Vecon 6/5, Fig. 6e); some of these nodules are cut by thin fissures. At the bottom of these levels, coarser material (fine sand) forms discontinuous laminations with the finer one; the groundmass is greyish with yellowish mottles and fine Fe-Mn granulations, and the calcareous material is arranged in concretionary forms (sample Vecon 6/6, Fig. 6f), as above.

Core AB 6

Stratigraphy

Between 5.00 and 4.30 m the silty and silty clay loam contains many hard and soft carbonatic nodules, often in horizontal laminae (Fig. 2); it is firm and with yellowish and greyish mottles. The overlying silty clay loam (4.30 ÷ 3.80 m) also contains few soft carbonatic

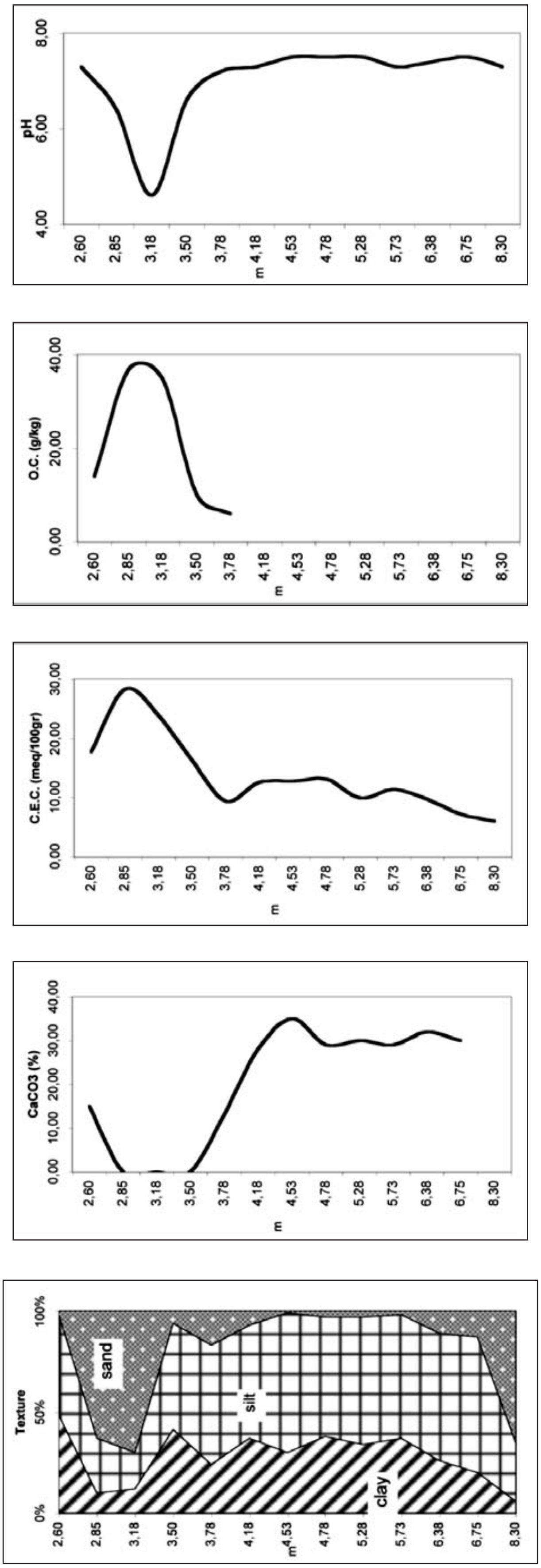

Fig. 4 - Pedological analyses of core Vecon 6

nodules, but the matrix is not carbonatic. Between 3.80 and 3.20 m there are centimetric alternances of silt, silty loam and loam, covered by a 40-cm thick layer of peat, the top 10 cm of which have been dated 585±50 BP (Rome-1205), 640 – 592 cal BP. Over the peat, between 2.80 and 2.30 m, is a clay to silty loam; partly decomposed plant remains (cuticles of canes) are commonly present in the lower 30 cm, while in the upper part some rootlets are present and the remaining organic matter is dispersed or in the form of carbonaceous flecks. See also Tab. 3 for details.

Texture and pedological analyses

The whole section is characterized by a relevant vertical variability, as evidenced by textural differences and by total carbonate and organic matter contents, pH and CEC values (Fig. 5). The upper sample (AB 6/1) is a fine clay silt with a neutral reaction, calcareous, with low CEC and moderate organic matter content. Beneath is a silty clay layer (sample AB 6/2), subacid, with medium CEC and high organic matter content.

The mineral fraction of the peaty layer underneath (sample AB6/3b) is a sandy loam; carbonate is absent, pH is acid, CEC and % of organic matter are high. Sample AB 6/4 is an acid loam, non calcareous, moderately active, with high organic matter content.

The underlying samples (AB 6/5, 6/6, 6/8 and 6/7) are characterized by textures ranging from silty clayey to silty. The pH increases to subalkaline values and therefore carbonate is present with relevant concentrations (up to 40%); instead, organic matter is low (<1%), as well as CEC.

Micromorphology

Sample AB 6/4 (Fig. 6a) presents a moderately developed subangular blocky microstructure; total voids are 20%, with interconnected planes and channels; basic mineral components are rounded quartz grains; organic components are partly decomposed fragments of tissue, which contribute to the grey-blackish colour of the matrix. The fine fraction is fine silty with close porphyric speckled b-fabric and randomly distributed clay domains with a weak birefringence.

The sample underneath (AB 6/5, Fig. 6b) presents similar subangular blocky microstructure, but the soil matrix appears bleached (yellowish to greyish), and ferrugineous features are present in the form of impregnative nodules and dendritic segregations, frequently bordered by clay papules. Textural pedofeatures are present in the form of fine and coarse laminations, with common fragments of terrestrial gasteropod shells.

In sample AB 6/6 there are common $CaCO_3$ crusts and nodules (Fig. 6c). Underneath, sample AB 6/8 (Fig. 6d) shows apedal to very weakly developed subangular blocky microstructure, with total voids <10%; calcitic features predominate in the form of weakly laminated calcareous crusts and channel infillings. Few shell fragments are present.

The groundmass is rather uniform in all samples. The coarse fraction (>5 μm) consists of medium and fine sand, where quartz grains dominate, followed by mica flakes, ferrugineous segregations and organic fragments.

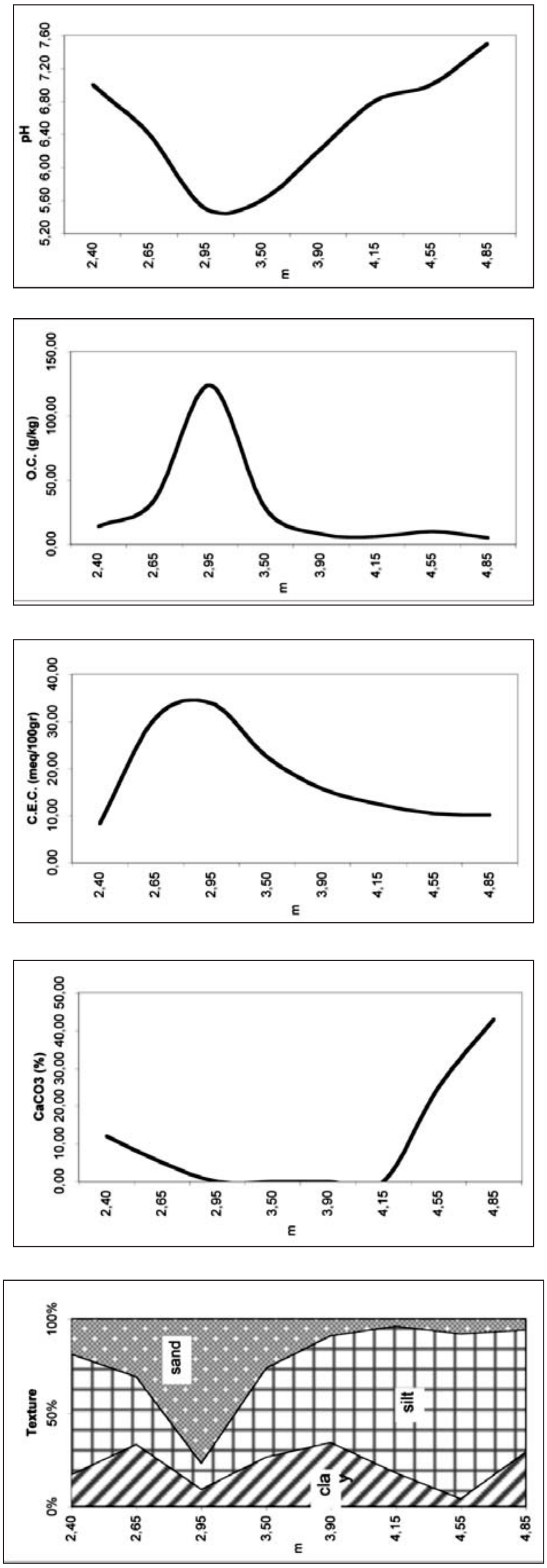

Fig. 5 - Pedological analyses of core AB 6

5. PALYNOLOGICAL ANALYSIS

Core PM1

In this core (Fig. 2, Fig. 7), samples PM 1/16 and from 7 to 1 present an APF (absolute pollen frequency) ranging from 900 to 3,400 grains per gram. Samples PM 1/15 - 8 proved palynologically quite sterile.

In sample PM 1/16, the NAP (herbaceous plant pollen) sharply prevails over the AP (arboreal and shrubby plant pollen). With regard to the AP, *Pinus* pollen is the most abundant; a large part of the grains is attributable to *Pinus sylvestris L.* or to *Pinus mugo* Turra. Other microthermic species are *Picea, Abies* and *Betula. Ephedra fragilis* type is also present. Elements of the oak mixed forest (such as *Quercus, Corylus, Carpinus*) and hygrophilous trees are scarce. Among the NAP, Cyperaceae dominate (37.7%), showing their highest percentage within the PM 1 core; other hygrophilous and hydrophilous plants (*Typha* cf. *latifolia, Potamogeton, Nymphaea*) are present. Gramineae are relatively abundant, followed by Chenopodia-ceae and *Artemisia*.

Samples PM 1/7 and PM 1/6 are characterized by very high percentages of Chenopodiaceae grains, up to 47%. These noticeable values are ac-companied by significant Plumbagina-ceae (cf. *Limonium*) pollen percentages (7.8% and 6.3%). Cyperaceae percentages drop. The AP are less numerous than in sample PM 1/16.

Samples PM 1/5 and PM 1/4 show a sharp increa-

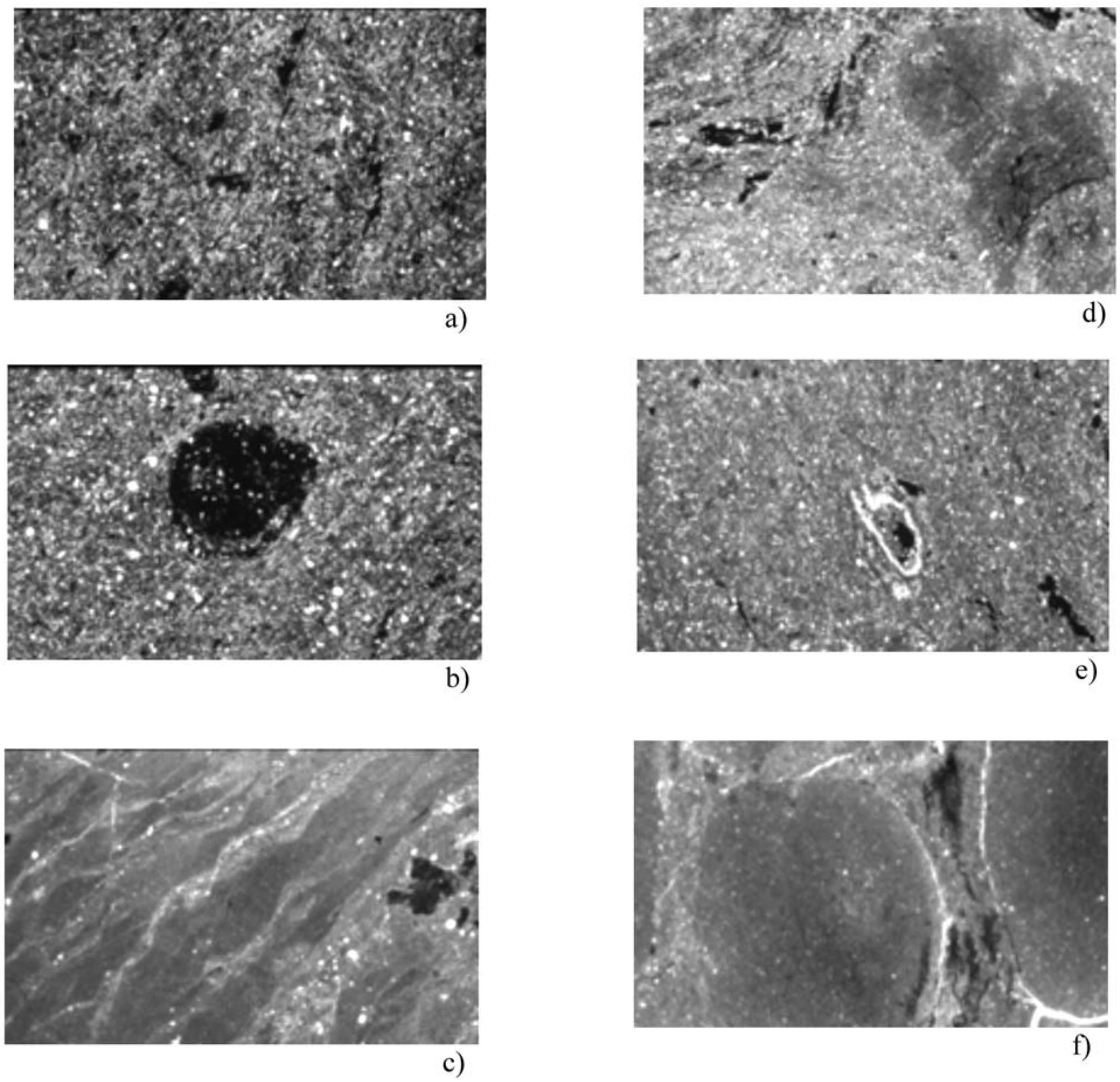

Fig. 6 - Thin sections of selected soil horizons: a) Cg horizon in core AB6 (sample 4, cross polarized light XPL): speckled b-fabric, with traces of subvertical rootlets; b) 2BCg horizon in core AB 6 (sample 5, XPL): iron – manganese nodule with clay rim, in non calcareous, closed-porphyric matrix ; c) 2Ckg1 horizon in core AB 6 (sample 6, plane polarized light PPL): laminated calcareous crusts; d) 2Ckg2 horizon in core AB 6 (sample 8, XPL): laminae with $CaCO_3$ nodules; e) 2Ckg1 horizon in core Vecon 6 (sample 5, XPL): septaria calcite nodule in compact matrix; f) 2Ckg2 horizon in core Vecon 6 (sample 6, PPL): dusty carbonatic nodules.

se of deciduous tree pollen, while *Pinus* pollen has low percentages. *Quercus* becomes the dominant genus among the AP, followed by *Corylus, Carpinus betulus* L. and other elements of the oak mixed forest; these plant curves show their maximum value in sample PM 1/4. *Fagus* curve achieves a maximum in sample PM 1/5. *Alnus* pollen is abundant, particularly in sample PM 1/5, where it is accompanied by *Salix*.

Among the NAP, Chenopodiaceae percentages sharply fall and reach their lowest value (11%) at PM 1/4. Plumbaginaceae curve follows the same trend as Chenopodiaceae. Cyperaceae and aquatic plants are scarce.

In samples PM 1/3 and PM 1/2, the percentage of the oak mixed forest elements slowly decreases, as well as the *Alnus* percentages. *Abies* shows a rise in sample PM 1/2 (8.4%). Among the NAP, Chenopodiaceae record firstly an increase and later a decrease; Cyperaceae are increasingly represented.

In sample PM 1/1, the AP present again an increased percentage. The oak mixed forest seems to be expanded, deciduous *Quercus* and *Corylus* being the best represented trees. *Castanea* achieves its highest percentage. *Alnus* reaches 8%. Among the NAP, Chenopodiaceae are well represented, while Cyperaceae have decreased, though their percentage remains significant.

Core Vecon 6

The most ancient samples Vecon 6/13 and Vecon 6/12 present very low pollen content, especially sample Vecon 6/13 (APF=100) (Fig. 2, Fig. 8).

In sample Vecon 6/12, most of the grains are referable to the NAP, expecially to Cichorioideae, Gramineae and Cyperaceae; *Sparganium/Typha angustifolia* is also present. Among the AP, *Pinus* pollen dominate; the grains are referable to some different species, among which *P. sylvestris* and *P. mugo*. Samples from Vecon 6/11 to Vecon 6/5 result quite palynologically sterile.

Samples Vecon 6/4, 6/3 and 6/1 are rich in grains, APF ranging from 2,300 to 16,600 grains per gram. On the contrary, sample Vecon 6/2 present a low APF (200 grains per gram) and badly preserved grains.

In the latter samples, AP percentage is low, suggesting a very scarce arboreal cover. However, the oak mixed forest plants are represented by different morphotypes, which are expecially numerous in sample Vecon 6/1. *Pinus*

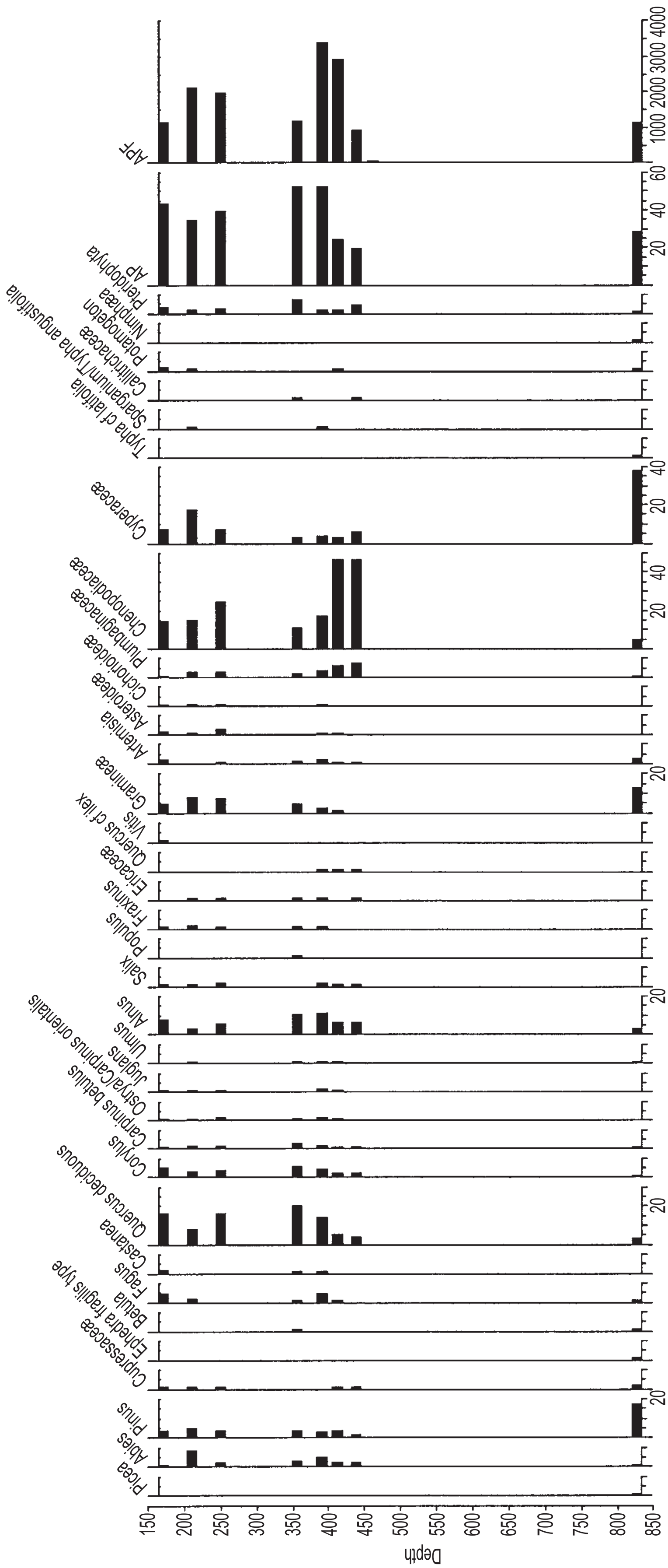

Fig. 7 - Percentage pollen diagram obtained from core PM 1

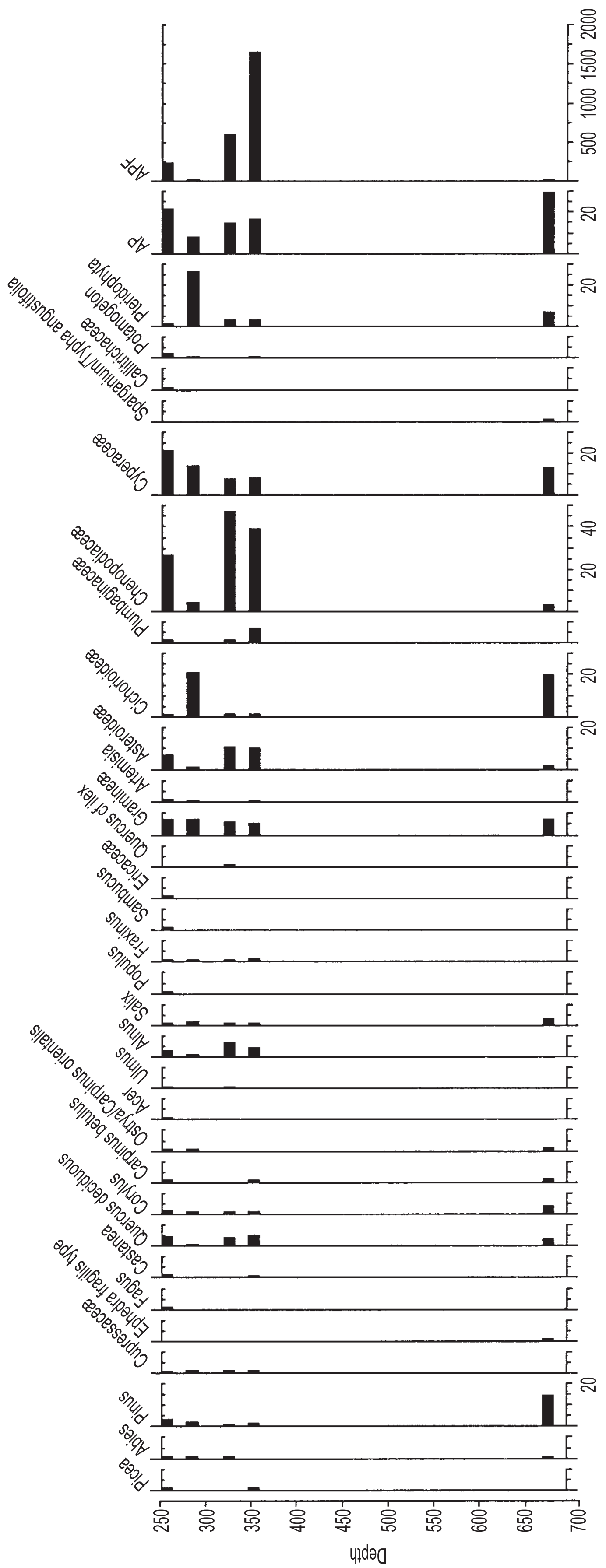

Fig. 8 - Percentage pollen diagram obtained from core Vecon 6

pollen is always present in low percentages. *Alnus* and *Salix*, with the sporadic occurrence of *Populus*, indicate the presence of wet environments, as well as Cyperaceae among the NAP. Cyperaceae percentage increases upwards where aquatic plants, such as Callitrichaceae and *Potamogeton*, are present too. Chenopodiaceae are very abundant throughout the section, with the exception of sample Vecon 6/2. Plumbaginaceae and Chenopodiaceae indicate the occurrence of brackish environments.

Core AB 6

Only samples AB 6/1, 6/2 and 6/3b present a sufficiently high pollen concentration to allow an exhaustive pollen analyses, APF ranging from 600 to 21,100 grains per gram (Fig. 2, Fig. 9). Samples AB 6/8, 6/7, 6/6, 6/5 and 6/4 proved almost sterile.

The AP percentages are very low (7 - 25%). Consequently, we can hypothesise that the arboreal cover was almost totally absent near the sampling site. The arboreal plant grains in the list may have been long- distance transported from mountain (i.e. *Picea, Abies*) and oak mixed forests (i.e. *Quercus, Carpinus, Corylus*).

Among the NAP, Chenopodiaceae pollen is the most abundant (34 - 39.2%). The examined morphotypes are similar to those of the Salicornieae, which grow on salty soils, as well as Plumbaginaceae (cf. *Limonium*) that are also present in the samples. The percentages of these last plants, which are generally underrepresented in the spectra (Heim, 1975), validate the widespread of brackish habitats. Cyperaceae, which indicate moist environments, are well represented. Other records significant for water habitats (*Juncus, Typha* cf. *latifolia, Sparganium/Typha angustifolia*, Callitrichaceae, *Potamogeton*) have been found especially in the lowest sample.

6. SEDIMENTARY ENVIRONMENTS AND FACIES

The characteristics of the lowermost sediments in core PM 1, in the interval 15.00 ÷ 5.30 m, allow their interpretation as fluvial deposits. Overbank fines are dominant; the only evident channel deposits are those of the graded sandy layer between 13.80 and 12.60 m, while the thinner sand bodies most probably represent crevasse splays. The peat on top of the channel body, dated 20,630±240 BP, marks the deactivation of the channel. The presence of several peaty layers within the floodplain sequences indicates the recurrence of events of diminished sedimentation in the flood basins and the formation of marshes with prevalent organic sedimentation. The radiocarbon dates show that they formed during the Last Glacial Maximum. Sediments with similar facies are found in core ER 32, between 8 and 6 m, and in core Vecon 6, between 10 and 6 m, where a channel body is present between 8.70 and 6.90 m, covered by silty loam natural levee. All these deposits belong to the Pleistocene Brenta sedimentary system, which extends at the back of the central sector of the Lagoon of Venice (Fig. 1); they represent the distal fringes of the Bassano megafan, in aggradation until after 14,500 BP. Geochronology is consistent with the palynological data. In fact, the sampled sediments in PM 1 and Vecon 6 (samples PM 1/16, Vecon 6/12), have low AP percentages, but relatively high values of *Pinus* pollen, particularly *Pinus sylvestris / mugo* pollen group; other plants from cold or cold-dry climate (*Picea, Abies, Betula, Ephedra* belonging to the *E. fragilis* pollen type) are also present. Actually, in all the samples of the three cores, the AP percentages are generally low or very low, suggesting that the arboreal cover was always scarce, or almost totally absent, at the sampling sites. Among the NAP, Gramineae and Cyperaceae are abundant; Chenopodiaceae show significant percentages. The results suggest the presence of woodlands characterized by *Picea, Pinus sylvestris* and/or *P. mugo* and *Betula*, trees that today grow in mountain areas; the Quercetum was poorly widespread. Lacustrine or marsh habitats were frequent; xerophilous plants occurred on dry, perhaps sandy, substrates. The spectra recorded are in agreement with those of previous palynological studies carried out on Pleistocene or Preboreal sediments from Veneto, Po plain and from the central Adriatic sea (Bertolani Marchetti, 1967; Paganelli, 1967; Paganelli & Miola, 1991; Accorsi *et al.*, 1996; Bertoldi, 1996; Lowe *et al.*, 1996; Paganelli, 1996a; 1996b).

Between 5.30 and 4.50 m in PM 1, 6.00 and 4.60 m in ER 32, 5.90 and 3.55 m in Vecon 6, 5.0 and 3.80 m in AB 6 there is evidence of post depositional weathering of the alluvial deposits. The most striking features are the abundant $CaCO_3$ nodules and mottling, evident both to macro- and microscopic observation, and the high matrix consolidation, measured on some cores with the pocket penetrometer (Tab. 1, 2, 3). All these elements are indicative of the *caranto* level, as described in previous literature (Gatto & Previatello, 1974; Alberotanza *et al.*, 1977; Tosi, 1994; Serandrei Barbero *et al.*, 2001). Nevertheless, it is to be noted that also the calcic horizons of the silty clay soils in the mainland, developed on the Late Pleistocene alluvial plain in the distal reaches of the Bassano megafan, at the immediate proximity of the lagoon, have similar characteristics (Giandon *et al.*, 2001); regarding the overconsolidation, the B and C horizons of these latter soils are commonly as firm as the caranto, with mean values of 3.0 - 4.0 kg/cm^2 to the pocket penetrometer. The different horizons of the *caranto* level observed in the cores (Fig. 2; Tab. 1, 2, 3) are thus, most likely, pedogenic calcic B and C horizons as well, having the silty clay calcareous sediments of the top of the underlying fluvial sequence as the parent material. The redistribution of carbonates along the profile, due to leaching in the upper horizons and reprecipitation in the lower ones, was associated with alternating oxidizing and reducing conditions, as evidenced by the abundant mottling. The non calcareous 2BCg horizon in core AB 6, between 3.80 and 4.00, probably represent the upper horizon of the original soil profile, depleted of $CaCO_3$ by vertical leaching.

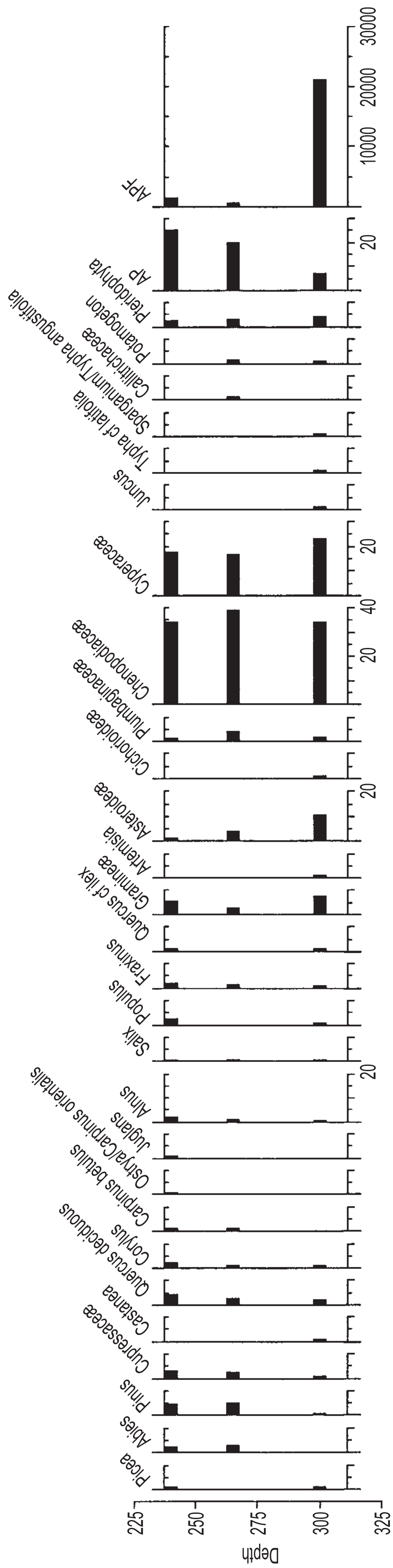

Fig. 9 - Percentage pollen diagram obtained from core AB 6

Tab. 1 - The main characteristics of the sampled interval in core PM 1.

Depth m	Sample #	Texture (USDA)	Structure (and p.p. test)	Munsell Colour	Mottles %, color, dimensions	$CaCO_3$ Nodules	$CaCO_3$ %	O. M. %	Plant remains	Shells	Lower boundary	Facies
1.50–1.80	1	Loamy sand	Laminated, soft (0.50 kg/cm²)	5Y4/1	No	No	8	15	No	No	Abrupt	Lagoon
1.80-1.90	No sample	Loamy sand loam	Massive, soft (0.50 kg/cm²)	5Y4/1	No	No	-	-	No	No	Abrupt	Lagoon
1.90-2.30	2	Sandy (0.50 kg/cm2)	Laminated, soft	5Y4/1	No	No	5	65	No	No	Abrupt	Lagoon
2.30-2.70	3	Silty loam	Laminated, soft (0.50 kg/cm²)	5Y4/1	No	No	5	19	No	Many, broken	Not observed	Lagoon
2.70-3.30	Core gap	-	-	-	-	-	-	-	-	-	-	-
3.30-3.50	No sample	Silty loam	Massive, soft (0.30 kg/cm²)	5Y5/1	15%, 5Y5/3, 5 mm	No	-	-	No	Common	Transitional, 2cm	Lagoon
3.50-3.70	4	Sandy loam	Massive, soft (0.30 kg/cm²)	5Y5/1	No	No	10	26	No	Common	Abrupt	Lagoon
3.70-3.80	No sample	Loamy sand	Massive, soft (0.30 kg/cm²)	5Y5/1	No	No	-	-	No	Many	Abrupt	Lagoon
3.80-4.00	5	Loam	Laminated, soft (0.30 kg/cm²)	5Y5/1	No	No	0	32	No	Common	Abrupt	Lagoon
4.00-4.50	6, 7	Silty clay loam; loam	Massive, soft (0.50 kg/cm²)	N5	No	No	0, 0	27, -	Many carbonaceous flecks	No	Transitional, 4cm	Salt marsh, A soil horizon
4.50-4.70	8	Silty loam	Massive, firm (1.75 kg/cm²)	5Y6/2	25%, 5Y6/1, 2 mm 10%, 5Y6/4, 2 mm	Hard, 2-5 mm, 5%	12	-	Some rootlets, Φ=1mm	No	Transitional 3cm	2BCk soil horizon
4.70-4.85	9	Silty loam	Massive, very firm (3.50 kg/cm²)	2.5Y6/3	20%, 5Y6/1, 3mm 15%, 5Y5/6, 3mm	Hard, 3 mm, 2%	21	-	No	No	Abrupt	2Ck1 soil horizon
4.85-5.30	10	Silty loam	Massive, very firm (3.50 kg/cm²)	2.5Y6/4	10%, N6, 5mm 10%, 2.5Y5/6, 3mm	Hard, 2-7 mm, 8%	30	-	No	No	Transitional, 5cm	2Ck2 soil horizon
5.30-5.50	11	Silty loam	Massive, very firm (3.50 kg/cm²)	5Y7/2	20%, 5Y6/4, 4 mm	No	38	-	No	No	Transitional, 8cm	2C soil horizon
5.50-6.00	15	Silty loam	Laminated, firm (1.20 kg/cm²)	N6	No	No	33	-	No	No	Not observed	Fluvial, overbank
6.00-7.00	Core gap	-	-	-	-	-	-	-	-	-	-	-
7.00-7.50	No sample	Sandy loam	Laminated, firm (1.75 kg/cm²)	N6	No	No	-	-	No	No	Abrupt	Fluvial, crevasse splay
7.50-7.80	16	Silty clay loam	Laminated, firm (1.75 kg/cm²)	5Y7/1	No	No	33	-	No	No	Abrupt	Fluvial, overbank
7.80-8.30	No sample	Sandy loam	Fining upward, soft (0.75 kg/cm²)	5Y7/1	No	No	-	-	No	No	Abrupt	Fluvial, crevasse splay

Tab. 2 - The main characteristics of the sampled interval in core Vecon 6.

Depth m	Sample #	Texture (USDA)	Structure (and p.p. test)	Munsell Colour	Mottles %, color, dimensions	$CaCO_3$ Nodules	$CaCO_3$ %	O. M. %	Plant remains	Shells	Lower boundary	Facies
2.40–2.80	1	Silty clay	Laminated, soft (0.75 kg/cm²)	5Y5/1	No	No	15	24	No	No	Abrupt	Lagoon
2.80-2.90	2	Sandy loam	Massive, soft (0.75 kg/cm²)	5Y4/1	No	No	0	64	No	No	Abrupt	Salt marsh, A soil horizon
2.90-3.45	3	Sandy loam	Massive, soft (0.75 kg/cm²)	5Y3/1	No	No	0	60	Many wood and cane fragments, 1÷3 mm	No	Abrupt	Salt marsh, AC soil horiz.
3.45-3.55	4	Silty clay	Massive, firm (1.25 kg/cm²)	5G5/1	No	No	0	17	Common wood and cane fragments, 1÷3 mm	No	Transitional, 3cm	Salt marsh, Cg soil horiz.
3.55-4.00	5	Silty loam	Massive, soft (0.75 kg/cm²)	5Y6/1	15%, 5Y6/8, 4mm	$CaCO_3$, hard, 3mm, 7%	13	9	No	No	Transitional, 3cm	2Ckg1 soil horizon
4.00-5.20	6,8,7	Silty clay loam	Massive, very firm (4.50 kg/cm²)	5Y7/1	30%, 2.5Y6/8, 15mm 20%, 10GY6/1, 20mm	$CaCO_3$, hard, 3mm, 5%	28, 35, 29	-	No	No	Transitional, 5cm	2Ckg2 soil horizon
5.20-5.90	9,10	Silty clay loam	Massive, very firm (4.50 kg/cm²)	N6	30%, N7, 20mm 15%, 5Y5/6, 10 mm	No	30, 29	-	No	No	Transitional, 10cm	2Cg soil horizon
5.90-6.20	No sample	Silty loam	Laminated, very firm (3.25 kg/cm²)	10Y6/1	No	No	-	-	No	No	Abrupt	Fluvial, e natural leve
6.20-6.90	11,12	Silty loam	Laminated, firm (1.75 kg/cm²)	10Y6/1	No	No	32,30	-	No	No	Abrupt	Fluvial, natural levee
6.90-8.70	13	Sandy loam	Laminated, soft	10Y6/1	No	No	-	-	No	No	Abrupt	Fluvial, channel

Tab. 3 - The main characteristics of the sampled interval in core AB 6.

Depth m	Sample #	Texture (USDA)	Structure (and p.p. test)	Munsell Colour	Mottles %, color, dimensions	$CaCO_3$ Nodules	$CaCO_3$ %	O. M. %	Plant remains	Shells	Lower boundary	Facies
2.30–2.50	1	Silty loam	Laminated	10Y5/1	No	No	12	24	Common carbonaceous flecks	No	Abrupt	Salt marsh
2.50-2.80	2	Clay loam	Laminated	10G4/1	No	No	5	59	Leaves of canes	No	Abrupt	Salt marsh
2.80-3.20	3b	Peat	Fibrous	10YR3/1	No	No	0	213	Peat	No	Transitional, 3cm	Salt marsh, O soil horizon
3.20-3.80	4	Loam	Laminated	5GY4/1	No	No	0	48	No	No	Abrupt	Cg soil horizon
3.80-4.00	5	Silty clay loam	Massive, firm	10Y5/1	15%, 5Y6/8, 4mm	Soft, 3mm, 3%	0	14	No	No	Not observed	2BCg soil horizon
4.00-4.30	6	Silty loam	Massive, firm	2.5Y6/2	25%, 5Y6/1, 3mm	Hard and soft, 3mm, 8%	0	11	No	No	Abrupt	2Ckg1 soil horizon
4.30-5.00	8,7	Silt, silty clay loam	Massive, firm	5Y6/1	30%, 5Y6/4, 5mm	Hard, 5mm, 4%	25,43	17,8	No	No	Not observed	2Ckg2 soil horizon

In order to estimate the time-length required for the development of these soil horizons, some considerations can be made. The deactivation of the Bassano megafan took place after 14,500 BP, probably before the onset of the Holocene, when the sea level was still more than 50 m below the present day one. From that moment onwards, sedimentation in the Bassano megafan stopped, and soil forming processes became dominant. The early and Middle Holocene mild environmental situation, with dense forest cover, involved optimal conditions for soil formation. At the same time, the continuous relative sea level rise brought about a progressive submersion of the alluvial plain that occupied the northern Adriatic basin during the last glacial sea lowstand. By 6000 BP, the lagoon of Venice had already started forming, which implies that the more distal fringes of the Bassano megafan, were submerged and pedogenesis had already ceased. All this allows a time - slice of 4000 to 8000 years for soil formation on this stretch of alluvial plain. The study area, in a more landward position, was still emerging at that time, and most probably all along the Middle to Late Holocene. In our research, no evidence has been gathered about when the study area evolved to paralic, brackish conditions. An indication is provided by a recent investigation carried out in the Ca' Tron area, on the northern lagoon shores about 15 km to the east of the study area, nearby the old mouth of the Sile River in the lagoon. Here, the maximum transgression on the Late Pleistocene alluvial plain has been dated to post roman times (Bondesan & Mozzi, 2002). If also in the study area the first lagoonal deposits were post roman, this would allow some other 4000 years to pedogenesis. In this framework, the studied *caranto* palaeosol may have formed in 8000 to 12,000 years.

The palynological data clearly show that the APF falls to very low values in these weathered horizons. The drastic decrease of APF is, here, probably due to the alternating oxidative-reductive conditions and leaching during the soil formation. Indeed, oxidation and subsequent wetting and drying cause damage of the exine (Horowitz, 1992). In the samples collected in the layers above the *caranto*, a decrease of the microthermic elements and an increase of the deciduous broadleaf trees is recorded. This trend may be considered an index of climatic improvement. Quercetum *s.l.* is well represented and *Quercus* appears to be the leader tree; it reaches the widest expansion in samples Vecon 6/4-3 and PM 1/5-4. The significant percentages of hygrophilous and hydrophilous plants, particularly *Alnus*, underline the presence of alluvial environments and the occurrence of water bodies. The consistency of these data with the literature about the Holocene (Bertolani Marchetti, 1967; Accorsi *et al*., 1989; 1996; Bertoldi, 1996; Lowe *et al.*, 1996; Paganelli, 1996a), indicate that the deposits formed in the Late Holocene. This is coherent with the probable post roman age of the whole sequence, and with the medieval ages of the radiocarbon dated organic horizons intercalated in the sediments (Fig. 2). As regards the vegetation with edaphic determinism, among the NAP the alternate prevalence of Cyperaceae and plants of fresh water habitats (T*ypha* cf. *latifolia, Sparganium/Typha angustifolia, Potamogeton*, Callitrichaceae) and halophytes (Chenopodiaceae and Plumbaginaceae) attests the presence of brackish environments, with episodes of varying salinity in the water and soils. This may be due to the alternating prevalence of sea water vs. fluvial fresh-water of rivers flowing into the lagoon. From a palynological point of view, the results are consistent with those of the previous literature. Particularly, the presence of sterile layers, which separate a lower group of sediments, attributed to a continental, fluvial environment, from an upper group with evident brackish characteristics, was observed by Bertolani Marchetti (1967).

The sediments that lie unconformably on top of the caranto (above the dotted line n. 16 in Fig. 2) were deposited in a paralic context, typical of the landward sector of the lagoon. Here, tidal processes interacted with fluvial activity, in a metastable equilibrium which could rapidly change in space and time. Subtidal flats, intertidal flats and tidal channels could alternate laterally (in space) or vertically (in the stratigraphy) with vegetated salt marshes and small deltas, the latter related to the delivery of fluvial sediments into the lagoon. Such geomorphic and sedimentary model applies well to the complex stratigraphic record of the studied cores (Fig. 2; Tab. 1, 2, 3). Considering the whole NE – SW transect of Fig. 2, the lowermost lagoonal deposits are found at depths comprised between 1 and 2.5 m below mean sea level.

In the observed lagoonal deposits there is a prevalence of subtidal / intertidal mud flat facies, with salt marshes (Tab. 1, 2, 3); only in core ER 32, at the depth of ca. 1.50 m below mean sea level, there is evidence of a sandy tidal channel (Fig. 2). It is, furthermore, possible to recognize two main sedimentary events (separated by the dash line n. 15 in Fig. 2). The sediments of the first one are altogether less than 1 m thick, and are capped by the organic horizons radiocarbon dated to the Middle Ages. These latter are pedogenetic A and O horizons, underlain by gley AC and C horizons, which constitute a weakly developed, subacid soil. The activity of soil forming processes implies the existence of a subaerial topographic surface, while the presence of near surface gley horizons indicates a high underground water table. This is consistent with the salt marsh environment shown by the pollen record. In fact, salt marshes lie immediately above the average high tide level, and are only seldom submerged during maximum high tides (Albani *et al*., 1984; Castiglioni, 1986). In Vecon 6, where the A and AC horizons are well developed, the micropedological analysis of the underlying Cg horizon allowed for the recognition of yellowish mottles and ferruginous nodules, which are indicative of occasional conditions above the water table. The greyish – greenish colour of the A horizon in PM 1 indicates a badly drained situation with permanent reducing conditions, and the same applies to the Cg horizons under the O horizons in core ER 32 and AB 6. The lateral variations from A horizons, with partly mineralized organic matter, and O horizons, made of indecomposed organic matter, can be interpreted as a hydro-pedosequence, where the former occupy the higher, relatively better drained topographic positions, and the latter the depressions. The average high tide level most probably used to cut the soil profile in cores ER 32 and AB 6 at the lower boundary of the O horizons. Therefore, the 1055 – 954 cal BP average high tide level is now ca. 2 m below the present mean sea level (core ER 32), while the one of 640

– 592 cal BP is 0.8 m below mean sea level (core AB 6). Taking the 0.3 m a.s.l. high tide average height of the present day lagoon of Venice (Albani *et al*., 1984; Castiglioni, 1986) as a reference, the mean sea level was respectively 2.3 and 1.1 m below the present one. This is a consequence of the relative sea level rise during the last centuries, deriving from the sum of the following phenomena: eustatic sea level rise, natural subsidence, man induced subsidence (since the second half of the 20th century).

The second event buried these weakly developed palaeosols in Late Medieval and modern times. On top are the artificial landfills related to the land reclamation at the lagoon fringes during the 20th century.

7. CONCLUSIONS

The study of the sedimentary, pedological and palinological features of the cores, has enabled to recognize the sequence of events occurred in the Late Quaternary at the landward margin of the central sector of the lagoon of Venice.

During the Last Glacial Maximum, the deposition of fluvial sediments took place in the study area, mainly as overbank fines with only limited sandy channel bodies. These deposits belong to the Pleistocene Brenta sedimentary system, the Bassano megafan, which corresponds to a large stretch of the central Veneto plain between the Alpine piedmont and the lagoon of Venice. Arboreal vegetation was scant, and mainly consisted of microthermic elements.

After the deactivation of this megafan, probably at the Pleistocene – Holocene transition, sedimentation in the area stopped and soil forming processes became dominant, acting on the calcareous, silty clay parent material of fluvial origin, probably for 8000 – 12,000 years. Processes of redistribution of carbonates along the soil profile led to the formation of calcic B and C horizons, characterized by the accumulation of $CaCO_3$ in nodules and crusts; just in one core (AB 6), the B horizon depleted of the carbonates by vertical leaching, which is normally on top of the calcic horizons, has been preserved. Alternating oxidizing and reducing conditions, related to the fluctuation of the underground watertable, brought about greyish and yellowish mottling, and alteration of the pollen grains originally present in the sediment. This palaeosol corresponds to the so-called *caranto* level *auctorum*. It is in physical continuity with the calcisols of the stretch of plain at the back of the lagoon, belonging to the Bassano megafan, and have similar pedogenetic features. It represents a major uncomformity in the stratigraphy of the lagoon area.

The first lagoonal deposits in the study area are, most probably, of post roman age. They lie directly on top of the *caranto* palaeosol at depths comprised between 1 and 3 m below mean sea level. Pollen analysis shows that salt marshes with halophytes formed in the higher parts of the tidal flats, while other areas evolved into more open lagoon environments, probably with recurrent input of fluvial sediments and water. Less than 1 m of sediments were deposited during a first sedimentary event. Its upper boundary corresponds to an unconformity of low rank, indicated by the presence of a slightly pedogenized level which formed in medieval times. The radiocarbon dating of organic O horizons of this soil, developed in a salt marsh environment, provides a chronostratigraphic support to the determination of the recent relative sea level rise. This is estimated to have been 2.3 m since 1055 – 954 cal BP to present day in Porto Marghera, EniRisorse area, and 1.1 m since 640 – 592 cal BP to present day in Porto Marghera - Fusina, ABIBES area. The sediments of the following, last sedimentary event, spanning since the Middle Ages to modern times, reach a maximum thickness of ca. 2 m.

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