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PALAEOHYDROGRAPHY AND EARLY SETTLEMENTS IN PADUA (ITALY)

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ABSTRACT: Mozzi P. *et al*., Palaeohydrography and early settlements in Padua (Italy). (IT ISSN 0394-3356)
This paper concerns the palaeohydrographic and geomorphological evolution of the alluvial plain around Padua during the last millennia, and the relative implications for the development of early settlements in the present urban area.
The first archaeological evidences in Padua date to the late Bronze Age (1400–1000 BC). Since the early Iron Age (9th century BC) the settlement experienced a progressive expansion and in the 6th century BC it was already an important urban centre. In the 2nd century BC Padua became a Roman *municipium*, being one of the most important cities in NE Italy. Latin historians wrote that it was crossed by a large river, called the *Meduacus*, which was identified with the Brenta River in previous archaeological studies. The Brenta River is an important Alpine river that now flows about 5 km NE of Padua. Since the Middle Ages the Bacchiglione River, a minor course partly fed by ground-water, has been flowing within the city centre along two characteristic meanders; it was artificially diverted only in the first half of the 20th century in order to protect the city from floodings.
As the recent urban expansion limits the possibility to investigate the urban area with remote sensing and field survey, the investigation focuses on the alluvial plain at the western outskirts of Padua. A 70 km^2 area was analysed through the integrated use of vertical and oblique aerial photographs, satellite images, digital terrain models (DTM), field survey and corings.
The most ancient Holocene channel belt recognized in the study area is the Mestrino-Rubano (MR) one, which incised the alluvial plain formed during the Late Glacial Maximum (LGM). It was formed by the Brenta River between the Lateglacial and 6300 cal BP. A palaeochannel named "La Storta" was recognized for a stretch of 13 km; it probably was the last active river bed in the MR channel belt, between 8400 and 6300 cal BP.
The present Bacchiglione River follows another, more recent Brenta River channel belt, named Veggiano-Selvazzano (VS) channel belt. The meanders in the city centre of Padua most probably belong to this channel belt. Chronostratigraphic data indicate that the VS channel belt was active in the 2nd millennium BC. This implies that Padua was probably crossed by the Brenta River during the Bronze Age. A single radiocarbon dating suggests that the VS Brenta River was active also during the 2nd–5th century AD. Such indication brings about the possibility that the Brenta River may have been flowing through the city also during the Iron Age and in Roman times, and that the Bacchiglione River established its present course in early Medieval times. This hypothesis has important implications for the reconstruction of the topography of ancient Padua, but it is based on a weak chronostratigraphy, which should be better investigated in the future. It contradicts geoarchaeological observations, which indicate no evidences of the sedimentary activity of such a large river in the city centre later than the end of the 2nd millennium BC. Moreover, previous geomorphological investigations show that the Brenta River was following the present direction since the beginning of the 1st millennium BC, which means that in the Iron Age and in Roman times the river would flow several kilometres east of the city.

RIASSUNTO: Mozzi P. et al., Paleoidrografia e insediamenti antichi a Padova (Italia). *(IT ISSN 0394-3356)*
Nella pianura veneta il popolamento umano è stato molto intenso a partire dall'Olocene medio e l'evoluzione geomorfologica ha spesso condizionato le modalità insediative. In questo studio si tenta di definire l'assetto paleoidrografico relativo ai primi insediamenti e allo sviluppo urbano antico della città di Padova. La recente espansione edilizia limita fortemente la possibilità di attuare tecniche di telerilevamento e di rilevamento di campagna. Le ricerche si sono quindi concentrate alla periferia occidentale di Padova e nei territori contermini, analizzando i tratti di pianura attivi durante l'Olocene medio e superiore.
Le prime tracce di frequentazione a Padova si riferiscono all'età del Bronzo recente-finale (XIV-X secolo a.C.). Dalla prima età del Ferro (IX secolo a.C.) Padova fu sede di un importante insediamento, che divenne compiutamente urbano attorno al VI secolo a.C. In epoca romana Padova era uno dei maggiori centri dell'Italia nord-orientale; nel II secolo a.C. assunse il titolo di municipium*. La città romana era attraversata da un ampio corso d'acqua denominato Meduacus dagli autori latini; negli studi archeologici questo fiume è associato al Brenta, che attualmente scorre alcuni chilometri a oriente della città (Fig.1). Fin dal Medioevo Padova è stata attraversata dal fiume Bacchiglione, un corso d'acqua minore alimentato in parte da risorgive, che fu deviato artificialmente al di fuori del centro nella prima metà del XX secolo per limitare il rischio di inondazioni. Il Bacchiglione nel centro della città segue due ampi meandri, con ogni evidenza ereditati da un precedente percorso del Brenta.*
Tramite l'uso combinato di fotografie aeree zenitali e oblique, immagini satellitari, modelli digitali del terreno (DTM), rilevamento sul terreno e carotaggi stratigrafici si è analizzata un'area di 70 km^2 situata a ovest del centro storico (Fig. 2). Nella ricerca sono stati effettuati 17 nuovi carotaggi con una sonda manuale fino ad una profondità di 8,5 m lungo transetti che hanno consentito di ricostruire sezioni stratigrafiche e raccogliere campioni poi datati con il radiocarbonio (Figg. 3, 4, 5, 6, 8). Questi dati, assieme alle indagini stratigrafiche effettuate nel 1992 in una cava presso Santa Maria di Veggiano (Fig. 7), a un nuovo carotaggio meccanico e ad altre informazioni geognostiche precedenti, hanno permesso di ricostruire l'assetto sedimentario del sottosuolo. Per definire la cronologia delle diverse direttrici fluviali sono state utilizzate datazioni al radiocarbonio su sedimenti organici e legni, oltre che il materiale archeologico eventualmente inglobato nei sedimenti.
Nell'area di studio sono state riconosciute due fasce di canali di età olocenica, attribuibili al Fiume Brenta sulla base delle dimensioni dei paleoalvei, della geometria dei corpi sedimentari e della composizione petrografica delle ghiaie (Fig. 2). Nei settori di pianura interposti fra le direttrici oloceniche affiorano i sedimenti alluvionali LGM e la superficie è caratterizzata da suoli con orizzonti calcici ben sviluppati, come già documentato in tutta la pianura veneto-friulana.
La fascia di canali più antica, chiamata Mestrino-Rubano (MR), è incisa nei depositi del LGM e ha un'età compresa tra il Tardoglaciale e 6300 cal BP; ha una larghezza media di alcuni chilometri e segue un andamento circa WNW-ESE. All'interno di questa fascia di canali è presente un paleoalveo particolarmente ben conservato, che si segue con continuità per oltre 13 km, noto come il paleoalveo de "La Storta": è probabile che questo sia l'ultimo percorso lungo questa direttrice, attivo tra 8400 e 6300 cal BP.
*L'altra fascia di canali è attualmente seguita dal Fiume Bacchiglione ed è in parte mascherata dai sedimenti di quest'ultimo corso d'acqua. Si tratta della cosiddetta fascia di canali di Veggiano-Selvazzano (VS), che era attiva nel II millennio a.C. Una sin*gola datazione su

un frammento di ramo a Santa Maria di Veggiano indica la possibilità che la deposizione delle ghiaie all'interno dell'alveo sia avvenuta anche tra il II-V secolo d.C.
Si dimostra dunque che il Brenta scorreva lungo la direttrice MR nell'Olocene iniziale e medio; invece la fascia di paleoalvei VS, formata anche essa dal Brenta, era attiva nell'Olocene finale e giungeva fino al centro della città anche durante l'età del Bronzo; probabilmente fu questa direttrice a formare i meandri che tutt'oggi caratterizzano il centro di Padova. L'eventuale passaggio del Brenta per il centro cittadino nel II-V secolo d.C. è suggerito dall'attivazione dell'alveo ghiaioso a Santa Maria di Veggiano, ma questa indicazione si basa su un'unica datazione al radiocarbonio ed è, pertanto, piuttosto debole e controversa. Infatti, l'ipotesi di un corso del Brenta per Padova nell'età del Ferro e in periodo romano non pare supportata dai dati geoarcheologici, che testimoniano una attività di sedimentazione fluviale in città piuttosto limitata, incompatibile con la dinamica di un fiume alpino. Inoltre, le ricerche geomorfologiche condotte precedentemente poco a nord e a est di Padova sembrano indicare che il Brenta scorreva lungo la sua attuale direzione già dall'inizio del I millennio a.C.

Keywords: palaeohydrography, channel belt, geoarchaeology, alluvial plain, Venetian Plain.

Parole chiave: paleoidrografia, fascia di canali, geoarcheologia, pianura alluvionale, pianura veneta.

1. INTRODUCTION

The geoarchaeological investigation of alluvial environments has received increasing attention in the last two decades (Kidder, 1996; Brown, 1997; 2008; Beach & Luzzadder-Beach, 2008). In fact, the majority of alluvial plains in the world have been inhabited since early prehistory and important ancient civilizations were rooted in floodplains. The reasons for this are obviously related to the large availability of natural resources for basic human needs, such as drinking water, hunting and fishing grounds, wild crops, pastures and fertile land which, even in dry regions, can be easily irrigated. Most important for the development of complex societies has been the role of rivers as local, regional and super-regional commercial routes.

Alluvial plains are not only attracting areas for human activities, but, in a geomorphic perspective, they are also characterized by the prevalence of depositional processes vs. erosional ones. The archaeological record is often preserved within alluvial sedimentary sequences, which also contain palaeoenvironmental proxies, such as pollens, seeds, wood, microfossils and faunal remains. The interfingering between archaeological and sedimentary archives provides high potentialities for understanding how human activities have been interacting with the dynamics of the natural environment, in terms of both opportunistic use of resources and mitigation of environmental constraints.

Living in alluvial plains may as well be problematic. Riverine settlements are subject to overbank flooding, levee breaches, and banks instability related to lateral channel migration. Surface water stagnation may severely limit agriculture and foster diseases such as malaria and cholera. When and where societal organization allowed it, huge efforts were carried out for the protection of settlements and fields from floods and for draining water-logged soils. The impact of these actions on the landscape is comparable to that associated with the opposite strive for irrigating dry lands on river terraces and interfluves. The network of dykes, canals and ditches built for water management "in the vast majority of, if not all, contemporary floodplains" makes them "in part artifacts and as such indicators of the impact of humans on the environment" (Brown, 1997, p.1).

The Venetian Plain was inhabited since Prehistory. Focusing just on postglacial cultures, the transition from the Mesolithic to Neolithic, Chalcolithic and the Bronze Age is well documented (Aspes, 1984). Already in the Iron Age, several settlements in lowland Veneto became urban centres (Chieco Bianchi & Tombolani, 1988), which were progressively subject to Roman influence since the 3rd century BC and later became incorporated in the Roman Empire. In the 1st century BC the Roman geographer Strabo describing the area populated by the Venetian people wrote that "some of their cities stand in the midst of water like islands, others are only partially surrounded. Such as lie above the marshes in the interior are situated on rivers navigable for a surprising distance" (*Geographia*, V, 1, 5), evidencing the strong relationships existing between surface water and settlements.

The origins of Padua as a major settlement trace back to the early Iron Age (De Min *et al*., 2005), with some evidence of Bronze Age frequentation. It is a fluvial city, presently crossed by the small Bacchiglione River but only few kilometres away from a larger river of Alpine origin, the Brenta River, which has been fundamental for the upbuilding of the alluvial plain (Fig. 1). Any understanding of the role played by the environment in the foundation and development of the city must rely on the recognition of the palaeohydrographic setting and its evolution.

Since early investigations, it was evident that the topography of the pre-Roman and Roman city was moulded by the geometry of the two large meanders which cross it (Gloria, 1876; Gasparotto, 1951; Bosio, 1981a, b). Recent geoarchaeological studies have addressed the problem of reconstructing the ancient hydrography in the city centre, mainly through geoarchaeological observations (Balista & Rinaldi, 2005). Though providing interesting and relevant data, the spot nature of these investigations, carried out in a limited number of rescue archaeological excavations, limits palaeohydrographic reconstruction. Moreover, the growing of the city since Protohistory to Medieval and Modern times has largely masked and cancelled the original fluvial landforms (Ferrarese *et al*., 2006), and the present urban setting hinders the execution of corings and digging of pits for the analysis of the fluvial sedimentary record.

In order to overcome these problems, this investigation focuses on the alluvial plain that extends at the western outskirts of Padua, where agricultural areas allow for more effective geomorphological and geological surveys. The new data presented here provide evidence on the Holocene evolution of the fluvial network upstream of the city and help in detecting the relations between rivers and early settlements.

2. GEOMORPHOLOGICAL SETTING

2.1. The Brenta River alluvial system

Padua lies in the distal sector of the alluvial system of the Brenta River. This river has a large mountain catchment, which extends for about 1800 km^2 in the Eastern Southern Alps and comprises part of the Dolomites. Average water discharge is about 70 m^3/s at the exit of the mountain catchment at Bassano del Grappa. The river presently flows some kilometres east of Padua and debouches in the Adriatic Sea.

In the last 20 ka several geomorphic changes occurred in the Brenta sedimentary system, mainly in response to changing climatic and environmental conditions (MOZZI, 2005; FONTANA *et al*., 2008). A major aggradation phase took place during the Last Glacial Maximum (LGM), when the sedimentary discharge supplied by the glacier hosted in the Brenta Alpine valley brought to the formation of an alluvial megafan in the plain; the Brenta megafan lies between the Sile River to the east and the Astico River to the west, and extends to the present coastal area of Venice (MOZZI, 2005). In the apical sector, from the piedmont down to the spring belt, the LGM deposits consist of tens of meters of thick amalgamated gravels. In its distal portion, the LGM alluvial sequence is formed by 15–20 m of fine-dominated deposits, with the intercalation of sandy channel bodies that generally have a thickness of 1–2 m (BONDESAN *et al*., 2008); in the centre of Padua medium sands are the coarsest LGM sediments (ILICETO *et al*., 2001).

At the end of LGM, around 17,500 cal BP, fan-head incision started in the Brenta megafan in response to glacial decay (MOZZI, 2005). This erosive tendency was common to the other megafans of the Venetian-Friulian Plain, namely Tagliamento and Piave megafans, which developed important fluvial incisions between the end of LGM and early Holocene (FONTANA, 2006; FONTANA *et al*., 2008, in press; CARTON *et al*., 2009). Aggradation occurred in these incisions during middle and late Holocene, leading them to fill-up almost totally and obscuring their topographic evidence. Soil formation took place in the interfluves between the incised valleys; the typical calcic soil that developed on fine-grained parent material in the distal reaches of the LGM megafan, known as “caranto”, is a stratigraphic marker of the Pleistocene–Holocene boundary, which can be traced throughout the Venetian-Friulian Plain (MOZZI *et al*., 2003; FONTANA *et al*., 2008).

In the apical portion of the Brenta megafan, post-glacial river downcutting resulted in the formation of 20 m high fluvial scarps. These scarps disappear about 10 km upstream of Padua, where the incisions are completely filled by Holocene deposits. In the centre of Padua (Cappella degli Scrovegni, see Fig. 2 for location), the sedimentary fill of the incised valley consists of a ca. 9 m thick, fining upward sequence, cut in LGM deposits (ILICETO *et al*., 2001). This valley fill shows a transition from coarse-grained sand with common 1–3 cm pebbles to medium-grained sands and sandy silt; a soil

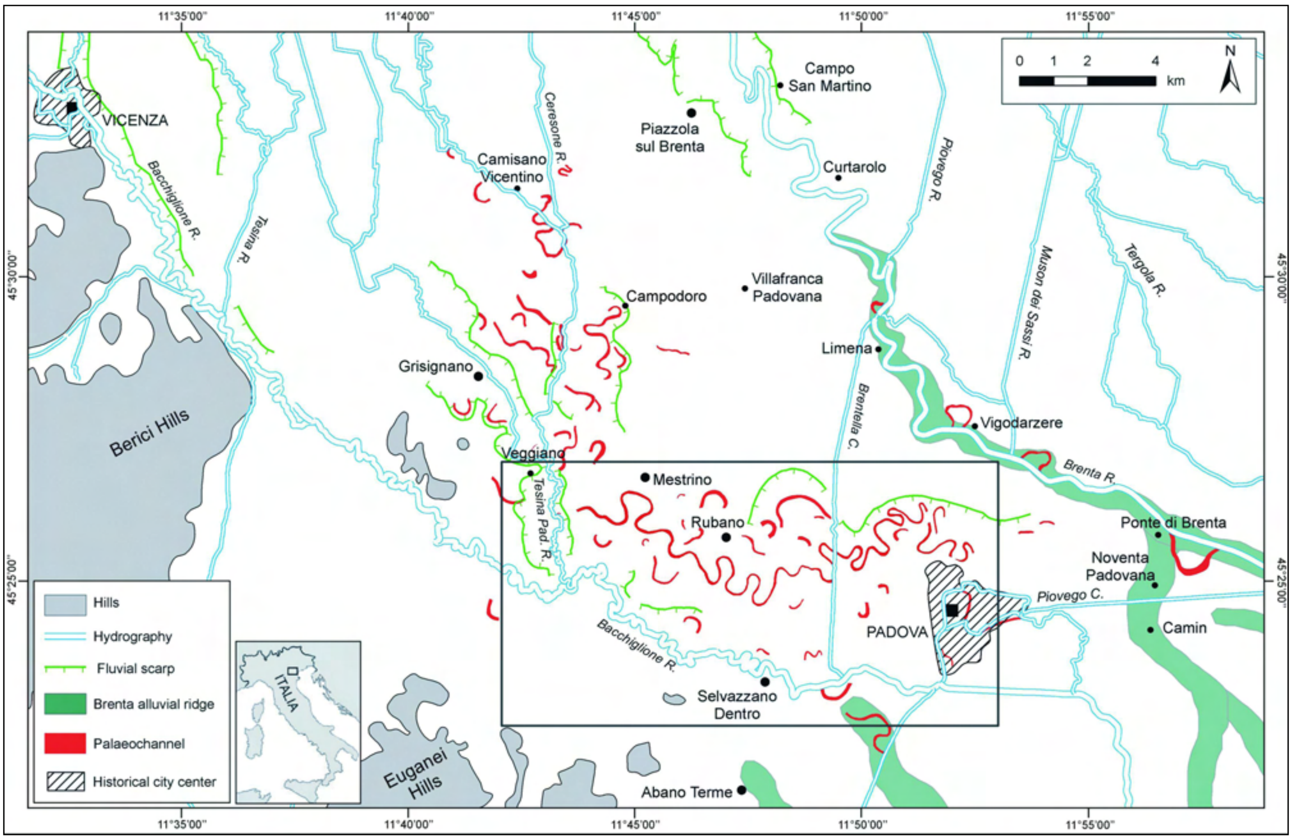


Fig. 1 - Study area location map (geomorphology outside of the study area after CASTIGLIONI, 1982a; CASTIGLIONI *et al*., 1987; MURST, 1997; FERRARESE *et al*., 2006; BONDESAN *et al*., 2010).

Inquadramento dell’area di studio (elementi geomorfologici fuori dall’area di studio da CASTIGLIONI, 1982a; CASTIGLIONI et al., *1987; MURST, 1997; FERRARESE* et al., *2006; BONDESAN* et al., *2010).*

with a fairly well developed calcic B horizon closes the sequence. At the surface, abandoned Brenta meandering channels have been recognized using aerial photographs in the alluvial plain west of Padua. They are likely to continue in the urban area (Castiglioni, 1982a, b; Baggio *et al*., 1992; Balista, 2004; Balista & Rinaldi, 2005), where they are masked by buildings, roads and other infrastructures. Radiocarbon datings carried out on the infilling of some abandoned channels NW of Padua indicate an early to middle Holocene deactivation (Castiglioni *et al*., 1987). One of these palaeochannels, known as "La Storta" palaoechannel (Castiglioni, 1982a, b; Castiglioni *et al*., 1987), was been mapped using remote sensing, high resolution DTMs and 19th century topographic maps for a distance of more than 10 km (Ferrarese *et al*., 2006).

In the alluvial plain south of Padua, several alluvial ridges are present with a NW–SE direction, indicating vertical aggradation of the alluvial plain (Favero, 1994, Bondesan *et al*., 2010; Murst, 1997). The geology of the plain portion that falls within 1:50,000 map 147 Monselice has been recently surveyed as part of CARG - Geological CARtography of Italy (Cucato & Sedea, in press). The survey indicates that middle Holocene aggradation of Brenta alluvial deposits occurred on top of the pedogenized LGM alluvial surface, on the interfluve that bounds to the south the post-glacial incision of Padua. The caranto palaeosoil at the top of the LGM sequence is usually well preserved at depth of 1 - 4 m from surface. Radiocarbon datings point to a time of deposition of this unit approximately comprised between 6500 and 4500 cal BP.

Radiocarbon datings of tree trunks embedded in gravelly channel deposits upstream of Piazzola sul Brenta indicate that in the 1st millenium BC the Brenta River was flowing along the same direction as present (Pellegrini *et al*., 1984). The Brenta River now follows an approximately NW–SE direction until Ponte di Brenta, ca. 5 km NE of Padua (Fig. 1). Downstream of Ponte di Brenta, the river formed several alluvial ridges which slope SE, with ages comprised between the beginning of the 1st millennium BC and the Middle Ages (Castiglioni *et al*., 1987; Mozzi *et al*., 2004; Bondesan *et al*. 2008).

2.2. The Bacchiglione River alluvial system

The Bacchiglione River has been flowing through Padua since the Middle Ages; only in the 20th century it was artificially diverted out of the city in order to prevent floodings. In the 1950s, long tracts of the river in the centre of Padua were filled and covered by roads. The Bacchiglione River about 15 km upstream of Padua has an average discharge of 27 m^3/s (Mozzi, 2008); about one third of the discharge is supplied by groundwater-fed springs located in the plain about 30 km NE of Padua. These springs are fed by the groundwater table which crops out along the so-called spring belt; this latter has a width of 5-10 km and marks, almost continuously, the transition between the gravelly permeable piedmont plain and the clayey-silty-sandy impermeable lower plain. The main tributary of the Bacchiglione River is the Astico River, which has a mountain catchment of 623 km^2 in the Venetian Prealps; the junction is located about 25 km upstream of Padua (the last reach of the Astico River before the junction is called Tesina River) (Fig. 1).

Due to its relatively low discharge and sedimentary load, the geomorphic activity of the Bacchiglione River has been much lower than the Brenta River (Castiglioni, 1992). The alluvial plain of the Bacchiglione

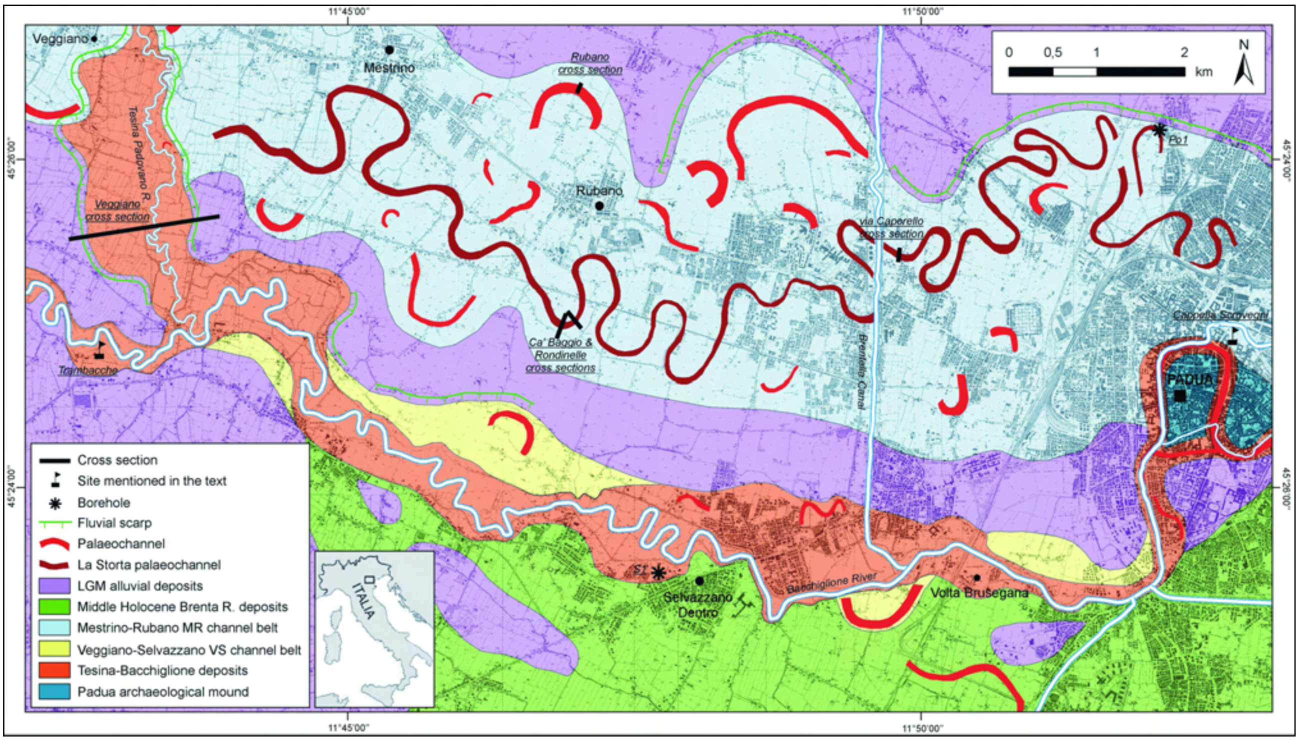


Fig. 2 - Geomorphological sketch of the study area with the location of cross sections, boreholes and sites mentioned in the text.

Schema geomorfologico dell'area di studio con l'ubicazione delle sezioni, dei sondaggi e dei siti citati nel testo.

River near Padua consists of a narrow belt, with an average width of less than 1 km (ARPAV, 2005; NINFO, 2003; MOZZI, 2008). At Trambacche, about 9 km upstream of Padua (Fig. 2), sediments attributed to the Bacchiglione River were cored in 2 boreholes to the depth of 8 m from surface (BIANCHIN CITTON, 1993). The lowest unit (8.0–3.5 m from surface, base unknown) consists of two main sequences where sandy channel bars are covered by a residual channel fill (lower sequence) and natural levees (upper sequence). Early to middle Bronze Age archaeological levels embedded in the alluvial sediments indicate that the upper sequence. formed in the second half of the 2nd millennium BC. Above lies a fine-grained overbank unit with hydromorphic soils which evidence a period of low aggradation (3.5–2.5 m from surface); the intercalation of anthropic deposits comprised between the final Bronze Age, the Iron Age and Roman Age points to a time of deposition which encompasses the 1st millennium BC. The top unit (2.5 m to surface) consists of a set of silty residual channel fill and sandy-silty crevasse deposits; pottery shards within the deposits indicate Medieval to Renaissance ages. Downstream of Padua, the Bacchiglione River is confined in a pre-existing depression related to the upbuilding of Brenta River alluvial ridges (CASTIGLIONI, 1992; ARPAV, 2005).

To be noted that the two meanders of the Bacchiglione River in the centre of Padua are much larger that those present upstream and downstream of the city. Basing on morphometric analysis they have been interpreted as belonging to a former Holocene Brenta River, later occupied and only slightly modified by the Bacchiglione River (CASTIGLIONI, 1982a, b; CASTIGLIONI *et al*., 1987). The thick body of coarse- to medium-grained sands, with lenses of fine gravels which is present on the northern bank of the western meander at Cappella degli Scrovegni (ILICETO *et al*., 2001) (Fig. 2), is consistent with the sedimentary activity of the Brenta River and supports this interpretation. The hypothesis that the Brenta River was still flowing through Padua during Roman times was proposed by archaeologists on the basis of findings of large Roman bridges and docks along the river banks and from the interpretation of writings by Titus Livius (Livy) and Pliny the Elder, who called this river the *Meduacus* (GASPAROTTO, 1951; BOSIO 1981a, b). Recent geoarchaeological investigations carried out in the city centre propose that the main course of the Brenta River may have been flowing through Padua until the end of the Bronze Age, but probably not later than the 10th–9th century BC (BALISTA & RINALDI, 2005).

3. ARCHAEOLOGICAL SETTING

The oldest traces of ancient settlements in the alluvial plain west of Padua date back to the Ancient Neolithic (CUPITÒ, 2006). Surface scatters of Neolithic flint artifacts and Bronze Age pottery were found few kilometres south of Trambacche (Monticello area, BIANCHIN CITTON, 1993) and near Via Po (CUPITÒ, 2006) (Fig. 2). Some scattered findings dating between Neolithic and the Bronze Age were collected north of "La Storta" palaeochannel, but not associated with important archaeological structures (LEONARDI, 1993). An early to middle Bronze Age settlement, with some evidence of pile-dwellings, was found at Trambacche with corings and the observation of stratigraphic sections on the present Bacchiglione River bed and banks (BIANCHIN CITTON, 1993); the reconstructed palaeoenvironmental setting suggests that the site was in a humid area near an abandoned meander of the Bacchiglione River, at the bottom of a slightly incised valley now filled by sediments.

During the late Bronze Age (1400–1000 BC) human groups inhabitated the area of the city of Padua, but traces are poor, mainly sealed by more recent anthropic aggradation (LEONARDI, 1990; DE VANNA *et al*., 1995; GROPPO, 2005; PIRAZZINI, 2005a, b). Padua experienced a major growing phase during the Iron Age, starting from the 9th century BC; by the 6th century BC it was already a large urban settlement (FOGOLARI & CHIECO BIANCHI, 1981; DE MIN *et al*., 2005). The city developed along the banks of the opposing bends of the meanders that mark the geomorphology of the city centre. Since the 2nd century BC Padua became a Roman *Municipium* named *Patavium*, connected to the main cities of *Atria* (Adria), *Altinum* (Altino), Concordia and Aquileia by an important consular road, the *via Annia* (BASSANI, 2010). After a period of crisis in early medieval times, the city flourished again in the 12th century AD, with important changes in the urban structure; large sectors of the present city still date to the 12th–15th century AD (BONETTO, 2009). The stacked layering of different cultural periods resulted in a very complex urban archaeological stratigraphy, with a maximum thickness of 7 m (DE MIN *et al*., 2005); it also produced an archaeological mound in the core of the city center, along the two meanders, which is up to 5–6 m higher than the surrounding alluvial plain and covers an area of about 1.5 km^2 (FERRARESE *et al*., 2006).

4. MATERIALS AND METHODS

A DTM based on 1 m contour lines derived from Regional Topographic Maps at scale 1:5,000 was used to identify and map the main landforms in the whole study area; a LiDAR DTM was also processed on a smaller sector centred on Padua.

Satellite images have been processed and analyzed for the detection of the palaeohydrography, as well as different sets of vertical aerial photographs at scales 1:17,000 to 1:33,000 and ortophotos with 1 m resolution. Oblique photos, acquired during low-altitude flights, were also used and proved to be very useful in this context (MOZZI & NINFO, 2009; MOZZI *et al.*, 2010).

The map of LGM deposits and of the Holocene channel belts in Fig. 2 is based on specific field surveys with shallow hand augerings, and geomorphological analysis of the LiDAR DTM, high resolution satellite images and aerial photographs. The geological units in the urban area of Padua have been determined using about 400 unpublished mechanical corings stored in geotechnical archives.

During field survey, boreholes were carried out with a hand-auger (Edelman combination-type, Ejikelkamp™), which allowed the extraction of semi disturbed sediment samples down to a maximum depth of 8.5 m. Peats and organic clay and silt were sampled with a cylinder sampler, which prevented contamination; samples for radiocarbon dating were collected from the inner part of the cores.

Five sections in sand pits in Santa Maria di Veggiano (in this paper: SM Veggiano) were described and sampled by G.B. Castiglioni and one of the authors (M. Cucato) in 1992. These unpublished data were included in the data set, adding to the information obtained from 17 boreholes drilled during the present research. A 20 m deep mechanical coring drilled for geotechnical purposes in Selvazzano Dentro was also described.

These stratigraphic data were supplemented by isolated cores and cross-sections previously examined by Castiglioni *et al*. (1987), in order to extend the data set near Rubano (Rubano cross-section) and in the NW outskirts of Padua (via Caporello section, and via Po borehole), where urbanization no longer allows field survey. Original field notes provided by G.B. Castiglioni were used to update the stratigraphic logs.

Wood and carbonaceous samples were stored in aluminium foil and later dried in oven at 60 °C. Conventional radiocarbon ages were obtained on selected samples of organic sediment or wood remains. Radiocarbon samples were selected in order to represent the period of channel activity, following recommendations of Berendsen & Stouthamer (2000). The samples collected in Ca' Baggio section were radiocarbon dated at the Ångstrom Laboratory (Uppsala, Sweden), whereas those from SM Veggiano were analyzed by Krueger Enterprises Inc. (Geochron Laboratories Division, Cambridge – Massachusetts, USA). Radiocarbon ages, including those from Castiglioni *et al*. (1987), were calibrated using Calib 6.0 online application (Stuiver & Reimer, 1993; Stuiver *et al*., 2010) and calibration curve IntCal09 (Reimer *et al*., 2009). The available radiocarbon datings and calibrations (2-sigma ranges) are presented in Table 1.

5. STRATIGRAPHIC DATA

5.1. Ca' Baggio and Rondinelle cross-sections

Thirteen hand augerings organized in two perpendicular cross sections (Ca' Baggio and Rondinelle) have been drilled across the abandoned river bed of the Brenta River known as "La Storta" palaeochannel, about 2 km SW of the town of Rubano (Fig. 2).

Two architectural arrangements are present in the Ca' Baggio (CB) cross section (Fig. 3A): at the southern end, a sand body is covered by an alternation of silty sand and silt, about 1.5 m thick, intercalated with a 50 cm thick organic layer in the core CB05. This sequence is capped by a calcic horizon observed in CB04 and CB05 corings. In the northern part of the section, a channel sand body, at least 5 m thick, cuts the sequence of finer sediment and the organic layer. The whole sequence is closed by fine-grained sediments (clay, silt and silty-clay). The organic layer sampled at 360 cm depth in CB05 gave an age of 8412-8193 cal BP.

The Rondinelle (RO) cross section is located perpendicular to the one of Ca' Baggio, linking to each other at CB03 borehole. Between RO01 and RO03 it shows a fining-upward sand to clay sequence with a calcic horizon at the top (Fig. 3B). Three sand bodies, interpreted as channel deposits, cut into this sequence. The largest sand body (centred at borehole CB03 and common to the two cross sections), is interpreted as being the channel deposits of La Storta palaeochannel, active after 8412–8193 cal BP. The other two minor sand bodies are probably relative to crevasse channels.

5.2. Via Caporello cross section

This cross section cuts La Storta palaeochannel in the NW outskirts of Padova in via Caporello street; it consists of 4 boreholes (Fig. 4). A sand body thicker

Tab. 1 - Radiocarbon datings mentioned in the text.

Datazioni al radiocarbonio citate nel testo.

Lab. code	Sample code	Depth (cm)	Age ^{14}C (BP)	+/-	Age cal (BP) (since...to)	Gauss-Boaga E	Gauss-Boaga N	References
UD-209	Rubano4	240-270	10190	150	12405-11306	1717897	5035692	Castiglioni et al. (1987)
UD-210	Rubano4	794-800	18100	700	23351-19889	1717897	5035692	Castiglioni et al. (1987)
UD-211	Rubano5	940-946	19200	250	23546-22304	1717853	5035581	Castiglioni et al. (1987)
Ua-38427	CB05-360	360	7515	63	8412-8193	1717826	5032966	-
UD-212	Po1	263-272	4650	220	5797-4828	1724467	5035105	Castiglioni et al. (1987)
UD-216	Po1	470	5020	200	6212-5437	1724467	5035105	Castiglioni et al. (1987)
UD-217	Po1	470	5650	200	6910-5990	1724467	5035105	Castiglioni et al. (1987)
Hv-13366	Caporello2	405	5645	70	6568-6297	1721526	5033700	Castiglioni et al. (1987)
Hv-13367	Caporello2	335	5215	100	6213-5745	1721526	5033700	Castiglioni et al. (1987)
GX-17985	Veggiano sec.1 C1	500-540	1805	80	1897-1541	1712494	5034013	Courtesy G.B. Castiglioni
GX-17986	Veggiano sec. 1 C4	460-500	1475	65	1449-1291	1712494	5034013	Courtesy G.B. Castiglioni
GX-18508	Veggiano sec. 2 C12	500	19210	250	23558-22311	1712536	5033966	Courtesy G.B. Castiglioni
GX-17987	Veggiano sec.1 C6	560	3470	140	4090-3437	1712494	5034013	Courtesy G.B. Castiglioni
GX-17988	Veggiano sec. 1 C9	560	3850	75	4440-4077	1712494	5034013	Courtesy G.B. Castiglioni
GX-18509	Veggiano sec. 2 C11	470-520	4790	155	5898-5258	1712545	5033962	Courtesy G.B. Castiglioni

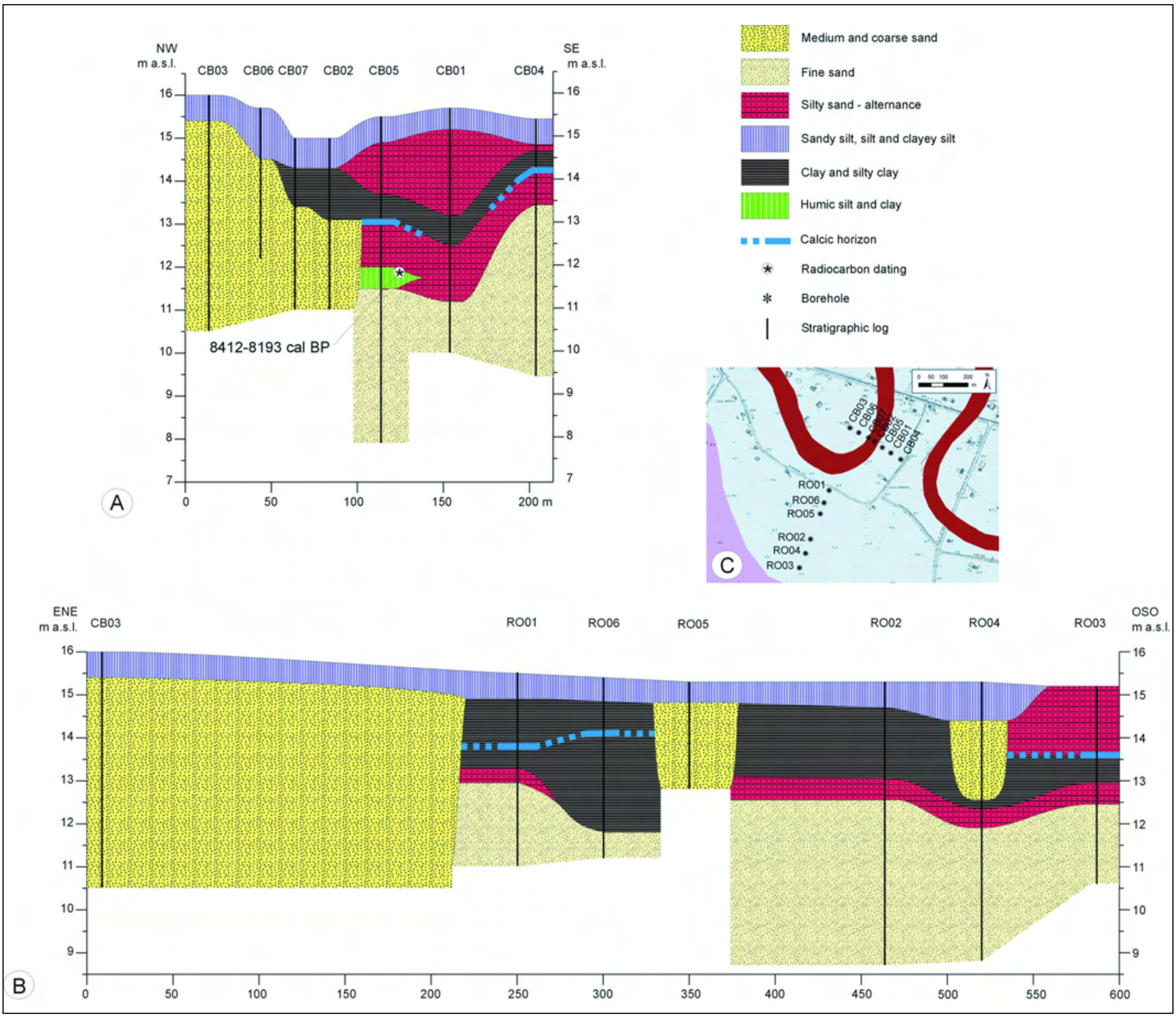


Fig. 3 - Ca' Baggio (A) and Rondinelle (B) cross sections and location map (C).

Sezioni stratigrafiche di Ca' Baggio (A) e Rondinelle (B) e loro ubicazione (C).

than 6 m is present in CAPOR2 core. An organic layer that lies on top of this sand body is interpreted as the residual channel fill after deactivation. Two samples of organic sediment were radiocarbon dated by CASTIGLIONI *et al*. (1987), providing ages of 6568–6297 cal BP and 6213–5745 cal BP respectively at the bottom and at the top of the layer. Chronostratigraphy thus suggests that the deactivation of La Storta palaeochannel took place not long before 6568–6297 cal BP.

5.3. PO1 borehole

PO1 core was drilled in an abandoned meander of the Brenta River near La Storta palaeochannel, in via Po street in the northern outskirts of Padua (Fig. 5). It shows a 2.5 m thick sand body covered by about 6 m of fine-grained sediments (silty clay and silt). Three radiocarbon dates were carried out by CASTIGLIONI *et al*. (1987): two wood remains embedded in silty clay at the depth of 470 cm gave ages of 6212–5437 cal BP and 6910–5990 cal BP; a sample of peaty clay at 263 cm depth gave an age of 5797–4828 cal BP. The buried sand deposits are interpreted as channel bars, covered by the mud infilling following deactivation: this suggests that the meander was abandoned before 7000– 6000 cal BP.

5.4. Rubano cross section

The Rubano cross section cuts an abandoned Brenta meander which is about 1.5 km N of La Storta palaeochannel (Fig. 6). The cross section shows a 4–7 m thick sand body, which is partly covered by 2.5 m of fine-grained sediments (clay and silty clay) interlayered

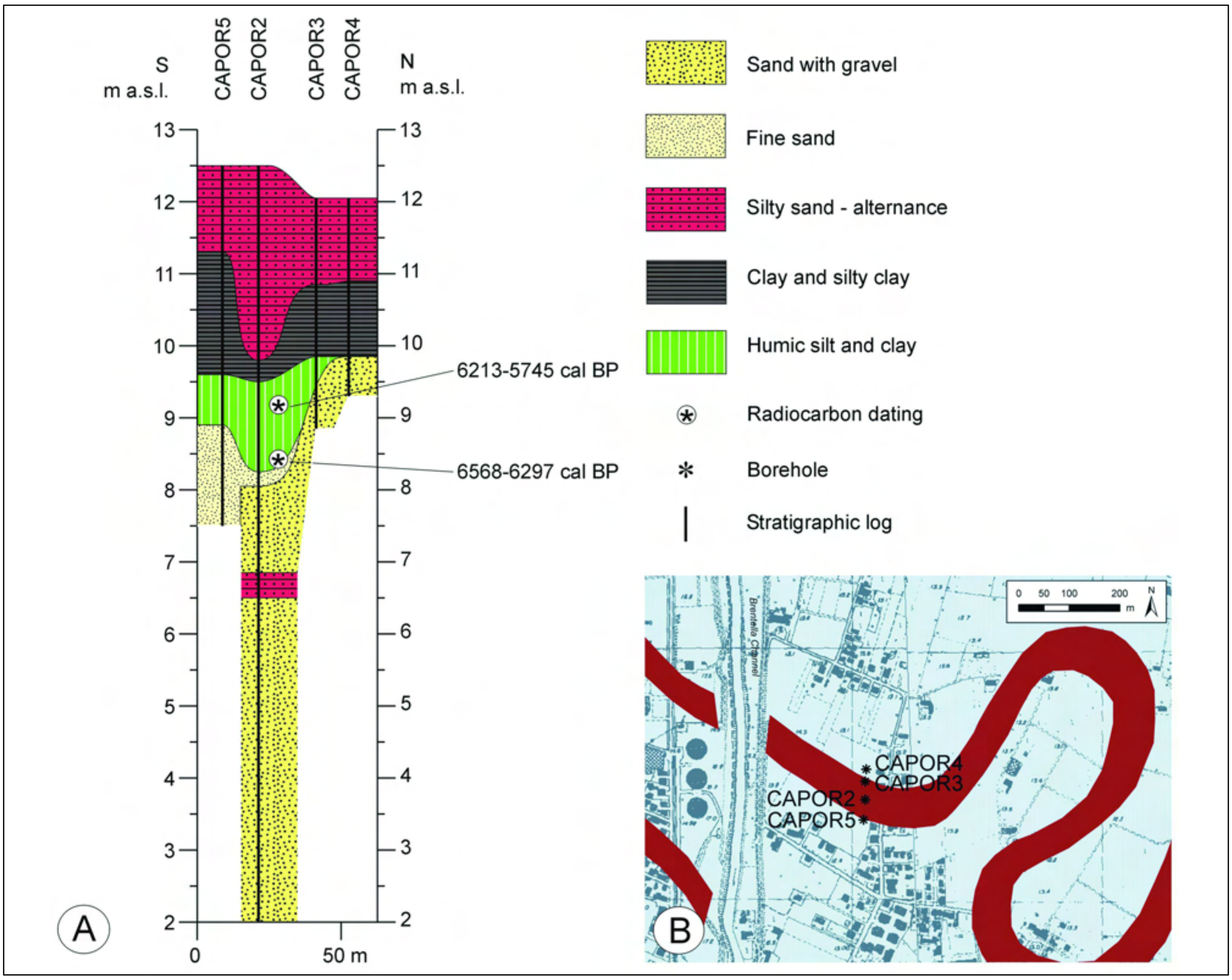


Fig. 4 – Via Caporello cross sections (A) and location map (B) (modified from CASTIGLIONI *et al.*, 1987).

Profilo stratigrafico di via Caporello (A) e sua ubicazione (B) (modificato da CASTIGLIONI et al., *1987).*

with two peat layers in the basal part. The radiocarbon dating of a peat sample at 240–270 cm depth gave an age of 12,405–11,306 cal BP (CASTIGLIONI *et al.*, 1987). Other two radiocarbon datings from peaty clay samples below the sand body, at depths of 800–794 and 940–946 cm, gave the ages of 23,351–19,889 and 23,546–22,304 cal BP respectively. The sand body is interpreted as deriving from channel bar deposition of a meander cut in LGM alluvium. The radiocarbon dating at the base of the top muddy deposit indicates a Lateglacial deactivation of this river channel, which is thus much older than La Storta palaeochannel.

5.5. SM Veggiano cross section

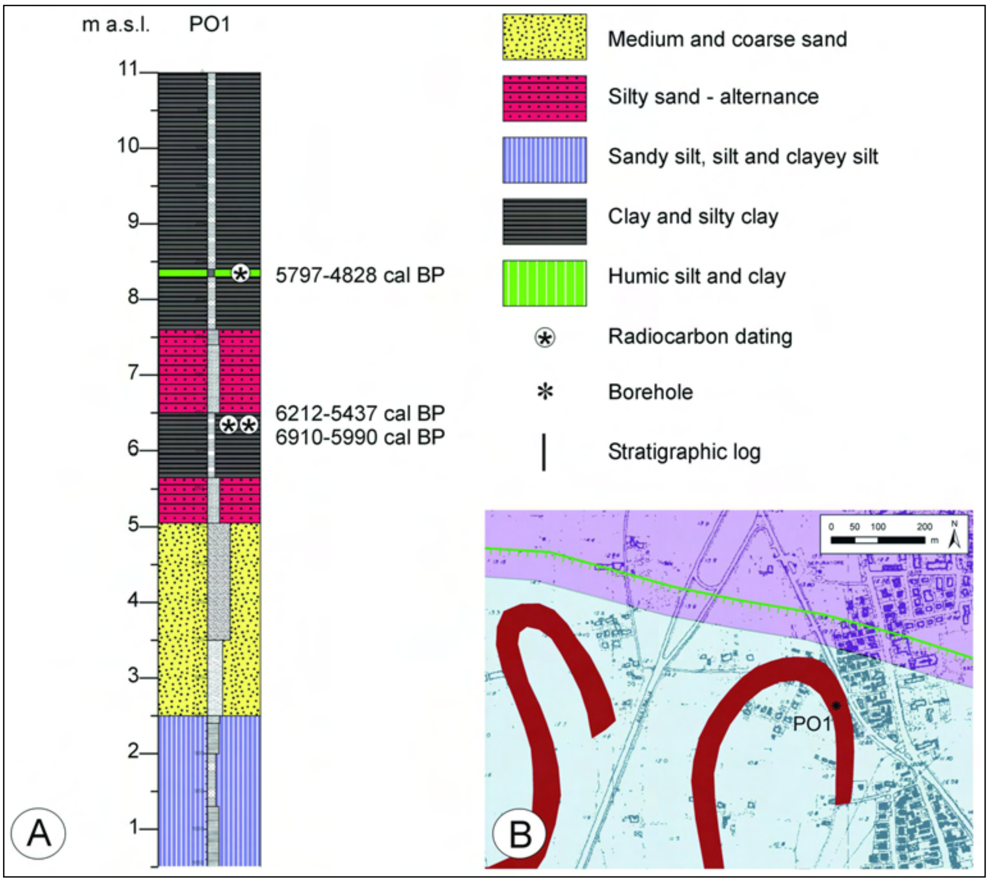
SM Veggiano cross section runs across the well-defined, approximately N-S depression presently followed by the Tesina Padovano River, a small river fed by groundwater and local surface runoff (Fig. 7). The stratigraphic data derive from 4 stratigraphic sections observed along the walls of sand and gravel pits (Sec. 1–4) and 17 manual boreholes.

Four different stratigraphic units were recognized. The lowest one consists of alternances of silt, clay and fine-grained sands in 30–50 cm thick layers, with the intercalation of peat layers. A radiocarbon dating carried out on peat at 500–515 cm depth in section 2 provided an age of 23,558–22,311 cal BP. This LGM age estimate is coherent with the sedimentary facies, which are typical of the glaciofluvial deposits of the distal Brenta megafan (MOZZI, 2005; MIOLA *et al.*, 2007; BONDESAN *et al.*, 2008). A well developed soil is present at the surface of this unit, which has calcic horizons with carbonate concretions up to 20%, often overlain by a leached horizon depleted in carbonate content. These pedofeatures allow to correlate this soil with the "caranto" paleosol which marks the top of the LGM sequence in the distal Brenta megafan in the entire Venetian area (GATTO & PREVIATELLO, 1974; MOZZI *et al.*, 2003; ARPAV, 2005) as well as in the other megafans of the Venetian-Friulian Plain (FONTANA *et al.*, 2008).

A rather homogeneous sedimentary unit, consisting of medium to coarse sands and gravels with evident cross-bedding, is cut in the LGM deposits. Pebbles mainly consist of carbonate rocks, metamorphic rocks, quartz (mainly metamorphic), volcanic

Fig. 5 - Stratigraphic log of PO1 borehole in via Po street in Padua (A) and location map (B) (modified from CASTIGLIONI *et al*., 1987).

Log stratigrafico del sondaggio PO1 di via Po a Padova (A) e sua ubicazione (B) (modificato da CASTIGLIONI et al., *1987).*



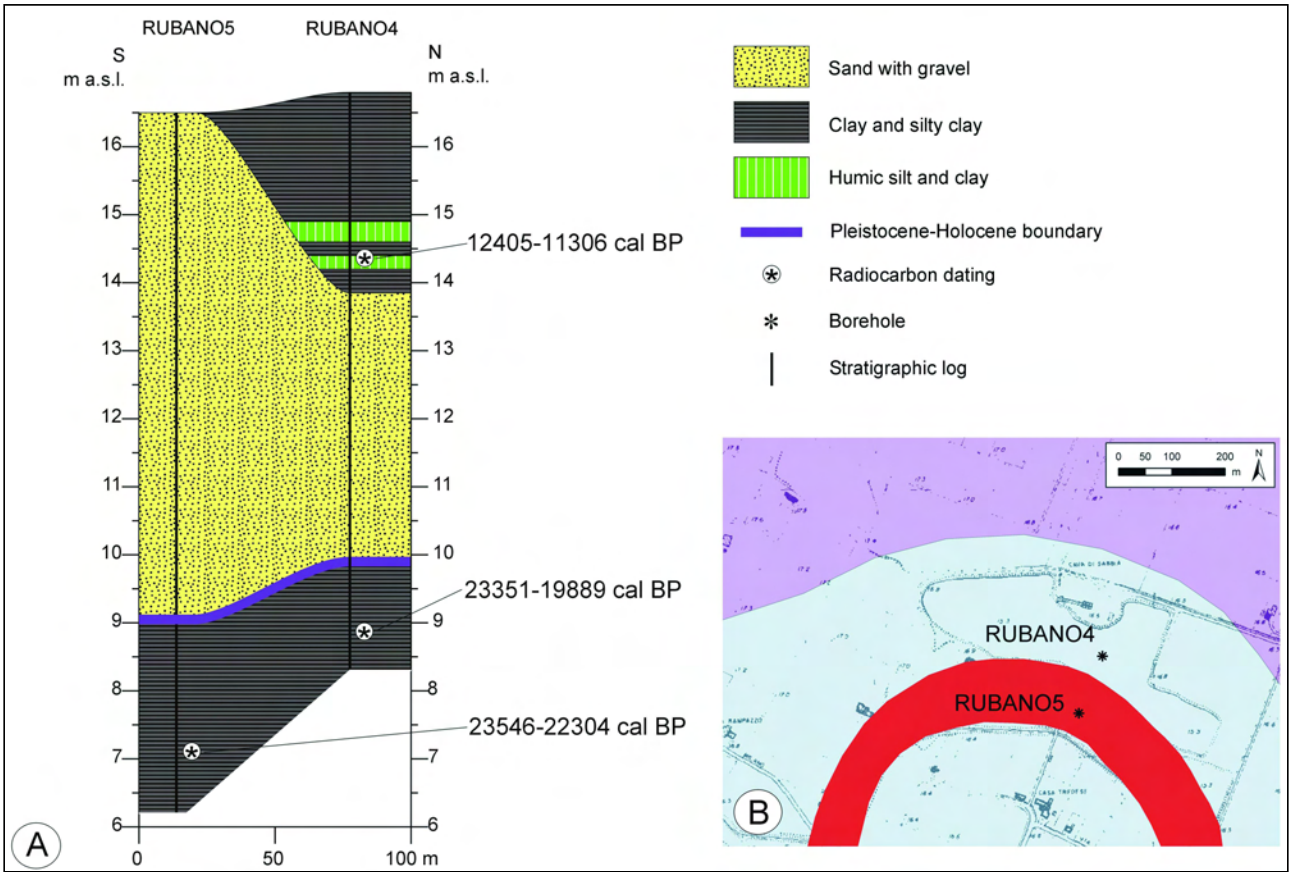


Fig. 6 - Rubano cross section (A) and location map (B) (modified from CASTIGLIONI *et al*., 1987).

Profilo stratigrafico di Rubano (A) e sua ubicazione (B) (modificato da CASTIGLIONI et al., *1987).*

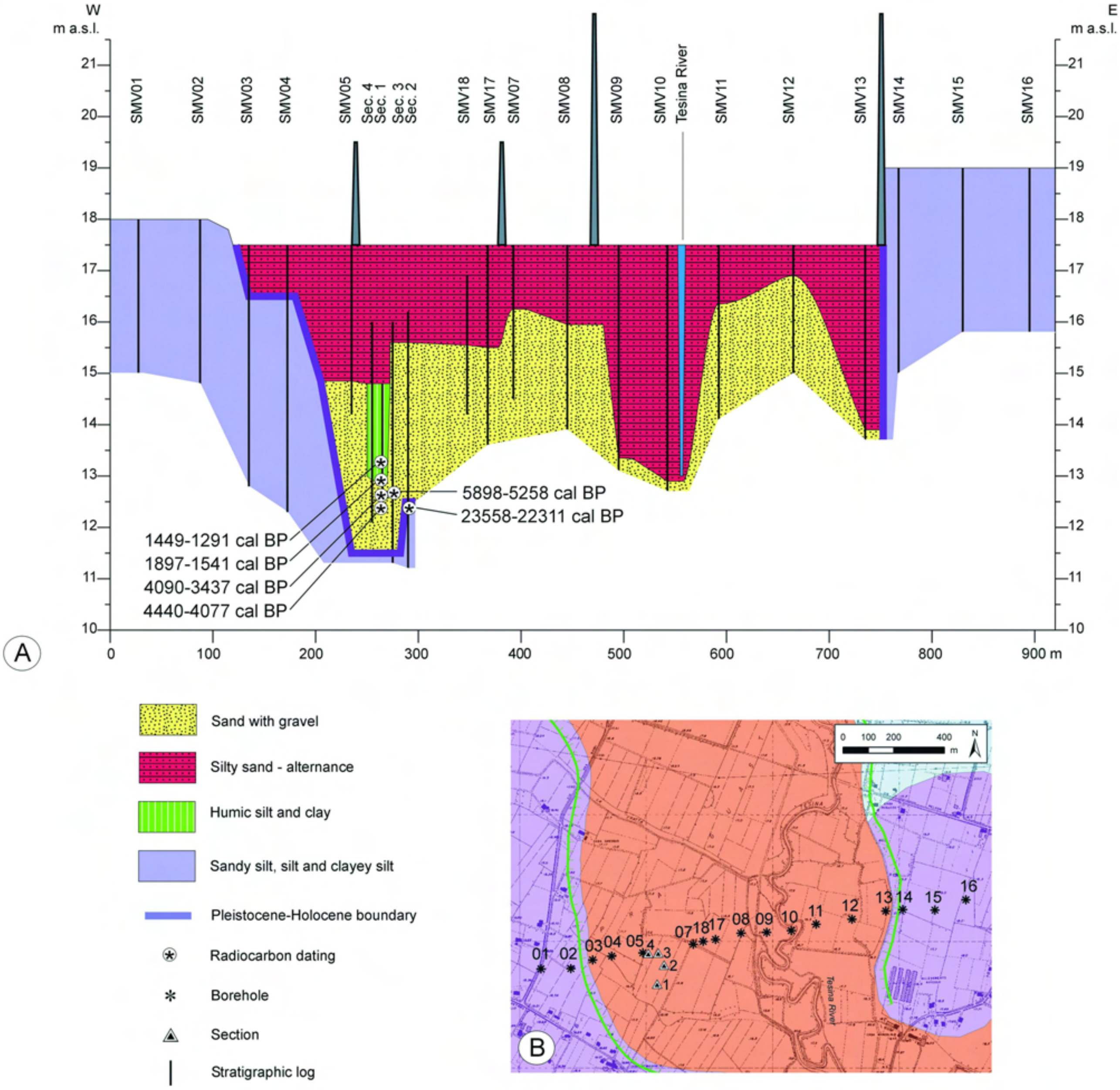


Fig. 7 – SM Veggiano cross section (A) and location map (B).
Profilo stratigrafico di SM Veggiano (A) e sua ubicazione (B).

rocks, intrusive rocks and flint, from the most to less abundant respectively. The sediments are interpreted as the amalgamation of channel bars of the Brenta River. This unit is at least 4 m thick, but the lower boundary has been reached only in few boreholes and pits. Several tree trunks, whose diameters range from 30 to 45 cm, were observed in the pits; various centimetric limb fragments and wood chips were also found. Radiocarbon dating of wood fragments located between 80 cm and 130 cm above the unit lower boundary in section 3, gave an age of 5898-5258 cal BP. Other radiocarbon datings, carried out on wood fragments in section 1, about 40 cm under the unit upper boundary, gave ages of 4440–4077 and 4090–3437 cal BP respectively. At the top of the layer (10–25 cm from the upper boundary) the radiocarbon dating of a limb fragment embedded in sandy gravel gave an age of 1897–1541 cal BP. Some pottery shards, attributed to the early Bronze Age (indicatively 2200–1800 BC: G. Leonardi, personal communication) were found inside these deposits, between 200 and 370 cm from the lower boundary, sometimes imbricated. They show evidence of rounded edges due to fluvial abrasion.

An organic-rich silt and clay unit, up to 3 m thick, was recognized in sections 2 and 4. It is interpreted as the residual channel fill after deactivation. A radiocarbon dating from wood fragments, placed 40 cm above the lower boundary, gave 1499–1291cal BP.

The uppermost unit is characterized by rather homogeneous fine sands with intercalation of sandy silt, for an overall thickness of 4–5 m, attributed to the present Tesina Padovano River.

5.6. S1 borehole

This 20 m deep borehole was drilled about 500 m south of the Bacchiglione River in the town of Selvazzano Dentro (Fig. 8). Starting the description from the bottom, a 3 m thick fine-grained sand body is here covered by 8 m of silty clay, with a peat layer at 16.7 m depth. At 9 m depth, the silty clay sequence is cut by an erosive surface, on which lies a gravelly sand body about 5 m thick. This layer is heterogeneous as for gravel fraction: the coarsest fraction (2–4 cm) is at the bottom, 9.0–7.8 m depth; between 7.8–6.4 m, pebbles reach the maximum size of 1.5 cm; the mean dimensions rise to 2–3 cm between 6.4–5.0 m depth, where common reworked carbonatic nodules are also present; the finest fraction (rare pebbles of 0.5–1 cm) is in the uppermost tract, 5.0– 3.8 m depth. Pebbles mainly consist of carbonate rocks, with common flint, metamorphic rocks (gneiss, schists) and porphyry. A fining upward sequence is present from 3.8 m depth to surface, ranging from fine sand to clay.

The stratigraphy of this borehole is coherent with that of SM Veggiano section and, though no radiometric dating of deposits is here available, the following correlations are proposed: the silty clay sequence is regarded as belonging to the LGM sequence, due to its typical fine-grained lithofacies with common peat layers; the gravelly sand layer correlates with the Brenta River coarse sand and gravel unit of SM Veggiano. The fine-grained sediments which close the sequence can be attributed to the recent sedimentary activity of the Bacchiglione River, and are equivalent to the fine sands and mud deposits of the Tesina Padovano River at SM Veggiano.

6. THE HOLOCENE CHANNEL BELTS

Geomorphological and stratigraphic data indicate that the alluvial plain west of Padua is characterized by the presence of two Holocene channel belts, cut in LGM sediments and locally bounded by low (<2m) erosive fluvial scarps (Fig. 2). The LGM deposits are exposed in the northern portion of the study area and in a W–E elongated area just north of the Bacchiglione River, on the interfluve between the two channel belts. South of the Bacchiglione River, the LGM deposits are mostly buried by middle Holocene sediments attributed to the Brenta River (Cucato & Sedea, in press).

Remote sensing and DTM processing allow good recognition of the northern channel belt, which has a maximum width of ca. 4 km and an overall WNW–ESE direction; we refer to it as the "Mestrino-Rubano" (MR) channel belt. The meander widths, the thickness of the sandy channel bodies and the relative coarse lithofacies and petrography of pebbles indicate that the MR meander belt is the result of the sedimentary activity of the Brenta River. Radiocarbon datings at Ca' Baggio and Rubano (see previous paragraph) show that this channel belt was active at the end of Lateglacial and in the early Holocene. The best preserved palaeohydrographic element is the La Storta palaeochannel, which has been mapped for about 13 km (channel length 32 km). Available chronostratigraphic data indicate that this palaeochannel was active between 8412–8193 cal BP (Ca' Baggio section) and 6568-6297 cal BP (Caporello section, Castiglioni *et al*., 1987), bracketing a period of about 2000 years. The remarkable preservation of its morphology is most probably due to the fact that it formed just before the deactivation of MR channel belt, and was thus preserved at surface as a relict fluvial landform.

At the western margin of the study area, extensive sand and gravel bodies of the Brenta River are found in the SM Veggiano cross section, as basal infill of a N-S valley incised in LGM deposits. Valley depth was >7 m in respect to the surrounding LGM alluvial plain, and probably averaged around 10 m. Some radiocarbon datings on tree trunks and wood fragments embedded in the gravels, as well as the presence of reworked early Bronze Age pottery shards, indicate channel deposition approximately between 6000–3500 cal BP. One radiocarbon date suggests that the last gravel deposition took place between the 2nd and the 5th century AD, whereas another shows that the residual channel fill was forming between the 6th and 8th century AD.

Facies assemblages and petrography of pebbles allow to correlate these deposits to the sand-and-gravel sedimentary body cored at Selvazzano Dentro, few kilometres downstream along the present course of the Bacchiglione River. This evidences the existence of a Brenta channel belt with a N-S direction down to Trambacche along the Tesina Padovano River valley, which continued ESE towards Padua following the same direction as the present Bacchiglione River.

This channel belt, to which we refer as the "Veggiano – Selvazzano" (VS) channel belt, is significantly younger than MR. Its geomorphic evidence is poor, as palaeochannels are mostly buried by the fine sandy and silty deposits of the Tesina Padovano and Bacchiglione rivers. However, about 5 km southwesw of the city centre near Volta Brusegana, a large abandoned meander is still detectable on aerial photographs, LiDAR, and 19th century historical maps. The channel width (about 90 m) and the large radius (about 400 m) allow to attribute this meander to the Brenta River rather than to the Bacchiglione River. It is thus part of VS channel belt, as indicated in map of Fig. 2.

The meanders of Padua city centre were interpreted in previous studies as the downstream continuation of La Storta palaeochannel (Castiglioni *et al*., 1987; Balista & Rinaldi, 2005). Detailed mapping with LiDAR and new remote sensing images indicates that this may not be the case, as La Storta palaeochannel runs at the northern outskirts of the city. The meanders in Padua are related to a more southern course of the Brenta River, which was probably running along the VS channel belt and entered the present urban area along the same direction which was later followed by the Bacchiglione River.

7. CONCLUSIONS

The new geomorphological and chronostratigraphic data presented in this paper integrate previous studies on the palaeohydrography of the alluvial plain of Padua in relation to early human settlements.

There are evidences that the last time that the Brenta River reached the city centre of Padua, it was arriving from the southwesw along the VS channel belt. After deactivation, the Bacchiglione River replaced the Brenta River along this channel belt.

Chronostratigraphic data indicate that the VS channel belt was active in the 2nd millennium BC. This implies that Padua was crossed by the Brenta River during the Bronze Age.

A single radiocarbon dating suggests that the sedimentary activity of the Brenta River along VS channel belt may have prolonged as late as the 5th century AD. Such indication brings about the possibility that the Brenta River may have been flowing through the city also during the Iron Age and in Roman times, and that the Bacchiglione River established its present course only in early Medieval times.

This hypothesis has important implications for the reconstruction of the topography of ancient Padua. However, it is based on rather weak chronostratigraphic evidence, which should be better investigated in the future. Some controversial points also need to be considered. The presence of such a large river in Iron Age and Roman Padua seems to be inconsistent with geoarchaeological data, which point to only minor fluvial activity in the city since the end of the 2nd millennium BC (Balista & Rinaldi, 2005). Another critical issue is that the Brenta River is regarded to have followed the present direction since the beginning of the 1st millennium BC (Castiglioni *et al.*, 1987; Pellegrini *et al.*, 1984), which means that in the Iron Age and in Roman times the river would have been flowing several kilometres east of the city.

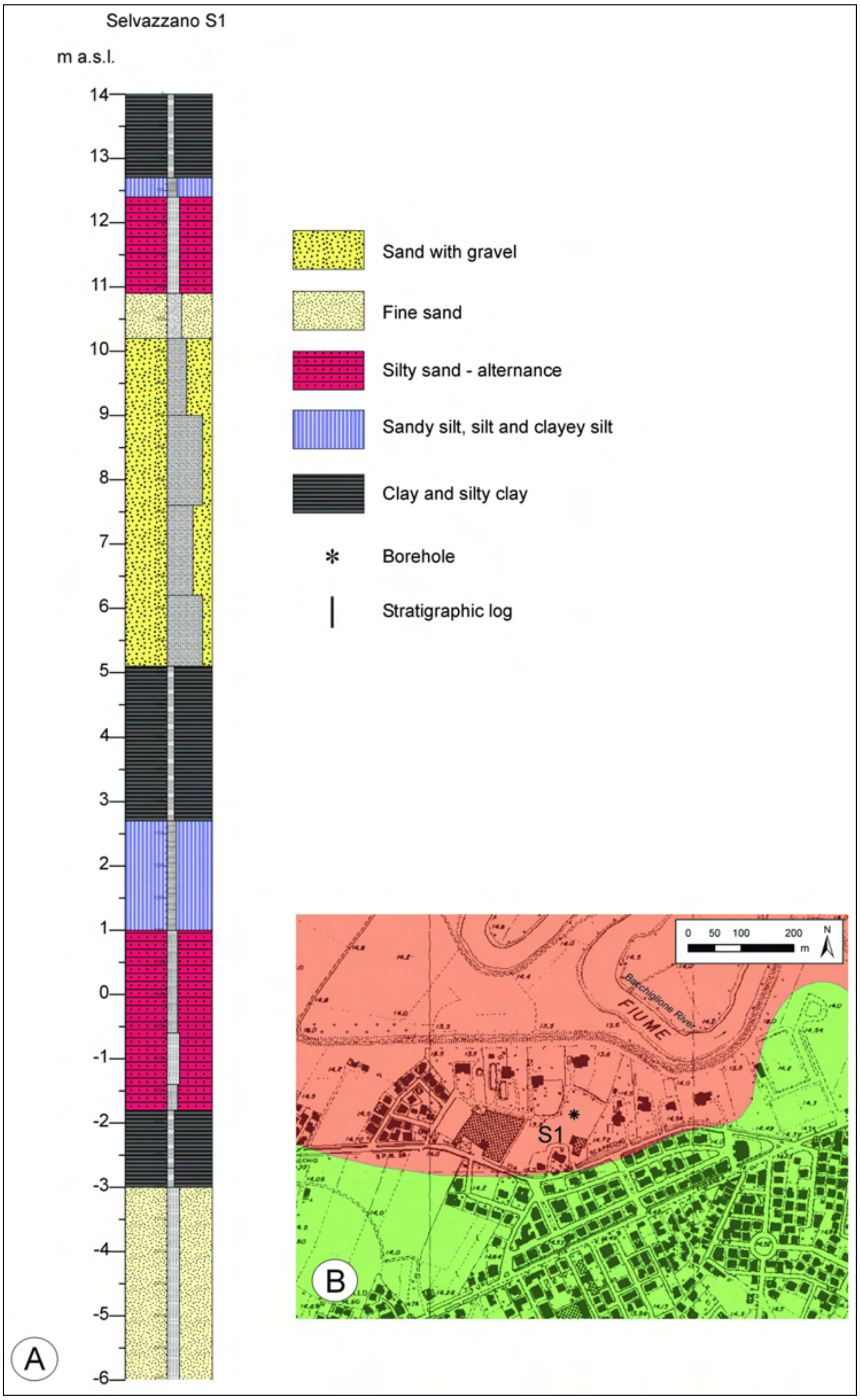


Fig. 8 - Stratigraphic log of S1 borehole at Selvazzano Dentro (A) and location map (B).

Log stratigrafico del sondaggio S1 a Selvazzano Dentro (A) e sua ubicazione (B).

8. ACKNOWLEDGMENTS

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