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INTEGRATING DIGITAL ELEVATION MODELS AND STRATIGRAPHIC DATA FOR THE RECONSTRUCTION OF THE POST-LGM UNCONFORMITY IN THE BRENTA ALLUVIAL MEGAFAN (NORTH-EASTERN ITALY)

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ABSTRACT: Stratigraphic cores and sections, geological maps and Digital Elevation Models (DEMs) were used for the three-dimensional reconstruction of a portion of the regional unconformity, which separates the Last Glacial Maximum (LGM) sedimentary complex from the post-LGM one. The investigation focused on the Brenta megafan, a ca. 3000 km^2 wide alluvial system that extends from the Alpine piedmont to the Venice Lagoon. During LGM the Brenta megafan experienced a major aggradation phase, which led the system to achieve its maximum extent. Fluvial downcutting started after 17.5 cal ka BP and led to the formation of incised valleys (IVs) in the plain, which reached depths up to 20-30 m. The interfluves between IVs experienced soil formation (Calcisols, Luvisols) until their burial by later deposits, or until present in the case of wide exposed stretches of LGM plain.

A DEM of the present surface of the Brenta megafan and a geological map of the LGM deposits were created in a Geographic Information System (GIS). Seventeen cores and sections with information on the nature (erosive vs. hiatal with soil formation) and depth of burial of the post-LGM unconformity, as well as on the stratigraphy of the alluvial succession, were introduced in the GIS as stratigraphic control points (SCPs). Contours of the base of post-LGM sediments with 2-m interval were available in the Venice Lagoon and its mainland. Different interpolation and statistical methods were applied for modeling the unconformity in the pedogenized interfluves and in IVs. Contours were interpolated with Triangulated Irregular Network (TIN) technique. SCPs were interpolated with Inverse Distance Weight (IDW) algorithm with the function cos^3. Linear trend equations between the exposed top of the valley fill, i.e. the topographic surface in the DEM, and the unconformity elevation were calculated in different reaches of IVs.

Data processing resulted in the production of a DEM of the post-LGM unconformity in the whole Brenta megafan with a cell size of 30x30 m. Morphometric analysis of the DEM enabled to evaluate the gradients of the unconformity in long and transverse profiles, as well as to calculate its overall extension (1491 km^2), the areas characterized by buried soils (970 km^2), and those which correspond to an erosive surface in IVs (521 km^2). The difference between the DEM of the unconformity and the present topographic surface allowed for the first calculation of the volume of alluvial and coastal sediments which lie on top of the unconformity (10.4 km^3), and of those which fill the IVs (4.3 km^3).

The unconformity was traced and modeled across a whole range of sedimentary environments, from braided gravel-bed channel belts (in the proximal sector) down to coastal barrier-and-lagoon systems. The method may be applied to neighboring megafans of the Venetian-Friulian and eastern Po Plain. Moreover, it can be extended offshore, in the shelf of Northern Adriatic Sea, to the tip of the deltaic systems, providing a valuable tool for basin-scale stratigraphic correlations and quantitative estimation of erosive processes and sedimentary storage.

Keywords: Last Glacial Maximum, unconformity, allostratigraphy, DEM, alluvial megafan, Venetian Plain.

1. INTRODUCTION

An unconformity is a surface between rock bodies that represents a significant hiatus or gap in the stratigraphic succession (Salvador, 1994). The importance of an unconformity is related to its geographical extent (e.g., regional-interregional traceability and/or correlatability) and the temporal interval of the stratigraphic hiatus. Whilst the concept of unconformity has a long history, starting from Hutton's and Jameson's works between the end of 18th and the beginning of the 19th century (Tomkeieff, 1962), the use of unconformities to formally subdivide and organize sedimentary successions has been receiving increasing attention only in more recent times. Allostratigraphy has been incorporated in the North American Stratigraphic Code (NACSN, 1983) and the International Stratigraphic Guide (Salvador, 1994). Several state geological surveys in the USA use an allostratigraphic approach in geological mapping (e.g., McCulloh et al., 2003; Heinrich et al., 2006; Breckenbridge et al., 2005). The Geological Survey of Italy has adopted unconformity-bounded stratigraphic units for the production of 1:50,000 scale geological maps (CARG project) (CNR, 1992; Pasquarè & Venturini, 2005).

The strength and weakness of allostratigraphy vs. lithostratigraphy or morphostratigraphy in subdiving Quaternary continental successions have been widely debated (e.g. Gibbard, 1985; Rawson et al., 2002; Hughes, 2007, 2010; Räsänen et al., 2009). A significant advantage of allostratigraphy in respect to lithostratigraphy is that it enables the setting up of a sequence framework which is particularly effective in basin-scale reconstructions, as it allows the definition of units with comparable ages but encompassing deposits with very varied sedimentary facies (Miall, 1996). An allostrati-

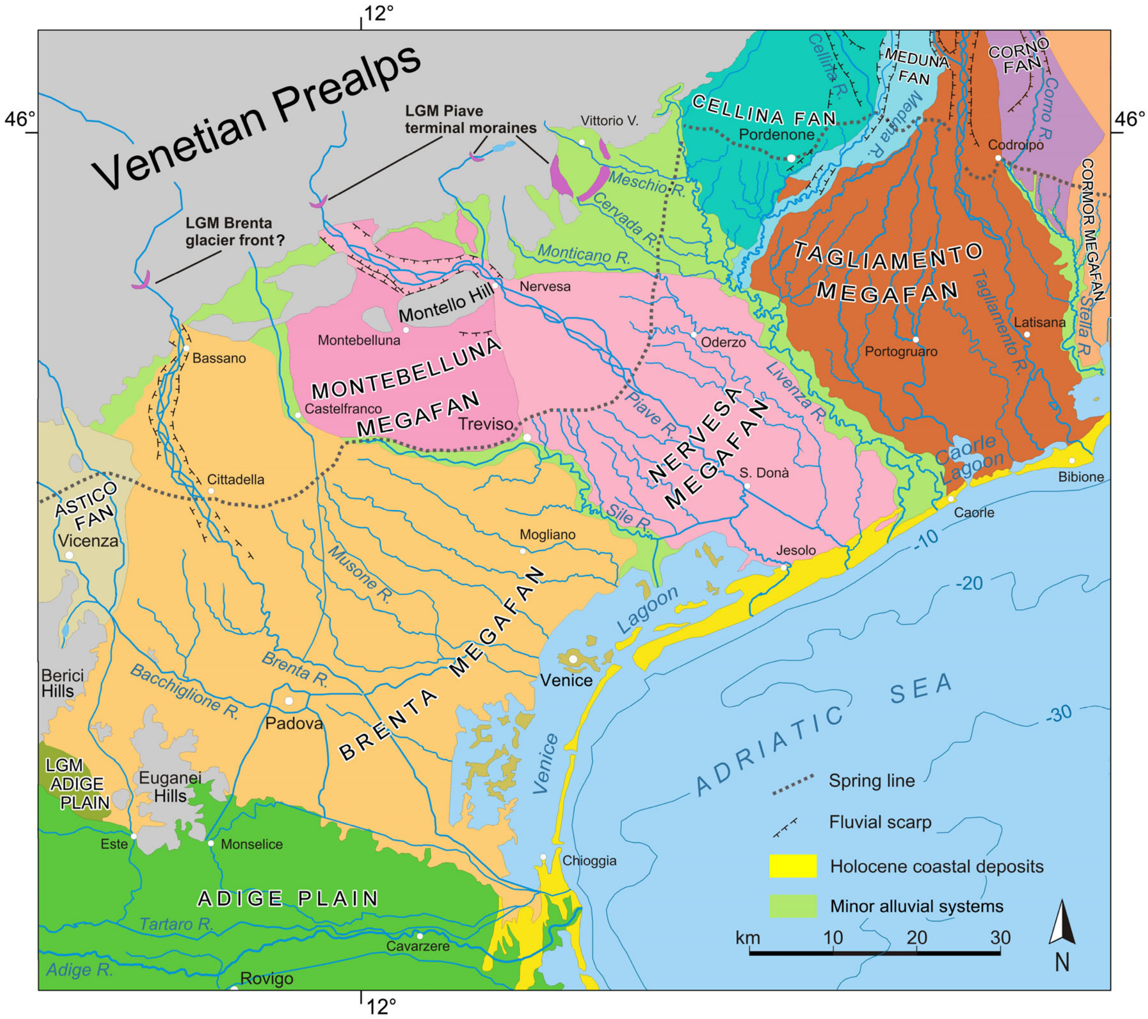

Fig. 1 - The megafans of the Venetian-Friulian Plain (modified from Fontana et al., 2008).

graphic approach enables genetically-related heterogenous deposits, e.g. interfingering alluvial and lacustrine deposits, to be grouped within a single stratigraphic unit (Hughes, 2007). Whilst allostratigraphy is a form of sequence stratigraphy (Hughes, 2007), it provides the possibility of separating sedimentary bodies of similar lithology basing on the presence of a significant unconformity (Rawson et al., 2002).

The hierarchic organization of a sedimentary succession in allomember, alloformation, allogroup, or subsynthem, synthem, supersynthem strictly depends on the magnitude of each bounding unconformity (e.g., Miall, 1988, 1991). To this respect, the analysis of unconformities is crucial for the definition of an allostratigraphic framework. Nevertheless, the recognition, tracing and ranking of unconformities is particularly problematic in Quaternary continental successions, where unconformities often correspond to erosive surfaces with irregular geometries, and need to be correlated across different sedimentary environments and basins that can be physically separated.

This paper proposes the integration of boreholes, geological maps and Digital Elevation Models (DEMs) to reconstruct the three-dimensional geometry and analyze the lateral variability of a portion of the regional unconformity, which separates the sedimentary complex of the Last Glacial Maximum (LGM) from the post-LGM one. The investigation focuses on the Brenta megafan (Fig. 1), a ca. 3000 km^2 wide alluvial system which was chosen in order to test the method across a whole range of sedimentary environments, from braided gravelly channel belts in the Alpine piedmont to clayey-silty distal plain, and extending also to the related deltas and lagoon. This unconformity formally represents the base of the postglacial synthem ("Po synthem") in several 1:50,000 scale CARG geological maps in the Friulian Plain (Zanferrari et al., 2008a, b, c; Fontana et al., 2012) and in the Venetian area (Tosi et al., 2007a, b; Cucato et al., 2012). It has been recognized in the underground of the Venetian-Friulian Plain (Mozzi et al., 2003; Primon & Fontana, 2008; Fontana et al., 2008, 2010, 2012), as well as in the Po Delta (Amorosi & Marchi, 1999; Correggiari et al., 2005; Stefani & Vincenzi, 2005), in the Northern Adriatic shelf (Trincardi & Argnani, 2003; Trincardi et al., 2011) and along its western coast (Amorosi et al., 2008). This investigation provides new insights for basin-scale correlatability of unconformities related to major Pleistocene glacial-interglacial cycles.

2. SETTINGS

2.1. Geology and geomorphology

The Brenta megafan is part of the foreland basin of the uplifting Eastern Southalpine chain (e.g., Castellarin et al., 1992; Carminati et al., 2003; Stefani et al., 2007; Barbieri et al., 2007). Within about 20 km from the mountain front the megafan is relatively steep (average gradient 3-5‰), consisting of gravel deposits, hundreds of metres thick, related to braided channel sedimentation (Mozzi, 2005). Further downstream, where topographic gradient gradually decrease to less than 1‰, the geomorphic features mainly consist of sandy fluvial ridges separated by silty-clayey floodbasins (Bondesan & Meneghel, 2004; Mozzi, 2005; Bondesan et al., 2008).

Climate change and eustasy forced by glacial-interglacial cycles appear to be the main driving factors in the Upper Pleistocene and Holocene evolution of the Brenta megafan (Mozzi, 2005; Mozzi et al., 2010), as well as of the other megafans of the Venetian-Friulian Plain (Fontana et al., 2008, 2010; Carton et al., 2009). A phase of maximum aggradation took place during the peak of LGM, that in a global perspective lasted between 26.5-19 cal ka BP (Clark et al., 2009). In that period the Eastern Southern Alps were occupied by extensive glacial systems (Ehlers & Gibbard, 2004): the Piave and Tagliamento glaciers reached the plain, building terminal moraine ridges (Carton et al., 2009; Monegato et al., 2007); the Astico glacier, connected by transfluence to both the Adige and Brenta glaciers, had its front few kilometres from the plain (Cucato, 2001; Rossato et al., 2013). The Brenta glacier front is regarded to have been located about 10 km upstream of the Brenta valley mouth, near Valstagna, but evidence of its precise position is lacking (Trevisan, 1939). In this period the Venetian-Friulian megafans achieved their maximum areal expansion (Fontana et al., 2008). The LGM Brenta megafan extended from the Sile R. to the Berici Hills (Mozzi et al., 2003; Mozzi, 2005; Monegato et al., 2011) (Fig. 1). The thickness of LGM deposits in the distal sectors of the Brenta megafan is about 20 m (Tosi et al., 2007a; Bondesan et al., 2008; Cucato et al., 2012), which is coherent with the thickness of 20-30 m observed in the lower tracts of most Venetian-Friulian megafans (Fontana et al., 2010). Aggradation in the Brenta megafan continued until about 17.5 cal ka BP, with apparent lower rates than at the peak of LGM (Mozzi, 2005; Fontana et al., 2010). In the Tagliamento megafan and in the other alluvial systems connected with the Tagliamento glacier (Corno, Cormor and Torre outwashes) the late LGM was instead characterized by an early phase of downcutting at the fanhead and the formation of telescopic fan lobes in the distal plain (Fontana, 2006; Fontana et al. 2008, in press).

A dramatic erosive phase took place in all the Venetian-Friulian megafans at the end of the LGM, during the deglaciation of the lowest sectors of the Southern Eastern Alps (Fontana et al. 2008, 2010). Fluvial downcutting in the Brenta megafan started after 17.5 cal ka BP and led to the formation of incised valleys (sensu Darlymple, 2006) in the plain (from now abbreviated as IV), which reached depths of 10-20 m (Iliceto et al., 2001; Mozzi, 2005; Mozzi et al., 2010; Cucato et al., 2012). The interfluves between IVs consist of the terraced LGM alluvial plain. These surfaces experienced soil formation until their burial by later deposits or, in the case of large outcropping stretches of LGM, until present (for further details on soils, see following paragraph 2.2.).

The proximal sector of the Brenta megafan was deactivated due to the entrenching of the river near the valley outlet (Mozzi, 2005). IVs are still detectable in the geomorphology of the upper tract of the megafan, near its apex, as they are laterally bounded by alluvial scarps which are more than 15 m high (Figs. 1 and 2) (Castiglioni, 1997; Mozzi, 2005). These scarps gradually decrease downstream, finally disappearing at a distance of about 40 km from the mountain front. At the North-Western outskirts of city of Padova, the scarps cut in LGM deposits are about 2-3 m high (Ferrarese et al., 2006; Mozzi et al., 2010; Ninfo et al., 2011). Here the oldest meander belts at the top of the valley fill were active between 12.0 and 6.5 cal ka BP (Mozzi et al., 2010). This suggests that the infilling of the IV took place during Late Glacial and early Holocene, and was basically completed by middle Holocene.

South of Padova, 2-5 m thick alluvial deposits dated between 6.5 and 4.5 cal ka BP cover the LGM deposits (Cucato et al., 2012). Towards SE, the Holocene Brenta deposits have ages varying between 4 and 1 cal ka BP and thickness of 2-4 m (Bondesan et al., 2008; Cucato et al., 2012). East of the Brenta R. and in other extensive stretches north of Padua and around the Euganei Hills, LGM portions crop out (Mozzi, 2005; ARPAV, 2005; Cucato et al., 2012).

The distal Brenta megafan is attached to the barrier-and-lagoon system of the Venice Lagoon, which started to form around 7.5-6.0 cal ka BP in response to sea-level rise (Favero & Serandrei Barbero, 1978; Brambati et al., 2003; Amorosi et al. 2008). The Venice Lagoon is presently bounded by dykes and large portions of the surrounding alluvial plain are reclaimed land below mean sea level (Fig. 2). The lagoonal and littoral deposits are part of the high-stand sedimentary wedge, consisting of sandy beach ridges, lagoons and deltas that rim the western sector of the northern Adriatic Sea. This sedimentary wedge covers the LGM alluvial deposits but it rapidly pinches out moving offshore (Trincardi et al., 2011). In wide portions of the northern Adriatic floor the fluvial LGM deposits are cropping out or covered by just a few-decimetres to 1-m-thick veneer of marine deposits, separated by a ravinement surface (Correggiari et al., 1996; Gordini et al., 2002, 2003; Trincardi et al., 2011).

2.2. Soils on LGM deposits

Recent soil surveys carried out in the Brenta megafan (Ragazzi et al., 2004; ARPAV, 2005; Dalla Rosa et al., 2012) evidence that the soils with the highest degree of development are those formed on the exposed LGM plain. Soils developed on LGM gravels show a characteristic profile differentiation, with calcium carbonate leaching in the epipedon and clay illuviation to deep Bt horizons. These well-drained soils have 30-40 cm thick argillic Bt horizons, with hue 7.5YR (Munsell Soil Color Charts), and are classified as Cutanic Luvisols in the FAO World Reference Base for Soil Resources (WRB) classification (Ragazzi et al., 2004). Soils on the silty-clay floodplain of the distal sector of the LGM megafan are characterized by marked vertical mobilization of car-

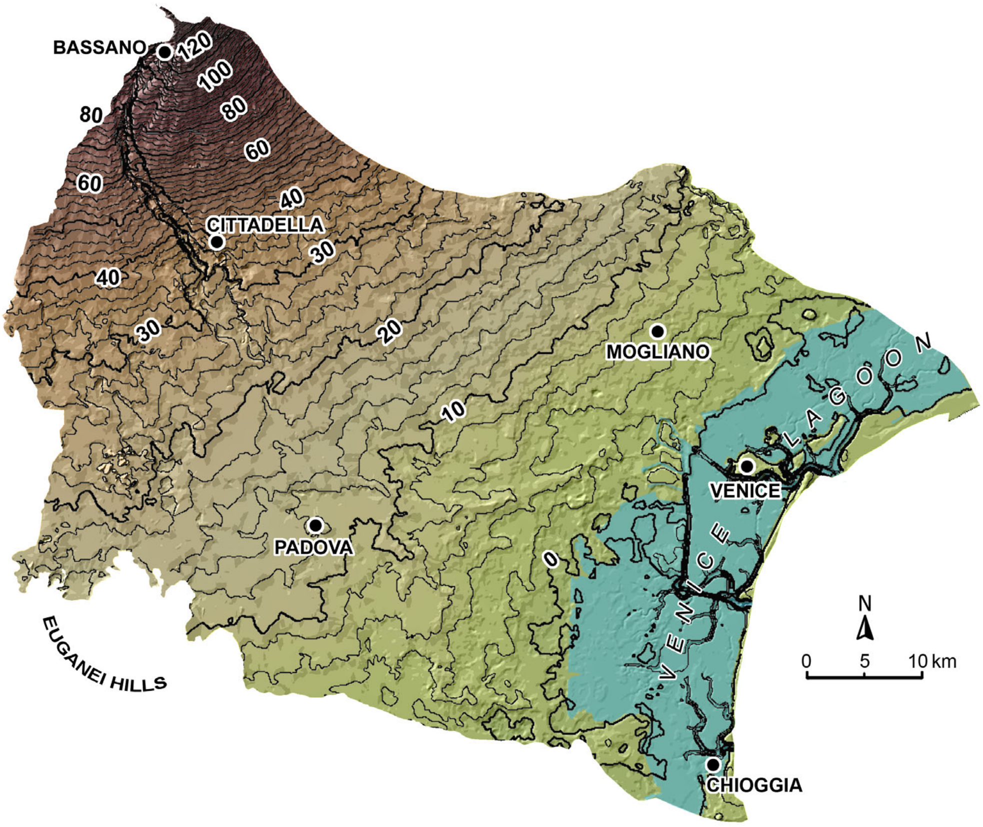

Fig. 2 - Hillshaded DEM of the Brenta megafan, with 2-m contours. The present Venice Lagoon is in light green.

bonates. Typically, 20-30 cm thick leached Bw horizons overlie some-decimetres-thick Bk and Ck calcic horizons (WRB Calcisols), often displaying gley pedofeatures (mottling, iron-manganese nodules) in relation to the poor drainage of the soils (WRB Gleyic Calcisols). The loamy-sandy soils of the adjacent fluvial ridges have leached epipedons but, depending on the local hydro-topographic conditions, do not always have Bk horizons and are classified as WRB Hypereutric(-Gleyic)-Cambisols. On the sandy channel deposits located in well-drained position on fluvial ridges, there are evidences of decarbonation of the top horizons, occasionally with traces of clay illuviation in the Bt/Bw horizons.

In the distal sector of the Brenta megafan the soils developed at the top of the LGM succession are often buried by Holocene deposits. In the Venice Lagoon the LGM deposits are covered by the Holocene deltaic and barrier-and-lagoon sedimentary complex. Though these sedimentary bodies may locally have erosive basal boundaries (e.g. channel scours, ravinement surface), the soils on top of LGM alluvium are largely preserved. The most known of these soils is the so-called "caranto paleosoil" (Gatto & Previatello, 1974; Mozzi et al., 2003; Donnici et al., 2011), which is characterized by well developed calcic and gley horizons on silty-clay parent material. From the geotechnical point of view the caranto is regarded as an "overconsolidated clay", as soil horizons are particularly stiff (in the average 3-5 kg/cm^2) if compared to overlying and underlying layers. This geotechnical property makes the caranto palaeosoil relatively easy to be recognized in cores, penetrometric tests and seismo-acoustic soundings (Stefanon, 1980; McClennen & Ammerman, 1997; Zecchin et al., 2009), thus allowing for reliable stratigraphic correlation and mapping. In fact, it has been commonly used as the stratigraphic marker of the boundary between the Upper Pleistocene fluvial sequence and the Holocene barrier-and-lagoon deposits (e.g., Tosi, 2007a, b). The LGM plain which was buried by middle and late Holocene alluvial sediments, S and SE of Padua, also displays Calcisols and Cambisols which correlate with the caranto paleosoil (Cucato et al., 2012).

To all effects, the buried caranto palaeosoil corresponds to the post-LGM unconformity and it is in physical continuity with the soils developed on the stretches of the presently exposed LGM alluvial plain. The typical fine-grained caranto palaeosoil is easily recognized in corings due to overconsolidation, abundance of carbonate nodules and evidence of iron mottling. Where sandy parent material is present, the soil properties are far less expressed and diagnostic, thus in the cores the detection of the post-LGM unconformity is less easy and probably often underestimated (Mozzi et al., 2003).

3. DATASETS AND PROCESSING

3.1. Synopsis

In the first step of the research, a DEM of the present topography of the Brenta megafan (Fig. 2) and a

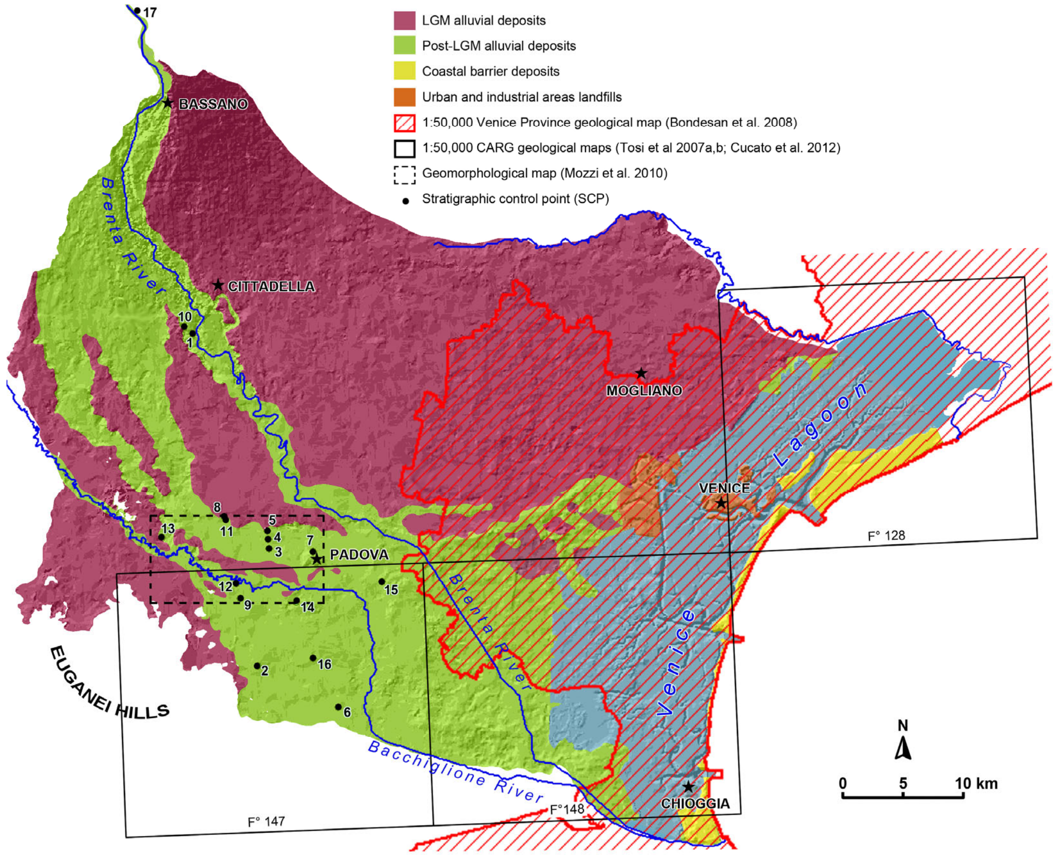

Fig. 3 - Geological sketch map of the Brenta megafan with location of SCPs (see Table 1), geological and geomorphological maps. The present Venice Lagoon is in light blue.

geological map of the LGM deposits (Fig. 3) were created. Subsequently, boreholes and sections with information on the nature and depth of burial of the post-LGM unconformity, as well as on the stratigraphy of the alluvial succession, were introduced in the Geographic Information System (GIS) as stratigraphic control points (SCP) (Fig. 3; Tab. 1). Additional information were derived from maps of the base of post-LGM sediments in the Venice Lagoon and its mainland (Tosi et al., 2007b; Primon & Fontana, 2008) (Fig. 4). Different correlation and interpolation methods were applied for modeling the unconformity in the pedogenized interfluves and in IVs. GIS operations were carried out using Microsoft Excel™ for calculation, ArcGIS 10.0™ for digitizing and interpolation of spot heights, and IDRISIgis™ for interpolation, filtering, and feature extraction. Processing procedures were carried out in a raster dataset with cells of 30 m.

3.2. The Digital Elevation Model

The DEM of present topography was produced within a collaborative project of the Department of Geography of the University of Padova and the Environmental Protection Agency of the Veneto Region (ARPAV), regarding the whole Venetian plain. The Ve-

SCP #	Unconformity type	Unconformity elev. (m asl)	Depth from surface (m)	Sediments above unconformity	Longitude (WGS84)	Latitude (WGS84)	Surface elev. (m asl)	Observation type	References
1	Erosive	22,5	4,3	Gravel	11°45'22.4"	45°34'56.0"	26,8	Section	Pellegrini et al., 1984
2	Buried soil	6	3,5	Overbank fines	11°48'54.8"	45°19'34.5"	9,5	Core	Cucato et al., 2012
3	Erosive	6	7,9	Sand with gravel	11°49'49.5"	45°25'45.0"	13,9	Core	Mozzi et al., 2010
4	Erosive	3	10,3	Sand with gravel	11°49'52.6"	45°24'56.5"	13,3	Core	Mozzi et al., 2010
5	Erosive	3	10,5	Sand with gravel	11°49'51.2"	45°25'22.4"	13,5	Core	Mozzi et al., 2010
6	Buried soil	1,5	3	Overbank fines	11°54'01.1"	45°17'34.3"	4,5	Core	Cucato et al., 2012
7	Erosive	-0,5	12,4	Sand with gravel	11°52'46.7"	45°24'44.3"	11,9	Core	Iliceto et al., 2001
8	Erosive	9	6,7	Sand with gravel	11°47'02.8"	45°26'27.1"	15,7	Core	Mozzi et al., 2010
9	Buried soil	11,8	1,2	Overbank fines	11°47'52.5"	45°22'41.1"	13	Core	Cucato et al., 2012
10	Erosive	21,5	8,9	Sand with gravel	11°44'52.1"	45°35'16.6"	30,4	Core	This paper
11	Erosive	9	7	Sand with gravel	11°47'06.5"	45°26'22.5"	16	Core	Mozzi et al., 2010
12	Erosive	5	9,2	Sand with gravel	11°47'39.8"	45°23'24.4"	14,2	Core	Mozzi et al., 2010
13	Erosive	11,5	5,6	Sand with gravel	11°42'57.1"	45°25'35.8"	17,1	Core	Mozzi et al., 2010
14	Buried soil	9	1,5	Overbank fines	11°51'33.1"	45°22'27.5"	10,5	Core	Cucato et al., 2012
15	Erosive	-4,2	14,6	Sand with gravel	11°57'12.7"	45°23'13.7"	10,4	Core	Cucato et al., 2012
16	Buried soil	4,3	4,5	Overbank fines	11°52'31.4"	45°19'51.0"	8,8	Core	Cucato et al., 2012
17	Erosive	125	3	Gravel	11°42'17.9"	45°49'33.2"	128	Section	This paper

Tab. 1 - The stratigraphic control points (SCPs).

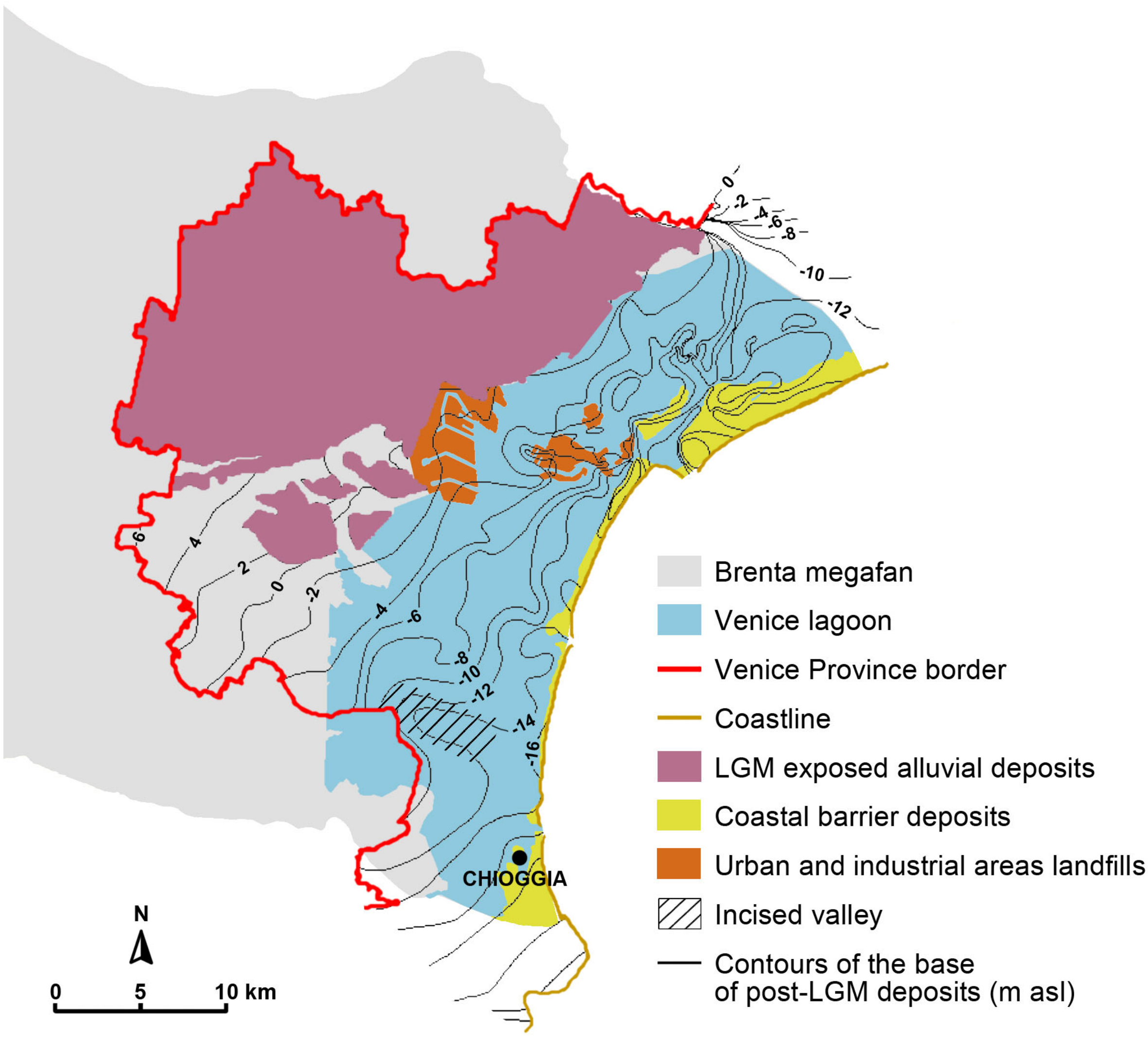

Fig. 4 - Map of the base of post-LGM sediments in the Province of Venice (Modified from Primon & Fontana, 2008).

neto Region produces maps at scale 1:10,000 and 1:5,000 (CTR - Carta Tecnica Regionale), which contain elevation points with declared range of error ±1.2 m, mostly deriving from analog stereo restitution of aerial images at average scale 1:18,000. The accuracy and density of 20-70 points per km^2 allow for a fairly detailed description of the main alluvial landforms (Castiglioni et al., 1987; Castiglioni, 1999; Castiglioni, 1997; Bondesan & Meneghel, 2004; Mozzi, 2005; Ferrarese et al., 2006; Ninfo et al., 2011). Contour lines with the spacing of 1 m for heights >5 m a.s.l., and 0.5 m in the areas below, were drawn on hard copy CTR maps. A manual interpolation was preferred to other automatic methods in the drawing of the contour lines, as this procedure allows the operator to discard all those points on modern artifacts which are regarded not to be representative of the surrounding topographic surface, such as roads and railway tracks on embankments, bridges, dikes, gravel and sand pits, farm yards, etc. The DEM was originated from interpolation of the contour lines with an optimized version of the Triangulated Irregular Network (TIN). The comparison of the CTR-derived DEM with LiDAR data in the surroundings of Padua shows that the CTR DEM provides a good approximation of the mean natural surface of the alluvial plain, even though it tends to "oversmooth" landforms (Ninfo et al., 2011). In the Venice Lagoon, the DEM results from the interpolation of 0.5-m bathymetric contours from Bondesan & Meneghel (2004).

3.3. Geological and geomorphological data

Geological and geomorphological surveys at scale 1:50,000 cover the whole distal sector of the Brenta megafan and some portions of its middle part (Bondesan & Meneghel, 2004; Tosi, 2007a, b; Cucato et al., 2012; Bondesan et al., 2008), providing indications on the extent of the LGM exposed surfaces (Fig. 3). Major fluvial landforms (e.g. fluvial scarps, incised valleys, alluvial ridges) were recognized and mapped on the DEM. Soil maps are also available in the whole study area at scale 1:250,000 (ARPAV, 2005), and scale 1:50,000 in the Venice and Padova Provinces and small parts of the

Vicenza Province (Ragazzi et al., 2004; Ragazzi & Zamarchi, 2008; Dalla Rosa et al., 2012). Routine physical-chemical analyses, chemical indexes of different iron forms (oxalate-extractable, dithionite-extractable and total iron) and micromorphological analyses of diagnostic horizons were carried out on selected soil samples during these surveys. These investigations helped in the recognition of soil chronosequences and the detection of the alluvial surfaces exposed to soil formation since LGM.

The definition of the general stratigraphic framework benefits of recent papers on the late Quaternary evolution of the Venetian-Friulian megafans and coastal areas (Amorosi et al., 2008; Fontana et al., 2008, 2010; Zecchin et al., 2009; Piovan et al., 2012) and, more specifically, of the Brenta megafan (Mozzi, 2005; Mozzi et al., 2010; Rossato et al., 2012). Maps of the depth of the post-LGM deposits in the underground of the Venice Lagoon, based on seismic soundings and corings, are provided by Tosi et al. (2007a,b). Primon & Fontana (2008) integrate these data with a large dataset of boreholes and correlate the caranto palaeosoil across the Venetian mainland, presenting the elevation a.s.l. of the post-LGM unconformity through 2 m contour lines. Cucato et al. (2012) provide indications on the thickness of post-LGM deposits in the plain S and SE of Padova, ranging between 2-5 m. Pellegrini et al. (1984) allow to identify the unconformity in the middle tract of the megafan. Data on the stratigraphy of the post-LGM valley fill and channel belts are presented in Iliceto et al. (2001), Mozzi et al. (2010) and Cucato et al. (2012). In SCP 10 (Fig. 3 and Tab. 1) the unconformity was recognized basing on lithofacies changes and its elevation is fully consistent with nearby SCP 1 from outcrop data (Pellegrini et al., 1984). SCP 17 is located in the terminal tract of the Brenta valley, where the post-LGM fluvial deposits directly lie on the limestone bedrock.

3.4. Subsurface data processing

The contour lines of the base of the post-LGM deposits from the maps of Primon & Fontana (2008) and Tosi et al. (2007b) were digitized and geo-referred (Fig. 4). The contour lines were interpolated with TIN technique, in order to produce an elevation surface of the unconformity in this distal reach of the megafan. This surface is after indicated as U_{dist}_1.

Elsewhere, the depth and nature of the unconformity (erosional vs. hiatal with soil formation) were derived from cores and stratigraphic sections (Tab. 1; Fig. 3). Each SCP provides the elevation and characteristics of the unconformity, as well as the stratigraphy of the sedimentary successions.

In the south-western corner of the megafan, the buried interfluve is limited to the N and E by IVs. Elevation data in this sector of the unconformity were provided by SCPs 9, 14, 2, and 6. The elevations of the unconformity were interpolated with an Inverse Distance Weight algorithm (IDW, applying the function $\cos^3$), which was chosen because of the relatively small dimensions of the area (221 km^2) and the even distribution of elevations. This procedure allowed to reconstruct the elevation surface of the unconformity, to which we refer as U_{dist}_2.

Upstream from Padova the incised valleys could be mapped in detail thanks to the morphological evidence of their lateral slopes. These correspond to the original fluvial scarps which are still recognizable in the DEM, even if they have been partly covered by middle and late Holocene sediments and largely remodelled by local erosive processes. Basing on the interpretation of contours in the map of Primon & Fontana (2008) (Fig. 4), it was possible to trace the floor of the IV in this very distal reach of the megafan between -10 and -16 m a.s.l. Nevertheless, a critical area is present between Padova and the northern boundary of the map of Primon & Fontana (2008): here the valleys are completely filled, loosing morphological evidence in the plain topography, and no stratigraphic data were available. The highest uncertainty concerns the valley width, which has been assumed as comparable to the upstream and downstream reaches.

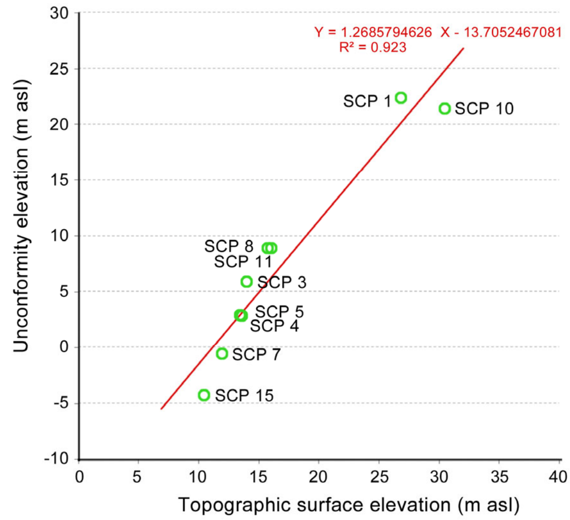

Fig. 5 - Linear regression of the elevation of the post-LGM unconformity vs. the present topographic surface in the middle reach of IV in the Brenta megafan (for location of SCPs see Fig. 3).

As regards the reconstruction of the longitudinal profiles of IVs, simple linear trends between the exposed top of the valley fill, i.e. the topographic surface in the DEM, and the unconformity elevation were calculated for each SCP.

The linear trend equation applied in the more upstream reach between SCPs 17, 10, 1 is the following:

$$U_{IV}\_1 = P_S * 1.034783306465 - 7.540390897056$$
$$R^2 = 0.998378264792$$

Where:
U_{IV}_1 = unconformity surface corresponding to the erosive valley floor upstream of SCP 1;
P_S = present topographic surface corresponding to the top of the post-LGM valley fill.

Between SCPs 10 and 1 and the cluster of SCPs in the area of Padova (Fig. 5) the equation is:

$$U_{IV}\_2 = P_S * 1.2685794626 - 13.7052467081$$
$$R^2 = 0.9229633297$$

Where:
U_{IV}_2 = unconformity surface corresponding to the ero-

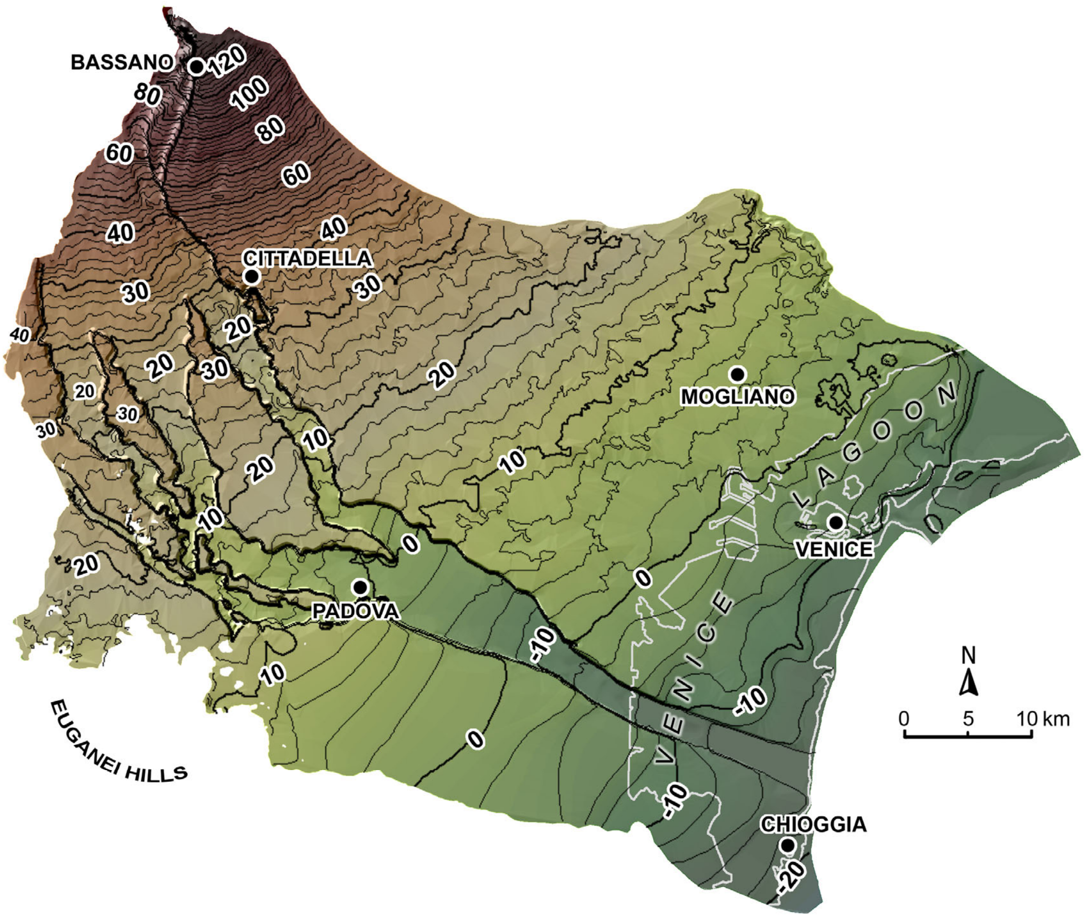

Fig. 6 - Hillshaded DEM of the post-LGM unconformity and exposed LGM deposits in the Brenta megafan, with 2-m contours. The white line indicates the margin of the present Venice Lagoon.

sive valley floor downstream of SCP 1;
P_S = present topographic surface corresponding to the top of the post-LGM valley fill.

The gradient of U_{IV}_2 was maintained downstream of SCP 15 to the intersection at -13 m a.s.l. with the floor of the incised valley recognizable in the map of Primon & Fontana (2008).

The processing of subsurface data allowed for the production of elevation surfaces relative to specific sectors of the unconformity: i. pedogenized top of LGM deposits in the interfluves (U_{dist}_1 and U_{dist}_2); ii. base of post-LGM deposits in IVs upstream of SCP 1 (U_{IV}_1); iii. base of post-LGM deposits in IVs downstream of SCP 1 (U_{IV}_2). U_{IV}_1 and U_{IV}_2 were merged with a max (maximum between two values) cell-by-cell function. The resulting DEM was then merged with U_{dist}_1 and U_{dist}_2 through a "covering" GIS operation, in order to produce the final DEM of the unconformity surface with cell size set at 30 m. This DEM was after merged with that of the outcropping LGM surface, as it can be seen in Fig. 6.

The production of the DEM of the unconformity allowed for the calculation of the volume of sediments which lie above it, separating IVs from interfluves. The operation was carried with the following work flow: i. extraction of the areas of deposition of post-LGM sediments on interfluves and in IVs; ii. subtraction of the elevations of the unconformity from the present topographic surface in each 30x30-m cell.

4. RESULTS AND DISCUSSION

Data processing allowed for the three-dimensional modeling of the post-LGM unconformity (Fig. 6). The low density of SCPs in the areas where isopach maps are not available represented the most problematic aspect. Nevertheless, the unconformity on pedogenized interfluves represents the buried continuation of the LGM plain, and it can be assumed that it maintains similar morphologies and regular gradient. This was checked in the U_{dist}_2 sector, where IDW interpolation proved to be effective. The recognition and modeling of the unconformity in IVs was also critical. Notwithstanding, the remarkably high correlation between the elevations of the unconformity (i.e., the bottom of the valley fill) and the topographic surface (i.e., the top of the valley fill) supports the application of linear trend equations in the interpolation procedure. In the lower reach (U_{IV}_2), where there are several SCPs, the correlation coefficient R^2 of the regression analysis is 0.923.

The post-LGM unconformity resulted to extend on

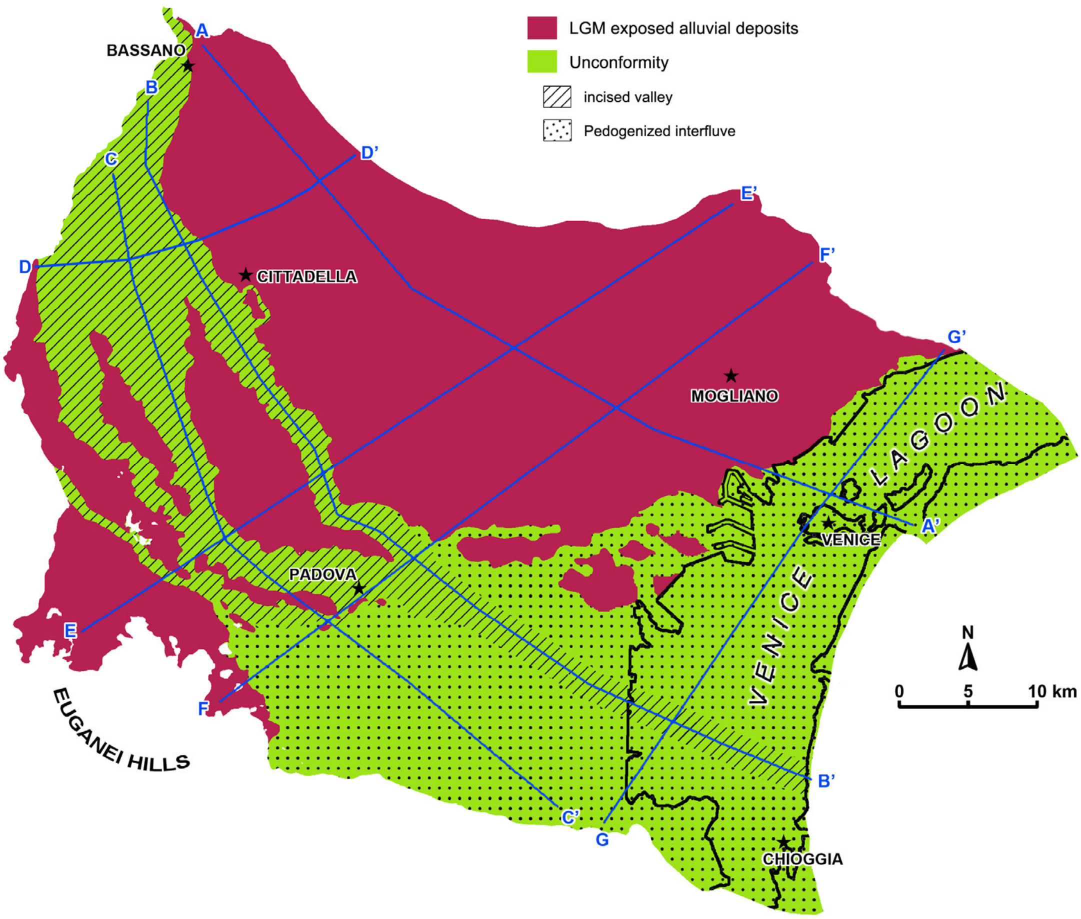

Fig. 7 - Sketch map of the post-LGM unconformity in the Brenta megafan, with location of cross sections of Figs. 8 and 9. The black line indicates the margin of the present Venice Lagoon.

Surface type	Area (km^2)	Area %	Sediments above unconformity (km^3)
Exposed LGM alluvial deposits	1427	48,9	-
Unconformity in incised valley	521	17,8	4,3
Unconformity on pedogenized interfluve	970	33,3	6,1
Total	2918	100	10,4

Tab. 2 - Extension of the post-LGM unconformity and volume of overlying sediments in the Brenta megafan.

about half of the Brenta megafan; the hiatal unconformity on interfluves represents one third of the total, while the erosive unconformity is significantly smaller (Tab. 2; Fig. 7). The total volume of sediments which lie above the post-LGM unconformity is 10.4 km3: 6.1 km^3 cover the interfluves and 4.3 km^3 fill the IVs.

The unconformity DEM evidences the continuity between the exposed LGM surface and the unconformity on the buried pedogenized interfluves (Fig. 6). In IVs, the unconformity corresponds to the erosive valley flanks and floors. Valley slopes are steep and range in height from about 20 m at the fanhead to 4-6 m in the distal sector; valley floors are rather flat and range in width around 2-6 km. This geometry is coherent with the IVs observed with good detail in the Tagliamento megafan, thanks to the availability of a large stratigraphic dataset and the marked contrast in sediment grain size of valley fills (Fontana, 2006; Fontana et al. 2008, 2012). To be noted that the Tagliamento and Piave megafans display multiple incisions in the distal sector. In the Brenta megafan this was not evident from available stratigraphic data, but the possibility that other IVs cross the distal reaches downstream of Padova cannot be excluded.

The relations between the unconformity and the present topographic surface across the megafan can be observed in the cross sections of Figs. 8 and 9. Cross section AA' and the downstream end of CC' are particularly effective in evidencing the continuity between ex-

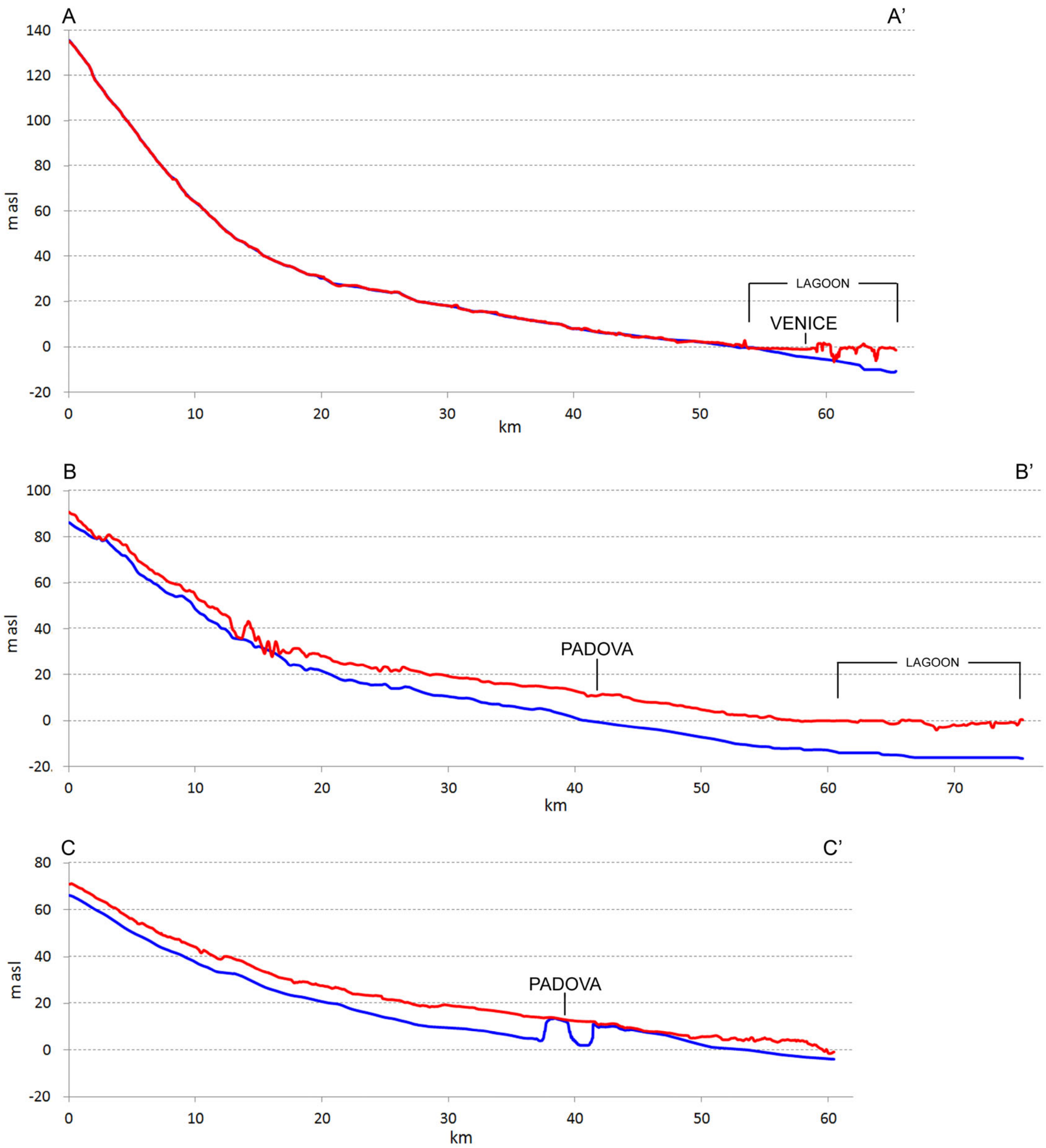

Fig. 8 - Longitudinal cross sections in the Brenta megafan, showing the present topographic surface (red line) and the post-LGM unconformity (blue line) (for locations see Fig. 7).

posed and buried LGM top surface, as well as the onlap of post-LGM coastal deposits on the interfluve unconformity.

Cross section BB' and the upper and middle portions of CC' intersect the erosive unconformity and the top surface of the sedimentary fill in IVs. In BB' it can be seen that both surfaces display a major knickpoint at around 30 m a.s.l., which corresponds to the transition from the gravelly piedmont sector to the fine-dominated lower portion. Upstream of this knickpoint both surfaces have similar gradient around 3.5‰. Downstream, the unconformity is slightly steeper (1‰) than the top surface of the valley fill (0.7‰). The unconformity keeps the same gradient below sea level and it dips to -18 m a.s.l. The present alluvial plain has a minor knickpoint around sea level, about 5 km upstream of the inner margin of the Venice lagoon, where the topographic gradient averages zero.

Cross sections represented in Fig. 9 are transverse to the longitudinal axis of the megafan. DD' evidences the convex morphology of the LGM megafan apex and the wide post-LGM incision. The overall convexity of the distributive systems is evident also in EE', which shows the almost complete infilling of IVs and their characteristic morphology with flat floor and steep slopes. Cross sections FF', GG', and the lower part of CC' document the complete infilling of IVs by post-LGM sediments, which also buried the surrounding interfluves. To be noticed that the eastern IV in FF' is significantly wider than the ones in EE'; this is due to the merging of two IVs and the slightly transverse direction of the cross section in respect to the valley.

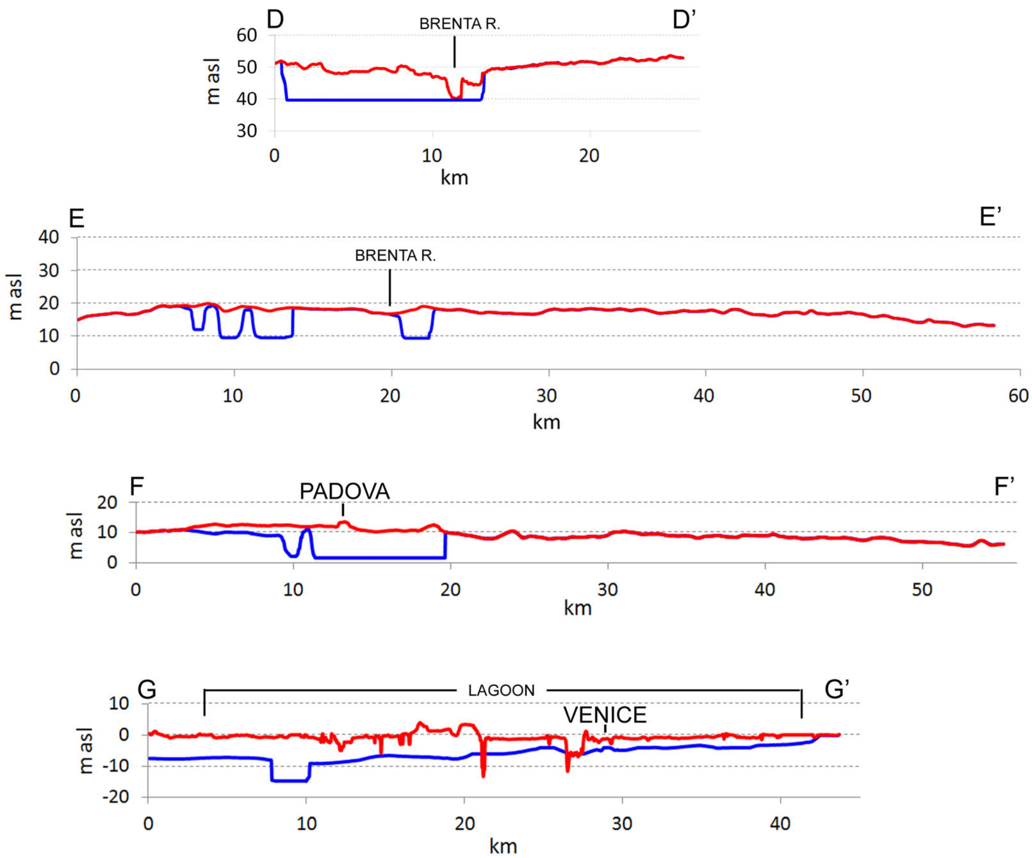

Fig. 9 - Transverse cross sections in the Brenta megafan, showing the present topographic surface (red line) and the post-LGM unconformity (blue line) (for locations see Fig. 7).

In the middle portion of the megafan, nearby Padova, the unconformity in the IVs is close to sea level (Fig. 6 and Fig. 9 - cross section BB'). This is due to the above-mentioned steeper gradient of the erosive unconformity in respect to present topographic surface, and implies that the river was related to a base level which was significantly lower than present. In fact, this is consistent with the timing of IVs downcutting, which took place not later than Late Glacial (Mozzi et al., 2010) when the Adriatic Sea was still lower than -50 m a.s.l. (Lambeck et al., 2004; Amorosi et al., 2008).

The Holocene relative sea-level rise conditioned the deposition of the coastal wedge on top of the unconformity, as evidenced at the downstream end of cross section AA', where the lagoonal sediments covering the unconformity pinch out landwards at 0 m a.s.l. Also the minor knickpoint around 0 m a.s.l. in the present alluvial plain in cross section BB' can be interpreted as the response of the fluvio-deltaic system to sea level. In the most distal sector, the unconformity is buried by barrier-and-lagoon deposits, which are up to 25 m thick, as evidenced in cross section GG'.

5. CONCLUSIONS

The interpolation and linear regression of stratigraphic and topographic data in the Brenta megafan resulted in the production of the DEM of the post-LGM unconformity from the eastern Southalpine piedmont to the Adriatic coast. This means that the depth of burial, the elevation a.s.l., and the nature (erosive vs. hiatal with soil formation) of the unconformity were mapped on a 30x30-m grid base on an area of ca. 3000 km^2. The reconstructed unconformity surface is coherent with local stratigraphic settings, showing the consistency of processing procedures. Nevertheless, the accuracy of results is evidently related to the number and geographic distribution of available SCPs. Thus, in the piedmont and medium sector of the megafan, it was possible to check the model only in few sites. Moreover, from Padova to the margin of Venice Lagoon the estimation of the width and precise path of the IV was only hypothesized.

Morphometric analysis of the DEM enabled to evaluate the gradients of the unconformity in long and transverse profiles, as well as to calculate its overall extension (1491 km^2), the areas where it is characterized by buried soils (970 km^2), and those where it corresponds to an erosive surface in IVs (521 km^2). The subtraction of the DEM of the unconformity from the present topographic surface allowed for the first calculation of the volume of post-LGM alluvial and coastal sediments (10.4 km^3), differentiating those which bury the interfluves (6.1 km^3) from IVs fills (4.3 km^3).

The three-dimensional modeling of this surface proved to be a valuable aid for the analysis of the forcing of sea level on the post-LGM progradation of the

Brenta megafan. The results evidence the correlatability of the unconformity across a wide distributive alluvial system and connected deltaic and barrier-and-lagoon systems. The method can potentially be applied to neighboring megafans of the Venetian-Friulian and eastern Po Plain and extended offshore to the tip of the deltaic systems. This provides a tool for basin-scale stratigraphic correlations and quantitative estimate of erosive processes and sedimentary storage during the post-LGM on the northern Adriatic shelf.

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