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ALLUVIAL PLAIN FORMATION DURING THE LATE QUATERNARY BETWEEN THE SOUTHERN ALPINE MARGIN AND THE LAGOON OF VENICE (NORTHERN ITALY)

ABSTRACT: MOZZI P., *Alluvial plain formation during the Late Quaternary between the Southern Alpine margin and the lagoon of Venice (Northern Italy).* (IT ISSN 1724-4757, 2005).

The geomorphology of the central Veneto plain has been analysed using a high-resolution DEM, remote sensing and field survey. The study area consists of three alluvial megafans: the Montebelluna megafan (Piave River, pre-LGM); the Nervesa megafan (Piave River, LGM - Upper Holocene); the Bassano megafan (Brenta River, LGM). The gravelly, cone-shaped, steep (0.8-0.4%) Montebelluna megafan outcrops just in the piedmont sector, as its distal reaches are buried by the Bassano and Nervesa megafans. These latter extend from the Southern Alps piedmont to the lagoon of Venice. Within a distance of 10-15 km from the Prealpine foothills, their apical parts are cone-shaped and rather steep (0.6-0.3%), consisting mainly of gravels. Through a gradual transition, the distal parts become markedly less steep (reaching values ≤ 0.1%) and articulated in systems of fluvial ridges and elongated depressions. The ridges are generally ≤ 1 km wide and several km long. They are mainly composed of sandy deposits, while the depressions are silty-clay.

The most significant erosive landforms are related to: i) the head trenching of the Bassano megafan, which probably took place at the end of the LGM because of a disequilibrium between solid and liquid discharges of the Brenta river, related to the de-glaciation of the mountain catchment; ii) the downcutting and lateral erosion of the eastern lobe of the Montebelluna megafan during the Upper Pleistocene and the Holocene, due to the tectonic uplift of the piedmont sector between the Aviano and Sacile faults.

Active tectonics at the buried Southern Alpine thrust front led to the faulting of the apical portions of the Montebelluna, Nervesa and Bassano megafans, with the formation of tectonic scarps. Geomorphological evidence of a south-west tectonic tilting of a relict alluvial surface is also detectable in the distal fringes of the Bassano megafan.

KEY WORDS: Alluvial plain, Fluvial megafan, Morphotectonics, Deglaciation, Venetian plain.

RIASSUNTO: MOZZI P., *Evoluzione tardoquaternaria della pianura alluvionale posta tra il margine alpino e la laguna di Venezia (Italia Settentrionale).* (IT ISSN 1724-4757, 2005).

Lo studio del microrilievo e di immagini aerofotografiche e satellitari, accompagnato dal rilevamento di terreno e da analisi sedimentologiche e stratigrafiche, hanno permesso di delineare le caratteristiche geomorfologiche dei principali sistemi alluvionali della pianura veneta centrale: il megafan di Montebelluna (Fiume Piave, pre-LGM); il megafan di Nervesa (Fiume Piave, LGM - attuale); il megafan di Bassano (Fiume Brenta, LGM). Il megafan di Montebelluna è costituito da depositi ghiaiosi e ha pendenze dello 0,8-0,4%; affiora solo nell'area pedemontana, dato che le sue propaggini distali sono sepolte dai megafan di Bassano e Nervesa. Questi ultimi si estendono dalle Prealpi fino all'area circumlagunare veneziana. Per una distanza di 10-15 km dal margine prealpino sono costituiti prevalentemente da ghiaie, hanno forma conoidale e pendenze comprese tra 0,6-0,3%. Più a valle, al di sotto della fascia delle risorgive, si articolano in bassi dossi fluviali, prevalentemente sabbiosi, con larghezze generalmente ≤ 1 km e lunghezze fino a decine di chilometri, separati da depressioni di forma allungata con granulometrie limoso-argillose; le estreme porzioni distali hanno gradienti ≤ 0,1%.

Le forme di erosione fluviale più significative sono: i) le scarpate poste all'apice del megafan di Bassano, sviluppatesi alla fine dell'LGM probabilmente a causa di un disequilibrio tra portate solide e liquide correlabile alla deglaciazione del bacino montano; ii) le scarpate presenti nel lobo orientale del megafan di Montebelluna, formatesi per incisione fluviale in risposta all'innalzamento tettonico del settore pedemontano compreso tra la linea di Aviano e quella di Sacile durante il Pleistocene Superiore e l'Olocene.

L'attività dei sovrascorrimenti sud-alpini ha portato alla formazione di scarpate tettoniche di alcuni metri nelle porzioni apicali dei megafan di Montebelluna, Nervesa e Bassano. Vi sono, inoltre, evidenze geomorfologiche di un basculamento verso sud-ovest delle porzioni distali del megafan di Bassano.

TERMINI CHIAVE: Pianura alluvionale, Megafan alluvionali, Morfotettonica, Deglaciazione, Pianura Veneta.

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My investigations in the Central Veneto plain started as a PhD thesis, and continued thanks to the Italian Ministry of Research MURST Projects 1996 and 1997 «The response of geomorphological processes to environmental changes», the soil mapping projects of the Environmental Protection Agency of the Veneto Region (ARPAV), the geomorphological survey at scale 1:50,000 of the Province of Venice, the geoarchaeological project sponsored by Fondazione Cassamarca at Ca' Tron. G.B. Castiglioni introduced me to the study of alluvial plains, and has always provided scientific support. I am in debt with him, and with friends and collegues of the Department of Geography of the University of Padua and ARPAV - Osservatorio Regionale Suolo, for the discussion of several of the data and ideas presented in this paper.

INTRODUCTION

This paper concerns the geomorphology of a stretch of the Veneto plain (eastern Po Plain), comprised between the foothills of the Venetian Alps and the lagoon of Venice, the Brenta river to the West and the Piave river to the East (figs. 1 and 2). It is meant as a contribution to the discussion on unconfined alluvial plain formation, resulting from the complex interaction of fluvial processes and allocyclic forcings (i.e., climatic change, sea-level fluctuations, active tectonics), on time scales 10^3-10^4 years.

THE GEOLOGICAL FRAMEWORK

The central Veneto plain represents the top of the Tertiary to Quaternary sedimentary infilling of a sector of the Southern Alps backthrust foredeep (Massari & *alii*, 1986; Massari, 1990), involved since the Upper Pliocene in the Southern Alpine thrusting. The present alpine thrust front is buried under the piedmont alluvial plain Quaternary deposits (Zanferrari, 1978; Pellegrini & Zanferrari, 1980) (fig. 1). The more external parts of the Southern Alps foredeep, corresponding to the monoclinal tectonic structure of the lower Veneto plain (Pieri & Groppi, 1981), have

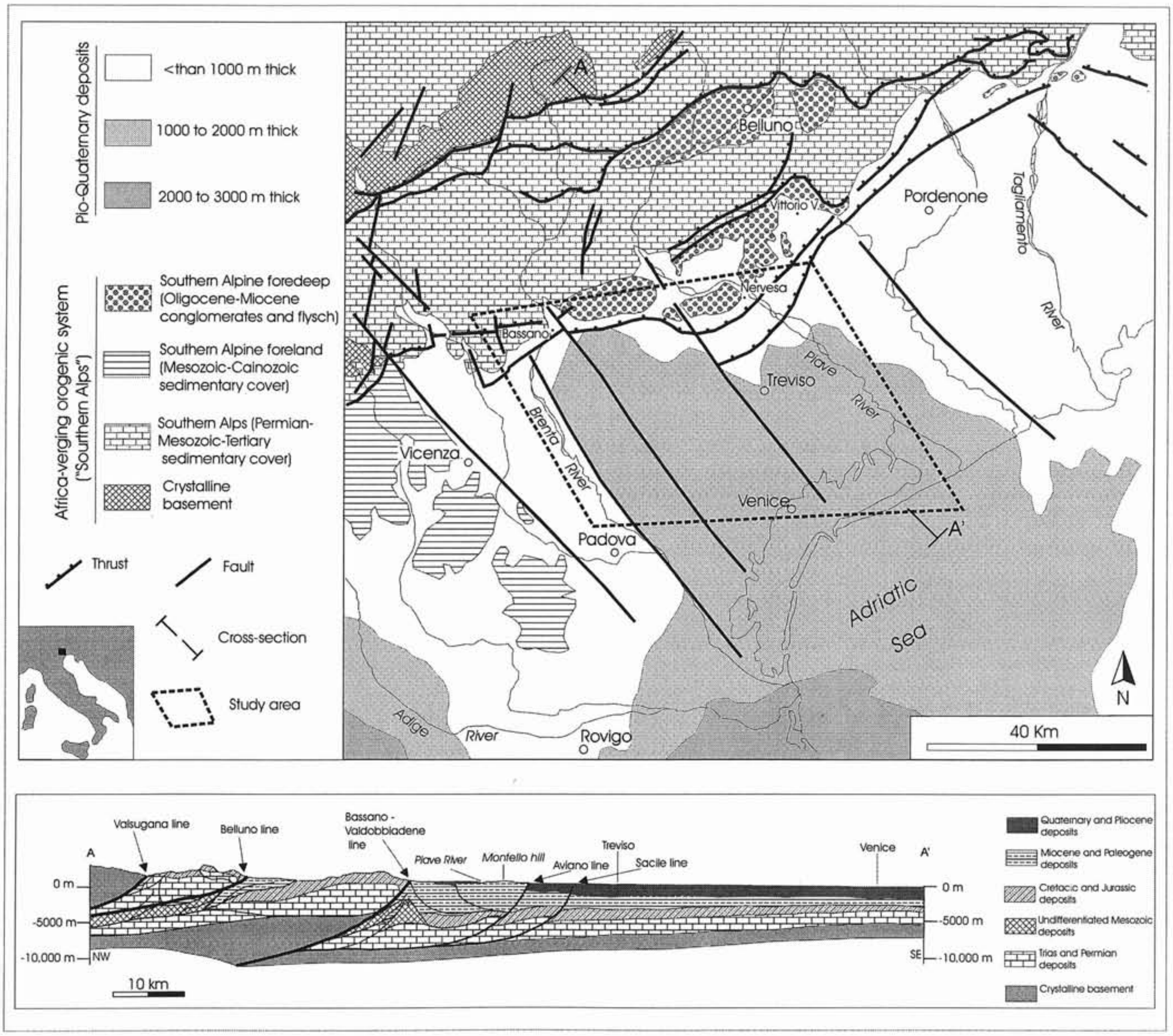

FIG. 1 - Geological sketch of central Veneto area, with geological cross-section (after Regione del Veneto, 1990, and Gasperi, 1997, modified).

been influenced since the Upper Miocene by the activity of the northward expanding Apennine foredeep, being thus subjected to southward tilting (Doglioni, 1993). In this geodynamic framework, the study area was involved in vertical tectonic movements throughout the Late Quaternary (Zanferrari & *alii*, 1982; Slejko & *alii*, 1987). The piedmont area has been uplifting (Pianetti & Zanferrari, 1980), while, further South, subsidence, also driven by sediment compaction, was continuous (Fontes & Bortolami, 1972; Bortolami & *alii*, 1977; Zanferrari & *alii*, 1980; Bortolami & *alii*, 1984; Carbognin & *alii*, 1984; Bondesan & *alii*, 2001; Carbognin & Tosi, 2003).

During the last glaciation, as well as during previous Quaternary glaciations, the Alps North of the study area hosted an extensive system of valley glaciers (Penck & Bruckner, 1909; Castiglioni, 2004). During the Last Glacial Maximum (LGM), the lower portion of the Piave glacier was divided in two main branches: an eastern one followed the Val Lapisina and reached the plain near Vittorio Veneto, North-East of the study area; a western one followed the present-day Piave valley and built frontal moraines within the valley some kilometres from the plain (Casadoro & *alii*, 1976; Venzo, 1977; Pellegrini & Surian, 1994). Poor preservation of glacial deposits in the narrow, locally canyon-like, Brenta valley has, up to now, not allowed the identification of the exact location of the LGM Brenta glacier frontal moraines. All studies undertaken agree that the glacier did not reach the plain, and most probably ended near Valstagna, about 10 km upstream of the valley mouth at Bassano del Grappa (Trevisan, 1939; Dal Piaz, 1946; Bartolomei, 1999; Cucato, 2003).

The LGM glacio-eustatic sea lowstand brought the whole northern Adriatic shelf to continental conditions. At 21,000-18,000 BP, the alluvial plain extended about 300 km South of the present Venetian coastal area; only after 8,000 BP the Adriatic coastline moved North of the position now occupied by the Po delta, as a consequence of the post-glacial sea-level rise (Colantoni & *alii*, 1990; Tosi, 1994; Correggiari & *alii*, 1996). The lagoon of Venice started forming at about 6,000 BP (Favero & Serandrei Barbero, 1980; Serandrei Barbero & *alii*, 2001a; Serandrei Barbero & *alii*, 2001b).

METHODS

Due to the low relief of the study area, topographic maps do not feature contour lines. The first step in the investigation was thus the tracing of 1-m contour lines, through manual interpolation of densely scattered, 0.1 m resolution elevation points extracted from 1:5,000 scale maps of the Regione del Veneto. Only meaningful data were interpolated, whereas those positioned on artifacts (roads, artificial levees, bridges, etc.), or in areas heavily influenced by human activities, were discarded. After digitalization of contour lines, a digital elevation model (DEM) was produced with original spatial resolution of 30 m. This method allowed the detection of the so-called «micro-relief» of the plain, that is, those landforms not perceptible either in the field or in aerial photograph stereo-pairs. Quantitative analyses on altitudes and slopes of selected landforms were also performed using the DEM, dividing the data full range into classes of specified amplitude (1 m for altitudes, 0.01% for slopes) and plotting relative pixel frequencies. Masks were used in order to select the single features to be analysed, taking into consideration only surfaces located above sea level. The GIS package used was Idrisi for Windows.

Multitemporal sets of black-and-white and colour panchromatic aerial photographs, with scales ranging between 1:33,000 and 1:17,000, were used for photointerpretation. Processing of an early spring Landsat Thematic Mapper image allowed the plain surface to be analysed in the near and thermal infrared spectral bands.

Field work consisted in describing and sampling stratigraphic sections and soil profiles, outcropping during the construction of gas pipelines, houses, roads, etc. Additionally, series of boreholes were drilled by hand auger. Sediments were observed to maximum depths of 4-5 m. Whenever possible, stratigraphically meaningful organic samples were radiocarbon-dated.

GEOMORPHOLOGY OF THE STUDY AREA

The main fluvial landforms

The study area comprises the Late Quaternary sedimentary systems of two rivers of Alpine origin, the Brenta and the Piave (Comel, 1955; Comel, 1964; Castiglioni, 1969; Broglio & *alii*, 1987; Mozzi, 1995; MURST, 1997; Bondesan & *alii*, 2002), whose watersheds cover most of the Dolomiti region. These alluvial systems have been recognized as being similar to the so-called «megafans» of the Indogangetic plains (Goahin & Parkash, 1990; Stanistreet & McCarthy, 1993; Blair & McPherson, 1994). Such terminology has been introduced in recent geomorphological works in the region (Mozzi & *alii*, 2003; Fontana & *alii*, 2004), and is used in this paper.

The north-western sector of the study area is occupied by the apical portion of the Bassano megafan (fig. 2), the existence of which was already known since early investigations in the Venetian plain (Taramelli, 1882; Dal Piaz, 1912; Trevisan, 1941; Comel, 1964). Deposits consist mainly of sequences of stacked gravel channel bodies with lenses of coarse sands, passing from coarse gravels with blocks in the uppermost tract, to fine gravels in the downstream reaches. Over a few-kilometres-wide transition belt, this relatively undifferentiated, convex, steep surface passes to a less steep sector composed of NW-SE and WNW-ESE-trending systems of sandy fluvial ridges, several kilometres long, separated by silty clay areas.

In several sites scattered in the distal parts of the megafan, peat layers incorporated in the fluvial series, at depths ranging between 1 and 20 m, have recently been ^{14}C dated, with maximum and minimum ages respectively 22,000 and 14,500 BP (Bondesan & *alii*, 2002). The positive correlation between increasing ages and burial depths

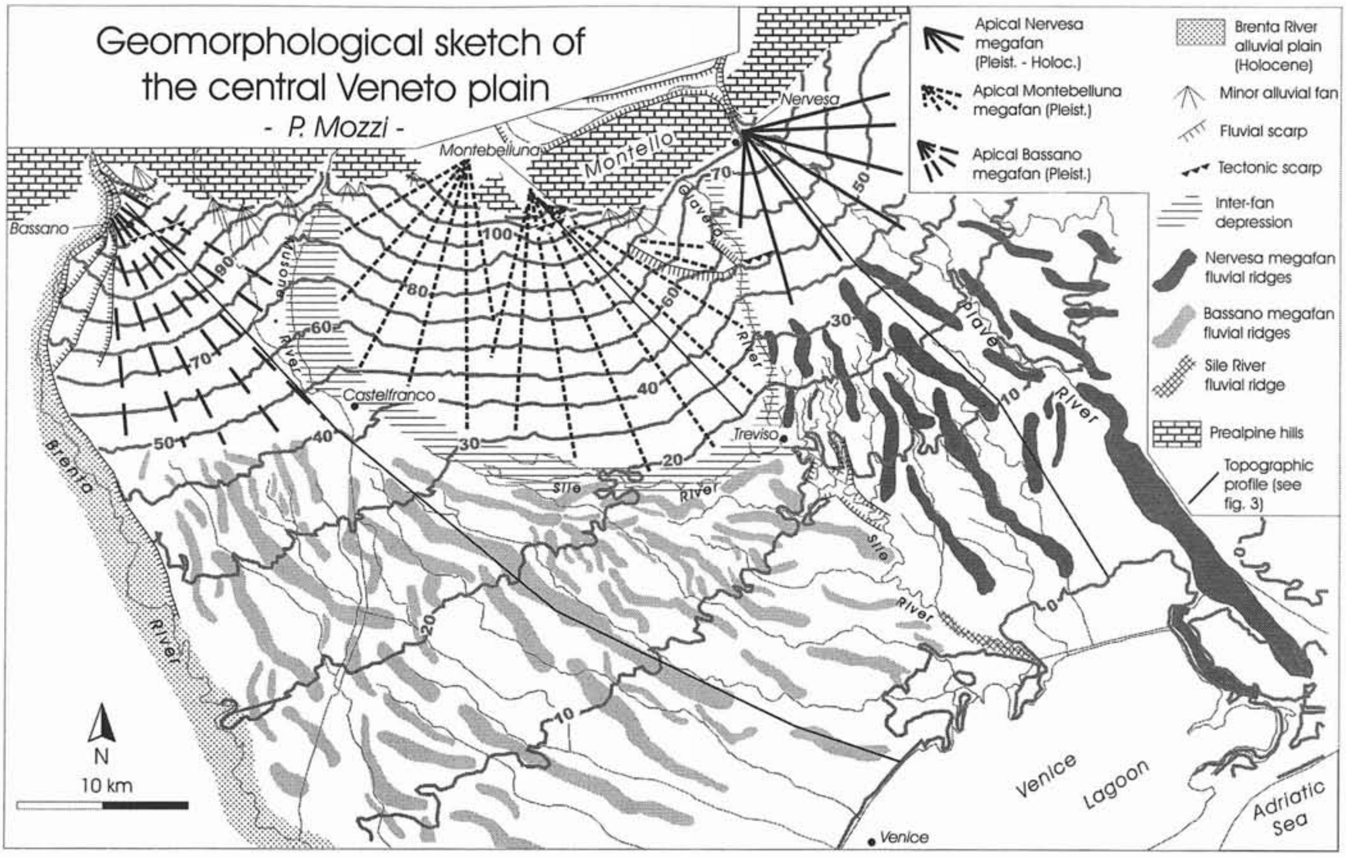

FIG. 2 - Geomorphological sketch of central Veneto plain, derived from the analysis of micro-relief, interpretation of aerial photographs and satellite images, and field survey.

of these peat deposits is indicative of a general vertical aggradation of the megafan in this time interval. The last dated depositional event, which built the present surface of the Bassano megafan, took place at about 14,000 BP; the following de-activation of the megafan was due to the fan-head trenching at the Brenta valley mouth near Bassano (for a discussion on the causes and timing of this incision, see the following paragraph «The role of climatic change...»). The erosional scarp related to the river downcutting is about 15 m high at the megafan apex, and decreases gradually until it disappears about 25 km downstream (fig. 2). Where the scarp is present, the Holocene Brenta floodplain lies at its foot; further downstream, the Holocene deposits cover the Upper Pleistocene surface (Castiglioni, 1982; Castiglioni & Pellegrini, 1981; Pellegrini & *alii*, 1984; Castiglioni & *alii*, 1987; Iliceto & *alii*, 2001). Other 2-4 m high scarps are located in the apical portion of the Bassano megafan, creating a flight of three major terraces with a rolling topography evident in the micro-relief. A 2-3 m deep incision of a single, 300 m wide channel may also be observed on the surface of the middle terrace in the micro-relief.

The eastern part of the study area is occupied by the Nervesa megafan, with its apex located at the final debouch of the Piave river into the plain, at Nervesa della Battaglia. The present-day course of the Piave river lies in the middle of the megafan. The convex apical portion is mainly gravelly. As observed in the Bassano megafan, here, too, there is a downstream transition to less steep distal tracts, characterized by sandy fluvial ridges within muddy floodplain. The maximum longitudinal extension of the Nervesa megafan from its apex to the present-day river mouth into the Adriatic is about 50 km. The lowermost, north-south segment of the Sile river may be regarded as the boundary between the distal tracts of the Bassano and Nervesa megafans. In this stretch, the springwater-fed Sile river flows first in an incised valley (with scarps of maximum 5 m), and then on top of a low fluvial ridge. Chronostratigraphic data indicate that this incision took place between ca. 7,500 and 3,500 BP: between 3,500 and 3,000 BP the Piave river followed this depression (Mozzi, 1998; Mozzi & Bondesan, 2003). The ridge consists of very fine sand and silt deposited by the Sile river during the last 2,000-3,000 years, possibly with occasional contributions of the Piave river.

As regards the age of the Nervesa megafan, a Middle to Late Holocene age can tentatively be accepted for the surface of the central sector of the Nervesa megafan (Giandon & *alii*, 2001; Ragazzi & *alii*, 2004; Bondesan & Furlanetto, 2004). Without human control, the Piave river would recurrently flood large sectors of the megafan, as happened when artificial levees broke during the last large flood of 1966 (Mattana, 1973), so these can be considered as «active» floodplains. On the other hand, in the south-western distal sector of the megafan, by the shores of the lagoon of Venice (Ca' Tron area), recent investigations have shown that the alluvial plain has an LGM age (the uppermost 20 m of sediments have been deposited between 22,000 and 17,000 BP) (Bondesan & Mozzi, 2002; Mozzi & Bondesan, 2003). The Nervesa megafan surface formed, thus, in different times since the Upper Pleistocene to present day.

Between the Bassano and Nervesa megafans lies a third large megafan, subdivided in two minor bodies with apexes located respectively, from West to East, in the Caerano and Biadene valleys. This steep, composite megafan («Montebelluna megafan») consists only of gravel deposits. It was built by the Piave river when it reached the plain on the western side of the Montello hill, rather than on the eastern side as it now does (Dal Piaz, 1942; Comel, 1955; Venzo, 1977). This change in the river direction (which took place outside of the study area and will not be discussed in this paper) is possibly related to the uplifting of the Montello hill, which is an active anticline on the top of the south-verging Aviano thrust, folding Messinian conglomerates (Venzo, 1977; Zanferrari & *alii*, 1982; Ferrarese & *alii*, 1998). The Montebelluna megafan is bounded on both sides by two elongated inter-fan depressions drained by the Musone (to the West) and Giavera (to the East) rivers. To the South, it abruptly terminates in an approximately W-E oriented depression, at the bottom of which the Sile river has its sources. Both the geomorphology and subsurface stratigraphy indicate that the south-western and southern fringes of the Montebelluna megafan are buried by the middle and distal portions of the Bassano megafan, and that the same occurs in the south-eastern lower reaches, buried by the Nervesa megafan (Bondesan & *alii*, 2002). What was not buried by the Brenta and Piave deposits corresponds to the megafan apex. The Montebelluna megafan is thus the oldest depositional surface in the study area; it can tentatively be considered older than 30,000 BP, thus of pre-LGM age, but probably still within the Upper Pleistocene (Bondesan & *alii*, 2002).

Traces of abandoned river channels are common in these three megafans, even though they are not represented in the geomorphological sketch of fig. 2 because of its small scale. Braided river channels are very abundant in the Montebelluna megafan and in the apical portions of the Nervesa megafan. In the western sector of the Montebelluna megafan they are quite homogeneously distributed on the plain surface, whereas in the central and eastern sectors they are organized in 1-2 km wide belts, elongated along the maximum slope. In the Nervesa megafan, discrete braided channel belts also occur. Braided channels have also been observed in the apical portion of the Bassano megafan, but the overall channel network is markedly less dense than in the case of the Montebelluna and Nervesa megafans. Single-channel abandoned river beds, slightly pensile over the plain, are common in the distal part of the Bassano megafan (Mozzi, 2004). They have markedly low sinuosity values, not exceeding 1.2, and widths of 130-350 m. Very similar palaeochannels exist also in the LGM portions of the Nervesa megafan (Bondesan & Mozzi, 2002), while, in the Holocene sectors, palaeochannels are meandering, with sinuosity varying between 1.4 and 1.8, but in some cases reaching a value of 2.8.

Topographic profiles across the Bassano, Nervesa and Montebelluna (eastern lobe) megafans are shown in fig. 3 (for locations, see fig. 2). In the normal profiles (upper graphic), the Nervesa megafan is slightly convex from its apex down to an altitude of approximately 30 m; the Montebelluna megafan is also very weakly convex in its central portion, approximately between 80 and 40 m. Instead, the Bassano megafan is overall homogeneously concave. Other features visible in the topographic profile are the very steep upper portion of the Montebelluna megafan, down to an altitude of about 105 m, and the step between 122 and 116 m in the Bassano megafan. The plotting of the topographic profiles in semi-logarithmic scales (lower graphic) enhance slope variations in the more distal stretches of the megafans. It outlines the presence of two knickpoints in the Bassano megafan, respectively at altitudes 8 and 2 m a.s.l., bounding a higher-gradient portion of the plain. The Nervesa megafan shows no evident knickpoints.

DEM processing was carried out in order to build frequency distribution curves of altitudes and slopes of the megafans (figs. 4 and 5). The altitude distribution curve of the Bassano megafan (fig. 4) is unimodal, with a well-defined peak at 15 m, but largely asymmetric. The curve of the Montebelluna megafan is again unimodal, the peak being spread around 60 m. The Nervesa megafan curve shows a slightly bimodal tendency, the main peak being at 5 m and the secondary peak at 55 m. The slope distribution curve of the Montebelluna megafan (fig. 5) is markedly unimodal, with most values concentrated in the 0.4-0.8% interval and the peak around 0.6%. The Nervesa and Bassano megafan curves are slightly bimodal, the Nervesa megafan showing a main peak at 0.07% and a secondary peak at 0.35%; the Bassano megafan shows a main peak at 0.1% and a secondary peak, better outlined than that of the Nervesa megafan, at 0.5%.

Landforms related to active tectonics

The surface of the Bassano megafan apex is crossed by a WSW-ENE-oriented scarp, evident in the micro-relief of the plain as a step about 6 m high in the gradually sloping plain (figs. 2, 3 and 6). Its orientation is obviously not consistent with the prevalent directions of the Brenta fluvial landforms, but it is consistent with the general trend of the Southern Alpine thrusts front buried in the Prealpine piedmont area (fig. 1). This landform has already been interpreted as a tectonic scarp by previous authors (Favero & Grandesso, 1982; MURST, 1997; Tellini & Pellegrini, 2001) and as such will be considered here. Evident in the

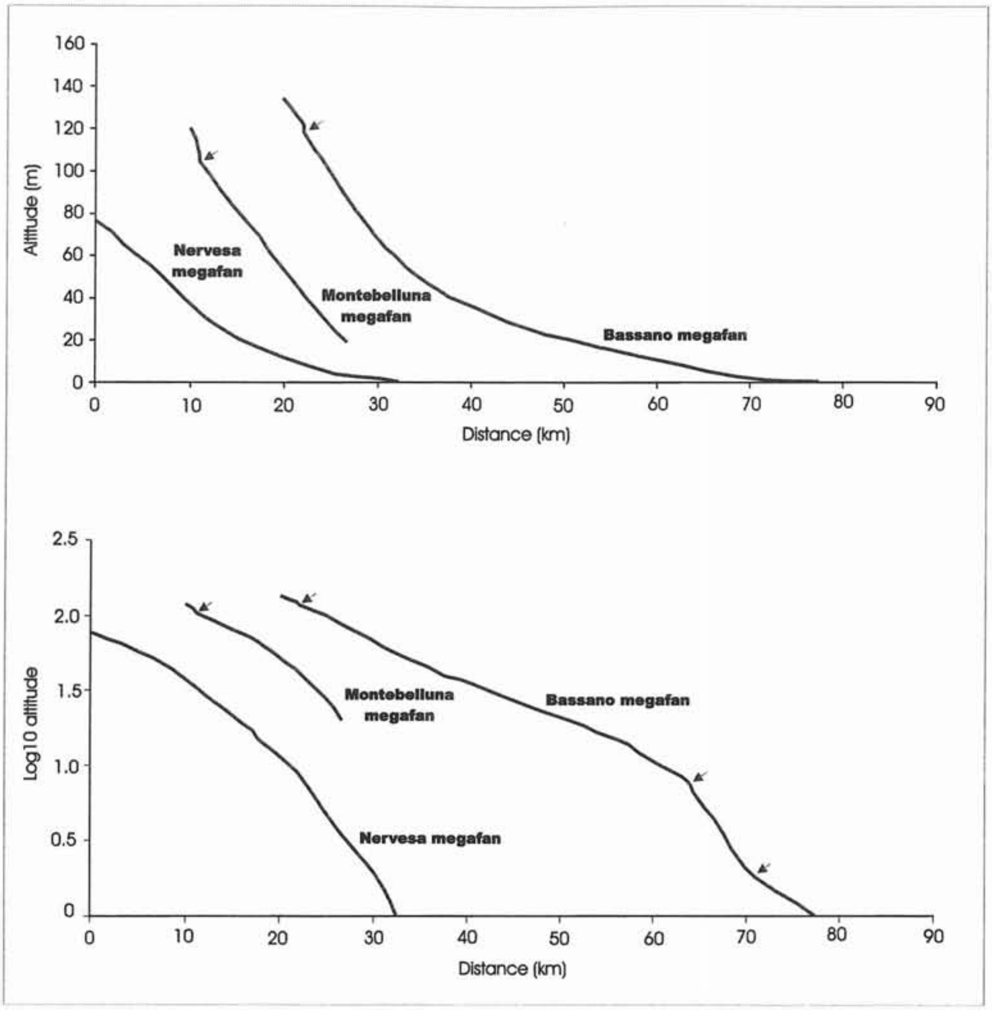

FIG. 3 - Longitudinal topographic profiles across the Nervesa, Montebelluna and Bassano megafans, in normal and semi-logarithmic scales (for location, see fig. 2). Arrows indicate knickpoints and anomalous slopes.

lower part of fig. 6 is also another apparent scarp. This latter is one of the several «false scarps» created during contour interpolation, due to systematic biases in the photogrammetric acquisition of the elevation spots in neighbouring maps. In fact, it lies exactly at the junction between two sheets of the 1:5,000 topographic map used in the elaboration.

An anomalous alluvial plain slope occurs in the distal fringes of the Bassano megafan. The slope increase between altitudes 8 and 2 m a.s.l., observable in the semi-logarithmic topographic profile of fig. 3, may represent a tectonic disturbance of the relict surface. In this regard, Castiglioni (1997) postulated the existence of active tectonics affecting the whole plain between the low Sile river and the inland of Venice, crossed by the topographic profile: interpreting the misfit of the springwater-fed drainage network with the orientation of the actual line of maximum slope of the plain, he suggested south-west tilting of the distal surface of the Bassano megafan, with relative vertical displacement of more than 9 m on a distance of about 30 km. The geological structure under this sector of the plain is a relatively undisturbed monocline crossed by a strike-slip fault (fig. 1); plain tilting may be related to differential subsidence of tectonic blocks.

A sharp slope increase exists at the eastern apex of the Montebelluna megafan (figs. 2, 3 and 7). This area approximately corresponds in depth to the Aviano fault, which runs at the foot of the Montello hill (see fig. 1). Such a morphology can be interpreted as another WSW-ENE-oriented tectonic scarp, due to the thrust uplift. The geomorphic result of tectonic activity on the relict plain surface is best detectable at the opening of the Biadene valley, because at the foot of the Montello evidence is masked by colluvial deposits and small alluvial fans of streams coming from the hill.

An important W-E fluvial scarp, about 8 m high, 500 m wide and 4 km long, can be recognized on the surface of the Montebelluna megafan (figs. 2 and 8). This indicates that fluvial incision of the fan took place before the deposition of the eastern lobe of the megafan, creating a divergent terrace, as the scarp height increases downstream. What is remarkable is that immediately to the East of the

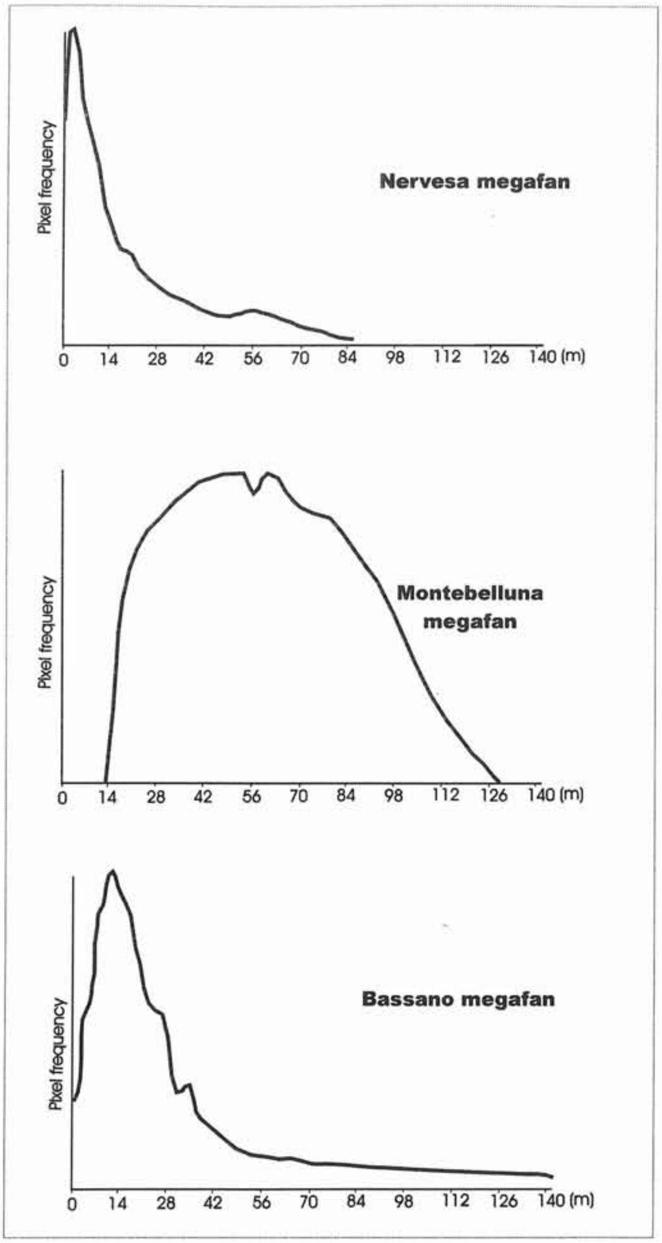

FIG. 4 - Frequency distribution curves of altitude classes (1 m) in Nervesa, Montebelluna and Bassano megafans, derived from processing of the digital elevation model.

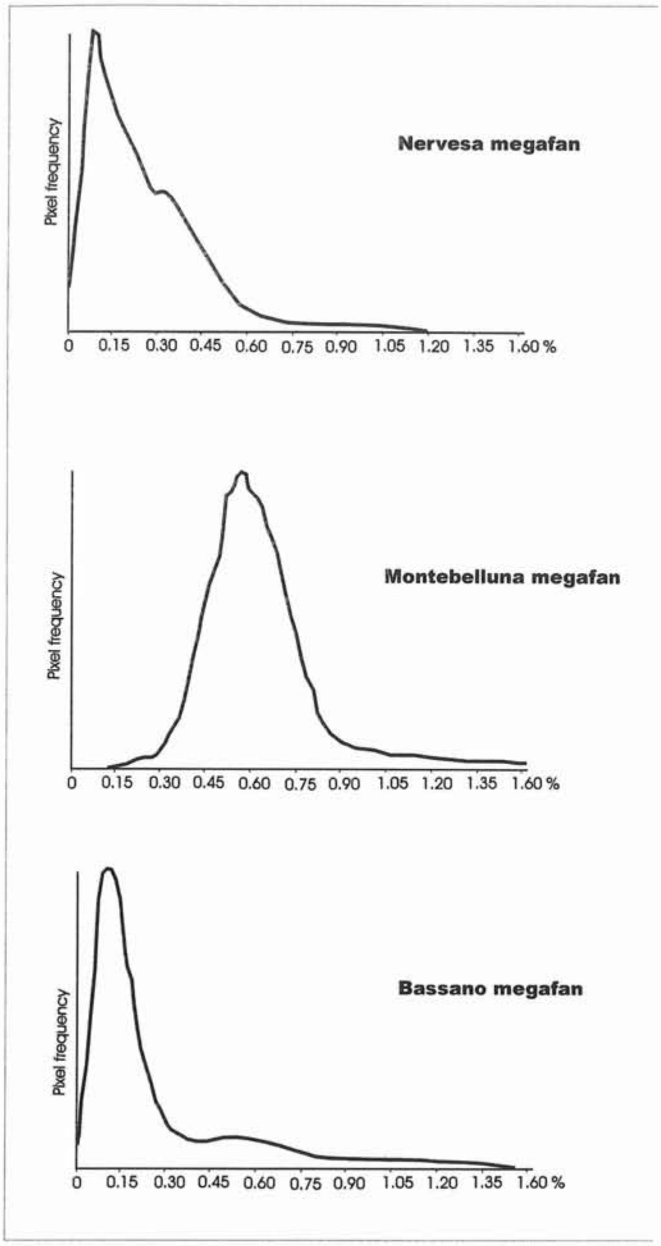

FIG. 5 - Frequency distribution curves of slope classes (0.01%) in Nervesa, Montebelluna and Bassano megafans, derived from processing of the digital elevation model.

inter-fan depression followed by the Giavera river, a smaller scarp, about 3 m high, with the same orientation is also present in the Nervesa megafan (figs. 2 and 8); here, evidence in the microrelief is limited, but a ground check confirmed its existence (F. Ferrarese, personal communication). The direction and morphology of this scarp cannot be related to fluvial processes and this latter seems, again, the expression of a tectonic displacement of the plain surface. Other evidences to be noted are that: i) fluvial erosion also took place on the eastern side of the Montebelluna megafan, due to the activity of the Giavera river and, possibly, of former branches of the Piave river, leading to the formation of a NNW-SSE scarp which terminates at the junction with the W-E scarp; ii) in correspondance of the northern termination of the NNW-SSE scarp, there is an anomalous slope decrease in the Nervesa megafan surface. Overall, such a situation seems to indicate a complex tectonic disturbance of the plain surface, consistent with the presence of the buried, active thrust front (Sacile Line) in this same area (see fig. 1). The cutting of

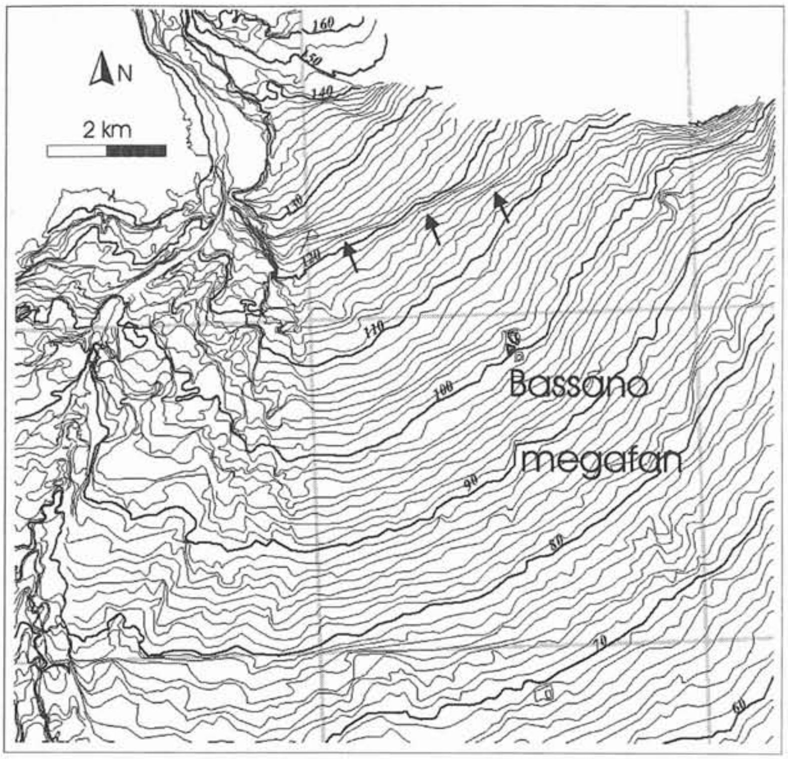

FIG. 6 - Micro-relief map of the apical portion of the Bassano megafan, with 1 m contour lines. Black arrows indicate the foot of the tectonic scarp (Favero & Grandesso, 1982; MURST, 1997; Tellini & Pellegrini, 2001) discussed in the text and shown in fig. 2. The light grey grid correspons to the boundaries of each 1:10,000 topographic map used for contour interpolation. A «false scarp» due to aerophotogrammetric bias, corresponding to junctions between map sheets, is visible in the lower-left sector of the map.

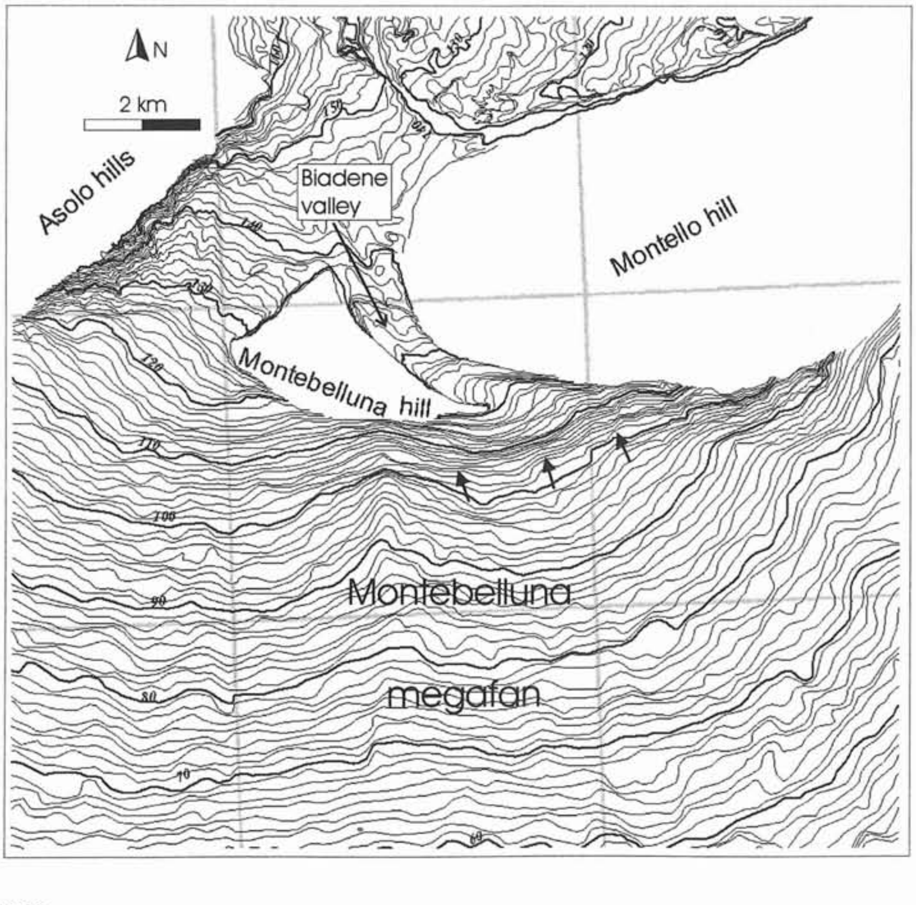

FIG. 7 - Micro-relief map of the eastern sector of the apical Montebelluna megafan, with 1 m contour lines. Black arrows indicate the foot of the tectonic scarp at the debouch of the Biadene valley, discussed in the text and shown in fig. 2. The light grey grid corresponds to the boundaries of each 1:10,000 topographic map used for contour interpolation.

erosional fluvial terraces during the Quaternary uplift of the Montello hill is well documented on the eastern side of the Biadene valley (Venzo, 1977; Ferrarese & *alii*, 1998); all these terraces have been folded by the further development of the Montello anticline. Our data indicate that when the Montebelluna megafan was active, in pre-LGM times, the alluvial plain piedmont sector North of the Sacile line was also uplifting, forcing the fluvial downcutting which led to the formation of the main E-W scarp (fig. 8). The continual uplifting after the de-activation of the Montebelluna megafan and the activation of the Nervesa fan, led to the erosion of the NNW-SSE scarp by the Giavera and/or Piave rivers. When also this western wing of the Nervesa megafan became inactive, surface faulting related to the Sacile fault brought to the formation of the minor W-E tectonic scarp across the Nervesa megafan; in this interpretation, the flat area North of the scarp may represent a sort of embryonal counter-slope.

THE ROLE OF CLIMATIC CHANGE, EUSTATISM AND TECTONICS

In order to approach the problem of the external forcing by climate and sea level on the evolution of the megafans in the study area, the focus will be on the Bassano megafan, as only here radiocarbon dates allow to estimate the ages of the main depositional and erosional phases. The upbuilding of the Bassano megafan took place during the LGM sea lowstand. This is evidently out-of-phase in regards to all the models concerning the response of alluvial systems to the single signal of changing base level, which would rather imply fluvial incision during lowstands (for a comprehensive review of the problem see Blum & Tornqvist, 2000). Conversely, fanhead trenching of the Bassano megafan was probably concomitant, as was the case for most of the alluvial fans of Alpine rivers along the margin of the central and eastern Po plain (Sorbini & *alii*, 1984; Guzzetti & *alii*, 1997; Castiglioni, 2001; Avigliano & *alii*, 2002; Fontana & *alii*, 2004), to the critical environmental transition which took place at the end of the last glaciation. This phenomenon can be explained considering that the hydrological parametres of the Brenta river, as much as those of the Piave river (Surian & Pellegrini, 2000) and of other Alpine rivers (Marchetti, 1996), most probably changed significantly as a consequence of deglaciation. The simple decrease of the river solid discharge, related to the trapping of the sediment load in the pro-glacial lakes that normally form during valley glaciers retreat and/or the stabilization of the mountain slope by the vegetation cover, may have led to river downcutting due to exceeding fluvial power. It is, thus, evident that no straightforward relation exists between the timing of glacio-eustatic sea level changes and the aggradational/erosional phases of the Bassano megafan. Its evolution has, instead, been controlled by the environmental («climatic» *s.l.*) changes in the Brenta catchment basin, an hypothesis which was already put forward by Trevisan (1941) in an early study on the Brenta river terraces.

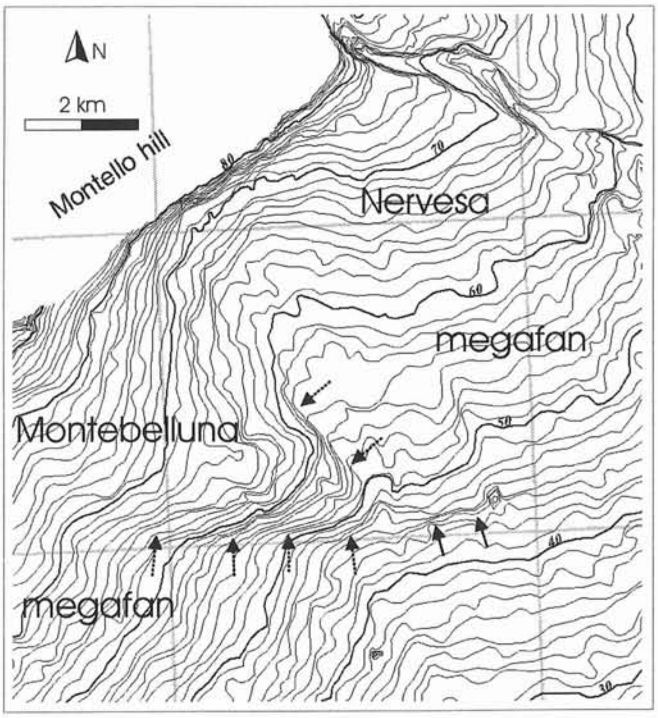

FIG. 8 - Micro-relief map at the contact between the Montebelluna and Nervesa megafans, with 1 m contour lines. Black arrows indicate the foot of the scarps (solid line for tectonic scarp, hatched line for fluvial scarp) discussed in the text and shown also in fig. 2. The light grey grid shows the boundaries of each 1:10,000 topographic map used for contour interpolation.

Concerning tectonics, evidence up to now gathered point out that in a <10 km-wide belt of alluvial plain at the foot of the Southern Alpine margin, a protracted uplifting trend during the Late Quaternary may have forced fluvial downcutting in the Montebelluna megafan, with the formation of a divergent terrace. In the immediate piedmont area, relict alluvial depositional surfaces of the Montebelluna, Bassano and Nervesa megafans have also been locally faulted by the Southern Alpine thrusts. Furthermore, there are some indications that the distal tract of the Bassano megafan may have been slightly tilted.

CONCLUSIONS

The alluvial plain studied here may be defined as a composite alluvial plain, in the sense that it consists of a mosaic of geomorphic surfaces formed by different rivers, at different times during the Late Quaternary. The major geomorphological features are three megafans formed by the Piave and Brenta rivers: the Montebelluna, Nervesa and Bassano megafans. The main role in the alluvial plain modelling was thus played by the sedimentary activity of these Alpine rivers.

It actually seems that the only significant erosional events are the result of the (complex) interplay between the fluvial system and external forcings. Fanhead trenching and the formation of fluvial terraces in the Bassano megafan most probably represent an aspect of the response of the Brenta system to variations of the balance between solid and liquid discharges, related to the dramatic changes of the environmental conditions in the catchment area during the Late Glacial/Early Holocene transition.

In the piedmont sector, the presence of fault scarps in alluvial surfaces even younger than 14,000 years proves the existence of surface tectonics related to the activity of the Southern Alpine thrusts. Such morphotectonic landforms are recognizable only in areas where fluvial processes are not anymore active, because these latter easily obliterate the vertical displacements that occur along the fault lines. Nevertheless, on longer (and, unfortunately, unknown) time spans, thrust tectonics seem to have some control on fluvial processes. In fact, the general uplift in the piedmont belt between the Aviano and Sacile faults has probably had a role in the formation of the large terrace of the Montebelluna megafan.

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