Buried architecture of the Quaternary Vittorio Veneto basin (NE Italy)

R. Avigliano, M.E. Poli and A. Zanferrari

Dipartimento di Georisorse e Territorio, Università di Udine, Italy

(Received: November 14, 2005; accepted: March 21, 2007)

ABSTRACT A geological survey and analysis of the borehole stratigraphies enabled us to characterise the buried architecture of the Quaternary basin of Vittorio Veneto (NE Italy). The study area belongs to the Neogene-Quaternary front of the eastern Southern Alps: the Montello and the Cansiglio thrusts show much evidence of Quaternary activity and are considered seismic sources capable of destructive earthquakes. As a result of the 1936 earthquake, strong site effects became manifest in Ceneda and Serravalle, located respectively to the south and north of Vittorio Veneto. A geological and geomorphological survey enabled us to point out the surficial characteristics of the Vittorio Veneto basin, carved in the Tertiary Molasse. In order to characterize lithology and geometry of the Quaternary sediments and reconstruct the geometry of the bedrock-surface, about sixty borehole stratigraphies were analyzed. Bedrock-surface dips gently northwards: an effect of the tectonic activity of the Montello thrust. Maximum thickness of Quaternary sediments (more than 80 m) is located south of the Serravalle gorge. Three Quaternary sedimentary units have been recognised in the subsurface of the Vittorio Veneto basin: 1) a sandy-gravelly body (with maximum thickness of about 70 m) of alluvial and glacial origin that almost completely fills the Vittorio Veneto basin and contains an important aquifer; 2) thinner sedimentary bodies (with medium thickness about 10-15 m) that form the alluvial fans at the base of the reliefs and are composed of a close sequence of silts, muds and clays interbedded with thin gravelly levels; 3) finally in the Lapisina valley, north of Serravalle gorge, prevailing sands with lenses of lacustrine silts and peat deposits form a sedimentary body that locally reaches 20-30 m in thickness.

1. Introduction

The knowledge of the buried geometries of the bedrock-surface of an alluvial basin and of the characteristics of its Quaternary infill is very important for seismic microzonation studies. Within the framework of the GNDT-2000 project "Damage scenarios of the Veneto-Friuli area", a detailed geological study was carried out in order to define the buried geometries of the Quaternary deposits and their relationships with the rock substratum in the Vittorio Veneto basin (Fig. 1).

The Vittorio Veneto basin (NE Italy) is located at the external Plio-Quaternary front of the eastern Southalpine Chain (ESC) that corresponds to the transition area between the Prealpine reliefs and the northern boundary of the Veneto-Friuli plain (Fig. 2).

According to Galadini *et al.* (2005) and Poli *et al.* (2008) the external thrusts of the ESC are

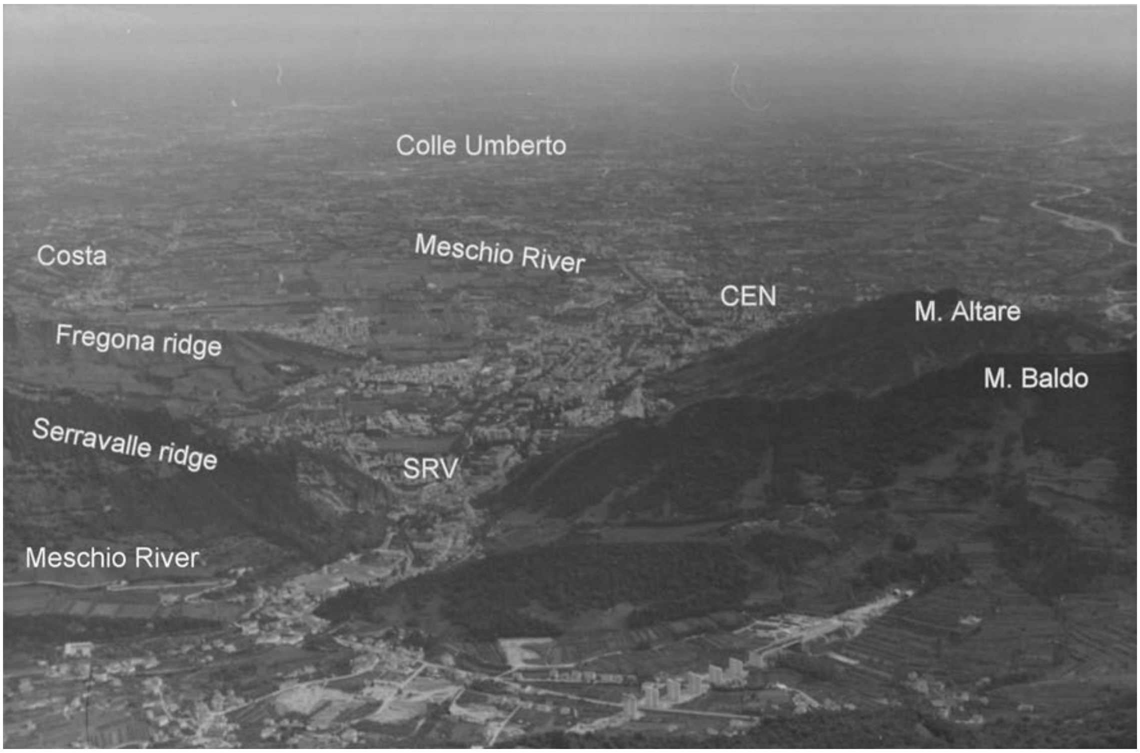

Fig. 1 - The Vittorio Veneto basin from the north: in the foreground, the Serravalle gorge carved in the Langhian calcarenites of M. Baldo Fm.; toward the south the Fregona - M. Altare ridge (in Upper Miocene conglomerates); in the background, the frontal morainic arc of Colle Umberto. SRV: Serravalle; CEN: Ceneda.

seismogenic structures capable of generating destructive earthquakes. In particular, in the study area two potential seismogenic sources, named Cansiglio and Montello respectively, are present. While the Montello segment is considered a silent source with a high level of seismic hazard (Galadini *et al.*, 2005; Burrato *et al.*, 2007), the Cansiglio structure is generally considered (Valensise and Pantosti, 2001; Sirovich and Pettenati, 2004; Galadini *et al.*, 2005) the source of the 1936 Alpago-Cansiglio earthquake [Ms= 5.8 from NT 4.1 catalogue (Camassi and Stucchi, 1997, 1998)]. The distribution of the highest intensity data-points (Monachesi and Stucchi, 2000) shows a wide area of seismic effects: in particular, in the city of Vittorio Veneto major damage (VIII MCS) hit the ancient localities of Ceneda and Serravalle, located respectively in the southwestern and in the northern side of Vittorio Veneto.

The aim of this paper is to describe the geometry of the Vittorio Veneto basin by means of the identification of the surficial and subsurficial relationships between the bedrock and the Quaternary deposits. Moreover, lithological characteristics of the Quaternary deposits and their 3D arrangement in the subsoil of the basin will be produced.

2. Tectonic setting

The study area belongs to the Neogene - Quaternary front of the ESC (Fig. 2), a south-verging

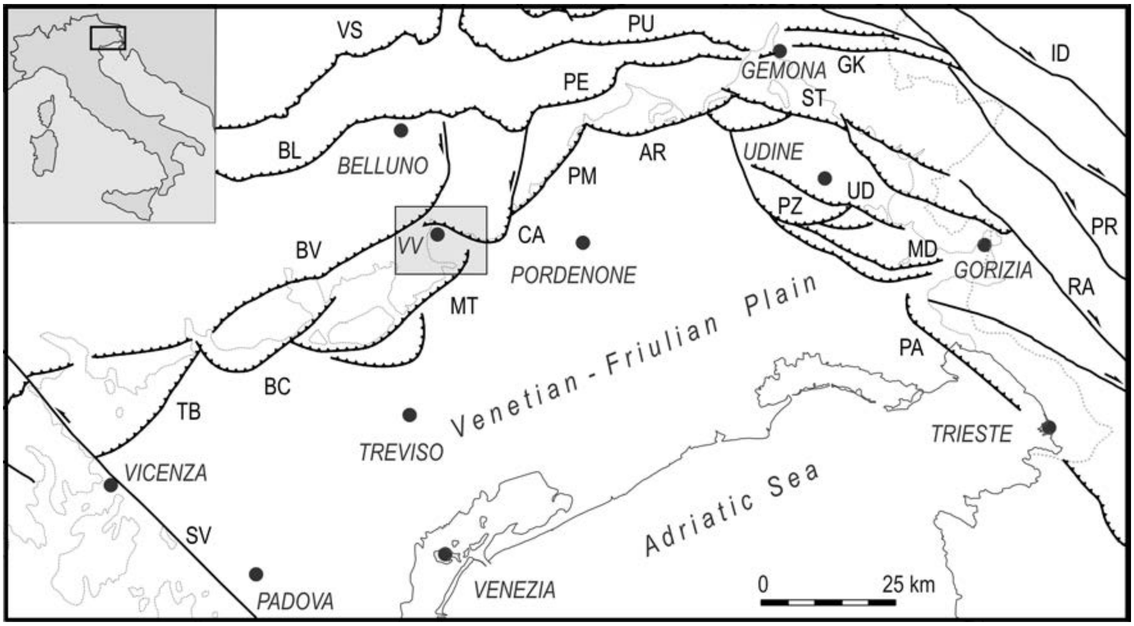

Fig. 2 - Simplified structural sketch of the Plio-Quaternary front of the eastern Southern Alps. Legend; AR, Arba-Ragogna thrust; BC, Bassano-Cornuda thrust; BL, Belluno thrust; BV, Bassano-Valdobbiadene thrust; CA, Cansiglio thrust; GK, Gemona-Kobarid thrust; ID, Idrija fault; MD, Medea thrust; MT, Montello thrust; PA, Palmanova thrust; PE, Periadriatic thrust; PM, Polcenigo-Maniago thrust; PR, Predjama fault; PU, Pinedo-Uccea thrust; PZ, Pozzuolo thrust; RA, Rasa fault; ST, Susans-Tricesimo thrust; SV, Schio-Vicenza fault; TB, Thiene-Bassano thrust; UD, Udine-Buttrio thrust; VS, Valsugana thrust. In the rectangle Vittorio Veneto (VV) study area.

thrust belt arranged in an embricate fan geometry, with fault propagation folding and fault bend folding as typical mechanisms of deformation. In the study area, the geological framework was strongly influenced by the Mesozoic inherited structures: from Early Jurassic to Late Createaceous the region was located in the transition area between the western margin of the Friuli Carbonate Platform (FCP) vs. the Belluno Basin (Cati *et al.*, 1987; Fantoni *et al.*, 2002). This inherited paleogeographic boundary played a fundamental role during the Cenozoic evolution of this sector of the ESC.

In the study area the following regional tectonic elements can be identified (Fig. 3).

1) The Bassano - Valdobbiadene thrust. The so-called "*flessura pedemontana*" represents the main morphostructural evidence in the Venetian sector. Structurally, it corresponds to the frontal ramp anticline of the WSW-ENE trending, S-verging Bassano-Valdobbiadene thrust that extends from Brenta Valley to Vittorio Veneto and overlaps the basinal Mesozoic carbonate succession on the Tertiary terrigenous sequences. According to Castellarin *et al.* (1992) and Selli (1998) the age of activity is Late Tortonian – Pliocene.

In the Fadalto area, the Bassano - Valdobbiadene thrust abruptly changes in striking from WSW-ENE to NNE-SSW giving rise to a complex left lateral transpressive belt that re-utilises, under the Neoalpine compression (with σ_1 about NW-SE), the Mesozoic inherited margin of the Friuli Platform vs. the Belluno Basin (Costa *et al.*, 1996; Doglioni, 1990).

East of Vittorio Veneto, by means of a dextral lateral ramp that re-utilises another segment of the W-margin of the FCP [Caneva fault in Doglioni (1990)], the Bassano - Valdobbiadene thrust trans-

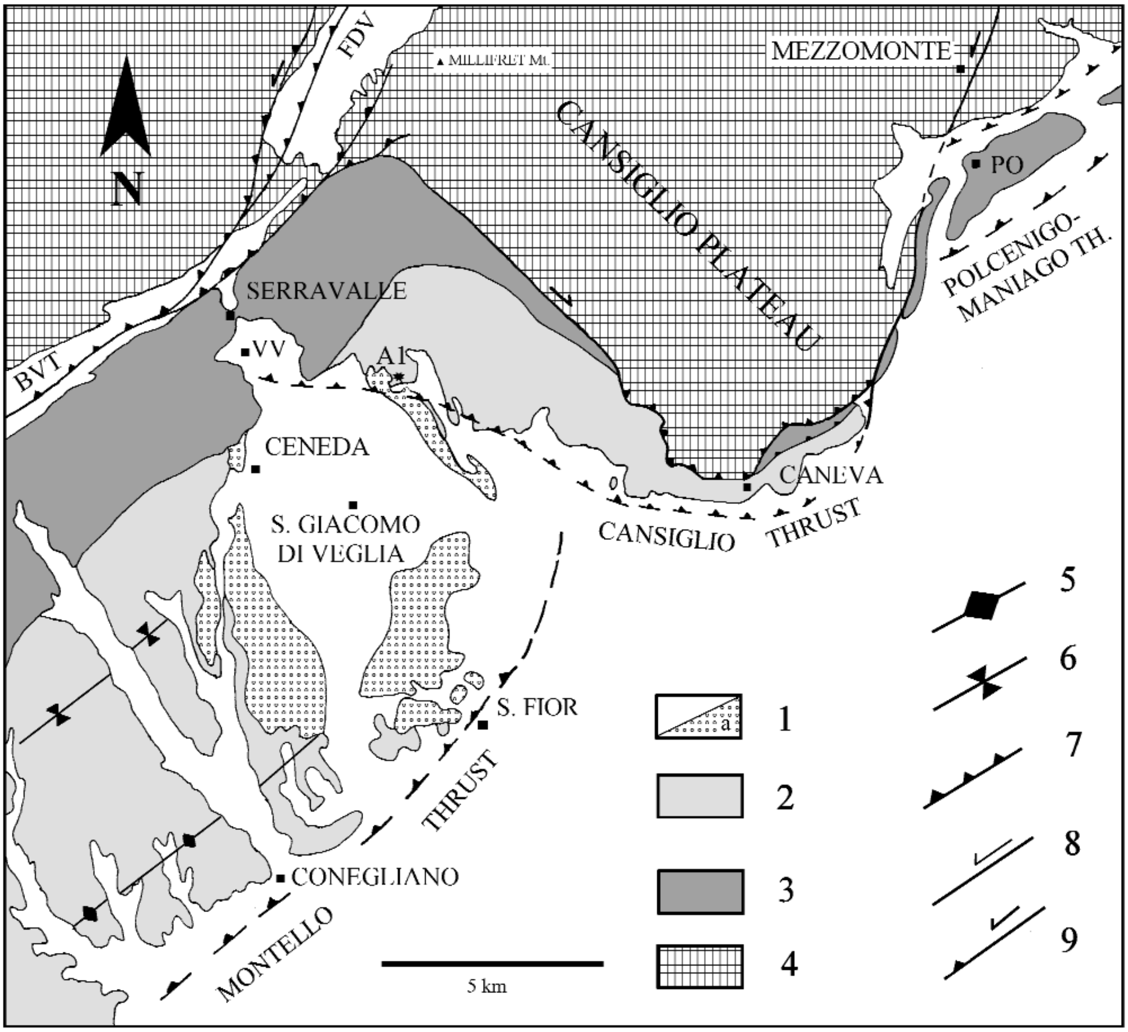

Fig. 3 - Geological sketch map of the Vittorio Veneto area. Legend: 1, indistinct Quaternary deposits; 1a, moraines of the Vittorio Veneto glacial tongue; 2, Conegliano complex (clays, sands, conglomerates; Middle-Pliocene - Lower Pleistocene); 3, Southalpine Molasse (Upper Oligocene-Miocene); 4, carbonate successions (Jurassic-Cretaceous), Scaglia Rossa Fm. (Upper Cretaceous - Lower Eocene), marly-arenaceous flysch (Eocene); 5, anticline; 6, syncline; 7, thrust; 8 strike-slip fault; 9, transpressive fault. A1: Anzano 1 well; BVT: Bassano-Valdobbiadene thrust; PO: Polcenigo, FDV: Fadalto valley.

fers deformation southwards, i.e. to the external thrust-belt bordering the Carnian Prealps toward the Friuli Plain (Zanferrari *et al.*, 2003; Galadini *et al.*, 2005).

2) The Cansiglio overthrust. The eastern portion of the reliefs that surround Vittorio Veneto, is bounded by the Cansiglio carbonate massif where the homonymous overthrust runs at the base. It involves both Mesozoic platform carbonates and Tertiary terrigenous sequence giving rise to a closed fan of tectonic wedges in the Carnian foothill. The Cansiglio overthrust presents clear evidence of recent tectonic activity and is considered the seismogenic source of the 1936 Cansiglio earthquake by Sirovich and Pettenati (2004), Galadini *et al.* (2005) and Poli *et al.* (2008). Since in the Anzano 1

well the Plio-Pleistocene Conegliano complex is doubled, we maintain that the Cansiglio thrust involves the Quaternary cover inside the Vittorio Veneto basin.

3) The Montello overthrust. It deals with a compressive WSW-ENE striking structure bordering the Venetian foothills from Montebelluna to Conegliano. Potentially it represents one of the most significant seismogenic structures in the ESC (Galadini *et al.*, 2005; Poli *et al.*, 2008). The analysis of the industrial reflection seismic lines of the region allowed us to reconstruct the buried geometry of this structure that shows its lateral termination, east of Conegliano, under the Cansiglio thrust (Galadini *et al.*, 2005).

The hangingwall of the Montello thrust is folded by the WSW-ENE striking Pieve di Soligo syncline - Santa Maria di Feletto anticline.

3. Geological framework of the Vittorio Veneto basin

The Vittorio Veneto basin, grooved today by the Meschio River, extends for about 10 km from the Serravalle gorge in the north as far as the morainic arc of Colle Umberto in the south (Figs. 1 and 3). The hills bordering the Vittorio Veneto basin are carved in the Tertiary Molasse, an about 3000 m thick, prevailing terrigenous sequence, Chattian to Messinian in age (Antonelli *et al.,* 1990; Massari *et al.*, 1986). Starting from the north, we observe the following stratigraphic succession (Fig. 4).

- Lower Cavanella Group *sensu* AGIP (Chattian – Burdigalian). It deals with an about 500 m thick succession of carbonate and terrigenous units (prevailing calcarenites and arenites with marls levels) cropping out on the southern slope of Lapisina valley (red in Fig. 4).

- Monte Baldo Fm. (Langhian): it consists of thick layers of glauconitic arenites, calcarenites and calcisiltites with interbedded marl levels cropping out in the Serravalle - Monte Baldo ridge (red in Fig. 4).

- Tarzo Marl (Serravallian): the hills between Olarigo and Borghel (blu in Fig. 4) are carved in the marls and clay-marls of this formation.

- Vittorio Veneto Sandstone (Tortonian *p.p.*): hybrid arenites (orange in Fig. 4) interbedded with thin siltite levels and thick conglomerate lenses (Monte Altare Conglomerate, brown in Fig. 4).

- Montello Conglomerate (Upper Tortonian – Messinian): the top of the Tertiary Molasse is made by thick bodies of mostly coarse grained conglomerates interbedded with sandy-muddy levels (brown in Fig. 4).

- Conegliano complex [Middle Pliocene - Lower Pleistocene, Caputo *et al.* (2003), Fantoni *et al.* (2002)]. It crops out in the southernmost sector of the Vittorio Veneto basin and it is made of prevailing sand - clay alternated with clays (with coal levels) and carbonate sands (yellow in Fig. 4). Conglomerate bodies variable in thickness and wideness are also frequent in this continental succession (brown in Fig. 4).

Structural assessment strongly influenced morphology of reliefs surrounding Vittorio Veneto (Figs. 1 and 4): monoclinal attitude of the rock beds (ENE-WSW striking, 60°-70° S-dipping) and differential erosion, linked to the alternation of soft and hard lithologies, give rise to a sequence of ENE-WSW striking “hogback” such as the Serravalle (in Monte Baldo calcarenites), Fregona and Monte Altare ridges (in Upper Miocene conglomerates) which alternate with wide valleys carved in soft rocks such as marls of the Tarzo Marl Fm.

Moving to the southern sector of the Vittorio Veneto basin, where more soft lithologies with sub-

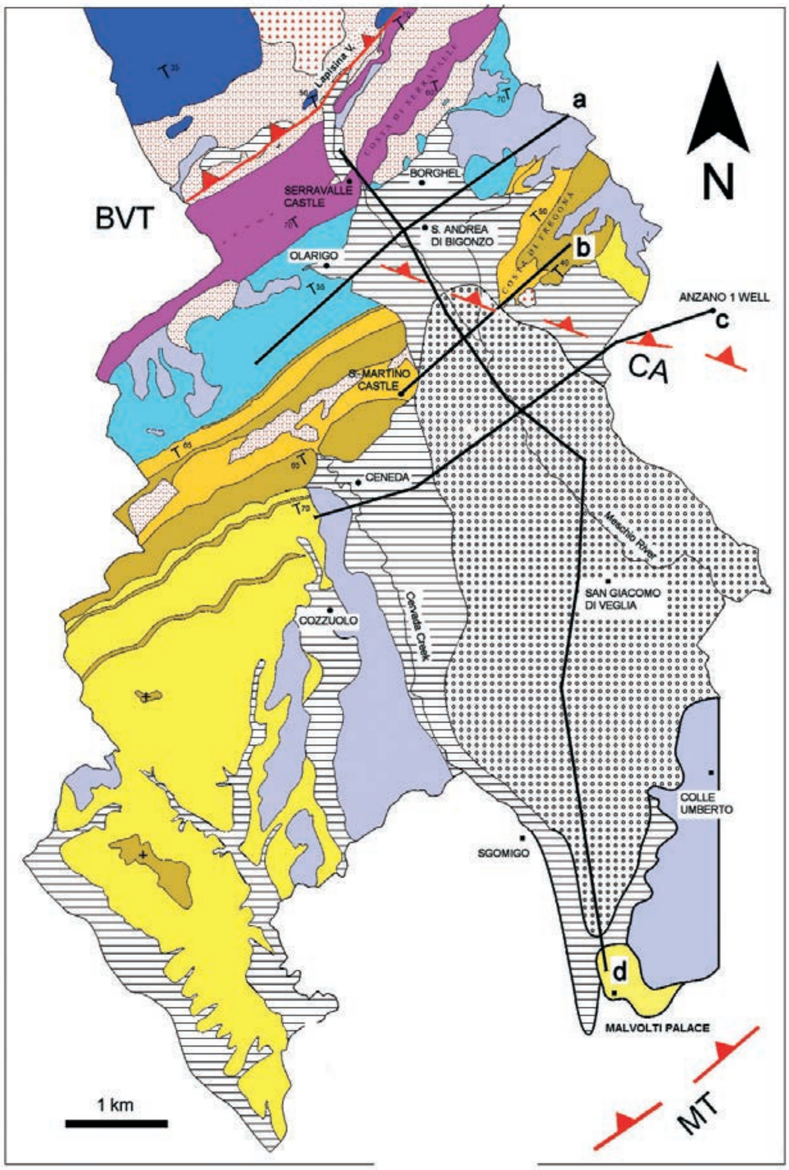

Fig. 4 - Geo-lithological map of the Vittorio Veneto municipality [modified from Piccin *et al.* (1987)]. Pre-Quaternary succession: dark-blue: limestones; red: prevailing calcarenites; blue: marls; orange: arenites; brown: conglomerates; yellow: pelites and sandstones. Quaternary deposits: violet: glacial deposits; ruled: fine alluvial and colluvial deposits; circles: coarse alluvial deposits; red dotted: detritical talus; red triangles: coarse detritus; red sketched line: fault. Black heavy lines: geological cross sections of Figs. 7a, 7b, 7c and 7d, respectively. VBT: Bassano - Valdobbiadene thrust; CA: Cansiglio thrust; MT: Montello thrust.

horizontal attitude crop out (pelites of the Conegliano complex), the valley becomes larger and larger confirming that lithology and structural elements of the rock substratum directly control the shape of the reliefs (Strazzer, 1994).

4. The Quaternary deposits of the Vittorio Veneto basin

Almost during the Last Glacial Maximum (LGM) (22-17 kyr BP - C^{14} uncalibrated), the Vittorio Veneto basin was occupied by a glacial lobe representing a transfluence of the Lapisina branch of the Piave glacier (Dell'Arche *et al.,* 1979). The ice mass extended across the plain, reached Colle

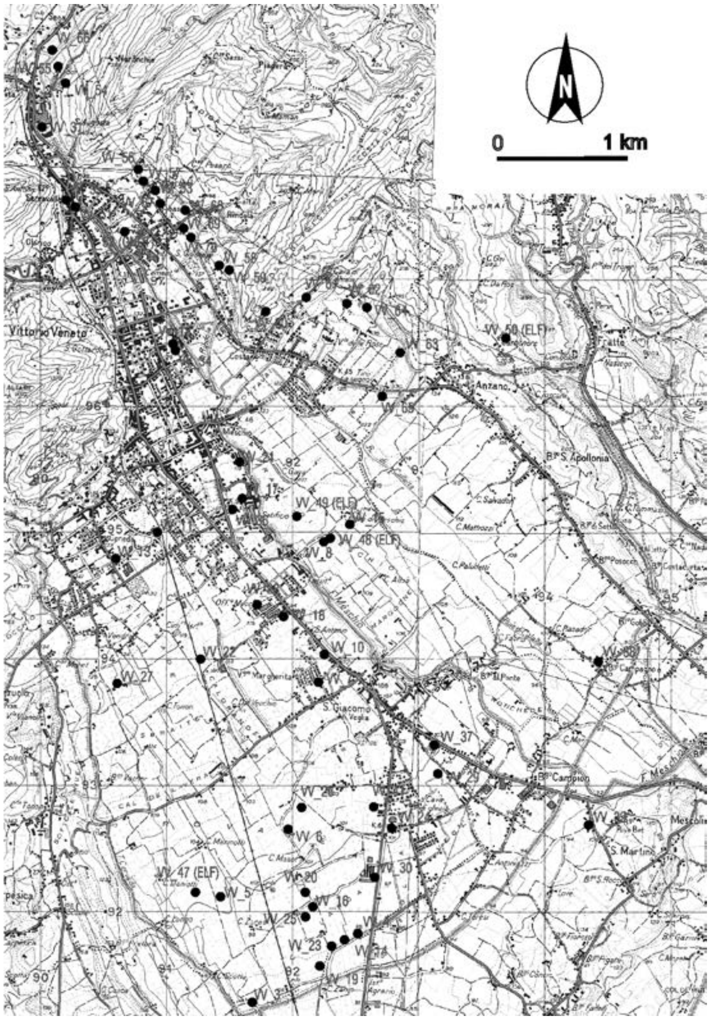

Fig. 5 - Location of boreholes in the Vittorio Veneto sedimentary basin [mostly from Dal Prà (1992) and I.C.E.S. (1992)]; analysed logs were included in the geo-referenced database of the project.

Umberto and formed the morainic amphitheatre (Fig. 3) (Ministero dei Lavori Pubblici, 1963). During the glacial retreat, intensive alluvial deposition in the Vittorio Veneto basin started and probably persisted up to the beginning of the Holocene.

Therefore, in the Vittorio Veneto basin the following Quaternary deposits crop out (Fig. 4).

Glacial deposits (Upper Pleistocene). The morainic ridges of the amphitheatre of Vittorio Veneto and part of the subsoil of the city are formed by glacial deposits of the LGM Piave glacier. Glacial deposits are mostly represented by lodgment and ablation tills and consist of a diamicton of prevailing gravels with pebbles and blocks. Various percentages of sandy-muddy matrices, depending on the glacial sedimentary condition, characterize these deposits.

Ancient glacial deposits (Middle Pleistocene) are also located out of the LGM amphitheatre, near Cozzuolo (Fig. 4). It is possible that pre-LGM glacial deposits are also present at the base of the sedimentary body that fills the Vittorio Veneto basin: the stratigraphical analysis of the available logs did not enable us to discriminate if the pebbly mudstone often located at a depth of about 100 m from

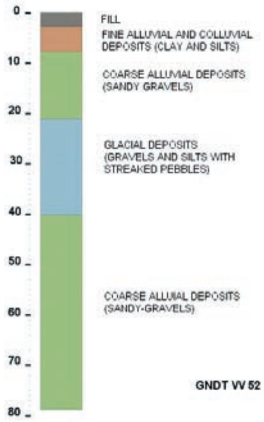

Fig. 6 - Simplified lithologic log of GNDT_VV52 well of Sant'Andrea di Bigonzo (Serravalle). For more explanations see the text.

the surface represents a pre-LGM lodgement till.

<u>Coarse alluvial deposits</u> (Upper Pleistocene - Holocene). The Quaternary filling of the Vittorio Veneto basin up to the surface are prevailing formed by fluvial and fluvioglacial deposits of the Piave glacier and by alluvial deposits of local streams. On the surface of the basin, fluvioglacial deposits of the Piave glacier cover glacial deposits more than 10-20 m in thickness, as the stratigraphies of the boreholes showed. Alluvial deposits consist of prevailing sandy - gravels with pebbles and discontinuous conglomerate levels. Moreover, on the north-eastern side of the Vittorio Veneto valley, above Borghel locality, ancient coarse eterometric and not graded gravelly deposits form a periglacial accumulation *glacis,* probably linked to the LGM climatic deterioration (Mattana, 1978). They have been hardly reworked and deeply carved a by post-glacial hydrographic network, forming a wide terracement (actually covered by fine colluvial deposits) bordered by steep scarps.

<u>Fine alluvial and colluvial deposits (Pleistocene – Holocene)</u>. They crop out at the base of the relies and form the detrital fans of Borghel, Rindola, Olarigo, Ceneda and Anzano. They are characterised by close alternations of prevailing silt and clay interbedded with thin gravel levels. In the Sant'Andrea di Bigonzo area, a six-meter thick lens of pelite is present under the first meters of filling material. In the Lapisina valley, north of the Serravalle gorge, prevailing sands interbedded with thin clay-silt and gravelly levels are present.

5. Subsurface geology

In order to characterise the lithology and architecture of the sedimentary cover and reconstruct the geometry of the bedrock-surface, about sixty stratigraphies (4 oil Elf boreholes, 40 water wells and 16 geognostic boreholes) of boreholes drilled in the sedimentary basin were collected (Fig. 5), analysed and included in the georeferenced database of the project. Moreover a logging borehole (VV_52 GNDT) has been drilled in the urban area of Vittorio Veneto (Sant'Andrea di Bigonzo in Serravalle).

The analysis of the stratigraphies enabled a careful description of the Quaternary sediments. In particular, even though the logging borehole of San Andrea di Bigonzo did not reach the bedrock, an accurate stratigraphical analysis of the core samples has been made (Fig. 6). The borehole pointed to the presence of an about 6 m thick level of prevailing silts and clays located at about 3 m from the surface. Under this pelite interval a thick gravelly body characterizes the sequence. Inside this sedimentary body, the presence of streaking pebbles and silty-matrix - gravels, enabled us to identify about 20 m of glacial deposits.

On the basis of the collected data, three Quaternary sedimentary units were identified and

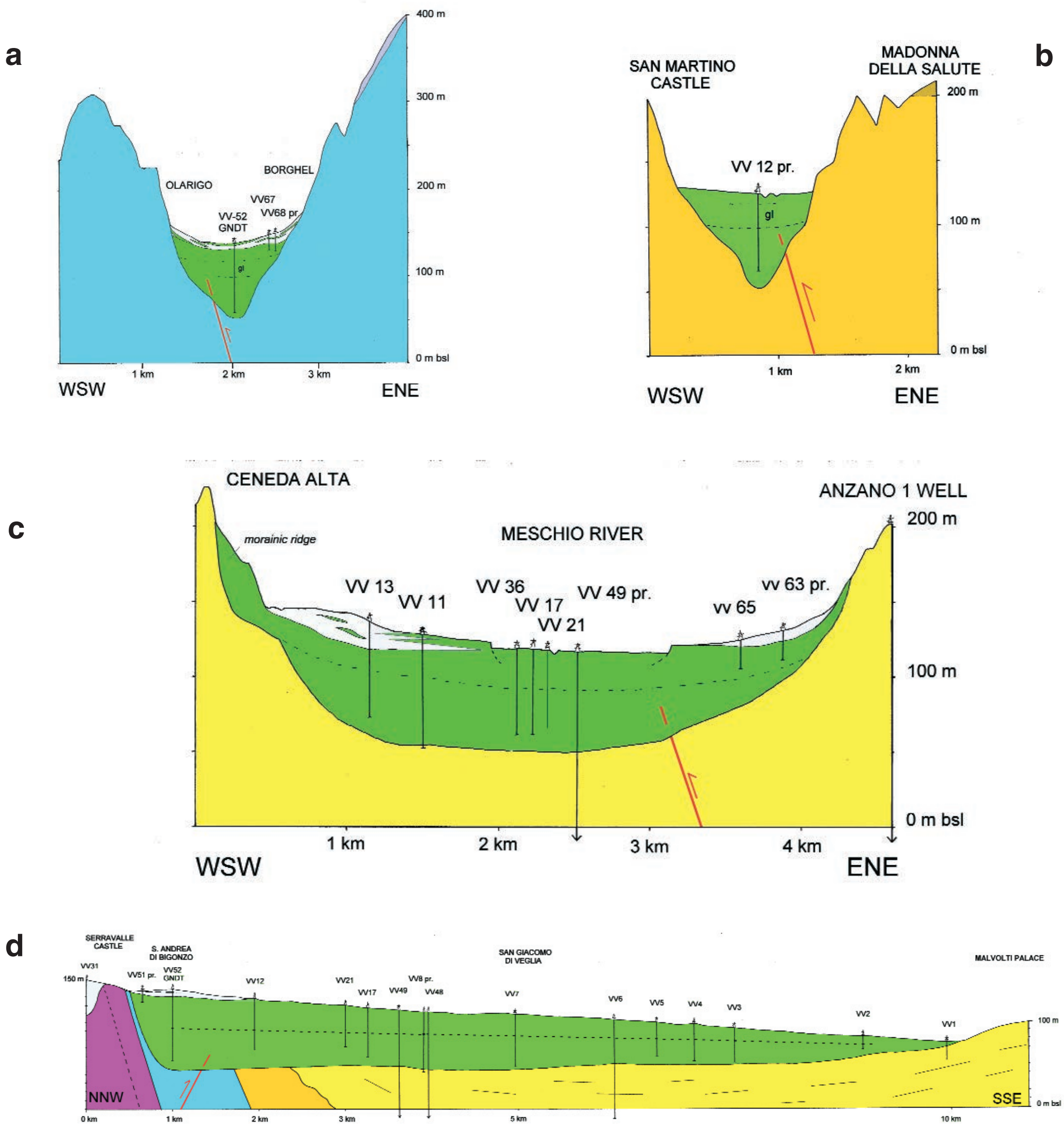

Fig. 7 - Geological sections (vertical exaggeration=10 times), location in Fig. 4, red line=Cansiglio thrust. a) WSW-ENE section "a". Legend: blue: marls of the rock-substratum (Tarzo Marl); green: prevailing gravels of alluvial and glacial origin; gl indicates glacial deposits recognised in GNDT_VV52 well; grey: fine alluvial and colluvial deposits; violet: outcropping glacial deposits. The GNDT_VV52 well did not reach the rock substratum which hypothetically has been located at about 90 m from the surface. b) WSW-ENE section "b". Pre-Quaternary substratum (Vittorio Veneto Sandstone and Montello Conglomerate): orange: arenites; brown: conglomerates. Quaternary deposits: green: gravely body; gl indicates hypothetical glacial deposits. c) WSW-ENE section "c". Hypothetical trend of the buried "geological" bedrock is worked out from well stratigraphies (marked VV). Pre-Quaternary substratum: yellow: pelites and sandstones of Conegliano Complex. Quaternary deposits: green: gravely or sandy-gravely body; grey: clay and silt. Broken line indicates the base of LGM till. d) N-S section "d". Hypothetical trend of the buried "geological" bedrock is worked out from well stratigraphies (marked VV). Pre-Quaternary substratum: violet: prevailing calcarenites and marls (Lower Cavanella Group and Monte Baldo Fm.); blue: marls (Tarzo Marl); orange: arenites and conglomerates (Vittorio Veneto Sandstone and Montello Conglomerate); yellow: pelites and sandstones of the Conegliano complex. Quaternary deposits: green: gravelly or sandy-gravelly body; grey: clay, silt and sand. Near Malvolti Palace rock-substratum rises up because of Montello thrust activity. Heavy dark lines indicate the water table; note the suspended groundwater level in Sant'Andrea di Bigonzo area.

depicted in the Vittorio Veneto basin.

Unit 1) The main one that almost completely fills the Vittorio Veneto basin, is a prevailing sandy-gravelly body (locally with levels of sand and conglomerates) of alluvial and glacial origin. It presents maximum thickness (more than 70 m) south of the Serravalle gorge but it gets thinner and thinner going toward the south. This sedimentary body contains an important aquifer: the depth of the water table ranges from 30-50 m in the northern portion of the basin to 10-15 m in the southern one (Fig. 7d).

Unit 2) The second unit is made up of thinner sedimentary bodies (with medium thickness of about 10-15 m) that form the alluvial and detritic fans located at the slope of the reliefs. They lay on the foregoing main gravelly body and are made up of a close alternation of silts, muds and clays interbedded with thin gravelly levels (Figs. 7a, 7c and 7d).

Unit 3) Finally, in the Lapisina valley, prevailing sands with lenses of lacustrine silts and peat deposits form a sedimentary body that locally reaches 20-30 m in thickness (Fig. 7d).

The sedimentary bodies of unit 1 and 2 are characterized by suspended surface aquifers.

Even if only a few wells have reached the geological bedrock, we attempted to reconstruct its buried geometry. As the geological cross-section of Fig. 7d shows, the bedrock-surface dips northward regularly with an about 0.33% incline: it passes from a quote lower than 40 m bsl (in the area of Sant'Andrea di Bigonzo the borehole did not reach the rock substratum) to a quote of 75 m bsl near Malvolti Palace. Here, the rock substratum crops out because of the tectonic activity of the Montello thrust. The Quaternary sedimentary body becomes thicker and thicker towards the north and reaches the depocentre (maximum thickness more than 80 m from the surface) south of the Serravalle gorge.

The E-W cross-sections (Figs. 7a, 7b and 7c) are less detailed in order to reconstruct the buried shape of the bedrock-surface because of a less borehole-covering. First of all, we can observe that the width of the valley is strongly influenced by structural elements as hardness and attitude of the rock-substratum: the basin is a narrow gorge up to San Martino Castle where hard lithologies prevail, while it widens between Ceneda and Costa because of the presence of the pelites of the Conegliano Complex. The basin shows the smaller width in Serravalle where today the River Meschio runs in a narrow gorge. North of the Serravalle gorge, the bedrock becomes deeper and the River Meschio runs on the alluvial-detrital fill, about 10 m thick.

5. Conclusive remarks

During the 1936 Cansiglio earthquake the hamlets of Ceneda and Serravalle were strongly hit inside the Vittorio Veneto basin, pointing out serious site effects.

In order to characterize the geometric features of the bedrock of this basin and of its Quaternary filling, a detailed geological study was carried out. The basin is carved in the Neogene mostly terrigenous deposits of the Molasse and is filled by thick Quaternary sediments.

By means of about sixty borehole stratigraphies, distribution of Quaternary bodies and bedrock arrangement were defined: a thick gravelly body occupies the basin as a whole; it is more than 70 m thick in the north but becomes thinner and thinner moving to the south because of the Montello thrust activity. Fine alluvial and detrital deposits forming alluvial fans, variable in thickness, lay on the gravelly body. In particular, the alluvial fan of Ceneda is about 20 m thick.

Finally, in the Lapisina valley, a sedimentary body with prevailing sands with lenses of lacustrine silts and peat deposits, locally reaches 20-30 m in thickness. Basin depocentre (more than 80 m thick) is located south of the Serravalle gorge; the width of the buried basin goes from about 1 km in the northern and central portion to about 4 km near Ceneda.

Bedrock-surface is tilted northward and the onlap geometry of the Quaternary sediments testifies the tectonic activity of the Montello thrust.

Detection of buried geometry of the bedrock and lateral heterogeneities in the Quaternary sediments of an intramontane basin represent a first fundamental step in order to explain damage distribution during a seismic event and represented the starting point for the seismic microzonation studies of Vittorio Veneto (see Priolo *et al.*, 2008).

Acknowledgements. The Authors express their gratitude to the Municipality of Vittorio Veneto, in particular to Arch. Antoniazzi and her staff. Many thanks also to Mr. Cervellin, for the accordance of the site use in San Andrea di Bigonzo. The Authors are grateful to an anonymous reviewer for comments and suggestions. The present research was developed in the framework of the activities of the project “Damage scenarios in the Veneto-Friuli area” financed by the National Group for the Defence against Earthquakes (GNDT).

REFERENCES

Antonelli R., Barbieri G., Dal Piaz G.V., Dal Pra A., De Zanche V., Grandesso P., Mietto P., Sedea R. and Zanferrari A.; 1990: *Carta geologica del Veneto alla scala 1:250.000.* Regione Veneto, Segreteria Regionale per il Territorio, University of Padova, 31 pp.

Burrato P., Poli M.E., Vannoli V., Zanferrari A., Basili R., and Galadini F.; 2008: *Sources of Mw 5+ earthquakes in northeastern Italy and western Slovenia: an updated view based on geological and seismological evidence.* Tectonophysics, DOI: 10.1016/j. tecto. 2007.07.009.

Camassi R. and Stucchi M.; 1997: *NT4. 1, un catalogo parametrico di terremoti di area italiana al di sopra della soglia del danno (versione NT4. 1.1).* C.N.R. GNDT, Milano, 96 pp.

Camassi R. and Stucchi M.; 1998: *NT4. 1, un catalogo parametrico di terremoti di area italiana al di sopra della soglia del danno (versione NT4. 1.1).* C.N.R. GNDT, http://emidius.itim.mi.cnr.it/NT/CONSNT.html.

Caputo R., Poli M.E. and Zanferrari A.; 2003: *Neogene-Quaternary twist tectonics in the Eastern Southern Alps, Italy.* Mem. Sc. Geol. special issue, 155-158.

Castellarin A., Cantelli L., Fesce A.M., Mercier J.L., Picotti V., Pini G.A., Prosser G. and Selli L.; 1992: *Alpine compressional tectonics in the Southern Alps. Relationships with the N-Apennines.* Annales Tectonicae, **6**, 62-94.

Cati A., Sartorio D. and Venturini S.; 1987: *Carbonate platforms in the subsurface of the northern Adriatic area.* Mem. Soc. Geol., It., **40**, 295-308.

Costa V., Doglioni C., Grandesso P., Masetti D., Pellegrini G.B. and Tracanella E.; 1996: *Note illustrative della Carta geologica d'Italia alla scala 1: 50000: Foglio 063 - Belluno.* Ist. Poligrafico e Zecca dello Stato, Roma, 74 pp.

Dal Prà A.; 1992: *Studio geologico e idrogeologico della Piana alluvionale di Vittorio Veneto finalizzato alla valutazione del fenomeno di inquinamento della falda con solventi clorurati.* Amministrazione Comunale di Vittorio Veneto e Provincia di Treviso. Internal report.

Dall'Arche L., Mattana U. and Toniello V.; 1979: *I limiti raggiunti dall'antico ghiacciaio del Piave nella Valle Lapisina e in Valmareno (Treviso).* Studi Trentini di Scienze Naturali, Volume in memoria di R. Costacurta, **56**, 39-52.

Doglioni C.; 1990: *Thrust tectonics examples from the Venetian Alps.* Studi Geol. Cam., vol. spec. 1990, 117-129.

Fantoni R., Catellani D., Merlini S., Rogledi S. and Venturini S.; 2002: *La registrazione degli eventi deformativi cenozoici nell'avampaese Veneto-Friulano.* Mem. Soc. Geol. It., **57**, 301-313.

Galadini F., Poli M.E. and Zanferrari A.; 2005: *Seismogenic sources potentially responsible for earthquakes with M?6 in the eastern Southern Alps (Thiene-Udine sector, NE Italy).* Geoph. J. Int., **161**, 739-762.

I.C.E.S.; 1992: *Comune di Vittorio Veneto progetto definitivo "S.S. n. 51 di Alemagna" Variante di Vittorio Veneto (Tangenziale Est) Collegamento la Sega-Ospedale.* Internal report.

Massari F., Grandesso P., Stefani S. and Zanferrari A.; 1986: *The Oligo-Miocene Molasse of the Veneto-Friuli region, Southern Alps.* Giorn. Geol., **48**, 235-255.

Mattana U.; 1978: *Terrazzi quaternari presso Vittorio Veneto.* Gruppo di Studio del Quaternario Padano, Quaderno n. **4**, 61-76.

Ministero dei Lavori Pubblici; 1963: *Carta geologica delle Tre Venezie. Foglio 38 Conegliano*. Ufficio Idrografico del Magistrato alle Acque di Venezia.

Monachesi G. and Stucchi M.; 2000: *DOM 4.1 an intensity database of damaging earthquakes in the Italian area.* http://emidius.mi.ingv.it/DOM/home.html.

Piccin M., Negri G. and Granziera C.; 1987: *Carta geologica del Comune di Vittorio Veneto e relazione geologica illustrativa relativa al territorio comunale.* Internal report.

Poli M.E., Burrato P., Galadini F. and Zanferrari A.; 2008:*Seismogenic sources responsible for destructive earthquakes in north-eastern Italy.* Boll. Geof. Teor. Appl., **49**, 301-313.

Priolo E., Poli M.E., Laurenzano G., Vuan A. and Barnaba C.; 2008: *Site response estimation in the Vittorio Veneto area (NE Italy). Part 2: mapping the local seismic effects in the urban settlement.* Boll. Geof. Teor. Appl., **49**, 387-400.

Selli L.; 1998: *The Valsugana thrust belt between Trento and Cima d'Asta; Neogene kinematics and Permian-Mesozoic structure within the evolutionary framework of the eastern southern Alps, northeastern Italy.* Mem. Soc. Geol. It., **53**, 503-541.

Sirovich L. and Pettenati F.; 2004: *Source inversion of intensity patterns of earthquakes: a destructive shock in 1936 in northeast Italy.* J. Geophys. Res., **109**, B10309, doi: 10.1029/2003JB002919.

Strazzer E.; 1994: *Geomorfologia del territorio compreso nella Tavoletta "Vittorio Veneto".* Università degli Studi di Padova. Tesi di Laurea Inedita, 97 pp.

Valensise G. and Pantosti D.; 2001: *Database of potential sources for earthquakes larger than M 5.5 in Italy, version 2.0.* Annali di Geofisica, suppl. to vol. **44**, 797-964.

Zanferrari A., Poli M.E. and Rogledi S.; 2003: *The external thrust-belt of the Eastern Southern Alps in Friuli (NE Italy).* Mem. Sc. Geol., special issue, **54**, 159-162.

Corresponding author: M. Eliana Poli
Dipartimento di Georisorse e Territorio
Università di Udine
Via Cotonificio 114, 33100 Udine, Italy
phone: +39 0432 558747; fax: +39 0432 558700; e-mail: eliana.poli@uniud.it.