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New stratigraphic and structural evidence for Late Pleistocene surface faulting along the Monte Olimpino Backthrust (Lombardia, N Italy)

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ABSTRACT

We summarize some preliminary results achieved during the investigations conducted for the CARG Project, geological sheet n. 75 "Como", i.e. the analysis of the Quaternary evolution of the "Monte Olimpino Backthrust" and the evaluation of its seismogenic activity. Cross-border field mapping between Ticino (CH) and Lombardia (IT) resulted in the finding of new outcrops (Borgo Vico site, in the northwestern sector of the urban area of Como) located along the front of the Monte Olimpino Backthrust, that allowed to recognize evidence for Late Pleistocene reverse surface faulting along this structure.

At Borgo Vico, a clastic Tertiary unit, the Villa Olmo Conglomerate, intercalated in the Chiasso Fm. of Early Oligocene age, is thrust over a Late Pleistocene fluvioglacial and glacio-lacustrine sequence (Comerci *et alii*, 2007).

Until now, the Monte Olimpino Backthrust was supposed by most authors to have been active until Tortonian times. Sileo *et alii* (2007) inferred a Pliocene activity and proposed, based on geomorphic evidence, that fault displacement was still taking place during Pleistocene. However, this is the first time that Pleistocene activity along the Monte Olimpino Backthrust has been documented by unequivocal tectonic offset of late Pleistocene deposits. Paleoseismological analyses are in progress in order to distinguish potential coseismic movement from fault creep during the observed recent displacement.

Key words: *CARG Project, capable fault, Villa Olmo Conglomerate, western Southern Alps,Quaternary.*

RIASSUNTO

Evidenze stratigrafiche e strutturali di fagliazione superficiale tardo pleistocenica lungo il Retroscorrimento di Monte Olimpino (Lombardia).

Nell'ambito del Progetto CARG (Cartografia Geologica), l'Università degli Studi dell'Insubria è stata incaricata della realizzazione del Foglio n. 75 "Como", alla scala 1:50000. Nel 2008 il Foglio "Como", in seguito alla formalizzazione di collaborazione tra il Servizio Geologico d'Italia (ISPRA), l'Università dell'Insubria ed il Servizio Geologico Svizzero, si evolve in un progetto internazionale. Tale collaborazione è finalizzata alla produzione di una carta geologica congiunta di entrambi i territori nazionali compresi all'interno dell'area del Foglio.

In questo lavoro ci si sofferma su alcuni recenti risultati, ottenuti tramite questo sforzo di ricerca congiunto, inerenti l'analisi dell'evoluzione quaternaria del Retroscorrimento di Monte Olimpino (e.g., Bernoulli *et alii*, 1989) e la valutazione della relativa potenziale attività sismogenica (sensu IAEA, 2002).

Recenti studi sull'attività neotettonica del retroscorrimento effettuati lungo nuovi affioramenti messi in luce durante l'attività di rilevamento geologico condotta lungo l'area di confine italo-svizzero, suggeriscono che l'attività del retroscorrimento, considerata dalla maggior parte degli Autori esaurita nel Tortoniano, sia da portare almeno fino al Pliocene Superiore (Sileo *et alii*, 2007).

In particolare nel presente lavoro viene descritto un nuovo affioramento, nel settore settentrionale del centro urbano della città di Como (quartiere di Borgo Vico), il cui significato stratigrafico e paleosismologico è di notevole importanza per la sismotettonica di quest'area.

La sequenza esposta a Borgo Vico è costituita da conglomerati dell'Oligocene Inferiore (Conglomerato di Villa Olmo - VOC), appartenenti alla porzione inferiore della Formazione di Chiasso (p.es. Gelati *et alii*, 1988), un'unità costituita da ca. 100-150 m di marne e torbiditi sottili di ambiente emipelagico e di scarpata.

La sequenza dei VOC è in contatto tettonico con una sequenza fluvioglaciale e glaciolacustre di età tardo pleistocenica. I sedimenti quaternari sono posti al letto di una faglia inversa (con giacitura N210/65) posta in stretta relazione con il MBt. I depositi glaciolacustri, lungo il contatto con la faglia, sono uncinati da pieghe da trascinamento che attestano il sollevamento del tetto della faglia. Questi primi dati evidenziano come l'ultima riattivazione della struttura sia da datare almeno al Pleistocene Superiore.

Sono in corso indagini di carattere paleosismologico finalizzate alla caratterizzazione genetica della fagliazione ed in particolare alla distinzione tra movimenti cosismici ovvero di creep asismico.

Parole chiave*: Progetto CARG, Alpi Meridionali occidentali, faglie capaci, Conglomerato di Villa Olmo, Quaternario.*

INTRODUCTION

Within the framework of the CARG (CARtografia Geologica) Project, the University of Insubria is in charge of the realization of the mapping of sheet n.75 "Como" at 1:50000 scale. In 2008 the project became international following the initiation of a cooperation between the Geological Survey of Italy/ISPRA, the Insubria University and the Swiss Geological Survey. This partnership is aimed at producing a joint geological map including areas of both Italian and Swiss national territories, with obvious advantages for the scientific and applied aspects of the project.

Here we focus on some of the recent results of our joint efforts, i.e. the analysis of the Quaternary evolution of the Monte Olimpino Backthrust (which in the following will be referred to as MBt), after Bernoulli *et alii* (1989), and the evaluation of its potential seismogenic activity (fault capability, sensu IAEA, 2002). The cross-border field mapping between Ticino and Lombardia resulted in the finding of new exposures along the front of the MBt, that allowed to infer significant tectonic activity along this fault during the Plio-Quaternary (Sileo *et alii*, 2007). In particular, in

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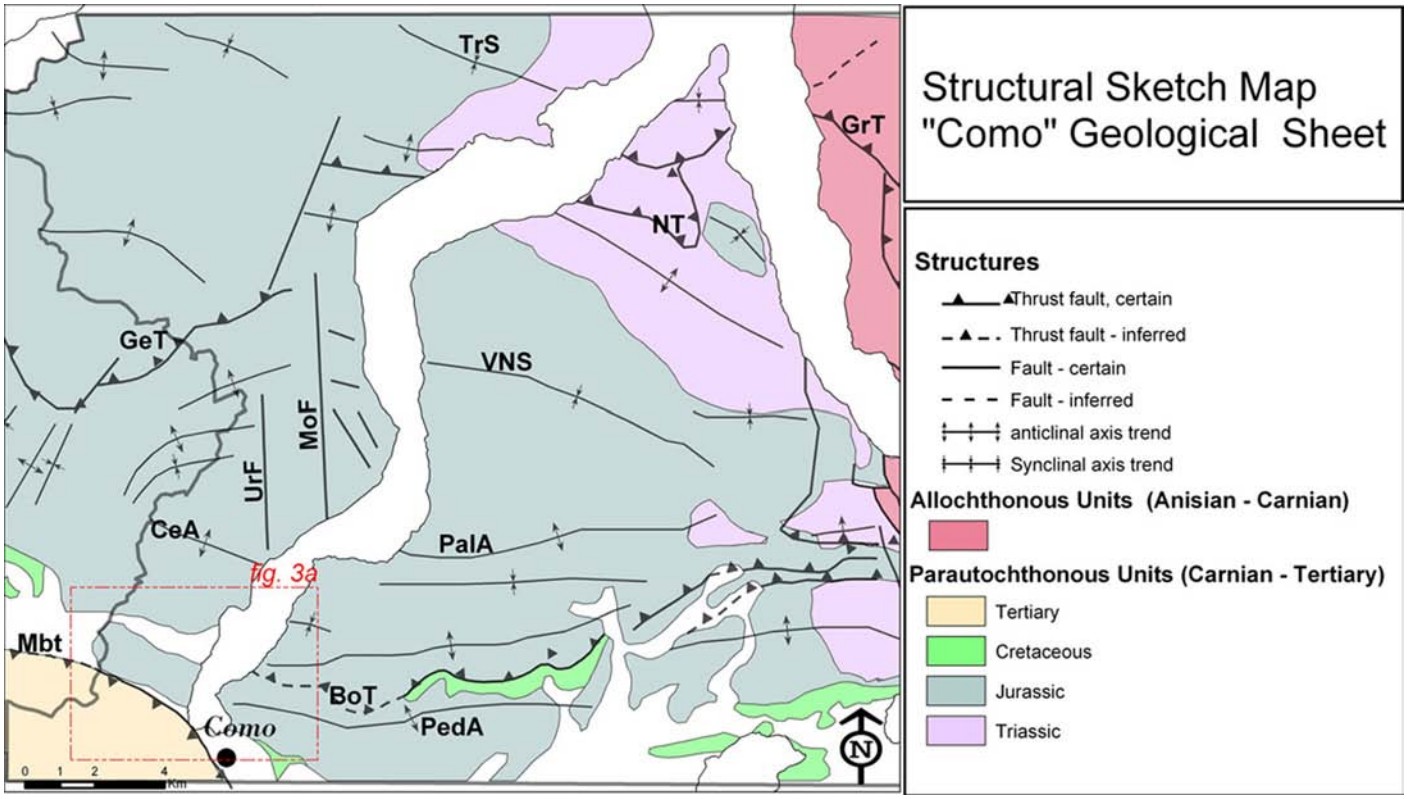

Fig. 1 - Structural sketch map of Sheet n. 75 "Como". Abbreviations are: BoT, Bolettone Thrust; CeA, Cernobbio Anticline; MBt, Monte Olimpino Backthrust; GeT, Generoso Thrust; GrT, Grigna Thrust, MoF, Moltrasio Fault; NT, Nuvolone Thrust; PalA, Palanzone Anticline; PedA, Pedemountain Anticline; TrS, Tremezzo Syncline; UrF, Urio Fault; VNS, Val Nosè Syncline.
- Schema strutturale del Foglio n. 75 "Como". Abbreviazioni: BoT, Sovrascorrimento del M. Bolettone; CeA, Anticlinale di Cernobbio; MBt, Retroscorrimento di Monte Olimpino; GeT, Sovrascorrimento del Generoso; GrT, Sovrascorrimento della Grigna, MoF, Faglia di Moltrasio; NT, Sovrascorrimento del M. Nuvolone; PalA, Anticlinale del Palanzone; PedA, Flessura marginale; TrS, Sinclinale di Tremezzo; UrF, Faglia di Urio; VNS, Sinclinale della Val Nosè.

this paper we describe a new outcrop located in the northwestern sector of the urban area of Como (Borgo Vico), that has significant implications for the stratigraphy and the palaeoseismicity of the area.

GEOLOGICAL FRAMEWORK AND PRE-QUATERNARY STRATIGRAPHY

The Chiasso Fm. and the Gonfolite Lombarda Gr. (Early Oligocene to Middle Miocene; e.g., Gelati *et alii*, 1988) constitute a foreland and foredeep sequence of terrigenous units representing the Tertiary synorogenic clastic wedge of the western Southern Alps. The Gonfolite units crop out in an E-W trending elongate belt, at the southern margin of the pre-alpine reliefs between Como and Varese (Fig. 1). The bedding of this clastic wedge shows high-angle southward dips in the northern sector, near Como, where it is thrust back onto the Mesozoic sedimentary sequence of the Lombardia Basin (e.g., Bernoulli *et alii*, 1989). The strata progressively onlap and are less dipping in the south, evidence of a syn-sedimentary growth of the MBt (Gelati *et alii*, 1988).

The whole sedimentary sequence can be divided into 4 depositional mega-cycles, related to a deep-sea fan depositional environment. The succession can be summarized as follows (e.g., Gunzernhauser, 1985; Gelati *et alii*, 1988, Fig. 2):

a) Chiasso Fm. (Rupelian – Early Chattian) – a sequence of fine-grained mudstones, thin-bedded turbidites

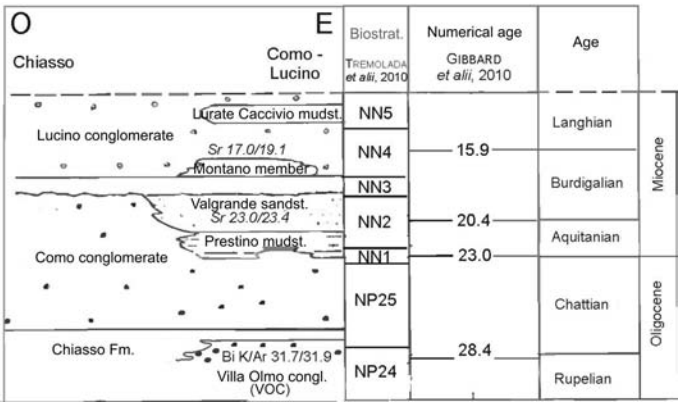

Fig. 2 - Stratigraphic Chart of the Rupelian to Miocene units between Como and Chiasso (after Bernoulli *et alii*, 1993 – modified). See Bernoulli *et alii* (1993) and references therein for furthers details.
- Schema stratigrafico delle unità dal Rupeliano al Miocene affioranti tra Como e Chiasso (da Bernoulli et alii*, 1993 – modificato). Vedi Bernoulli* et alii *(1993) e lavori citati per ulteriori dettagli.*

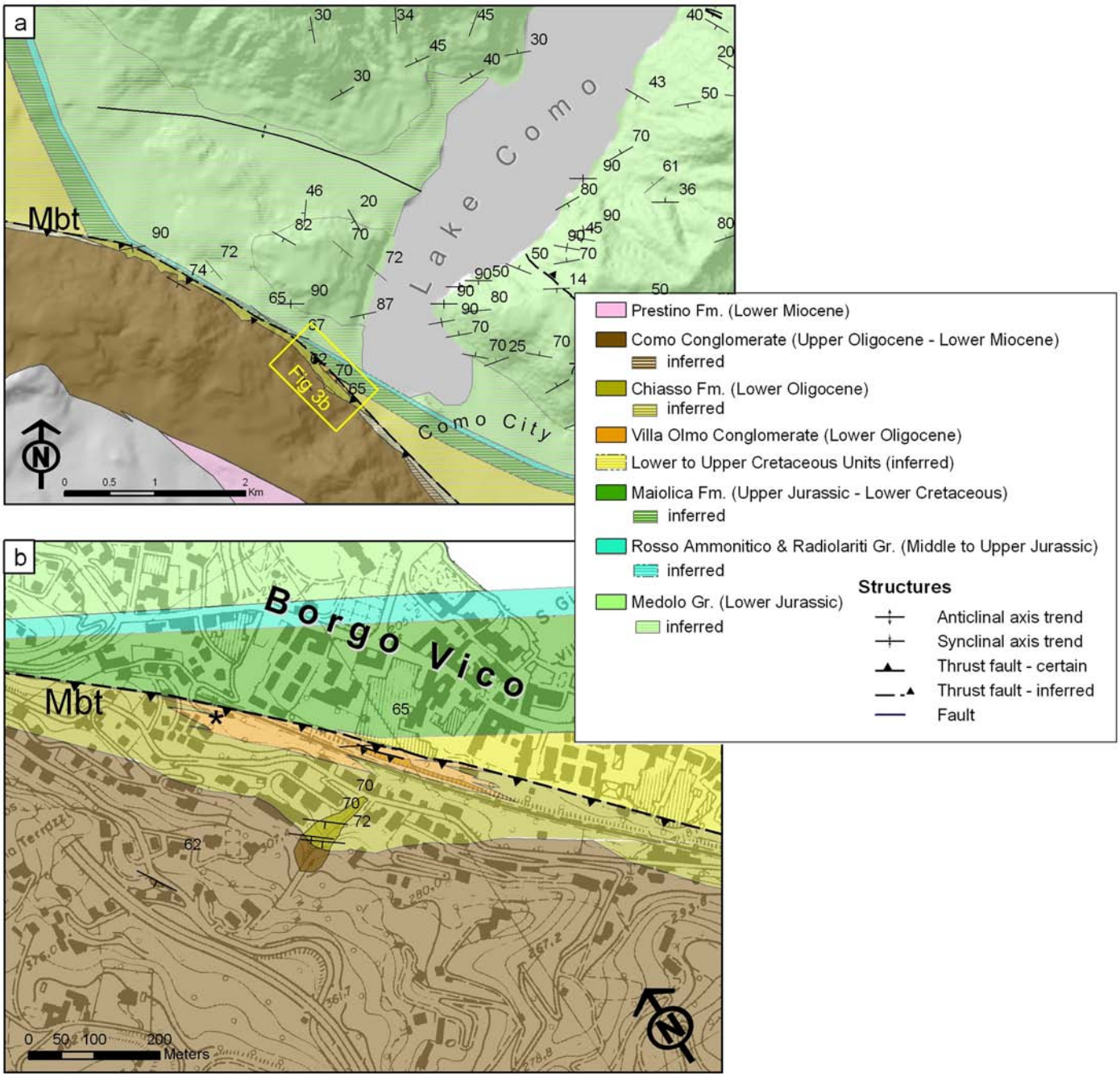

Figura 3: (a) Simplified geologic map of the Como area and (b) details of the Borgo Vico outcrop. Star indicates the location of the only previously known outcrop of the Villa Olmo Conglomerate described in literature (Valdisturlo *et alii*, 1998)
*(a) carta geologica dell'area comasca e (b) dettaglio dell'area relativa all'affioramento di Borgo Vico. La stella indica la posizione dell'unico affioramento precedentemente noto e descritto in letteratura (*Valdisturlo et alii*, 1998)*

and intercalated coarse deep-water conglomerates (Villa Olmo Conglomerate - VOC);

b) Como Conglomerate and lateral coeval units (Chattian - Burdigalian) – overlying with a major erosive unconformity the Chiasso Fm., these coarse conglomerates and interbedded sandstones represent the filling of a deep-water canyon system, passing laterally to mudstones and thin-bedded turbidites (Prestino Mudstones) and upward into thick-bedded sandstones of the Valgrande Sandstone Fm;

c) Lucino Conglomerate and lateral coeval units (Burdigalian - Langhian) – this cycle is separated from the underlying units by an erosional hiatus and it's represented by conglomerates and sandstones passing laterally to thin-bedded turbidites and mudstones (Lurate Caccivio Mudstones and Montano Member; Fig. 2);

d) Gurone Sandstones (Burdigalian) – outcropping only in the Varese area: these conglomerates, sandstones and mudstones unconformably overlay the previous depositional cycle.

The outcrop described in this paper, which will be illustrated in detail in the next section, exposes the lower-

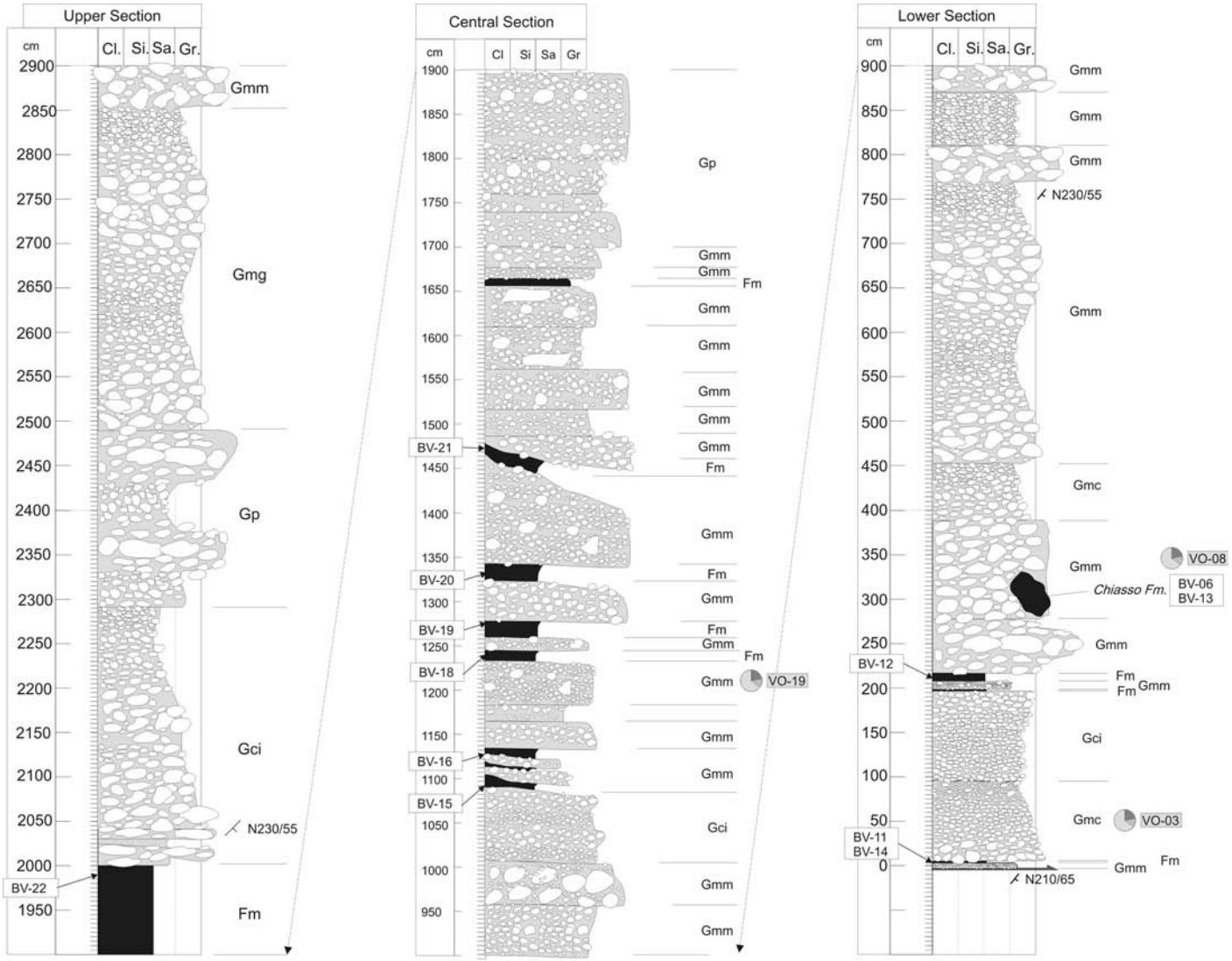

Fig. 4 - Stratigraphic column of the Villa Olmo Conglomerate cropping out at Borgo Vico. Abbreviations on the right refer to Miall-like facies attribution (e.g., Miall, 1985). BV numbers indicate samples collected for paleontological analyses; VO numbers indicate samples site for petrographic analysis.

- colonna stratigrafica della sezione del Conglomerato di Villa Olmo affiorante presso il sito di Borgo Vico. Le sigle sulla destra si riferiscono alle facies descritte da Miall (1985). La serie progressiva BV indica i campioni raccolti per effettuare analisi paleontologiche; la serie progressiva VO indica il punto ove sono state effettuate le stazioni di analisi petrografica sulla componente clastica.

most part of the Villa Olmo Conglomerate (VOC) that was previously known only from a single outcrop located near a railway tunnel (star on Fig. 3b; e.g. Longo, 1968, Gelati *et alii*, 1988; Valdisturlo *et alii*, 1998).

The VOC have been already analyzed by Valdisturlo *et alii* (1998) and Di Giulio *et alii* (2001) who described two stacked conglomerates bodies of 40 m in thickness. These are arranged as two fining-upward units passing from clast-supported coarse-grained conglomerates at the base, to pebbly sandstones at the top. Field observations show that the VOC is certainly overlain by the Chiasso Fm. and also suggest that the VOC is laterally replaced by lens-shaped bodies of sandstones belonging to the Chiasso Fm.

The age of the VOC is still debated to be Rupelian (Gelati *et alii*, 1988, Bernoulli *et alii*, 1989; Di Giulio *et alii*, 2001) or Chattian (Tremolada *et alii*, 2010). A K/Ar age of 31.7 – 31.9 Ma for a tonalite pebble in the VOC (Giger & Hurford, 1989, Fig. 2) seems to be more consistent with a Chattian age, otherwise implying an exceedingly short time span between cooling, erosion and subsequent deposition.

STRUCTURAL FRAMEWORK AND NEOTECTONIC ACTIVITY

The "Como" Sheet area is located at the southern margin of the Southern Alps: a fold and thrust belt characterized by an overall vergence of thrusting and folding toward the South (e.g., Schmid *et alii*, 2004 and reference therein). The major structures (Fig. 1) are trending E-W and are related to different alpine compressive tectonic phases ini-

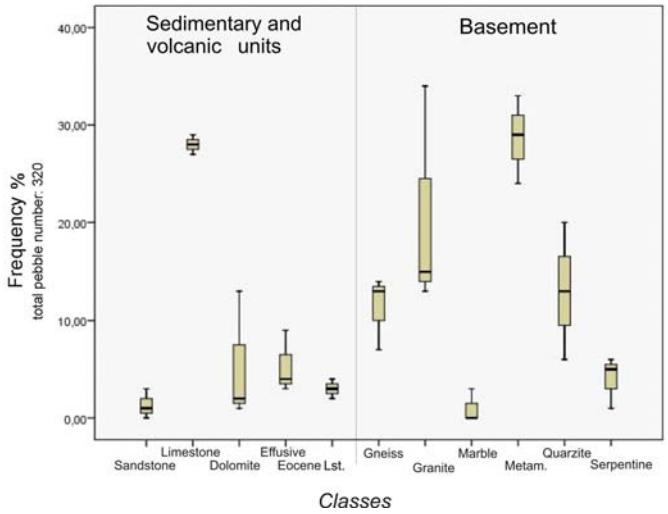

Fig. 5 - Box & whiskers plot illustrating the detrital composition of the Villa Olmo Conglomerate calculated on the three analyzed stations (see Fig. 4).
- Diagramma a scatola della petrografia dei clasti del conglomerato di Villa Olmo campionata su tre stazioni indicate in Fig.4.

tiating during the Late Cretaceous (e.g., Castellarin *et alii*, 1992; Schönborn, 1992). N-S trending structures, inherited from previous tectonic phases (i.e., Triassic to Jurassic rifting, e.g., Bertotti *et alii*, 1993) and Mesozoic paleogeographical domains, were re-activated during alpine orogeny with strike-slip or transpressive kinematics and now cut off or induce a segmentation of the E-W trending thrusts and folds (Fig.1).

At the southern margin of the "Como" Sheet area (Figs. 1 and 3), the MBt separates the Gonfolite Lombarda Group and the Chiasso Fm. from the underlying Mesozoic sedimentary succession along a "younger-on-older" thrust. A lower age bracket for this thrusting is given by the Val Grande Fm. (Aquitanian to Burdigalian) which is clearly involved in the tectono-sedimentary sequence of MBt (Bernoulli *et alii*, 1989). An upper age bracket of the MBt activity has usually been placed in Late Miocene, based on the presence of the apparently undeformed Messinian Pontegana Conglomerate (e.g., Longo, 1968, Felber, 1993; Bini *et alii*, 2001) outcropping a few kilometers NW of Como and cutting across all older structures. Indeed, most authors suggested that shortening in the western Southern Alps had ceased by the late Messinian, after the so-called «Lombardic Tectonic Phase» (14 to 6 Ma; e.g. Schumacher *et alii*, 1997), due to the northward propagation of the Northern Apennines lithospheric flexure, which tilted and deactivated the pre-existing south verging Alpine structures (e.g. Doglioni, 1993; Fantoni *et alii*, 2004; Castellarin *et alii*, 2006; Scardia *et alii*, 2006).

However, several lines of evidence for a recent tectonic activity in the area has been pointed out in the literature (e.g. Bini *et alii*, 1992; Felber, 1993; Zanchi *et alii*, 1995, 1997; Bini *et alii*, 2001, Chunga *et alii*, 2007). Zanchi *et alii* (1997) and Bini *et alii* (2001) show that the whole mountain front on the MBt hangingwall displays evidence for a post-Miocene to Pleistocene uplift, and that Pliocene to Pleistocene deposits in the surroundings are affected by systematic fracturing and faulting at the meso-scale with centimetric to decimetre offsets. Sileo *et alii* (2007)

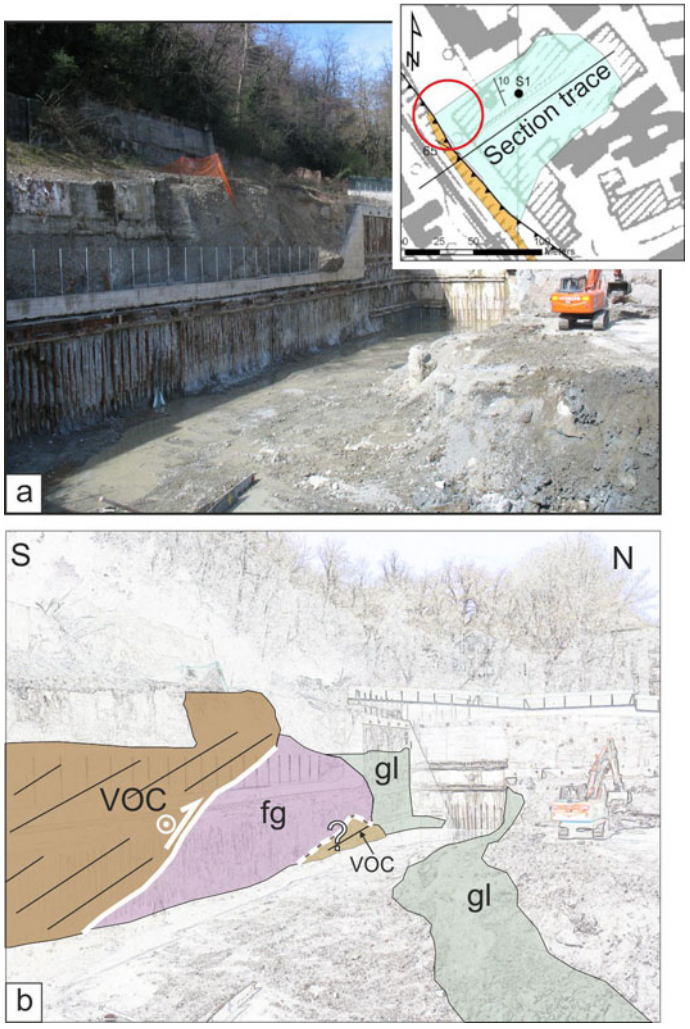

Fig. 6 - (a) photograph, taken from the east of the north-western sector of the building yard in Borgo Vico Site and (b) drawing of the outcrop detail. "VOC" is thrust onto "fg" unit and both are unconformably overlain by "gl" sequence. Inset shows map view and location of S1 exploration well. Red circle marks the location of the outcrop.
- Fotografia ripresa da est (a) del settore di NW del cantiere di Borgo Vico ed interpretazione (b) delle unità affioranti. Il Conglomerato di Villa Olmo (VOC) è sovrascorso su "fg" ed entrambe le unità sono ricoperte da depositi glaciolacustri "gl" . L'inserto in alto a destra mostra la mappa del sito e la posizione del sondaggio S1. Il cerchio rosso indica la posizione dell'affioramento.

described at Novazzano site a reverse fault between Como Conglomerates and the Castel di Sotto Clays (Pliocene), attesting a reactivation of this structure after the Early Pliocene.

The outcrop described in this paper brings the age of youngest tectonic movements along the MBt to Late Pleistocene; it has some important implications both for the recent tectonic and geomorphic evolution of this sector of the western Southern Alps, and possibly in terms of seismic hazard assessment.

THE BORGO VICO OUTCROP

The Borgo Vico outcrop, unfortunately no longer accessible, is located at the north-western margin of the

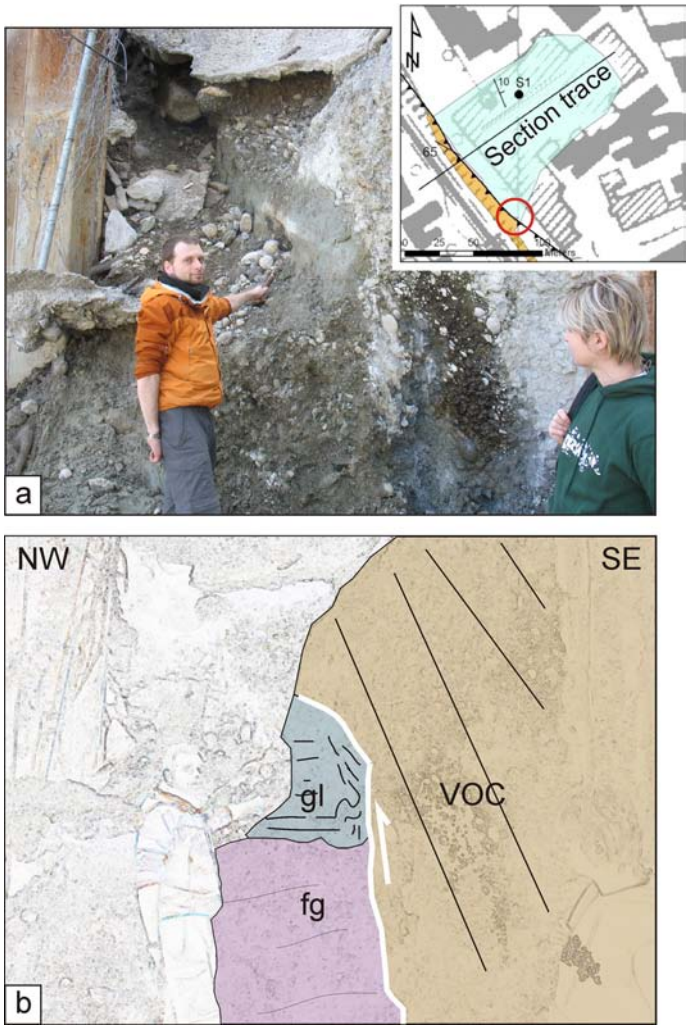

Fig. 7 - (a) photograph taken from the north, of the south-eastern sector of the building yard at Borgo Vico and (b) drawing of the tectonic contact between the Villa Olmo Conglomerate and the glaciolacustrine and fluvioglacial deposits. Note the upward-directed drag-folding affecting the "gl" unit along the contact with VOC. Inset shows map view and location of S1 exploratory well. Red circle marks the location of the outcrop. See text for abbreviations for the stratigraphic units.
- Fotografia ripresa da nord (a) del settore SE del cantiere di Borgo Vico ed interpretazione (b) del contato tettonico tra il Conglomerato di Villa Olmo e i depositi glaciolacustri e fluvioglaciali quaternari. Si notino le pieghe da trascinamento che deformano "gl" lungo il contatto con VOC. L'inserto in alto a destra mostra la mappa del sito e la posizione del sondaggio S1. Il cerchio rosso indica la posizione dell'affioramento. Per le abbreviazioni delle unità stratigrafiche si rimanda al testo.

Como urban area. Here, excavation works carried out for building foundations have exposed a tectonic contact between the lowermost known occurrence of the VOC and Late Pleistocene fluvioglacial and glaciolacustrine sediments.

Villa Olmo Conglomerate (Voc)

The sequence exposed at this site consists of a few stacked bodies of conglomerate with intercalated thin beds of sandy silts and marls (Fig. 4). Conglomerate beds are typically a few decimeters to a few meters thick, coarse, clast or matrix-supported with both normal and inverse grading. They can be related to channel-fill deposits incised into slope to base-of-slope sediments. Current indicators (i.e., flute cast) point out a flow direction from NW to SE (N158).

The petrographical composition of the clasts has been analyzed in three stations along the sequence (Fig. 4 and 5). A minimum count of 100 pebbles per station has been attained. Results mainly confirm the observations of Carrapa & Di Giulio (2001) showing a dominance of metamorphic rocks coming from the basement of the Central and Southern Alps (overall 48%), subordinate plutonic (17%), highly variable along the section, and an important presence of limestones and dolostones of the South-Alpine sedimentary cover (31%).

The presence of clasts of Eocene nummulitic limestones (Ternate Fm., e.g., Bernoulli 1980) in the VOC testifies to the emersion and erosion, at that time, of Late Eocene deep-water deposits whose shallow-water source area is now completely eroded in the near-Como area. Some marlstone clasts, probably derived from the Chiasso Formation, are also embedded in the conglomerate, suggesting intrabasinal reworking. Samples for palaeontological analysis were collected at every fine-grained layer and are presently under investigation.

The strata dip is to the SW at high angle (55 – 65 degrees), and the overlying Chiasso Fm., outcropping further south, presents a slight angular unconformity (N210/70, Fig. 3b) with the Como Conglomerate.

Quaternary Deposits

The older Pleistocene unit is an ice-contact flow till - "fg", outcropping along the rock cliff (Figs. 6, 7 and 8). It's a matrix-supported chaotic conglomerate, not cemented, with sub-rounded polymictic clasts in a grey loam–sandy matrix. Bedding is hardly distinguishable and grossly lens-shaped. The clasts also include pebbles from the VOC. No datable material or a well-preserved weathered profile is present but an LGM age is inferred based on lack of overconsolidation and on stratigraphic relationships. The conglomerates pass upward, through a steeply dipping unconformity surface, to a glaciolacustrine unit "gl". This unit is composed of grey thin-bedded or massive clayey silts and fine sands, with many dropstones enclosed (Figs. 6 and 7). Bedding is sub-horizontal or slightly inclined (ca. 5 degrees) toward the NE. This unit is here at least 24 m thick, based on 4 m of outcrop (Fig. 6) and a 20 m deep well (S1 on Figs. 6, 7 and 9). More than 10 shallow exploration wells were drilled in the excavation area and all available stratigraphic logs were taken into account. Comerci *et alii* (2007) extensively studied the subsurface geology of the Como metropolitan area and "gl" can be well correlated to their Unit 3: a Late Glacial glaciolacustrine inorganic sequence. This unit deposited in an ice–contact lake, during the northward retreat of the glacier from the Como area, until drainage was inverted, ca. 17000 cal. BP (Comerci *et alii*, 2007), and the lake level progressively dropped to the present level.

"Gl" unit is unconformably overlain, along a diachronous erosional surface, by sands and small pebbles (sh) representing progressively lower Holocene lake-shore

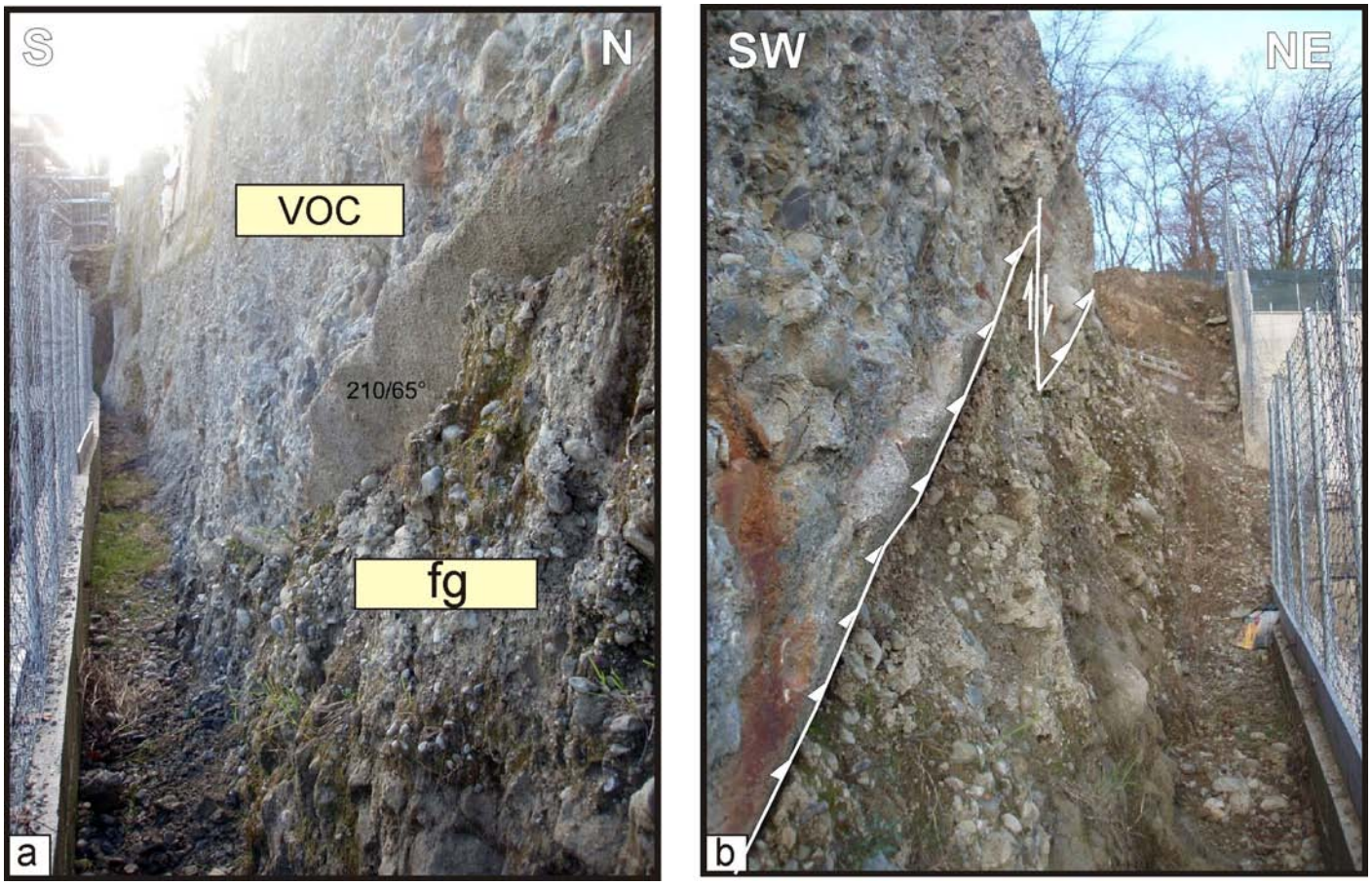

Fig. 8 - photographs of the fault plane taken from the northern (a) and southern (b) end of the excavation wall.
- piano di faglia visto dall'estremità settentrionale (a) e meridionale (b) della parete di scavo.

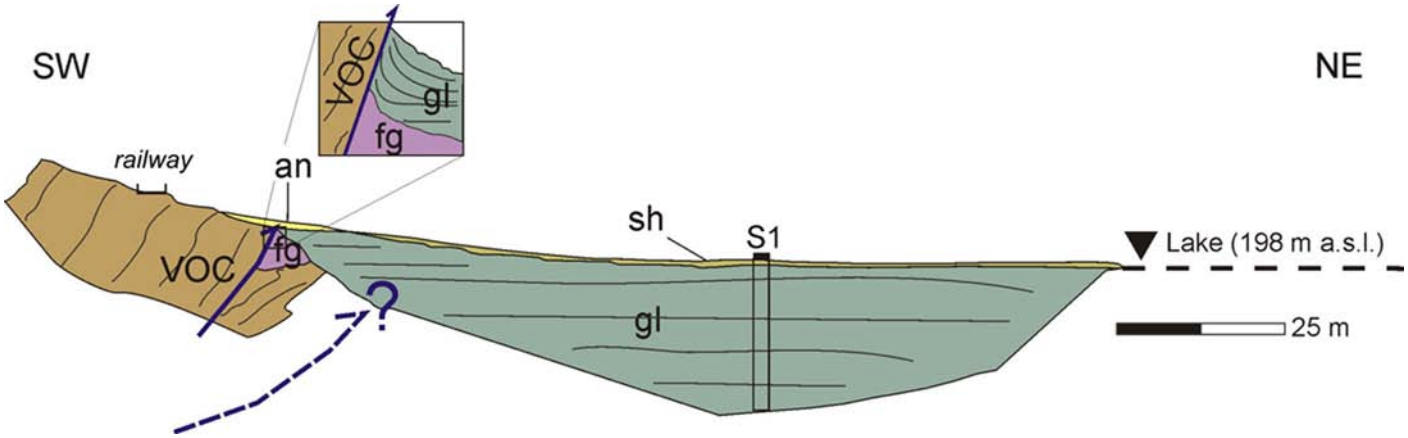

Fig. 9 - A SW-NE geological profile across the Villa Olmo reverse fault. Section trace and S1 well location are drawn on the map in the inset of figure 6 and 7.
- profilo geologico passante attraverso la faglia di Villa Olmo. La traccia della sezione e l'ubicazione del pozzo S1 sono indicate nella mappa nelle figure 6 e 7.

levels (Comerci *et alii*, 2007). The youngest unit is represented by landfill and colluvial deposits (an).

The formational contacts and cross-cutting relationships are summarized in Figure 9.

Monte Olimpino Backthrust (Mbt)

At Borgo Vico the VOC is thrust onto a probably Late Pleistocene fluvioglacial unit along a reverse fault (dipping N210/65 ; Figs. 6, 7 and 8). The observed fault is not strictly coinciding with the MBt, but probably represent a secondary splay located in the hanging wall of the main thrust. Indeed, below the fluvioglacial deposit another spur of VOC crops out at the very base of the excavation (Fig. 6).

In the NE sector of the outcrop, the fault plane is almost parallel to the bedding in the VOC (Fig. 6); secondary

high-angle faults offset the main fault plane with centimetre throw and reverse displacement. To the SE, faulting cuts off bedding planes vertically (Fig. 7) and drag folds affect the laminae of the glacio-lacustrine deposits along the fault contact. Fine-grained intervals of VOC show bedding-parallel shear, probably related to secondary flexural slip faults.

Even if a primary stratigraphic contact between VOC and the underlying fluvioglacial sediments can be invoked (due, for example, to the presence of a pre-existing oversteepened excavation) however, drag-folding of glaciolacustrine laminae testifies a centimetric to decimetre movement, younger than 17.000 yrs BP, along this contact and related to the main MBt itself.

CONCLUSIONS

The outcrop at Borgo Vico exposes the lowermost strata of the Villa Olmo Conglomerate: a clastic deposit of Late Oligocene fed from the N to NW. Our data are largely in line with the observations in the only outcrop previously known (Valdisturlo *et alii*, 1998).

The Villa Olmo Conglomerate is thrust onto a Late Pleistocene fluvioglacial and lacustrine sequence, whose deformation and faulting postdates the latest movement along the main thrust. The exposed reverse fault is directly linked with the MBt even though at the moment it is not possible to assess where the main fault tip is located. The presence, further north, of a rock spur made of VOC seems to indicate that this fault lies in the hanging-wall of the Monte Olimpino backthrust (Fig. 9). The MBt tip has to be located, based on geological mapping, in close proximity to this point.

Fault plane orientation, consistent with that of the MBt, indicates compressive tectonics here directed ca. NNE-SSW and characterized by quite-vertical surface faulting.

The described outcrop displays, for the first time in this area, geological evidence of at least Late Pleistocene compressive tectonics and surface faulting directly associable with a well known structure.

According to IAEA (2002) a fault is defined as "capable" if it shows potential for displacement and/or deformation at or near the ground surface. On the basis of geological, geophysical, geodetic or seismological data, a fault shall therefore be considered capable if it shows evidence of past movement within such a period that it is reasonable to infer that further movements at or near the surface may occur. In highly active areas, where both earthquake data and geological data consistently reveal short earthquake recurrence intervals, periods on the order of tens of thousands of years may be appropriate for the assessment of capable faults. In less active areas, it is likely that much longer periods are appropriate.

In western Lombardy the Italian seismic catalogues (e.g., CPTI, 2004) quote very rare weak to moderate earthquakes (i.e., the Nov. 26, 1396, Io VII-VIII MCS, Monza and the May 12, 1802, Io VII-VIII MCS, Soncino earthquake) with epicenters generally located in the plain SE of our area, suggesting that our area could be characterized by long recurrence intervals.

Paleoseismological analyses are in progress in order to distinguish potential coseismic movement from fault creep along this late Pleistocene displacement.

Our study shows how detailed field observations within the CARG project can provide valuable geological evidence of neotectonic activity by detailed mapping of capable (sensu IAEA, 2002) faults. This basic geological information has certainly to be considered a vital element for the evaluation and mitigation of seismic hazard in terms of both ground shaking and surface faulting.

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