Remarks on the Quaternary tectonics of the Insubria Region
(Lombardia, NW Italy, and Ticino, SE Switzerland)

Giancario Sileo (*), Francesca Giardina (**), Franz Livio (*), Alessandro M. Michetti (*), Karl Mueller (***) & Eutizio Vittori (***)

ABSTRACT

In the foothills of the Southern Alps between Lake Garda and Lake Maggiore, the relations between the recent tectonic evolution and the accompanying seismic potential have been overlooked. Published interpretations of structures consider shortening to cease at the end of the Messinian; this is in contrast with geomorphic and stratigraphic evidence for Plio-Quaternary reverse faulting and folding presented in this paper.

Evidence for Quaternary shortening near Lake Garda includes Quaternary folds with 200 m of structural relief recorded by Lower-Middle Pleistocene deposits. These crop out on top of the Castenedolo and Ciliverge Hills, within the epicentral area of the historical December 25, 1222 Brescia earthquake (epicentral intensity IX MCS, Me 6.2; Guidobono, 2002).

Shortening further west may also be occurring, but there is no record of local damaging historical earthquakes along the foothills of the Alps. This motivated us to review available data and undertake new reconnaissance field work, in order to better understand the Quaternary tectonic evolution of the Southern Alps near Lake Como in the Insubria region.

We focused our studies on two major structures located east and west of Como, respectively, the Gonfolite backthrust and the Albese con Cassano anticline. The Gonfolite backthrust, first recognized by Bernoulli et alii (1989) and reported as late Miocene in age, is accompanied by geomorphic features consistent with Quaternary compressional structures. Our new field mapping suggests that this thrust offsets deposits of Pliocene and possibly younger age. Neotectonic evidence for the recent evolution of Albese con Cassano anticline was first presented by Orombelli (1976). Our investigations confirm Orombelli’s observations, and suggest that the Albese con Cassano is an actively growing anticline that accumulated ca. 200 m of post-Middle Pleistocene vertical displacement. In addition, paleoliquefaction features in Mid-Pleistocene proglacial deposits at this site suggest that growth of this structure has been accompanied by strong local earthquakes.

Evidence of Quaternary tectonics in the Insubria region is consistent with that observed in the well-known seismic area near Lake Garda. Therefore, the seismic potential of this area should be carefully re-evaluated based on the examination of available geological data and the results of new ad hoc paleoseismological analyses. Current assessment of seismic hazard, based on the historical seismic catalog, supposedly heavily underestimates the earthquake potential in one of the most vulnerable areas of the whole Europe.

KEY WORDS: Quaternary tectonics, Central-Southern Alps, seismic hazard, compressional tectonics.

INTRODUCTION

Active shortening and related seismicity in Northern Italy is the result of the growth of two thrust belts of opposite polarity, the Alps and the Apennines (e.g. Serva, 1990; Doglioni, 1993; Castellarin et alii, 2000; Boccaletti & Martelli, 2004; fig. 1a).

Pliocene shortening in the Southern Alps and northern Po Plain has been documented on geological basis to decrease from east to west (e.g. Serva, 1990; Bigi et alii, 1990; Fantoni et alii, 2004; Galadini et alii, 2005; Castellarin et alii, 2006). Historical seismicity follows the same trend, and the frequency of strong seismic events decreases from Friuli toward Lake Garda, and then Lake Maggiore, where no historical seismicity with epicentral intensity greater than VI MCS is documented (e.g. Working Group CPTI, 2004; fig. 1b). Furthermore,
based on GPS data, the western Southern Alpine mountain front is currently characterized by noteworthy shortening rates of ca. 1.1 mmyr⁻¹, even though half of the value (2.2 mmyr⁻¹) inferred for the seismically-active eastern Southern Alps in Friuli (e.g. SERPELLONI et alii, 2005; D’AGOSTINO et alii, 2006).

West of the Veneto-Friuli regions, the best evidence of active shortening is shown in the Lake Garda area. Desio (1965) described the morphological and stratigraphic expression of several Pleistocene anticlines outcropping southwest of Lake Garda, near Castenedolo and Ciliverghe (fig. 1a). These structures were subsequently studied by other workers, including BARONI & CREMASCHI (1986), CASTALDINI & PANIZZA (1991), CURZI et alii (1992), LOCATELLE & VERCESI (1998), CARCANO & PICCINI (2002). At least 200 m of structural relief has been documented in the Lower Pleistocene marine deposits affected by the Castenedolo anticline (CURZI et alii, 2002). A similar Middle Pleistocene uplift has been recently derived from magnetostratigraphic analysis along a borehole drilled southwest of Castenedolo (SCARDIA et alii, 2006). Faulting and tilting in Middle Pleistocene glacial deposits has been observed in the Ciliverghe Hill, belonging to the same structure of Castenedolo (BARONI & CREMASCHI, 1986). The presence of Quaternary structures inferred from geological data is in agreement with the historical and instrumental seismicity data. Castenedolo and Ciliverghe are located within the epicentral area of the December 25, 1222, Brescia earthquake (MAGRI & MOLIN, 1986; GUIDOBDONI, 1986; SERVA, 1990; GUIDOBDONI, 2002), arguably the largest historical seismic event that has occurred in the Po Plain (WORKING GROUP CPTI, 2004): the intensity IX MCS attributed to this earthquake is equivalent to a macroseismically derived magnitude of 6.2 (see GUIDOBDONI, 2002). Besides, the seismicity of this area and the mechanism of faulting has been more recently documented by the November 24, 2004, Salò earthquake (e.g. MICHETTI et alii, 2004; fig. 1b), a moderate event characterized by a reverse faulting local mechanism (an overview of the historical seismicity near Salò is available in INGV, 2004). Likewise, a south-verging, blind reverse fault has been hypothesized as the causative tectonic structure for the May 12, 1802, Soncino earthquake by BURRATO et alii (2003; fig. 1). Based on a detailed analysis of drainage network anomalies, these Authors suggest that the Southern Alps beneath the Po Plain in Lombardia are characterized by active shortening accommodated by thrust faulting and growing anticlines. This is in agreement with interpretations by ROEDER (1992), who, based on structural analysis of subsurface data along the Po Plain piedmont belt in Lombardia, indicated “draping and/or warping of Pliocene sediments over deeper thrust architecture related to recent foothills thrusting at low strain rate”.

Even if the studies described above consistently propose a Quaternary tectonic setting due to active Alpine shortening, the interpretation of the nature and features of Quaternary deformation along the Lombardia foothills and piedmont belt is still controversial. Several Authors suggest that shortening in the western Southern Alps virtually ceased in the late Messinian after the so-called “Lombardic Tectonic Phase” (14 to 6 Myr B.P.; e.g. SCHUMACHER et alii, 1996), due to the northward propagation of the Northern Apennines lithospheric flexure, which tilted and deactivated the pre-existing south verging Alpine structures (e.g. BERNONI et alii, 1989; DOGLIONI, 1993; FANTONI et alii, 2004; CASTELLARIN et alii, 2006; SCARDIA et alii, 2006). Others point out that during the Late Alpine deformation the inner Western Alps are characterized by Neogene to ongoing extension (MANCKETLOW, 1992; SUE & TRICART, 2003; GROSJEAN et alii, 2004). PICCOTTI et alii (1995) and BERTOTTI et alii (1997) have argued that even the Central-Southern Alps and the Northern Apennines are currently experiencing crustal extension, because of a post-Messinian state-of-stress change related to the bulging of the Apennine Foreland.

In the area between Lake Maggiore and Lake Como, this poor understanding of the Quaternary tectonic setting has resulted in contrasting interpretations of the observed evidence of neotectonics and paleoseismicity (e.g. CASTALDINI & PANIZZA, 1991; ZANCHE et alii, 1997). For instance, opposing interpretations have been presented to explain the Quaternary uplift of Mt. Morone, east of Varese (e.g. FELBER, 1993; ZANCHE et alii, 1997; BINI et alii, 2001; figs. 2 and 3). BINI et alii (2001) suggest that the uplift could be interpreted as due either to reverse faulting along the Gonfolite backthrust or to late-Alpine extensional tectonics.

This motivated us to review available data and undertake new reconnaissance field work, in order to better understand the Quaternary tectonic evolution of the Southern Alps near Lake Como in the Insubria region. In the first step of this project, we focused our studies on two major structures located east and west of Como, respectively, the Gonfolite backthrust and the Albese con Cassano anticline, both displaying evidence of recent deformation according to literature data (e.g. OROMBELLI, 1976; FELBER, 1993; ZANCHE et alii, 1997; BINI et alii, 2001). We seek to demonstrate whether 1) these features are produced by active shortening or extension, and 2) they can be compared to the Quaternary deformation observed in the seismically-active portion of the western Southern Alps near Lake Garda. This paper illustrates initial results of new field mapping and geomorphic analyses along these two structures. In the next step of this research, we have conducted a more regional study in collaboration with ENI Exploration and Production, including the reinterpretation of subsurface data in the whole Lombardia sector of the Po Plain and adjoining foothills; results from this further research will be presented elsewhere in a companion paper. The revision of the available literature based on new field data collected so far and presented here allows to draw some significant conclusions, even if preliminary, on the Quaternary tectonics of the Insubria region, and to delineate a rather new scenario for its seismicity potential.

GEOLLOGICAL AND GEOMORPHOLOGICAL SETTING OF THE INSUBRIA REGION

Insubria extends between Lake Maggiore and Lake Como along the foothills of the western Southern Alps (fig. 1a). The oldest strata exposed here include Late Triassic to Early Jurassic mainly carbonatic sediments deposited in the Jura-Cretaceous Lombardian Basin following the opening of the Tethys Ocean (WINTERER &BOSELLINI, 1981; GIANOTTI & PEROTTI, 1987; BERTOTTI et alii, 1993). The outset of the Alpine orogenesis then shed sequences of flysch (Cretaceous to Eocene) and molasse southward into the Po Plain Foredeep. The latter is repre-
sented by the Oligo-Miocene sequence of the Lombardian Gonfolite Group, which outcrops in Western Lombardy and is largely represented in the subsurface of the northern Po Plain (SCIUNNACH & TREMOLADA, 2004; FANTONI et alii, 2004). The Gonfolite Group is made by up to 3000 m of resedimented conglomerates and sandstones, and can be linked to a foredeep tectonic basin superimposed on an active continental margin (e.g. GELATI et alii, 1988, 1991). After deep erosion during the Messinian as a result of a drop of the regional base level, Pliocene marine clays were deposited in small troughs within the piedmont belt (e.g. «Argille di Castel di Sotto»; BINI et alii, 2001; fig. 4). Locally, coarse alluvial deposits are found beneath the Pliocene clays, such as in the area west of Como («Ponte-gana Conglomerates», tentatively dated at the late Messinian; see BINI et alii, 2001, and reference therein; fig. 4). This succession is covered by the Quaternary glacial and fluvi-glacial sediments related to climatic-driven fluctuations of the ice tongues of the Abduan glacier system (BINI et alii, 2001).
Insubria underwent thin-skinned shortening during the phase of the Alpine orogenesis that generated the Southern Alps (e.g. DOGLIONI, 1993; FANTONI et alii, 2004), producing a system of mostly south-verging thrusts and folds (e.g. SCHÖNBORN, 1992). Sediments deposited in the foredeep of the Southern Alps during this period and the external part of the belt are deeply buried beneath the Po Plain as shown in seismic reflection data (PIERI & GROPPI, 1981). These are represented by the Upper Oligocene to Lower Miocene deepwater clastic strata of the Gonfolite Lombarda Group (GELATI et alii, 1988), that unconformably overlie the mainly carbonatic Meso-Cenozoic succession.

From the geomorphic point of view, Insubria stretches east-west across the Lombardia and Ticino foothills at the junction between the Alps and the Po Plain, with elevations ranging from 198 m (the level of Lake Como) and 1704 m a.s.l. (the elevation of Mt. Generoso, the highest peak in the area). The digital elevation model shown in fig. 2 clearly illustrates the strong glacial imprint on the landscape, described in detail by several authors, such as NANGERONI (1970), OROMBELLI (1976), BERNOUlli et alii (1989), MONTRASIO (1990), MOSCARIELLO et alii (2000) and BINI et alii (2001).

Since the Middle Pleistocene, several major glacial expansions covered this area with large, up to 2 km thick, ice tongues (NANGERONI, 1970; BINI et alii, 1998; MOSCARIELLO et alii, 2000; MUTTONI et alii, 2003). Successive advances and retreats of glacial flows coming from the Central Alps occupied the valleys and reached the piedmont belt and the northern Po Plain. In particular, during the Late Pleistocene the Insubria region was affected by several important glacial pulsations of the major ice tongue coming from Valtellina, i.e. the Abduan glacier (e.g. BINI et alii, 2001). During the Last Glacial Maximum (LGM, 22 to 20 kyr B.P.; e.g. IVY-HOCHS et alii, 2004, and references therein) in the area between Como and Varese the landscape was mostly covered by ice, and the whole drainage network was filled by glacial tongues up to an elevation of 1100 m near Mt. Generoso and 800 m in the surrounding of Como town (fig. 2; e.g. BINI et alii, 1998, and references therein). During the LGM and previous glacial maxima, in this sector the glacial processes were dominantly erosional, and most of the glacial to fluvo-glacial sediments have a post-LGM age. The major accumulation of glacial deposits took place further south, between Como and Milan, where the huge piedmont lobes and terminal moraines of the Abduan glacier were located during the LGM. The area south of the Varese and Como foothills is also characterized by a gently south-sloping fluvioglacial and fluvial outwash plain (sandur-like environment), essentially built during the LGM. This wide low-gradient depositional surface is a typical feature of all the piedmont belts around the Po Plain, and corresponds to the so-called «Livello fondamentale della pianura» of PETRUCCI & TAGLIAVINI (1969), who first defined the basic features of this regional geomorphic unit (see CASTIGLIONI & PELLEGRINI, 2001; MARCHETTI, 2002; and references therein).

Two major tectonic structures in the Insubria region show geomorphic features clearly unrelated to glacial erosion and indicative of a recent tectonic activity, the Gonfolite backthrust and the Albese con Cassano anticline. The evidence for Quaternary deformation and faulting along these structures has been already described in the literature by several Authors (e.g. OROMBELLI, 1976; FELBER, 1993; ZANCHI et alii, 1997; BINI et alii, 2001). In the next sections we revise the published data and describe...
the results of new field mapping and geomorphic analyses. We show that the evidence of Quaternary shortening along these tectonic structures can be compared with those previously described for the Southern Alps structures southwest of Lake Garda.

**THE GONFOLITE BACKTHRUST**

West of the city of Como, the Gonfolite backthrust is located at the base of a 20 km long, steeply inclined, north-facing mountain front (figs. 2 and 3). During the construction of a railway tunnel in the Como area, a tectonic contact between the Gonfolite Lombarda Group and the carbonatic Mesozoic Succession was documented and mapped for the first time (e.g. BERNOULLI et alii, 1989). This structure is the surface expression of a major north-verging backthrust, reportedly dated to the Tortonian (see FANTONI et alii, 2004; SCIUNNACH & TREMOLADA, 2004, for recent revisions of the relevant literature).

Despite many Authors regard the Gonfolite backthrust as a Miocene structure, evidence for more recent activity has been pointed out (e.g. BINI et alii, 1992; FELBER, 1993; ZANCHI et alii, 1995, 1997; BINI et alii, 2001). ZANCHI et alii (1997) and BINI et alii (2001) were able to show that the whole mountain front in the hangingwall of the Gonfolite backthrust (figs. 3 and 4) 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 decimetric offsets. Near Novazzano (fig. 2), FELBER (1993) described a tectonic contact between the Gonfolite Lombarda Group and the Pliocene Formation of the Castel di Sotto Clays, outcropping along the thalweg of a small valley. He interpreted this contact as a possible normal fault, due to the normal drag of the Pliocene bedding along the fault plane. ZANCHI et alii (1995, 1997) revised this outcrop giving the same interpretation of normal faulting.

The drainage along the Faloppia Valley, one of the originally south-sloping valleys carved in the Lombardia foothills during the Messinian drop of the Mediterranean Sea level (see FINCKH, 1978; FELBER et alii, 1991, 1994), was later inverted due to the raising of the Gonfolite relief.

Around Monte Morone (figs. 2 and 3), ancient terminal moraines have a single arc morphology in map view, while younger terminal moraines are arranged in two separate lobes. The uplift of Monte Morone influenced the morphology of the local terminal moraines associated to the Lake Lugano ice tongue. Mt. Morone elevation is 496 m a.s.l., more than 100 m higher than the surrounding glacial outwash plain; this value can be taken as a rough estimate of the minimum local vertical uplift. The lack of direct dating does not allow to more precisely constrain the timing of this uplift. Since the onset of major Quaternary glaciations in the Southern Alps is regarded as having occurred at ca. 0.9 Myr B.P. (e.g. BINI et alii, 1998; MUTTONI et alii, 2003; SCARDIA et alii, 2006), it is reasonable to hypothesize that the uplift of Monte Morone occurred during the Middle Pleistocene.

The systematic offset of karstic conduits and collapse of speleothems beneath the Mt. Campo dei Fiori at the western margin of the Gonfolite backthrust near Varese.
(fig. 2) are interpreted by Bini et alii (1992) as due to Quaternary shortening. Speleothems of the Mt. Campo dei Fiori cave system have been dated to ca. 350 kyr B.P. based on U-Th dating, and the observed collapses and deformations of the cave system is regarded as younger than 350 kyr B.P. This is interpreted as evidence of paleoseismicity due to the growth of a south-verging fold facing the north-verging Gonfolite backthrust during the Middle Pleistocene.

It is important to remark that Zanchi et alii (1997) preferred interpretation is that the overall pattern of Plio-Pleistocene tectonic activity in the area is characterized by surface north-south extension due to «superficial accommodation of deformations related to south-verging blind thrusting at depth, locally producing differential uplifting and possibly reactivation of some of the major Late Miocene thrust surfaces». However, these Authors indicate that alternative active tectonic models are possible.

In order to review these literature data and provide better constraints for the age, nature and amount of post-Messinian to recent displacement along the Gonfolite backthrust we conducted new field mapping and geomorphological analysis (figs. 3 and 4). We first mapped at 1:10,000 scale the area along the thrust from Como to Mt. Morello (fig. 2). During the field work, we re-visited the outcrop described by Felber (1993) and Zanchi et alii (1995; 1997) in a ca. 15 m deep stream incision near Novazzano, where a fault plane juxtaposes the Oligo-Miocene conglomerates of the Lombardian Gonfolite Group against the Pliocene Formation of the «Castel di Sotto Clays». The outcrop was better exposed than in 1993 and 1997 (as made clear by the comparison of the present-day aspect of the outcrop shown in fig. 5 with fig. 9 in Zanchi et alii, 1995), probably because of the valley floor downcutting occurred during the November 2000 and November 2002 flooding events in the Lombardia and Ticino Region. Our re-examination of this outcrop confirms previous observations about the bedding of the Gonfolite Lombarda Group (strike N190, dip 70°-80°). Also, the geometry of the upper part of the fault plane corresponds to that described by other Authors; the fault plane is almost vertical and dips to the north, and the Castel di Sotto Clays are dragged against the fault plane, while few tens of meters away from the fault plane this formation takes again the original horizontal bedding. However, in the lower part of the fault plane, certainly newly exposed, the dip progressively shift to the south moving down along the exposed section, bringing the Gonfolite Group directly above the Castel di Sotto Clays. The Castel di Sotto Clays in this lower part of the fault plane are over-

![Fig. 4 - Geological sketch map of the Gonfolite backthrust area.](image-url)
turned, with a planar bedding dipping south by 70°-80° (fig. 5). We interpreted this fault plane as an outcrop of the Gonfolite backthrust documented by Bernoulli et alii (1989). Field mapping around the Novazzano site allowed us to confirm that the Gonfolite backthrust largely affects the Castel di Sotto Clays, as shown in the geological section of fig. 6. Minimum amount of vertical component of Pliocene offset is 200 m. Therefore, in contrast to previous interpretations, the Gonfolite backthrust did not cease its activity in the Late Miocene.

Fig. 5 - Outcrop of the Gonfolite backthrust at the Novazzano site (see location in fig. 2): a) the tectonic contact between Castel di Sotto Clays and Gonfolite Lombarda Group; b) our interpretation; c) particular of the overturned Castel di Sotto Clays in the footwall of the Gonfolite backthrust (photos taken by Giancanio Sileo on July 2004).

Fig. 6 - Geological cross section across the Gonfolite backthrust. Minimum amount of vertical component of Pliocene offset is 200 m. Therefore, in contrast to previous interpretations, the Gonfolite backthrust did not cease its activity in the Late Miocene.

Fig. 6 - Sezione geologica attraverso il retroscorrimento della Gonfolite.
Unfortunately, until now we were not able to observe reverse displacement of Pleistocene deposits along the fault zone. Direct observations of the fault plane can only be done in a few spots, due to the dense vegetation cover and diffuse man occupation of land, and in these spots there are no exposures of well bedded Pleistocene sediments across the fault zone. For instance, in the Novazzano site only coarse glacial deposits outcrop in the upper part of the section of fig. 5, but they are badly exposed and it is impossible to understand if they are faulted or not (see also ZANCHI et alii, 2005). Further work is in progress to stratigraphically define the youngest movements along the fault using geophysical prospecting and exploratory trenching. However, we were able to confirm the presence of normal fault systems at the mesoscale affecting the Pliocene and Pleistocene deposits in the nearby Mendrisiotto area, interpreted by ZANCHI et alii (1997) as the accommodation at surface of continuing fault slip on deep-seated South-Alpine compressional structures. Our new data therefore support the interpretation mentioned above about the recent reactivation of some Late Miocene thrust.

Also the geomorphic relations along the fault strongly suggest a Quaternary activity for the Gonfolite backthrust. The new field data allow to precisely constrain the trace of the backthrust, and therefore to better understand the relationships between the fresh geomorphologic expression of the Gonfolite reliefs and the presence of the fault. In the Chiasso Plain and near Novazzano the front of the Gonfolite reliefs is in contact with the Mesozoic carbonatic sequence of the Lombardian Basin. Near Mt. Olimpino we mapped outcrops of the Liassic formations of the «Moltrasio Limestone» and «Rosso Ammonitico» at a distance of a few tens of meters from the outcrop of the Oligo-Miocene marls and conglomerates at the base of the Gonfolite range front. All the Lias to Oligocene
sequence is missing. This contact is therefore clearly the surface expression of the Gonfolite backthrust (SILEO et alii, 2005), and is constantly located along the break in slope at the base of the Gonfolite range front. As already pointed out, in this area Quaternary glacial erosion was very strong and the pulsations of the Abduan ice tongue obliterated all preexistent structures and relief. In particular, in the Chiasso plain several episodes of glacial advances and retreats are well documented (BINI et alii, 2001). Since the glacial flow was from the north, and the Gonfolite range front is facing north (figs. 2 and 3), the base of the range front should not be coincident with the fault trace. In other words, due to the glacial erosion the range front should have been retreated somewhere south of the trace of the backthrust. Glacial erosional processes wiped out the bedrock Mesozoic carbonatic formations in the Chiasso Plain but apparently they did not affect seriously the Gonfolite reliefs, which are made by much softer rocks. This is a serious geomorphic anomaly for a landscape carved by glacial erosion. Lack of retreat of the Gonfolite mountain front is a strong evidence that fault slip has been capable, during the Quaternary, to withstand the glacial erosive activity. This is also suggested by the very regular curved trace of the range front in map view (fig. 2), for a length of about 20 km, with the concavity facing south. It seems very unlike that this regular morphology is only controlled by selective erosional processes. In fact, as shown in fig. 7 the sinuosity index of this front is ca. 1.2, indicating an active tectonic mountain front (KELLER & PINTER, 1996). Again, if the morphology of the Gonfolite relief was due to erosion, it is not clear why the harder carbonate bedrock in the footwall has been almost completely removed while the relatively softer conglomerates and marls in the hangingwall today form an outstanding range front.

Summarizing, the Gonfolite backthrust did not cease to slip in the late Miocene, as commonly accepted in the literature. Shortening was certainly reactivated during the Pliocene, as observed near Novazzano, and produced significant uplift along the Gonfolite range front. Geomorphic evidence and mesostructural analysis (ZANCHI et alii, 1995, 1997; BINI et alii, 2001) along the whole range front strongly suggest that shortening and fault slip along the Gonfolite backthrust took place also during the Quaternary. Vertical uplift during Middle Pleistocene is poorly constrained, likely in the order of 100 m at Mt. Morone, located near the western termination of the Gonfolite relief.

THE ALBESCE CON CASSANO ANTICLINE

Observations related to Quaternary deformation and displacement at this site have been already described by OROMBELLI (1976) and ZANCHI et alii (1997). The Albese con Cassano Hill (fig. 8) is an east-west trending ridge, located at the foothills of Lake Como (fig 2), linked to the presence of an east-west trending smooth anticline (Albese con Cassano anticline; fig. 2), which locally affects the southward dipping Mesozoic mainly carbonatic succession. Based on new detailed field mapping, we interpret this structure as the western termination of the Mt. Barro thrust (BERSEZIO et alii, 1990; fig. 2) which, due to a reduced cumulated displacement, is here blind and marked only by its associated fault related folding.

Commonly, drainage pattern is strongly influenced by tectonic structures and can record their medium to long term activity (BURBANK & ANDERSON, 2001). A stream which crosses an uplifting area can in fact maintain its antecedence or be diverted, depending on the ratio between uplift and erosional rates. In the closeness of Albese con Cassano Hill, the Cosia Stream and its tributaries change their trend from north-south to east-west, recording an abrupt deviation in the local drainage pattern (figs. 7 and 8); the drainage divide is marked by the presence of three wind gaps, aligned with the deviated streams. This diversion has been ascribed to the growing of the Albese con Cassano anticline, which has locally prevailed over the erosive strength of the Cosia Stream (see CHUNGA et alii, 2006, and references therein). As already illustrated in the past (NANGERONI, 1970; OROMBELLI, 1976), a sequence of glacial and fluvio-glacial deposits (informally here called Albese con Cassano Conglomerates) outcrops on top of this relief. Facies analysis of the Albese con Cassano Conglomerates clearly relates them to a sandur-like depositional environment (well-bedded, well-rounded gravel and sand of open pro-glacial
alluvial plain). Field mapping at 1:10,000 scale performed for the new Geological Map of Italy, Sheet n. 75, «Como» (CARG Project, Geological Survey of Italy), allowed us to study in detail the spatial and vertical distribution of the Albese con Cassano Conglomerates. They crop out in two sites, between Como ad Lecco (Albese con Cassano and Madonna della Neve sites; fig. 2) at an elevation ranging between 550 m and 650 m a.s.l., directly overlying the Moltrasio Limestone Fm. At the Albese con Cassano site they are mainly horizontal on top of the hill and appear-ently south-dipping moving south (see the geological map of fig. 14 in ZANCI et alii, 1996; and our fig. 9); these conglomerates can be therefore seen as growth strata, recording the progressive deformation of the Albese con Cassano anticline. Their limited distribution in space is due to the extensive erosional activity exerted by the Abd-uan Glacier during the Quaternary. These conglomerates could therefore be preserved only in particular positions, acting like a sort of geomorphic refugee, while they completely lack, at the same elevations, in other nearby locali-

![Geologic sketch map of Albese con Cassano area](https://example.com/fig9.png)

Fig. 9 - Geologic sketch map of Albese con Cassano area (from CHUNGA et alii, 2006, modified). The reverse fault just north of Albese con Cassano is illustrated in fig. 11a; the soft-sediment deformations in fig. 11b-d are located at the junction between the Cosia and the Valloni streams.

Carta geologica schematica dell’area di Albese con Cassano (modificato da CHUNGA et alii 2006). La faglia inversa a nord di Albese con Cassano è illustrata in fig. 11a; le deformazioni nei sedimenti lacustri illustrate in fig. 11b fino in fig. 11d, sono posizionati alla giunzione fra i torrenti Cosia e Valloni.
ties along the mountain front and in the surrounding hills. Unfortunately, there is no absolute dating for these conglomerates but, based on regional stratigraphy, degree of weathering and soil development, they have been attributed to the Middle Pleistocene (OROMBELLI, 1976; NANGERONI, 1970; BINI, 1993). As already pointed out, this age is in agreement with the glacial chronology commonly accepted for the Southern Alps (e.g. BINI, 1993; MUTTONI et alii, 2003; SCARDIA et alii, 2006), which refers the beginning of the formation of the most important Lario Amphitheatre’s frontal moraines to the Middle Pleistocene.

As already illustrated by OROMBELLI (1976), facies analysis of the Albese con Cassano Conglomerates has demonstrated that they have been deposed as part of a wide glacial outwash plain, which is definitely incompatible with their present geomorphic setting and elevation. In fact, they outcrop over 200 m higher than the facing plain (ca. 350 m a.s.l.), that represents the upper part of the regional gentle sloping surface of the LGM outwash plain described above («Livello Fondamentale della Piana»). In agreement with OROMBELLI (1976), we also consider the Albese con Cassano Conglomerates correlative to similar cemented conglomerates preserved beneath the adjacent fluvioglacial plain, and encountered during the excavation of water wells (fig. 10).

Additional field observations confirm the Quaternary activity of the Albese con Cassano anticline (figs. 9 and 11). As already described by OROMBELLI (1976) and ZANCHI et alii (1997), the oldest depositional units are displaced by a secondary steep reverse fault (figs. 9 and 11a). The vertical offset of about 5 m affecting the conglomerates and underlying glacial till indicates recent tectonic shortening. This outcrop was newly exposed after a landslide in late 2003 and has been subsequently covered by reparation works. Also, the glaciolacustrine deposits entrenched in the basal Middle Pleistocene units (fig. 9) and outcropping along the Cosia Stream valley floor show evidence for coseismic liquefaction probably related to a local seismogenic source, as recently discussed by CHUNGA et alii (2006; fig. 11b-c).

Summarizing into a consistent structural framework all the observed evidence for Quaternary uplift and deformation, we propose that the Albese con Cassano Hill is a growing anticline that has absorbed ca. 200 m of vertical displacement from Middle Pleistocene to present. This is clearly indicated by the evident anomaly in the drainage pattern, the presence of a syntectonic sequence of deformed conglomerates (growth strata), and reverse displacement along a secondary fault. The age of the Albese con Cassano Conglomerates is at the moment the main source of error. We regard this structure as an active fault-propagation fold formed above a blind Mt. Barro fault, a ca. 20 Km long south-verging thrust in the Mesozoic carbonatic succession of the Lombardy sedimentary sequence. East of Mt. Barro this thrust is segmented by a north-south major structural lineament (Lecco Line; JADOU & GAETANI, 1986; GIANOTTI & PECORTI, 1986; BERSEZIO et alii, 1990).
Fig. 11 - Field observations of Quaternary shortening and paleoseismicity in the Mid-Pleistocene glacial deposits outcropping on top of the Albese con Cassano hill (see locations in fig. 2): a) reverse fault (ca. 5 m of displacement) in the basal Mid Pleistocene glacial deposits, i.e. from top to the bottom, fluvioglacial polygenic conglomerates and glacial till; b) and c) soft-sediment deformation in younger Mid-Pleistocene proglacial lake deposits; d) paleoliquefaction in the same deposits.

– Osservazioni di terreno nei depositi glaciali Medio-Pleistocenici affioranti alla sommità del rilievo di Albese con Cassano (vedi fig. 2): a) faglia inversa (circa 5 m di dislocazione) nei depositi glaciali basali Medio-Pleistocenici, i.e., dall’alto verso il basso, conglomerati poligenici e till glaciale; b) e c) deformazioni in sedimenti lacustri proglaciali Medio-Pleistocenici; d) paleoliquefazioni negli stessi depositi.
DISCUSSION AND CONCLUSIONS

The revision of the literature data, new field mapping at 1:10,000 scale and detailed geomorphic observation allow us to confirm previous interpretations by ROEDER (1992) and ZANCHI et alii (1997) about the post-Messinian to Quaternary reactivation of Late Miocene thrusts in the Insubria region at low strain rates, and under a continued north-south shortening. A similar conclusion has been drawn by BURRATO et alii (2003), based on the study of the causative fault of the May 12, 1802, Soncino earthquake (fig. 1), for the whole frontal sector of western Southern Alps underneath the Po Plain. The resulting scenario is therefore different from the reported deactivation of the western Southern Alps after the main phase of emplacement of the foredeep fold and thrust belt («Lombardic Phase» of SCHUMACHER et alii, 1996; 14 to 6 Myr B.P.).

Based on previous geological studies, GPS data, and new data presented in this paper, we can argue that the Insubria region is currently contracting at a very slow velocity (averaging 1 mm/yr). We reach this conclusion based on evidence from long term strain in the Quaternary deposits and in spite of a lack of large historical earthquakes. We also suggest that strain rates in the lake Maggiore and Lake Como are lower than in the Lake Garda region. This is consistent with both long and short term patterns of contraction in the Northern Apennines and Southern Alps, which can be related to rotational opening of the Tyrrenian Sea (BURRATO et alii, 2003; GIARDINA et alii, 2004; SERPELLONI et alii, 2005; D’AGOSTINO et alii, 2005). However, evidence of Quaternary shortening in the Insubria region is not very different in terms of both a) style of faulting and folding, and b) local fault parameters (as derived from observed uplift rates) from that known southwest of Lake Garda.

We suggest that the strong effect of glaciations in this region, including excavation of deep valleys and deposition of large terminal moraines at the active mountain front, has obscured additional evidence of active shortening. In a similar stratigraphic and geomorphic setting, and within a moderately active tectonic region, the identification of reliable strain and chronological markers is not an easy task. Very detailed geomorphologic and stratigraphic investigation is needed to detect the relatively small tectonic signal in the local landscape. Only specific careful geomorphological and geological analysis might allow to evaluate more precisely the displacement history, amount and nature of each Quaternary structure identified in the study area. It should be clear that the research in this field is still at an early stage. One goal of this note is to promote further study on the poorly documented Quaternary tectonic of this region. In fact, none of the known Quaternary tectonic structures in the Lombardian Southern Alps has been quantitatively characterized until now. At present, what we know about the growing anticlines near Lake Garda, located within the epicentral area of the Me 6.2, December 25, 1222, Brescia earthquake (GUIDOBONI, 2002) is only the amount of Middle Pleistocene structural relief (ca. 200 m; CURZI et alii, 1992). For the causative structure of the Me 5.7, May 12, 1802, Soncino earthquake, we only have a preliminary estimate of the fault size (10 km of fault length by 6 km of fault width) and coseismic slip (less than 0.5 m at depth; maximum surface vertical displacement ca. 0.15 m; BURRATO et alii, 2003). In agreement with this conclusion our knowledges about the two major Quaternary tectonic structures in the Insubria region, bring us to suppose that they have controlled the recent growth of the Gonfolite Range Front west of Como, and of the Albese con Cassano Hill east of Como. We assessed a fault length of ca. 20 km for both structures, and a Middle Pleistocene structural relief of ca. 200 m for the Albese con Cassano anticline. A vertical uplift of a few hundreds of meters during the Middle Pleistocene along the Gonfolite backthrust hangingwall is also a reasonable estimate, but this value is poorly supported by the available data.

If our hypothesis will be confirmed, eventual data on earthquakes magnitude and recurrence times associated to the investigated structures should be taken into account in future seismic hazard estimates.

At this preliminary point of our work, the review of the literature data and our new mapping and investigations suggest that Quaternary shortening should occur in a continuous belt in the foothills of Southern Alps between Lake Garda and Lake Maggiore. North-south directed Quaternary shortening and its relations with the current seismicity level has been well documented in the eastern part of the Southern Alps (e.g. SERVA, 1990; CASTALDINI & PANIZZA, 1991; BENEDETTI et alii, 2001; GALADINI et alii, 2005). New detailed geological and paleoseismological investigations are needed in order to prove, but also to disprove, that similar relations are valid also in the western Southern Alps and in particular in the Insubria region.

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