A Model of Como (N Italy) Urban Subsurface: A Multidisciplinary Tool for Hydraulic, Hydrogeologic and Subsidence Risk Management

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Abstract

The city of Como lies on the shores of Lake Como and is built on a sedimentary basin made of at least 155 m of post-LGM (Last Glacial Maximum) lacustrine, palustrine and alluvial deposits. The area is threatened by different kinds of geological hazards, mainly related to lake flooding and subsidence; the city is also particularly vulnerable in case of possible strong ground shaking, because of the local high liquefaction potential and the likely occurrence of slope instabilities and amplification phenomena. We applied a multidisciplinary approach aimed at reconstructing the late Quaternary and Holocene evolution of the area, based on field surveys and the analyses of stratigraphic and geotechnical data, hydrogeological and subsidence monitoring. Our model has been tested during the design of the new defense system for the mitigation of the flood hazard. We anticipated that the worst geological problems for this facility would have occurred in the area where, according to our model, the Roman lake harbour was located. We realized at this site a specific campaign consisting in the drilling of 7 new boreholes, a number of ^{14}C dating, and geotechnical and seismic surveys. A previously unrecognized organic silty unit, rich in archaeological remains and consistent with our hypothesis, has been found. This unit is the most critical for engineering planning due to its very bad mechanical properties. These results demonstrate that the model can be used as a predictive tool for hazard management and for a more efficient urban planning.

Keywords

Landscape evolution • Urban geology • Subsidence • Risk mitigation

174.1 Introduction and Geographic Setting

The landscape evolution of an area is governed by “extreme” natural events, which are able to change the geography and stratigraphy of entire regions. Since modern landscapes are very often urban landscapes, frequently hosting high risk plants and huge economical properties, from the societal point of view such natural events typically represent major geological hazards. Even if many efforts have been developed in order to characterize the causes and dynamics of geohazards, losses are continuously increasing due to a growing population density, which usually generates an obviously incautious use of the land. In this note we describe how the mapping of the subsurface geology beneath the city of Como, N Italy, allowed to build a model of the recent landscape evolution suitable for assessing local natural hazards and mitigating the associated risks.

The study area is located in a coastal setting at the S end of the W, hydrologically closed, branch of Lake Como. To the E, the city is bordered by the Monte Olimpino Backthrust, a regional N-verging structure, that shows evidence for Pliocene to Quaternary activity. The urban area is built on a small, flat alluvial plain, surrounded by mountain slopes, with outcropping Oligo-Miocene conglomerates (Gonfolite Group) to the W and Mesozoic limestone

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(Medolo Group) to the E. The deep and narrow sedimentary basin beneath the city was repeatedly shaped during the Quaternary by the glacial erosion and finally filled up by a thick sequence of Pleistocene sediments. Only the upper ca. 150 m of this sequence have been directly explored by boreholes. This most recent sedimentary package is composed of more than 120 m of late-glacial and Holocene, mostly silty, lacustrine sediments followed by up to 35 m of organic palustrine deposits (Comerci et al. 2007).

The Como urban area is characterized by significant (2–4 mm/yr) long-term subsidence due to the compaction of these young unconsolidated deposits. After the World War II subsidence reached rates an order of magnitude higher (ca. 2 cm/yr), due to groundwater overexploitation (Comune di Como 1980; Comerci et al. 2007). The area affected by ground sinking is spatially quite limited, but effects are critical for the economy of the whole city, because of the increased risk of inundation and consequent damages to buildings and infrastructures next to the lake shore. Beyond undoubted negative effects for road network, tourism and city image, these phenomena are also posing significant safety problems.

174.2 Modeling the Subsurface Geology of the Como Basin

In the late 1990s our research group started a systematic study of the subsurface geology in the Como urban area, collecting and integrating available data in a unitary perspective. We compiled more than 250 borehole logs, covering a territory of 5 km^2 and including the entire urban area (Fig. 174.1). Most of the boreholes are some tens of meters deep, but ca. 5 % of them reaches depth higher than 120 m. Two cores were drilled specifically for scientific purposes in 2005 in Piazza Verdi, about 200 m inland from the shore of Lake Como. Multidisciplinary analyses performed on the Piazza Verdi cores allowed calibration of the whole database of subsurface information. We also conducted field surveys at 1:10.000 scale for the realization of the new official geological map of Italy (CARG project, Sheet 75 "Como"), and 17 radiocarbon dates were obtained at different sites. Paleoseismological analyses were made on the western border of the Como plain (Borgovico site). Research included also systematic groundwater measurements for characterizing the interactions between lake and groundwater levels, both under natural conditions and in conjunction with artificial groundwater lowering. Subsidence rates were estimated from hydrometric data, comparing lake levels daily recorded in measurement points located on stable bedrock and compressible sediments, respectively. Finally, the evolution of the city in the past 2000 years was reconstructed by means of archaeological and historical data. Adjustments of the local drainage network and a succession of city walls and coastlines, dated at different historical periods since the Roman Age, have been identified based on archaeological findings and old city maps. The first results of this research have been published in Comerci et al. (2007) and summarized below.

The generalized stratigraphic succession of the whole urban area is composed, from the top, of 1–10 m of heterogeneous reworked material with archaeological remains; alluvial sands and gravels are present down to the depth of

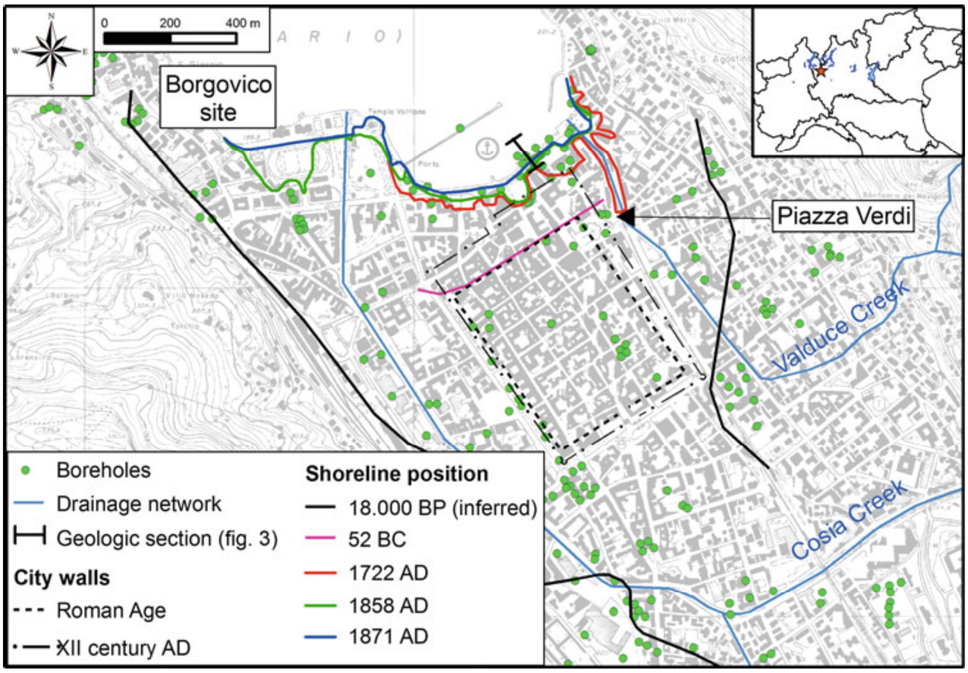

Fig. 174.1 Map of the Como urban area, based on the "Carta Tecnica Regionale" at a 1:10.000 scale, showing the available borehole logs, the local drainage network and coastline migrations

15–24 m. Under this sandy gravel unit we found up to 30 m of palustrine organic and highly compressible silts, in Piazza Verdi dated between 4 and 15 kyr BP. Below 40–60 m from the ground surface, there are more than 100 m of glaciolacustrine clays and silts with dropstones. The sequence is normally consolidated at least down to 70 m from the surface, thus it was never overloaded.

All the borehole logs were digitized and located on a georeferenced topographical map (CTR, Carta Tecnica Regionale); then, core logs were analyzed in order to identify the elevation of stratigraphic boundaries and thickness and extent of sedimentary units; finally, a set of 2D maps were drawn using ArcGIS® functions (Ferrario 2013).

The Holocene organic silts, widespread in most of the sedimentary basin area, are the main responsible of long-term subsidence; the unit thickness was sliced in 6 classes (0 m; 1 ÷ 2 m; 3 ÷ 5 m; 6 ÷ 10 m; 11 ÷ 15 m; >15 m) and plotted on the topographic map (Fig. 174.2). In the coastal area, maximum values are higher than 30 m; this area is obviously the most affected by subsidence phenomena. In the eastern part of the urban area this unit is absent, due to an old and now abandoned alluvial fan related to the local drainage network.

174.3 Applying the Model for the Mitigation of the Flood Hazard

In order to avoid or at least minimize economic losses, a new integrated defense system against floods is presently under construction, consisting of rows of mobile gates which are intended to protect the town during events of very high level of Lake Como. This facility has a strategic role and its importance is critical for the urban management and city planning in the next decades; therefore, all the involved aspects should be properly assessed for identifying the possible influence on the subtle geological equilibrium typical of the area.

During the project planning, the Insubria University acted as a consultant for the evaluation of geologic and geotechnical aspects: thus, it has been possible to use the model presented before as a predictive tool, in order to identify those features critical for geohazard assessment.

Several data were yet available on the lake shore area: during 1997, 10 continuous core drillings were realized, and in situ (SPT, Lefranc permeability tests, CPTU) and laboratory tests were performed. Analyzing the results of the 1997 campaign, we predicted that the most critical situation could arise from the stratigraphic setting on the eastern side of the lake shore, where sediments with very poor mechanical properties were expected. Therefore, we planned a new campaign, consisting in the drilling of 7 boreholes and the execution of 2 cross-hole seismic surveys, 10 DPSH and laboratory tests.

The investigations were performed in 2013 and were aimed at identifying submerged structures and characterizing the 3D architecture and engineering behaviour of sediments, both in static and dynamic conditions. Results confirm our hypothesis, because along the coast an organic silty layer, up to 6 m thick and very rich in archaeological remains was recognized; ^{14}C dating reports an age of few centuries AD

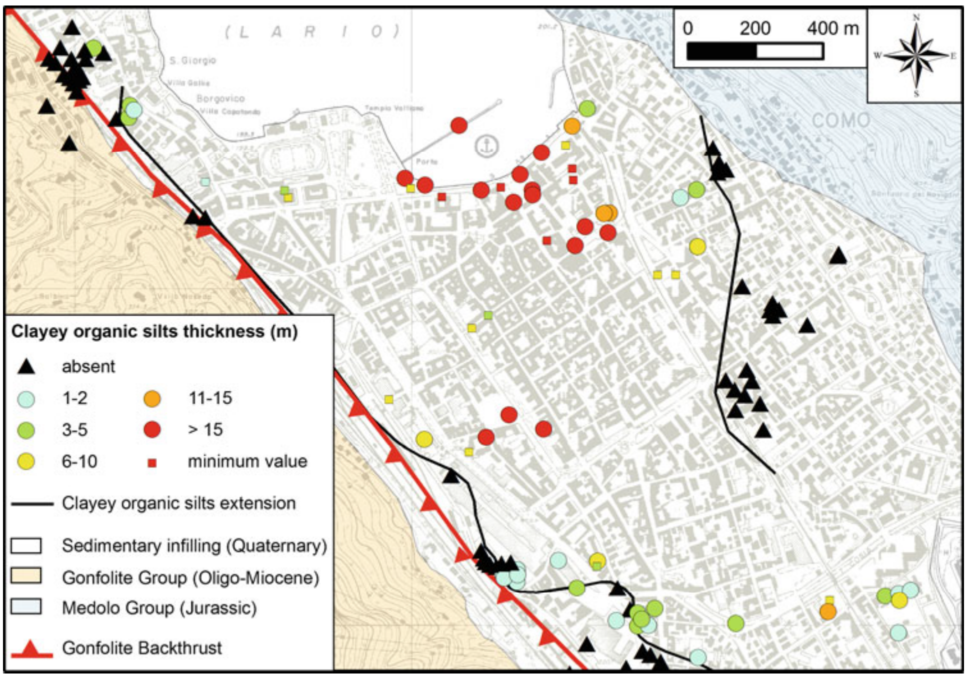

Fig. 174.2 Thickness of the organic clayey silts; values up to over 30 m are recorded in the lake shore area. Square symbols represent minimum values (boreholes don't reach the unit lower limit)

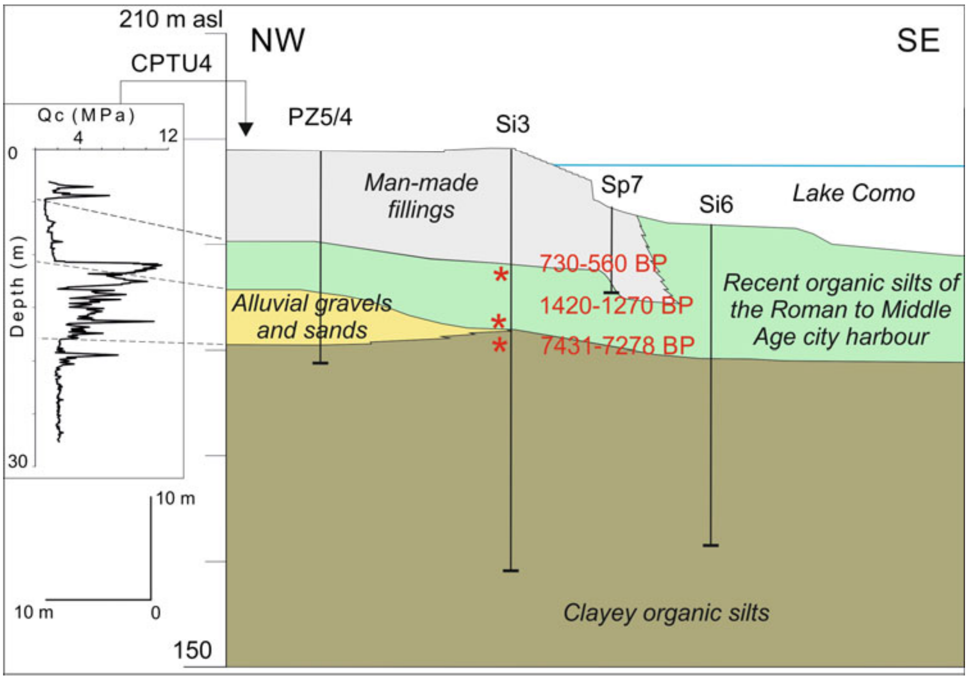

Fig. 174.3 Geologic section in the lake shore area, showing the thickness of man-made deposits and the underlying silts and sands. CPTUs and ^{14}C values are also shown (age in cal yr BP)

(upper to lower Middle Ages; Fig. 174.3). This unit shows very poor mechanical properties and is related to a closed low-energy environment, such as a sheltered harbour or a dock. These deposits had never been investigated before, and their role for engineering and environmental characterization is fully defined here for the first time. The recognition of stratigraphic boundaries and sedimentary facies was based on core drillings and piezocone test interpretation and enabled to draw detailed geological sections.

Our research, based on a thorough revision of available data, systematic monitoring and new data acquisition, allowed to build a conceptual model suitable for explaining the recent evolution of the study area. We presented here a case history, focused on a single project and a specific kind of hazard, namely lake flooding; this case has immediate consequences on territorial management, but we believe that our approach has wide applications and is useful well beyond this single case and the geographic area considered here. Indeed, our model can be used in a predictive way, for unveiling both potential criticalities or new perspectives. For instance, our work can be a base for archaeological studies, aimed at revealing the migration of the harbour position since Roman times. In a broader perspective, it is possible to apply the methodological approach adopted here in all those cases where risks of natural or anthropic origin have to face with cultural heritages.

Our results demonstrate that a more detailed knowledge of the Holocene stratigraphy of Como, and in general of metropolitan areas in regions with ancient civilization, can lead to a more accurate urban planning: indeed, a rigorous geological analysis is the only suitable strategy to (a) face the problems posed by the geological instability that can affect the environmental safety of the urban network or local critical facilities, (b) provide the basis for civil engineering and urban planning countermeasures, and (c) optimize resource utilization.

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