Available online http://amq.aiqua.it
ISSN (print): 2279-7327, ISSN (online): 2279-7335

Alpine and Mediterranean Quaternary, 31 (2), 2018, 195 - 205 https://doi.org/10.26382/AMQ.2018.13

THE STRATIFIED GROWTH OF CHIETI FROM ROMAN TIMES TO TOMORROW: A NEW, GEOLOGY-BASED CONSCIENCE IN CITY PLANNING AND RENEWAL

Silvano Agostini

Soprintendenza Archeologica belle arti e paesaggio dell'Abruzzo, L'Aquila, Italy

Corresponding author: S. Agostini <silvano.agostini@beniculturali.it>

ABSTRACT: Human settlement grew around and at the foot of the hill of Chieti partly conditioned by the local geological and geomorphological characteristics, and partly transforming them. The hill is vulnerable, due to its geological structure and geomorphological evolution. Following the stratification of human activities and the intense construction activity on the hill, particularly after the Second World War, monuments and both ancient and recent buildings suffered several stability issues. Three of the city's most important archaeological monuments are taken as emblematic of the interplay between local geology and human impact. The analysis shows that sound knowledge of how Quaternary geological processes operated in time and space needs to become a permanent part of urban planning policy and urban renewal. In fact, the latter have to be strongly sensitive to the equilibrium between the impact of human activities and environmental geology, and able to predict how existing infrastructures respond to the effects of climate change (e.g. new rainfall regime). Geological culture is the basis for redesigning the city with less, or no, use of concrete and more widespread use of bioengineering.

Keywords: Urban geoarchaeology, Southern Italy, Abruzzi Periadriatic region, Plio-Pleistocene marine deposits

1. INTRODUCTION

The geological and geomorphological characteristics of the town of Chieti (*Teate Marrucinorum* in pre-Roman and Roman times) have conditioned and have been partly transformed by the impact and spread of human settlement around and at the foot of the hill. *"Super omnia, quae umquam audita sunt, erit prodigium in nostro aevo Neronis principis ruina factum in agro Marrucino, Vetti Marcelli e primis equestris ordinis oliveto universo viam publicam transgresso arvisque inde e contrario in locum oliveti profectis",* Plinius Secundus C., Naturalis Historia Liber XVII 245. "A portent that will eclipse all those ever heard of occurred in our own day in the territory of the Marruccini, at the fall of the emperor Nero: an olive grove belonging to a leading member of the equestrian order named Vettius Marcellus bodily crossed the public highway, and the crops growing on the other side passed over in the opposite direction" (Rackhaman, 1961). These words clearly show that the hill of Chieti was known to be highly vulnerable and unstable already twenty centuries ago; for its characteristics it was the object of wonder, chronicles and a memory to be passed on. The vulnerability of the hill on which Chieti stands is determined by its natural geological structure and geomorphological evolution. The geological context is not exclusive to the town; in fact, it characterises the entire mid-Adriatic coastal hill belt (Centamore & Nisio, 2003; Centamore et al., 2003).

Owing to its vulnerability, the hill of Chieti always reacted directly or indirectly to the stratification of human activities with instability phenomena which affected the built fabric at any time and no matter what construction technique was used. We must first observe that hydrogeological instability turns into a major problem when urban space is developed, following a plan, or not, without any background knowledge of geology. In other words, repeated out burts of instability have always occurred not only due to the mistaken belief that the hill's geological processes are static, rather than dynamic, but also adopting wrong strategies to contrast the unbalances caused by human impact which induced further acceleration of the processes. This error could also be perpetuated in the future. It is worth emphasising that the absence of geological culture does not imply lack of technology and technical solutions (land defences, reclamation) aimed at preventing and limiting the risks inherent in the management of Chieti's subsurface instability; rather, there has been prolonged absence of material and cultural responsibility in land management. Today, special attention is devoted worldwide to the quality of life, not only in urban areas. This implies tackling hydrogeological issues, as well as the risks posed to property, and to life itself. We also need to plan and implement more appropriate, effective and all-encompassing prevention measures and broad interventions. Administrators and citizens need to recover a neglected geological culture, but this is no longer enough. Much more must be done.

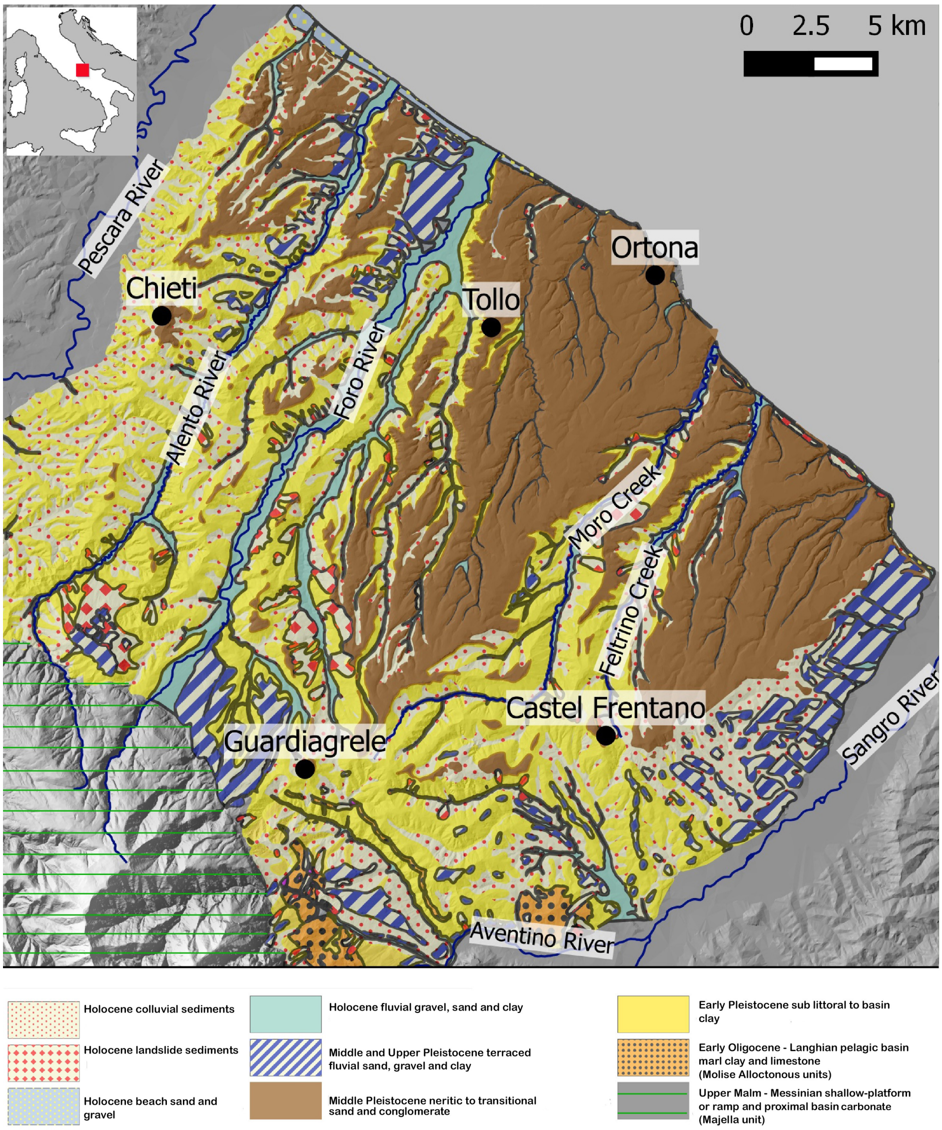

Fig. 1 - Geological map of the Abruzzi Periadriatic belt (modified from Racano et al., 2018)

2. THE GEOLOGICAL AND GEOMORPHOLOGICAL CONTEXT

The hill of Chieti is located in southern Abruzzi, in the peri-Adriatic region of central Italy. This area is characterised by a thick sequence of Upper Pliocene-Middle Pleistocene marine deposits, which cover the deep tectonic units of the northeast verging Apennine fold and thrust belt (Fig. 1). The Plio-Quaternary facies and morphostructural setting resulted from the complex interplay of tectonic faulting, uplifting and tilting, eustatic sea-level excursions, and climatic changes. Particularly significant landforming processes were the lateral diversions of river courses, the topographic settings, as well as the formation of different orders of alluvial terraces, which are scattered at various elevations. Quaternary regional uplift and surface deformation led some authors (Pizzi, 2003; Racano et al., 2016; Racano et al., 2018) to consider the thrust system beneath the area still active Like most peri-Adriatic plateaus, the hill of Chieti has a flat summit and flanks that slope down progressively more gently as we move to the underlying valleys. This physiography was created by modelling processes that acted over the last million years on the rocks of the local stratigraphic succession. The resulting stratigraphic setting controls both the groundwater circulation, with interstitial waters that spill over (or spring) at mid-slope elevation, and the incessant erosion and denudation processes. At first, the city developed following the hill's original morphology; later on, the hill was drastically transformed.

The lithostratigraphic succession consists of four principal units (U1-U4) organized in two main groups (1 and 2). The first and second units (1 in Fig. 2 and U1 and U2 in Fig. 3) can be ascribed to the Mutignano Formation, (FMTa, FMTc and FMTd according to CARG subdivision in Barberi et al., 2018a; Barberi et al.,

Fig. 2 - Simplified geo-lithological map: 1 - sand with lenses of conglomerate (U2 and U2 cgl in Fig. 3), gravel and lacustrine clays (U3 in Fig. 3), colluvial and anthropic sediments (U1 cl and U1 r in Fig. 3); 2 - clays (U1 in Fig. 3); TT - Roman Theatre area, TP - Roman Temples area, BC - Roman Baths and Cisterns area. A-B-C, D-B: trace of geological cross-section (Fig. 3).

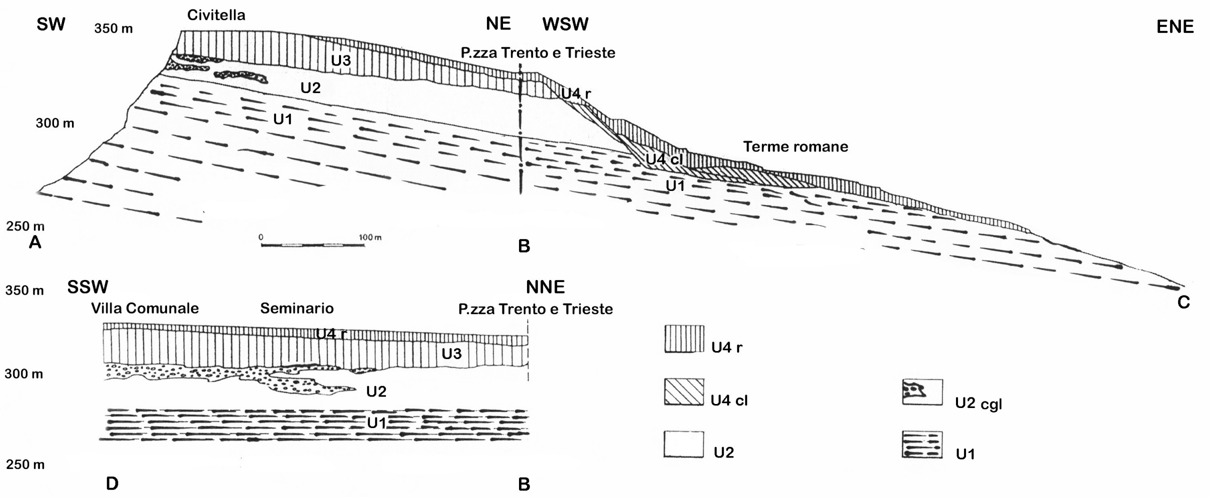

Fig. 3 - Geological cross sections. U4 r - recent anthropogenic and colluvial sediments, U4 cl - ancient colluvial and landslide deposits, U3 - pebbles and lacustrine clays, U2 - sands and lenses of conglomerate (cgl), U1 - clays.

2018b). Part of the third unit (2 in Fig. 2 and U3 in Fig. 3) can be attributed to the Mutignano Formation and another part to the Ripa Teatina Formation (FMTd and RPT according to CARG subdivision in Barberi et al., 2018a, Barberi et al., 2018b). The fourth unit includes the colluvial cover, soils, fluvial deposits, as well as landslide (U4 cl in Fig. 3) and antrophic deposits (U4 r in Fig. 3). The base of the hill is completely encircled by Lower Pleistocene grey clays of submerged platform (bathyal to neritic environments), which form a hydrogeologically impermeable complex (U1 in Fig. 3). The clays are followed, upwards, by a thin, vertically continuous and concordant layer of alternating sands and clays, and then by overlaying littoral sands, also dating to the Early Pleistocene (U2 and bottom of U3 in Fig. 3). The U2 unit contains the main aquifer, which consists of a hydrogeological complex with medium to high permeability. The aquifer is fed by rainwater and today also by fluids leaking from water and sewage mains, old cisterns, modern water storage facilities and tanks, sometimes containing highly toxic liquids. Differential erosional processes created very steep, almost vertical scarps in the hillslope profile (Fig. 4), at the level of well-cemented sands at the top of the sandy unit (transition from U2 to U3 in Fig. 3). Many other artificial scarps, sometimes quite extended along the sides of the hill, were dug to create the foundations for buildings; this activity became more intense and aggressive in the post-war time (Fig. 5). A unit of continental conglomerates, silts and sands fills discontinuities in the uppermost parts of the hill and crops out at the edge of the scarps. It rests on an unconformable surface that results from a former gentle uplift and modelling which occurred after the surfacing and eastward migration of the coastline at the end of the Early Pleistocene, about one million years ago. On top of the hill, the fourth unit is covered by remnants of red palaeosol with a truncated profile (Fig. 6), which can be likely referable to lower Middle Pleistocene Alfisols (Barberi et al., 2018a). Knowledge of the stratigraphy of the surface cover is very important for city planning and urban geology. The deposit consists of colluvium and accumulations from ancient landslides (U4 cl in Fig. 4), as well as of material associated with human activities from various periods and recent landslides (U4 r in Fig. 4). The mechanical and hydrogeological behaviour of this stratigraphically heterogeneous unit, which often includes both permeable and impermeable bodies of variable thickness, may be very different. Although this unit represents the first substratum of the city, it has often been investigated with approaches that are inadequate in Quaternary geology. This led to erroneous interpretations of the deposits, which have sometimes been ascribed to the second or even to the third unit. In particular, the colluvial cover contains each minor superimposed aquifers in which the water that derives from leaks of the town's water mains is canalized along lines of flow following the subsurface palaeo-drainage. These recent covering layers also contain human-made cavities (cisterns, tunnels, etc.), in which water accumulates causing damages to the road network, to the retaining walls as well as triggering landslides. This brief introduction on the geological and geomorphological setting of Chieti is followed by a description of three cases, emblematic of the inter-relationship

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Fig. 4 - Unstable areas map: 1 - escarpment edge with structural control, 2 - escarpment edge, 3 - gully erosion, 4 - rill erosion, 5 - earth flow, 6 - surficial deformation, 7 - sliding landslide, 8 - colluvial and anthropogenic sediments with thickness less than 2 m, 9 - colluvial and anthropogenic sediments with thickness larger than 2 m, 10 - incipient earthflow, 11 - terraced alluvial deposits, 12 - bedrock, 13 - historic center and suburbs, TT - the Roman Theatre area, TP - Roman Temples area, BC - Roman Baths and Cisterns area.

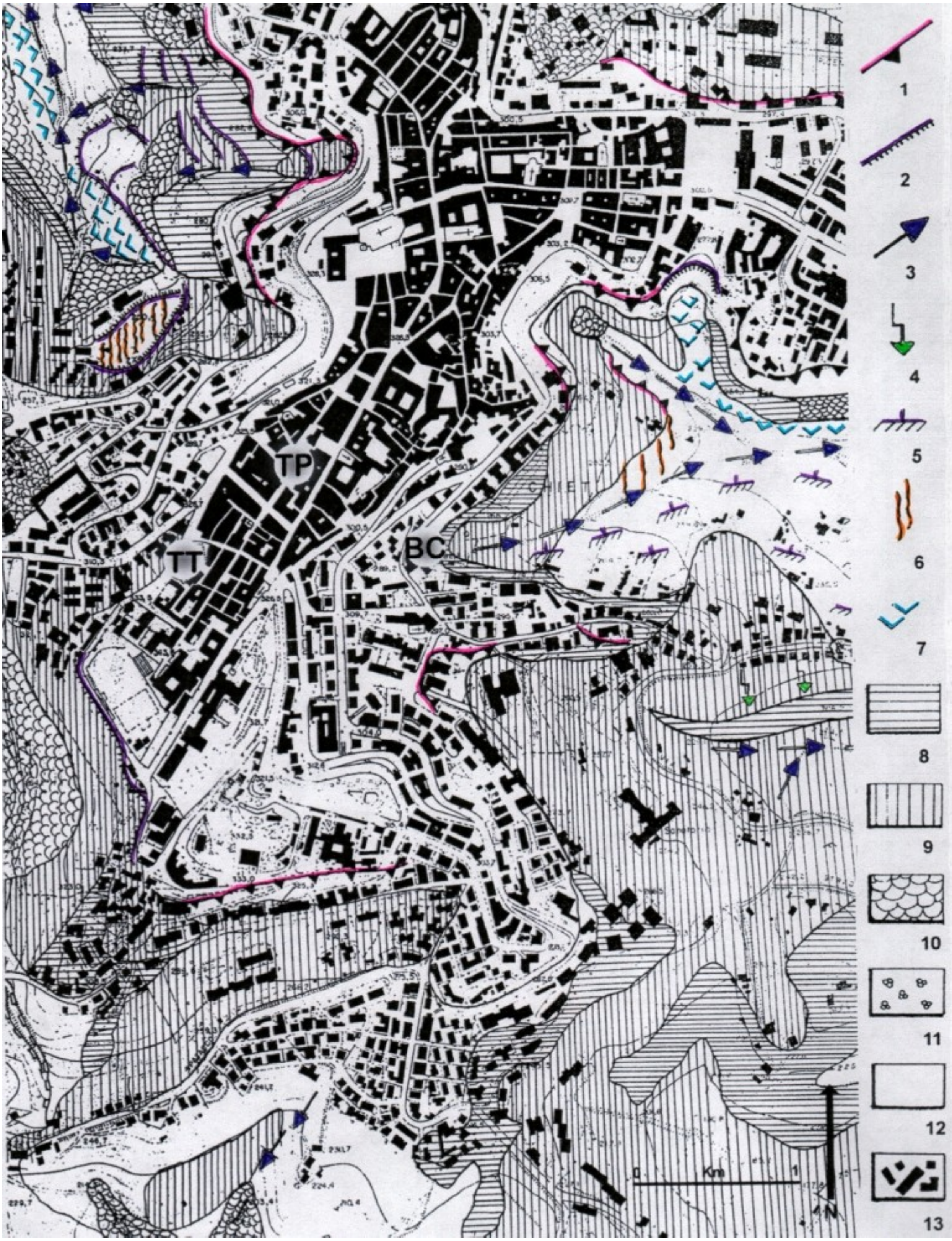
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Fig. 5 - Urban modern buildings above and below the escarpment edge of the western hillslope.

Fig. 6 - Red palaeosol (Alfisols) on the erosion surface topping unit U3.

Fig. 7 - The Roman Theater in the upper edge of the western hill slope. The left part of the ring corridor, the Scaenae Frons, the Pulpitum and the Orchestra are missing due to a landslide-associated collapse.

Fig. 8 - Retaining walls and drainage tunnels of the Roman age on the edge of the western hill slope.

between the geology of the hill-city system and human impact. These areas have been studied in detail, because they are three of the town's most important archaeological monuments. All three the sites were affected, already in ancient times, by extensive public works of urban transformation for the creation of *Teate Marrucinorum*.

2. 1. The Roman theatre area

The Roman theatre was built on top of the hill of Chieti, on the edge of, and in part against, the western central slope (Figs. 2, 3, 4). The slope was partly excavated in a fashion also observed elsewhere in Italy and in the Roman provinces (Bieber, 1961; Sartorio Pisani & Ciancio Rossetto, 1994; Martella & Menozzi, 2008; Vermeulen, 2018). This structure was located above the

Fig. 9 - Retaining walls on the escarpment edge of the eastern hill slope.

natural scarp produced by the differential erosion between unit U2 and part of unit U3 and underlying unit U1 (Figs. 2, 3, 4). The geological instability of the area is demonstrated not only by the collapse of most of the ancient structures (Fig. 7), but also by the general morphological irregularity which today characterises the upper margin of slope. The mass movements directly affect the soils (here considered in the geotechnical sense) at mid-hillside elevation above the clayey unit U1. The plastic deformations, subsidence and traction processes, which are still active today in the unit U1 deposits, led to the recession of the hill. The associated deformations and the widespread landslides (Fig. 4) have created a precarious hydrological equilibrium on this intensely urbanised slope; they also affected the arrangement of strategic infrastructures, such as the town's principal water main. In fact, past and recent buildings were erected disregarding the active morphological evolution of the hillside and its natural process of auto-stabilisation through the dynamics of erosion, recession, transport and accumulation at the base of the slope.

2.2. The Roman temples area

The substrate of the area of the Roman temples (Agostini & Romano, 2000) is characterized by material of variable thickness laying directly on the conglomerate sands of unit U2 (Fig. 3). Here the original land shape can be reconstructed based both on the archaeological structure, which originally lay underground, known as the Roman Tunnel, and on historical photos. The watershed line descended from the hilltop, passing slightly west of the site occupied by the Roman temples. The temples were built against the slope of the hill, with the façades facing today's Corso Marrucino, which remained the town's main axis throughout the centuries. The current façade of the temples was originally the edifice's rear side. Today, in this area, the groundwater table is over 30 m below the ground level and therefore much lower than its level in the classical period, as confirmed by the depth of the temples' sacred well. In this area the characteristics of the unit U2 (sands and cemented conglomerated sands) favoured the excavation and construction of clad with bricks hypogeal environments and also of extensive underground quarries with broad and high chambers and pillars cut into the natural substratum. The access to the quarries was in particular at the foot of the western slope. Archive studies show that the aforementioned chambers were used until about two centuries ago, when the artificial hypogea were still located at the edge of the city. Today they lay below the 1950 to 1960 urban fabric and below the road network. In this area of the town, alongside the underground quarries, there are numerous tunnels, icehouses and wells; these structures were often discovered accidentally, exposed by instability phenomena. Extensive hypogea have been identified under important public buildings following oral tradition, but most of all based on documents in historical archives and on the results of recent surveys. Loss of historical memory, but also water and sewage leaking from defective pipes (modern ones, both known and unknown 16th and17th century

Fig. 10 - Roman Baths and Cisterns area. The right portion of the Roman bath collapsed following a sliding landslide (probably in the18th century) and recently reconstructed in the 1950s. The 19th century buildings and the road have been build over the cisterns while the urban modern buildings lie over the steep eastern hillslope and the escarpment edge.

ones, as well as archaeological structures of the Roman period), has caused repeated collapses and settlement of road surfaces, seepage in buildings and damage throughout the entire hillside. Ironically, the way in which the Romans designed and constructed the substructures on the slopes can still be seen in the area of the Roman temples (Fig. 8). Uphill and downhill from the walls there was an organized drainage network designed to avoid overpressure of the saturated terrain on the buildings and generally capable to regulate the waters at the margin and along the side of the hill.

2.3. THE ROMAN BATHS AND CISTERNS AREA

The archaeological area of the Roman baths and cisterns (Agostini, 1987; Agostini & Campanelli, 1994; Agostini et al., 1994; Scichilone et al., 1987;) is located about halfway up the eastern side of the hill of Chieti. Following the location of natural springs, the buildings were constructed in a natural thalweg, the head of which once reached today's Piazza Trento e Trieste (Figs. 2, 3, 4).

Like today, in the classical period the groundwater that discharged from perennial springs drained into the sediments of units U2 and U3, and flowed over the impermeable unit U1 located at about the same level as the base of cisterns. Along the slope, the thalweg is filled with U4 cl unit deposits and the U4 r unit deposits. In fact, the jagged borders of the surface capping the hill were sculpted by the torrents that carved their way through the slopes. Upstream, the heads of the torrents were wider than today. The thalweg was incised at the end of the Late Pleistocene and by the Early Holocene it was filled with fluvial deposits often over 20 m thick. The latter were subsequently covered by human-dumped debris, which sometimes reaches considerable thicknesses. Further north of the archaeological area of the Roman baths and cisterns, there are also thick prisms of palaeo and recent landslide accumulations. The colluvial unit often covers the typical scarps formed in the U2 and U3 sands. This side of the hill regularly retreated due to a succession of slope failures (Fig. 9). The middle and lower part of the slope, which rests on the U3 clays, is affected by slow deformation that occasionally triggered landslide falls in the overlying unit. Modern buildings largely load upon these sediments (Fig. 10). On the right side of the thalweg, where the Roman baths and associated cisterns are located, Roman and late Renaissance canalisations, including sections that had been restored in the 1960s and 1970s, are now crushed and deformed. The Roman canalisations, which served the baths and which were fed by the water reserves in the underground cisterns, were subsequently used as extra-urban water sources to irrigate gardens and crops. Similarly, the 18th and 19th century sewers, which had truncated numerous rooms of the Roman baths, damaging and sometimes destroying them completely, have only recently been conveyed into a new pipeline. More generally, the poor state of the water network on the hillside above the archaeological site of the Roman baths and cisterns imposed the implementation of specific remediation measures which saved the monument from accelerated and alarming deterioration. Emblematic and impossible to resolve is that the surface of the vaults of the underground cisterns serve as the viaduct of the provincial road above. The walls of the cisterns built against the hillside act as a retaining wall on which there has been an alarming urbanization after the Second World War (Fig. 10).

3. CONCLUSIONS

The three cases briefly described, each from a different context (hilltop-Roman Theatre; hilltop margin - upper part of the slopes-Temples; mid-lower slopes-Baths), are textbook examples of the interactions between natural sediments and anthropogenic cover types (buildings and spaces for human activity), of the ancient Roman-PreRoman hilly town and successive urban development (Bini et al., 2018; Mozzi et al., 2018; Vermeulen et al., 2018). A number of focused studies, either accomplished or underway, seized the opportunity of the presence of archaeological monuments to identify the most appropriate solutions to safeguard them. These researches accessed and processed large amounts of archival documents and reviewed information from over 300 wells. Thanks to the wider perspective provided by these studies, we now have a historical memory, which can be used to decipher the relationships between environmental and urban geology, including its cultural aspects. The interpretation of the data shows that the geological context has received scarce, if any, attention in the past. Also no care has been paid to the impact that the aggressive urban development could have on the vulnerable hydrogeomorphological system of the hill of Chieti; the matter was rather conveniently dismissed as "the hydrogeological instability of the hill of Chieti". No need to say that all the processes and events are considered to be a pre-existing legacy, and not, as is in fact the case, the consequence of a lack of planning, or of recurrent planning issues. The interpretation of fresh information reveals also problems in the remediation techniques that have been employed. Therefore the way in which the town is planned and renewed needs to be thoroughly revised; this cannot be postponed any longer. It cannot neglect genuine geological culture, especially aware of how Quaternary geological processes operated in time and space and sensitive to the equilibrium between the impact of human disturbance and environmental geology. City planning and renewal projects must be able to predict to what extent existing infrastructure are capable to respond to the effects of climate change (e.g. new rainfall regime). This new conscience will be the basis for redesigning the town with less, or no, concrete and more attention to bioengineering.

ACKNOWLEDGMENTS

The author expresses his appreciation to the contribution provided by the two reviewers.

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Ms. received: Marz 12, 2018
Final text received: November 28, 2018